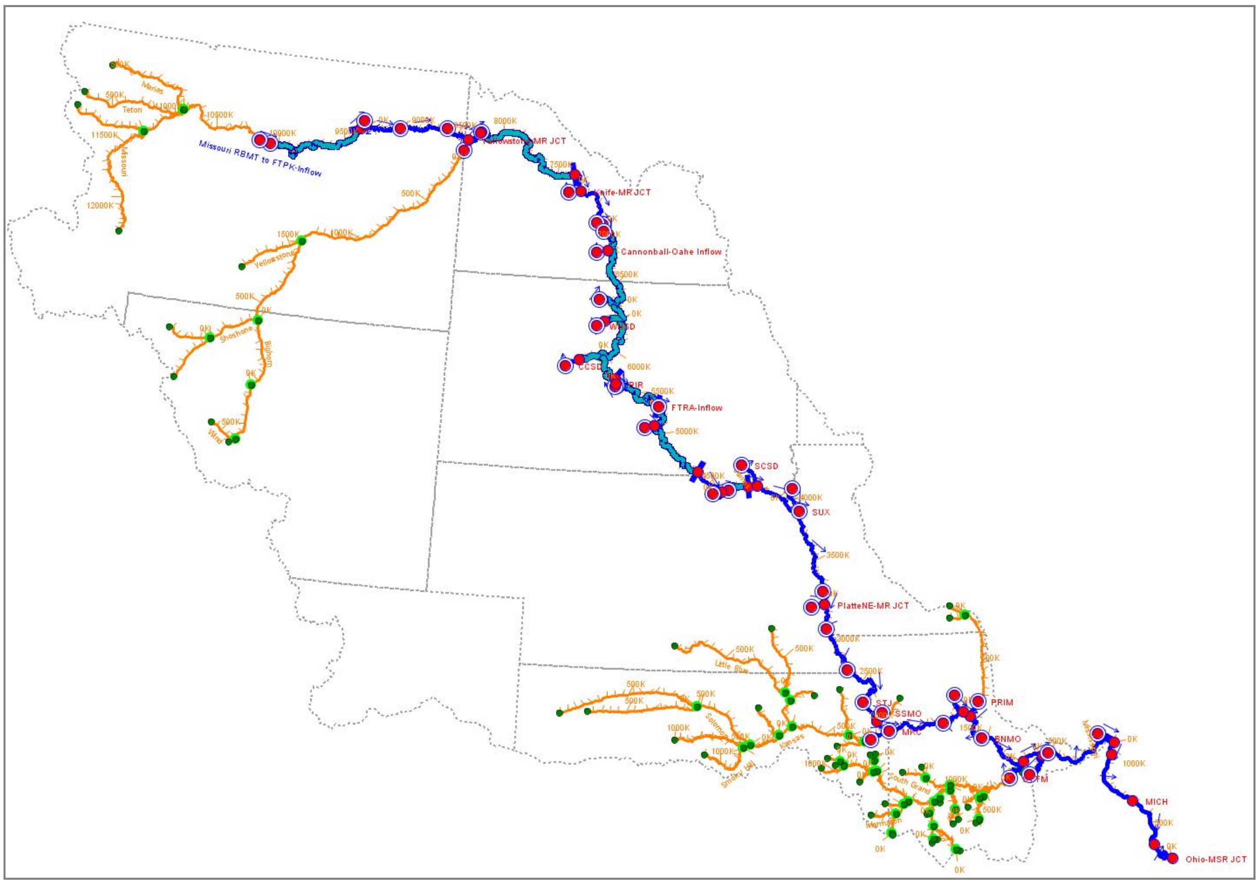
US Army Corps of Engineers ®
Omaha District

Missouri River Mainstem HEC-ResSim Modeling

Missouri River Mainstem Reservoir Simulation Report



HYDROLOGIC ENGINEERING BRANCH

ENGINEERING DIVISION

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USACE—Omaha District
FINAL

EXECUTIVE SUMMARY

This model development is part of the larger Missouri River Recovery modeling project. The project involves the creation of a detailed suite of models for the Missouri River basin that will aid in the evaluation of scenarios reflecting a wide-range of hydrologic conditions. The objective of this element of the project was to develop a computer reservoir model capable of simulating the Missouri River system of reservoirs' (System) operation for the flow of record for assessment of various operational alternatives on the mainstem portion of the Missouri River. To accomplish the objective, the computer model HEC-ResSim was utilized to simulate operations at the six mainstem dams on the Missouri River. Prior to model creation, much effort was spent developing required input data such as local inflow, evaporation, and dam and reservoir physical parameters; all parameters are explained in detail within this report.

The System is operated for eight congressionally authorized purposes. The System is unique and contains six reservoirs with dramatic differences in storage distribution and long river reaches in between. There are four target locations downstream of the System for which releases are planned, the farthest having an approximate travel time of six days from the most downstream reservoir. In normal operation, System releases are typically planned from downstream to upstream. For these and other reasons including limitations in ResSim's standard features for tandem reservoir system and downstream control operations, modeling such an involved river system required the development of complex scripted rules. Rather than attempt to capture every historic operation, strategic modeling goals were established which outlined tasks critical to meeting this project element's objective.

Since the initial development of the ResSim model, improvements were made to the model that allowed the model to better simulate System operations. Improvements include:

- Updated Fort Randall-Gavins Point release logic
- Updated local flow forecasting
- Updated service level logic
- Updated flood target logic
- Updated runoff forecasts
- Updated steady release
- Updated Oahe-Big Bend release logic
- Added a maximum surcharge curve to each reservoir
- Updated Gavins Point guide curve
- Updated System flood evacuation logic

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ACRONYMS

AOP………………… . Annual Operating Plan

CMA…………………. Centered Moving Average

CR…………………… Coefficient Routing

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

DCP…………………. Data Collection Platform

DRM .... Daily Routing Model

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

E-A-C…………………Elevation-Area-Capacity

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

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

FTT .... Flow to Target

GIS .... Geographic Information System

HEC .... Hydrologic Engineering Center

HMS…………………. Hydrologic Modeling Software (by HEC)

WAT…………………. Watershed Analysis Tool (by HEC)

MAF…………………..Million acre-feet

MO…………………… Missouri

MR…………………… Missouri River

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

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

MS…………………… Mississippi

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

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 .... River Analysis System

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

ResSim……………......Reservoir Simulation Software (by HEC)

RM…………………… River Mile

SR............................ Steady Release

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

WAPA .... Western Area Power Administration Home

WCM………………… Water Control Manual

1 INTRODUCTION

The Missouri River Mainstem ResSim model (System ResSim Model) was created as a base model for planning studies which could be used in the future to simulate and analyze broad scale watershed alternatives. The objective of this ResSim model is to simulate System operation for a period of record to evaluate alternative regulation scenarios and assess conditions on the Missouri River. The need for a System ResSim Model has been discussed in conjunction with various federal studies for many years. The System ResSim Model was constructed to be adaptable allowing for multiple alternatives to modeled while still adequately simulating System overall operations.

2 BACKGROUND

2.1 BASIN DESCRIPTION

The Missouri River is 2,341 miles long and drains one sixth of the United States encompassing 529,350 square miles. The Missouri River reservoir system, which became fully operational in 1967, consists of six Corps dams with a total storage capacity of 72.4 million acre-feet (MAF), which makes it the largest reservoir system in North America. Figure 2-1 shows how the Missouri River System reservoirs compare to other USACE reservoirs in the United States. The System is operated to serve eight congressionally authorized project purposes of flood control, navigation, irrigation, hydropower, water supply, water quality, recreation, and fish and wildlife. Runoff from above the mainstem reservoir system dams is stored in the six reservoirs where it serves project purposes. Water is released from the mainstem reservoir system as directed by the System's Master Manual (U.S. Army Corps of Engineers, 2006). Figure 2-2 shows the Missouri River Basin.

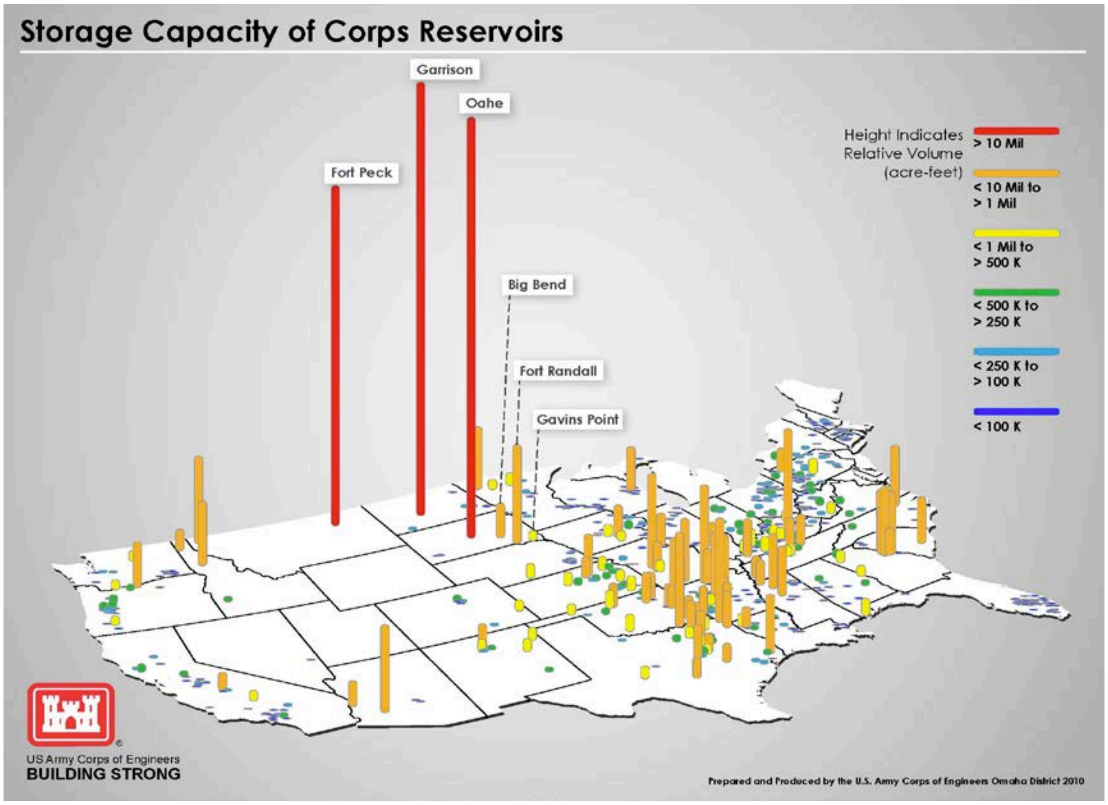


Figure 2-1: Storage capacity of Corps reservoirs.

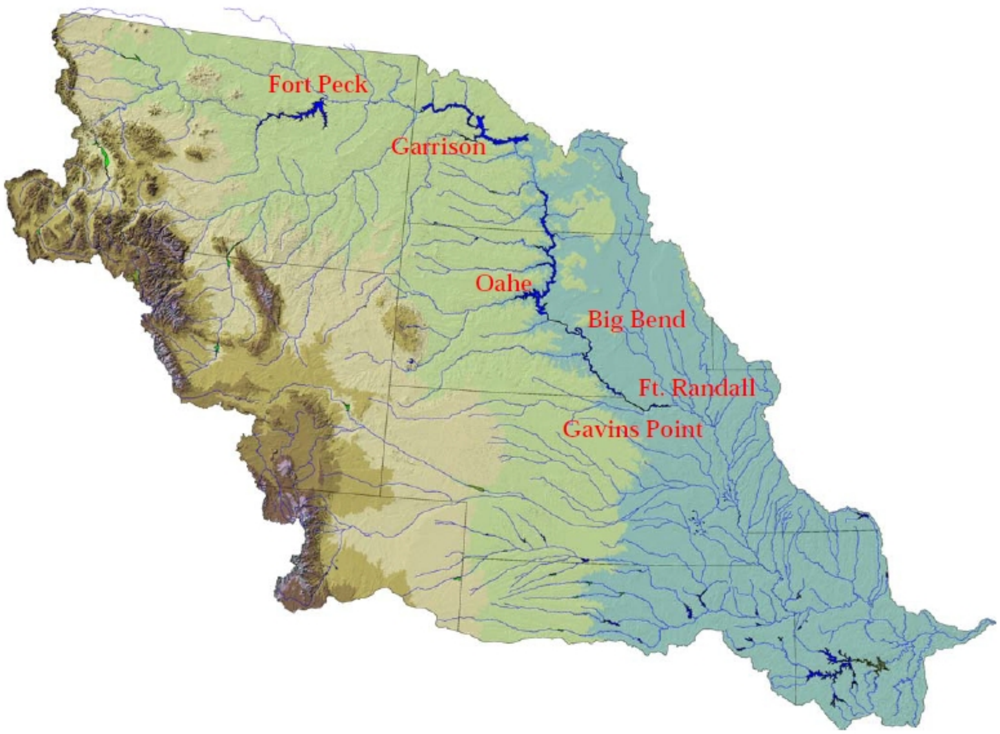


Figure 2-2: Missouri River Basin

2.2 MAINSTEM PROJECTS

The six Corps dams spanning the Missouri River control runoff from approximately half of the basin. Those six dams, from the upper three large reservoirs 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. Four of the System reservoirs were named by Congress: Lake Sakakawea (Garrison Dam); Lake Sharpe (Big Bend Dam); Lake Francis Case (Fort Randall Dam); and Lewis and Clark Lake (Gavins Point Dam). The reservoirs have a combined capacity of over 72.4 MAF. The System storage capacity is divided into four unique storage zones for regulation purposes, as shown in Figure 2-3. The Permanent Pool Zones are intended to remain permanently filled with water to ensure the maintenance of minimum power heads, minimum irrigation diversion levels, and minimum reservoir elevations for water supply, recreation, and fish and wildlife purposes. The Carryover Multiple Use Zones are intermediate zones that provide a storage reserve for irrigation, navigation, power production, water supply, recreation, and fish and wildlife during extended droughts. The Annual Flood Control and Multiple Use Zones provide storage for the annual capture and retention of normal and flood runoff and for annual multiple-purpose regulation of this impounded water. The Exclusive Flood Control Zones are reserved exclusively for regulation of the largest of floods and are generally empty. Figure 2-4 shows a profile of the mainstem projects, including the elevations of the projects and locations in river miles above the mouth of the Missouri River near St. Louis and also displays the relative proportion of storage capacity in each of the projects.

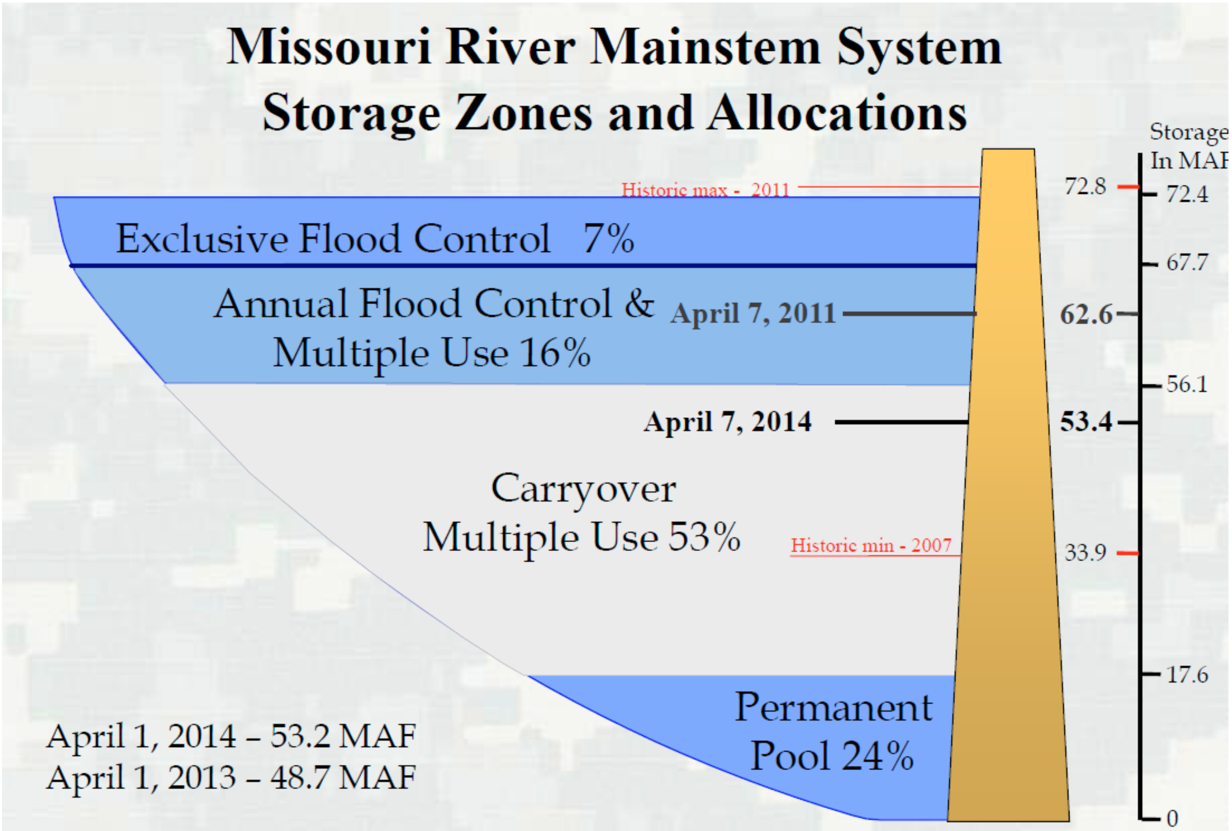


Figure 2-3: System storage zones.

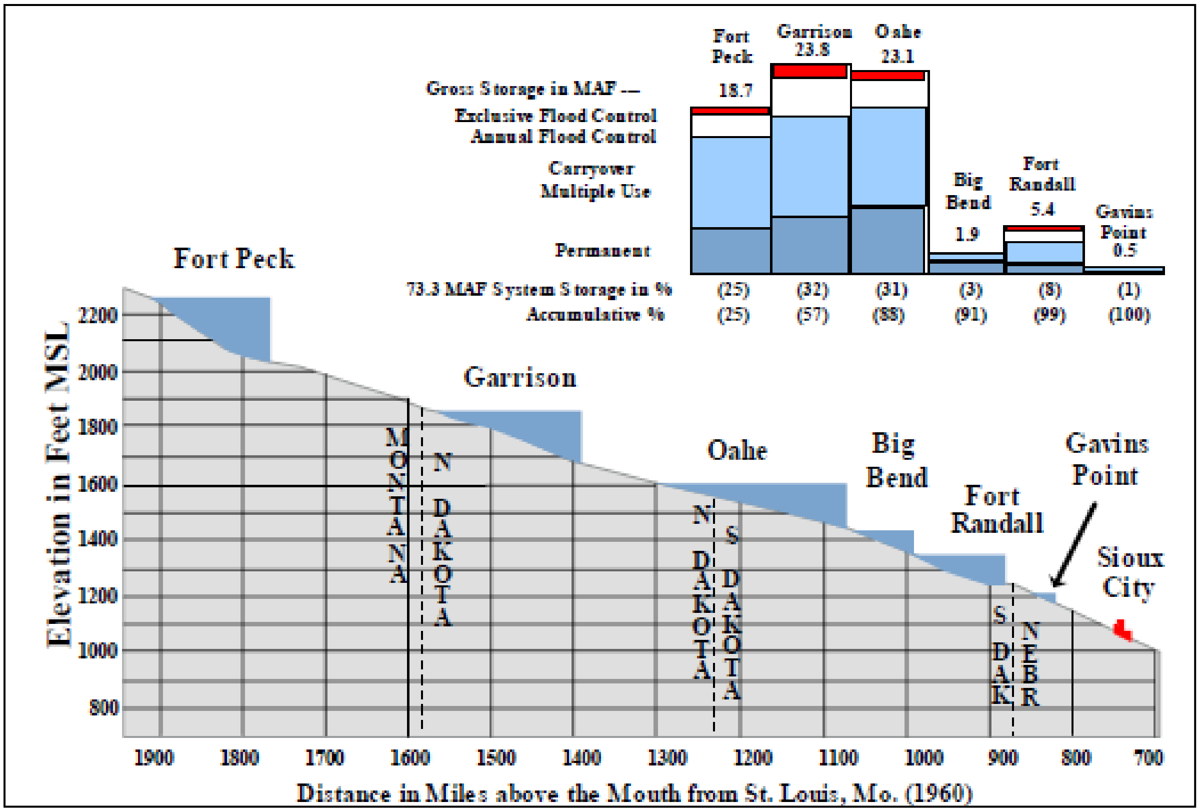


Figure 2-4: Profile of mainstem System and storage capacities

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 as shown in Figure 2-4. 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.

The individual projects are described briefly in the following sections, from upstream to downstream. Individual project descriptions were taken from the *Water Control Manual (WCM) Master Manual (Volume 1)* (U.S. Army Corps of Engineers, 2006). More detailed information on each project can be found in the Water Control Manual (WCM) for that specific project (Volumes 2-7). Other pertinent data for all projects are presented in the Summary of Engineering Data shown in Appendix A – Pertinent Data.

2.2.1 Fort Peck

Fort Peck Dam is located on the Missouri River at river mile (RM) 1772 in northeastern Montana, 17 miles southeast of Glasgow, Montana and 9 miles south of Nashua. Construction of the Fort Peck project was initiated in 1933 and embankment closure was made in 1937. The Fort Peck Dam embankment is nearly 4 miles long (excluding the spillway) and rises over 250 feet above the original streambed. Fort Peck Dam remains the largest dam embankment in the United States

(126 million cubic yards of fill), the second largest volume embankment in the world, and the largest "hydraulic fill" dam in the world. Fort Peck Lake is the third largest Corps reservoir in the United States. When full, the reservoir is 134 miles long. The concrete spillway is over 1 mile long. In 1943, the first unit of the power installation went on line, and the third unit became operational in 1951, completing construction of the first powerplant. Construction of a second powerplant began in the late 1950's and the two units of this plant became operational in 1961. The Permanent Pool Zone (inactive storage) of the reservoir was initially filled (elevation 2150) in April 1942 and the Carryover Multiple Use Zone (elevation 2234) first filled in 1947, 5 years later. Drought conditions during the late 1950's, combined with withdrawals to provide water for the initial fill of other System projects, resulted in a drawdown of the reservoir level to elevation 2167.4 in early 1956, followed by a generally slow increase in pool elevation. The Carryover Multiple Use Zone was finally refilled in July 1964. Generally, it has remained filled from that time with the exception of the droughts of 1987 to 1993 and 1999 to 2010. Exclusive flood control storage space was first used in 1969, and then again in 1970, 1975, 1976, 1978, 1979, 1996, 1997, and 2011.

2.2.2 Garrison

Garrison Dam is located in central North Dakota on the Missouri River at RM 1390, about 75 river miles northwest of Bismarck, North Dakota and 11 miles south of the town of Garrison, North Dakota. Construction of the project was initiated in 1946, closure was made in April 1953, and the navigation and flood control functions of the project were placed in operation in 1955. Garrison Dam is currently the fifth largest earthen dam in the world. The first power unit of the project went on line in January 1956, followed by the second and third units in March and August of the same year. Power units 4 and 5 were placed in operation in October 1960. Lake Sakakawea first reached its minimum operating level in late 1955. Due to the drought conditions it was not until 10 years later, in 1965, that the Carryover Multiple Use Zone was first filled. Generally, it remained filled from that time through 2002, except for the two drought periods to date. Exclusive flood control storage space was used in 1969, 1975, 1995, 1997, 2010 and 2011. Lake Sakakawea is the largest Corps reservoir. When full, the reservoir is 178 miles long and up to 6 miles wide. The reservoir contains almost a third of the total storage capacity of the System, nearly 24 MAF, which is enough water to cover the State of North Dakota to a depth of 6 inches.

2.2.3 Oahe

Oahe Dam is located on the Missouri River at RM 1072, 6 miles northwest of Pierre, South Dakota. Construction of Oahe Dam was initiated in September 1948. Closure of the dam was completed in 1958, and deliberate accumulation of storage was begun in late 1961, just before the first power unit came on line in April 1962. The last of the seven power units became operational in July 1966. Permanent Pool storage space in Lake Oahe was first filled in 1962 and the Carryover Multiple Use Zone was filled in 1967. Generally, the Carryover Multiple Use Zone remained filled from that time through 2002, except for seasonal drawdowns in the interest of increased winter power generation and the two drought periods to date. The Exclusive Flood Control Zone in Lake Oahe was used in 1975, 1984, 1986, 1995, 1996, 1997, 1999, 2010 and 2011. Lake Oahe is the second largest Corps reservoir, with just over 23 MAF of storage capability. When full, the reservoir is 231 miles long, with 2,250 miles of shoreline.

2.2.4 Big Bend

Big Bend Dam is located on the Missouri River at RM 987, near Fort Thompson, South Dakota and about 20 miles upstream from Chamberlain, South Dakota. Lake Sharpe extends 80 miles upstream to the vicinity of the Oahe Dam. The project is basically a run-of-the-river power development with regulation of flows limited almost entirely to daily and weekly power operations. Construction began in 1959, with closure in July 1963. The first power unit was placed on line in October 1964, and the last of the eight units began operation during July 1966. Since full operation began, the reservoir has been held very near the normal operating level of elevation 1420.

2.2.5 Fort Randall

Fort Randall Dam is located on the Missouri River at RM 880, about 6 miles south of Lake Andes, South Dakota. Lake Frances Case extends to Big Bend Dam. Construction of the project was initiated in August 1946, closure was made in July 1952, initial power generation began in March 1954, and the project reached an essentially complete status in January 1956, when the eighth and final unit of the 320,000-kilowatt installation came into service. The reservoir filling was initiated in January 1953 and reached the minimum operating pool elevation of 1320 feet on November 24, 1953.

2.2.6 Gavins Point

Gavins Point Dam is located on the Missouri River at RM 811 on the Nebraska-South Dakota border, 4 miles west of Yankton, South Dakota. Lewis and Clark Lake extends 37 miles to the vicinity of Niobrara, Nebraska. Construction was initiated in 1952, and closure was made in July 1955, with initial power generation beginning in September 1956. The third and final unit of the 100,000-kilowatt installation came into service in January 1957. Total project power generation has since been uprated to 132,000 kilowatts.

2.3 MISSOURI RIVER MAINSTEM SYSTEM OPERATIONS

The Missouri River mainstem system is very large and complex. The following sections summarize the mainstem System operation components as described in *Missouri River Mainstem Reservoir System: System Description and Regulation* (U.S. Army Corps of Engineers, 2007), but do not provide every detail of the Master Manual and individual project WCM's.

2.3.1 System Regulation

2.3.1.1 Overview

The System is regulated to serve the congressionally authorized purposes of flood control, navigation, hydropower, irrigation, water supply, water quality control, recreation, and fish and wildlife. Overall System regulation follows the "water control plan" presented in the Master Manual. Each of the six System dams also has an individual water control manual that presents more detailed information on its regulation. System regulation is in many ways a repetitive annual cycle. Most of the year's water supply is produced by runoff from winter snows and spring and summer rains which increase System storage. After reaching a peak, usually during July, System storage declines until late winter when the cycle begins anew. A similar pattern may be found in releases from the System, with the higher releases from mid-March to late-November, followed by low rates of winter releases from late-November until mid-March, after which the cycle repeats.

The Water Control Calendar of Events, shown in Figure 2-5, displays the time sequence of many of these cyclic events. The water control plan is designed to achieve the multipurpose objectives of the System given these cyclical events. The two primary high-risk flood seasons shown are the plains snowmelt season, which extends from late February through April, and the mountain snowmelt period, which extends from May through July. Runoff during both of these periods may be augmented by rainfall. The winter ice-jam flood period extends from mid-December through February. The highest average power generation period extends from mid-April to mid-October, with high peaking loads during the winter heating season (mid- December to mid-February) and the summer air conditioning season (mid-June to mid-August). The normal 8-month navigation season extends from April 1st through November 30th during which time System releases are scheduled, in combination with downstream tributary flows, to meet downstream target flows. Winter releases after the close of navigation season are much lower, and vary depending on the need to conserve or evacuate System storage while managing downstream river stages for water supply given ice conditions. Minimum release restrictions and pool fluctuations for fish spawning management generally occur from April through June. Gavins Point spring pulses, which are designed to cue spawning of the endangered pallid sturgeon, have been provided in March and May of some years. Nesting of the two federally protected bird species, the endangered interior least tern and the threatened piping plover, occurs from mid-May through mid-August.

Generally speaking, the System has three seasons per year. The Navigation season typically runs April 1 to December 1. The winter season goes from December 1 to March 1. The open water non-navigation season includes the March 1 to April 1 timeframe and may also include time between a shortened navigation season and the winter season.

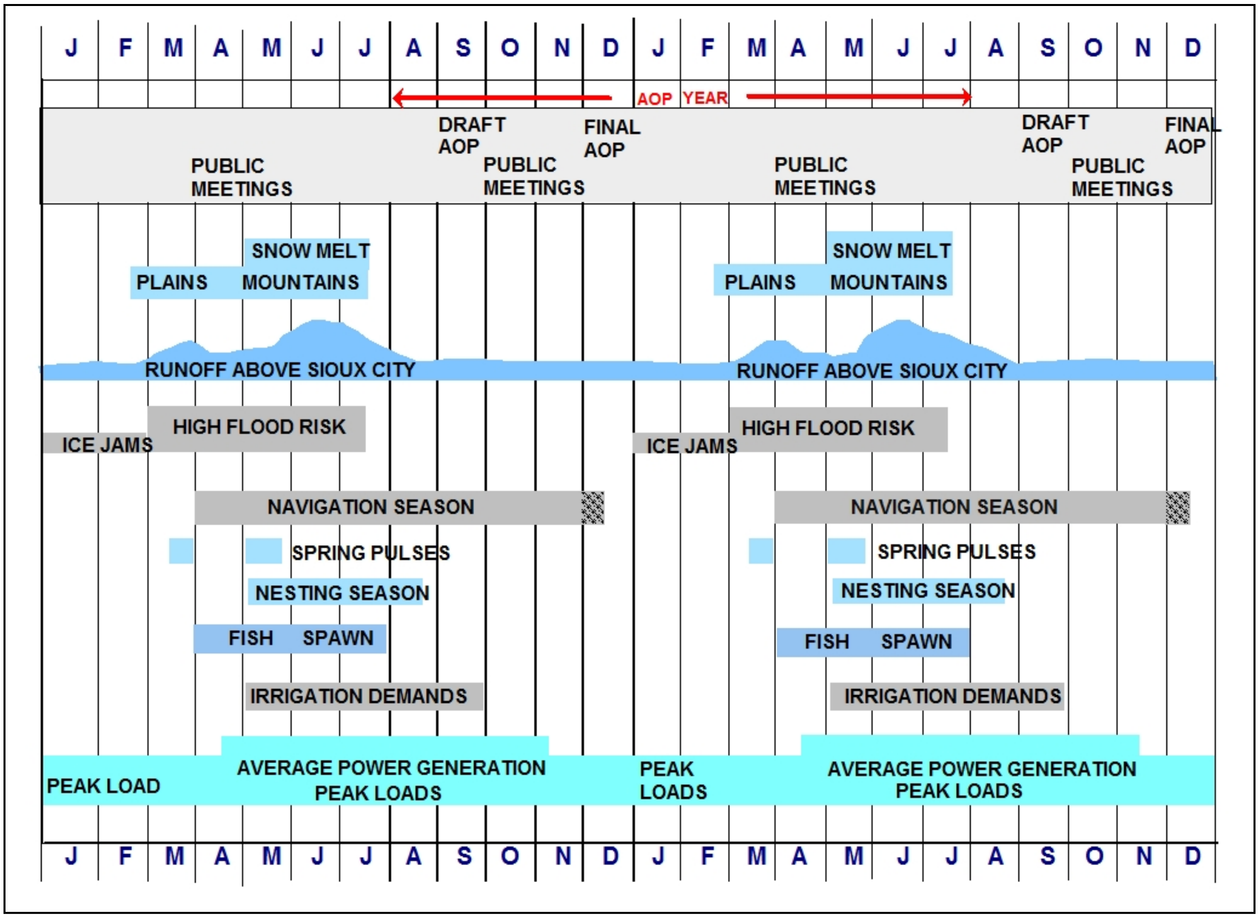


Figure 2-5: Water control calendar of events.

2.3.1.2 Intrasystem Regulation - General

Much of the flexibility of the System is derived from intrasystem regulation, or the transfer of water from one reservoir to another. This is due to the fact that System releases necessary to support downstream water requirements are defined within a relatively narrow range and inflow to the System is subject to only very minor regulatory control by upstream tributary reservoirs.

Intrasystem regulation is an important tool in the management of water in the System to meet the authorized purposes. It is used to regulate individual reservoir levels in the System to balance or unbalance the water in storage at each project, to smooth the annual System regulation by anticipating unusual snowmelt runoff, to maintain the seasonal capability of the hydropower system, and to improve conditions for the reservoir fish spawn and recruitment. It also can be used to maintain stages on the open river reaches between projects at desirable levels. Intrasystem adjustments may also be used to meet emergencies, including the protection of human health and safety, protection of significant historic and cultural properties, or to meet the provisions of applicable laws including the Endangered Species Act. These adjustments are made to the extent reasonably possible after evaluating impacts to other System uses, are generally short term in nature, and continue only until the issue is resolved.

The presence of large reservoirs in the System increases intrasystem regulation flexibility. A small reservoir such as Gavins Point with storage of less than one-half million acre-feet can only tolerate a large difference between inflow and release for less than a day. Big Bend is in this category as well. To a lesser extent, so is Fort Randall, although its carryover-multiple use and annual flood control and multiple use storage of nearly 3 MAF make possible significant storage transfers and flow differentials extending a month or more. But it is the upper three large reservoirs of Fort Peck, Garrison, and Oahe, with their combined 37.0 MAF of carryover multiple-use storage plus an additional 10.1 MAF of annual flood control multiple-use storage, that provide the flexibility to adjust intrasystem regulation to better serve authorized purposes.

2.3.1.3 Seasonal Intrasystem Regulation Patterns

Factors that influence intrasystem regulation may vary widely from year to year; however, regulation of the System generally follows a regular seasonal pattern. Some of these factors, such as the amount of System storage and the magnitude and distribution of inflow received during the year, can affect the timing and magnitude of individual System project releases. The levels of each of the six System reservoirs are checked on a daily basis and compared to the water control plan and the AOP. Adjustments to the amount of water transferred between reservoirs are made when necessary to achieve the desired volume of water in each project and to maximize power generation.

2.3.1.3.1 *Summer Release Patterns*

Intrasystem regulation to meet the needs of power generation follows a regular seasonal cycle. Releases from Gavins Point are generally at their highest during the navigation season when downstream flow requirements are highest. Since Gavins Point reservoir is small, these releases must be backed up with similar magnitude releases from Fort Randall, and Fort Randall, in turn, requires similar support flows from Oahe via Big Bend. Here the chain can be interrupted; Oahe is large enough to support high releases for extended periods without high inflows. Generation at Fort Peck and Garrison are held to lower levels during the summer to allow more winter hydropower production unless the evacuation of water accumulated in the flood control zones or the desire to balance or unbalance storage among the upper three projects becomes an overriding consideration.

2.3.1.3.2 *Winter Release Patterns*

With the onset of the non-navigation season, conditions are reversed. Gavins Point releases drop to about one-third to slightly greater than half of summer levels and the reduction in releases proceeds upstream, curtailing daily average releases from Fort Randall, Big Bend, and Oahe. At this time, Fort Peck and Garrison daily releases are usually maintained at relatively high levels (within the limits imposed by downstream ice cover) to partially compensate for the reduction of generation downstream where high winter releases could result in significant flood damages in urban areas when the formation of ice impedes the flow.

2.3.1.3.3 *Drawdown of Fort Randall Reservoir*

An additional means of partially compensating for the reduced hydropower generation associated with the lower winter release rate from Gavins Point is the autumn drawdown of Fort Randall reservoir. In this regulation, releases from Oahe and Big Bend are reduced several weeks before the close of the navigation season. This leaves Fort Randall with the task of supplying a large portion of downstream flow requirements for the remainder of the navigation season, a process that results in evacuation of a portion of its carryover storage space. This vacated carryover storage space is then refilled with higher releases from Oahe and Big Bend during the non-navigation season, allowing winter releases from the upstream projects to substantially exceed those from Fort Randall.

Fort Randall reservoir is normally drawn down to 1337.5 feet msl, which provides about 1,200,000 acre-feet of recapture storage capacity. During severe drought periods, the flexibility exists to draw down to elevation 1320.0 feet msl. This provides an additional recapture space of about 800,000 acre-feet and increases the average winter energy generation about 150 million kilowatt hours (kWh).

2.3.1.3.4 *Recapture at Oahe*

While not as significant (in terms of pool level fluctuation) as the drawdown and recapture regulation plan at Fort Randall reservoir, a similar recapture regulation plan at Oahe is coordinated with upstream Garrison and Fort Peck releases to significantly increase the amount of winter energy generation. During the 4-month winter period, Garrison releases normally can be expected to be at least 1 MAF more than Oahe releases. Recapture of these upstream releases generally results in a rise of about 5 feet or greater in Oahe reservoir elevation during the winter months, depending on the current storage level and whether the upper three reservoirs are intentionally unbalanced.

2.3.1.3.5 *Balancing/Unbalancing the Upper Three Reservoirs*

In the past, the percentage of occupied storage in each of the upper three reservoirs was balanced at the beginning of March of every year. However, intentionally unbalancing the water stored in the upper three reservoirs can benefit the reservoir fisheries and increase tern and plover habitat. However, drought conditions, flood risk concerns, and other reasons have prevented implementation of reservoir unbalancing.

2.3.1.4 Short-Term Intrasystem Adjustments

The interaction among projects described above, repeated as it is year after year, might make intrasystem regulation appear to be a routine and rigid procedure. However, routine regulation is often disrupted by the short-term extremes of nature. Heavy rains may raise river stages near the flood level, necessitating a release reduction at one project and a corresponding increase at others. Very hot or very cold weather may create sharp increases in the demand for power. Inflows for a week or for a season may concentrate disproportionately in one segment of the System, causing abrupt shifts in regulating objectives. In addition, short-term intrasystem adjustments are occasionally required to meet emergencies, including the protection of human health and safety, protection of significant historic and cultural properties, or to meet the provisions of applicable laws, including the Endangered Species Act. These adjustments are made to the extent possible after evaluating impacts to other System uses, are generally short term in nature, and continue only until the issue is resolved.

2.3.1.5 Project Release Limits

Limitations imposed upon System regulation (maximums and minimums) are related not only to System or individual project storage, which is varied in accordance with the flood control restrictions previously given and the requirements for active storage pools, but also to releases.

2.3.1.5.1 *Maximum Rates – Summer*

During the summer, releases at all projects other than Gavins Point are normally within the powerplant release capacity, the river channel downstream usually being more than adequate to carry such releases. Releases from all projects will usually be made through the powerplant. At times, support for the downstream navigation flows may require releases from Gavins Point in excess of powerplant capacity. At all projects, special regulation considerations may require releases bypassing the powerplants but usually for only relatively short periods of time. Unusually large inflows during any particular year may require significant releases beyond those through the powerplants at any or all projects to evacuate flood waters and thereby maintain the future flood control capability of the System.

2.3.1.5.2 *Maximum Rates – Winter*

Releases are more restricted during the winter period. Complete ice cover can be expected to form over northern portions of the Missouri River every winter and minor ice cover occasionally as far downstream as the river's mouth. During and after formation, this ice cover significantly reduces the flow capacity of the river channel. In addition, during periods of ice formation and subsequent breakup, a substantial risk of ice jam formation and associated flooding exists. The maximum allowable winter releases are those that will not significantly increase the probability of flooding or intensify potential flooding during periods of ice cover. In the upper Missouri River, releases may be limited during periods of ice formation and then gradually increased once a stable ice cover is in place. Once formed, the ice cover can be expected to remain through the winter. Below Sioux City, ice formation or ice breakup can occur repeatedly throughout the season and may also jeopardize downstream navigation structures such as dikes and revetments. Since the travel time of any release from the System to areas of vulnerability is much longer than the time for which reliable forecasts of such events can be made, it is necessary to schedule winter System releases at a conservative level. During periods of normal or below water supply, winter releases from Gavins Point range from 9,000 cubic feet per second (cfs) to 17,000 cfs. During years with low winter releases, ice formation can result in significant stage reductions on the lower river; therefore, it is often prudent to increase System releases prior to the onset of river ice forming or even during a significant jam to maintain adequate stages at water intakes. Experience during recent years indicates that increasing System releases speeds the recovery of the river to more normal stages and assures that the downstream water intakes are operational sooner or affected less by the icing conditions. The maximum daily winter release from Gavins Point usually ranges between 12,000 and 25,000 cfs. With an excess water supply and evacuation of flood control storage space as a primary consideration, an average Gavins Point release rate of between 25,000 and 30,000 cfs is scheduled. The extent and location of river ice cover is important in determining the release rate. Experience accumulated during past winters indicates that at times it may be necessary to reduce System releases below these levels when bank full to slightly above bank full stages occur in the Nebraska City to St. Joseph reach of the Missouri River.

No daily release limitations exist at Big Bend, where releases are made almost directly into the downstream reservoir area of Fort Randall. The maximum ice-covered channel capacity below Fort Peck and Garrison are estimated to be about 15,000 and 27,000 cfs, respectively, except during ice formation. Releases are limited to lower levels while the river initially freezes because the ice cover is usually rough and jagged, which creates a less efficient channel and causes river stages to increase. Releases are increased once the ice cover and streambed have stabilized and both have smoothed sufficiently to accommodate increased releases without increasing river stages. Winter releases from Fort Randall are generally 1,000 to 2,000 cfs lower than those from Gavins Point, but during periods of ice formation may be scheduled at or slightly higher than Gavins Point releases to prevent rapid declines in the Gavins Point pool elevation. At Oahe, peak hourly releases may be constrained to prevent urban flooding in the Pierre and Fort Pierre areas if severe ice conditions develop below the project.

2.3.1.5.3 *Minimum Releases*

There are no minimum daily flow requirements from Oahe or Big Bend except that, to the extent possible, weekend releases from Oahe are typically held above 3,000 cfs during the daytime hours of the recreation season in the interest of downstream fishing and boating. In addition, during periods of ice formation a one-unit minimum may be imposed at Oahe to prevent ice formation in the channel directly below the dam. Minimum daily releases from Fort Peck and Fort Randall are typically maintained during the fish spawning seasons. Fort Peck also has a year-round instantaneous minimum release of 3,000 cfs for the trout fishery below the dam. During periods of high inflow below the project, releases may be scheduled below 3,000 cfs for flood damage reduction, but these instances are rare. Minimum daily releases at Fort Peck, Garrison, Fort Randall, and Gavins Point are established as those necessary to supply water quality control and downstream water intake requirements, which generally also furnish more than an adequate quantity of water for irrigation withdrawals below the reservoirs. At Garrison a minimum average daily release of 9,000 cfs has been established as a guide to provide for downstream intakes. Access problems have been experienced at municipal, industrial, powerplant, and irrigation intakes along the length of the river due to channel degradation, inadequate intake screens, sandbar formation, winter ice formation, or relatively high elevation of the intakes. Temporary increases above the open-water minimum release rates may be made to the extent reasonably possible to allow intake owners to take remedial action.

2.3.1.5.4 *Hourly Fluctuation of Release Rates*

At all projects except Gavins Point, hourly release rates may vary widely as necessary to meet fluctuating power loads. Gavins Point is operated for water targets so no hydropower peaking occurs. Minimum hourly release restrictions are applicable at Fort Peck and Garrison due to downstream intakes. A uniform peaking release pattern has been established during the summer months at Garrison and Fort Randall for endangered birds nesting along the river below the projects, and may be reinstated at Fort Peck if nesting patterns deem it necessary.

2.3.2 Recurring Operational Considerations

2.3.2.1 Flood Control

Flood control is the only authorized project purpose that requires the availability of empty storage space rather than impounded water. Actual flood events are generally unpredictable; therefore, detailed routing of specific major flood flows is accomplished when floods occur. There is a recurring pattern of high-risk flood periods during each year: a season when snowmelt, ice jams, and protracted heavy rains will almost surely occur with or without generating consequent floods; and a season when these situations are most unlikely and the flood threat is correspondingly low. The high-risk flood season begins about March 1st and extends through the summer. As a consequence, regulation of the System throughout the fall and winter months is predicated on the achievement of a System storage level at or below the base of the annual flood control zone by the start of the runoff season, approximately March 1st. Exceptions to this will occur due to the availability of replacement flood control storage in major upstream tributary reservoirs.

Due to release limitations imposed by the formation of a downstream ice cover, a major portion of the required flood control space in the System must be evacuated prior to the winter season. Gavins Point winter releases exceeding 25,000 cfs are not normally scheduled. In general, individual System projects will also be scheduled to be near or below their respective base of annual flood control by March 1st. Some departure is possible due to the availability of upstream tributary flood control storage space, and/or recognition of the relative difficulty or ease by which the water in storage may be transferred downstream to other projects in the System during the winter or during the flood season.

During all but excessively dry years, water stored in the reservoirs will increase during the March-July period. The base of exclusive flood control defines the maximum level of storage that will be accumulated for purposes other than flood control. Water stored in the annual flood control and multiple-use zones will normally be released through the powerplant of each of the individual projects except when evacuation of this zone prior to the winter season necessitates higher flow rates requiring outlet tunnel or spillway releases. When the exclusive flood control zone in a particular reservoir is encroached upon, the control of subsequent flood inflows becomes the paramount factor. During such periods, releases may substantially exceed the powerplant release capacity with the evacuation rate of any project dependent upon existing flood conditions, the potential for further inflows, and conditions of other reservoirs in the System. Maximum release rates at such times are based upon the Master Manual flood control criteria and the flood control status of the System. Detailed information regarding the adjustment of service levels for flood control evacuation and downstream flood control constraints can be found in Chapter 7 of the Master Manual.

Below Fort Peck, minor downstream flooding will occur when open-water flows exceed 35,000 cfs. Open-water channel capacity below each of the other reservoirs was approximated at 100,000 cfs or more at the time the reservoirs were constructed (1950's). In addition, releases may need to be reduced to less than the immediate downstream channel capacity due to uncontrolled actual and potential tributary flows below each project, particularly below Gavins Point, Garrison, and Fort Randall.

Guidance from the Daily Routing Model (DRM) and discussions with the Missouri River Basin Water Management (MRBWM) team suggested channel capacities listed in the rules tables in Section 4.3.2.

2.3.2.2 Water Requirements Below Gavins Point

Just as the water supply and upstream uses must be evaluated each year to determine the net supply into the System, so must System release rates be established. This is the only means of regulating the System storage, since the weather and its resultant effects are not subject to control. Daily releases from Gavins Point, commonly referred to as the System releases, fall into two classes. Open-water releases, generally in the range of 21,000 to 35,000 cfs, are made in support of Missouri River navigation and other downstream uses. In years with above-normal water supply or extended periods of downstream flooding, the navigation releases are increased to the extent necessary to evacuate the flood control storage space by the succeeding March, with due consideration of reduced channel capacities during the winter ice-cover period. System releases during the non-navigation season generally range from 9,000 to 30,000 cfs, and are made for water supply, water quality control, power production, and flood evacuation purposes.

2.3.2.2.1 *Navigation Season Requirements*

The Missouri River navigation channel extends for 734.8 miles from near Sioux City, Iowa (River Mile 732.3) to the mouth (River Mile 0) near St. Louis, Missouri. Navigation on the Missouri River is limited to the normal ice-free season with a full-length season normally extending from April 1st through November 30th at the mouth. To permit a viable navigation industry during the ice-free months, it is desirable to maintain navigable flows throughout this 8-month period. During past navigation seasons in years of adequate water supply, 10-day extensions either at the beginning or end of this normal season have been scheduled, downstream river ice conditions permitting.

Construction of the navigation works was declared complete in September 1981. In years with adequate water supply, System releases are scheduled to provide adequate flows for navigation at the target locations of Sioux City, Omaha, Nebraska City, and Kansas City, if navigation is occurring on the reaches associated with those targets. If navigation is not occurring in one or more upstream reaches, flows may be allowed to fall below the respective targets, depending on the needs of other authorized project purposes at the time. The target flows increase in a downstream direction because of the increased flow requirements needed to maintain corresponding navigation channel widths and flow depths with naturally increasing channel dimensions. The assignment of target flows is based upon available water supply that, when combined with winter releases needed to ensure water supply requirements and winter hydropower demand, obligates all of the available water supply during a normal year. These target flows may need to be evaluated and adjusted periodically to ensure compatibility between available water supply and current navigation channel conditions.

2.3.2.2.2 *Navigation Service Level and Season Length*

As described in the Master Manual, flow support for navigation and other downstream purposes is defined based on service level. Full service, 35,000 cfs, results in target flows of 31,000 cfs at Sioux City and Omaha, 37,000 cfs at Nebraska City and 41,000 cfs at Kansas City. Similarly, a minimum service, 29,000 cfs, results in target flow values of 6,000 cfs less than the full-service target flows.

Day-by-day regulation of the System to support navigation requires forecasts of inflow to the various river reaches below the System. These daily forecasts, along with anticipated navigation traffic or the absence of traffic in the various river reaches, are used to determine the target location (Sioux City, Omaha, Nebraska City, or Kansas City). After determining the target location, releases from the System are adjusted so that, in combination with the forecast tributary inflows, the resultant flow will meet the target flow at the control location. During periods when the target location is Kansas City, navigation flow support can also be provided from three Kansas basin reservoirs (Tuttle Creek, Milford, and Perry) since those projects are authorized to support Missouri River navigation. This regulation conserves water in the System and may also minimize incidental take of the Endangered Species Act (ESA)-protected species.

Regulation experience has shown that the full-service target flows will be adequate to maintain the designed 9-by-300-foot channel with a minimum of groundings and little or no emergency dredging. Slightly greater flows are required at the mouth (approximately 45,000 cfs) but tributary flows below Kansas City are usually adequate to provide the needed incremental flows.

Selection of the appropriate service level is based on the actual volume of System storage on March 15th and July 1st of each year. During years when flood evacuation is required, the service level is calculated monthly, or more frequently if required, to facilitate a smooth transition in System release adjustments.

The water control plan calls for suspension of Missouri River navigation if System storage is at or below 31 MAF on March 15th of any year. It should be noted that the occurrence of System storage at or below 31 MAF would likely coincide with a national drought emergency.

Assuming the System storage is above 31 MAF on March 15th, a navigation season will be supported. The System storage check for navigation season length is made on July 1st of each year. A full 8-month navigation season will be provided if System storage is 51.5 MAF or above on July 1st, unless the navigation season is extended to evacuate flood control storage. However, if System storage falls below 51.5 MAF on July 1st, a shortened navigation season will be provided to conserve water.

The System release required to meet minimum- and full-service target flows varies by month in response to downstream tributary flows. In general, higher releases are needed to meet flow targets during years with below normal runoff in the upper basin than during years with higher upper basin runoff. The target location early in the season is generally at Sioux City with adequate tributary flows meeting the other downstream flow targets. Tributary flows normally decrease during the summer and the target location moves from Sioux City to Nebraska City, and then to Kansas City as the runoff season progresses. This requires higher releases from the System as the season progresses through summer. Often the target location moves upstream during the fall as downstream tributary flows traditionally increase. With normal inflows below the System, Sioux City flows will average about 35,000 cfs over the entire 8-month navigation season during periods when full-service navigation targets are utilized for System regulation.

2.3.2.2.3 *Release Patterns during Nesting Season*

In general, releases from Gavins Point are adjusted as needed to meet target flow levels on the lower Missouri River, taking advantage of downstream tributary runoff. However, during the nesting season of the endangered interior least tern (tern) and the threatened piping plover (plover), care must be taken to avoid impacts to nesting areas. These two bird species are listed as threatened and endangered under the ESA and are protected under that Act. Several scenarios have been used in past years to regulate the System during the nesting season. Under the Steady-Release (SR) scenario, when the birds begin to initiate nesting activities in early to mid-May, the release from Gavins Point is set to the level expected to be required to meet downstream flow targets through August and maintained at that level until the end of the nesting season. This regulation results in releases that exceed the amount necessary to meet downstream flow targets during the early portion of the nesting season, and may result in targets being missed if basin conditions are drier than expected during the summer.

Gavins Point releases under the Flow-to-Target (FTT) scenario are adjusted as needed throughout the nesting season to meet downstream flow targets and would typically result in increasing releases as the nesting season progresses. This is due to reduced tributary inflows downstream as the summer heat builds, evaporation increases, and precipitation diminishes. Increasing releases as the nesting season progresses has the potential to inundate nests and chicks on low-lying emergent sandbar habitat. Compared to the SR scenario, this scenario conserves more water in the System, which keeps the reservoirs at the upper three System projects at relatively higher levels. However, this scenario also increases the risk of inundating nests. The FTT scenario also ensures that targets on the lower river are met throughout the nesting season.

A third scenario for Gavins Point releases combines features of the other two options. This scenario, called the Steady Release – Flow-to-Target (SR-FTT) scenario, sets Gavins Point releases at an initial steady rate and then allows releases to be adjusted upward or downward during the nesting season to meet downstream flow targets, if necessary. Depending on the rate of the initial steady release, this regulation makes a larger amount of habitat available early in the nesting season and saves additional water in the upper three reservoirs when compared to the SR scenario. The SR-FTT scenario also reduces the potential for flooding nests when compared to the FTT scenario. The SR-FTT regulation also provides certainty for downstream users that releases could be increased if needed to meet Missouri River flow targets.

Under each of these regulation scenarios, releases from Gavins Point may be increased every third day to encourage terns and plovers to build their nests on higher habitat so that the nests would not be inundated later when higher releases are required to meet the regulation objectives of the System. This pattern of increasing releases every third day is referred to as “cycling”. Cycling is generally not used during years when System storage is high but has been used during extended drought, when water conservation is of primary importance. Cycling is suspended when endangered and threatened chicks hatch to reduce the risk of stranding chicks on low-lying sandbars. Unfledged chicks can be lost if stranded on low-lying sandbars that are subsequently totally inundated. Cycling of Gavins Point releases when releases are reduced for downstream flood control during the protected bird species nesting season has also been used to keep birds nesting at sufficiently high elevations to maintain room for release increases when downstream flooding has subsided. The daily variation in releases is normally limited to 8,000 cfs to minimize adverse effects on downstream river users and fish.

2.3.2.2.4 *Non-navigation Season Requirements*

When releases are not being made for downstream flow support during navigation season, other factors, including water quality control and water supply, are used to establish the System release rates. System project release levels necessary to meet downstream water supply purposes generally exceed the minimum release levels necessary to meet minimum downstream water quality requirements. The minimum daily flow requirements established for water supply are designed to prevent operational problems at municipal and thermal powerplant intakes.

In years of excess inflows and storage, several options are utilized to evacuate flood control storage, including an extension of the navigation season, increased winter releases, and the provision of summer and fall releases above full service. Because releases above full service increase the risk of downstream flooding, the first option normally utilized is up to a 10-day extension of the navigation season. This increases the service to navigation by providing a longer season and to hydropower by increasing the amount of winter energy generation. If additional evacuation is required, winter releases are increased to evacuate flood control storage, and finally, the summer and fall service levels are increased. Increasing winter releases slightly increases the risk of minor ice-induced flooding; however, open-water flooding during the summer and fall has a higher flood damage potential because of the value of the agricultural crops on the floodplain at that time of year. Moderate increases above full-service requirements during the open-water summer and fall season can be beneficial to the navigation and power purposes.

With normal or below normal inflows and storage, conservation measures may be implemented that reduce navigation and hydropower releases during the open-water season based on System storage, and may provide less than full-service navigation flows and season lengths of less than 8 months as described previously. Winter System releases are also reduced as a drought conservation measure. The winter System release rate is determined based on a September 1 System storage check. This release rate in combination with average downstream tributary flows is normally sufficient to meet downstream water supply intake requirements, but may be adjusted based on tributary flows and the potential for ice formation. In an extended drought, System releases from Gavins Point may be reduced to a level that results in only the minimum flows necessary for downstream water intake or water quality requirements. Based on typical downstream tributary flow contributions, the minimum releases are 9,000 cfs during the non-summer open-water season (March-April and September- November), 18,000 cfs during the summer open-water season (May-August), and 12,000 cfs during the winter period (December-February). These minimum releases for downstream water intakes are average values; actual releases may vary significantly from the listed values.

2.3.2.3 Water Requirements Above Gavins Point

2.3.2.3.1 *Water Supply*

The minimum releases established for water supply are designed to prevent operational problems at municipal and thermal powerplant intakes at numerous locations along the Missouri River.

At Fort Peck, a minimum daily average release of 3,000 cfs is satisfactory for municipal water supply. During periods of high inflow below the project, releases may be scheduled below 3,000 cfs for flood damage reduction, but these instances are rare. To the extent possible, releases are maintained above 6,000 cfs during the irrigation season.

At Garrison, it is desirable to maintain minimum average daily releases of at least 9,000 cfs during the open-water season and the ice-cover season to provide sufficient river depths for continued operation of municipal, irrigation, and powerplant water intakes in North Dakota. In this reach of the river, as well as that below Fort Peck, fluctuations in release levels at times require the resetting of irrigation pumping facilities to maintain access to available water or to prevent inundation of pumps.

2.3.2.3.2 *Power Production*

Since the completion of the power production facilities at the System projects, virtually all project releases have been made through the respective powerplants. When releases are exceptionally high due to flood control storage evacuation, spillway releases are necessary at Gavins Point and Fort Randall and on rare occasions at Fort Peck and Garrison. The six System dams support 36 hydropower units with a combined plant capacity of 2,524 megawatts (MW) of potential power generation. These units provide an average of 9.3 million megawatt-hours (MWh) of energy per year. WAPA markets hydroelectric energy and capacity from the System. Firm energy is marketed on both an annual and a seasonal basis, recognizing the seasonal pattern of releases made for navigation and required for flood control. During the navigation season, releases from the four uppermost reservoirs are varied in an effort to generate the greatest amount of energy at the times the power loads are the greatest. During the winter period, the most critical with respect to maintaining load requirements, releases from Fort Peck and Garrison are scheduled at relatively higher rates as permitted by the downstream ice cover to compensate for reduced power production at the downstream powerplants. The fall drawdown at Fort Randall makes available space for recapture of winter power releases from upstream reservoirs.

3 DATA

3.1 GIS DATA

GIS (ArcGIS 10) was used to create the ResSim stream alignment, computation points and reservoirs, and background maps (see Figure 3-1). The stream alignment was created from multiple sources. The Missouri and Mississippi Rivers were created by converting river mile point files (gathered from NWK and MVS, respectively) to polylines. Inflow tributaries were primarily digitized from background imagery from the mainstem to the first upstream tributary gage; however, the upper Missouri, Yellowstone, Kansas, Chariton, and Osage Rivers used a combination of source data and were extended using a coarser river shapefile provided by MRBWM. The Kansas, Chariton, and Osage Rivers were primarily created by NWK. Stream alignments for ResSim were imported directly from the polylines shapefiles.

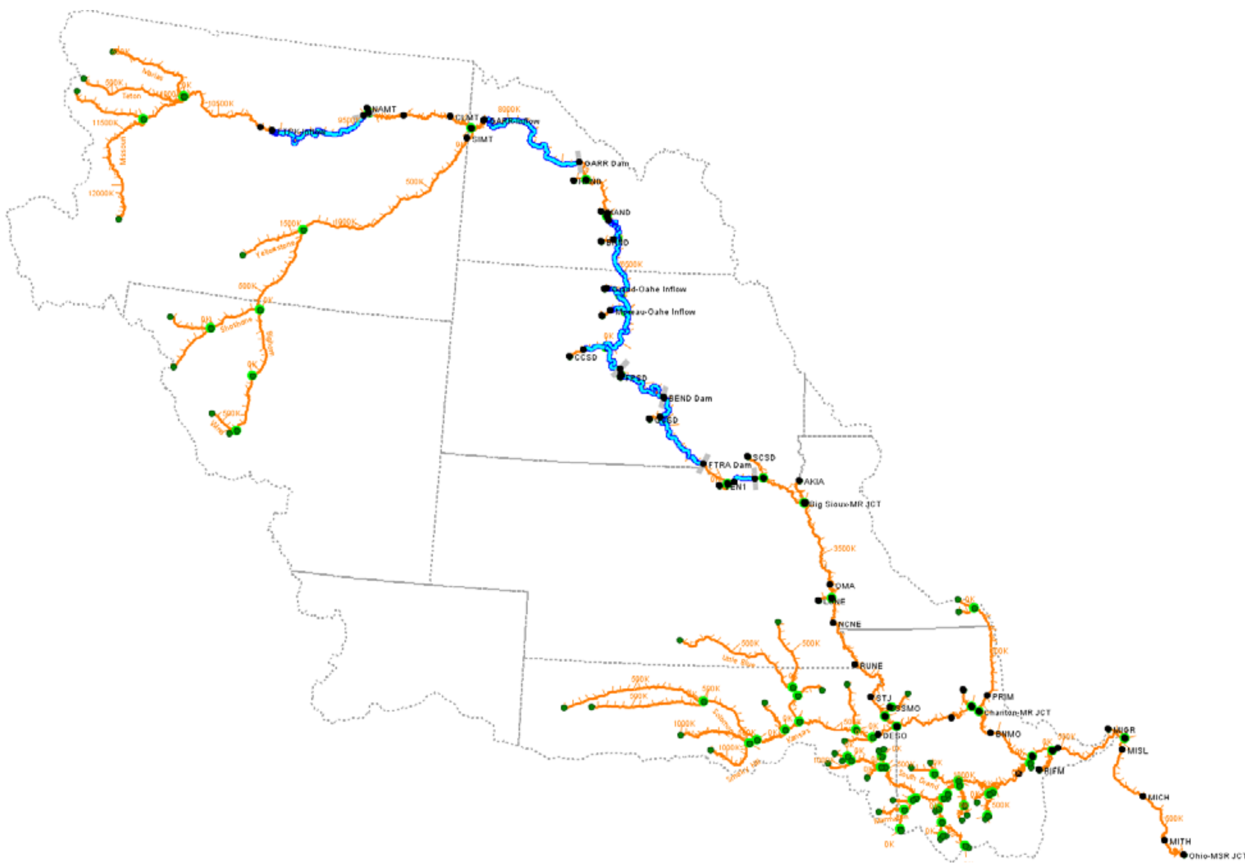


Figure 3-1: ResSim stream alignment and computation points.

ResSim model computation points were created for all gages, junctions, dams, and reservoir inflows in GIS. Missouri and Mississippi River stream gages and dams were located and placed by river mile. Confluence points were created based on the intersection of stream alignments. Mainstem reservoir inflow points were approximated based on information regarding the length of the reservoirs from the Master Manual, with a couple exceptions: BEND-Inflow was moved to 1 mi downstream of Bad River-MR Junction, and FTRA-Inflow moved to 1 mi downstream of Big

Bend. At the time configuration was created, ResSim did not have a tool to directly import computation points, so they were imported directly into the Watershed interface using HEC-WAT. Table 3-1 provides the primary gages on the mainstem Missouri River, their identifying abbreviation, and their location. Figure 3-2 provides a GIS overview of the ResSim project study area.

Table 3-1: Mainstem Gage ID and Locations.

DCP 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
FTRA	Missouri River at Fort Randall
BEND	Missouri River at Big Bend
OAHE	Missouri River at Oahe
BIS	Missouri River at Bismarck, ND
GARR	Missouri River at Garrison
CLMT	Missouri River at Culbertson, MT
WPMT	Missouri River at Wolf Point, MT
FTPK	Missouri River at Fort Peck
RBMT	Missouri River at Landusky (Robinson Bridge), MT

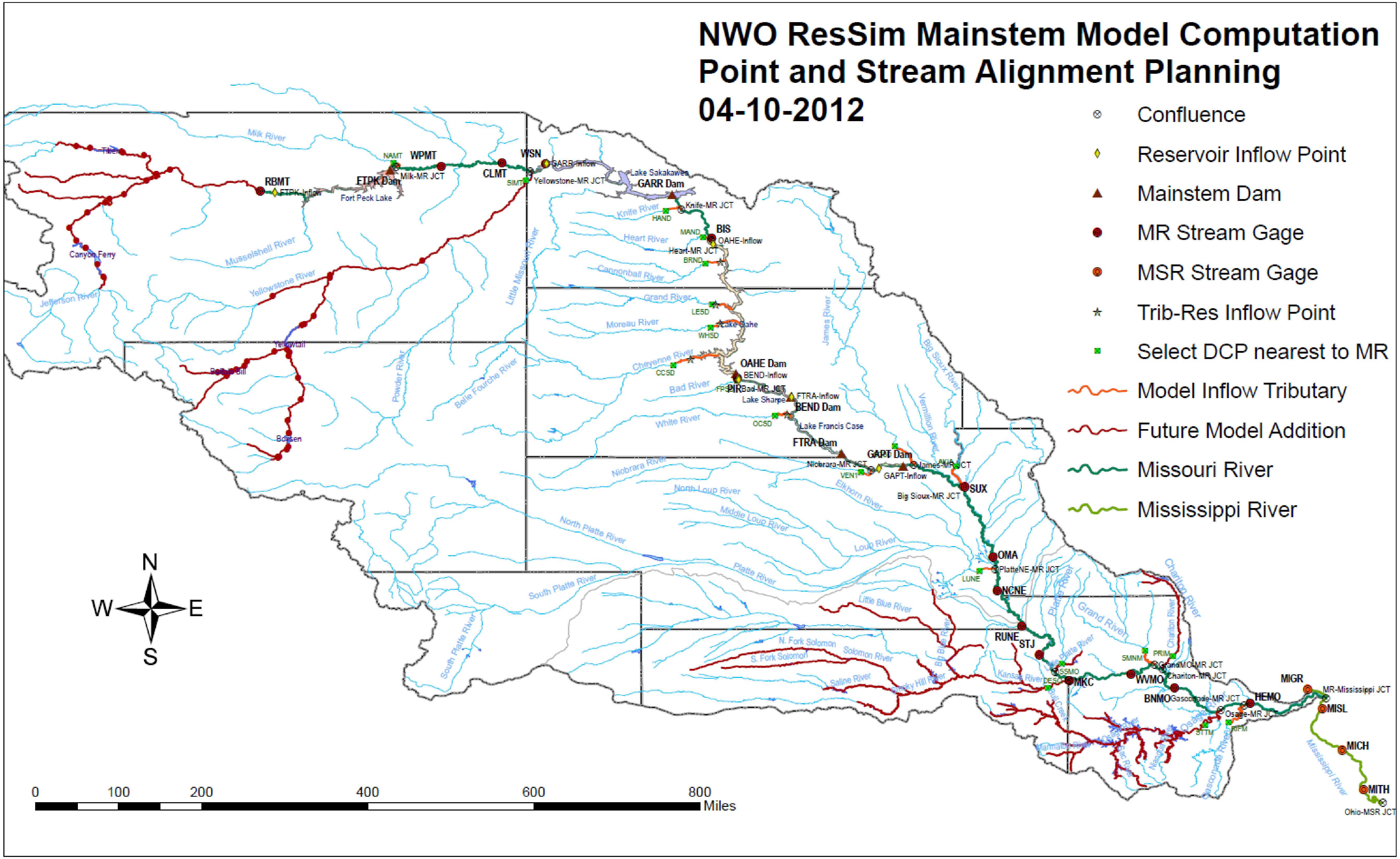


Figure 3-2: GIS study map.

3.2 OBSERVED DATA

To create a complete flow data set for the entire period of record (POR) from 1898-2011, several different sources of data (defined in the following sections) were necessary. USGS gage data and observed inflow/outflow data from MRBWM (mrrppcs-rev timeseries 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 *Upper Mississippi River System Flow Frequency Study* (UMRSFFS) data did not extend upstream of Sioux City prior to the completion of the reservoirs. 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 1 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. For all locations at Sioux City and downstream, the UMRSFFS “observed” data was used.

Final POR data for use in ResSim is stored in the DSS file “Input_Data.dss”. The data used for the final POR construction at each gage is shown in Table 3-2.

Table 3-2: Sources for POR data set construction.

Gage	Time Period	Source
RBMT	1898-2011	Upper Missouri ResSim
FTPK	1898-1937	DRM, no dams no depletions
	1938-2011	MRBWM
WPMT	1898-1928	DRM, no dams no depletions
	1929-2011	USGS
CLMT	1898-1938	DRM, no dams no depletions
	1938-1941	DRM, observed
	1941-1952	USGS
	1952-1958	DRM, observed
	1958-2011	USGS
GARR	1898-1938	DRM, no dams no depletions
	1938-1954	DRM, observed
	1954-2011	MRBWM
BIS	1898-1927	DRM, no dams no depletions
	1928-2011	USGS
OAHE	1898-1929	DRM, no dams no depletions
	1930-1959	DRM, observed
	1959-2011	MRBWM
PIR	1933-1965	USGS
BEND	1898-1929	DRM, no dams no depletions
	1930-1963	DRM, observed
	1963-2011	MRBWM
FTRA	1898-1929	DRM, no dams no depletions
	1930-1952	DRM, observed
	1953-2011	MRBWM
GAPT	1898-1929	DRM, no dams no depletions
	1929-1955	DRM, observed
	1955-2011	MRBWM
SUX	1898-1928	UMRSFFS
	1929-1931	USGS
	1932-1938	UMRSFFS

Gage	Time Period	Source
	1938-2011	USGS
OMA	1898-1928	UMRSFFS
	1928-2011	USGS
NCNE	1898-1929	UMRSFFS
	1929-2011	USGS
RUNE	1898-1949	UMRSFFS
	1949-2011	USGS
STJ	1898-1928	UMRSFFS
	1928-2011	USGS
MKC	1898-1928	UMRSFFS
	1928-2011	USGS
WVMO	1898-1928	UMRSFFS
	1928-1977	USGS
	1977-1978	UMRSFFS
	1978-2011	USGS
BNMO	1898-1925	UMRSFFS
	1925-2011	USGS
HEMO	1898-1928	UMRSFFS
	1928-2011	USGS
MISL	1898-2011	USGS

3.2.1 USGS

USGS data were considered the most accurate data option and were used for flow data at all locations and time periods for which it was available. USGS data was imported from the USGS website using HEC-DSSVue.

3.2.2 MRBWM

The MRBWM Division data were used for reservoir inflow, outflow, storage, and energy data at each reservoir location after that reservoir was online. This was the best data available at 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 an input data set, 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.

3.2.3 UMRSFFS

The UMRSFFS was completed in 2004 by a task force consisting of team members from USACE, USGS, NWS, USBR, NRCS, FEMA, 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. The daily flow data from this study were used in the ResSim model for locations downstream of Gavins Point dam when USGS data were not available. More information on modeling associated with the UMRSFFS can be found in the study report.

3.2.4 DRM

The DRM was developed by MRBWM in 1997. It is used for long range planning studies. DRM data was the only data available for most locations upstream of Gavins Point prior to the completion of the reservoirs. These flow data were used for locations and time periods when USGS, MRBWM, and UMRSFFS data were unavailable. More detail on the assumptions and operation of the DRM program can be found in the *DRM User's Manual (USACE, 1997)* and the *Mainstem Master Manual (2006)*.

3.2.5 USBR Depletions

USBR provided 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, which for this set of depletions, was 2007. The USBR HUC8 depletions were used to calculate local and total depletions at the DCP 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 did 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. 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. Table 3-3 lists the factors associated with the DCP locations and corresponding HUC8's.

In some cases the USBR depletions, when added to the local flow datasets, produced very large negative inflows. These large negative inflows have a substantial impact on reservoir operations and can cause issues with other models. At the time of this report, a draft document was being completed that assessed the USBR depletions and how to apply them to local flow datasets in the Missouri River Basin.

Table 3-3: 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**	

3.3 ROUTING PARAMETERS

Various hydrologic routing methods were analyzed to determine the most appropriate methods and parameters. The process was very involved and complex, and therefore, is explained in complete detail in Appendix B – Routing Parameter Determination Summary. The final routing parameters using the coefficient routing method used in the model are shown in Table 3-4.

Table 3-4: Coefficient method final routing parameters.

Reach	A1 (d)	A2 (d-1)	A3 (d-2)
RBMT-FTPK	0.000	1.000	0.000
FTPK-WPMT	0.103	0.659	0.238
WPMT-CLMT	0.189	0.552	0.259
CLMT-GARR	0.085	0.411	0.504
GARR-BIS	0.057	0.503	0.440
BIS-OAHE	0.000	0.000	1.000
OAHE-BEND	0.766	0.234	0.000
BEND-FTRA	0.647	0.353	0.000
FTRA-GAPT	0.005	0.637	0.358
GAPT-SUX	0.175	0.538	0.287
SUX-OMA	0.168	0.722	0.110
OMA-NCNE	0.588	0.412	0.000
NCNE-RUNE	0.588	0.412	0.000
RUNE-STJ	0.775	0.225	0.000
STJ-MKC	0.426	0.449	0.125
MKC-WVMO	0.476	0.524	0.000
WVMO-BNMO	0.354	0.618	0.028
BNMO-HEMO	0.381	0.434	0.185
HEMO-MISL	0.222	0.778	0.000

3.4 LOCAL FLOWS

Local flows at each Missouri River gage and reservoir location were computed by subtracting the routed upstream 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 flows. One reason for this is the compatibility of using multiple data sources. Another possible reason for the large negative local flow is using general routing parameters that aren't applicable to all events. However, the routing parameters used are the parameters that were tested and worked best for recent events. The routing parameter determination is described in more detail in Appendix B – Routing Parameter Determination Summary. 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 was available, but should still be mentioned. The local flows at Rulo are an example of this. UMRSFFS data were used upstream at Nebraska City and routed to Rulo, then subtracted from the UMRSFFS data at Rulo. The USGS gage at Nebraska City came online in 1929, which can be easily seen in the local flows (green) on the graph in Figure 3-3.

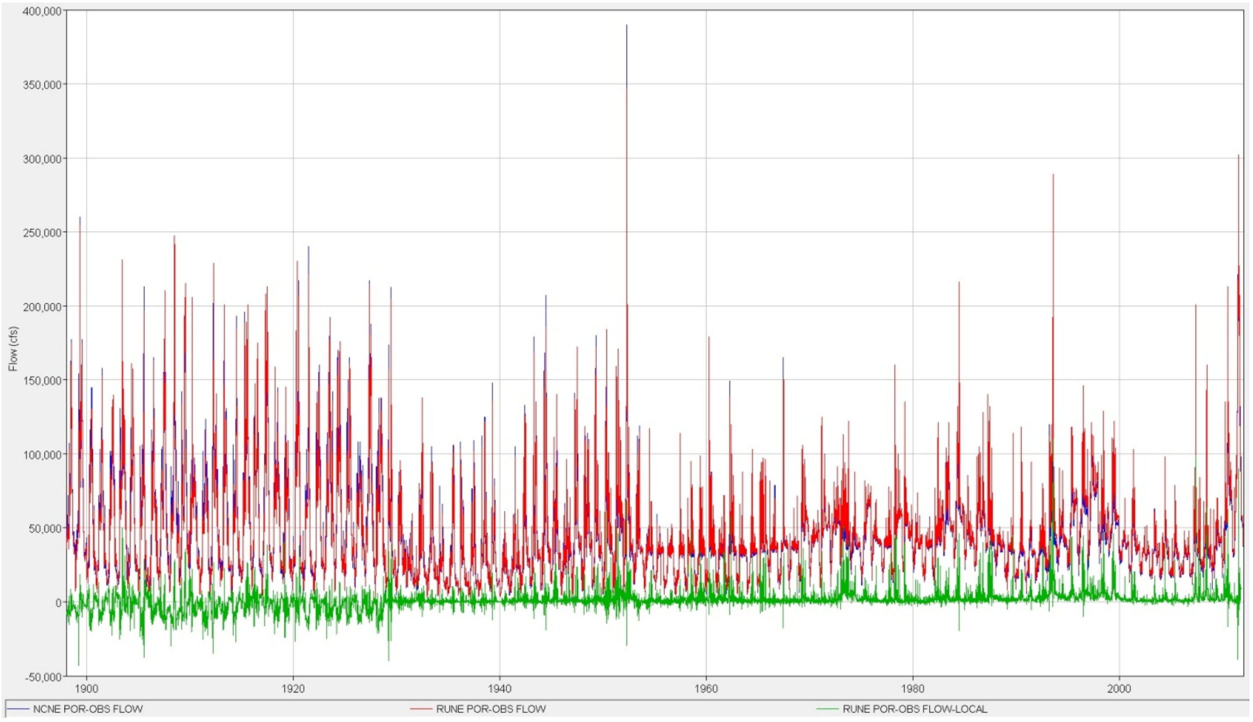


Figure 3-3: Rulo unadjusted local flow for POR.

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 are thought to be more reliable than the DRM data, since the DRM data for 1898-1929 were based on estimated monthly flows with an average daily distribution while the UMRSFFS was based on daily stages converted to flows from a stage-discharge relationship based on flow measurements.

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.

Calculated local flows include many instances of negative inflows. ResSim is capable of incorporating negative flows when performing basic routing calculations; however, flow travel times can exceed six days to the most downstream target at Kansas City, and accounting for large negative flows could produce unrealistic reservoir releases. Some of the negative flows are realistic where large withdrawals of water from the basin (especially upper portions) actually occurred or flows are ice-affected. However, calculated negative local flows are often due to gage measurement errors or assumptions with routing parameters. In these cases, the negative flows are not realistic. To correct this problem, the local flow data sets were adjusted using three different methods to reduce the large negative local inflows.

The first method used a 3-day centered moving average (CMA) in order to smooth 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). The local flow datasets were further smoothed to limit negative inflows to -2,000 cfs since withdrawals greater than that were attributed to routing or data errors and not considered realistic. Table 3-5 summarizes all the changes made to every data set. Year dates are from January 1 of the first year listed through December 31 of the last year listed, unless otherwise specified in the notes.

Table 3-6 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 3-5: Local flow adjustments summary.

Gage	Time Period	Adjustment	Notes
FTPK	1898-1928	13-Day CMA	Jun 1908 zeroed and redistributed.
	1929-2011	3-Day CMA	
WPMT	1898-2011	3-Day CMA	
CLMT	1898-2011	3-Day CMA	
GARR	1898-2011	3-Day CMA	
BIS	1898-1928	3-Day CMA	
	1928-1929	31-Day CMA	15 Mar 1928 - 15 Oct 1929
	1929-2011	3-Day CMA	Routing adjusted 1930-1953. Nov 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
	1929-2011	3-Day CMA	Routing adjusted 1930-1953.
BEND	1898-2011	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.
	1957-2011	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.
	1954-2011	3-Day CMA	
SUX	1898-1929	31-Day CMA	
	1930-2011	3-Day CMA	Apr 1943 & Jun 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.
	1930-2011	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	
	1930-2011	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	
	1930-2011	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 mass neg, but don't want to ave over longer period than this.
	1929-2011	3-Day CMA	Routing adjusted 1898-1928, Apr 1952, Jun 2010, & Jun-Jul 2011.
MKC	1898-1928	31-Day CMA	
	1929-2011	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.
	1930-2011	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 ave over longer period than this.
	1930-2011	3-Day CMA	Routing adjusted Jul 1951, Jul-Aug 1981, & Jul-Aug 1993.
HEMO	1898-2011	3-Day CMA	Jul 1993 & May 2007 zeroed and redistributed.

Table 3-6: 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 were stored in the file “Input_Data.dss”. They have a part F pathname of “HISTORIC: CALCULATED”.

3.5 EVAPORATION

Best available evaporation data for the Missouri River POR were obtained from the DRM. Assessment of the data was performed prior to incorporation into the ResSim model. There was a significant change in how evaporation data was measured between 1966 and 1967. MRBWM Division recommended using the DRM net evaporation data, which is total evaporation minus precipitation. The DRM evaporation data is consistent with the data used by MRBWM for their water management tasks, and corresponds well with the other data used from MRBWM in this study (all reservoir data). Evaporation data from the DRM was computed by two different processes. Prior to 1967 the evaporation was computed using the data from the Long Range Study model (LRS). Beginning in 1967, historic lake evaporation values were used in determining evaporation in the DRM model by using a ratio of the computed reservoirs areas to the areas determined from historic elevations.

3.5.1 Evaporation Rates Pre-1967

Monthly normal annual lake evaporation rates (in inches) for each of the mainstem reservoirs were developed using the Weather Bureau Technical Paper No. 37 (TP-37). Using Plate 2 of TP-37, the normal annual lake evaporation amounts were obtained and are listed in Table 3-7. Initially, Gavins Point evaporation losses were considered insignificant due to the small surface area and no annual lake evaporation was listed.

It was assumed that the evaporation through the entire period of record with the exception of the 1930-1941 drought period would approach the normal. Evaporation was reduced by the average annual precipitation over each of the reservoirs to obtain the normal annual net evaporation and is listed in Table 3-7. The net evaporation listed in Table 3-7 for Gavins Point Dam was taken from the LRS model input.

Table 3-7: Normal annual lake and net evaporation from TP-37.

Project	Normal Annual Lake Evaporation (inches/year)	Normal Annual Net Evaporation (inches/year)
Fort Peck	39.0	27.6
Garrison	35.0	21.1
Oahe	35.5	19.3
Big Bend	37.0	18.1
Fort Randall	37.5	13.4
Gavin Point	n/a	14.0

Note: Net Evaporation = Normal annual lake evaporation – Normal annual precipitation

During the 1930-1941 drought period, annual evaporation was computed for each year using the following procedures. The period 1942-1962 was considered a normal period and by utilizing the normal annual evaporation depths obtained from the Weather Bureau Technical Paper with temperature, humidity and wind data at or near each of the reservoirs during the 1942-1962 period, an appropriate constant was derived for each project to solve the empirical equation:

Evaporation = K (wind) (water surface vapor pressure – vapor pressure of air)

It was assumed that the water surface temperature would, over the course of a year, equal the observed air temperature. The constant derived above, in combination with the observed wind, humidity and temperature data, was then used for computing the annual evaporation from each project for each of the drought years. Annual net evaporation was determined by subtracting out observed precipitation at each of the projects and is listed in Table 3-8.

Table 3-8: Annual net evaporation during 1930-1941.

	Annual Net Evaporation Data (inches/year)					
Year	FTPK	GARR	OAHE	BEND	FTRA	GAPT
1898-1928	27.6	21.5	19.3	13.4	18.1	14.0
1929	27.6	21.5	19.3	25.4	18.1	24.0
1930	26.2	29.0	23.2	25.7	28.7	21.0
1931	34.8	26.5	33.5	35.9	38.9	30.0
1932	27.1	24.2	29.6	33.4	35.0	33.0
1933	37.0	38.0	46.1	43.4	45.0	42.0
1934	41.0	44.9	56.3	49.6	55.4	48.0
1935	34.0	17.4	31.6	27.0	37.9	18.0
1936	57.6	50.3	63.7	48.7	60.7	37.2
1937	41.3	29.8	38.9	34.0	44.6	24.0
1938	22.7	21.8	38.3	28.2	37.3	21.6
1939	37.8	24.0	39.4	37.0	41.4	30.0
1940	25.2	20.9	35.0	40.3	43.9	36.0
1941	26.6	7.0	23.6	22.3	27.4	18.0
1942-1966	27.6	21.5	19.3	13.4	18.1	14.0

Note: Drought period from 1930 to 1941. Evaporation for BEND and GAPT looks suspect in 1929.

From an analysis of available surface temperature and precipitation records of the mainstem reservoirs the seasonal distribution of the annual net evaporation was estimated and is listed in Table 3-9.

Table 3-9: Monthly Distribution of DRM Evaporation Prior to 1967.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percent	0.0	0.0	0.0	0.0	7.0	5.0	19.0	20.0	19.0	13.0	12.0	5.0

The initial evaporation input to the ResSim model for each dam from 1898 to 1966 is equal to the annual evaporation times the monthly distribution ratio divided by the number of days in the month.

3.5.2 Evaporation Rates Post-1966

Data after 1966 was based on measurements taken at each of the projects. The data are based on pan evaporation except during the winter periods when it was estimated. It should be noted that some projects have quit measuring pan evaporation during the spring, summer and fall and have instead started using estimated values year round.

For the data based on pan evaporation, observed pan measurements were taken daily and then factored by an average monthly pan coefficient to come up with the lake evaporation. During periods when pan evaporation readings were not taken, the evaporation is considered to be a constant for each particular month and normal monthly representative pan evaporation values were used. These are taken from the 1973 report titled, *Missouri River Main Stem Reservoir System, Reservoir Evaporation Estimates, MRD-RCC Technical Report JE-73,* and are listed in Table 3-10. Both the measured and normal monthly pan evaporation are factored by the normal pan to lake evaporation coefficient which were also taken from the June 1973 report and are listed in Table 3-11. Table 3-12 lists the normal monthly lake evaporation based on the normal monthly pan evaporation (Table 3-10) multiplied by the normal monthly pan to lake coefficient (Table 3-11).

Table 3-10: Normal monthly pan evaporation in inches.

Month	Fort Peck	Garrison	Oahe	Big Bend	Fort Randall	Gavins Point
January	0.62	0.51	1.02	0.80	1.02	0.74
February	0.74	0.58	1.14	0.98	1.16	0.91
March	1.68	1.42	2.24	1.97	2.31	1.91
April	3.50	2.79	4.70	4.48	4.27	4.19
May	6.96	6.35	7.80	7.83	6.74	7.30
June	8.05	7.07	8.51	8.47	7.54	8.30
July	10.45	8.97	10.74	10.85	9.00	9.64
August	10.22	8.56	10.44	10.31	8.13	8.41
September	5.97	6.63	7.25	7.26	5.07	5.57
October	4.03	4.07	4.92	4.06	4.42	4.46
November	1.96	1.38	2.25	1.83	2.34	1.79
December	0.83	0.70	1.19	1.04	1.24	0.87
Annual	**55.01**	**48.03**	**62.20**	**59.88**	**53.24**	**54.09**

Note: Taken from Figure 9 of the *Missouri River Main Stem Reservoir System, Reservoir Evaporation Estimates, MRD-RCC Technical Report JE-73.* Based on available pan data from 1963-1972. During months pan data were not available, pan depths were computed by mass-transfer equation assuming pan water temperature to be equivalent to air temperature. Values shown for Oahe and Big Bend are believed to be unrepresentative. Representative pan data requires an adjustment factor of 0.80 for Oahe and 0.90 for Big Bend. See Report JE-73 for more detail.

Table 3-11: Normal monthly pan to lake evaporation coefficients.

Month	Fort Peck	Garrison	Oahe	Big Bend	Fort Randall	Gavins Point
January	1.28	0.70	0.73	0.63	0.70	0.70
February	0.70	0.70	0.56	0.63	0.70	0.70
March	0.60	0.70	0.49	0.54	0.63	0.62
April	0.11	0.14	0.13	0.47	0.19	0.53
May	0.22	0.20	0.16	0.35	0.32	0.53
June	0.32	0.21	0.18	0.39	0.37	0.53
July	0.39	0.26	0.22	0.53	0.42	0.56
August	0.64	0.64	0.50	0.70	0.78	0.70
September	1.21	1.13	0.89	0.82	1.31	0.93
October	1.32	1.44	1.19	1.05	1.42	0.97
November	2.57	3.74	2.22	1.52	1.62	1.59
December	4.22	5.04	3.42	1.36	1.39	1.57

Note: Taken from Figure 11 of the *Missouri River Main Stem Reservoir System, Reservoir Evaporation Estimates, MRD-RCC Technical Report JE-73*

Table 3-12: Normal monthly lake evaporation.

Month	Fort Peck	Garrison	Oahe	Big Bend	Fort Randall	Gavins Point
January	0.79	0.36	0.74	0.50	0.71	0.52
February	0.52	0.41	0.64	0.62	0.81	0.64
March	1.01	0.99	1.10	1.06	1.46	1.18
April	0.38	0.39	0.61	2.11	0.81	2.22
May	1.53	1.27	1.25	2.74	2.16	3.87
June	2.58	1.48	1.53	3.30	2.79	4.40
July	4.08	2.33	2.36	5.75	3.78	5.41
August	6.54	5.48	5.22	7.22	6.34	5.89
September	7.22	6.36	6.45	5.97	6.64	5.18
October	5.32	5.86	5.85	4.26	6.26	4.33
November	5.04	5.16	5.00	2.78	3.79	2.85
December	3.50	3.53	4.07	1.41	1.72	1.37
Annual	**38.51**	**33.62**	**34.82**	**37.72**	**37.27**	**37.85**

Note: Taken from Figure 12 of the *Missouri River Main Stem Reservoir System, Reservoir Evaporation Estimates, MRD-RCC Technical Report JE-73.*

Daily and monthly evaporation outputs from the DRM for 1898-2011 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. Figure 3-4 and Figure 3-5 below show a sample daily and monthly evaporation plot for Lake Oahe using DRM data. Figure 3-6 provides a plot of annual evaporation based on the DRM data.

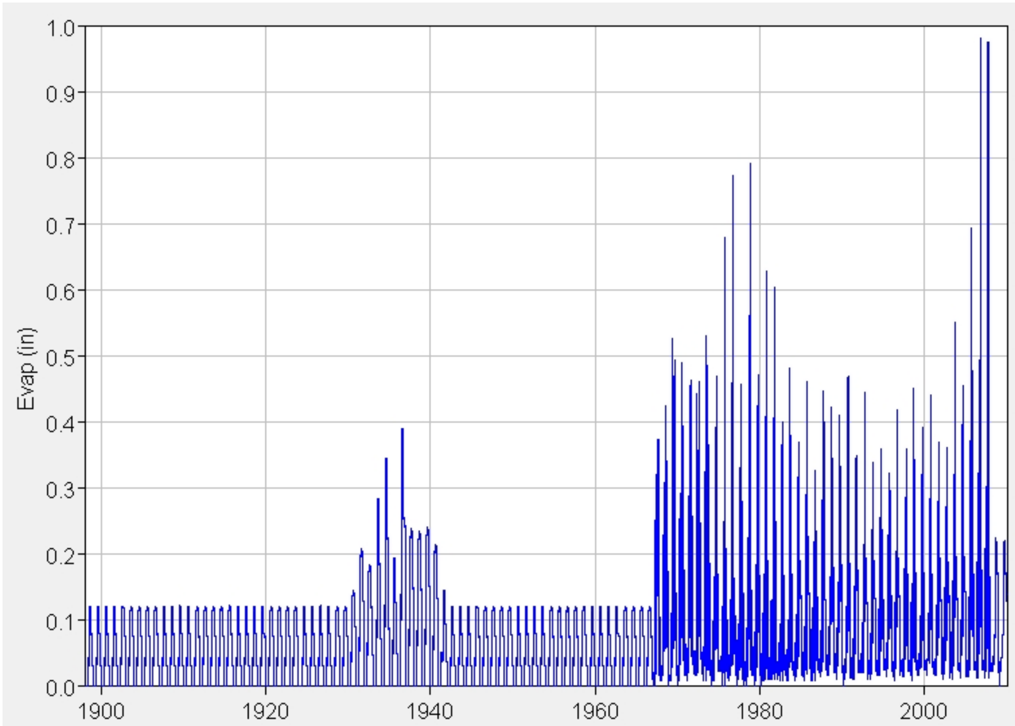


Figure 3-4: Oahe DRM daily evaporation.

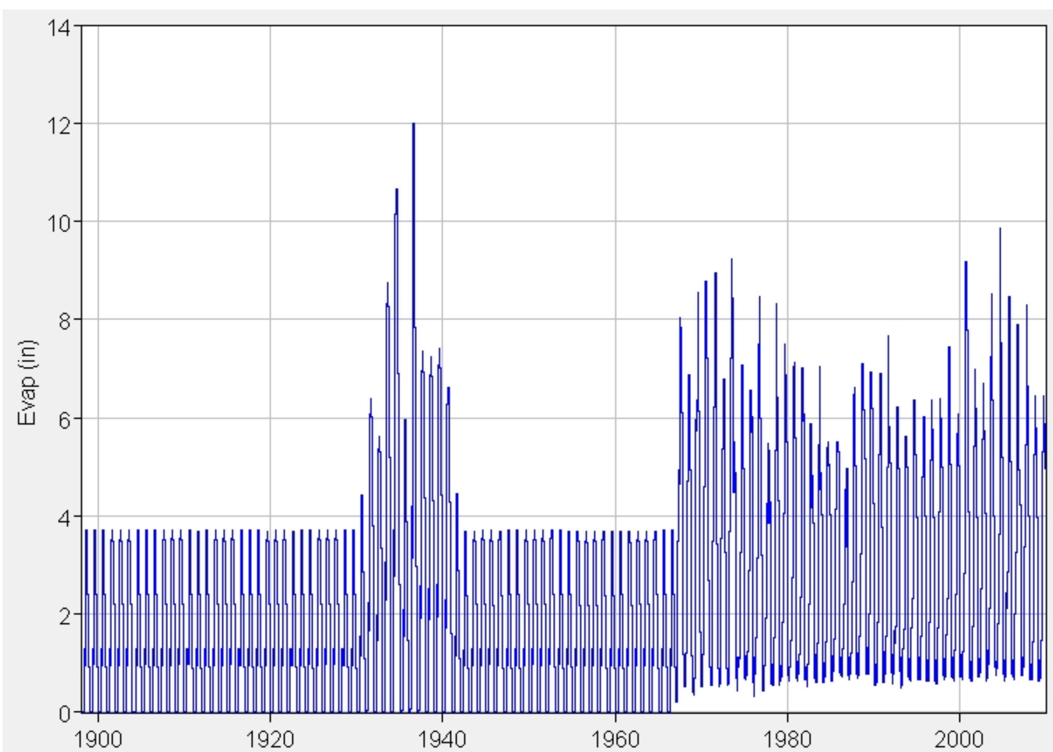


Figure 3-5: Oahe DRM monthly evaporation.

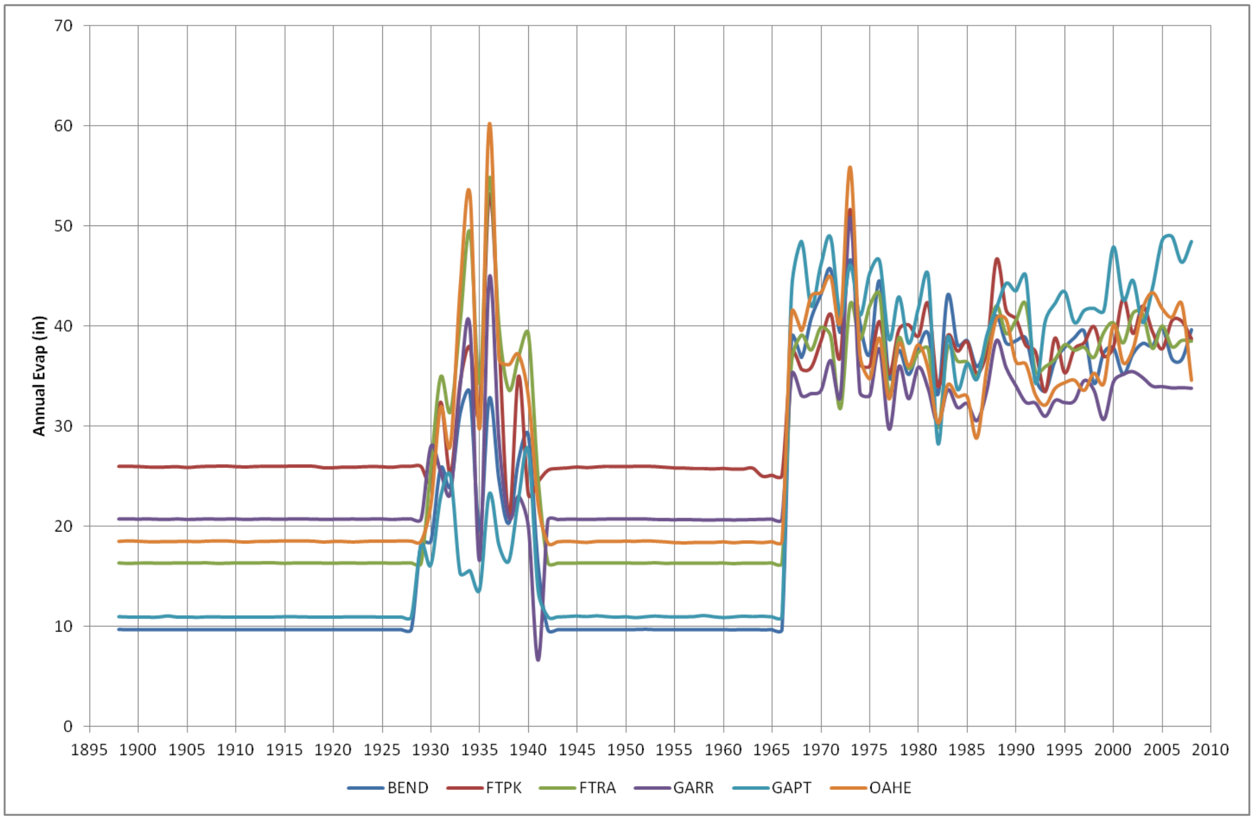


Figure 3-6: Annual DRM evaporation at the mainstem projects.

3.5.3 Inflow Loss due to Evaporation Computations

The computations for calculating inflow loss due to evaporation (flow-evap) in the DRM model are essentially the same for all six dams. If the year is pre-1967, the DRM uses the information from the Long Range Study (LRS) model. The flow-evap is computed by multiplying the factor (feet of evaporation per day) described in Section 3.5.1 by the difference in the reservoir area less the channel area, as was done in the LRS evaporation computations. The flow-evap from the portion of the reservoir occupied by the original channel area was assumed to be included in the depletion computations. If the computation year is post-1966 then the flow-evap is computed by multiplying the historic evaporation by the ratio of DRM computed area to historic area. The evaporation values in the MRBWM database do not consider channel area, and it was not used in the computations post-1966.

The computations for calculating evaporation in the ResSim model do not differentiate the two periods of evaporation data and are computed differently than the DRM. ResSim flow-evap computations compute a daily evaporation flow with units of cfs by converting the daily evaporation depth (data discussed in Sections 3.5.1 and 3.5.2) to feet and then multiplying the depth by the reservoir area, which varies with the pool elevation.

Although there are computational differences, it was decided that the DRM evaporation data was acceptable for the ResSim model.

3.6 RESERVOIR DATA

The following sections summarize the physical reservoir data used at the mainstem reservoirs in the ResSim model. A sequential release allocation in ResSim was applied to all the mainstem projects with priority release given first to the Powerplant, second to Outlet Works (if applicable), and third to spillway flow.

3.6.1 Elevation-Area-Capacity Curves

Elevation-Area-Capacity (E-A-C) curves for each mainstem reservoir were obtained from surveys performed by the channel sedimentation section of NWO. These data were entered into the ResSim model in 1 ft increments but are summarized in 10 ft increments and list in Appendix C – Elevation-Area-Capacity Curves. The following list summarizes the survey data used at each location:

- Fort Peck from 2007 survey
- Garrison from 2011 survey
- Oahe from 2010 survey
- Big Bend from 2012 survey
- Fort Randall from 2011 survey
- Gavins Point from 2011 survey

3.6.2 Spillway Flow

Spillway rating curves were obtained from the Hydraulics Section of NWO. These curves were not used for the Master Manual update, but they are the latest and "best" available as of May 2012. The following figures display the spillway rating curves used for each project in the model. It should be noted that these curves represent the maximum capacity with all gates fully utilized.

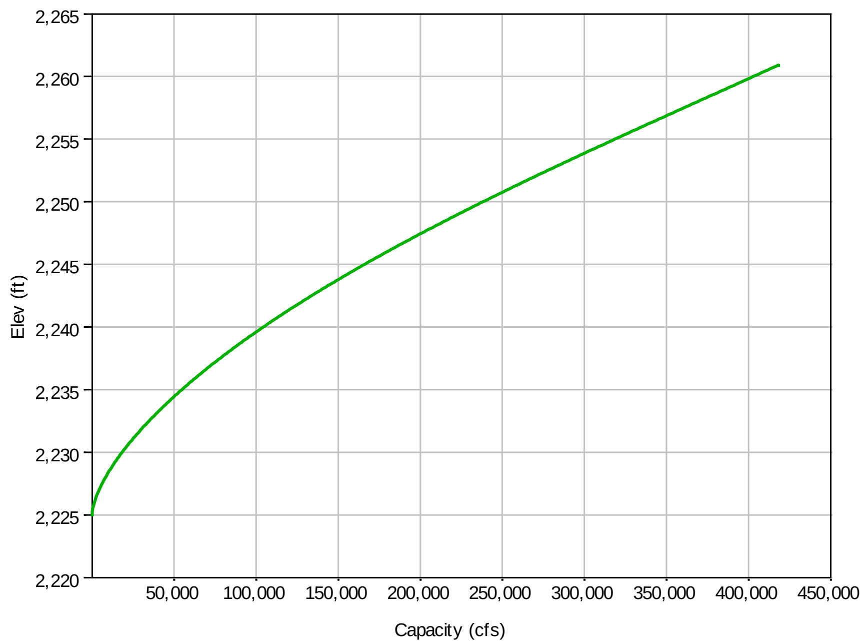


Figure 3-7: Fort Peck spillway capacity curve.

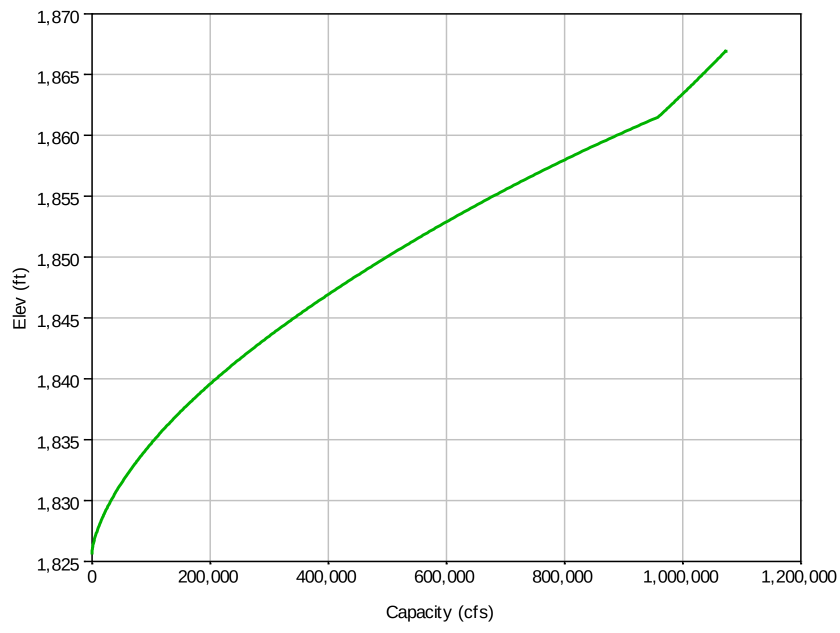


Figure 3-8: Garrison spillway capacity curve.

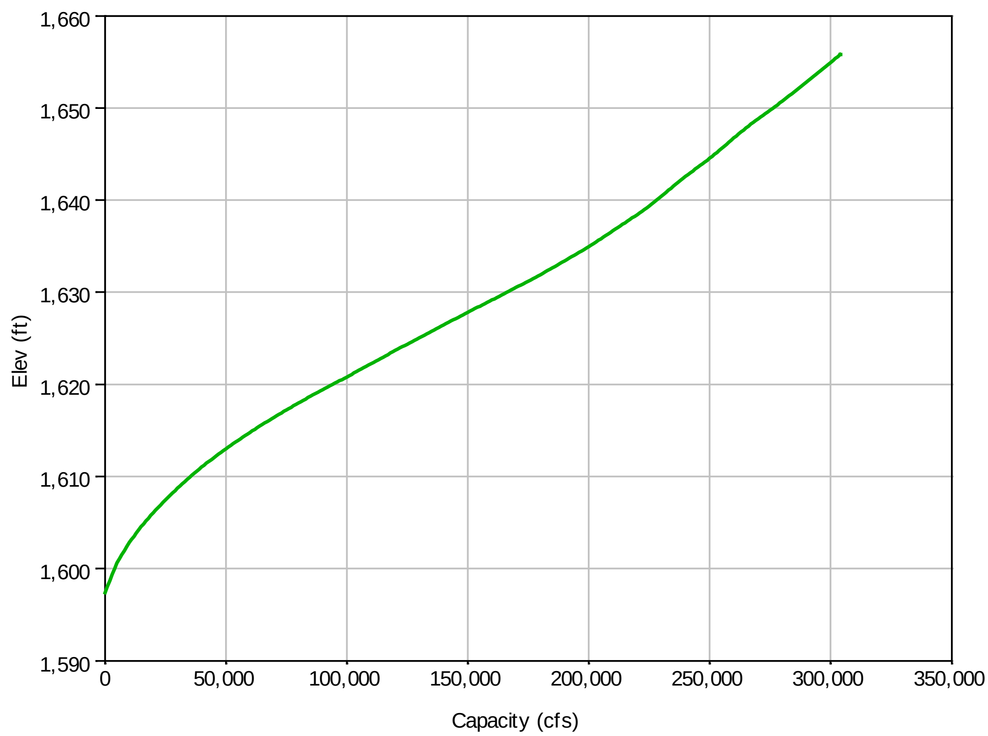


Figure 3-9: Oahe spillway capacity curve.

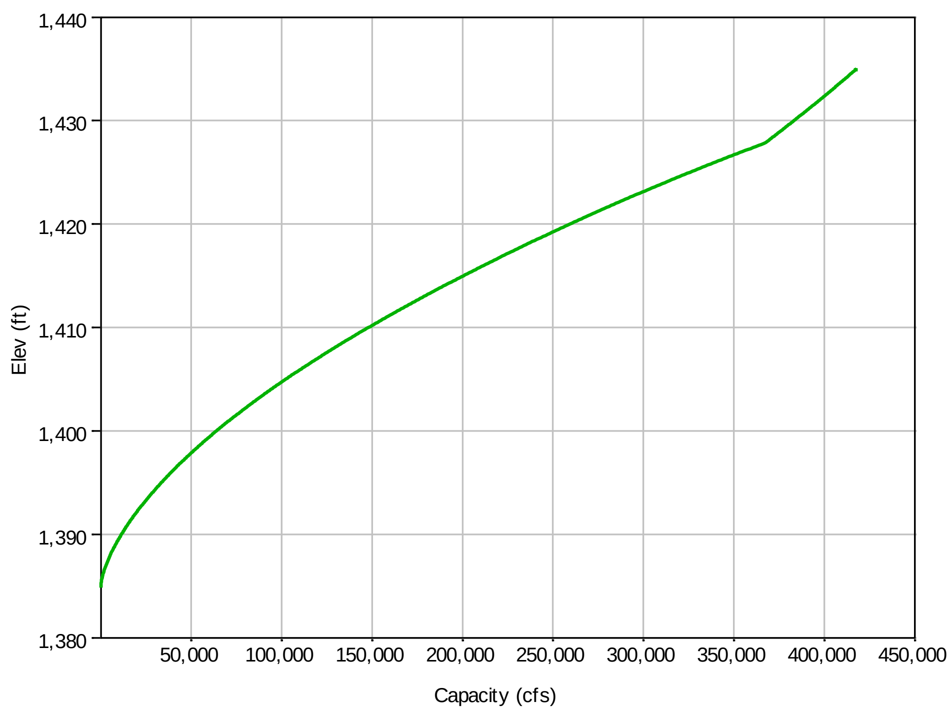


Figure 3-10: Big Bend spillway capacity curve.

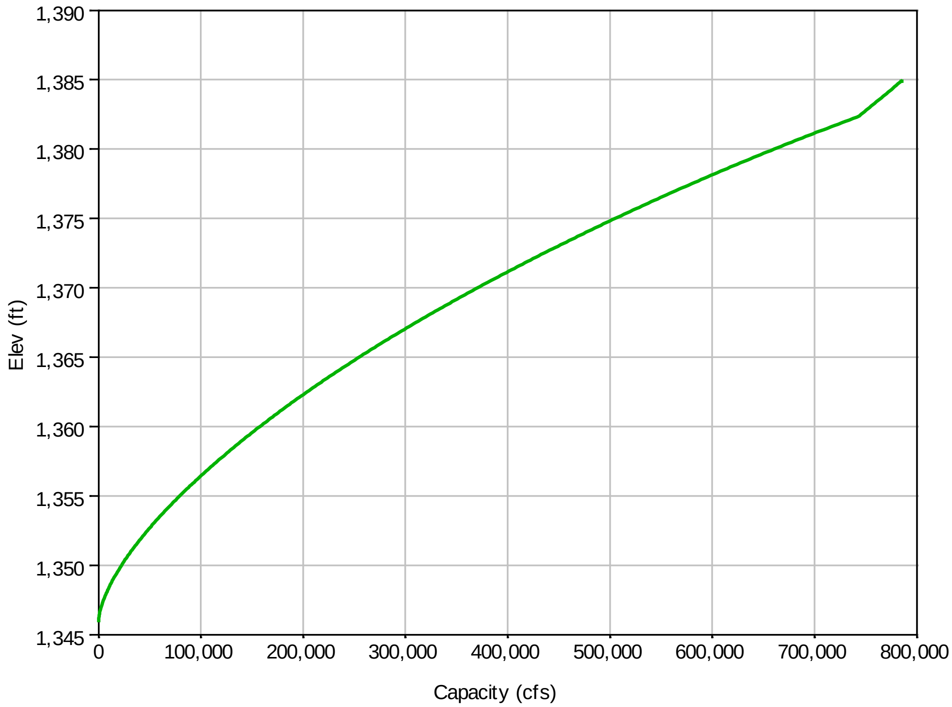


Figure 3-11: FTRA spillway capacity curve.

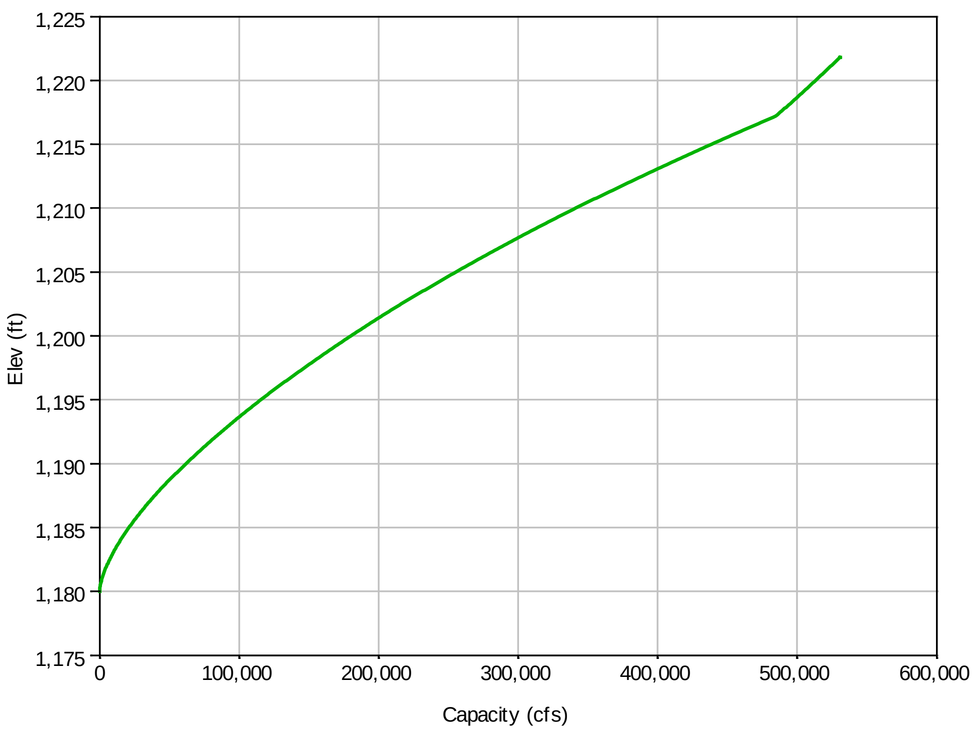


Figure 3-12: Gavins Point spillway capacity curve.

3.6.3 Outlet Works Flow

Outlet works flow is considered release through the dam not made by the powerhouse or the spillway but released through the flood control tunnels. Curves are provided below for Garrison, Oahe, and Fort Randall. Although Fort Peck does have outlet works, the curves were not included because the the outlet tunnels are not to be operated unless absolutely necessary because of problems with the ring gates. Garrison and Oahe outlet works release were estimated from the March 2004 Master Manual curves. Big Bend and Gavins Point have no flood control tunnel outlet works. Fort Randall curve was the best available as of May 2012 and was provided by the Hydraulics Section (NWO). The elevation-discharge curve for elevations lower than 1320 were estimated based on a second order polynomial equation of the upper curve.

The following figures display the outlet works rating curves for Garrison, Oahe, and Fort Randall.

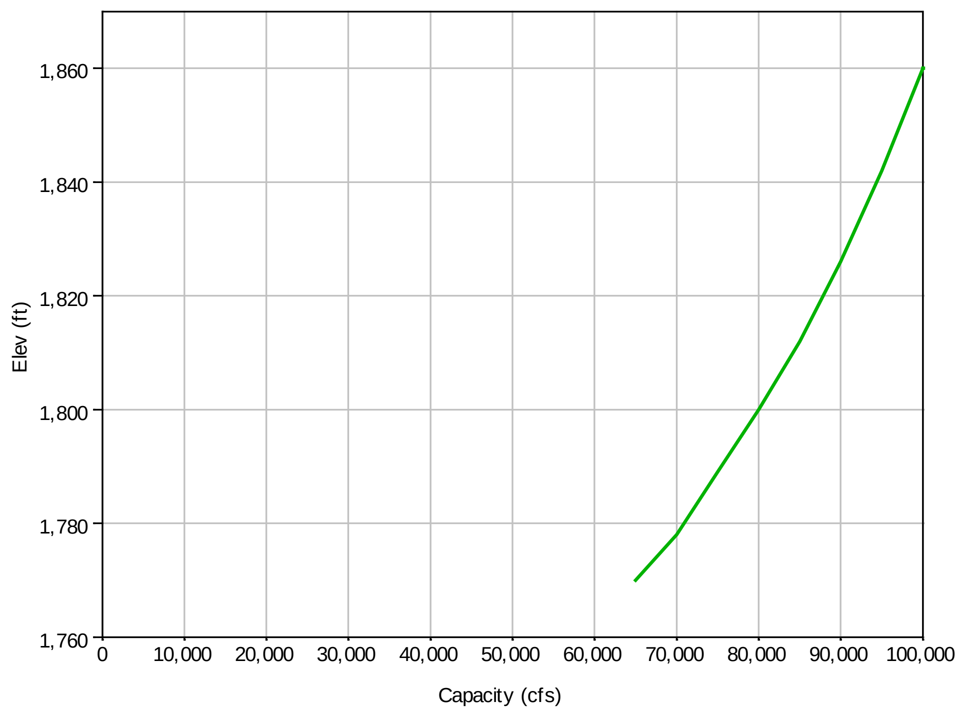


Figure 3-13: Garrison outlet works capacity curve.

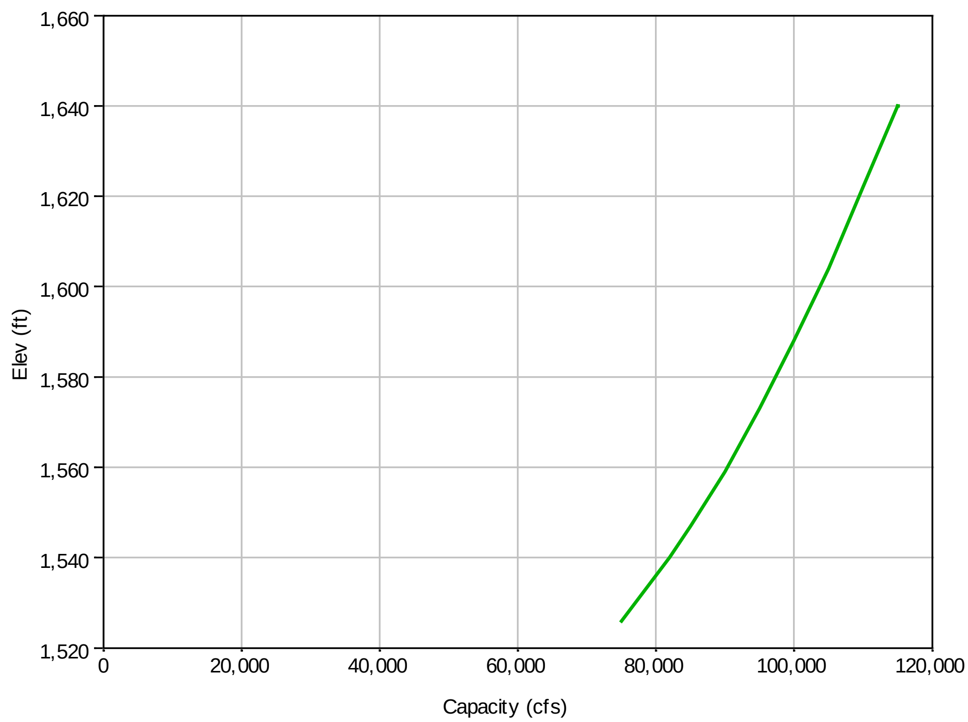


Figure 3-14: Oahe outlet works capacity curve.

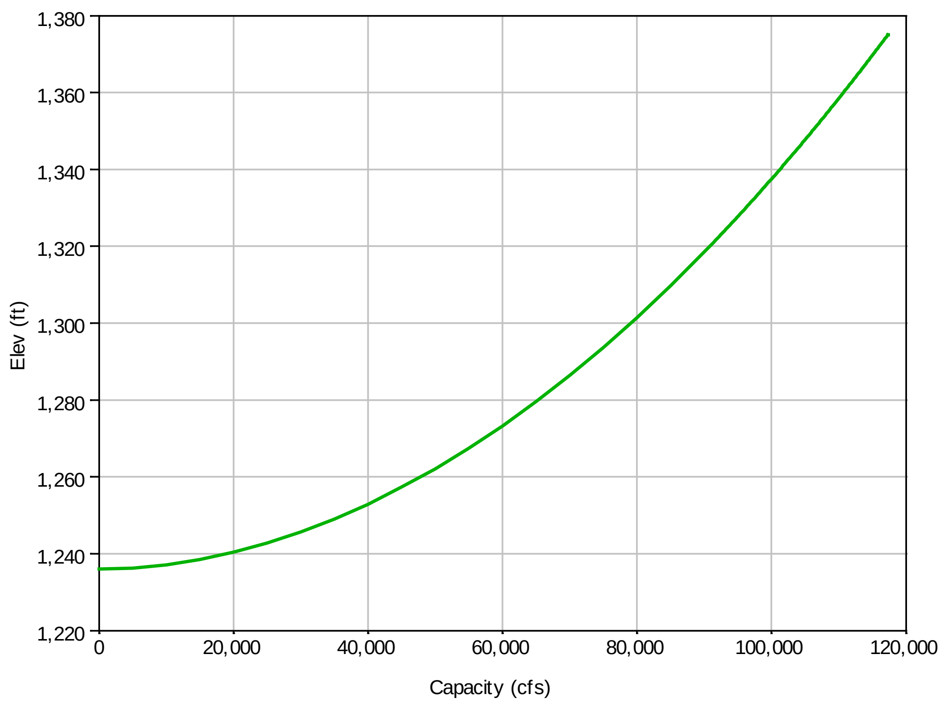


Figure 3-15: Fort Randall outlet works capacity curve.

3.6.4 Powerhouse Flow

Release capacity through the powerhouses was determined based on the reservoir "Powerplant Characteristics" curves in the Master Manual and a "PowerplantCharacteristics" spreadsheet from MRBWM in May 2012, with the exception of Big Bend. Big Bend required additional examination since flow capacity depends partially on the downstream Lake Francis Case water surface elevation. Maximum release through the powerhouse at Big Bend was entered as an operational Rule within ResSim stating that maximum release is a function of Lake Sharpe (Big Bend) tailwater current value.

It should be noted that all project powerhouse release capacity curves had to be adjusted slightly in ResSim from their actual Master Manual curves. This affected only the portion of the upper end of the curve when capacity began to decrease with elevation. This was adjusted in ResSim so that the curve remained at a constant release as the elevation increased. It had to be changed in ResSim because ResSim adjusted the capacity flows, but wrongfully would not release the remaining desired flow through the spillways/outlet works.

The following figures display the powerhouse discharge capacity for the other 5 projects.

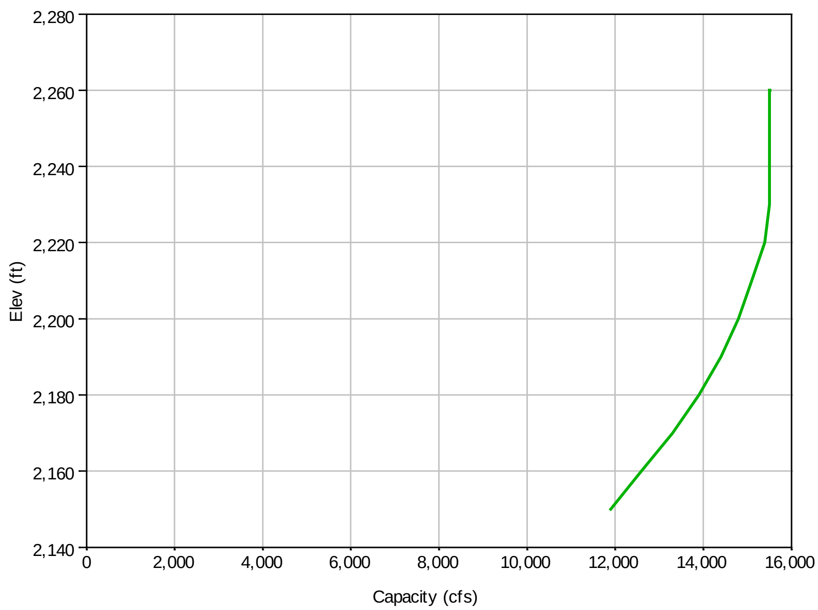


Figure 3-16: Fort Peck powerhouse discharge capacity.

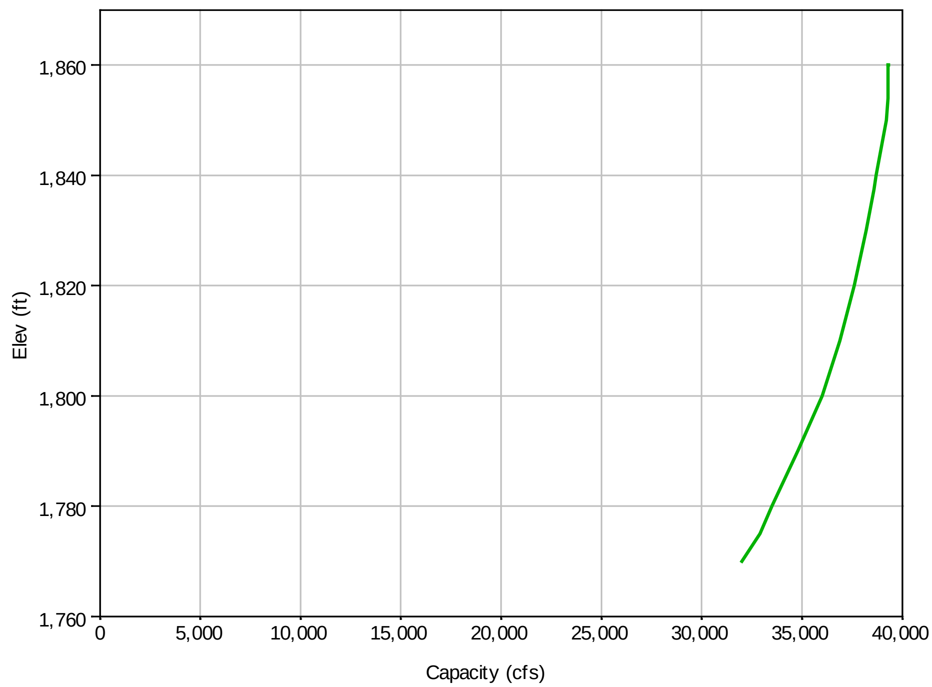


Figure 3-17: Garrison powerhouse discharge capacity.

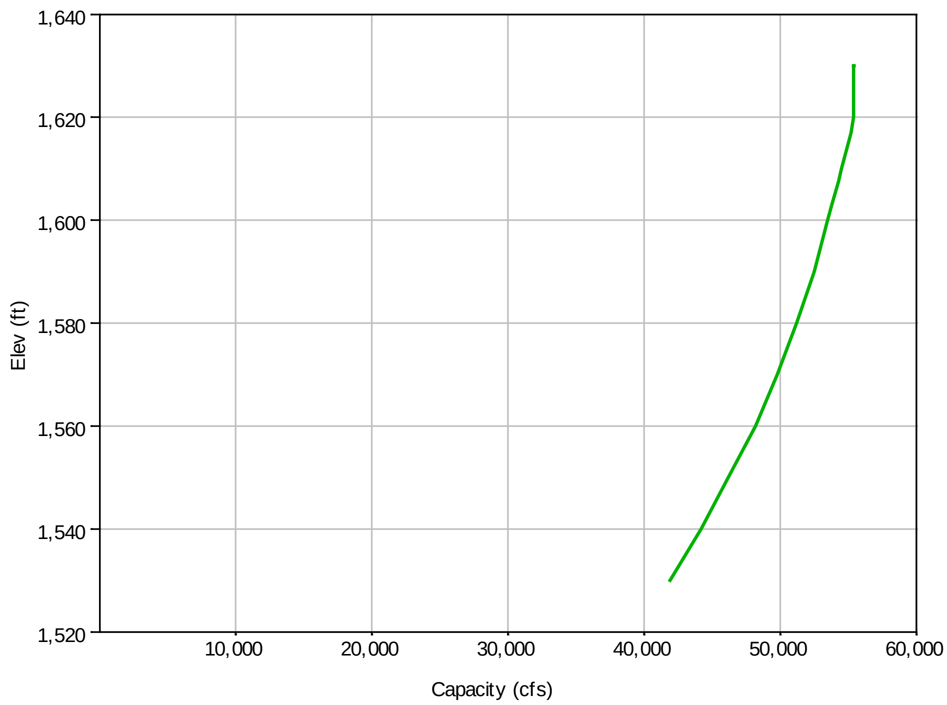


Figure 3-18: Oahe powerhouse discharge capacity.

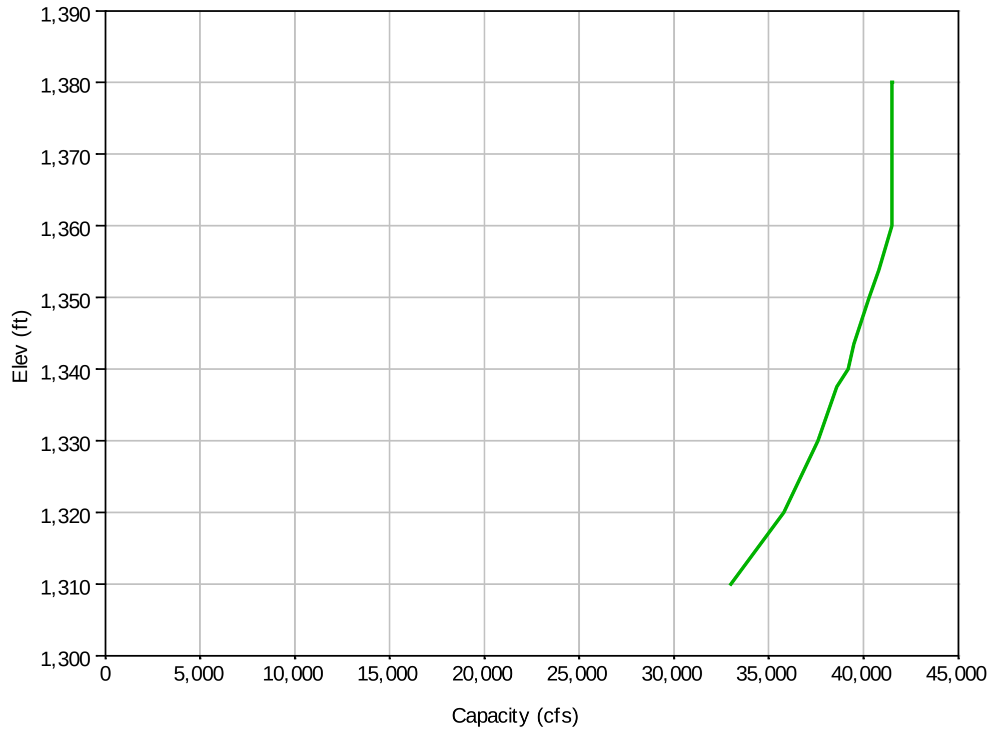


Figure 3-19: FTRA powerhouse discharge capacity.

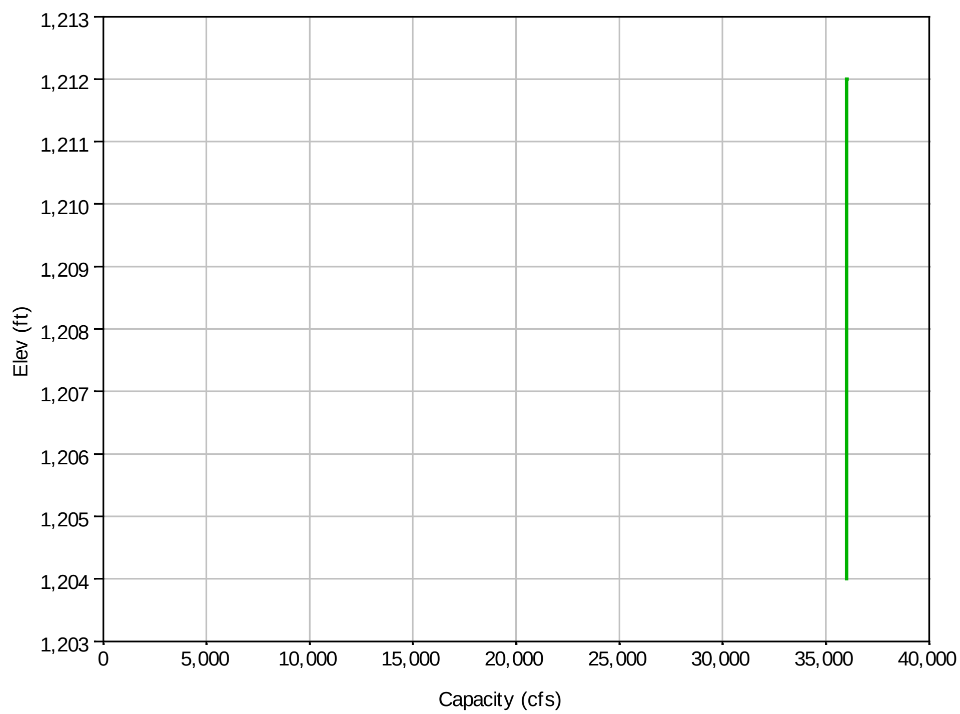


Figure 3-20: Gavins Point powerhouse discharge capacity.

3.6.5 Power Generation Capacity

Power generation capacity curves were determined based on the reservoir "Powerplant Characteristics" curves in the Master Manual. The following figures display the power generation capacity of the projects.

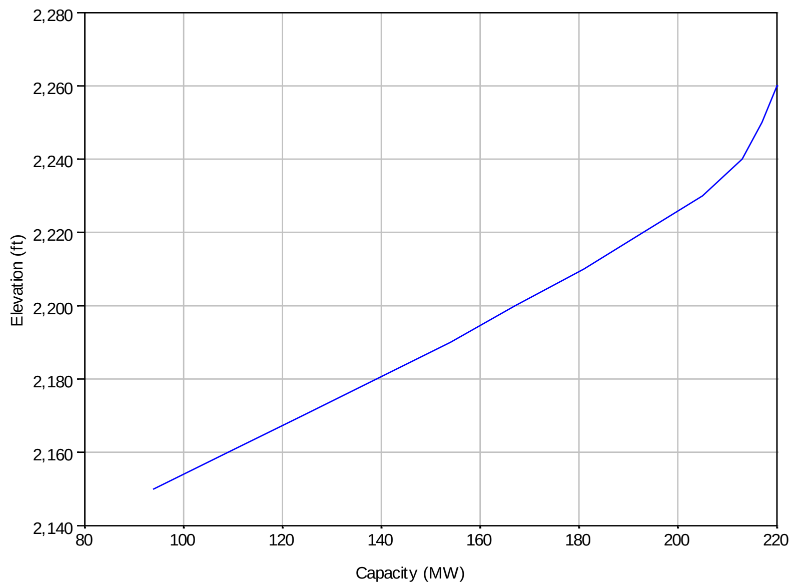


Figure 3-21: Fort Peck power generation capacity.

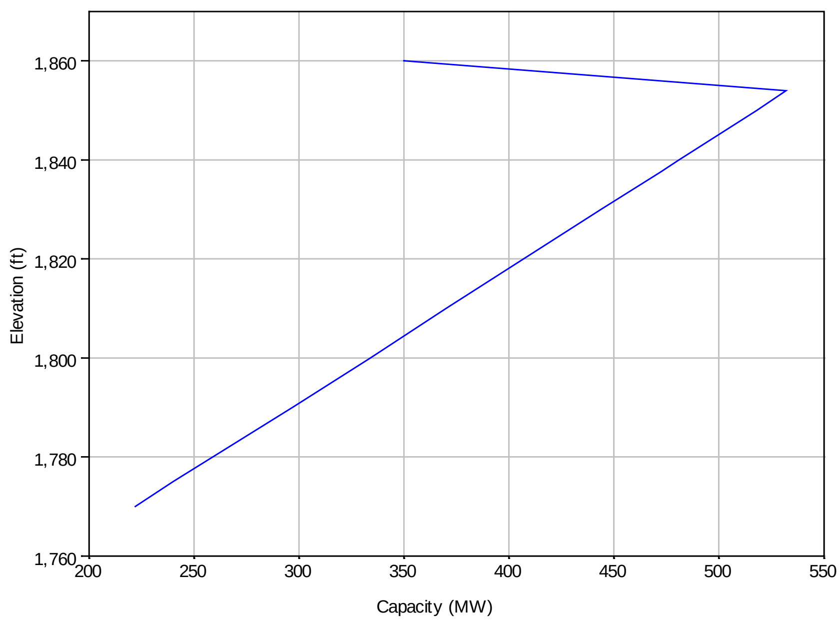


Figure 3-22: Garrison power generation capacity.

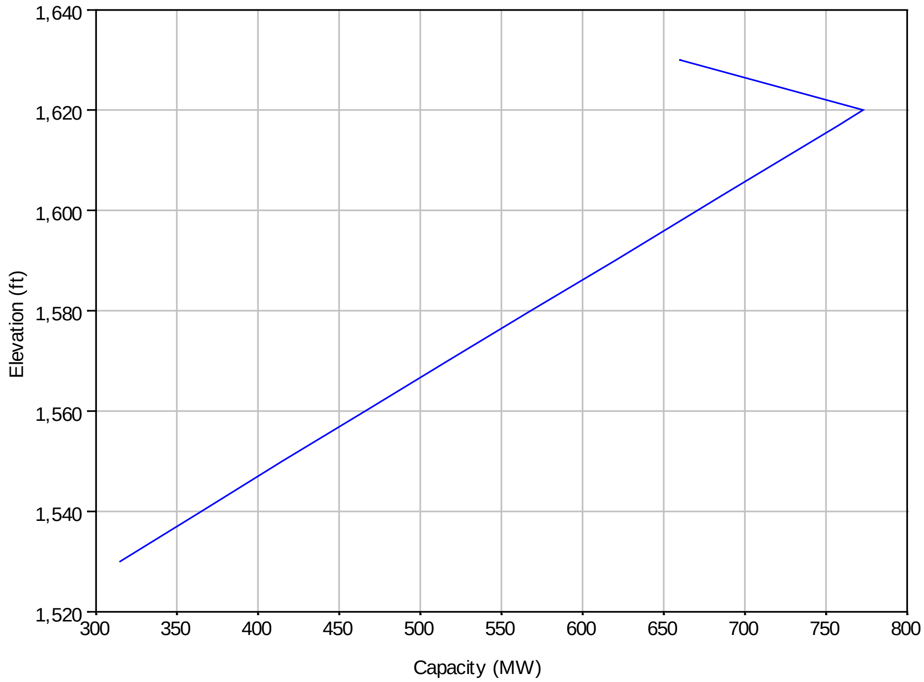


Figure 3-23: Oahe power generation capacity.

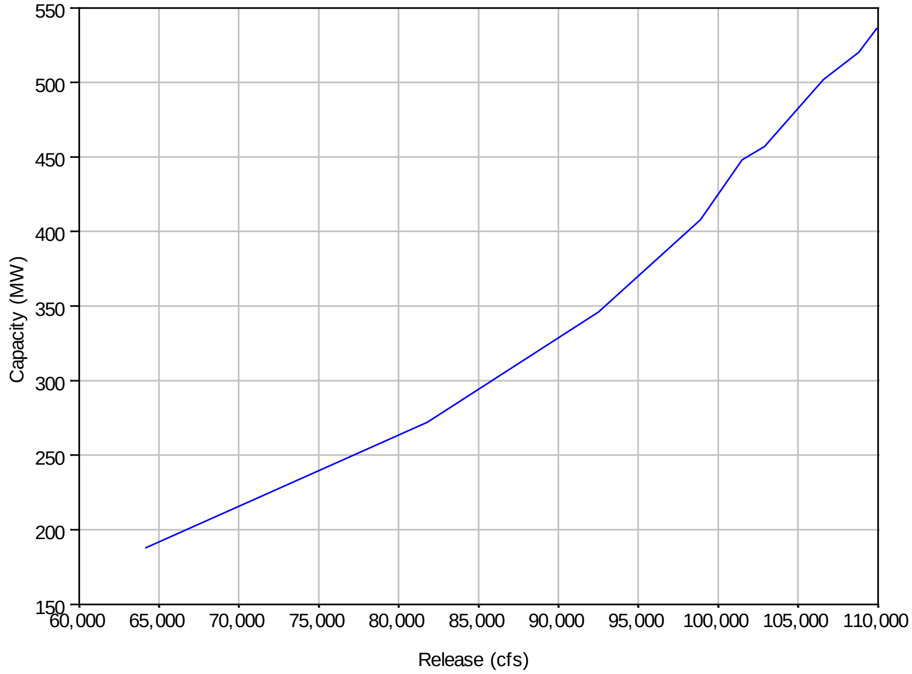


Figure 3-24: Big Bend power generation capacity.

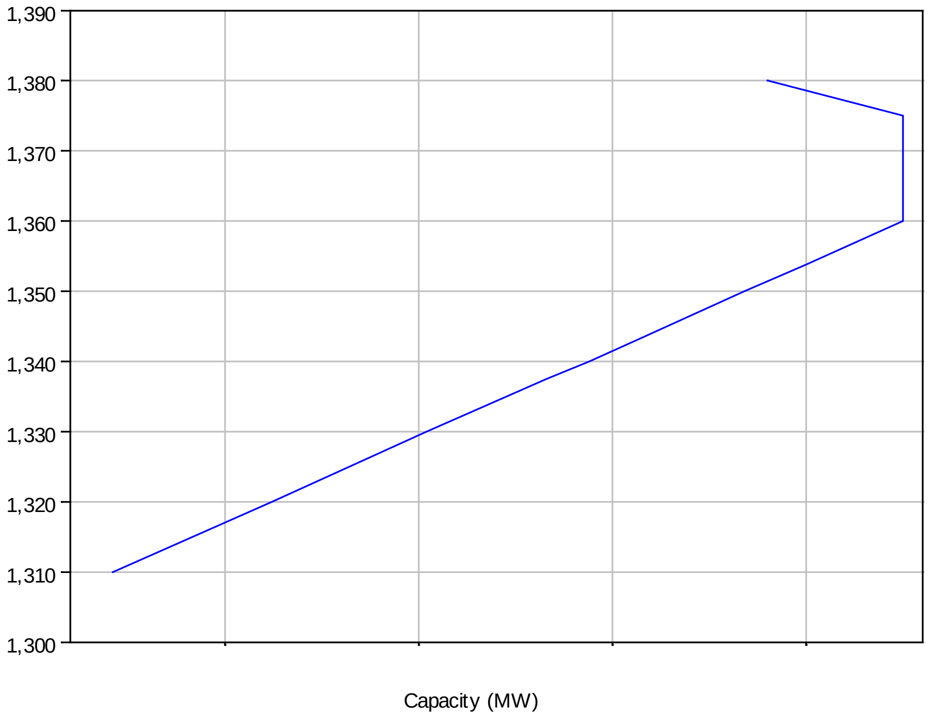


Figure 3-25: Fort Randall power generation capacity.

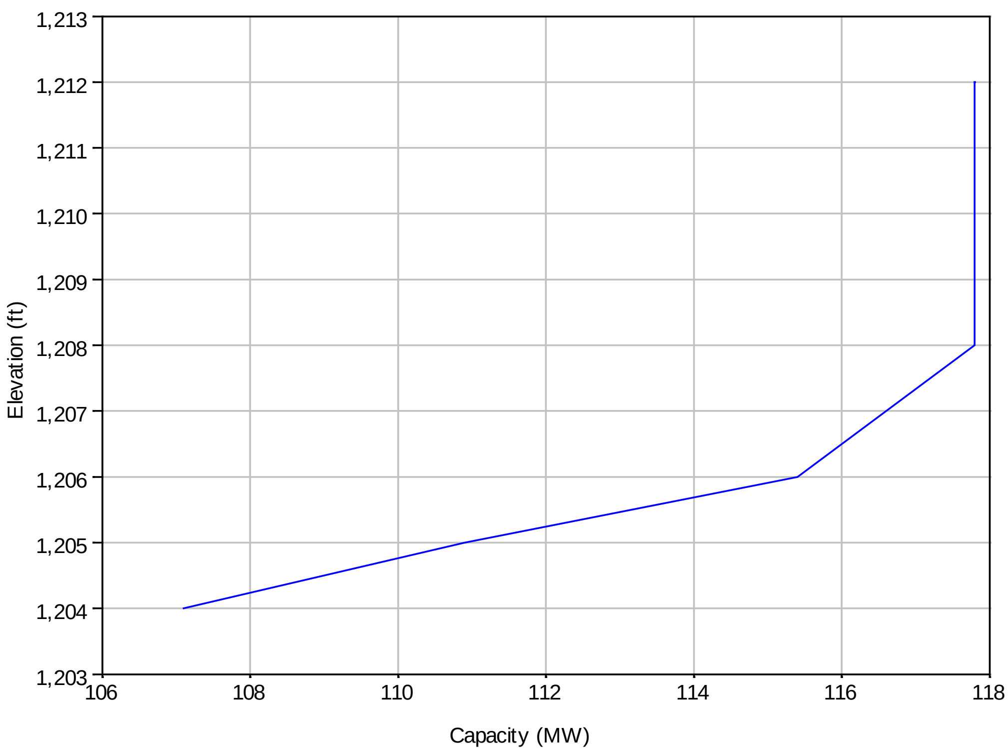


Figure 3-26: Gavins Point power generation capacity.

3.6.6 Tailwater

Tailwater below the projects was determined primarily using the 1992 Emergency System Operation Plan (ESOP) reports in combination with the tailwater rating curves from the Master Manual. Tailwater within ResSim was created at the same hierarchy level as the release outlets because the curves were developed assuming total outflow. The following figures display tailwater curves for all projects. It should be noted that the tailwater at Oahe is the highest elevation from downstream Lake Sharpe and the rating curve. Likewise, the tailwater at Big Bend is the highest elevation from downstream Lake Francis Case and the rating curve.

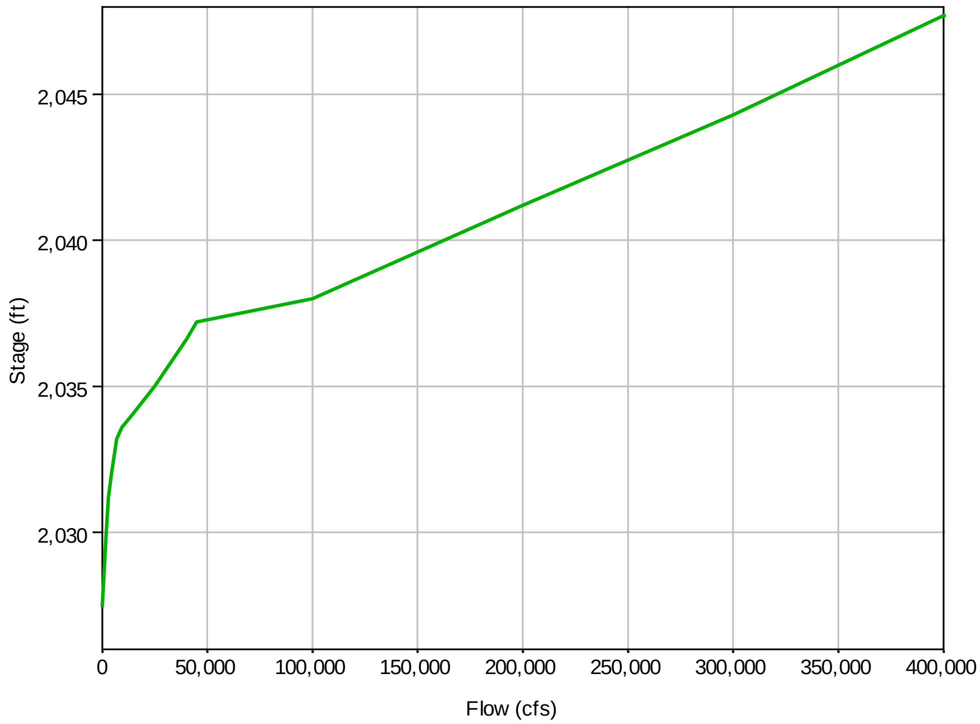


Figure 3-27: Fort Peck tailwater.

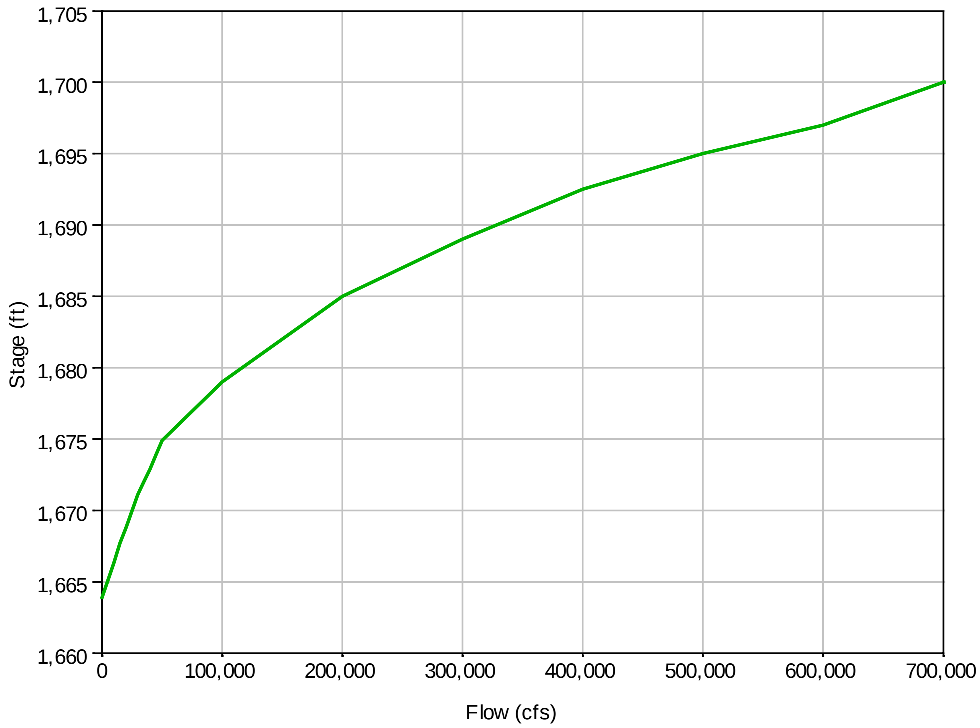


Figure 3-28: Garrison tailwater.

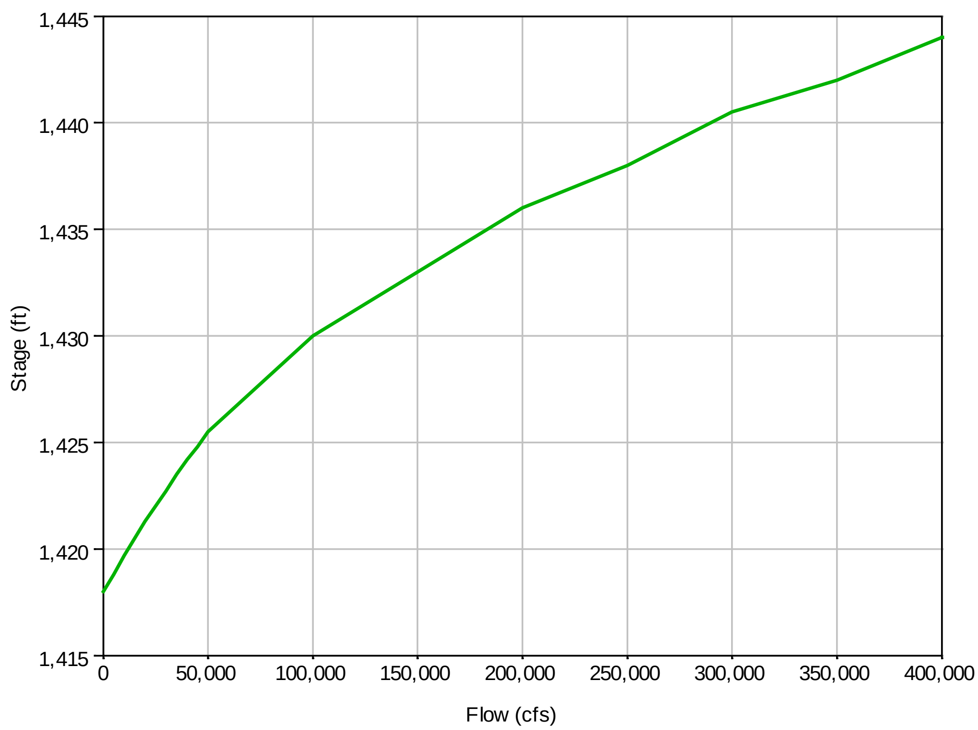


Figure 3-29: Oahe tailwater.

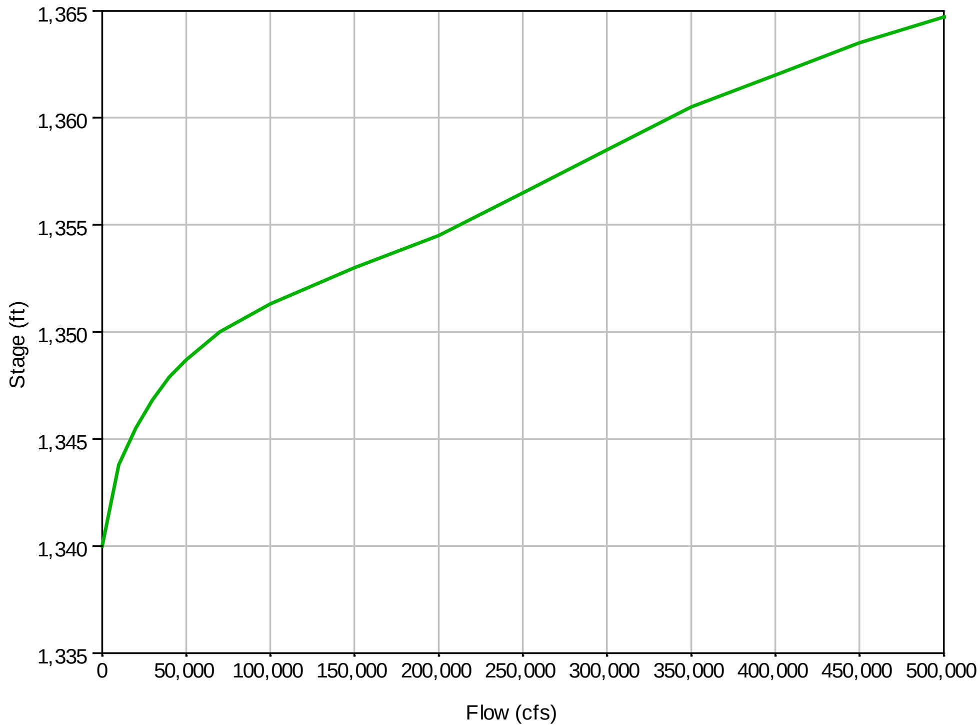


Figure 3-30: Big Bend tailwater.

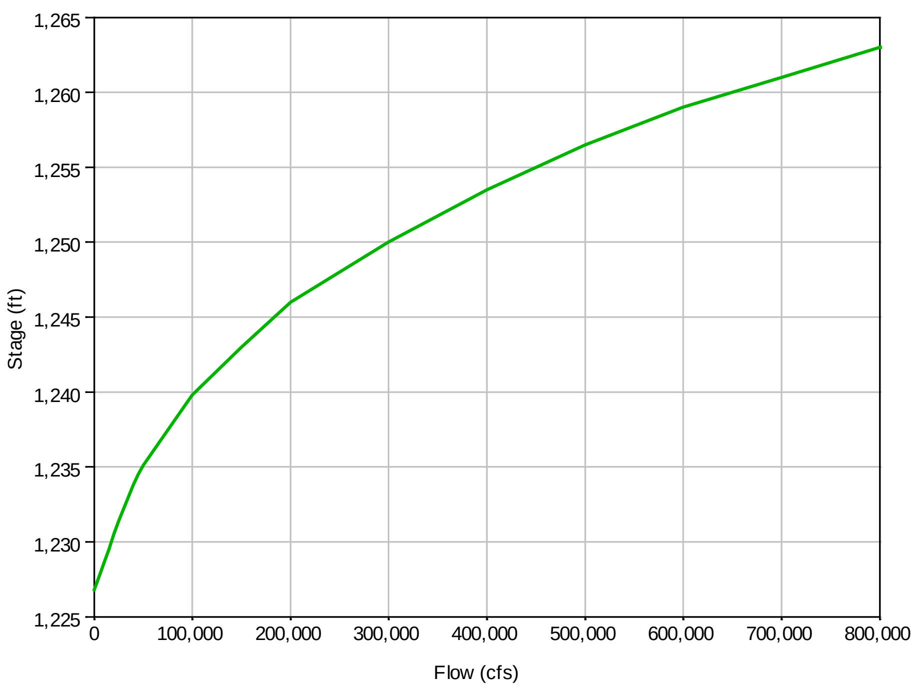


Figure 3-31: Fort Randall tailwater.

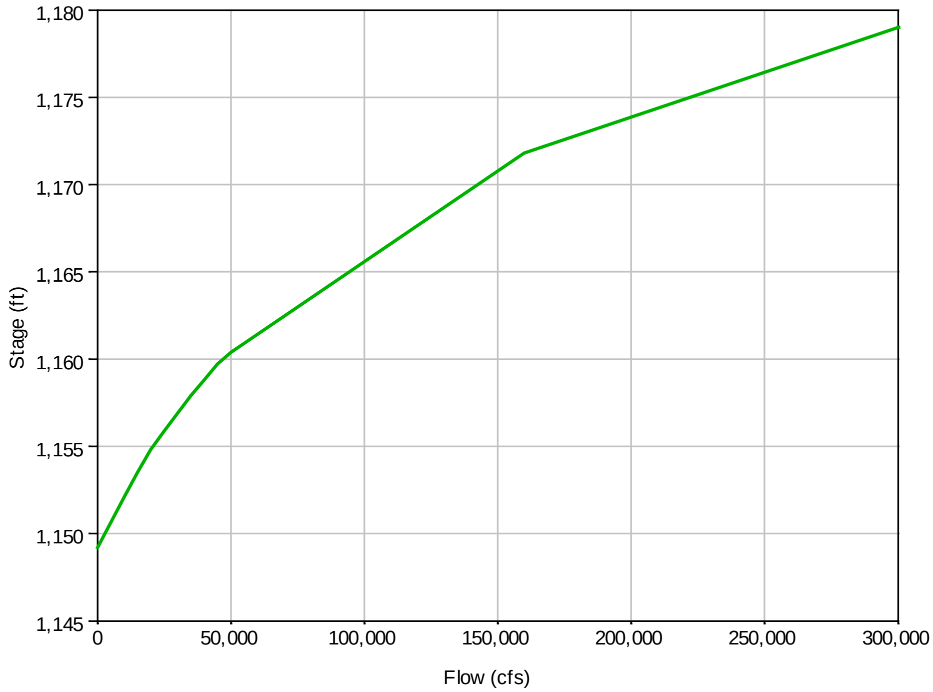


Figure 3-32: Gavins Point tailwater.

3.6.7 Power Efficiencies

Reservoir efficiency in ResSim can be entered as a constant or a function of reservoir elevation, release, or operating head. MRBWM performed analysis on observed data and developed relationships for Fort Peck, Big Bend, Fort Randall, and Gavins Point. It was determined the relationships with efficiency as a function of differential head based on observed data, mostly post-1997, provided the best correlation. The curves were then extended to the minimum and maximum potential head, based on the equations for the lines of the 2^{nd} order polynomials. For the extreme ends of the curves, some calculated efficiencies were less than what has been historically observed. For these differential heads, the minimum observed efficiency was used. Garrison and Oahe required additional analysis due to the irregular nature of the observed data. The curves were also extended to the minimum and maximum potential head, but based on a linear fit rather than a 2^{nd} order polynomial fit. The final efficiency curves for the projects are shown in the following figures.

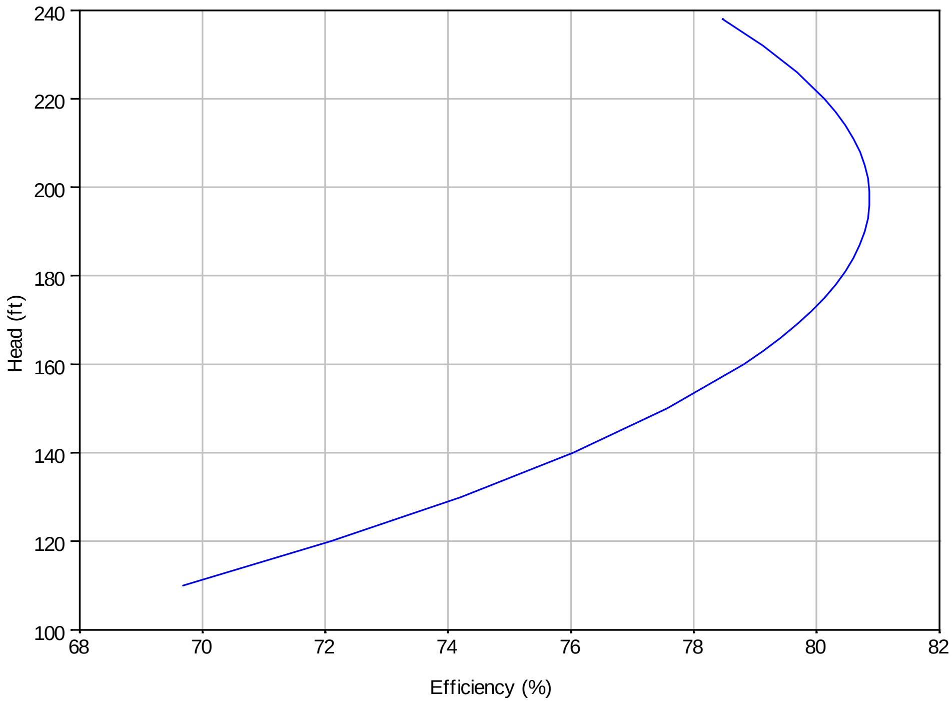


Figure 3-33: Fort Peck powerplant efficiency.

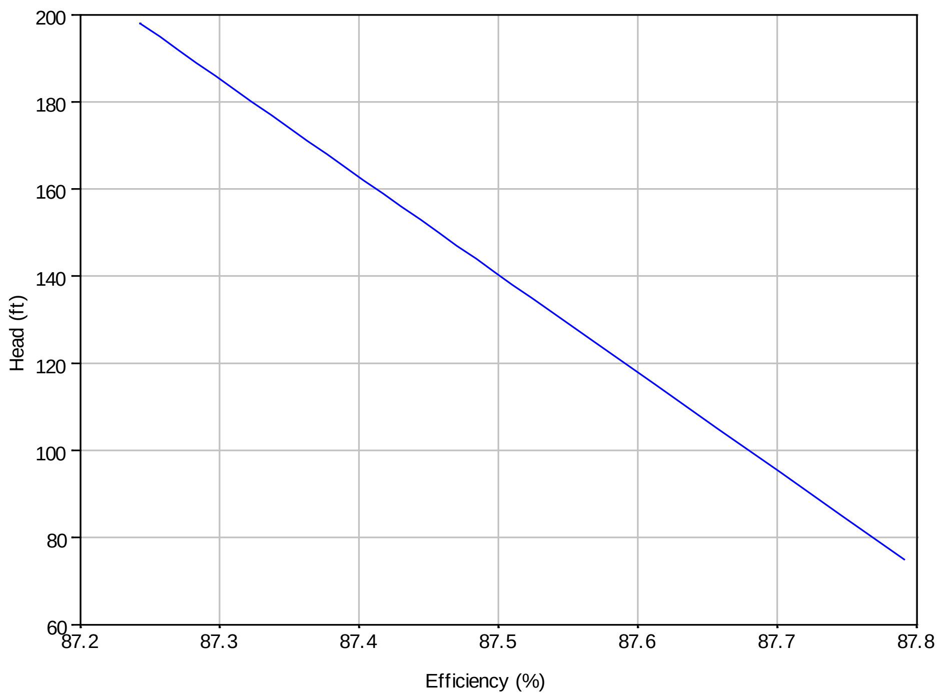


Figure 3-34: Garrison powerplant efficiency.

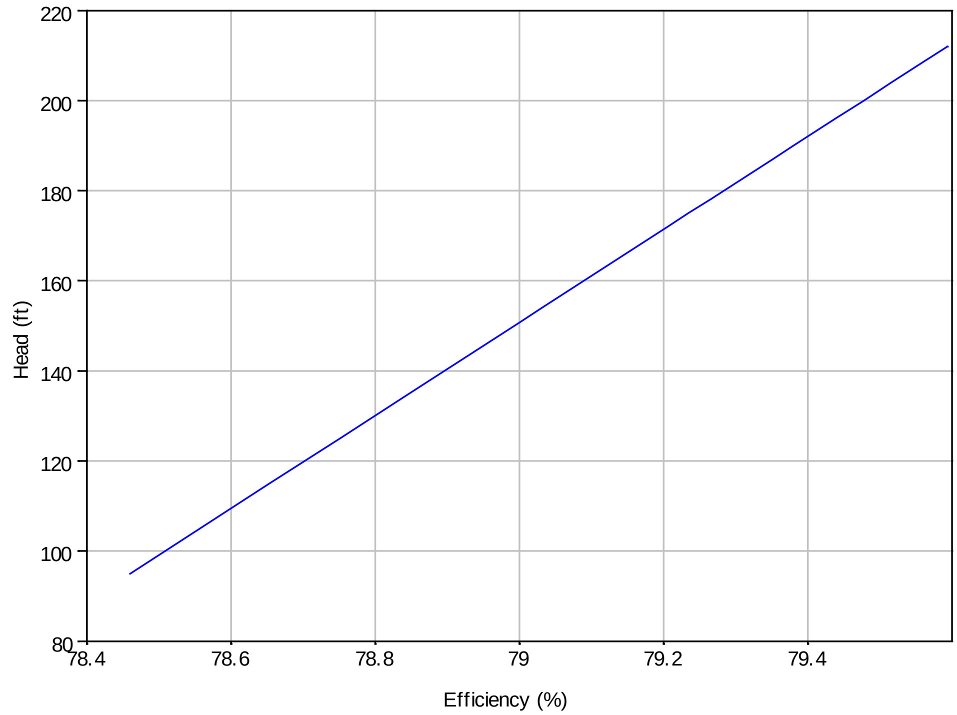


Figure 3-35: Oahe powerplant efficiency.

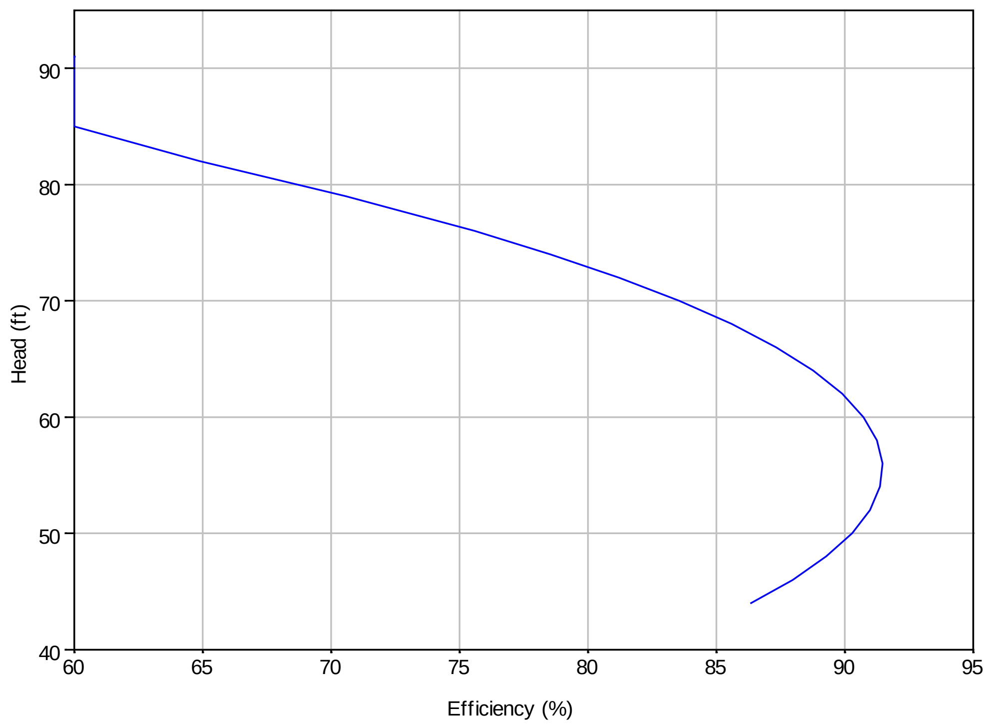


Figure 3-36: Big Bend powerplant efficiency.

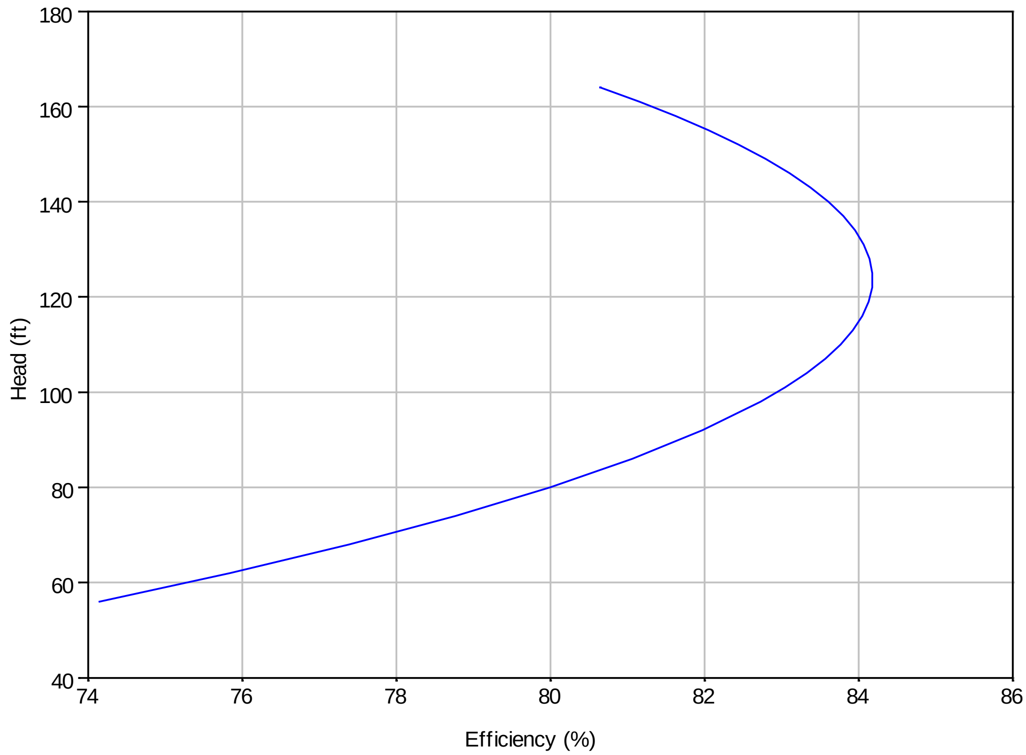


Figure 3-37: Fort Randall powerplant efficiency.

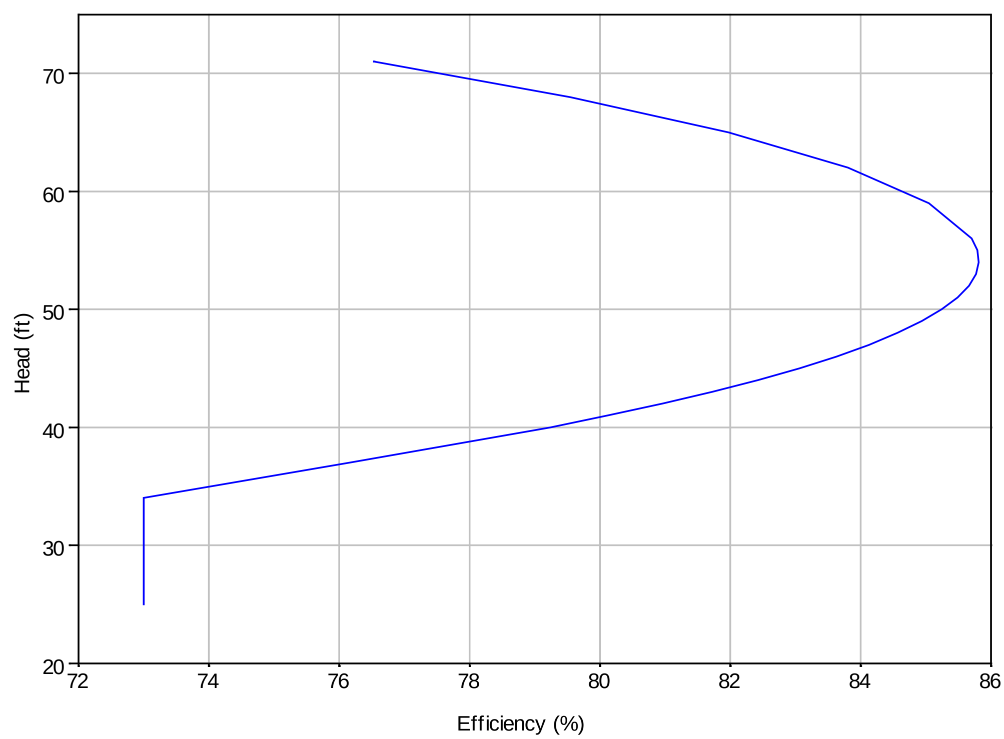


Figure 3-38: Gavins Point powerplant efficiency.

4 RESSIM MODELING

4.1 RESSIM PROGRAM OVERVIEW

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

The model was simulated using a daily time interval. ResSim version 3.3, build 3.3.1.117R, from March 2017 was used for modeling in this project.

4.2 MODELING EXTENTS

A ResSim stream alignment provides the framework for what streams can be modeled in desired networks. The stream alignment created for the Missouri River Mainstem model (Figure 3-1) extends from the headwaters of the Missouri River down to the Ohio-Mississippi River confluence and includes major tributaries such as the Yellowstone, Kansas, Chariton, and Osage Rivers as well as segments of minor tributaries. The Network created for the mainstem model (Figure 4-1) begins at the Landusky, MT gage located just upstream of Fort Peck on the Missouri River and terminates at the Mississippi-Ohio River confluence. It does not include the upper Missouri, Yellowstone, Kansas, Chariton, or Osage River Basins available from the stream alignment. These basins are being developed in ResSim externally, but having a common stream alignment is expected to facilitate combining the models in the future. At the downstream end, the model is only functional to the Hermann; MO gage (HEMO), as this is the last point which local flow is added into the System. No data for the Mississippi River was collected or included for modeling, but the stream itself was included in the Network for potential future alternative analyses.

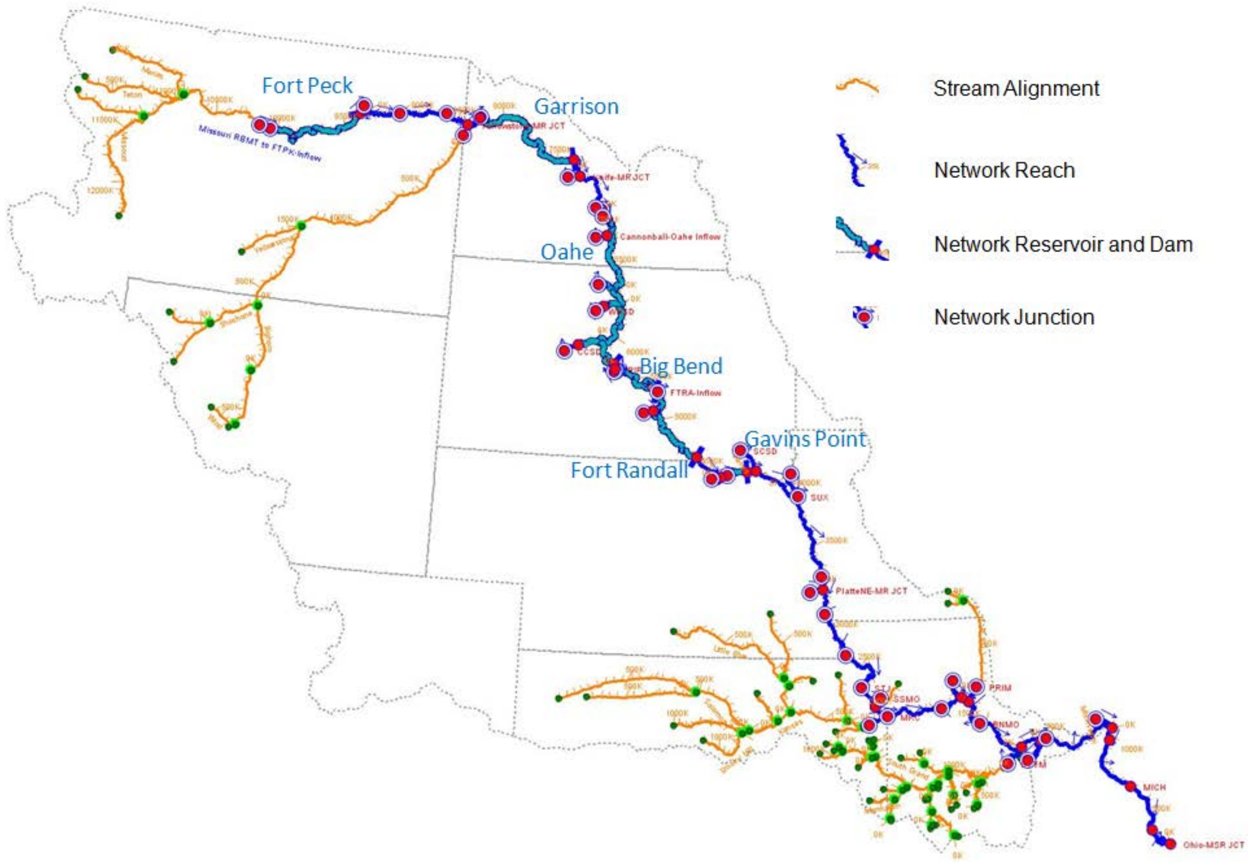


Figure 4-1: Missouri River Mainstem System ResSim Network.

4.3 MODELING STRATEGY

4.3.1 Overview

The objective of this ResSim model is to simulate System operation for the period of record for assessment of base conditions on the Missouri River. Early efforts focused on data and model planning and development. Later efforts emphasized model operations development and validation of model performance.

Missouri River System operation is extremely complex. Section 2.3 described the Mainstem System operation as outlined in the Master Manual. Various characteristics make it unique such as the physical arrangement of the reservoirs with the upper three holding most of the storage and the travel times between the reservoirs. Also the combined storage capacity of all six System reservoirs is 72.4 MAF, about three times the annual runoff into the System above Sioux City. This high ratio of storage capacity to runoff lends an unusual degree of flexibility to the regulation of the multipurpose reservoir system. In contrast, the ratio of reservoir storage capacity to annual runoff in the Columbia and Ohio River basins is 1:5, approximately one acre-foot of storage for each five acre-feet of annual runoff.

The concept of using a traditional guide curve is not applicable for the mainstem reservoirs, especially in the upper three reservoirs where their enormous storage provides flexibility for operation (see Section 2.3.1.3). All the reservoirs are in series, and releases must be planned systematically. Normal regulation releases are first determined from the most downstream dam, Gavins Point. These releases take into account the downstream flow targets (Sioux City, Omaha, Nebraska City, and Kansas City), the incremental local flows between the flow targets, and the routing time it takes for water to reach the targets. Once a daily release has been determined at Gavins Point, releases are planned at the next upstream reservoir, again accounting for local flows, routing, and special reservoir conditions. The progression of release decisions moves upstream. In essence, the upstream three reservoirs supply the volume needed at the most downstream Gavins Point to meet target flows. Big Bend passes water from Oahe and provides peaking power. Fort Randall follows a seasonal guide curve that lowers pool elevations in the fall to allow for higher winter hydropower releases from the upstream projects.

Releases from Gavins Point are generally highest during the navigation season when downstream flow requirements are highest. Since Gavins Point reservoir is small, these releases must be backed up with similar magnitude releases from Fort Randall, and Fort Randall requires similar support flows from Oahe via Big Bend. Here operations shift from a daily requirement to managing volume for the year; Oahe has enough storage to support high releases for extended periods without high inflows and can also attenuate high inflows. Releases from Fort Peck and Garrison are therefore set to ensure the amount of storage in the upper three reservoirs are balanced by the end of the runoff year (~01Mar).

Because of the unique nature of the System, considerable time was spent deciding how it could best be modeled using HEC-ResSim. Face-to-face meetings between NWO, MRBWM, and HEC were required to discuss strategies to put historic operations into HEC-ResSim. The ResSim model does not capture every detail stated in the Master Manual and cannot capture special operations not outlined in the Master Manual; rather focus was turned to major decision-making criteria. Major ResSim goals were established and included the following:

- System Regulation
    - Achieve System storage balance and storage level at the base of the Flood Control and Multiple Use Zone prior to the start of next runoff season (~March 1)
    - Operate the upper three dams (Fort Peck, Garrison, and Oahe) to pass sufficient volume through to Gavins Point so that it can meet downstream targets.
    - Meet Fort Randall's fall drawdown criteria and general guide curve elevation targets.
- Recurring Operational Considerations
    - Perform scheduled System checks on March 15 and July 1 to assess System storage and forecasted runoff which would determine the service level for navigation and flood evacuation operations. The July 1 check would also determine the navigation season length.
    - Perform additional weekly System storage and forecasted runoff checks during flood storage evacuation operations. This would allow increasing releases for unforecasted runoff. For example, if the System was in flood storage evacuation and an assessment was performed May 1, flow targets would be set for the entire month. If multiple large rainfall events were to occur a week later, without

additional System checks, releases would remain constant and pool levels could rise drastically.

- Keep releases below channel capacities when possible to reduce flooding.
- Perform System storage check September 1 to determine Gavins Point winter releases. Also determine if a 10 day navigation season extension is warranted.
- During navigation season, make releases from Gavins Point sufficient to meet navigation flow targets downstream (FTT scenario). Also provide a secondary option to operate some form of the SR-FTT scenario.
- Establish and meet water supply/water quality/environmental flows.

It was desired to model these concepts and operations using the standard rules in ResSim whenever possible. Rate of change and minimum releases were all entered as standard rules. Summaries of the rule stacks are provided in Section 4.3.2.

It was realized a scripted state variable approach would be required to apply the service level concept to determine downstream flow targets during the navigation season. Once downstream targets had been established, ResSim's standard features could theoretically be used to determine releases for all the reservoirs to meet those targets and maintain proper pool elevations. The standard features in ResSim, however, could not accomplish this task because of ResSim's computation progression. During a simulation, ResSim begins computations at the most upstream reservoir and progresses downstream, but the operations of the Missouri River reservoirs are reversed. Releases are set at the furthest downstream reservoir and progress upstream. Because ResSim computes releases from upstream reservoirs first and the furthest downstream reservoir, Gavins Point, has little storage, ResSim would not compute the necessary releases from the upper 3 reservoirs to supply Gavins Point with enough volume to keep its pool elevation above the inactive pool while also releasing enough water to meet downstream flow requirements. If a reservoir's pool elevation reaches its inactive zone during a ResSim simulation, ResSim will override all rules and lower releases until the pool elevation rises above the inactive zone. This frequently occurred at Gavins Point, which caused the model to consistently miss downstream flow targets.

To overcome the limitations of the standard features of ResSim within the time constraints for the Recovery Program, two modeling decisions were made. First, two models would be used to properly operate the System. A Downstream model was created that consisted of one reservoir with a capacity equal to the System capacity located at Gavins Point and all of the downstream gage locations. This model would be responsible for assessing the System storage and making releases for downstream operations: service level, navigation season length, flood constraints, water supply, etc. A System model would then set Gavins Point's releases equal to the releases computed from the Downstream model and determine the releases for the other five reservoirs. The second decision was to use scripts to operate five of the reservoirs: Fort Randall, Big Bend, Oahe, Garrison, and Fort Peck. Utilizing scripts to set releases at these reservoirs allows ResSim to first set releases at Fort Randall and progress upstream. The initial two model approach was used to model several alternatives for the Draft Environmental Impact Statement (EIS), part of the Missouri River Recovery Program. Details of this modeling approach can be found in the *Mainstem Missouri River Reservoir Simulation Report* (U.S. Army Corps of Engineers, 2015).

After completion of alternative modeling for the Draft EIS, several modeling improvements were made allowing the ResSim model to better simulate operations. These improvements are summarized in the following paragraphs and are described in more detail in Section 4.3.3.

The first improvement was updating the scripted rule that set releases from Fort Randall to keep Gavins Point operating at its guide curve elevation. With the updated logic, the model was able to limit fluctuations at Gavins Point, which eliminated the need for two separate models.

After the two models were combined back into one model, a new local flow forecasting method was implemented in the model. The initial method was copied from the DRM, which used a predetermined recession. Each forecasted value was equal to a summation of a percentage of the first and second day of observed flows, always resulting in forecasted local flows with gradual recessions. This was originally done to ensure that flood impacts were not underestimated by providing the model with known local flows. For example, if the model was provided with a perfect local flow forecast, reservoir releases could be reduced to prevent downstream flows from exceeding flood targets. In reality, forecasts are never perfect so there is always some risk that flood targets will be exceeded due to an inaccurate forecast and reservoir releases not being reduced in time. The updated method for forecasting local flows is more dynamic, but still utilizes the previous two days of observed local flows. If the previous two days of observed local flows are rapidly increasing or decreasing, the forecasted local flows will rapidly recede for a few days before the recession is gradually reduced. If the previous two days of observed local flows are steady, the forecasted local flows will slowly recede. This dynamic method allows the model to better meet flow targets while also not underestimating the flood impacts caused by an inaccurate forecast.

Four improvements dealing with flood evacuation and flood targets were also made to the model. Prior to July 1, the service level is not allowed to increase unless the increased service level is at least 40,000 cfs. This was an oversite in the original model since this criteria is in the Master Manual. It helps reduce the possibility that the service level is increased early in the season and then the forecasted high runoff does not materialize. Another improvement was done to the System flood evacuation logic, which along with increased service level, ensures that the stored flood waters are evacuated prior to the start of next year’s runoff. In the old model, predefined releases were needed to help the model match historic flood evacuation releases due to the interaction between flood target requirements (reduce releases) and flood evacuation (increase releases). During real-time operations, increasing the service level and a monthly forecast of releases allows water managers to balance those requirements and ensure all flood waters are evacuated. With the improvement to the System flood evacuation logic, the predefined releases were removed and the model now utilizes a monthly forecast of releases, helping it balance the flood target and evacuation requirements. Another improvement corrected an error in the flood target logic. When the service level was at or below full service in the old model, the full service flood targets were used by reducing the service level to minimum service. The model now correctly ignores the full service flood targets when the service level is at or below full service and only uses the minimum flood targets. The final flood evacuation improvement dealt with reservoirs in surcharge. During extreme flood events, such as the 2011 event, the reservoirs can enter their surcharge zones. During real-time operations, instead of using the induced surcharge or emergency regulation curves from each project's water control manual, the spillway gates are opened at the same rate as the pool rises and the total project release can be regulated with flood tunnels, if the project has them, or the powerhouse. To model this, surcharge curves were developed that represent a minimum spillway release occurring if the top of the gates equaled the pool elevation. This allowed the model to operate the dam for a specified release while also ensuring that spillway releases were representative of gates opening to follow the rising reservoir.

The monthly runoff forecasts were updated to include all available historic runoff forecasts and were migrated from text files to DSSVue time series. The old model used the DRM text files, which only included runoff forecasts for Jan-Jul. The model then had to estimate a runoff forecast for Aug-Dec. Historic runoff forecasts (1971-2012) were obtained from MRBWM and used to create new DSSVue time series containing Jan-Dec monthly forecasts. For years prior to 1971, the DRM Jan-Jul runoff forecasts were used with the addition of estimated runoff forecasts for Aug-Dec created with assistance from MRBWM.

The final three improvements were minor and did not significantly alter the results of the model. During real-time operations, Big Bend's pool typically begins the week near elevation 1421.0 ft and is drawdown to near 1420.4 ft by Friday, then refilled to near 1421.0 ft over the weekend. This type of operation was added to the model to better simulate Big Bend operations. An error in Gavins Point's guide curve elevations was corrected, so the reservoir rises from 1206.0 ft to 1207.5 ft during September instead of August. The final improvement dealt with the steady release period. The old model operated for a steady release from Gavins Point between May 15 and July 15. The new model uses an updated period, May 15 to August 15, to better reflect operations during the endangered bird species' nesting period.

4.3.2 Rules

Summaries of the rule stacks used in HEC-ResSim for each of the mainstem reservoirs and explanations of reservoir guide curves and special operations are provided in Table 4-1 through Table 4-7. Criteria for the rules were identified from the Master Manual, DRM, and observations of historic operations. The rules appear as they were ordered within the model.

Table 4-1: Fort Peck operations/rule stack.

Pool Zone	Rule Name	Description
Surcharge (Guide Curve)	Fcst Runoff[1, 2]	Scripted rule to combine forecasted monthly runoff into a runoff season volume (Mar-Feb) and a calendar year volume (Jan-Dec).
	Fcst GAPT Releases[1, 2]	Scripted rule to forecast GAPT releases for the remainder of the runoff season (Mar-Feb).
	Fcst Local Flow[1, 2, 3, 4]	Scripted rule to forecast all local inflow for the basin.
	Service Level[2, 3]	Runs the ServiceLevel state variable which computes the service level, navigation season length, System storage, etc. No decisions are based on this state variable in the System model, but it is still computed because it produces variables such as System storage. Placed at FTPK because ResSim calculates from upstream to downstream.
	ServiceLevel_x1k[2, 3]	Runs the ServiceLevel_x1K state variable. Calculates navigation target discharges at the downstream target locations based on the service level. No decisions are based on this state variable in the System model, but it is still computed because the ServiceLevel state variable is computed. Placed at FTPK because ResSim calculates from upstream to downstream.
	System Flood Evac[2]	Scripted rule calculates a minimum release necessary to evacuate all flood storage prior to the beginning of the next runoff season (~01Mar).
	Nav, WS, & Flood Targets[2, 3, 4]	Scripted rule that sets GAPT releases to ensure all downstream navigation, water supply, and flood targets are met. FTRA releases are set to ensure that GAPT stays at its guide curve elevation.
	Steady Release[3]	Scripted rule that runs between 15May and 15Aug only when a flood downstream flood target is not being exceeded. Sets a steady GAPT release during the endangered bird species nesting season. Releases are increased if flows at a downstream navigation target location are forecasted to drop below the target flow. After releases are increased, a new steady release is maintained.
	Alt 1 – Spawning Cue[3]	Scripted rule that calculates spawning cue releases from GAPT.
	BEND & FTRA Guide Curve[4]	Scripted rule that calculates releases from OAHE to keep BEND at its operating elevation. Calculates releases from BEND to keep FTRA at its guide curve elevation.
	Spillway Surcharge Release[2]	A minimum release rule specified at the spillway to minimize spillway flow when the pool enters the surcharge zone. Mimics the real-time operation of raising the spillway gates as the pool rises.
	Reservoir Flood Evac[2]	Scripted rule that calculates releases for any reservoir operating in its respective flood control zones to prevent the reservoir from rising uncontrollably
	Reservoir Flood Control[2]	Scripted rule that computes a reduced release for any reservoir where the downstream reservoir is operating with a nearly full flood control zone.
	FTPK & GARR Balancing Release[1, 2]	Scripted rule to set releases at FTPK and GARR that will unbalance/balance storage in FTPK, GARR, and OAHE.
	FTPK & GARR Water Supply[4]	Scripted rule that ensures minimum discharges are met at WPMT, CLMT, and BIS

Pool Zone	Rule Name	Description
	Compute Block	A minimum release rule operating as a function of MKC flow. Rule creates a compute block to ensure all points between FTPK and MKC are computed simultaneously.
Exclusive Flood Control	Fcst Runoff[1, 2]	See description in the Surcharge Zone
	Fcst GAPT Releases[1, 2]	See description in the Surcharge Zone
	Fcst Local Flow[1, 2, 3, 4]	See description in the Surcharge Zone
	Service Level[2, 3]	See description in the Surcharge Zone
	ServiceLevel_x1k[2, 3]	See description in the Surcharge Zone
	ROC Limit for Flood - Increase	Limits release rate of change increase to 375 cfs/hour (9,000 cfs per day).
	ROC Limit for Flood - Decrease	Limits release rate of change decrease to 500 cfs/hour (12,000 cfs per day).
	System Flood Evac[2]	See description in the Surcharge Zone
	Nav, WS, & Flood Targets[2, 3, 4]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Alt 1 – Spawning Cue[3]	See description in the Surcharge Zone
	BEND & FTRA Guide Curve[4]	See description in the Surcharge Zone
	Spillway Surcharge Release[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Control[2]	See description in the Surcharge Zone
	FTPK & GARR Balancing Release[1, 2]	See description in the Surcharge Zone
	FTPK & GARR Water Supply[4]	See description in the Surcharge Zone
Flood Control & Multiple Use	Fcst Runoff[1, 2]	See description in the Surcharge Zone
	Fcst GAPT Releases[1, 2]	See description in the Surcharge Zone
	Fcst Local Flow[1, 2, 3, 4]	See description in the Surcharge Zone
	Service Level[2, 3]	See description in the Surcharge Zone
	ServiceLevel_x1k[2, 3]	See description in the Surcharge Zone
	ROC Limit for Normal - Increase	Limits release rate of change increase to 250 cfs/hour (6,000 cfs per day).
	ROC Limit for Normal - Decrease	Limits release rate of change decrease to 125 cfs/hour (3,000 cfs per day).
	System Flood Evac[2]	See description in the Surcharge Zone
	Nav, WS, & Flood Targets[2, 3, 4]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Alt 1 – Spawning Cue[3]	See description in the Surcharge Zone
	BEND & FTRA Guide Curve[4]	See description in the Surcharge Zone
	Spillway Surcharge Release[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Control[2]	See description in the Surcharge Zone
	FTPK & GARR Balancing Release[1, 2]	See description in the Surcharge Zone
	FTPK & GARR Water Supply[4]	See description in the Surcharge Zone

Pool Zone	Rule Name	Description
Carryover Multiple Use	Fcst Runoff[1, 2]	See description in the Surcharge Zone
	Fcst GAPT Releases[1, 2]	See description in the Surcharge Zone
	Fcst Local Flow[1, 2, 3, 4]	See description in the Surcharge Zone
	Service Level[2, 3]	See description in the Surcharge Zone
	ServiceLevel_x1k[2, 3]	See description in the Surcharge Zone
	ROC Limit for Normal - Increase	See description in the Flood Control and Multiple Use Zone
	ROC Limit for Normal - Decrease	See description in the Flood Control and Multiple Use Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	Nav, WS, & Flood Targets[2, 3, 4]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Alt 1 – Spawning Cue[3]	See description in the Surcharge Zone
	BEND & FTRA Guide Curve[4]	See description in the Surcharge Zone
	Spillway Surcharge Release[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Control[2]	See description in the Surcharge Zone
	FTPK & GARR Balancing Release[1, 2]	See description in the Surcharge Zone
	FTPK & GARR Water Supply[4]	See description in the Surcharge Zone
Permanent	Fcst Runoff[1, 2]	See description in the Surcharge Zone
	Fcst GAPT Releases[1, 2]	See description in the Surcharge Zone
	Fcst Local Flow[1, 2, 3, 4]	See description in the Surcharge Zone
	Service Level[2, 3]	See description in the Surcharge Zone
	ServiceLevel_x1k[2, 3]	See description in the Surcharge Zone
	ROC Limit for Normal - Increase	See description in the Flood Control and Multiple Use Zone
	ROC Limit for Normal - Decrease	See description in the Flood Control and Multiple Use Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	Nav, WS, & Flood Targets[2, 3, 4]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Alt 1 – Spawning Cue[3]	See description in the Surcharge Zone
	BEND & FTRA Guide Curve[4]	See description in the Surcharge Zone
	Spillway Surcharge Release[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Control[2]	See description in the Surcharge Zone
	FTPK & GARR Balancing Release[1, 2]	See description in the Surcharge Zone
	FTPK & GARR Water Supply[4]	See description in the Surcharge Zone
No Storage (Inactive)	--	No rules apply to the No Storage or Inactive Zone

[1]Seasonal intrasystem operation
[2]Flood control operation
[3]Water requirement below Gavins Point operations
[4]Water requirement above Gavins Point operation

Table 4-2: Garrison operations/rule stack.

Pool Zone	Rule Name	Description
Surcharge (Guide Curve)	Spillway Surcharge Release[2]	A minimum release rule specified at the spillway to minimize spillway flow when the pool enters the surcharge zone. Mimics the real-time operation of raising the spillway gates as the pool rises.
	Balancing Release[1, 2]	Relates GARR release to “FTPK & GARR Balancing Release” scripted rule (see FTPK rules) on a 1 to 1 basis.
	Reservoir Flood Evac[2]	Relates GARR release to “Reservoir Flood Evac” scripted rule (see FTPK rules) on a 1 to 1 basis.
	Water Supply Release[4]	Relates GARR release to “FTPK & GARR Water Supply” scripted rule (see FTPK rules) on a 1 to 1 basis.
Exclusive Flood Control	Reservoir Flood Control – Max[2]	Relates GARR release to “Reservoir Flood Evac” scripted rule (see FTPK rules) on a 1 to 1 basis, but set to a maximum release. Occurs when the GARR_Flood_Control state variable value does not equal 0.0.
	Reservoir Flood Control – Min[2]	Relates GARR release to “Reservoir Flood Evac” scripted rule (see FTPK rules) on a 1 to 1 basis, but set to a minimum release. Occurs when the GARR_Flood_Control state variable value equals 0.0.
	ROC Limit for Flood - Increase	Limits release rate of change increase to 375 cfs/hr (9,000 cfs/day).
	ROC Limit for Flood - Decrease	Limits release rate of change decrease to 500 cfs/hr (12,000 cfs/day).
	Balancing Release[1, 2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Water Supply Release[4]	See description in the Surcharge Zone
Flood Control & Multiple Use	Reservoir Flood Control – Max[2]	See description in the Exclusive Flood Zone
	Reservoir Flood Control – Min[2]	See description in the Exclusive Flood Zone
	ROC Limit for Normal - Increase	Limits release rate of change increase to 250 cfs/hr (6,000 cfs/day).
	ROC Limit for Normal - Decrease	Limits release rate of change decrease to 125 cfs/hr (3,000 cfs/day).
	Balancing Release[1, 2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Water Supply Release[4]	See description in the Surcharge Zone
Carryover Multiple Use	Reservoir Flood Control – Max[2]	See description in the Exclusive Flood Zone
	Reservoir Flood Control – Min[2]	See description in the Exclusive Flood Zone
	ROC Limit for Normal - Increase	See description in the Flood Control & Multiple Use Zone
	ROC Limit for Normal - Decrease	See description in the Flood Control & Multiple Use Zone
	Balancing Release[1, 2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Water Supply Release[4]	See description in the Surcharge Zone
Permanent	Reservoir Flood Control – Max[2]	See description in the Exclusive Flood Zone
	Reservoir Flood Control – Min[2]	See description in the Exclusive Flood Zone
	ROC Limit for Normal - Increase	See description in the Flood Control & Multiple Use Zone
	ROC Limit for Normal - Decrease	See description in the Flood Control & Multiple Use Zone
	Balancing Release[1, 2]	See description in the Surcharge Zone

Pool Zone	Rule Name	Description
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Water Supply Release[4]	See description in the Surcharge Zone
No Storage (Inactive)	--	No rules apply to the No Storage or Inactive Zone

[1]Seasonal intrasystem operation
[2]Flood control operation
[3]Water requirement below Gavins Point operations
[4]Water requirement above Gavins Point operation

Table 4-3: Oahe operations/rule stack.

Pool Zone	Rule Name	Description
Surcharge (Guide Curve)	Spillway Surcharge Release[2]	A minimum release rule specified at the spillway to minimize spillway flow when the pool enters the surcharge zone. Mimics the real-time operation of raising the spillway gates as the pool rises.
	BEND Guide Curve Release[4]	Relates OAHE release to "BEND & FTRA Guide Curve" scripted rule (see FTPK rules) on a 1 to 1 basis.
	Reservoir Flood Evac[2]	Relates OAHE release to "Reservoir Flood Evac" scripted rule (see FTPK rules) on a 1 to 1 basis.
Exclusive Flood Control	Zero Spillway Release[2]	Limits the spillway releases to 0 cfs. The spillway at OAHE is not used unless absolutely necessary.
	ROC Limit for Normal - Increase	Limits release rate of change increase to 833 cfs/hr (20,000 cfs/day).
	ROC Limit for Normal - Decrease	Limits release rate of change increase to 833 cfs/hr (20,000 cfs/day).
	BEND Guide Curve Release[4]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
Flood Control & Multiple Use	ROC Limit for Normal - Increase	See description in the Exclusive Flood Control Zone
	ROC Limit for Normal - Decrease	See description in the Exclusive Flood Control Zone
	BEND Guide Curve Release[4]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
Carryover Multiple Use	ROC Limit for Normal - Increase	See description in the Exclusive Flood Control Zone
	ROC Limit for Normal - Decrease	See description in the Exclusive Flood Control Zone
	BEND Guide Curve Release[4]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
Permanent	ROC Limit for Normal - Increase	See description in the Exclusive Flood Control Zone
	ROC Limit for Normal - Decrease	See description in the Exclusive Flood Control Zone
	BEND Guide Curve Release[4]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
No Storage (Inactive)	--	No rules apply to the No Storage or Inactive Zone

[1]Seasonal intrasystem operation
[2]Flood control operation
[3]Water requirement below Gavins Point operations
[4]Water requirement above Gavins Point operation

Table 4-4: Big Bend operations/rule stack.

Pool Zone	Rule Name	Description
Surcharge Zone	Spillway Surcharge Release[2]	A minimum release rule specified at the spillway to minimize spillway flow when the pool enters the surcharge zone. Mimics the real-time operation of raising the spillway gates as the pool rises.
	Reservoir Flood Evac[2]	Relates BEND release to "Reservoir Flood Evac" scripted rule (see FTPK rules) on a 1 to 1 basis.
	Power Release – Tailwater[4]	Maximum release from the power plant based on the tailwater elevation
	FTRA Guide Curve Release[4]	Relates BEND release to "BEND & FTRA Guide Curve" scripted rule (see FTPK rules) on a 1 to 1 basis.
Exclusive Flood Control (Guide Curve)	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Power Release – Tailwater[4]	See description in the Surcharge Zone
	FTRA Guide Curve Release[4]	See description in the Surcharge Zone
Flood Control & Multiple Use	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Power Release – Tailwater[4]	See description in the Surcharge Zone
	FTRA Guide Curve Release[4]	See description in the Surcharge Zone
Permanent	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Power Release – Tailwater[4]	See description in the Surcharge Zone
	FTRA Guide Curve Release[4]	See description in the Surcharge Zone
No Storage (Inactive)	--	No rules apply to the No Storage or Inactive Zone

[1]Seasonal intrasystem operation
[2]Flood control operation
[3]Water requirement below Gavins Point operations
[4]Water requirement above Gavins Point operation

Table 4-5: Fort Randall operations/rule stack.

Pool Zone	Rule Name	Description
Surcharge (Guide Curve)	Spillway Surcharge Release[2]	A minimum release rule specified at the spillway to minimize spillway flow when the pool enters the surcharge zone. Mimics the real-time operation of raising the spillway gates as the pool rises.
	Nav, WS, & Flood Target Release[2, 3, 4]	Relates FTRA release to "Nav, WS, & Flood Target Release" scripted rule (see FTPK rules) on a 1 to 1 basis.
	System Flood Evac[2]	Relates FTRA release to "System Flood Evac" scripted rule (see FTPK rules) on a 1 to 1 basis.
	Reservoir Flood Evac[2]	Relates FTRA release to "Reservoir Flood Evac" scripted rule (see FTPK rules) on a 1 to 1 basis.
	Steady Release[3]	Relates FTRA release to "Steady Release" scripted rule (see FTPK rules) on a 1 to 1 basis.
	Spawning Cue[3]	Relates FTRA release to "Alt 1 – Spawning Cue" scripted rule (see FTPK rules) on a 1 to 1 basis.
Exclusive Flood Control	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone

Pool Zone	Rule Name	Description
	Spawning Cue[3]	See description in the Surcharge Zone
Flood Control & Multiple Use	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Spawning Cue[3]	See description in the Surcharge Zone
Guide Curve	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Spawning Cue[3]	See description in the Surcharge Zone
Permanent	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	Reservoir Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Spawning Cue[3]	See description in the Surcharge Zone
No Storage (Inactive)	--	No rules apply to the No Storage or Inactive Zone

[1]Seasonal intrasystem operation
[2]Flood control operation
[3]Water requirement below Gavins Point operations
[4]Water requirement above Gavins Point operation

Fort Randall's operation includes an annual drawdown during the autumn. Guidance from MRBWM suggested a drop from elevation 1355 ft to 1337.5 from Labor Day to the end of the navigation season. The pool will refill during the winter power season and be near the base of flood control and multiple use on March 1 (elevation 1350 ft.). Table 4-6 below summarizes the guide curve used in ResSim. Linear interpolation is applied between dates.

Table 4-6: Fort Randall guide curve.

Date	Elevation (ft)
1-Jan	1341.8
1-Mar	1350.0
1-Apr	1355.0
1-Sep	1355.0
1-Dec	1337.5

Table 4-7: Gavins Point operations/rule stack.

Pool Zone	Rule Name	Description
Surcharge (Guide Curve)	Spillway Surcharge Release[2]	A minimum release rule specified at the spillway to minimize spillway flow when the pool enters the surcharge zone. Mimics the real-time operation of raising the spillway gates as the pool rises.
	Nav, WS, & Flood Target Release[2, 3, 4]	Relates GAPT release to "Nav, WS, & Flood Target Release" scripted rule (see FTPK rules) on a 1 to 1 basis.
	System Flood Evac[2]	Relates GAPT release to "System Flood Evac" scripted rule (see FTPK rules) on a 1 to 1 basis.
	FTRA Flood Evac[2]	Relates GAPT release to "Reservoir Flood Evac" scripted rule (see FTPK rules) on a 1 to 1 basis.
	Steady Release[3]	Relates GAPT release to "Steady Release" scripted rule (see FTPK rules) on a 1 to 1 basis.
	Spawning Cue[3]	Relates GAPT release to "Alt 1 – Spawning Cue" scripted rule (see FTPK rules) on a 1 to 1 basis.
Exclusive Flood Control	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	FTRA Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Spawning Cue[3]	See description in the Surcharge Zone
Flood Control & Multiple Use	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	FTRA Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Spawning Cue[3]	See description in the Surcharge Zone
Guide Curve (Guide Curve)	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	FTRA Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Spawning Cue[3]	See description in the Surcharge Zone
Permanent	Nav, WS, & Flood Target Release[2, 3, 4]	See description in the Surcharge Zone
	System Flood Evac[2]	See description in the Surcharge Zone
	FTRA Flood Evac[2]	See description in the Surcharge Zone
	Steady Release[3]	See description in the Surcharge Zone
	Spawning Cue[3]	See description in the Surcharge Zone
No Storage (Inactive)	--	No rules apply to the No Storage or Inactive Zone

[1]Seasonal intrasystem operation
[2]Flood control operation
[3]Water requirement below Gavins Point operations
[4]Water requirement above Gavins Point operation

Table 4-8: Gavins Point guide curve.

Date	Elevation (ft)
1-Jan	1207.5
1-Feb	1207.5
1-Mar	1206.0
1-Sep	1206.0
1-Oct	1207.5
1-Dec	1207.5

4.3.3 Description of Scripted Rules

4.3.3.1 Fcst Runoff

The purpose of the Fcst Runoff script is to compute a runoff year (Mar-Feb) forecast for each project reach and compute a runoff year and calendar year (Jan-Dec) forecast for the System above Gavins Point Dam. At the beginning of each month, the script retrieves the monthly calendar year runoff forecasts for the remaining months in the calendar year from a DSS file. Since the monthly forecasts are based on calendar year forecasts but the runoff year spans Jan and Feb of the following year, the script estimates runoff for Jan and Feb based on the Dec runoff quantile (lower decile, lower quartile, median, upper quartile, or upper decile), to create a complete runoff year forecast. For example, if the Dec runoff is forecasted to be between a lower quartile and a median runoff, the Jan and Feb runoff would be a lower quartile runoff. The statistics for each project and the System above Gavins Point Dam are located in a ConfigFile.txt file, which is imported at the beginning of the script.

The following summary of the monthly calendar year runoff forecasts used in the script was provided by NWD MRBWM:

> "The long-range runoff forecast is presented as the Calendar Year Runoff forecast. This forecast is developed shortly after the beginning of each calendar year and is updated at the beginning of each month to show the actual runoff for historic months of that year and updated forecasts for the remaining months of the year. This forecast presents monthly inflows in MAF from five incremental drainage areas, as defined by the individual System projects, plus the incremental drainage area between Gavins Point Dam and Sioux City. Due to their close proximity, the Big Bend and Fort Randall drainage areas are combined. Summations are provided for the total Missouri River reach above Gavins Point Dam and for the total Missouri River reach above Sioux City. The runoff forecast is adjusted as data becomes available to the common level of basin development, which has been selected as 1949. The 1949 development year is the most recent year that is not affected, to a great extent, by water resource development in the Missouri River basin. By adjusting runoffs to this common level of development, a consistent historical runoff data set has been created by river reach."

"The forecast of monthly inflows accounts for the three primary runoff components - mountain snowpack, plains snowpack and rainfall. The MRBWM has developed an analytical technique to forecast snowpack runoff from mountainous regions. The mountain snowpack runoff is captured by Fort Peck and Garrison during the May-June-July period. Snow accumulated over the plains area is frequently a major contributor to System inflows during March and April. To date, few reliable procedures for making accurate quantitative volume runoff forecasts for plains snowmelt are available that consider basin soil conditions during successive wet and/or dry years. However, the MRBWM is actively working with HEC and CRREL, as well as other governmental entities, to improve existing plains snowmelt techniques. Runoff from rainfall events, which mostly occurs between March and October, is particularly difficult to determine more than a few days in advance. The MRBWM utilizes long-term 3-month precipitation outlooks from the NOAA CPC as well as drought monitor maps and various soil moisture models to qualitatively factor those into the long-term runoff forecast."

"Records of runoff forecasts were available from 1971 to present. At the time of development, 1971-1997 records were used to correlate runoff forecasts to actual runoff. The correlation coefficients were applied to historic runoff values to obtain forecast files for years prior to 1971."

The script also tracks observed monthly runoff for each project throughout the simulation. This is used to adjust the current month's forecast as the simulation progresses through the month. On the first of the month, the calendar and runoff year forecasts use 100 percent of the current month's forecasted runoff. If there are at least 40 percent of the days remaining in the month, a fraction of the current month's forecast is used to compute the remaining forecasted runoff. If there are less than 40 percent of the days remaining in the month, a fraction of the observed runoff is used for the remaining forecasted runoff. For example, if the current date is May 25 and the Fort Peck has had 1000 acre-ft of runoff to-date, the remaining May runoff would be 193 acre-ft ((1 – (25-31)) * 1000 acre-ft). This is done to account for major differences in forecasted runoff to observed runoff.

After the current month's forecasted runoff is calculated and added to remaining months to create the calendar and runoff year forecasts, each project's forecasted runoff is written to state variables in the model (e.g. FTPK_Fcst_Runoff_RY, GARR_Fcst_Runoff_RY, etc.). The projects' runoff forecasts are then combined into System forecasts above Gavins Point Dam and written to Fcst_Runoff_CY and Fcst_Runoff_RY state variables.

4.3.3.2 Fcst GAPT Release

The Fcst GAPT Release scripted rule forecasts the volume of water that will leave the Mainstem Reservoir System via Gavins Point Dam for the remainder of the runoff year. This is accomplished by first calculating the quantile for the calendar year forecast based on historic data and then using the quantile to look up normal Gavins Point releases required to meet the specified service level for each remaining month of the navigation season, shown in Table 4-9. The script accounts for shortened, lengthened, or years with no navigation seasons. Releases are linearly interpolated if the service level is greater than minimum service (29,000 cfs) and less than full service (35,000 cfs).

Table 4-9: Gavins Point releases needed to meet target flows from Plate 3 in the AOP.

1950 to 1996 Data (kcfs)								
	Median, Upper Quartile, Upper Decile Runoff							
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Full Service	26.7	28.0	27.9	31.6	33.2	32.6	32.0	31.1
Minimum Service	20.7	22.0	21.9	25.6	27.2	26.6	26.0	25.1
	Lower Quartile, Lower Decile Runoff							
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Full Service	29.8	31.3	31.2	34.3	34.0	33.5	33.1	31.2
Minimum Service	23.8	25.3	25.2	28.3	28.0	27.5	27.1	25.2

For example, if the July calendar year runoff forecast was a median quartile and the service level was full service for a full 8-month navigation season, the forecasted Gavins Point Dam releases from July through November are 31,600; 33,200; 32,600; 32,000; and 31,100 cfs, respectively. This corresponds to a total volume of 9.742 MAF released during the remainder of the navigation season.

Once releases are determined for the remainder of the navigation season, fall water supply releases (if there is a shortened navigation season) and winter releases are calculated and added to the total runoff year releases from Gavins Point Dam. For an 8-month navigation season and a winter release of 17,000 cfs, the volume released from Gavins Point Dam from December through February is 0.771 MAF, so there is a total of 10.513 MAF forecasted to be released from Gavins Point Dam for the remainder of the runoff season. This volume is written to a state variable and used in other scripted rules. This scripted rule does not set a release value at a dam.

4.3.3.3 Fcst Local Flow

In order for the model to perform internal forecasting of pool elevations and flows at target locations, an incremental or local flow needs to be forecasted to account for travel time. The Fcst Local Flow scripted rule creates the necessary flow forecasts and writes them to state variables.

Two different forecasting methods are used depending on whether the forecast location is a river gage or a reservoir. At all mainstem dam locations, the first day of the forecast includes an increase or decrease in flow equal to half of the rate of change between the previous two days of observed flows. For example, if the observed local flow increased from 1,000 cfs to 2,000 cfs over the last two days, the first day of forecasted flow is equal to 2,500 cfs ((2,000 cfs – 1,000 cfs) / 2 + 2,000 cfs). A recession coefficient is then calculated and used for days two through five of the forecasted flows. For days six through fourteen, a new recession coefficient is calculated for each day that slowly decreases the recession coefficient to simulate the forecasted flow returning to a baseflow. This method for forecasting was done to help the model account for the flashy nature of the local flows that can occur at Gavins Point Dam. Since Lewis and Clark Lake is operated within a small elevation band and the reservoir has little storage, rainfall runoff can cause the reservoir to fluctuate rapidly if the model does not have enough time to adjust releases from Fort Randall Dam. A forecast that fluctuates with observed data and assumes flows will continue to increase while the observed data is showing a rising limb on the hydrograph gives the model a better ability to regulate Lewis and Clark Lake.

At all locations downstream of Gavins Point Dam, the first day of forecasted flow is recessed by 40 percent of the rate of change between the previous two days of observed flow. The recession for the second day of forecasted flow reduces the rate of change by 90 percent. The third through fourteenth days of forecasted flow continue to recede, but with less of a recession; each day's rate of change is reduced by an additional four percent. For example, if the observed local flow increased from 1,000 cfs to 2,000 cfs over the last two days, the previous day's observed flow is reduced by 400 cfs ((2,000 cfs – 1,000 cfs) * 0.4), so the first day of forecasted flow is equal to 1,600 cfs (2,000 cfs – 400 cfs). The first day's rate of change is then reduced by 0.9, equaling 360 cfs (400 cfs * 0.9), so the second day of forecasted flow is equal to 1,240 cfs (1,600 cfs – 360 cfs). The second day's rate of change is reduced by 0.86 (0.9 – 0.04), equaling 310 cfs (360 kcfs * 0.86), so the third day of forecasted flow is equal to 930 cfs (1,240 cfs – 310 cfs). Repeating the same process, the fourth day through the fourteenth day's forecasted flows are all receding but at a slower rate.

4.3.3.4 Service Level State Variable

The Service Level state variable script is a key component to the ResSim model. When run, it produces numerous state variables which are used for various release decisions.

The service level script primarily creates System state variables that are used to determine releases from Gavins Point Dam during the navigation and winter release seasons. It brings in data from outside sources such as historic forecasted runoff data, historical quantile flows and releases, and Plate VI-1 (Figure 4-2) from the Master Manual to make calculations. Much of the script looks at defining a service level for the System. Service level determines flow targets at four locations downstream of Gavins Point. Full service, 35,000 cfs, results in target flows of 31,000 cfs at Sioux City and Omaha, 37,000 cfs at Nebraska City and 41,000 cfs at Kansas City. Similarly, minimum service, 29,000 cfs, results in target flow values of 6,000 cfs less than the full-service levels. Storage evacuation service levels are those above 35,000 cfs that set higher targets downstream and aid in evacuating flood water.

The first of three required System assessments is performed on March 15 to determine the initial service level. The service level depends on water supply and is estimated from Plate VI-1 (Figure 4-2) from the Master Manual. Water supply for the script is determined from the actual current System storage and the forecasted remaining calendar year runoff volume above Gavins Point Dam. This service level sets the downstream targets until July 1 with exceptions. If the service level is in the storage evacuation category, additional service level checks are performed so that targets can be updated to release more appropriate volumes of water. Another exception occurs if it is desired to use a SR-FTT scenario. In this case, FTT is practiced until the nesting season begins on May 15. Gavins Point then releases at an initial steady rate through August 15. If cycling is desired as part of an alternative operation, releases from Gavins Point will cycle 6,000 cfs every other day from May 5 until June 1st then will return to a steady release for the month of June. The steady release rate is determined from the "Gavins Point Releases Needed to Meet Target Flows" section of Plate 3 in the AOP, which is summarized in Table 4-9. The idea is to release a rate sufficient to meet target requirements during the driest part of the nesting season. This prevents the endangered birds from nesting on sandbars early in the season that would get inundated later when Gavins Point releases are increased to meet flow targets.

Intermittent System assessments are performed monthly between April 1 and November 1 allowing the model to check whether the service level needs to be increased to a storage evacuation service level. If a System assessment shows a storage evacuation service level is required, the service level is increased and the System will be assessed every week until a storage evacuation service level is no longer required or the navigation season ends. This allows the model to better adjust releases during high runoff years. For example, the monthly forecasts may anticipate a certain flood evacuation service level on May 1, but higher than anticipated runoff in the upcoming weeks would necessitate an even higher service level.

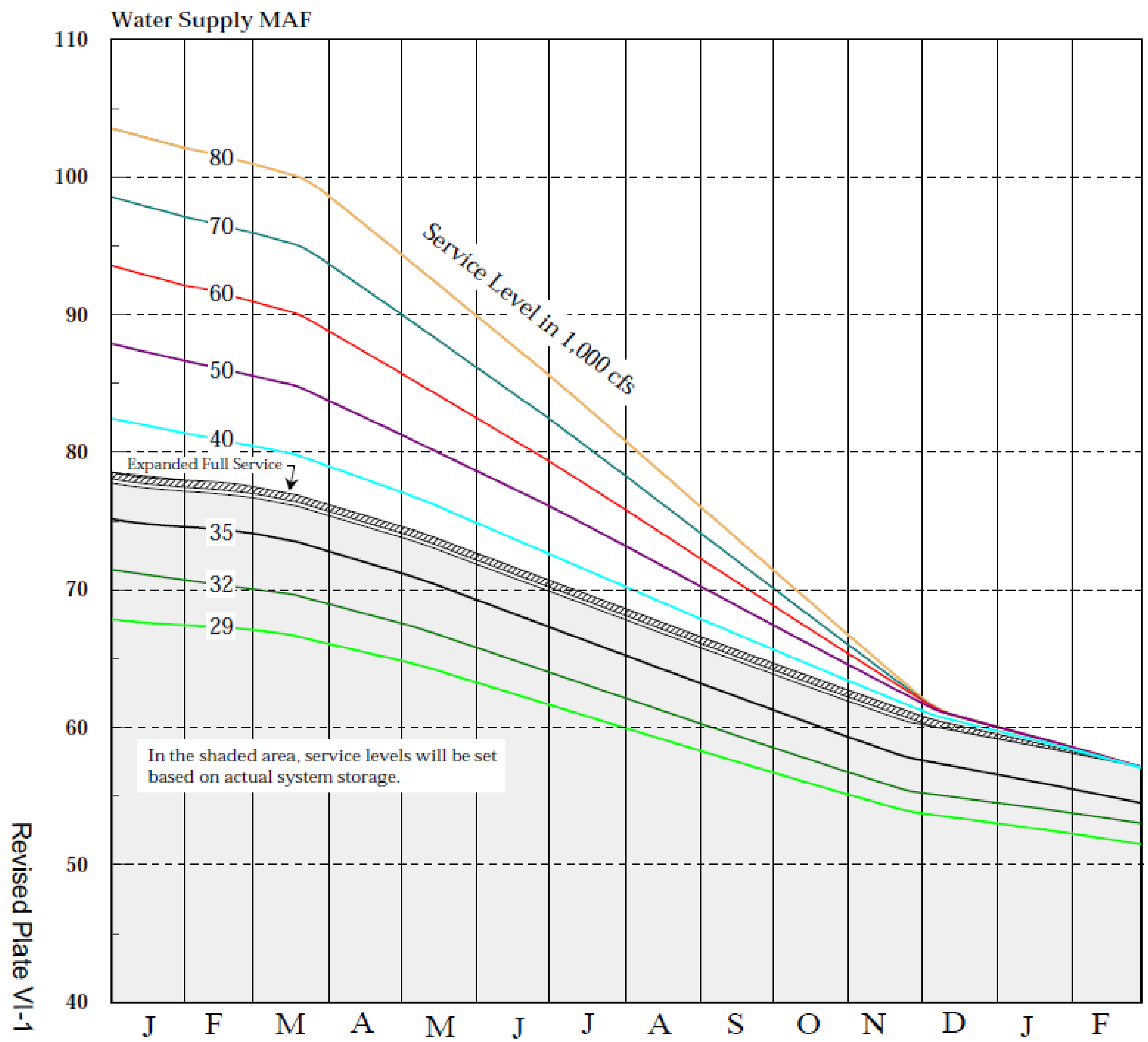
The second of three required assessments is performed on July 1. Like the March 15 assessment, service level for the remaining navigation season is determined using Figure 4-2. Also, based on current System storage, the navigation season length is determined at this time. A full season would imply a closure date of December 1 near the mouth at St. Louis.

The final required System assessment is performed September 1. At this time, it is decided, based on a System Flood Evacuation release, whether a 10 day extension to the navigation season is warranted, postponing closure date to December 10. The System Flood Evacuation release is an average release during the remainder of the navigation season necessary to evacuate all of the stored flood waters. It is based on the monthly forecasted runoff and time remaining in the navigation season. This is not specified in the Master Manual, but is included to simulate real-time regulation adjustments. The System Flood Evacuation release is described in more detail in Section 4.3.3.2. A navigation season extension is done to evacuate more storage from the reservoirs prior to the main ice season. Also on September 1, the current System storage is used to determine the average winter releases from Gavins Point.

Table 4-10 below summarizes the state variables produced in the Service Level state variable.

Table 4-10: Service Level Script Output State Variables.

State Variables	Brief Description
Service_Level	Determined from Plate VI-1 in the Master Manual. Sets the minimum flow targets at SUX, OMA, NCNE, and MKC during the navigation season. Value in cfs.
GAPT_Steady_Release	When running the SR-FTT scenario without cycling, this is the desired release out of Gavins Point from May 15 to August 15.
GAPT_Cycled_Release	When running the SR-FTT scenario with cycling, this is the desired release out of Gavins Point from May 15 to August 15.
GAPT_Winter_Release	Determined from the Sept. 1 assessment, this is the desired release out of Gavins Point from Dec. 1 (or Dec. 10 during an extended season) to Mar. 1
Navigation_End_Date	The last day for navigation season in a given year at the Mouth.
Mainstem_Storage	Total storage from six mainstem reservoirs.
Fcst_Runoff	Forecasted remainder calendar year runoff. Combines forecast from given year text file and historic runoff.
WaterSupply	Summation of FcstRunoff and MainstemStorage. Used to determine ServiceLevel.



Notes:
1. Water supply consists of the accumulation of the following:
 a. Actual system storage
 b. Forecast remaining calendar year runoff volume (1949 basin development level) above Gavins Point Dam.
 c. Departure of total tributary storage from base level. (See text.)

2. Expanded full service consists of the following:
 a. Maintenance of 35,000 cfs service level through the navigation season.
 b. Extension of the navigation season for up to 10 days beyond the normal closing date of 1 December at the mouth of the Missouri River.
 c. Winter releases averaging 20,000 cfs from Gavins Point.

3. The relationship between the service level and target flow is as given in the table below:

Target Flows - 1,000 cfs

Service Level	Sioux City & Omaha	Nebraska City	Kansas City
29.0 1/	25.0	31.0	35.0
35.0 2/	31.0	37.0	41.0
40.0 3/	36.0	42.0	46.0
50.0 3/	46.0	52.0	56.0

1/ Minimum service level
2/ Full service level
3/ Storage evacuation service level

Misssouri River
Mainstem Reservoir System
Service Level

U. S. ARMY ENGINEER DIVISION, NORTHWESTERN
CORPS OF ENGINEERS, OMAHA, NEBRASKA
MARCH 2006

Figure 4-2: Service Level Determination Chart (from Plate VI-1 in Master Manual).

4.3.3.1 Service Level x1k State Variable

The Service Level x1k state variable is responsible for setting navigation target flows based on the service level computed in the Service Level state variable. This state variable first checks if there will be a navigation season based on the service level calculated in the Service Level state variable. If the service level is undefined on March 15 (no navigation season due to low System storage), the DryYear state variable is set to 1.0; if the service level has a value on March 15 (there will be a navigation season), the DryYear state variable is set to 0.0.

Next the Service Level x1k state variable sets the navigation target flows using the criteria in Table 4-11. The target flows for Sioux City, Omaha, Nebraska City, and Kansas City are saved to SL_SUX, SL_OMA, SL_NCNE, and SL_MKC slave state variables, respectively. These slave state variables are then used in other scripted rules to ensure navigation requirements are met. The target flows are only written to the slave state variables during the navigation season at each target location, which are summarized in Table 4-12. The navigation end dates are based on the NavigationEndDate state variable computed in the Service Level state variable.

Table 4-11: Navigation target flows related to service level. Summarized from Table VII-1 in the Master Manual (U.S. Army Corps of Engineers, 2006).

Target Location	Flow Target Deviation from Service Level
Sioux City	- 4,000 cfs
Omaha	- 4,000 cfs
Nebraska City	+ 2,000 cfs
Kansas City	+ 6,000 cfs

Table 4-12: Navigation season at each target location. Summarized from Section 7-03.4.1 in the Master Manual.

Target Location	Opening Date	Closing Date
Sioux City	March 23	Nav End Date – 9 days (November 22**)
Omaha	March 25	Nav End Date – 7 days (November 24**)
Nebraska City*	March 26	Nav End Date – 6 days (November 25**)
Kansas City	March 28	Nav End Date – 4 days (November 27**)
Mouth	April 1	Nav End Date (December 1**)

*There is no navigation start or end dates specified in the Master Manual for Nebraska City. For modeling purposes, they were assumed to be 1 day after Omaha's start and end dates.

**Example dates listed are for a normal 8-month navigation season.

4.3.3.2 System Flood Evac

System Flood Evac is a scripted rule that resides in Fort Peck's operation set and assists in the evacuation of the System's flood storage. Based on the Master Manual, Plate VI-1 (shown in Figure 4-2) is used to evacuate flood storage by increasing the Service Level, which in turn increases the navigation target flows and flood targets. If the flood targets, discussed in more detail in Section 4.3.3.3, are exceeded, releases from Gavins Point are reduced until downstream flows recede below the flood targets. This reduces the risk of downstream flooding impacts while also evacuating the System's flood storage. During real-time operations, releases from Gavins Point may not be decreased if the reduction in releases has no impact on the peak flow at downstream locations, which helps to evacuate water while also keeping releases as low as possible by evacuating water for a longer period. In the model, tributary forecasts are always receding so this real-time decision cannot be captured. The model reduces releases from Gavins Point every time a flood target is exceeded. This shortens the amount of time available to evacuate all of the flood storage and increases required releases; in some years, not all of the System's flood storage is evacuated if abnormally high fall releases are required to evacuate all of the System's flood storage.

The System Flood Evac scripted rule was developed to overcome this model limitation by computing a minimum release required to evacuate all of the System's flood storage. On the 1st and 15th of each month, the System is assessed and an average release is computed by first computing the remainder of days in the navigation season and winter release season. If the end of the navigation season is not yet known, December 1 is assumed to be the end of the navigation season. Nine days prior to the end of the navigation season, releases will begin to be decreased so that the flow at each target location is met until their respective closing dates, see Table 4-12. Therefore, the number of days remaining of navigation releases is the difference between the current day and nine days prior to the computed navigation season end date. The number of days remaining in the winter release period is the total number of days between the end of the navigation season or December 1, whichever is later in the year, and March 1 of the following year.

A winter release volume is computed by multiplying the known or assumed Gavins Point winter release of 17,000 cfs prior to September 1 and then converting it to a volume (acre-ft). The volume needed to be evacuated during the navigation season is computed by adding the forecasted runoff for the remainder of the runoff year (Fcst_Runoff_RY state variable) to the current mainstem storage (Mainstem_Storage state variable) and subtracting the winter release volume and the System's carryover storage. An average release for the remainder of the navigation season is equal to the navigation season evacuation volume, converted from acre-ft to cfs, divided by the number of days remaining in the navigation season. If the calculated average release is greater than 40,000 cfs on October 1 or later, Gavins Point's winter release is increased by 1,000 cfs until the System's flood storage is forecasted to be evacuated or the winter release exceeds 27,000 cfs. If the average release exceeds 27,000 cfs between the end of the navigation season and March 1, the average release is set to 27,000 cfs and not all of the System's flood storage will be evacuated prior to the start of the next runoff season.

4.3.3.3 NAV, WS, & Flood Targets

The WS, NAV, and Flood Targets scripted rule is responsible for ensuring Gavins Point's releases meet navigation target flows, water supply requirements, and reducing Gavins Point's releases to reduce downstream flooding. If there is a navigation season, which is determined on March 15, navigation requirements begin to be assessed on March 15 when an 14-day forecast is created by routing Gavins Point releases and local inflows downstream and checking navigation target flows at Sioux City, Omaha, Nebraska City, and Kansas City. Gavins Point releases are increased or decreased by 500 cfs until each target flow is met. Navigation target flows are discussed in more detail in Section 4.3.3.1.

Once a release is set for navigation, flood targets are assessed using the same 14-day forecast created for navigation releases and checking if the forecasted flows exceed the current flood targets at Omaha, Nebraska City, and Kansas City. If the flood targets are exceeded, Gavins Point releases are decreased to minimize flooding while still providing service to navigation at the other locations as necessary. Although ResSim contains standard flood control features that allow reservoirs to set releases such that downstream flood target flows are not exceeded, ResSim's standard flood control features do not allow for the duel check of minimizing flooding while still meeting the navigation requirements. To accomplish this, the scripted rule first calculates the flood target at each of the three target locations: Omaha, Nebraska City, and Kansas City, using the criteria in Table 4-13. If the lower of the two flood targets, the full-service flood target, is exceeded and the service level is greater than full service, the navigation target flows are set to full service. Then Gavins Point releases are decreased by 500 cfs until either flows at the three flood target locations are less than the full-service flood targets or releases reach a minimum required to meet the full-service navigation target flows at Sioux City, Omaha, Nebraska City, and Kansas City. If the service level is full service or less, the full service flood targets are not used because no reduction in navigation targets would occur. If the higher of the two flood targets, minimum-service flood target, is exceeded, the navigation target flows are set to minimum service. Gavins Point releases are then decreased by 500 cfs until either flows at the three flood target locations are less than the minimum-service flood targets or releases reach a minimum required to meet the minimum-service navigation target flows at Sioux City, Omaha, Nebraska City, and Kansas City. If flood targets require releases less than 9,000 cfs during March – November, the flood target logic will be overwritten and a minimum release of 9,000 cfs will be specified. If none of the flood target flows are exceeded, normal navigation releases will occur. A more verbose explanation of the flood targets is seen in Section 7-04.15 in the Master Manual (U.S. Army Corps of Engineers, 2006). Once flows recede below the flood targets, navigation target flows return to their original values.

Table 4-13: Downstream flood targets. Summarized from Tables VII-7 and VII-8 in the Master Manual (U.S. Army Corps of Engineers, 2006).

	Flood Targets	
	Full Service (1st Level)	Minimum Service (2nd Level)
Omaha	Target Flow + 10,000 cfs	Target Flow + 15,000 cfs
Nebraska City	Target Flow + 10,000 cfs	Target Flow + 20,000 cfs
Kansas City	Target Flow + 30,000 cfs	Target Flow + 60,000 cfs

4.3.3.1 Steady Release Scripted Rule

The Steady Release scripted rule sets Gavins Point release to the Steady Release state variable value. The Steady Release state variable is computed by the Service Level scripted rule described in Section 4.3.1.4. The steady release is effective from May 15 – August 15, the current estimate of endangered species nesting season. If releases above the steady release are required to meet navigation targets, the script will set a new steady release and hold that release throughout the remainder of the period. If a flood event occurs, the Steady Release scripted rule will allow releases to be reduced to releases specified by the WS, NAV, and Flood Targets scripted rule. Following the flood event, the Steady Release scripted rule will increase flows back to the peak Steady Release set during that year.

4.3.3.1 Alt 1 – Spawning Cue

The Alt 1 – Spawning Cue scripted rule is used to simulate the bimodal spawning cue during March and May, which is used to benefit the pallid sturgeon. The first part of the spawning cue script checks the System storage on March 1 and May 1. If the System storage is less than 40.0 MAF on March 1, the March cue is cancelled. If there is enough storage on March 1 for the March cue to occur, the script begins checking Gavins Point releases when releases are increased for the navigation season. The March cue is initiated when downstream locations first meet their flow targets for the navigation season and Gavins Point releases stop increasing. The maximum March pulse is 5,000 cfs. A pulse is the amount of flow above normal navigation releases for the purpose of a spawning cue. The March spawning cue release is held constant for 2 days and then releases are reduced 1,000 cfs per day until Gavins Point releases reach required navigation releases.

Two checks occur after the magnitude of the March pulse has been determined. The first check sets the maximum March spawning cue release to 35,000 cfs if the release would have originally exceeded 35,000 cfs. The second check looks at the downstream spring pulse flow limits. The March spawning cue releases are routed downstream to Omaha, Nebraska City, and Kansas City. If the March spawning cue releases cause flows at Omaha, Nebraska City, or Kansas City to exceed 41,000 cfs, 47,000 cfs, or 71,000 cfs, respectively, the pulse is reduced by 500 cfs until a pulse magnitude is calculated that no longer exceeds the downstream flow limits or the pulse is canceled because any magnitude will exceed the flow limits.

On May 1, the System storage is checked again and if the System storage is below 40.0 MAF, the May spawning cue is cancelled. If there is sufficient System storage for the May spawning cue, the cue is initiated on May 1. The maximum May pulse is first prorated by the System storage;

the maximum May pulse is set to 16,000 cfs if the System storage is greater than or equal to 54.5 MAF. If the System storage is less than 54.5 MAF, the maximum May pulse is linearly interpolated to 12,000 cfs when the System storage is 40.0 MAF. The maximum May pulse is prorated a second time based on forecasted runoff. If the remaining forecasted annual runoff is a median runoff, no change is made to the first prorated maximum May pulse. An additional 4,000 cfs can be added to the first prorated maximum May pulse if the remaining forecasted runoff is upper quartile. An additional 4,000 cfs can be subtracted from the first prorated maximum May pulse if the remaining forecasted runoff is lower quartile.

Once the maximum May pulse has been prorated, the first 3 days of releases for the May spawning cue, May 1-3, are increased by 1/3 of the maximum May pulse. The May spawning cue is held at its peak for 2 days, May 3-4, before releases are reduced by 15% of the maximum May pulse for the next 2 days, May 5-6. Over the next 8 days, May 7-14, the remaining 80% of the maximum May pulse is reduced equally per day until releases reach normal navigation releases.

With the maximum May pulse set, the spawning cue is routed downstream and the flow limits are checked at Omaha, Nebraska City, and Kansas City. If flow limits are exceeded at any of those locations, the maximum May pulse is reduced by 500 cfs and a new spawning cue is routed downstream and flow limits are checked again. This process is repeated until a May pulse that does not exceed the downstream flow limits is reached. If any magnitude of pulse exceeds the flows limits, the May spawning cue is cancelled.

4.3.3.2 BEND & FTRA Guide Curve

The BEND & FTRA Guide Curve scripted rule is responsible for two tasks: redraw Fort Randall's guide curve so the drawdown coincides with the end of the navigation season and set releases from both Big Bend and Oahe. Fort Randall's guide curve is adjusted on September 1 at the beginning of the fall drawdown by calculating daily drawdown and refill rates. The drawdown rate is equal to the total drawdown height divided by the total drawdown days. For example, the guide curve elevation on September 1 is 1355.0 and the minimum elevation reached by the end of the navigation season is 1337.5 ft, so the total drawdown height is 17.5 feet. If the end of the navigation season is December 1, the total number of days between September 1 and the end of the navigation season is 91 days. Therefore, in order for Fort Randall to reach its minimum elevation by December 1, the reservoir needs to be drawn down by 0.19 ft per day (17.5 ft / 91 days). If the navigation season was shortened to November 1, the reservoir would need to be drawn down by 0.29 ft per day (17.5 ft / 61 days).

Each time step of the simulation, releases from Big Bend and Oahe are computed based on the day of the week. Beginning on Monday, Fort Randall's guide curve elevation five days in the future, five days of forecasted incremental inflows, and releases from Fort Randall are retrieved from state variables. Big Bend's releases are equal to the sum of Fort Randall's releases minus the sum of the incremental inflows divided by the number of forecasting days. For example, if releases and incremental inflows at Fort Randall are forecasted to be 30,000 cfs and 2,000 cfs Monday through Friday, respectively, Big Bend's releases would initially be set to 28,000 cfs. Releases of 28,000 cfs would keep Fort Randall's reservoir level, but the guide curve fluctuates throughout the year and the reservoir level may not be exactly at its guide curve elevation. For these reasons, Big Bend's initial release schedule is adjusted up to a maximum of 6,000 cfs to account for the variabilities. During the week, Oahe's releases are 3,000 cfs less than Big Bend's releases, which draws the Big Bend reservoir down approximately one foot. Oahe's releases are compared against a maximum release, which is the combined capacity of Oahe's powerplant and flood tunnels. Oahe has an earthen spillway so if possible, the spillway is not used unless the pool elevation is going to the exceed the top of the spillway gates while they are in a closed position, 1620.0 ft. If Oahe's releases exceed the maximum capacity and its pool elevation is not exceeding 1620.0 ft, Oahe's releases are set to the maximum capacity and Big Bend's releases are set to 3,000 cfs more than Oahe's releases.

Big Bend releases Tuesday through Thursday are equal to Monday's releases. Oahe releases are typically set to something less than Big Bend's releases. Since Big Bend has a small incremental drainage area, nearly all of the inflow into Big Bend is a result of releases from Oahe, so setting releases from Oahe to Big Bend releases less a value draws down Lake Sharpe. The rate at which Lake Sharpe is drawn down is dependent on Oahe and Big Bend's release difference, and for modeling purposes, these rates are grouped into categories. The first category is based on releases from Big Bend. When weekday releases are 15,000 cfs or less, refilling Lake Sharpe over the weekend becomes difficult because the reduction in releases from Big Bend is limited. The second category is based on pool elevation. If Lake Sharpe's pool elevation is between 1420.4 ft and 1421.2 ft, releases from Oahe are 3,000 cfs less than releases from Big Bend, but if the pool elevation rises above 1421.2 ft, the difference between Oahe's and Big Bend's releases is 6,000 cfs. Releases from Oahe are equal to releases from Big Bend when Lake Sharpe's weekday pool elevation is between 1420.3 ft and 1420.4 ft. When Lake Sharpe's pool elevation falls below 1420.3 ft, releases from Oahe are increased to 3,000 cfs above releases from Big Bend to help ensure Lake Sharpe is able to refill over the weekend. If releases from Big Bend are less than 15,000 cfs, the release relationships change. When Lake Sharpe's pool elevation is greater than or equal to 1421.2 ft, Oahe's releases are 6,000 cfs less than Big Bend's releases. If Lake Sharpe's pool elevation is between 1420.6 ft and 1421.2 ft, then releases from Oahe are only 1,500 cfs less than releases from Big Bend. Any time Lake Sharpe's weekday elevation is between 1420.5 ft and 1420.6 ft and Big Bend releases are less than 15,000 cfs, releases from Oahe are equal to releases from Big Bend. Oahe releases are increased to 3,000 cfs greater than releases from Big Bend if Lake Sharpe's pool elevation falls below 1420.5 ft.

On the weekend, the logic shifts to setting releases from Oahe first. Releases from Oahe are decreased by 2,000 cfs each day, so releases on Saturday are 2,000 cfs less than releases on Friday and releases on Sunday are 2,000 cfs less than releases on Saturday. Releases from Big Bend are based on refilling Lake Sharpe. Initially set equal to releases from Oahe, releases from Big Bend are reduced until Lake Sharpe is refilled halfway to 1421.0 ft on Saturday. The process is repeated on Sunday, so Lake Sharpe reaches 1421.0 ft by Sunday night. If releases from Big Bend cannot be reduced enough to refill Lake Sharpe, releases from Oahe are increased to help refill Lake Sharpe.

4.3.3.3 Reservoir Flood Evac

The Reservoir Flood Evac scripted rule determines when and if an individual reservoir should start evacuating its flood storage instead of storing additional water to alleviate downstream flooding. Elevation triggers were established for the four largest reservoirs: Fort Peck, Garrison, Oahe, and Fort Randall. A reservoir forecast is computed if the previous pool elevation is greater than or equal to the reservoir's respective elevation trigger.

When Fort Peck's previous elevation has reached 2244.0 ft, which is 2.0 ft below the top of the Flood Control and Multiple Use Zone, a reservoir inflow forecast is computed by routing all incremental forecasted flows for gages upstream of the reservoir: Landusky, MT and Fort Peck. Releases are initially set to the previous day's release for the entire forecast period of seven days. A forecasted storage and pool elevation is computed based on the forecasted inflow and releases; evaporation is not accounted for in the forecast because of the short duration. If the maximum initial forecasted pool elevation is at least 2249.5 ft and the minimum pool elevation rate-of-change (ROC) is greater than 0.0 ft for all days in the forecast, a release ROC is set to 6,000 cfs. If the maximum initial forecasted pool elevation is between 2249.0 ft and 2249.5 ft and the minimum pool elevation ROC is less than -0.5 ft or the maximum initial forecasted pool elevation is between 2246.0 ft and 2249.5 ft and the minimum pool elevation ROC is less than -0.25 ft, a release ROC is set to -3,000 cfs. If the maximum initial forecasted pool elevation is between 2246.0 ft and 2249.5 ft and the forecasted pool elevation is increasing for each day, a release ROC is set to 3,000 cfs. If none of the previous criteria is met, then a release ROC is set to 0.0. All forecasted releases are increased by the specified release ROC and pool elevations are forecasted again; the maximum pool elevation from this initial forecast is saved and used later.

Beginning at the end of the forecast period, the 7th forecast day, a new release ROC is calculated based on the most recent pool elevation forecast and releases on the 7th forecast day is increased or decreased by the release ROC. A new pool elevation forecast is created and the new maximum forecasted pool elevation is compared to the initial maximum forecasted pool elevation. If the new maximum is greater than the initial maximum, the release change is undone. This criteria ensures that a reduction in releases does not cause the pool to rise. New elevation ROCs are computed based on the most recent forecasted pool elevations. The new elevation ROCs are used when the process is repeated but now releases on the 6th and 7th forecast days. If the new maximum forecasted pool elevation has still not exceeded the initial maximum forecasted pool elevation, the process is repeated but for releases on the 5th, 6th, and 7th forecast days. This continues until all 7 forecast days have been assessed.

For example, releases are initially set to 10,000 cfs for every forecasted day resulting in the pool increasing each day reaching a maximum forecasted pool elevation of 2247.0 ft. Releases on the 7th forecast day are increased by 3,000 cfs to 13,000 cfs and the pool elevations are re-forecasted. The pool is still increasing each day reaching a maximum forecasted pool elevation of 2247.0 ft, which does not exceed the initial maximum pool of 2247.0 ft. Next, both the 6th and 7th forecast days are assessed. Releases on the 7th forecast day are increased by another 3,000 cfs to 16,000 cfs and the pool elevations are forecasted. The pool is still increasing each day reaching a maximum forecasted pool elevation of 2247.0 ft, which does not exceed the initial maximum pool of 2247.0 ft. Then releases on the 6th forecast day are increased by 3,000 cfs to 13,000 cfs and the pool elevations are forecasted. The pool is still increasing each day reaching a maximum forecasted pool elevation of 2247.0 ft, which does not exceed the initial maximum pool of 2247.0 ft, so the process continues, but now releases on the 5th, 6th, and 7th forecast days are assessed.

After increasing releases for each day by 3,000 cfs resulting in releases of 13,000 cfs, 16,000 cfs, and 19,000 cfs for the 5th, 6th, and 7th forecast days, respectively, the pool is still increasing each day reaching a maximum forecasted pool elevation of 2246.4 ft, which does not exceed the initial maximum pool of 2247.0 ft. The process continues, but now releases on the 4th, 5th, 6th, and 7th forecast days are assessed. After increasing releases for each day by 3,000 cfs resulting in releases of 13,000 cfs, 16,000 cfs, 19,000 cfs, 22,000 cfs for the 4th, 5th, 6th, and 7th forecast days, respectively, the pool elevation is no longer increasing every day and the maximum forecasted pool elevation is 2246.1 ft. Although the pool is no longer increasing every day, it is not decreasing by 0.25 ft, which would trigger a release reduction. Therefore, the iteration continues, but releases do not need to increase above 22,000 cfs. The final release forecast after all forecast days have been assessed shows releases of 10,000 cfs for the 1st through 3rd forecast days followed by releases increasing by 3,000 cfs per day beginning on the 4th forecast day.

Flood evacuation for Garrison is computed in a similar manner except with different elevation and release ROC criteria. When Garrison's previous elevation has reached 1848.0 ft, which is 2.0 ft below the top of the Flood Control and Multiple Use Zone, a reservoir inflow forecast is first computed by routing all incremental forecasted flows for gages upstream of the reservoir: Fort Peck Release, Wolf Point, Culbertson and Garrison. Releases are initially set to the previous day's release for the entire forecast period of seven days. A forecasted storage and pool elevation is computed based on the forecasted inflow and releases; evaporation is not accounted in the forecast because of the short duration. If the maximum initial forecasted pool elevation is at least 1853.5 ft and the minimum pool ROC is greater than 0.0 ft for all days in the forecast, a release ROC is set to 6,000 cfs. If the maximum initial forecasted pool elevation is between 1853.0 ft and 1853.5 ft and the minimum pool elevation ROC is less than -0.5 ft or the maximum initial forecasted pool elevation is between 1850.0 ft and 1853.5 ft and the minimum pool elevation ROC is less than -0.25 ft, a release ROC is set to -3,000 cfs. If the maximum initial forecasted pool elevation is between 1850.0 ft and 1853.5 ft and the forecasted pool elevation is increasing for each day, a release ROC is set to 3,000 cfs. If none of the previous criteria is met, then a release ROC is set to 0.0. All forecasted releases are increased by the specified release ROC and pool elevations are forecasted again; the maximum pool elevation from this initial forecast is saved and used later. Releases are then adjusted in the same iterative manner as described with releases from Fort Peck.

Flood evacuation for Oahe is computed in a similar manner except with different elevation and release ROC criteria and with the addition of maximum release criteria. Unlike Fort Peck and Garrison, Oahe has an earthen spillway, which has never been utilized within the period of record. A maximum release equal to the total capacity of the power plant and flood tunnels less 2,000 cfs, for conservatism, limits the forecasted releases unless the pool elevation exceeds 1620.0 ft or the top of the spillway gates. If the pool elevation is greater than 1620.0 ft, the model would utilize the spillway while the reservoir surcharges and the spillway gates open as the pool elevation rises. With the maximum release criteria defined, flood evacuation for Oahe resumes the typical methodology. When Oahe's previous elevation has reached 1615.0 ft, which is 2.0 ft below the top of the Flood Control and Multiple Use Zone, a reservoir inflow forecast is first computed by routing all incremental forecasted flows for gages upstream of the reservoir: Garrison release, Bismarck, and Oahe. Releases are initially set to the previous day's release for the entire forecast period of seven days. A forecasted storage and pool elevation is computed based on the forecasted inflow and releases; evaporation is not accounted for in the forecast because of the short duration. If the maximum initial forecasted pool elevation is at least 1619.0 ft and the minimum pool elevation ROC is greater than 0.2 ft for all days in the forecast or the maximum forecasted pool elevation exceeds 1620.0 ft, a release ROC is set to 10,000 cfs. If the maximum initial forecasted pool elevation is at least 1619.0 ft and the minimum pool elevation ROC is less than -0.5 ft or the previous observed pool elevation is less than 1620.0 ft and the previous release was greater than maximum release criteria, a release ROC is set to -3,000 cfs. If the maximum initial forecasted pool elevation is at least 1617.0 ft and the minimum pool elevation ROC is less than -0.25 ft, a release ROC is set to -6,000 cfs. If the maximum initial forecasted pool elevation is at least 1619.0 ft and the forecasted pool elevation is increasing each day, a release ROC is set to 6,000 cfs. If the maximum initial forecasted pool elevation is between 1617.0 and 1619.0 ft and the forecasted pool elevation is increasing each day, a release ROC is set to 3,000 cfs. If none of these criteria a met, a release ROC is set to 0 cfs. All forecasted releases are increased by the specified release ROC and pool elevations are forecasted again; the maximum pool elevation from this initial forecast is saved and used later. Releases are then adjusted in the same iterative manner as described with releases from Fort Peck.

Big Bend will be in flood evacuation whenever Oahe is releasing for flood evacuation because it is treated as a run-of-the-river project. Big Bend flood evacuation releases are set using similar logic to what is described in Section 4.3.3.2 except that Oahe's releases are first set. Then releases from Big Bend are set to draw down the reservoir during the week and refill it over the weekend.

Flood evacuation for Fort Randall is computed in a similar manner as Fort Peck except with different elevation and release ROC criteria. When Fort Randall's previous elevation has reached 1363.0 ft, which is 2.0 ft below the top of the Flood Control and Multiple Use Zone, releases are initially set equal to the difference between releases from Gavins Point and the forecasted incremental inflow to Gavins Point. Releases from Fort Randall are checked to ensure that each day's ROC does not exceed 8,000 cfs. Incremental inflows into Gavins Point can fluctuate rapidly, causing releases from Fort Randall to fluctuate rapidly. Checking a release ROC helps keep the model from overcompensating by releasing too much or too little. A forecasted storage and pool elevation is computed based on the forecasted inflow and releases; evaporation is not accounted for in the forecast because of the short duration. If the maximum initial forecasted pool elevation is at least 1374.0 ft and the sum of the elevation ROCs is greater than 0 or if the maximum initial forecasted pool elevation is at least 1374.5 ft, a release ROC is set to 8,000 cfs. If the sum of the elevation ROCs is less than 1.5 ft, a release ROC is set to -3,000 cfs. If the maximum initial forecasted pool elevation is greater than 1370.0 ft and the sum of the elevation ROCs is greater than 1.0 ft, a release ROC is set to 3,000 cfs. If none of the criteria is met, a release ROC is set to 0 cfs. All forecasted releases are increased by the specified release ROC and pool elevations are forecasted again. Releases are then adjusted in the same iterative manner as described with releases from Fort Peck.

Gavins Point will be in flood evacuation whenever Fort Randall is releasing for flood evacuation because it is treated as a run-of-the-river project. Gavins Point flood evacuation releases are set by routing Fort Randall's flood evacuation releases down to the reservoir and adding the forecasted incremental inflow to Gavins Point. Based on the total inflow, a release from Gavins Point is set to keep its reservoir near its guide curve elevation.

4.3.3.4 Reservoir Flood Control

Competing with the model's requirement to evacuate flood storage is its requirement to store water to reduce downstream flooding. The Reservoir Flood Control scripted rule determines when a reservoir should reduce releases to lower downstream flows and only applies to Fort Peck, Garrison, and Oahe.

A pseudo flood control zone is specified for each of the upper three reservoirs to be used in this scripted rule only. Fort Peck's zone has a top elevation equal to the top of its exclusive flood control zone and a bottom elevation equal to 1 ft less than the bottom of its flood control and multiple use zone. Both Garrison and Oahe's zones have top elevations equal to the top of their respective exclusive flood control zones and bottom elevations equal to 2 ft less than the bottom of their respective flood control and multiple use zones.

A percentage of occupied pseudo flood control zones are calculated when a reservoir's previous elevation exceeds the bottom of its specified pseudo flood control zone. If a reservoir has not exceeded the bottom of its pseudo flood control zone, the percentage is set to 0. If the difference between the percentages of occupied pseudo flood control zones at the downstream reservoir and the reservoir being assessed is greater than the reservoirs difference threshold and the downstream's percentage increased from the previous time step, releases from the current reservoir is decreased by a release ROC. After decreasing the release, the new release is checked against the reservoir's minimum release for this scripted rule. If the release is less than the minimum release, the release is set to the minimum release. The difference threshold was established for Fort Peck and Garrison through calibration. Fort Peck's difference threshold is 3 percent and Garrison's difference threshold is 2 percent. Since there is not a reservoir downstream of Oahe with a significant amount of flood control storage, a difference threshold was not defined for Oahe. Fort Peck's and Garrison's release ROCs are 8,000 cfs and 9,000 cfs, respectively, and their minimum releases for the scripted rule are 5,000 cfs and 10,000 cfs, respectively.

As an example, if Fort Peck is the current reservoir being assessed and its current elevation is 2247.0 ft, Fort Peck's percentage of occupied pseudo flood control zone is 40 percent ((2247-2245) / (2250-2245)). Garrison has experienced higher inflows so its percentage of occupied pseudo flood control zone is 50 percent. The difference between the two reservoirs' percentage of occupied pseudo flood control zones is 10, which is greater than Fort Peck's difference threshold of 3 percent, so Fort Peck's release is decreased by 8,000 cfs. On the next time step, Fort Peck's percentage of occupied pseudo flood control zone is 43 percent and Garrison's is 56 percent, which is a difference of 7 percent. This is still greater than Fort Peck's difference threshold of 3 percent, so Fort Peck's release is decreased by 8,000 cfs again. This process is repeated until the difference no longer exceeds the threshold.

4.3.3.5 FTPK & GARR Balancing Release

The reservoir balancing scripted rule sets releases at Fort Peck and Garrison in order to balance the carryover storage for Fort Peck, Garrison, and Oahe. Releases from Fort Peck and Garrison typically follow an annual pattern: high releases during the summer, lower releases in the fall, and medium releases in the winter. Figure 4-3 and Figure 4-4 shows the detailed flow patterns for both Fort Peck and Garrison.

On the 1st of each month except for February and the 15th of each month except for January and February, a forecast is completed for the percentage of total carryover storage that will be utilized at Fort Peck, Garrison, and Oahe on March 1 of the following year based on runoff forecasts for all six reservoirs and forecasted Gavins Point releases. The forecast for the winter months is completed on January 1st so there are not any sudden release changes at Fort Peck or Garrison if the reservoirs are unbalanced. In addition to the forecasts completed on the 1st and 15th, the balancing forecast may be completed on the 7th and 21st of each month, except for January and February, if pool elevations at Fort Peck, Garrison, or Oahe exceed their flood elevations of 2244.0 ft, 1845.0 ft, and 1616.0 ft, respectively. A target storage is calculated for Fort Peck, Garrison, and Oahe based on the percentage of the System carryover storage (i.e. if the forecasted percentage of total System storage is 90%, the target storage at Fort Peck, Garrison, and Oahe would be equal to 90% of their respective carryover storages.). Based on forecasted inflows into Fort Peck and the percentage of System carryover storage, the release pattern at Fort Peck is adjusted up or down so that Fort Peck reaches its target storage by March 1 of the following year. It is possible that Fort Peck will not reach its target because there are minimum and maximum releases at Fort Peck that could prevent Fort Peck's releases from going as high or low as needed to reach its target. For example, if Fort Peck's pool elevation is in its Annual Flood Control and Multiple Use Zone and the Standard release pattern is decreased until the fall releases reach its minimum release pattern, releases would no longer be reduced and Fort Peck's carryover storage would likely be unbalanced at the start of next year's runoff season. Once Fort Peck's releases are set for the remainder of the year, they are routed downstream to Garrison where they are added to Garrison's forecasted inflows. Based on the forecasted total inflows into Garrison and the percentage of System carryover storage, Garrison's release pattern is adjusted up or down so that Garrison reaches its target storage by March 1 of the following year.

Minimum and maximum releases at Fort Peck and Garrison are scaled depending on the pool elevation to allow for drought conservation releases. At Fort Peck, normal minimum releases when the pool is at the top of the carryover storage zone are linearly interpolated down to the drought minimum releases when the pool is 35 ft above the permanent pool. Normal maximum releases when the pool is at the top of carryover storage zone are linearly interpolated up to the flood maximum releases when the pool reaches the top of the exclusive flood control zone. At Garrison, normal minimum releases when the pool is at the top of the carryover storage zone are linearly interpolated down to the drought minimum releases when the pool is 10 ft above the permanent pool. Normal maximum releases when the pool is at the top of carryover storage zone are linearly interpolated up to the flood maximum releases when the pool reaches the top of the exclusive flood control zone.

Oahe is allowed to float throughout the year based on Garrison and Gavins Point releases; however, there are several checks to ensure Oahe does not get too unbalanced or its pool elevation does not get too high compared to Garrison. If Oahe's March 1 forecasted storage is greater than its target storage, half of the difference between Oahe's forecasted March 1 storage is added to Garrison's target storage and half is added to Fort Peck's target storage. Garrison's releases will be scaled up or down if the difference between Garrison's and Oahe's current percent of carryover storage is ± 5.0 percent. Fort Peck's releases will also be scaled up or down if the difference between Fort Peck's and Garrison's current percent of carryover storage is ± 5 percent.

Adjustments are also made to Fort Peck's and Garrison's releases for tern and plover operations. Summer releases are typically held constant if there are no immediate concerns with the upper three reservoirs. Garrison's releases are held constant from May 15 – Sep 15 if Garrison's pool elevation is between 1775.0 ft and 1850.0 ft and Oahe's pool elevation is greater than 1545.0 ft. Fort Peck's releases are held constant from May 15 – Sep 15 if Fort Peck's pool elevation is between 2195.0 ft and 2246.0 ft and Garrison's pool elevation is greater than 1775.0 ft.

Figure 4-3: Plot of release schedules for Fort Peck used in the reservoir balancing script.

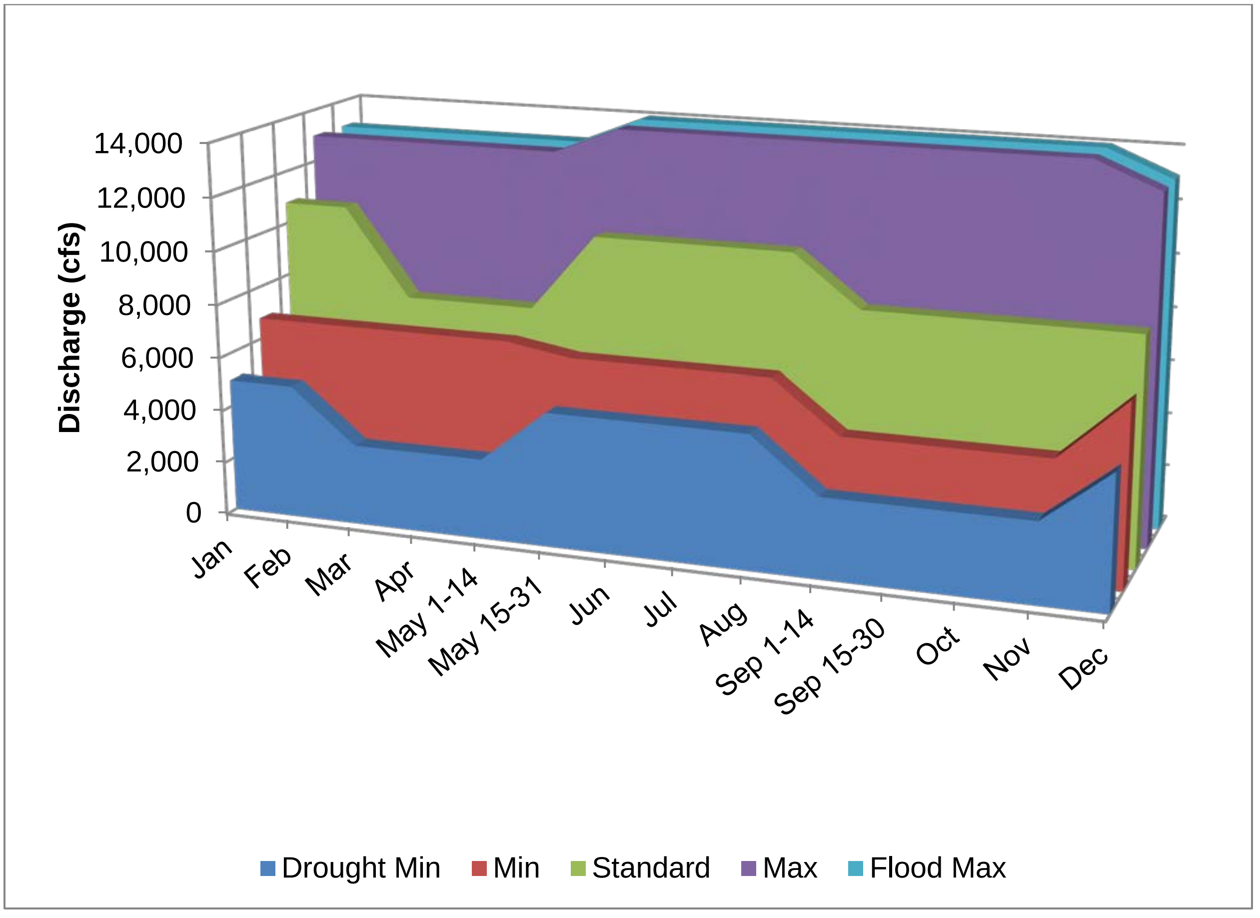


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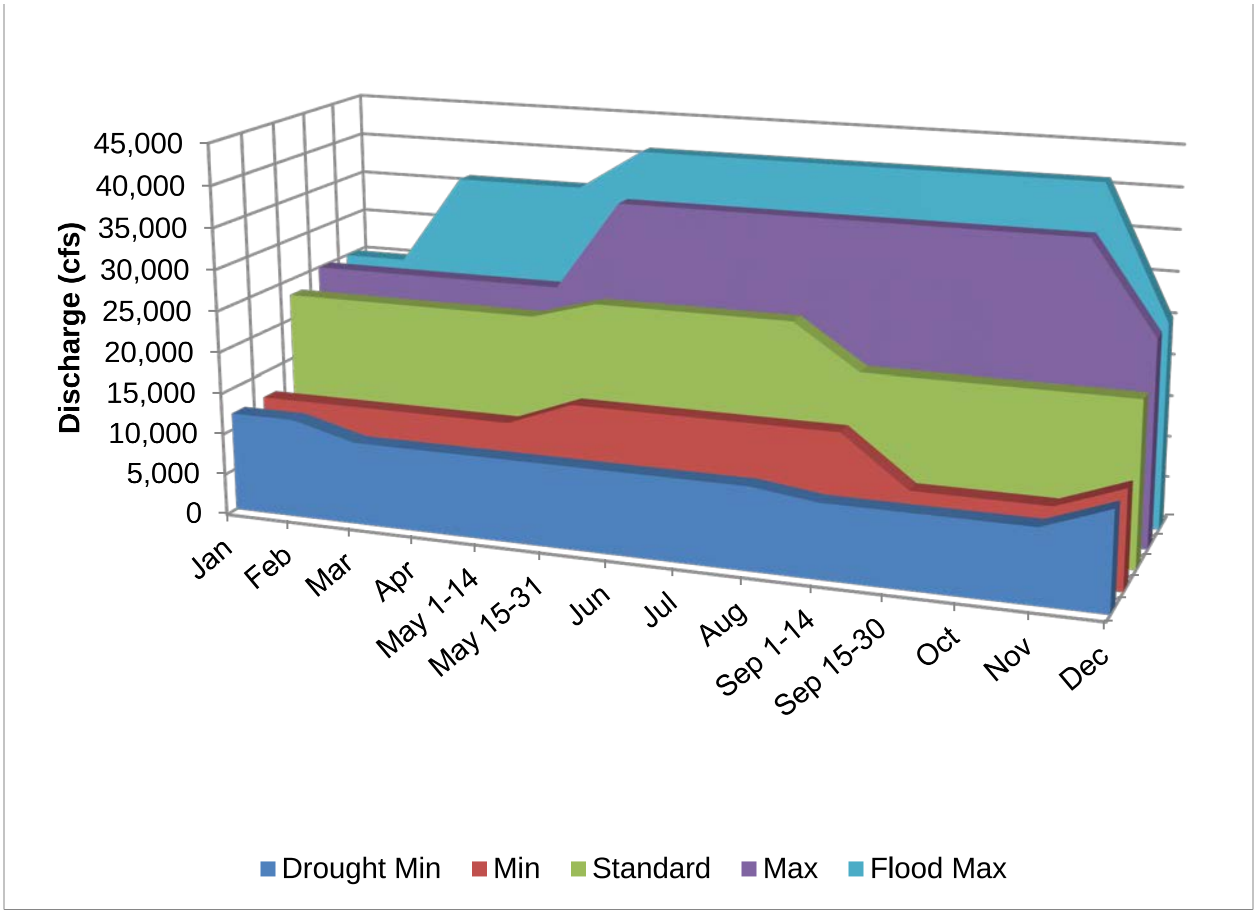
Figure 4-4: Plot of release schedules for Garrison used in the reservoir balancing script.



4.3.3.6 FTPK & GARR Water Supply

The upstream water supply scripted rule uses the releases at Fort Peck and Garrison that are calculated in the reservoir balancing scripted rule and checks downstream water supply requirements. Fort Peck's releases are routed downstream to Wolf Point and Culbertson. If 3,000 cfs is not observed at both locations during March – May 14 and September – November, Fort Peck's releases are increased until that criteria is met. If 5,000 cfs is not observed at both locations during May 15 – August and December – February, Fort Peck's releases are increased until that criteria is met. Then Garrison's releases are routed downstream to Bismarck. If 10,000 cfs is not observed at Bismarck during March – August, Garrison's release are increased until that criteria is met. If 9,000 cfs is not observed at Bismarck during September – November, Garrison's release is increased until that criteria is met. If 12,000 cfs is not observed at Bismarck during December – February, Garrison's release is increased until that criteria is met.

5 EVALUATION OF MODEL PERFORMANCE

5.1 CALIBRATION COMPARISON

Calibration of the model was based on the period of March 1, 1998 – Dec 31, 2012. This period was selected as the calibration period because it contains a large drought period, multiple flood events and occurs in the recent history where water management policies in the observed period closely match what is used in the model. Figure 5-1 through Figure 5-6 display the ResSim operations versus historic operations for the calibration period.

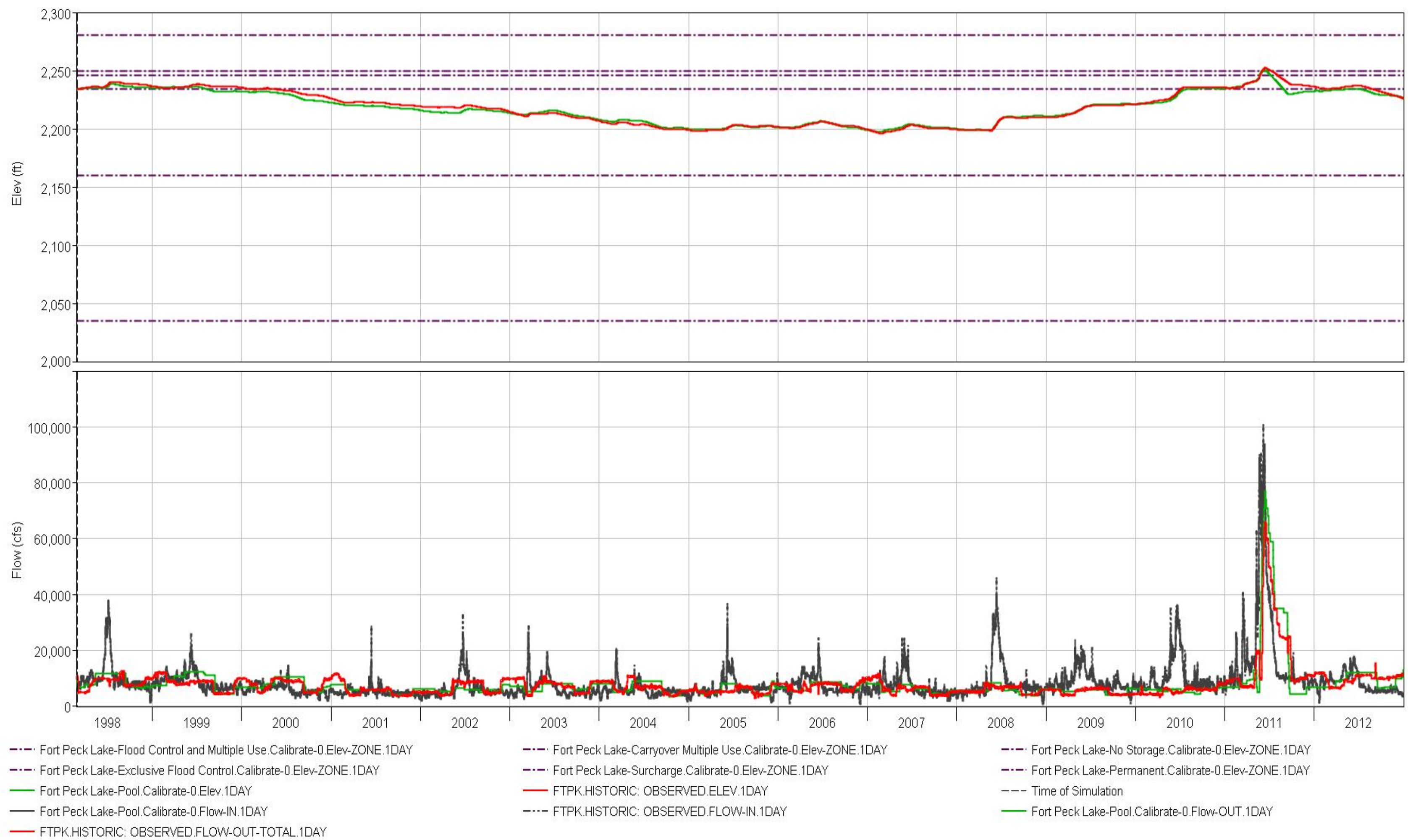


Figure 5-1: ResSim versus historic operations at Fort Peck Dam 1998-2012.

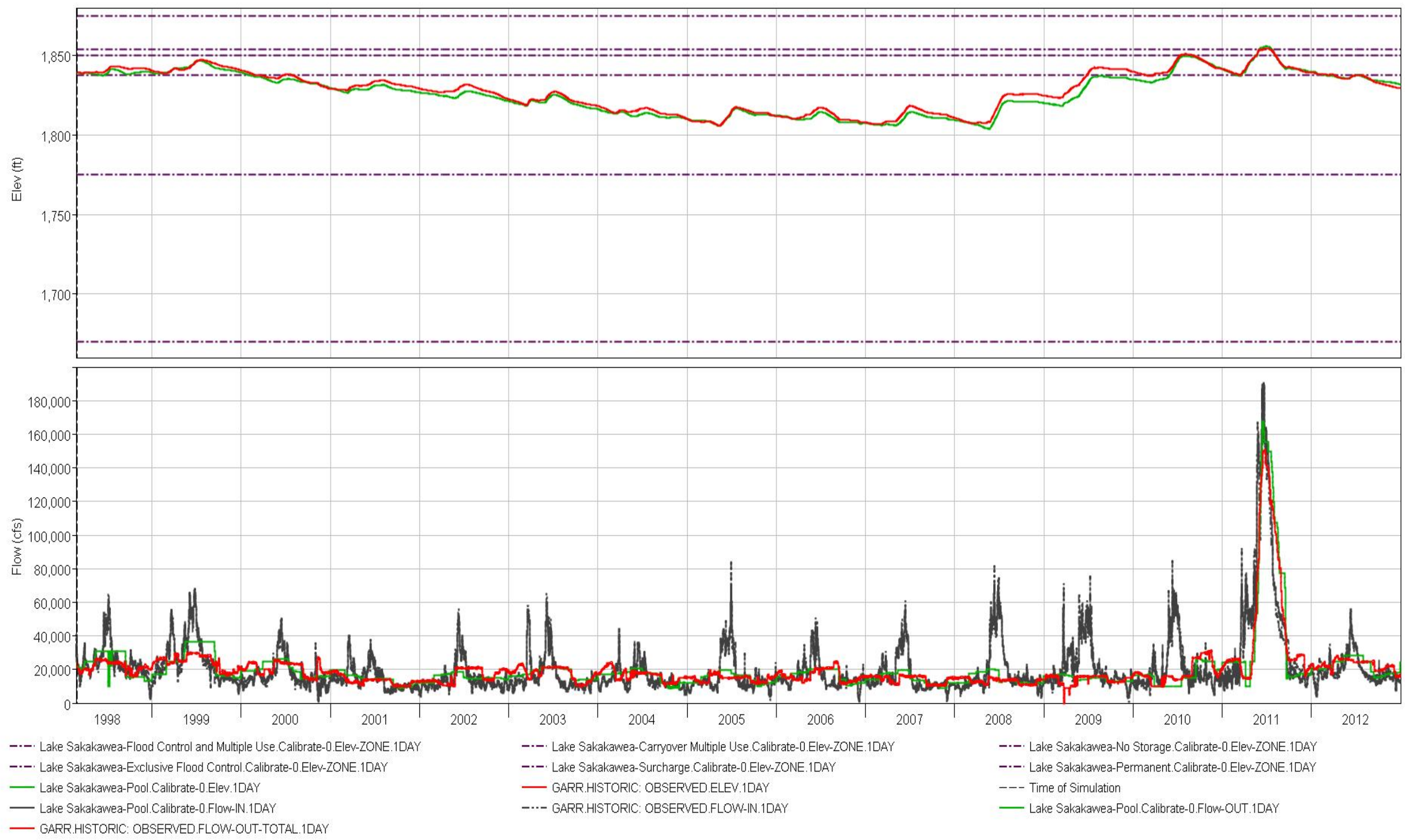


Figure 5-2: ResSim versus historic operations at Garrison Dam 1998-2012.

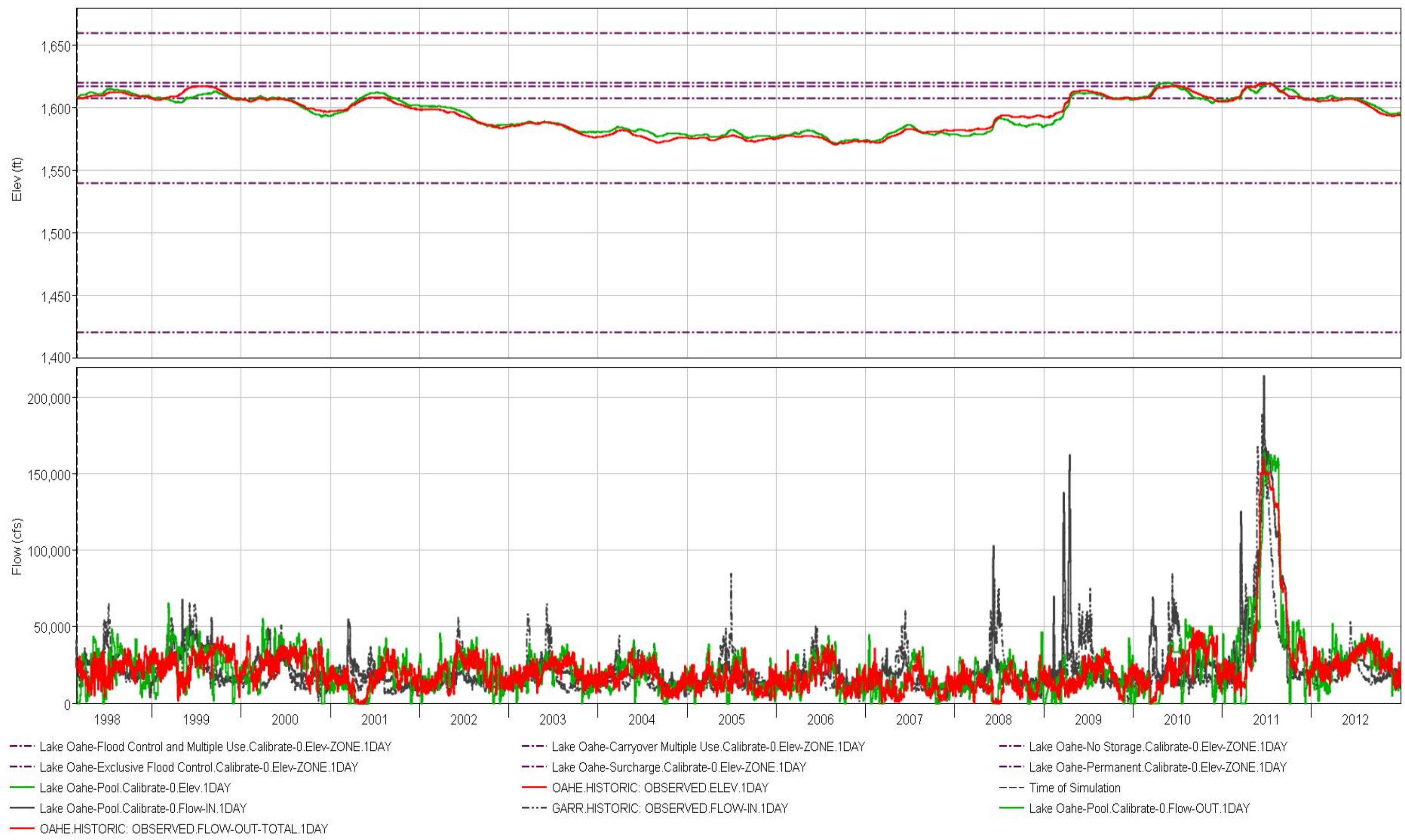


Figure 5-3: ResSim versus historic operations at Oahe Dam 1998-2012.

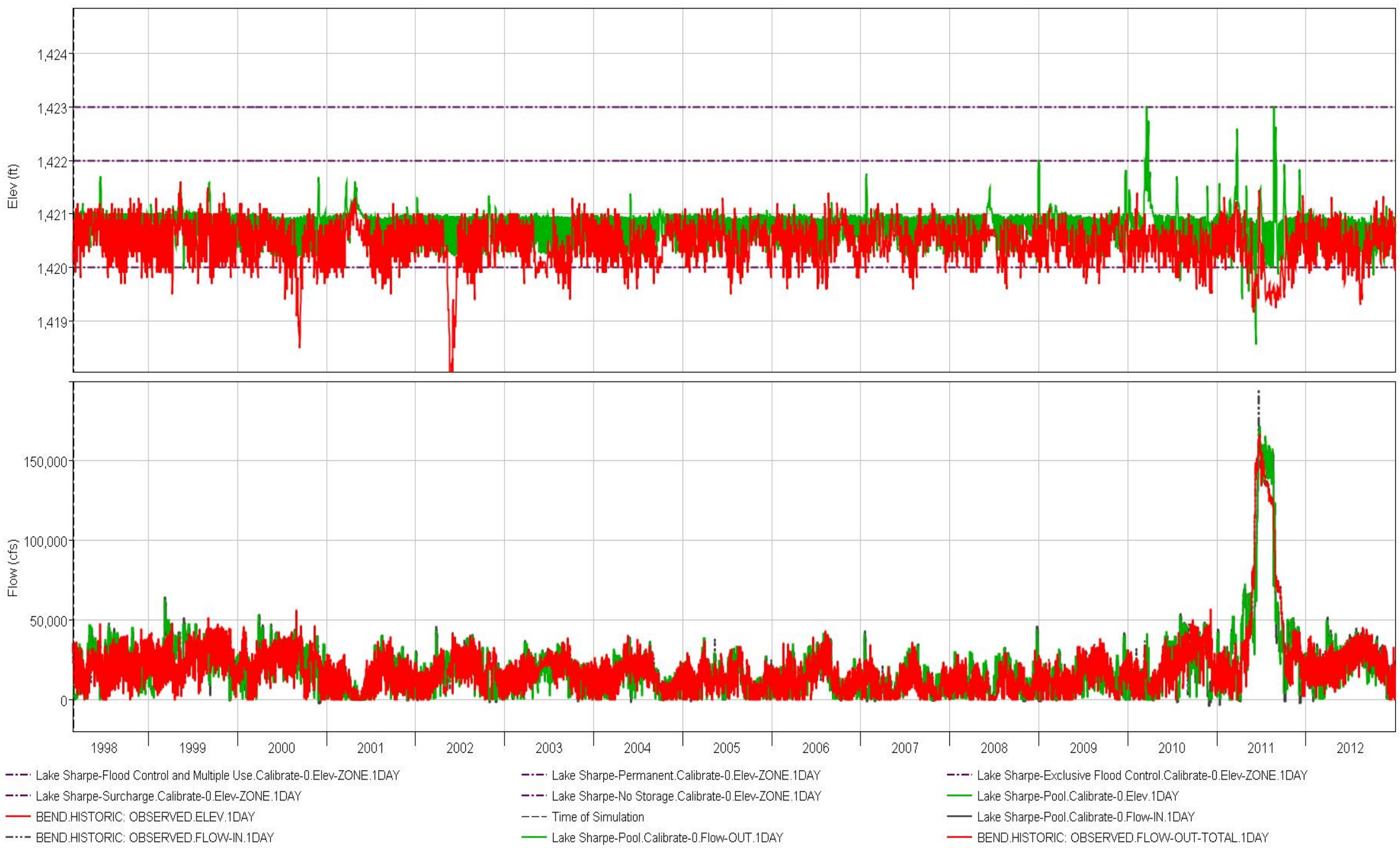


Figure 5-4: ResSim versus historic operations at Big Bend Dam 1998-2012.

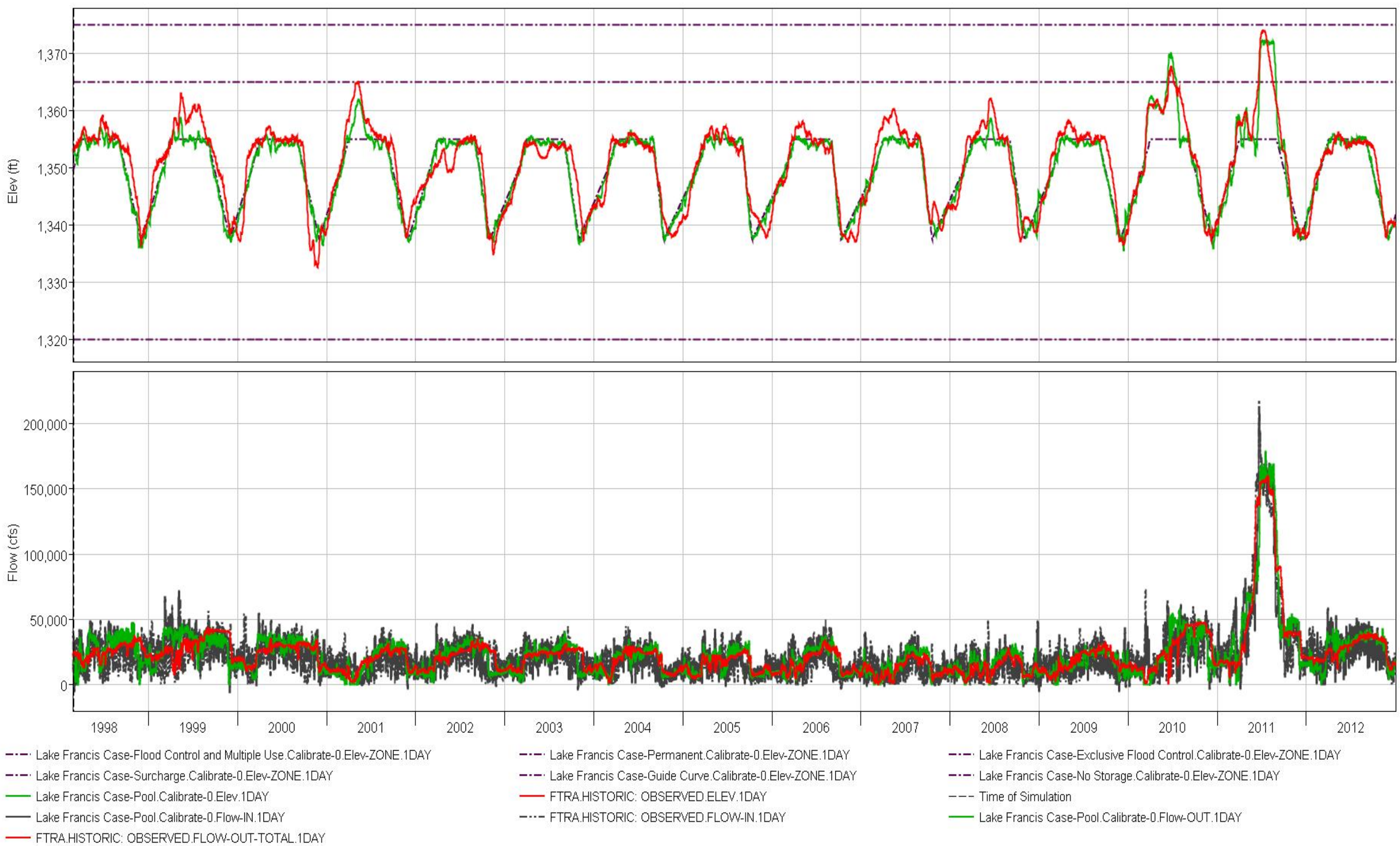


Figure 5-5: ResSim versus historic operations at Fort Randall Dam 1998-2012.

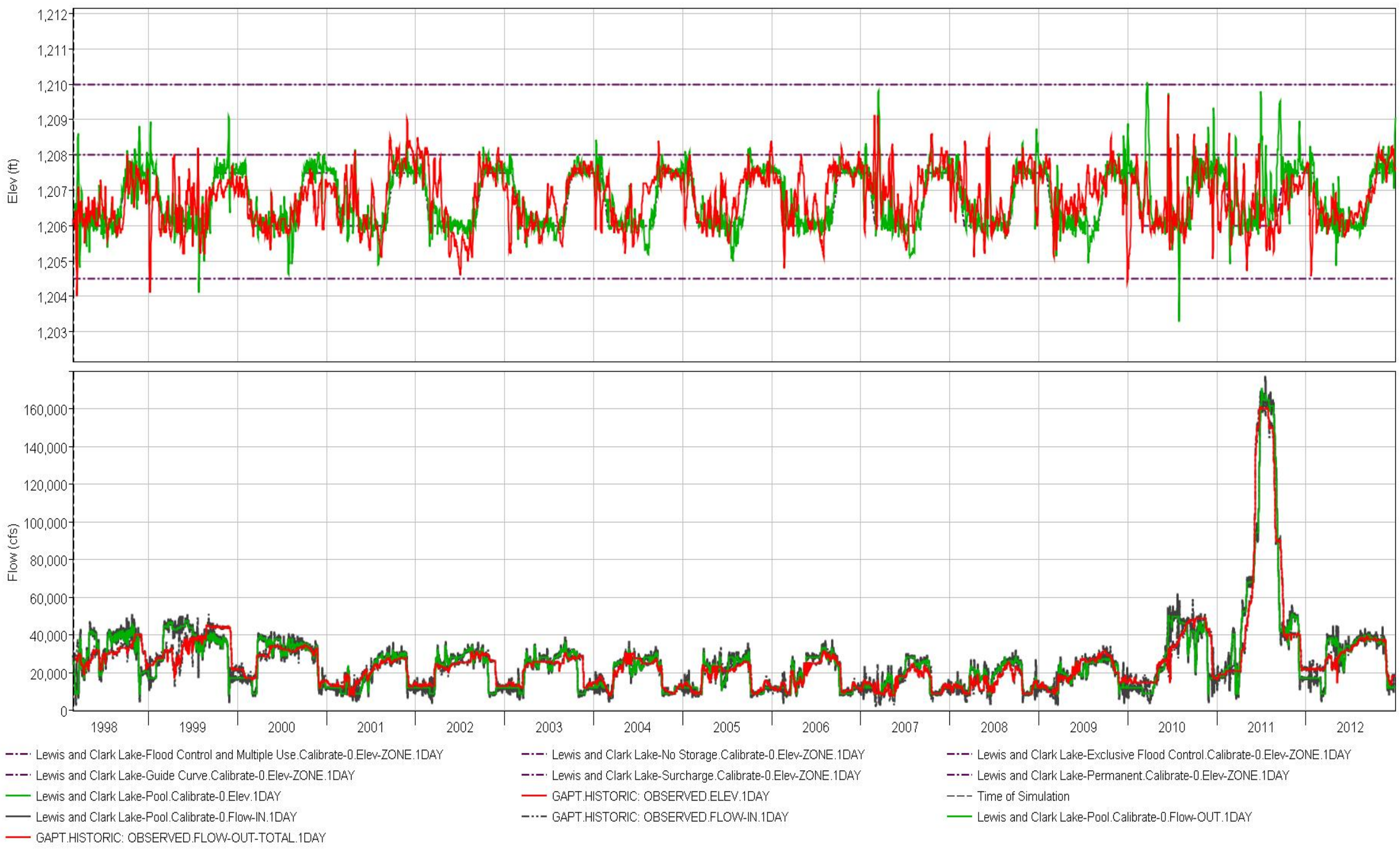


Figure 5-6: ResSim versus historic operations at Gavins Point Dam 1998-2012.

The above plots show a variety of information, but the most valuable pieces that explain the System operation are the pool elevations at Fort Peck, Garrison and Oahe and the releases from Gavins Point.

Gavins Point releases follow the general trend of releases to meet navigation and other release targets as well as evacuate excessive floodwaters when necessary. Gavins Point missed navigation targets only when the computed local flow forecasts significantly diverged from observed flows. Local flow forecasts were included to make the simulation similar to downstream forecasting during real-time operations.

The pool elevations at the upper three projects follow the historic trends and maintain the proper balance of storage in all three projects. These elevations also validate Gavins Point's annual release volume, as the bulk of the System inflow originates above the upper three reservoirs.

The objective of this ResSim model is to simulate System operation for the period of record for assessment of base conditions on the Missouri River. It should be noted that the ResSim model will never fully be able to operate the reservoirs to exactly match historic operations because of changes in operation over time, changes in basin depletions and other water development within the basin, and special short term operations that departed from typical rules in the water control manuals or from the rules in the model that were adapted from general guidance in the manual. The end product should be representative to a reasonable degree of historic operations and ensuring that all major operational decisions occur correctly. There are instances where special operations have occurred due to situational occurrences, political requests, environmental, and changes in policy. Such instances that have required adjustments from normal operations include but are not limited to:

- Dam maintenance
- Near real-time adjustments to adjust max flows for endangered species
- Navigation flow target adjustments to account for barge traffic (or lack thereof)
- Release adjustments to mitigate ice impacts
- Others

5.2 POOL PROBABILITY COMPARISON

Comparisons of 1998-2012 pool probability plots are shown below; including data from earlier in the period-of-record did not allow for an accurate comparison because System operations have changed throughout the period-of-record. The plots show the observed and modeled pool probability data. The pool elevations at the upper three projects follow the historic trends and maintain the proper balance of storage in all three projects. It should be noted that since only 13 years of data was used to produce these probability plots, the probabilities associated with the pool elevations should only be used for comparison of modeled data to observed data.

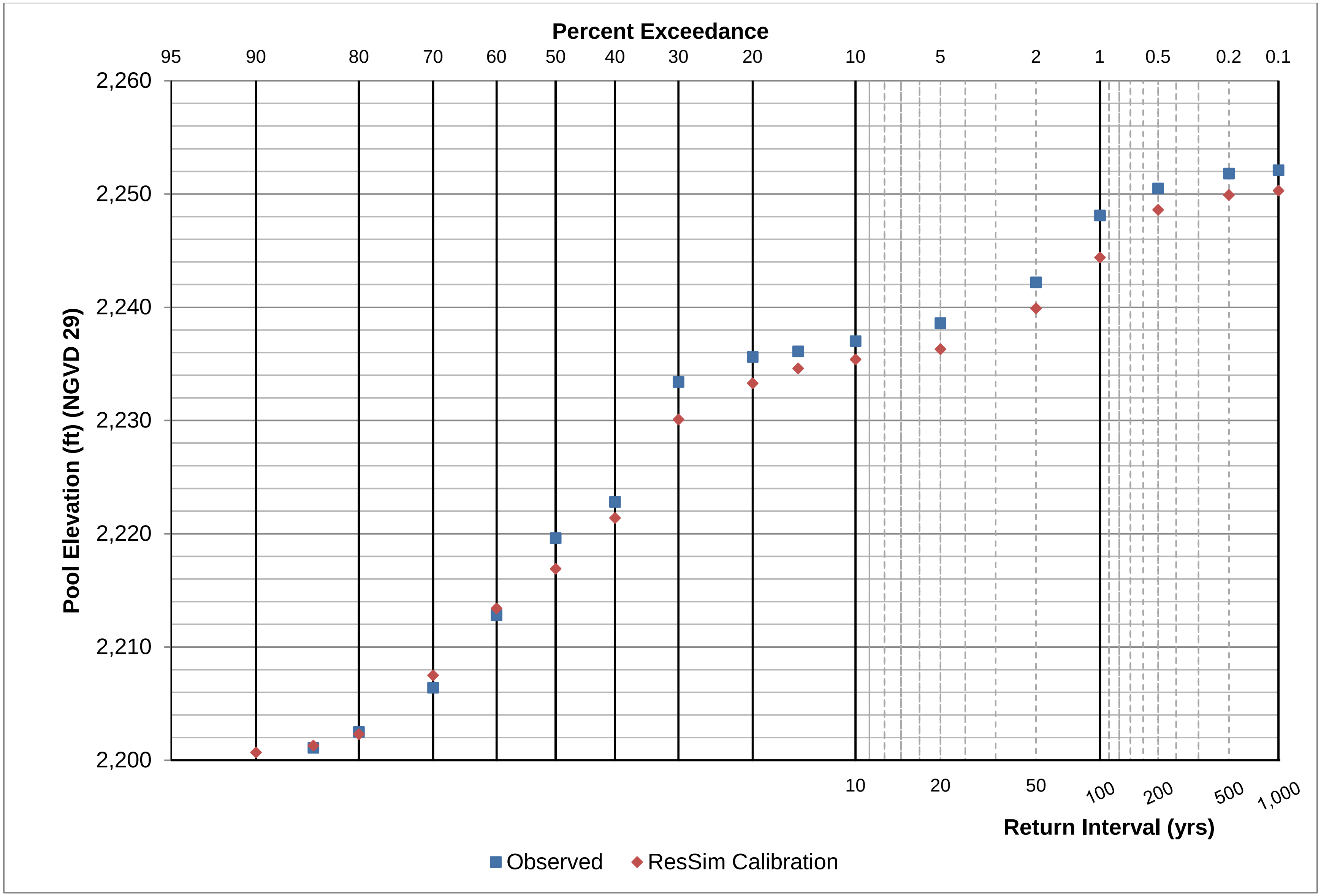


Figure 5-7: Fort Peck Lake pool probability curve for years 1998-2012.

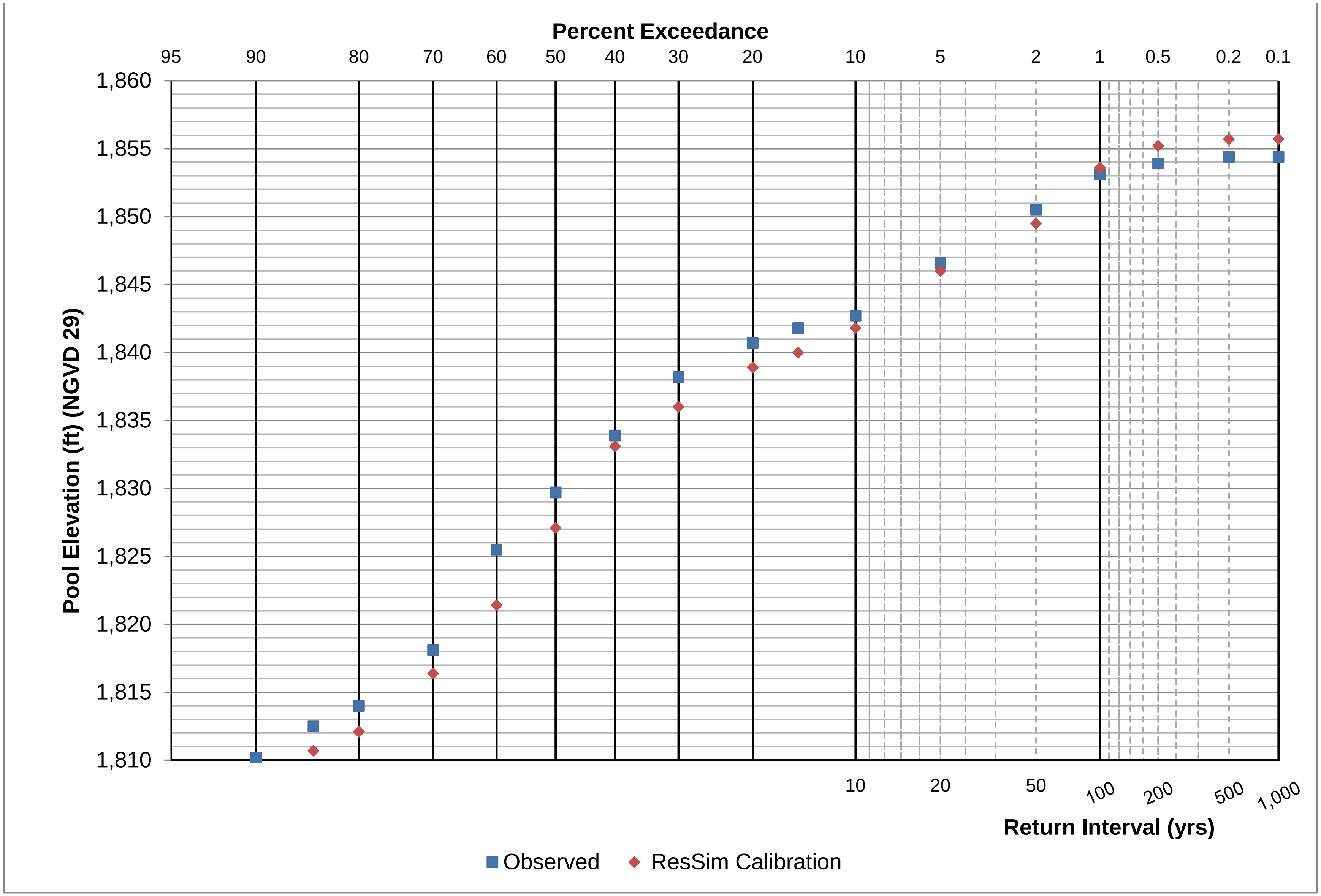


Figure 5-8: Lake Sakakawea pool probability curve for years 1998-2012.

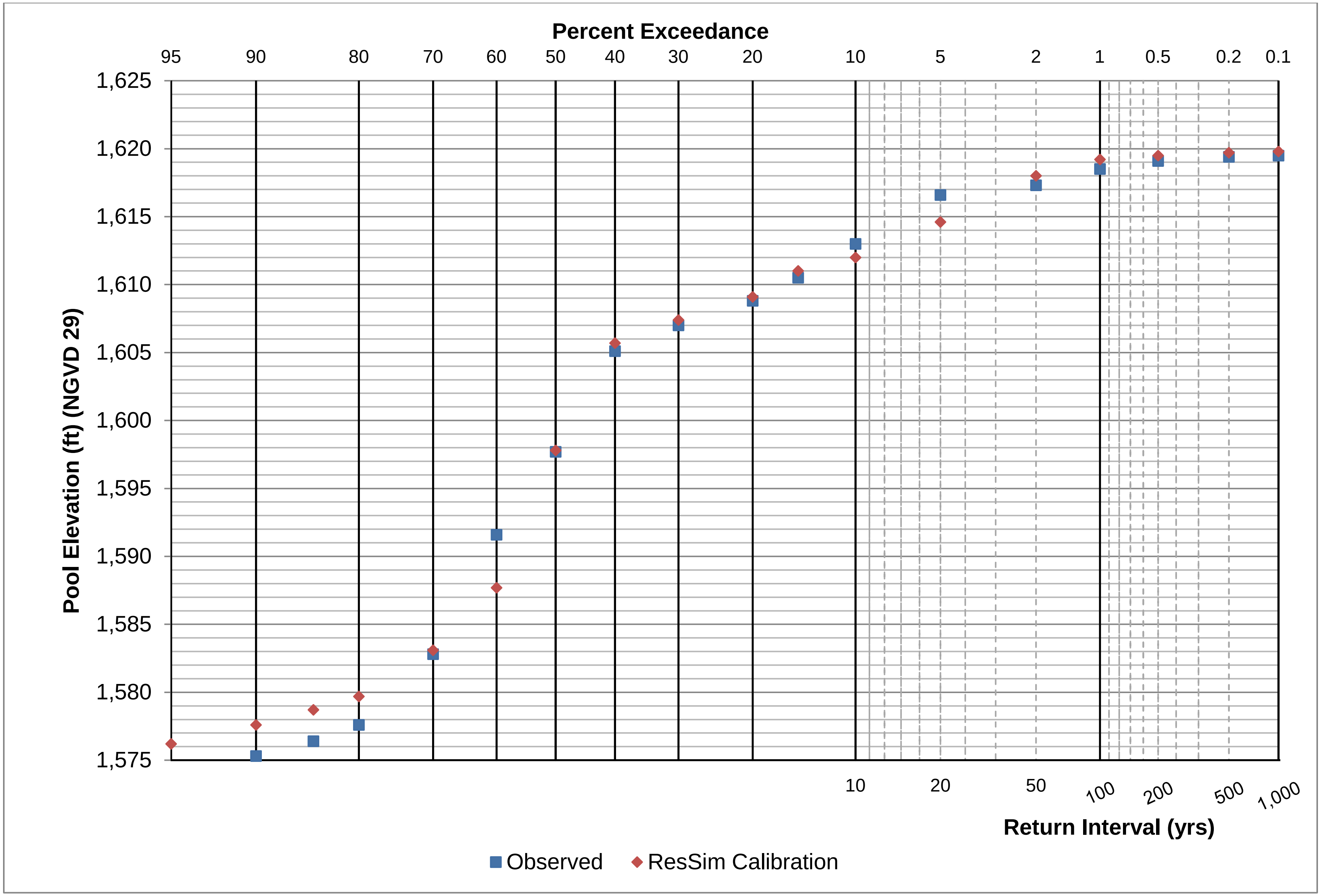


Figure 5-9: Lake Oahe pool probability curves for years 1998-2012.

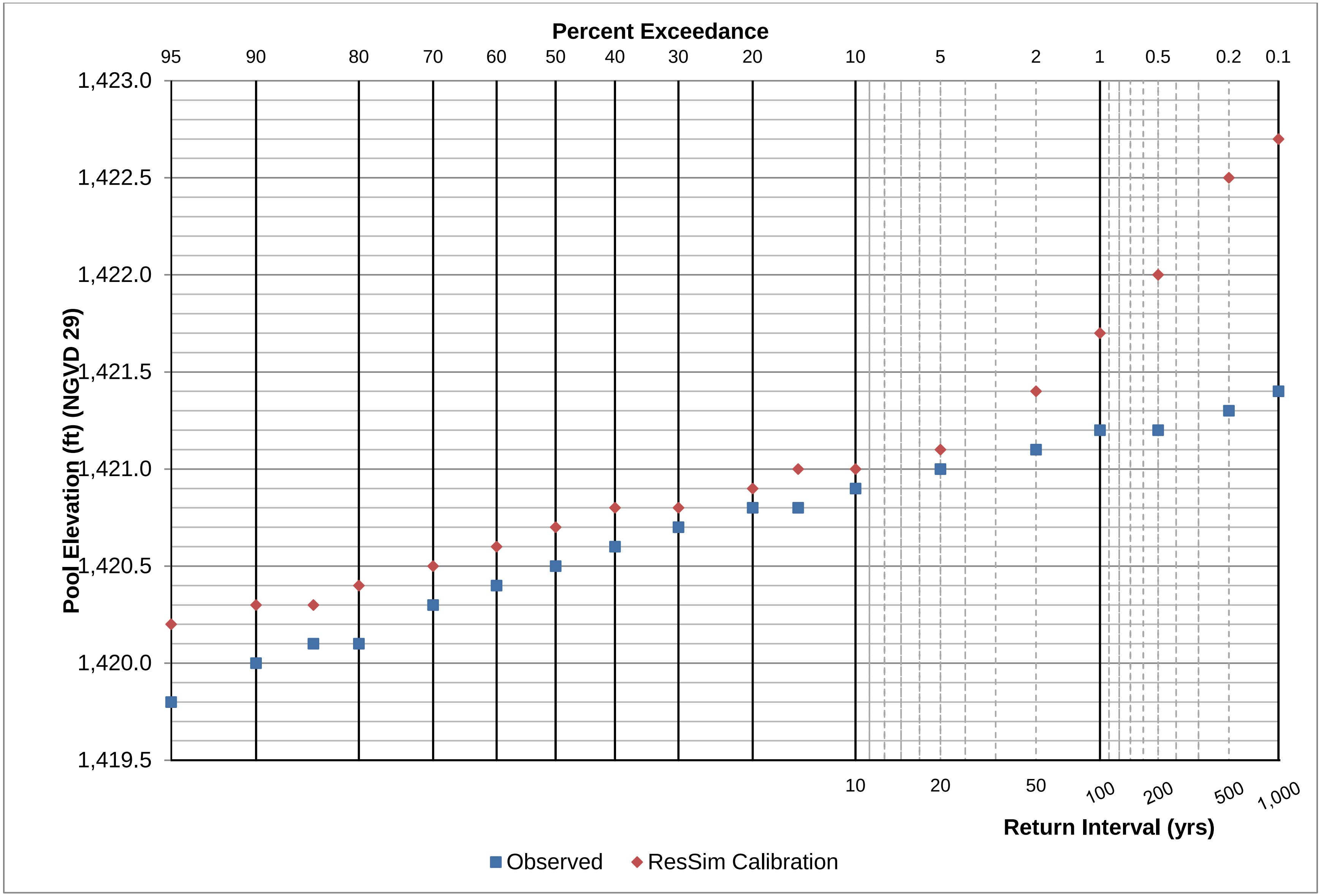


Figure 5-10: Lake Sharpe pool probability curves for years 1998-2012.

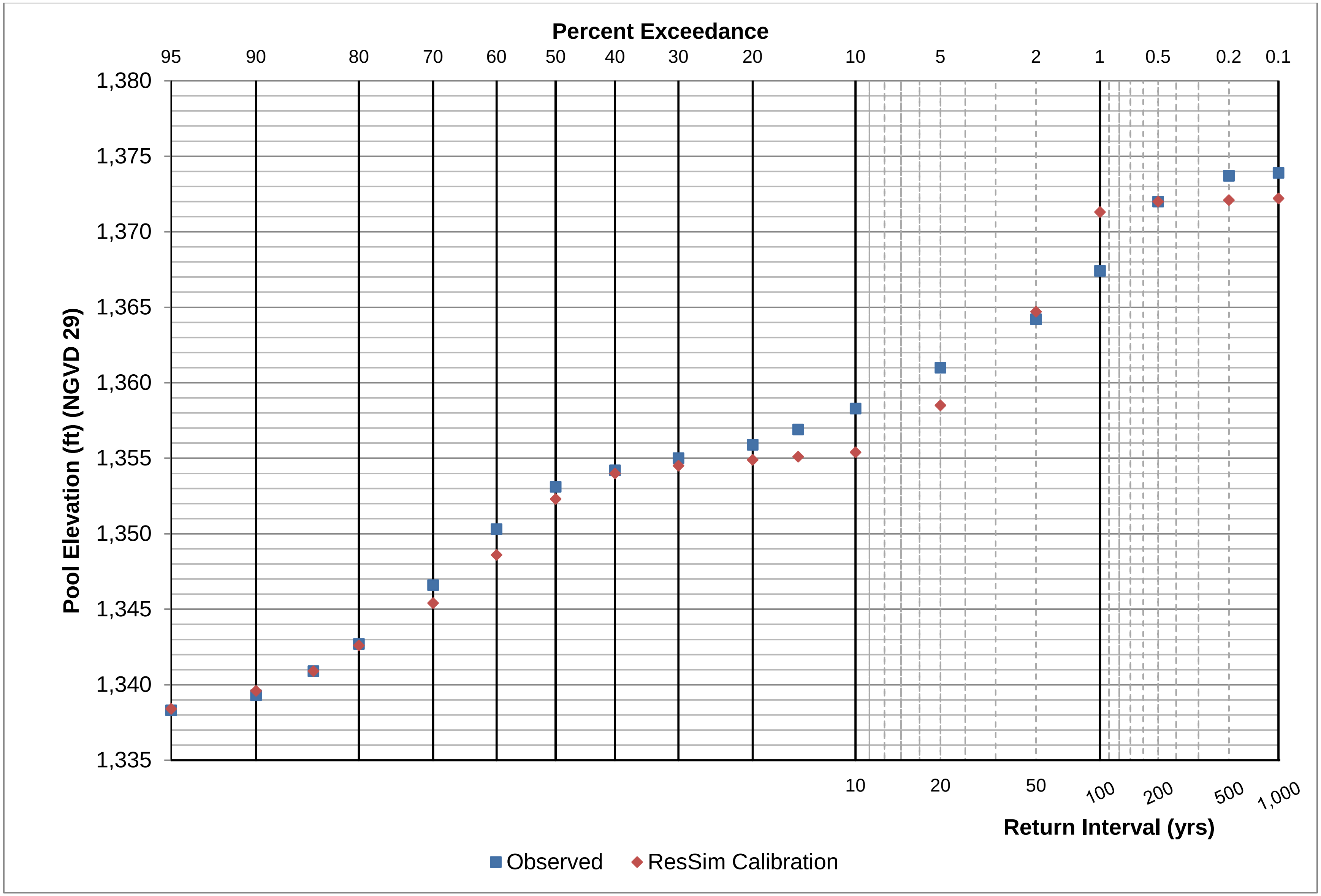


Figure 5-11: Lake Francis Case pool probability curves for years 1998-2012.

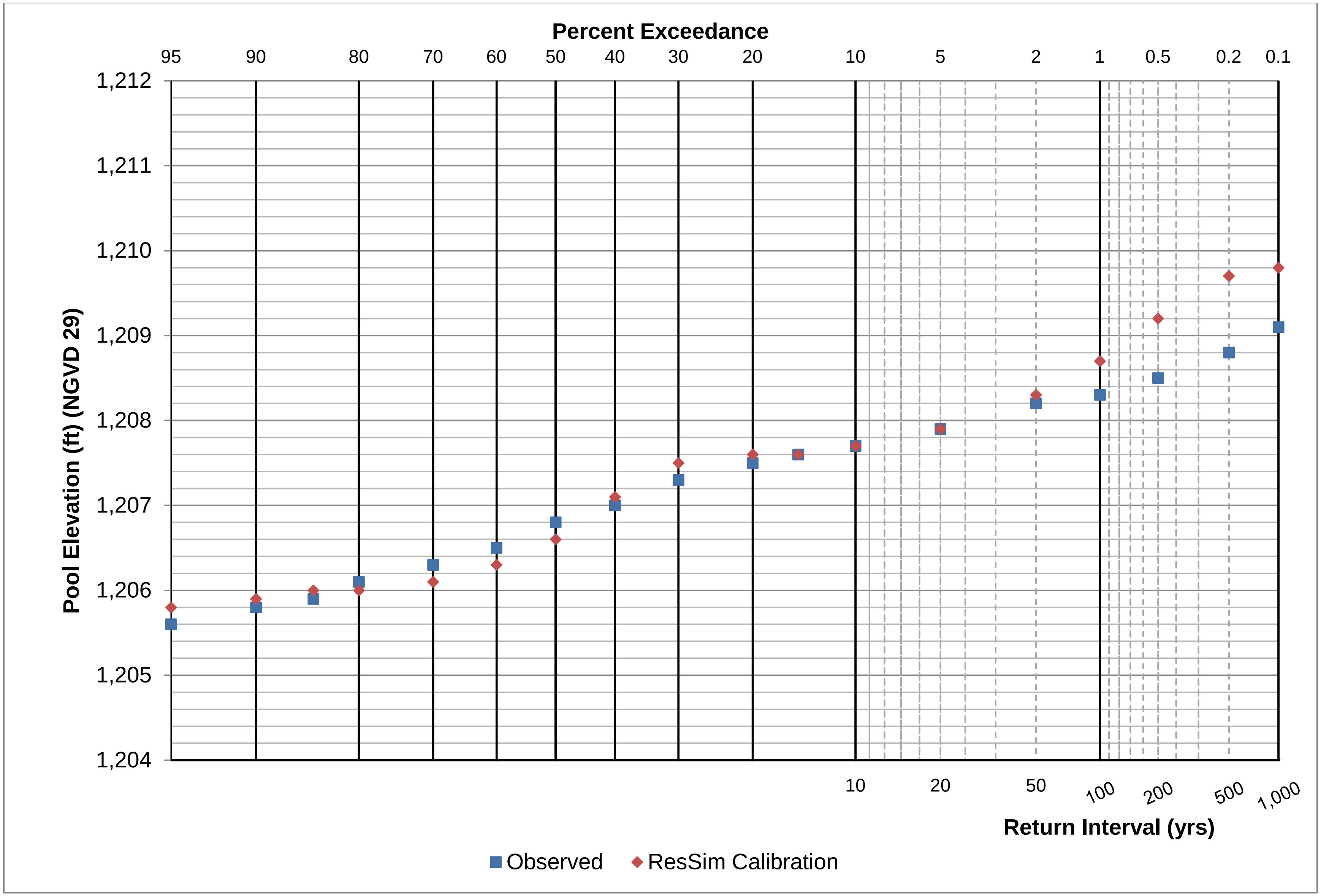


Figure 5-12: Lewis and Clark Lake pool probability curves for years 1998-2012.

5.3 RELEASE AND FLOW PROBABILITY COMPARISON

Comparisons of 1998-2012 release and flow plots are shown below; including data from earlier in the period-of-record did not allow for an accurate comparison because System operations have changed throughout the period-of-record. The plots show the observed and modeled release probability data. The releases at the upper three projects follow the historic trends and maintain the proper balance of storage in all three projects. It should be noted that since only 13 years of data was used to produce these plots, the probabilities associated with the releases should only be used for comparison of modeled data to observed data.

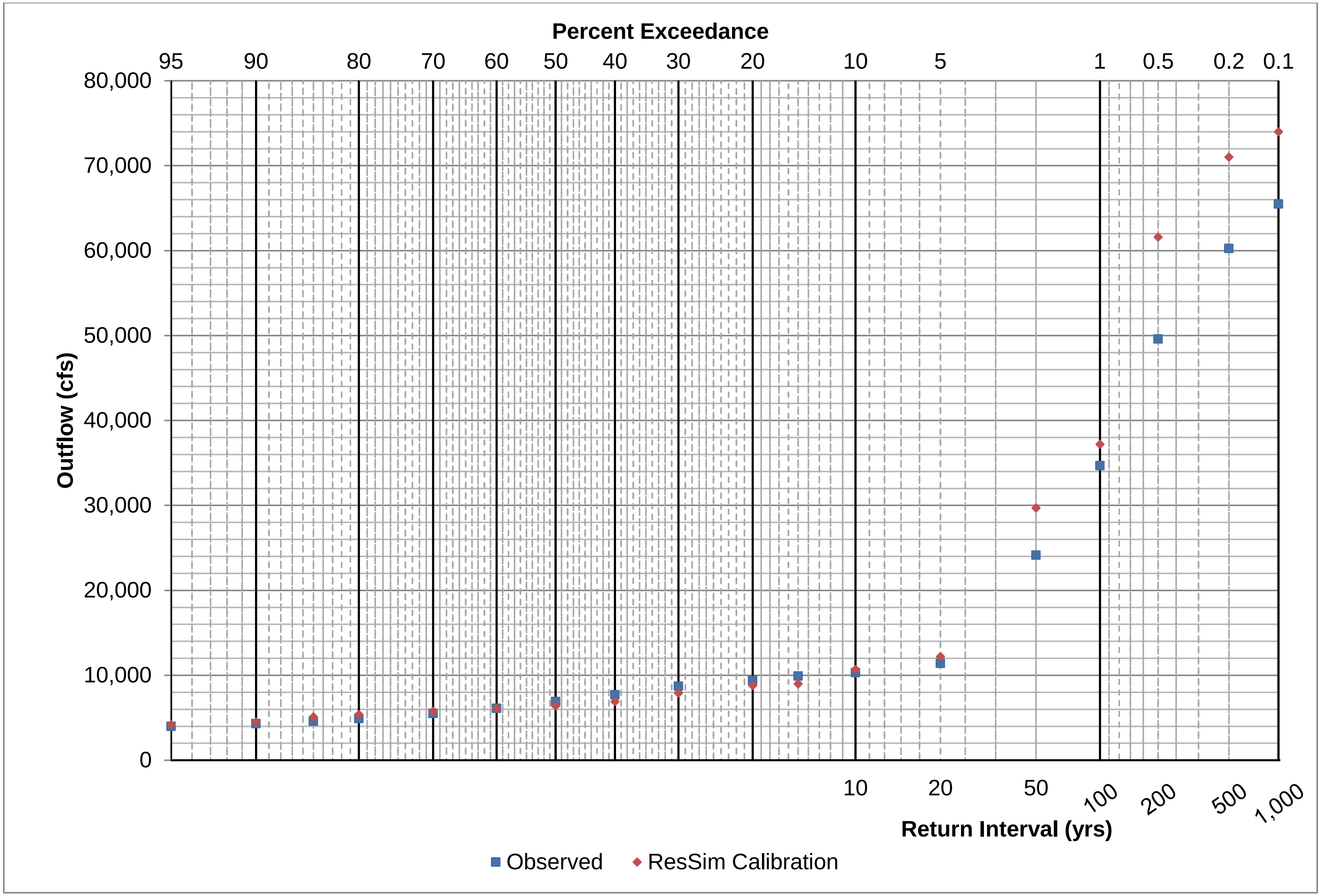


Figure 5-13: Fort Peck Lake release probability curves for years 1998-2012.

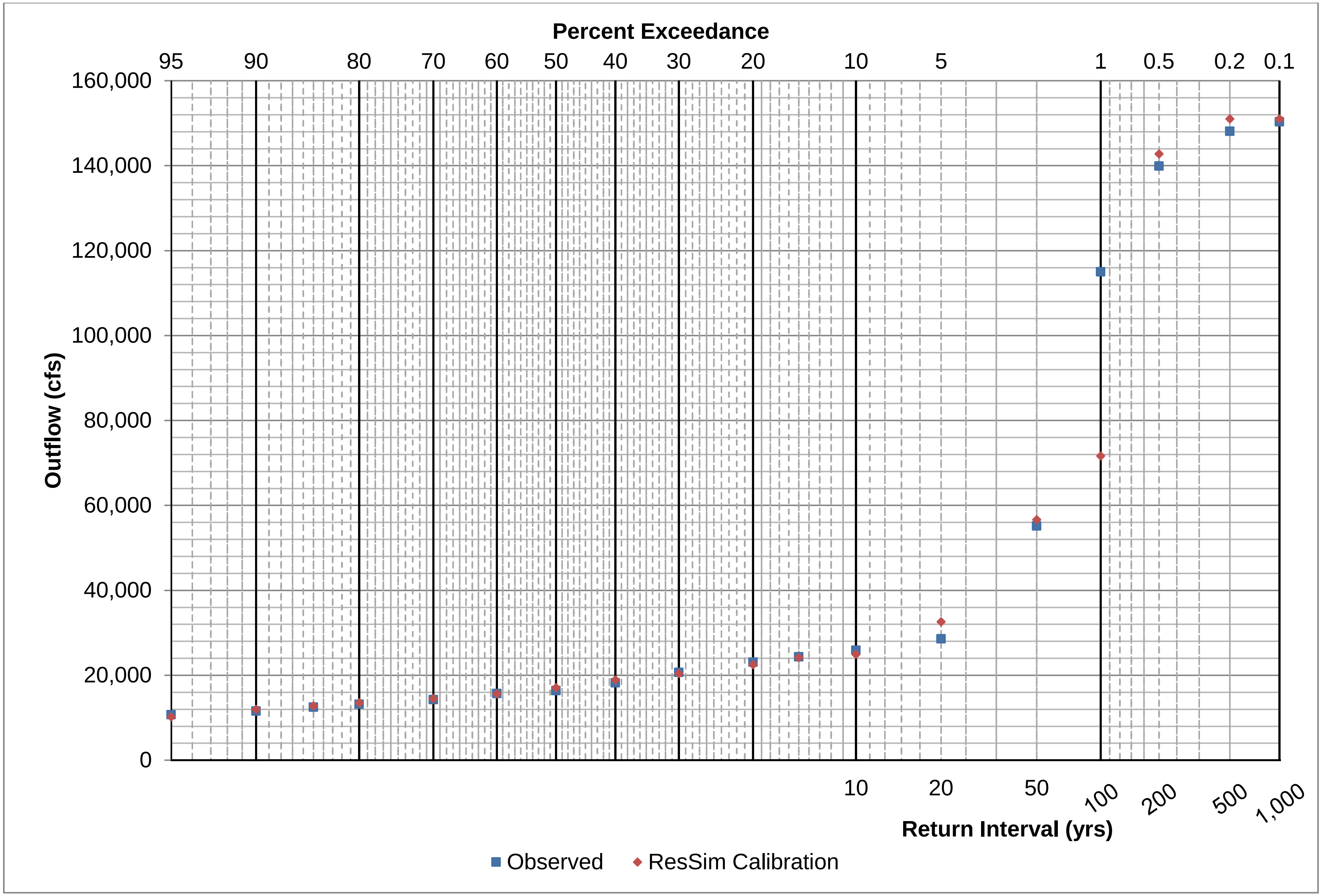


Figure 5-14: Lake Sakakawea release probability curves for years 1998-2012.

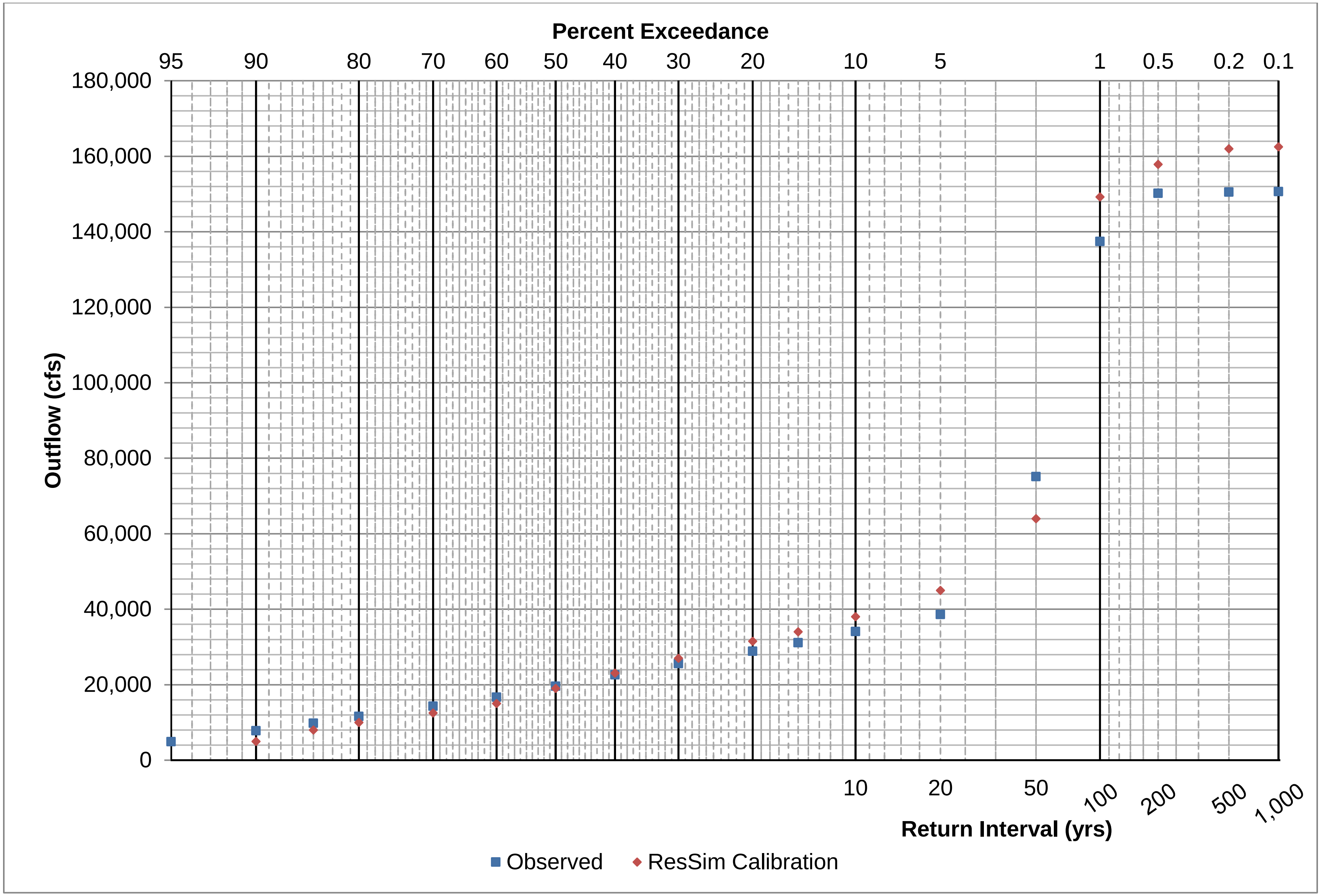


Figure 5-15: Lake Oahe release probability curves for years 1998-2012.

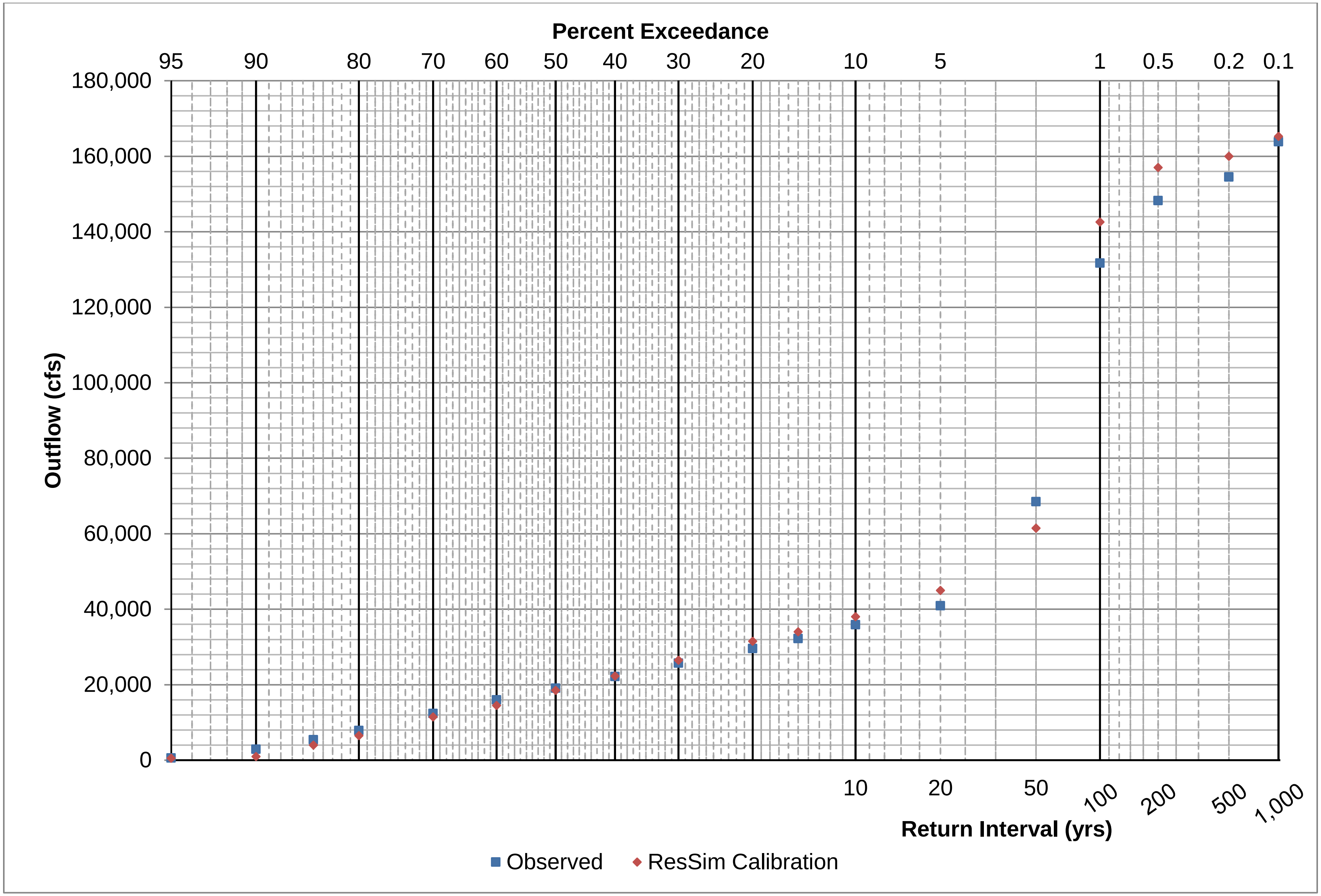


Figure 5-16: Lake Sharpe release probability curves for years 1998-2012.

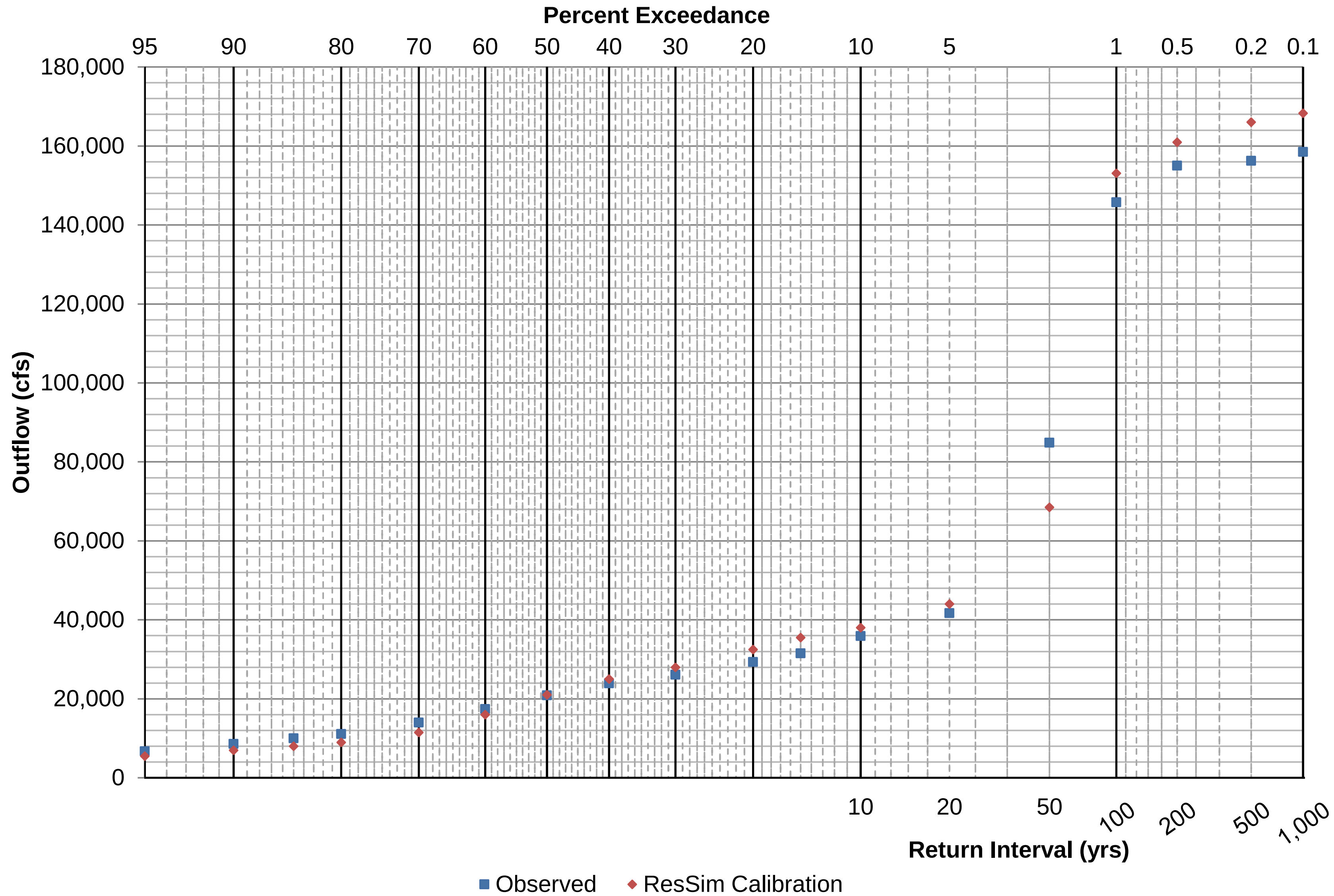


Figure 5-17: Lake Francis Case release probability curves for years 1998-2012.

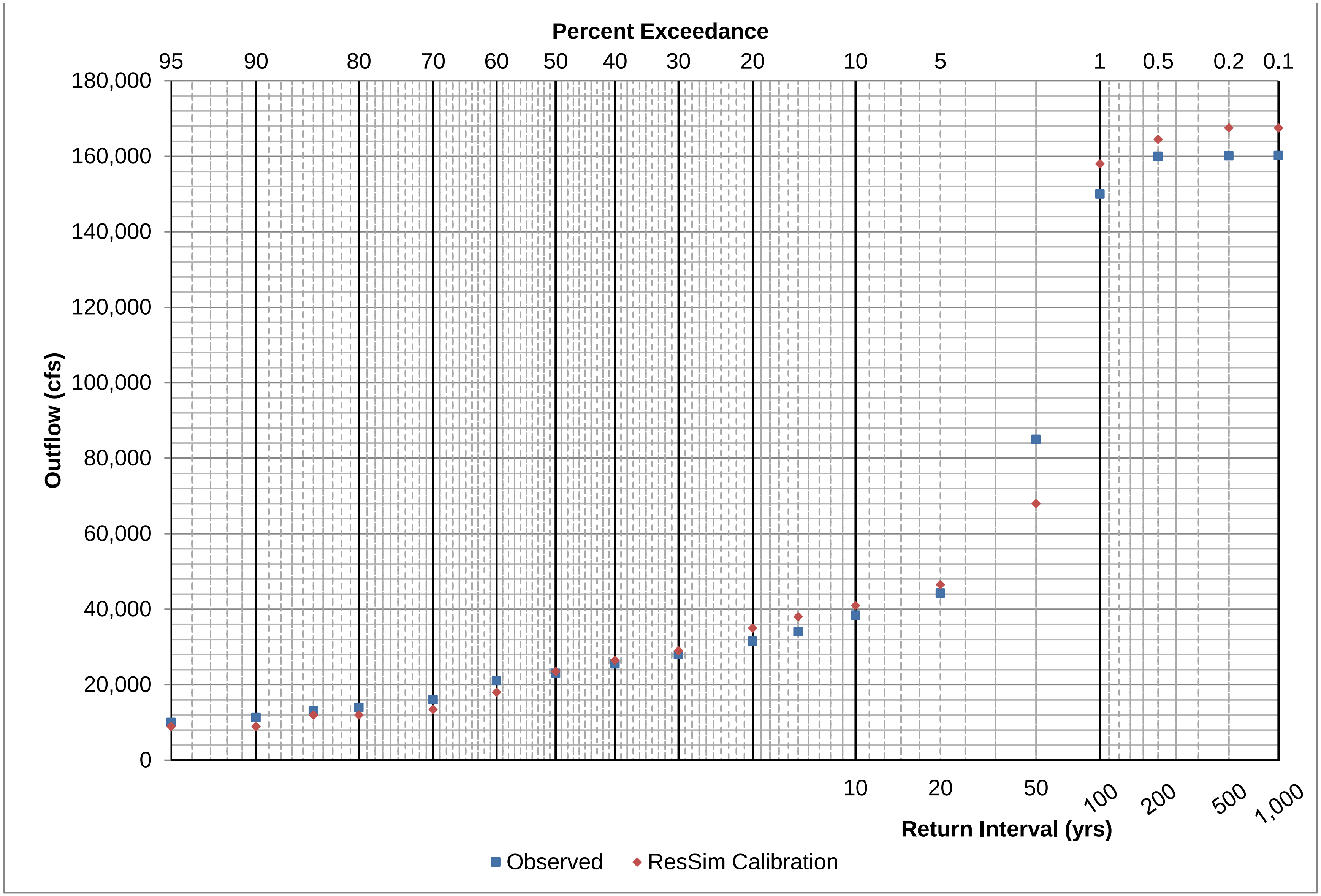


Figure 5-18: Lewis and Clark Lake release probability for years 1998-2012.

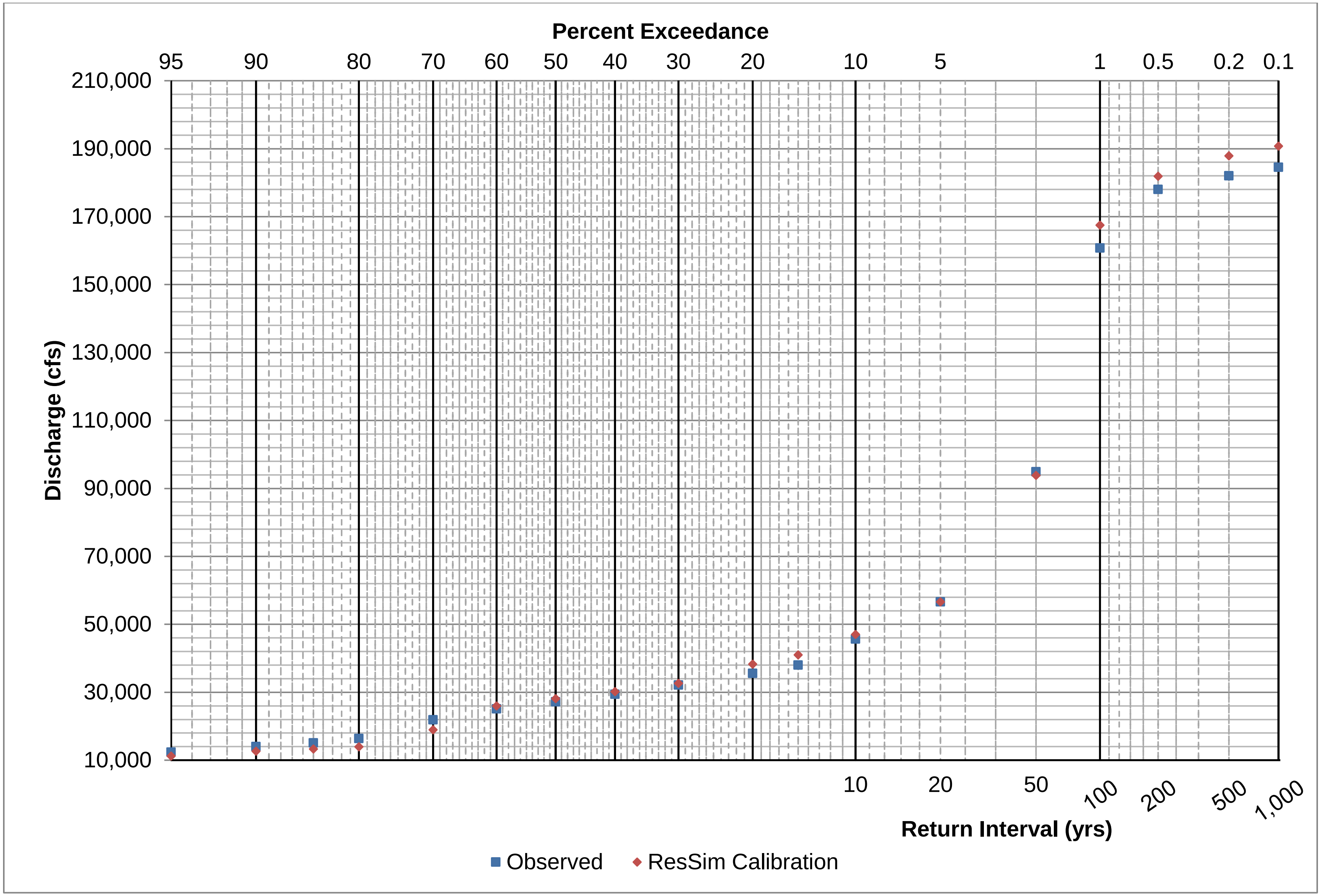


Figure 5-19: Sioux City, IA flow probability curves for years 1998-2012.

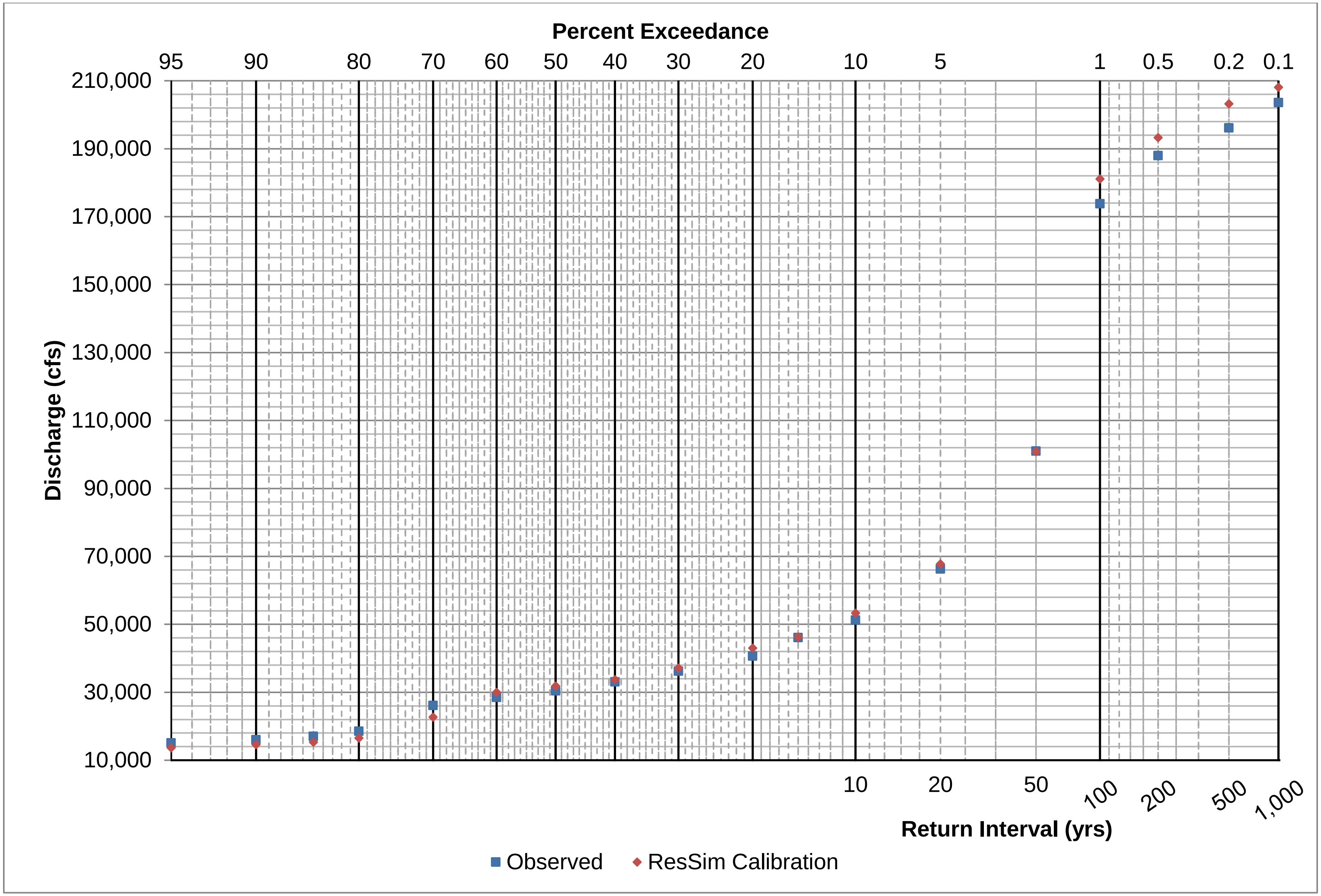


Figure 5-20: Omaha, NE flow probability curves for years 1998-2012.

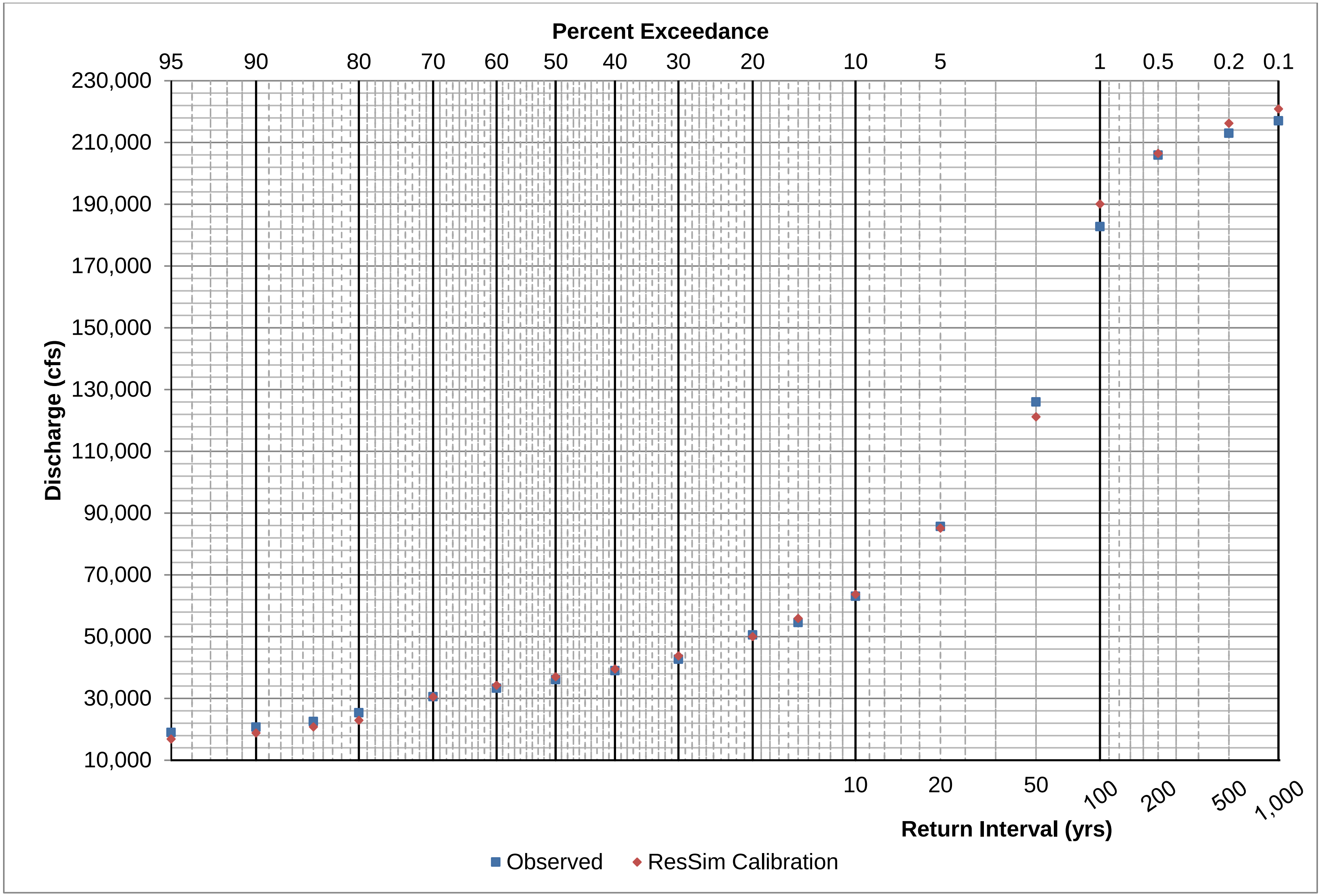


Figure 5-21: Nebraska City, NE flow probability curves for years 1998-2012.

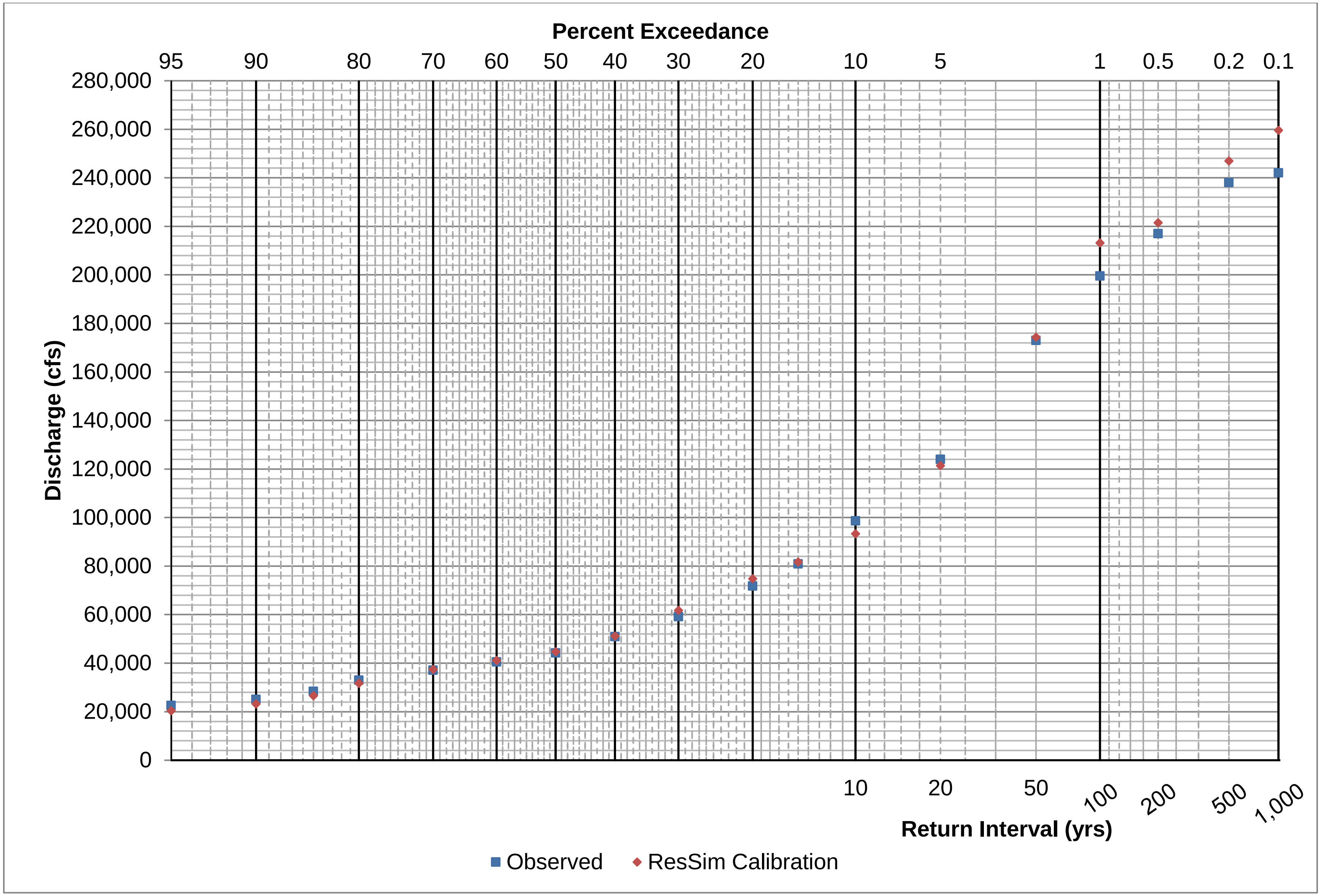


Figure 5-22: Kansas City, MO flow probability curves for years 1998-2012.

5.1 DECISION COMPARISONS

Since operations change throughout the period-of-record and a model will never be able to perfectly reproduce real-time decisions, a better estimate of model performance was checking operational decisions based on the simulated information. To check this, several key operational decisions were assessed during the period-of-record, 1930-2012: service level, navigation target flows, water supply requirements, navigation end date, winter release, flood targets, steady release, balancing storage in the upper three reservoirs, water supply requirements between reservoirs, and guide curve operations at Big Bend, Fort Randall, and Gavins Point Dams. Each of these operational decisions was described in more detail in Section 2.3.

5.1.1 Service Level

Normally, service level is calculated two times per year: March 15 and July 1. The March 15 storage check determines if there will be a navigation season and if there is a navigation season, the service level for the first half of the navigation season. Table 5-1 lists the service level requirements, which are based on water in System storage. Service level is linearly interpolated for System storages between the values listed in Table 5-1.

Table 5-1: Service level requirements. Summarized from Table VII-2 in the Master Manual (U.S. Army Corps of Engineers, 2006).

Date	Service Level (cfs)	Water in System Storage (MAF)
March 15	35,000 cfs (full service)	54.5 or more
March 15	29,000 cfs (minimum service)	31.0 – 49.0
March 15	No service	31.0 or less
July 1	35,000 cfs (full service)	57.0 or more
July 1	29,000 cfs (minimum service)	50.5 or less

Several years were checked for service level calculations to ensure that years with full service, minimum service, no service, and interpolated service levels were correctly calculated on March 15 and July 1. In 1966, the simulated System storage on March 15 was approximately 56.4 MAF, which is greater than the minimum System storage for full service of 54.5 MAF. The model correctly set the service level to 35,000 cfs or full service for the first half of the season. The inceased service level during May is due to an increased water supply forecast (System storage + calendar year runoff forecast), which causes the model to set a higher service level to evacuate stored flood waters. The simulated System storage on July 1 was approximately 58.7 MAF, which is greater than the System storage for full service of 57.0 MAF. The model correctly set the service level to 35,000 cfs or full service for the remainder of the navigation season. Figure 5-23 shows a summary plot of the state variables calculated in the Service Level state variable for 1966, which includes the System storage and the service level.

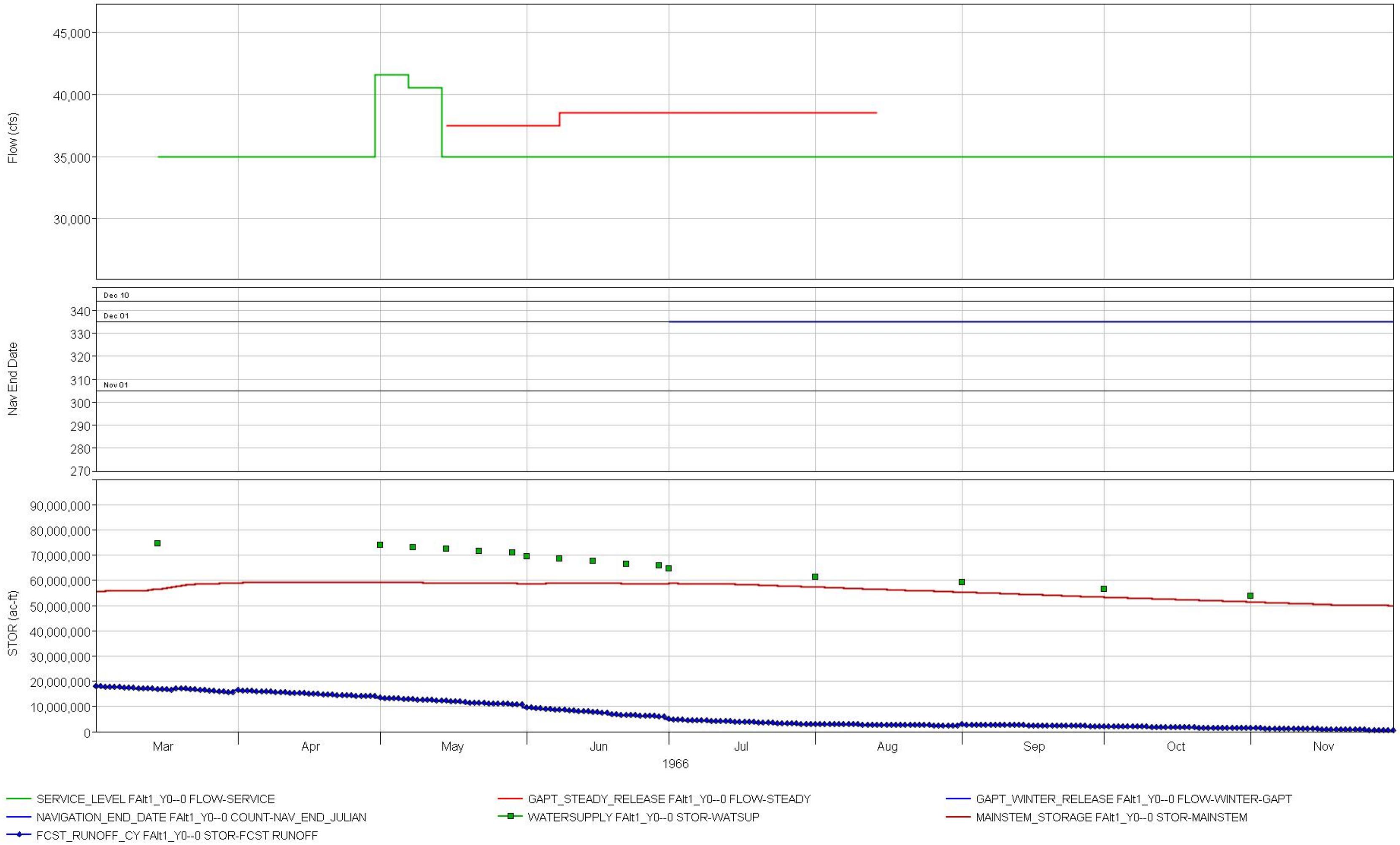


Figure 5-23: Plot of service level and System storage in 1966.

In 2002, the simulated System storage on March 15 was approximately 47.1 MAF, which is less than the upper limit for minimum service of 49.0 MAF. The model correctly set the service level to 29,000 cfs or minimum service for the first half of the season. The simulated System storage on July 1 was approximately 46.8 MAF, which is less than the upper limit for minimum service of 50.5 MAF. The model correctly set the service level to 29,000 cfs or minimum service for the remainder of the navigation season. Figure 5-24 shows a summary plot of the state variables calculated in the Service Level state variable for 2002, which includes the System storage and the service level.

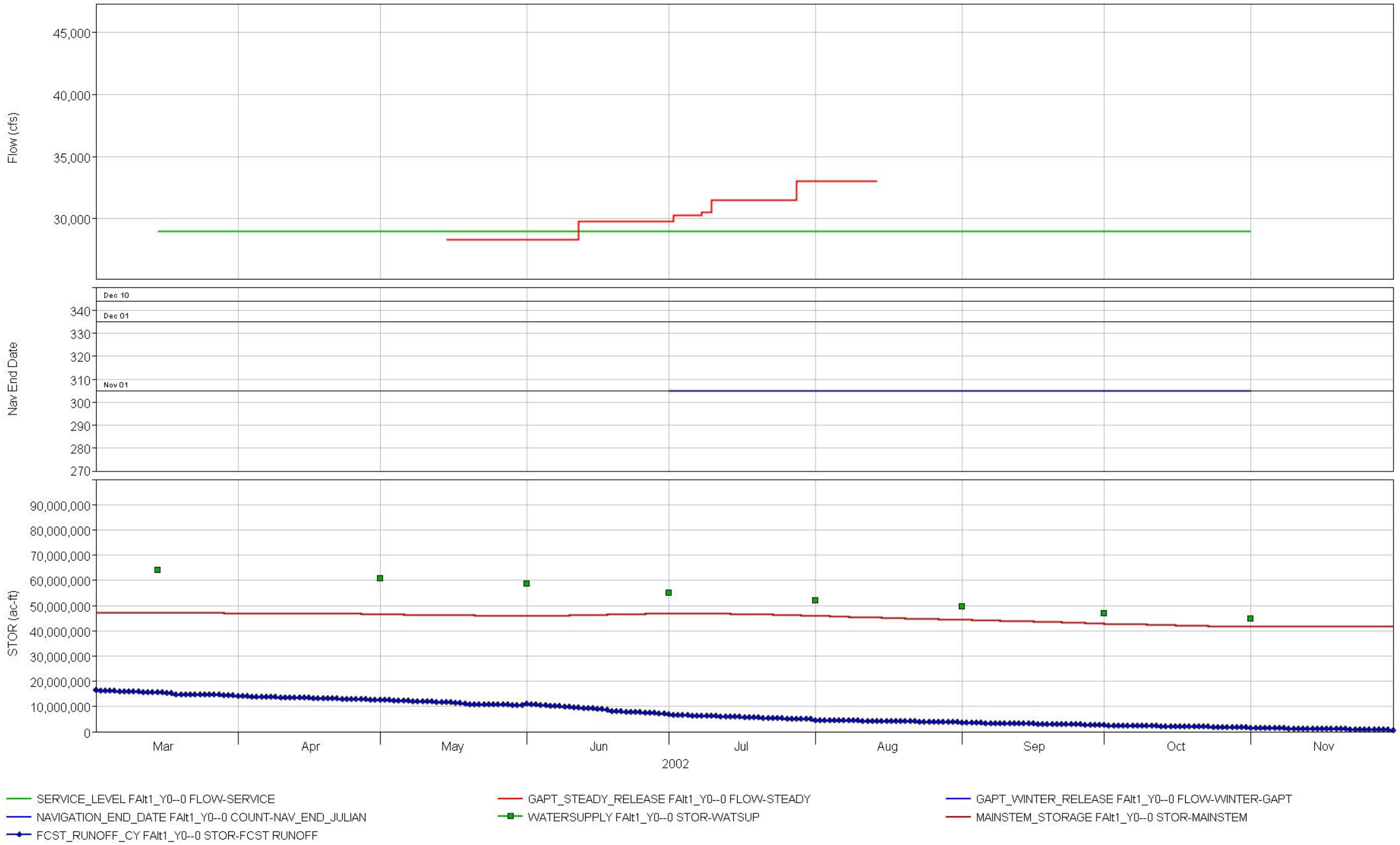


Figure 5-24: Plot of service level and System storage in 2002.

In 1988, the simulated System storage on March 15 was 52.97 MAF, which is between the full service limit of 54.5 MAF and upper limit for minimum service of 49.0 MAF. Interpolating between those limits, the model correctly set the service level to 33,300 cfs for the first half of the season. The simulated System storage on July 1 was 50.91 MAF, which is between the full-service limit of 57.0 MAF and upper limit for minimum service of 50.5 MAF. Interpolating between those limits, the model correctly set the service level to 29,400 cfs for the remainder of the navigation season. Figure 5-25 shows a summary plot of the state variables calculated in the Service Level state variable for 1988, which includes the System storage and the service level.

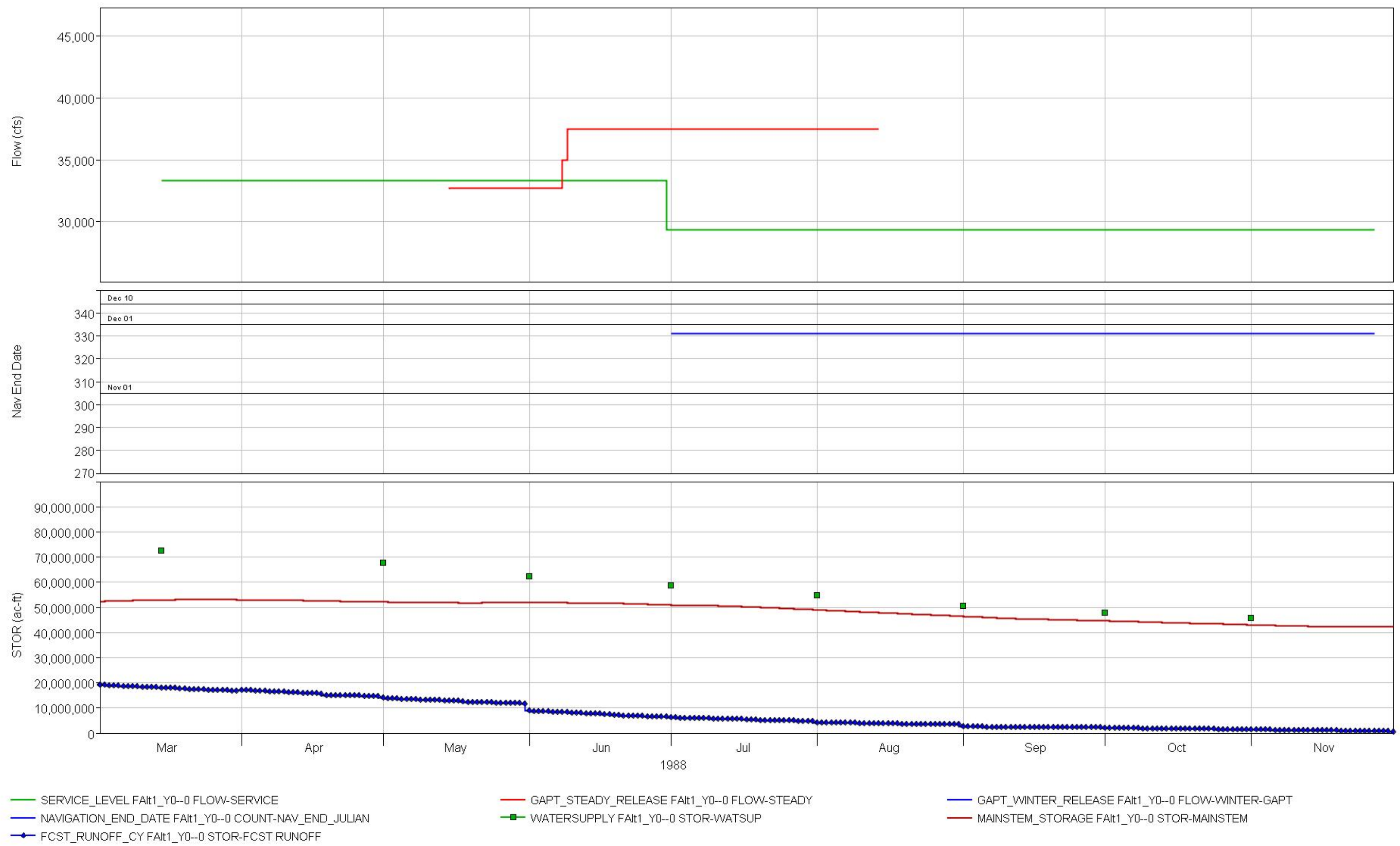


Figure 5-25: Plot of service level and System storage in 1988.

5.1.2 Navigation Targets

Meeting navigation flows at the four target locations is a critical piece of the Missouri River operations. During non-flood periods, navigation target flows are calculated by adjusting the service level with the information in Table 4-11. Gavins Point releases are set so that the navigation target flows are met at each target location. The hatched area in Figure 5-26 represents the target flows at Sioux City, Omaha, Nebraska City, and Kansas City. On the plot, the beginning and end of the hatched area represents the beginning and end of the navigation season at each location. In perfect operations, the flows would never be lower than the target flows; however, this is not reasonable because travel times between Gavins Point and the target locations require the use of local inflow forecasts. These forecasts can vary and flows may drop below the target flow for short periods. The times when navigation targets are missed usually coincide with local flows at the controlling location receding quicker than the forecasted local inflow. The controlling location is the target location that requires Gavins Point releases to be adjusted because local inflows are not high enough to meet the navigation target with current Gavins Point releases; this location is identified as the location where the flow is equal to the navigation target flow (see Figure 5-26).

In 1956, the service level is 29,000 cfs or minimum service, which results in navigation target flows of 25,000 cfs at Sioux City and Omaha, 31,000 cfs at Nebraska City, and 35,000 cfs at Kansas City. The model correctly calculates and operates for the navigation targets; the days a navigation target flow is not met are attributed to times when the local inflow forecasts did not accurately capture the hydrograph of the local inflows. An example of this occurs at the end of July while Kansas City was the controlling location. Kansas City local inflows began to recede more quickly than the forecasted local inflows causing flows at Kansas City to fall below the navigation target flow. Due to the travel time between Gavins Point and Kansas City, it took the model a couple days to forecast flows missing target and another couple days before the increase in Gavins Point releases reached Kansas City.

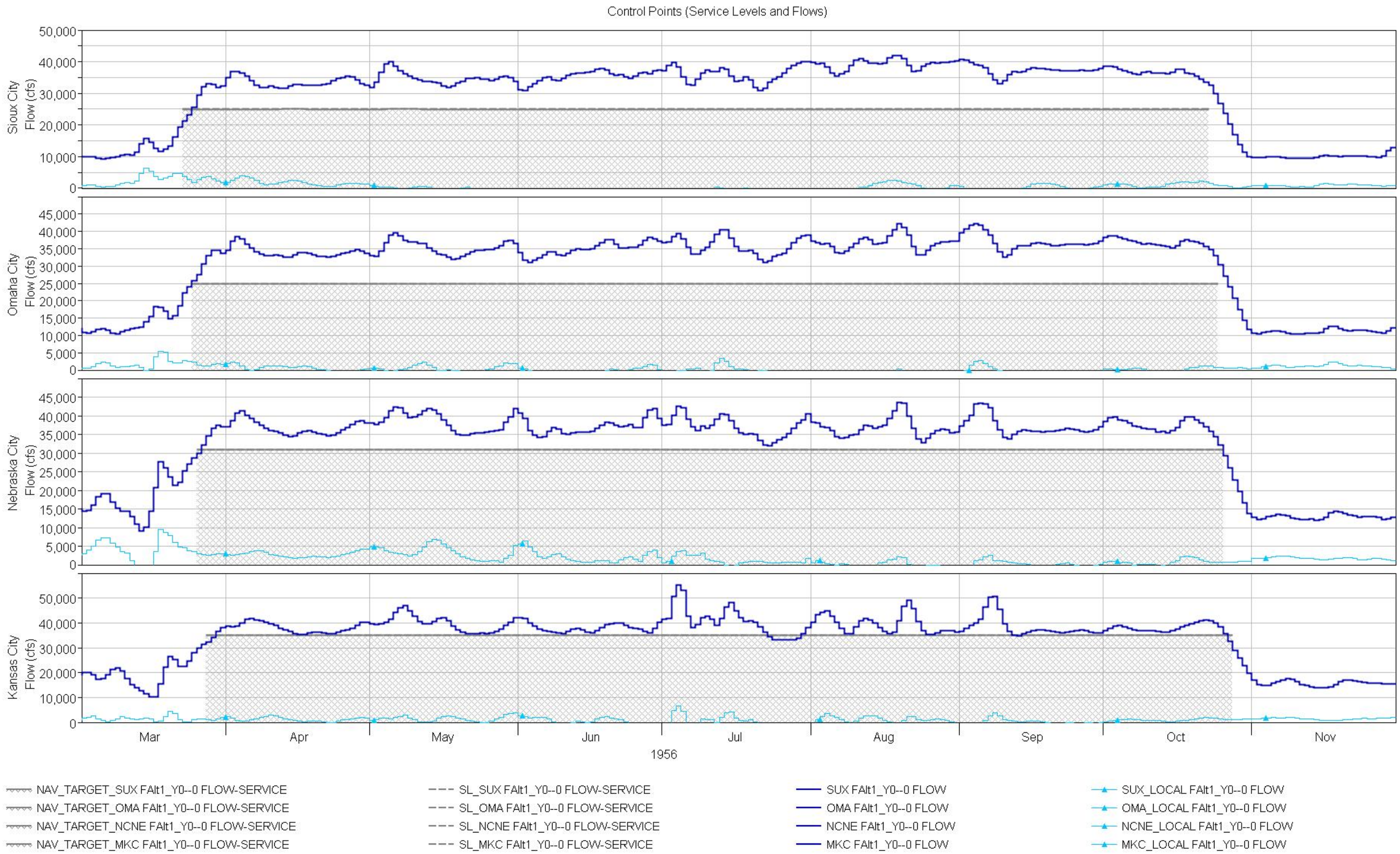


Figure 5-26: Control points plot of target flows and simulated flows at each of the target locations.

5.1.3 Steady Release

The System operates for a steady release between May 15 and August 15 when the least terns and piping plovers are nesting. The steady release during this period is based on the System release typically needed to ensure full service or minimum service for a below median forecasted runoff or a median or greater forecast forecasted runoff during the month of July. In 1957, the service level on March 15 is 29,000 cfs or minimum service; the May 1 forecasted calendar year runoff is 15.1 MAF, which is less than the median calendar year runoff of 24.6 MAF. Using the data in Table 4-9, the steady release for minimum service and a forecasted runoff less than the median runoff is 28,300 cfs, which the model correctly calculates and applies for releases on May 15 shown in Figure 5-28.

Flow at the four navigation target locations are still checked during steady release operations. If at any point flow at a target location is forecasted to fall below the navigation target, releases from Gavins Point are increased until the flow reaches the navigation target flow. A new steady release is then specified based on the increased Gavins Point release. This is shown in Figure 5-28 at the end of May as the releases from Gavins Point are increased because flows at Sioux City were forecasted to drop below the navigation target. A new steady release of 32,500 cfs is used during the first half of June.

Flood targets are also checked during steady release operations. If a flood target flow at one of the three target locations is forecasted to be exceeded, steady release operations will be ignored and releases from Gavins Point will be reduced to lower the flood risk downstream. This is also shown in Figure 5-28. During the end of June through July, high flows at Omaha, Nebraska City, and Kansas City require a reduction in releases from Gavins Point. Steady release operations resume at the end of July once downstream flows have receded, but a release of 35,000 cfs is required to meet Kansas City's navigation target flow, so the steady release is increased and set to 35,000 cfs for the remainder of the steady release period.

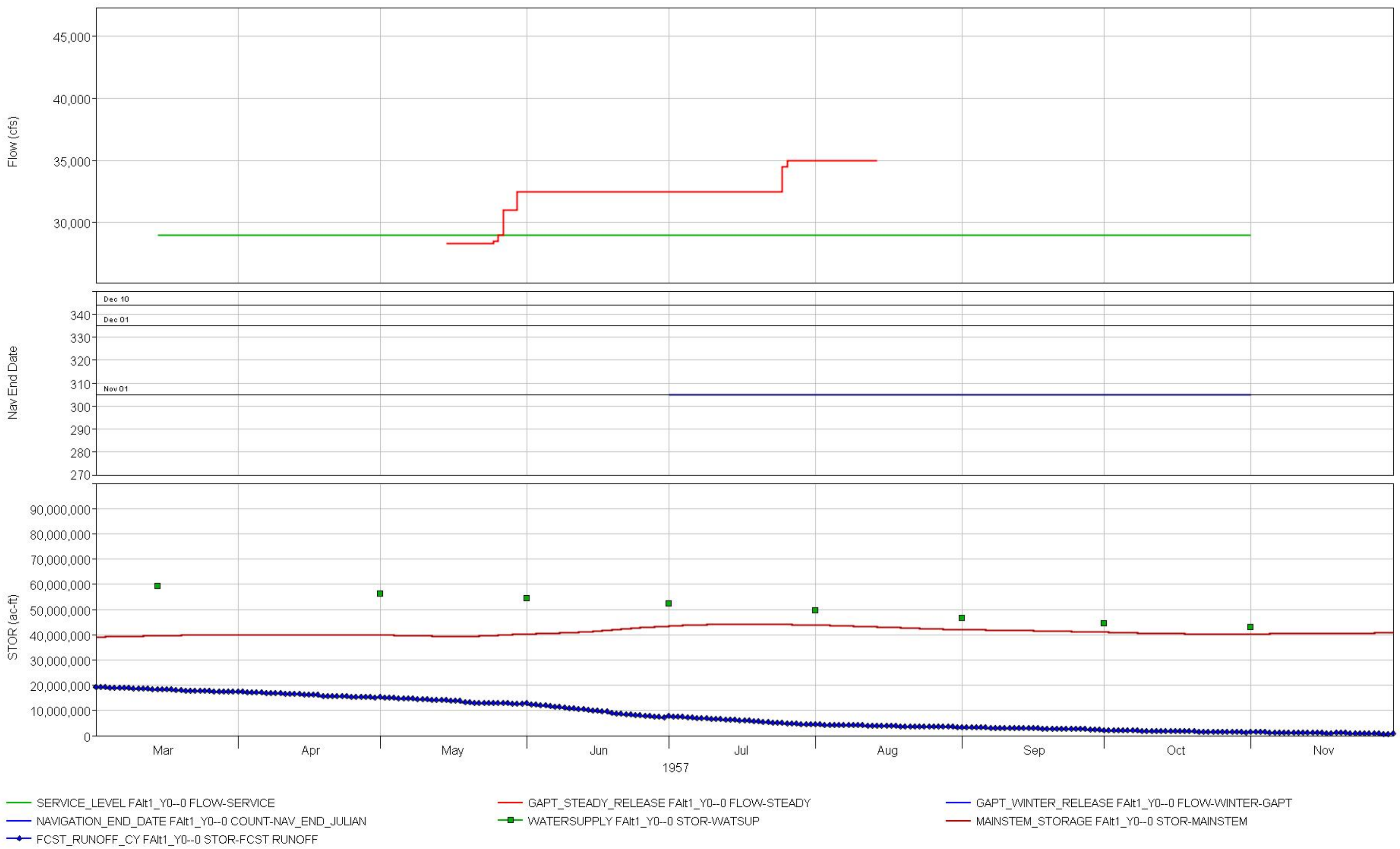


Figure 5-27: Plot of forecasted runoff and steady release in 1957.

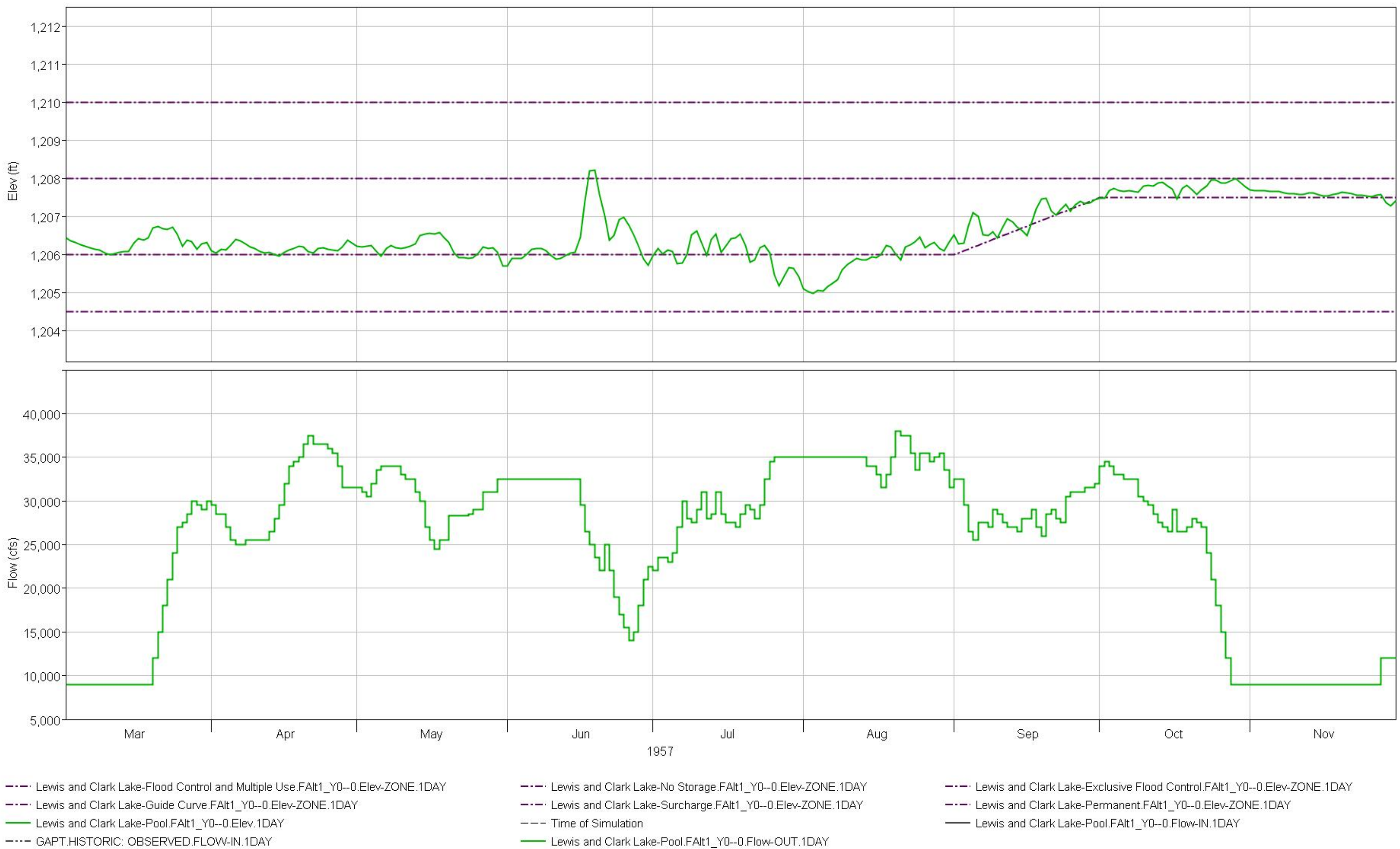


Figure 5-28: Plot of System releases in 1957.

5.1.4 *Navigation End Date*

The end of the navigation season or season length is determined on System storage on July 1 and the criteria are summarized in Table 5-2. If the System storage is between any of the two thresholds, the end date will be linearly interpolated.

Table 5-2: Navigation end date or season length criteria. Summarized from Table VII-3 in the Master Manual (U.S. Army Corps of Engineers, 2006).

Date	System Storage (MAF)	Season Closure Date at Mouth of the Missouri River
March 15	31.0 or less	No season
July 1	51.5 or more	December 1 – 8-month season
July 1	46.8 through 41.0	November 1 – 7-month season
July 1	36.5 or less	October 1 – 6-month season

In 1954, the System storage on July 1 is approximately 53.5 MAF. This is above the System storage amount for a full 8-month season, so the end date is December 1 and the season length is eight months. The model correctly calculates the end date for the navigation season and sets the end date to December 1, shown in Figure 5-29 as Julian days. In 1955 the System storage on July 1 is 47.62 MAF, which is between the thresholds for an 8-month season and a 7-month season. The model correctly interpolates the end date and sets the end date to Julian day 310 or November 6 as shown in Figure 5-30.

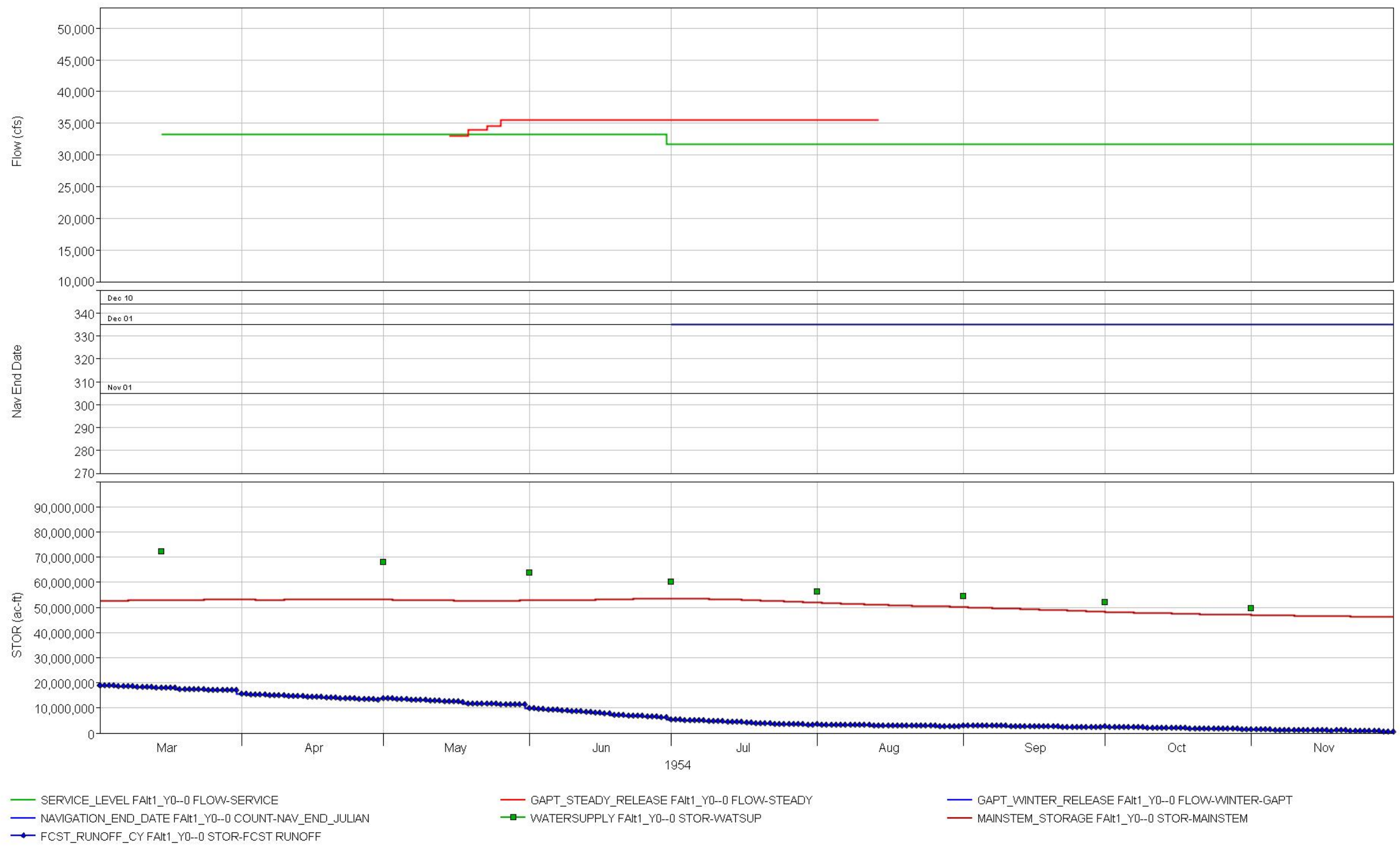


Figure 5-29: Plot of the navigation end date in 1954.

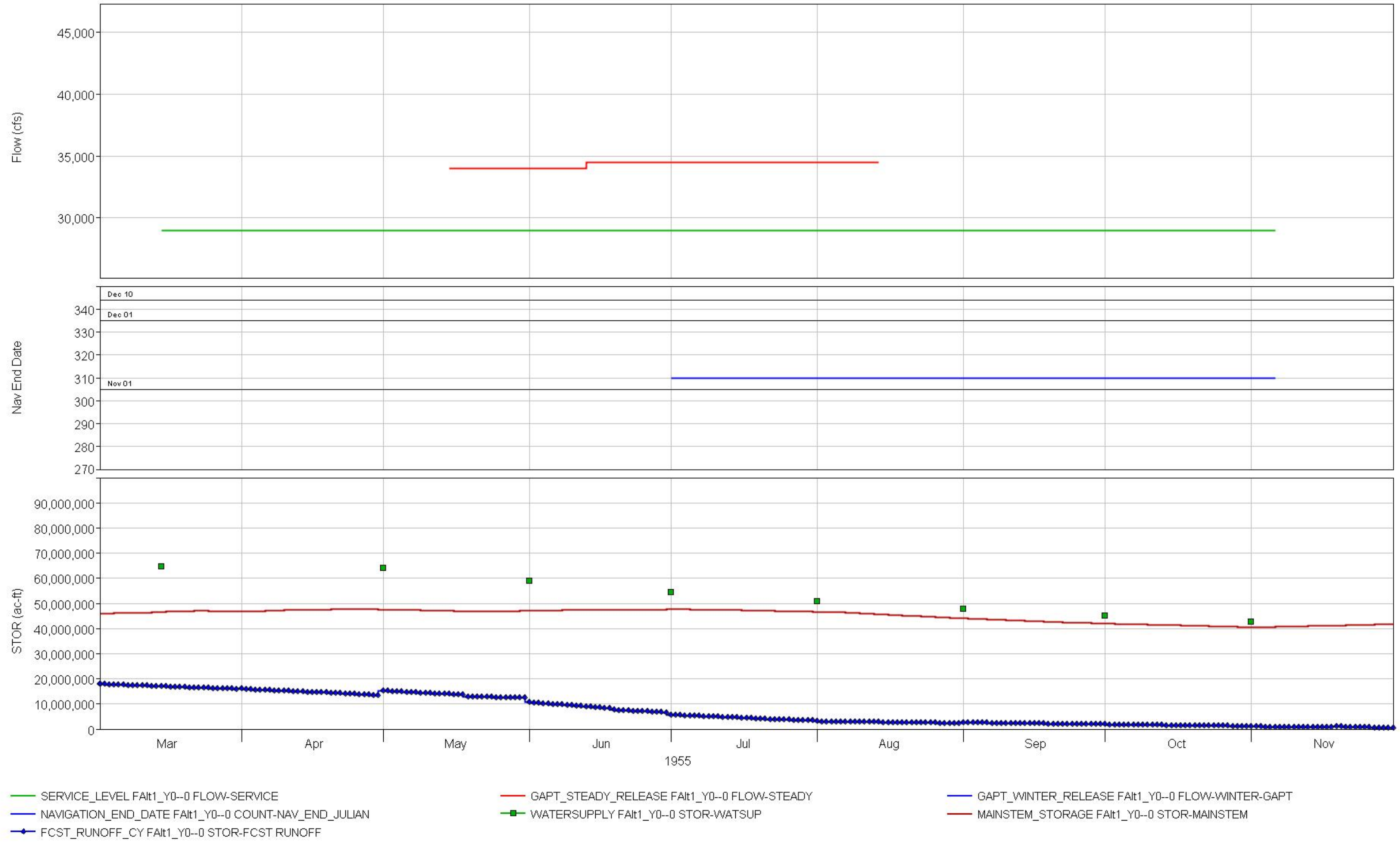


Figure 5-30: Plot of the navigation end date in 1955.

5.1.5 Winter Release

The winter release from Gavins Point is based on the System storage on September 1; the criteria are summarized in Table 5-3. If the System storage is between the thresholds for a 17,000 cfs winter release and a 12,000 cfs winter release, the winter release is linearly interpolated.

Table 5-3: Winter release from Gavins Point criteria. Summarized from Table VII-4 in the Master Manual (U.S. Army Corps of Engineers, 2006).

September 1 System Storage (MAF)	Average Winter Release from Gavins Point (cfs)
58.0 or more	17,000
55.0 or less	12,000

On September 1, 2007, the System storage is approximately 41.7 MAF, which is below the threshold for a 12,000 cfs winter release. Based on the System storage, the model sets the winter release to 12,000 cfs and applies it during the winter release period. On September 1, 1987, the System storage is 56.79 MAF, which is between the thresholds for a 17,000 cfs and 12,000 cfs winter release. The model interpolates the winter release and applies a release of 14,989 cfs during the winter release period. These results are shown in Figure 5-31 and Figure 5-32.

Winter releases described in Table 5-3 are minimum releases during the winter. Releases may be increased above the values specified in Table 5-3 if higher releases are required to evacuate all of the System's flood control storage prior to the start of the next runoff season. Figure 5-33 shows an example of this in the winter of 2010-2011. The winter release was set to 17,000 cfs based on the September 1 System storage check, but throughout January and February, releases were increased up to 23,500 cfs to ensure all of the System's flood control storage was evacuated. Higher than normal winter releases are explained in more detail in Section 7-03.5.2 of the Master Manual (U.S. Army Corps of Engineers, 2006).

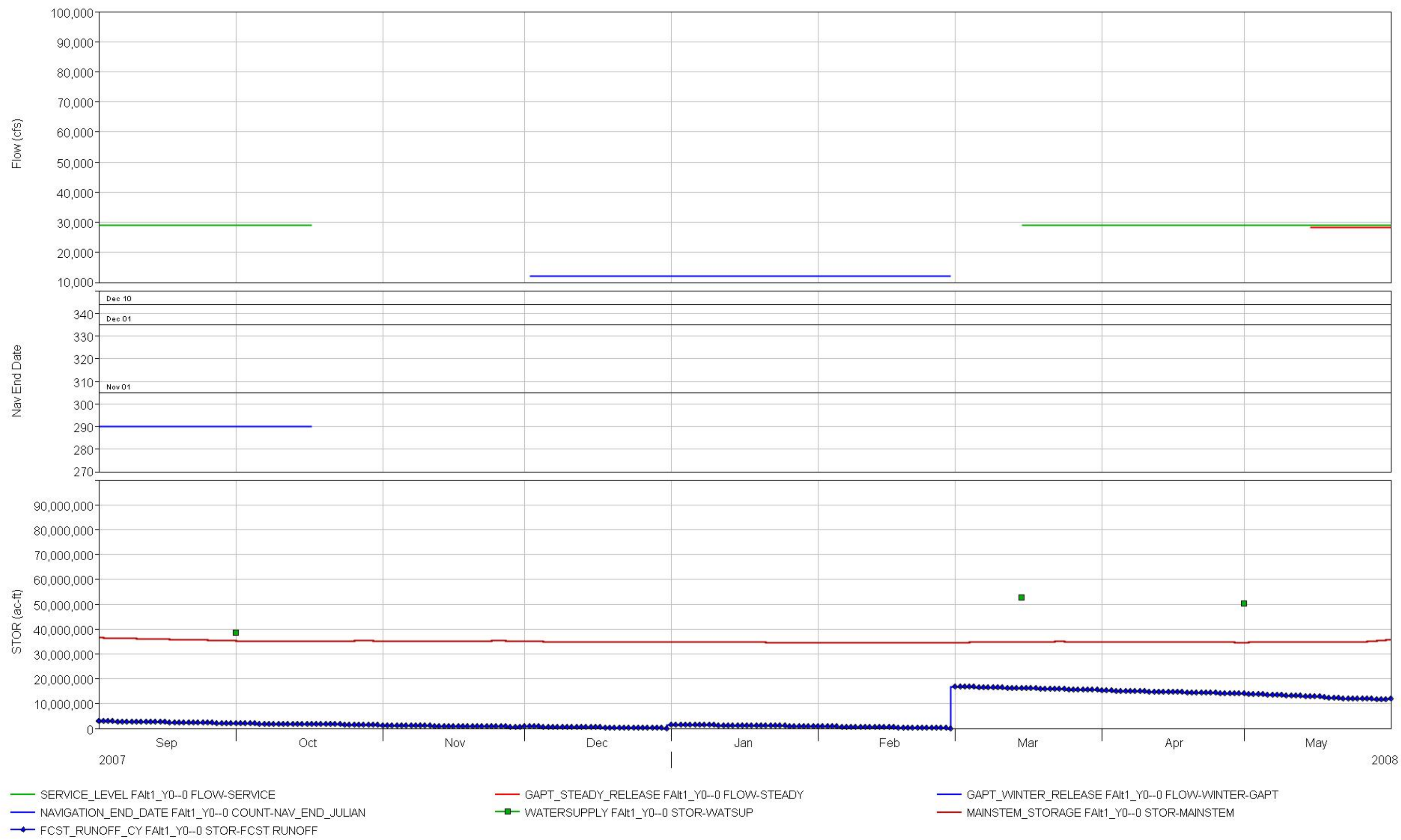


Figure 5-31: Plot of winter releases in 2007-2008.

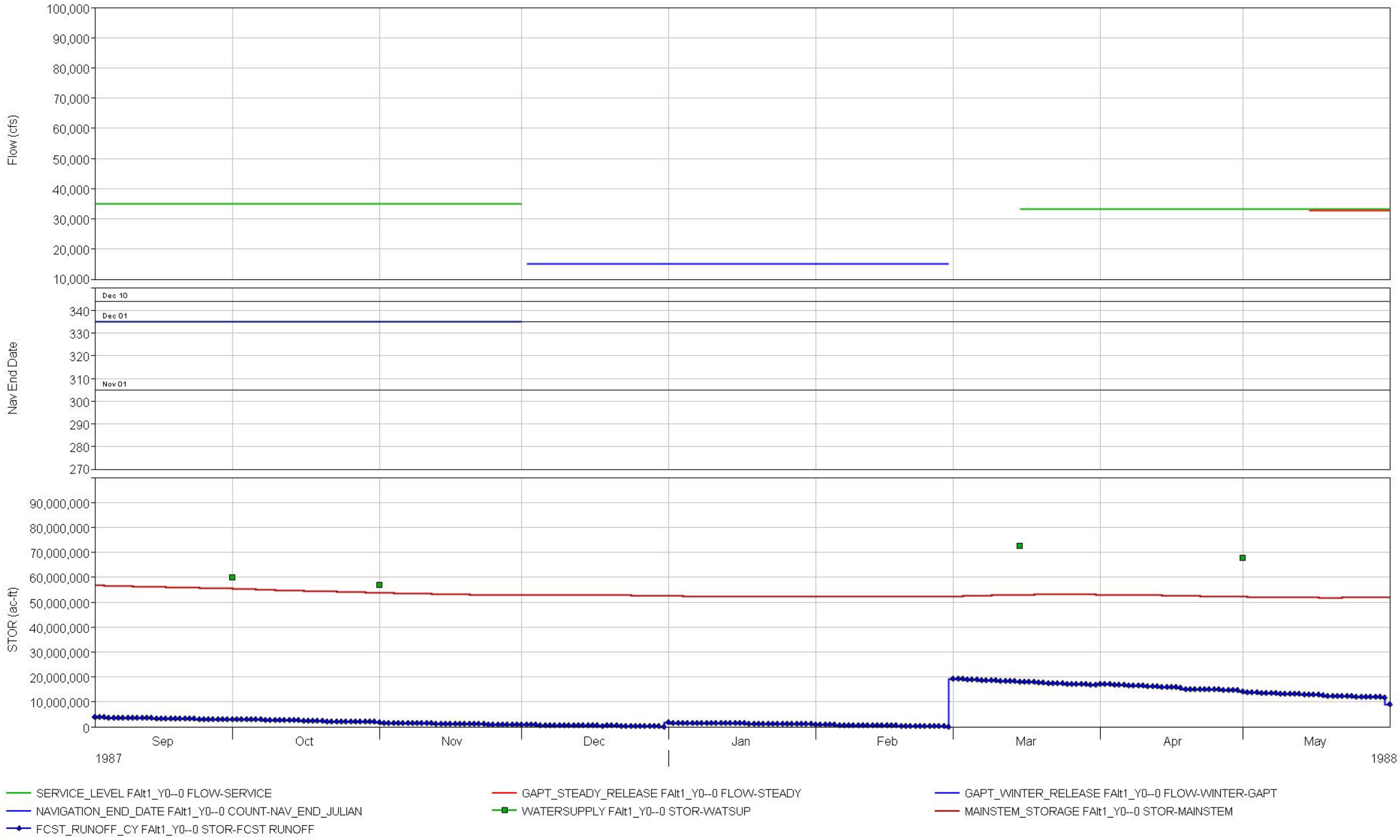


Figure 5-32: Plot of winter releases in 1987-1988.

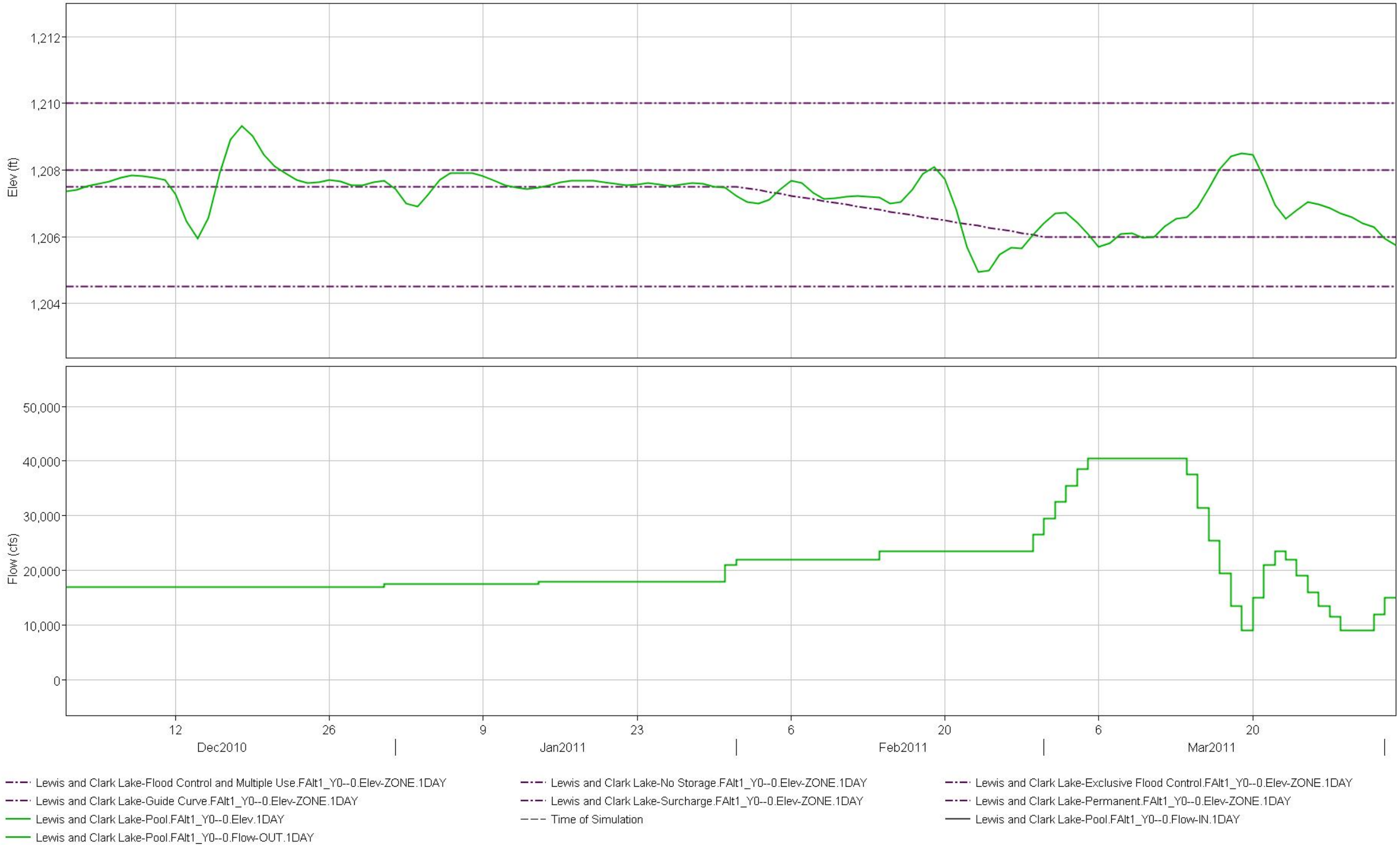


Figure 5-33: Plot of Gavins Point releases and System storage in 2010-2011.

5.1.6 Flood Targets

One of the main purposes of the Missouri River main stem dams is to provide flood control. Flood control on the Missouri River is more complicated than most systems because it needs to be balanced with navigation requirements and evacuating all of the System's flood storage. Gavins Point releases are reduced to alleviate downstream flooding but only to an extent that navigation targets are still met. Real-time operation can slightly differ from this during extreme flood events because parts of the river may be closed to navigation, which means that Gavins Point releases can be reduced further if certain navigation targets do not need to be met. For modeling purposes, it was assumed that the river was never closed for navigation during the period-of-record and all navigation targets would be met. An additional consideration in real-time regulation is that navigation targets may not be met in reaches without commercial navigation.

The flood target criteria are based on a two tier system and are summarized in Table 4-13. The first tier, full-service flood targets, is for smaller magnitude flooding when the service level is greater than full service or 35,000 cfs. This tier is not used for smaller floods when the service level is full service or less. An example of the model reducing Gavins Point releases for full-service flood targets is shown in Figure 5-34. In Figure 5-34, the gray hatched areas are the navigation requirements that Gavins Point is operating for and the gray dotted line is the navigation targets based on service level. On October 30, 1975, the target flow at Omaha is 39,544 cfs and the full-service flood target is 49,544 cfs. Flow at Omaha is forecasted to exceed the full-service flood target of 49,544 cfs during the next 14 days, so navigation targets are set to full service and Gavins Point releases are then decreased until forecasted flows at Omaha drop below the full service flood target or full service navigation targets will not be met at all four target locations if releases are further reduced. In this case, releases were slightly reduced and the forecasted flows at Omaha no longer exceeded full service navigation target.

On November 1, 1975, the second tier of flood targets were forecasted to be exceeded at Omaha. The second tier, minimum-service flood targets, is for larger magnitude flooding occurring during any service level. On November 1, 1975, the target flows at Omaha are still 39,544 cfs and the minimum service flood target is 54,544 cfs. Flows at Omaha are forecasted to exceed the minimum service flood target during the next 14 days, so navigation targets are further reduced to minimum service and Gavins Point releases are decreased to alleviate downstream flooding. Figure 5-34 shows an example of this between November 1 and November 9.

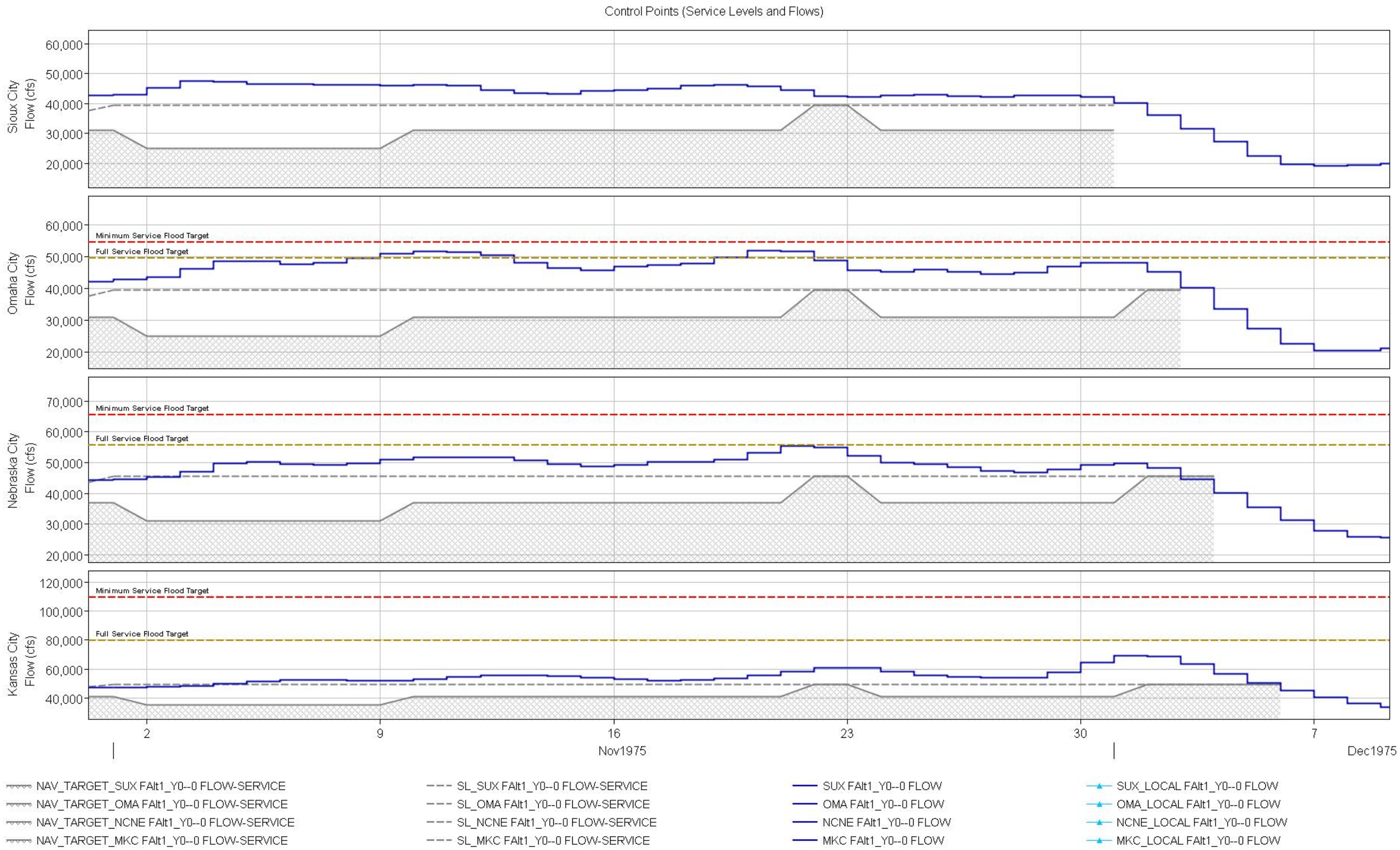


Figure 5-34: Plot of target locations with full-service flood target reductions in 1975.

5.1.7 Water Supply

Below Gavins Point, navigation releases provide enough water to meet water supply requirements, so the only time a release is made for water supply is during winter release periods or during years of shortened or no navigation seasons. Section 7-11.3.5 of the Master Manual contains the criteria that the model's water supply requirements are based on:

> "When the water-in-storage in the System is at normal or higher levels, releases for the navigation and power production purposes and to evacuate flood control storage during the navigation season and winter period will normally be at levels that are deemed to be sufficient for the downstream water supply needs. During extended droughts, Gavins Point Dam releases are reduced. Some intakes require more than 9,000 cfs (minimum release required in the early 1990's) during the open-water season for effective operation. These intakes should be modified as soon as possible to ensure that they can remain operational as the Corps continues to pursue lowering the Gavins Point Dam release in the non-navigation months during drought periods to this rate. A winter Gavins Point Dam minimum release rate of 12,000 cfs has been established as the guide in meeting downstream water supply requirements during this period. Intakes typically have higher requirements during the winter period because of the effects of river ice in reducing the capacity of their intakes. If Gavins Point Dam release rates are reduced below 12,000 cfs for water conservation, continued surveillance of these intakes will be required, and, if appropriate, additional releases may be required to assure adequate water levels for uninterrupted intake operation. During the critical and more difficult winter period, release rates may be adjusted according to river icing conditions to assure that the water supply service is provided downstream. During drought years when System storage is low enough to reduce or eliminate the navigation season, a Gavins Point Dam release of 18,000 cfs has been established as meeting the summer water supply requirement. Intake owners should modify their intakes as soon as possible if a summer Gavins Point Dam release rate of 18,000 cfs will not be adequate to meet their needs."

Real-time operations allows for some flexibility in meeting water supply needs during droughts, such as increasing releases temporarily to ensure water supply intakes have access to the water. However, the model does not have this flexibility. Strict dates and flows were used in the model for water supply operations. The dates are listed in Section 7-03.6.1 of the Master Manual and are summarized in Table 5-4.

Table 5-4: Water supply dates and flows summarized from Sections 7-03.6.1 and 7-11.3.5 of the Master Manual (U.S. Army Corps of Engineers, 2006).

Date	Minimum Gavins Point Release for Water Supply (cfs)
March-April, September-November	9,000
May-August	18,000
December-February	12,000

In 1991, there was a shortened navigation season ending on November 1. Between November 1 and December 1, the System was operating for water supply requirements downstream of Gavins Point; the model reduced Gavins Point's releases to 9,000 cfs at the end of the navigation season until December 1, as shown in Figure 5-35. The model has added logic for water supply that treats the minimum Gavins Point releases for water supply as minimum flows at three locations: Omaha, Nebraska City, and Kansas City. This helps to alleviate water supply impacts that would occur due to the increased depletions used in the model to create a simulation representative of the current basin development. With this added logic, the model could specify Gavins Point releases above the minimum releases specified in Table 5-4 if local inflows were not sufficient to meet water supply requirements at the three locations. Figure 5-35 also shows Gavins Point's releases at the beginning of the winter release period operating for a winter release of 12,000 cfs. Downstream forecasted flows are computed and used to check the minimum flow requirements at the target locations similar to the navigation forecasts. These downstream forecasts show that flows at Omaha will fall below the minimum flow of 12,000 cfs unless releases from Gavins Point are increased above the minimum release criteria. Figure 5-36 shows the four target locations and the minimum water supply requirements at the three water supply target locations. Flows at Omaha remain above the minimum flow of 12,000 cfs in early December as a result of increased releases from Gavins Point.

In 1935, the System is not operating for navigation because System storage was below the navigation preclude; therefore, the System is operating for water supply throughout the entire year. During May-August, the model assesses downstream conditions and sets Gavins Point's releases to at least 18,000 cfs, see Figure 5-37, and forecasts downstream flows to ensure a minimum of 18,000 cfs is observed at Omaha, Nebraska City, and Kansas City as shown in Figure 5-38. With the exception of three days in August, releases from Gavins Point are higher than the minimum required release of 18,000 cfs to ensure that at least 18,000 cfs is observed at Omaha.

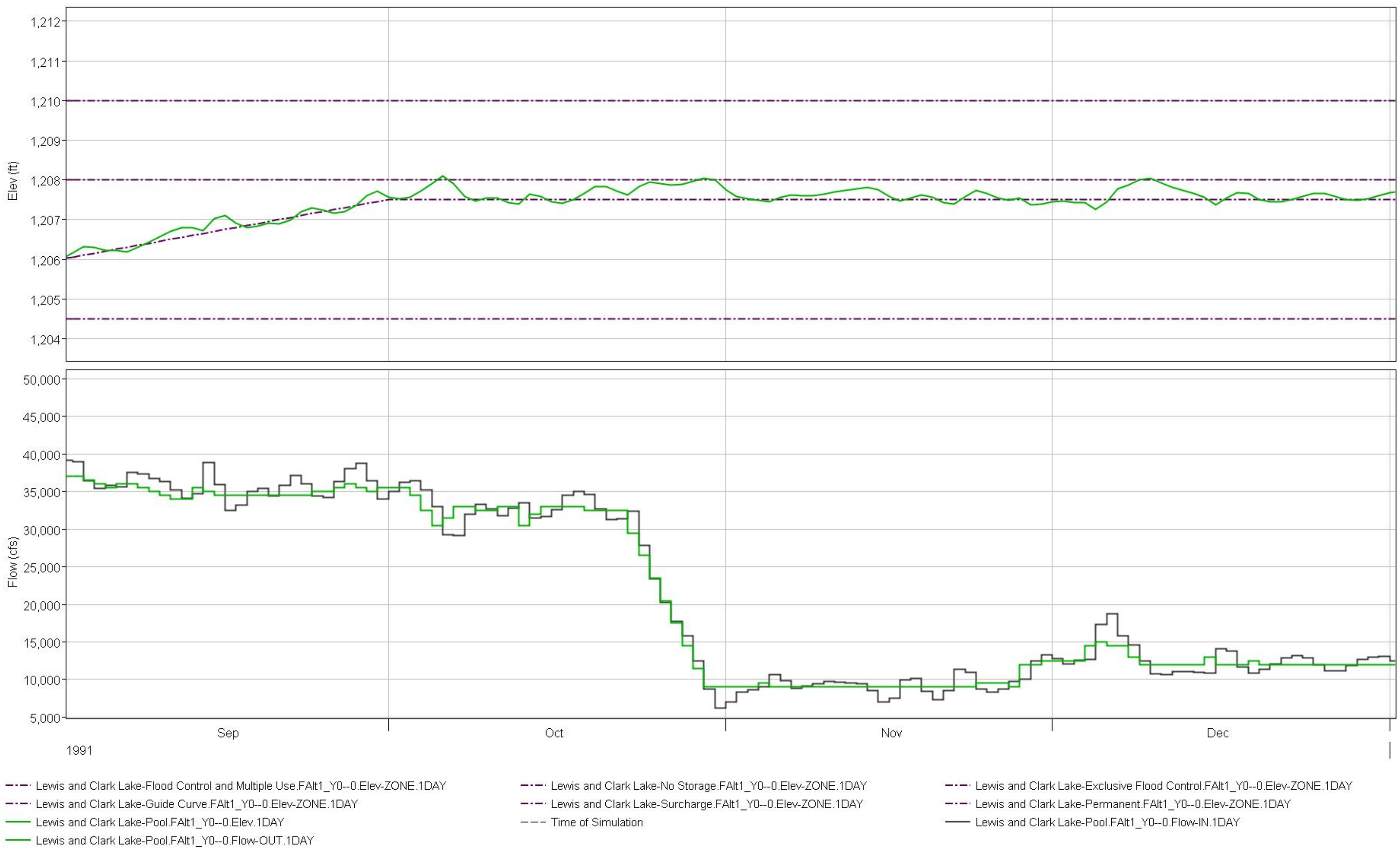


Figure 5-35: Plot of Gavins Point releases in 1991 operating for water supply during fall and winter.

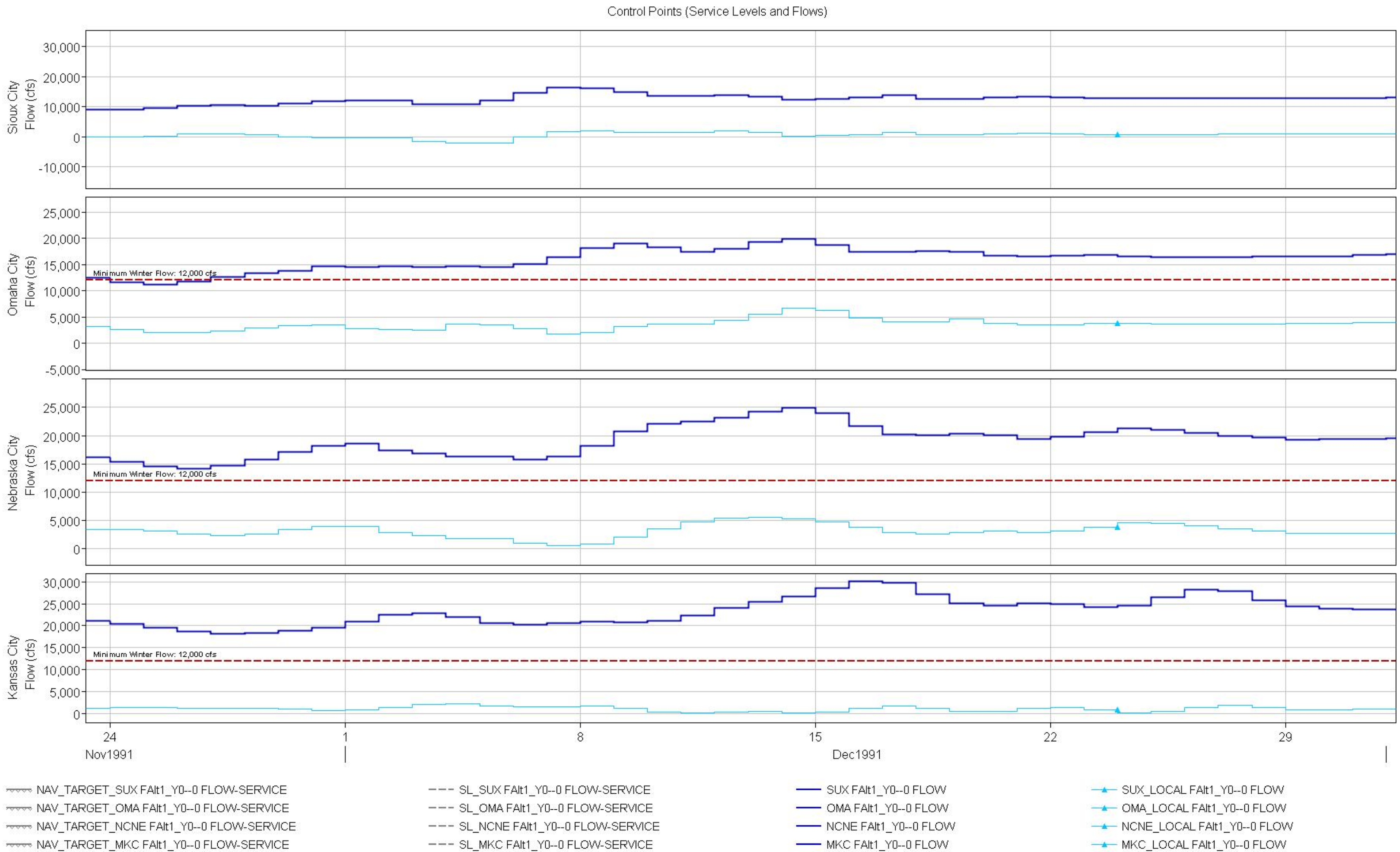


Figure 5-36: Plot of target locations operating for 12,000 cfs water supply in 1991.

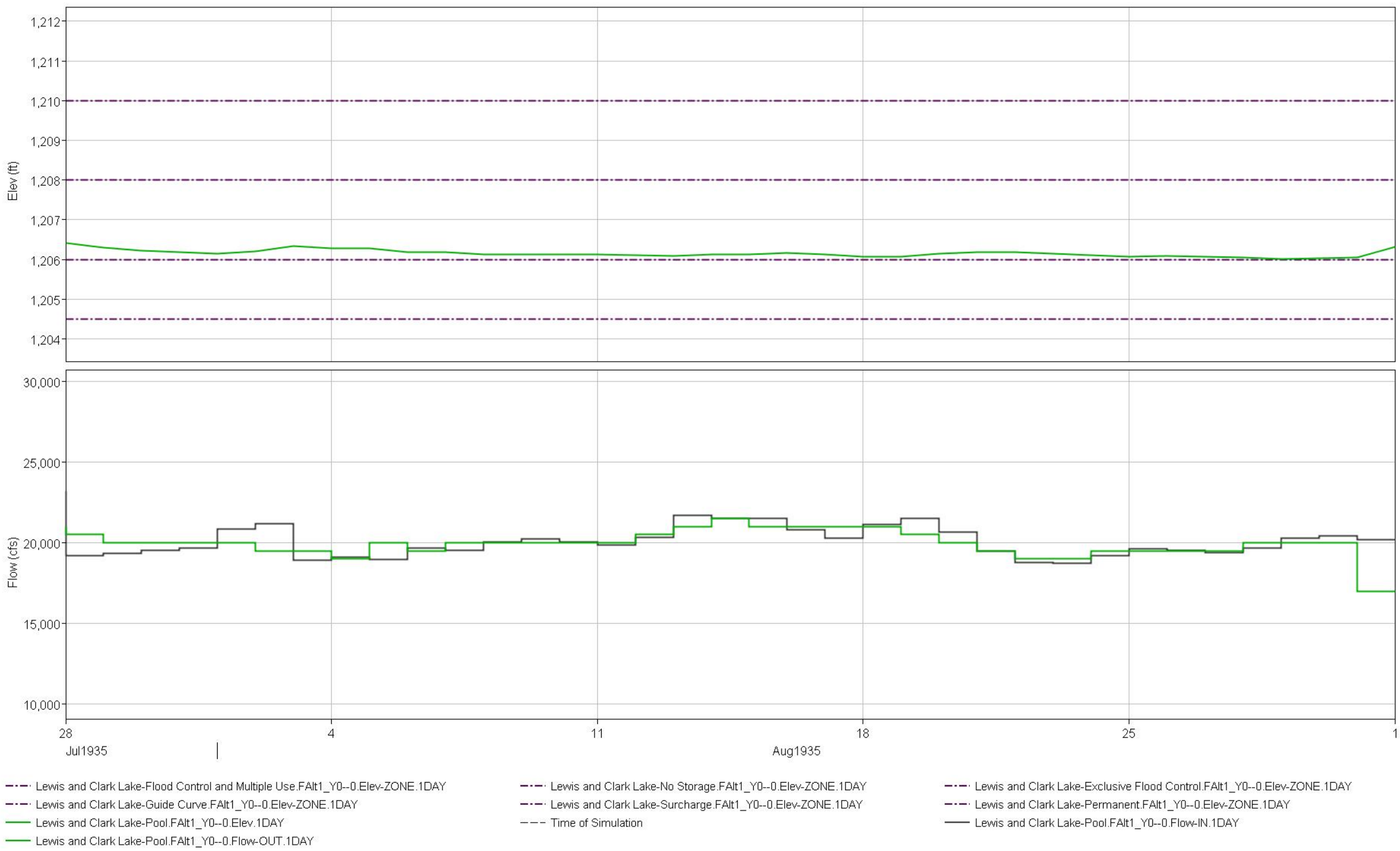


Figure 5-37: Plot of Gavins Point releases in 1935 operating for water supply during summer.

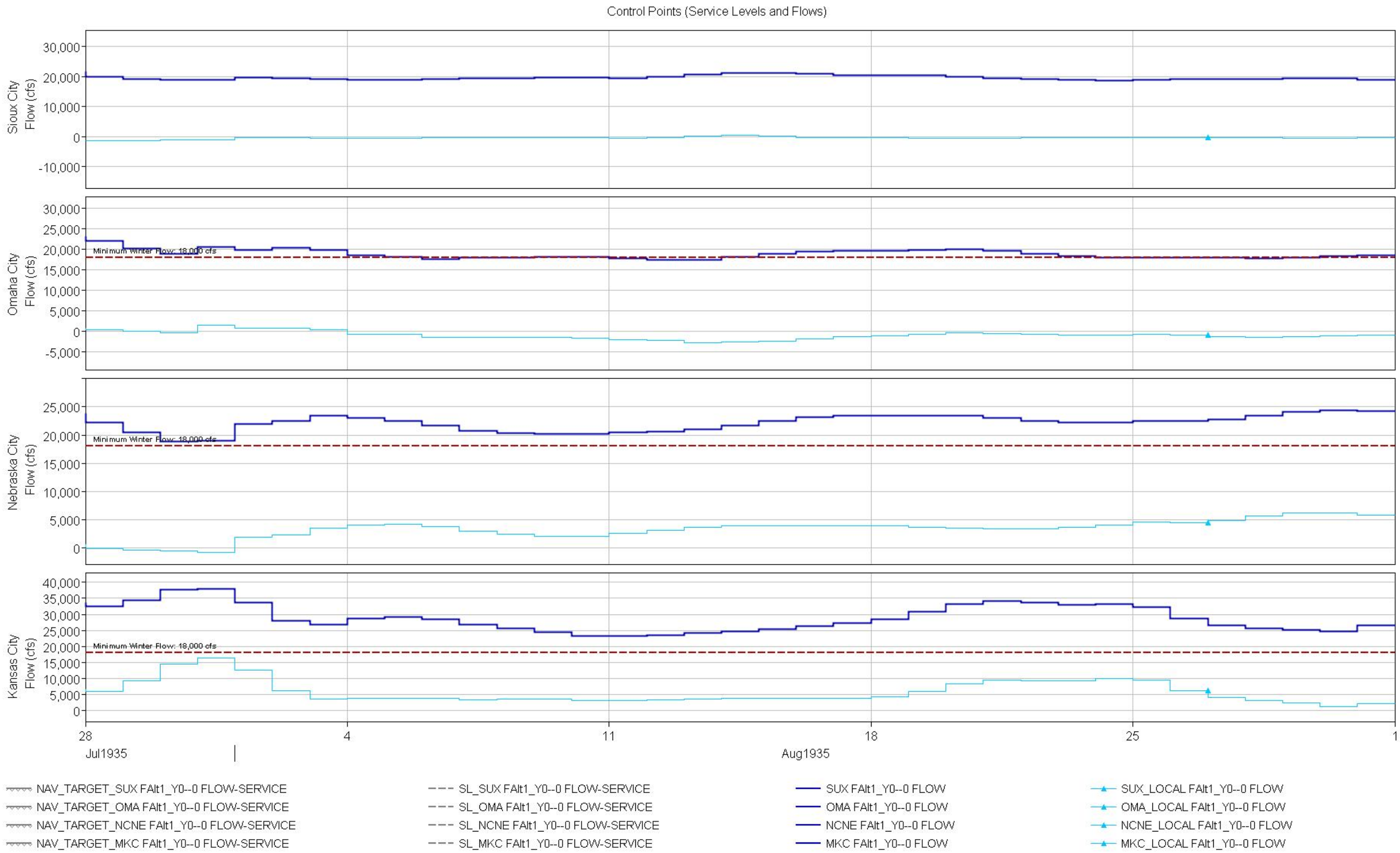


Figure 5-38: Plot of target locations operating for 18,000 cfs water supply in 1935.

Similar to downstream water supply requirements, water supply in the Fort Peck to Garrison and Garrison to Oahe reaches is based on minimum releases from the upstream project. In order to treat the upstream water supply the same as the downstream, logic was added to the model that treats minimum releases at Fort Peck as minimum flow requirements at Wolf Point and Culbertson and minimum releases at Garrison as minimum flow requirements at Bismarck. During March 1 – May 14 and September 1 – November 30, if 3,000 cfs is not forecasted at both Wolf Point and Culbertson, releases from Fort Peck are increased until 3,000 cfs is forecasted at both locations. During May 15 – August 31 and December – February, water supply operations are the same except the minimum flow requirement is increased to 5,000 cfs. Figure 5-39 shows Fort Peck releases during 1937 when Fort Peck's reservoir has been drawn drown during the severe drought of the 1930's. During 1937, the model is trying to set the Fort Peck's releases to 3,000 and 5,000 cfs during their respective periods. However, due to the large amount of depletions occurring in the Fort Peck to Garrison reach, especially during the summer months, releases are periodically increased above the minimum releases to meet the water supply requirements. Figure 5-40 shows flows at Culbertson, MT, which is the controlling location for most of the year.

Water supply operations at Garrison are dependent on one location: Bismarck. During March 1 – August 31, if 10,000 cfs is not forecasted to occur at Bismarck, releases from Garrison are increased until 10,000 cfs is forecasted to occur at Bismarck. During September 1 – November 30, similar operations occur except the minimum flow requirement is 9,000 cfs. A 12,000 cfs minimum flow requirement is used during December 1 – February 28/29. Since Garrison's reservoir is not affected by the 1930's drought as severely as Fort Peck's reservoir and there are less depletions in the Garrison to Oahe reach, releases from Garrison are increased for short durations to ensure the minimum flow requirement is met at Bismarck. Figure 5-41 shows Garrison's releases during 1938 when releases were increased above minimum releases for short periods in the winter and early spring to meet minimum flow requirements at Bismarck. Figure 5-42 shows the flows at Bismarck during 1938.

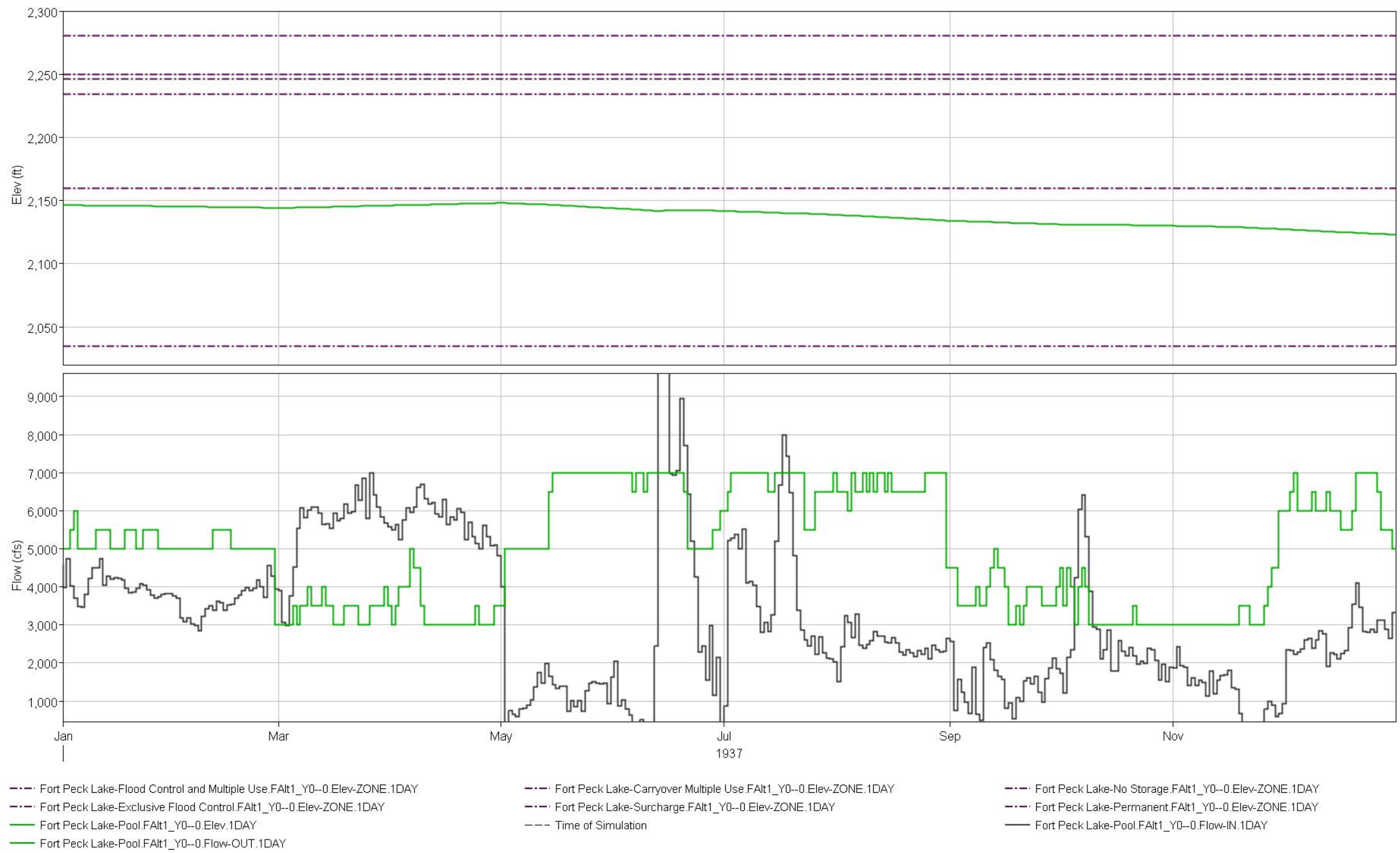


Figure 5-39: Fort Peck releases during 1937.

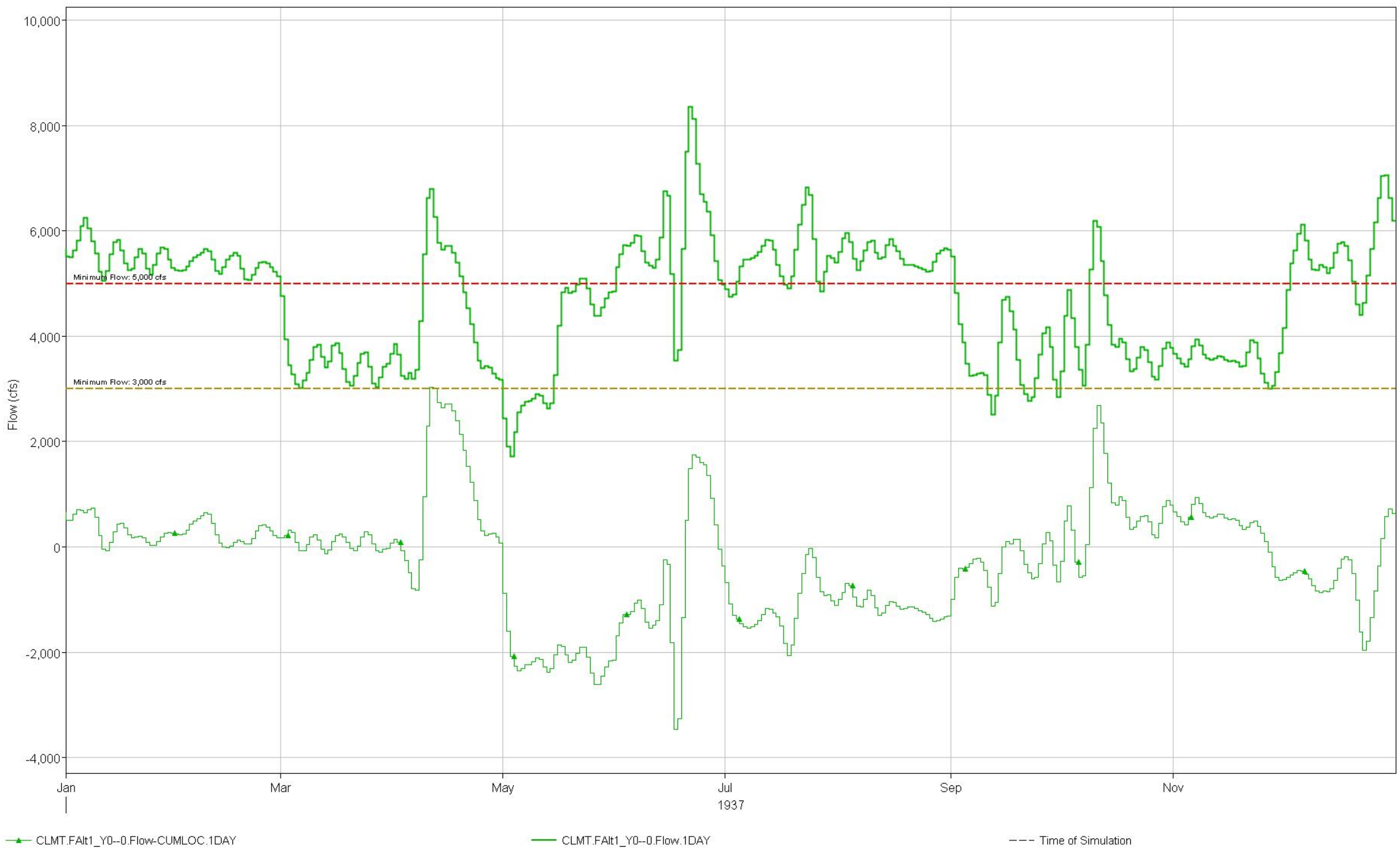


Figure 5-40: Flow at Culbertson, MT in 1937.

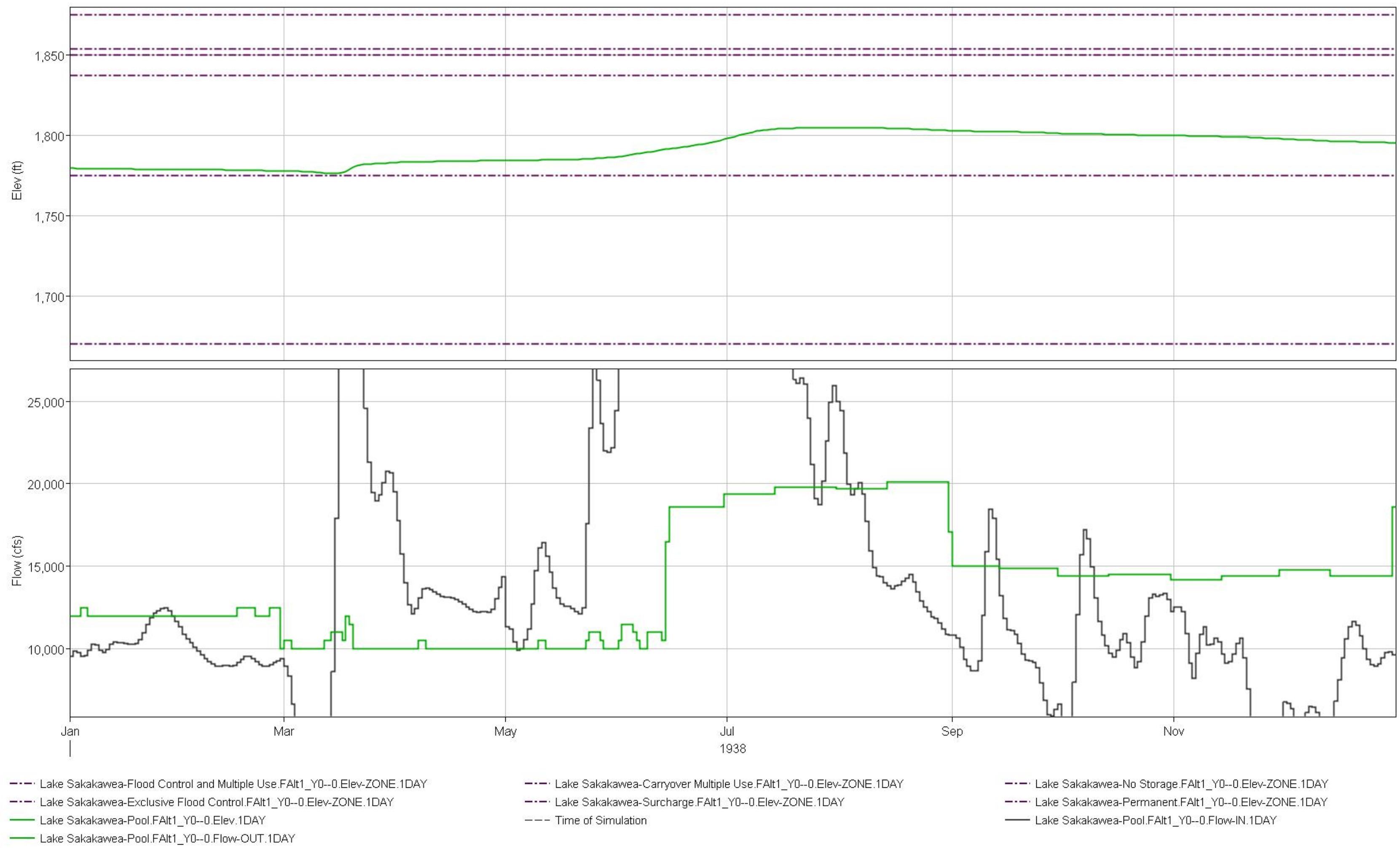


Figure 5-41: Garrison releases during 1938.

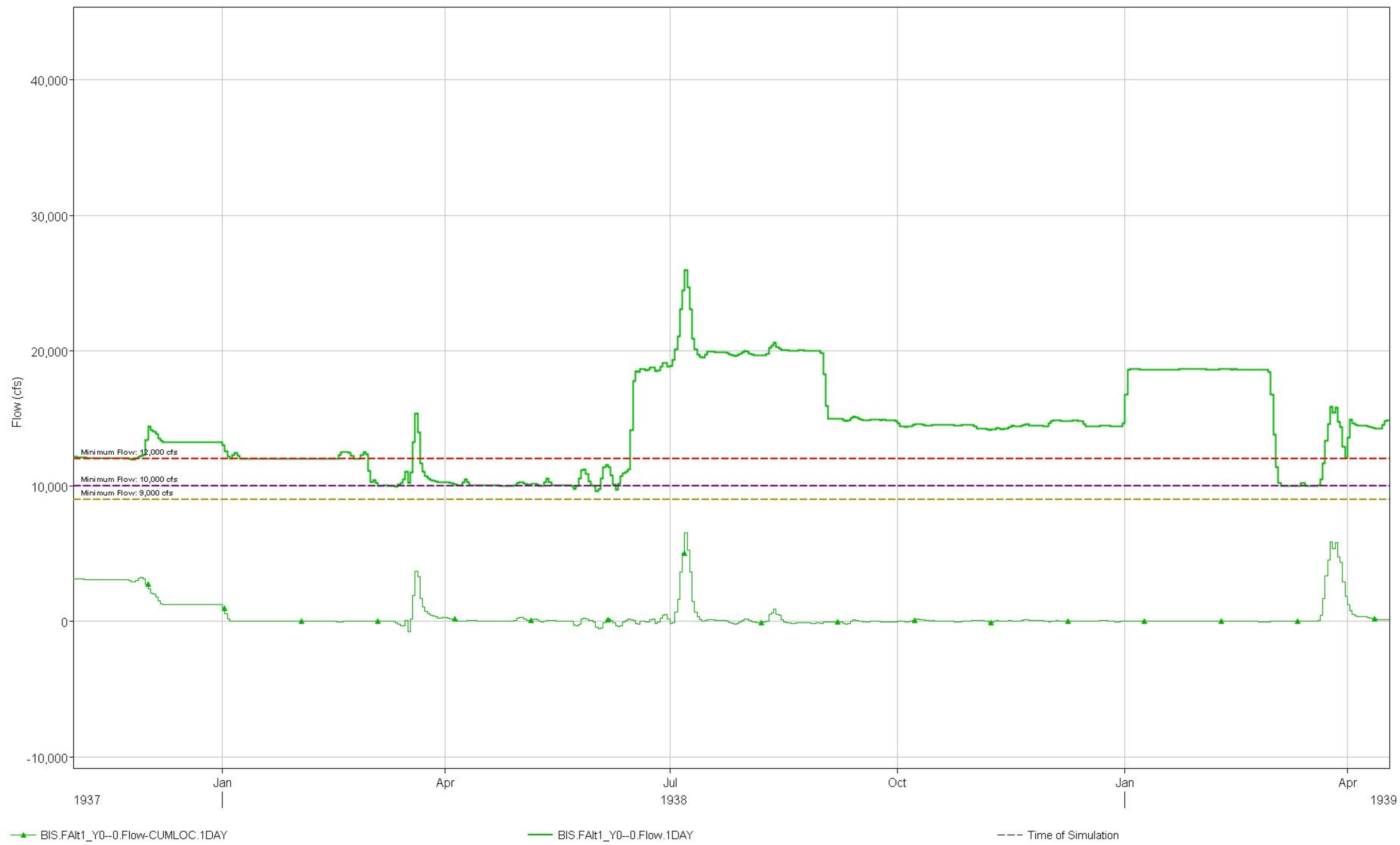


Figure 5-42: Flow at Bismarck, ND in 1937.

5.1.8 System Balancing

System balancing consists of balancing the percentage of occupied carryover storage in the upper three reservoirs: Fort Peck, Garrison, and Oahe. Based on forecasted Gavins Point releases, total System inflows, and current System storage, Fort Peck's and Garrison's releases are adjusted so the percent of Fort Peck's, Garrison's, and Oahe's percent of occupied carryover storage is equal to the System's percent of occupied carryover storage. To achieve balanced System storage, Fort Peck's and Garrison's releases are adjusted up or down while Oahe is allowed to float, meaning that Oahe's storage will move up or down to allow Fort Peck and Garrison to reach their target percentages. Typically, Oahe's percentage of occupied carryover storage would be near the System's occupied carryover storage because over 90 percent of the System's carryover storage resides in Fort Peck, Garrison, and Oahe. There are limits to these adjustments; Fort Peck and Garrison follow general release patterns with minimum and maximum releases, so it is possible that Fort Peck and Garrison will not be able to reach their target storages by March 1. Oahe's ability to float is also limited. If Oahe's percent of carryover storage becomes more than 5 percent different than Garrison's, Garrison's releases will then be adjusted to keep Oahe's storage within a reasonable difference.

Figure 5-43 shows how the target percentage varies throughout the runoff year and how each reservoir's percent of occupied carryover storage converges to that percentage in 1930. In this year, forecasted releases and runoff were similar to what actually occurred throughout the runoff year so releases from Fort Peck and Garrison were able to be adjusted enough to ensure all three reservoirs reached the target percentage. Figure 5-44 shows an example of an unbalanced System occurring due to release limitations. During 1937, runoff into Fort Peck is extremely low, but there are minimum release requirements at Fort Peck. Fort Peck's minimum releases are higher than the inflow so the reservoir continues to be drawn down and there is no way for System storage to reach a balanced state. This can also occur if the forecasted releases and runoff diverge from actual releases and inflow that occur throughout a year. Under these conditions, the System would begin the runoff year unbalanced and would attempt to rebalance System storage by the start of the next runoff season. In both Figure 5-43 and Figure 5-44, the top plot shows Fort Peck's current percent occupied carryover storage (blue), Garrison's current percent occupied carryover storage (red), Oahe's current percent occupied carryover storage (green), and the combined forecasted percent occupied carryover storage (gray dashed). The bottom three plots show each reservoir's target storage and current storage.

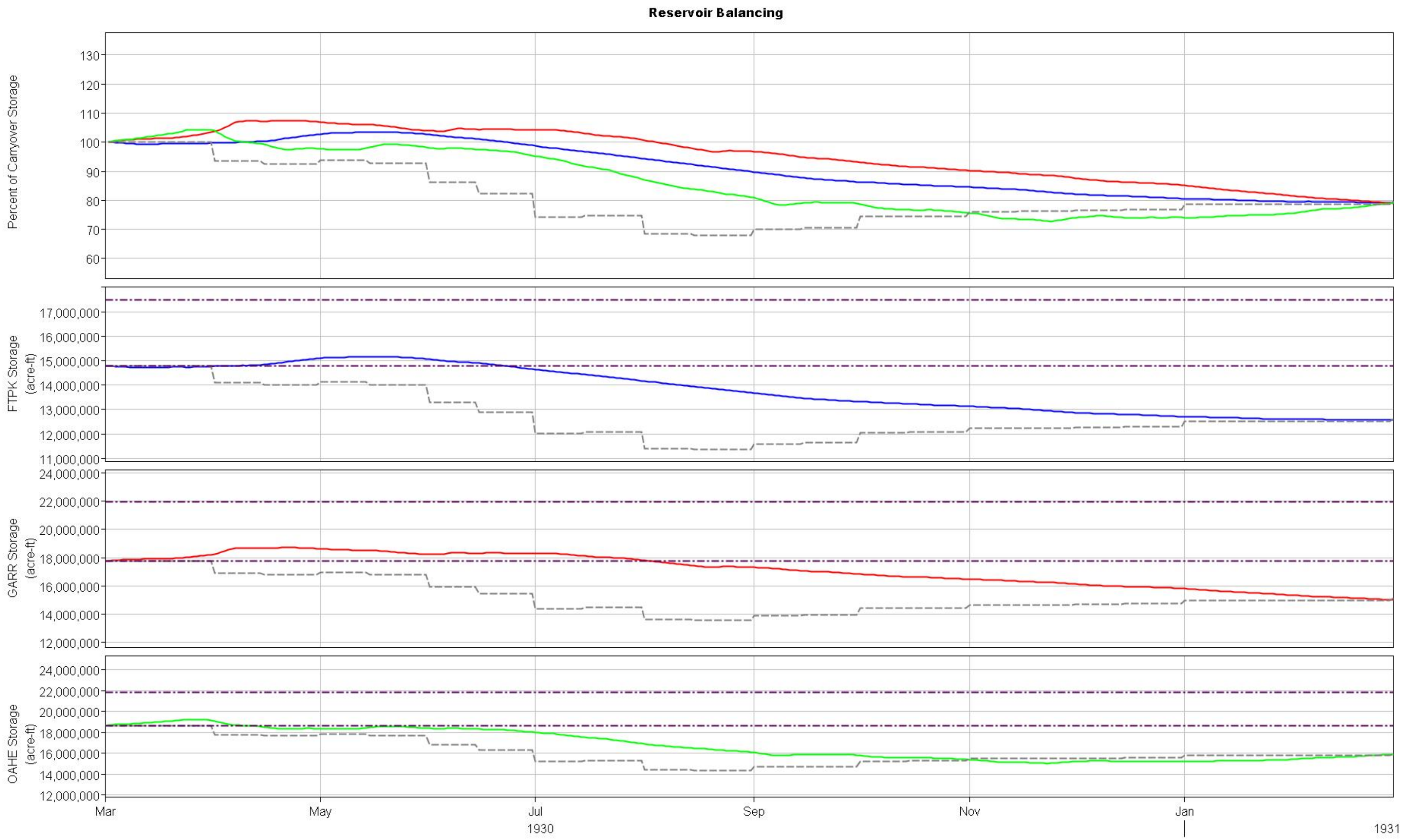


Figure 5-43: Plot of Fort Peck's, Garrison's, and Oahe's percent of occupied carryover storage and reservoir storages in 1930-1931.

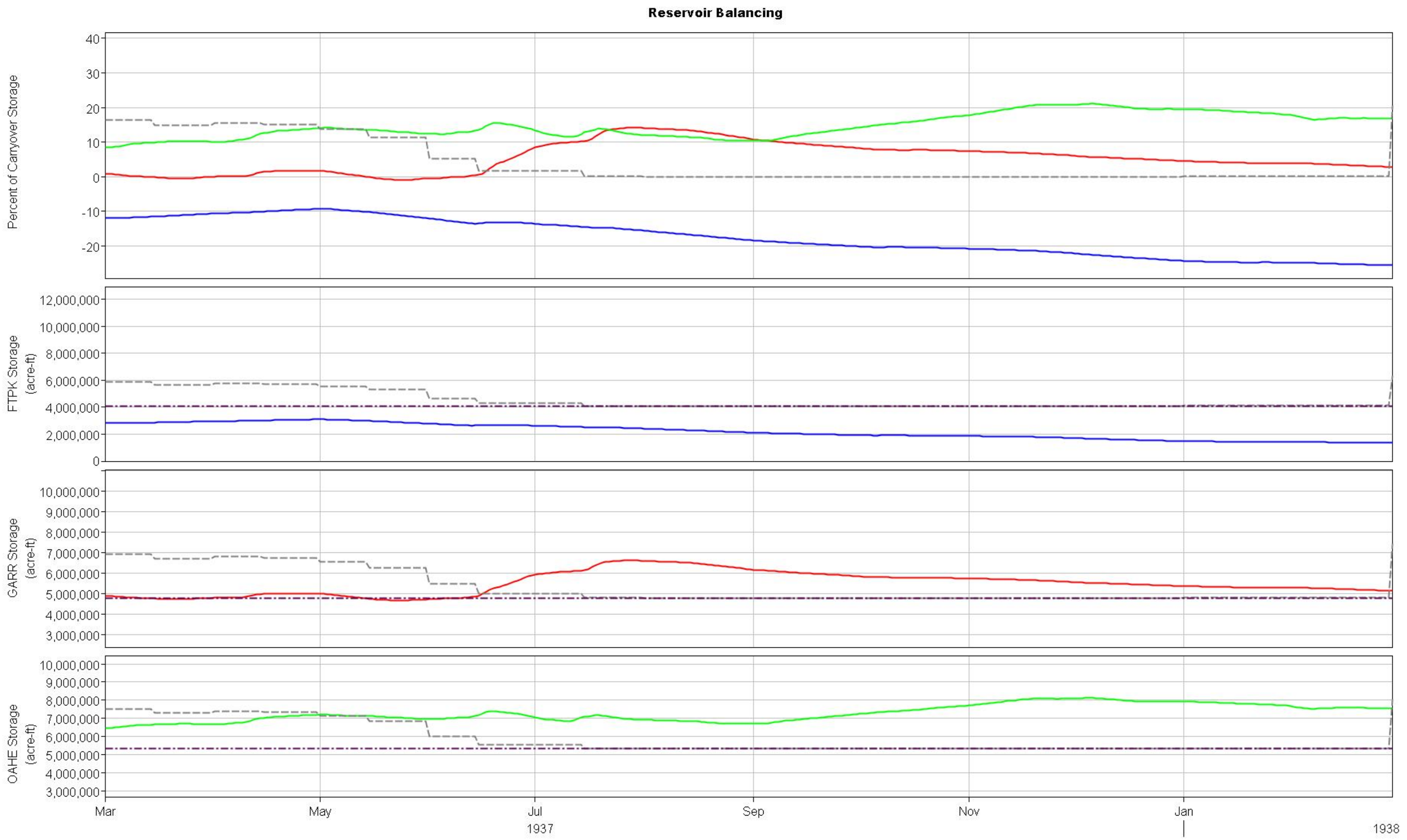


Figure 5-44: Plot of Fort Peck's, Garrison's, and Oahe's percent of occupied carryover storage and reservoir storages in 1937-1938.

5.1.9 Guide Curve Operations

Guide curve operations occur at Big Bend, Fort Randall, and Gavins Point. Big Bend's pool elevation typically is drawn down from 1421.0 to 1420.4 ft between Monday and Friday and then refilled back to 1421.0 between Saturday and Sunday. Since Big Bend's pool operates within a small range, the reservoir is essentially run of the river, so releases will be similar to inflows. Figure 5-45 shows the guide curve operations at Big Bend during 1964. Fort Randall's guide curve operations are more complex than Big Bend. Fort Randall's pool elevation begins at 1350.0 ft on March 1 and rises to 1355.0 ft by April 1; its pool elevation is held at 1355.0 ft through August. On September 1, Fort Randall begins to draw down its pool reaching a pool elevation of 1337.5 ft on the last day of the navigation season. The reservoir is then refilled to 1350.0 ft over the winter. Figure 5-46 shows Fort Randall's guide curve operations with a navigation end date of December 1 and Figure 5-47 shows Fort Randall's guide operations with a navigation end date of November 1. Gavins Point's guide curve operations keep the pool elevation within a small range. On March 1, Gavins Point's pool elevation is 1206.0 ft and remains at 1206.0 ft during the summer. On September 1, Gavins Point's pool begins to rise so that it reaches elevation 1207.5 ft by October 1. Gavins Point's pool elevations remain at 1207.5 ft through January. On February 1, its pool begins to decrease so it reaches an elevation of 1206.0 ft by March 1. Figure 5-48 shows Gavins Point's guide curve operations in 1956.

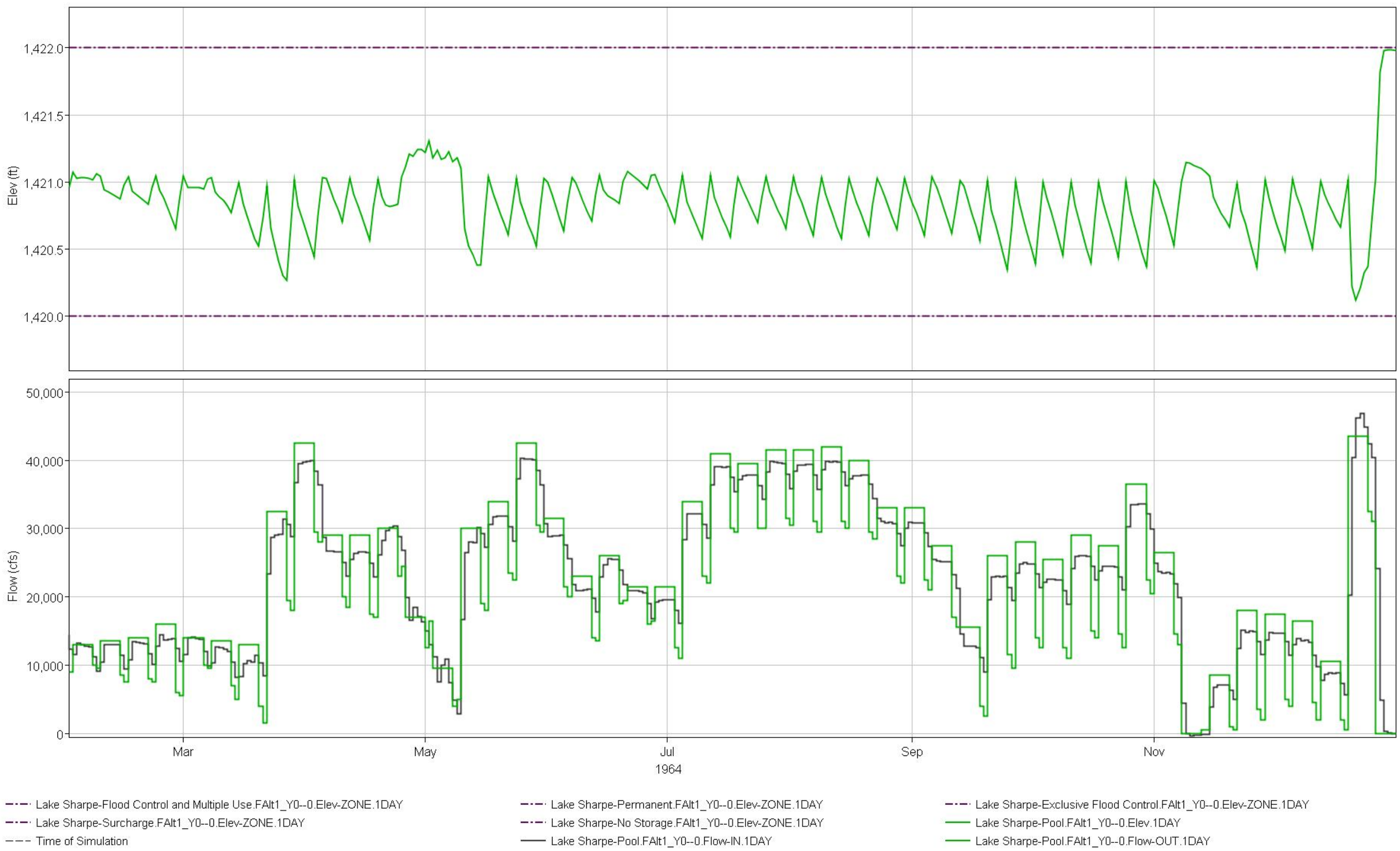


Figure 5-45: Plot of Big Bend guide curve operations in 1964.

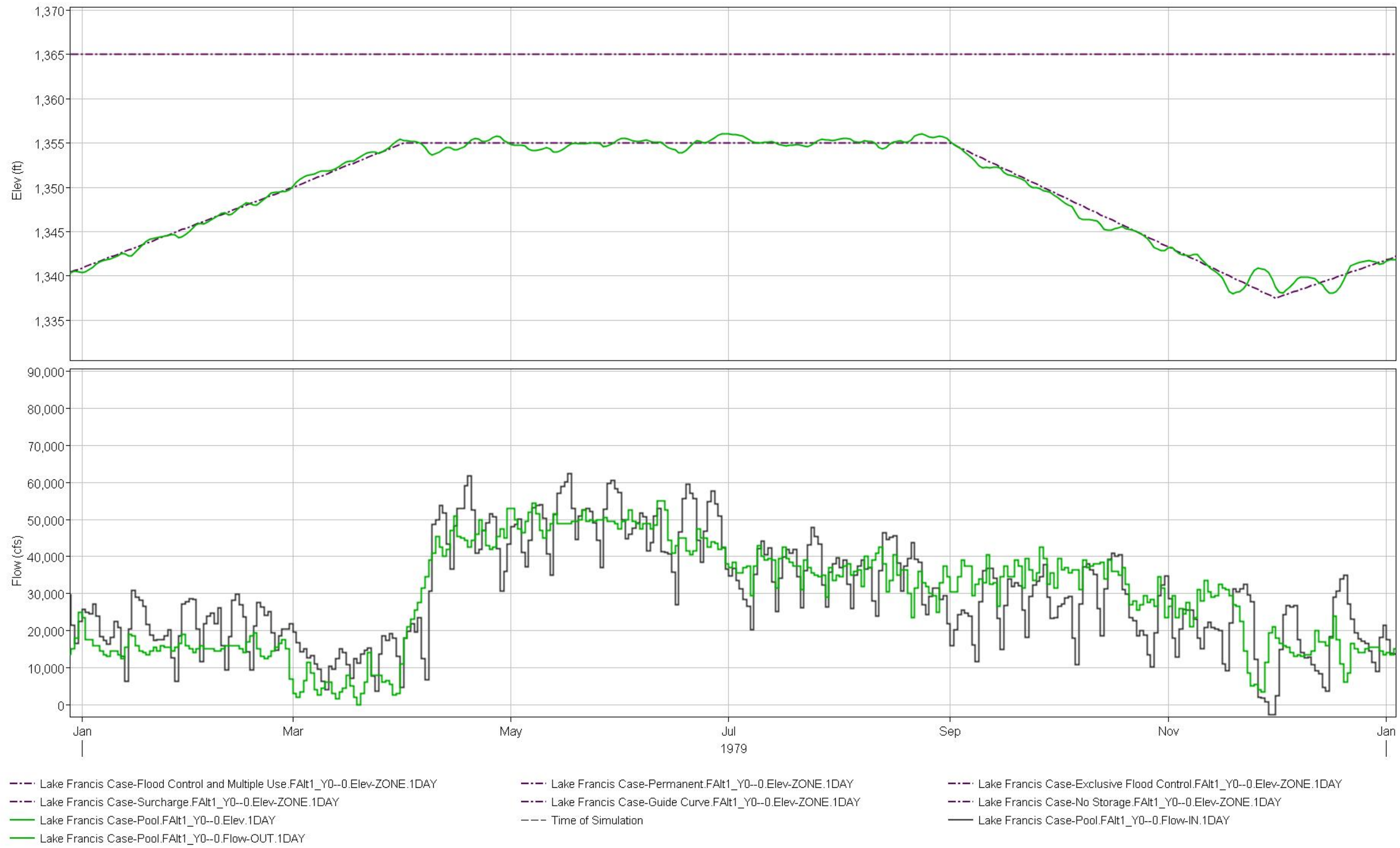


Figure 5-46: Plot of Fort Randall guide curve operations with a navigation end date of December 1, 1979.

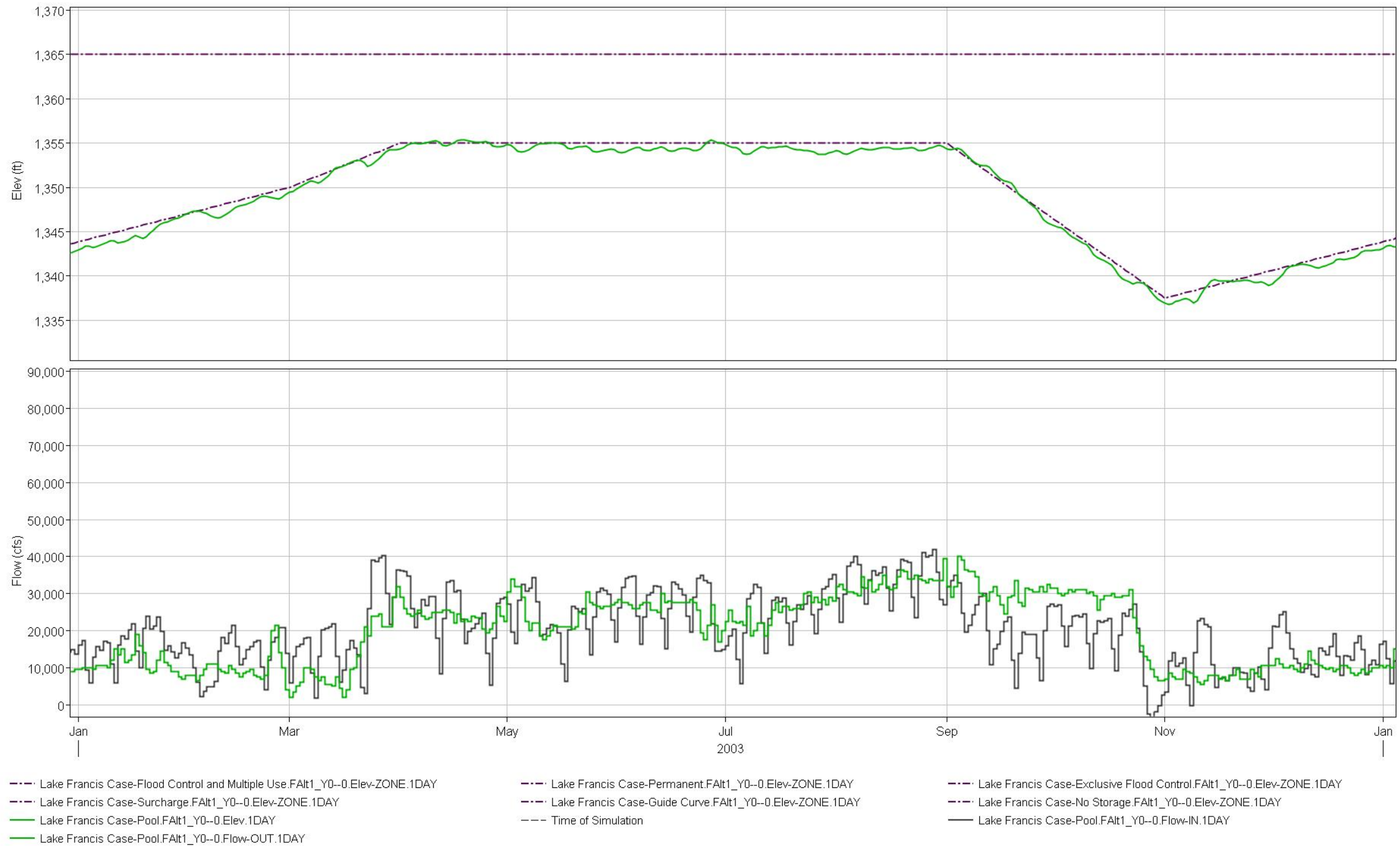


Figure 5-47: Plot of Fort Randall guide curve operations with a navigation end date of November 1, 1932.

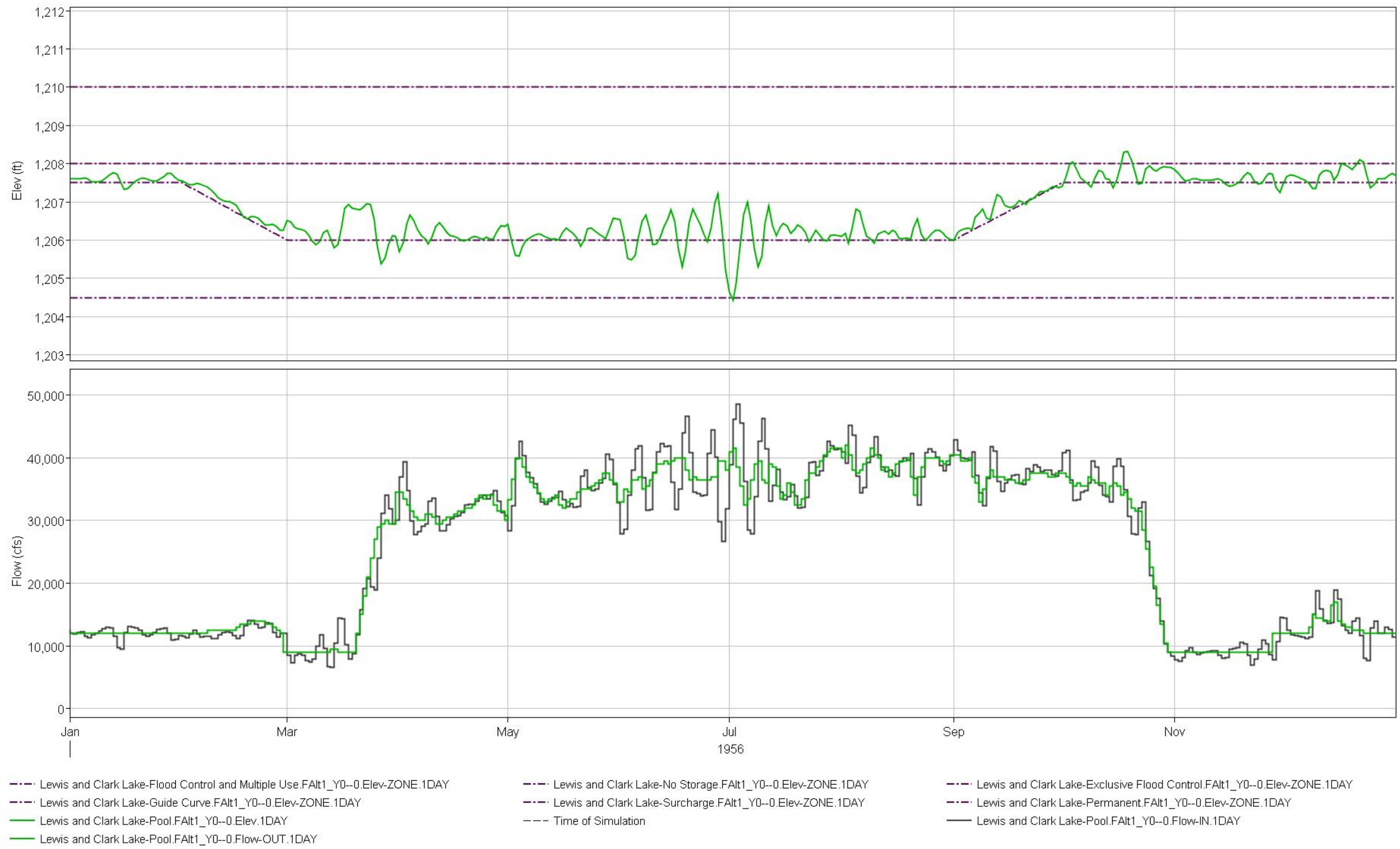


Figure 5-48: Plot of Gavins Point’s guide curve operations in 1956.

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7 APPENDIX A – PERTINENT DATA

Summary of Engineering Data - Missouri River Main Stem System

Item No.		Fort Peck Dam - Fort Peck Lake	Garrison Dam - Lake Sakakawea	Oahe Dam - Lake Oahe	Big Bend Dam - Lake Sharpe	Fort Randall Dam - Lake Francis Case	Gavins Point Dam - Lewis & Clark Lake	Total	Item No.
1	Location of Dam	Near Glasgow, Montana	Near Garrison, ND	Near Pierre, SD	21 miles upstream Chamberlain, SD	Near Lake Andes, SD	Near Yankton, SD		1
2	River Mile - 1960 Mileage	Mile 1771.5	Mile 1389.9	Mile 1072.3	Mile 987.4	Mile 880.0	Mile 811.1		2
3	Total & incremental drainage areas in square miles	57,500	181,400 (2) 123,900	243,490 (1) 62,090	249,330 (1) 5,840	263,480 (1) 14,150	279,480 (1) 16,000		3
4	Approximate length of full reservoir (in valley miles)	134, ending near Zortman, MT	178, ending near Trenton, ND	231, ending near Bismarck, ND	80, ending near Pierre, SD	107, ending at Big Bend Dam	25, ending near Niobrara, NE	755 miles	4
5	Shoreline in miles (3)	1520 (elevation 2234)	1340 (elevation 1837.5)	2250 (elevation 1607.5)	200 (elevation 1420)	540 (elevation 1350)	90 (elevation 1204.5)	5,940 miles	5
6	Average total & incremental inflow in cfs	10,200	25,600 15,400	28,900 3,300	28,900	30,000 1,100	32,000 2,000		6
7	Max. discharge of record near damsite in cfs	137,000 (June 1953)	348,000 (April 1952)	440,000 (April 1952)	440,000 (April 1952)	447,000 (April 1952)	480,000 (April 1952)		7
8	Construction started - calendar yr.	1933	1946	1948	1959	1946	1952		8
9	In operation (4) cal. yr.	1940	1955	1962	1964	1953	1955		9
	Dam and Embankment								
10	Top of dam elevation in feet msl	2280.5	1875	1660	1440	1395	1234		10
11	Length of dam in feet	21,026 (excluding spillway)	11,300 (including spillway)	9,300 (excluding spillway)	10,570 (including spillway)	10,700 (including spillway)	8,700 (including spillway)	71,596	11
12	Damming height in feet (5)	220	180	200	78	140	45	863 feet	12
13	Maximum height in feet (5)	250.5	210	245	95	165	74		13
14	Max. base width, total & w/o berms in feet	3500, 2700	3400, 2050	3500, 1500	1200, 700	4300, 1250	850, 450		14
15	Abutment formations (under dam & embankment)	Bearpaw shale and glacial fill	Fort Union clay shale	Pierre shale	Pierre shale & Niobrara chalk	Niobrara chalk	Niobrara chalk & Carlile shale		15
16	Type of fill	Hydraulic & rolled earth fill	Rolled earth filled	Rolled earth fill & shale berms	Rolled earth, shale, chalk fill	Rolled earth fill & chalk berms	Rolled earth & chalk fill		16
17	Fill quantity, cubic yards	125,628,000	66,500,000	55,000,000 & 37,000,000	17,000,000	28,000,000 & 22,000,000	7,000,000	358,128,000 cu. yds	17
18	Volume of concrete (cubic yards)	1,200,000	1,500,000	1,045,000	540,000	961,000	308,000	5,554,000 cu. yds.	18
19	Date of Closure	24 June 1937	15 April 1953	3 August 1958	24 July 1963	20 July 1952	31 July 1955		19
	Spillway Data								
20	Location	Right bank - remote	Left bank - adjacent	Right bank - remote	Left bank - adjacent	Left bank - adjacent	Right bank - adjacent		20
21	Crest elevation in feet msl	2225	1825	1596.5	1385	1346	1180		21
22	Width (including piers) in feet	820 gated	1336 gated	456 gated	376 gated	1000 gated	664 gated		22
23	No., size and types of gates	16 - 40' x 25' vertical lift gates	28 - 40' x 29' Tainter	8 - 50' x 23.5' Tainter	8 - 40' x 38' Tainter	21 - 40' x 29' Tainter	14 - 40' x 30' Tainter		23
24	Design discharge capacity, cfs	275,000 at elev 2253.3	827,000 at elev 1858.5	304,000 at elev 1644.4	390,000 at elev 1433.6	633,000 at elev 1379.8	584,000 at elev 1221.4		24
25	Discharge capacity at maximum operating pool in cfs	230,000	660,000	80,000	270,000	508,000	345,000		25

Remarks

(1) Includes 4,280 square miles of non-contributing areas.

(2) Includes 1,350 square miles of non-contributing areas.

(3) With pool at base of flood control.

(4) Storage first available for regulation of flows.

(5) Damming height is height from low water to maximum operating pool. Maximum height is from average streambed to top of dam.

(6) Based on latest available storage data.

(7) River regulation is attained by flows over low-crested spillway and through turbines.

(8) Length from upstream face of outlet or to spiral case.

(9) Based on 8th year (1961) of drought drawdown (From study 8-83-1985).

(10) Affected by level of Lake

	Reservoir Data (6)								
26	Max. operating pool elev & area	2250 msl 245,000 acres	1854 msl 383,000 acres	1620 msl 386,000 acres	1423 msl 61,000 acres	1375 msl 102,000 acres	1210 msl 29,000 acres	1,207,000 acres	26
27	Max. normal op pool elev & area	2246 msl 240,000 acres	1850 msl 365,000 acres	1617 msl 362,000 acres	1422 msl 60,000 acres	1365 msl 94,000 acres	1208 msl 25,000 acres	1,146,000 acres	27
28	Base flood control elev & area	2234 msl 211,000 acres	1837.5 msl 308,000 acres	1607.5 msl 311,000 acres	1420 msl 57,000 acres	1350 msl 76,000 acres	1204.5 msl 21,000 acres	985,000 acres	28
29	Min. op. pool elev. & area	2160 msl 89,000 acres	1775 msl 125,000 acres	1540 msl 115,000 acres	1415 msl 50,000 acres	1320 msl 36,000 acres	1204.5 msl 21,000 acres	437,000 acres	29
	Storage allocation & capacity								
30	Exclusive flood control	2250-2246 971,000 a.f.	1854-1850 1,495,000 a.f.	1620-1617 1,107,000 a.f.	1423-1422 61,000 a.f.	1375-1365 986,000 a.f.	1210-1208 54,000 a.f.	4,673,000 a.f.	30
31	Flood control & multiple use	2246-2234 2,704,000 a.f.	1850-1837.5 4,211,000 a.f.	1617-1607.5 3,208,000 a.f.	1422-1420 118,000 a.f.	1365-1350 1,306,000 a.f.	1208-1204.5 79,000 a.f.	11,625,000 a.f.	31
32	Carryover multiple use	2234-2160 10,700,000 a.f.	1837.5-1775 12,951,000 a.f.	1607.5-1540 13,353,000 a.f.		1350-1320 1,532,000 a.f.		38,536,000 a.f.	32
33	Permanent	2160-2030 4,088,000 a.f.	1775-1673 4,794,000 a.f.	1540-1415 5,315,000 a.f.	1420-1345 1,631,000 a.f.	1320-1240 1,469,000 a.f.	1204.5-1160 295,000 a.f.	17,582,000 a.f.	33
34	Gross	2250-2030 18,463,000 a.f.	1854-1673 23,451,000 a.f.	1620-1415 22,983,000 a.f.	1423-1345 1,810,000 a.f.	1375-1240 5,293,000 a.f.	1210-1160 428,000 a.f.	72,416,000 a.f.	34
35	Reservoir filling initiated	November 1937	December 1953	August 1958	November 1963	January 1953	August 1955		35
36	Initially reached min. operating pool	27 May 1942	7 August 1955	3 April 1962	25 March 1964	24 November 1953	22 December 1955		36
37	Estimated annual sediment inflow	17,200 a.f. 1070 yrs.	21,600 a.f. 1080 yrs.	14,100 a.f. 1630	3,400 a.f. 530	15,800 a.f. 340 yrs.	2,500 a.f. 170 yrs.	73,900 a.f.	37
	Outlet Works Data								
38	Location	Right bank	Right Bank	Right Bank		Left Bank			38
39	Number and size of conduits	2 - 24' 8" diameter (nos. 3 & 4)	1 - 26' dia. and 2 - 22' dia.	6 - 19.75' dia. upstream, 18.25' dia. Downstream	None (7)	4 - 22' diameter	None (7)		39
40	Length of conduits in feet (8)	No. 3 - 6,615, No. 4 - 7,240	1529	3496 to 3659		1013			40
41	No., size, and type of service gates	1 - 28' dia. cylindrical gate 6 ports, 7.6' x 8.5' high (net opening) in each control shaft	1 - 18' x 24.5' Tainter gate per conduit for fine regulation	1 - 13' x 22' per conduit, vertical lift, 4 cable suspension and 2 hydraulic suspension (fine regulation)		2 - 11' x 23' per conduit, vertical lift, cable suspension			41
42	Entrance invert elevation (msl)	2095	1672	1425	1385 (11)	1229	1180 (11)		42
43	Avg. discharge capacity per conduit & total	Elev. 2250 22,500 cfs - 45,000 cfs	Elev. 1854 30,400 cfs - 98,000 cfs	Elev. 1620 18,500 cfs - 111,000 cfs		Elev 1375 32,000 cfs - 128,000 cfs			43
44	Present tailwater elevation (ft msl)	2032-2036 5,000 - 35,000 cfs	1669-1677 15,000- 60,000 cfs	1422-1427 20,000-55,000 cfs	1351-1355(10) 25,000-100,000 cfs	1228-1237 10,000-60,000 cfs	1153-1161 15,000-60,000 cfs		44

Francis case. Applicable to pool at elevation 1350.

(11) Spillway crest.

(12) 1967-2013 Average

(13) Source: Annual Report on Civil Works Activities of the Corps of Engineers. Extract Report Fiscal Year 1999.

	Power Facilities and Data									
45	Avg. gross head avail in feet (14)	194	161	174	70	117	48	764 feet	45	
46	Number and size of conduits	No. 1-24'8" dia., No. 2-22'4" dia.	5 - 29' dia., 25' penstocks	7 - 24' dia., imbedded penstocks	None: direct intake	8 - 28' dia., 22' penstocks	None: direct intake		46	
47	Length of conduits in feet (8)	No. 1 - 5,653, No. 2 - 6,355	1829	From 3,280 to 4,005		1074		55,083	47	
48	Surge tanks	PH#1: 3-40' dia., PH#2: 2-65' dia.	65' dia. - 2 per penstock	70' dia., 2 per penstock	None	59' dia, 2 per alternate penstock	None		48	
49	No., type and speed of turbines	5 Francis, PH#1-2: 128.5 rpm, 1-164 rpm , PH#2-2: 128.6 rpm	5 Francis, 90 rpm	7 Francis, 100 rpm	8 Fixed blade, 81.8 rpm	8 Francis, 85.7 rpm	3 Kaplan, 75 rpm	36 units	49	
50	Disch. cap. at rated head in cfs	PH#1, units 1&3 170', 2-140' 8,800 cfs, PH#2-4&5 170'-7, 200 cfs	150' 41,000 cfs	185' 54,000 cfs	67' 103,000 cfs	112' 44,500 cfs	48' 36,000 cfs		50	
51	Generator nameplate rating in kW	1&3: 43,500; 2: 18,250; 4&5: 40,000	3 - 121,600, 2 - 109,250	112,290	3 - 67,276, 5 - 58,500	40,000	44,100		51	
52	Plant capacity in kW	185,250	583,300	786,030	494,320	320,000	132,300	2,501,200 kw	52	
53	Dependable capacity in kW (9)	181,000	388,000	534,000	497,000	293,000	74,000	1,967,000 kw	53	
54	Avg annual energy, million kWh (12)	1,046	2,251	2,625	981	1,726	725	9,354 million kWh	54	
55	Initial generation, first and last unit	July 1943 - June 1961	January 1956 - October 1960	April 1962 - June 1963	October 1964 - July 1966	March 1954 - January 1956	September 1956 - January 1957	July 1943 - July 1966	55	Corps of Engineers, U.S. Army
56	Estimated cost September 1999 Completed project (13)	$158,428,000	$305,274,000	$346,521,000	$107,498,000	$199,066,000	$49,617,000	$1,166,404,000	56	Compiled by Missouri River Division August 2014

8 APPENDIX B – 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 8-1 below is a summary of the routing methods available in each program.

Table 8-1: 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
Muskingum-Cunge Prismatic	N/A	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

8.1 COEFFICIENT ROUTING

The Coefficient Routing parameters from the USACE 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 8-2 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 DRM Coefficient Routing parameters were tested using HEC-ResSim.

Table 8-2: 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

8.2 STRADDLE-STAGGER ROUTING

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 Rulo-St. Joseph 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:

Straddle = Stagger + 1 day.

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 8-3. The HMS basin schematic used for Straddle-Stagger routing is shown in Figure 8-1.

Table 8-3: 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

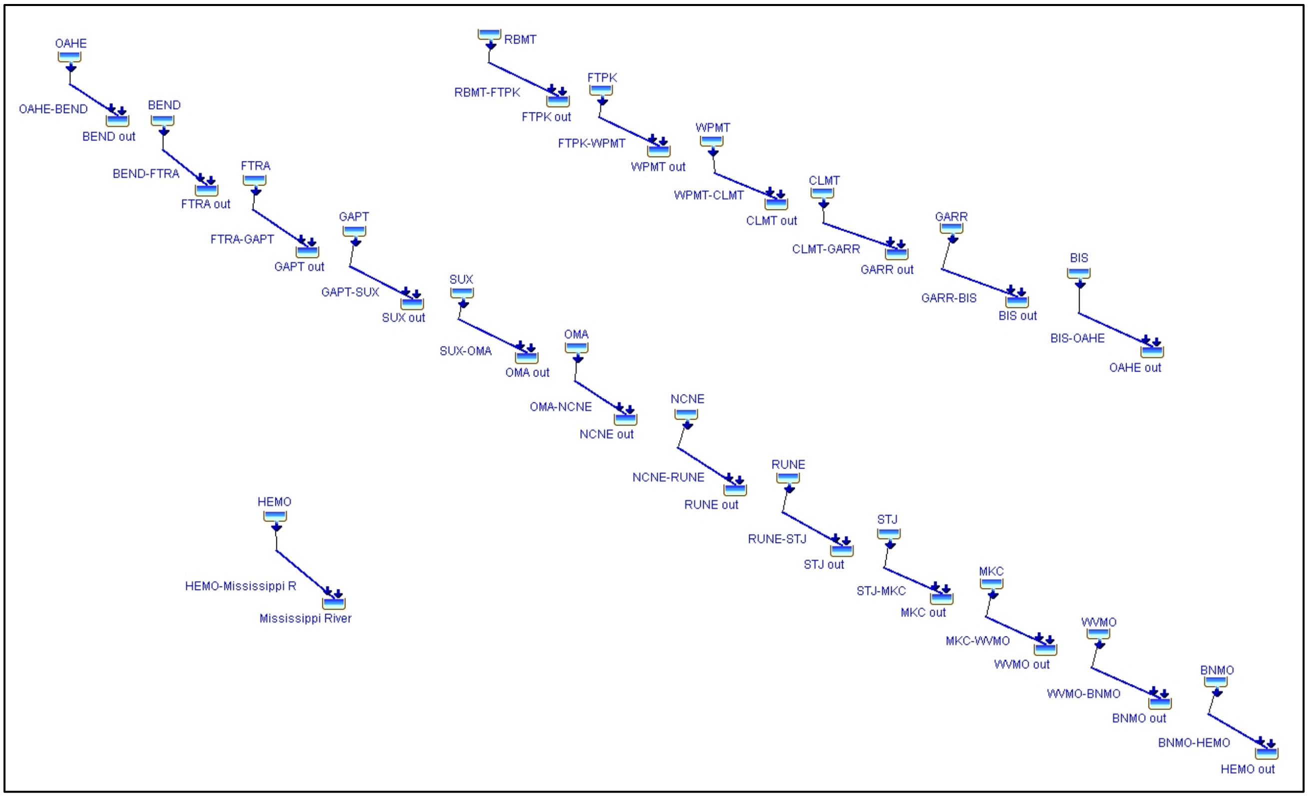

Figure 8-1: Straddle-Stagger and Muskingum HMS basin schematic.

8.3 MUSKINGUM ROUTING

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, zeros 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:

Subreaches = $K/\Delta t$,

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 8-4. 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 8-4 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 8-4: Calibrated Musking 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

8.4 MUSKINGUM-CUNGE ROUTING

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 8-5. The HMS basin schematic used for Muskingum-Cunge and Modified Puls routing is shown in Figure 8-2.

Table 8-5: 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

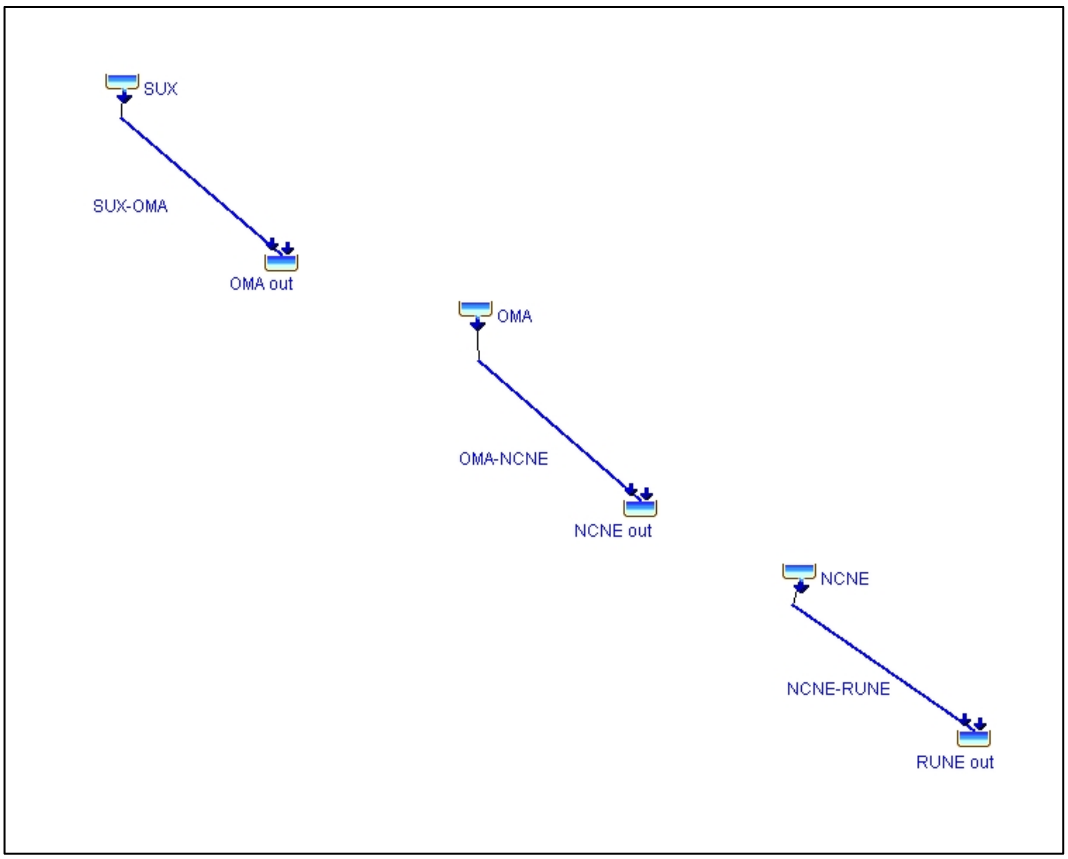

Figure 8-2: Muskingum-Cunge and Modified Puls HMS basin schematic.

8.5 MODIFIED PULS ROUTING

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 Sioux City-Omaha storage-discharge curve. The Omaha to Plattsmouth and Plattsmouth to Nebraska City storage-discharge curves were combined into the Omaha-Nebraska City storage-discharge curve. The Nebraska City to Brownville and Brownville to Rulo storage-discharge curves were combined into the Nebraska City-Rulo storage-discharge curve. The number of subreaches in each reach is determined using the same procedure as the Muskingum Routing method, and had previously been determined to be 1 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 8-6.

Table 8-6: 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

8.6 RESULTS

Of the four routing methods tested using HMS, which does not include the coefficient method, the Straddle-Stagger routing method was best. The Straddle-Stagger routing results closely approximate the timing of the observed events. The resulting peak flows do not always match the observed event peak flows, but this is mainly because the incremental local or ungaged flow between the upstream and downstream gages has not been factored into the model at this point. The Muskingum Routing results are very similar to the Straddle-Stagger Routing results, and also approximate the timing of the observed events fairly well. However, the Straddle-Stagger method produces 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 do not approximate the timing of the observed events as closely as the other routing methods. The hydrographs produced by this routing method are considerably flatter and delayed compared to the observed events. Comparison hydrograph results for the 3 reaches that tested all four routing methods are shown in the Figures in Section 8.6.1 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 Gavins Point to Hermann was also broken up at Rulo, to better observe the timing effects of the routing parameters. When the Gavins Point outflow hydrograph is routed all the way to Hermann without any additional flow added between those locations, the difference in modeled and observed flow is so great that it becomes difficult to locate and compare the timing of the peaks. For this reason, the observed Rulo flow was routed downstream to Hermann 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 8-3. Section 8.6.2 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.

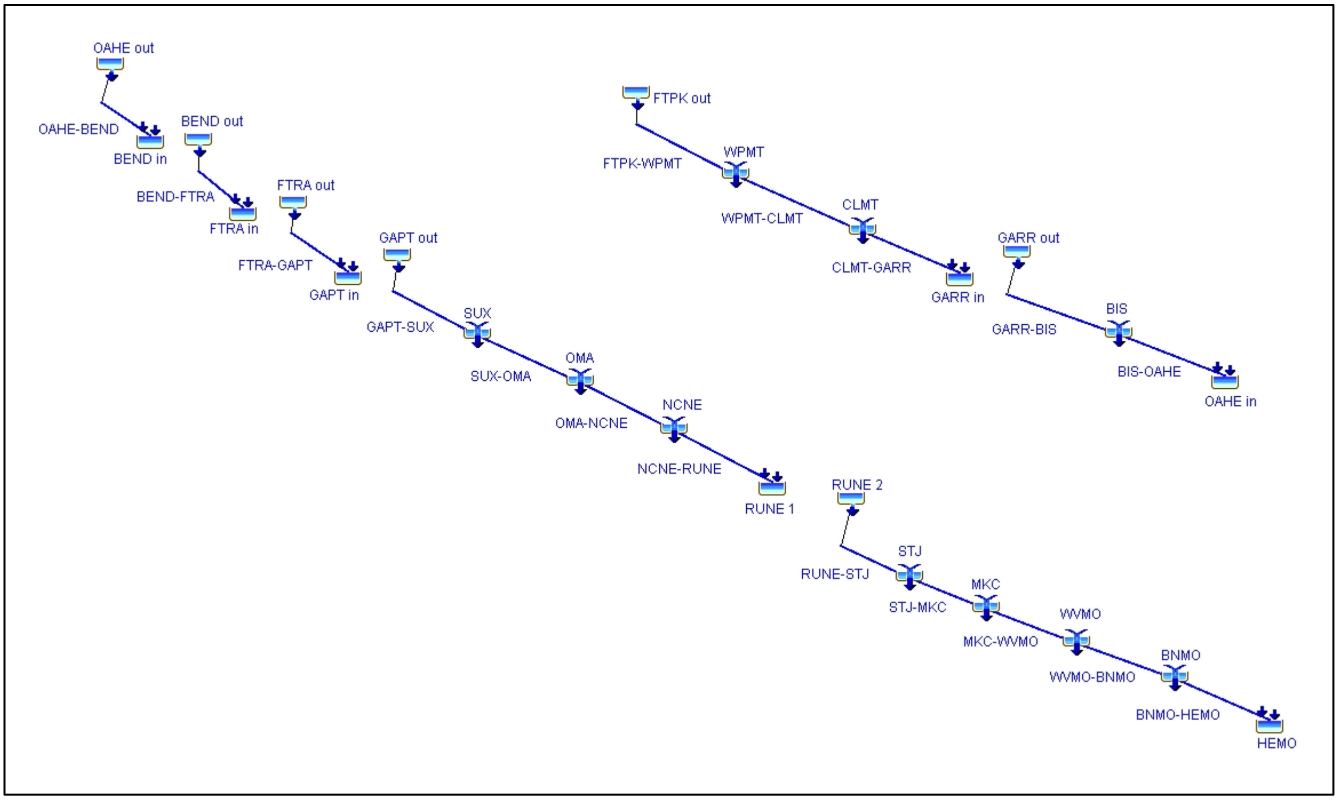

Figure 8-3: Straddle-Stagger composite routing HMS basin schematic.

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 8-1. Four reaches that will be used in the final ResSim model do not have Coefficient routing parameters defined in the DRM: Landusky, MT-Fort Peck, CLMT-Garrison, 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 Section 8.6.2. The Coefficient routing results compared to the Straddle-Stagger routing results and the observed flows for all other reaches during the 2011 event are shown in Section 8.6.3. Coefficient routing results are in blue, Straddle-Stagger routing results are in red, and the observed flows 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 (Nebraska City-Rulo, St. Joseph-Kansas City, and Kansas City-Waverly). The final routing parameters for use in the ResSim model are shown in Table 8-7.

Table 8-7: 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

8.6.1 Modified Puls, Muskingum-Cunge, Muskingum, and Straddle-Stagger Routing Method Comparison Plots

Figure 8-4: Sioux City-Omaha 2011 event.

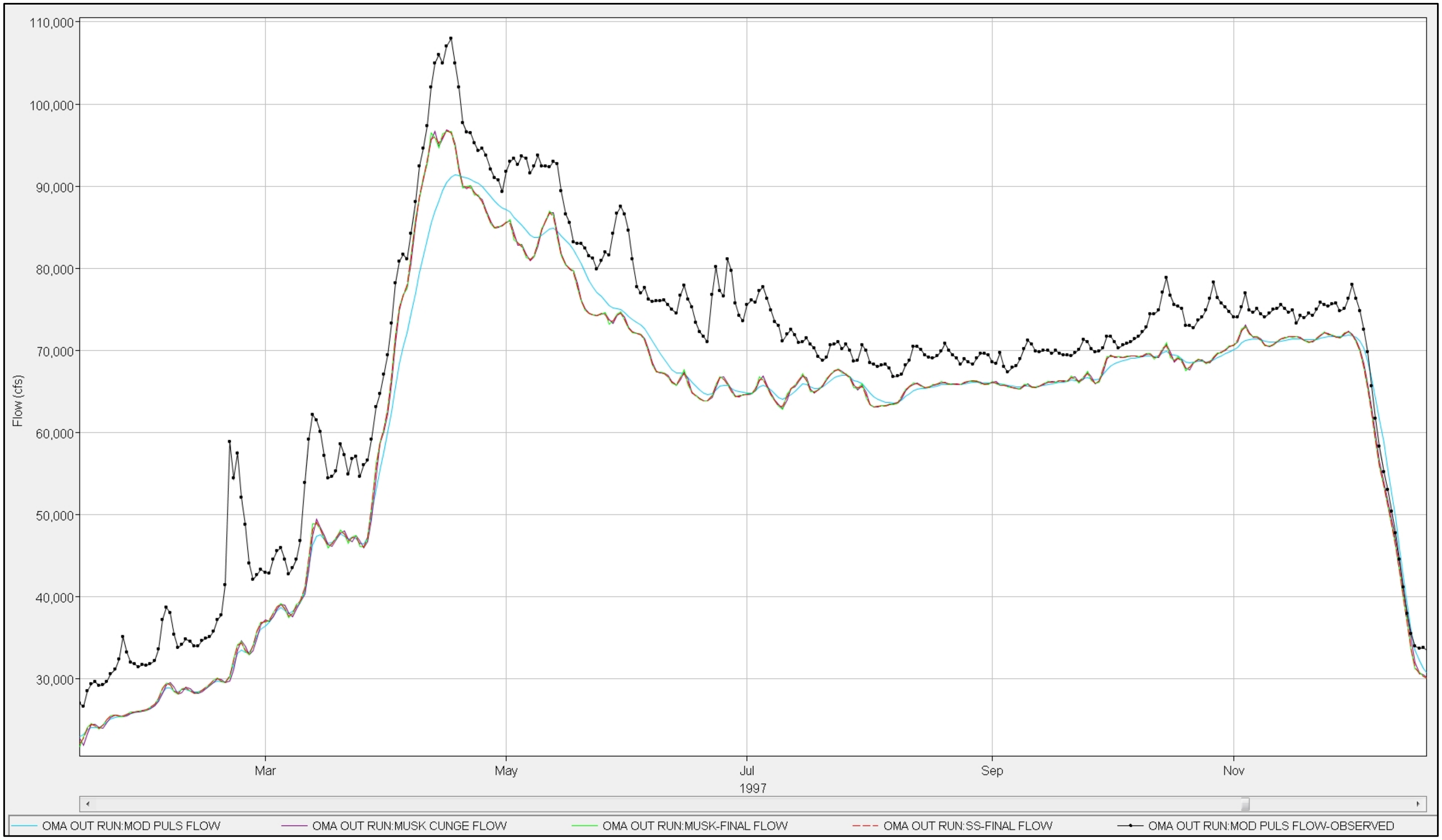

Figure 8-5: Sioux City-Omaha 1997 event.

Figure 8-6: Sioux City-Omaha 1993 Event.

Figure 8-7: Omaha-Nebraska City 2011 Event.

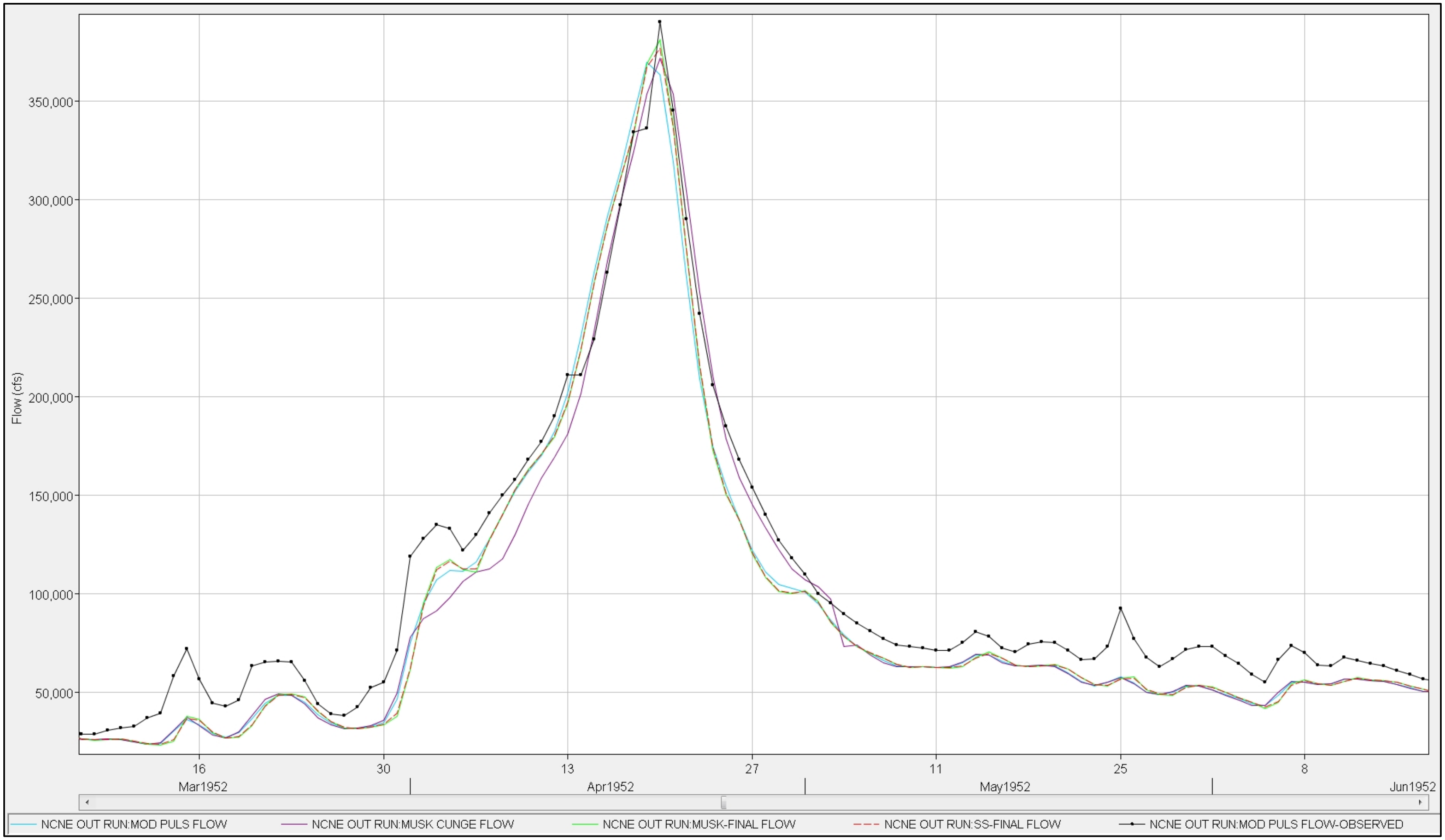

Figure 8-8: Omaha-Nebraska City 1952 Event.

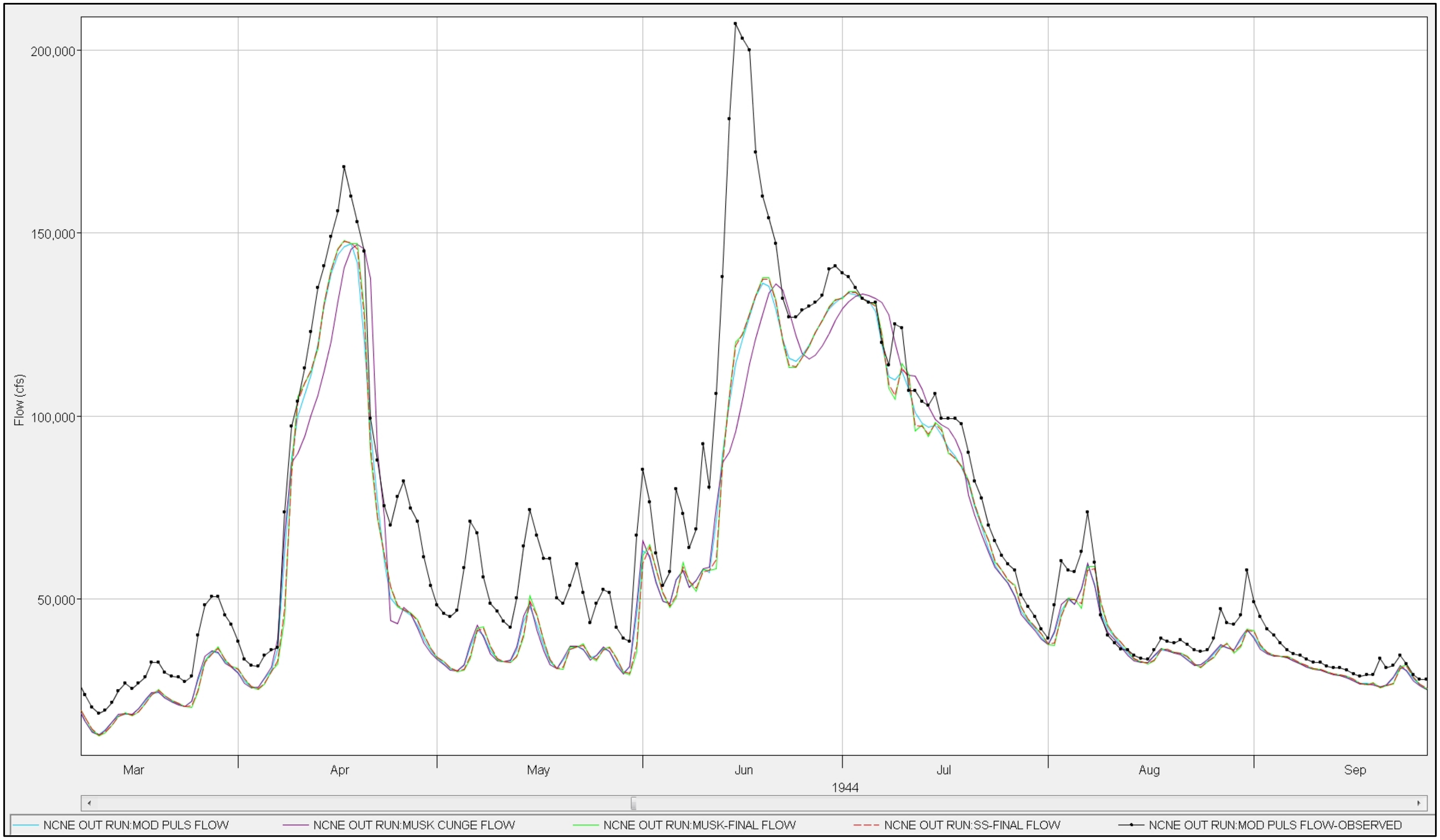

Figure 8-9: Omaha-Nebraska City 1944 Event.

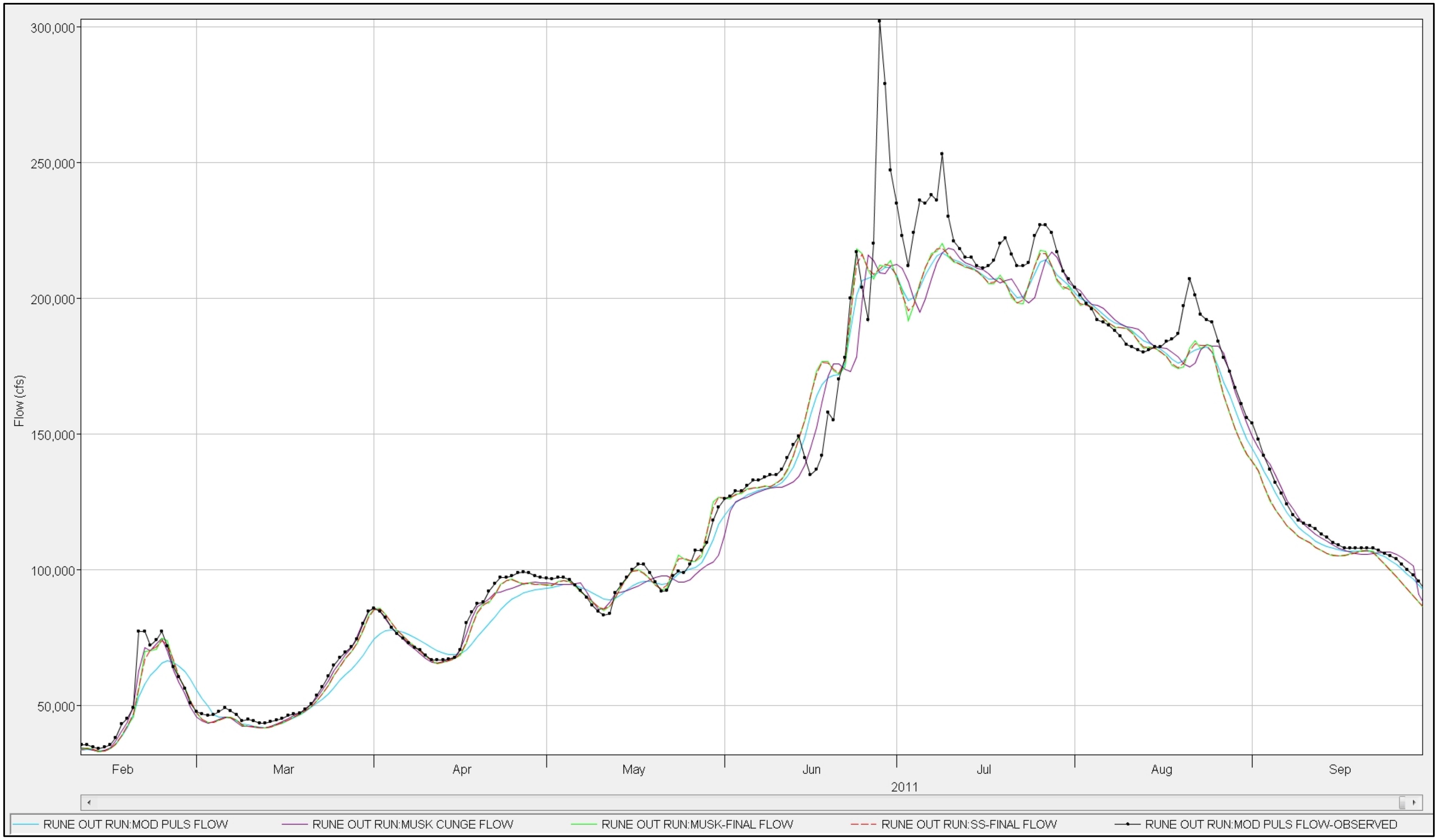

Figure 8-10: Nebraska City-Rulo 2011 Event.

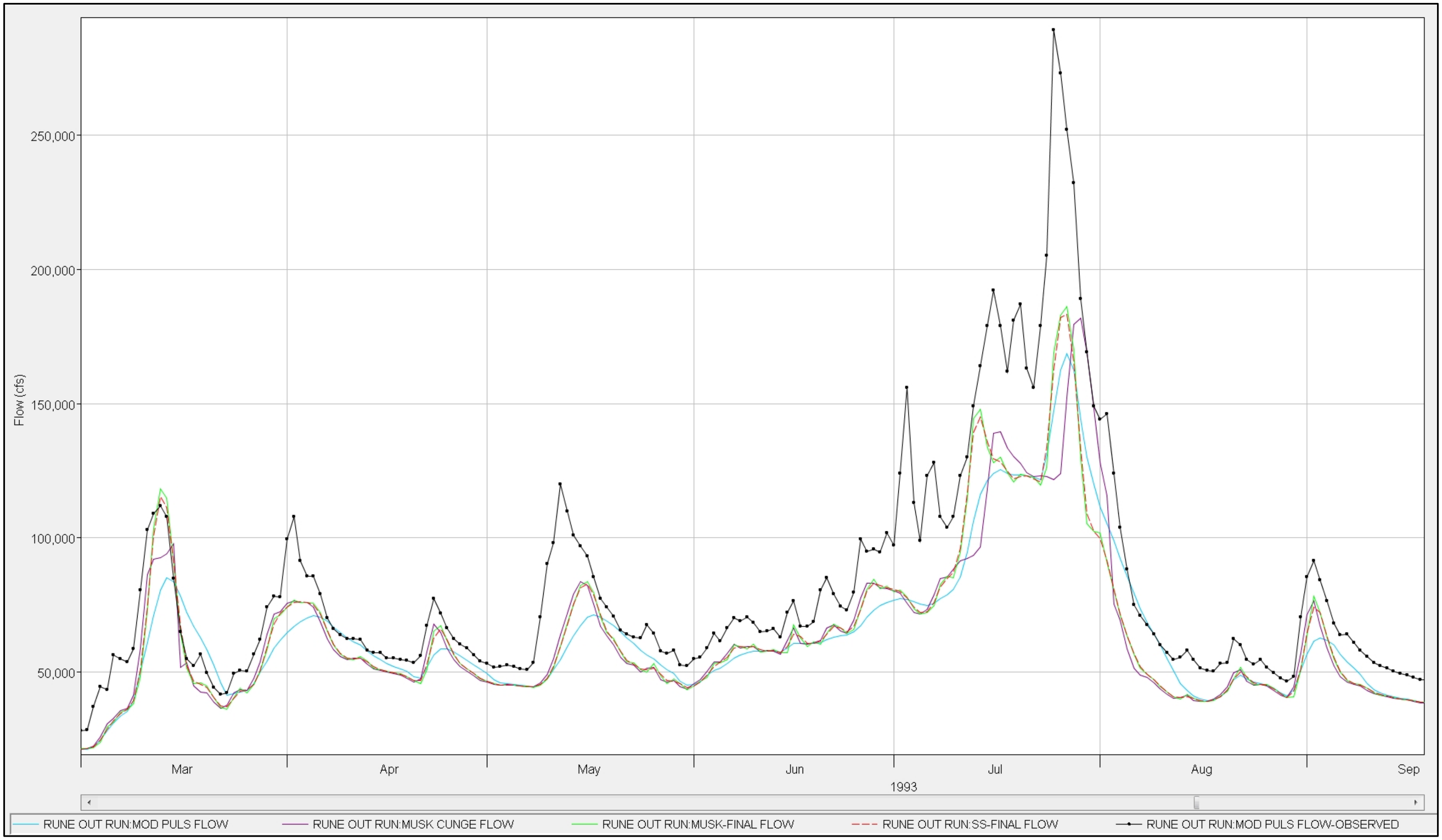

Figure 8-11: Nebraska City-Rulo 1993 Event.

Figure 8-12: Nebraska City-Rulo 1984 Event.

8.6.2 Straddle-Stagger Routing Results

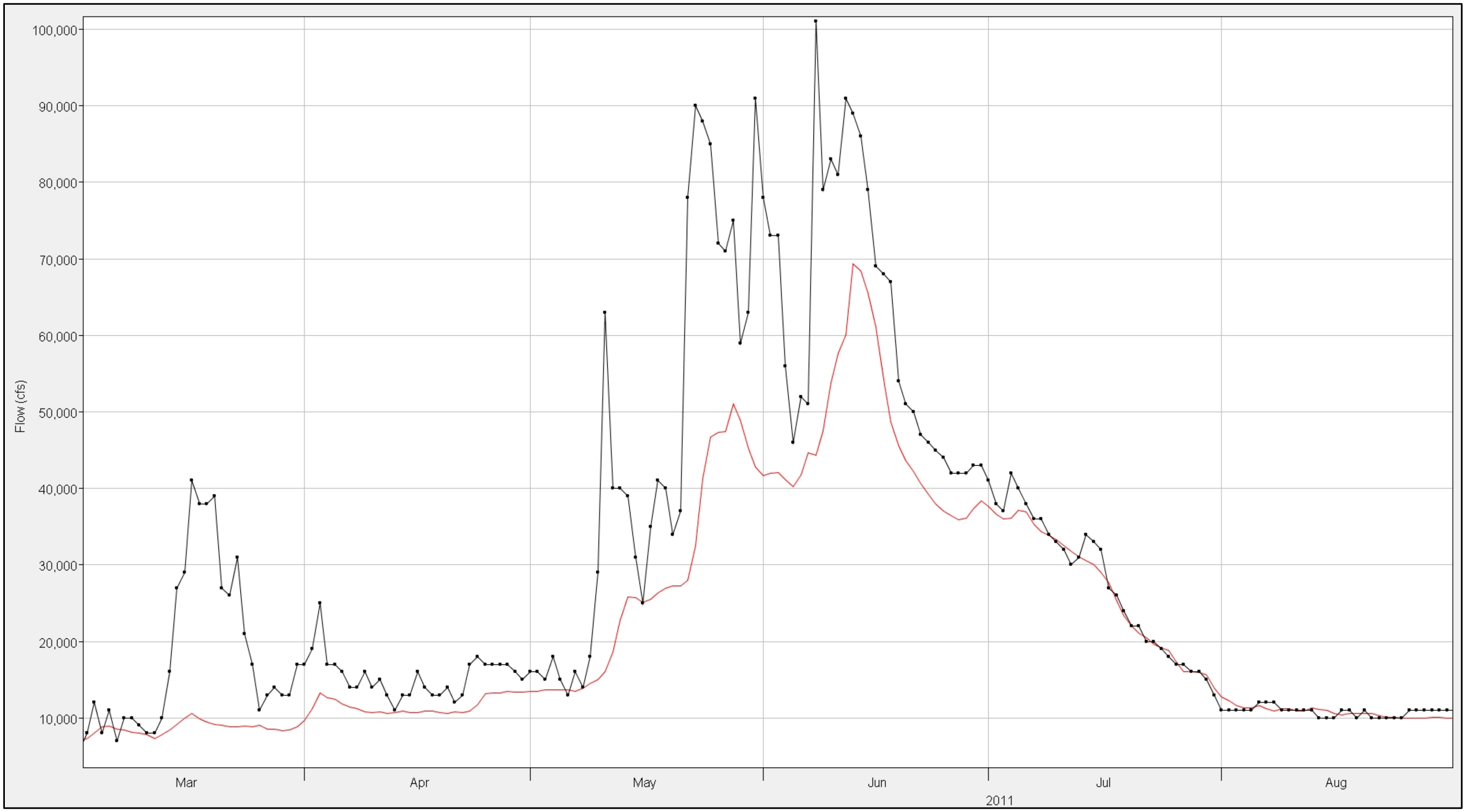

Figure 8-13: Straddle-Stagger routing results for Landusky, MT-Fort Peck during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

Figure 8-14: Straddle-Stagger routing results for Fort Peck-WPMT during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

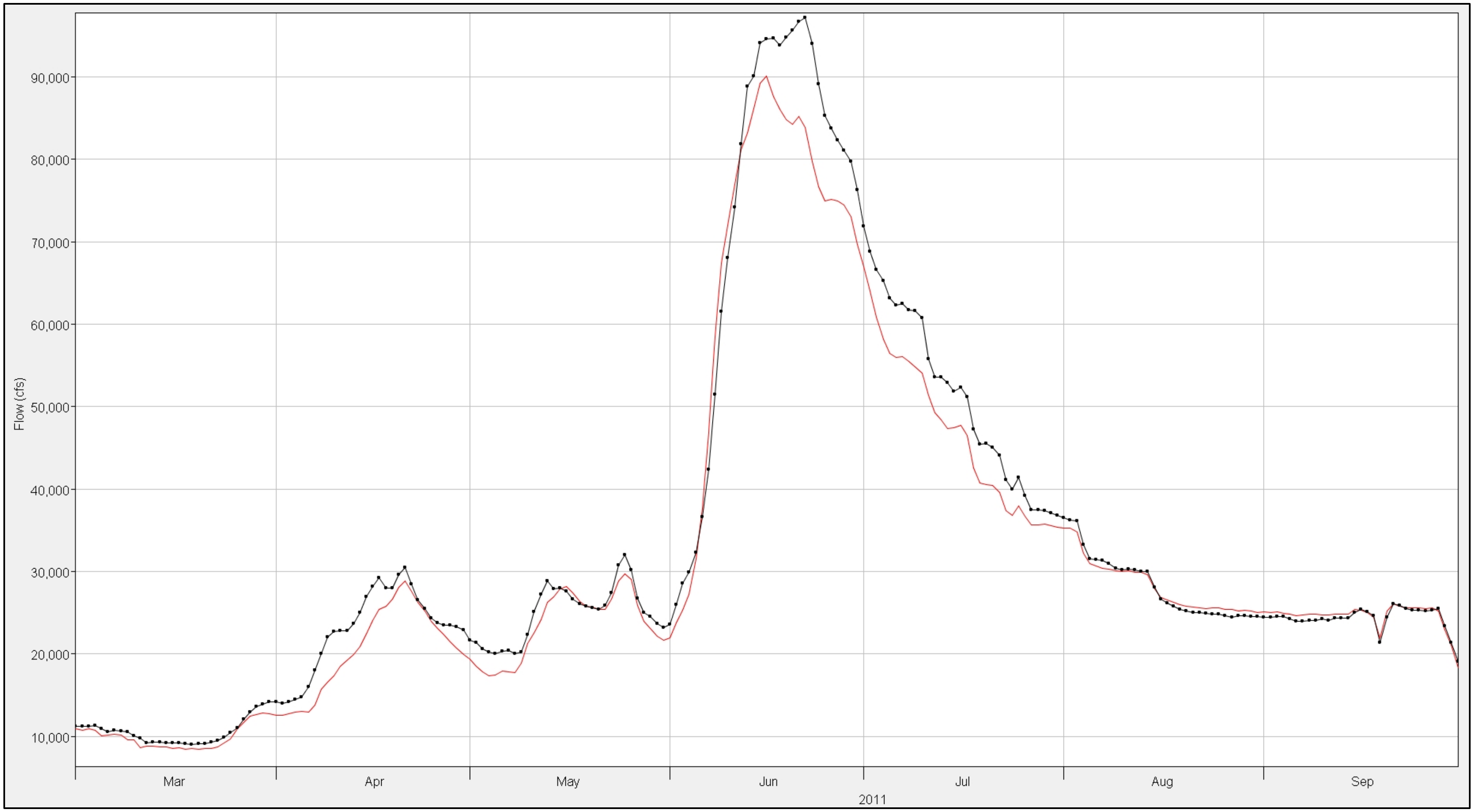

Figure 8-15: Straddle-Stagger routing results for WPMT-CLMT during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

Figure 8-16 Straddle-Stagger routing results for CLMT-Garrison during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

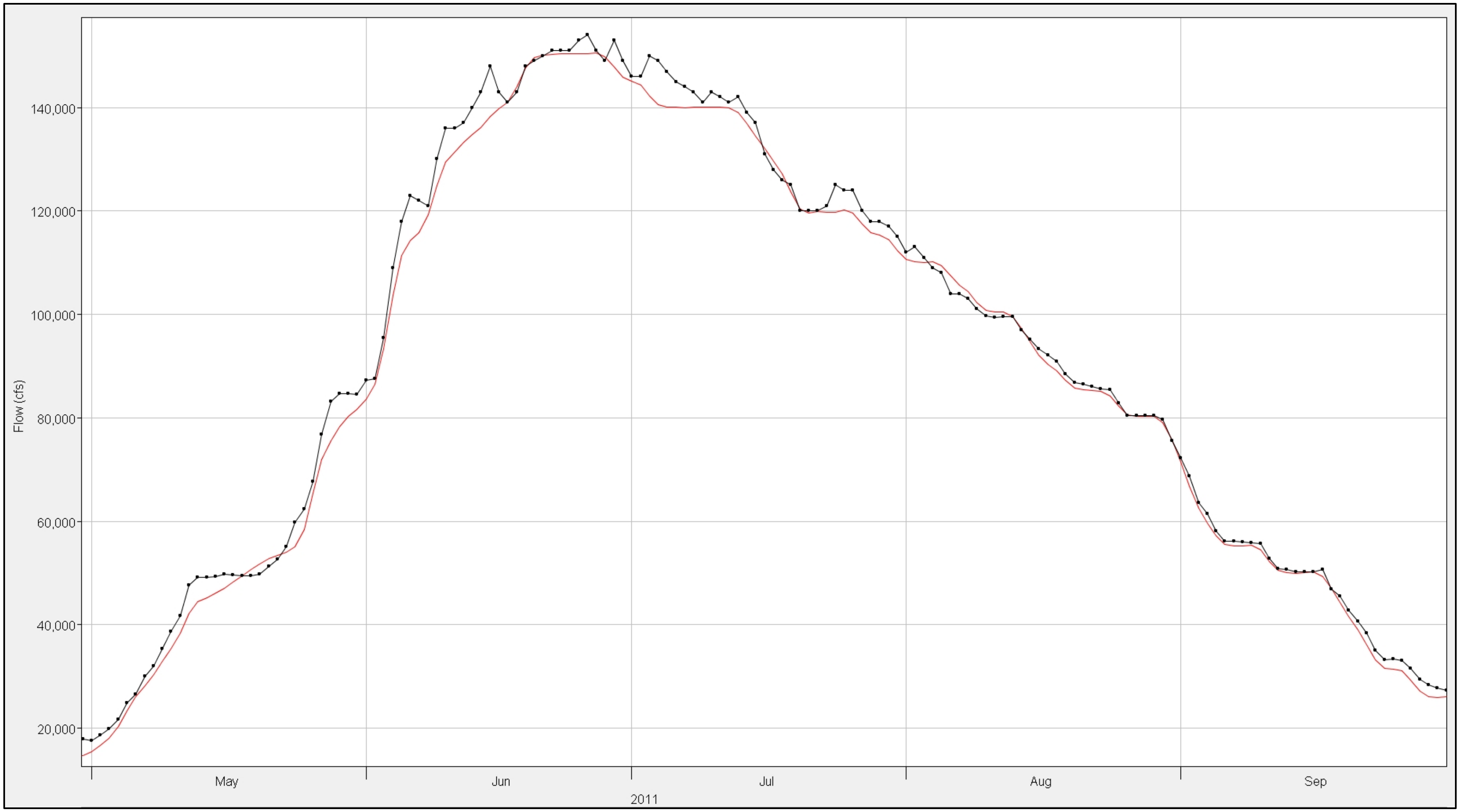

Figure 8-17: Straddle-Stagger routing results for Garrison-BIS during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

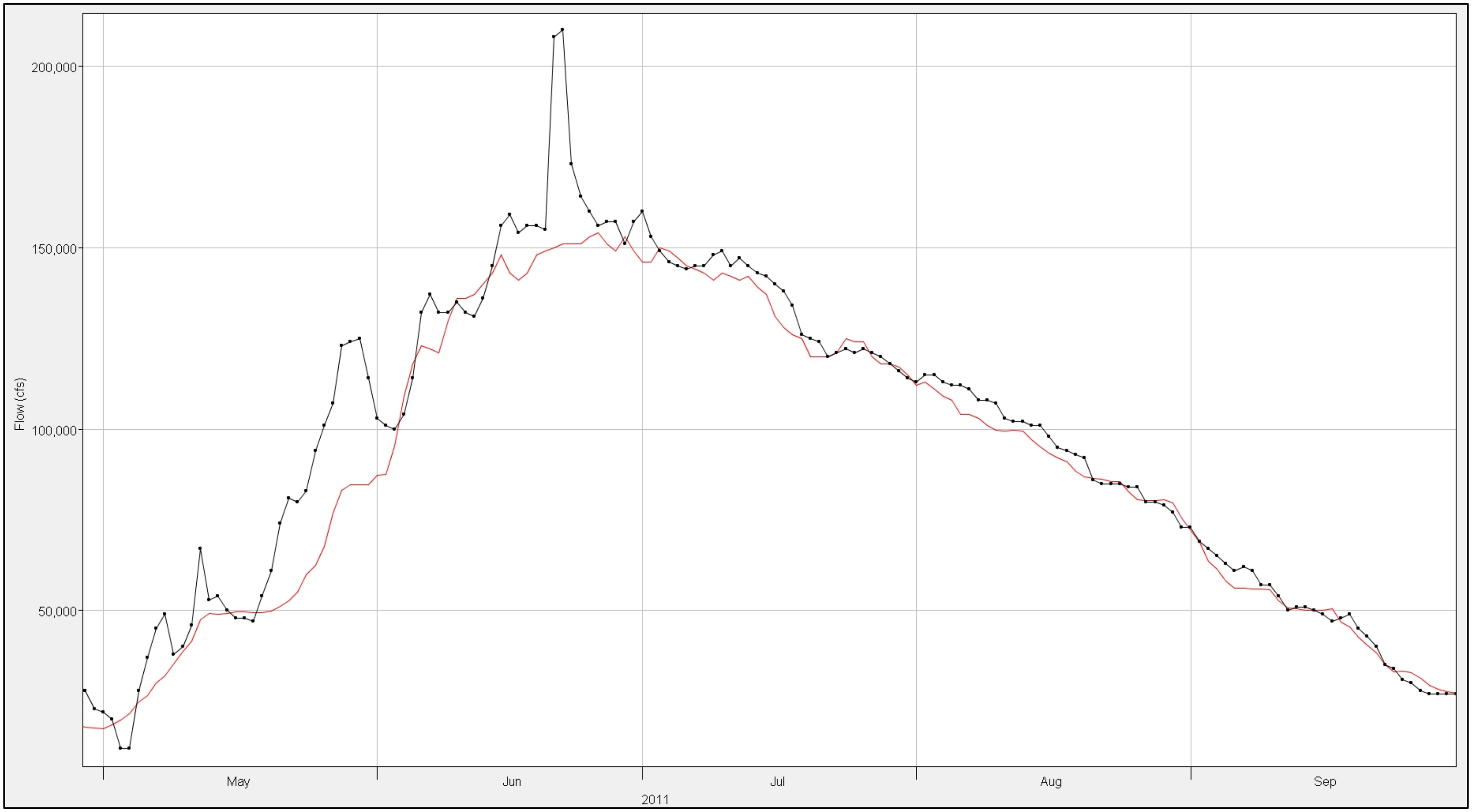

Figure 8-18: Straddle-Stagger routing results for BIS-Oahe during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

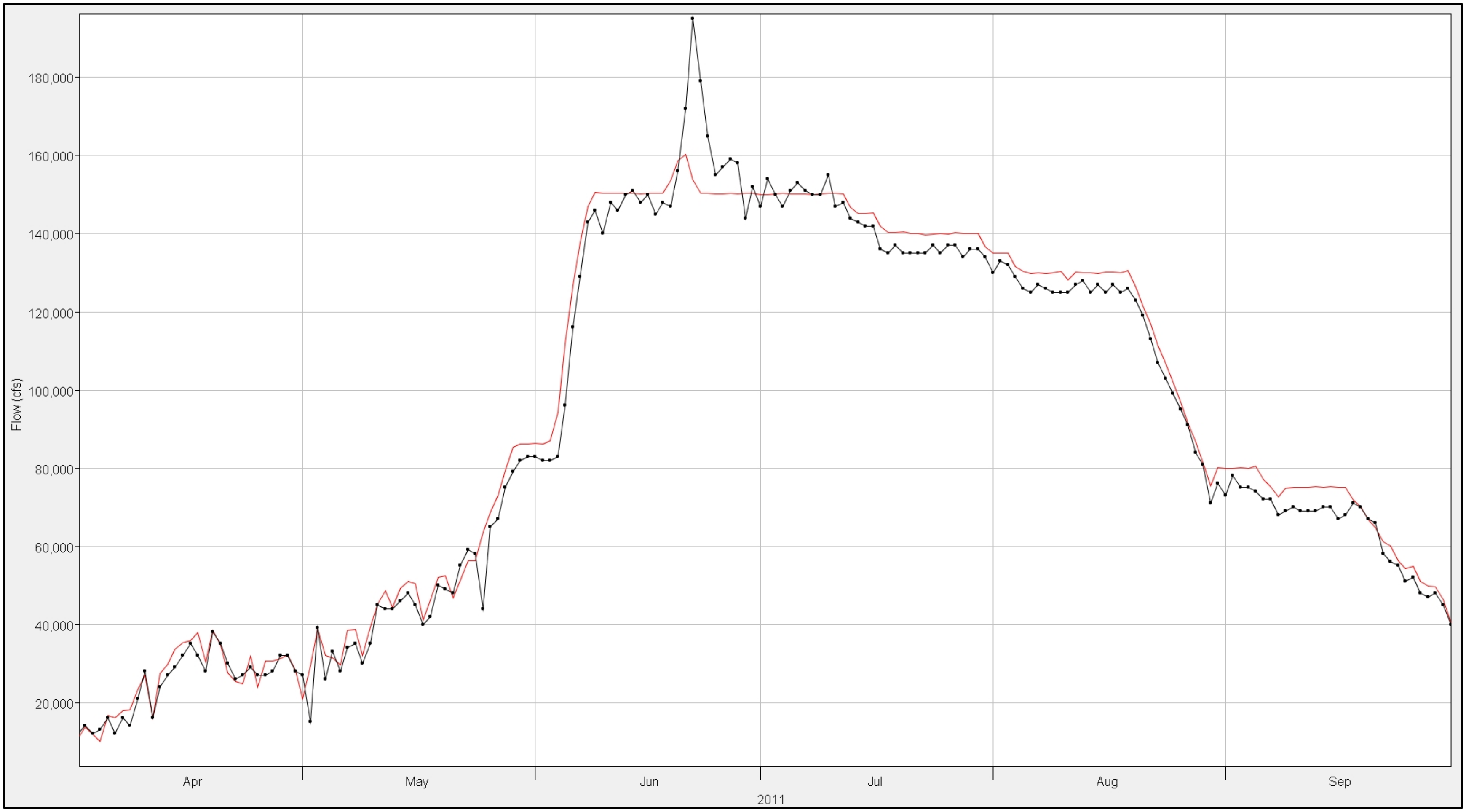

Figure 8-19: Straddle-Stagger routing results for Oahe-Big Bend during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

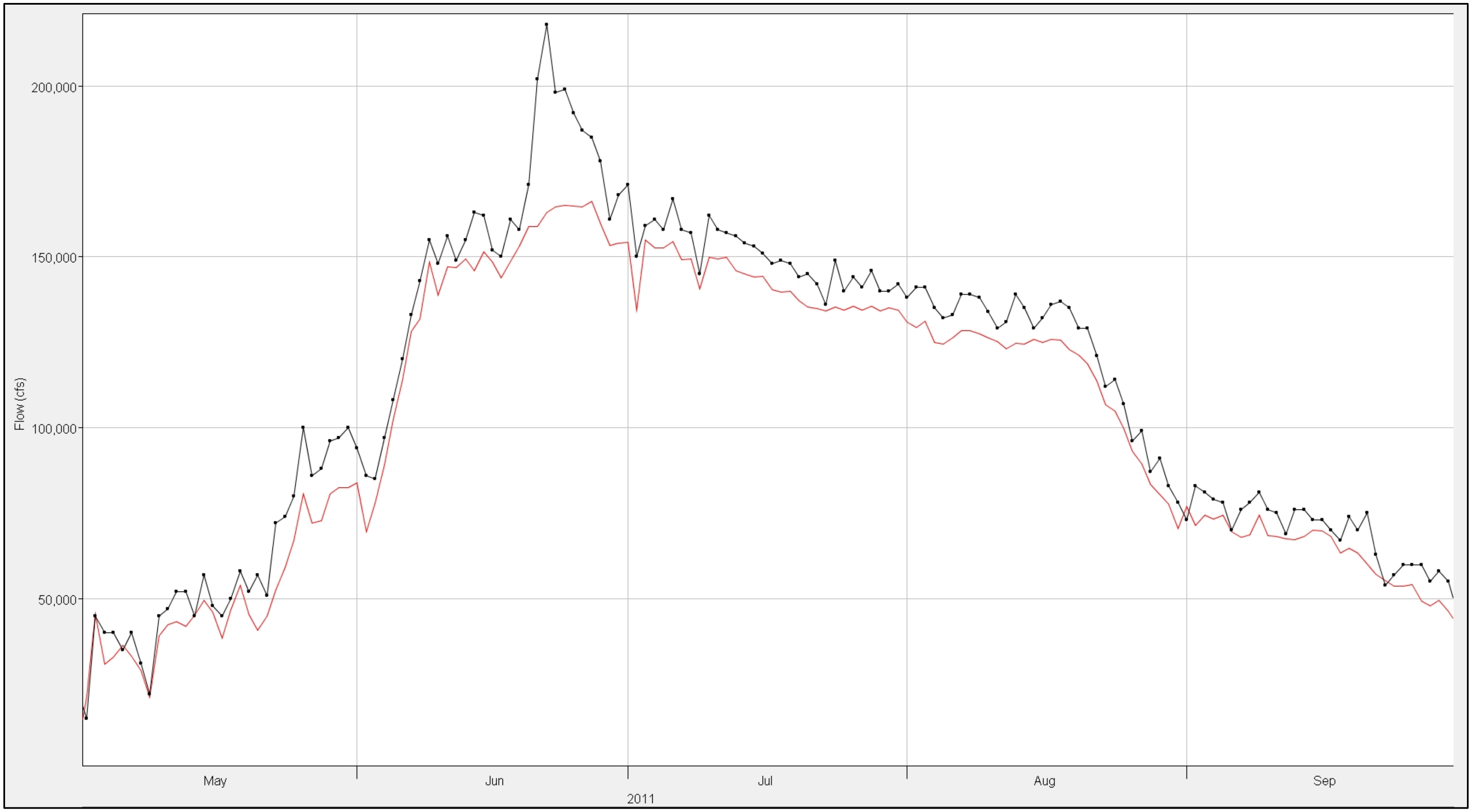

Figure 8-20: Straddle-Stagger routing results for Big Bend-Fort Randall during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

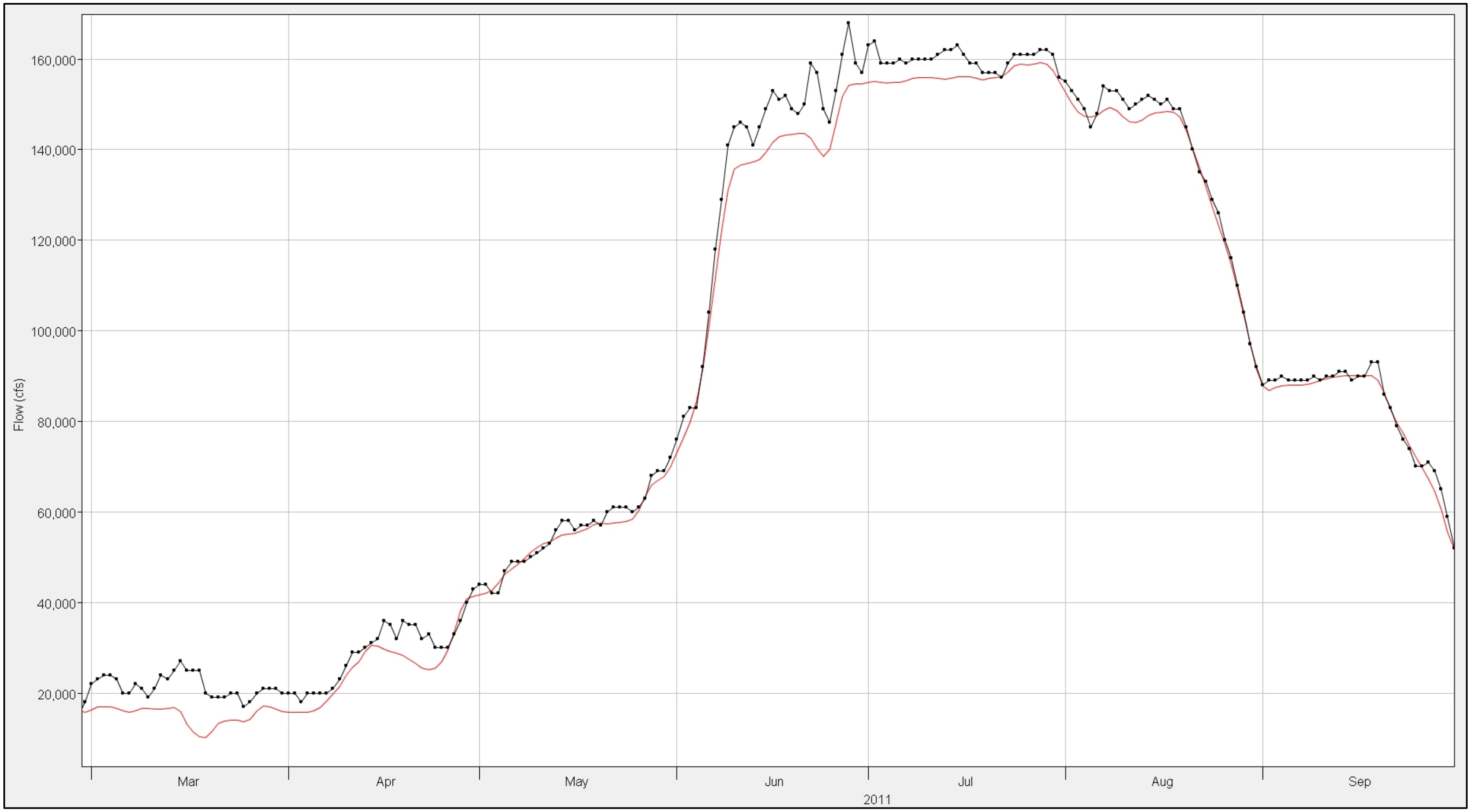

Figure 8-21: Straddle-Stagger routing results for Fort Randall-Gavins Point during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

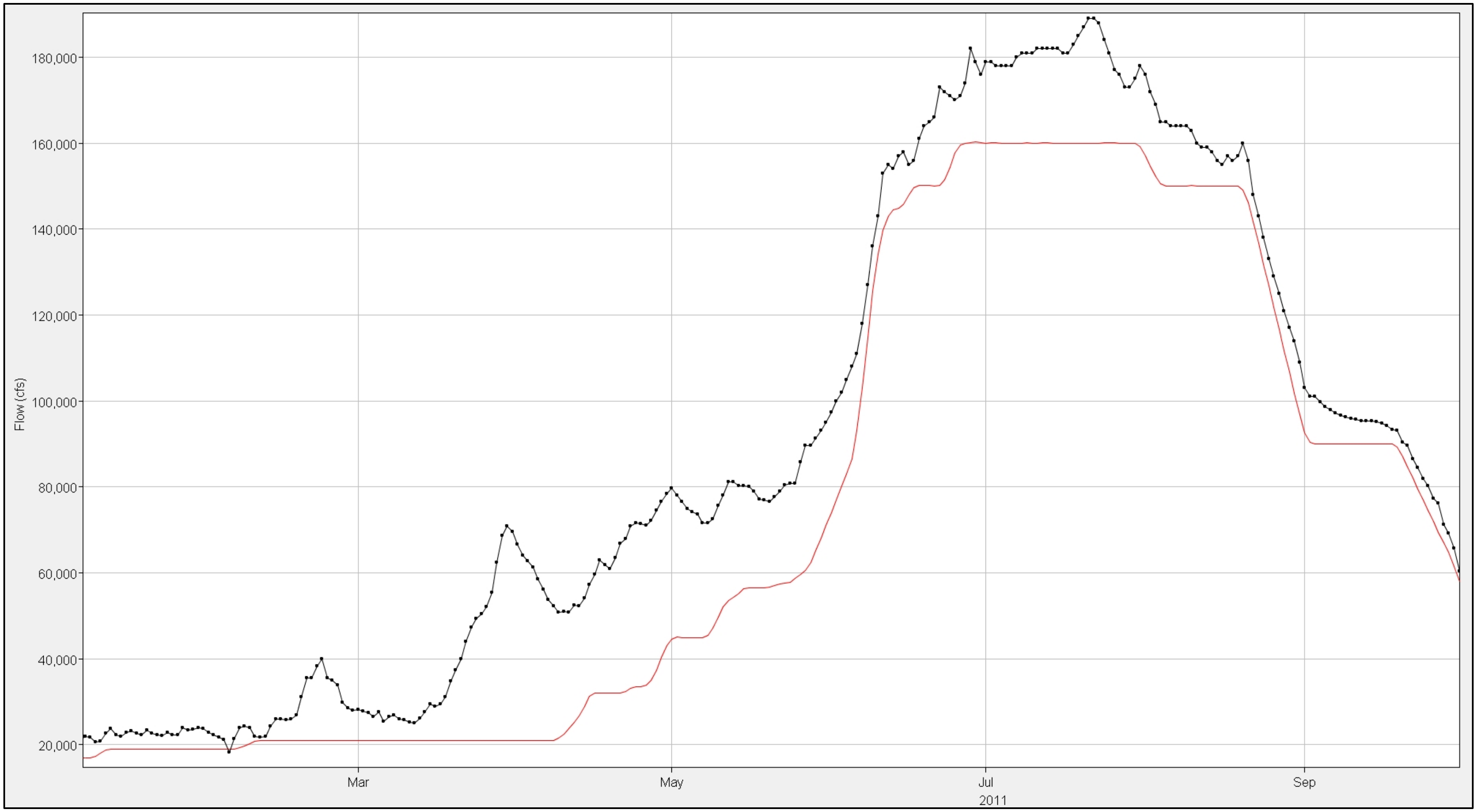

Figure 8-22: Straddle-Stagger routing results for Gavins Point-Sioux City during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

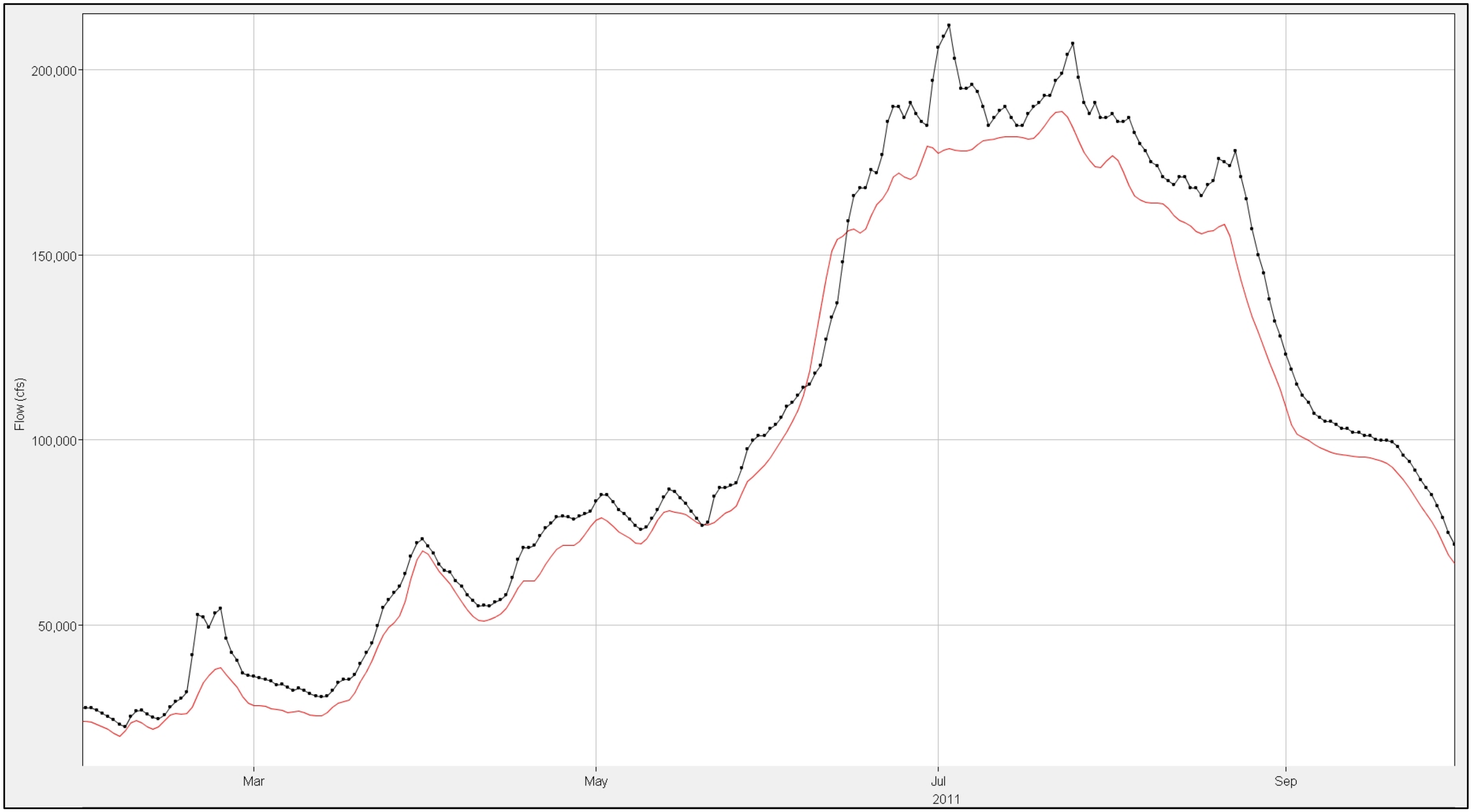

Figure 8-23: Straddle-Stagger routing results for Sioux City-Omaha during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

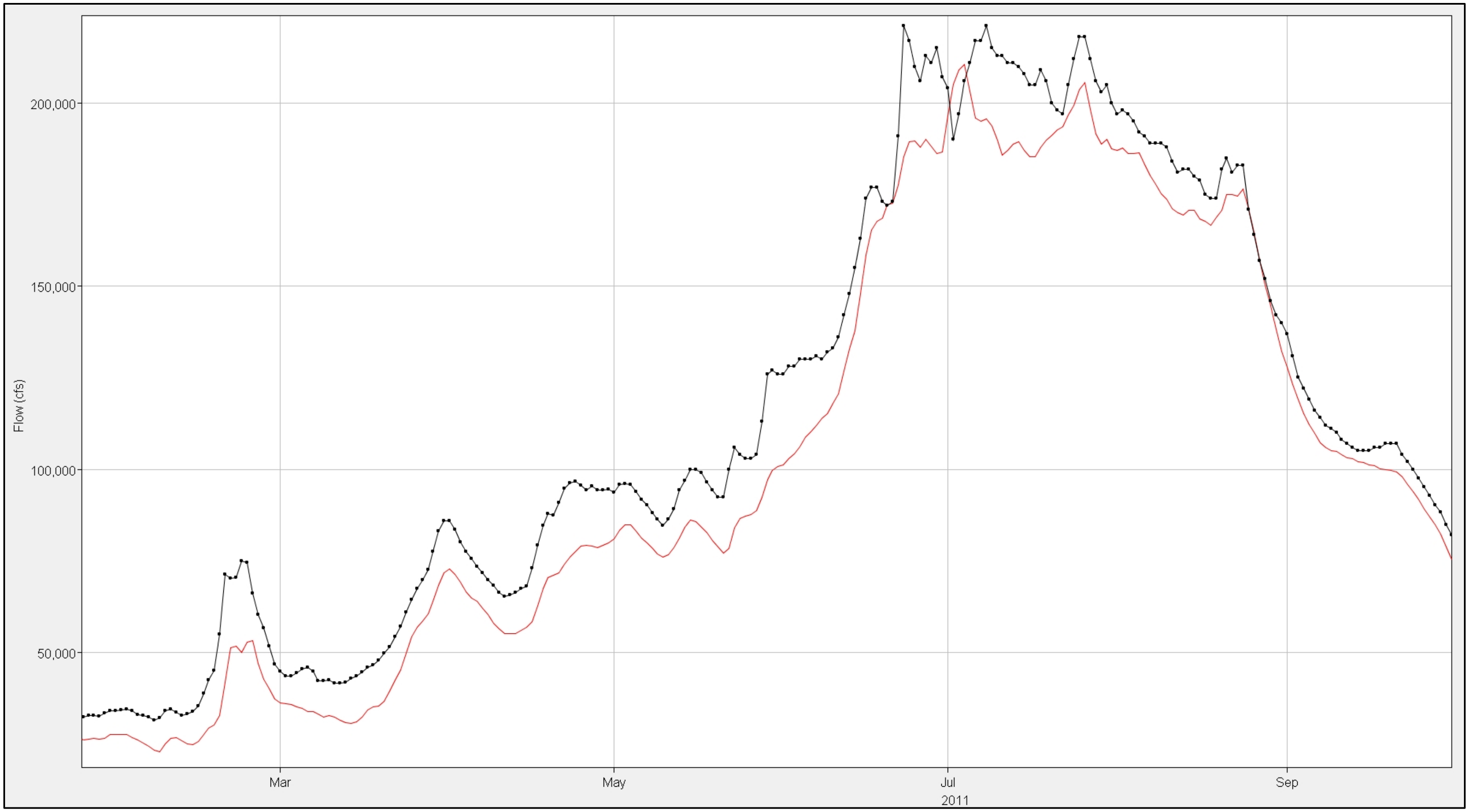

Figure 8-24: Straddle-Stagger routing results for Omaha-Nebraska City during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

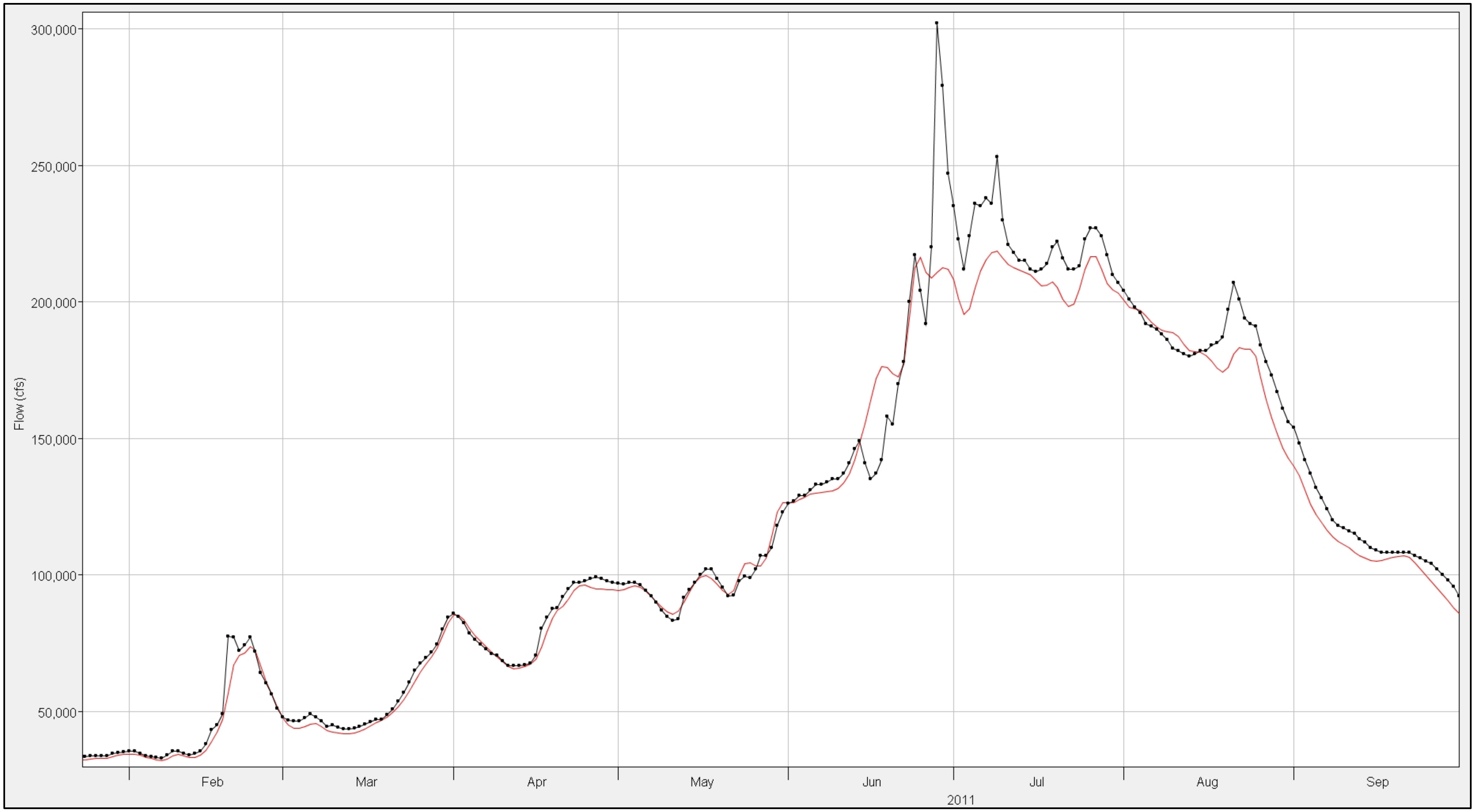

Figure 8-25: Straddle-Stagger routing results for Nebraska City-Rulo during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

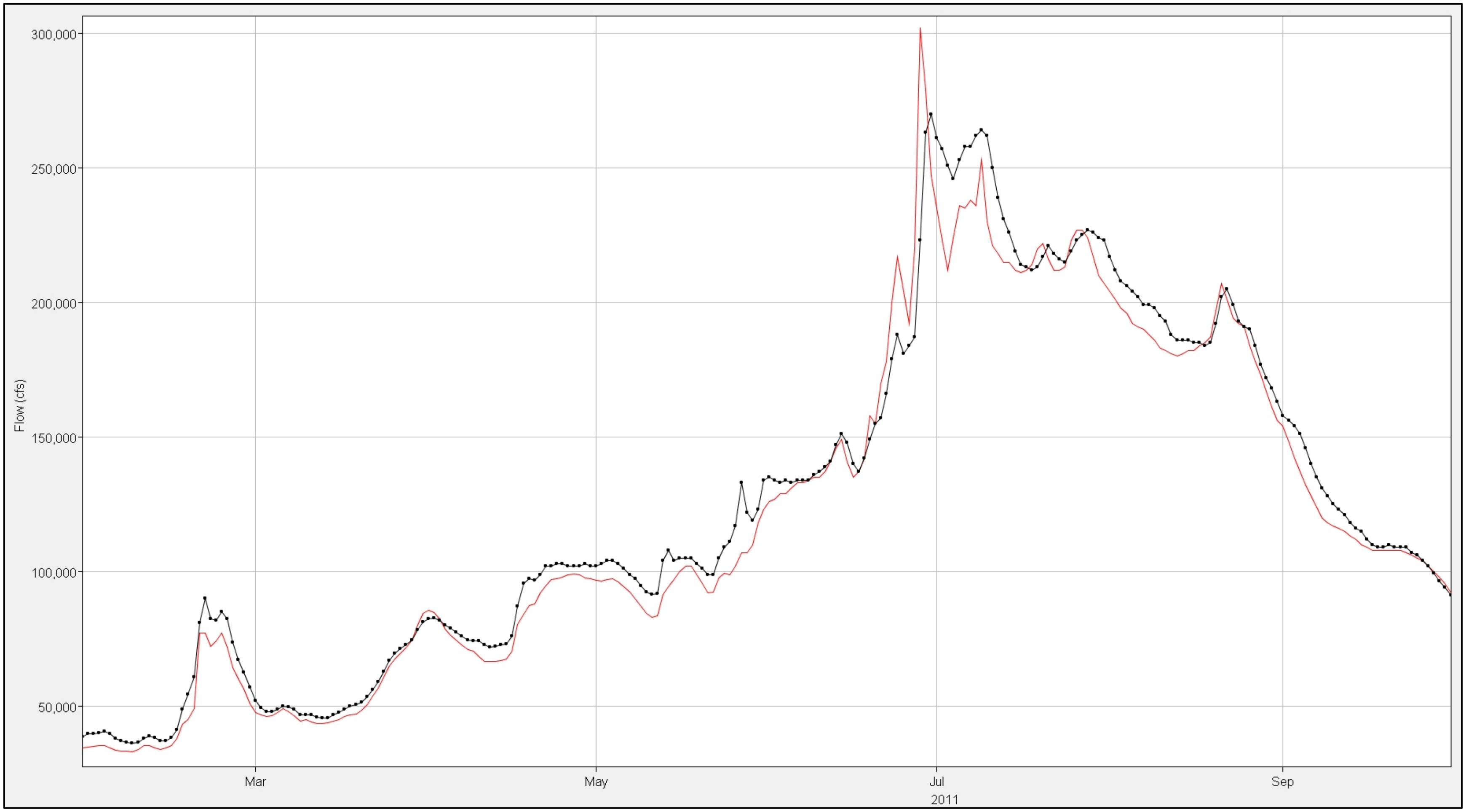

Figure 8-26: Straddle-Stagger routing results for Rulo-St. Joseph during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

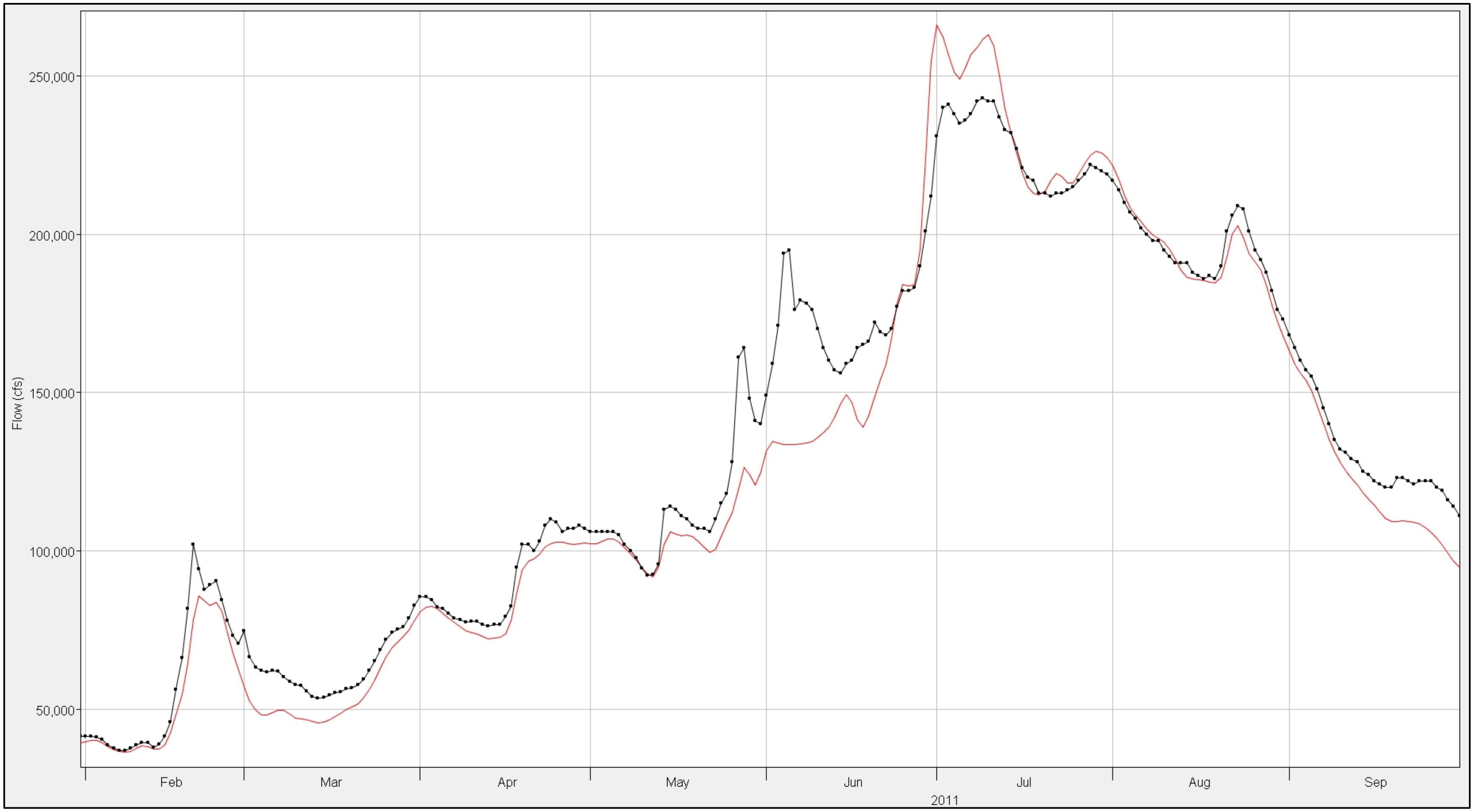

Figure 8-27: Straddle-Stagger routing results for St. Joseph-Kansas City during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

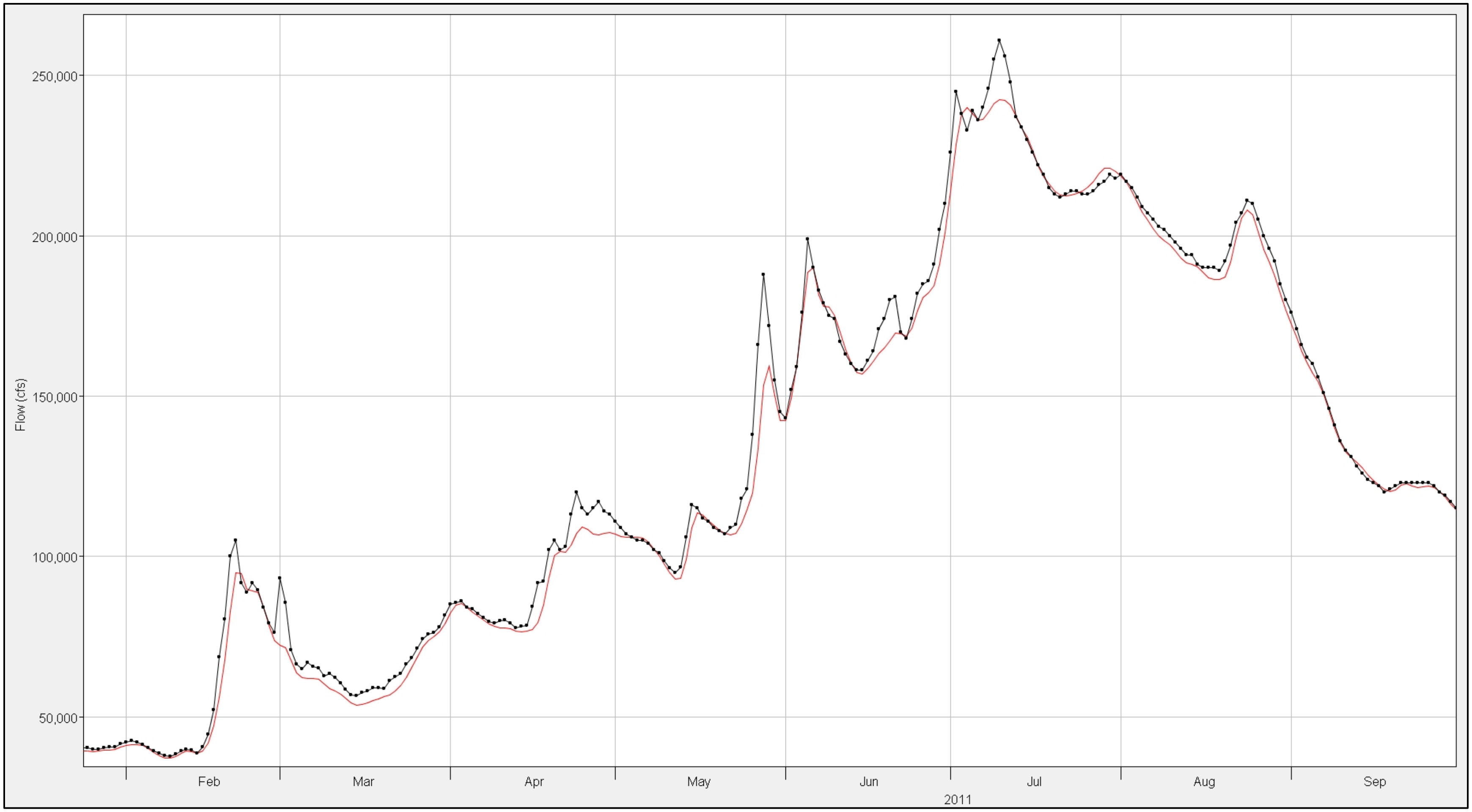

Figure 8-28: Straddle-Stagger routing results for Kansas City-Waverly during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

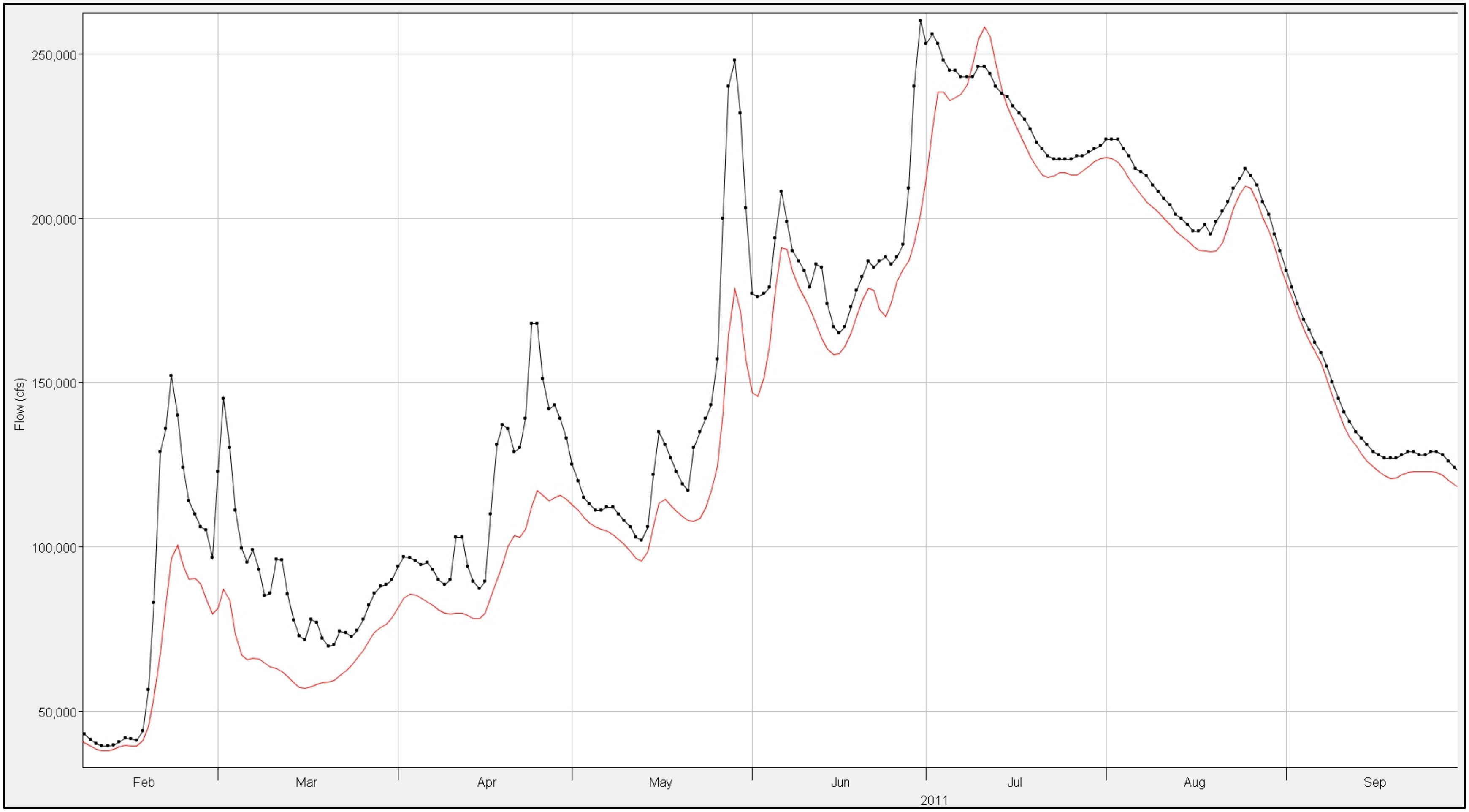

Figure 8-29: Straddle-Stagger routing results for Waverly-Boonville during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

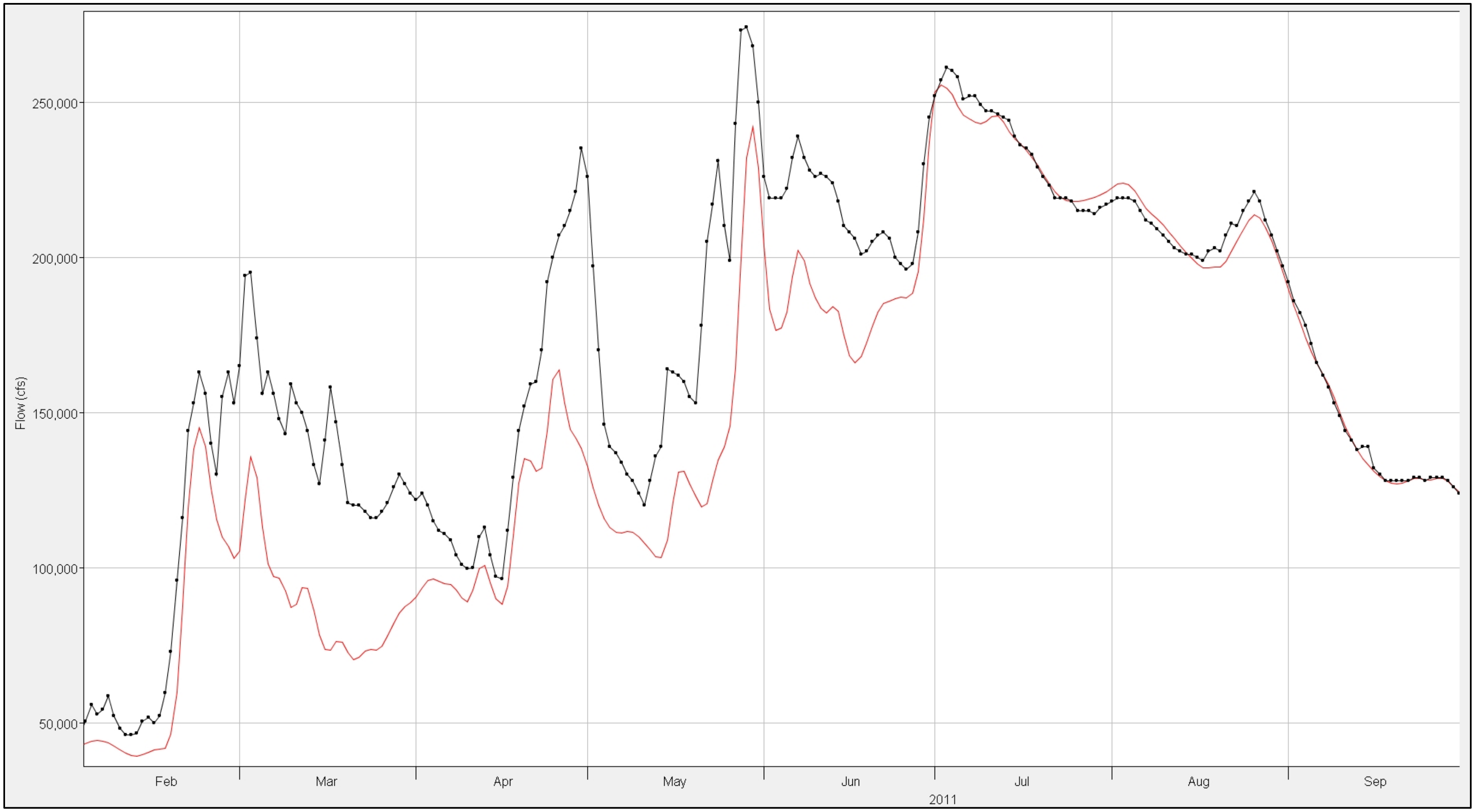

Figure 8-30: Straddle-Stagger routing results for Boonville-Hermann during 2011. Red data are the Straddle-Stagger data and black data are the observed data.

8.6.3 Straddle-Stagger vs. Coefficient Routing Plots

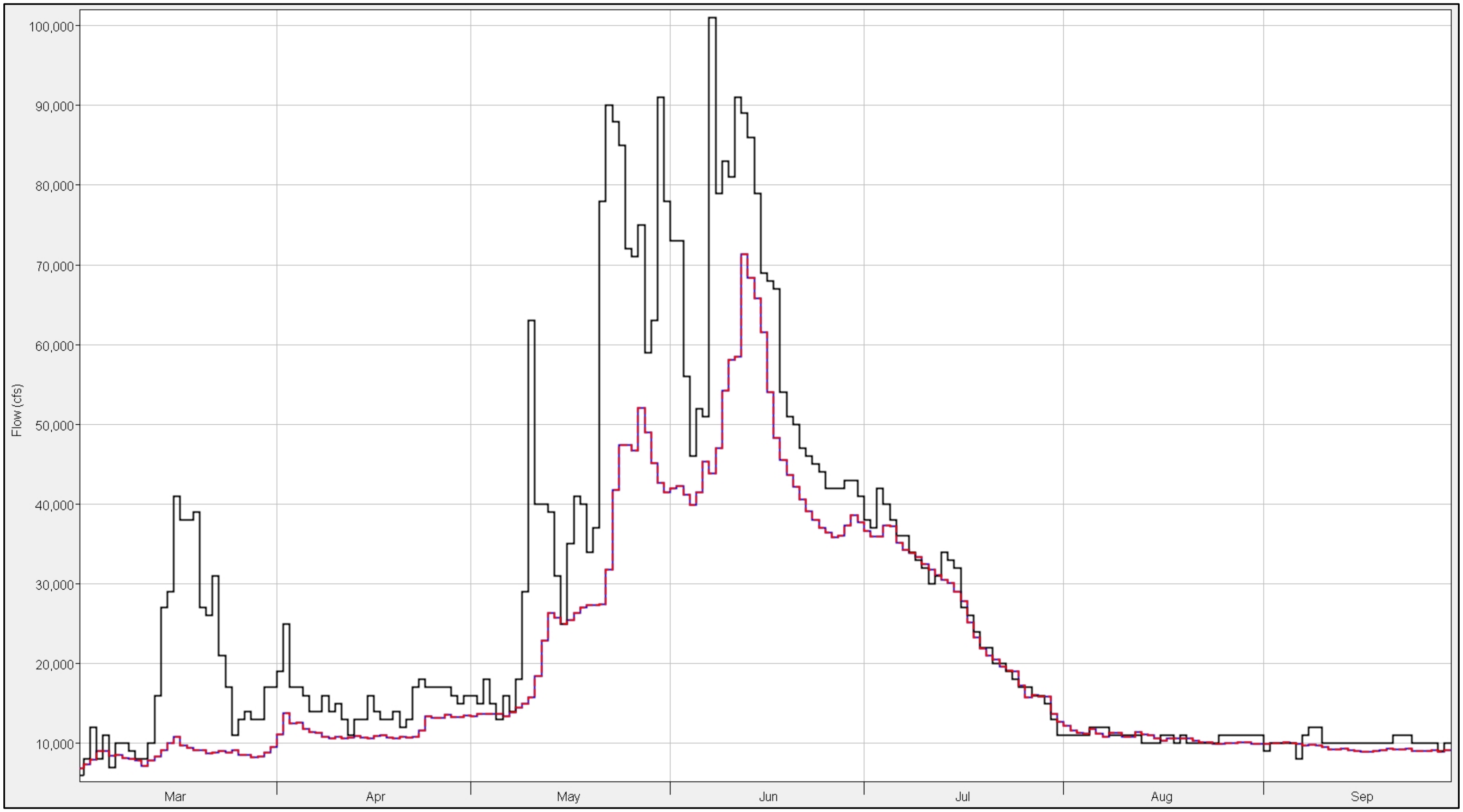

Figure 8-31: Straddle-Stagger vs. Coefficient routing results for Landusky, MT-Fort Peck during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

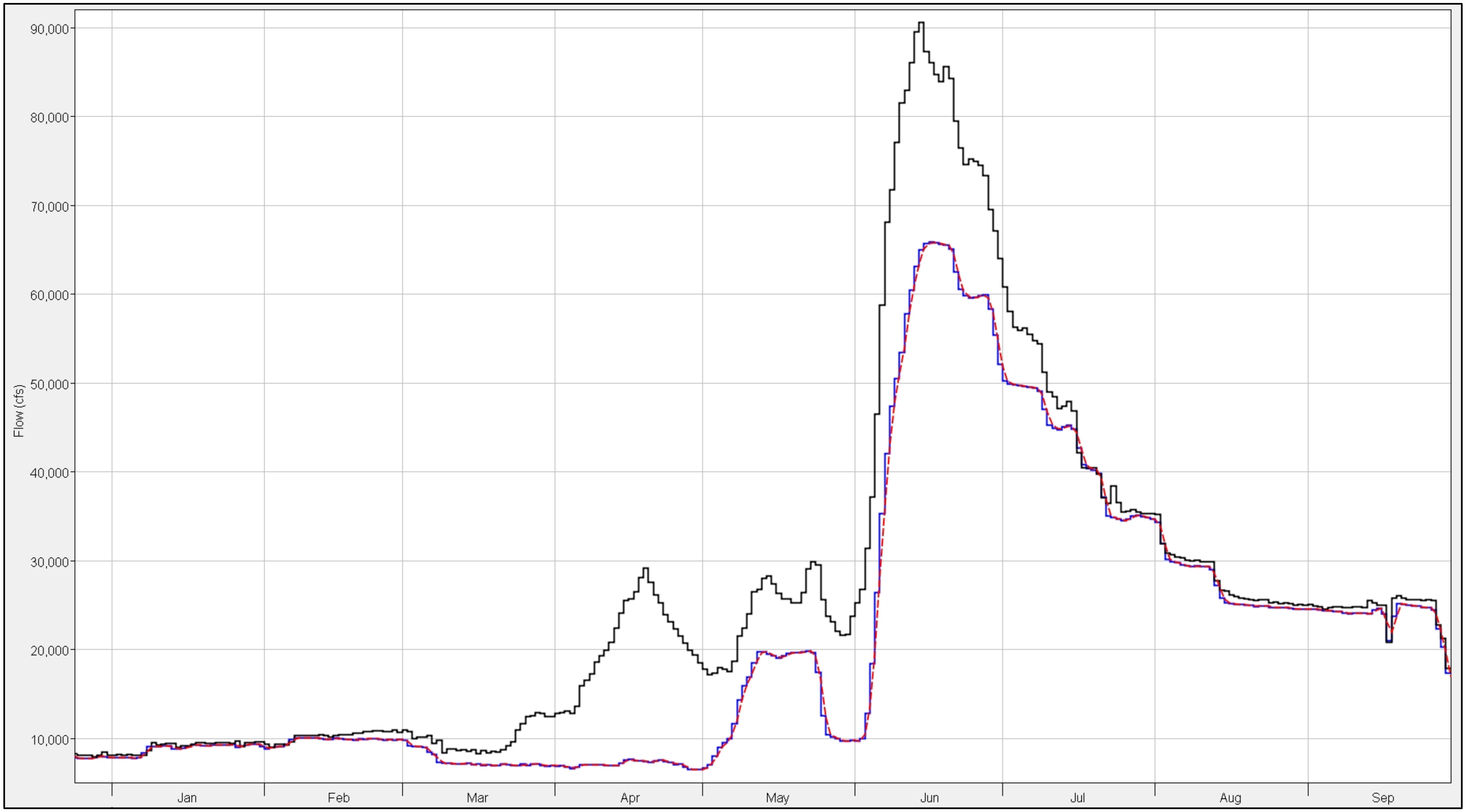

Figure 8-32: Straddle-Stagger vs. Coefficient routing results for Fort Peck-WPMT during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

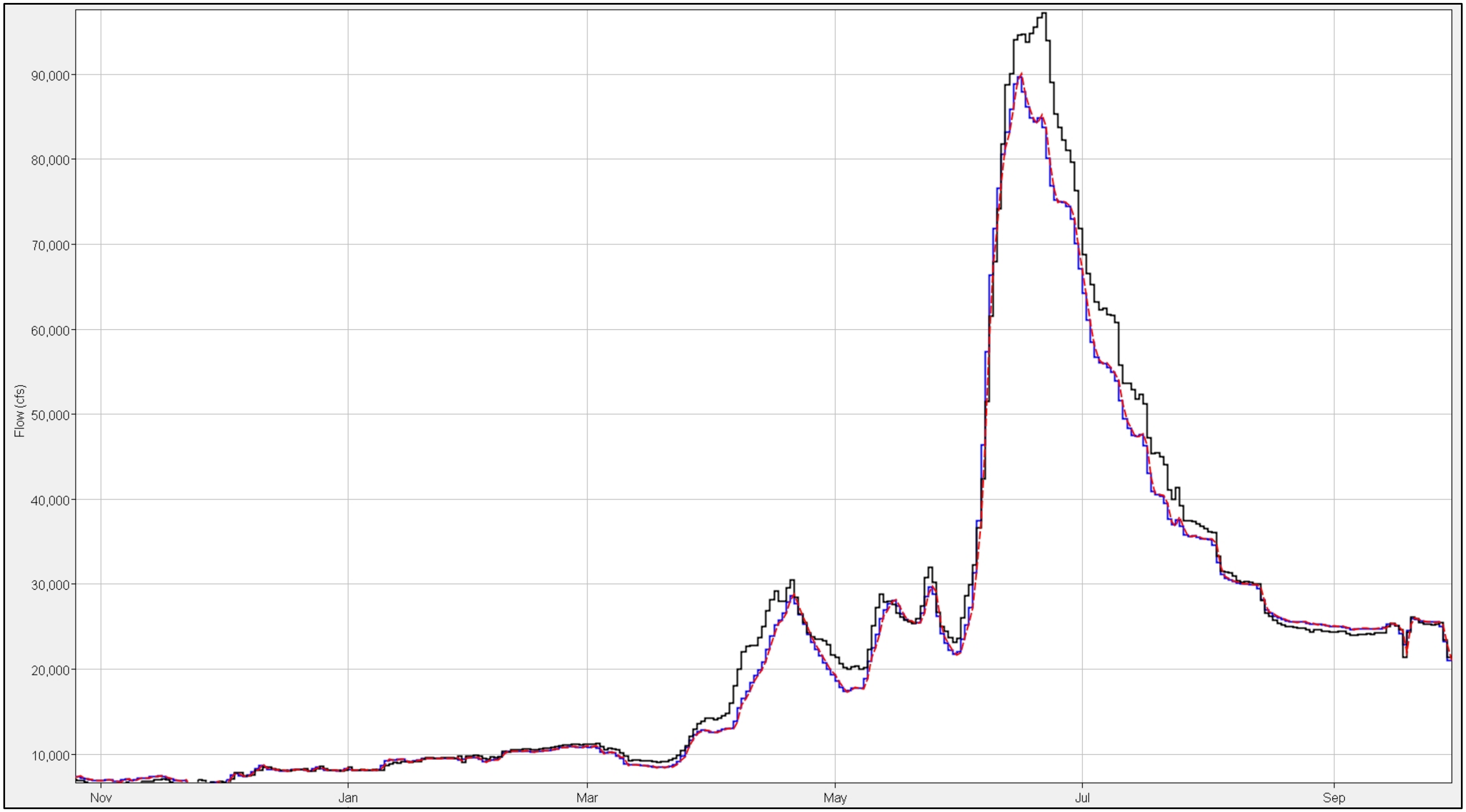

Figure 8-33: Straddle-Stagger vs. Coefficient routing results for WPMT-CLMT during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

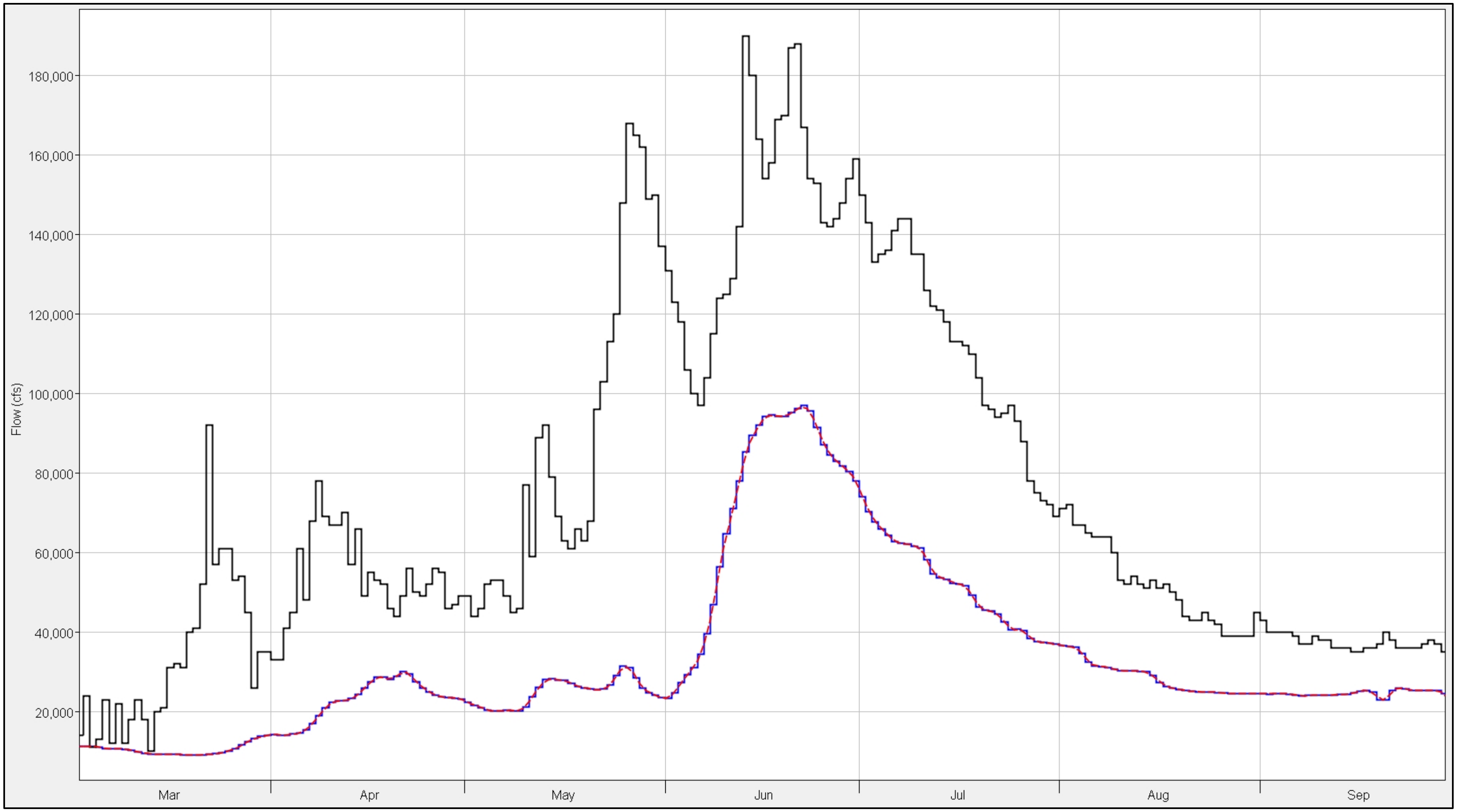

Figure 8-34: Straddle-Stagger vs. Coefficient routing results for CLMT-Garrison during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

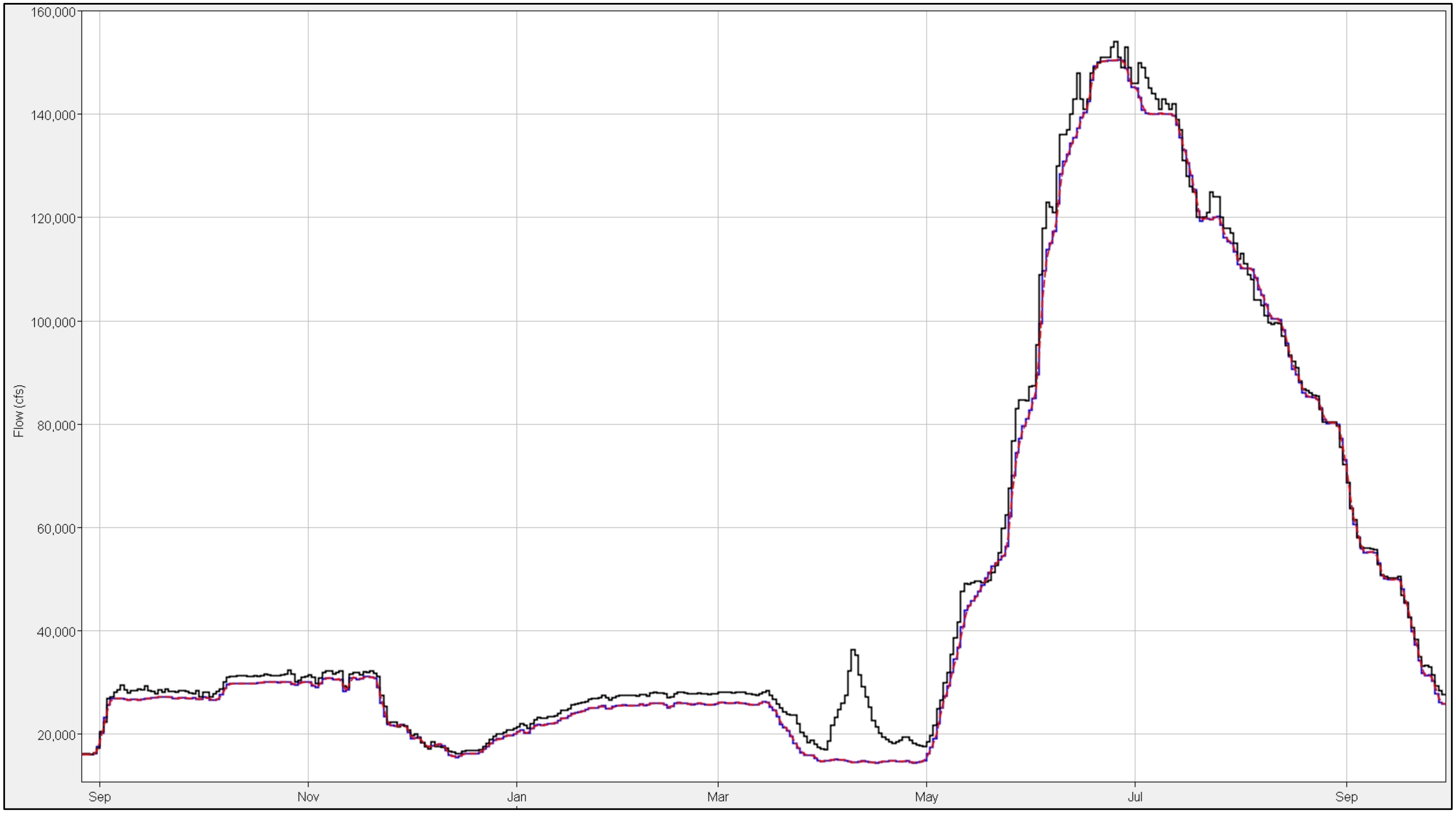

Figure 8-35: Straddle-Stagger vs. Coefficient routing results for Garrison-BIS during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

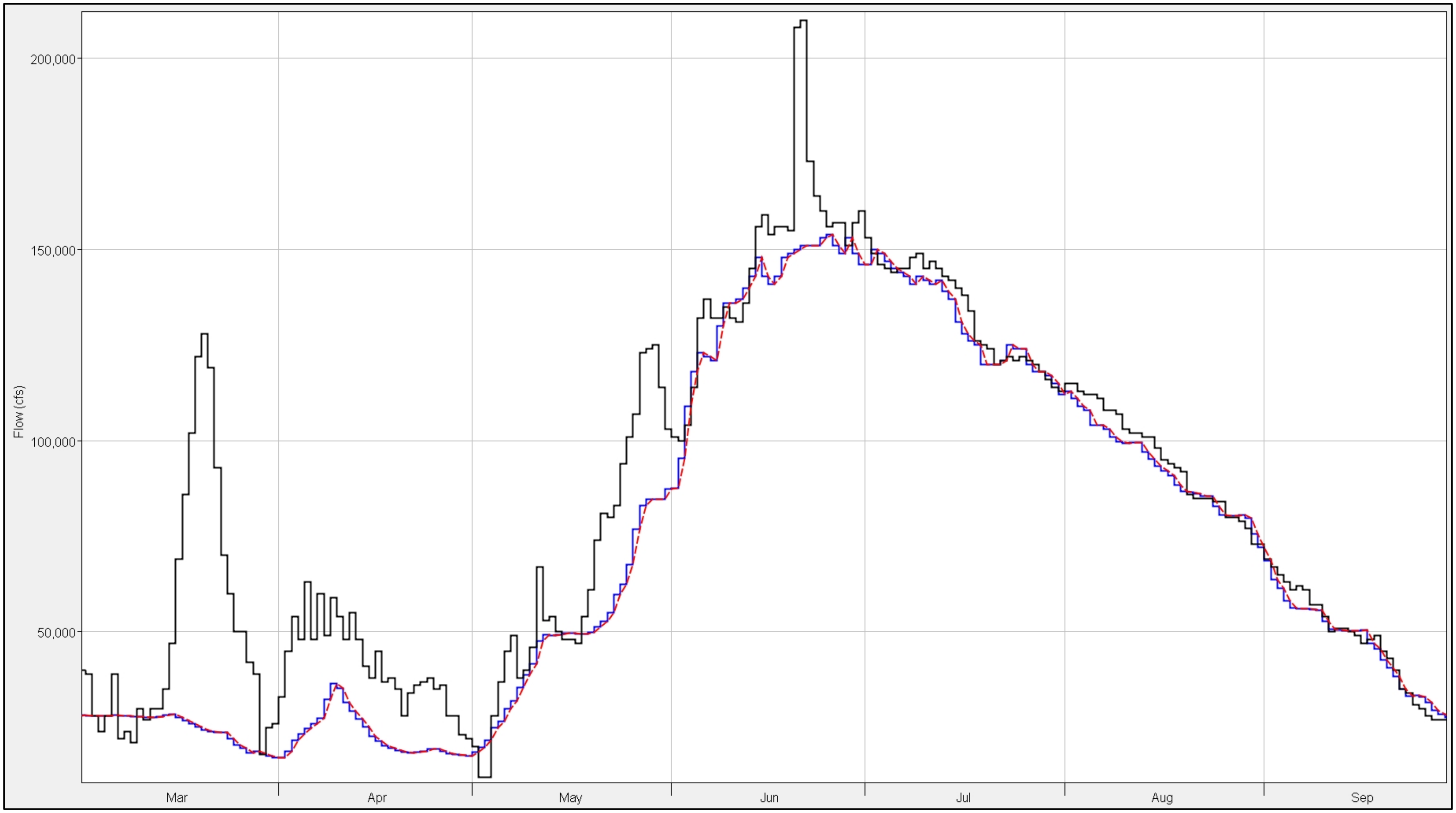

Figure 8-36: Straddle-Stagger vs. Coefficient routing results for BIS-Oahe during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

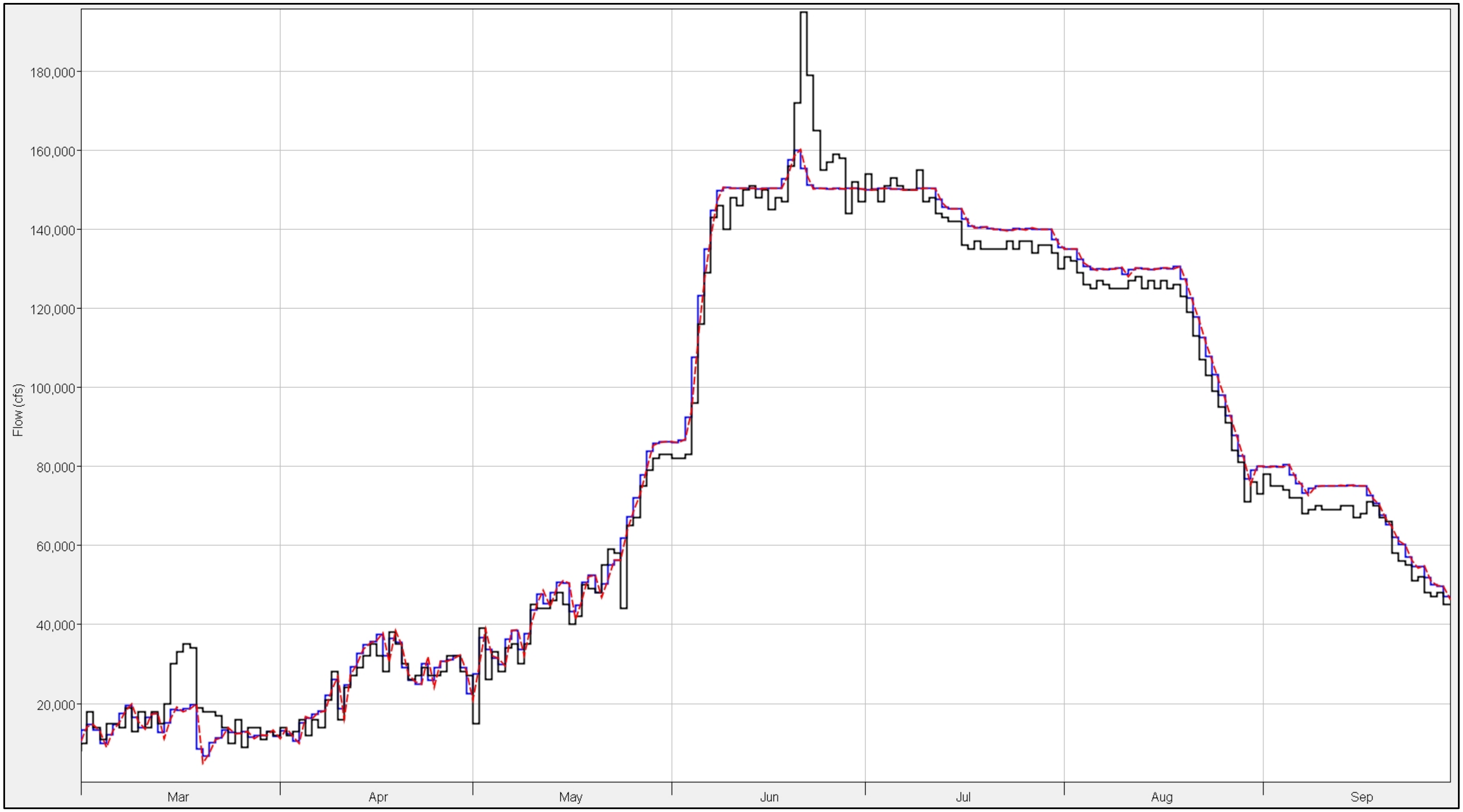

Figure 8-37: Straddle-Stagger vs. Coefficient routing results for Oahe-Big Bend during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

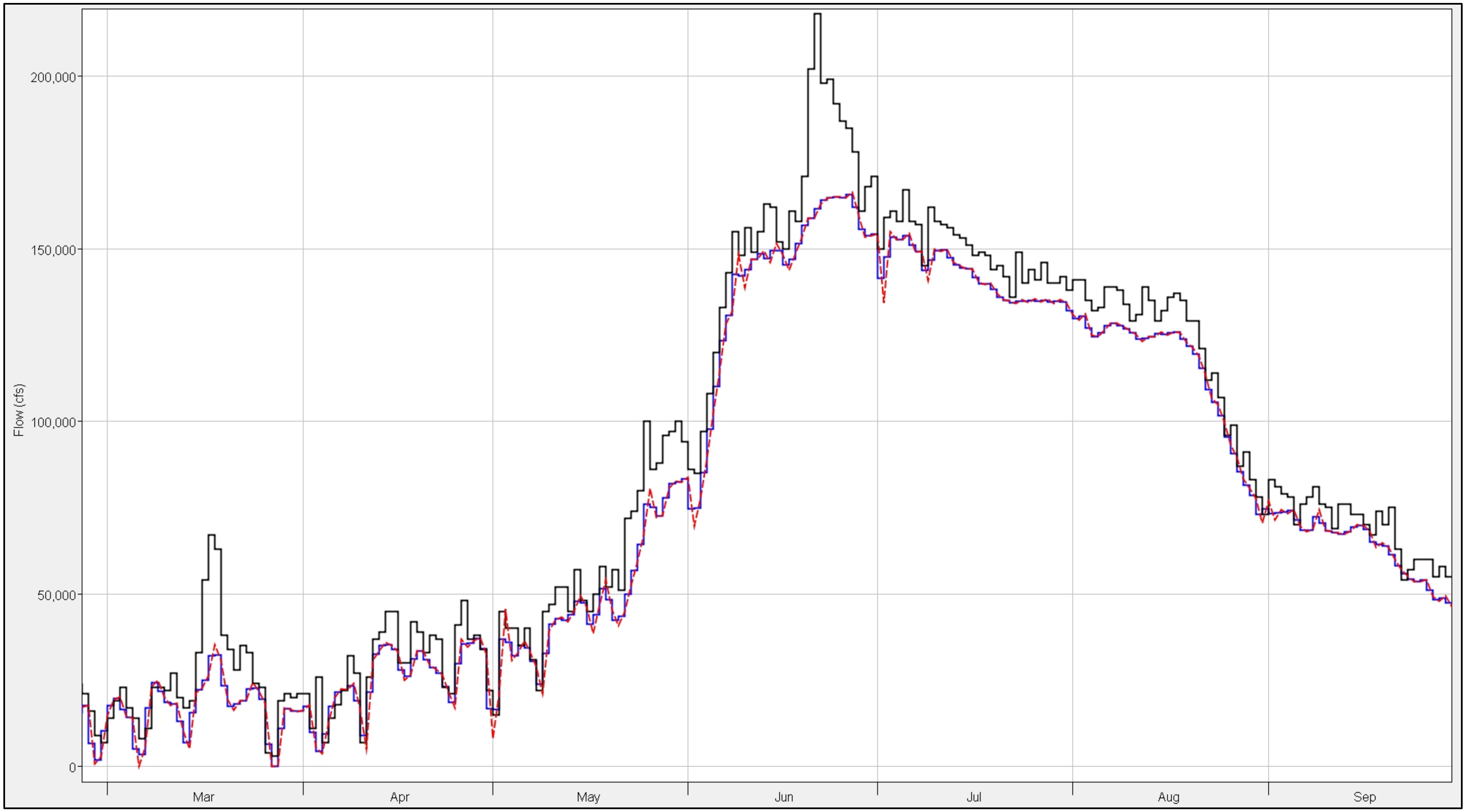

Figure 8-38: Straddle-Stagger vs. Coefficient routing results for Big Bend-Fort Randall during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

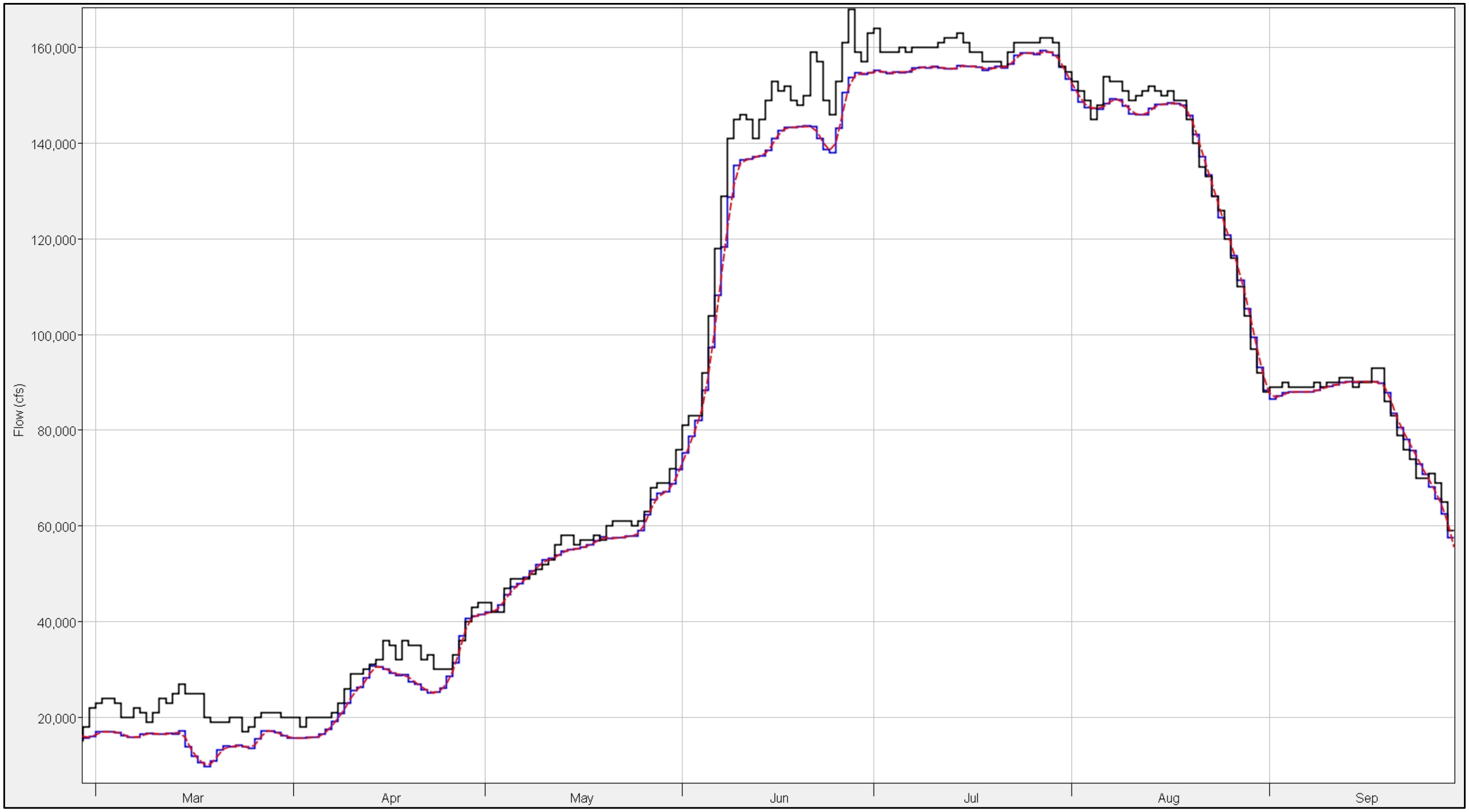

Figure 8-39: Straddle-Stagger vs. Coefficient routing results for Fort Randall-Gavins Point during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

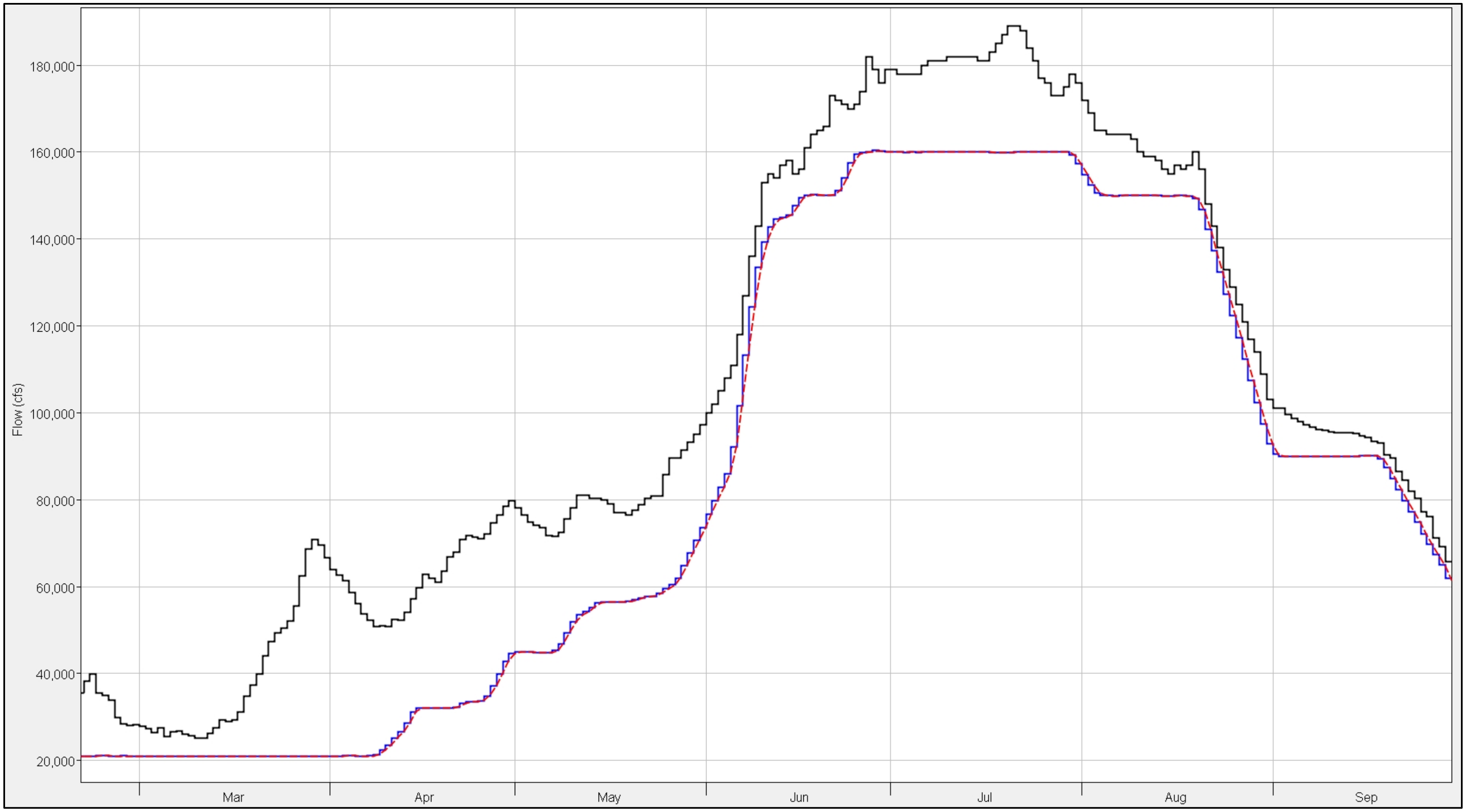

Figure 8-40: Straddle-Stagger vs. Coefficient routing results for Gavins Point-Sioux City during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

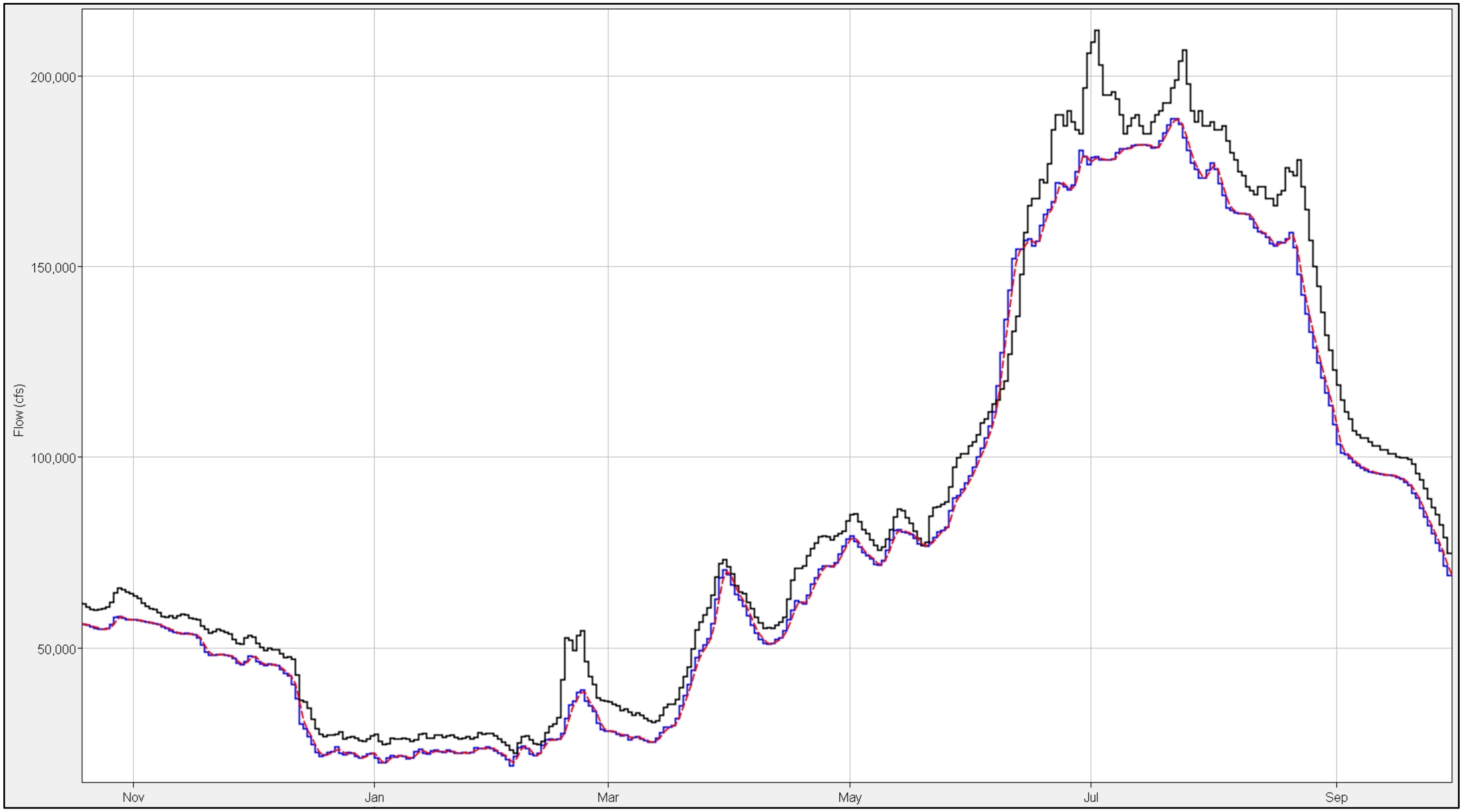

Figure 8-41: Straddle-Stagger vs. Coefficient routing results for Sioux City-Omaha during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

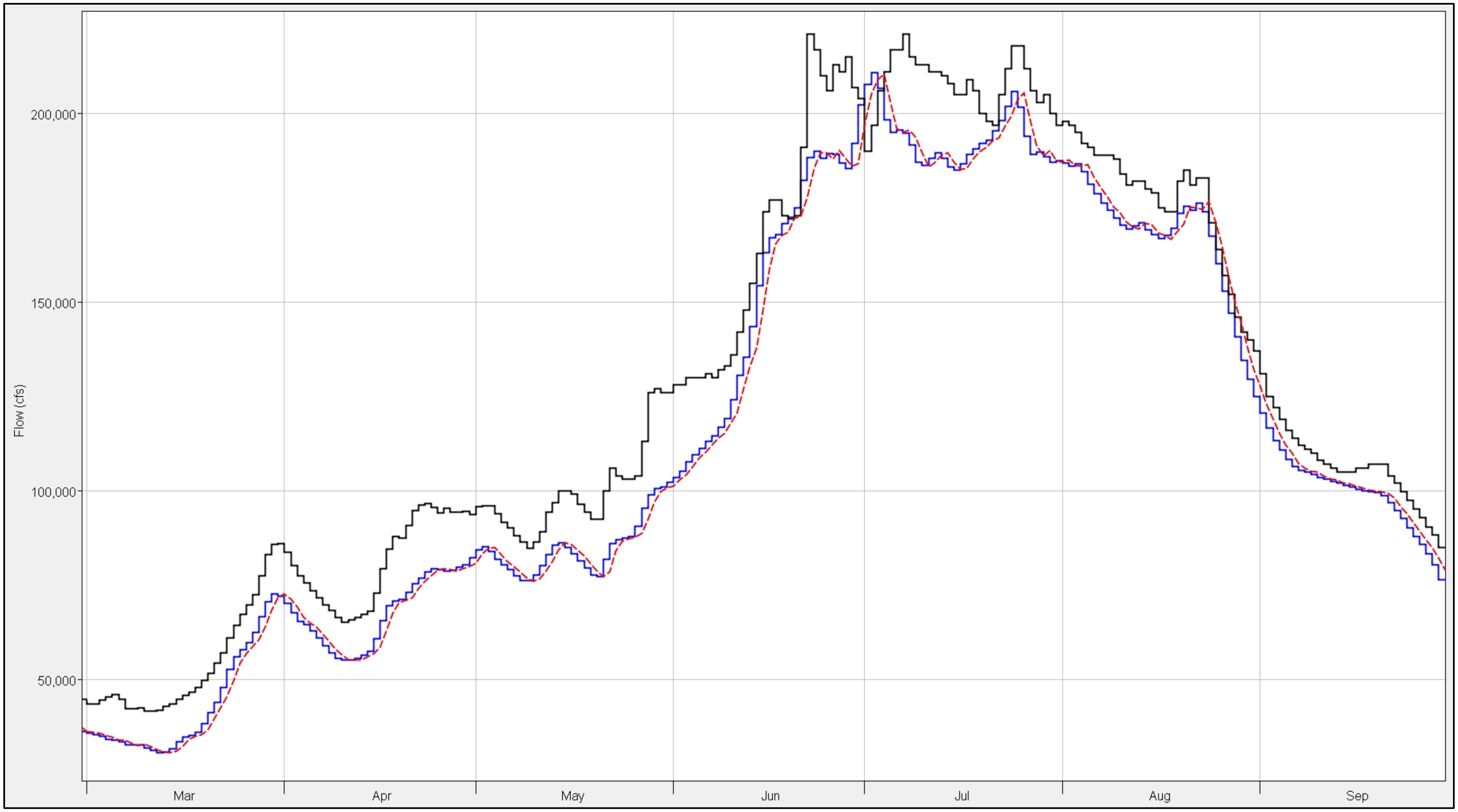

Figure 8-42: Straddle-Stagger vs. Coefficient routing results for Omaha-Nebraska City during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

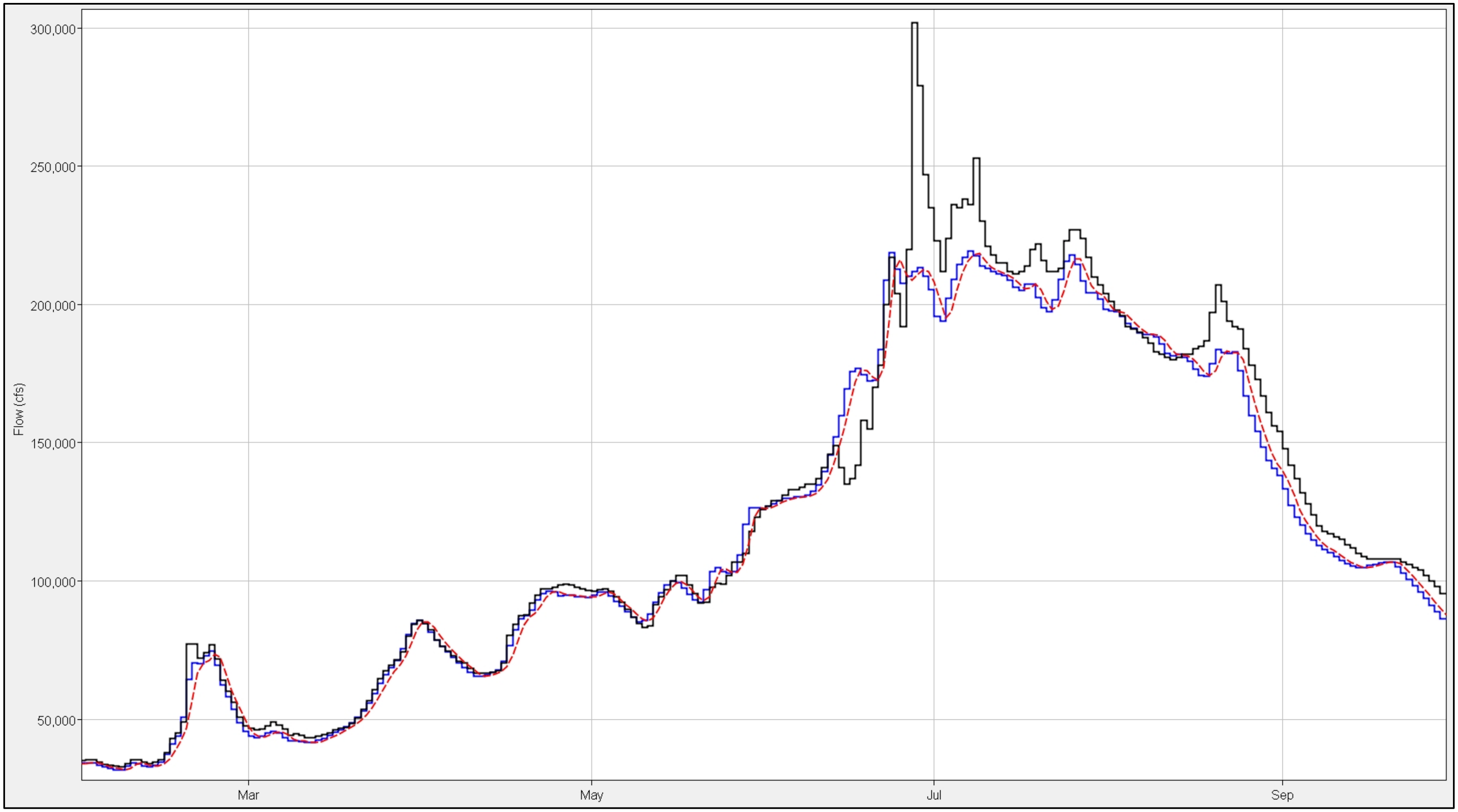

Figure 8-43: Straddle-Stagger vs. Coefficient routing results for Nebraska City-Rulo during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

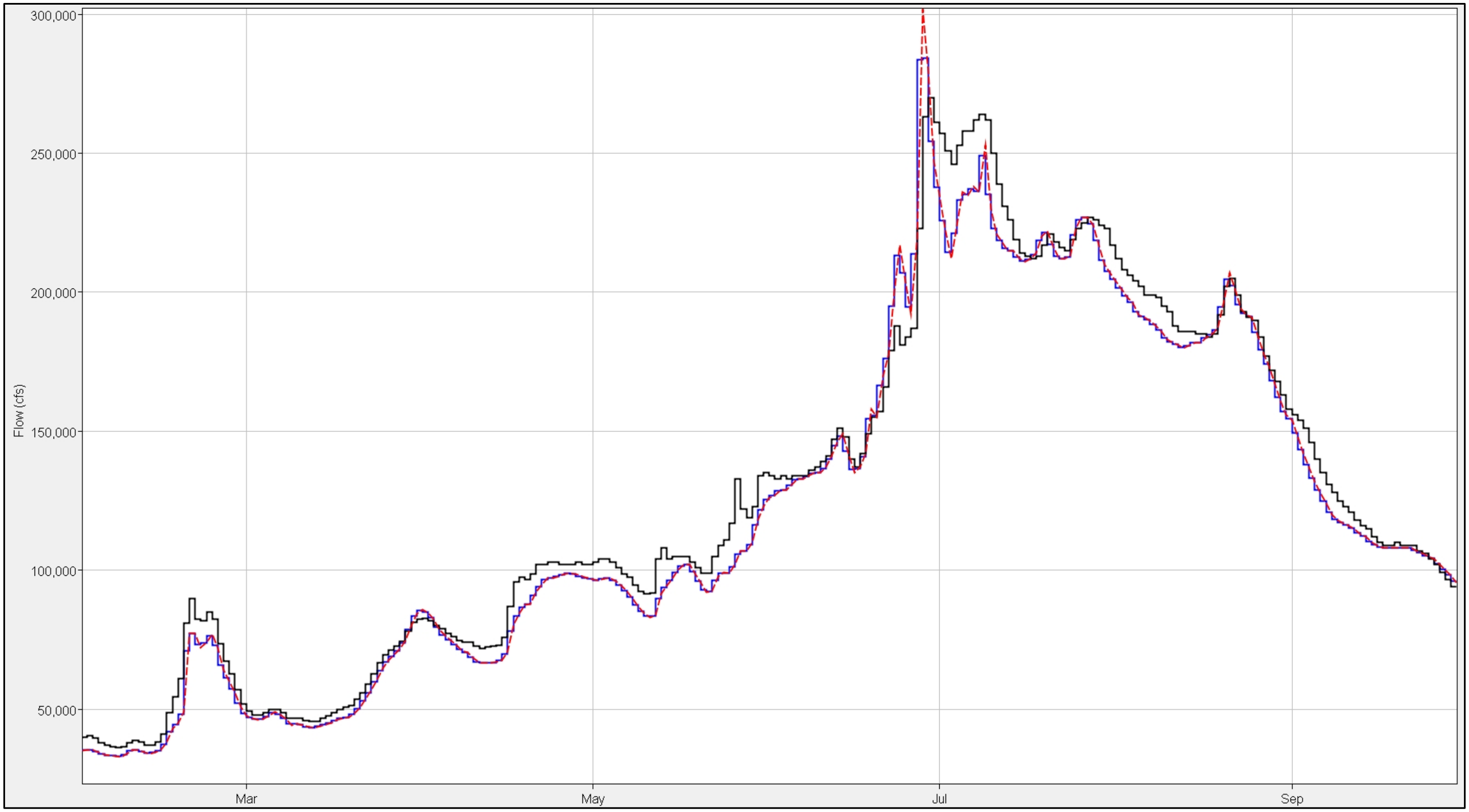

Figure 8-44: Straddle-Stagger vs. Coefficient routing results for Rulo-St. Joseph during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

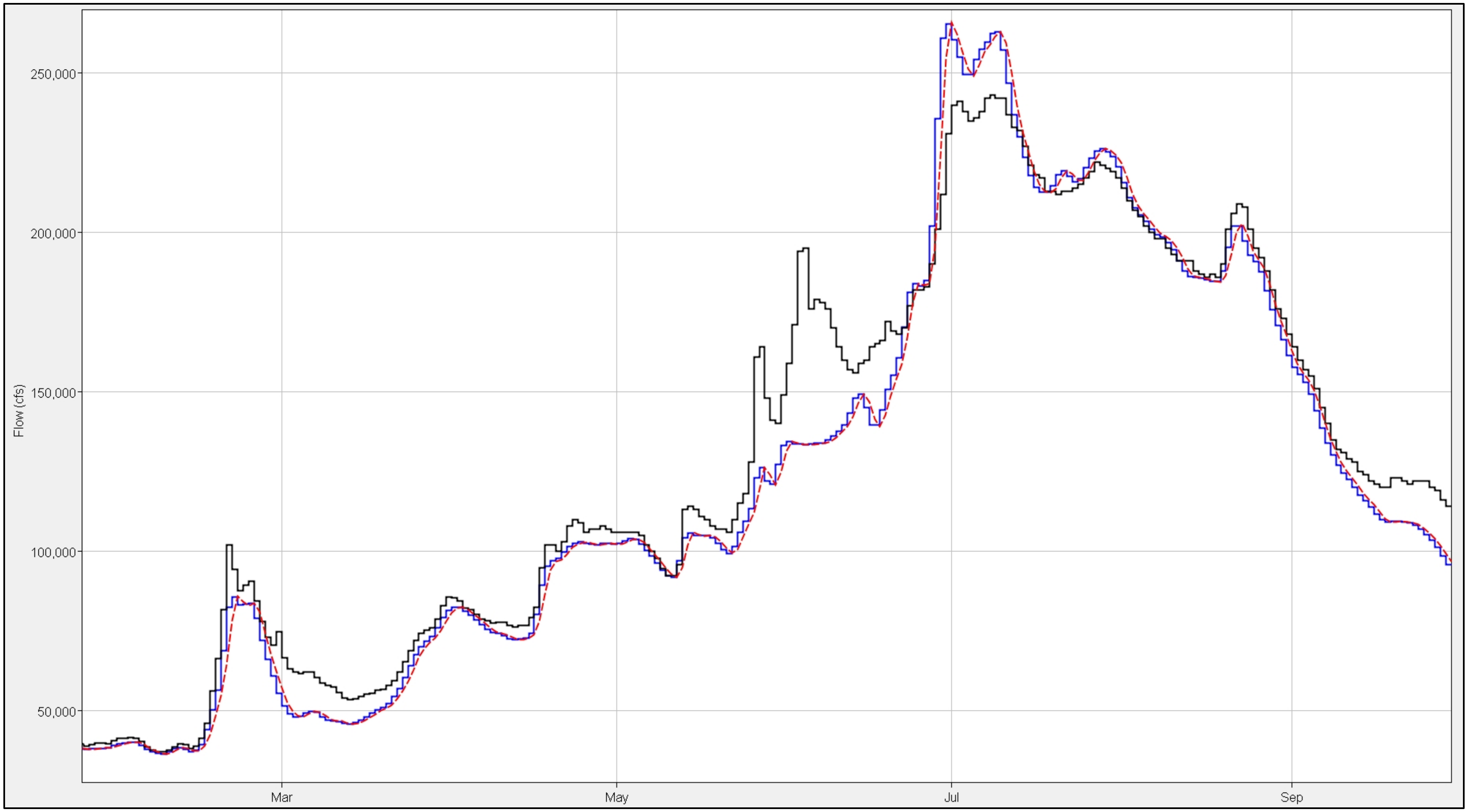

Figure 8-45: Straddle-Stagger vs. Coefficient routing results for St. Joseph-Kansas City during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

Figure 8-46: Straddle-Stagger vs. Coefficient routing results for Kansas City-Waverly during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

Figure 8-47: Straddle-Stagger vs. Coefficient routing results for Waverly-Boonville during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

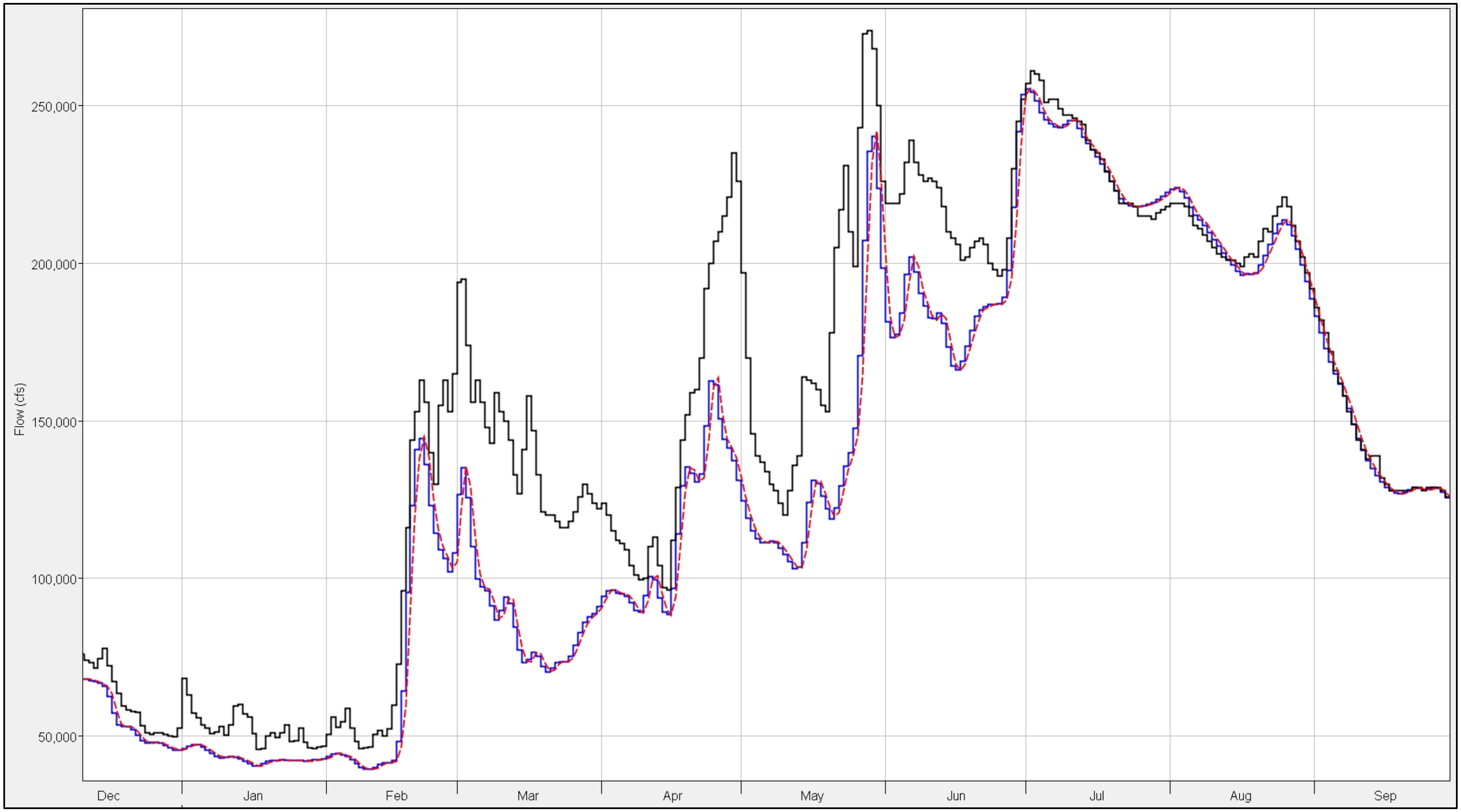

Figure 8-48: Straddle-Stagger vs. Coefficient routing results for Boonville-Hermann during 2011. Red data are the Straddle-Stagger data, blue data are the Coefficient Routing data, and black data are the observed data.

9 APPENDIX C – ELEVATION-AREA-CAPACITY CURVES

Table 9-1: Fort Peck E-A-C curves.

Elevation (ft MSL)	1938		1961		1972		1986		2007	
	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)
2030	0	0			0	0	0	0	0	0
2040	622	2,181			481	1,215	418	1,052	292	620
2050	2,655	16,992			1,523	11,910	1,480	11,057	1,479	9,482
2060	6,248	59,718			4,309	36,742	4,264	35,511	3,802	31,318
2070	11,523	146,693			10,211	105,667	10,043	103,630	9,100	88,046
2080	18,245	294,187			15,710	241,136	15,440	236,456	14,882	213,827
2090	25,561	513,490			21,562	421,887	21,086	413,557	20,221	385,404
2100	32,990	806,331			29,752	683,040	28,711	663,076	27,343	619,756
2110	41,900	1,177,239			37,914	1,018,844	37,047	990,681	35,709	933,443
2120	52,600	1,648,861			48,893	1,448,197	48,098	1,410,784	46,360	1,335,932
2130	63,342	2,229,806			61,013	1,999,578	60,371	1,955,609	58,579	1,861,991
2140	73,836	2,915,274			71,231	2,664,321	70,442	2,613,376	69,608	2,506,539
2150	84,458	3,707,094			80,779	3,422,616	79,683	3,362,492	79,022	3,252,813
2160	96,052	4,607,263			91,512	4,283,325	90,348	4,211,053	89,461	4,087,903
2170	109,574	5,633,247			105,630	5,261,144	104,794	5,178,658	103,394	5,045,002
2180	124,519	6,802,725			120,435	6,398,446	119,809	6,309,129	118,608	6,156,918
2190	140,022	8,125,401			135,050	7,670,171	134,099	7,573,749	132,175	7,415,889
2200	155,595	9,603,732			151,509	9,103,662	149,655	8,993,728	146,595	8,801,156
2210	171,820	11,239,176			167,734	10,700,542	164,592	10,565,907	163,400	10,349,820
2220	189,155	13,043,127			184,632	12,460,490	179,404	12,286,952	180,590	12,069,610
2230	207,287	15,024,749			203,422	14,398,579	200,565	14,169,679	201,130	13,964,500
2240	226,543	17,191,882			225,265	16,536,942	226,691	16,309,409	225,065	16,094,980
2250	246,486	19,557,492			248,844	18,908,686	245,898	18,687,731	245,405	18,462,840
2260					272,182	21,513,811	260,066	21,214,285	262,180	21,000,000

Table 9-2: Garrison E-A-C curves.

Elevation (ft MSL)	1960		1964		1969		1973		1979		1988		2011	
	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)
1660					0	0			0	0	0	0	0	0
1670					50	45			16	12	31	43	7	5
1680					390	2,198			459	1,748	626	2,194	460	1,566
1690					2,943	13,823			2,837	13,947	3,464	14,592	2,632	10,805
1700					10,006	72,971			10,155	74,234	10,427	75,086	9,136	57,993
1710					20,424	223,716			20,454	225,156	20,738	226,141	19,492	196,970
1720					33,343	489,398			33,369	491,353	33,765	492,365	32,467	450,235
1730					50,527	901,503			50,696	903,851	50,705	904,837	47,931	848,553
1740					69,057	1,503,890			69,553	1,509,609	69,283	1,507,914	65,344	1,410,589
1750					86,123	2,279,887			86,735	2,291,547	86,512	2,289,440	83,684	2,156,262
1760					103,703	3,227,111			103,749	3,243,579	103,501	3,237,910	101,552	3,083,880
1770					120,663	4,353,155			120,533	4,366,654	120,369	4,359,411	118,070	4,186,230
1780				5,655,000	139,081	5,644,972			139,625	5,660,645	138,809	5,646,736	136,204	5,446,709
1790				7,164,000	162,084	7,147,374			162,477	7,169,843	161,295	7,139,184	157,953	6,913,512
1800				8,924,000	190,988	8,902,478			190,359	8,923,653	188,998	8,877,219	183,545	8,609,286
1810				11,015,000	223,593	10,977,253			221,396	10,985,496	219,955	10,921,980	215,125	10,589,550
1820				13,445,000	255,681	13,374,543			251,380	13,350,318	249,665	13,275,410	247,910	12,913,020
1830				16,227,000	287,896	16,092,973			280,843	16,014,439	280,520	15,916,490	280,485	15,547,850
1840				19,361,000	326,791	19,148,446			319,936	18,990,770	320,600	18,893,560	320,190	18,528,780
1850				22,855,000	368,139	22,635,302			365,281	22,429,151	364,265	22,331,620	364,935	21,956,050
1860				28,714,000	405,966	26,504,047			407,323	26,290,764	404,810	26,176,420		25,827,400

Table 9-3: Oahe E-A-C curves.

Elevation (ft MSL)	1958		1963		1976		1989		2010	
	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)
1410	0	0	0	0	0	0	0	0	0	0
1420	388	479	141	95	94	104	107	73	44	8
1430	3,142	15,559	2,965	12,793	2,425	9,875	2,687	9,708	2,445	8,392
1440	8,144	69,670	7,597	64,642	6,754	54,231	6,995	55,360	6,485	50,377
1450	15,580	185,082	14,318	170,608	13,257	151,047	13,282	151,352	12,359	139,740
1460	24,499	385,321	22,982	356,213	21,539	324,427	20,735	322,090	19,962	299,110
1470	33,015	674,786	32,075	631,915	30,977	585,104	29,475	567,191	29,079	540,342
1480	42,040	1,047,136	41,438	998,783	40,571	944,926	39,166	912,471	39,042	881,474
1490	52,459	1,519,113	51,730	1,463,135	50,921	1,398,604	49,835	1,351,384	49,895	1,321,971
1500	63,459	2,098,234	62,784	2,035,614	62,188	1,965,744	61,420	1,909,988	61,082	1,879,701
1510	74,982	2,790,154	74,520	2,720,929	73,665	2,643,307	73,319	2,580,093	72,775	2,544,087
1520	87,973	3,602,003	87,132	3,528,919	85,492	3,440,773	85,462	3,376,665	85,356	3,335,994
1530	102,916	4,555,039	102,034	4,469,694	100,162	4,360,548	99,705	4,291,179	98,802	4,252,065
1540	119,558	5,665,381	118,947	5,575,386	117,493	5,451,212	116,560	5,373,030	115,352	5,314,664
1550	137,863	6,951,740	137,255	6,853,754	135,339	6,713,790	133,628	6,622,830	132,594	6,559,882
1560	159,859	8,433,616	159,673	8,332,298	157,881	8,170,491	155,510	8,049,792	152,181	7,968,796
1570	189,020	10,167,201	189,003	10,064,984	185,464	9,885,339	182,933	9,737,896	179,831	9,610,441
1580	221,114	12,222,428	221,076	12,120,275	217,121	11,890,306	213,150	11,711,030	212,675	11,569,960
1590	251,529	14,587,363	251,442	14,484,279	246,996	14,225,997	245,190	14,002,600	244,405	13,863,320
1600	283,829	17,259,233	283,800	17,155,559	279,626	16,839,532	281,010	16,618,390	279,520	16,461,230
1610	323,665	20,283,660	323,650	20,179,914	324,309	19,847,994	325,765	19,630,460	325,930	19,463,330
1620	402,345	23,750,945	402,327	23,646,924	372,842	23,337,619	384,075	23,136,960	385,585	22,982,900
1630		27,697,702	530,502	27,593,647	420,512	27,304,239	197,795	27,111,970		26,973,320
1640		27,722,841		27,618,786						

Table 9-4: Big Bend E-A-C curves.

Elevation (ft MSL)	1971		1975		1979		1983		1991		1997		2012	
	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)
1340	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1350	1,093	3,568	1,066	3,411	970	3,058	983	3,090	1,105	3,688	836	2,445	816	2,256
1360	6,113	33,747	6,107	33,206	5,812	30,355	5,905	30,790	6,145	33,811	5,449	27,069	5,597	27,341
1370	12,913	127,749	12,863	127,413	12,483	121,194	12,594	123,029	12,720	128,285	11,747	113,160	12,035	115,925
1380	19,706	292,088	19,622	290,551	19,217	280,150	19,260	282,725	19,178	288,203	18,307	262,285	18,464	268,103
1390	26,616	522,019	26,556	520,053	25,960	505,600	25,910	508,251	25,623	511,864	24,659	479,172	24,532	484,949
1400	34,996	825,711	34,738	822,796	33,911	800,465	33,603	801,915	32,941	801,525	31,842	756,297	31,692	759,803
1410	45,576	1,223,842	45,317	1,216,897	44,899	1,186,424	44,679	1,183,202	43,898	1,173,817	43,146	1,119,548	43,478	1,122,745
1420	57,289	1,738,238	57,332	1,730,407	57,439	1,699,819	57,372	1,696,921	57,261	1,681,585	57,007	1,621,484	57,646	1,631,474
1430	68,992	2,369,650	69,295	2,363,543	69,598	2,334,939	69,284	2,330,055	70,189	2,318,770	70,615	2,259,568	71,120	2,275,184

Table 9-5: Fort Randall E-A-C curves.

Elevation (ft MSL)	1953		1962		1967		1973		1977		1981		1986		1996		2011	
	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)
1240	733	1,248	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1250	5,378	27,917	3,045	13,518	2,536	11,045	2,110	9,368	1,625	6,275	1,862	6,814	1,849	6,118	1,737	5,215	1,438	3,178
1260	11,207	110,127	9,424	78,250	8,697	66,648	7,717	55,824	7,425	46,563	7,623	48,313	7,523	49,913	7,637	48,875	7,486	46,443
1270	17,543	252,548	15,803	202,744	14,733	185,552	13,585	164,526	13,721	155,782	13,978	161,604	13,483	157,225	13,779	158,550	13,362	153,493
1280	24,279	461,328	22,931	394,927	21,299	361,757	20,220	328,193	20,377	321,323	20,390	328,222	19,907	319,981	20,061	324,578	19,276	313,738
1290	30,597	737,790	28,954	660,435	27,554	611,221	26,709	568,755	26,778	563,058	26,923	569,032	26,422	555,383	26,042	559,475	25,134	538,898
1300	36,908	1,073,281	33,869	973,089	31,578	911,014	30,707	860,337	30,696	854,868	30,700	860,594	30,678	846,562	30,297	843,949	28,936	814,716
1310	43,989	1,476,600	39,643	1,338,492	36,371	1,243,410	35,544	1,183,573	35,711	1,177,846	35,212	1,184,336	34,873	1,168,853	33,632	1,164,645	32,744	1,117,544
1320	51,503	1,953,477	45,069	1,765,786	43,107	1,640,182	42,281	1,572,921	41,966	1,570,252	40,523	1,567,781	39,787	1,544,734	37,911	1,517,486	36,100	1,469,353
1330	60,068	2,507,594	52,735	2,241,872	53,032	2,108,396	51,708	2,031,629	50,776	2,019,489	48,966	2,003,741	47,736	1,967,337	45,845	1,926,136	42,615	1,842,451
1340	70,172	3,156,164	64,790	2,824,241	66,946	2,704,215	65,053	2,610,434	64,039	2,589,583	62,908	2,560,989	61,155	2,504,173	59,783	2,439,591	57,772	2,329,032
1350	80,669	3,911,368	78,250	3,538,916	80,418	3,446,994	78,952	3,333,194	78,426	3,301,265	78,666	3,266,567	77,137	3,192,643	76,747	3,124,368	76,206	3,000,732
1360	89,985	4,768,539	89,564	4,387,428	90,871	4,309,984	90,090	4,187,121	90,186	4,155,848	90,887	4,125,597	90,214	4,044,439	89,808	3,971,266	89,779	3,849,085
1370	97,907	5,709,863	98,022	5,327,738	98,976	5,262,357	98,365	5,132,497	98,417	5,101,953	98,511	5,072,842	98,514	4,992,846	98,438	4,916,698	98,323	4,791,967
1380	105,559	6,726,414	105,837	6,347,239	106,605	6,289,050	105,995	6,153,801	106,001	6,123,540	106,029	6,094,354	105,987	6,013,896	106,176	5,939,141	106,236	5,814,844
1390	113,668	7,821,409	113,602	7,444,414	114,507	7,394,667	113,733	7,252,463	113,695	7,222,043	113,868	7,193,985	114,284	7,113,260	114,052	7,040,305	114,126	6,916,642

Table 9-6: Gavins Point E-A-C curves.

Elevation (ft MSL)	1966		1970		1975		1980		1985		1995		2007		2011	
	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)	Area (acres)	Capacity (ac-ft)
1160		0		0	0	0	0	0	0	0	0	0	0	0	0	0
1170		3,912		3,695	933	3,695	727	2,683	500	1,707	451	1,053	371	728	232	325
1180		28,393		26,426	4,252	26,380	3,976	22,650	3,489	17,687	3,486	15,631	3,393	14,543	2,855	11,211
1190		102,878		98,340	10,889	98,041	10,727	92,726	10,768	82,480	10,276	74,110	9,921	71,711	9,828	61,148
1200		265,196		255,885	20,666	252,880	20,313	245,285	20,234	239,709	19,713	223,547	18,819	215,126	18,259	209,203
1210		535,314		521,648	32,356	516,783	31,961	503,764	31,414	491,701	30,880	469,928	29,956	450,070	28,552	428,033
1220		920,674		902,211	44,331	901,209	44,257	886,525	42,323	867,354	42,677	841,701	43,373	815,335	41,878	782,807
1230					56,040	1,402,946	56,103	1,388,132	51,114	1,333,327	56,132	1,322,734			54,625	1,265,235