Missouri River Recovery Program Management Plan Environmental Impact Statement
HEC-RAS Modeling Alternatives Report

DRAFT

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USACE, Northwestern Division
Omaha and Kansas City Districts

EXECUTIVE SUMMARY

Hydrologic analysis was performed to support the Missouri River Recovery Program (MRRP) evaluation for the Management Plan (ManPlan) and integrated Environmental Impact Statement (EIS). This document summarizes alternative analysis performed using HEC-RAS (RAS).

In a previous effort (USACE 2015b), five separate HEC-RAS models were developed for the Missouri River reaches from downstream of Ft. Peck Dam to the mouth at St. Louis (Ft Peck Dam to Lake Sakakawea, Garrison Dam to Lake Oahe, Ft Randall Dam to Lewis and Clark Lake, Gavins Point Dam to Rulo, NE, and Rulo, NE, to the mouth at St. Louis). The model geometry and calibration efforts vary for each of the model reaches. Models were constructed from the best available geometry and calibrated. Each model can generally be thought of as representative of 2012 conditions as documented in USACE 2015b.

Hydrologic analysis utilized a period of record (POR) methodology to evaluate alternative conditions. Flows were developed for the Missouri River basin for the period of record used in the RAS analysis from March 1930 through December 2012. Therefore, the POR consists of 82 full years of record from 1931 through 2012 with a model stability and initial startup period in 1930. All flows were corrected to current level depletions to reflect basin water development. Therefore, comparison of hydrologic model results from either HEC-ResSim (ResSim) or RAS to observed conditions is not possible.

Alternative conditions were simulated through the reservoir system using ResSim. The results were used to provide reservoir releases to the RAS models. ResSim discussion is provided in a separate report.

Alternative analysis was performed using the five separate HEC-RAS calibrated current condition models. The HEC-RAS models were revised for each alternative by adding pallid sturgeon habitat to the current condition models downstream of Gavins Point Dam. All HEC-RAS modeling efforts are for the current geomorphic condition only. No adjustments were made to the models to reflect future aggradation / degradation.

Results from the HEC-RAS models were provided to Human Considerations (HC) team members for the comparison of alternative conditions. All model results are based on a simulated period of record routed through reservoir models to test reservoir rule changes and alternative condition river geometries. POR flows represent a hypothetical condition with all flows corrected to current water development levels within the basin. All model results are based on the stage-flow relationship developed from the model calibration period and differences in future habitat quantities between alternatives. Variations in the stage-flow relationship due to past and future aggradation / degradation are not included. Model geometry for all alternatives, including the no action, has been altered from the current condition. In summary, ***none of the alternative analysis hydrologic model results should be used to estimate flow-frequency, stage-frequency, or stage-flow relationships. Model results are suitable for comparison between study alternatives, comparison to historic events or observed conditions is not meaningful.***

Statistical comparisons of results between alternatives were performed for the POR. Critical factors that should be considered when comparing results between alternatives include:

1) Small number of pulses
2) Reservoir releases from the Mainstem System as calculated by ResSim
3) The habitat additions to the river geometry
4) Storage changes within the river and floodplain
5) Timing of reservoir releases and downstream inflows, combined with HEC-RAS routing, during the POR
6) HEC-RAS output interval may mask minor differences
7) Comparison of results on a POR basis can mask impacts due to flow changes. For example, an alternative with high NED benefits over the long term could have larger impacts than other alternatives in a single year.

The performed hydrologic evaluation of the complex Missouri River System provides a powerful alternative analysis tool for assessing differences between alternatives. However, comparison between alternatives should recognize that minor and insignificant differences can occur due to many factors that were identified for RAS modeling analysis uncertainty and limitations summarized as:

1) The dynamic Missouri River, with significant sediment transport, could affect future geometry and constructed habitat
2) Climate change and natural climate variability could affect historic POR inflows
3) POR has limited of number of implemented pulses for several alternatives which restricts the ability to evaluate possible impacts
4) No analysis was performed to assess the potential for change in flood risk on the Missouri River System (reservoirs and levees)
5) Riverbed and floodplain aggradation / degradation trends are not included in static HEC-RAS modeling
6) POR flow record required the estimation of ungaged inflow, also flow sources could be different
7) Levee performance and interior drainage analysis was simplified
8) Simplifying assumptions were necessary when constructing HEC-RAS models

An interior drainage evaluation was also performed at four selected locations using the HEC-RAS alternative condition model and HEC-HMS models that were used to develop inflows. Uncertainties regarding the interior drainage pump operation and culvert sediment levels were evaluated with a sensitivity analysis. Analysis demonstrated that these inputs have a high impact on results.

A brief channel capacity evaluation was performed to provide an indication of the flow rate at which flow begins to leave the main channel and enter the floodplain. The estimated channel capacity varies considerably within the reach and may change over time. Following the channel capacity estimates, an evaluation of flood potential was conducted at two locations. Analysis determined that alternative flow pulse releases exceed channel capacity within the Fort Randall reach downstream of the Niobrara River confluence. Within the Nebraska City area, the change in flood potential varies with some flow pulse alternatives showing a change in flood potential.

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ACRONYMS

AM…….Adaptive Management

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

BSNP..... Bank Stabilization and Navigation Project

EIS…….Environmental Impact Statement

ESH……...Emergent Sandbar Habitat

HC ..... Human Considerations

HEC ..... Hydrologic Engineering Center

ManPlan…….Management Plan

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

MRRP ..... Missouri River Recovery Program

NWK…….. Northwest Division Kansas City District

NWO…… Northwest Division Omaha District

POR..... Period of Record

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

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

RPA……...Reasonable and Prudent Actions

SWH…….Shallow Water Habitat

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

USACE…… United States Army Corps of Engineers

USFWS…….United States Fish and Wildlife Service

USGS ..... United States Geological Survey

1 INTRODUCTION

A series of hydrologic evaluations were conducted in support of the Missouri River Recovery Program (MRRP) evaluation for the Management Plan (ManPlan) and Integrated Environmental Impact Statement (EIS). The various hydrologic evaluations are summarized in the *Missouri River Recovery Program Management Plan Environmental Impact Statement, Summary of Hydrologic Engineering Analysis* (USACE 2016f). This report provides documentation on the HEC-RAS (RAS) alternative analysis.

The Missouri River unsteady RAS model was created as a base model for planning studies which could be used to simulate and analyze broad scale watershed alternatives. Model geometry development and calibration for the existing conditions is documented in *Missouri River Unsteady RAS Model Calibration Report* (USACE 2015b).

The objective of the RAS alternative modeling was to simulate the Management Plan alternatives which include both geometry and reservoir operation flow changes.

Outputs from the RAS modeling effort were used by conceptual and quantitative ecological models for evaluating species responses to management actions in the Environmental Effects Analysis portion of the study, and evaluation of the effects to basin stakeholder interests and authorized purposes in the Management Plan Analysis. Evaluation of the RAS modeling outputs was performed by the Human Considerations (HC) team.

2 STUDY ALTERNATIVES

Management actions, and the intended environmental effects, are described in detail within the EIS study documentation. These actions are briefly summarized in this document to provide context for those aspects of the alternatives that were implemented with RAS modeling.

Numerous management actions were developed to benefit the least tern and piping plover by providing suitable emergent sandbar habitat (ESH) within the reservoir and open river reaches. Omaha District has an existing ESH Program and has mechanically constructed ESH in the Gavins Point river reach and upper Lewis and Clark Lake at various locations during the period from 2004 to 2010. Methods to create new ESH (flow manipulation and mechanical construction) are conducted by redistributing sand within the existing river cross section. No stabilization of sandbars is included. Therefore, sandbar habitat tends to decay with time as sandbar elevation decreases due to normal sediment processes. Experience has also shown that the conveyance of the section is the same with no net change in flow area. For these reasons, ESH related actions of the alternatives were not included in the RAS models and are not included in the brief alternative summary within this document.

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

- ResSim computed flow releases were evaluated with the RAS models.

Management actions were also developed to add varying rates of additional pallid habitat in the Missouri River between Ponca, NE, and the mouth. Consequently, the new pallid habitat only affects the downstream two RAS models (Gavins to Rulo and Rulo to St. Louis). Pallid habitat, also known as shallow water habitat (SWH), was assumed to consist of interception and rearing complexes (IRC habitat) and backwater areas. Pallid habitat is created by removing river alluvial material. SWH constructed via chutes and IRC habitat is flow through and will alter current river conveyance. Backwater habitat consists of small areas that are not flow through and do not alter conveyance.

- Pallid habitat geometry changes were evaluated with the RAS models.

The following sections describe the alternatives in additional detail. Note that only those portions of each alternative that pertain to the RAS models is included in the description. Additional actions, such as ESH creation, pallid propagation, and etc. are not included in this brief description.

2.1 Background Information From 2003 BiOp

Omaha and Kansas City District have conducted numerous actions to implement reasonable and prudent alternatives from the 2003 BiOp (USFWS 2003). A brief background is summarized in this section to provide relevant information. Refer to the Affected Environment section of the Missouri River Recovery Management Plan and Environmental Impact Statement (MRRMP-EIS) for additional information regarding historic actions.

2.1.1 Shallow Water Habitat

SWH was defined as areas on the Missouri River downstream of Ponca, NE, (RM 752) with flow depths less than 5 feet and velocities less than 2 fps measured at the flow defined as the 50% exceedance discharge from the August flow duration curve(s). The SWH restoration goal stated in the 2003 BiOp is to achieve an average of 20-30 acres of SWH per mile of river. Historically, over 100 acres of SWH per river mile existed prior to Corps construction activities for the BSNP and mainstem Missouri River dams. The 2003 BiOp estimated that approximately 3,000 acres of SWH existed on the system. This goal would require the restoration of 12,035 acres to 19,565 acres (20-30 acres per mile). SWH has been constructed by both Omaha and Kansas City District within the main channel of the river via structure modifications and off-channel using side channel chutes or backwaters in the adjacent floodplain. The most recent accounting of Missouri River SWH was conducted with 2012 / 2013 survey data and is reported in the *2014 Shallow Water Habitat Accounting Report* (USACE 2014).

2.1.2 Emergent Sandbar Habitat

ESH acreage targets were established to meet least tern and piping plover biological metrics (population and productivity) for the open river reaches downstream of Garrison, Fort Randall, and Gavins Point dams and also Lewis and Clark Lake. To meet these targets, intermittent

mechanical construction and vegetative management actions were performed within the Omaha District in the period through 2010. Since the 2011 flood event, which resulted in significant sandbar creation, no ESH mechanical construction actions have been performed.

2.2 ALTERNATIVE 1 – NO ACTION

Under the No-Action Alternative, the MRRP would continue to be implemented as it is currently. The current program does not implement all Reasonable and Prudent Actions (RPA) included in the 2003 Amended BiOp (USFWS 2003).

2.2.1 Pallid Habitat

Pallid habitat construction would continue to occur as part of the SWH program. The SWH restoration goal as outlined in the 2003 Amended BiOp (USFWS, 2003) is to achieve an average of 20–30 acres of SWH per river mile. Under the No-Action Alternative, the USACE would achieve the low end of this acreage target (i.e., 20 acres per river mile between Ponca, Nebraska, and the mouth). This equates to a total of 15,060 acres of SWH. Existing habitat on the system was used to determine the additional pallid habitat required. Since acreage above the target goal by segment is not required, adjusting for excess acreage in the Osage River to the mouth reach and acreage change since the 2012 RAS model geometry creation due to construction actions, 3,999 acres additional habitat is to be created (Table 2-1). For purposes of evaluating potential impacts to the human environment, modeling assumed that the additional SWH acreage would be created as follows (Table 2-2):

- Approximately 3,519 acres of in-channel SWH created through channel or top-width widening. A conceptual width of 250 feet was assumed for projects between Ponca and Rulo (20 projects encompassing 48 river miles) and 300 feet for projects downstream of Rulo (24 projects encompassing 57 river miles). Actual project width and size will vary by site.
- Approximately 480 acres of off-channel backwaters, assuming 8 new backwaters with each creating 60 acres of SWH.

Table 2-1. Summary of Projected Shallow Water Habitat Creation Under the No-Action Alternative

River Reach	RM Start	RM End	Miles in Reach	20 acres per mile of SWH	Existing Acreage[1]	Acreage Change 2012 to 2015[2]	2015 Target Acres of SWH[3]
Ponca to Sioux City	753	735	18	360	120	0	240
Sioux City to Platte River	735	595	140	2,800	1,682	97	1,021
Platte River to Rulo	595	498	97	1,940	1,290	-22	672
Rulo to Kansas River	498	367	131	2,620	1,270	221	1,129
Kansas River to Osage River	367	130	237	4,740	3,710	93	937
Osage River to Mouth	130	0	130	2,600	2600[4]	NA[4]	0
		Total	**753**	**15,060**	NA[4]	**389[5]**	**3,999[5]**

1 Existing acreage estimate derived from 2014 SWH Accounting Report (USACE 2014).
2 Includes additional chute habitat added between 2012 RAS model geometry creation and 2015 to include acreage change due to construction actions. Acreage reduction results due to estimated habitat change and response to construction.
3 Target acreage included in RAS models See appendices D & E for further details.
4 Acreage above 2600 ignored, no new acreage required in this segment since existing exceeds the 20 ac/mi goal.
5 Excludes acreage in the Osage River to mouth reach for purposes of demonstrating alternative 1 acreage increase.

Table 2-2. Projected Composition of Shallow Water Habitat Creation Type Under the No-Action Alternative

River Reach	Target Acres of SWH	Channel Widening[1]			Backwaters[2]	
		Acres	Miles	# of Projects	Acres	# of Projects
Ponca to Sioux City	240	180	5.9	2	60	1
Sioux City to Platte River	1,021	601	19.8	9	420	7
Platte River to Rulo	672	672	22.2	9	0	0
Rulo to Kansas River	1,129	1,129	31.1	14	0	0
Kansas River to Osage River	937	937	25.8	10	0	0
Osage River to Mouth	0	0	0	0	0	0
Total	**3,999**	**3,519**	**105**	**44**	**480**	**8**

1 Acreage amounts assume a top width of 250 feet for projects between Ponca and Rulo and 300 feet for projects downstream of Rulo.

2 Assumes 60 acres of SWH are created by each project.

Table 2-3 summarizes the amount of land acquisition that was assumed to be required to implement the identified amount of SWH. Land acquisition was estimated by comparing additional acreage with existing public lands. This estimate required a rough layout of potential sites using the exclusion criteria that considers aspects such as surrounding infrastructure. Refer to Appendix D and E for a thorough discussion of the excluded area criteria. Land acquisition estimates were provided to the HC team for use with preparing alternative cost estimates.

Table 2-3. Land Acquisition Requirements to Implement Early Life History Pallid Sturgeon Habitat Under Alternative 1

River Reach	Target Acres of SWH	Additional Land Required – Habitat Only (acres)	Additional Land Required – Total (acres)*
Ponca to Sioux City	240	240	1,848
Sioux City to Platte River	1,021	0	0
Platte River to Rulo	672	0	0
Rulo to Kansas River	1,129	675	5,198
Kansas River to Osage River	937	0	0
Osage River to Mouth	0	0	0
Total	**3,999**	**915**	**7,046**

* For estimating purposes, it was assumed that 7.7 acres of land acquisition are required for every 1 acre of habitat needed. This is based on historic implementation data and accounts for factors such as parcel size and other real estate acquisition considerations.

2.2.2 Reservoir Operations

Under Alternative 1 (Alt 1), the Missouri River Mainstem Projects would continue to be operated as they are currently. Operations within the ResSim model were set up to closely follow the Master Manual that is used during real-time operations of the System; however, the model does have limitations and cannot capture all real-time decisions that occur.

For the No-Action Alternative, the USACE assumed implementation of the plenary spring pulse as described in the Master Manual (USACE 2006). The bimodal Gavins Point spring pulse plan includes flow pulses in March and May. The magnitude of both the March and May Gavins Point spring pulses would be constrained by the Gavins Point spring pulse downstream flow limits. Pulse magnitude varies with James River inflows and is also constrained by multiple factors. Refer to the ResSim Alternatives report (USACE 2016b) for additional details regarding the reservoir operations changes.

2.3 Alternative 2 – U.S. Fish and Wildlife Service 2003 Biological Opinion Projected Actions

Alternative 2 represents the USFWS interpretation of the management actions that would be implemented as part of the 2003 Amended BiOp RPA (USFWS, 2003). Whereas the No-Action Alternative only includes the continuation of management actions the USACE has implemented

to date for BiOp compliance, Alternative 2 includes additional iterative actions and expected actions that the USFWS anticipates would ultimately be implemented through AM and as impediments to implementation were removed.

2.3.1 Pallid Habitat

Pallid habitat construction would occur as part of the SWH program. Under Alternative 2, the USACE would achieve the upper end of the 20–30 acres of SWH per river mile acreage target (i.e., 30 acres per river mile between Ponca, Nebraska, and the mouth). This equates to a total of 22,590 acres of SWH. Existing SWH projects and natural habitat resulted in a total of 11,832 acres (11,325 plus 507), leaving 10,758 acres to be created (Table 2-4). For the purposes of evaluating potential impacts to the human environment, modeling assumed that the additional SWH acreage would be created as follows (Table 2-5):

- Approximately 9,858 acres of in-channel SWH would be created through channel widening. A conceptual width of 250 feet was assumed for projects between Ponca and Rulo (60 projects encompassing 118.2 river miles) and 450 feet for projects downstream of Rulo (48 projects encompassing 115 river miles). Actual project width and size will vary by site.
- Approximately 900 acres of off-channel backwaters, assuming 15 new backwaters with each creating 60 acres of SWH.

Table 2-4. Summary of Projected Shallow Water Habitat Creation Under Alternative 2

River Reach	RM Start	RM End	Miles in Reach	30 acres per mile of SWH	Existing Acreage[1]	Acreage Change 2012 to 2015[2]	2015 Target Acres of SWH[3]
Ponca to Sioux City	753	735	18	540	120	0	420
Sioux City to Platte River	735	595	140	4,200	1,682	97	2,421
Platte River to Rulo	595	498	97	2,910	1,290	-22	1,642
Rulo to Kansas River	498	367	131	3,930	1,270	221	2,439
Kansas River to Osage River	367	130	237	7,110	3,710	93	3,307
Osage River to Mouth	130	0	130	3,900	3,253	118	529
		Total	**753**	**22,590**	**11,325**	**507**	**10,758**

1 Existing acreage estimate derived from 2014 SWH Accounting Report (USACE 2014).
2 Includes additional chute habitat added between 2012 RAS model geometry creation and 2015 to include acreage change due to construction actions. Acreage reduction results due to estimated habitat change and response to construction.
3 Target acreage included in RAS models for alternative. See appendices D & E for further details.

Table 2-5. Projected Composition of Shallow Water Habitat Creation Type Under Alternative 2

River Reach	Target Acres of SWH	Channel Widening[1]			Backwaters[2]	
		Acres	Miles	# of Projects	Acres	# of Projects
Ponca to Sioux City	420	240	7.9	4	180	3
Sioux City to Platte River	2,421	1,761	58.1	32	660	11
Platte River to Rulo	1,642	1,582	52.2	24	60	1
Rulo to Kansas River	2,439	2,439	44.7	19	0	0
Kansas River to Osage River	3,307	3,307	60.6	25	0	0
Osage River to Mouth	529	529	9.7	4	0	0
Total	**10,758**	**9,858**	**233**	**108**	**900**	**15**

1 Acreage amounts assume a top width of 250 feet for projects between Ponca and Rulo and 450 feet for projects downstream of Rulo.
2 Assumes 60 acres of SWH are created by each project.

Land acquisition to implement the SWH requirements described is summarized in Table 2-6.

Table 2-6. Land Acquisition Requirements to Implement Early Life History Pallid Sturgeon Habitat Under Alternative 2

River Reach	Target Acres of SWH	Additional Land Required – Habitat Only (acres)	Additional Land Required – Total (acres)*
Ponca to Sioux City	420	420	3,234
Sioux City to Platte River	2,421	925	7,123
Platte River to Rulo	1,642	675	5,198
Rulo to Kansas River	2,439	1,985	15,285
Kansas River to Osage River	3,307	1,932	14,876
Osage River to Mouth	529	0	0
Total	**10,758**	**5,937**	**45,716**

* For estimating purposes, it was assumed that 7.7 acres of land acquisition are required for every 1 acre of habitat needed. This is based on historic implementation data and accounts for factors such as parcel size and other real estate acquisition considerations.

2.3.1 Reservoir Operations

Alternative 2 (Alt 2) represents the U.S. Fish and Wildlife Service (USFWS) interpretation of the management actions that would be implemented as part of the 2003 Amended BiOp RPA (USFWS 2003). Operational criteria include different early and late spring spawning cues (March and May), low summer flows, and a maximum winter release limit.

The USFWS determined in the 2003 Amended BiOp (USFWS, 2003) that restoration of a normalized river hydrograph below Gavins Point Dam was necessary to avoid jeopardizing the continued existence of the pallid sturgeon. Several biologically relevant features were identified for a flow action below Gavins Point Dam including (1) flows to cue spawning that are sufficiently high for an adequate duration; and (2) flows that provide for connection of low-lying lands adjacent to the channel. The spawning cue release from Gavins Point Dam would be bimodal (i.e., consisting of two separate flow pulses) and would be implemented in every year if conditions are met. The USFWS 2003 Amended BiOp (USFWS, 2003) also called for modification to System operations to allow for summer flows that are sufficiently low to provide for SWH as rearing, refugia, and foraging areas for larval, juvenile, and adult pallid sturgeon. Refer to the ResSim Alternatives report (USACE 2016b) for additional details regarding the reservoir operations changes.

2.3.2 Floodplain Connectivity

The BiOp geometry integrates floodplain connectivity along with SWH criteria set forth in the 2003 Amended BiOp. Coordination with the USFWS produced a Planning Aid Letter (USFWS, 2015)

detailing the modeling assumptions for the BiOp alternative. A total of 100,000 acres of SWH and floodplain connectivity were assumed for both districts. To calculate the goal amount of only floodplain connectivity, 22,590 acres (30 ac/mi * 753 mi) was subtracted from the 100,000 acres to obtain 77,410 acres.

Mapping of existing floodplain connectivity was performed by using a RAS model calibrated to 2012 conditions to calculate a water surface profile for the 20% annual chance exceedance event (20% ACE or 5-year). The 5-year flow input for the model was obtained from the 2003 Upper Mississippi River System Flow Frequency Study (USACE, 2003). Existing floodplain connectivity acres (147,652 acres) surpass the total acres available for floodplain connectivity (100,000 acres) therefore, no changes were made to the RAS models. Refer to Appendix D and E for specific details in each of the RAS modeling reaches regarding the floodplain connectivity analysis.

2.4 Pallid Habitat Actions Common to Alternatives 3–6

Under Alternatives 3–6, the USACE would create three high-quality spawning habitat sites. The spawning sites are at locations separate from the IRC habitat. Although spawning habitat specific characteristics are undefined, it was assumed for the purposes of this analysis that these areas do not significantly modify conveyance and were not included in the RAS model.

Under Alternatives 3–6, construction of pallid habitat would occur following the IRC (interception and rearing complexes) concept. Best available science indicates that future acreage required to construct IRCs would most likely be achieved through channel widening. For the purposes of evaluating potential impacts to the human environment, modeling assumed that about 3,380 acres of channel widening would be implemented to create IRCs under Alternatives 3–6 (Table 2-7). A conceptual width of 250 feet was assumed for projects between Ponca and Rulo and 300 feet for projects downstream of Rulo.

Table 2-7. Summary of Projected IRC Creation Under Alternatives 3–6

River Reach	River Mile Start	River Mile End	Miles in Reach	Target Acres of IRC habitat[1]
Ponca to Sioux City	753	735	18	0
Sioux City to Platte River	735	595	140	276
Platte River to Rulo	595	498	97	585
Rulo to Kansas River	498	367	131	670
Kansas River to Osage River	367	130	237	1,389
Osage River to Mouth	130	0	130	460
			Total	**3,380**

1 All acreage achieved through channel widening. Acreage amounts assume a top width of 250 feet for projects between Ponca and Rulo and 300 feet for projects downstream of Rulo.

Land acquisition to implement the requirements described is summarized in Table 2-8.

Table 2-8. Land Acquisition Requirements to Implement IRC Under Alternatives 3–6

River Reach	Target Acres of SWH	Existing Public Lands Available for Habitat Development (acres)[1]	Additional Land Required – Habitat Only (acres)	Additional Land Required – Total (acres)[2]
Ponca to Sioux City	0	420	0	0
Sioux City to Platte River	276	276	0	0
Platte River to Rulo	585	585	0	0
Rulo to Kansas River	670	454	216	1,664
Kansas River to Osage River	1,389	1,375	14	108
Osage River to Mouth	460	460	0	0
Total	**3,380**	**3,150**	**230**	**1,772**

1 Existing public lands includes USACE, USFWS, and state conservation owned lands. Acreage was based on identifying government owned lands that may be appropriate for habitat development; however, these areas do not necessarily represent actual locations of future habitat development.

2 For estimating purposes, it was assumed that 7.7 acres of land acquisition are required for every 1 acre of habitat needed. This is based on historic implementation data and accounts for factors such as parcel size and other real estate acquisition considerations.

2.5 Alternative 3 – Mechanical Construction Only

Alternative 3 (Alt 3) consists of mechanical construction of emergent sandbar habitat (ESH). Operational criteria consist of removing the early and late spring spawning cues in Alt 1. Pallid habitat construction is as described in Table 2-7.

2.6 Alternative 4 – Spring Habitat-Forming Flow Release

Under Alternative 4 (Alt 4), the early and late spring spawning cues in Alt 1 are removed from the operational criteria and a spring ESH-creating reservoir release from Gavins Point and Garrison is added. During the period of flow releases for ESH-creation release, ResSim downstream flood targets are increased to increase the potential for ESH-creation releases to be implemented.

Alternative 4 reservoir operations would be similar to Alternative 1 (current operations), with the addition of a high spring release designed to create ESH for the least tern and piping plover. If implementation conditions are met (USACE 2016b), the habitat-forming flow release would be implemented on April 1 with a release of up to 60 kcfs out of Gavins Point Dam, and as often as every four years. To achieve the Gavins Point Dam release, Fort Randall Dam releases would be increased a similar amount as Gavins Point and releases from Garrison Dam would be approximately 17.5 kcfs less than the Gavins Point release. Implementation conditions (system storage, downstream flood restrictions) could result in partial flow releases with truncated duration.

Implementation conditions (system storage, downstream flood restrictions) could result in partial flow releases with truncated duration. The duration of the release would increase as release magnitude is decreased to meet habitat forming objectives.

Pallid habitat construction for Alternative 4 is as described in Table 2-7.

2.7 ALTERNATIVE 5 – FALL HABITAT-FORMING FLOW RELEASE

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

Alt 5 reservoir operations would be similar to Alternative 1 (current operations), with the addition of a high fall release designed to create ESH for the least tern and piping plover. If implementation conditions are met (USACE 2016b), the habitat-forming flow release would be implemented on October 17 with a release of up to 60 kcfs out of Gavins Point Dam, and as often as every four years. To achieve the Gavins Point Dam release, Fort Randall Dam releases would be increased a similar amount as Gavins Point and releases from Garrison Dam would be approximately 17.5 kcfs less than the Gavins Point release.

Implementation conditions (system storage, downstream flood restrictions) could result in partial flow releases with truncated duration. The duration of the release would increase as release magnitude is decreased to meet habitat forming objectives.

Pallid habitat construction for Alternative 5 is as described in Table 2-7.

2.8 ALTERNATIVE 6 – PALLID STURGEON SPAWNING CUE

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

Under Alternative 6, the USACE would attempt a spawning cue release every 3 years consisting of a bimodal pulse in March and May. For the March pulse, the peak Gavins Point release is double the navigation release that occurs on the day the pulse is initiated. For the May pulse, the peak Gavins Point release would be double the steady release that occurs on the day the pulse is initiated (May 18). Both pulses would be formed by increasing flows by 2,200 cfs /day to the peak, maintain the peak for two days, and then receded by 1,700 cfs/day to the navigation target flow. These spawning cue releases would not be started or would be terminated whenever flood targets are exceeded.

Pallid habitat construction for Alternative 6 is as described in Table 2-7.

3 PERIOD OF RECORD ANALYSIS

Hydrologic analysis utilized a period of record (POR) methodology to evaluate alternative conditions with the RAS and ResSim modeling effort for the MRRMP-EIS. As used in hydrologic models for flood-runoff analysis, period of record analysis refers to applying a hydrologic model to simulate a continuous period of record of streamflow. Detailed documentation of the data

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

3.1 METHODOLOGY

Flows for all required inflow points to all hydrologic models were developed for the Missouri River basin for the period of record used in the ManPlan Study analysis for the period from March 1930 through December 2012. When gage data was unavailable, other methods were used to determine inflow for the entire POR. Estimated daily flow for the POR was used to provide all RAS model inflows. Although the hydrologic models provided results from a portion of 1930, HC team analysis was only performed for the 82 year period from January 1, 1931 through December 31, 2012.

POR development requires relatively sophisticated hydrologic models capable of simulating all extremes of the hydrologic cycle, including detailed simulation of flood events, drought years, and seasonal fluctuations. Due to study needs, the POR was assembled using daily flow values. Assembling the immense data set within the large Missouri River basin study area to accurately include all inflows, evaporation, and other consumptive water use required extensive data collection and processing from multiple sources. The final POR input data set allows accurate simulation of the MRRMP-EIS base condition and alternative conditions.

3.2 RESULTS

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

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

4 HEC-RAS MODELING OF ALTERNATIVES

Hydrologic model development was conducted to create a robust suite of models suitable for study use. Outputs of the RAS models were used in concert with other modeling programs such as HEC-Ecosystem Functions Model (HEC-EFM) and HEC-Flood Impact Analysis (HEC-FIA) to perform impacts analysis.

RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. Common outputs include stage, duration/timing of inundation, water velocities, flow areas/routes, water temperature, and sediment loads. Unsteady flow analysis was chosen as the method of hydraulic modeling due to the need to analyze time series stage and flow data. Both the biological considerations (e.g., seasonal habitat requirements) and the human considerations (e.g., potential changes in flows that could affect flood risk, agricultural practices,

and etc.) are affected by the timing of river flows. RAS was used to more accurately route discharges from reservoirs and tributaries to points downstream and to simulate impacts of mechanical changes in river channel geometry. These models simulate how proposed alternatives and management actions would impact river stage and discharge over a wide range of basin hydrologic conditions.

The purpose of the RAS models was to create a baseline that closely represents current river conditions and to provide a tool to evaluate potential hydraulic changes resulting from proposed management actions or alternatives (e.g. channel reconfiguration and/or flow management). The baseline or existing conditions models were modified to represent a future condition under the No Action and action alternatives.

An overview of the steps necessary to complete the alternative condition modeling is summarized as:

a) Revise ResSim model for each flow alternative
b) Revise RAS models to reflect new pallid habitat
c) Using the POR flows, simulate ResSim for each alternative
d) Using the POR flows, ResSim model reservoir releases and pool levels, and the revised RAS model geometries, simulate each alternative through the suite of RAS models
e) Provide summary output at key locations from the ResSim and RAS models for use with the HC team analysis

4.1 Previously Created HEC-RAS Models

RAS models were previously created for the study with the intent to revise the models in the future for alternative condition analysis. Refer to the *Missouri River Recovery Program Management Plan Environmental Impact Statement Existing Conditions Unsteady RAS Model Calibration* Report (USACE 2015b) for a detailed description of HEC- RAS model development and calibration. The RAS models for the calibration condition within each reach were based on geometry and calibration representative of the current, or approximately 2012, river conditions.

Varying availability of terrain and bathymetric data, the presence of the Mainstem reservoirs, and the need to take advantage of local knowledge of river conditions led the staff in the Kansas City and Omaha Districts to develop 5 separate RAS models for discrete reaches of the Missouri River. These reaches are: Fort Peck Dam to Garrison Dam; Garrison Dam to Oahe Dam; Fort Randall Dam to Gavins Point Dam; Gavins Point Dam to Rulo, Nebraska (district boundary) and Rulo, Nebraska the mouth of the Missouri River at St. Louis, MO. The boundary between the Kansas City and Omaha Districts is at Rulo, NE, therefore the Gavins Point to the mouth reach has an overlap from Nebraska City, NE to St. Joseph, MO in order to provide an accurate transition of flows between the two model reaches.

Figure 4-1 provides the locations of the individual RAS models. The Oahe to Big Bend and Big Bend to Randall reaches were not modeled in RAS due to the lack of riverine conditions between the dams.

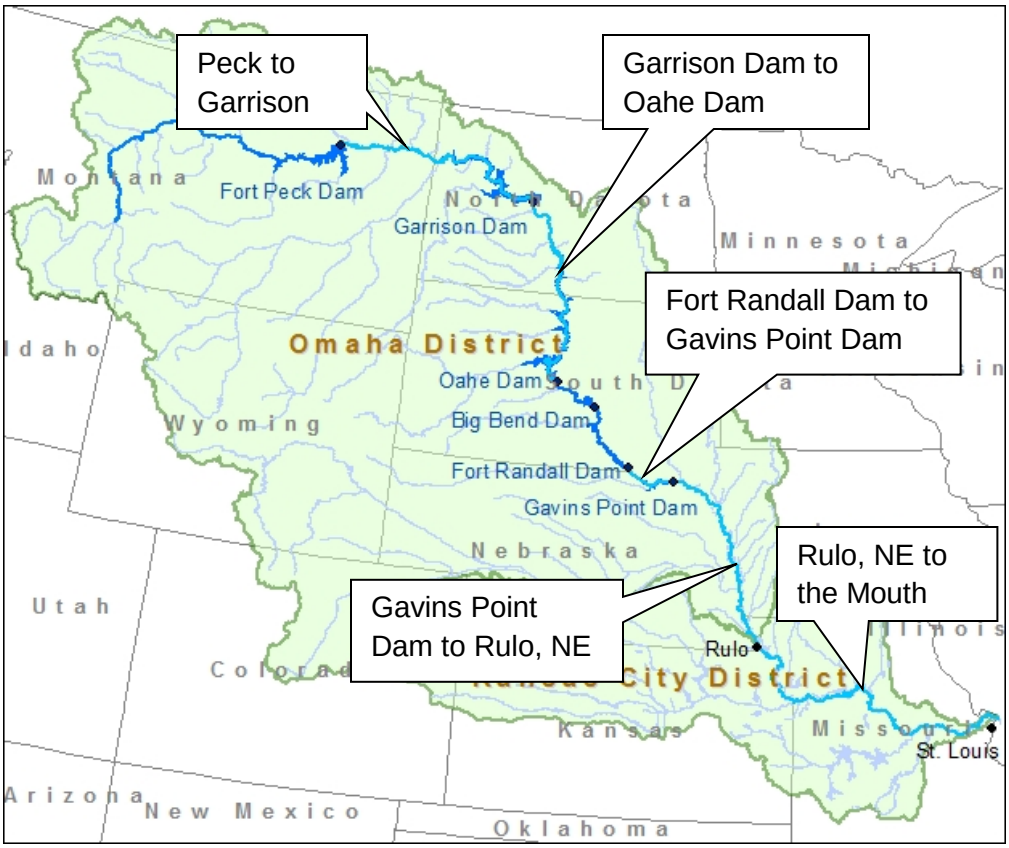


Figure 4-1. Location of RAS Modeled Reaches

Modifications were performed to implement RAS modeling of alternatives. Study alternatives were applied to the RAS models using the following guidance:

- Since the sediment processes are dynamic with generally no net change in cross sectional area, the ESH creation actions were not evaluated with the RAS models.
- ResSim computed flow releases were evaluated with all five of the RAS models for each alternative.
- Pallid habitat geometry changes were evaluated with the RAS models in the two RAS models downstream of Gavins Point Dam only
- Backwater pallid habitat was not modeled as these areas, with a single river connection and an orientation that is typically not aligned with flow, do not significantly alter overall floodplain conveyance

4.2 Geometry Changes for Alternative Analysis

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

4.2.1 Changes to Existing (2012) Calibration Model

During RAS model development, several intermediate geometries were constructed in order to obtain the final base geometry before adding in the various pallid habitat alternatives. These modifications were necessary to develop an updated current condition model that includes changes to the 2012 model geometry that occurred in both Omaha and Kansas City Districts. Changes consisted of adding habitat projects constructed since the 2012 model creation and revising existing chute invert and width elevations to reflect estimations of future modifications. Refer to the RAS modeling Appendices D and E for specific details on changes within each model.

4.2.2 Pallid Habitat

The pallid habitat configurations that were modeled to implement the alternatives, previously described in the study alternative section, are summarized as:

1. **No Action** - Assumes habitat construction activities follow current practices to achieve 20 acres/mile of SWH, the minimum target specified in the 2003 Amendment to the 2000 Biological Opinion.
2. **Biological Opinion as Projected (BiOp)** - Guidance from the U.S. Fish & Wildlife (USFWS) was provided to create a geometry which represents an ideal implementation of the 2003 Biological Opinion. It assumes habitat construction accomplishes 30 acres/mile of SWH, and performs at a wider range of flows including a summer low, median August, and spring pulse. Floodplain connectivity was evaluated, but the requirement was met so no changes to the RAS geometry were necessary. A thorough description of the floodplain connectivity evaluation is contained within Appendices D and E.
3. **Interception-Rearing Complexes (IRC)** - SWH construction activities proceed based on findings made by the Effects Analysis (EA) team. It assumes habitat construction accomplishes 260 acres/year based on current annual habitat construction rates.

Pallid habitat was only added to the Gavins to Rulo (Omaha District) and Rulo to the Mouth (Kansas City District) models. All other RAS models upstream of Gavins Point Dam do not have habitat construction geometry changes.

4.2.3 Areas Excluded from New Pallid Habitat Construction

Locations selected for habitat construction in the RAS model are theoretical and do not reflect actual locations of future mitigation projects. However, the following areas were intentionally avoided when making modifications to RAS models. For the BiOp as Projected geometry in the Gavins to Rulo reach, satisfying all of these criteria was not always possible due to the amount of habitat added. Implementation within the RAS models varied somewhat between Omaha and Kansas City Districts based on reach specific issues and are stated within Appendix D and E. A general summary of common criteria used is:

1) Reaches of river within a 10,000-ft radius of an airport (per FAA AC 150/5200-33, (FAA, Aug 2007)

2) Areas within 1/4 mile upstream or downstream of small town infrastructure along the river bank, on that side of the river only
3) Areas within 1/4 mile upstream or downstream of power plant or municipal water intakes, on both sides of the river
4) Areas within 1/4 mile upstream or downstream of barge loading facilities and other river related industrial infrastructure along the river bank, on that side of the river only
5) Areas within 1/4 mile upstream or downstream of bridges, on both sides of the river
6) Areas within 1/4 mile upstream and downstream of Federal/PL 84-99 levees lying close to the river bank (approximately 1000 feet or less), on that side of the river only.
7) Reaches adjacent to larger cities, particularly where the channel is confined by urban levees
8) Widening projects were not located in the same bend as new or existing chutes or widening to avoid excessive navigation channel flow loss
9) The outside bend within Kansas City District based on past performance experience

4.2.4 Implementation within HEC-RAS

Creation of the new habitat areas within HEC-RAS required defining habitat elevation and size. Elevations of pallid habitat are defined using reference flows such as the August 50% exceedance level and median monthly flows. Reference flows were implemented with steady flow RAS modeling runs to determine profiles for use with setting habitat elevations.

Top width widening was the primary means of adding pallid habitat (both SWH and IRC) to all three geometries. Widening width, depth, and design invert elevation varied by alternative and by spatial location on the river. Widening areas alter geometry within the RAS model that affects computed conveyance and results. This also impacted model parameters: flow roughness, overbank ineffective areas, levee points, and permanent ineffective areas in the channel. An example of how habitat creation was implemented within the RAS model from Rulo to the Mouth is shown in Figure 4-2. Implementation was slightly different between the two RAS models (Gavins to Rulo and Rulo to the Mouth). Refer to Appendix D and E for additional details regarding RAS model implementation.

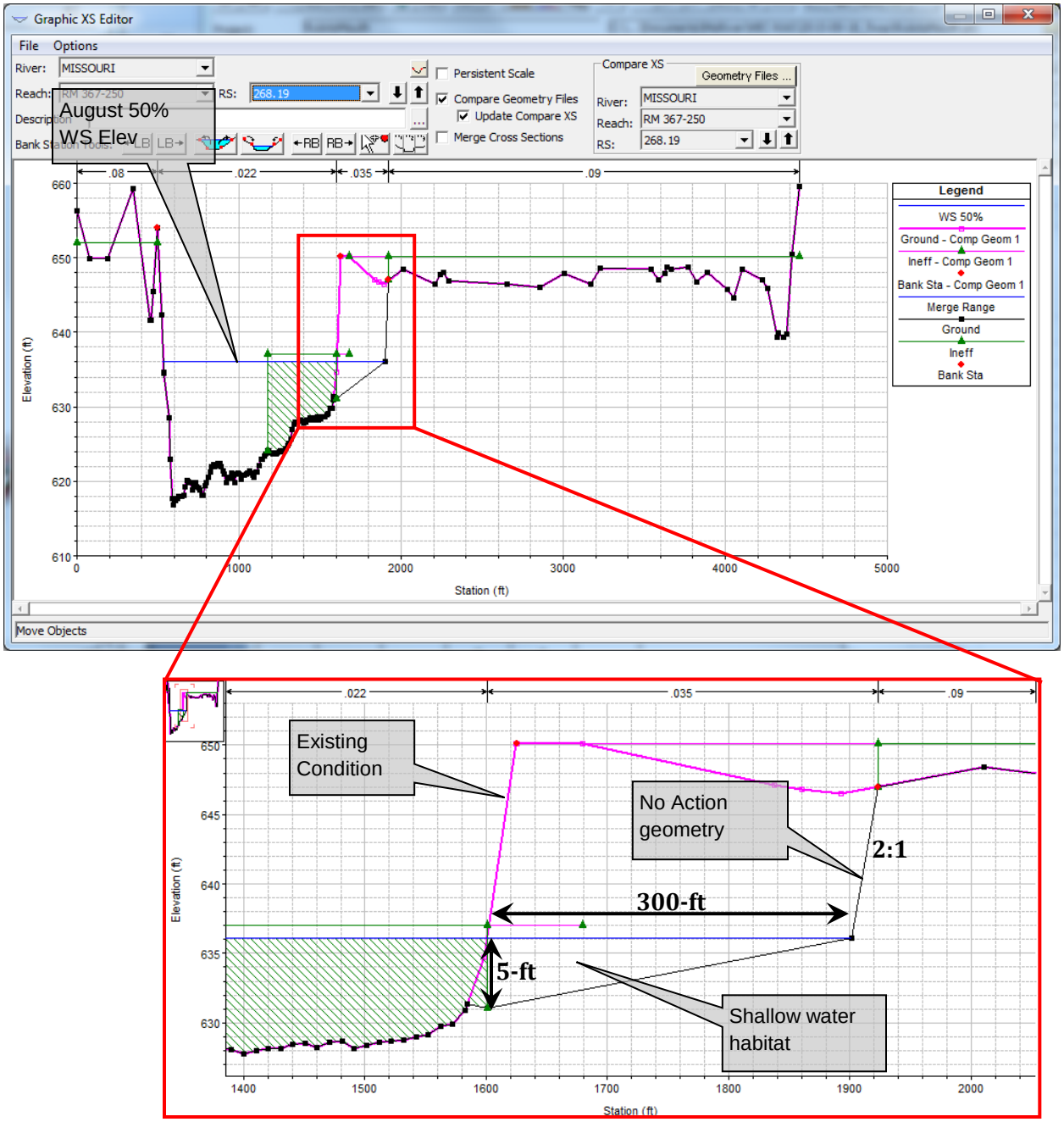


Figure 4-2. Widened cross section – No Action

A summary of the created geometries, habitat target metric, and the reference flow used in design are provided in Table 4-1.

Table 4-1. Geometry Summary

Geometry	Target Habitat	Reference Flow (cfs)
No Action	20 acre/mile	August 50% exceedance
BiOp	30 acre/mile + floodplain connectivity	Summer low, Median August, & Spring Pulse
IRC	260 acre/year for 13 years	Median June

Geometry revisions previously discussed in this section are summarized as:

- Revisions were necessary to transition the model from the 2012 calibration version to a new current condition model that reflects modifications already constructed or in construction
- The no action and alternative conditions all include geometry changes from the calibration condition model to reflect variations in future habitat
- Geometry changes for alternatives with new pallid habitat are only necessary for the two RAS models located downstream of Gavins Point Dam
- All geometry changes are assumed to occur instantaneously without consideration of a construction time window
- All RAS modeling efforts are for the current geomorphic condition only. No adjustments were made to the models to reflect possible future aggradation / degradation.
- Several of the alternatives are intended to create ESH via flow releases. ESH dynamic changes during the POR simulation are not included within the RAS models.

4.3 Flow Changes

Revisions to reservoir releases were a primary component of all six alternatives. The flow changes were modeled in ResSim as described in the ResSim alternative modeling detailed documentation *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report* (USACE 2016b). Flow alternatives are conducted for the purposes of emergent sandbar habitat (ESH) creation and pallid spawning benefit. The reservoir pool elevations and dam outflows determined with the ResSim model were used as input for the various RAS models for each of the six flow alternatives as previously described in Section 2.

Table 4-2 summarizes the ranges of releases from Gavins point, as well as the number of years in which the release was eliminated, partially or fully completed within HEC-ResSim. Evaluation of HEC-ResSim output is informative when examining the changes that occurred in the RAS model results.

Table 4-2. Summary of Management Action Flows Simulated over the Period of Record

Alternative	Month	Frequency during 82-year Period of Record (1931-2012)			
		Eliminated[1]	Partial Completion[2]	Full Completion/Duration[3]	
		No. of Years	No. of Years	No. of Years	Percent Years of POR
1 – No Action	March	48	4	30	37
	May	53	8	21	26
	Both months			**16**	**20**
2 – USFWS 2003 BiOp Projected Actions	March	40	24	18	22
	May	42	25	15	18
	Both months			**10**	**12**
3 – Mechanical Construction Only		not applicable, no flow management action included			
4 – Spring Habitat-Forming Flow Release		67	7	**10** [4]	**12**
5 – Fall Habitat-Forming Flow Release		73	2	**7** [4]	**8**
6 – Pallid Sturgeon Spawning Cue	March	39	26	17	21
	May	65	6	11	13
	Both months			**11**	**13**

[1] Eliminated: Hydrological conditions in these years would not have been appropriate for any release.

[2] Partial Completion: Releases would have occurred but not at the full planned volume or duration (1 day minimum)

[3] Full Completion/Duration: Releases would have occurred for the full planned volume and duration.

[4] Shown values for spring (Alternative 4) and fall (Alternative 5) are deliberate releases, do not include events when targeted flow release levels would have been achieved "naturally" during normal operations.

4.4 ALTERNATIVE GEOMETRY AND FLOW PAIRING

Each flow alternative was paired with a geometry alternative to produce six total alternatives that were run through the RAS models. The No Action geometry was paired with the No Action flow for Alternative 1. The BiOp geometry was combined with the BiOp flow for Alternative 2. The IRC geometry was paired with flow alternatives 3 through 6 to produce Alternatives 3, 4, 5, and 6. Table 4-3 provides a listing of the geometry and flow pairings for each alternative.

Table 4-3. Alternative Geometry and Flow Pairings

Alternative	Geometry	Flow
Alternative 1	No Action	No Action
Alternative 2	BiOp	BiOp Projected
Alternative 3	IRC	Mechanical Only
Alternative 4	IRC	Spring Habitat Forming Release
Alternative 5	IRC	Fall Habitat Forming Release
Alternative 6	IRC	Pallid Sturgeon Spawning Cue

4.5 HEC-RAS MODEL VERSION

All alternatives runs were performed in RAS 5.0 Beta (21-August-2015) because that was the most current version as of October and November 2015, when most of the runs were completed. Official release of RAS 5.0 was on 4-March-2016 and 5.0.1 on 22-Apr-2016, at which point evaluation of results by the HC teams was well underway and it would have unnecessarily compromised schedule to re-run the simulations.

5 HEC-RAS MODEL RESULTS

Hydrologic model results, consisting of computed daily flow and elevation information, was compiled from the RAS models at key locations throughout the basin. Results from the hydrologic modeling were provided to the HC team members for the comparison of alternative conditions. The model results at key locations were developed in summary form for comparison between alternatives.

The HC team member analysis used the daily (instantaneous 2400 value for each day) flow and water surface elevation output to analyze effects to various resources that include: hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply. The HC team performed an extensive analysis on each of the alternatives for all of the resources and provide a detailed comparison of results. For this report, only the hydraulic model output is presented.

To express the changes compared with the No Action alternative, the model results were evaluated by 1) statistical evaluation comparing min, max, and percentiles, and 2) duration analysis plots. Due to the basin size, number of models, model complexity, and the number of alternatives developed, typical model outputs such as profiles and flood area mapping were not developed.

Refer to the HEC-ResSim and RAS alternative analysis reports for detailed documentation of the results for each modeling effort (USACE 2016b, USACE 2016e).

5.1 COMPARISON OF ALTERNATIVE RESULTS

For the comparison of results, flow and water surface elevation were analyzed to compare the differences between the No Action Alternative and the remaining five alternatives. Tables comparing min, max, and percentile flows and stages at key locations were developed for each RAS model and are contained within the respective model appendix.

However, caution should be used when trying to draw conclusions only from the statistics tables. The FIA models used by the HC team that compute structural and agricultural damages from flood events will provide a more complete alternative impact assessment because they incorporate all cross sections along the river in addition to the single site statistics. In addition, tabulating the changes for the entire period of record can mask impacts of the alternative on individual events within the POR.

An example of results comparison at St. Joseph, derived from the Rulo to the mouth RAS model output, is provided in Table 5-1 and Table 5-2.

Table 5-1. Flow (cfs) statistics on the period of record at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	7,416	7,537	7,416	7,416	7,416	7,416
10%	18,181	18,170	18,250	18,020	18,231	18,094
25%	26,258	25,180	26,443	25,719	26,317	25,931
50%	39,282	38,478	39,156	38,950	39,046	38,988
75%	50,589	52,358	50,527	51,032	50,703	51,328
90%	68,612	69,893	68,614	70,557	69,439	69,001
Max	292,224	293,577	297,961	297,991	297,994	297,977

Table 5-2. Elevation (NAVD 88 ft) statistics on the period of record at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	787.8	787.8	787.8	787.8	787.8	787.8
10%	791.3	791.3	791.3	791.2	791.3	791.3
25%	793.8	793.4	793.8	793.6	793.8	793.7
50%	797.4	797.1	797.4	797.3	797.4	797.3
75%	799.6	799.7	799.6	799.7	799.7	799.8
90%	802.6	802.4	802.6	802.9	802.8	802.6
Max	820.3	819.2	820.8	820.8	820.8	820.8

In the above tables, the min and max are the lowest daily flow or elevation and the highest daily flow or elevation output for each alternative over the period of record.

Calculated flow changes do not necessarily occur on the same date from alternative to alternative. For example, the minimum flow shown in Table 5-1 at St. Joseph is 7,416 cfs for Alternatives 1, 3, 4, 5, and 6. In the model output, this occurred on 3 Dec 1955, as shown by the hydrograph output in Figure 5-1. The low summer flow Gavins Point release rule during the months of July and August allowed the navigation season to extend one to two weeks longer in Alternative 2 than the other Alternatives, with the result of increasing the lowest few days of flow at St. Joseph.

Figure 5-1. Alternatives Flows at St. Joseph – 1955

Seasonal duration analysis was also performed at key locations using POR results. Seasonal dates chosen for the duration analysis coincide with the current System operational seasons: spring (1Mar to 30Apr), summer (1May to 31Aug), fall (1Sep to 30Nov), and winter (1Dec to 28Feb). The greatest difference can usually be seen closer to the reservoir release point and in the spring and winter durations due to the spring pulses and resulting lower winter flows. An example duration analysis for the spring period (1 Mar to 30 Apr) at Sioux City comparing alternatives plot is shown in Figure 5-2. In this example, alternatives 2, 4, and 6 illustrate changes due to flow modifications during this period.

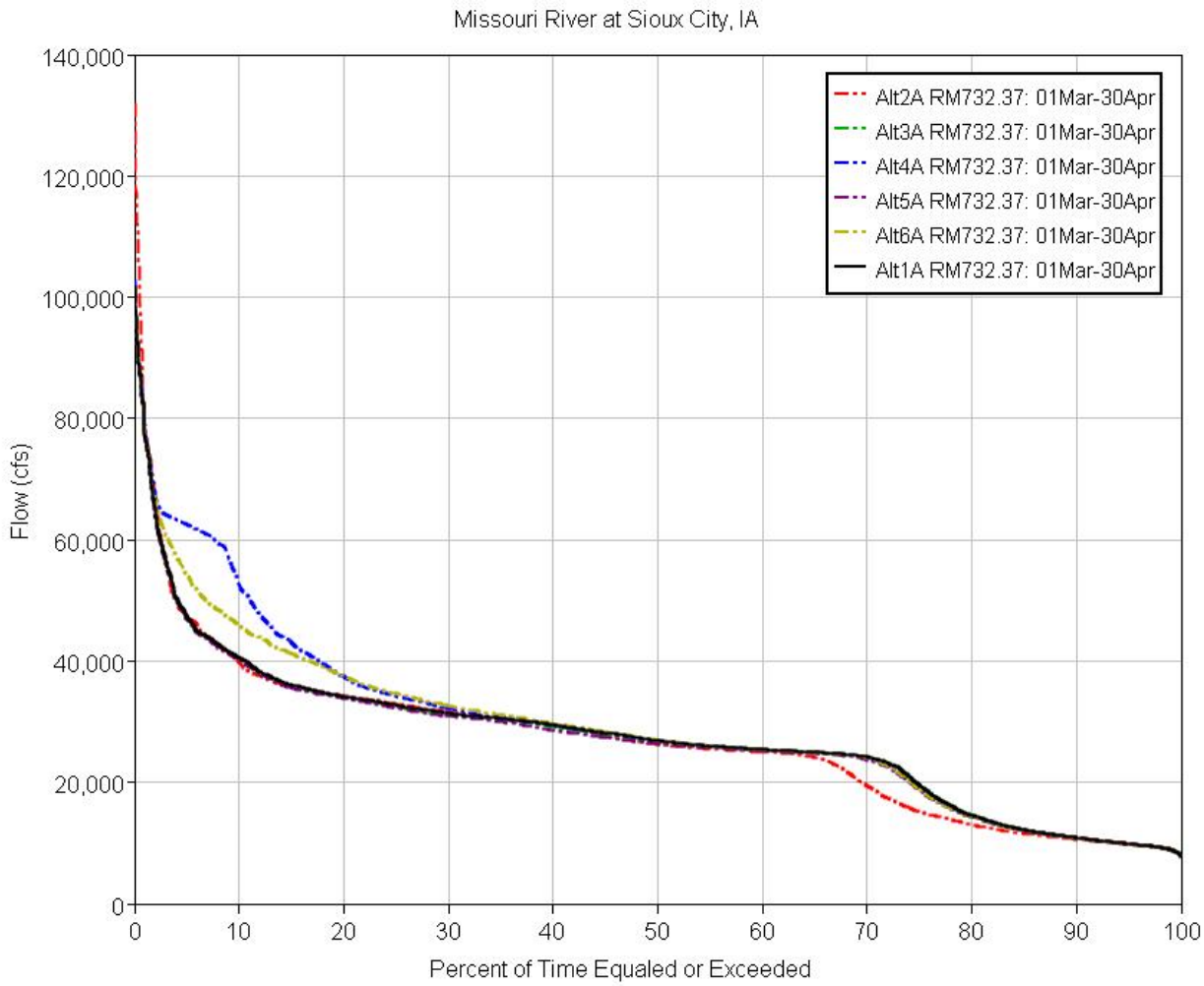


Figure 5-2. Sioux City Spring (1 Mar to 30 Apr) Duration for POR

5.2 Factors to Consider in Analysis of Results

The analysis of flow and stage changes between alternatives at a certain location is influenced by an array of variables. For example, even when the reservoir release has no change, the flow or stage calculated from alternative to alternative at a downstream location may change because of minor variations in the RAS unsteady flow routing and the habitat additions to the river geometry. Differences in the unsteady flow routing, levee storage cells, and the overall amount of constructed habitat are causes for variation in peak flow and stage when an alternative does not include a change in reservoir releases.

From alternative to alternative the primary factors that should be considered when evaluating changes between alternatives include:

a. Small number of pulses
b. Reservoir releases from the Mainstem System as calculated by HEC-ResSim
c. The pallid sturgeon habitat additions to the river geometry
d. Storage changes in the river and floodplain

e. Timing of reservoir releases and downstream inflows, combined with RAS routing, during the POR
f. RAS output interval may mask minor differences
g. Comparison of results on a POR basis can mask impacts due to flow changes

5.2.1 Small Number of Pulses

Each of the flow alternatives were developed with a specific set of rules that restrict implementation. The number of times a pulse occurs for each alternative is illustrated within Table 4-2. Several of the flow alternatives are implemented less than ten times during the POR simulation. Downstream impacts are highly dependent on local inflows that combine with reservoir releases. Since the number of implemented pulses is small, results analysis is limited by the downstream tributary conditions of these few occurrences.

5.2.2 HEC-ResSim Flow Change

Flow calculated by the RAS model at a downstream location not only depends on how the reservoir System releases changed, but also how those changes carry downstream and were combined with inflow during the POR. Minor variation can occur in HEC-ResSim flow releases due to model scripting (USACE, 2016b). These flow changes would carry forward into RAS model results.

5.2.3 Change in Results – Habitat Additions

There is evidence that habitat construction tends to lower the river stages in the project vicinity and slightly upstream of the habitat location and generally has a minor dampening effect on the hydrograph, lowering peak flows downstream of the habitat location (Jacobson, Linder, & Bitner, 2015). However, other experiences such as observations during the 2010 and 2011 flow events indicate that habitat project changes to peak river levels may be variable and minor (USACE 2012 and USACE 2013) due to factors such as the overall river flow distribution within the floodplain and sediment transport. The dynamic nature of the Missouri River and sediment transport contribute to the uncertainty regarding habitat construction impacts. For this study, the RAS modeling effort does not attempt to address Missouri River channel dynamics or sediment transport changes with a static model geometry for the entire POR. Therefore, the most likely explanation for variation in peak flow and stage within the two RAS models downstream of Gavins Point Dam is the difference in constructed habitat and RAS model geometry change.

Pallid habitat is not added equally within the alternatives and thus the impact on results will vary. For instance, the difference in added habitat between Alt 1 to Alts 3-6 that affects conveyance, excluding backwater habitat, is relatively small (3,519 acres vs. 3,380 acres, Table 2-2 and Table 2-7). However, the distribution of added habitat changes significantly with habitat upstream of Rulo, NE, decreasing from 1,453 ac to 861 ac while habitat downstream of Rulo, NE, increases from 2,066 ac to 2,519 ac (Table 2-2 and Table 2-7). Because of the habitat distribution variation, differences between alternatives varies with location and is not consistent.

Results variation from constructed habitat is shown by the increase in the maximum flow and stage at St. Joseph for Alternatives 3-6 (which have less habitat construction) when compared to Alternative 1, as shown in Table 5-1 and Table 5-2. The maximum flow for the period of record at St. Joseph occurred in all Alternatives during the simulated flood of 1993. Releases out of Gavins Point Dam from the Res-Sim model are identical for all the alternatives during this year, which means all differences observed at downstream locations are due to habitat additions to the river geometry or slight variations in unsteady flow routing in combination with levee storage areas. Alternatives 3-6 all utilize the IRC geometry configuration, whereas Alternative 1 uses the No Action geometry configuration which results in more new pallid habitat (3,519 acres vs. 3,380 acres, Table 2-2 and Table 2-7). Within the Rulo to Kansas City reach, less habitat overall was added to the Alt 3-6 geometry (670 ac) than the Alt 1 No Action geometry (1,129 ac). Upstream habitat changes, unsteady flow computations, and timing with levee storage areas, may also contribute to results differences.

Examination of other events illustrate inconsistencies and difficulty when examining results between alternatives with variable added habitat and flow changes. For example, the BiOp geometry had the most habitat added, both upstream of Rulo and in the Rulo to Kansas City reach. The maximum stage for Alt 2 at St Joseph, as shown in Table 5-2, was significantly lower than the other alternatives, however the flow was slightly increased as compared to Alt 1, see Table 5-1. Unsteady flow routing introduces the effects of the looped rating curve, where the stage-flow relationship varies on the rising and falling limb of the event hydrograph. Multiple factors that affect the stage-flow relationship may be occurring within the model results.

5.2.4 Change in Results - Storage

Storage within the RAS model is a factor that influences the timing and magnitude of flows at all levels is the interaction of downstream conveyance features that represent storage. Storage interacts with the conveyance in the main river by taking on water when the river is rising, and returning water when the river is falling. Only within the Rulo to the mouth model, this interaction happens at low flow with the navigation structures represented by permanent ineffective areas in the channel. Within all models at bank full flows, this interaction happens with storage areas that represent tributaries and tiebacks with low lying connection to the river, and also in low lying floodplain areas between the high banks and adjacent levees or bluffs. At the highest flow levels, this interaction happens with transfer of flow from the Missouri River channel to the large protected areas behind the levees that were modeled in RAS with storage areas. Additional flow area from habitat projects may seem small compared to a fully inundated floodplain, but even slight differences in the river water surface elevation could change the interaction of the river with the storage areas and alter the timing and magnitude of water to reach a certain location. Without extensive testing and sensitivity runs it is difficult to determine the magnitude of storage changes on alternative result comparison.

5.2.5 Change in Results – Unsteady Routing

Coupling the ResSim and RAS models provides a powerful alternative analysis tool that provides a high quality basis for assessing differences. Comparison between alternatives should recognize that minor and insignificant differences can occur due to the nuances of unsteady flow

computations. Flow calculated by the RAS model at a downstream location not only depends on how the reservoir System releases changed, but also how those changes carry downstream and were combined with inflow during the POR. Minor variation can occur in HEC-ResSim flow releases due to model scripting (USACE, 2016b). Even when the reservoir release has no change, the flow or stage calculated from alternative to alternative at a downstream location may change because of minor variations in the RAS unsteady flow routing, timing of downstream inflows, and flow attenuation due to the habitat additions to the river geometry.

5.2.6 HEC-RAS Output Interval

Minor differences were noted in model output that were in the range of a few hundred cfs and a few tenths foot of stage. Review of model results indicated that some of this difference is due to the RAS alternative models output interval that were configured to report one value per 24 hour period. In contrast to ResSim, the single value is not the daily average. The RAS model computes stage and flow at the computation interval (varies from ten to 30 minutes within each individual RAS model) for the entire period of record, but only reports the instantaneous value that occurs at hour 2400 on each day. Due to the watershed size and long duration Missouri River flow events, number of hydrographs and locations required for HC team economic evaluations, and the POR length, the daily reporting time was deemed appropriate. This means that slight shifts in timing from alternative to alternative can carry over into the results as small fluctuations in the reported peak flow. A brief evaluation was conducted as reported within Appendix D and E. Changes were determined to be a small factor on the order of 0.1 foot difference. This level is not likely to significantly impact the HC results evaluation which uses annual peak stage for damage computations.

5.2.7 Results Based on POR

Comparison of results is based on the POR methodology. Due to the large number of daily values, the limited number of pulse occurrences for many of the alternatives, and the limited pulse duration, the POR methodology that relies on comparing annual peaks or flow duration statistics for the entire 82 years may not identify change in risk to human considerations. Figure 5-3 illustrates how flows may change between alternatives.

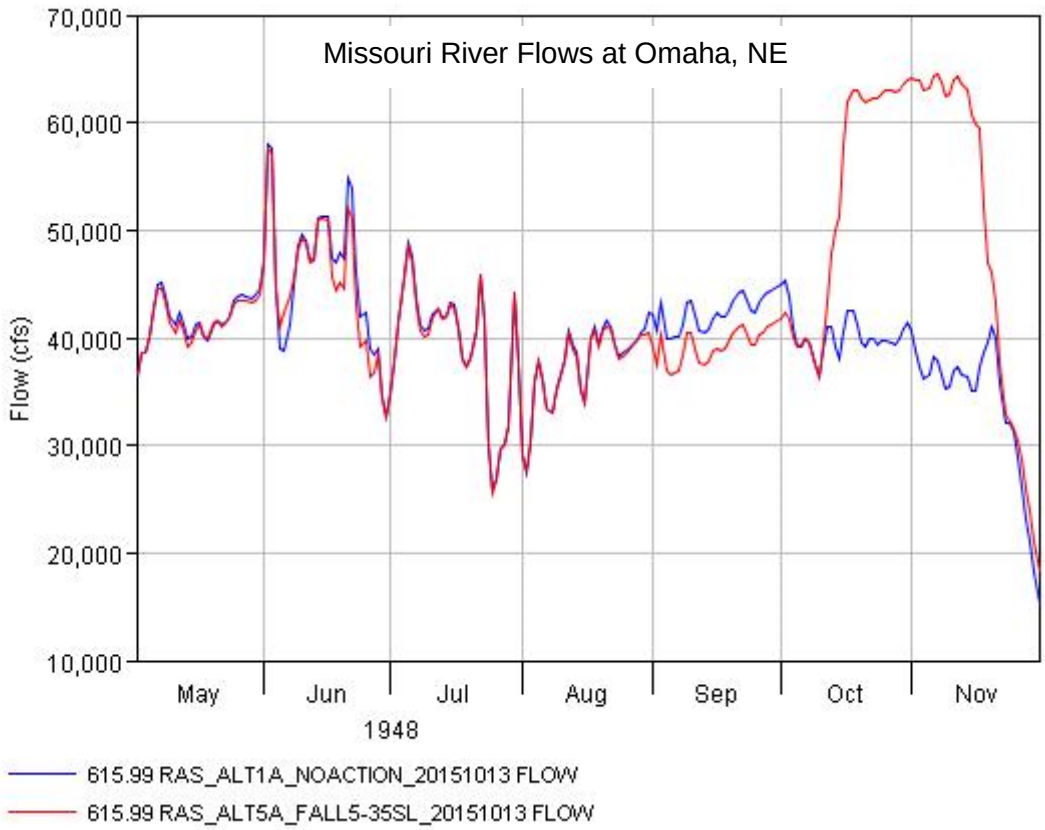


Figure 5-3. Example Comparison of Alt 1 and 5 flows at Omaha, NE

Although the 82 year POR length is statistically significant, alternatives that include flow release changes for a relatively few number of years, often less than ten, can be obscured when averaged over the entire POR. In addition, this small sample size limits possible combinations with downstream inflow. Further, proximity to the upstream dam is a factor when considering the relative magnitude of the pulse change to normal river flow.

If the statistics are compared during the pulse year instead of for the entire POR, results are significantly different. As an example, the change in statistics between Alternatives 1 and 5 using the entire POR and only 7 months in 1948, a year that included a flow pulse release for alternative 5, is shown in Table 5-3.

Table 5-3. Comparison of Omaha Flow (cfs), Alt. 1 and 5, POR and Flow Pulse Duration

	82 Year POR Length			1 May to 20 Nov, 1948		
	Alt 1	**Alt 5**	**Difference (Alt 5-1)**	**Alt 1**	**Alt 5**	**Difference (Alt 5-1)**
Min	7,029	7,029	0	25,676	25,623	-53
10%	13,218	13,243	25	35,511	36,330	818
25%	18,073	18,173	99	38,576	39,003	427
50%	31,424	31,185	-239	40,815	41,113	298
75%	38,558	38,538	-20	43,191	46,952	3,761
90%	49,388	49,925	537	45,836	62,681	16,845
Max	206,235	206,262	27	58,056	64,444	6,389

6 INTERIOR DRAINAGE EVALUATION

Interior drainage refers to the conveyance of flow from interior, or landward side, of the levee to the Missouri River channel. Typical Missouri River levee systems have gravity flow culverts or pump stations to allow local drainage to exit the interior of the levee and drain to the river. Each culvert typically would include one or more closures, such as a flap gate or sluice gate, to prevent river water from backing up into the leveed area. When river levels are higher than the culvert outlets and this coincides with heavy local rainfall, ponding water can cause flooding on the interior of the levee. Additionally, when river levels are above the interior ground level, seepage through the ground under the levee can also cause flooding on the interior. Refer to the RAS alternative condition model report for a detailed discussion of interior drainage model creation and results within Appendix D and E.

The flow change alternatives have the potential to significantly impact interior drainage. Using a flow of 75,000 cfs, which is just below the flood target of 82,000 cfs for Nebraska City in the ResSim model, Figure 6-1 illustrates that the RAS model computed profile is either partially or fully over all of the flap gates on L-536 and L-575 levee units (circled in red). The steady flow profile analysis illustrates that the risk for interior drainage impact is high for any flow pulse since the downstream flood target elevation results in interior drainage blockage at some locations.

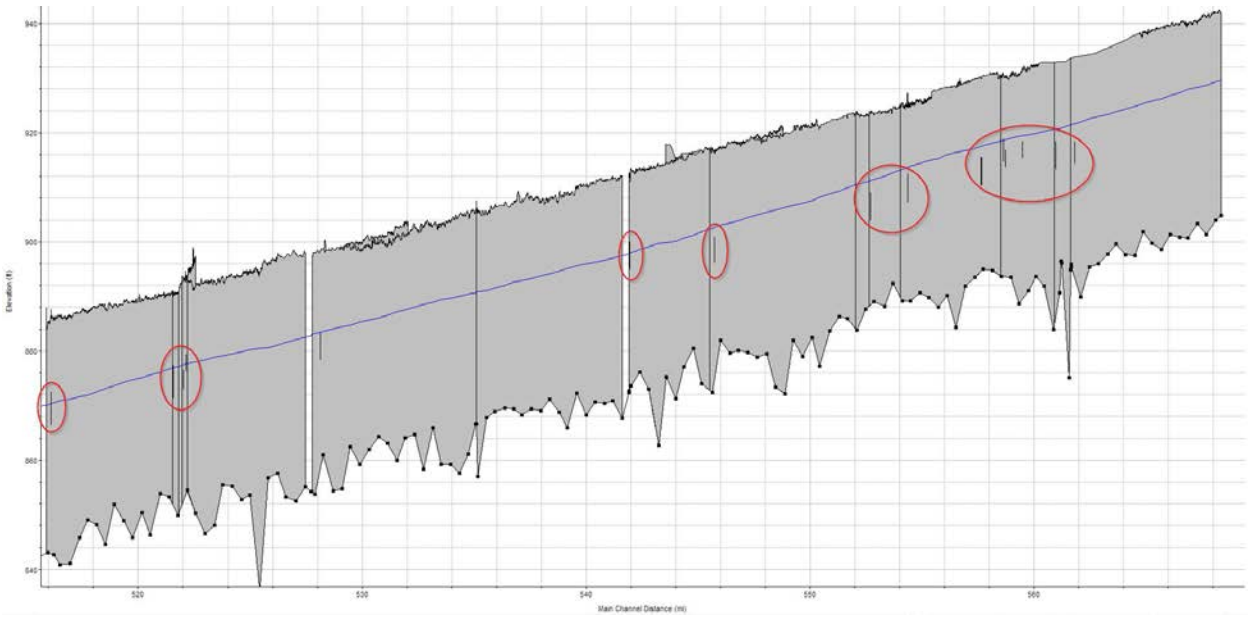


Figure 6-1: 75,000 cfs HEC-RAS Steady Profile and Flap Gates

6.1 CONDUCTED EVALUATION

To evaluate interior drainage flooding, and measure differences between the proposed alternatives and Alt 1, a sub-set of the seven sites evaluated for the Master Manual (USACE 1998) were modeled in detail. Four sites were selected, L-575 and L-536 in the Omaha District and L-488 and L-246 in the Kansas City District.

The interior drainage evaluation was conducted using the alternative condition RAS models. All sites are located downstream of Omaha, NE, within the reach in which federal levees were constructed. Consequently, only the Gavins to Rulo and Rulo to the mouth RAS models were used in the interior drainage analysis. Figure 6-2 shows an area map with the locations of the four sites on the river.

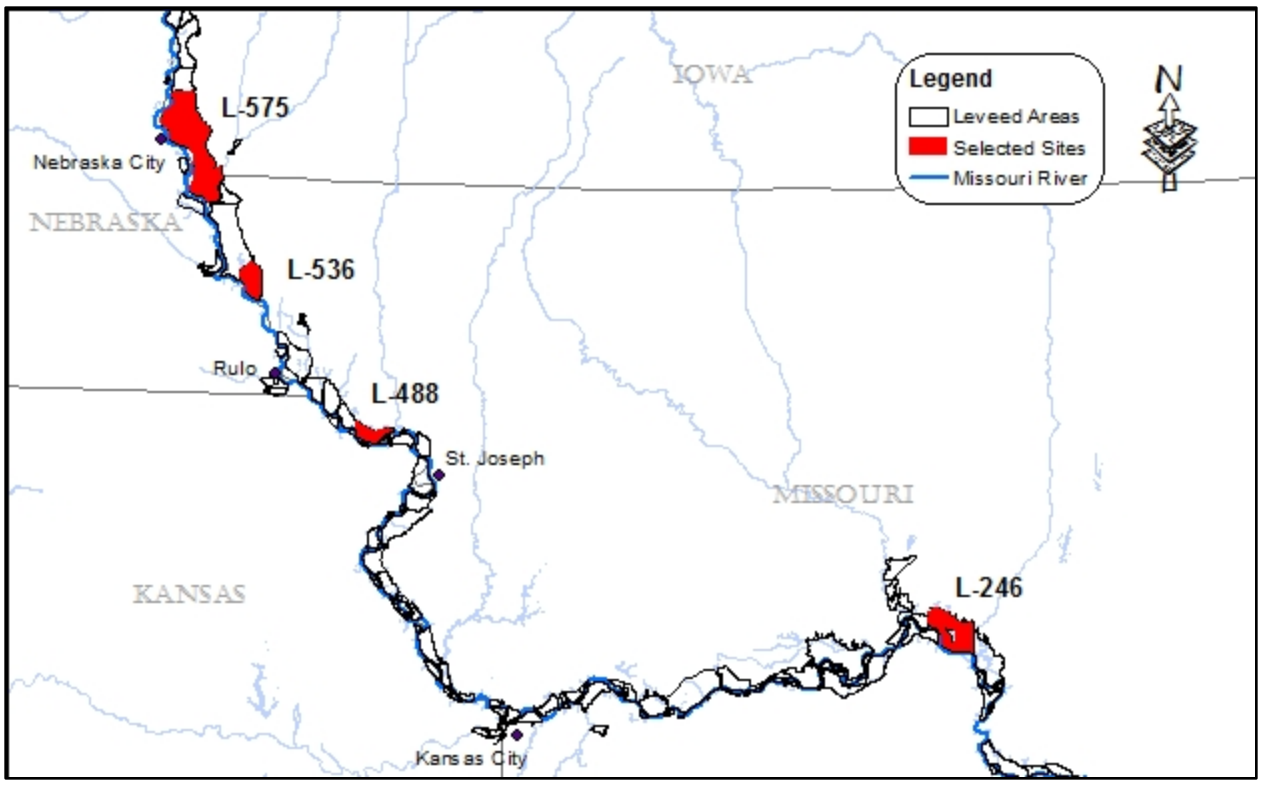


Figure 6-2. Interior Drainage Sites

6.2 INTERIOR DRAINAGE DATA ASSEMBLY

Drainage basins for each unit were drawn using the best available LiDAR data and previously delineated basins from the Master Manual were used as a guide (USACE, 1998). Lateral structures were used to model levee alignments. Culvert and flapgate data was assembled from the best available survey information and the levee unit O&M manuals. For the two units within the Omaha District (L-575 and L-536), the best available pump data was obtained from the updated O&M manual. However, it is noted that pumps are not always maintained and operated by the levee drainage districts so there is very little current information known. RAS requires a pump capacity curve including losses. Since such little information was known about the pumps, pump capacity curves were developed using manufacturer's information or representative curves. Friction and minor losses were included in the final pump capacity curves.

Seepage into the interior area during periods of high river stage was accounted for by use of a lateral inflow hydrograph boundary condition to each storage area in the RAS interior drainage model. A reference cross section was chosen to calculate the seepage into each lateral structure piece. Missouri River stage output from each alternative was used to calculate the seepage with a daily time step. For each day in the POR, the differential head was calculated and was multiplied by the seepage rate and the length of levee or number of relief wells. The final interior drainage

model contained lateral inflow hydrographs of total seepage for each storage area for each alternative.

6.3 Interior Area Rainfall

An HEC-HMS model provided rainfall inflow hydrographs to each storage area for the POR for the levee unit interior drainage basins. Each storage area inflow dataset was input into the RAS model as a lateral inflow hydrograph. Unlike the seepage, which had alternative specific inflows, the same rainfall input was used for all of the alternative runs.

6.4 Interior Drainage Evaluation results

Interior drainage analysis was performed by modifying the respective RAS alternative condition model with the above parameters. Since the interior drainage model significantly effects unsteady flow computations, results may be compared only with other interior drainage model results.

To express the changes compared with the No Action alternative, the water surface elevation model results were evaluated by the same statistical evaluations made on the full models. Output tables are available in Appendix D and E. All of the alternatives show minor water surface elevation differences. Alternative 2 has the greatest impact (higher water surface elevations) among the alternatives.

The interior drainage models provide a powerful tool to assess the complicated interaction between reservoir releases upstream of a levee unit on interior ponding resulting from rainfall and/or seepage. However, limited conclusions can be extrapolated to the entire river. With such slight differences compared to Alt 1, it is difficult to separate the impact of flow changes from the reservoirs from the impact of added habitat to make global conclusions. Changes are highly localized, depending upon factors such as how low the culvert outlet is and the interior area available for ponding before damages occur.

6.5 Sensitivity Analysis and Results

A series of sensitivity runs were conducted for the interior drainage analysis within the Omaha District as presented in Appendix D. They included three actions either alone or in combination: all pumps removed, culverts filled with sediment halfway, and a simulated pulse every year (spring or fall, depending on the alternative). Reasons for running each sensitivity are as follows:

- All of the pumps removed - conducted due to the uncertainty with the pumps' physical and operational information.
- Culverts half filled with sediment - conducted because of a comparison to limited temporary gage data revealed that the model's water surface elevations were generally low.
- Simulated pulse every year - conducted to analyze if the timing and amount of pulses had a large effect on the results.

Sensitivity analyses indicated that changes in assumptions about the interior drainage structures have a large impact on results. Removing all pumps had the most effect on the storage area water

surface elevations. The culvert sediment and pulse every year runs produced minimal differences compared to the no pumps run. The risk of flooding from interior drainage is much more a function of the conditions of the interior drainage structures (culverts and pumps) at specific sites. Alternative 2 has relatively larger impacts compared with Alternatives 3-6.

- Interior drainage analysis determined that alternative 2 had the largest impact
- A steady flow profile analysis at Nebraska City determined that the risk for interior drainage impact is raised for any flow pulse since the downstream flood target elevation at Nebraska City corresponds to river water levels above culvert invert elevations. River levels at this level or higher can reduce capacity of gravity flow levee drainage structures.
- Uncertainties regarding the interior drainage pump operation and culvert sediment levels were evaluated with a sensitivity analysis. Analysis demonstrated that these inputs have a high impact on results.

7 CHANNEL CAPACITY ANALYSIS

Channel capacity estimates were performed to provide an indication of the flow rate at which bank elevations are overtopped and flow begins to leave the main channel and enter the floodplain. Channel capacity estimates were performed with the one-dimensional RAS models calibrated to 2012 conditions by comparing steady flow profiles with top of bank elevations at each cross section combined with reviewing the best available floodplain topography. Floodplain flow connectivity was not assessed. The estimated channel capacity does not necessarily correlate with the onset of flood damage. In addition, channel capacity is typically highly variable along the channel bank due to wide variation in bank elevations. The quality of the channel capacity estimate is affected by numerous factors including how representative the model cross sections are of river geometry, local channel geometry variation, low spots in bank elevations, and the floodplain topography accuracy. Within the reservoir delta areas where the river enters the downstream lake, the channel capacity estimate is not meaningful.

A Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood risk as a result of flow release changes would be required to fully assess how an alternative impacts potential flood risk. Refer to the *Summary of Hydrologic Engineering Analysis* (USACE 2016f) for additional details on the risk analysis methodology.

7.1 CHANNEL CAPACITY ESTIMATES AT SELECT LOCATIONS

Channel capacity estimates were performed to provide an indication of reaches susceptible to flooding and if any of the alternatives may alter flood risk. Within selected model reaches, the minimum flow that exceeded bank elevations was determined at a representative area. These areas were selected based on flood potential. For instance, the degradation reach immediately downstream of Gavins Point Dam has much higher channel capacity than areas further downstream. For that reason, the Nebraska City vicinity was selected as more representative of flood risk when evaluating alternatives. Refer to the individual appendices for each RAS model reach for additional information regarding reach characteristics and the channel capacity

estimates. A summary of the channel capacity estimates is provided in Table 7-1. Due to the large distance downstream of Gavins Point Dam, a channel capacity estimate was not performed for the river between Rulo, NE and the mouth at St. Louis.

Table 7-1. Channel Capacity Estimates

Location	Representative Area[1]	From RM	To RM[2]	Channel Capacity (kcfs) [3]
Fort Peck Dam to Lake Sakakawea	Below the Yellowstone River	1771.5	-	35 to 40
Garrison Dam to Bismarck, ND	Bismarck, ND	1389.9	1314.6	55 to 60
Downstream of Bismarck, ND to Lake Oahe	Vicinity of Schmidt, ND	1314.6	-	35 to 40
Fort Randall Dam to Lewis & Clark Lake	Below the Niobrara River	880.0	-	35 to 40
Gavins Point Dam to Rulo, NE	Nebraska City, NE	811.1	498.0	80 to 85

1 Since the model reaches are up to several hundred miles in length, the estimated capacity should be regarded as an indication for the onset of flooding at the representative area, not the entire reach.
2 Downstream boundaries that are reservoir pools are not a static location and change with pool elevations.
3 The channel capacity estimate is based on an evaluation of hydraulic model results. The estimated channel capacity refers to the flow level at which significant water levels exceed bank elevations (may represent ponding water and not necessarily flow through connectivity). Values vary considerably within the reach and may change over time.

7.2 Flood Potential Evaluation

Following the channel capacity estimate, an additional brief evaluation was conducted of two areas to provide an indication of the potential for an alternative to change flood risk. From the channel capacity estimates shown in Table 7-1, two areas were selected that appeared to have the highest potential for a change in flood risk: 1) the Fort Randall Dam reach downstream of the Niobrara River; 2) the Nebraska City area downstream of Gavins Point Dam.

7.2.1 Downstream of the Niobrara River

For the reach downstream of the Niobrara River between Fort Randall Dam and Lewis and Clark Lake, it was determined that any of the proposed flow releases to provide spawning cues or ESH habitat exceed the existing channel capacity and would result in 100% flood risk potential for that area.

7.2.2 Nebraska City Area

For the Nebraska City area, a simplified evaluation was conducted to compare the number of days that each alternative has the potential to exceed the estimated channel capacity of 80,000 to 85,000 cfs. This was performed by comparing the number of days in the POR that the sum

of the downstream inflow between Gavins Point and Nebraska City exceeded the capacity remaining after accounting for the Gavins Point Dam release.

A simplified example to present the evaluation method is as follows:

Alt 3 Scenario:

Total inflow downstream (Gavins release minus Nebraska City flow) was 30,000 cfs
Alt 3 normal Gavins Point Dam daily release of 35,000 cfs
Flood potential not counted (80,000 capacity is greater than the 35,000 release plus the 30,000 cfs downstream inflow)

Alt 4 Scenario:

Total inflow downstream (Gavins release minus Nebraska City flow) was 30,000 cfs
Alt 4 ESH Gavins Point Dam daily release of 60,000 cfs
Flood potential day counted (80,000 capacity is less than the 60,000 cfs release plus the 30,000 cfs downstream inflow)

The above computation was performed for all alternatives at Nebraska City. The percent exceedance for each alternative was calculated from the days above capacity compared to the total number of days. In order to simplify the computation, flow release periods were reduced to month long lengths. Values were calculated only for the month time period during the alternative specific pulse flow release period. Flood potential was computed as the number of days that downstream inflow plus Gavins Point Dam release exceeds channel capacity. The flood potential was expressed as a percent time exceeded that was computed from the total number of days exceeding capacity compared to the total number of pulse release days.

Results determined that most of the alternatives have the potential to alter flood risk at Nebraska City with most of the alternatives resulting in a greater than 10% change in flood potential during the flow release period. Results are illustrated in Figure 7-1.

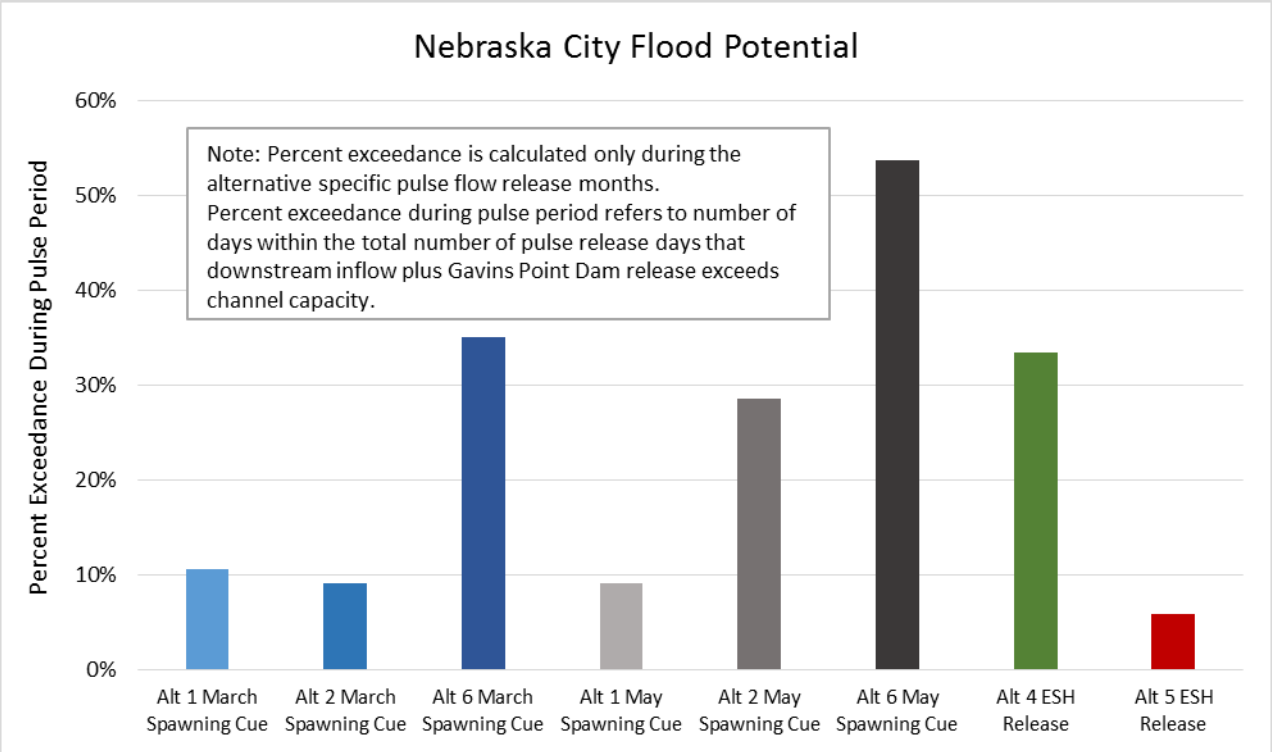


Figure 7-1. Nebraska City Flood Potential

7.3 SUMMARY

Channel capacity estimates were performed to provide an indication the flow rate at which bank elevations are overtopped and flow begins to leave the main channel and enter the floodplain. The channel capacity estimate is based on an evaluation of hydraulic model results and vary considerably within the reach and may change over time. Following the channel capacity estimates, an evaluation of flood potential was conducted at two locations.

- Capacity estimates refer to the minimum capacity within a large reach, are highly variable, and may change over time.
- Within the Fort Randall reach downstream of the Niobrara River confluence, flow release above channel capacity is included in all alternatives. Flood severity variation between alternatives occurs due to changes in flow increase magnitude and duration.
- Within the Nebraska City area, the flood potential varies with most of the alternatives showing a greater than 10% increase in flood potential.

8 SOURCES OF UNCERTAINTY AND LIMITATIONS

The performed hydrologic evaluation of the complex Missouri River System provides a powerful alternative analysis tool for assessing differences between alternatives. Comparison between alternatives should recognize that minor and insignificant differences can occur due to many sources. Multiple factors contribute to the uncertainty in the HEC-ResSim and RAS model results

including the dynamic nature of the river system itself, river response to flood events and construction projects, the availability and quality of terrain data to represent the channel and floodplain geometry, and the quality of hydrologic data. In addition, the analysis relies on the simulation of the 82-year period of record using daily average outflows from an HEC-ResSim model input into a fixed bed RAS model, with stage and flow output. Sources of uncertainty and limitations of model output include:

1. Dynamic River - Each reach-specific model represents a snapshot in time on a dynamic river system that has experienced variance in the stage discharge relationship over time. The Missouri River is a sand bed river in all of the model reaches. Channel depth varies with scour during high flow periods and deposition during low flow periods. River banks can expand or contract depending on river flows. Channel bed forms change in magnitude and migrate over time. In most instances the Missouri River channel varies within a fairly well known range of depth and magnitude of bed forms and the models are designed to be a reasonable representation of this dynamic equilibrium. Evaluating dynamic change to Missouri River habitat projects was beyond the scope of this analysis and not attempted.
2. Climate Change – The POR evaluation used the historic inflows with adjustment to current level of depletions. The historic inflows may not be comparable to future conditions. A climate change assessment of the Missouri River basin indicates increases to both temperature and precipitation along with increasing trends in extreme floods and droughts (USACE 2016d).
3. POR Limited Sample Size - Several of the alternatives include flow changes. Within the POR, the downstream impact of the flow change is only evaluated with the inflow that occurred historically. The conditions during a pulse year in the future could vary greatly from the small sample of pulse events included in the POR analysis.
4. Risk Analysis - The Missouri River System as currently operated provides substantial flood damage reduction and benefits to the entire basin. The current HEC-ResSim and RAS analysis, which employs an 82 year period of record simulation, shows the potential for negative impacts to flood damage reduction and dam safety for alternatives that include changes in reservoir flow releases. The current study methodology does not simulate a sufficient number of events and possible runoff combinations within the large Missouri River basin to evaluate potential change in downstream flood risk and dam safety or to quantify the associated uncertainties.

   Scoping efforts were conducted to determine a Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood damage reduction as a result of flow release changes. The risk analysis primary components include further development of the period of record flow data set, HEC-ResSim and RAS model modifications, development of levee fragility curves, assignment of uncertainty, assembly and debugging of models, Monte Carlo simulation, analysis of results, and reporting. The Monte Carlo methodology properly assesses the effects of the alternative operation changes because it increases the sample size of flow data and number of combinations of flow periods that may occur in the future so that impacts can be characterized with greater confidence.

Without such analysis, the impacts of operational changes will only be known for a limited number of flow pulse and downstream inflow combinations. Potential impacts to flood risk management were identified by evaluation of the outputs from the HEC-ResSim and RAS analysis that could be quantified with the risk analysis.

5. Bed and Floodplain Aggradation / Degradation Trends - Significant change in Missouri River geometry continues to occur as a result of channel aggradation and degradation. The observed aggradation/degradation trends, as discussed in the *Missouri River Stage Trends* study (USACE 2012c), result from both natural variability in river morphology as well as from man made changes such as the historical construction of flood control projects, channel cutoffs, and channel and bank stability projects. Modeled reaches that include dams generally have a degrading reach below the dam and an aggrading reach in the headwaters of the downstream reservoir. Although alternative analysis is performed for the future, no adjustments were made to account for aggradation / degradation trends. Additionally, the analysis does not try to project where sediment may accumulate in the floodplain or include projections of future change in floodplain roughness. For habitat alternatives, it was assumed that any bed or floodplain changes would be either negligible, similar between each alternative, or mitigated during more detailed design of river widening projects.
6. Limited Stream Gage Records and Flow Sources in the POR - The Missouri River, major tributaries, and ungaged inflows included in the RAS in the POR model are the only flow sources. During the early portion of the POR (1930 to about 1950), many of the stream gages had not been installed. Therefore, a significant percentage of the drainage area feeding each model is ungaged during the early years of the POR. Modeling requires estimation of ungaged inflows in order to match flow and stage records at the Missouri River gages. Details of ungaged flow estimation for each model are discussed in the reach-specific appendices and POR report. In addition, the inflow sources, rates, and volumes are limited to those that occurred in the historic record as modeled within RAS. In reality, a wide variety of downstream flows should be expected due to localized rainfall and subsequent runoff.
7. Levee Performance and Interior Drainage – The limited scope of the interior drainage evaluation identified that many culverts are at a low flow level that are easily impacted by high Missouri River flow levels. Additional flooding of the interior can occur through seepage under levee foundations during prolonged high water, or through failure of levees prior to overtopping. Levee breach formation has occurred in the past on the Missouri River prior to levee overtopping. Assumptions regarding levee performance and how repairs occur after each event were greatly simplified for the POR evaluation. Detailed interior drainage calculations, which account for only river levels, localized rainfall and runoff, and underseepage was conducted at only four levee systems.
8. RAS Model Simplifying Assumptions - Simplifying assumptions were necessary for the construction of RAS models for a system of this scale and complexity. Bridges were not included. Floodplain flow areas were all considered as one-dimensional flow areas. Levee breaches without overtopping were not included. The RAS model construction

methodology, which relies on cross sections of the river channel and adjacent floodplain to represent conveyance, was assumed to be not significantly altered by any of the alternatives. Alternatives were also assumed to have no effect on channel bed forms and flow roughness.

9 REFERENCES

FAA. (Aug 2007). *Advisory Circular No 150/520-33B Hazardous Wildlife Attractants on or Near Airports.* U.S. Department of Transportation Federal Aviation Administration.

Fischenich, C.J. (2014). *Draft, Models, Data and Literature to Support Habitat Analyses for the Missouri River Effects Analysis.*

Jacobson, Linder, Bitner (2015)

2012 and 2013 reports cited regarding SWH / sediment during flood?

Jacobson, R.B., Annis, M.L., Colvin, M.E., James, D.A., Welker, T.L., and Parsley, M.J., 2016. Missouri River *Scaphirhynchus albus* (pallid sturgeon) effects analysis—Integrative report 2016: U.S. Geological Survey Scientific Investigations Report 2016–5064, 154 p., http://dx.doi.org/10.3133/sir20165064.

USACE (1998). *Missouri River Mainstem Reservoir System, Master Water Control Manual, Missouri River Basin.* U.S. Army Corps of Engineers, Northwestern Division – Missouri River Basin, Reservoir Control Center, Omaha, NE.

USACE 2000. ER 1105-2-100, *Planning Guidance Notebook*.

USACE 2003. *Upper Mississippi River System Flow Frequency Study - Hydrology and Hydraulics Appendix F.* Omaha, NE, U.S. Army Corps of Enginers.

USACE 2006. ER 1105-2-101, *Risk Analysis for Flood Damage Reduction Studies*

USACE 2012a. *Post 2011 Flow Shallow Water Habitat Reconnaissance Report*, Office Report, Omaha District, February 2012.

USACE 2012b. EM 1110-2-1619, *Risk Analysis for Flood Risk Management Studies.*

USACE 2012c. *Missouri River Stage Trends,* Missouri River Basin Water Management Division, U.S. Army Corps of Engineers, Omaha NE, August 2012

USACE 2013. *Construction Reference Plane (CRP) Historical Analysis,* Prepared by West Consultants, Omaha District.

USACE 2014. *2014 Shallow Water Habitat Accounting Report.* Kansas City and Omaha Districts, U.S. Army Corps of Engineers.

USACE 2015a. *Mainstem Missouri River Reservoir Simulation Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE 2015b. *Missouri River Recovery Program Management Plan Environmental Impact Statement Existing Conditions Unsteady HEC-RAS Model Calibration Report.* Aug 2015. U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE 2016a. *ECB 2016-25, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects.*

USACE 2016b. *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE 2016c. *Missouri River Recovery Management Plan - Climate Change.* Omaha, NE, U.S. Army Corps of Engineers.

USACE 2016d. *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE 2016e. *Missouri River Recovery Program Management Plan Environmental Impact Statement, HEC-RAS Modeling Alternatives Report.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE 2016f. *Missouri River Recovery Program Management Plan Environmental Impact Statement, Summary of Hydrologic Engineering Analysis.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USFWS 2003. *U.S. Fish and Wildlife Service 2003 Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System.*

US Army Corps of Engineers ®

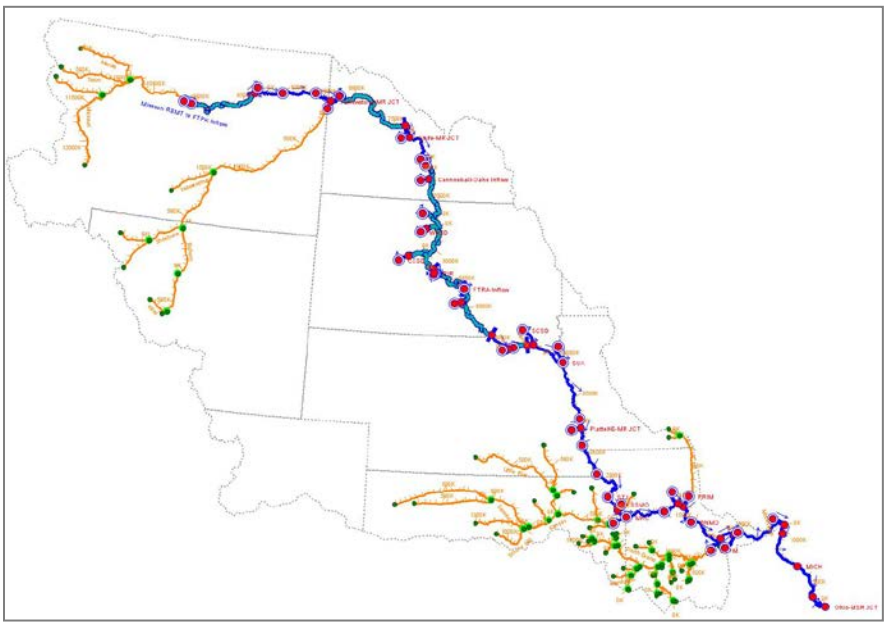
Omaha District

Missouri River Unsteady HEC-RAS Model
Alternatives Analysis

DRAFT

Appendix A

Fort Peck Dam to Garrison Dam



December 2016

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ACRONYMS

BiOp……..Biological Opinion

CFS…… Cubic Feet per Second

ESH……..Emergent Sandbar Habitat

HC……..Human Considerations

HEC ..... Hydrologic Engineering Center

IRC……Interception-Rearing Complexes

MAF…….. Million acre-feet

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

NAD 1983…… ... North American Datum of 1983

NAVD 88…… . North American Vertical Datum of 1988

NGVD 29…… National Geodetic Vertical Datum of 1929

NWK…….. Northwest Division Kansas City District

NWO…… Northwest Division Omaha District

POR..... Period of Record

RAS ..... HEC River Analysis System Software (HEC-RAS)

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

RM……1960 River Mile

SWH…….....Shallow Water Habitat

USACE……..United States Army Corps of Engineers

USFWS……United States Fish and Wildlife Service

USGS ..... United States Geological Survey

1 INTRODUCTION

The Missouri River unsteady HEC-RAS model was developed for the Missouri River Recovery Program Management Plan and Integrated Environmental Impact Statement (MRRPMP-EIS) to assist in the assessment of a suite of actions to meet Endangered Species Act (ESA) responsibilities for the piping plover, the interior least tern, and the pallid sturgeon using USACE authorities. Model geometry development and calibration for the existing conditions is documented in *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix A Fort Peck Dam to Garrison Dam* (USACE 2015). The objective of the HEC-RAS modeling is to simulate the Management Plan alternatives which include both geometry and flow changes relative to the No Action alternative. The Human Considerations (HC) team performed an extensive analysis on each of the alternatives for each of the resources (hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply) and provide a detailed comparison of results. For this report, only the hydraulic model output is presented; there is no alternative selection or discussion. This Appendix is for the Fort Peck Dam to Garrison Dam reach of the Missouri River as part of the Omaha District.

Six alternatives, including the No Action alternative, were simulated in HEC-RAS from March 1930 to December 2012, however the HC team only used complete year data for their analysis from January 1, 1931 to December 31, 2012. Development of inflow records at current depletion levels to use as boundary conditions for the HEC-ResSim and HEC-RAS models is documented in the report, *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (USACE 2016c). Each alternative has unique flow releases from the reservoirs, as simulated by the ResSim model.

2 GEOMETRY

For the Fort Peck Dam to Garrison Dam model, no geometry changes were modeled. All alternative runs used the current conditions (2012) calibrated geometry.

3 FLOW ALTERNATIVES

A total of six flow alternatives were modeled in HEC-ResSim (ResSim). Reservoir pool elevations and dam outflow output from the ResSim model was used as input for the HEC-RAS (RAS) model for each of the six flow alternatives. A brief summary of the flow alternatives is provided below. For more details, see the ResSim technical report, *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report* (2016a).

Tributary and ungaged inflows were kept consistent between alternatives. More details on the Period of Record (POR) flow dataset used can be found in the report *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (2016c).

3.1 ALTERNATIVE 1 - NO ACTION

Under Alternative 1 (Alt 1), the Missouri River Mainstem Projects would continue to be operated as they are currently. Operations within the ResSim model were set up to closely follow the Master Manual that is used during real-time operations of the System; however, the model does have limitations and cannot capture all real-time decisions that occur.

3.2 ALTERNATIVE 2 - U.S. FISH & WILDLIFE SERVICE 2003 BIOLOGICAL OPINION PROJECTED ACTIONS

Alternative 2 (Alt 2) represents the U.S. Fish and Wildlife Service (USFWS) interpretation of the management actions that would be implemented as part of the 2003 Amended BiOp RPA (USFWS 2003). Operational criteria include different early and late spring spawning cues, low summer flows, and a maximum winter release limit.

3.3 ALTERNATIVE 3 - MECHANICAL CONSTRUCTION ONLY

Alternative 3 (Alt 3) consists of mechanical construction of emergent sandbar habitat (ESH). Operational criteria consist of removing the early and late spring spawning cues in Alt 1.

3.4 ALTERNATIVE 4 - SPRING HABITAT-FORMING FLOW RELEASE

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

3.5 ALTERNATIVE 5 - FALL HABITAT-FORMING FLOW RELEASE

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

3.6 ALTERNATIVE 6 - PALLID STURGEON SPAWNING CUE

Alternative 6 (Alt 6) replaces the early and late spring spawning cues with different spawning cues. The early spring spawning cue in Alt 6 occurs at the same time as the early spring spawning cue in Alt 1 but with a higher peak release. The late spring spawning cue in Alt 6 occurs later in May than the late spring spawning cue in Alt 1 and has a larger peak release. Please note that the name of this alternative changed towards the end of the study from Alternative 7 to Alternative 6 (original Alternative 6 was abandoned). The models were not re-run so all of the model and file names are still labeled Alternative 7.

4 SIMULATION OF ALTERNATIVES

Each flow alternative from ResSim was run through HEC-RAS with the current conditions geometry. Alternative names match in both ResSim and RAS.

5 RESULTS

All alternatives runs were performed in HEC-RAS 5.0 Beta (21-August-2015) because that was the most current version as of October and November 2015, when most of the runs were completed. Official release of HEC-RAS 5.0 was on 4-March-2016 and 5.0.1 on 22-Apr-2016, at which point evaluation of results by the economists and human considerations teams was well underway and it would have unnecessarily compromised schedule to re-run the simulations.

Model output contains a considerable amount of information, not easily condensed to simple conclusions. Each of the six alternative runs produced 82 years (March 1930 – December 2012) of stage and flow hydrographs. To express the changes compared with the No Action alternative, the model results were evaluated by statistical evaluation and duration analysis plots.

Results from the 82-year runs for the six alternatives were provided to the Human Considerations (HC) team for analysis. They used the daily (instantaneous 2400 value for each day) flow and water surface elevation output to analyze effects to various resources that include: hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply. The HC team performed an extensive analysis on each of the alternatives for all of the resources and provide a detailed comparison of results. For this report, only the hydraulic model output is presented.

5.1 STATISTICS

For the statistical evaluation, daily flow and water surface elevation results were analyzed to compare the differences between the No Action Alternative and the remaining five alternatives. All of the alternatives show minor changes, while Alternative 4 shows the most difference with respect to both flow and water surface elevation. Tables showing the differences between calculated statistics for both flow and water surface elevation for below Fort Peck Dam, Wolf Point, Culbertson, Williston, and Lake Sakakawea (elevation only) can be seen in Plate 1 and Plate 2. The statistics calculated include: the 10th, 25th, 50th, 75th, and 90th- Percentiles, and the Minimum and Maximum. It should be noted that the percentile statistics calculated are from a duration analysis and not a Bulletin 17B flow frequency analysis.

The min and max are the lowest daily flow or stage and the highest daily flow or stage output for each alternative over the period of record. For model stability, a minimum flow of 2,500 cfs was used for Fort Peck outflow in RAS. As seen in the tables, the minimum flow varies slightly between alternatives while the maximum flow shows greater differences. Caution should be used when trying to draw conclusions from the statistics alone. The economic models (HEC-FIA) provide a more complete analysis of how high flows effect total damages for each alternative because they incorporate all of the cross section output, whereas these tabular statistics only capture one location.

Stage statistics have been rounded to the nearest tenth of a foot, which is equivalent to 1.2 inches. This helps demonstrate how flow changes impact river elevations, which is the more tangible result. For example, even though the 90th percentile flow for Culbertson in Alternative 4 was 140-

cfs higher than in Alternative 1, there is less than an inch of impact to the water surface elevation of the river, and therefore zero reported change.

It is also important to note that the HEC-RAS alternative models, although they have a 30 minute computation interval, have been configured to report one value per 24 hour period, and unfortunately that one value is not a daily average. The HEC-RAS model reports the value that lands on 2400 of each day. The most reasonable output interval was chosen as daily due to the size of watershed being modeled, POR length, and the number of hydrograph locations necessary for HC analysis. This means that slight shifts in timing from alternative to alternative can carry over into the results as small fluxuations in the reported flow. Changes in timing are a small factor, not likely to significantly impact any results evaluation, but should be kept in mind when making comparison at a precise level such as in the statistics tables.

5.2 Seasonal Duration Plots

A duration analysis was also performed for the alternative output. Seasonal duration plots for key main stem locations including below Fort Peck Dam, Wolf Point, Culbertson, Williston, and Lake Sakakawea (elevation only) are shown in Plate 3 through Plate 22. Seasonal dates chosen for the duration analysis coincide with the current System operational seasons: spring (1Mar to 30Apr), summer (1May to 31Aug), fall (1Sep to 30Nov), and winter (1Dec to 28Feb). There are minimal changes in all seasons for most of the reach. The most notable differences can be seen in the pool elevations in Lake Sakakawea.

5.3 Limitations

The analysis relies on the simulation of the 82-year period of record using daily average outflows from an HEC-ResSim model input into a fixed bed HEC-RAS model, with stage and flow output. While the analysis coupled with species and human considerations models can be used to show relative benefits and potential impacts based on historic flows, there are limitations in the conclusions that can be drawn based on some of the simplifying assumptions.

1. **POR Methodology** - An 82-year period of record, adjusted to current level of depletions, was used and may not be comparable to future conditions. A climate change assessment of the Missouri River basin indicates increases to both temperature and precipitation along with increasing trends in extreme floods and droughts (USACE 2016b). The conditions during a pulse year in the future could vary greatly from the small sample of pulse events included in the POR analysis.
2. **No Risk Analysis** - The Missouri River system as currently operated provides substantial flood damage reduction and benefits to the entire basin. The current HEC-ResSim and HEC-RAS analysis, which employs an 82-year period of record simulation, shows the potential for negative impacts to flood damage reduction and dam safety for alternatives that include changes in reservoir flow releases. The current study methodology does not simulate a sufficient number of events and possible runoff combinations within the large Missouri River basin to evaluate potential change in downstream flood risk and dam safety.

Scoping efforts were conducted to determine a Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood damage reduction as a result of flow release changes. The risk analysis primary components include further development of the period of record flow data set, HEC-ResSim and HEC-RAS model modifications, development of levee fragility curves, assignment of uncertainty, assembly and debugging of models, Monte Carlo simulation, analysis of results, and reporting. The Monte Carlo methodology properly assesses the effects of the alternative operation changes because it increases the sample size of flow data and number of combinations of flow periods that may occur in the future so that impacts can be characterized with greater confidence. Without such analysis, the impacts of operational changes will only be known for events and combinations of events that have already occurred. Statistics calculated based on the 83-years of record should therefore be used with caution, and with the understanding of the consequences of using only a small sample of years.

3. **Stable Bed and Floodplain** - The hydraulic modeling to date is based on the existing conditions geometry. The analysis does not account for how the bed of the Missouri River may respond to flow changes. Additionally, the analysis does not try to project where sediment may accumulate in the floodplain or include projections of future change in floodplain roughness. This carries with it the necessary assumptions that any bed and floodplain changes would be either negligible or similar between each alternative.

5.4 Channel Capacity Analysis

Channel capacity estimates were performed to provide an indication of the flow rate at which bank elevations are overtopped and flow begins to leave the main channel and enter the floodplain. Channel capacity estimates were performed with the one-dimensional RAS model calibrated to 2012 conditions by comparing steady flow profiles with top of bank elevations at each cross section combined with reviewing the best available floodplain topography. Floodplain flow connectivity was not assessed. The estimated channel capacity does not necessarily correlate with the onset of flood damage. In addition, channel capacity is typically highly variable along the channel bank due to wide variation in bank elevations. The quality of the channel capacity estimate is affected by numerous factors including how representative the model cross sections are of river geometry, local channel geometry variation, low spots in bank elevations, and the floodplain topography accuracy. Within the reservoir delta areas where the river enters the downstream lake, the channel capacity estimate is not meaningful. While channel capacity varies within the reach and through time, a range for the entire Fort Peck to Lake Sakakawea reach is 35,000 to 40,000 cfs.

A Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood risk as a result of flow release changes would be required to fully assess how an alternative impacts potential flood risk. Refer to the *Summary of Hydrologic Engineering Analysis* (USACE 2016d) for additional details on the risk analysis methodology.

6 CONCLUSIONS

The unsteady HEC-RAS model analysis gives a means to systematically evaluate differences in river elevations for various reservoir and habitat alternatives given the limitations presented in Section 5.3. These results can be fed into additional species and human considerations models, such as HEC-FIA, to screen alternatives for relative benefits and potential economic impacts. The outputs should be carefully examined with an eye towards the model limitations and judgement applied where needed to mitigate any potential pitfalls of the hydraulic analysis.

If flow change alternatives are considered for implementation, additional risk and uncertainty analysis is recommended to more comprehensively quantify risk of spring or fall pulse flows.

The analysis presented in this report is based off of the existing conditions HEC-RAS models. The steps of this analysis could be repeated if predictions of bed change are made for any of the alternatives. Having both analysis completed would provide a range of reasonable results throughout the planning horizon.

7 REFERENCES

USACE (2015). *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix A Fort Peck Dam to Garrison Dam.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016a). *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016b). *Missouri River Recovery Management Plan - Climate Change.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016c). *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE (2016d). *Missouri River Recovery Program Management Plan Environmental Impact Statement, Summary of Hydrologic Engineering Analysis.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USFWS (2003). *U.S. Fish and Wildlife Service 2003 Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System.* U.S. Fish and Wildlife Service.

APPENDIX A

FORT PECK DAM TO GARRISON DAM

PLATES

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Fort Peck - XS 1769.04							
Alt 1A	4,334	5,862	8,000	10,847	13,000	3,000	59,837
Alt 2A	4,400	5,857	8,100	10,897	13,000	3,000	66,000
Change from Alt 1A	66	-5	100	51	0	0	6,163
Alt 3A	4,332	5,831	8,126	10,800	13,000	3,000	57,201
Change from Alt 1A	-2	-31	126	-47	0	0	-2,636
Alt 4A	4,200	5,799	7,800	11,091	13,000	3,000	66,000
Change from Alt 1A	-134	-63	-200	244	0	0	6,163
Alt 5A	4,304	5,833	8,100	10,895	13,000	3,000	66,000
Change from Alt 1A	-30	-29	100	48	0	0	6,163
Alt 6A	4,322	5,825	8,100	11,034	13,000	3,000	58,400
Change from Alt 1A	-12	-38	100	187	0	0	-1,437
Wolf Point - XS 1701.31							
Alt 1A	4,756	6,167	8,570	11,444	13,697	2,555	80,290
Alt 2A	4,769	6,141	8,642	11,377	13,689	2,506	91,170
Change from Alt 1A	13	-26	71	-68	-7	-49	10,880
Alt 3A	4,735	6,161	8,601	11,426	13,738	2,555	82,917
Change from Alt 1A	-21	-7	30	-18	42	0	2,627
Alt 4A	4,652	6,089	8,539	11,708	13,860	2,502	91,177
Change from Alt 1A	-104	-79	-31	264	164	-53	10,887
Alt 5A	4,718	6,165	8,713	11,426	13,691	2,555	86,359
Change from Alt 1A	-37	-2	143	-18	-5	0	6,069
Alt 6A	4,754	6,146	8,660	11,498	13,675	2,506	84,710
Change from Alt 1A	-1	-22	90	53	-21	-49	4,420
Culbertson - XS 1620.65							
Alt 1A	4,892	6,240	8,763	11,579	14,063	2,040	91,844
Alt 2A	4,936	6,226	8,817	11,517	14,063	2,040	94,397
Change from Alt 1A	44	-14	54	-61	1	0	2,553
Alt 3A	4,856	6,230	8,780	11,562	14,085	2,040	89,396
Change from Alt 1A	-36	-10	17	-17	22	0	-2,447
Alt 4A	4,739	6,195	8,758	11,885	14,203	2,040	94,421
Change from Alt 1A	-153	-45	-5	306	140	0	2,577
Alt 5A	4,833	6,266	8,865	11,584	14,024	2,040	97,565
Change from Alt 1A	-59	25	102	6	-38	0	5,721
Alt 6A	4,901	6,219	8,820	11,623	14,045	2,040	89,380
Change from Alt 1A	9	-21	57	44	-18	0	-2,464

Plate 1: Alternative Flow Statistics from POR Duration

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Williston - XS 1552.61							
Alt 1A	10,547	12,930	17,227	23,336	37,151	4,221	164,821
Alt 2A	10,554	12,931	17,200	23,331	37,063	4,211	164,988
Change from Alt 1A	7	0	-27	-5	-88	-10	167
Alt 3A	10,550	12,926	17,221	23,358	37,210	4,223	163,756
Change from Alt 1A	3	-4	-6	21	59	2	-1,065
Alt 4A	10,438	12,878	17,109	23,455	37,450	4,070	165,270
Change from Alt 1A	-110	-52	-118	119	299	-152	449
Alt 5A	10,544	12,956	17,211	23,342	37,161	4,223	166,684
Change from Alt 1A	-3	25	-16	6	10	2	1,863
Alt 6A	10,570	12,956	17,214	23,367	37,184	4,175	163,952
Change from Alt 1A	23	26	-13	31	33	-46	-869

Plate 1 cont'd: Alternative Flow Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Fort Peck - XS 1769.04							
Alt 1A	2028.6	2029.4	2030.4	2031.6	2032.4	2027.6	2040.7
Alt 2A	2028.6	2029.4	2030.4	2031.6	2032.4	2027.6	2041.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Alt 3A	2028.6	2029.4	2030.5	2031.6	2032.4	2027.6	2040.3
Change from Alt 1A	0.0	0.0	0.1	0.0	0.0	0.0	-0.3
Alt 4A	2028.5	2029.4	2030.3	2031.6	2032.4	2027.6	2041.7
Change from Alt 1A	-0.1	0.0	-0.1	0.1	0.0	0.0	1.0
Alt 5A	2028.5	2029.4	2030.4	2031.6	2032.4	2027.6	2041.5
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Alt 6A	2028.6	2029.4	2030.4	2031.6	2032.4	2027.6	2040.6
Change from Alt 1A	0.0	0.0	0.0	0.1	0.0	0.0	-0.1
Wolf Point - XS 1701.31							
Alt 1A	1958.9	1959.7	1960.9	1962.1	1962.9	1957.1	1974.5
Alt 2A	1958.9	1959.7	1961.0	1962.1	1962.9	1957.0	1975.0
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.1	0.6
Alt 3A	1958.8	1959.7	1960.9	1962.1	1962.9	1957.1	1974.6
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Alt 4A	1958.8	1959.7	1960.9	1962.2	1963.0	1957.0	1975.0
Change from Alt 1A	-0.1	0.0	0.0	0.1	0.1	-0.1	0.6
Alt 5A	1958.8	1959.7	1961.0	1962.1	1962.9	1957.1	1974.8
Change from Alt 1A	0.0	0.0	0.1	0.0	0.0	0.0	0.3
Alt 6A	1958.9	1959.7	1961.0	1962.1	1962.9	1957.0	1974.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.1	0.2
Culbertson - XS 1620.65							
Alt 1A	1887.1	1887.8	1888.8	1889.8	1890.6	1885.6	1901.9
Alt 2A	1887.2	1887.8	1888.8	1889.8	1890.6	1885.6	1902.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Alt 3A	1887.1	1887.8	1888.8	1889.8	1890.6	1885.6	1901.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	-0.2
Alt 4A	1887.1	1887.7	1888.8	1889.9	1890.6	1885.6	1902.1
Change from Alt 1A	-0.1	0.0	0.0	0.1	0.0	0.0	0.2
Alt 5A	1887.1	1887.8	1888.9	1889.8	1890.6	1885.6	1902.4
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Alt 6A	1887.2	1887.8	1888.8	1889.8	1890.6	1885.6	1901.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	-0.2

Plate 2: Alternative Water Surface Elevation Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Williston - XS 1552.61							
Alt 1A	1843.6	1844.8	1846.6	1849.0	1852.1	1838.8	1862.0
Alt 2A	1843.6	1844.8	1846.6	1849.0	1852.1	1838.8	1862.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Alt 3A	1843.6	1844.8	1846.6	1849.0	1852.1	1838.8	1862.0
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Alt 4A	1843.5	1844.8	1846.6	1849.0	1852.1	1838.6	1862.1
Change from Alt 1A	-0.1	0.0	-0.1	0.0	0.0	-0.1	0.1
Alt 5A	1843.6	1844.8	1846.6	1849.0	1852.1	1838.8	1862.2
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Alt 6A	1843.6	1844.8	1846.6	1849.0	1852.1	1838.7	1862.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Lake Sakakawea - XS 1391.08							
Alt 1A	1809.1	1819.4	1833.1	1838.8	1842.7	1775.3	1855.3
Alt 2A	1807.3	1817.7	1832.6	1839.1	1842.9	1774.0	1855.7
Change from Alt 1A	-1.8	-1.7	-0.5	0.4	0.2	-1.3	0.4
Alt 3A	1809.1	1819.5	1833.2	1838.8	1842.7	1774.8	1855.8
Change from Alt 1A	0.0	0.1	0.1	0.1	0.0	-0.5	0.4
Alt 4A	1805.7	1817.7	1831.8	1838.3	1842.3	1773.2	1855.5
Change from Alt 1A	-3.4	-1.7	-1.3	-0.5	-0.4	-2.1	0.2
Alt 5A	1808.9	1819.3	1832.4	1838.1	1842.3	1774.8	1855.8
Change from Alt 1A	-0.2	-0.1	-0.7	-0.7	-0.4	-0.5	0.5
Alt 6A	1807.3	1818.0	1832.4	1838.6	1842.6	1772.9	1855.8
Change from Alt 1A	-1.8	-1.4	-0.7	-0.1	-0.1	-2.4	0.5

Plate 2 cont'd: Alternative Water Surface Elevation Statistics from POR Duration

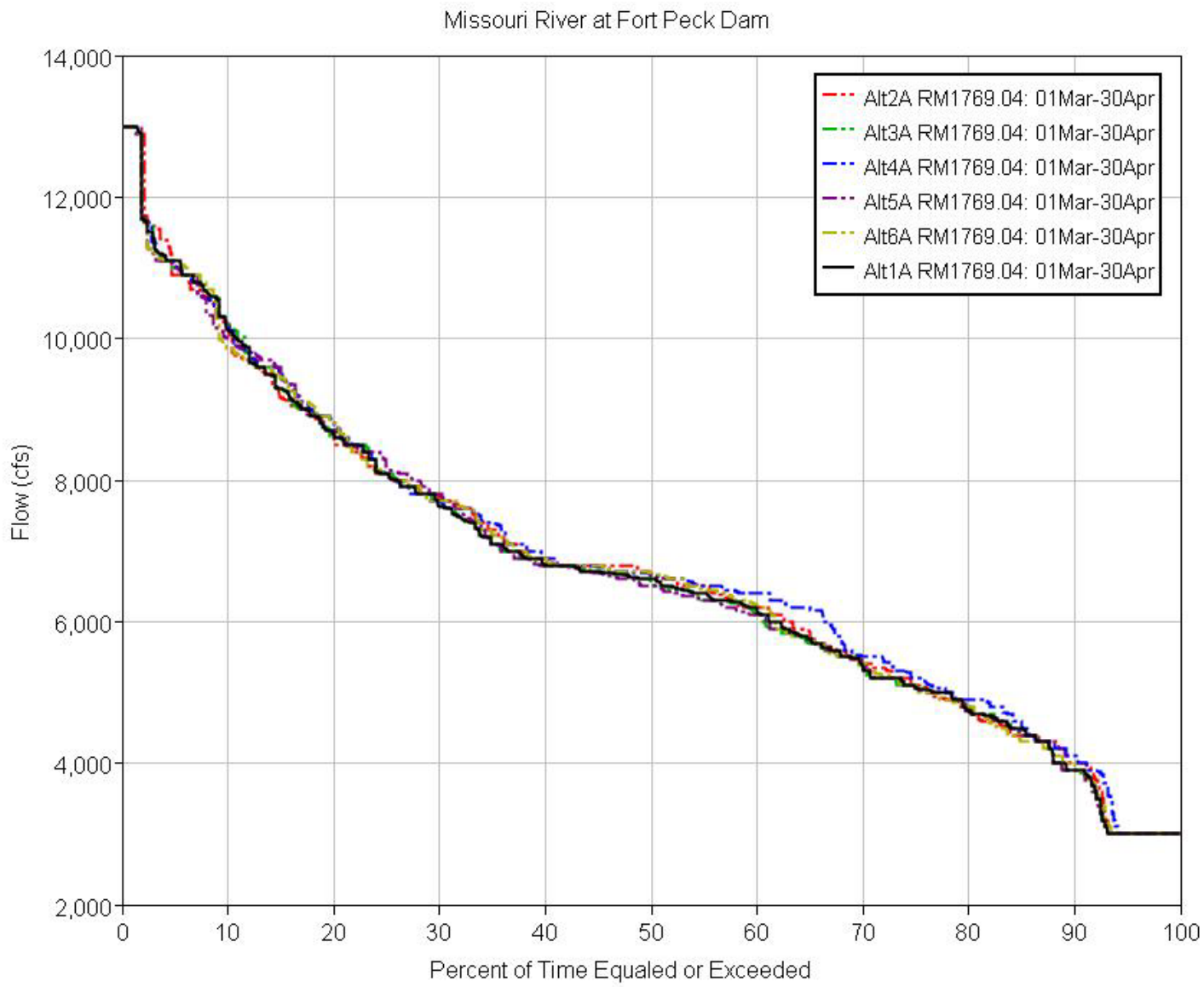


Plate 3: Fort Peck Spring Duration

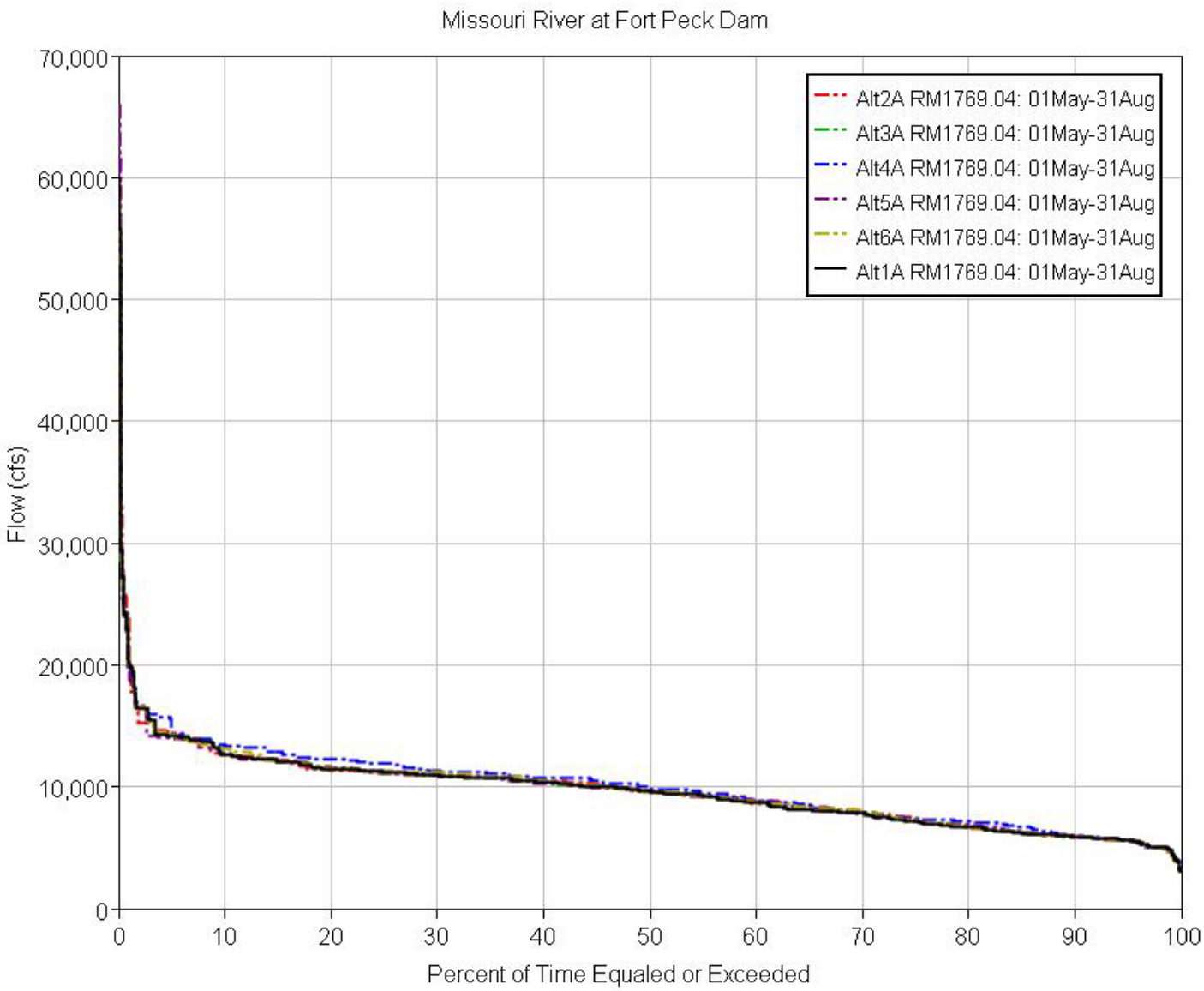


Plate 4: Fort Peck Summer Duration

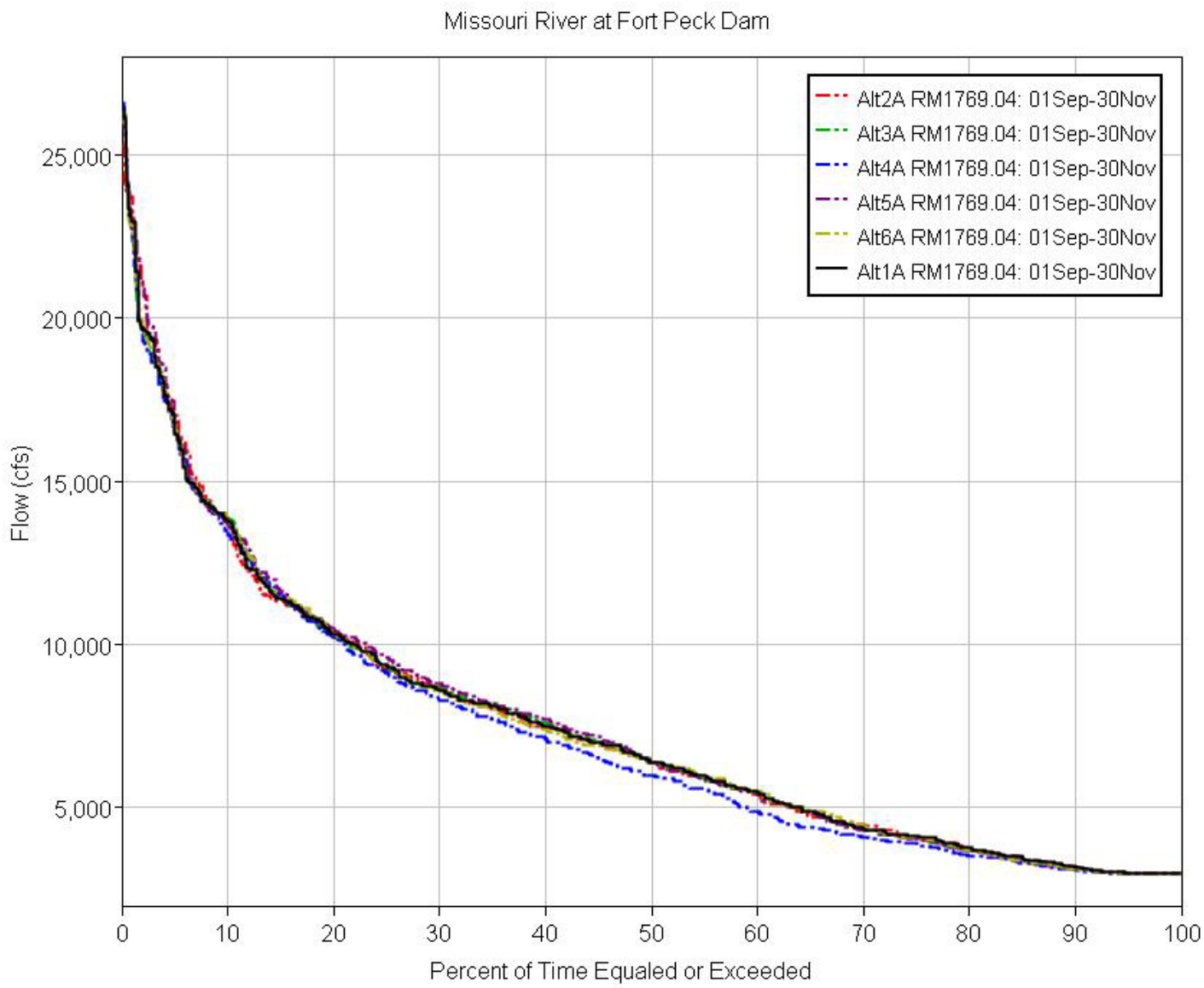


Plate 5: Fort Peck Fall Duration

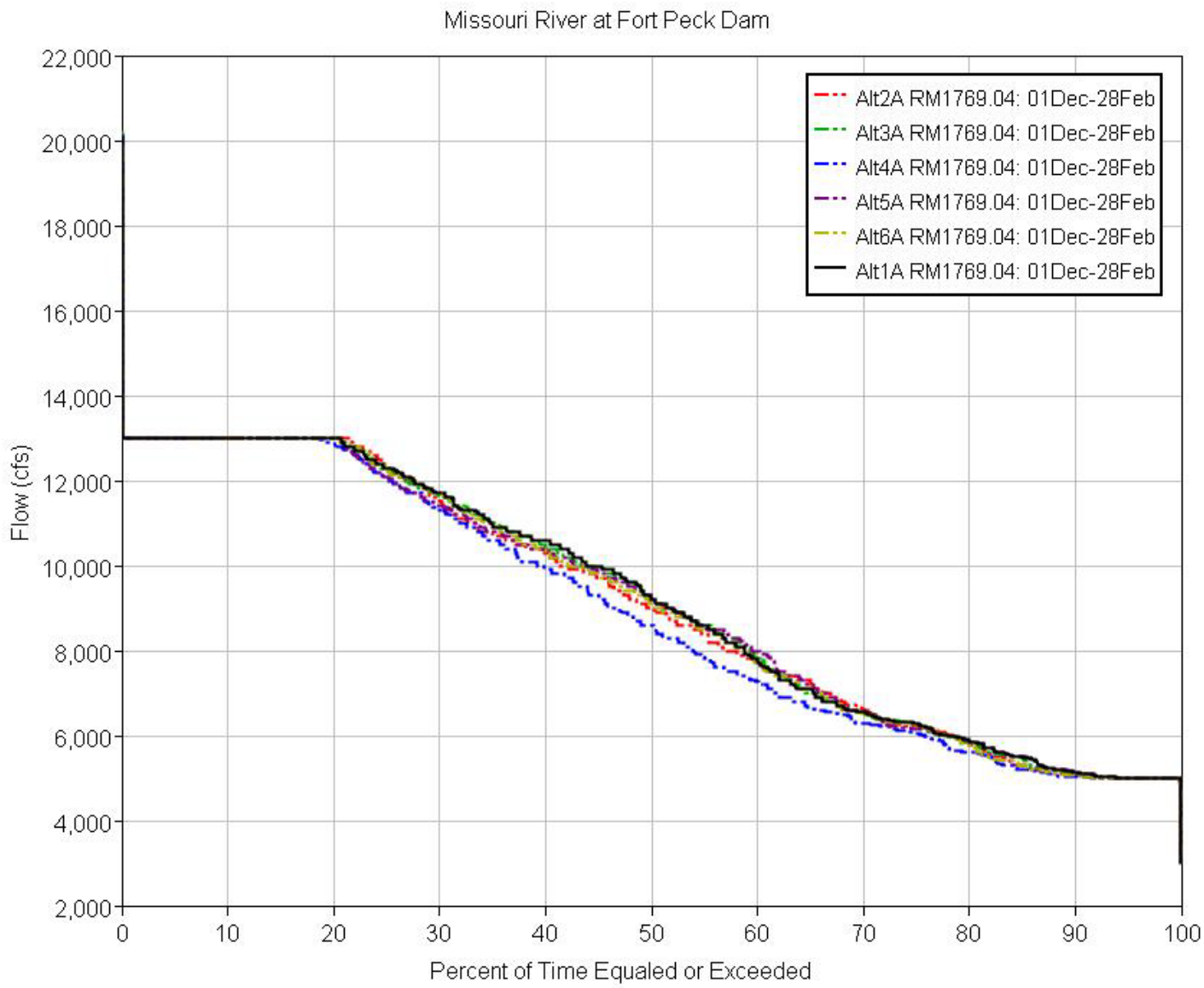


Plate 6: Fort Peck Winter Duration

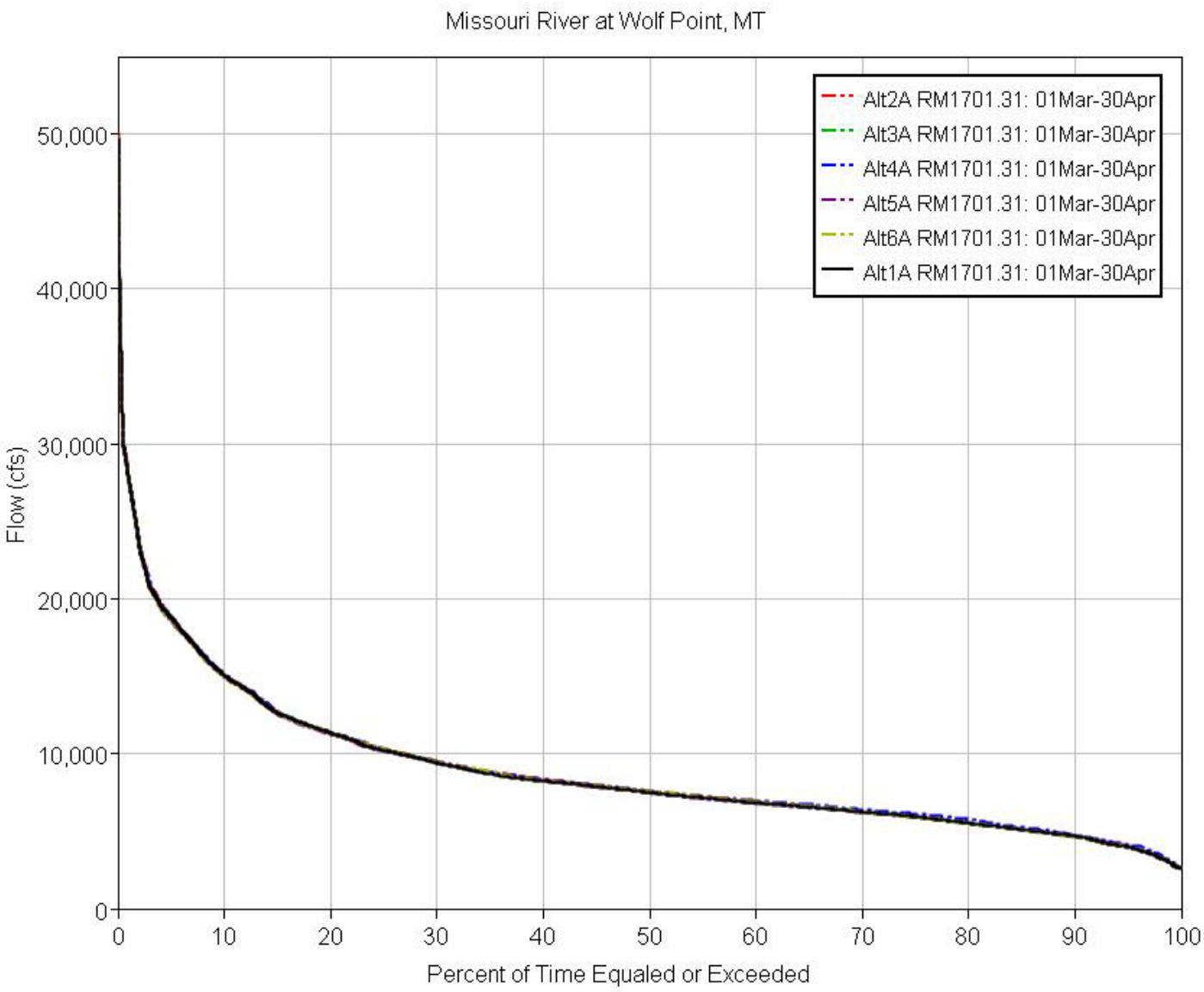


Plate 7: Wolf Point Spring Duration

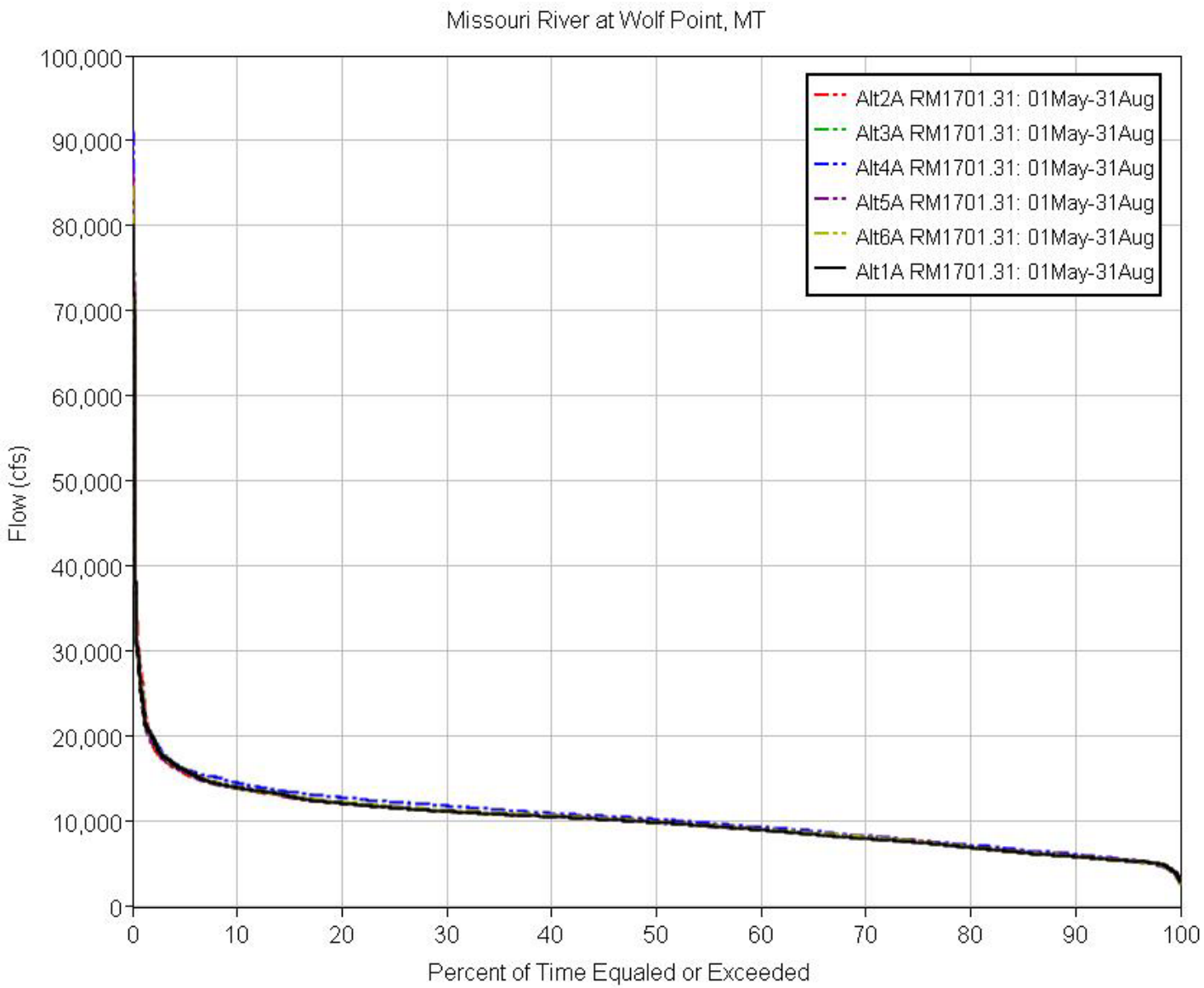


Plate 8: Wolf Point Summer Duration

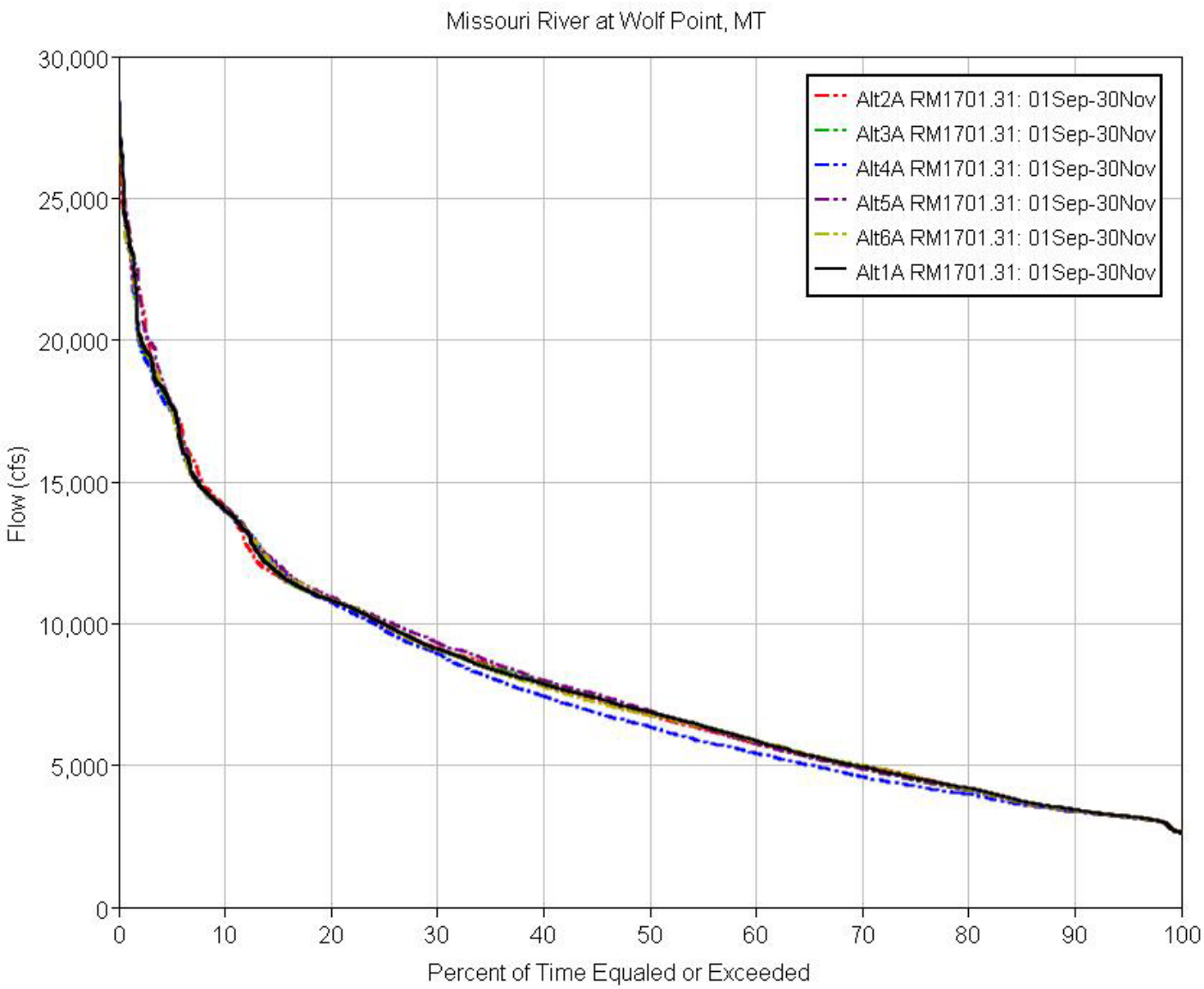
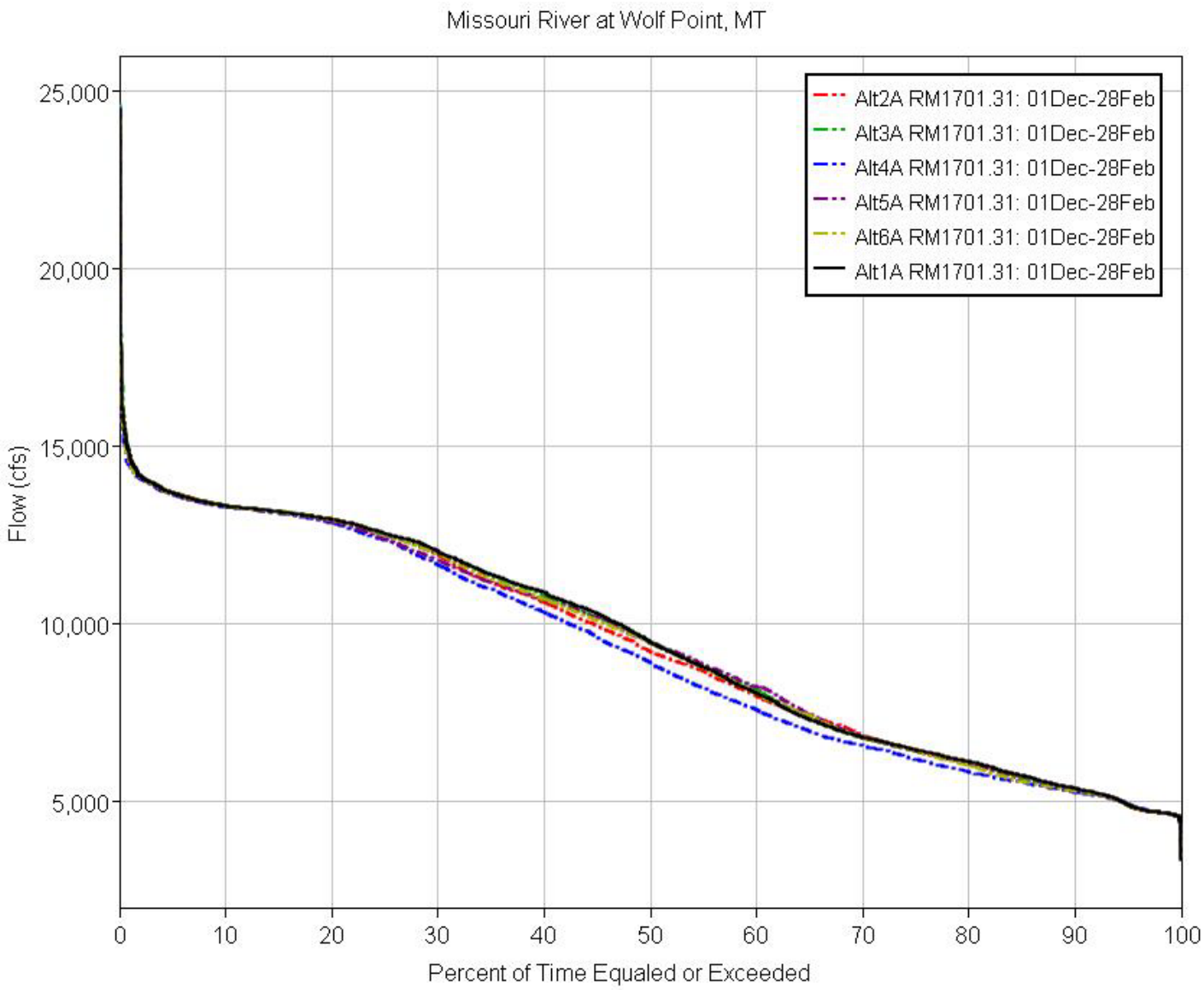


Plate 9: Wolf Point Fall Duration



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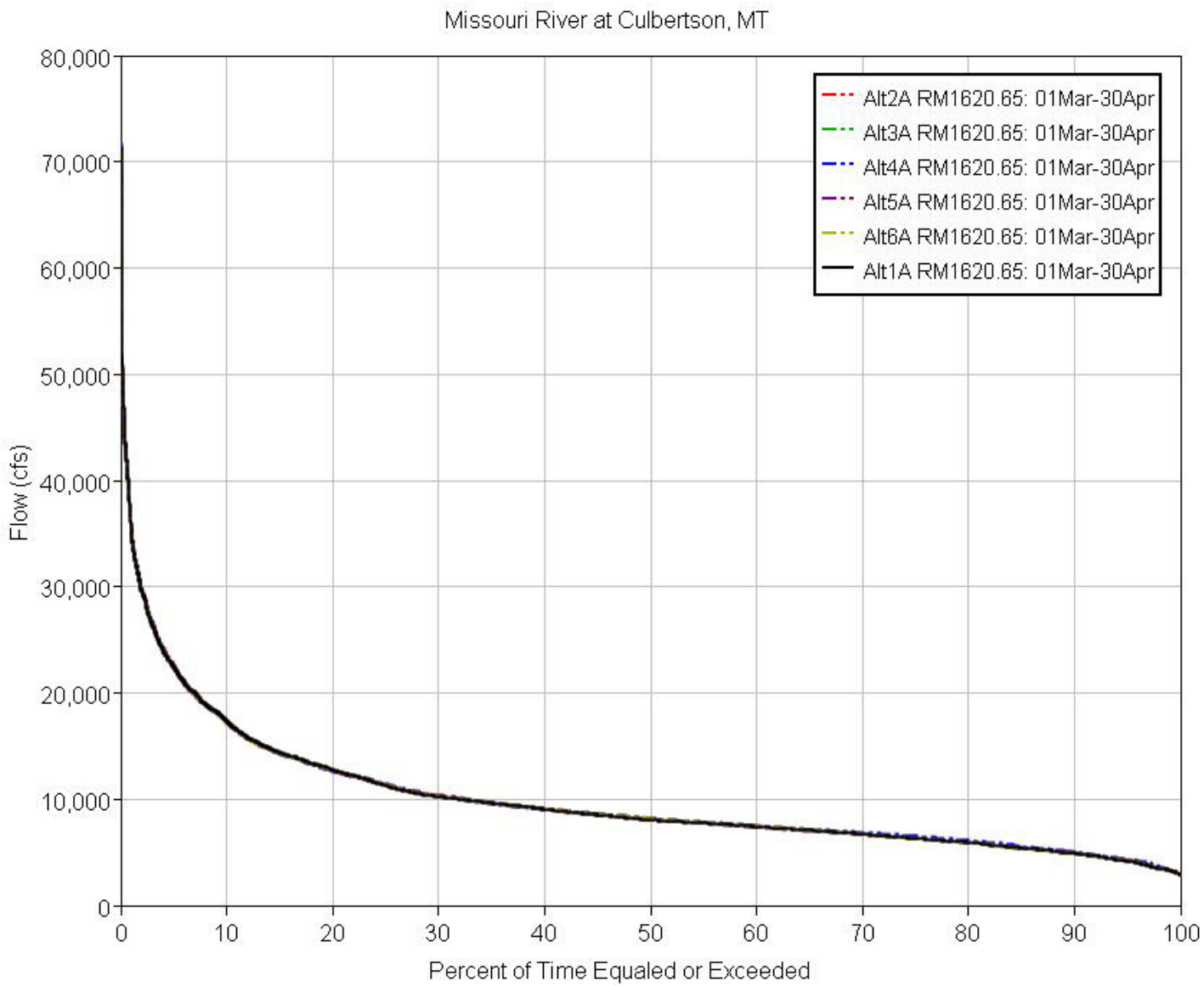


Plate 11: Culbertson Spring Duration

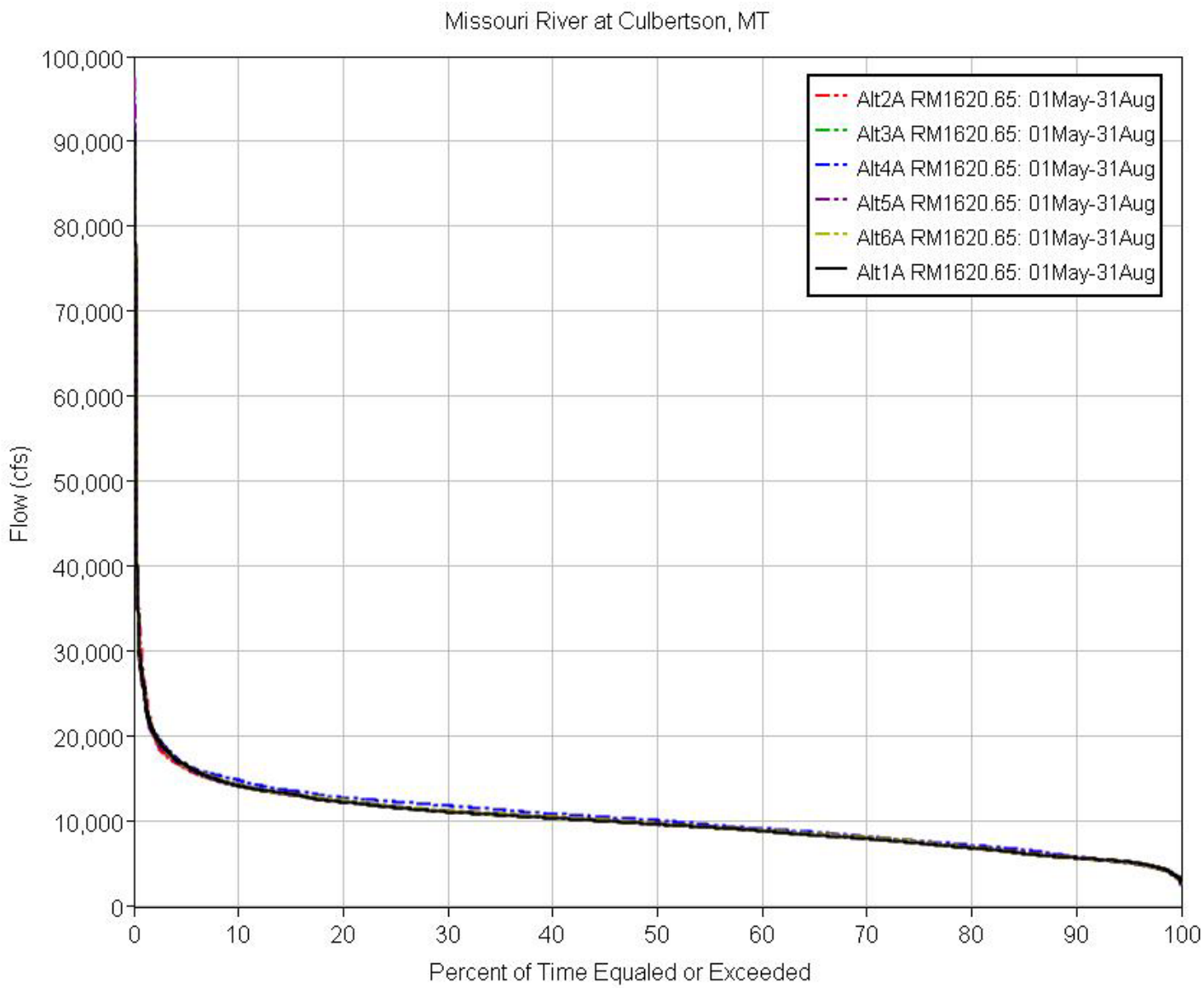


Plate 12: Culbertson Summer Duration

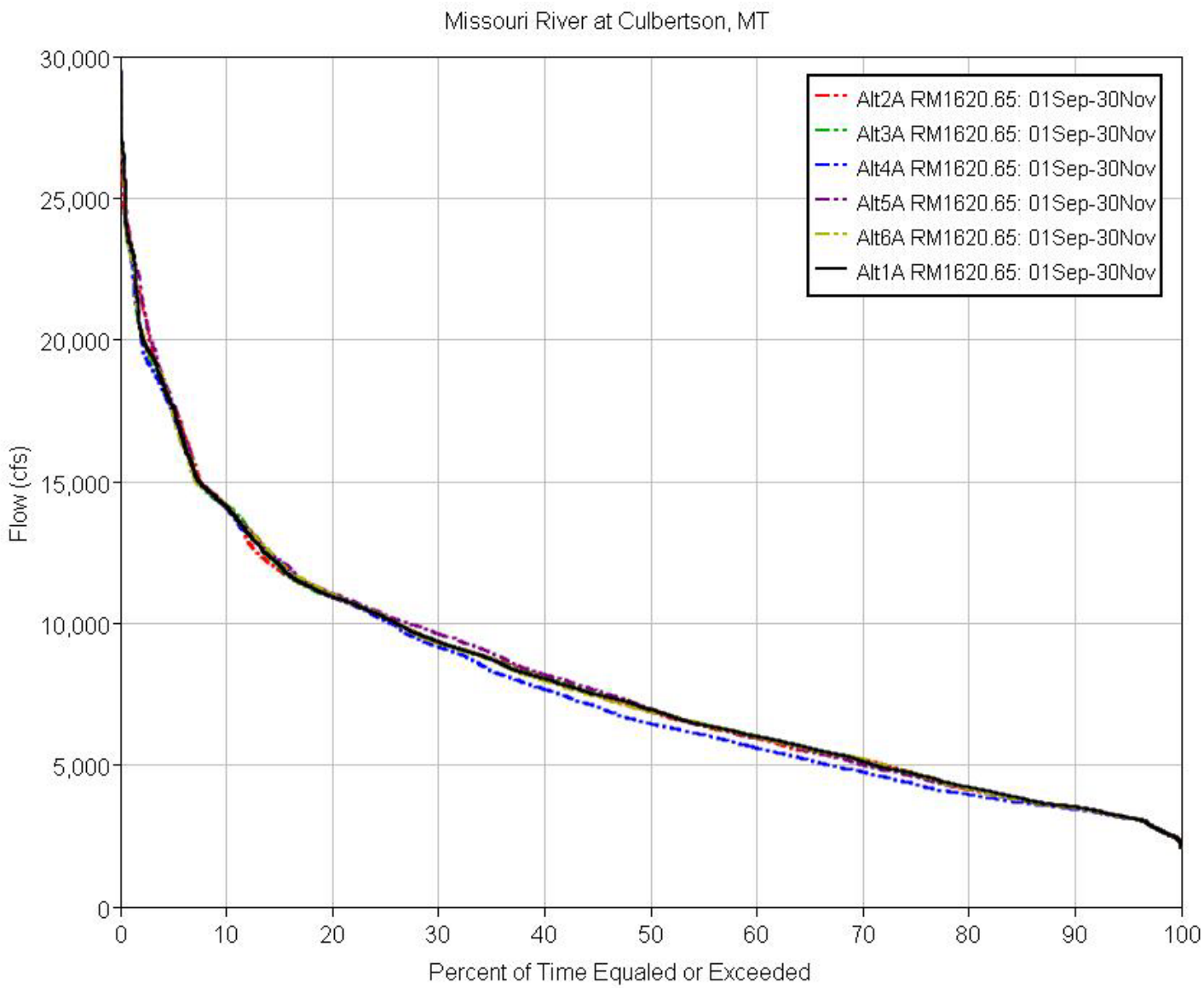


Plate 13: Culbertson Fall Duration

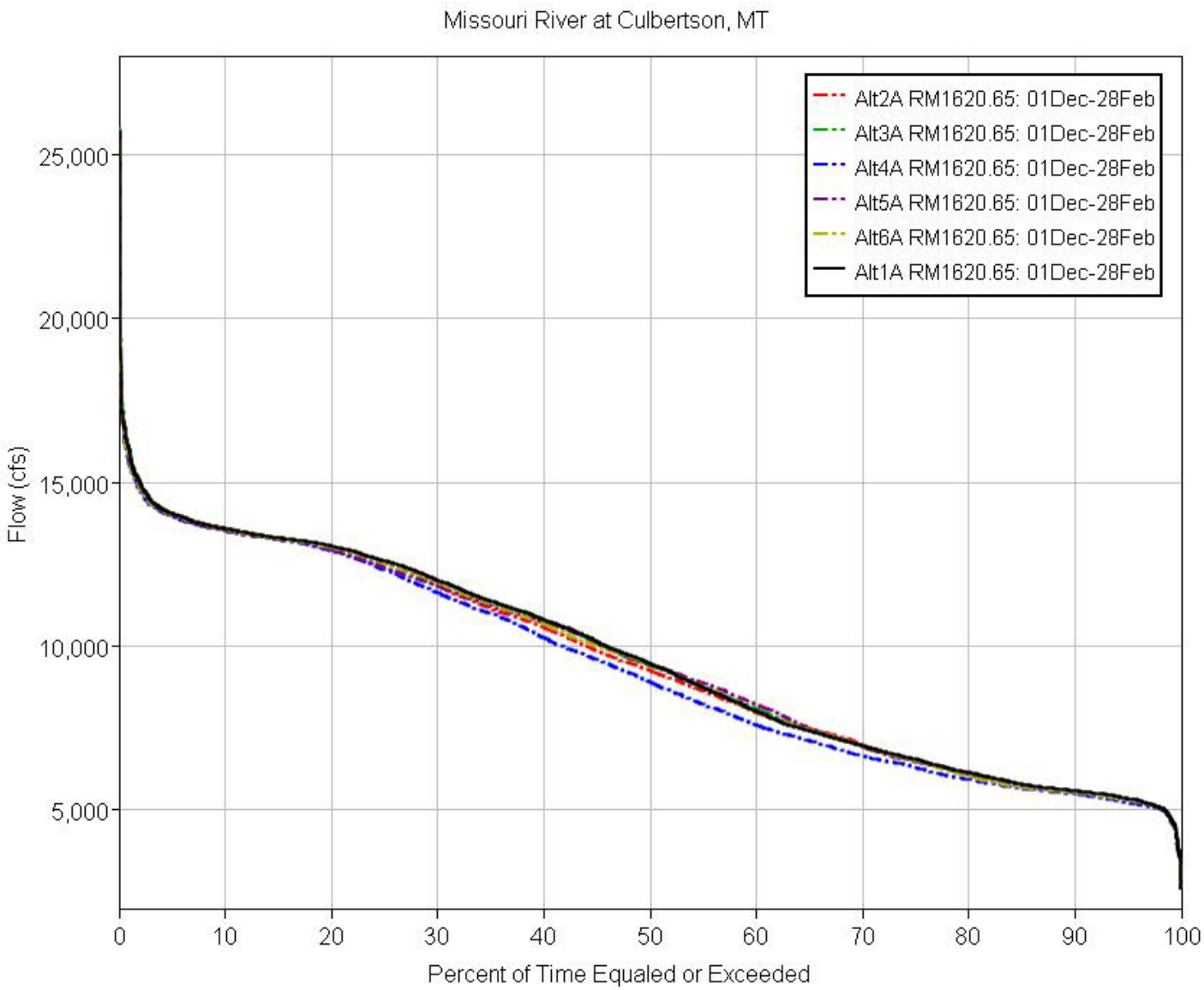


Plate 14: Culbertson Winter Duration

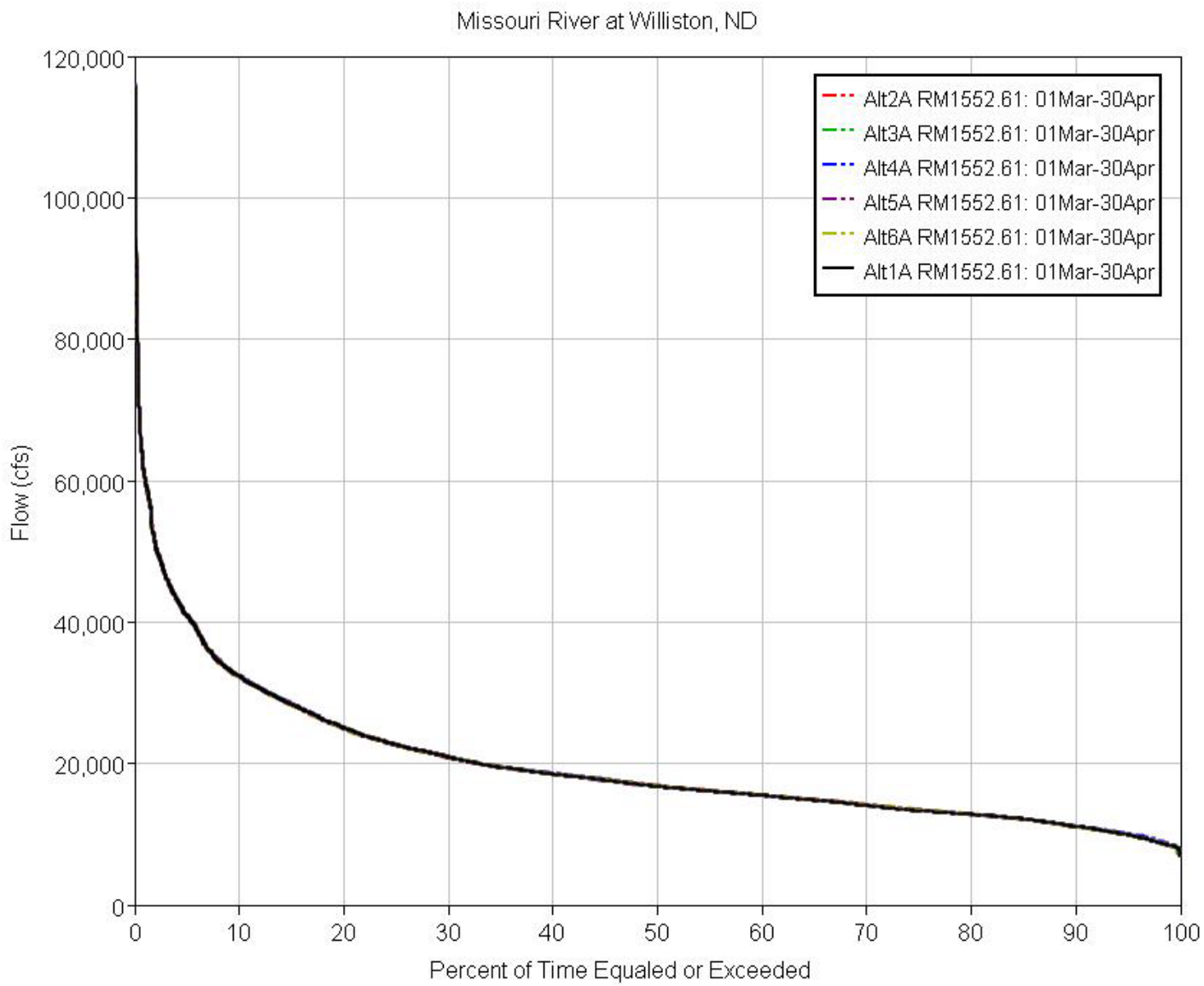
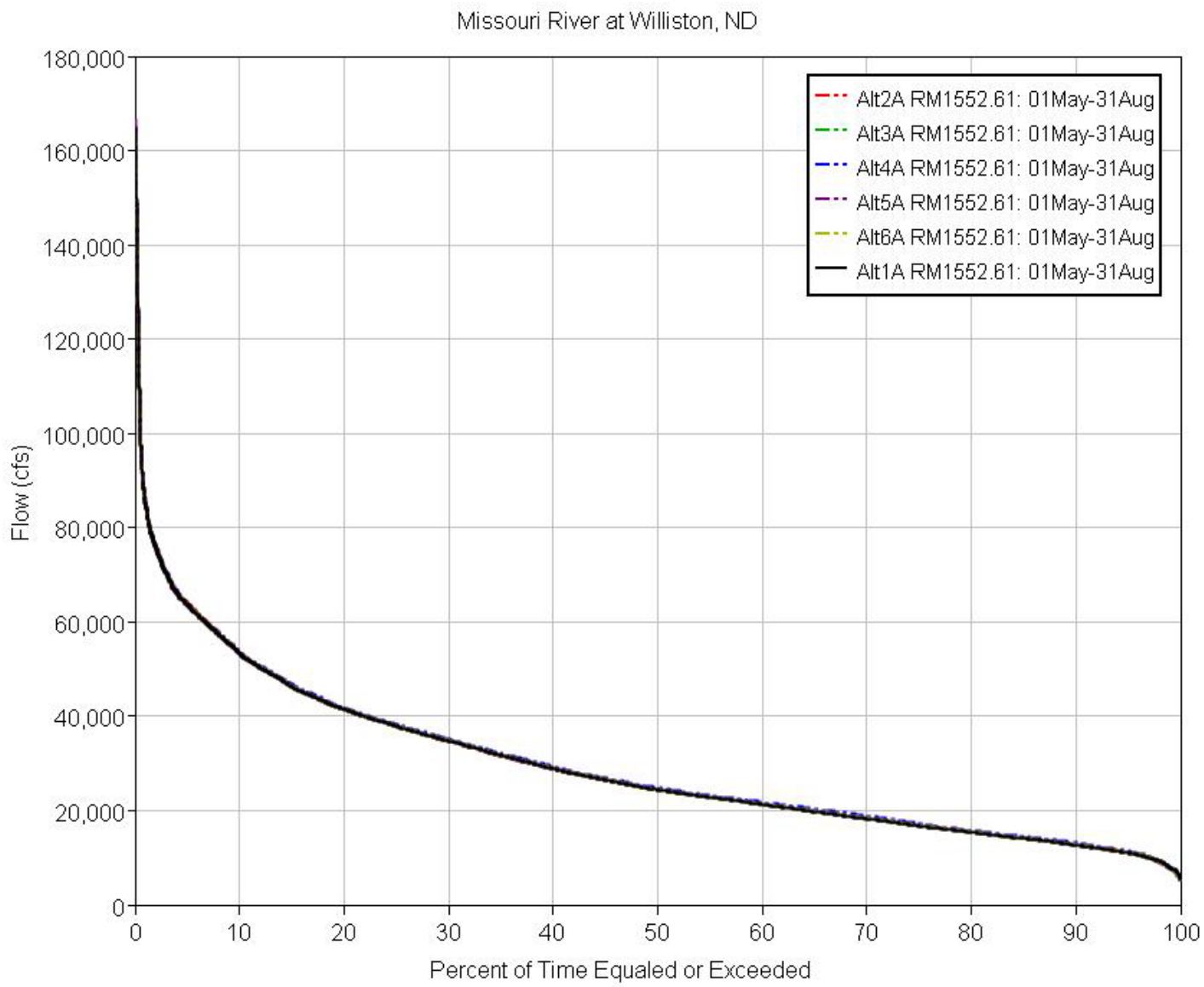


Plate 15: Williston Spring Duration



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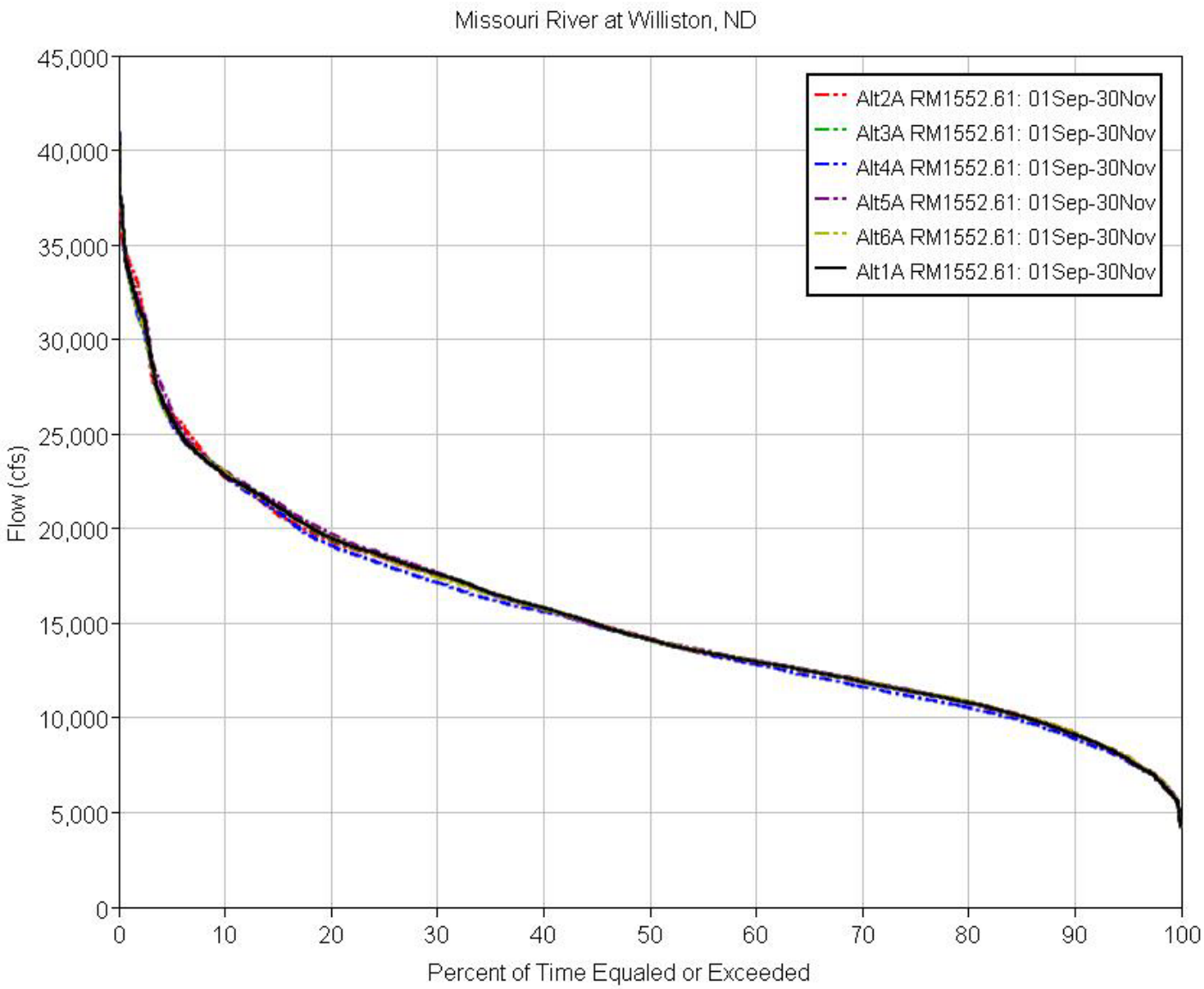


Plate 17: Williston Fall Duration

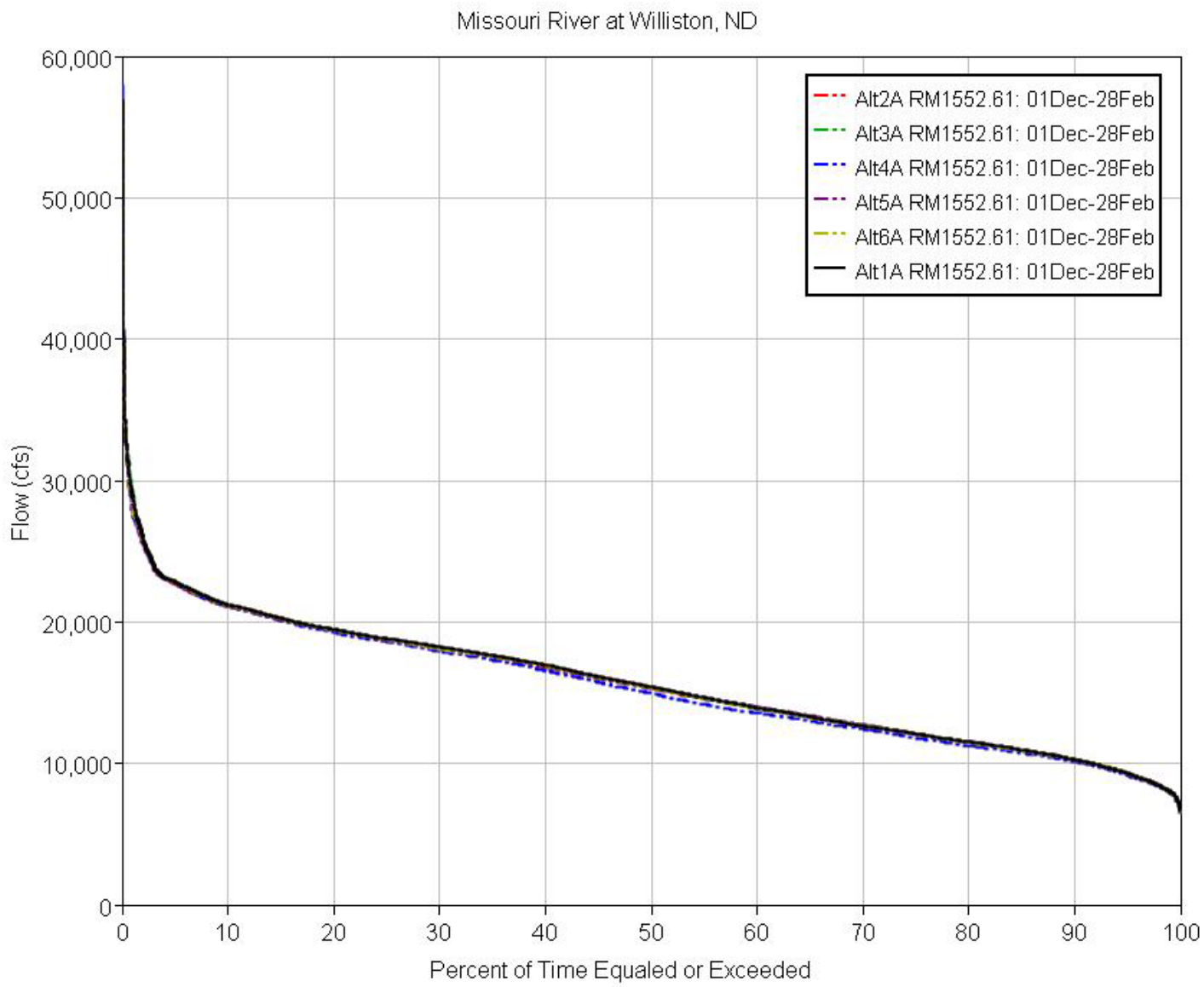


Plate 18: Williston Winter Duration

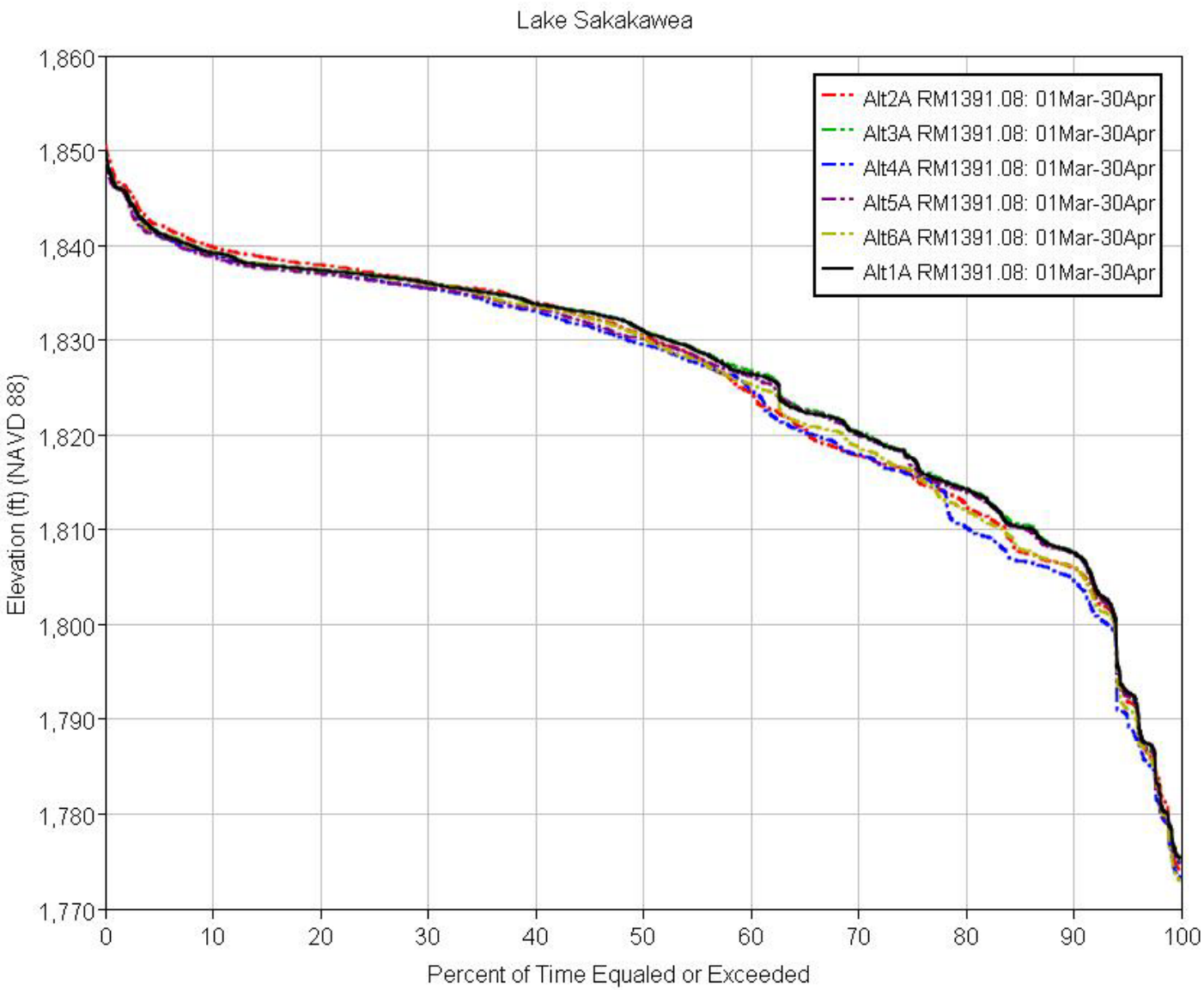


Plate 19: Lake Sakakawea Spring Duration

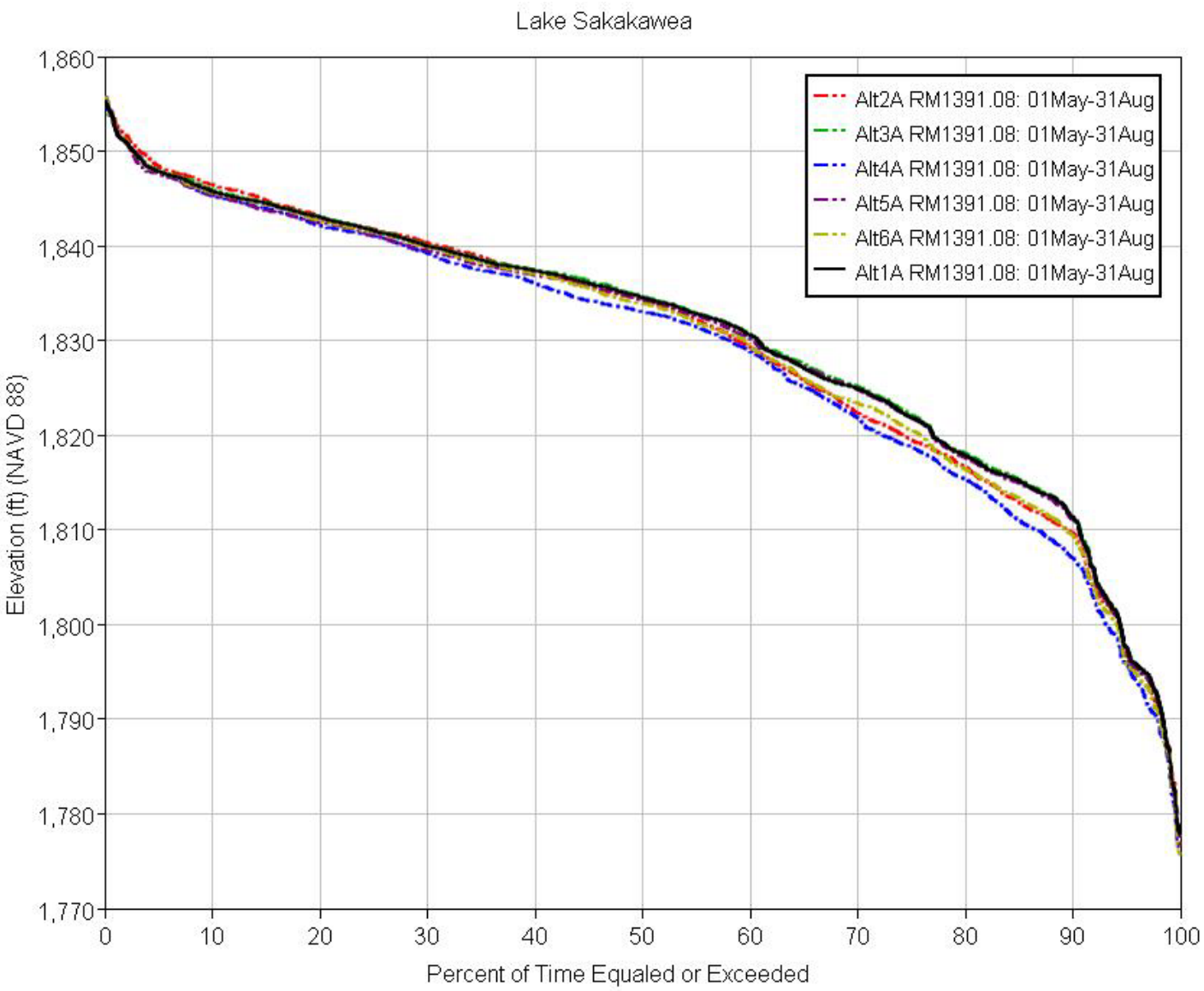


Plate 20: Lake Sakakawea Summer Duration

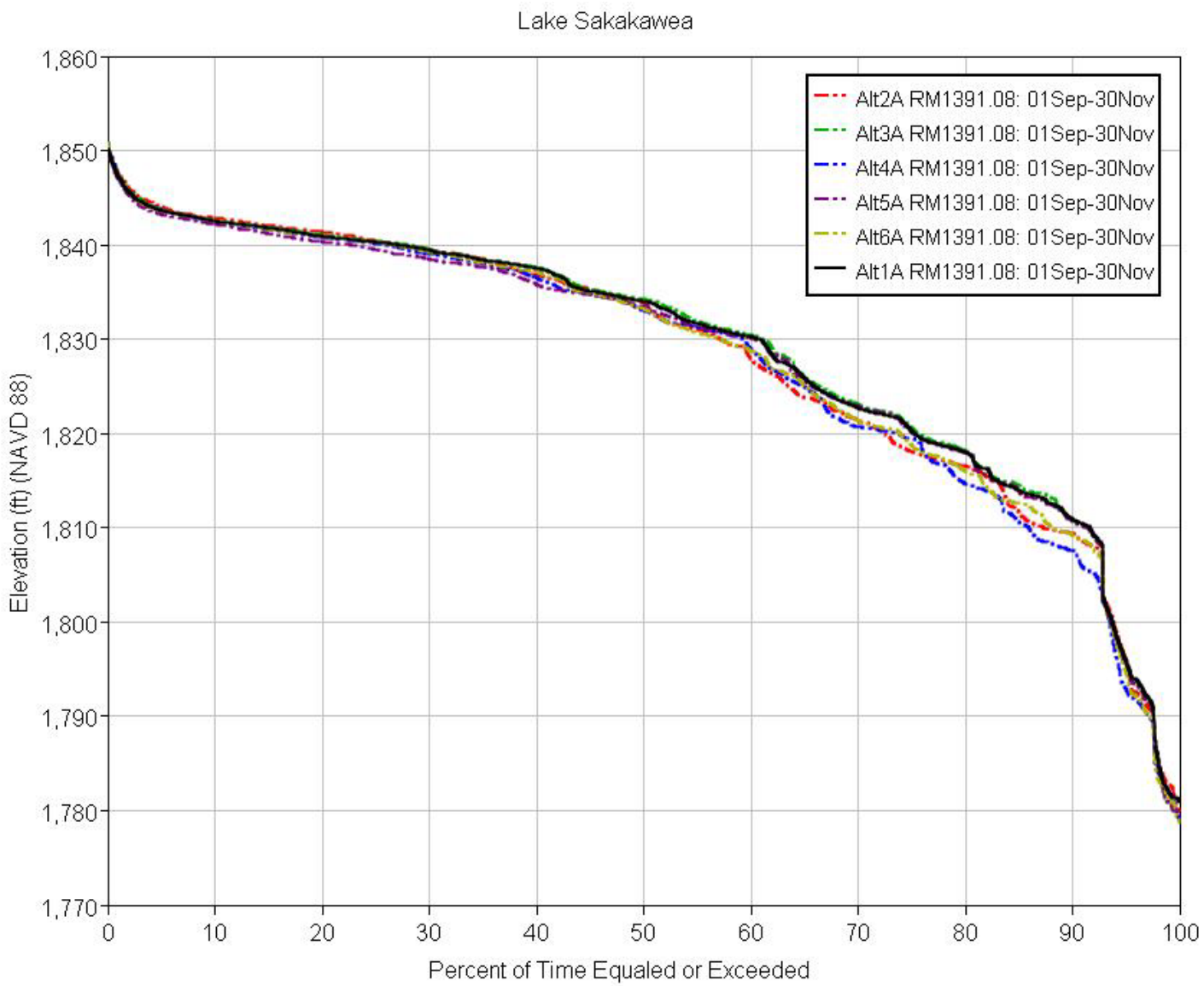


Plate 21: Lake Sakakawea Fall Duration

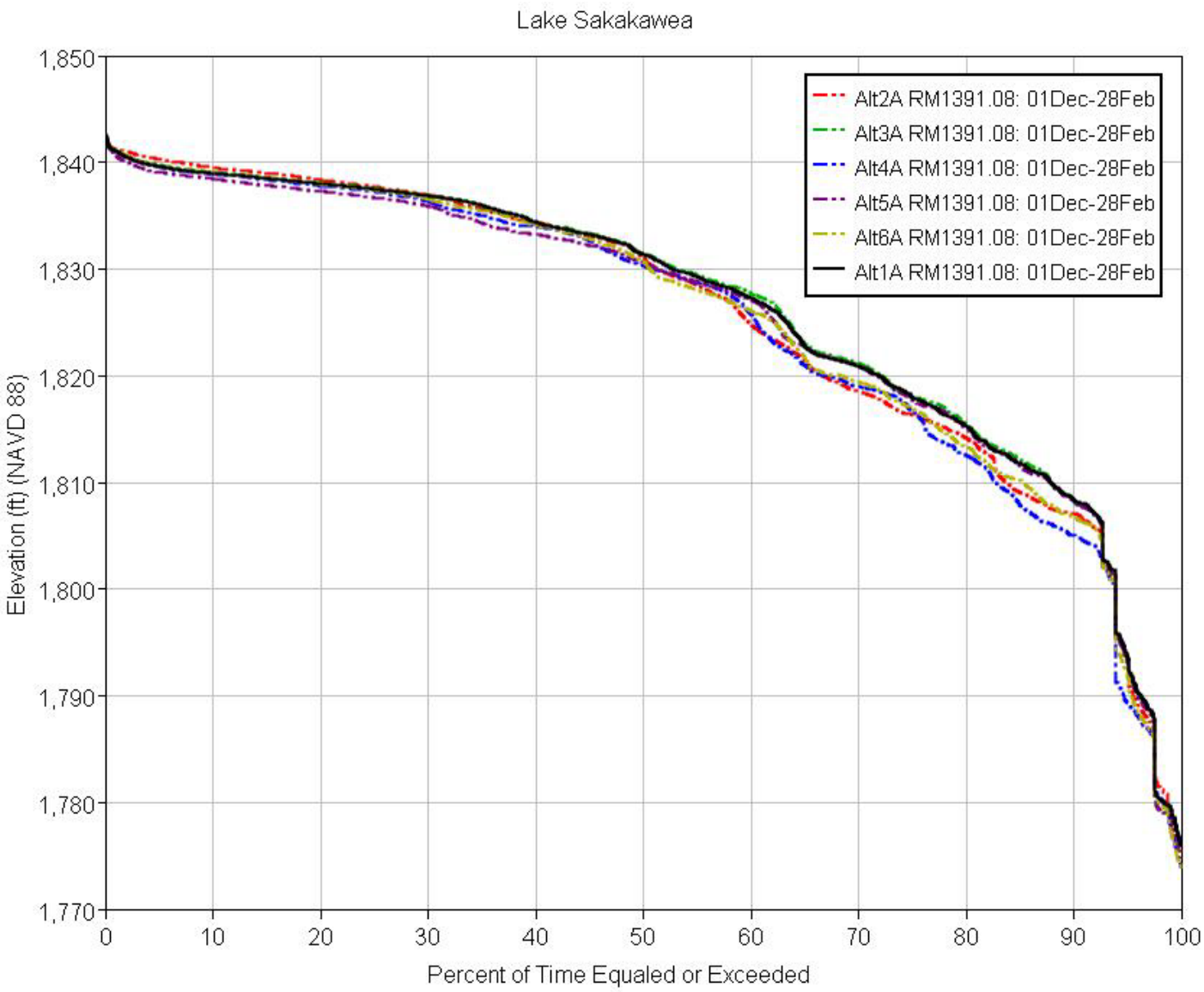


Plate 22: Lake Sakakawea Winter Duration

US Army Corps of Engineers ®

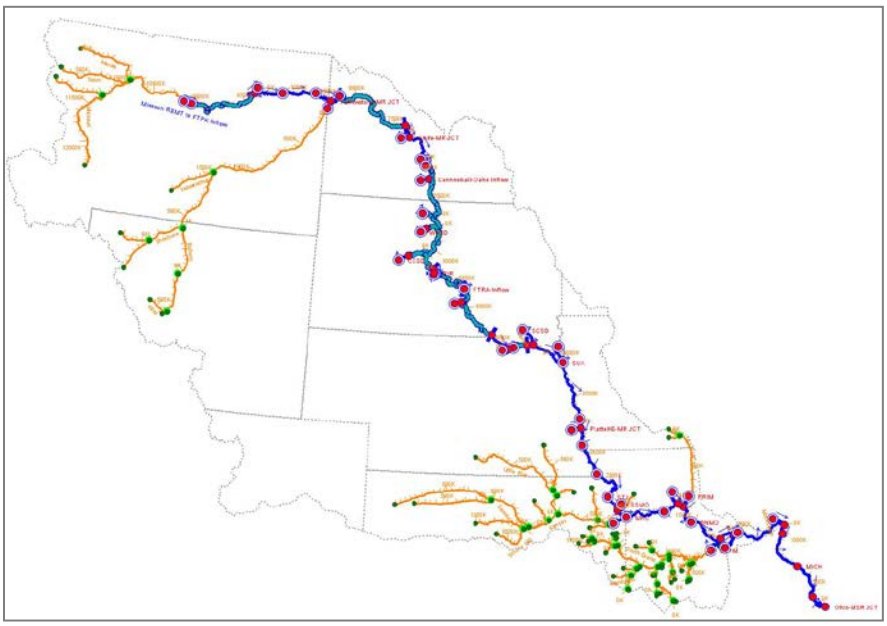
Omaha District

Missouri River Unsteady HEC-RAS Model
Alternatives Analysis

DRAFT

Appendix B

Garrison Dam to Oahe Dam



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ACRONYMS

BiOp……..Biological Opinion

CFS…… Cubic Feet per Second

ESH……..Emergent Sandbar Habitat

HC……..Human Considerations

HEC ..... Hydrologic Engineering Center

IRC……Interception-Rearing Complexes

MAF…….. Million acre-feet

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

NAD 1983…… ... North American Datum of 1983

NAVD 88…… . North American Vertical Datum of 1988

NGVD 29…… National Geodetic Vertical Datum of 1929

NWK…….. Northwest Division Kansas City District

NWO…… Northwest Division Omaha District

POR..... Period of Record

RAS ..... HEC River Analysis System Software (HEC-RAS)

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

RM……1960 River Mile

SWH…….....Shallow Water Habitat

USACE……..United States Army Corps of Engineers

USFWS……United States Fish and Wildlife Service

USGS ..... United States Geological Survey

1 INTRODUCTION

The Missouri River unsteady HEC-RAS model was developed for the Missouri River Recovery Program Management Plan and Integrated Environmental Impact Statement (MRRPMP-EIS) to assist in the assessment of a suite of actions to meet Endangered Species Act (ESA) responsibilities for the piping plover, the interior least tern, and the pallid sturgeon using USACE authorities. Model geometry development and calibration for the existing conditions is documented in *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix B Garrison Dam to Oahe Dam* (USACE 2015). The objective of the HEC-RAS modeling is to simulate the Management Plan alternatives which include flow changes relative to the No Action alternative. The Human Considerations (HC) team performed an extensive analysis on each of the alternatives for each of the resources (hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply) and provide a detailed comparison of results. For this report, only the hydraulic model output is presented; there is no alternative selection or discussion. This Appendix is for the Garrison Dam to Oahe Dam reach of the Missouri River as part of the Omaha District.

Six alternatives, including the No Action alternative, were simulated in HEC-RAS from March 1930 to December 2012, however the HC team only used complete year data for their analysis from January 1, 1931 to December 31, 2012. Development of inflow records at current depletion levels to use as boundary conditions for the HEC-ResSim and HEC-RAS models is documented in the report, *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (USACE 2016c). Each alternative has unique flow releases from the reservoirs, as simulated by the ResSim model.

2 GEOMETRY

For the Garrison Dam to Oahe Dam model, no geometry changes were modeled. All alternative runs used the current conditions (2012) calibrated geometry.

3 FLOW ALTERNATIVES

A total of six flow alternatives were modeled in HEC-ResSim (ResSim). Reservoir pool elevations and dam outflow output from the ResSim model was used as input for the HEC-RAS (RAS) models for each of the six flow alternatives. A brief summary of the flow alternatives is provided below. For more details, see the ResSim technical report, *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report* (2016a).

Tributary and ungaged inflows were kept consistent between alternatives. More details on the Period of Record (POR) flow dataset used can be found in the report *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (2016c).

3.1 ALTERNATIVE 1 - NO ACTION

Under Alternative 1 (Alt 1), the Missouri River Mainstem Projects would continue to be operated as they are currently. Operations within the ResSim model were set up to closely follow the Master Manual that is used during real-time operations of the System; however, the model does have limitations and cannot capture all real-time decisions that occur.

3.2 ALTERNATIVE 2 - U.S. FISH & WILDLIFE SERVICE 2003 BIOLOGICAL OPINION PROJECTED ACTIONS

Alternative 2 (Alt 2) represents the U.S. Fish and Wildlife Service (USFWS) interpretation of the management actions that would be implemented as part of the 2003 Amended BiOp RPA (USFWS 2003). Operational criteria include different early and late spring spawning cues, low summer flows, and a maximum winter release limit.

3.3 ALTERNATIVE 3 - MECHANICAL CONSTRUCTION ONLY

Alternative 3 (Alt 3) consists of mechanical construction of emergent sandbar habitat (ESH). Operational criteria consist of removing the early and late spring spawning cues in Alt 1.

3.4 ALTERNATIVE 4 - SPRING HABITAT-FORMING FLOW RELEASE

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

3.5 ALTERNATIVE 5 - FALL HABITAT-FORMING FLOW RELEASE

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

3.6 ALTERNATIVE 6 - PALLID STURGEON SPAWNING CUE

Alternative 6 (Alt 6) replaces the early and late spring spawning cues with different spawning cues. The early spring spawning cue in Alt 6 occurs at the same time as the early spring spawning cue in Alt 1 but with a higher peak release. The late spring spawning cue in Alt 6 occurs later in May than the late spring spawning cue in Alt 1 and has a larger peak release. Please note that the name of this alternative changed towards the end of the study from Alternative 7 to Alternative 6 (original Alternative 6 was abandoned). The models were not re-run so all of the model and file names are still labeled Alternative 7.

4 SIMULATION OF ALTERNATIVES

Each flow alternative from ResSim was run through HEC-RAS with the current conditions geometry. Alternative names match in both ResSim and RAS.

5 RESULTS

All alternatives runs were performed in HEC-RAS 5.0 Beta (21-August-2015) because that was the most current version as of October and November 2015, when most of the runs were completed. Official release of HEC-RAS 5.0 was on 4-March-2016 and 5.0.1 on 22-Apr-2016, at which point evaluation of results by the economists and human considerations teams was well underway and it would have unnecessarily compromised schedule to re-run the simulations.

Model output contains a considerable amount of information, not easily condensed to simple conclusions. Each of the six alternative runs produced 83 years (March 1930 – December 2012) of stage and flow hydrographs. Responses to the Res-Sim flow changes in combination with habitat geometry changes are complex. To express the changes compared with the No Action alternative, the model results were evaluated by statistical evaluation and duration analysis plots.

Results from the 83-year runs for the six alternatives were provided to the Human Considerations (HC) team for analysis. They used the daily (instantaneous 2400 value for each day) flow and water surface elevation output to analyze effects to various resources that include: hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply. The HC team performed an extensive analysis on each of the alternatives for all of the resources and provide a detailed comparison of results. For this report, only the hydraulic model output is presented.

5.1 STATISTICS

For the statistical evaluation, daily flow and water surface elevation results were analyzed to compare the differences between the No Action Alternative and the remaining five alternatives. Tables showing the differences between calculated statistics for both flow and water surface elevation for below Garrison Dam, Hensler, Price, Bismarck, Schmidt, and Lake Oahe (elevation only) can be seen in Plate 1 and Plate 2. The statistics calculated include: the 10th, 25th, 50th, 75th, and 90th- Percentiles, and the Minimum and Maximum. It should be noted that the percentile statistics calculated are from a duration analysis and not a Bulletin 17B flow frequency analysis.

The min and max are the lowest daily flow or stage and the highest daily flow or stage output for each alternative over the period of record. For model stability, a minimum flow of 2,000 cfs was used for Garrison Dam outflow. As seen in the tables, the minimum and maximum flow or stage for the period of record remains unchanged from alternative to alternative. Caution should be used when trying to draw conclusions from the statistics alone. The economic models (HEC-FIA) provide a more complete analysis of how high flows effect total damages for each alternative because they incorporate all of the cross section output, whereas these tabular statistics only capture one location.

Stage statistics have been rounded to the nearest tenth of a foot, which is equivalent to 1.2 inches. This helps demonstrate how flow changes impact river elevations, which is the more tangible result. For example, even though the 90th percentile flow for Schmidt in Alternative 2 was 166-cfs lower than in Alternative 1, there is less than an inch of impact to the water surface elevation of the river, and therefore zero reported change.

It is also important to note that the HEC-RAS alternative models, although they have a 30 minute computation interval, have been configured to report one value per 24 hour period, and unfortunately that one value is not a daily average. The HEC-RAS model reports the value that lands on 2400 of each day. The most reasonable output interval was chosen as daily due to the size of watershed being modeled, POR length, and the number of hydrograph locations necessary for HC analysis. This means that slight shifts in timing from alternative to alternative can carry over into the results as small fluxuations in the reported flow. Changes in timing are a small factor, not likely to significantly impact any results evaluation, but should be kept in mind when making comparison at a precise level such as in the statistics tables.

5.2 Seasonal Duration Plots

A duration analysis was also performed for the alternative output. Seasonal duration plots for key main stem locations including below Garrison Dam, Hensler, Price, Bismarck, Schmidt, and Lake Oahe (elevation only) are shown in Plate 3 through Plate 26. Seasonal dates chosen for the duration analysis coincide with the current System operational seasons: spring (1Mar to 30Apr), summer (1May to 31Aug), fall (1Sep to 30Nov), and winter (1Dec to 28Feb). Alternative 4 shows the most difference in the spring duration due to the spring pulses in that alternative. Alternative 5 shows the most difference in the fall duration due to the fall pulses in that alternative.

5.3 Limitations

The analysis relies on the simulation of the 83-year period of record using daily average outflows from an HEC-ResSim model input into a fixed bed HEC-RAS model, with stage and flow output. While the analysis coupled with species and human considerations models can be used to show relative benefits and potential impacts based on historic flows, there are limitations in the conclusions that can be drawn based on some of the simplifying assumptions.

1. **POR Methodology** - An 82-year period of record, adjusted to current level of depletions, was used and may not be comparable to future conditions. A climate change assessment of the Missouri River basin indicates increases to both temperature and precipitation along with increasing trends in extreme floods and droughts (USACE 2016b). The conditions during a pulse year in the future could vary greatly from the small sample of pulse events included in the POR analysis.
2. **No Risk Analysis** - The Missouri River system as currently operated provides substantial flood damage reduction and benefits to the entire basin. The current HEC-ResSim and HEC-RAS analysis, which employs an 82-year period of record simulation, shows the potential for negative impacts to flood damage reduction and dam safety for alternatives that include changes in reservoir flow releases. The current study methodology does not simulate a sufficient number of events and possible runoff combinations within the large Missouri River basin to evaluate potential change in downstream flood risk and dam safety.

   Scoping efforts were conducted to determine a Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood damage reduction as a result of flow release changes. The risk analysis primary components include further development

of the period of record flow data set, HEC-ResSim and HEC-RAS model modifications, development of levee fragility curves, assignment of uncertainty, assembly and debugging of models, Monte Carlo simulation, analysis of results, and reporting. The Monte Carlo methodology properly assesses the effects of the alternative operation changes because it increases the sample size of flow data and number of combinations of flow periods that may occur in the future so that impacts can be characterized with greater confidence. Without such analysis, the impacts of operational changes will only be known for events and combinations of events that have already occurred. Statistics calculated based on the 82-years of record should therefore be used with caution, and with the understanding of the consequences of using only a small sample of years.

3. **Stable Bed and Floodplain** - The hydraulic modeling to date is based on the existing conditions geometry. The analysis does not account for how the bed of the Missouri River may respond to flow changes. Additionally, the analysis does not try to project where sediment may accumulate in the floodplain or include projections of future change in floodplain roughness. This carries with it the necessary assumptions that any bed and floodplain changes would be either negligible or similar between each alternative.

5.4 Channel Capacity Analysis

Channel capacity estimates were performed to provide an indication of the flow rate at which bank elevations are overtopped and flow begins to leave the main channel and enter the floodplain. Channel capacity estimates were performed with the one-dimensional RAS model calibrated to 2012 conditions by comparing steady flow profiles with top of bank elevations at each cross section combined with reviewing the best available floodplain topography. Floodplain flow connectivity was not assessed. The estimated channel capacity does not necessarily correlate with the onset of flood damage. In addition, channel capacity is typically highly variable along the channel bank due to wide variation in bank elevations. The quality of the channel capacity estimate is affected by numerous factors including how representative the model cross sections are of river geometry, local channel geometry variation, low spots in bank elevations, and the floodplain topography accuracy. Within the reservoir delta areas where the river enters the downstream lake, the channel capacity estimate is not meaningful. While channel capacity varies within the reach and through time, a range for the Bismarck, ND area is 55,000 to 60,000 cfs and for the Schmidt, ND area is 35,000 to 40,000 cfs.

A Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood risk as a result of flow release changes would be required to fully assess how an alternative impacts potential flood risk. Refer to the *Summary of Hydrologic Engineering Analysis* (USACE 2016d) for additional details on the risk analysis methodology.

6 CONCLUSIONS

The unsteady HEC-RAS model analysis gives a means to systematically evaluate differences in river elevations for various reservoir and habitat alternatives given the limitations presented in Section 5.3. These results can be fed into additional species and human considerations models, such as HEC-FIA, to screen alternatives for relative benefits and potential economic impacts. The outputs should be carefully examined with an eye towards the model limitations and judgement applied where needed to mitigate any potential pitfalls of the hydraulic analysis.

If flow change alternatives are considered for implementation, additional risk and uncertainty analysis is recommended to more comprehensively quantify risk of spring or fall pulse flows.

The analysis presented in this report is based off of the existing conditions HEC-RAS models. The steps of this analysis could be repeated if predictions of bed change are made for any of the alternatives. Having both analysis completed would provide a range of reasonable results throughout the planning horizon.

7 REFERENCES

USACE (2015). *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix B Garrison Dam to Oahe Dam.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016a). *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016b). *Missouri River Recovery Management Plan - Climate Change.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016c). *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE (2016d). *Missouri River Recovery Program Management Plan Environmental Impact Statement, Summary of Hydrologic Engineering Analysis.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USFWS (2003). *U.S. Fish and Wildlife Service 2003 Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System.* U.S. Fish and Wildlife Service.

APPENDIX B

GARRISON DAM TO OAHE DAM

PLATES

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Garrison - XS 1388.30							
Alt 1A	12,000	15,700	20,230	23,427	27,427	9,000	151,000
Alt 2A	12,000	15,653	20,300	23,470	27,000	9,000	151,000
Change from Alt 1A	0	-47	70	43	-427	0	0
Alt 3A	12,000	15,891	20,113	23,376	27,385	9,000	151,000
Change from Alt 1A	0	191	-117	-51	-43	0	0
Alt 4A	12,000	15,500	19,900	23,300	27,738	9,000	151,000
Change from Alt 1A	0	-200	-330	-127	311	0	0
Alt 5A	12,000	15,421	19,979	23,441	27,900	9,000	151,000
Change from Alt 1A	0	-279	-252	15	473	0	0
Alt 6A	12,000	15,600	20,185	23,632	27,300	9,000	151,000
Change from Alt 1A	0	-100	-45	205	-127	0	0
Hensler - XS 1362.68							
Alt 1A	12,372	16,122	20,881	24,357	28,780	8,693	154,795
Alt 2A	12,339	16,008	21,009	24,391	28,495	8,693	154,795
Change from Alt 1A	-33	-113	128	34	-285	0	0
Alt 3A	12,413	16,192	20,866	24,367	28,829	8,693	154,795
Change from Alt 1A	41	71	-15	10	49	0	0
Alt 4A	12,358	15,902	20,565	24,300	28,798	8,693	154,795
Change from Alt 1A	-14	-220	-317	-57	18	0	0
Alt 5A	12,382	15,881	20,639	24,322	28,944	8,693	154,795
Change from Alt 1A	10	-240	-242	-35	165	0	1
Alt 6A	12,355	15,994	20,854	24,671	28,527	8,693	154,795
Change from Alt 1A	-17	-127	-27	314	-253	0	1
Price - XS 1338.15							
Alt 1A	12,836	16,447	21,451	25,107	29,891	7,503	159,583
Alt 2A	12,778	16,401	21,557	25,056	29,574	7,503	159,583
Change from Alt 1A	-58	-45	106	-52	-317	0	0
Alt 3A	12,890	16,477	21,393	25,097	29,962	7,503	159,583
Change from Alt 1A	53	31	-58	-11	71	0	0
Alt 4A	12,766	16,207	21,121	25,031	30,061	7,515	159,583
Change from Alt 1A	-70	-239	-330	-76	170	12	0
Alt 5A	12,815	16,199	21,213	25,080	30,371	7,503	159,583
Change from Alt 1A	-22	-247	-238	-28	479	0	0
Alt 6A	12,847	16,340	21,387	25,232	29,609	7,503	159,583
Change from Alt 1A	10	-106	-64	124	-283	0	0

Plate 1: Alternative Flow Statistics from POR Duration

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Bismarck - XS 1314.80							
Alt 1A	12,942	16,550	21,597	25,271	30,367	7,683	161,058
Alt 2A	12,889	16,490	21,719	25,228	30,029	7,684	161,058
Change from Alt 1A	-53	-60	122	-43	-338	0	0
Alt 3A	12,990	16,579	21,538	25,296	30,359	7,684	161,058
Change from Alt 1A	48	30	-59	26	-8	0	0
Alt 4A	12,863	16,333	21,255	25,224	30,411	7,766	161,058
Change from Alt 1A	-79	-217	-343	-47	45	82	0
Alt 5A	12,894	16,301	21,345	25,275	30,732	7,684	161,058
Change from Alt 1A	-48	-249	-252	5	365	0	0
Alt 6A	12,976	16,452	21,555	25,439	30,077	7,684	161,057
Change from Alt 1A	34	-98	-43	169	-289	0	0
Schmidt - XS 1297.51							
Alt 1A	13,052	16,732	21,791	25,533	31,169	7,890	161,717
Alt 2A	13,000	16,711	21,980	25,473	31,003	7,890	161,718
Change from Alt 1A	-52	-21	189	-60	-166	0	1
Alt 3A	13,102	16,786	21,756	25,541	31,058	7,890	161,715
Change from Alt 1A	51	54	-36	8	-111	0	-2
Alt 4A	12,977	16,551	21,428	25,470	31,152	7,904	161,717
Change from Alt 1A	-75	-181	-363	-64	-17	14	0
Alt 5A	13,011	16,533	21,578	25,518	31,468	7,890	161,716
Change from Alt 1A	-41	-199	-213	-15	299	0	-2
Alt 6A	13,083	16,674	21,782	25,705	30,929	7,890	161,715
Change from Alt 1A	31	-58	-10	172	-240	0	-2

Plate 1 cont'd: Alternative Flow Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Garrison - XS 1388.30							
Alt 1A	1668.0	1669.0	1670.1	1670.8	1671.7	1667.0	1686.1
Alt 2A	1668.0	1669.0	1670.1	1670.8	1671.6	1667.0	1686.1
Change from Alt 1A	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
Alt 3A	1668.0	1669.1	1670.1	1670.8	1671.7	1667.0	1686.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	1668.0	1669.0	1670.0	1670.8	1671.7	1667.0	1686.1
Change from Alt 1A	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0
Alt 5A	1668.0	1668.9	1670.0	1670.8	1671.8	1667.0	1686.1
Change from Alt 1A	0.0	-0.1	-0.1	0.0	0.1	0.0	0.0
Alt 6A	1668.0	1669.0	1670.1	1670.9	1671.6	1667.0	1686.1
Change from Alt 1A	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Hensler - XS 1362.68							
Alt 1A	1652.1	1653.2	1654.4	1655.2	1656.1	1650.8	1669.5
Alt 2A	1652.1	1653.2	1654.4	1655.2	1656.1	1650.8	1669.5
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 3A	1652.2	1653.2	1654.4	1655.2	1656.1	1650.8	1669.5
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	1652.1	1653.2	1654.3	1655.1	1656.1	1650.8	1669.5
Change from Alt 1A	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0
Alt 5A	1652.1	1653.2	1654.3	1655.1	1656.2	1650.8	1669.5
Change from Alt 1A	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0
Alt 6A	1652.1	1653.2	1654.4	1655.2	1656.1	1650.8	1669.5
Change from Alt 1A	0.0	0.0	0.0	0.1	-0.1	0.0	0.0
Price - XS 1338.15							
Alt 1A	1638.0	1638.8	1639.8	1640.6	1641.5	1635.9	1654.1
Alt 2A	1638.0	1638.8	1639.9	1640.6	1641.4	1635.9	1654.1
Change from Alt 1A	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
Alt 3A	1638.0	1638.8	1639.8	1640.6	1641.5	1635.9	1654.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	1638.0	1638.8	1639.8	1640.5	1641.5	1635.9	1654.1
Change from Alt 1A	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
Alt 5A	1638.0	1638.8	1639.8	1640.6	1641.5	1635.9	1654.1
Change from Alt 1A	0.0	-0.1	0.0	0.0	0.1	0.0	0.0
Alt 6A	1638.0	1638.8	1639.8	1640.6	1641.4	1635.9	1654.1
Change from Alt 1A	0.0	0.0	0.0	0.0	-0.1	0.0	0.0

Plate 2: Alternative Water Surface Elevation Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Bismarck - XS 1314.80							
Alt 1A	1622.7	1623.6	1624.7	1625.6	1626.9	1621.0	1638.7
Alt 2A	1622.7	1623.6	1624.8	1625.6	1626.8	1621.0	1638.7
Change from Alt 1A	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
Alt 3A	1622.7	1623.6	1624.7	1625.6	1626.9	1621.0	1638.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	1622.7	1623.6	1624.7	1625.6	1626.9	1621.0	1638.7
Change from Alt 1A	0.0	0.0	-0.1	0.0	0.0	0.0	0.0
Alt 5A	1622.7	1623.6	1624.7	1625.6	1627.0	1621.0	1638.7
Change from Alt 1A	0.0	-0.1	-0.1	0.0	0.1	0.0	0.0
Alt 6A	1622.7	1623.6	1624.7	1625.7	1626.8	1621.0	1638.7
Change from Alt 1A	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
Schmidt - XS 1297.51							
Alt 1A	1613.4	1614.5	1615.9	1617.0	1618.6	1611.6	1627.8
Alt 2A	1613.3	1614.5	1616.0	1617.0	1618.6	1611.6	1627.8
Change from Alt 1A	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Alt 3A	1613.4	1614.5	1615.9	1617.0	1618.7	1611.6	1627.8
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	1613.3	1614.5	1615.8	1617.0	1618.7	1611.6	1627.8
Change from Alt 1A	0.0	0.0	-0.1	0.0	0.1	0.0	0.0
Alt 5A	1613.3	1614.5	1615.9	1617.0	1619.0	1611.6	1627.8
Change from Alt 1A	0.0	0.0	-0.1	0.0	0.3	0.0	0.0
Alt 6A	1613.4	1614.5	1616.0	1617.1	1618.6	1611.6	1627.8
Change from Alt 1A	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
Lake Oahe - XS 1073.04							
Alt 1A	1,575.7	1,585.8	1,601.0	1,608.2	1,613.1	1,550.0	1,620.7
Alt 2A	1,573.0	1,584.1	1,600.5	1,607.7	1,613.1	1,546.2	1,620.8
Change from Alt 1A	-2.7	-1.7	-0.4	-0.5	-0.1	-3.8	0.1
Alt 3A	1,575.7	1,586.0	1,601.2	1,608.4	1,613.2	1,549.1	1,620.8
Change from Alt 1A	0.0	0.3	0.2	0.1	0.1	-0.8	0.0
Alt 4A	1,571.0	1,583.7	1,599.9	1,607.7	1,612.9	1,538.1	1,620.8
Change from Alt 1A	-4.7	-2.1	-1.0	-0.6	-0.3	-11.9	0.0
Alt 5A	1,575.5	1,585.7	1,600.5	1,608.1	1,612.8	1,549.1	1,620.7
Change from Alt 1A	-0.1	-0.1	-0.5	-0.1	-0.3	-0.8	0.0
Alt 6A	1,573.0	1,584.0	1,600.1	1,607.7	1,613.0	1,544.6	1,620.8
Change from Alt 1A	-2.7	-1.8	-0.9	-0.5	-0.1	-5.4	0.0

Plate 2 cont'd: Alternative Water Surface Elevation Statistics from POR Duration

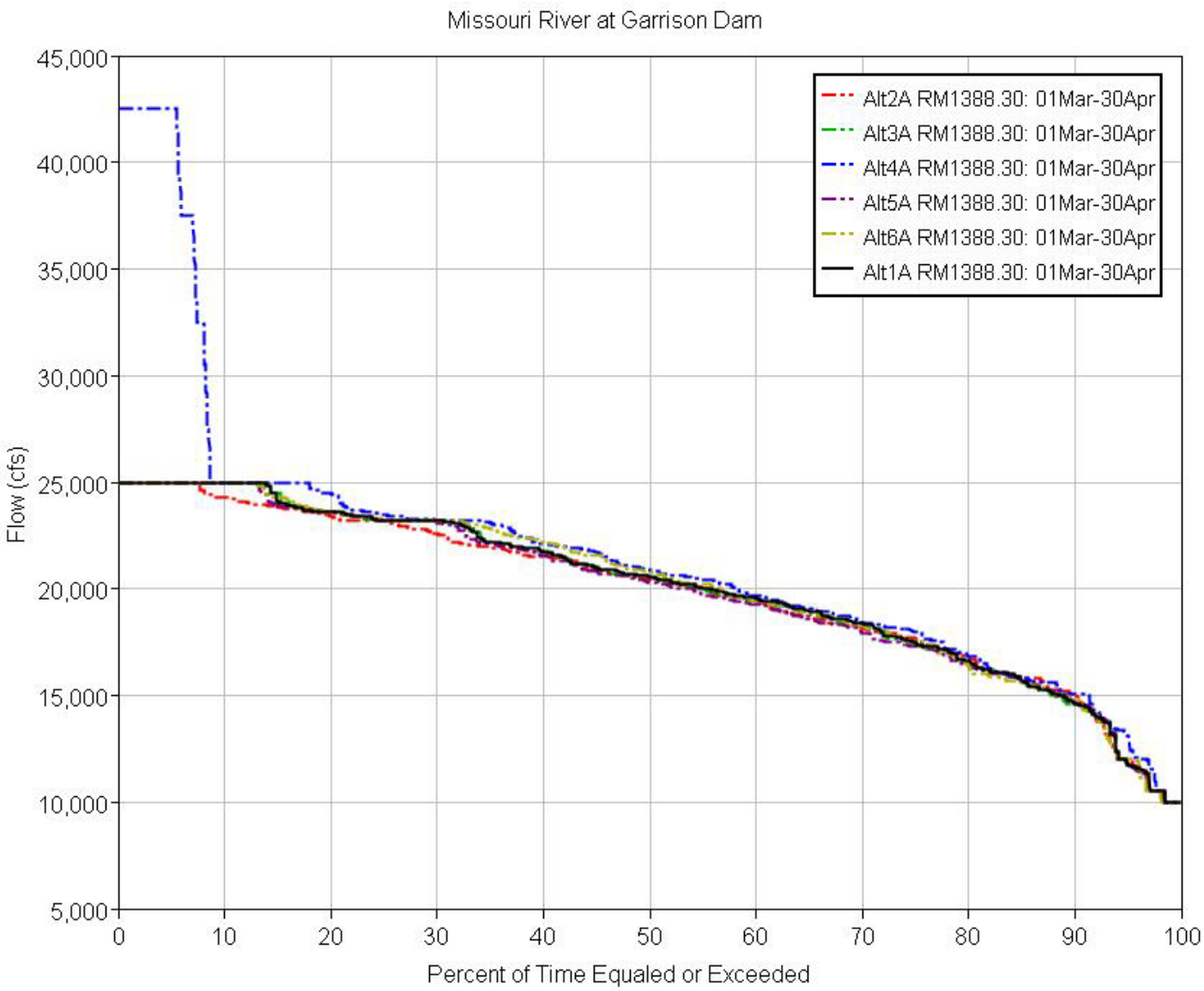


Plate 3: Garrison Spring Duration

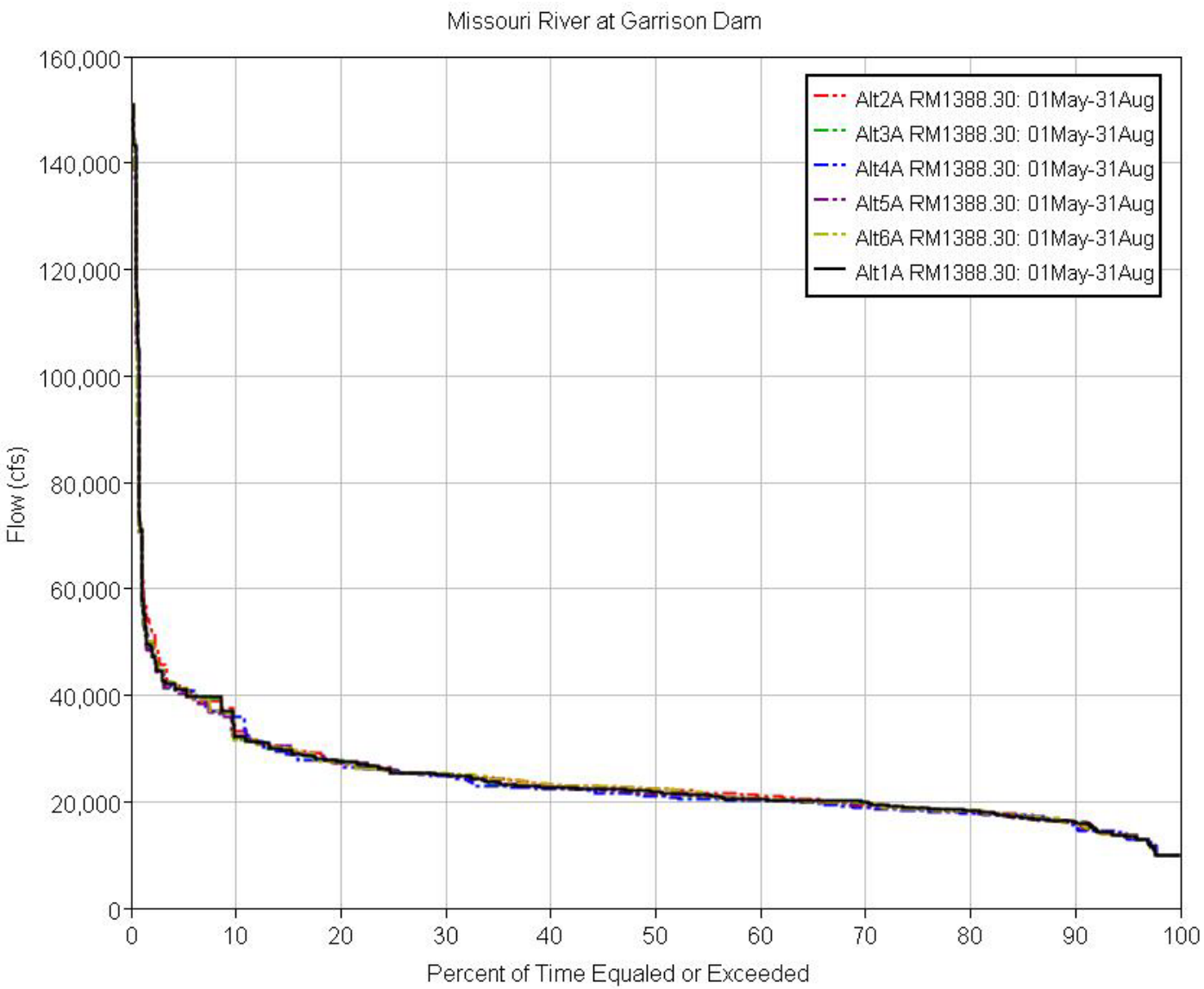


Plate 4: Garrison Summer Duration

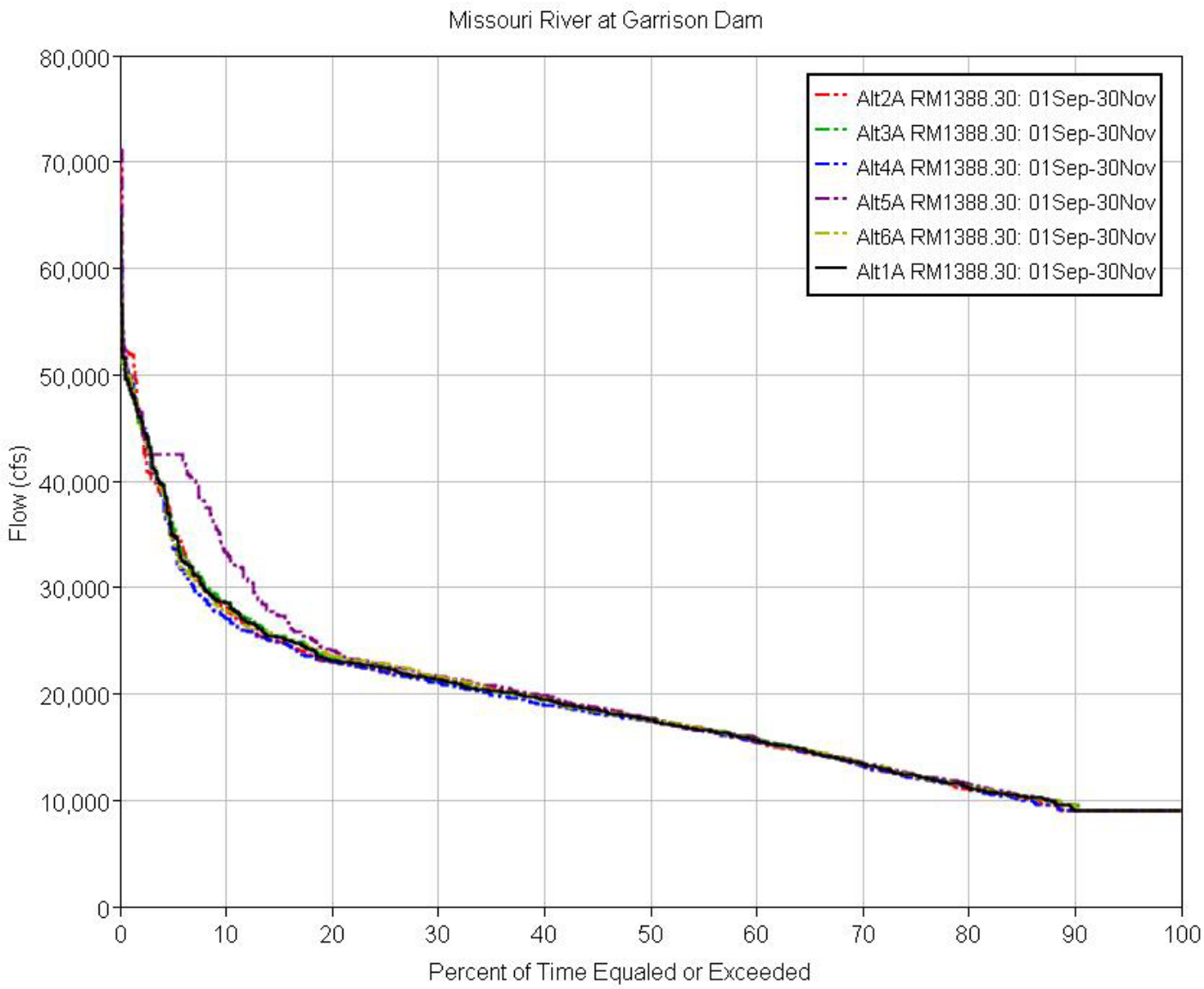


Plate 5: Garrison Fall Duration

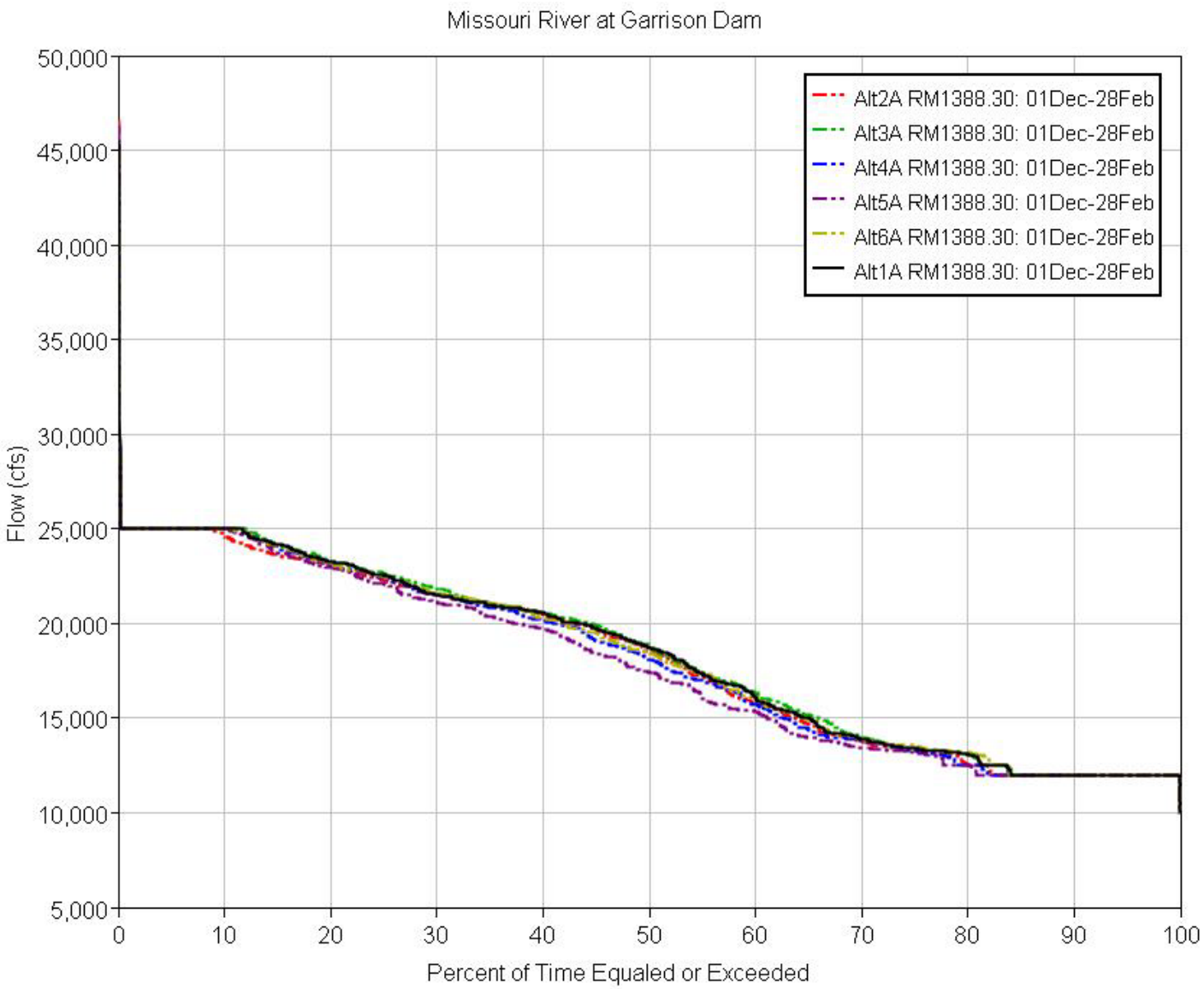


Plate 6: Garrison Winter Duration

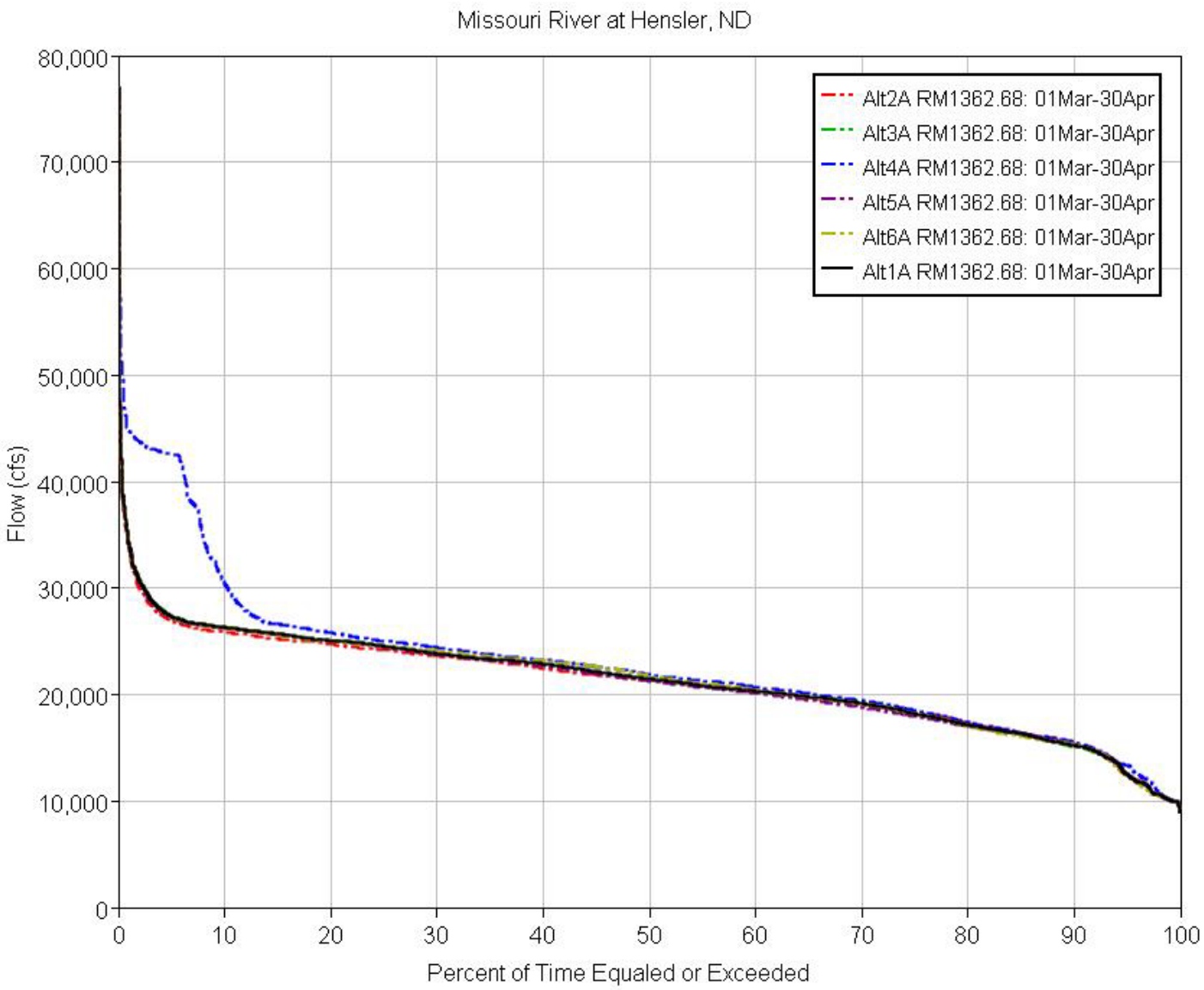


Plate 7: Hensler Spring Duration

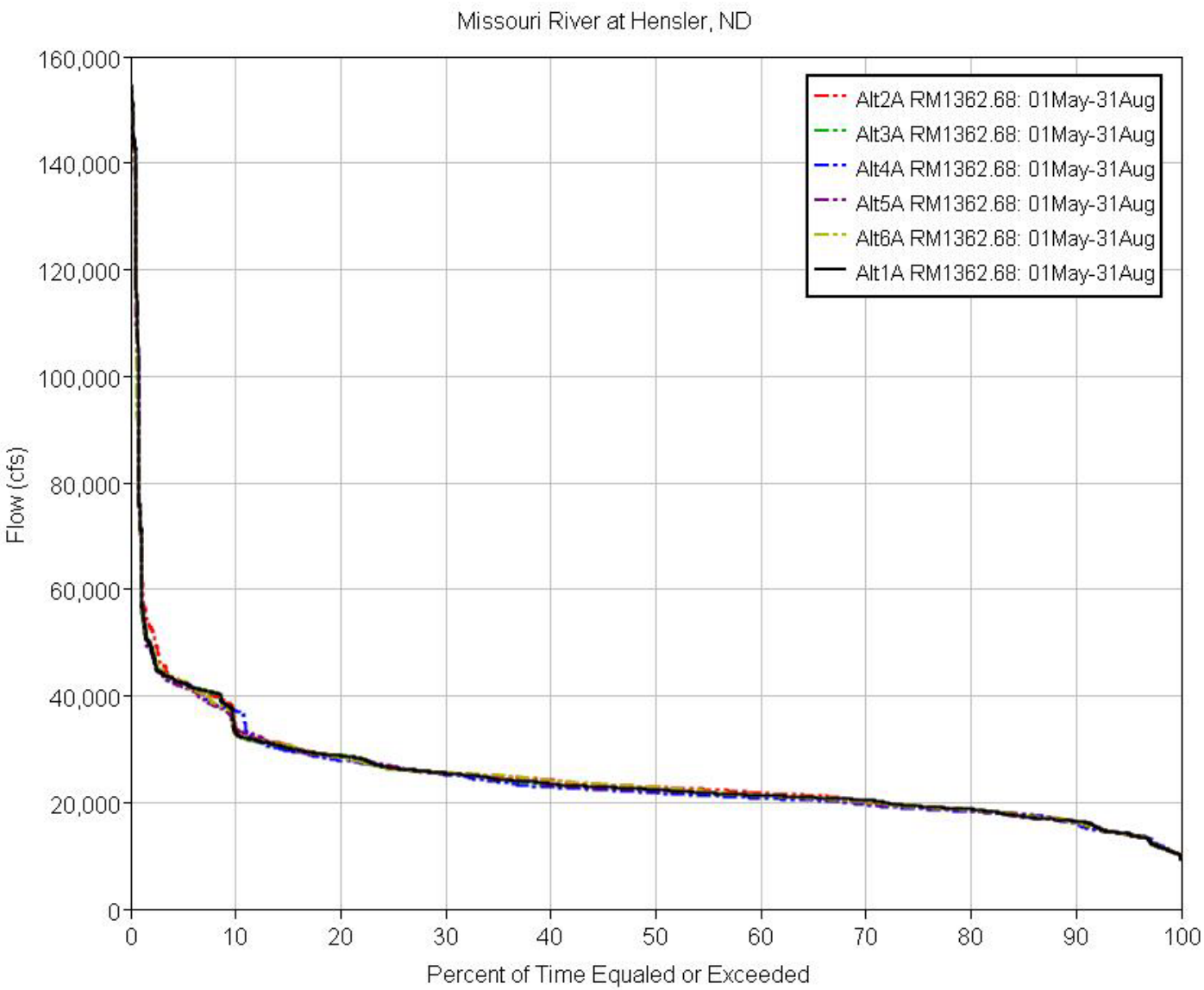


Plate 8: Hensler Summer Duration

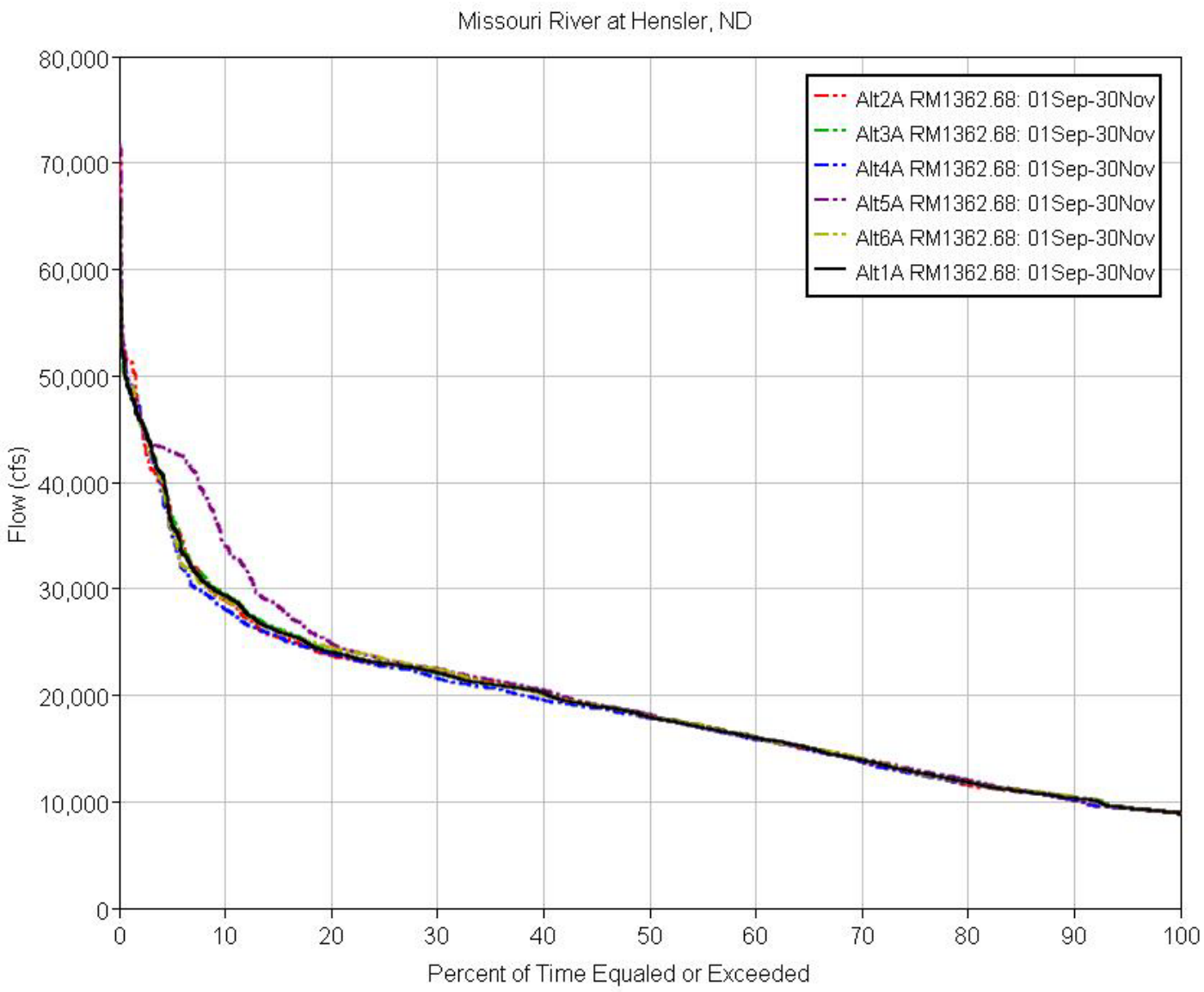


Plate 9: Hensler Fall Duration

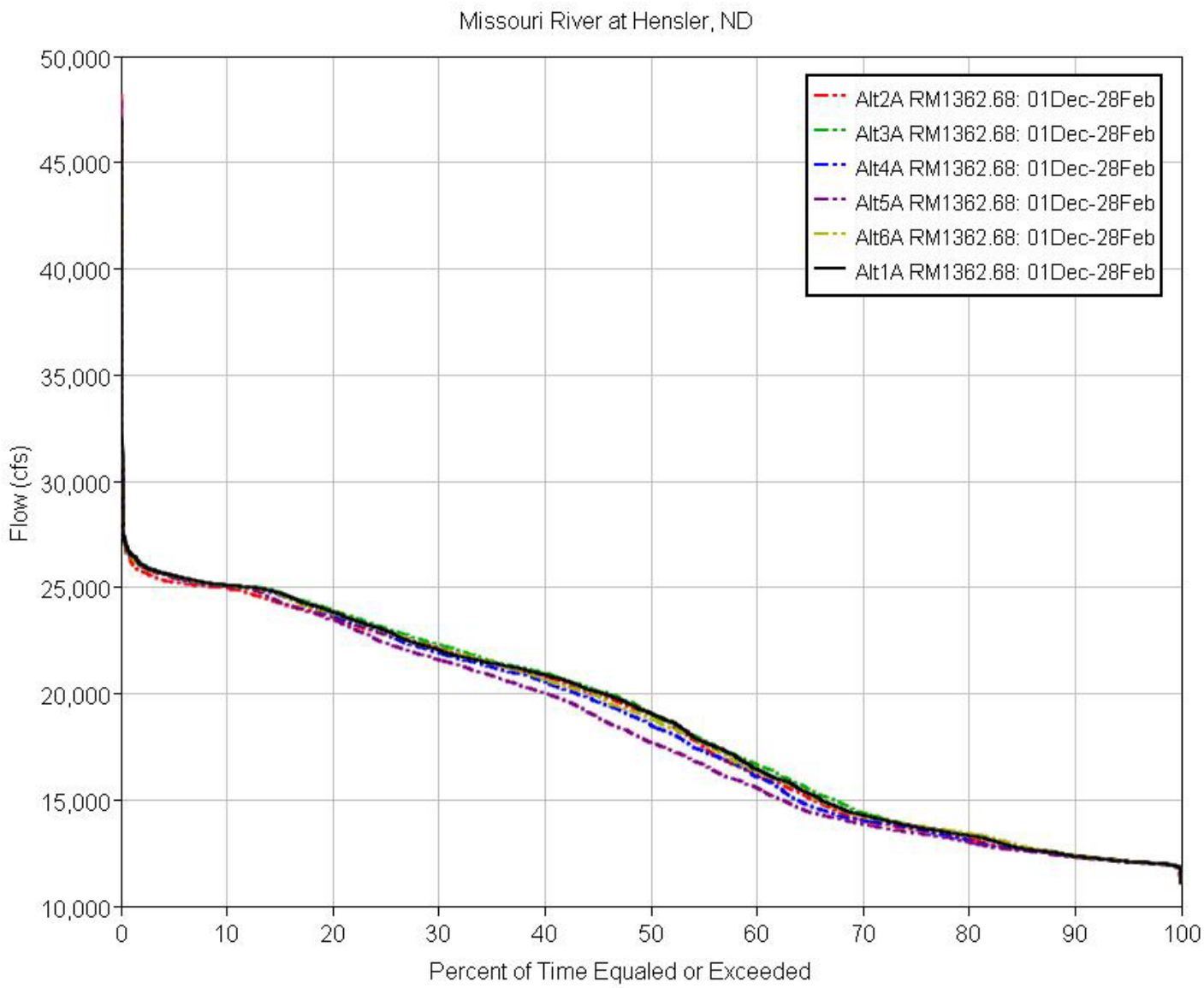


Plate 10: Hensler Winter Duration

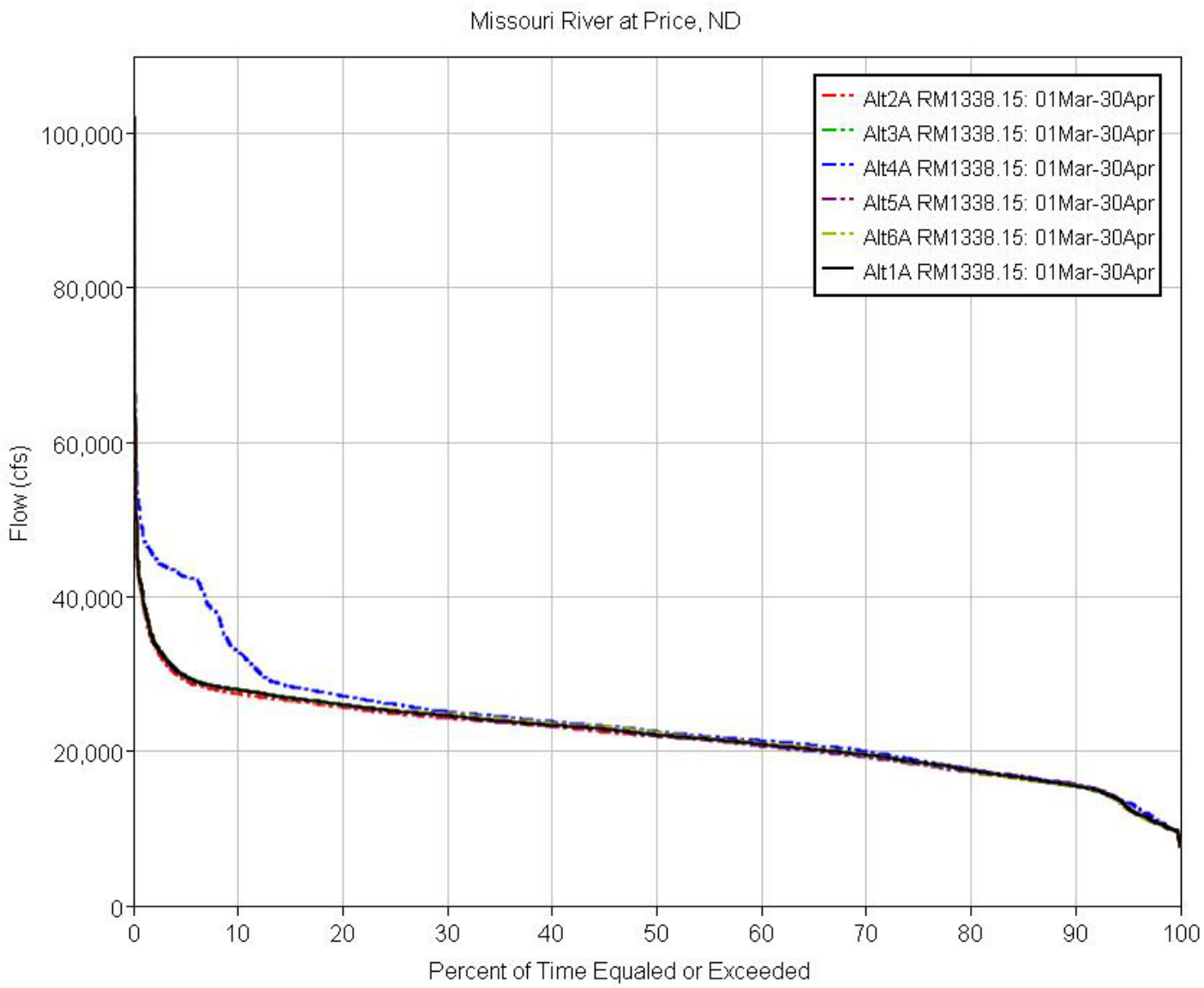


Plate 11: Price Spring Duration

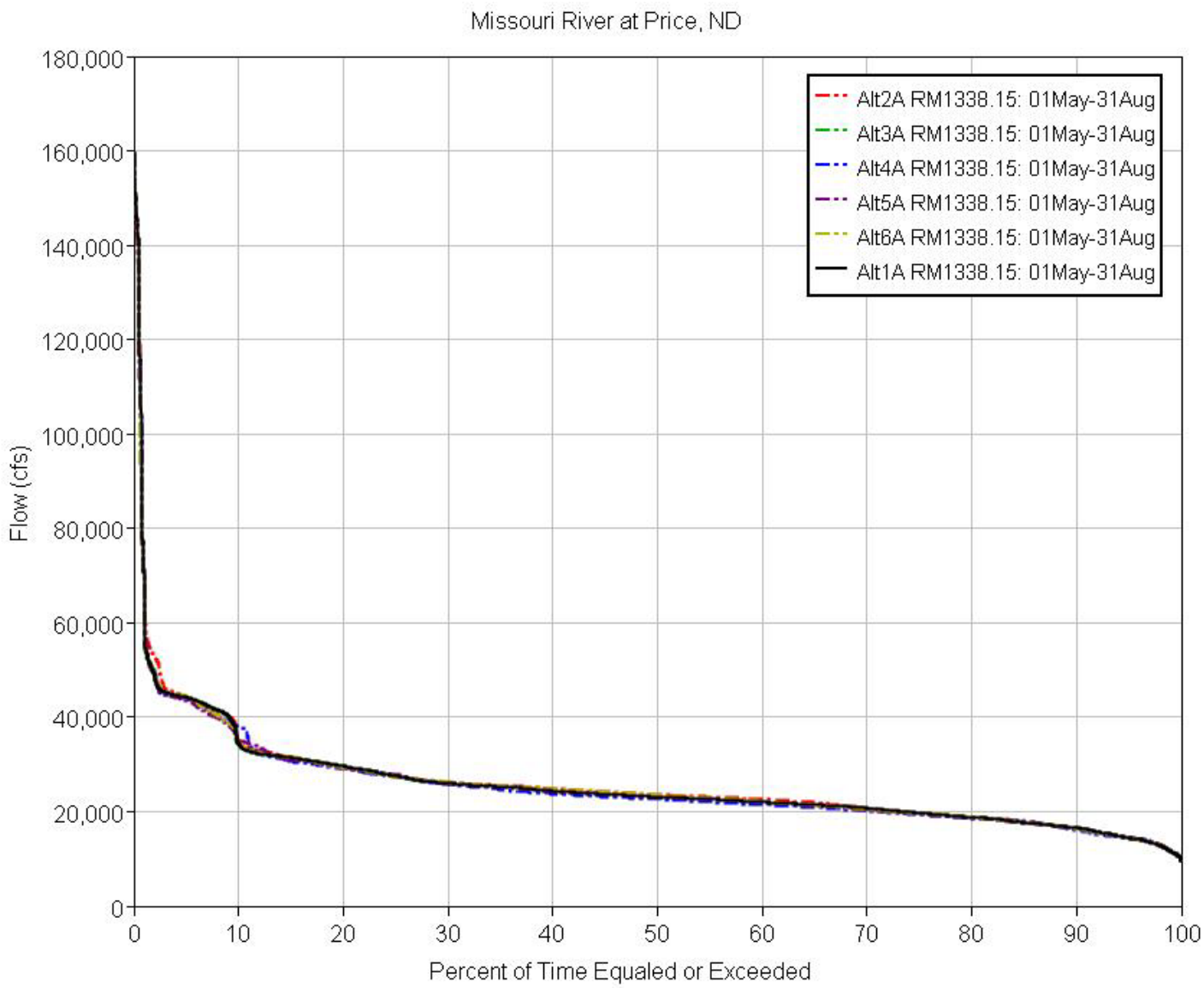


Plate 12: Price Summer Duration

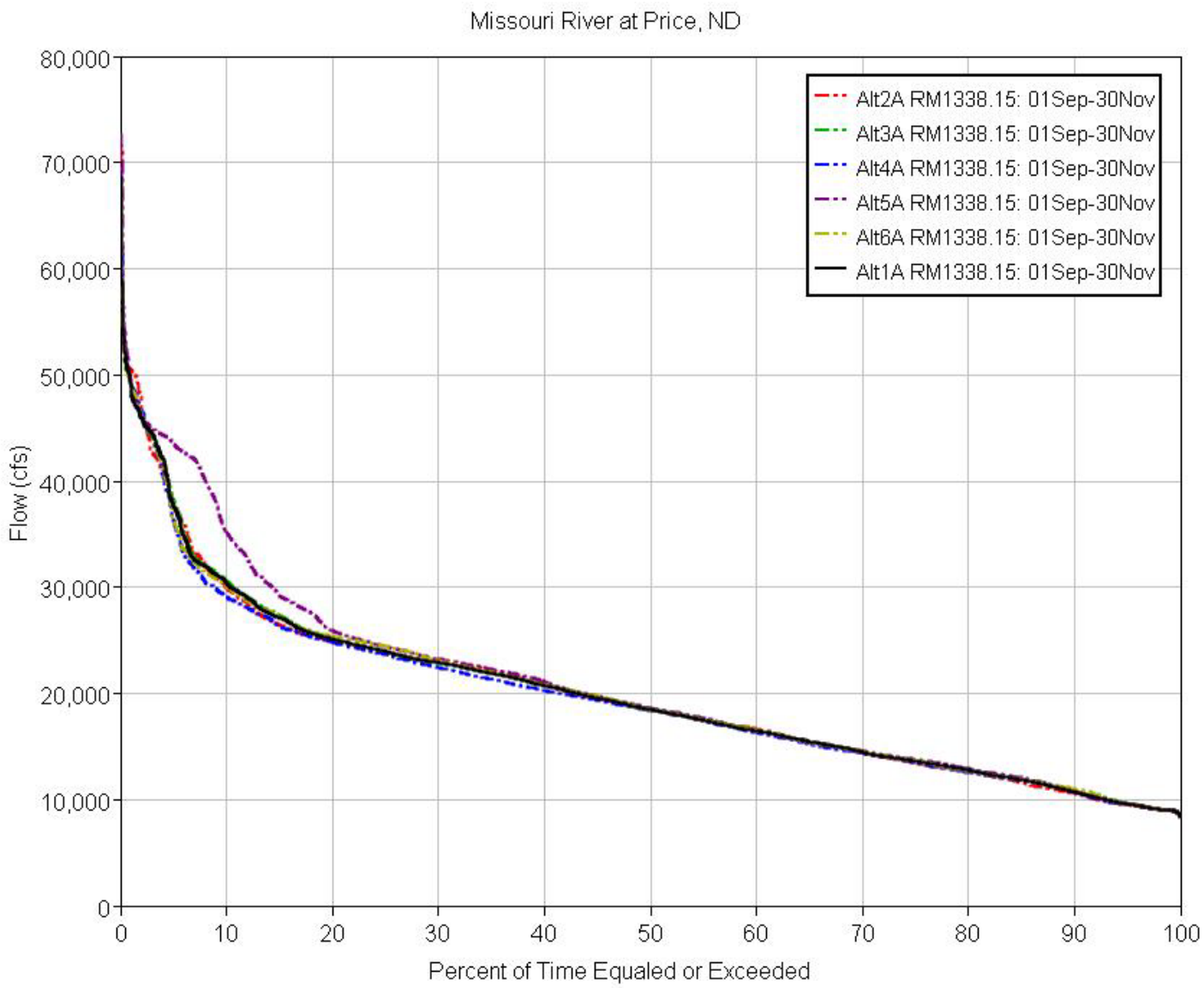


Plate 13: Price Fall Duration

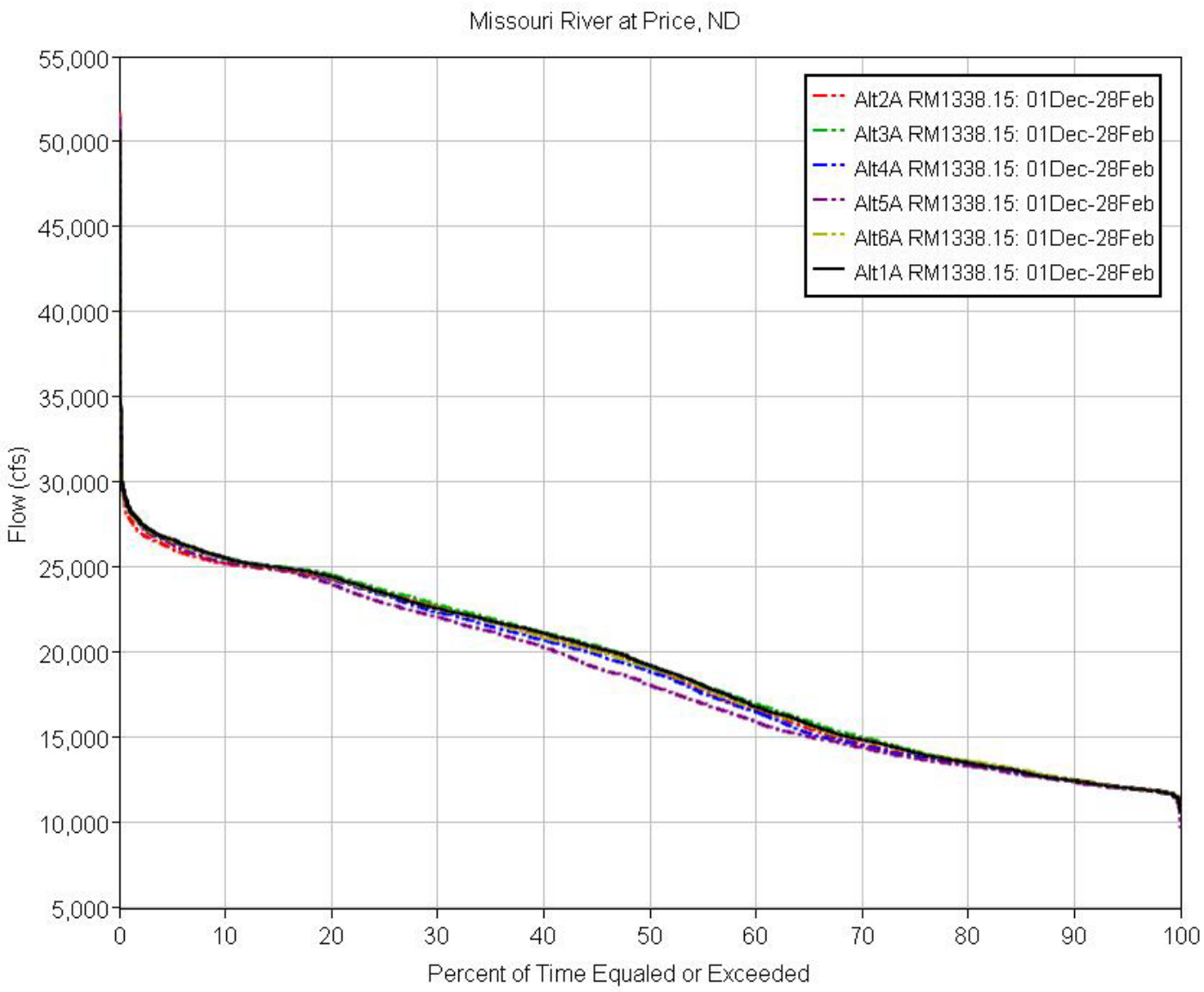


Plate 14: Price Winter Duration

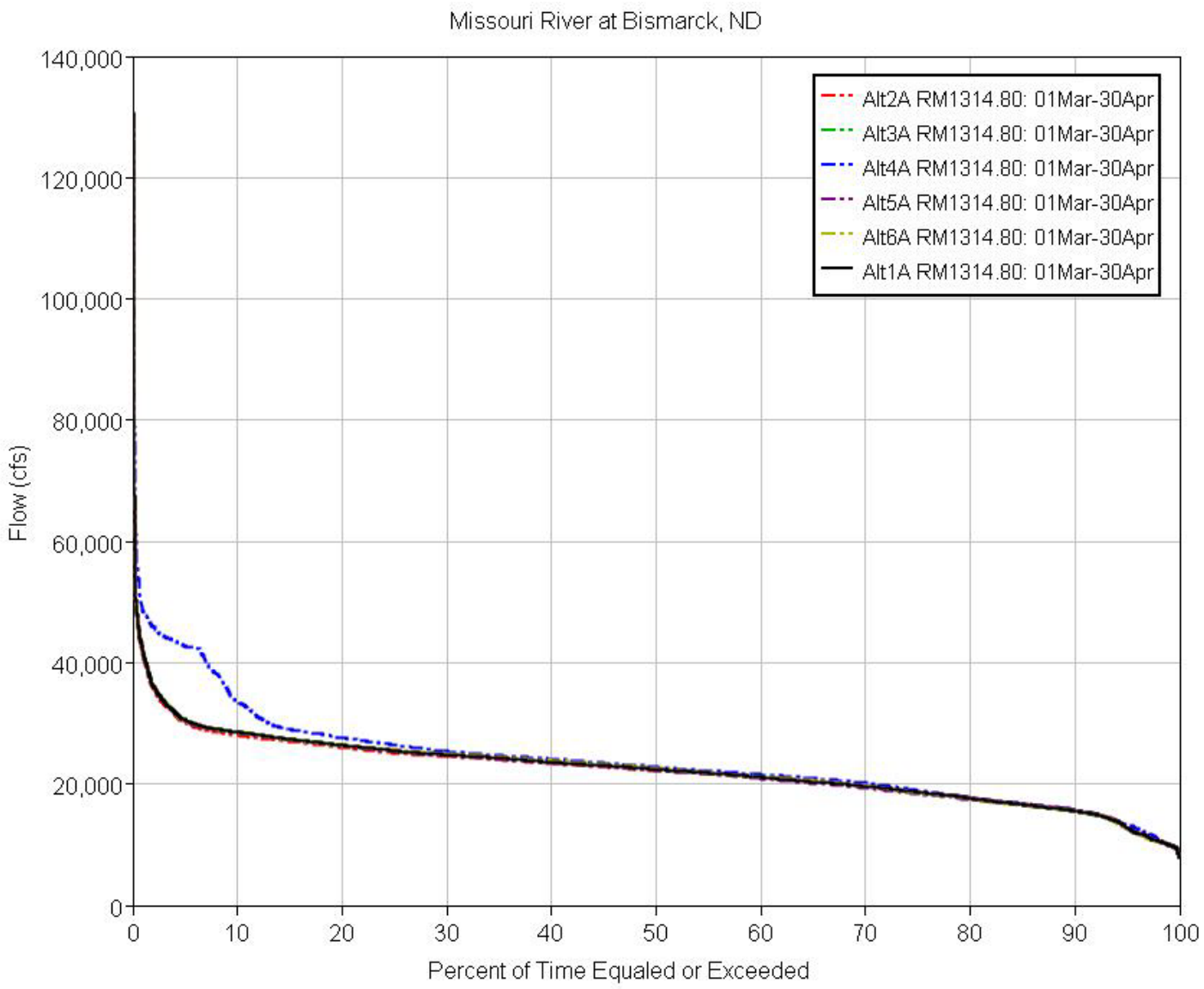


Plate 15: Bismarck Spring Duration

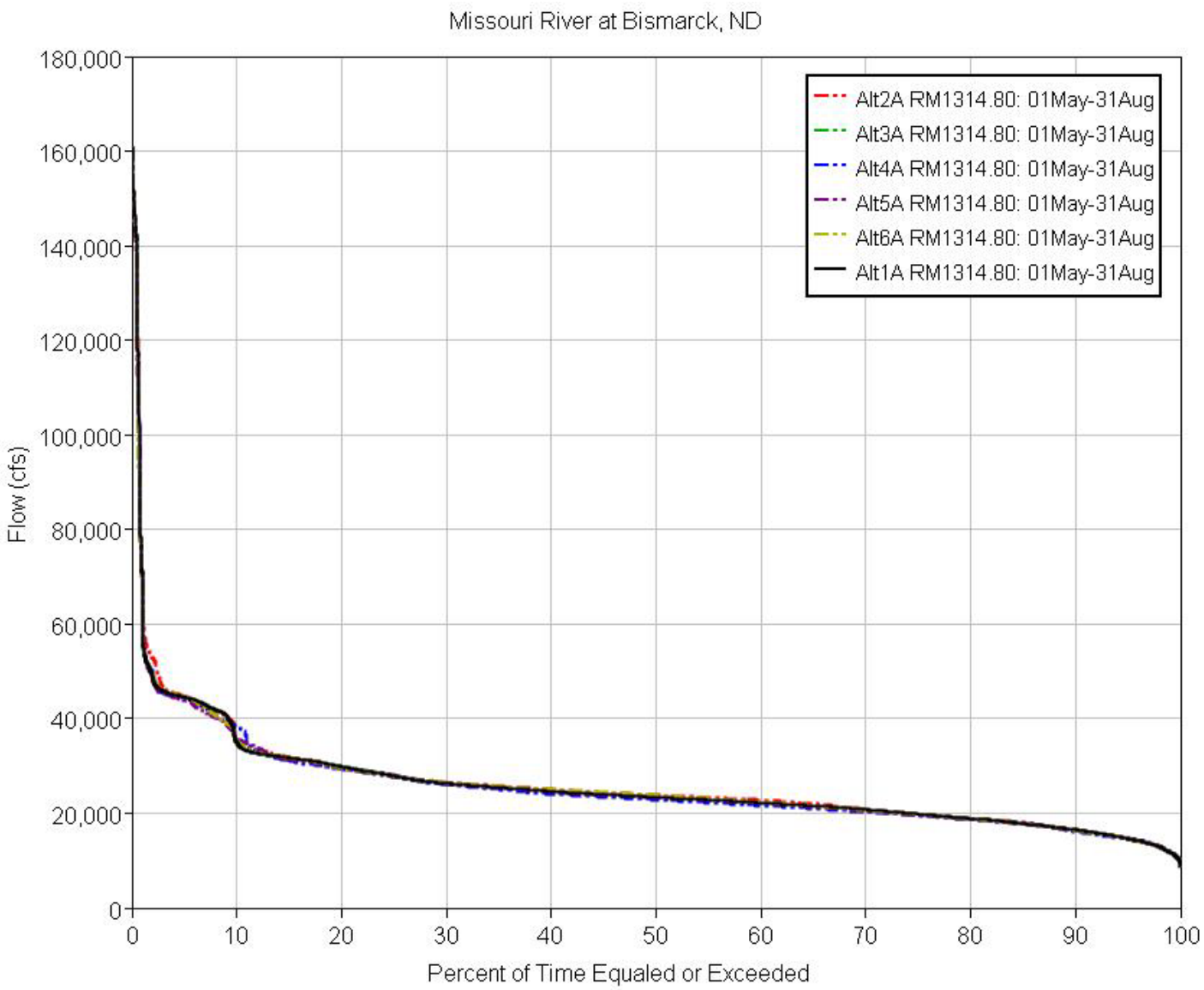


Plate 16: Bismarck Summer Duration

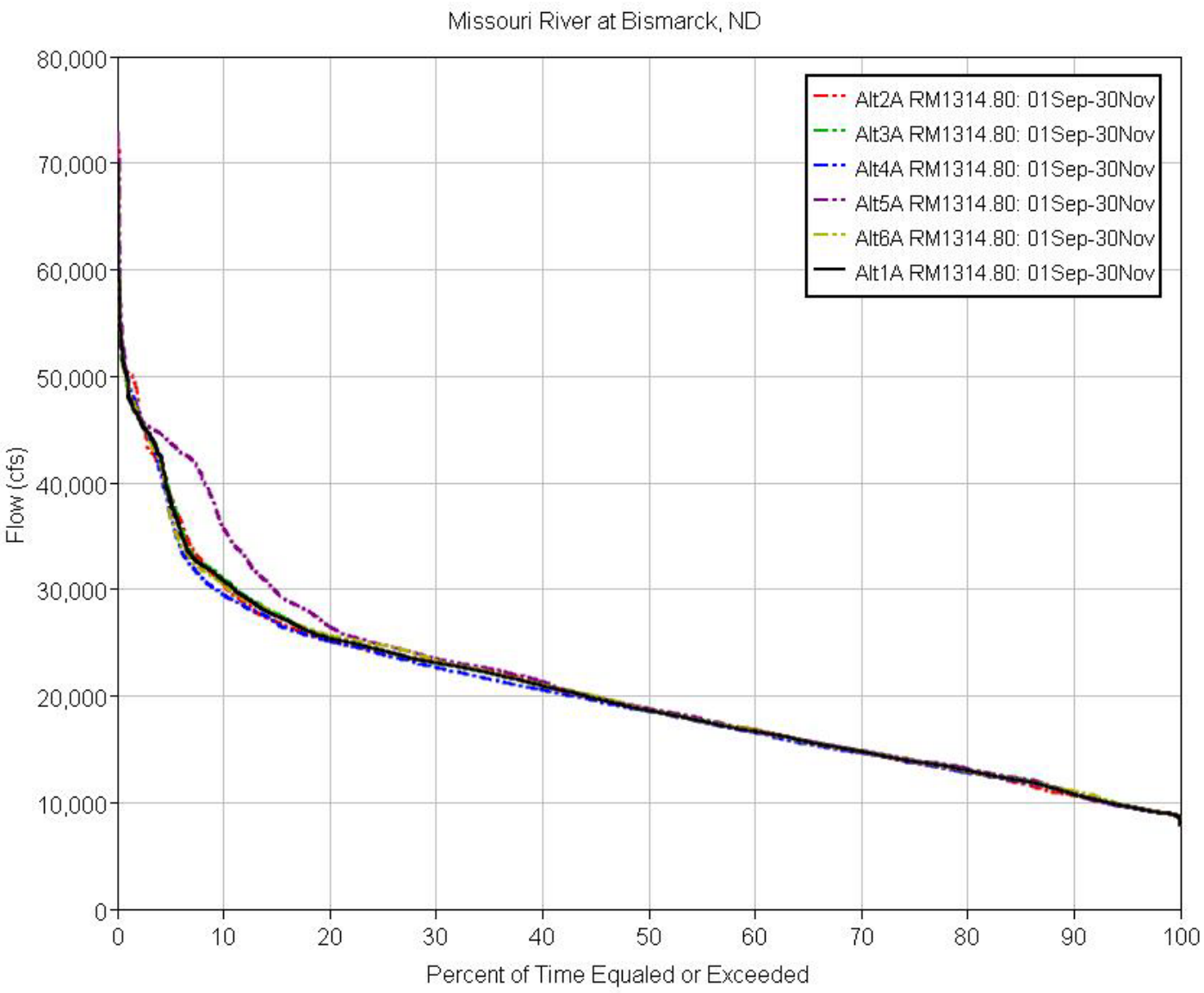


Plate 17: Bismarck Fall Duration

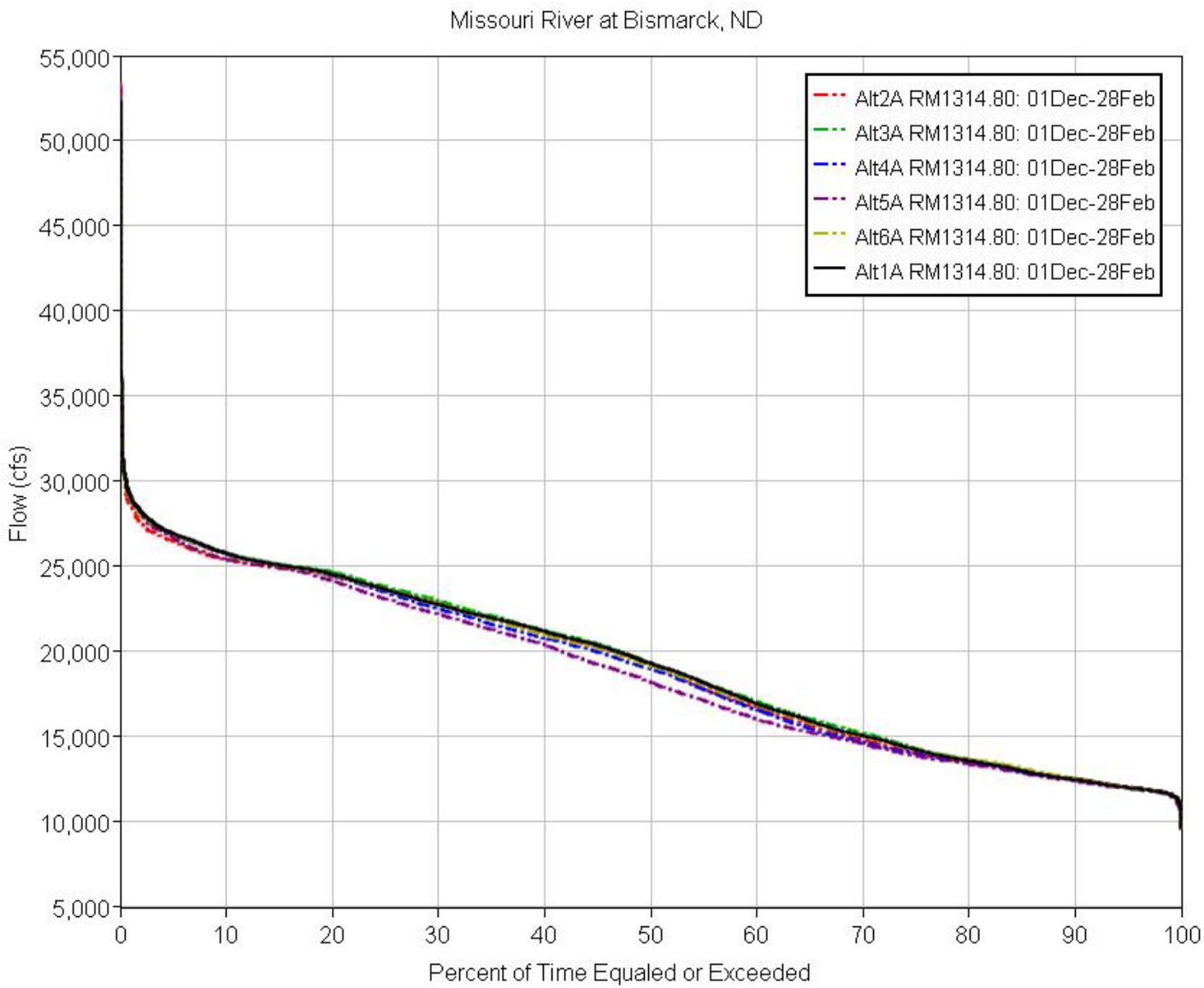


Plate 18: Bismarck Winter Duration

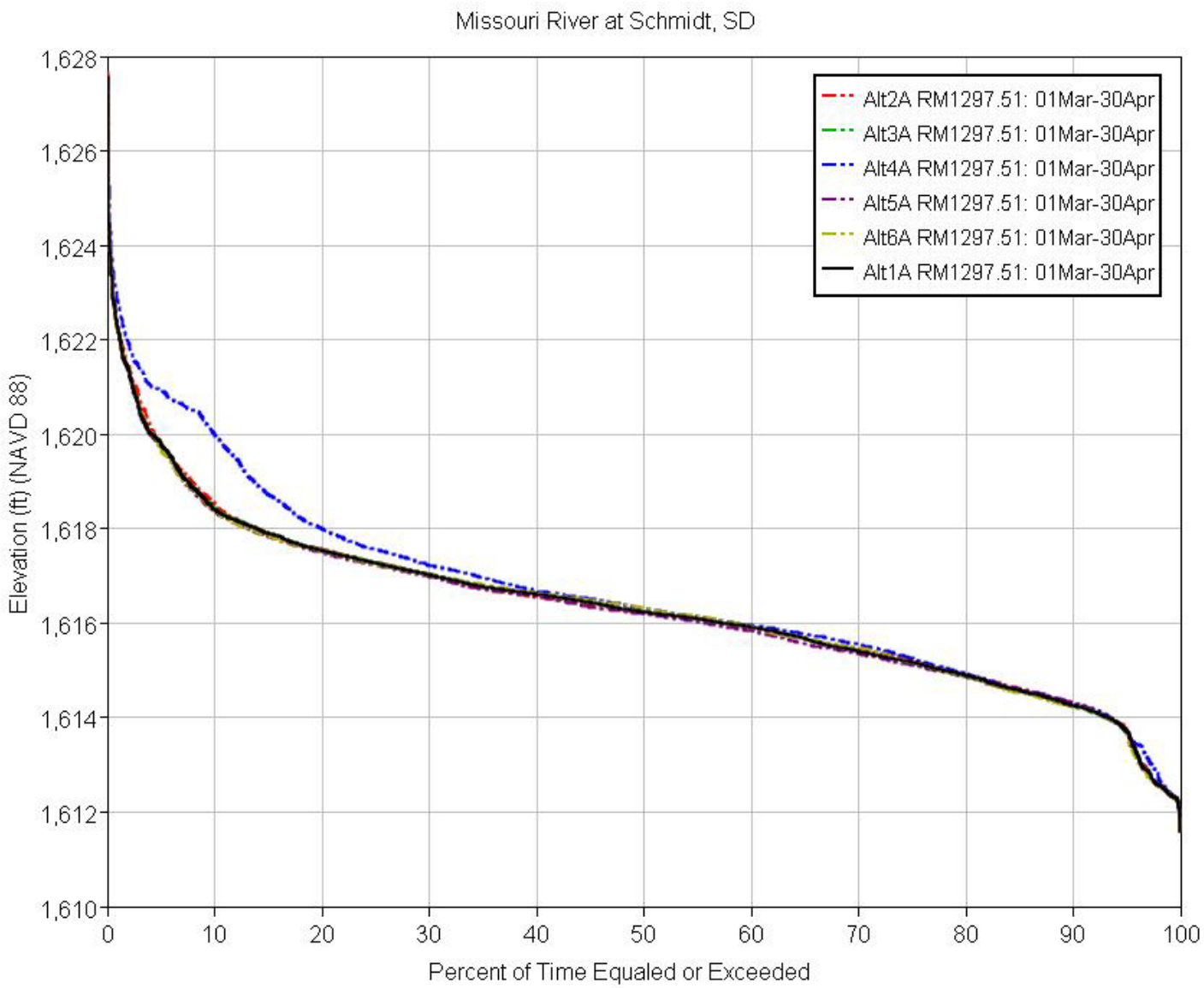


Plate 19: Schmidt Spring Duration

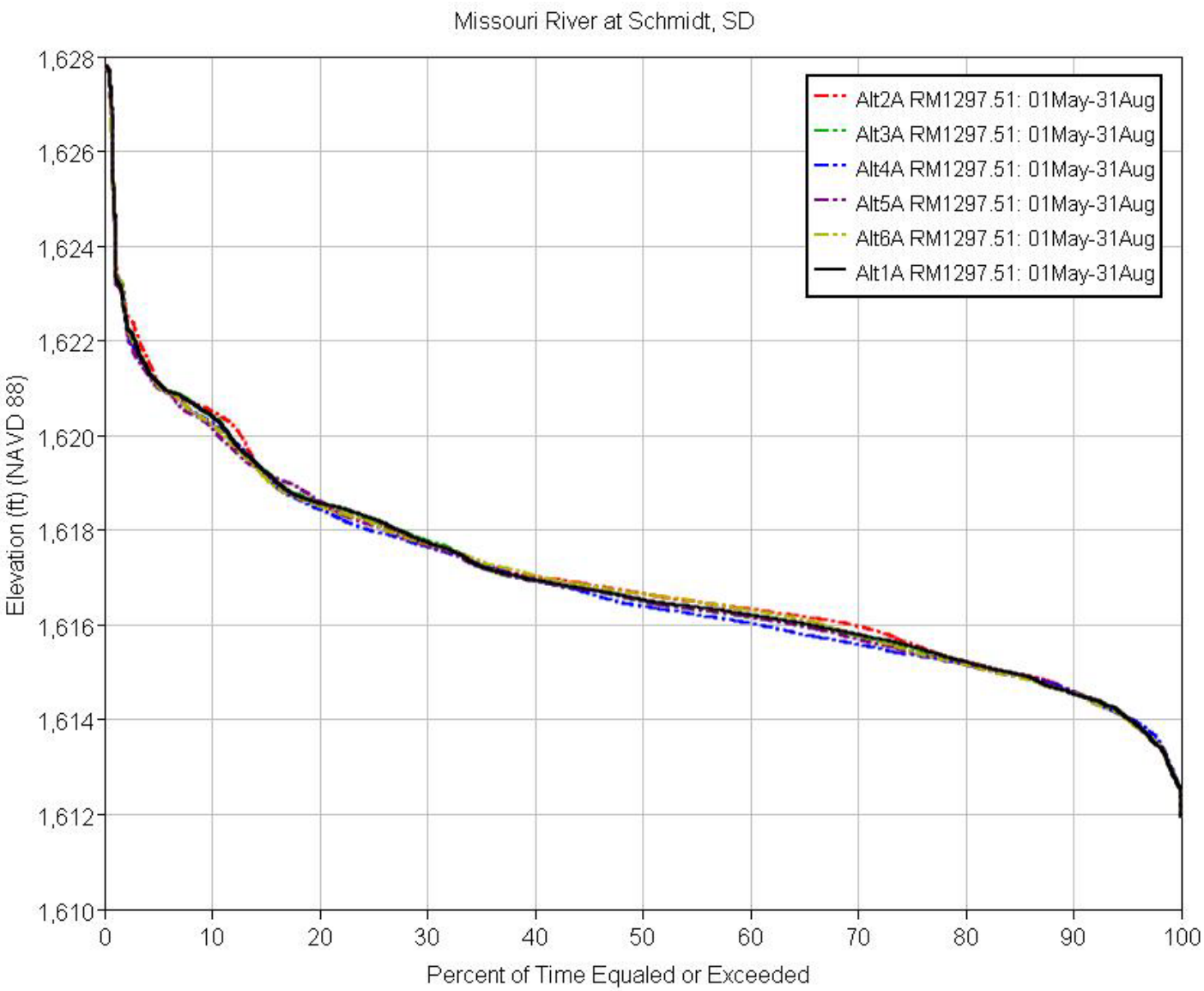


Plate 20: Schmidt Summer Duration

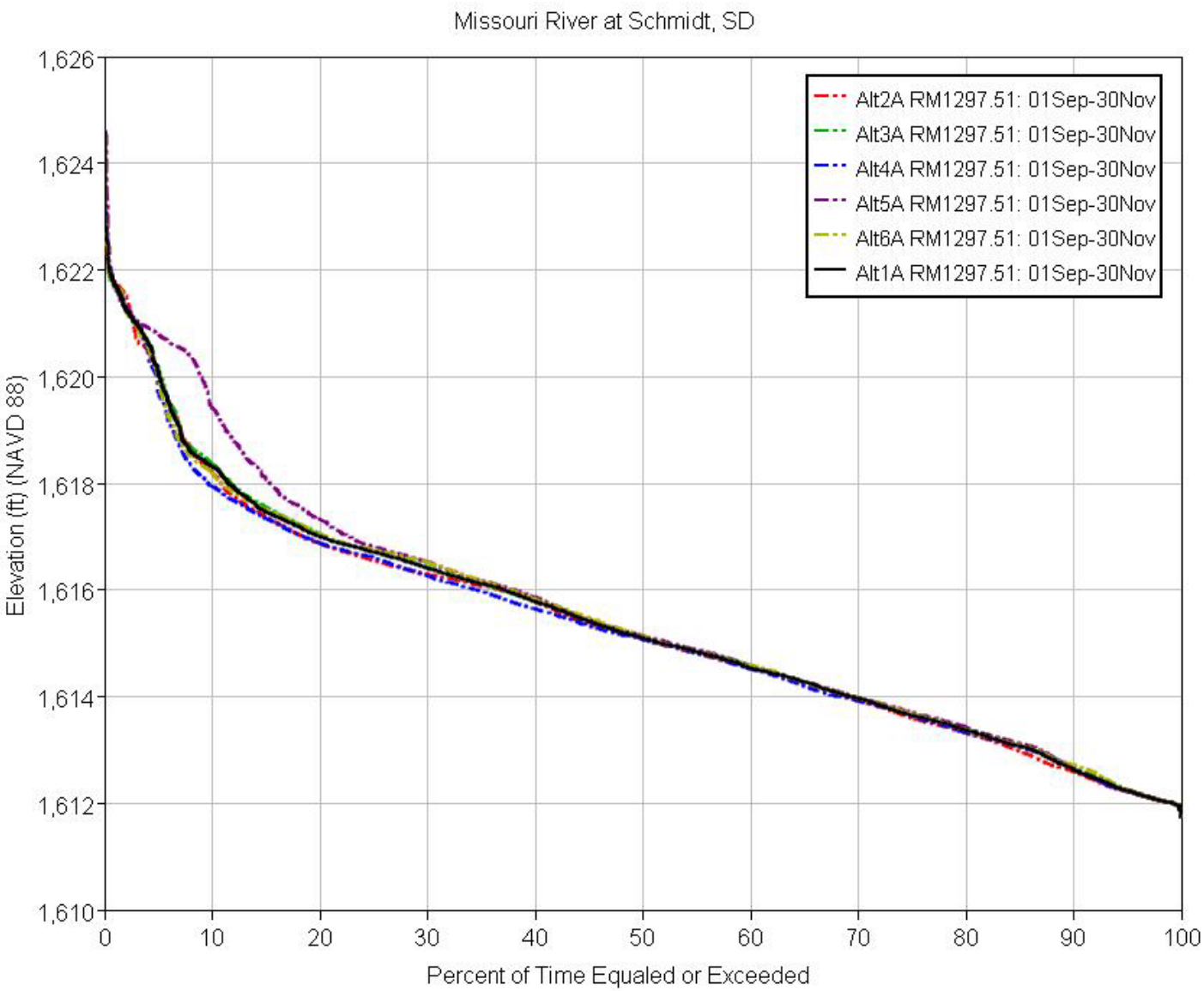


Plate 21: Schmidt Fall Duration

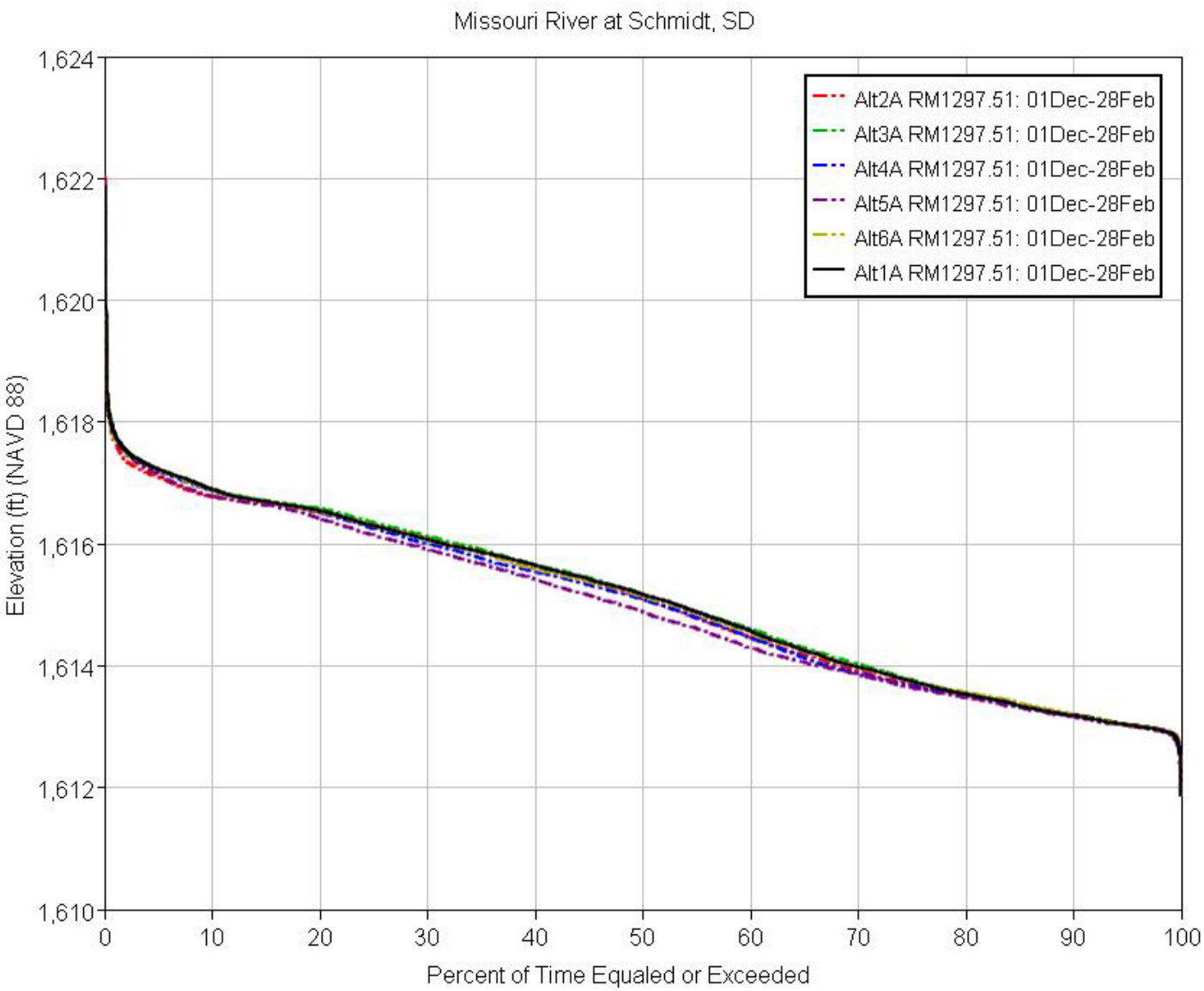


Plate 22: Schmidt Winter Duration

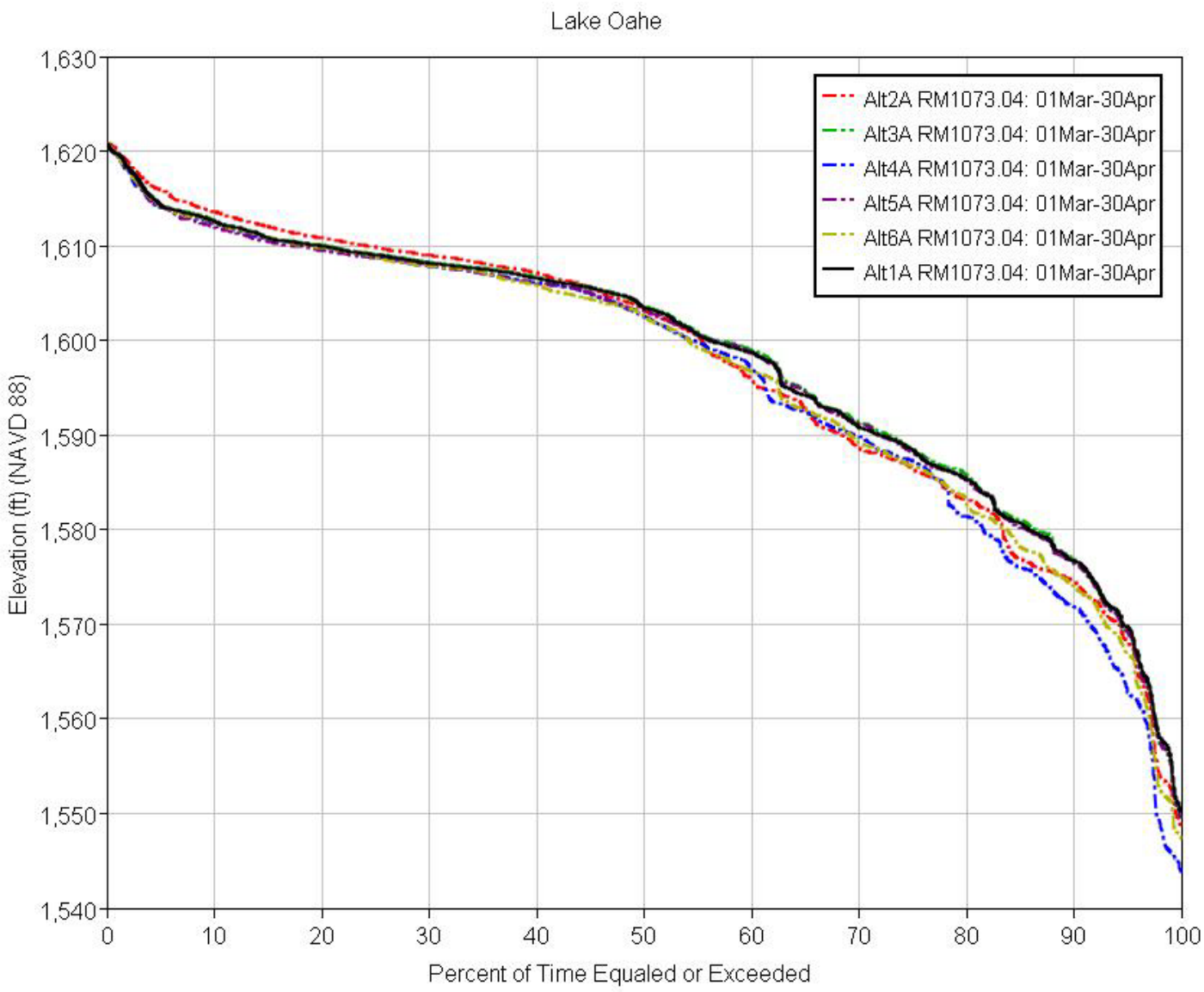


Plate 23: Lake Oahe Spring Duration

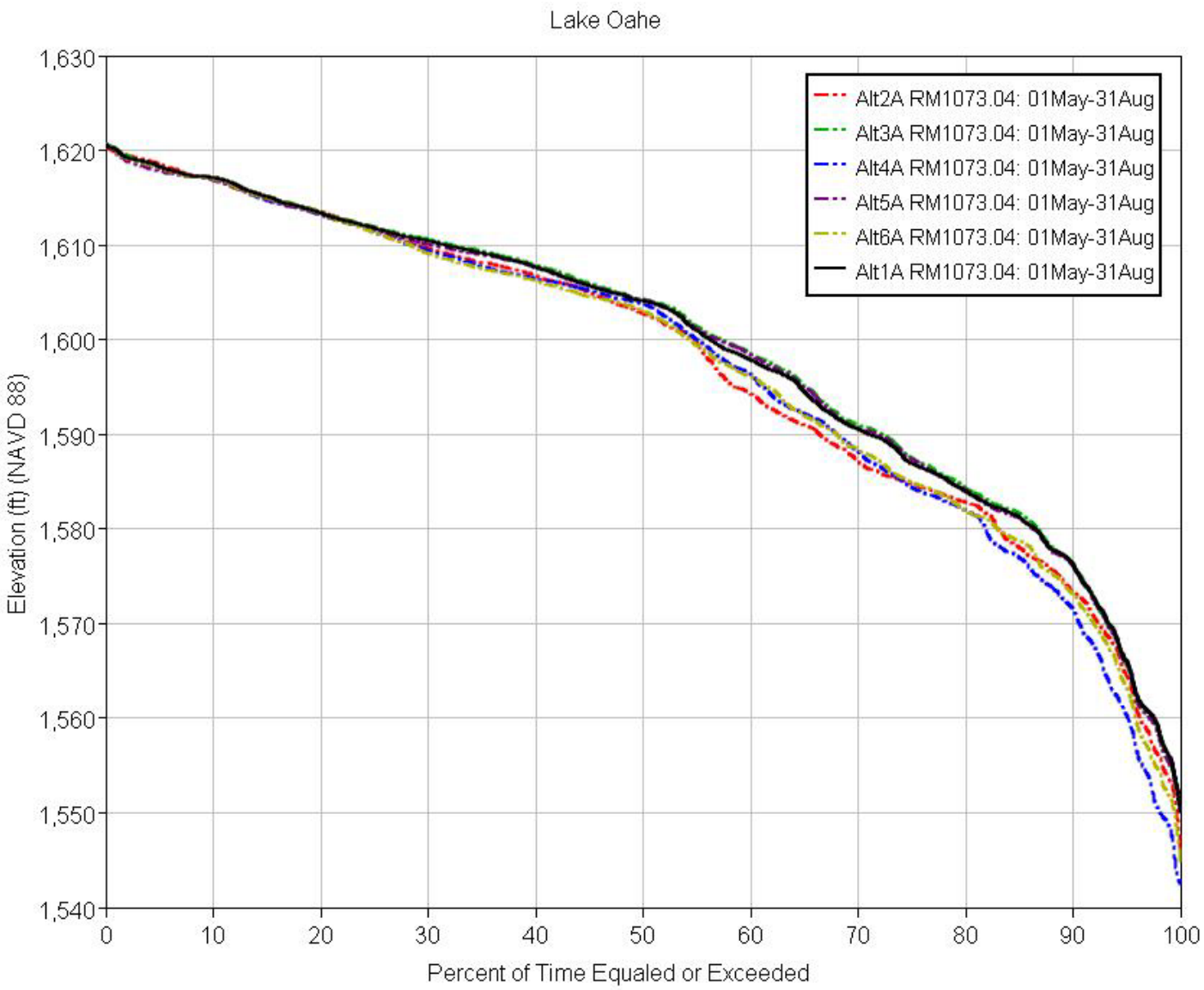


Plate 24: Lake Oahe Summer Duration

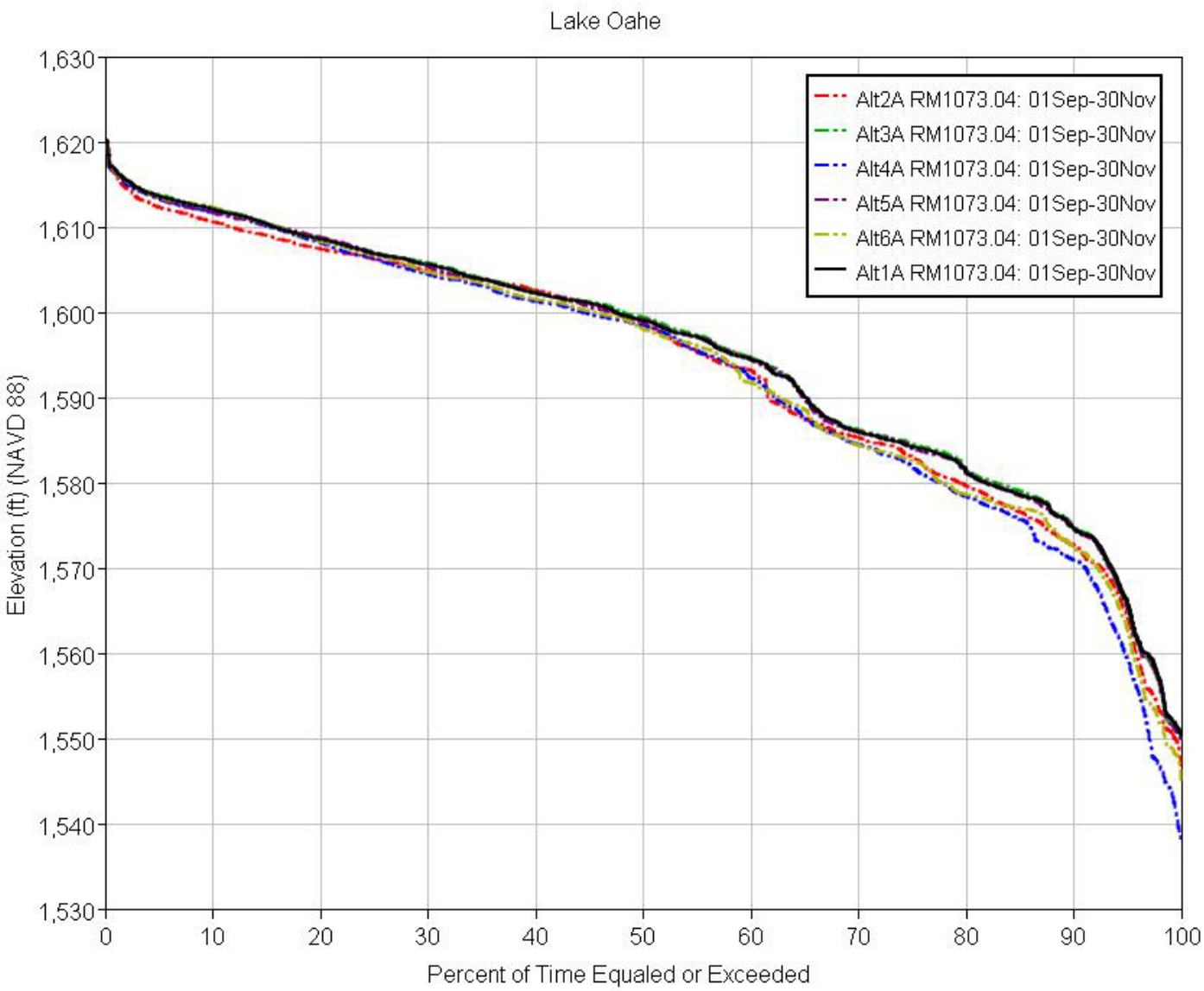


Plate 25: Lake Oahe Fall Duration

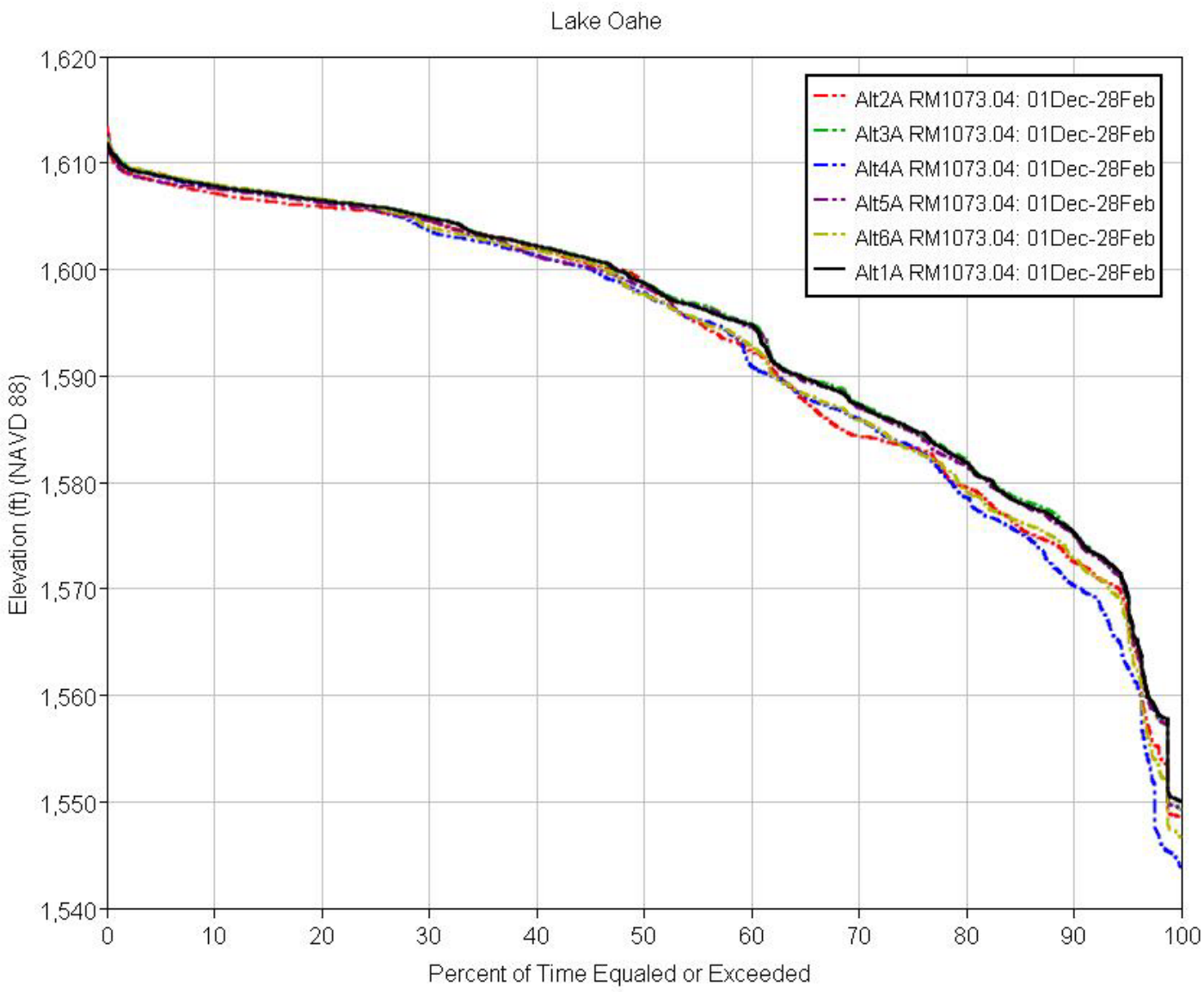


Plate 26: Lake Oahe Winter Duration

US Army Corps of Engineers ®

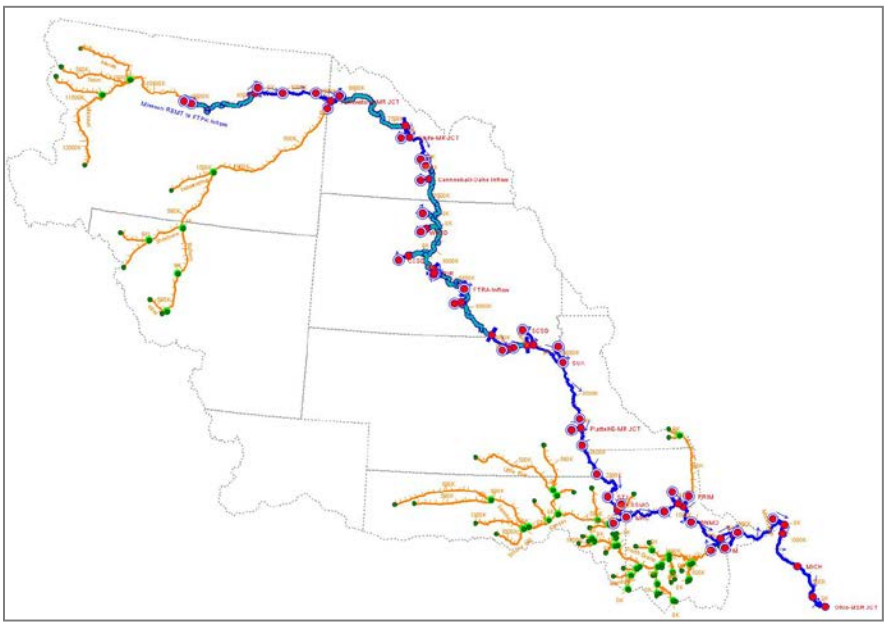
Omaha District

Missouri River Unsteady HEC-RAS Model
Alternatives Analysis

DRAFT

Appendix C

Fort Randall Dam to Gavins Point Dam



December 2016

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ACRONYMS

BiOp……..Biological Opinion

CFS…… Cubic Feet per Second

ESH……..Emergent Sandbar Habitat

HC……..Human Considerations

HEC ..... Hydrologic Engineering Center

IRC……Interception-Rearing Complexes

MAF…….. Million acre-feet

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

NAD 1983…… ... North American Datum of 1983

NAVD 88…… . North American Vertical Datum of 1988

NGVD 29…… National Geodetic Vertical Datum of 1929

NWK…….. Northwest Division Kansas City District

NWO…… Northwest Division Omaha District

POR..... Period of Record

RAS ..... HEC River Analysis System Software (HEC-RAS)

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

RM……1960 River Mile

SWH…….....Shallow Water Habitat

USACE……..United States Army Corps of Engineers

USFWS……United States Fish and Wildlife Service

USGS ..... United States Geological Survey

1 INTRODUCTION

The Missouri River unsteady HEC-RAS model was developed for the Missouri River Recovery Program Management Plan and Integrated Environmental Impact Statement (MRRPMP-EIS) to assist in the assessment of a suite of actions to meet Endangered Species Act (ESA) responsibilities for the piping plover, the interior least tern, and the pallid sturgeon using USACE authorities. Model geometry development and calibration for the existing conditions is documented in *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix C Fort Randall Dam to Gavins Point Dam* (USACE 2015). The objective of the HEC-RAS modeling is to simulate the Management Plan alternatives which include flow changes relative to the No Action alternative. The Human Considerations (HC) team performed an extensive analysis on each of the alternatives for each of the resources (hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply) and provide a detailed comparison of results. For this report, only the hydraulic model output is presented; there is no alternative selection or discussion. This Appendix is for the Fort Randall Dam to Gavins Point Dam reach of the Missouri River as part of the Omaha District.

Six alternatives, including the No Action alternative, were simulated in HEC-RAS from March 1930 to December 2012, however the HC team only used complete year data for their analysis from January 1, 1931 to December 31, 2012. Development of inflow records at current depletion levels to use as boundary conditions for the HEC-ResSim and HEC-RAS models is documented in the report, *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (USACE 2016c). Each alternative has unique flow releases from the reservoirs, as simulated by the ResSim model.

2 GEOMETRY

For the Fort Randall Dam to Gavins Point Dam model, no geometry changes were modeled. All alternative runs used the current conditions (2012) calibrated geometry.

3 FLOW ALTERNATIVES

A total of six flow alternatives were modeled in HEC-ResSim (ResSim). Reservoir pool elevations and dam outflow output from the ResSim model was used as input for the HEC-RAS (RAS) models for each of the six flow alternatives. A brief summary of the flow alternatives is provided below. For more details, see the ResSim technical report, *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report* (2016a).

Tributary inflows were kept consistent between alternatives. Due to the lack of flow gages in this reach, no ungaged inflows were calculated. More details on the Period of Record (POR) flow dataset used can be found in the report *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (2016c).

3.1 ALTERNATIVE 1 - NO ACTION

Under Alternative 1 (Alt 1), the Missouri River Mainstem Projects would continue to be operated as they are currently. Operations within the ResSim model were set up to closely follow the Master Manual that is used during real-time operations of the System; however, the model does have limitations and cannot capture all real-time decisions that occur.

3.2 ALTERNATIVE 2 - U.S. FISH & WILDLIFE SERVICE 2003 BIOLOGICAL OPINION PROJECTED ACTIONS

Alternative 2 (Alt 2) represents the U.S. Fish and Wildlife Service (USFWS) interpretation of the management actions that would be implemented as part of the 2003 Amended BiOp RPA (USFWS 2003). Operational criteria include different early and late spring spawning cues, low summer flows, and a maximum winter release limit.

3.3 ALTERNATIVE 3 - MECHANICAL CONSTRUCTION ONLY

Alternative 3 (Alt 3) consists of mechanical construction of emergent sandbar habitat (ESH). Operational criteria consist of removing the early and late spring spawning cues in Alt 1.

3.4 ALTERNATIVE 4 - SPRING HABITAT-FORMING FLOW RELEASE

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

3.5 ALTERNATIVE 5 - FALL HABITAT-FORMING FLOW RELEASE

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

3.6 ALTERNATIVE 6 - PALLID STURGEON SPAWNING CUE

Alternative 6 (Alt 6) replaces the early and late spring spawning cues with different spawning cues. The early spring spawning cue in Alt 6 occurs at the same time as the early spring spawning cue in Alt 1 but with a higher peak release. The late spring spawning cue in Alt 6 occurs later in May than the late spring spawning cue in Alt 1 and has a larger peak release. Please note that the name of this alternative changed towards the end of the study from Alternative 7 to Alternative 6 (original Alternative 6 was abandoned). The models were not re-run so all of the model and file names are still labeled Alternative 7.

4 SIMULATION OF ALTERNATIVES

Each flow alternative from ResSim was run through HEC-RAS with the current conditions geometry. Alternative names match in both ResSim and RAS.

5 RESULTS

All alternatives runs were performed in HEC-RAS 5.0 Beta (21-August-2015) because that was the most current version as of October and November 2015, when most of the runs were completed. Official release of HEC-RAS 5.0 was on 4-March-2016 and 5.0.1 on 22-Apr-2016, at which point evaluation of results by the economists and human considerations teams was well underway and it would have unnecessarily compromised schedule to re-run the simulations.

Model output contains a considerable amount of information, not easily condensed to simple conclusions. Each of the six alternative runs produced 82 years (March 1930 – December 2012) of stage and flow hydrographs. To express the changes compared with the No Action alternative, the model results were evaluated by statistical evaluation and duration analysis plots.

Results from the 82-year runs for the six alternatives were provided to the Human Considerations (HC) team for analysis. They used the daily (instantaneous 2400 value for each day) flow and water surface elevation output to analyze effects to various resources that include: hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply. The HC team performed an extensive analysis on each of the alternatives for all of the resources and provide a detailed comparison of results. For this report, only the hydraulic model output is presented.

5.1 STATISTICS

For the statistical evaluation, daily flow and water surface elevation results were analyzed to compare the differences between the No Action Alternative and the remaining five alternatives. All of the alternatives show minor changes, while Alternative 2 shows the most difference with respect to both flow and water surface elevation. Tables showing the differences between calculated statistics for both flow and water surface elevation for below Fort Randall Dam, Greenwood, Verdel, Niobrara, and Lewis and Clark Lake can be seen in Plate 1 and Plate 2. The statistics calculated include: the 10th, 25th, 50th, 75th, and 90th- Percentiles, and the Minimum and Maximum. It should be noted that the percentile statistics calculated are from a duration analysis and not a Bulletin 17B flow frequency analysis.

The min and max are the lowest daily flow or stage and the highest daily flow or stage output for each alternative over the period of record. For model stability, a minimum flow of 2,000 cfs was used for Fort Randall Dam outflow in RAS. The ResSim model output for Fort Randall Dam produces daily outflows below the RAS minimum flow of 2,000 cfs, however the impacts to the HC analysis should be minimal. As seen in the tables, the minimum flow varies slightly between alternatives while the maximum flow shows greater differences. The dramatic reduction in the minimum flow for Verdel may have been caused by relatively low Missouri River flows coupled with a backwater effect of high Niobrara River flows, just downstream of Verdel. Caution should be used when trying to draw conclusions from the statistics alone. The economic models (HEC-FIA) provide a more complete analysis of how high flows effect total damages for each alternative because they incorporate all of the cross section output, whereas these tabular statistics only capture one location.

Stage statistics have been rounded to the nearest tenth of a foot, which is equivalent to 1.2 inches. This helps demonstrate how flow changes impact river elevations, which is the more tangible result. For example, even though the maximum flow for Greenwood in Alternative 2 was 245-cfs higher than in Alternative 1, there is less than an inch of impact to the water surface elevation of the river, and therefore zero reported change.

It is also important to note that the HEC-RAS alternative models, although they have a 30 minute computation interval, have been configured to report one value per 24 hour period, and unfortunately that one value is not a daily average. The HEC-RAS model reports the value that lands on 2400 of each day. The most reasonable output interval was chosen as daily due to the size of watershed being modeled, POR length, and the number of hydrograph locations necessary for HC analysis. This means that slight shifts in timing from alternative to alternative can carry over into the results as small fluxuations in the reported flow. Changes in timing are a small factor, not likely to significantly impact any results evaluation, but should be kept in mind when making comparison at a precise level such as in the statistics tables.

5.2 Seasonal Duration Plots

A duration analysis was also performed for the alternative output. Seasonal duration plots for key main stem locations including below Fort Randall Dam, Greenwood, Verdel, Niobrara, and Lewis and Clark Lake are shown in Plate 3 through Plate 22. Seasonal dates chosen for the duration analysis coincide with the current System operational seasons: spring (1Mar to 30Apr), summer (1May to 31Aug), fall (1Sep to 30Nov), and winter (1Dec to 28Feb). Alternatives 4 and 6 have the most notable differences during the spring duration due to the spring pulses included in those alternatives. Lower winter releases can be seen for Alternative 2 and are caused by storage usage due to the spring pulses.

5.3 Limitations

The analysis relies on the simulation of the 82-year period of record using daily average outflows from an HEC-ResSim model input into a fixed bed HEC-RAS model, with stage and flow output. While the analysis coupled with species and human considerations models can be used to show relative benefits and potential impacts based on historic flows, there are limitations in the conclusions that can be drawn based on some of the simplifying assumptions.

1. **POR Methodology** - An 82-year period of record, adjusted to current level of depletions, was used and may not be comparable to future conditions. A climate change assessment of the Missouri River basin indicates increases to both temperature and precipitation along with increasing trends in extreme floods and droughts (USACE 2016b). The conditions during a pulse year in the future could vary greatly from the small sample of pulse events included in the POR analysis.
2. **No Risk Analysis** - The Missouri River system as currently operated provides substantial flood damage reduction and benefits to the entire basin. The current HEC-ResSim and HEC-RAS analysis, which employs an 82-year period of record simulation, shows the potential for negative impacts to flood damage reduction and dam safety for alternatives that include changes in reservoir flow releases. The current study

methodology does not simulate a sufficient number of events and possible runoff combinations within the large Missouri River basin to evaluate potential change in downstream flood risk and dam safety.

Scoping efforts were conducted to determine a Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood damage reduction as a result of flow release changes. The risk analysis primary components include further development of the period of record flow data set, HEC-ResSim and HEC-RAS model modifications, development of levee fragility curves, assignment of uncertainty, assembly and debugging of models, Monte Carlo simulation, analysis of results, and reporting. The Monte Carlo methodology properly assesses the effects of the alternative operation changes because it increases the sample size of flow data and number of combinations of flow periods that may occur in the future so that impacts can be characterized with greater confidence. Without such analysis, the impacts of operational changes will only be known for events and combinations of events that have already occurred. Statistics calculated based on the 83-years of record should therefore be used with caution, and with the understanding of the consequences of using only a small sample of years.

3. **Stable Bed and Floodplain** - The hydraulic modeling to date is based on the existing conditions geometry. The analysis does not account for how the bed of the Missouri River may respond to flow changes. Additionally, the analysis does not try to project where sediment may accumulate in the floodplain or include projections of future change in floodplain roughness. This carries with it the necessary assumptions that any bed and floodplain changes would be either negligible or similar between each alternative.

5.4 Channel Capacity Analysis

Channel capacity estimates were performed to provide an indication of the flow rate at which bank elevations are overtopped and flow begins to leave the main channel and enter the floodplain. Channel capacity estimates were performed with the one-dimensional RAS model calibrated to 2012 conditions by comparing steady flow profiles with top of bank elevations at each cross section combined with reviewing the best available floodplain topography. Floodplain flow connectivity was not assessed. The estimated channel capacity does not necessarily correlate with the onset of flood damage. In addition, channel capacity is typically highly variable along the channel bank due to wide variation in bank elevations. The quality of the channel capacity estimate is affected by numerous factors including how representative the model cross sections are of river geometry, local channel geometry variation, low spots in bank elevations, and the floodplain topography accuracy. Within the reservoir delta areas where the river enters the downstream lake, the channel capacity estimate is not meaningful. While channel capacity varies within the reach and through time, a range for the area below the Niobrara River is 35,000 to 40,000 cfs.

A Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood risk as a result of flow release changes would be required to fully assess how an alternative impacts potential flood risk. Refer to the *Summary of Hydrologic Engineering Analysis* (USACE 2016d) for additional details on the risk analysis methodology.

6 CONCLUSIONS

The unsteady HEC-RAS model analysis gives a means to systematically evaluate differences in river elevations for various reservoir and habitat alternatives given the limitations presented in Section 5.3. These results can be fed into additional species and human considerations models, such as HEC-FIA, to screen alternatives for relative benefits and potential economic impacts. The outputs should be carefully examined with an eye towards the model limitations and judgement applied where needed to mitigate any potential pitfalls of the hydraulic analysis.

If flow change alternatives are considered for implementation, additional risk and uncertainty analysis is recommended to more comprehensively quantify risk of spring or fall pulse flows.

The analysis presented in this report is based off of the existing conditions HEC-RAS models. The steps of this analysis could be repeated if predictions of bed change are made for any of the alternatives. Having both analysis completed would provide a range of reasonable results throughout the planning horizon.

7 REFERENCES

USACE (2015). *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix C Fort Randall Dam to Gavins Point Dam.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016a). *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016b). *Missouri River Recovery Management Plan - Climate Change.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016c). *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE (2016d). *Missouri River Recovery Program Management Plan Environmental Impact Statement, Summary of Hydrologic Engineering Analysis.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USFWS (2003). *U.S. Fish and Wildlife Service 2003 Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System.*

APPENDIX C

FORT RANDALL DAM TO GAVINS POINT DAM

PLATES

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Fort Randall - XS 879.04							
Alt 1A	7,323	12,131	22,780	32,223	40,087	2,000	164,916
Alt 2A	6,923	11,546	22,014	32,701	42,137	2,000	165,145
Change from Alt 1A	-400	-585	-766	478	2,050	0	229
Alt 3A	7,322	12,327	22,751	32,093	40,135	2,000	168,183
Change from Alt 1A	-1	197	-30	-130	48	0	3,267
Alt 4A	6,952	11,784	22,511	32,286	40,643	2,000	160,533
Change from Alt 1A	-371	-347	-269	63	556	0	-4,384
Alt 5A	7,323	12,084	22,518	32,140	40,468	2,000	160,531
Change from Alt 1A	0	-46	-263	-83	381	0	-4,385
Alt 6A	7,176	11,928	22,604	32,441	40,795	2,000	169,297
Change from Alt 1A	-147	-203	-176	217	708	0	4,381
Greenwood - XS 862.98							
Alt 1A	7,694	12,023	22,767	32,047	39,673	1,803	160,300
Alt 2A	7,246	11,442	22,017	32,534	41,787	1,809	160,545
Change from Alt 1A	-448	-580	-750	487	2,113	6	245
Alt 3A	7,642	12,192	22,744	31,979	39,733	1,809	163,834
Change from Alt 1A	-52	169	-23	-68	60	6	3,535
Alt 4A	7,356	11,646	22,520	32,173	40,335	1,807	160,299
Change from Alt 1A	-338	-377	-247	126	662	4	0
Alt 5A	7,607	11,942	22,530	31,982	40,100	1,812	160,300
Change from Alt 1A	-87	-81	-236	-65	427	8	0
Alt 6A	7,515	11,828	22,621	32,325	40,385	1,806	165,069
Change from Alt 1A	-179	-195	-145	278	712	3	4,769
Verdel - XS 844.78							
Alt 1A	7,740	12,103	22,825	31,985	39,537	561	160,394
Alt 2A	7,387	11,511	22,047	32,459	41,693	670	160,409
Change from Alt 1A	-353	-592	-778	474	2,156	109	15
Alt 3A	7,739	12,268	22,776	31,921	39,578	670	162,514
Change from Alt 1A	-1	165	-49	-64	41	109	2,120
Alt 4A	7,454	11,691	22,620	32,065	40,234	659	160,395
Change from Alt 1A	-287	-412	-206	80	698	98	1
Alt 5A	7,705	12,027	22,607	31,898	39,991	674	160,395
Change from Alt 1A	-36	-76	-219	-87	455	113	1
Alt 6A	7,608	11,905	22,688	32,221	40,225	664	163,882
Change from Alt 1A	-132	-198	-137	236	688	103	3,487

Plate 1: Alternative Flow Statistics from POR Duration

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Niobrara - XS 842.93							
Alt 1A	9,847	13,925	24,706	33,411	40,830	3,332	163,081
Alt 2A	9,616	13,265	23,907	33,864	43,097	3,104	163,180
Change from Alt 1A	-231	-661	-799	453	2,268	-228	98
Alt 3A	9,853	14,094	24,674	33,386	40,923	3,652	165,243
Change from Alt 1A	6	169	-32	-25	93	319	2,162
Alt 4A	9,667	13,369	24,540	33,476	41,470	3,165	163,081
Change from Alt 1A	-180	-556	-166	65	640	-167	0
Alt 5A	9,849	13,810	24,508	33,317	41,262	3,134	163,081
Change from Alt 1A	2	-115	-198	-93	432	-199	0
Alt 6A	9,791	13,698	24,598	33,647	41,561	3,235	166,605
Change from Alt 1A	-56	-228	-108	236	731	-97	3,524

Plate 1 cont'd: Alternative Flow Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Fort Randall - XS 879.04							
Alt 1A	1229.1	1230.6	1233.0	1234.8	1235.8	1226.4	1248.8
Alt 2A	1228.9	1230.5	1232.9	1234.8	1236.1	1226.4	1248.8
Change from Alt 1A	-0.2	-0.2	-0.2	0.1	0.3	0.0	0.0
Alt 3A	1229.1	1230.7	1233.0	1234.7	1235.8	1226.4	1249.0
Change from Alt 1A	0.0	0.1	0.0	0.0	0.0	0.0	0.2
Alt 4A	1228.9	1230.5	1233.0	1234.8	1235.9	1226.4	1248.7
Change from Alt 1A	-0.2	-0.1	0.0	0.0	0.1	0.0	-0.1
Alt 5A	1229.1	1230.6	1233.0	1234.8	1235.9	1226.4	1248.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	-0.1
Alt 6A	1229.0	1230.6	1233.0	1234.8	1235.9	1226.4	1249.1
Change from Alt 1A	-0.1	-0.1	0.0	0.0	0.1	0.0	0.3
Greenwood - XS 862.98							
Alt 1A	1222.2	1223.4	1225.8	1227.7	1228.9	1219.8	1239.6
Alt 2A	1222.1	1223.2	1225.6	1227.7	1229.2	1219.8	1239.6
Change from Alt 1A	-0.1	-0.1	-0.2	0.1	0.3	0.0	0.0
Alt 3A	1222.2	1223.4	1225.7	1227.6	1228.9	1219.8	1239.7
Change from Alt 1A	0.0	0.1	0.0	0.0	0.0	0.0	0.1
Alt 4A	1222.2	1223.3	1225.7	1227.7	1229.0	1219.8	1239.6
Change from Alt 1A	-0.1	-0.1	0.0	0.0	0.1	0.0	0.0
Alt 5A	1222.2	1223.3	1225.7	1227.6	1228.9	1219.8	1239.6
Change from Alt 1A	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Alt 6A	1222.2	1223.3	1225.7	1227.7	1229.0	1219.8	1239.8
Change from Alt 1A	0.0	0.0	0.0	0.0	0.1	0.0	0.1
Verdel - XS 844.78							
Alt 1A	1215.1	1216.5	1219.1	1220.6	1221.5	1212.0	1229.1
Alt 2A	1215.0	1216.3	1218.9	1220.6	1221.8	1211.9	1229.1
Change from Alt 1A	-0.1	-0.2	-0.2	0.1	0.3	-0.1	0.0
Alt 3A	1215.1	1216.6	1219.1	1220.6	1221.5	1212.1	1229.2
Change from Alt 1A	0.0	0.1	0.0	0.0	0.0	0.1	0.1
Alt 4A	1215.0	1216.3	1219.0	1220.6	1221.6	1212.0	1229.1
Change from Alt 1A	-0.1	-0.2	0.0	0.0	0.1	0.0	0.0
Alt 5A	1215.1	1216.5	1219.0	1220.6	1221.6	1212.0	1229.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 6A	1215.1	1216.4	1219.0	1220.6	1221.6	1212.0	1229.3
Change from Alt 1A	0.0	-0.1	0.0	0.0	0.1	0.0	0.2

Plate 2: Alternative Water Surface Elevation Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Niobrara - XS 842.93							
Alt 1A	1214.1	1215.5	1218.0	1219.4	1220.3	1210.6	1227.7
Alt 2A	1214.0	1215.3	1217.8	1219.5	1220.5	1210.3	1227.7
Change from Alt 1A	-0.1	-0.2	-0.2	0.1	0.2	-0.3	0.0
Alt 3A	1214.1	1215.6	1218.0	1219.4	1220.3	1210.8	1227.8
Change from Alt 1A	0.0	0.1	0.0	0.0	0.0	0.2	0.1
Alt 4A	1214.1	1215.4	1218.0	1219.4	1220.3	1210.4	1227.7
Change from Alt 1A	-0.1	-0.2	0.0	0.0	0.1	-0.2	0.0
Alt 5A	1214.1	1215.5	1218.0	1219.4	1220.3	1210.4	1227.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.2	0.0
Alt 6A	1214.1	1215.5	1218.0	1219.4	1220.4	1210.5	1227.8
Change from Alt 1A	0.0	-0.1	0.0	0.0	0.1	-0.1	0.2
Springfield - XS 832.43							
Alt 1A	1206.9	1207.3	1207.8	1208.4	1208.8	1204.8	1214.8
Alt 2A	1206.9	1207.3	1207.8	1208.4	1208.9	1204.5	1214.8
Change from Alt 1A	0.0	0.0	0.0	0.0	0.1	-0.3	0.0
Alt 3A	1206.9	1207.3	1207.8	1208.4	1208.8	1204.3	1214.9
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.5	0.1
Alt 4A	1206.9	1207.3	1207.8	1208.4	1208.9	1204.5	1214.8
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.3	0.0
Alt 5A	1206.9	1207.3	1207.8	1208.4	1208.9	1204.5	1214.8
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.3	0.0
Alt 6A	1206.9	1207.3	1207.8	1208.4	1208.8	1204.6	1214.9
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.2	0.2
Lewis & Clark Lake - XS 812.74							
Alt 1A	1,206.5	1,206.7	1,207.0	1,207.6	1,207.8	1,199.4	1,212.7
Alt 2A	1,206.5	1,206.7	1,207.0	1,207.6	1,207.8	1,198.2	1,212.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-1.1	0.0
Alt 3A	1,206.5	1,206.7	1,207.0	1,207.6	1,207.8	1,198.5	1,212.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.9	0.0
Alt 4A	1,206.5	1,206.7	1,207.0	1,207.6	1,207.7	1,199.4	1,212.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 5A	1,206.5	1,206.7	1,207.0	1,207.6	1,207.8	1,197.2	1,212.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-2.2	0.0
Alt 6A	1,206.5	1,206.7	1,207.0	1,207.6	1,207.7	1,198.7	1,212.7
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	-0.7	0.0

Plate 2 cont'd: Alternative Water Surface Elevation Statistics from POR Duration

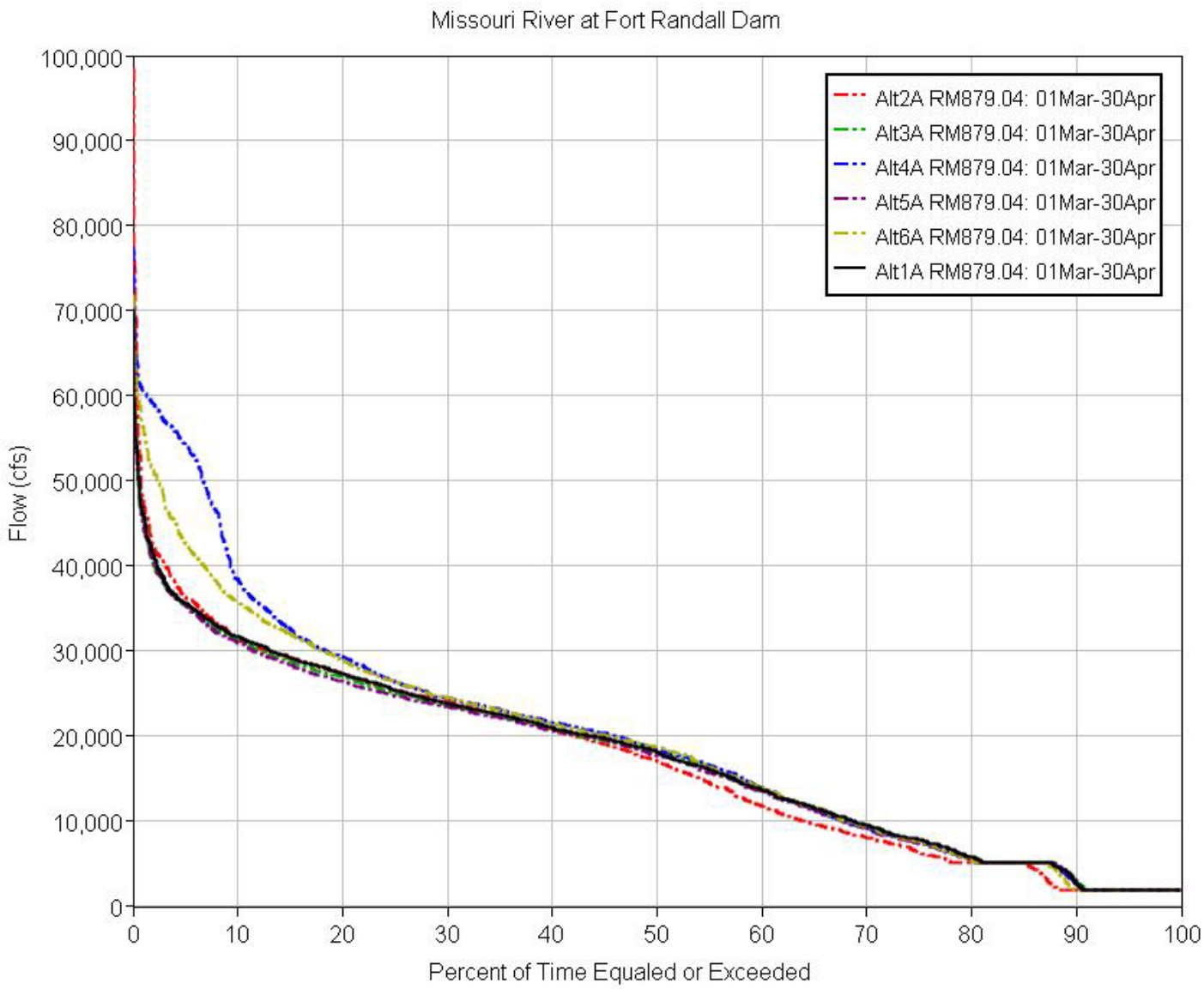


Plate 3: Fort Randall Spring Duration

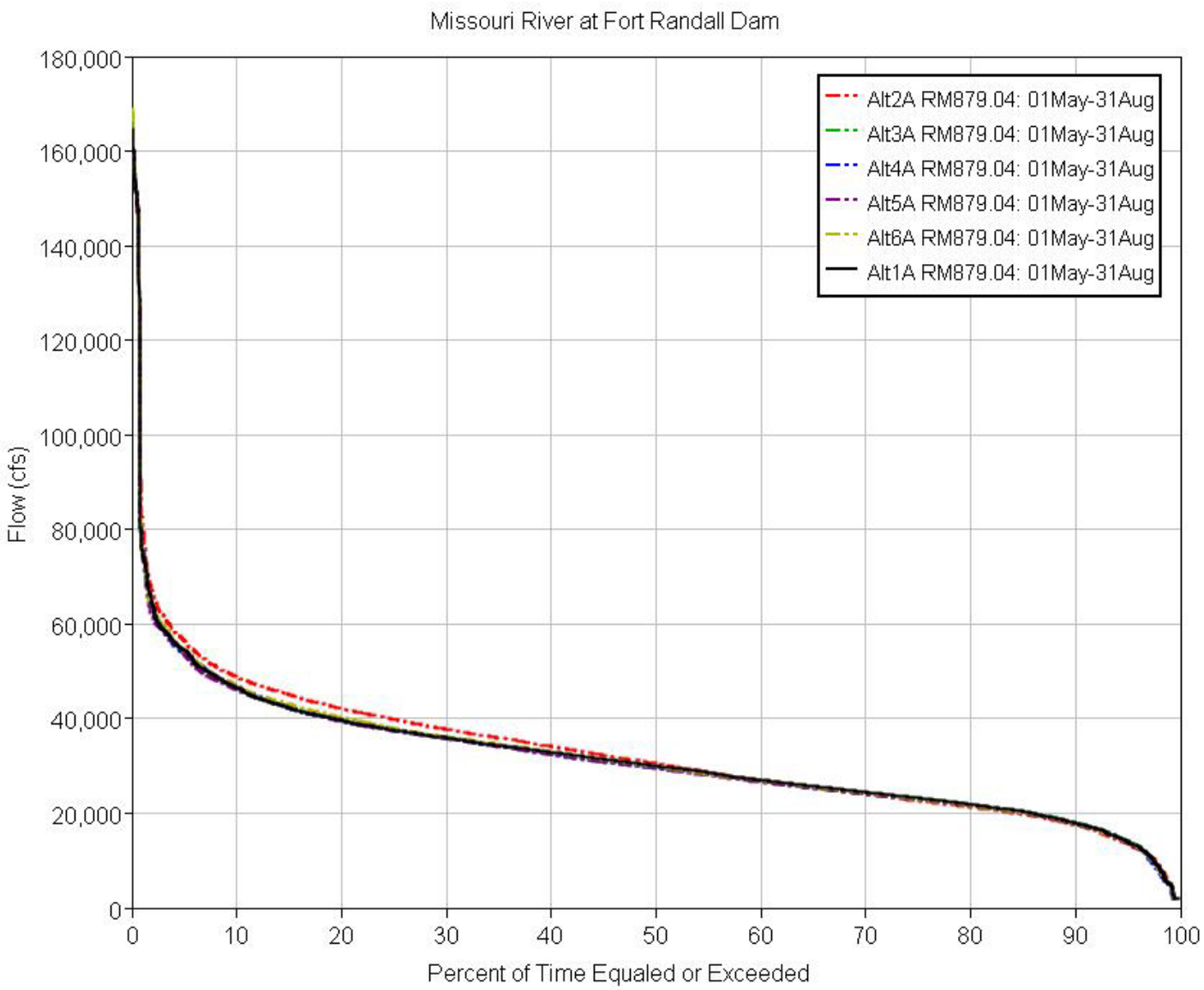


Plate 4: Fort Randall Summer Duration

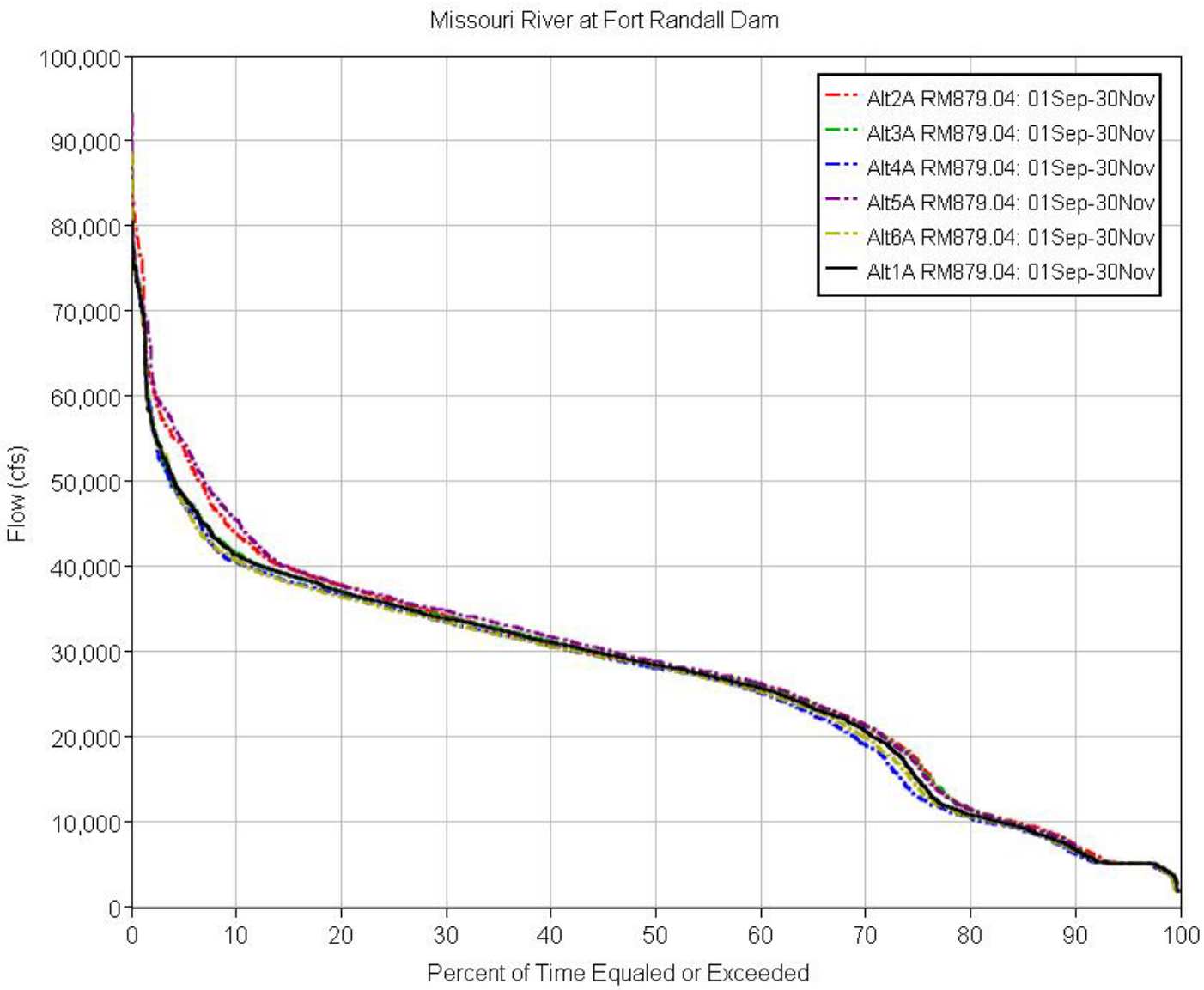


Plate 5: Fort Randall Fall Duration

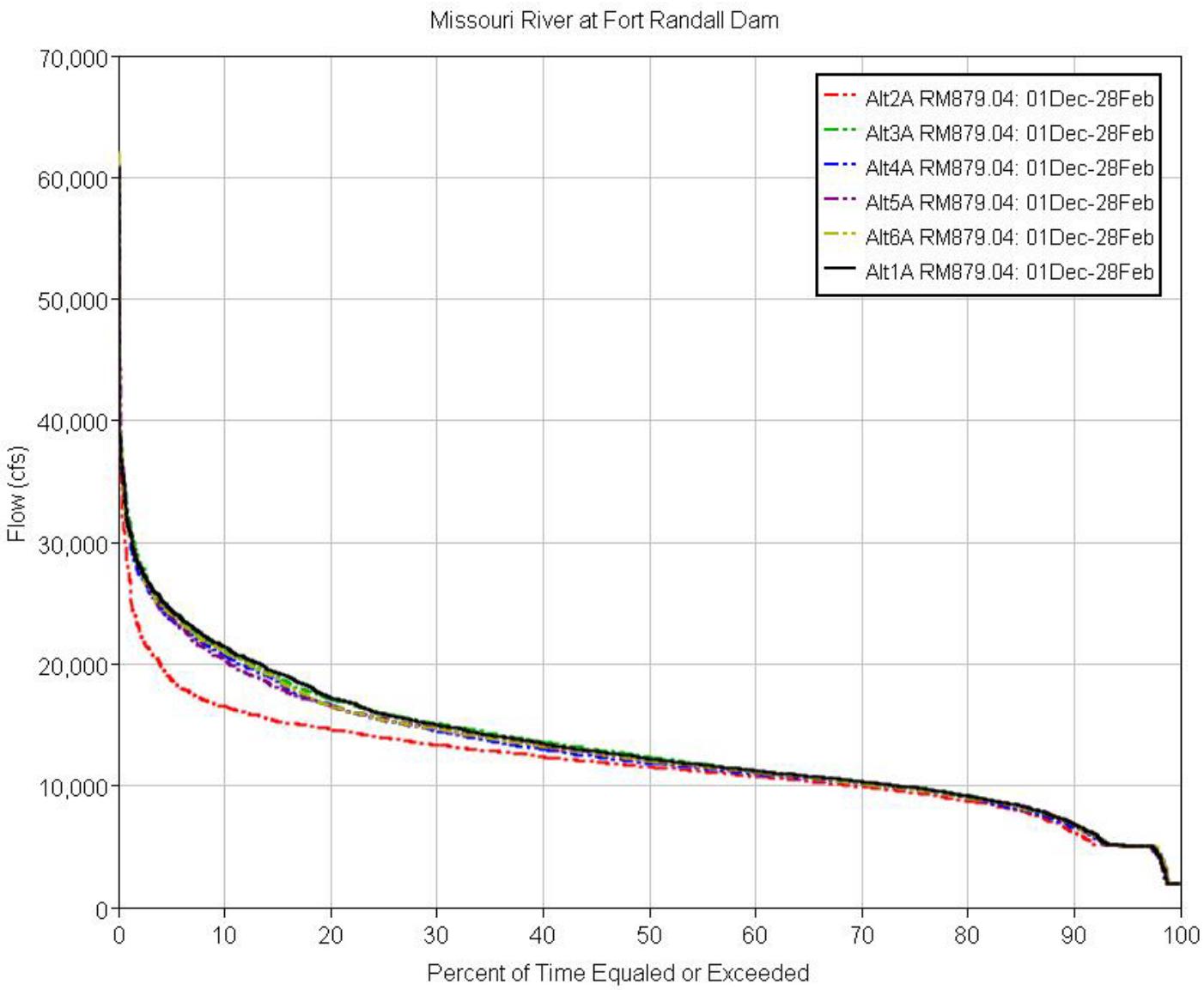
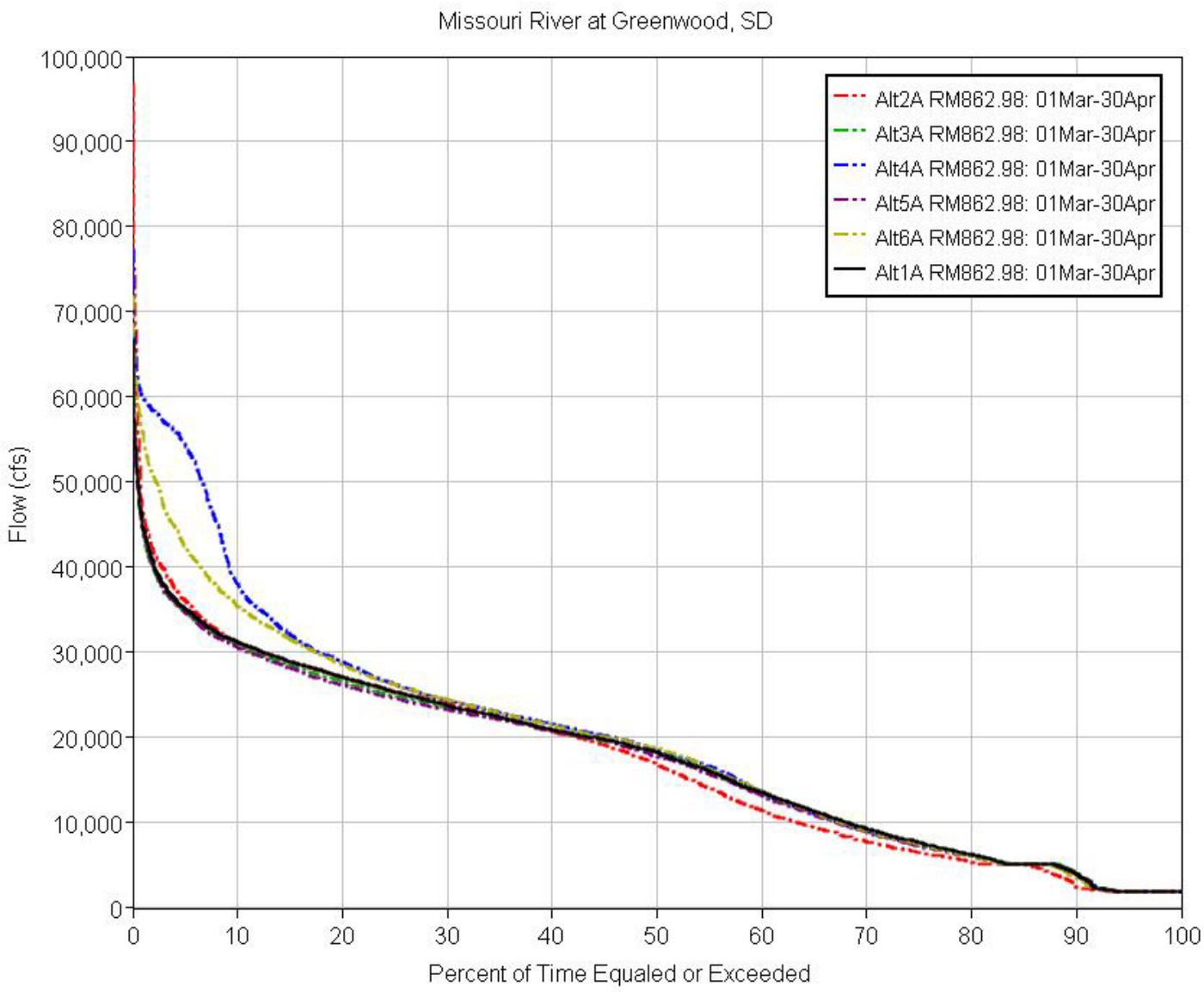


Plate 6: Fort Randall Winter Duration



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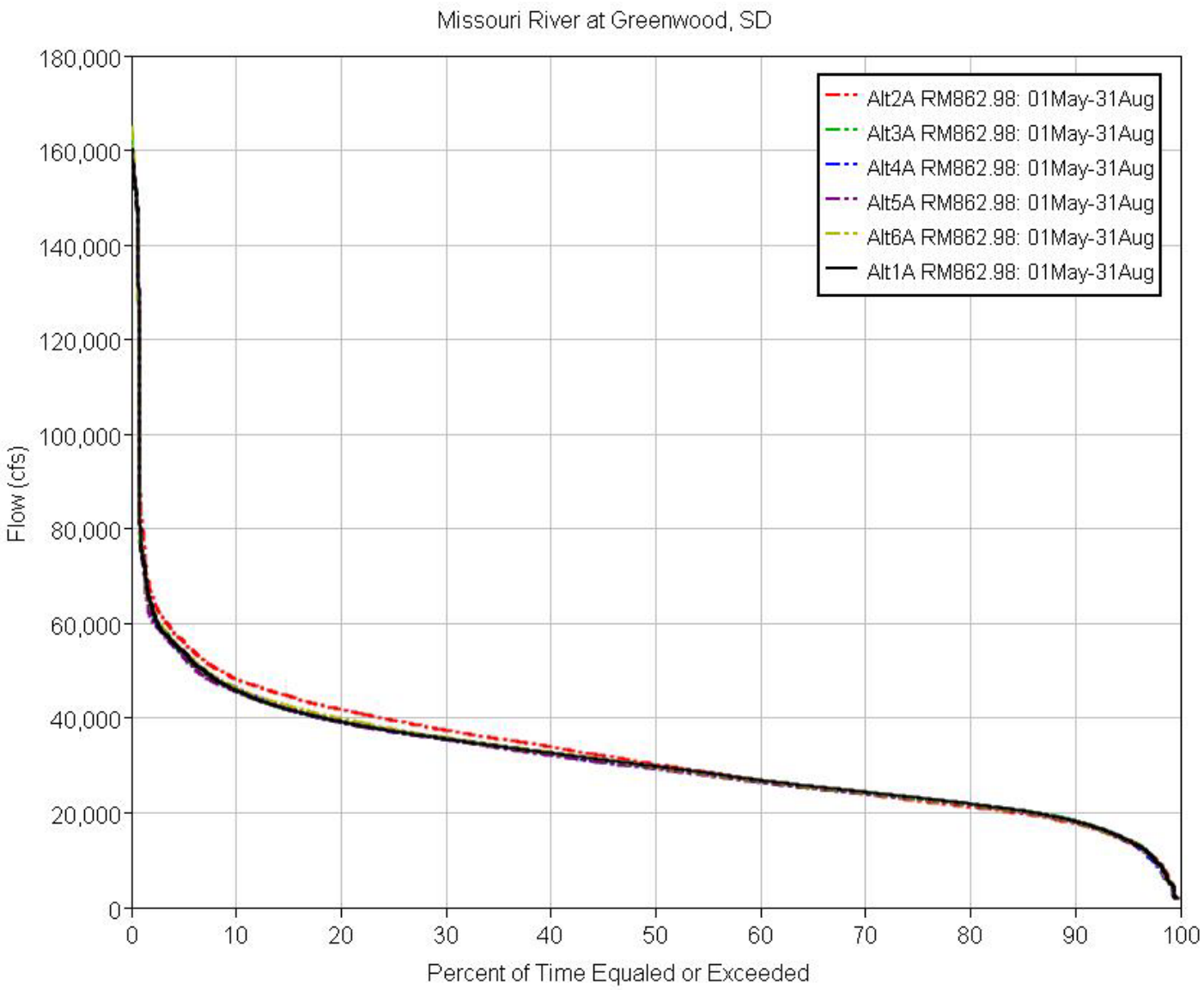

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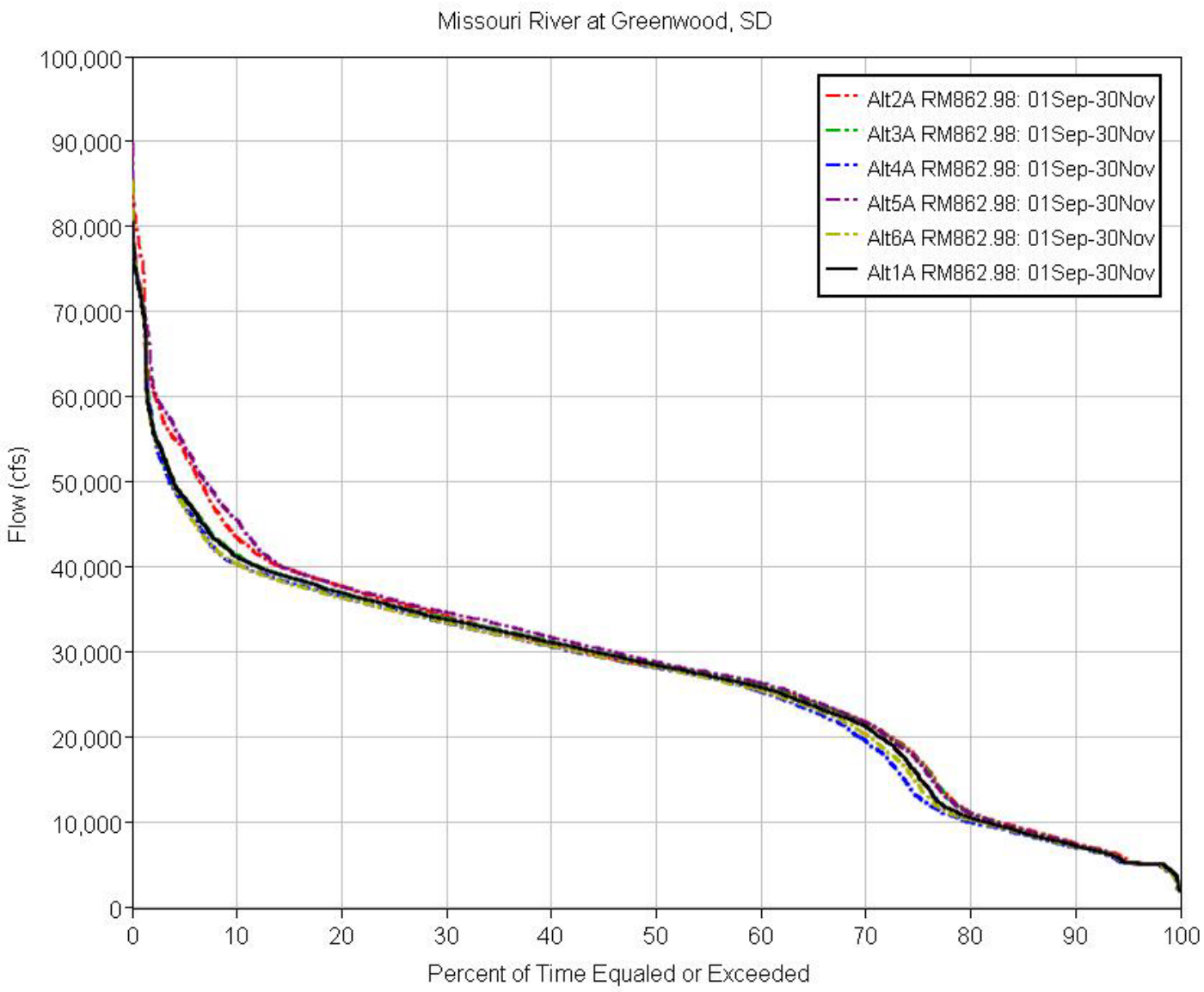


Plate 9: Greenwood Fall Duration

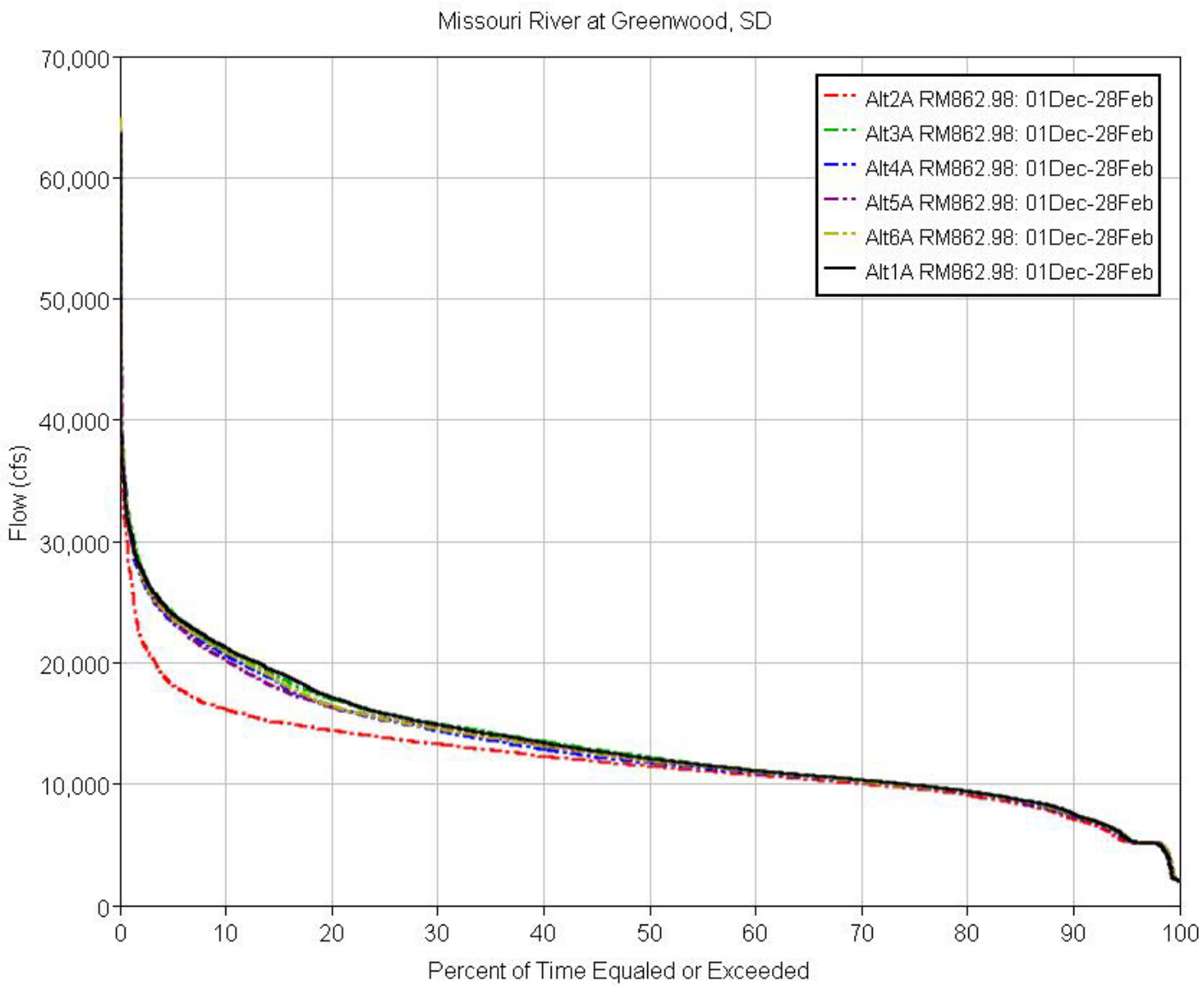


Plate 10: Greenwood Winter Duration

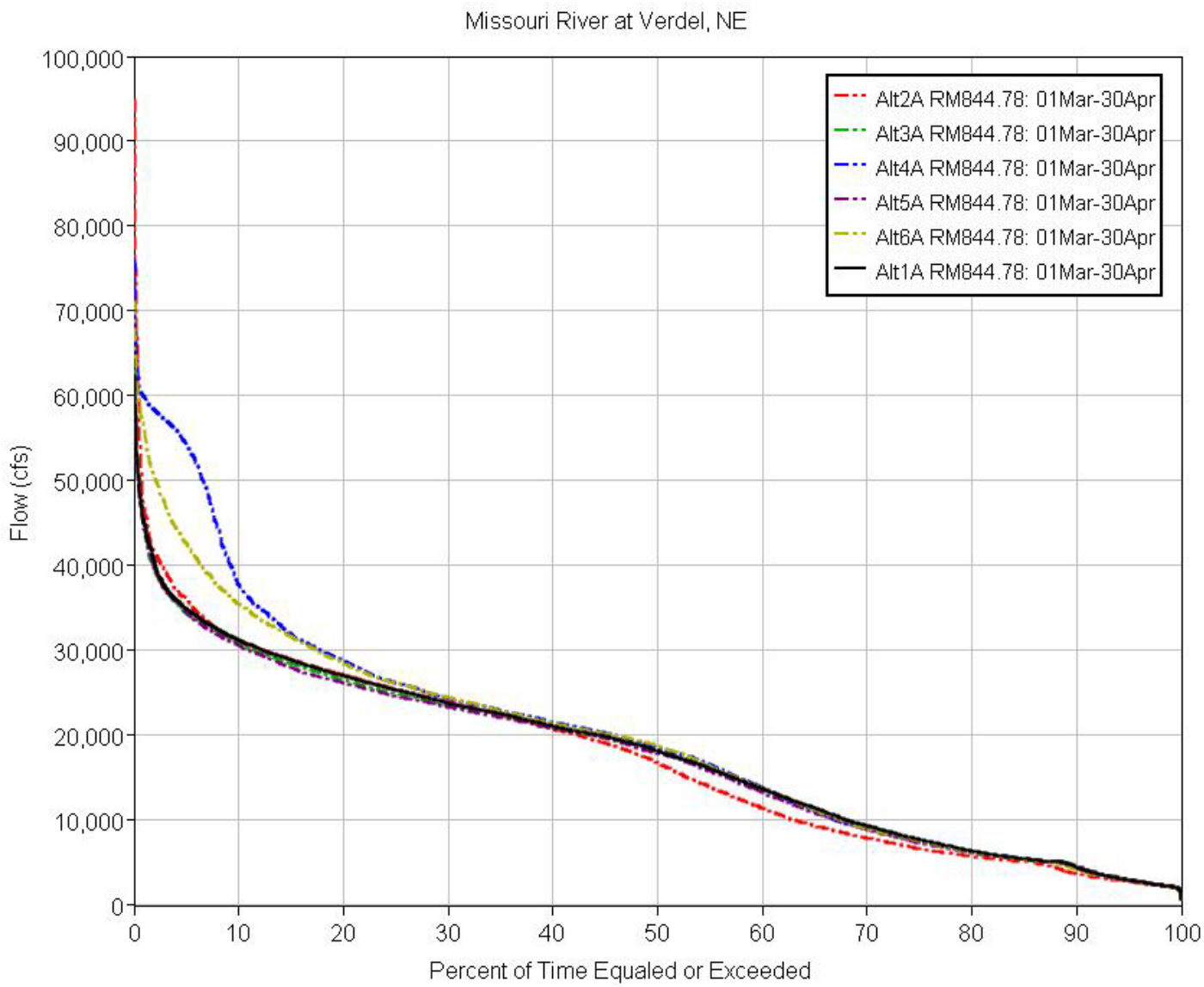
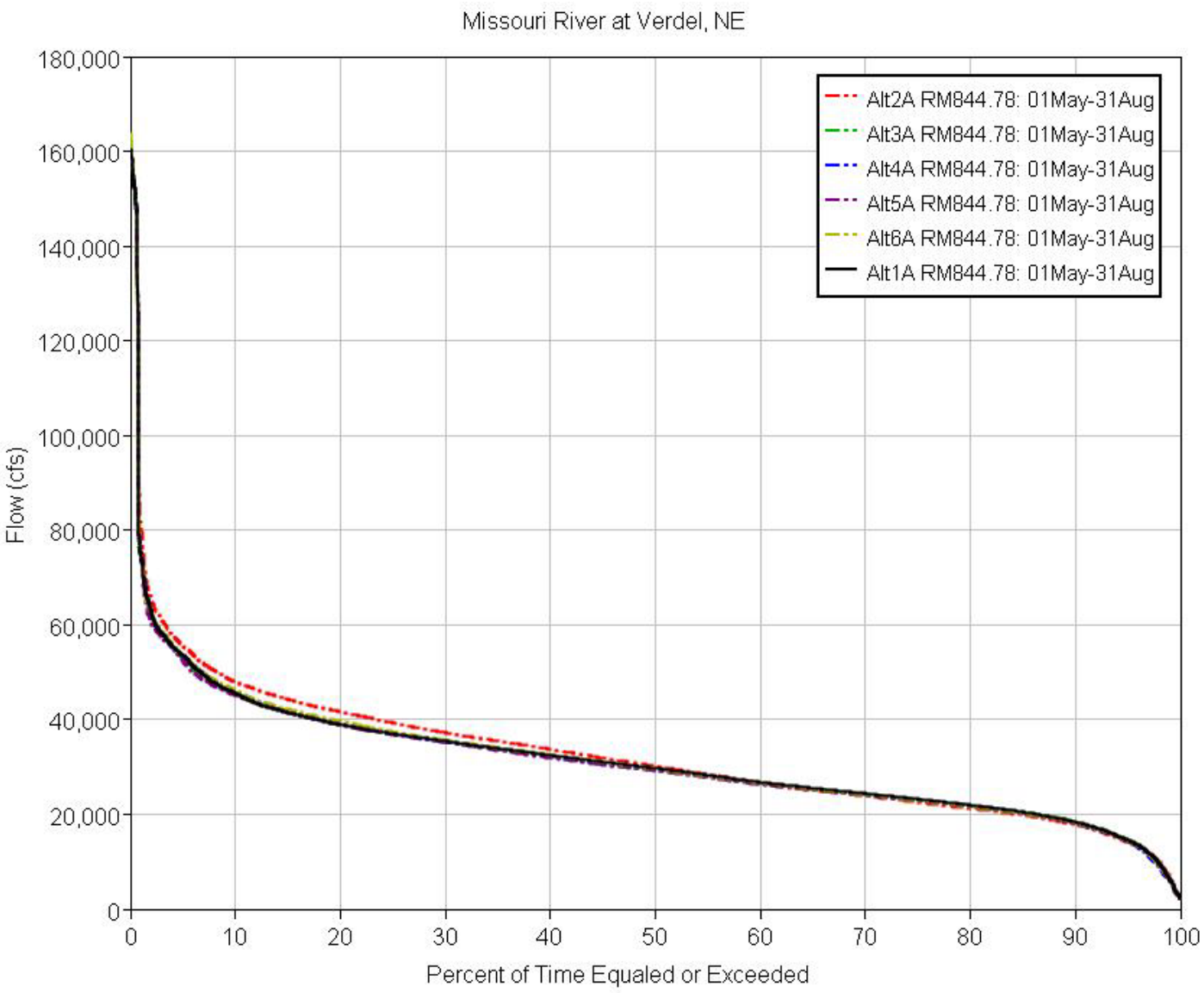


Plate 11: Verdel Spring Duration



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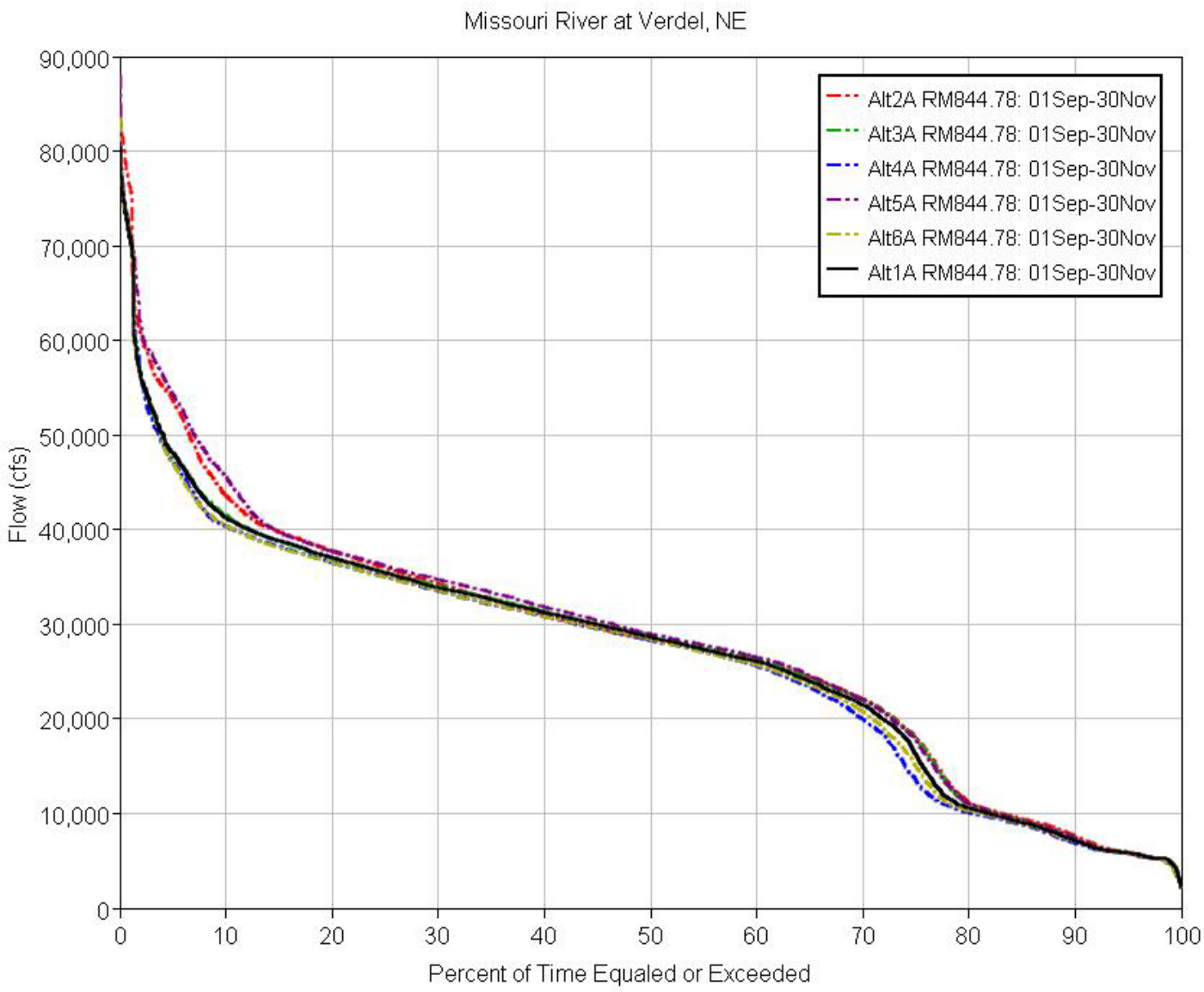

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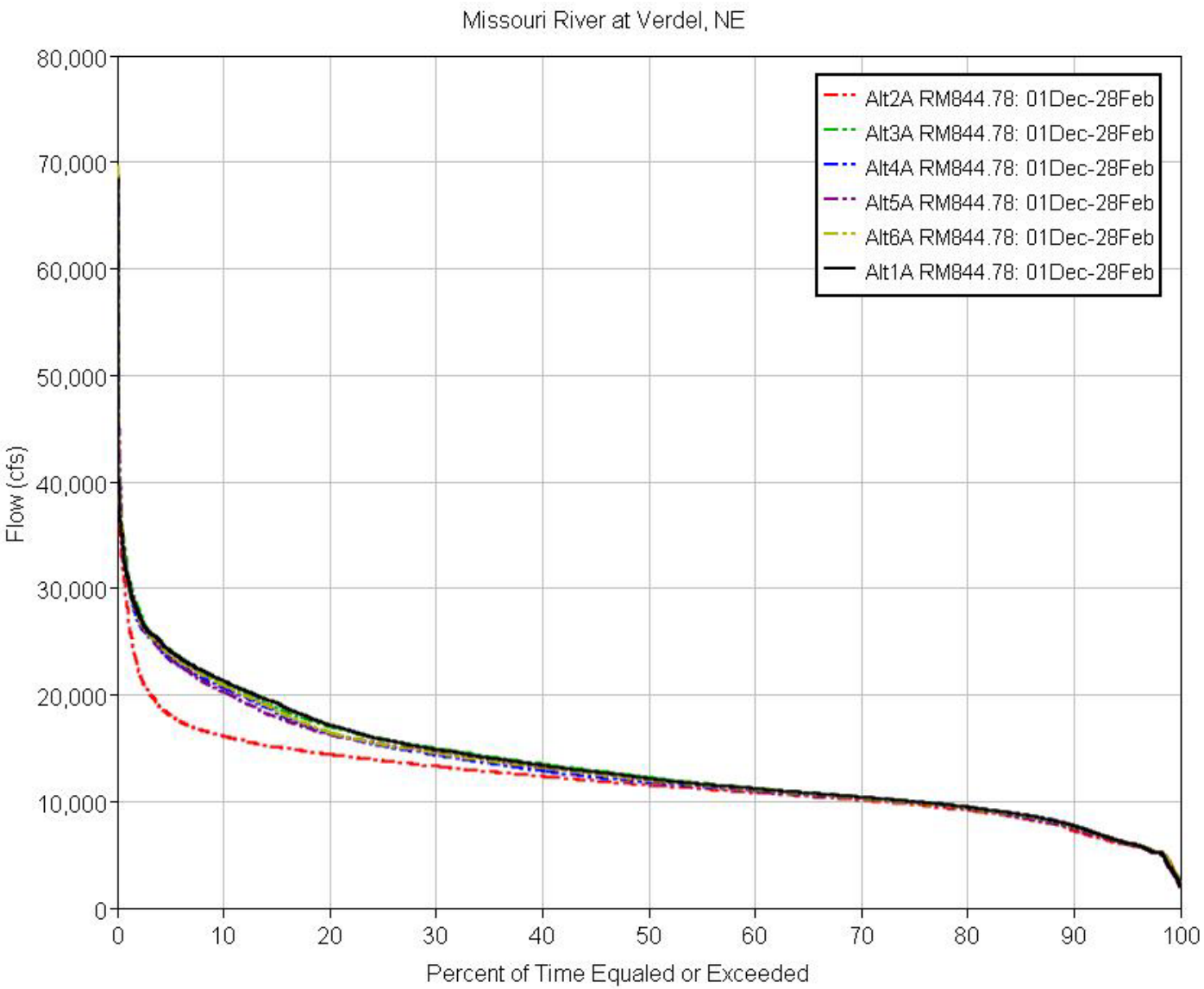

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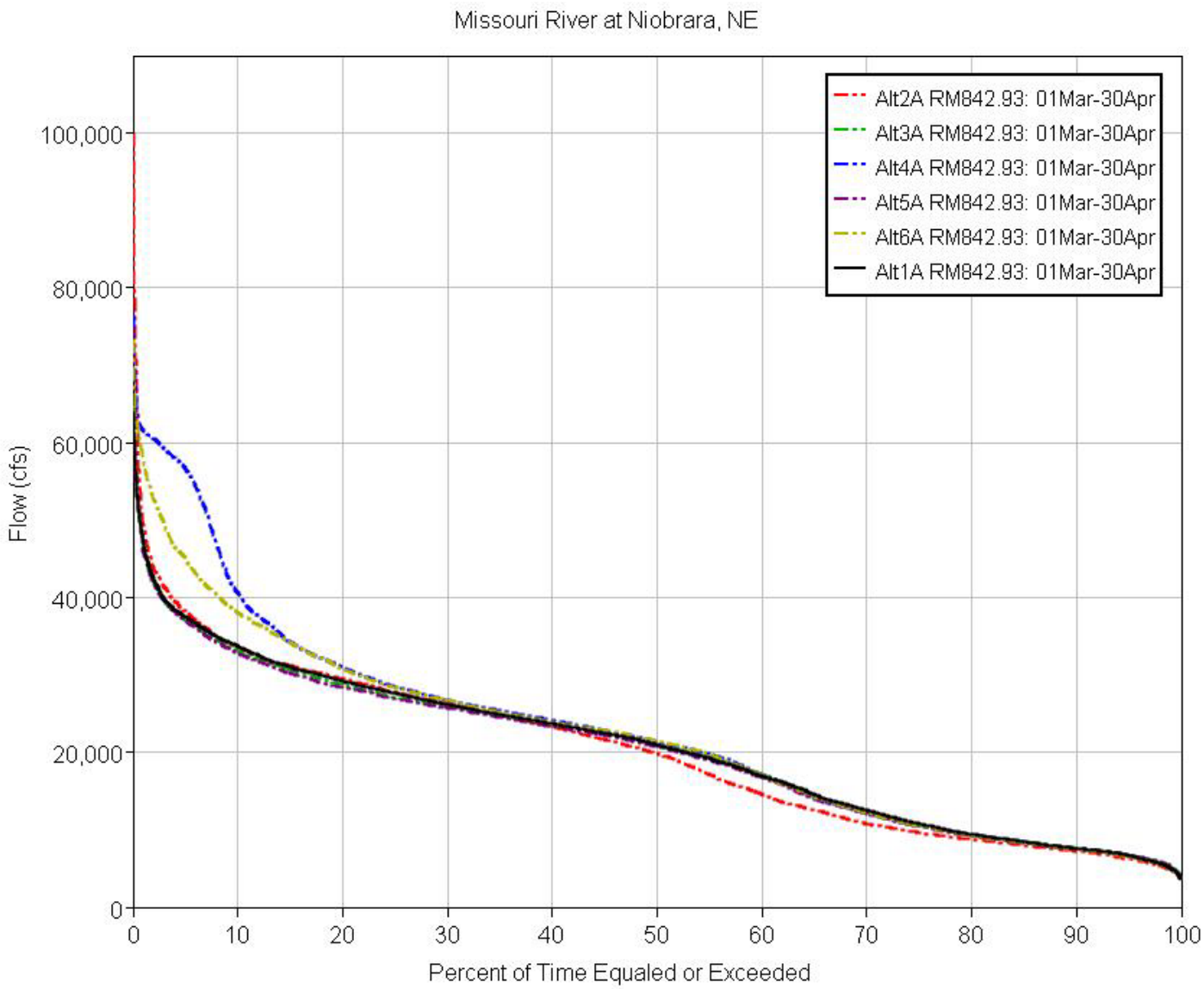


Plate 15: Niobrara Spring Duration

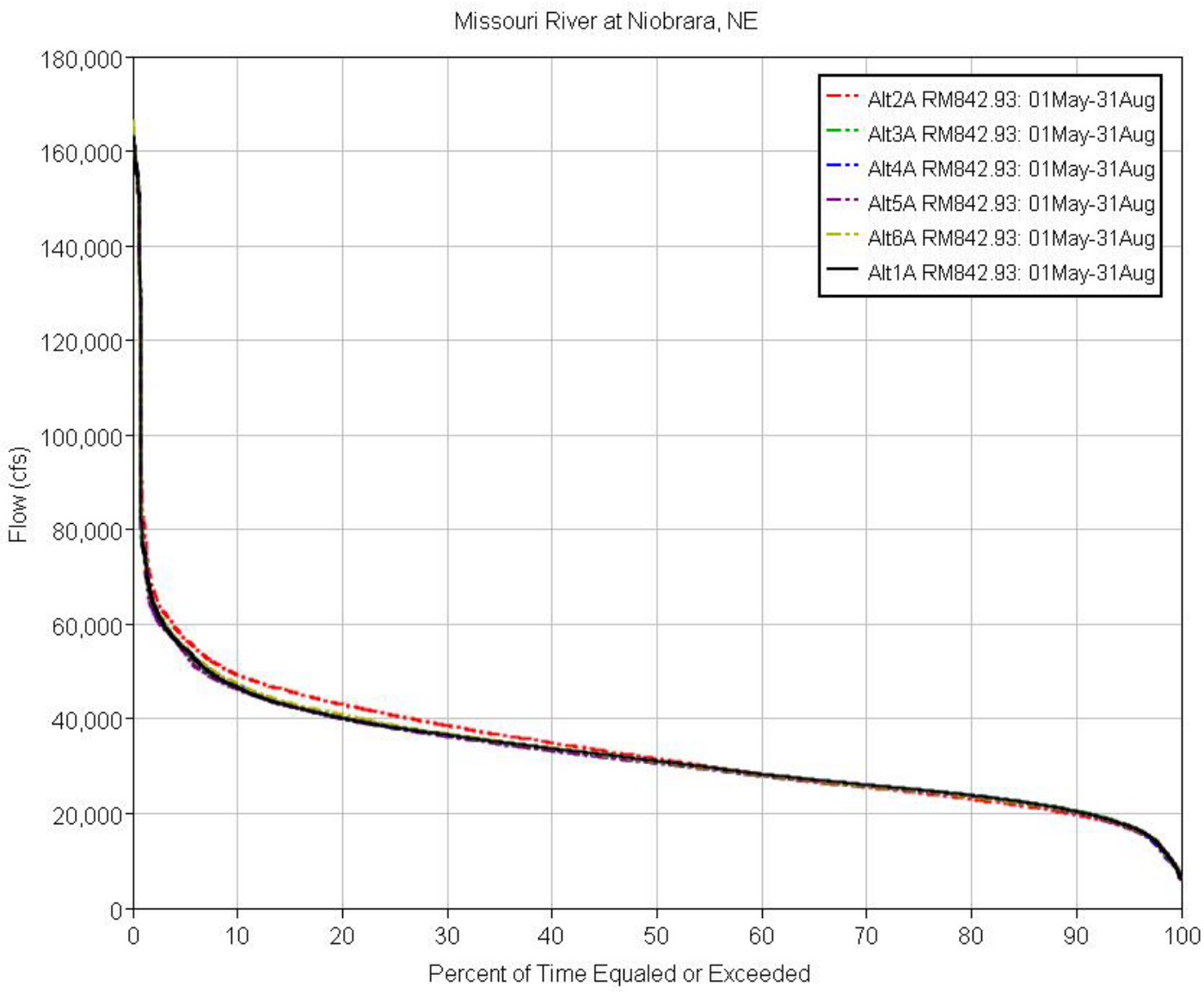


Plate 16: Niobrara Summer Duration

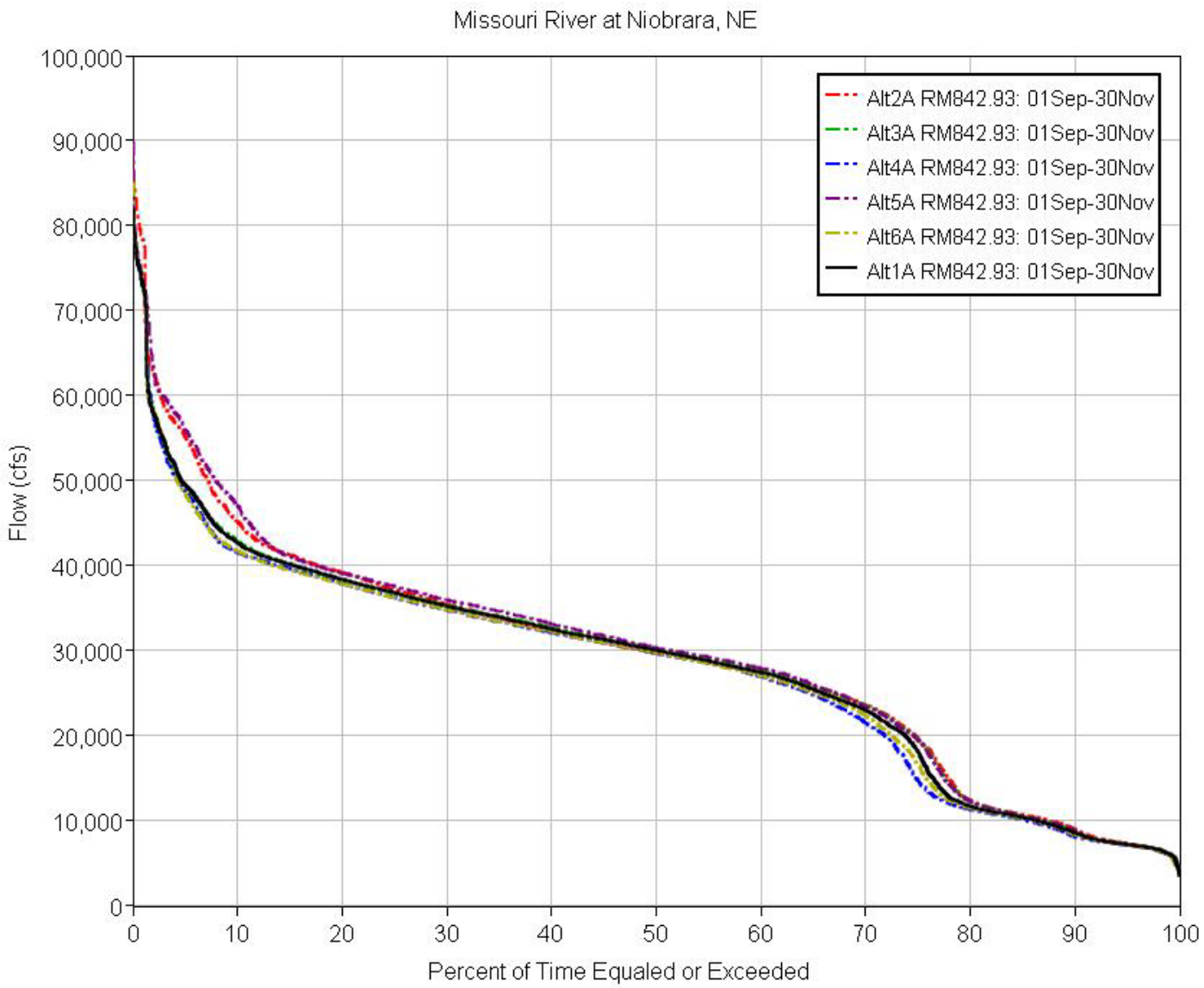


Plate 17: Niobrara Fall Duration

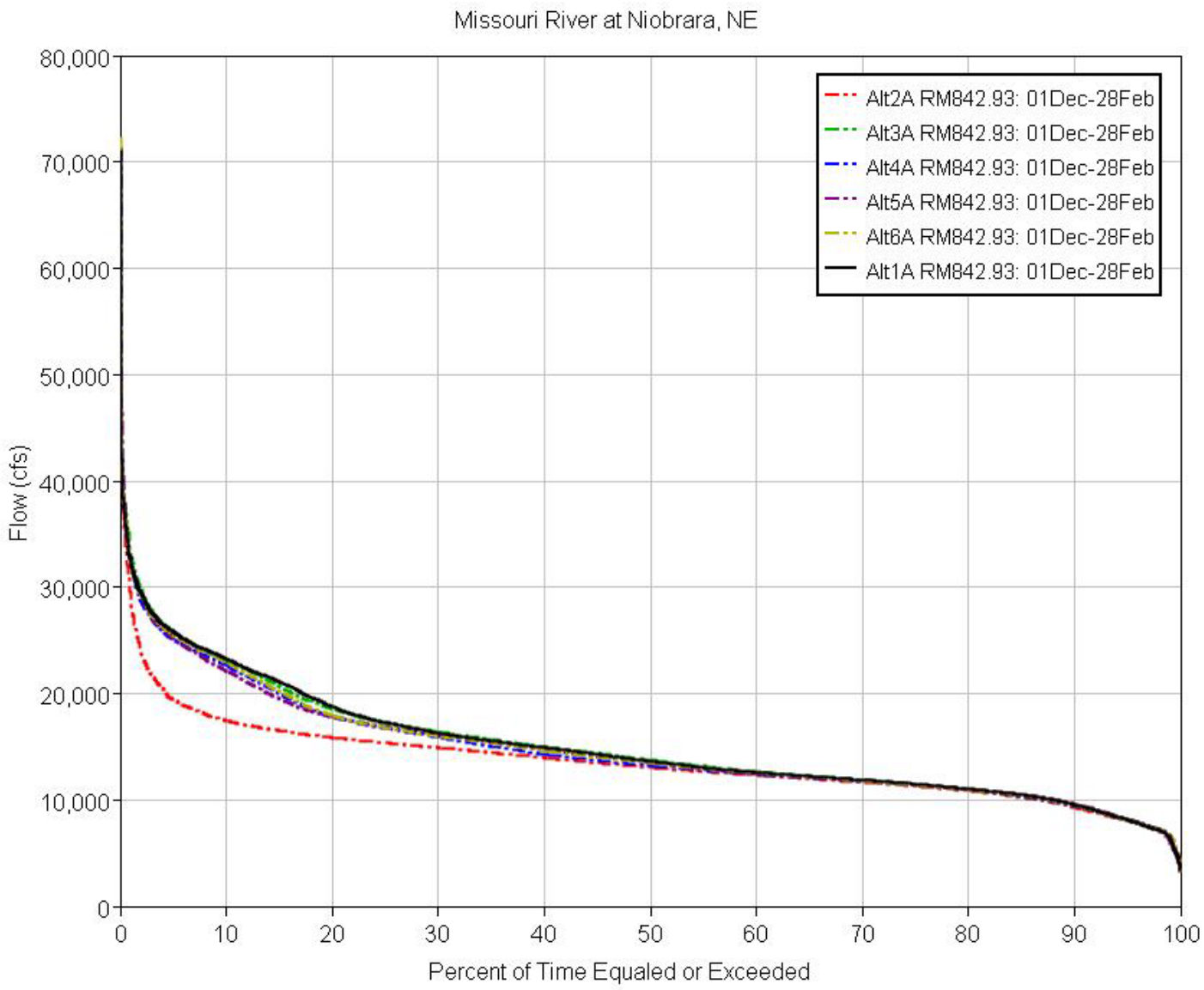


Plate 18: Niobrara Winter Duration

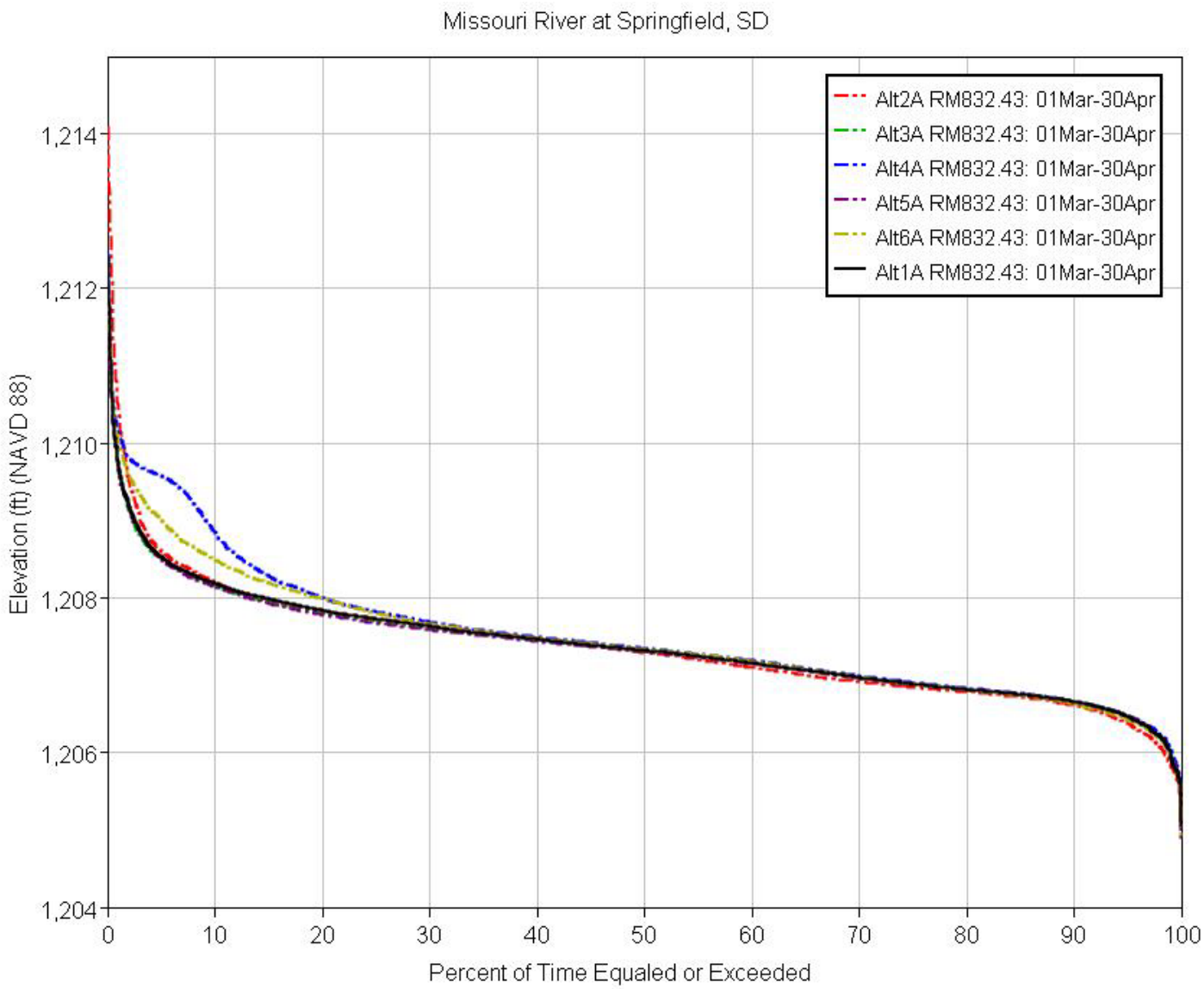


Plate 19: Springfield Spring Duration

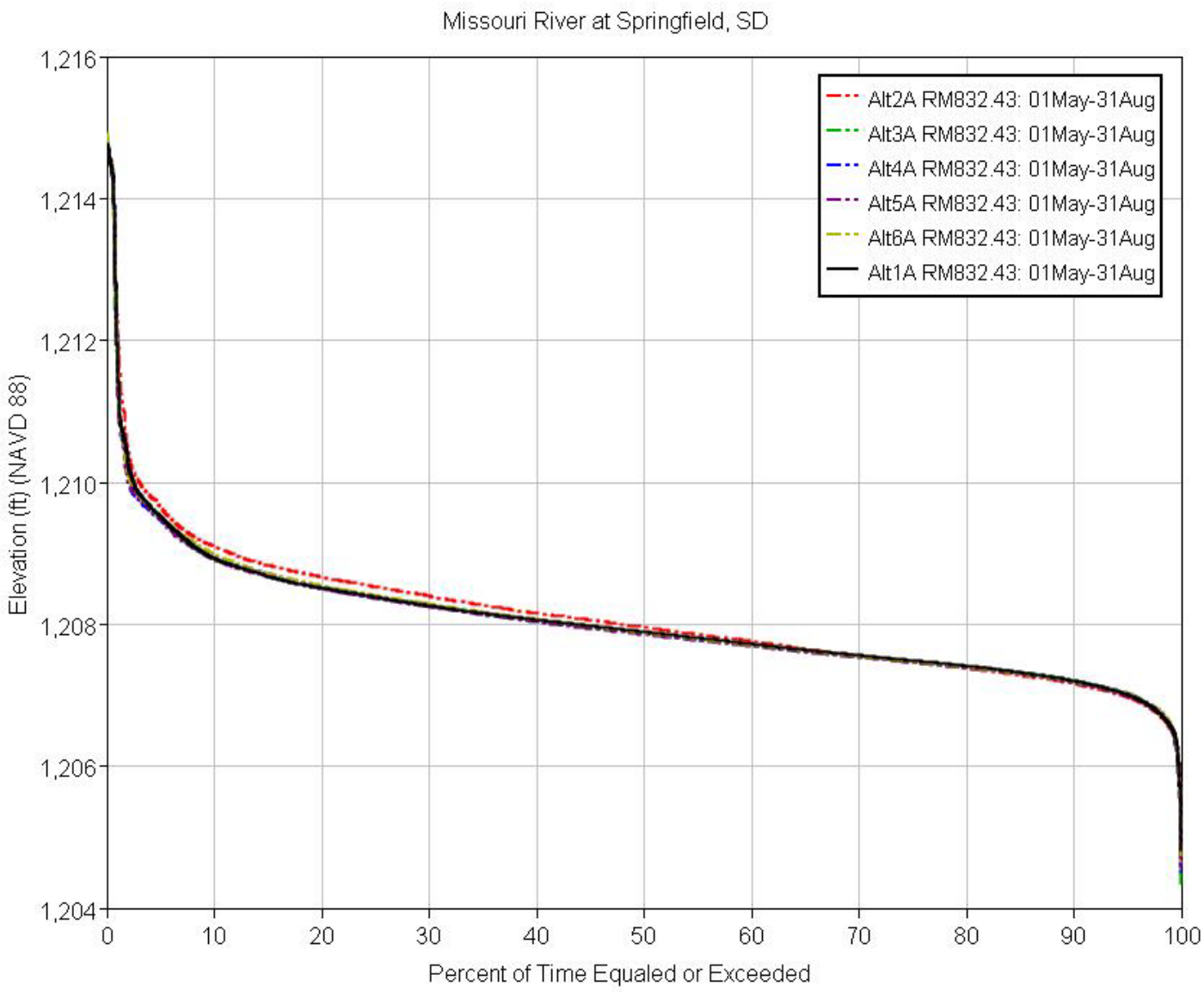


Plate 20: Springfield Summer Duration

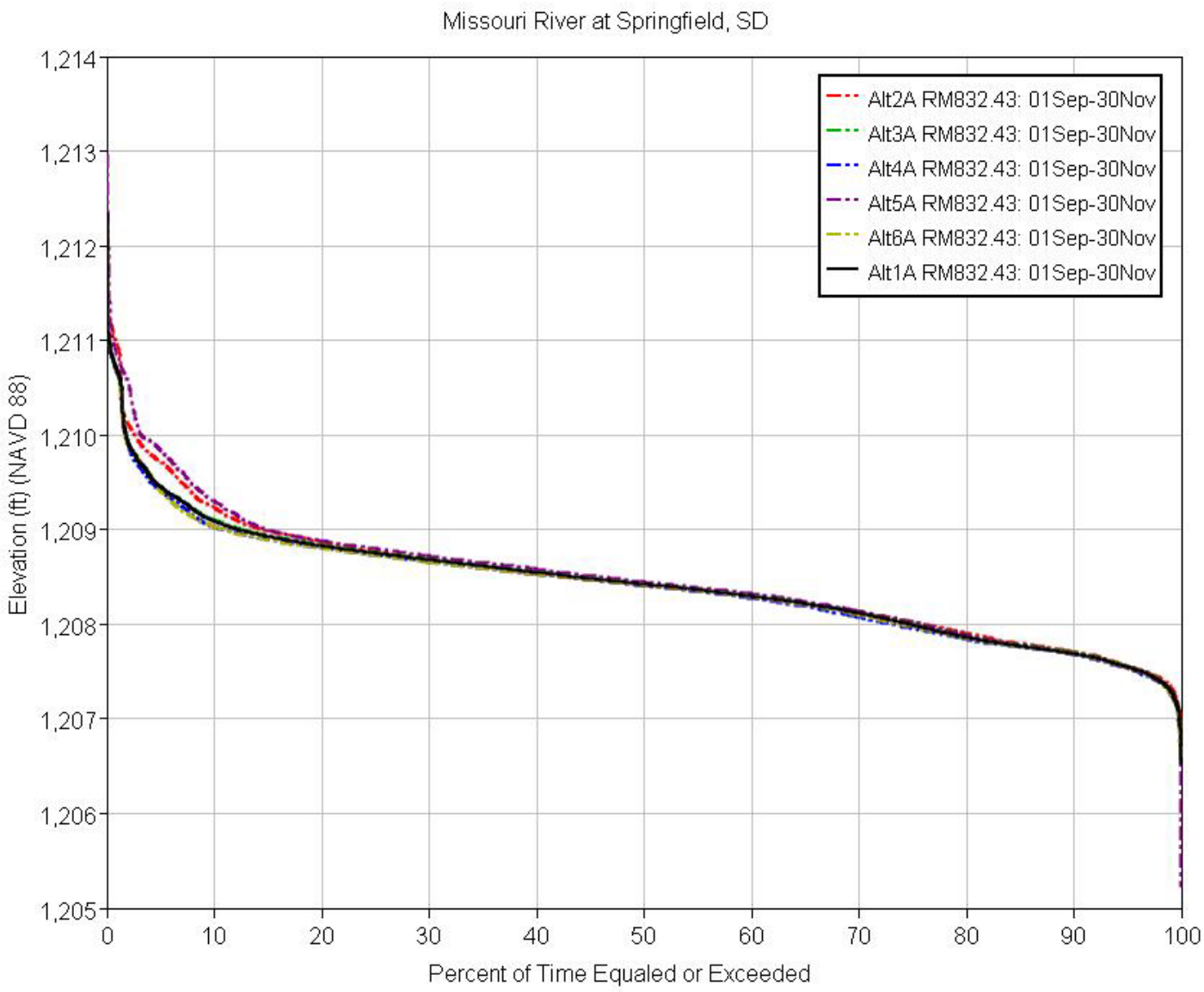


Plate 21: Springfield Fall Duration

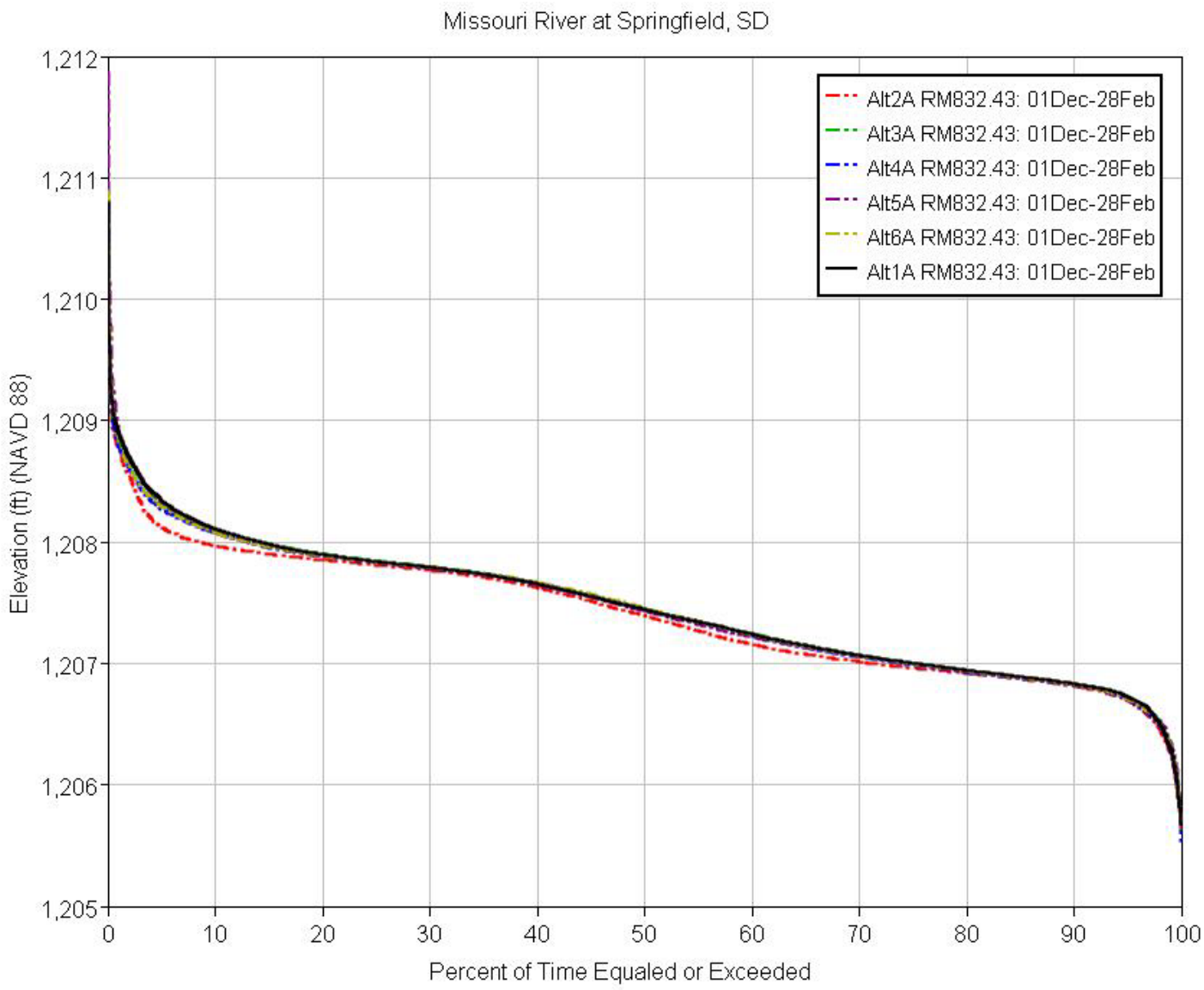


Plate 22: Springfield Winter Duration

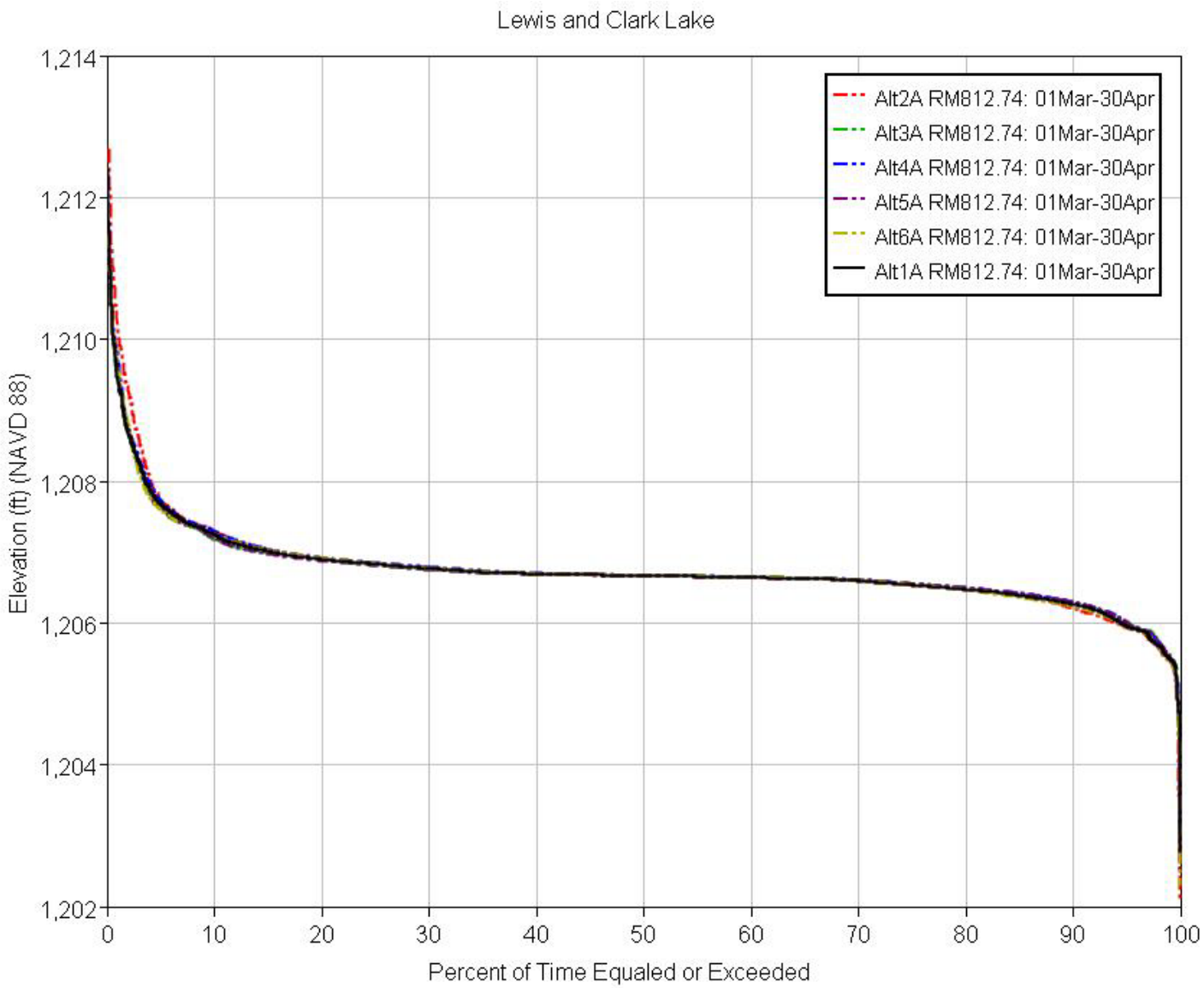


Plate 23: Lewis and Clark Lake Spring Duration

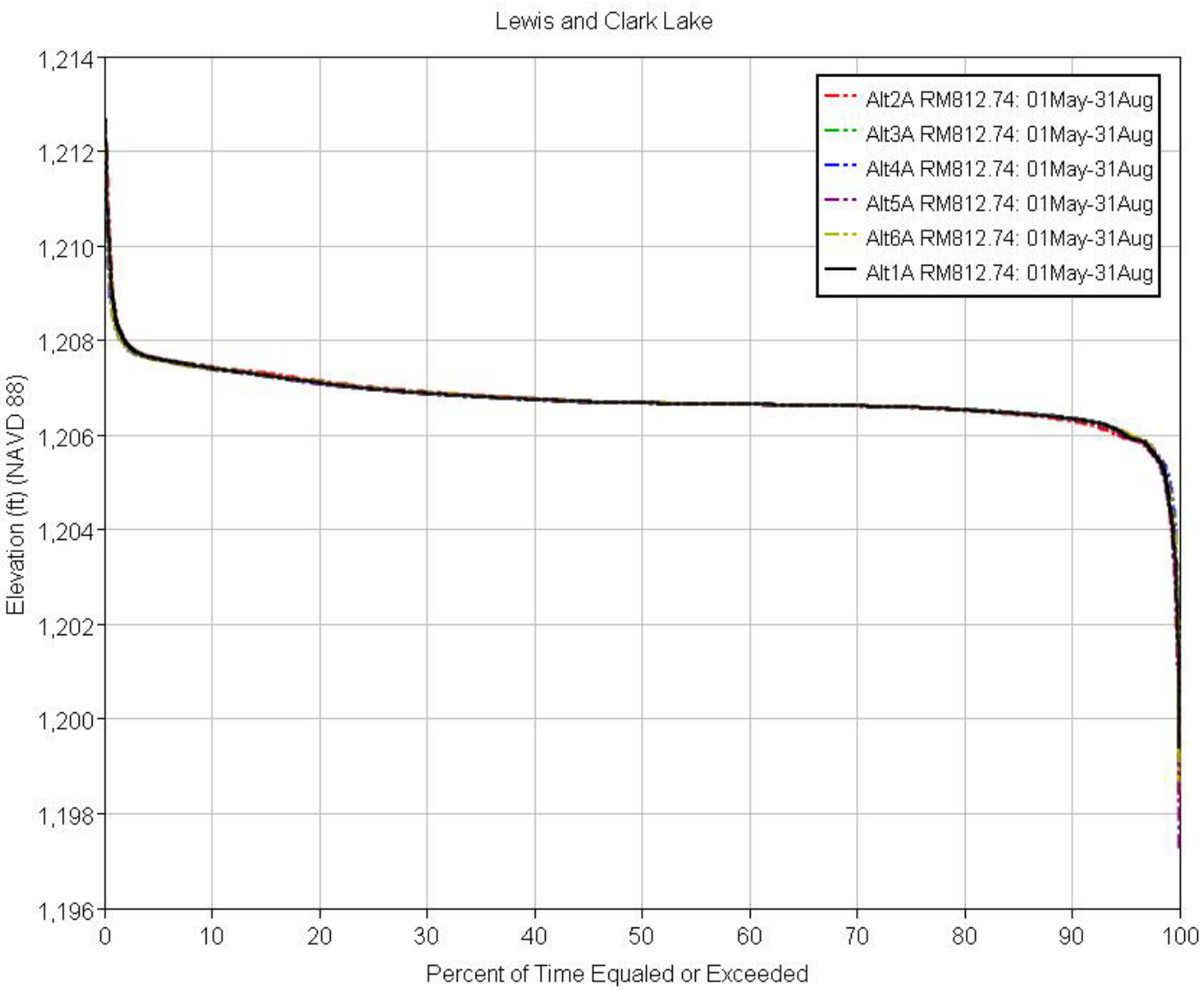


Plate 24: Lewis and Clark Lake Summer Duration

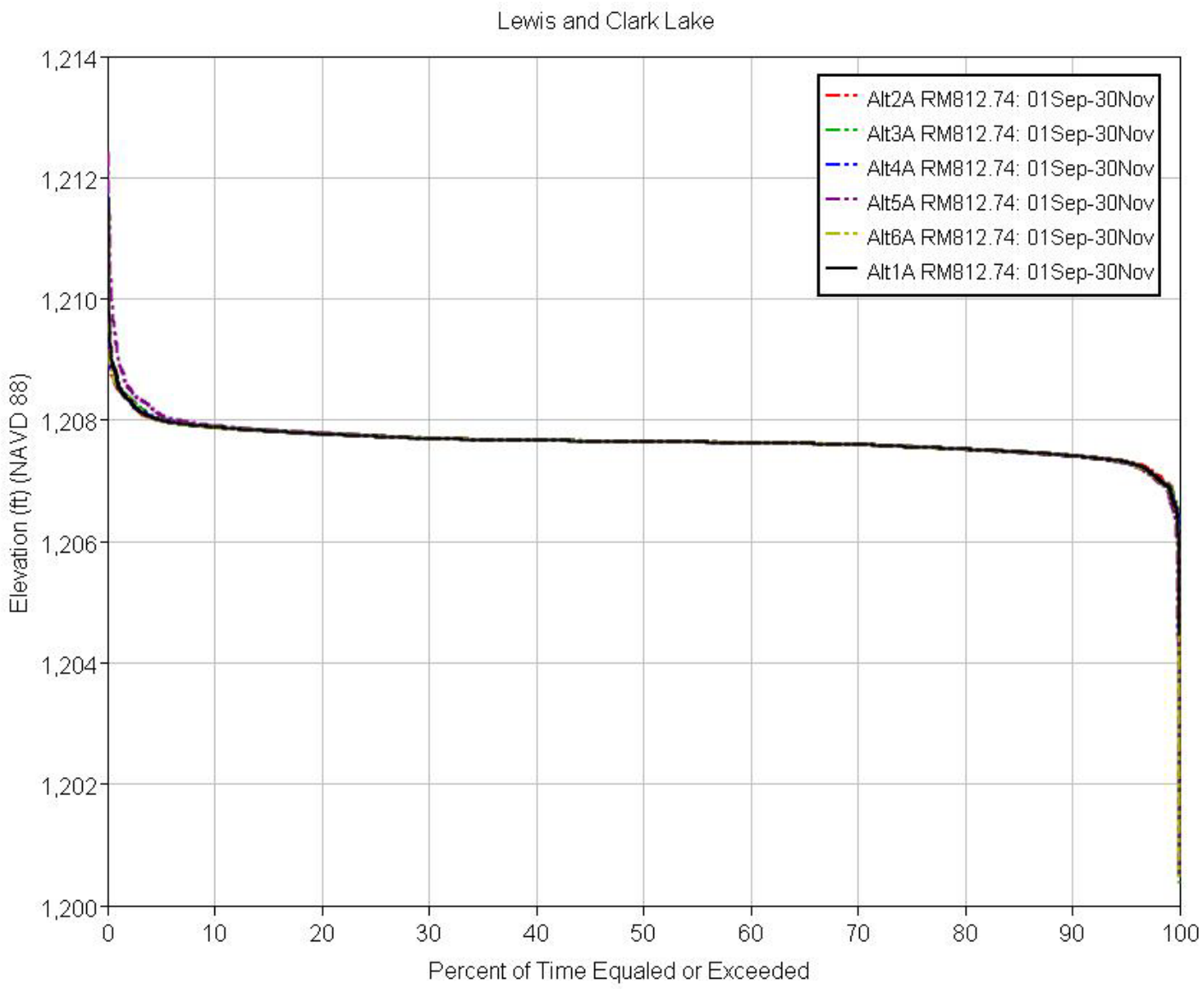


Plate 25: Lewis and Clark Lake Fall Duration

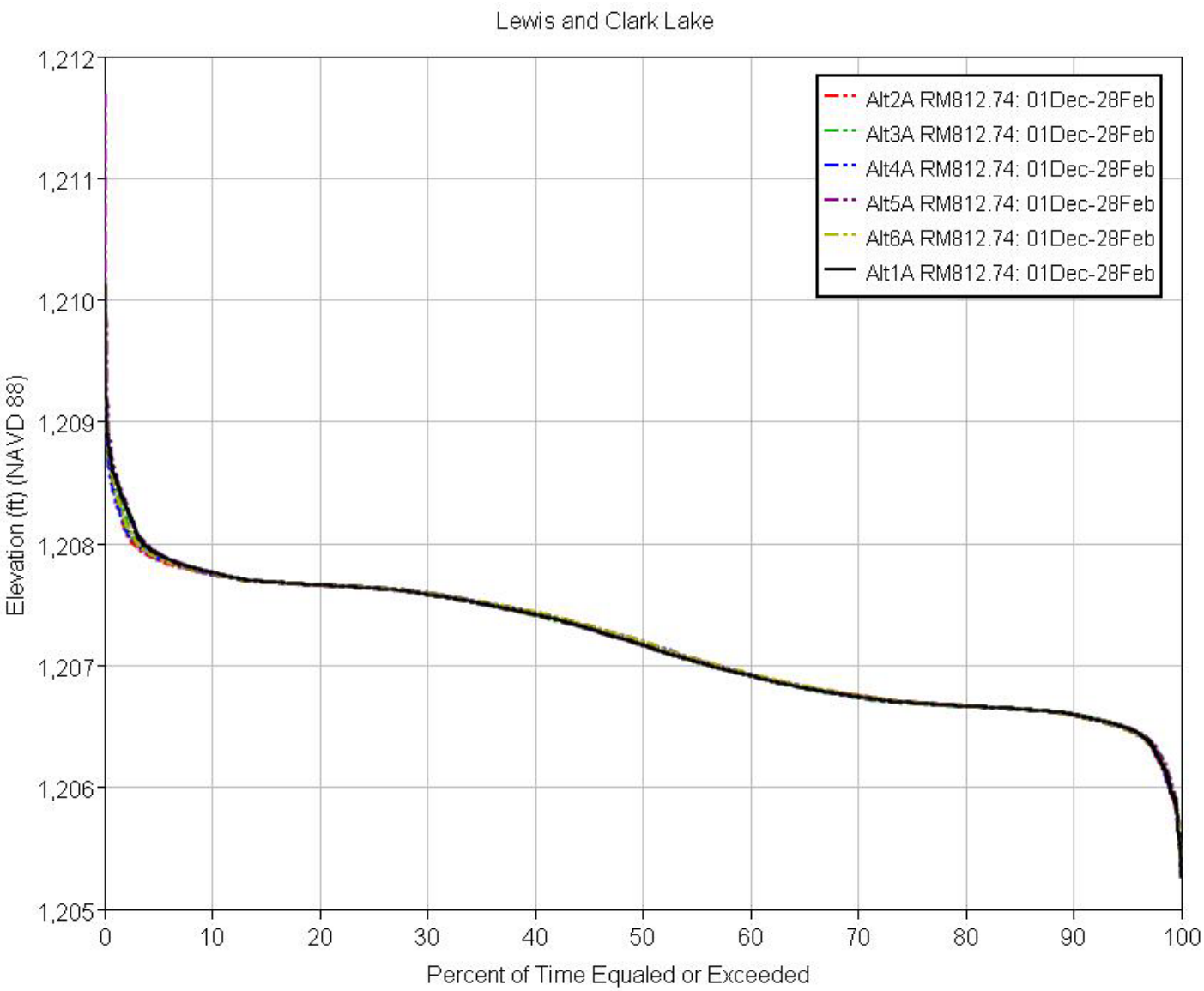


Plate 26: Lewis and Clark Lake Winter Duration

US Army Corps of Engineers ®

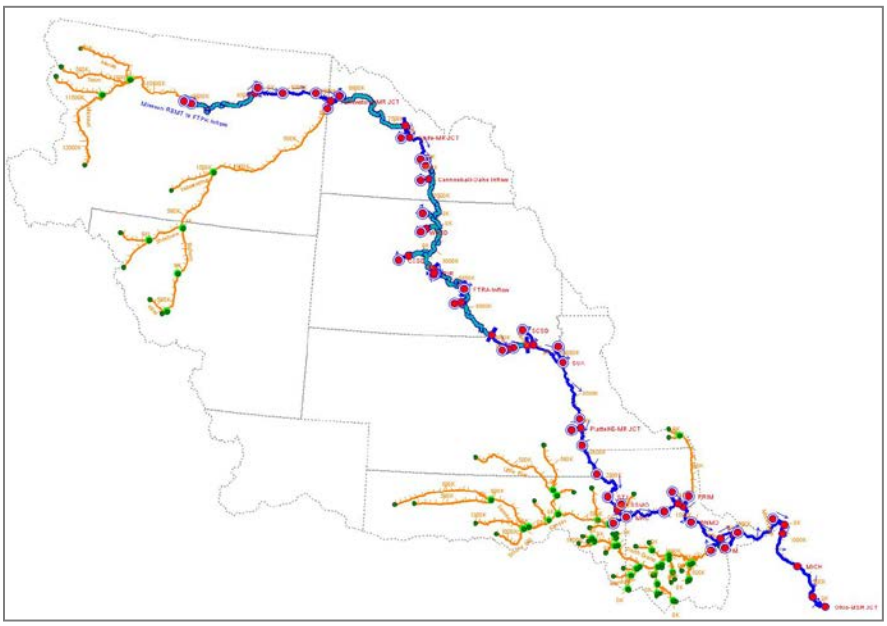
Omaha District

Missouri River Unsteady HEC-RAS Model
Alternatives Analysis

DRAFT

Appendix D

Gavins Point Dam to Rulo, NE



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ACRONYMS

BiOp……..Biological Opinion

CFS…… Cubic Feet per Second

ESH……..Emergent Sandbar Habitat

HC……..Human Considerations

HEC ..... Hydrologic Engineering Center

IRC……Interception-Rearing Complexes

MAF…….. Million acre-feet

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

NAD 1983…… ... North American Datum of 1983

NAVD 88…… . North American Vertical Datum of 1988

NGVD 29…… National Geodetic Vertical Datum of 1929

NLD……...National Levee Database

NWK…….. Northwest Division Kansas City District

NWO…… Northwest Division Omaha District

POR..... Period of Record

RAS ..... HEC River Analysis System Software (HEC-RAS)

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

RM……1960 River Mile

ROD……..Record of Decision

SWH…….....Shallow Water Habitat

USACE……United States Army Corps of Engineers

USFWS……United States Fish and Wildlife Service

USGS ..... United States Geological Survey

1 INTRODUCTION

The Missouri River unsteady HEC-RAS (RAS) model was developed for the Missouri River Recovery Program Management Plan and Integrated Environmental Impact Statement (MRRPMP-EIS) to assist in the assessment of a suite of actions to meet Endangered Species Act (ESA) responsibilities for the piping plover, the interior least tern, and the pallid sturgeon using USACE authorities. The objective of the HEC-RAS modeling is to simulate the Management Plan alternatives which include both geometry and flow changes relative to the No Action alternative. The Human Considerations (HC) team performed an extensive analysis on each of the alternatives for each of the resources (hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply) and provide a detailed comparison of results. For this report, only the hydraulic model output is presented; there is no alternative selection or discussion. This Appendix is for the Gavins Point Dam to Rulo, NE, reach of the Missouri River as part of the Omaha District. The Omaha District and the Kansas City District models include an overlap reach at the Rulo, NE, the district boundary. This report will focus only on the Omaha District portion of the model. Refer to Kansas City District's report (Appendix E) for details regarding the downstream model from Rulo, NE to St. Louis, MO.

Six alternatives, including the No Action alternative, were simulated in HEC-RAS from March 1930 to December 2012, however the HC team only used complete year data for their analysis from January 1, 1931 to December 31, 2012. Development of inflow records at current depletion levels to use as boundary conditions for the HEC-ResSim and HEC-RAS models is documented in the report, *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (USACE 2016d). Each alternative has unique flow releases from the reservoirs, as simulated by the Res-Sim models. Three HEC-RAS geometries were developed, representing three proposed habitat construction configurations on the river.

2 GEOMETRY

Model geometry development and calibration for the existing conditions is documented in *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix D Gavins Point Dam to Rulo, NE* (USACE 2015a). The alternative geometries contain all of the major features from the calibration models including: levee and ineffective points, roughness values, and lateral structures representing levee systems.

Three geometries were created for the alternatives analysis. Modifications generally included the addition of shallow water habitat (SWH) in the form of river widening at a specified reference flows. Modifications to previously constructed habitat were also included in the geometries while backwaters were not and are only accounted for in the acreage goals. The configurations modeled included:

1. **No Action -** Assumes habitat construction activities follow current practices to achieve 20 acres/mile of SWH, the minimum target specified in the 2003 Amendment to the 2000 Biological Opinion.

2. **Biological Opinion as Projected (BiOp) -** Guidance from the U.S. Fish & Wildlife (USFWS) was provided to create a geometry which represents an ideal implementation of the 2003 Biological Opinion (2003 BiOp) (USFWS 2003). It assumes habitat construction accomplishes 30 acres/mile of SWH, and performs at a wider range of flows including a summer low, median August, and spring pulse. Floodplain connectivity was evaluated, but the requirement was met so no changes to the HEC-RAS geometry were necessary.
3. **Interception-Rearing Complexes (IRC) -** SWH construction activities proceed based on findings made by the Effects Analysis team. It assumes habitat construction accomplishes 260 acres/year based on current annual habitat construction rates.

SWH was only added to the Gavins to Rulo (Omaha District) and Rulo to the Mouth (Kansas City District) models. All other HEC-RAS models upstream of Gavins Point Dam do not have SWH geometry changes.

Table 2-1: Geometry Summary

Geometry	Target SWH	Reference Flow (cfs)
No Action	20 acre/mile	August 50% exceedance
BiOp	30 acre/mile + floodplain connectivity	Summer low, Median August, & Spring Pulse
IRC	260 acre/year	Median June

2.1 Changes to Existing (2012) Model

For the Gavins to Rulo reach model, several geometries were constructed in order to obtain a final base geometry to apply the modifications to for each of the alternative geometries. Figure 2-1 is a flow chart of the RAS geometries created. First, the existing (2012) geometry was modified to include projects that were constructed or awarded between 2012 and 2015. The August 50% exceedance flows from the 2007 update along with the 2012 geometry was used to assign inverts to the added projects. The current design criteria for SWH in chutes is 5 ft below the August 50% exceedance profile. Widths were assigned based on the 2014 SWH Accounting Report (USACE 2015b) and/or 2014 aerial imagery. This new geometry is named “2015 Base” and coupled with the August 50% exceedance profile was used for assigning inverts to all other models. The “2015 Base” model was then modified to reflect fully evolved chutes and top width widening for all of the projects; this geometry is called “Built-Out SWH”. With a few exceptions, all chutes were modeled with a 200 ft top width, invert elevation of 5 ft below August 50% exceedance (from the 2015 Base geometry), and 2H:1V side slopes. Top width widening projects were modeled with a 250 ft top width and inverts were 0 - 5 ft below the August 50% exceedance. All chutes used an n-value of 0.043. The “Built-Out SWH” geometry was used as the starting point for all three of the alternative geometries: No Action, BiOp, and IRC. The following sections describe the changes made to each of the alternative geometries in more detail.

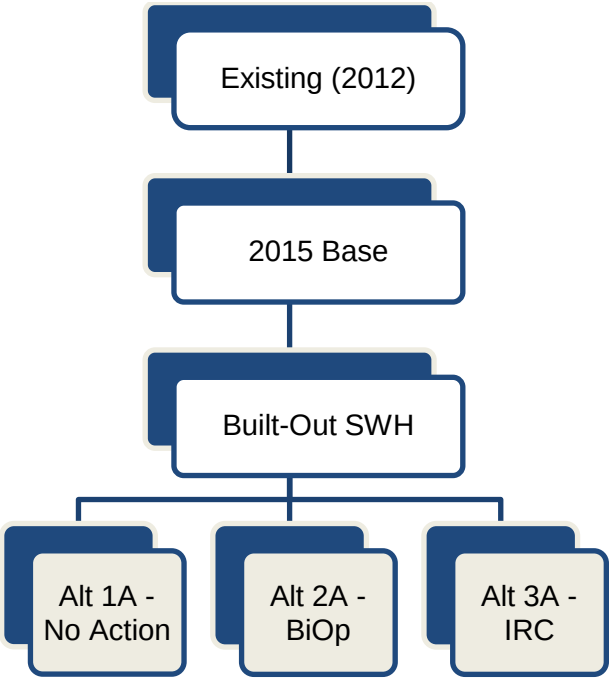


Figure 2-1: RAS Geometry Flow Chart

No new chutes were added to the HEC-RAS models, primarily because recent emphasis has been on top width widening projects. All chutes included in the 2014 SWH Acreage Accounting were counted as existing SWH. Some chutes were not altered whereas some were set to a reduced top width at sites where 200 feet would be unrealistic. See Table 2-2 for a list of chute top widths. The existing geometry was modified to produce these dimensions. At chutes with multiple channels, such as Sandy Point Chute, the combined top width of both channels was limited to 200 feet.

Table 2-2: Chute Top Widths

Site Name	US River Mile	DS River Mile	Chute Length (Feet)	2014 GIS Measured Area (Acres)	Built-out Area (Acres)	Built-out Top Width (Feet)
Glovers Point	713.4	711.2	11,100	5	5	20
Middle Decatur Bend	688.2	687.4	4,640	4	21	200
Lower Decatur Chute*	687.3	684.9	2,400	0	0	0
Fawn Island	674.1	673.3	2,979	16	16	234
Little Sioux Bend	668.3	666.8	7,400	19	34	200
Sandy Point Bend	658	656.4	6,505	30	30	200
Tyson Chute (w/o upper end)	655.5	653.1	9,234	16	16	75
California Bend - NE	650.1	648.5	9,230	14	14	66
California Bend - IA	650.3	649.6	4,000	8	8	87
Boyer Chute	637.8	633.7	16,760	63	77	200
Lower Calhoun Bend*	637.6	637.1	2,750	0	0	0
Council Bend	617.8	616.8	5,630	26	26	200
Plattsmouth	594.5	592.1	12,070	0	55	200
Tobacco Island	588.4	586.3	16,300	46	75	200
Upper Hamburg	555.9	552.2	15,950	152	73	200
Lower Hamburg	553.3	550.7	12,960	79	60	200
Kansas Bend	546.4	544.4	7,180	42	33	200
Nishnabotna	543.6	542.5	5,780	24	27	200
Deroin Bend	520.4	516.4	18,140	172	83	200
Rush Bottoms	501.5	500.1	8,400	28	39	200

*Note that Lower Decatur Chute and Lower Calhoun Bend projects were filled in from the 2011 flood event. They are not expected to be restored and will therefore have 0 acres of habitat.

2.2 ALTERNATIVE GEOMETRY OVERVIEW

The "Built-Out SWH" geometry was modified to produce the three alternative geometries: No Action, BiOp, and IRC. Amounts of habitat added to each geometry were based on the 2003 Amended BiOp (USFWS 2003), discussions with USFWS, and calculations of existing SWH from the 2014 SWH Accounting Report (USACE 2015b).

2.2.1 No Action Geometry

The No Action geometry assumes habitat construction activities follow current practices to achieve 20 acres/mile of SWH, the minimum target specified within the 2003 BiOp (USFWS 2003) of 20 – 30 ac/mi. Habitat was distributed by the 2003 BiOp reaches, and the 2014 Shallow Water Habitat Accounting Report (USACE 2015b) was used to determine the acreage deficit within each reach to attain the 20 ac/mi goal. Habitat was placed to provide 0 – 5 ft of depth at August 50% exceedance flows, which is the current design criteria for SWH. Most of the SWH added to reach the goal was in the form of top width widening while backwaters were incorporated as well.

Backwaters were not included in the model geometry because they provide limited conveyance that cannot be evaluated by the one-dimensional HEC-RAS model.

2.2.2 BiOp Geometry

The BiOp as projected geometry assumes the maximum habitat goal of 30 acres/mile of SWH from the 2003 BiOp. Similar to the No Action geometry, habitat was distributed by 2003 BiOp reaches, and the 2014 Shallow Water Habitat Accounting Report was used to determine the acreage deficit within each reach to attain the 30 ac/mi goal. Habitat was placed to provide 0 – 5 ft of depth at three different flow levels: low summer flow, mid-August, and Spring Pulse. Section 2.4.2 provides further details of the reference flows. Most of the SWH added to reach the goal was in the form of top width widening while backwaters were incorporated as well. Backwaters were not included in the model geometry because they provide limited conveyance that cannot be evaluated by the one-dimensional HEC-RAS model. Part of the BiOp requirement was achieving floodplain connectivity, and a separate analysis was conducted as documented in Section 2.7 to ensure the requirements were met, although no changes to the HEC-RAS model were necessary.

2.2.3 IRC Geometry

Assumes SWH construction activities proceed based on findings made by the Effects Analysis team. The total amount of habitat was based on the current SWH implementation rate of about 130 acres/year per district for a total of 260 acres/year. Assuming a 15-year implementation period and that IRC habitat construction will begin at no more than 2 years after the ROD is signed, this results in a 13-year construction window. Therefore, the total amount of IRC habitat for both districts is 3,380 acres (260 acre/year * 13 years = 3,380 acres).

Distribution was based on conversations with the Effects Analysis team, who specified upper and lower boundaries based on their knowledge of larval pallid spawning locations, drift rates, and timing of interception. Sioux City is the upstream threshold for IRC placement, with the area between the Nebraska Platte River and the Osage River more likely to be successful. Chutes and existing habitat may be modified to meet IRC habitat criteria, but for purposes of the HEC-RAS modeling these were not counted toward the target acreage. Habitat was placed to provide 0 – 6 ft of depth at median June flows. Section 2.4.3 provides further details of the reference flows. All of the SWH added to the geometry was in the form of top width widening.

2.3 ACRES OF HABITAT

Acres of habitat added to each of the three alternative geometries was based on the 2003 Amended BiOp, discussions with USFWS, or calculations of existing SWH from the 2014 SWH Accounting Report. Three components of shallow water habitat were taken into account when calculating how much habitat to add: top width widening, modifications to previously constructed projects, and backwaters. The Gavins to Rulo reach underwent significant changes during the 2011 flood, and the adjustment of existing chutes, top width widening, and backwater projects to sustainable dimensions required numerous changes to the HEC-RAS geometry.

2.3.1 No Action Alternative

Acres of SWH added to HEC-RAS to meet 20 ac/mi for the No Action geometry were broken down by 2003 BiOp segment for even distribution of habitat along the river. Table 2-3 shows the acres needed to reach the goal acreage by segment. The total goal acres needed for the Gavins to Rulo reach was 2,008 acres.

Table 2-3: Acres of SWH - No Action Geometry

Reach	Segment	RM Start	RM End	Miles	Required Acres (20 ac/mi)	SWH Acres Existing (2014 SWH Report)	SWH Acres Needed to Reach Goal
Ponca to Sioux City	11	753	735	18	360	120	240
Sioux City to Platte River	12	735	595	140	2,800	1,682	1,118
Platte River to Rulo (NWO)	13	595	498	97	1,940	1,290	650
Rulo to Kansas River (NWK)	13	498	367	131	2,620	1,270	1,350
Kansas River to Osage River	14	367	130	237	4,740	3,710	1,030
Osage River to Mouth	15	130	0	130	2,600	2,600*	0
Omaha District				255	5,100	3,092	2,008
Kansas City District				498	9,960	7,580	2,380
Total				753	15,060	10,672	4,388

*Existing acres for segment 15 (3,253 acres) exceeds 20 ac/mi.

For the No Action Alternative geometry, the breakdown of habitat type for the Omaha District is shown in Table 2-4 and is about 72% top width widening, 24% backwaters, and 4% changes to existing SWH.

Table 2-4: SWH Type - No Action Geometry

Reach	Segment	Widening (acres)	Widening (miles) [1]	Number of Widening Projects	Backwaters (acres)	Number of Backwater Projects	Changes to Existing SWH (acres)[3]
Ponca to Sioux City	11	180	5.9	2	60	1	0
Sioux City to Platte	12	601	19.8	9	420	7	97
Platte to Rulo (NWO)	13[2]	672	22.2	9	0	0	-22
Total		1,453	48	20	480	8	75

1 Assumes average widening width of 250-ft in the Omaha District.
2 Segment 13 is from the Platte River to the Kansas River and is divided at Rulo by the District boundary.
3 Changes to Existing SWH includes repairs to projects following the 2011 flood which decreased acreage in some projects.

Miles were converted to acres by multiplying the length of top width widening in miles by width and converting units to acres. For widening, the length measurement started and ended about halfway between cross sections, since this most appropriately reflects the interpolation between cross sections made by HEC-RAS during computations.

2.3.2 BiOp Alternative

Acres of SWH added to HEC-RAS to meet 30 ac/mi for the BiOp as Projected geometry were broken down by 2003 BiOp segment for even distribution of habitat along the river. Table 2-5 shows the acres needed to reach the goal acreage by segment. The total goal acres needed for the Gavins to Rulo reach was 4,558 acres.

Table 2-5: Acres of SWH - BiOp as Projected Geometry

Reach	Segment	RM Start	RM End	Miles	Required Acres (30 ac/mi)	SWH Acres Existing (2014 SWH Report)	SWH Acres Needed to Reach Goal
Ponca to Sioux City	11	753	735	18	540	120	420
Sioux City to Platte River	12	735	595	140	4,200	1,682	2,518
Platte River to Rulo (NWO)	13	595	498	97	2,910	1,290	1,620
Rulo to Kansas River (NWK)	13	498	367	131	3,930	1,270	2,660
Kansas River to Osage River	14	367	130	237	7,110	3,710	3,400
Osage River to Mouth	15	130	0	130	3,900	3,253	647
Omaha District				255	7,650	3,092	4,558
Kansas City District				498	14,940	8,233	6,707
Total				753	22,590	11,325	11,265

For the BiOp Alternative geometry, the breakdown of habitat type for the Omaha District is shown in Table 2-6 and is about 79% top width widening, 20% backwaters, and 2% changes to existing SWH.

Table 2-6: SWH Type - BiOp Geometry

Reach	Segment	Widening (acres)	Widening (miles) [1]	Number of Widening Projects	Backwaters (acres)	Number of Backwater Projects	Changes to Existing SWH (acres)
Ponca to Sioux City	11	240	7.9	4	180	3	0
Sioux City to Platte	12	1,761	58.1	32	660	11	97
Platte to Rulo (NWO)	13[2]	1,582	52.2	24	60	1	-22
Total		3,583	118	60	900	15	75

1 Assumes average widening width of 250-ft in the Omaha District.
2 Segment 13 is from the Platte River to the Kansas River and is divided at Rulo by the District boundary.
3 Changes to Existing SWH includes repairs to projects following the 2011 flood which decreased acreage in some projects.

Miles were converted to acres by multiplying the length of top width widening in miles by width and converting units to acres. For widening, the length measurement started and ended about halfway between cross sections, since this most appropriately reflects the interpolation between cross sections made by HEC-RAS during computations.

2.3.3 IRC Alternative

The total amount of habitat for the IRC alternative geometry was based on current SWH implementation rates, which equates to about 130 acres/year per district for a total of 260 acres/year. Assuming a 15-year implementation period and that IRC habitat construction will begin at no more than 2 years after the ROD is signed, this results in a 13-year construction window. Therefore, the total amount of IRC habitat for both districts is 3,380 acres (260 acre/year * 13 years = 3,380 acres).

Due to larval drift rates, among other factors, IRC habitat distribution does not extend upstream of Sioux City (RM 735) and is concentrated more heavily below the Platte River (RM 595). A few projects were located between Sioux City and the Platte River to determine if these areas are viable IRC locations. Approximate IRC habitat rates were used to set the total amount of acres for each reach as seen in Table 2-7. Existing habitat sites may be modified to meet IRC criteria as a part of this alternative, however, this will not be represented in HEC-RAS because of minimal impacts to water surface elevations, and will not be counted towards the target acres as a conservative assumption.

Table 2-7: Acres of Habitat - IRC Geometry

Reach	Segment	RM Start	RM End	Miles	IRC Habitat Rate (ac/mi)	Target Acres*
Ponca to Sioux City	11	753	735	18	0	0
Sioux City to Platte River	12	735	595	140	2.0	276
Platte River to Rulo (NWO)	13	595	498	97	6.0	585
Rulo to Kansas River (NWK)	13	498	367	131	5.1	670
Kansas River to Osage River	14	367	130	237	5.9	1,389
Osage River to Mouth	15	130	0	130	3.5	460
Omaha District				255	3.4	861
Kansas City District				498	5.1	2,519
Total				753	4.5	3,380

*As a conservative assumption, existing habitat sites were not counted towards the goal acreage.

As shown in Table 2-8, top width widening was the only type of habitat added to the HEC-RAS model.

Table 2-8: Habitat Type - IRC Geometry

Reach	Segment	Widening (acres)	Widening (miles) *	Number of Widening Projects
Ponca to Sioux City	11	0	0	0
Sioux City to Platte	12	276	9.1	4
Platte to Rulo (NWO)	13**	585	19.3	7
Total		861	28.4	11

*Assumes average widening width of 250-ft in the Omaha District.
**Segment 13 is from the Platte River to the Kansas River and is divided at Rulo by the District boundary.

2.3.4 Public Ownership Acreage Analysis

To assist the economic analysis team, an analysis was performed to calculate the amount of existing publicly owned lands available for new habitat construction. This information was used to determine the amount and cost of additional lands that would need to be purchased. Existing public lands includes USACE, USFWS, and state conservation owned lands suitable for habitat development, and was accumulated by counting publicly owned river front acres available in each BiOp segment, so existing public land availability is a constant between alternatives. Values in the tables were capped at the target. Suitability of particular sites for the type of habitat to be constructed was not considered. Furthermore, the additional lands required acreage is habitat only, a factor would need to be used to convert from habitat land to total real estate tract purchase size. See Table 2-9, Table 2-10, and Table 2-11 for a listing of public ownership acreage availability for each geometry.

Table 2-9: Public Ownership Acreage - No Action Geometry

		Widening (ac)			Backwaters (ac)			Total[1]
Reach	**Seg**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Addt'l Lands Req'd (ac)**
Ponca to Sioux City	11	180	0	180	60	0	60	**240**
Sioux City to Platte River	12	601	601	0	420	420	0	**0**
Platte River to Rulo (NWO)	13	672	672	0	0	0	0	**0**
Rulo to Kansas River (NWK)	13	1,129	454	675	-	-	-	**675**
Kansas River to Osage River	14	937	937	0	-	-	-	**0**
Osage River to Mouth	15	0	0	0	-	-	-	**0**
Omaha District		1,453	1,273	180	480	420	60	**240**
Kansas City District		2,066	1,391	675	-	-	-	**675**
Total		3,519	2,664	855	480	420	60	**915**
Total Percentage		-	76%	24%	-	87.5%	12.5%	**-**

1 Note that chutes (NWK) and changes to existing SWH (NWO) are not shown because they reside on existing public lands. Also, this acreage is habitat only and does not include a factor for total real estate tract purchase size.
2 Includes existing public lands that are available for habitat placement. This number is capped at the target acres and is not the total acres of existing public lands.

Table 2-10: Public Ownership Acreage - BiOp Geometry

		Widening (ac)			Backwaters (ac)			Total[1]
Reach	**Seg**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Addt'l Lands Req'd (ac)**
Ponca to Sioux City	11	240	0	240	180	0	180	**420**
Sioux City to Platte River	12	1,761	836	925	660	660	0	**925**
Platte River to Rulo (NWO)	13	1,582	907	675	60	60	0	**675**
Rulo to Kansas River (NWK)	13	2,439	454	1,985	-	-	-	**1,985**
Kansas River to Osage River	14	3,307	1,375	1,932	-	-	-	**1,932**
Osage River to Mouth	15	529	529	0	-	-	-	**0**
Omaha District		3,583	1,743	1,840	900	720	180	**2,020**
Kansas City District		6,275	2,358	3,917	-	-	-	**3,917**
Total		9,858	4,101	5,757	900	720	180	**5,937**
Total Percentage		-	42%	58%	-	80%	20%	**-**

1 Note that chutes (NWK) and changes to existing SWH (NWO) are not shown because they reside on existing public lands. Also, this acreage is habitat only and does not include a factor for total real estate tract purchase size.
2 Includes existing public lands that are available for habitat placement. This number is capped at the target acres and is not the total acres of existing public lands.

Table 2-11: Public Ownership Acreage - IRC Geometry

		Widening (ac)			Backwaters (ac)			Total[1]
Reach	**Seg**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Addt'l Lands Req'd (ac)**
Ponca to Sioux City	11	0	0	0	-	-	-	**0**
Sioux City to Platte River	12	276	276	0	-	-	-	**0**
Platte River to Rulo (NWO)	13	585	585	0	-	-	-	**0**
Rulo to Kansas River (NWK)	13	670	454	216	-	-	-	**216**
Kansas River to Osage River	14	1,389	1,375	14	-	-	-	**14**
Osage River to Mouth	15	460	460	0	-	-	-	**0**
Omaha District		861	861	0	-	-	-	**0**
Kansas City District		2,519	2,289	230	-	-	-	**230**
Total		3,380	3,150	230	-	-	-	**230**
Total Percentage		-	93%	7%	-	-	-	**-**

1 Note that chutes (NWK) and changes to existing SWH (NWO) are not shown because they reside on existing public lands. Also, this acreage is habitat only and does not include a factor for total real estate tract purchase size.
2 Includes existing public lands that are available for habitat placement. This number is capped at the target acres and is not the total acres of existing public lands.

2.3.5 Excluded Areas

Locations selected for habitat construction in the HEC-RAS model are theoretical and do not reflect actual locations of future mitigation projects. However, the following areas were intentionally avoided when making modifications to HEC-RAS models. For the BiOp Alternative geometry, satisfying all of the below criteria was not always possible due to the amount of habitat added.

1) Reaches of river within a 10,000-ft radius of an airport (per FAA AC 150/5200-33) (FAA 2007)
2) Areas within 1/4 mile upstream or downstream of small town infrastructure along the river bank, on that side of the river only
3) Areas within 1/4 mile upstream or downstream of power plant or municipal water intakes, on both sides of the river
4) Areas within 1/4 mile upstream or downstream of barge loading facilities and other river related industrial infrastructure along the river bank, on that side of the river only
5) Areas within 1/4 mile upstream or downstream of bridges, on both sides of the river
6) Areas within 1/4 mile upstream and downstream of Federal/PL 84-99 levees lying close to the river bank, on that side of the river only.

7) Reaches adjacent to larger cities (e.g. Omaha and Sioux City), particularly where the channel is confined by urban levees
8) Widening projects were not located in the same bend as new or existing chutes or widening to avoid excessive navigation channel flow loss.

2.4 REFERENCE FLOWS

Reference flows were used to set design elevations for SWH added to the geometries. Reference flows were run through the "2015 Base" geometry in steady flow, and the resulting water surface profile along with the specified depth was used to set the invert for added SWH.

2.4.1 No Action Geometry

August 50% exceedance flows from the 2007 SWH Profile Report (USACE 2007) were run through the "2015 Base" geometry to obtain invert elevations 5 feet below the profile. Flows for the mainstem gage locations are shown in Table 2-12 and a full list of flows used in RAS can be seen in Plate 1.

Table 2-12: No Action August 50% Duration Flows - Mainstem Gages

Location	River Mile	August 50% Duration Flow (cfs)
Gavins Point Dam	810.9	32,630
Sioux City	732.37	33,430
Decatur	691.03	34,220
Omaha	616.03	36,630
Nebraska City	562.6	40,050
Rulo	498.04	42,170

2.4.2 BiOp Geometry

Three reference flows were used for the BiOp geometry: low summer flow, mid-August, and Spring Pulse. Flows were calculated by starting with the Gavins Point release (from MRBWMD *Hydrologic Statistics Technical Report* (USACE 2013)) and adding incremental flows at major tributaries. Incremental flows were calculated by the MRBWMD in the *Missouri River Incremental Flows Below Gavins Point Technical Report* (USACE 2014a) for the pre-dam and post-dam time periods, at statistical levels of minimum, median, and maximum, lower and upper decile and quartiles. Median pre-dam records were used because they incorporate the drought of the 30's and are therefore slightly lower than the post-dam statistic. Incremental flows for the months of July, August, and May, were used for summer low, median August, and spring pulse, respectively. July incremental flows were added downstream of the summer low Gavins Release (21,000 cfs), because the summer low condition centers primarily on this month. May incremental flows were added downstream of the spring pulse because the second spring pulse specified occurs during

this month. Flows for the mainstem gage locations and the incremental flows between them are listed in Table 2-13 below. A full list of flows used in the model is shown in Plate 1.

Table 2-13: BiOp Reference Flows - Mainstem Gages

Location	River Mile	Low Summer Flow (cfs)	Mid-August Flow (cfs)	Spring Pulse Flow (cfs)
Gavins Point Dam	810.9	21,000	36,900	48,800
Incremental Flow		2,200	1,700	3,200
Sioux City	732.37	23,200	38,600	52,000
Incremental Flow		2,600	1,700	2,400
Omaha	616.03	25,800	40,300	54,400
Incremental Flow		5,000	3,400	7,300
Nebraska City	562.6	30,800	43,700	61,700
Incremental Flow		1,900	1,300	2,200
Rulo	498.04	32,700	45,000	63,900

2.4.3 IRC Geometry

The reference flow for the IRC geometry was the median June flow, which includes the median June release from Gavins Point Dam (from MRBWMD *Hydrologic Statistics Technical Report* (USACE 2013)) plus June incremental flows from the *Missouri River Incremental Flows Below Gavins Point Technical Report* (USACE 2014a). Flows for the mainstem gage locations and the incremental flows between them are listed in Table 2-14 below. A full list of flows used in the model is shown in Plate 1.

Table 2-14: IRC Mid-June Reference Flows - Mainstem Gages

Location	River Mile	Mid-June Flow (cfs)
Gavins Point Dam	810.9	32,200
Incremental Flow		3,400
Sioux City	732.37	35,600
Incremental Flow		3,200
Omaha	616.03	38,800
Incremental Flow		8,300
Nebraska City	562.6	47,100
Incremental Flow		2,700
Rulo	498.04	49,800

2.5 TOP WIDTH WIDENING

Top width widening was a SWH component added to all three alternative geometries. Cross sections were widened by 250 ft upstream of Rulo (Omaha District) and 300 ft downstream of Rulo (Kansas City District) by use of the channel design/modification editor in RAS. Depths and reference flow water surface profiles both vary between alternatives. The widened area was assigned a Manning's n-value of 0.035 which is rougher than the main channel because it accounts for depth variability and additional structures that are likely to be included in a typical project. This value was selected based on past experience with top width widening projects' varying topography however, future projects may perform differently. Levee and ineffective points were adjusted to match the new high bank station but remained at the same elevation. Keeping the levee and ineffective point elevations the same assumes that the overbank topography would remain similar to existing conditions. This also minimizes the difference between the 2012 calibration geometry. Figure 2-2 is a comparison between the top width widening for all three alternative geometries at a sample cross section.

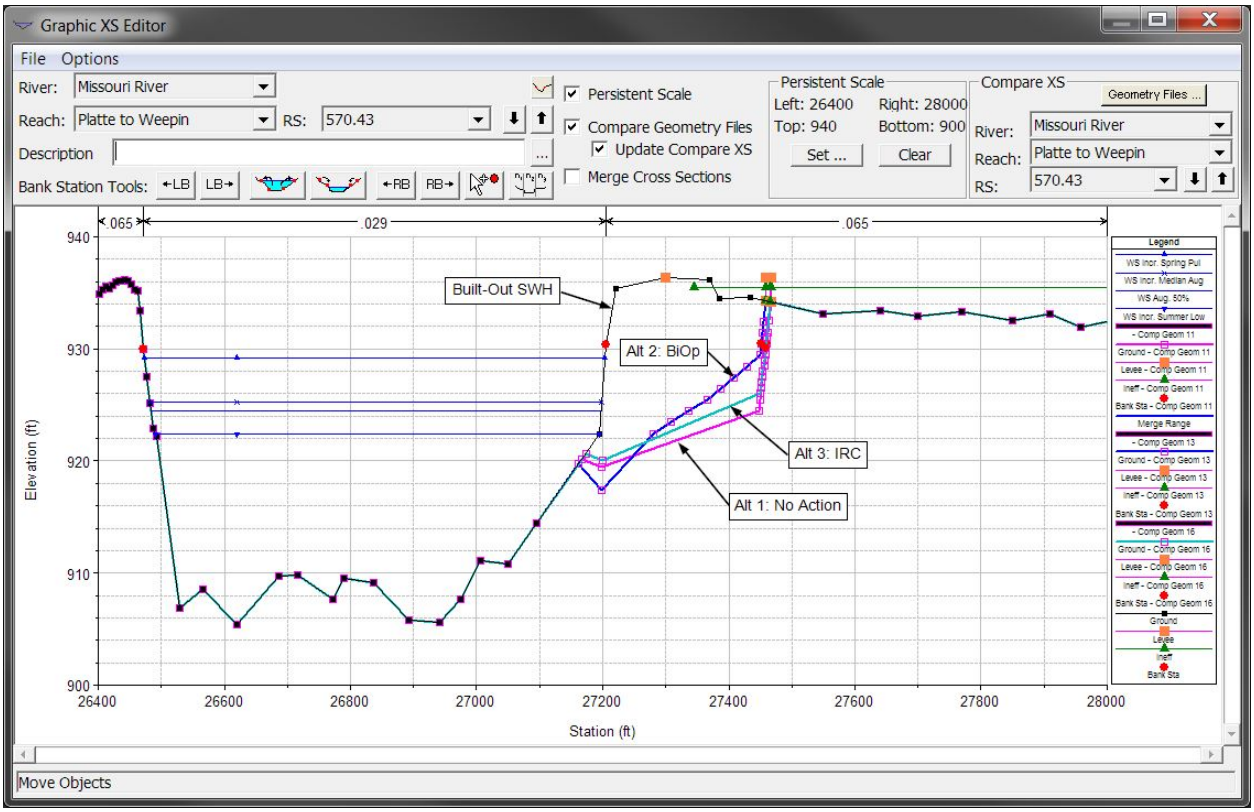


Figure 2-2: Comparison of Top Width Widening - All Geometries

2.5.1 No Action Geometry

Top width widening was added to cross sections in the HEC-RAS model based on the calculated habitat that needed to be added to the 2003 BiOp reaches. Depths range from 0 to 5 ft with respect to the August 50% water surface elevation at each cross section. An example of the top

width widening cross-section modification for the No Action alternative geometry is shown in Figure 2-3.

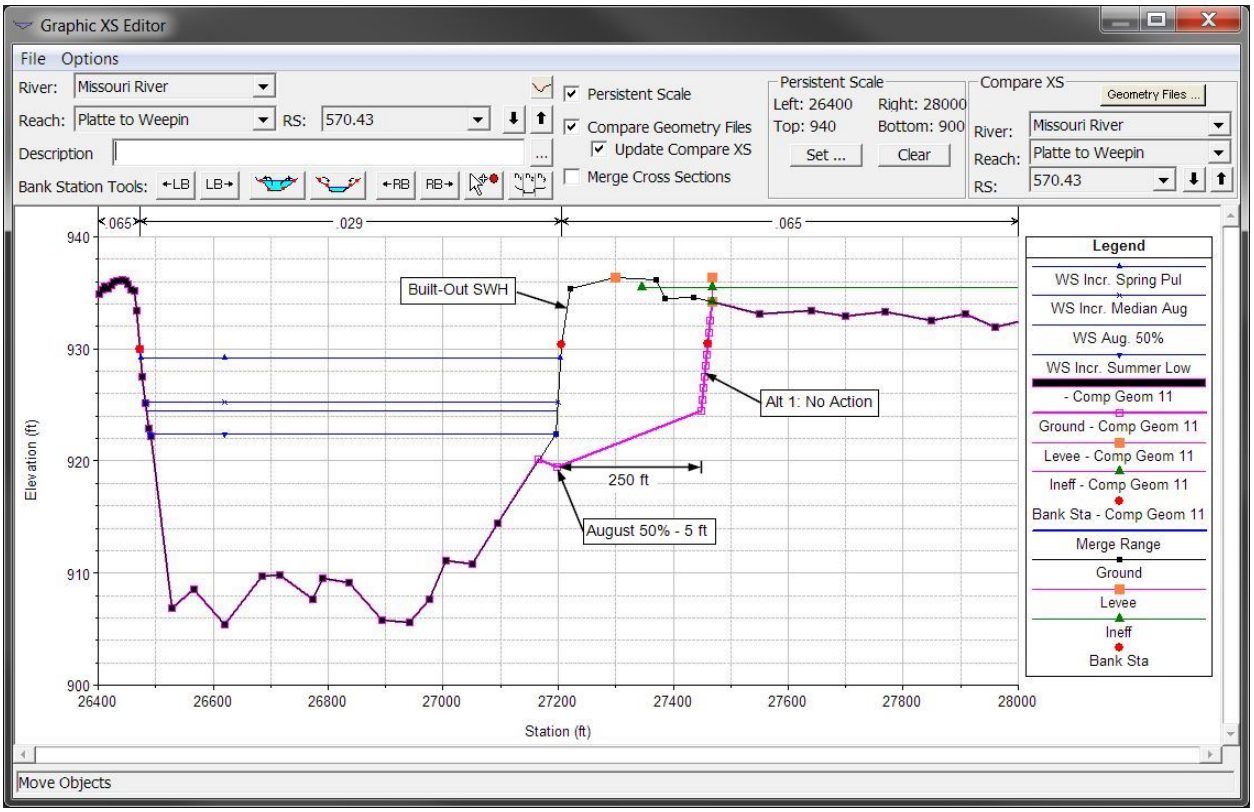


Figure 2-3: Example Top Width Widening for No Action Geometry

2.5.2 BiOp Geometry

Top width widening was added to cross sections in the HEC-RAS model based on the calculated habitat that needed to be added to the 2003 BiOp reaches. Depths range from 0 - 5 ft at three flow levels: low summer flow, mid-August, and Spring Pulse. A series of five templates was used to expedite the insertion of top width widening. The water surface elevation difference was calculated between the spring pulse and median August profiles and between the median August and the summer low flow profiles. The numbers were then rounded to the nearest foot and a template was selected with that combination of elevation differences. The templates always start 5 ft below the low summer flow, rise to the calculated template distance to the mid-August flow, and then rise to the calculated template distance to the Spring Pulse flow. Each flow level is approximately a third of the width or about 83 ft. If multiple templates were calculated for a proposed project, the most dominant template was chosen for all cross sections in the project. The number of projects that used each template is shown in Table 2-15. An example of the top width widening cross-section modification for the BiOp alternative geometry is shown in Figure 2-4.

Table 2-15: BiOp Geometry Top Width Widening Templates

Template	Number of Projects
Low Summer to Mid-August Difference: 3 ft Mid-August to Spring Pulse Difference: 3 ft	11
Low Summer to Mid-August Difference: 4 ft Mid-August to Spring Pulse Difference: 3 ft	33
Low Summer to Mid-August Difference: 4 ft Mid-August to Spring Pulse Difference: 4 ft	1
Low Summer to Mid-August Difference: 3 ft Mid-August to Spring Pulse Difference: 4 ft	14
Low Summer to Mid-August Difference: 2 ft Mid-August to Spring Pulse Difference: 3 ft	1

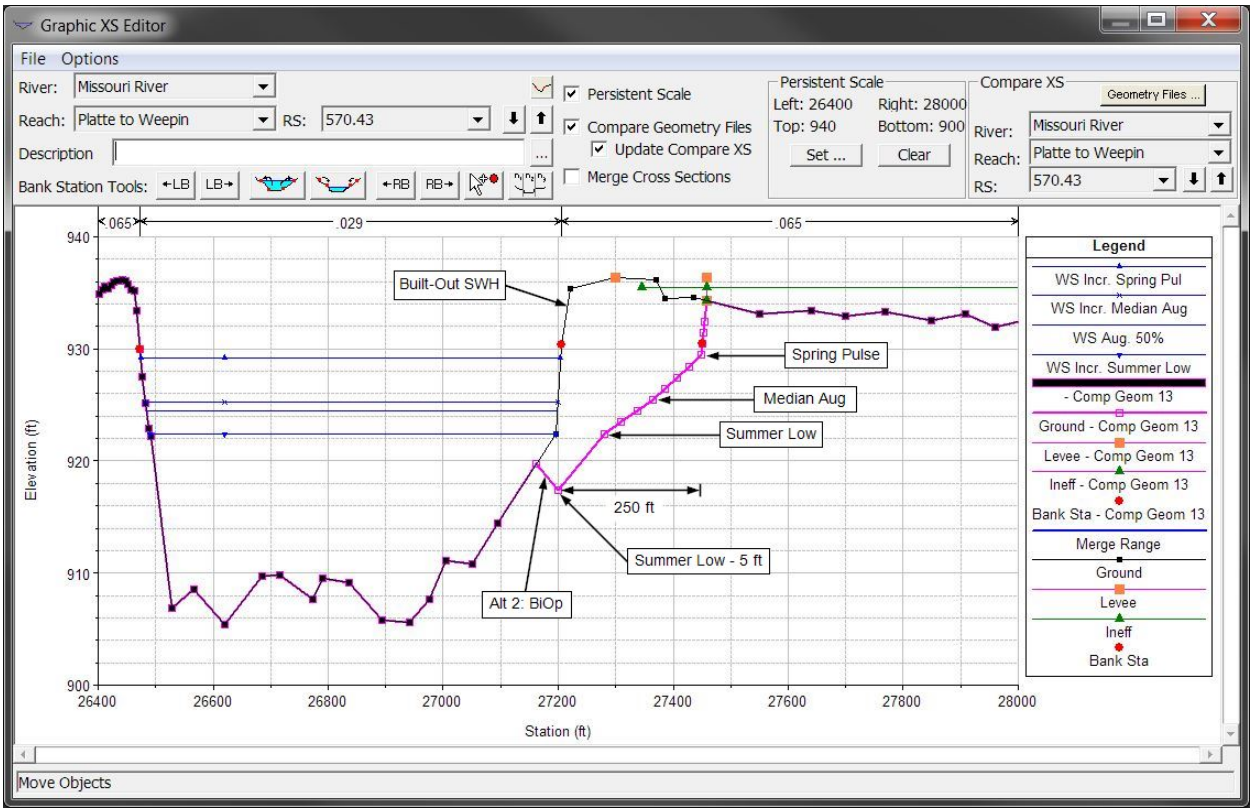


Figure 2-4: Example Top Width Widening for BiOp Geometry

2.5.3 IRC Geometry

Top width widening was added to cross sections in the HEC-RAS model based on the calculated habitat that needed to be added to the 2003 BiOp reaches. Depths range from 0 to 6 ft with respect to the mid-June water surface elevation at each cross section. The widened area was assigned a Manning's n-value of 0.035. An example of the top width widening cross-section modification for the IRC alternative geometry is shown in Figure 2-5.

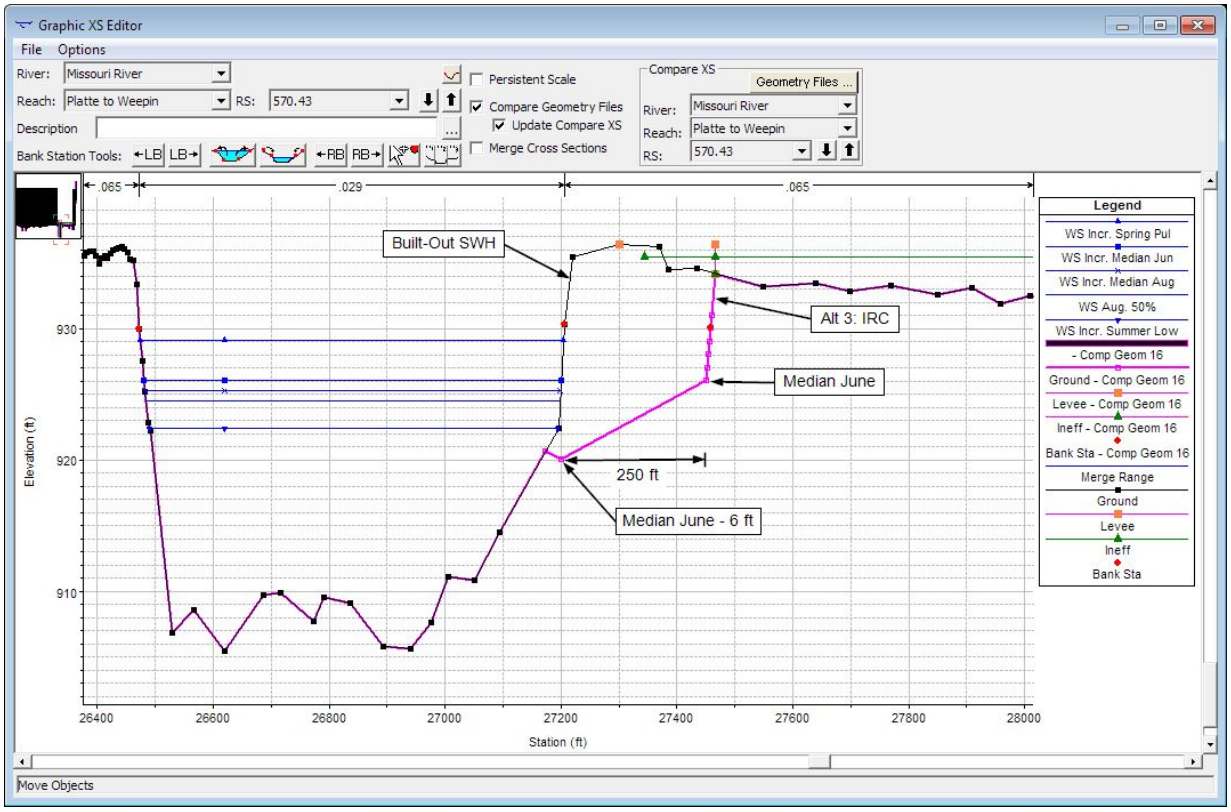


Figure 2-5: Example Top Width Widening for IRC Geometry

2.6 BACKWATERS

Backwaters provide limited conveyance that cannot be evaluated by the one-dimensional HEC-RAS model. Therefore, while the acreage was accounted for, modifications to the HEC-RAS model were not made. See Table 2-4 and Table 2-6 for the total number of backwaters added to each segment for each alternative. No backwater acres were added for the IRC alternative.

2.7 FLOODPLAIN CONNECTIVITY

The BiOp geometry integrates floodplain connectivity along with SWH criteria set forth in the 2003 Amended BiOp. Coordination with the U.S. Fish and Wildlife Service (USFWS) produced a Planning Aid Letter (USFWS 2015) detailing the modeling assumptions for the BiOp alternative. A total of 100,000 acres of SWH and floodplain connectivity were assumed for both districts. To calculate the goal amount of only floodplain connectivity, 22,590 acres (30 ac/mi * 753 mi) was subtracted from the 100,000 acres to obtain 77,410 acres.

Mapping of existing floodplain connectivity was performed by using the HEC-RAS model calibrated to 2012 conditions to calculate a water surface profile for the 20% annual chance exceedance event (20% ACE or 5-year). Table 2-15 lists the flow and stage for the 20% ACE or 5-year flow used in the model. The 5-year flow input into the model was obtained from the 2003 Upper Mississippi River System Flow Frequency Study (USACE, 2003). Calculated floodplain connectivity acres by state are listed for each district and in total in Table 2-16. Existing floodplain

connectivity acres (147,652 acres) surpass the total acres available for floodplain connectivity (100,000 acres) therefore, no changes were made to the HEC-RAS model.

The calculated acres of existing floodplain inundation with connectivity includes:

- Areas lower in elevation than the computed 20% ACE water surface and judged to be connected to the main channel.
- Private lands not protected by levees, including fringe areas between levees and river bank and areas without any discernable protection that would be inundated at the reference flow.

Areas excluded from the existing floodplain connectivity acres:

- Area behind all active/maintained levees, including federal levees, levees in the PL84-99 program and smaller agricultural levees often found between the federal/ program levees and the river bank. No distinction was made as to levee reliability or performance risk.
- Inundated area well outside the bluff line or in tributary backwater areas.
- Missouri River main channel as determined by the boundary of the August 50% duration flow extent (from the 2014 SWH Accounting report).

Table 2-16: 20% ACE (5-yr) Flow and Stage

Location	River Mile	20% ACE (5-year) Flow (cfs)	20% ACE (5-year) Stage (ft, NAVD88)
Ponca	751	64,100	1097.4
Sioux City	734	66,800	1079.4
Decatur	691	70,500	1041.2
Omaha	616	85,300	975.1
Nebraska City	563	118,600	928.1
Rulo	498	132,300	861.4

The 100,000 inundation acreage includes both the main channel and connected floodplain area (shallow water habitat). The 77,410 inundation acreage includes only the connected floodplain. The calculated acres of floodplain connectivity shown in Table 2-16 includes some forms of shallow water habitat (chutes), but excludes others (areas between the river banks). For this reason, the calculated acres were compared to the full portion of authorized acres, and was considered acceptable because existing exceeded authorized even without counting some of the shallow water habitat acres.

Table 2-17: Acres of Floodplain Connectivity by State

State	Acres of Existing Floodplain Connectivity (20% ACE inundation)[2]			Authorized Acres Available for SWH & Floodplain Connectivity	Acres to be added to HEC-RAS
	NWO	NWK	Total[1]		
Iowa	16,120	0	16,120	14,228	0
Kansas	0	8,565	8,565	6,976	0
Missouri	8,020	83,130	91,150	62,813	0
Nebraska	31,550	267	31,817	15,983	0
Total	**55,690**	**91,962**	**147,652**	**100,000[3]**	**0**

1) Does not imply ownership, includes both public and private lands.
2) Does not include the main channel acres defined by median August flows.
3) This total includes both SWH and floodplain connectivity. Floodplain connectivity only is 77,410 acres.

3 FLOW ALTERNATIVES

A total of six flow alternatives were modeled in ResSim. Reservoir pool elevations and dam outflow output from the ResSim model was used as input for the unsteady RAS model for each of the six flow alternatives for the POR. A brief summary of the flow alternatives is provided below. For more details, see the ResSim technical report, *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report* (2016b).

Tributary and ungaged inflows were kept consistent between alternatives. More details on the Period of Record (POR) flow dataset used can be found in the report *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling* (2016e).

3.1 ALTERNATIVE 1 - NO ACTION

Under Alternative 1 (Alt 1), the Missouri River Mainstem Projects would continue to be operated as they are currently. Operations within the ResSim model were set up to closely follow the Master Manual that is used during real-time operations of the System; however, the model does have limitations and cannot capture all real-time decisions that occur. This includes a plenary bimodal spawning cue attempt each year, one in March and one in May.

3.2 ALTERNATIVE 2 - U.S. FISH & WILDLIFE SERVICE 2003 BIOLOGICAL OPINION PROJECTED ACTIONS

Alternative 2 (Alt 2) represents the U.S. Fish and Wildlife Service (USFWS) interpretation of the management actions that would be implemented as part of the 2003 Amended BiOp RPA (USFWS 2003). Operational criteria include different early and late spring spawning cues (March and May), low summer flows, and a maximum winter release limit.

3.3 ALTERNATIVE 3 - MECHANICAL CONSTRUCTION ONLY

Alternative 3 (Alt 3) consists of mechanical construction of emergent sandbar habitat (ESH). Operational criteria consist of removing the early and late spring spawning cues in Alt 1.

3.4 ALTERNATIVE 4 - SPRING HABITAT-FORMING FLOW RELEASE

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

3.5 ALTERNATIVE 5 - FALL HABITAT-FORMING FLOW RELEASE

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

3.6 ALTERNATIVE 6 - PALLID STURGEON SPAWNING CUE

Alternative 6 (Alt 6) replaces the early and late spring spawning cues with different spawning cues. The early spring spawning cue in Alt 6 occurs at the same time as the early spring spawning cue in Alt 1 but with a higher peak release. The late spring spawning cue in Alt 6 occurs later in May than the late spring spawning cue in Alt 1 and has a larger peak release. Please note that the name of this alternative changed towards the end of the study from Alternative 7 to Alternative 6 (original Alternative 6 was abandoned). The models were not re-run so all of the model and file names are still labeled Alternative 7.

4 SIMULATION OF ALTERNATIVES

Each flow alternative was paired with a geometry alternative to produce six total alternatives that were run through HEC-RAS. The No Action geometry was paired with the No Action flow for Alternative 1. The BiOp geometry was combined with the BiOp flow for Alternative 2. The IRC geometry was paired with flow alternatives 3 through 6 to produce Alternatives 3, 4, 5, and 6. See Table 4-1 for a complete listing of the geometry and flow pairings for each alternative.

Table 4-1: Alternative Geometry and Flow Pairings

Alternative	Geometry	Flow
Alternative 1	No Action	No Action
Alternative 2	BiOp	BiOp Projected
Alternative 3	IRC	Mech Only
Alternative 4	IRC	Spring Habitat Forming Release
Alternative 5	IRC	Fall Habitat Forming Release
Alternative 6*	IRC	Pallid Sturgeon Spawning Cue

*Formerly known as Alternative 7, which corresponds to all HEC-RAS model runs and file names.

5 RESULTS

All alternatives runs were performed in HEC-RAS 5.0 Beta (21-August-2015) because that was the most current version as of October and November 2015, when most of the runs were completed. Official release of HEC-RAS 5.0 was on 4-March-2016 and 5.0.1 on 22-Apr-2016, at which point evaluation of results by the economists and human considerations teams was well underway and it would have unnecessarily compromised schedule to re-run the simulations.

Model output contains a considerable amount of information, not easily condensed to simple conclusions. Each of the six alternative runs produced 83 years (March 1930 – December 2012) of stage and flow hydrographs. Responses to the ResSim flow changes in combination with habitat geometry changes are complex. To express the changes compared with the No Action alternative, the model results were evaluated by statistical evaluation and duration analysis plots.

Results from the 83-year runs for the six alternatives were provided to the Human Considerations (HC) team for analysis. They used the daily (instantaneous 2400 value for each day) flow and water surface elevation output to analyze effects to various resources that include: hydropower, cultural resources, fish & wildlife (exclusive of listed species), flood risk, irrigation, recreation, thermal power, and water supply. The HC team performed an extensive analysis on each of the alternatives for all of the resources and provide a detailed comparison of results. For this report, only the hydraulic model output is presented.

5.1 STATISTICS

For the statistical evaluation, flow and water surface elevation results were analyzed to compare the differences between the No Action Alternative and the remaining five alternatives. Tables showing the differences between calculated statistics for both flow and water surface elevation for below Gavins Point Dam, Sioux City, Omaha, Nebraska City, and Rulo can be seen in Plate 2 and Plate 3. The statistics calculated include: the 10th, 25th, 50th, 75th, and 90th- Percentiles, and the Minimum and Maximum. It should be noted that the percentile statistics calculated are from a duration analysis and not a Bulletin 17B flow frequency analysis.

The min and max are the lowest daily flow or stage and the highest daily flow or stage output for each alternative over the period of record. For model stability, a minimum of 5,000 cfs was used for Gavins Point Dam outflow in RAS. As seen in the tables, the minimum flow or stage for the period of record remains unchanged from alternative to alternative. The maximum flow or stage differences are also essentially unchanged (within 1%) and increase in the downstream direction. Caution should be used when trying to draw conclusions from the statistics alone, especially for peak flows. The economic models (HEC-FIA) provide a more complete analysis of how high flows effect total damages for each alternative because they incorporate all of the cross section output, whereas these tabular statistics only capture one location.

Flow and stage changes between alternatives at a location are influenced by an array of variables. From alternative to alternative the two primary changes to the hydraulic model were flow out of the Mainstem Missouri River reservoir system as calculated by HEC-ResSim, and the habitat additions to the river geometry. Flow calculated by the HEC-RAS model at a downstream location

not only depends on how the Gavins point release changed, but also how those changes carry downstream. Even when the Gavins point release has no change, the flow or stage calculated from alternative to alternative at a downstream location may change because of the habitat additions to the river geometry.

It is also important to note that the HEC-RAS alternative models, although they have a 30 minute computation interval, have been configured to report one value per 24 hour period, and unfortunately that one value is not a daily average. The HEC-RAS model reports the value that lands on 2400 of each day. The most reasonable output interval was chosen as daily due to the size of watershed being modeled, POR length, and the number of hydrograph locations necessary for HC analysis. This means that slight shifts in timing from alternative to alternative can carry over into the results as small fluxuations in the reported flow. Changes in timing are a small factor, not likely to significantly impact any results evaluation, but should be kept in mind when making comparison at a precise level such as in the statistics tables.

Stage statistics have been rounded to the nearest tenth of a foot, which is equivalent to 1.2 inches. This helps demonstrate how flow changes impact river elevations, which is the more tangible result. For example, even though the maximum flow for Nebraska City in Alternative 2 was 613-cfs lower than in Alternative 1, there is less than an inch of impact to the water surface elevation of the river, and therefore zero reported change.

5.2 Seasonal Duration Plots

A duration analysis was also performed for the alternative output. Seasonal duration plots for key main stem locations including Gavins Point, Sioux City, Omaha, Nebraska City, and Rulo are shown in Plate 4 through Plate 23. Seasonal dates chosen for the duration analysis coincide with the current System operational seasons: spring (1Mar to 30Apr), summer (1May to 31Aug), fall (1Sep to 30Nov), and winter (1Dec to 28Feb). The greatest difference can usually be seen in the spring and winter durations due to the spring pulses and resulting lower winter flows.

5.3 Limitations

The analysis relies on the simulation of the 83-year period of record using daily average outflows from an HEC-ResSim model input into a fixed bed HEC-RAS model, with stage and flow output. While the analysis coupled with species and human considerations models can be used to show relative benefits and potential impacts based on historic flows, there are limitations in the conclusions that can be drawn based on some of the simplifying assumptions.

1. **POR Methodology -** An 83-year period of record, adjusted to current level of depletions, was used and may not be comparable to future conditions. A climate change assessment of the Missouri River basin indicates increases to both temperature and precipitation along with increasing trends in extreme floods and droughts (USACE 2016d). The conditions during a pulse year in the future could vary greatly from the small sample of pulse events included in the POR analysis.
2. **No Risk Analysis -** The Missouri River system as currently operated provides substantial flood damage reduction and benefits to the entire basin. The current HEC-

ResSim and HEC-RAS analysis, which employs an 83 year period of record simulation, shows the potential for negative impacts to flood damage reduction and dam safety for alternatives that include changes in reservoir flow releases. The current study methodology does not simulate a sufficient number of events and possible runoff combinations within the large Missouri River basin to evaluate potential change in downstream flood risk and dam safety.

Scoping efforts were conducted to determine a Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood damage reduction as a result of flow release changes. The risk analysis primary components include further development of the period of record flow data set, HEC-ResSim and HEC-RAS model modifications, development of levee fragility curves, assignment of uncertainty, assembly and debugging of models, Monte Carlo simulation, analysis of results, and reporting. The Monte Carlo methodology properly assesses the effects of the alternative operation changes because it increases the sample size of flow data and number of combinations of flow periods that may occur in the future so that impacts can be characterized with greater confidence. Without such analysis, the impacts of operational changes will only be known for events and combinations of events that have already occurred. Statistics calculated based on the 83-years of record should therefore be used with caution, and with the understanding of the consequences of using only a small sample of years.

3. **Stable Bed and Floodplain -** The hydraulic modeling to date is based on revisions to the existing conditions hydraulic model to account for varying amounts and distributions of habitat through river widening and continued development of SWH projects such as chutes. The analysis does not account for how the bed of the Missouri River may respond to river widening activities. Additionally, the analysis does not try to project where sediment may accumulate in the floodplain or include projections of future change in floodplain roughness. This carries with it the necessary assumptions that any bed and floodplain changes would be either negligible, similar between each alternative, or mitigated during more detailed design of river widening projects.

4. **Flood Source -** The Missouri River, major tributaries, and ungaged inflows included in the HEC-RAS model are the only flood sources, water floods areas protected by levees from levee overtopping. In reality, flooding can also occur due to localized rainfall and subsequent runoff, through seepage under levee foundations during prolonged high water, or through failure of levees prior to overtopping. While the level of effort required to model all levees systems with detailed rainfall runoff and underseepage flow calculations was considered prohibitive, more detailed analysis was conducted for four levee systems, two in Omaha District and two in Kansas City District. The two Omaha District interior drainage models are discussed in Section 6.

   Past experience on the Missouri River indicates that a majority of levee breaches occur following levee overtoppings when water flows into or exits the levee system. However, breaches prior to overtopping have occurred and may occur again in the future. Predicting breach formation through the period of record simulation was considered infeasible due to the unknown location of levee breaches during future events and

factors such as repairs and improvements made by levee sponsors or USACE after each event. Levee breaches, and the corresponding increase in depth within the levee protected area, may affect potential flood damages.

5.4 Channel Capacity Analysis

Channel capacity estimates were performed to provide an indication of the flow rate at which bank elevations are overtopped and flow begins to leave the main channel and enter the floodplain. Channel capacity estimates were performed with the one-dimensional RAS model calibrated to 2012 conditions by comparing steady flow profiles with top of bank elevations at each cross section combined with reviewing the best available floodplain topography. Floodplain flow connectivity was not assessed. The estimated channel capacity does not necessarily correlate with the onset of flood damage. In addition, channel capacity is typically highly variable along the channel bank due to wide variation in bank elevations. The quality of the channel capacity estimate is affected by numerous factors including how representative the model cross sections are of river geometry, local channel geometry variation, low spots in bank elevations, and the floodplain topography accuracy. The degradation reach immediately downstream of Gavins Point Dam has a much higher channel capacity than areas further downstream. For that reason, the Nebraska City vicinity was selected as more representative of flood risk for the Gavins Point to Rulo, NE reach. For the Nebraska City area the channel capacity estimate is from 80,000 to 85,000 cfs. Due to the large distance downstream of Gavins Point Dam, a channel capacity estimate was not performed for the river between Rulo, NE and the mouth at St. Louis, MO.

A Monte Carlo risk analysis methodology capable of assessing impacts to dam safety and flood risk as a result of flow release changes would be required to fully assess how an alternative impacts potential flood risk. Refer to the *Summary of Hydrologic Engineering Analysis* (USACE 2016g) for additional details on the risk analysis methodology.

6 INTERIOR DRAINAGE ANALYSIS

An interior drainage analysis was performed for two federal levee units in Omaha District, L-536 and L575. The No Action alternative RAS model geometry (Alternative 1) was modified for these two levee units and the six flow alternatives were run. The geometry modifications included dividing storage areas into smaller sub-basins, sub-dividing lateral structures and adding storage area connections, and adding culverts and pumps. Two lateral inflow hydrographs representing rainfall and levee seepage were also added. A sensitivity analysis was also performed to determine if pumps, culvert sediment, or flow pulses had a large effect on the results.

6.1 Levee Unit L-575 Description

Levee Unit L-575 is located along the left bank of the Missouri River in Fremont County, Iowa; Atchison County, Missouri; and Nemaha County, Nebraska between River Miles 574 and 544. The upstream end of the levee unit includes a left bank tieback on Plum Creek and the downstream end includes a right bank tieback on the Nishnabotna River.

6.2 Levee Unit L-536 Description

Levee Unit L-536 is located along the left bank of the Missouri River in Atchison and Holt Counties, Missouri between River Miles 522 and 516. On the upstream end of the levee unit, there is a tieback along the left bank of Rock Creek and the downstream end includes a tieback on the right bank of Mill Creek.

6.3 Basin Delineation & Lateral Structure Modification

The L-575 drainage area was separated into eight basins and L-536 into four basins for this analysis. Basins were drawn using the best available LiDAR data and previously delineated basins from the Master Manual were used as a guide (USACE, 1998). Maps of the L-575 and L-536 basins are shown in Plate 24 and Plate 25.

Lateral structures had to be subdivided in the RAS geometry because lateral structures can only be connected to one storage area. The ArcMap extension GeoRAS was used to extract the data. The lateral structures were updated with the post-2011 flood setback levee alignments, elevations, and culvert information. The National Levee Database (NLD) did not contain the latest information from the setback levees so design elevations were used. Storage area connections were also required for between each of the storage areas. The LiDAR surface was used to extract elevations for the storage area connections.

6.4 Culvert Data

The L-536 O&M manual was updated in 2014 and the L-575 O&M manual was in the process of being updated at the time of this study. Tables containing updated culvert data were used in this analysis. Several structures had been removed or moved to new setback levees. Structures in place as of 2015 were compiled and input into the HEC-RAS geometry. The list of L-536 and L-575 culverts and the parameters used in RAS are shown in Plate 30 and Plate 31. Culvert locations are shown on the basin map on Plate 24 and Plate 25.

6.5 Pump Data

The best available pump data was contained in the updated O&M manual's table of culverts. However, it is noted that pumps are not always maintained and operated by the levee drainage districts so there is very little current information known. Pump information was gathered from the original O&M manual, periodic inspection reports, and previous efforts from the Master Manual Interior Drainage Analysis (USACE, 1998). As was done in the Master Manual Interior Drainage Analysis, the pump on elevations were set to the top of the culvert and pump off elevations were set 1 foot below the on elevation. Pump data for both L-575 and L-536 are shown in Plate 32.

HEC-RAS requires a pump capacity curve including losses. Since such little information was known about the pumps, Design Branch, Mechanical Section was tasked with providing pump capacity curves for this analysis. Curves were provided for seven of the eighteen pumps. Multiple curves were very similar and effective duplicates were removed, leaving four total pump curves used in the analysis. The pump capacity curve used for each pump was assigned based on the size given in the O&M manual table. Friction and minor losses were included in the final pump

capacity curves. Due to the pumps being at permanent pump stations that go through the levee, the “highest elevation in the pump line” option in HEC-RAS was left blank. The pump curves and pump curve loss parameters are shown in Plate 33 and Plate 34.

6.6 Seepage Calculations

Seepage into the interior area during periods of high river stage was accounted for by use of a lateral inflow hydrograph boundary condition to each storage area in the HEC-RAS interior drainage model. Each piece of lateral structure bounding the storage areas was analyzed. Longer stretches were further sub-divided into sections of 10,000 ft or less. A reference cross section was chosen to calculate the seepage into each lateral structure piece. Missouri River stage output from each alternative was used to calculate the seepage with a daily time step. Note that higher river levels affect interior groundwater levels, and is not accounted for in this analysis.

A geotechnical engineer provided maximum (at the levee crest) seepage rates for both levee units. The seepage rate follows a linear relationship from the maximum (levee crest) to the zero point (usually the levee toe). For relief wells in levee unit L-536, a head of 2.5 feet was considered the zero point. See Attachment 1, the Geotechnical Seepage Tech Report, *L575 and L536 Seepage Flow Determinations* (USACE 2016a) for further details. For L-575, the seepage rates given were separated into berm, non-berm, and relief well. For L-536, the seepage rates given were separated into levee/berm and relief well. Total lengths of each seepage rate category were calculated for each lateral structure piece.

For each day in the POR, the differential head was calculated and was multiplied by the seepage rate and the length of levee or number of relief wells. The first seepage iteration used the river stage output from Alternative 1. The second seepage iteration used the river stage output from each alternative. The seepage calculations for all of the lateral structure pieces connected to a storage area were added together. The final interior drainage model contained lateral inflow hydrographs of total seepage for each storage area for each alternative.

6.7 Rainfall Data

An HEC-HMS model provided rainfall inflow hydrographs to each storage area for the POR for the two levee unit basins. Each storage area inflow dataset was input into the HEC-RAS model as a lateral inflow hydrograph. Unlike the seepage, which had alternative specific inflows, the same rainfall input was used for all of the alternative runs. For more information on the HEC-HMS model and its components, see Attachment 2, *Missouri River Interior Drainage Hydrologic Analysis* (USACE 2016c).

6.8 Results

All interior drainage alternative runs were performed in HEC-RAS 5.0 Beta (21-August-2015), the same version as the full alternative runs. Results from the 83-year runs for the six alternatives were provided to the HC team for analysis. They used the daily storage area elevation output to analyze effects to flood risk. The HC team performed an extensive analysis on each alternative and provide a detailed comparison of results. For this report, only the hydraulic model output is presented.

To express the changes compared with the No Action alternative, the water surface elevation model results were evaluated by the same statistical evaluations made on the full models. All of the alternatives show minor differences between water surface elevation. Tables showing differences between the calculated statistics for water surface elevation for the twelve storage areas can be seen in Plate 26. The statistics calculated include: the 10th, 25th, 50th, 75th, and 90th-Percentiles, and the Minimum and Maximum. Alternative 2 has the greatest impact (higher water surface elevations) among the alternatives.

An example output can be seen in Plate 28. It shows the interior storage area (575A) and exterior (cross section 571.2) water surface elevations. Higher river water surface elevations cause flap gates to close and produce higher water surface elevations in the interior area.

The interior drainage models provide a powerful tool to assess the complicated interaction between reservoir releases upstream of a levee unit on interior ponding resulting from rainfall and/or seepage. However, limited conclusions can be extrapolated to the entire river. With such slight differences compared to No Action, it is difficult to separate the impact of flow changes from the reservoirs from the impact of added habitat to make global conclusions. Changes are highly localized, depending upon factors such as how low the culvert outlet is and the interior area available for ponding before damages occur.

6.9 Sensitivity Analysis and Results

A series of sensitivity runs were conducted for the interior drainage analysis. They included three actions either alone or in combination: all pumps removed, culverts filled with sediment halfway, and a simulated pulse every year (spring or fall, depending on the alternative). Reasons for running each sensitivity are as follows:

- All of the pumps removed - conducted due to the uncertainty with the pumps' physical and operational information.
- Culverts half filled with sediment - conducted because of a comparison to limited temporary gage data revealed that the model's water surface elevations were generally low.
- Simulated pulse every year - conducted to analyze if the timing and amount of pulses had a large effect on the results.

An example output plot from the interior drainage sensitivity is shown in Plate 29. Adding the culvert sediment increased the minimum elevation that the storage area could drain down to while taking out all of the pumps increased the water surface elevation when the flap gates were blocked.

The simulated pulse every year was achieved by setting the flow below the Platte River to be 75,000 cfs during the pulse timeframes (either spring or fall) with appropriate ramp up and ramp down time. 75,000 cfs was chosen because it is just below the flood target of 82,000 cfs for Nebraska City in the ResSim model. As seen in Figure 6-1, a flow of 75,000 cfs produces a profile that either partially or fully covers all of the flap gates on L-536 and L-575 (circled in red).

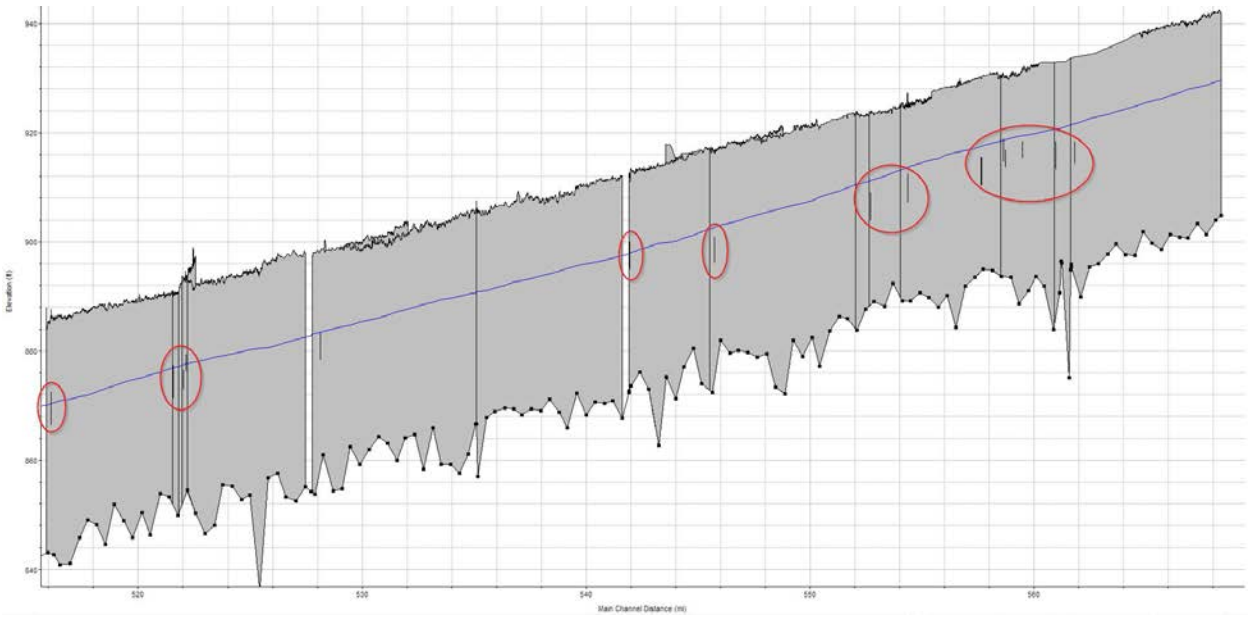


Figure 6-1: 75,000 cfs Profile and Flap Gates

Sensitivity analyses indicated that changes in assumptions about the interior drainage structures have much larger effects than the differences between the alternatives. The results from the sensitivity runs were analyzed and revealed that taking out all of the pumps had the most effect on the storage area water surface elevations. The culvert sediment and pulse every year runs produced minimal differences compared to the no pumps run. Statistics of the results and the difference between them and the matching alternative's results can be found in Plate 27. The risk of flooding from interior drainage is much more a function of the conditions of the interior drainage structures (culverts and pumps) at specific sites. Alternative 2 has relatively larger impacts compared with Alternatives 3-6.

A timestep sensitivity analysis was also performed for the interior drainage model. The timestep used for the alternatives and interior drainage models was 30 minutes. A sensitivity run using a 2-minute timestep was conducted and compared to the original output. A comparison of the annual max stage timeseries was performed since the flood risk analysis (HEC-FIA) uses peak stages only. As seen in Table 6-1, for the cross sections and storage areas, the annual max results were generally within 0.05 ft. There is a max difference of 0.1 ft for the cross sections and -0.35 ft for the storage areas. Another factor considered with the timestep sensitivity is the total model runtime. The original interior drainage model (30-min timestep) took 6.5 hours to run while the 2-min timestep model took almost 10 times longer at 63 hours. This was not a feasible run time to conduct numerous runs in a reasonable amount of time.

Table 6-1: Timestep Sensitivity Results

	Stage - Annual Max (ft)		
XS	**Min**	**Max**	**Mean**
591.15	-0.0005	0.002	0.0006
580.98	-0.0007	0.01	0.002
570.83	-0.0009	0.02	0.003
562.74	0.00006	0.02	0.005
560.32	0.00006	0.02	0.005
550.61	-0.001	0.04	0.008
540.15	-0.002	0.04	0.009
530.01	-0.002	0.06	0.01
520.25	-0.002	0.09	0.02
510.03	-0.003	0.1	0.02
500.15	-0.0007	0.1	0.02
SA			
575 A	-0.05	0.05	0.003
575 B	-0.18	0.05	-0.005
575 C	-0.009	0.02	0.002
575 D	-0.02	0.02	0.002
575 E	-0.06	0.07	0.002
575 F	-0.11	0.05	0.0004
575 G	-0.02	0.06	0.007
575 H	-0.35	0.09	-0.009
536 A	-0.03	0.07	0.005
536 B	-0.02	0.05	0.003
536 C	-0.03	0.11	0.006
536 D	-0.04	0.05	0.003

7 CONCLUSIONS

The unsteady HEC-RAS model analysis gives a means to systematically evaluate differences in river elevations for various reservoir and habitat alternatives given the limitations presented in Section 5.3. These results can be fed into additional species and human considerations models, such as HEC-FIA, to screen alternatives for relative benefits and potential economic impacts. The outputs should be carefully examined with an eye towards the model limitations and judgement applied where needed to mitigate any potential pitfalls of the hydraulic analysis. An advantage to the alternative modeling in this study is the ability to account for differences in flow routings and river stages with varying amounts and distributions of habitat.

If flow change alternatives are considered for implementation, additional risk and uncertainty analysis is recommended to more comprehensively quantify risk of spring or fall pulse flows.

The analysis presented in this report is based off of alterations to the existing conditions HEC-RAS models. The steps of this analysis could be repeated if predictions of bed change are made for any of the alternatives. Having both analysis completed would provide a range of reasonable results throughout the planning horizon.

8 REFERENCES

FAA (2007). *Advisory Circular No. 150/520-33B Hazardous Wildlife Attractants on or Near Airports.* U.S. Department of Transportation, Federal Aviation Administration.

USACE (1998). *Missouri River Master Water Control Manual, Review and Update Study, Volume 11: Interior Drainage Study.* U.S. Army Corps of Engineers, Northwestern Division – Missouri River Region, Omaha, NE, August 1998.

USACE (2003). *Upper Mississippi River System Flow Frequency Study - Hydrology and Hydraulics Appendix F.* Omaha, NE, U.S. Army Corps of Enginers.

USACE (2007). Office Report. *Missouri River Gavins Point Dam to Rulo, NE Shallow Water Habitat Profile, August Flow Duration.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2013). *Hydrologic Statistics Technical Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2014a). *Missouri River Incremental Flows Below Gavins Point Technical Report*. Omaha, NE, U.S. Army Corps of Engineers.

USACE (2014b). *Operation and Maintenance Manual, Missouri River Levee Units L-561, L-550, L-536.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2015a). *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix D Gavins Point Dam to Rulo, NE.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2015b). *Shallow Water Habitat Accounting Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016a). *L575 and L536 Seepage Flow Determinations.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016b). *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016c). *Missouri River Interior Drainage Hydrologic Analysis.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016d). *Missouri River Recovery Management Plan - Climate Change.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016e). *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE (2016f). *Operation and Maintenance Manual, Missouri River Levee Unit L-575.* Omaha, NE, U.S. Army Corps of Engineers.

USACE (2016g). *Missouri River Recovery Program Management Plan Environmental Impact Statement, Summary of Hydrologic Engineering Analysis.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USFWS (2003). *U.S. Fish and Wildlife Service 2003 Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System.* U.S. Fish and Wildlife Service.

USFWS (2015). *Planning Aid Letter Regarding the Missouri River Recovery Management Plan-EIS: USFWS 2003 BiOp Projected Actions Alternative.* Yankton, SD, U.S. Fish and Wildlife Service.

APPENDIX D

GAVINS POINT DAM TO RULO, NE

PLATES

River	Reach	RS	(Alt 1) Aug 50% Flow (cfs)	(Alt 2) Summer Low Flow (cfs)	(Alt 2) Mid-August Flow (cfs)	(Alt 2) Spring Pulse (cfs)	(Alt 3-6) Mid-June Flow (cfs)
Big Nemaha	River	13.66	201	574	399	599	674
Big Sioux River	Gage to Mouth	50.93	643	148	115	216	229
Boyer River	Gage to Mouth	15.74	299	152	100	141	187
James River	combined	55.606	273	1331	1029	1936	2057
Little Nemaha	Gage to Mouth	10.52	241	203	139	235	289
Little Sioux	REACH # 8	13.51	765	1119	732	1033	1378
Missouri River	Gavins to James	810.87	32627	21000	36900	48800	32200
Missouri River	Gavins to James	805.77	32607	21001	36901	48802	32202
Missouri River	James to Vermill	800.58	32880	22332	37930	50738	34259
Missouri River	James to Vermill	787.64	32884	22375	37963	50800	34325
Missouri River	James to Vermill	779.17	32852	22472	38038	50941	34474
Missouri River	Verm to BigSux	771.77	32874	22556	38103	51064	34605
Missouri River	Verm to BigSux	762.98	32839	22582	38123	51102	34645
Missouri River	Verm to BigSux	753.93	32804	22608	38144	51140	34686
Missouri River	Verm to BigSux	745.52	32802	22633	38163	51176	34724
Missouri River	Verm to BigSux	737.11	32791	23048	38483	51778	35365
Missouri River	BigSux to LilSux	734.1	33434	23196	38598	51994	35594
Missouri River	BigSux to LilSux	732.37	33428	23200	38600	52000	35600
Missouri River	BigSux to LilSux	732.17	33438	23221	38614	52020	35626
Missouri River	BigSux to LilSux	730.98	33582	23504	38799	52281	35975
Missouri River	BigSux to LilSux	724.87	33678	23551	38830	52324	36033
Missouri River	BigSux to LilSux	719.6	33775	23591	38856	52362	36083
Missouri River	BigSux to LilSux	713.98	33858	23615	38872	52384	36113
Missouri River	BigSux to LilSux	706.3	33978	23648	38893	52414	36153
Missouri River	BigSux to LilSux	697	34123	23688	38919	52451	36202
Missouri River	BigSux to LilSux	691.03	34221	23707	38931	52468	36225
Missouri River	BigSux to LilSux	683.21	34338	23825	39008	52577	36370
Missouri River	BigSux to LilSux	676.28	34441	23929	39076	52673	36498
Missouri River	BigSux to LilSux	669.82	34673	24026	39140	52763	36618
Missouri River	LSux to Soldier	669.32	35438	25145	39872	53796	37996
Missouri River	LSux to Soldier	664.94	35527	25191	39902	53839	38053
Missouri River	Soldier to Boyer	664.03	35628	25322	39987	53960	38214
Missouri River	Soldier to Boyer	654.88	35765	25356	40009	53991	38256
Missouri River	Soldier to Boyer	649.16	35869	25377	40023	54011	38282
Missouri River	Soldier to Boyer	647.55	35916	25419	40050	54049	38333
Missouri River	Soldier to Boyer	641.55	36011	25564	40144	54182	38511

Plate 1: RAS Reference Flow Input

River	Reach	RS	(Alt 1) Aug 50% Flow (cfs)	(Alt 2) Summer Low Flow (cfs)	(Alt 2) Mid-August Flow (cfs)	(Alt 2) Spring Pulse (cfs)	(Alt 3-6) Mid-June Flow (cfs)
Missouri River	Boyer to Platte	635.22	36310	25716	40244	54323	38698
Missouri River	Boyer to Platte	627.3	36430	25760	40272	54363	38752
Missouri River	Boyer to Platte	621.75	36543	25790	40292	54391	38789
Missouri River	Boyer to Platte	616.03	36632	25800	40300	54400	38800
Missouri River	Boyer to Platte	609.89	36665	25813	40309	54419	38822
Missouri River	Boyer to Platte	605.49	36725	25822	40315	54432	38837
Missouri River	Boyer to Platte	596.48	36833	25852	40335	54475	38886
Missouri River	Platte to Weepin	595	39806	30749	43665	61624	47014
Missouri River	Platte to Weepin	587.4	39874	30766	43676	61648	47042
Missouri River	Platte to Weepin	580.98	39910	30776	43683	61663	47059
Missouri River	Platte to Weepin	574.1	39949	30787	43690	61679	47077
Missouri River	Weeping to Nishn	568.7	40015	30796	43696	61691	47091
Missouri River	Weeping to Nishn	562.35	40049	30800	43700	61700	47100
Missouri River	Weeping to Nishn	555.14	40201	31215	43984	62181	47690
Missouri River	Weeping to Nishn	547.81	40354	31637	44273	62670	48291
Missouri River	Nishna to LilNem	542.02	41298	31971	44501	63056	48765
Missouri River	Nishna to LilNem	535.7	41426	32134	44612	63244	48996
Missouri River	LilNemah to Tark	527.8	41667	32337	44751	63479	49285
Missouri River	LilNemah to Tark	522.29	41798	32400	44794	63552	49375
Missouri River	LilNemah to Tark	517.42	41896	32487	44854	63653	49499
Missouri River	LilNemah to Tark	511.94	42009	32585	44921	63766	49638
Missouri River	Tarkio to BigNem	507.68	42165	32661	44973	63854	49746
Missouri River	Tarkio to BigNem	498.04	42362	32700	45000	63900	49800
NISHNABOTNA	Nishnabotna	61570	944	334	228	386	474
Nodaway	Nodaway	28.91	100	100	100	100	101
Platte River	Platte River	16.74	2973	4897	3330	7149	8128
SOLDIER	REACH # 10	12.28	101	131	85	121	161
Tarkio	Gage to Mouth	13.56	156	76	52	88	108
VERMILLION	REACH # 4	10.75	22	84	65	123	131
WEEPING	REACH # 16	6.5	66	9	6	12	14

Plate 1 cont'd: RAS Reference Flow Input

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Gavins Point - XS 810.87							
Alt 1A	10,500	13,644	25,181	33,320	40,000	9,000	160,000
Alt 2A	9,500	13,000	25,000	33,643	42,202	9,000	160,000
Change from Alt 1A	-1,000	-644	-181	323	2,202	0	0
Alt 3A	11,000	13,863	25,148	33,100	40,000	9,000	160,000
Change from Alt 1A	500	219	-33	-220	0	0	0
Alt 4A	9,500	13,000	25,100	33,500	40,100	9,000	160,000
Change from Alt 1A	-1,000	-644	-81	180	100	0	0
Alt 5A	11,000	13,500	25,100	33,100	40,000	9,000	160,000
Change from Alt 1A	500	-144	-81	-220	0	0	0
Alt 6A	10,000	13,355	25,100	33,600	40,500	9,000	160,000
Change from Alt 1A	-500	-289	-81	280	500	0	0
Sioux City - XS 732.37							
Alt 1A	12,219	16,077	28,500	35,629	44,508	7,693	188,742
Alt 2A	12,191	15,397	27,569	36,059	46,838	7,693	188,737
Change from Alt 1A	-28	-680	-931	429	2,330	0	-6
Alt 3A	12,229	16,214	28,414	35,568	44,481	7,693	188,753
Change from Alt 1A	10	136	-86	-61	-27	0	11
Alt 4A	12,184	15,408	28,207	35,615	45,571	7,693	188,755
Change from Alt 1A	-35	-669	-293	-14	1,063	0	12
Alt 5A	12,238	16,148	28,244	35,576	44,734	7,693	188,754
Change from Alt 1A	19	70	-256	-54	226	0	12
Alt 6A	12,188	15,796	28,197	35,798	45,288	7,693	188,754
Change from Alt 1A	-31	-281	-303	169	780	0	12
Omaha - XS 615.99							
Alt 1A	13,218	18,073	31,424	38,558	49,388	7,029	206,235
Alt 2A	13,220	17,454	30,603	39,304	51,762	7,030	206,055
Change from Alt 1A	3	-619	-821	746	2,374	1	-180
Alt 3A	13,257	18,188	31,336	38,477	49,362	7,029	206,262
Change from Alt 1A	39	115	-88	-81	-26	0	27
Alt 4A	13,146	17,658	31,199	38,626	51,092	7,029	206,262
Change from Alt 1A	-72	-416	-226	68	1,704	0	27
Alt 5A	13,243	18,173	31,185	38,538	49,925	7,029	206,262
Change from Alt 1A	25	99	-239	-20	537	0	27
Alt 6A	13,169	17,892	31,120	38,888	50,338	7,029	206,262
Change from Alt 1A	-48	-181	-304	329	950	0	27

Plate 2: Alternative Flow Statistics from POR Duration

Flow (cfs)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Nebraska City - XS 562.74							
Alt 1A	16,697	23,044	36,213	44,793	59,172	6,288	227,670
Alt 2A	16,681	22,372	35,225	46,183	60,552	6,286	227,057
Change from Alt 1A	-16	-672	-988	1,390	1,380	-3	-613
Alt 3A	16,764	23,197	36,139	44,718	59,166	6,288	227,793
Change from Alt 1A	67	154	-74	-75	-7	0	123
Alt 4A	16,531	22,700	35,850	44,945	60,933	6,288	227,793
Change from Alt 1A	-166	-344	-363	152	1,761	0	123
Alt 5A	16,715	23,130	35,972	44,746	59,963	6,288	227,793
Change from Alt 1A	18	86	-240	-47	791	0	123
Alt 6A	16,612	22,846	35,880	45,359	59,859	6,288	227,793
Change from Alt 1A	-85	-197	-333	566	686	0	123
Rulo - XS 498.07							
Alt 1A	17,308	24,263	37,512	47,078	63,231	6,026	275,174
Alt 2A	17,308	23,533	36,486	48,867	64,762	6,024	275,067
Change from Alt 1A	0	-730	-1,026	1,789	1,530	-2	-107
Alt 3A	17,391	24,431	37,389	47,051	63,308	6,025	274,947
Change from Alt 1A	83	168	-123	-27	76	0	-226
Alt 4A	17,132	23,845	37,102	47,490	65,074	6,025	274,949
Change from Alt 1A	-176	-417	-411	412	1,843	0	-224
Alt 5A	17,355	24,357	37,225	47,112	64,177	6,025	274,949
Change from Alt 1A	46	94	-287	34	945	0	-224
Alt 6A	17,230	23,992	37,170	47,927	63,784	6,025	274,948
Change from Alt 1A	-78	-271	-342	850	552	0	-225

Plate 2 cont'd: Alternative Flow Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Gavins Point - XS 810.87							
Alt 1A	1152.1	1152.8	1155.6	1157.0	1158.1	1151.4	1172.6
Alt 2A	1151.8	1152.6	1155.5	1157.1	1158.6	1151.4	1172.6
Change from Alt 1A	-0.3	-0.2	-0.1	0.1	0.5	0.0	0.0
Alt 3A	1152.2	1152.9	1155.6	1157.0	1158.1	1151.4	1172.6
Change from Alt 1A	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	1151.7	1152.7	1155.6	1157.0	1158.2	1151.4	1172.6
Change from Alt 1A	-0.3	-0.2	0.0	0.0	0.1	0.0	0.0
Alt 5A	1152.1	1152.8	1155.6	1157.0	1158.2	1151.4	1172.6
Change from Alt 1A	0.1	-0.1	0.0	0.0	0.1	0.0	0.0
Alt 6A	1151.8	1152.7	1155.6	1157.1	1158.3	1151.4	1172.6
Change from Alt 1A	-0.2	-0.1	0.0	0.1	0.1	0.0	0.0
Sioux City - XS 732.37							
Alt 1A	1062.7	1064.2	1068.7	1070.7	1072.9	1060.6	1093.4
Alt 2A	1062.7	1064.0	1068.4	1070.8	1073.3	1060.6	1092.9
Change from Alt 1A	0.0	-0.2	-0.3	0.1	0.4	0.0	-0.5
Alt 3A	1062.7	1064.3	1068.7	1070.7	1072.9	1060.6	1093.4
Change from Alt 1A	0.0	0.1	0.0	0.0	0.0	0.0	0.1
Alt 4A	1062.7	1064.0	1068.6	1070.7	1073.2	1060.6	1093.4
Change from Alt 1A	0.0	-0.2	-0.1	0.0	0.3	0.0	0.1
Alt 5A	1062.7	1064.3	1068.6	1070.7	1073.0	1060.6	1093.4
Change from Alt 1A	0.0	0.0	-0.1	0.0	0.1	0.0	0.1
Alt 6A	1062.7	1064.1	1068.6	1070.8	1073.1	1060.6	1093.4
Change from Alt 1A	0.0	-0.1	-0.1	0.1	0.2	0.0	0.1
Omaha - XS 615.99							
Alt 1A	955.5	957.4	962.1	964.1	966.8	952.7	985.0
Alt 2A	955.5	957.2	961.8	964.1	967.2	952.7	984.7
Change from Alt 1A	0.0	-0.2	-0.3	0.0	0.3	0.0	-0.3
Alt 3A	955.5	957.5	962.1	964.1	966.8	952.7	985.0
Change from Alt 1A	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Alt 4A	955.5	957.3	962.1	964.1	967.3	952.7	985.0
Change from Alt 1A	0.0	-0.1	-0.1	0.0	0.4	0.0	0.0
Alt 5A	955.5	957.5	962.1	964.1	967.0	952.7	985.0
Change from Alt 1A	0.0	0.0	-0.1	0.0	0.2	0.0	0.0
Alt 6A	955.5	957.4	962.1	964.2	967.1	952.7	985.0
Change from Alt 1A	0.0	-0.1	-0.1	0.1	0.2	0.0	0.0

Plate 3: Alternative Water Surface Elevation Statistics from POR Duration

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Nebraska City - XS 562.74							
Alt 1A	909.6	911.6	914.9	916.8	919.6	905.3	934.1
Alt 2A	909.6	911.4	914.7	917.1	920.0	905.3	934.1
Change from Alt 1A	0.0	-0.2	-0.2	0.3	0.4	0.0	0.0
Alt 3A	909.7	911.7	914.9	916.8	919.6	905.3	934.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	909.6	911.5	914.9	916.8	920.0	905.3	934.1
Change from Alt 1A	-0.1	-0.1	-0.1	0.1	0.4	0.0	0.0
Alt 5A	909.6	911.6	914.9	916.8	919.8	905.3	934.1
Change from Alt 1A	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Alt 6A	909.6	911.6	914.9	916.9	919.8	905.3	934.1
Change from Alt 1A	0.0	-0.1	-0.1	0.1	0.2	0.0	0.0
Rulo - XS 498.07							
Alt 1A	841.7	843.4	846.6	848.7	851.8	837.8	865.9
Alt 2A	841.7	843.3	846.5	849.0	852.4	837.8	865.9
Change from Alt 1A	0.0	-0.2	-0.2	0.3	0.6	0.0	0.0
Alt 3A	841.8	843.5	846.6	848.7	851.8	837.8	865.9
Change from Alt 1A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alt 4A	841.7	843.3	846.6	848.7	852.5	837.8	865.9
Change from Alt 1A	0.0	-0.1	-0.1	0.1	0.6	0.0	0.0
Alt 5A	841.7	843.5	846.6	848.7	852.2	837.8	865.9
Change from Alt 1A	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Alt 6A	841.7	843.4	846.6	848.8	852.0	837.8	865.9
Change from Alt 1A	0.0	-0.1	-0.1	0.1	0.2	0.0	0.0

Plate 3 cont'd: Alternative Water Surface Elevation Statistics from POR Duration

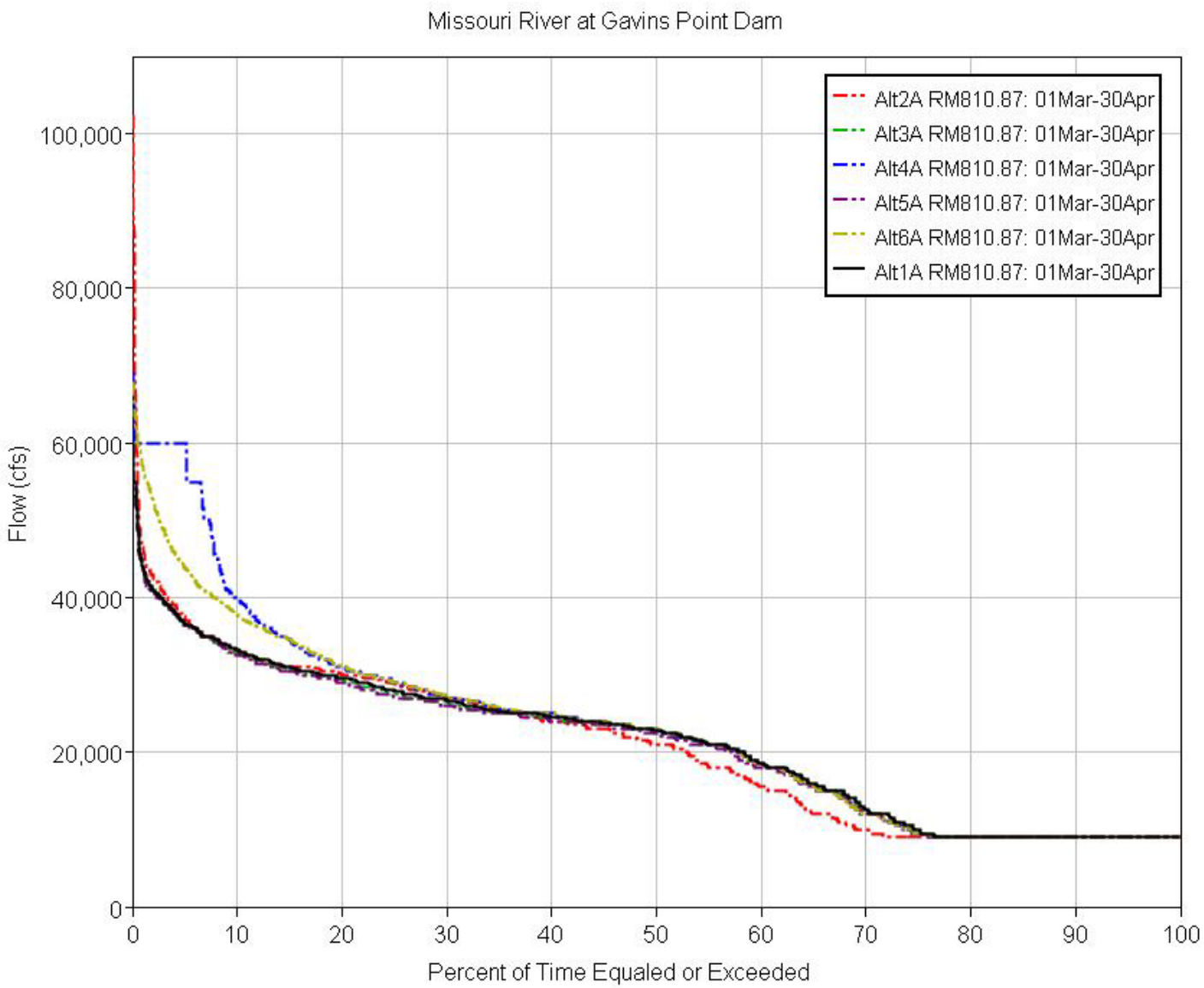


Plate 4: Gavins Point Spring Duration

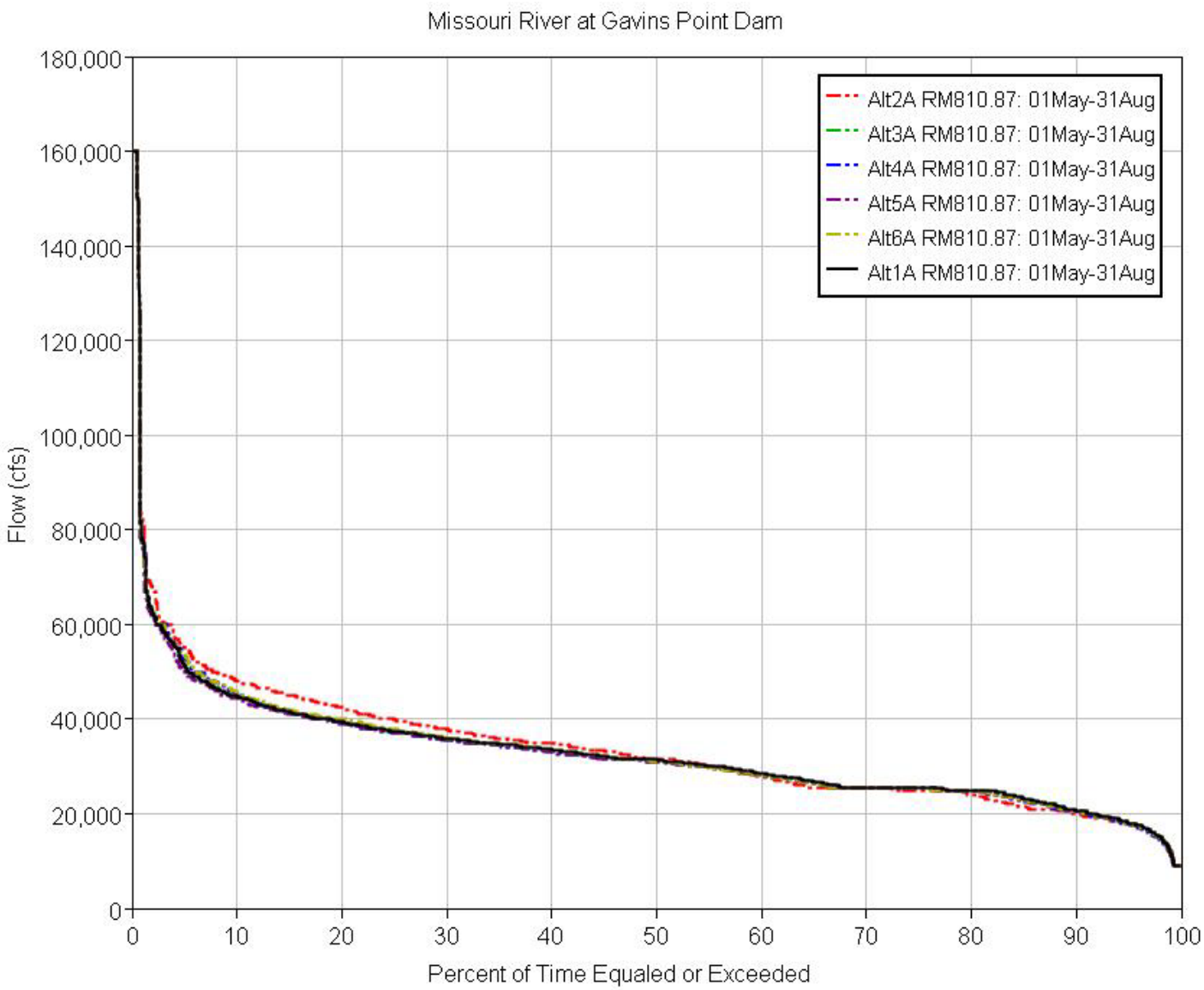


Plate 5: Gavins Point Summer Duration

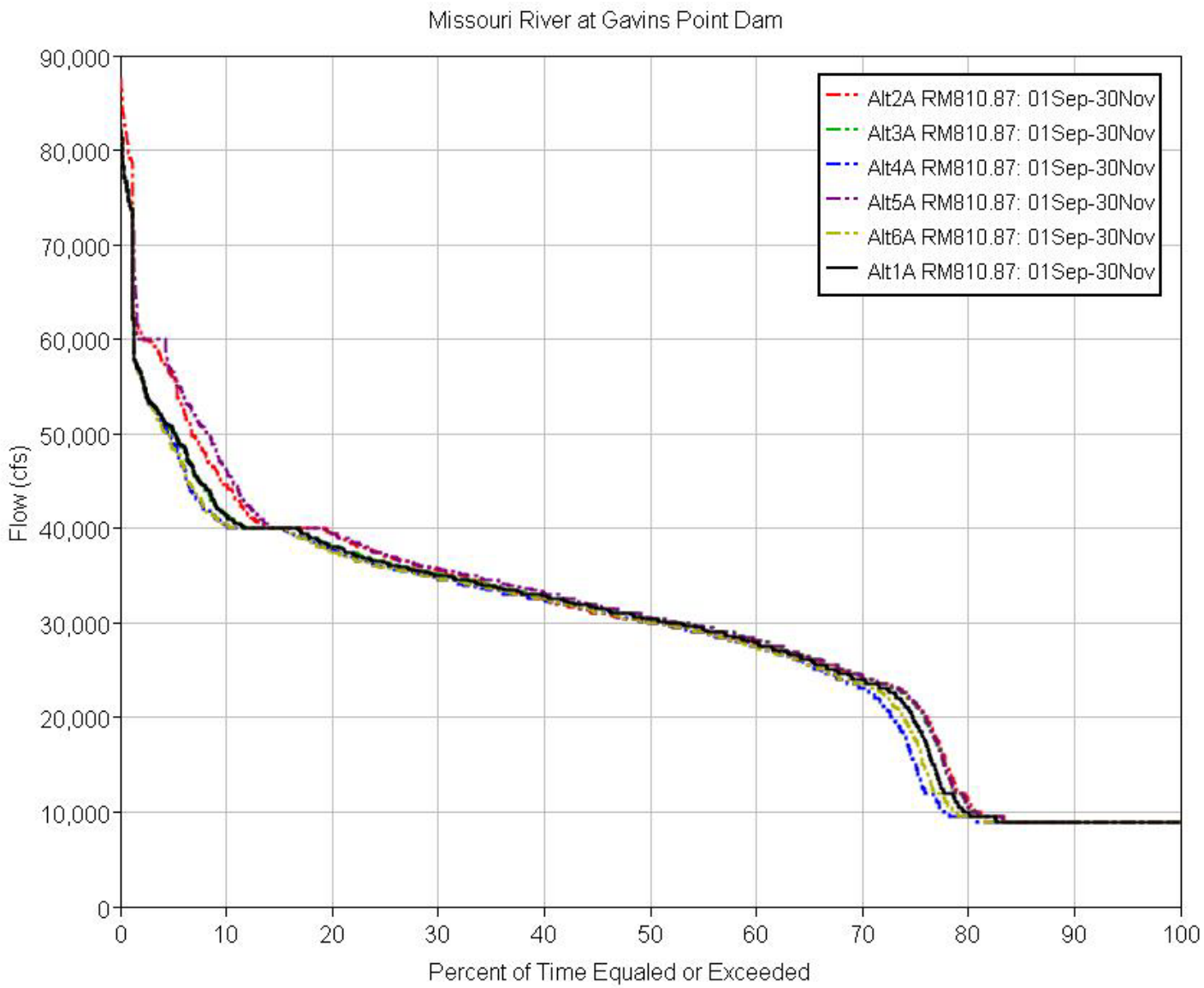


Plate 6: Gavins Point Fall Duration

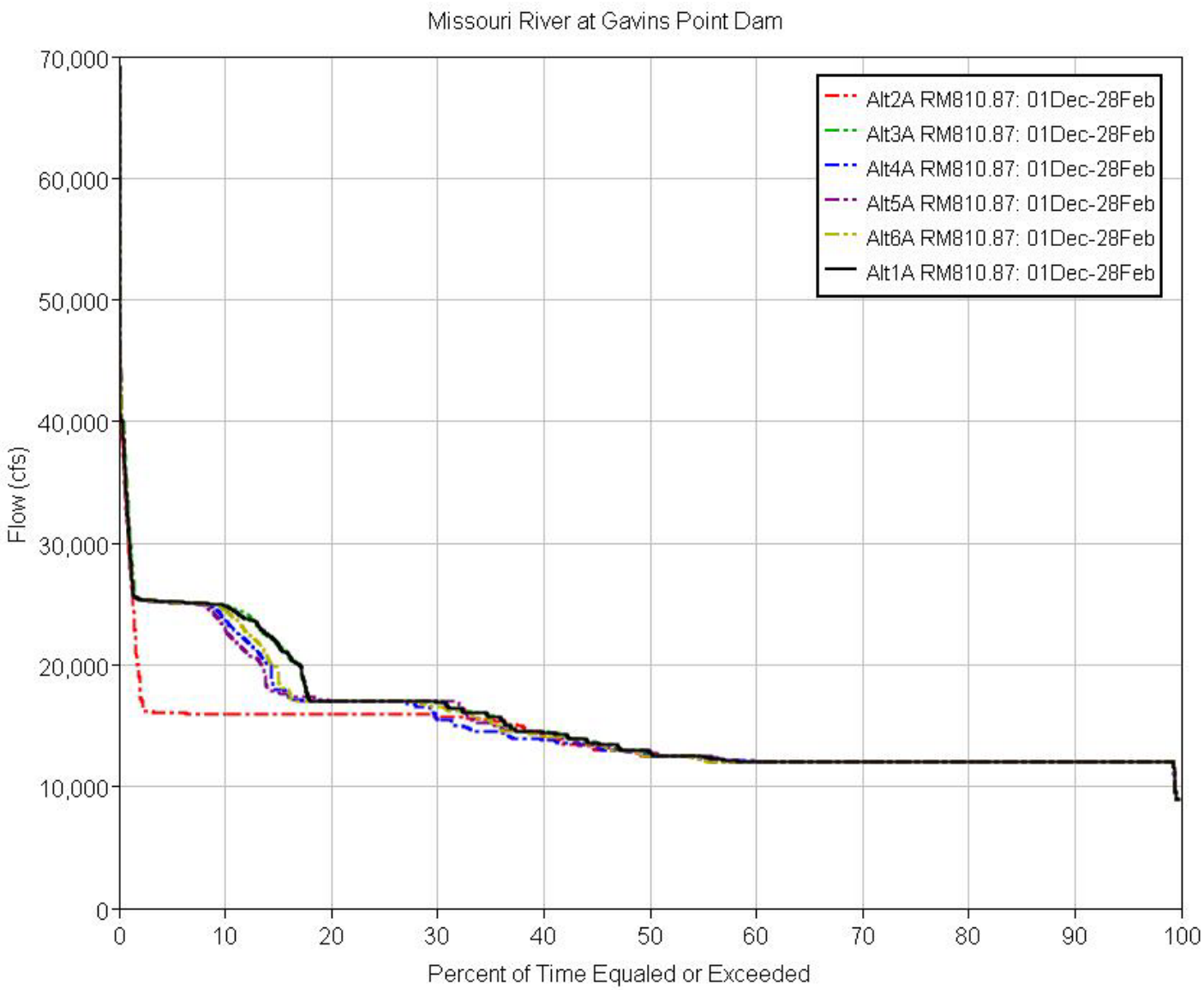


Plate 7: Gavins Point Winter Duration

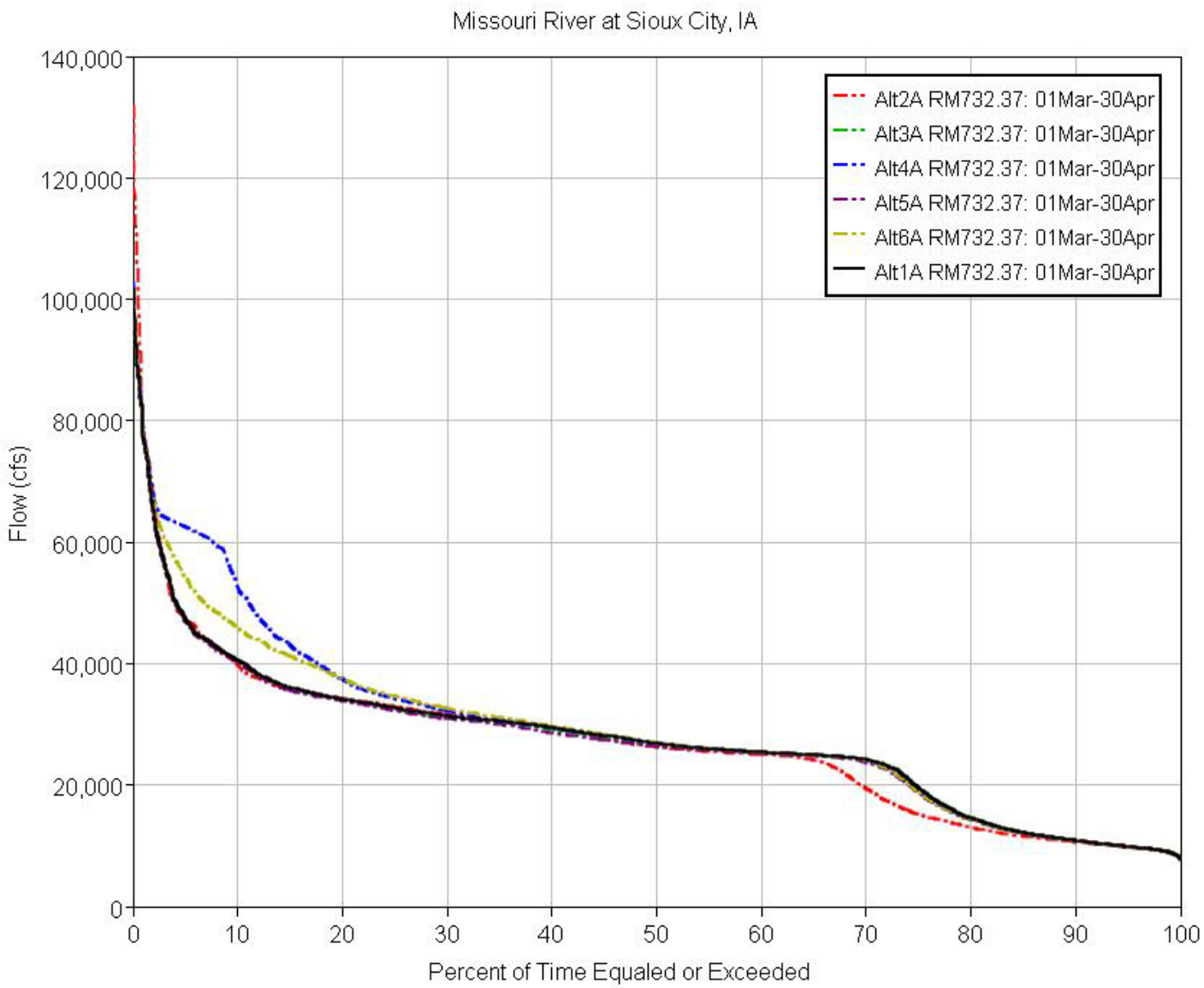


Plate 8: Sioux City Spring Duration

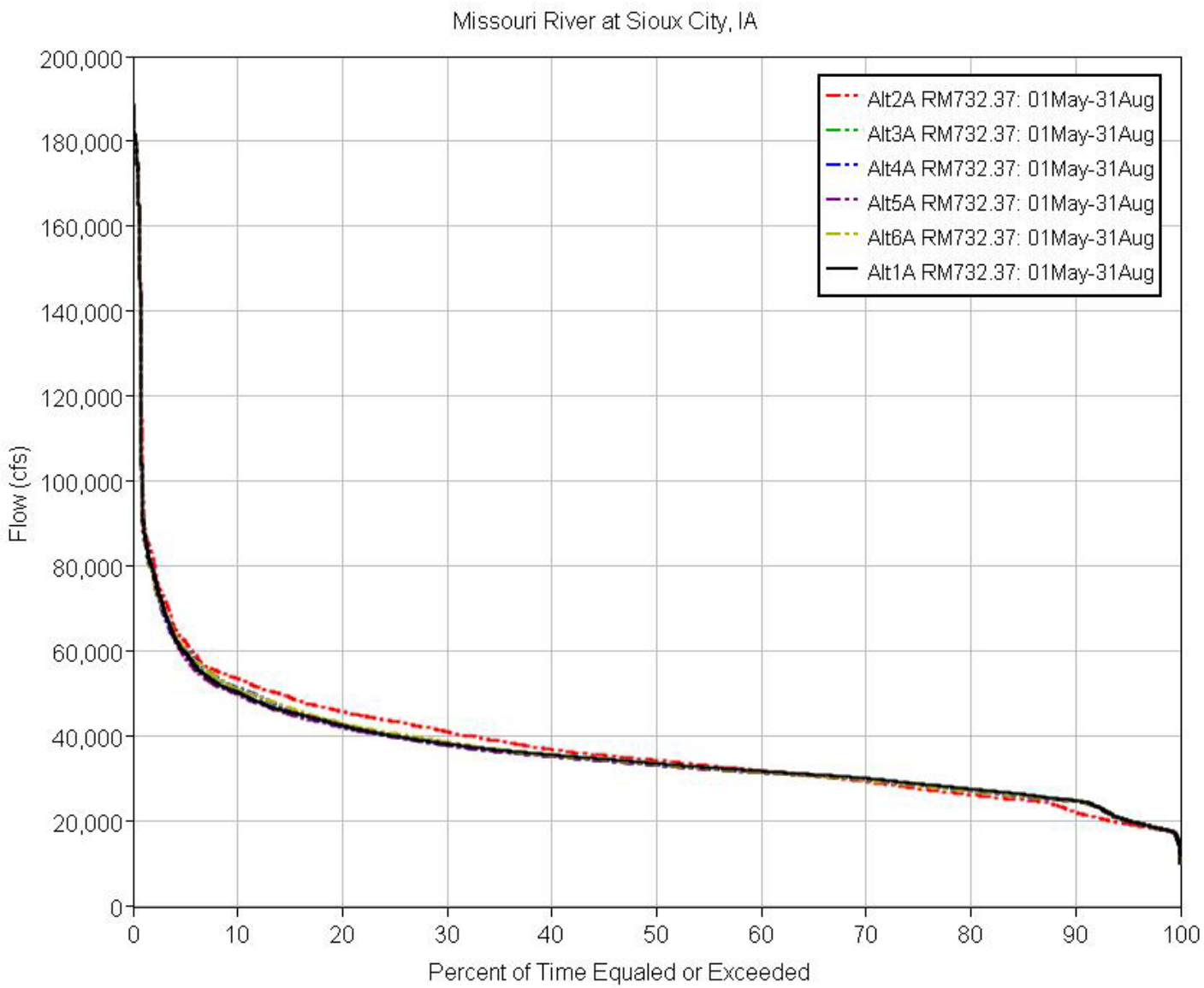


Plate 9: Sioux City Summer Duration

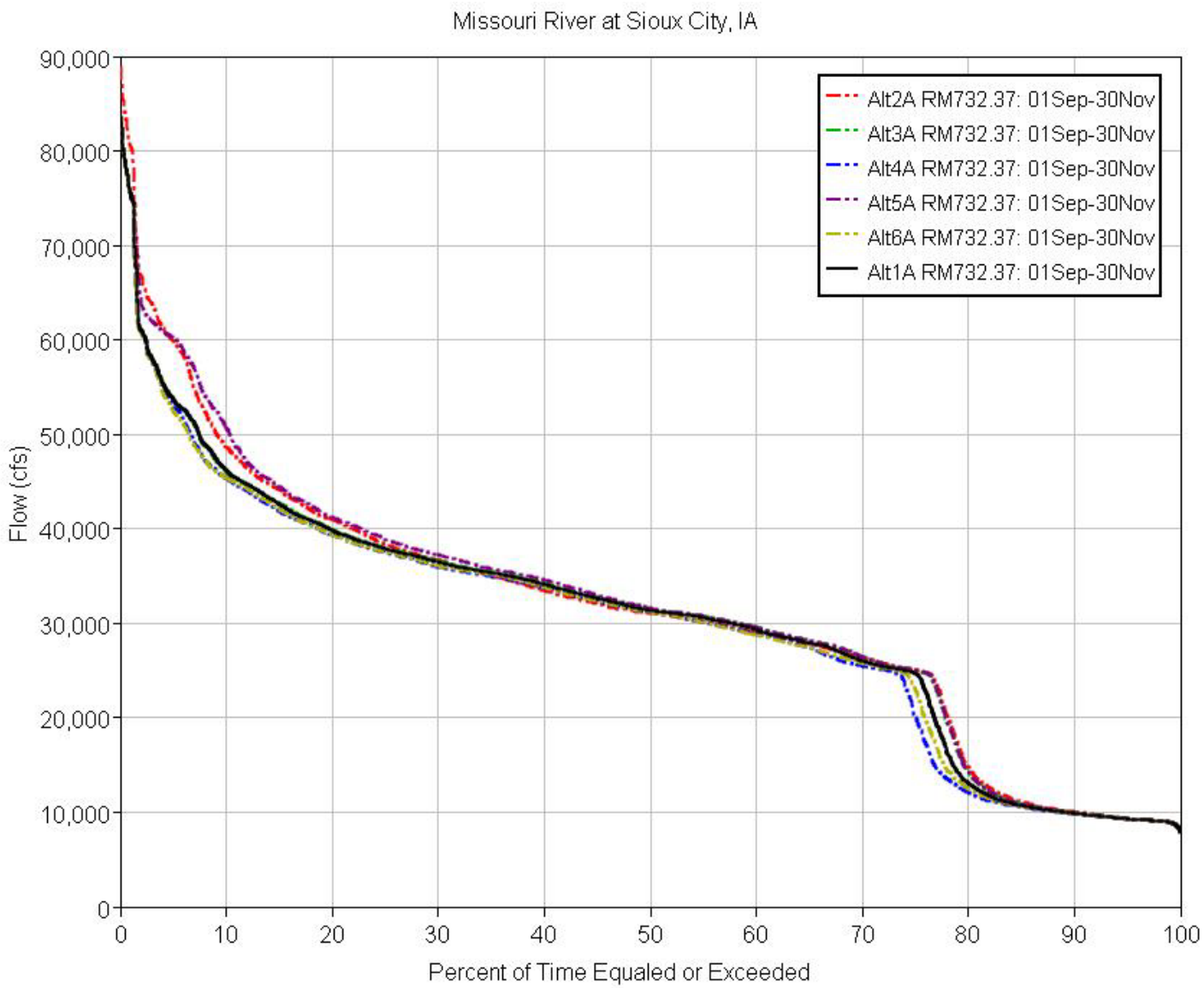


Plate 10: Sioux City Fall Duration

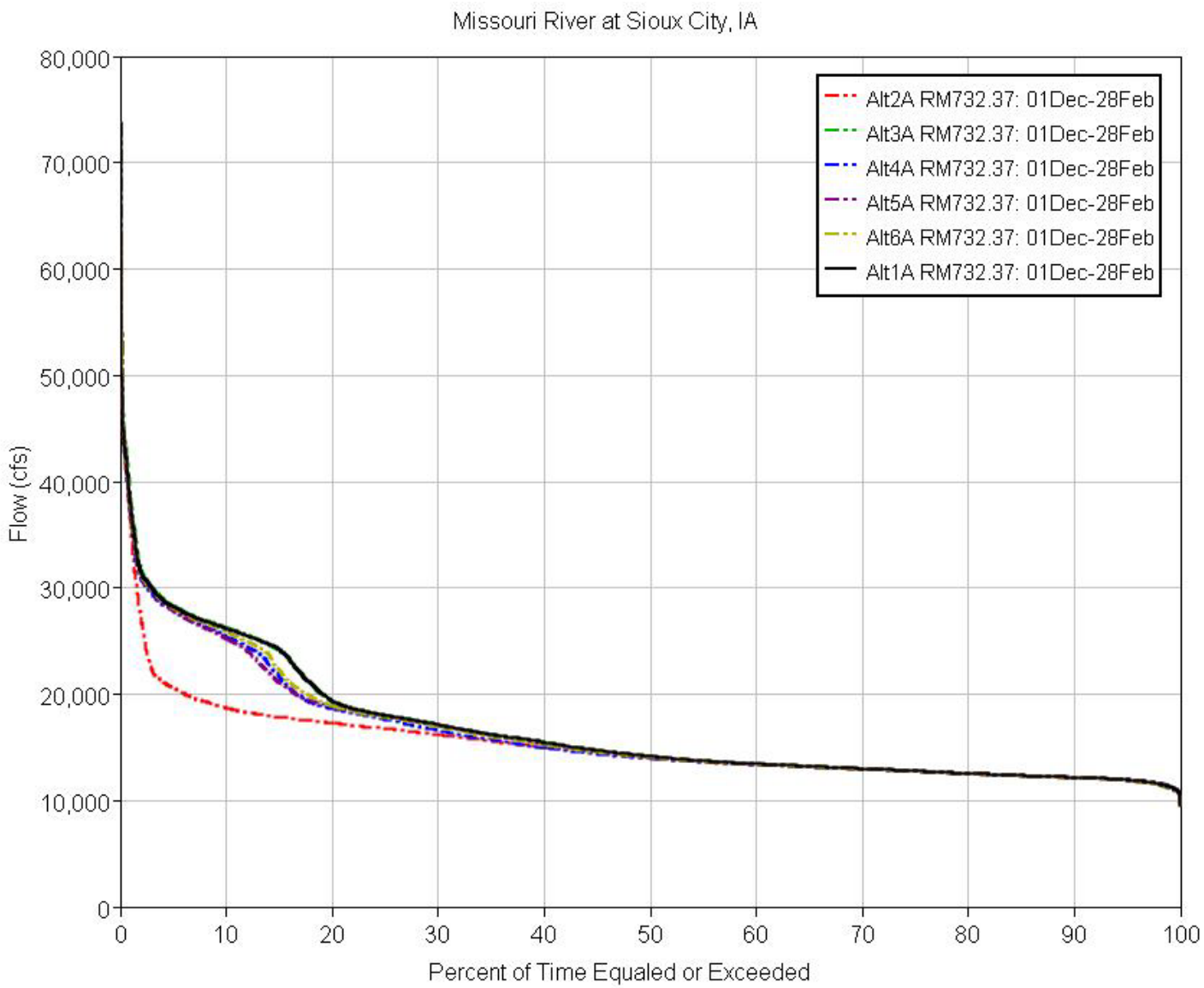


Plate 11: Sioux City Winter Duration

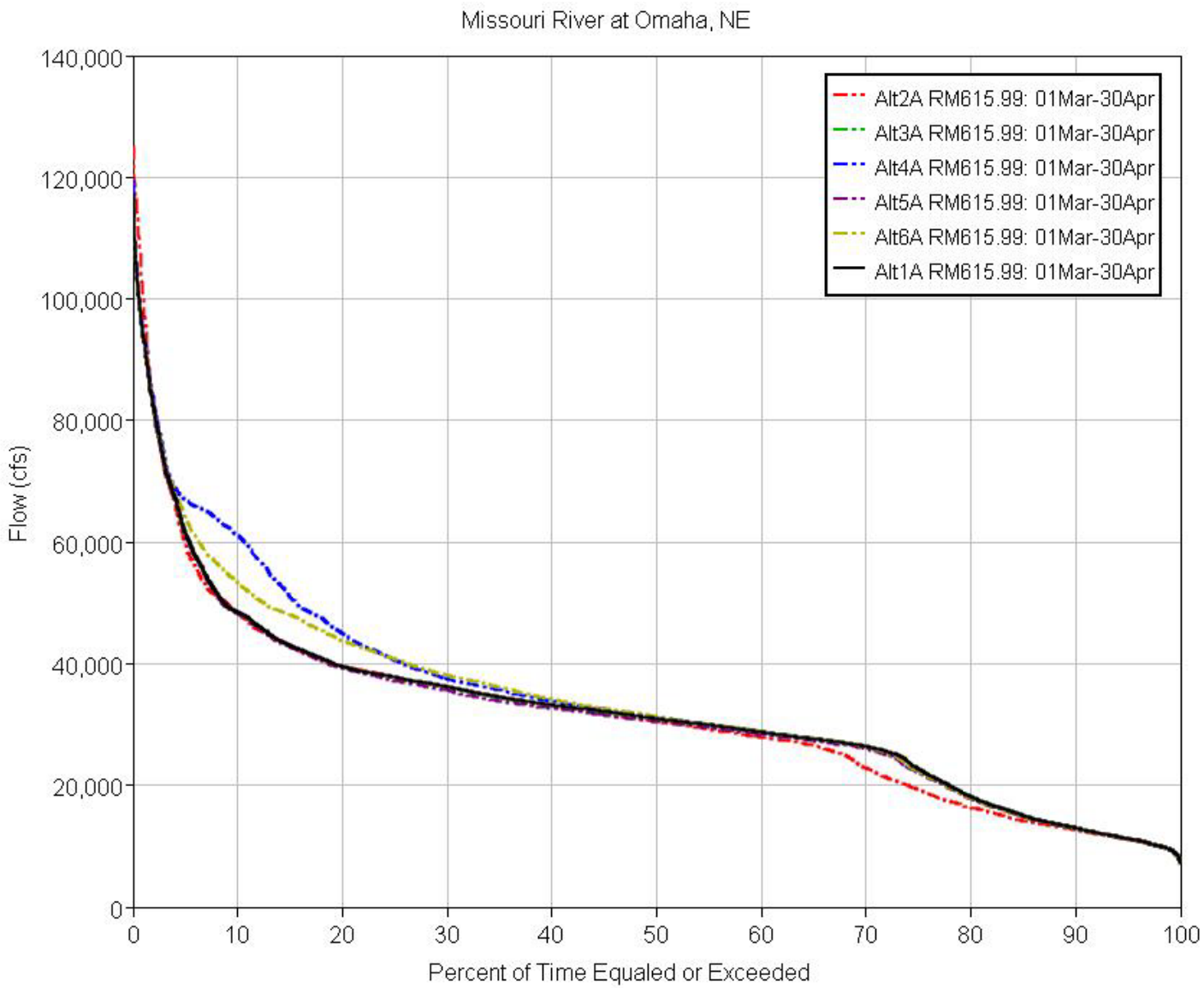


Plate 12: Omaha Spring Duration

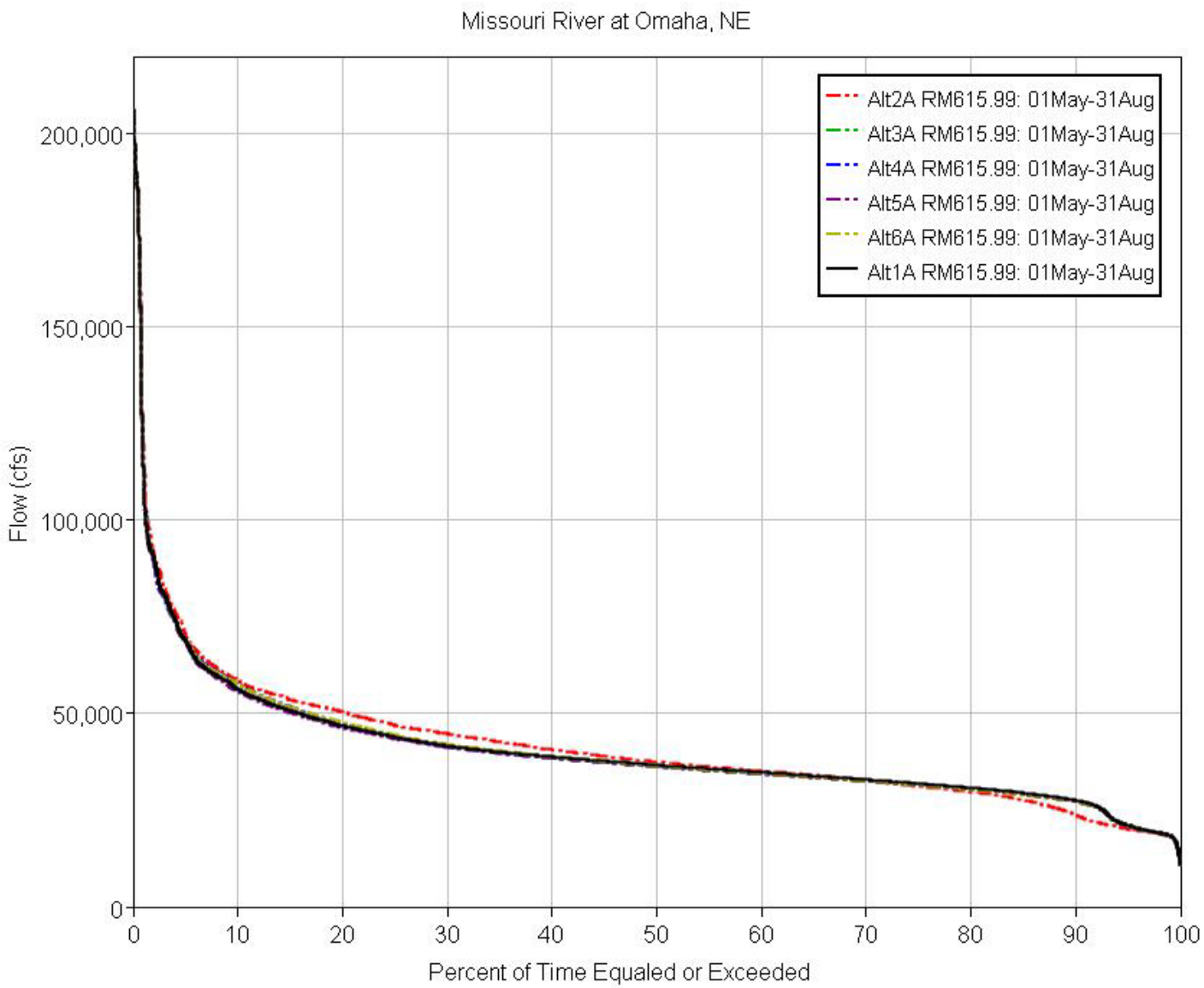


Plate 13: Omaha Summer Duration

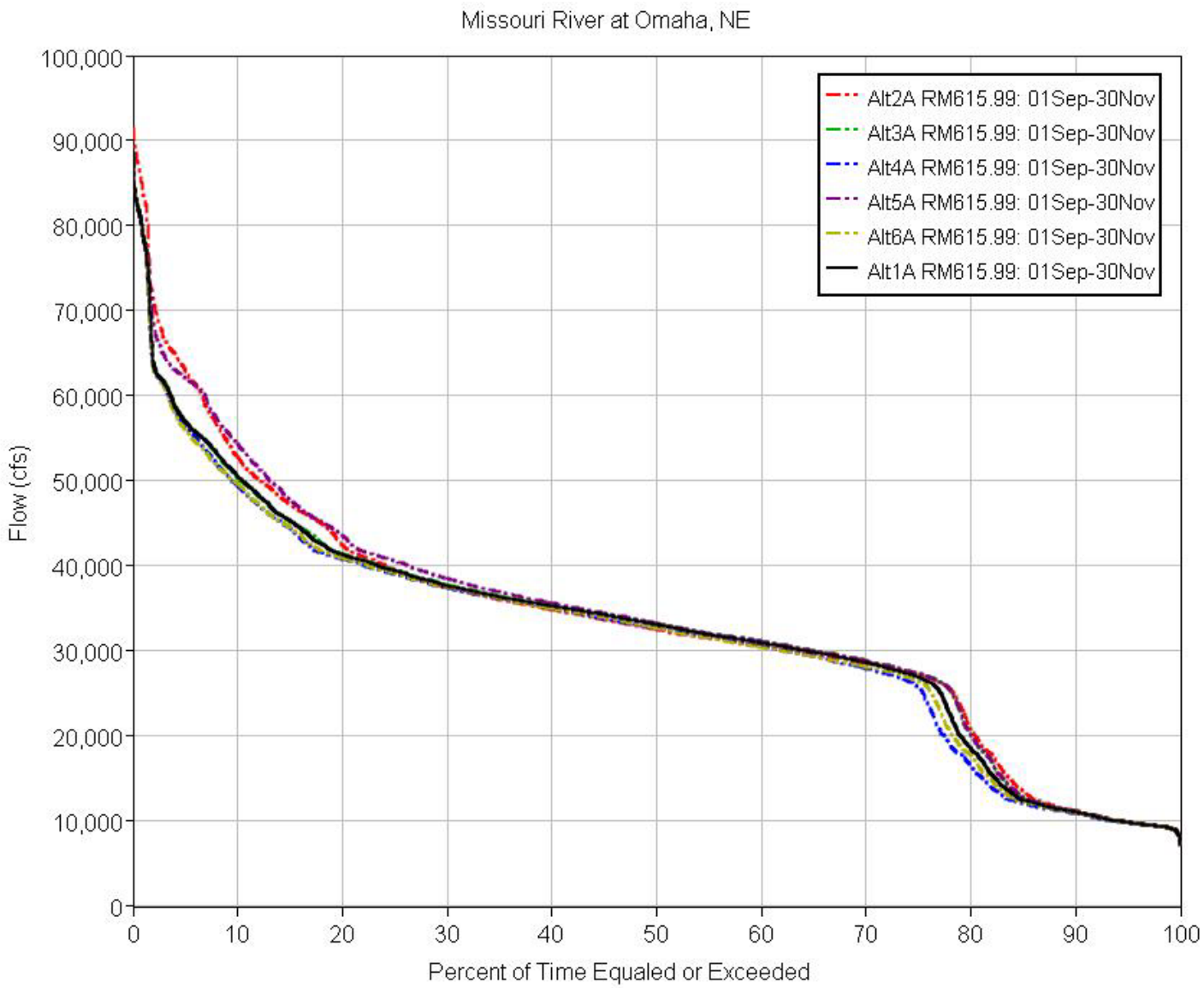


Plate 14: Omaha Fall Duration

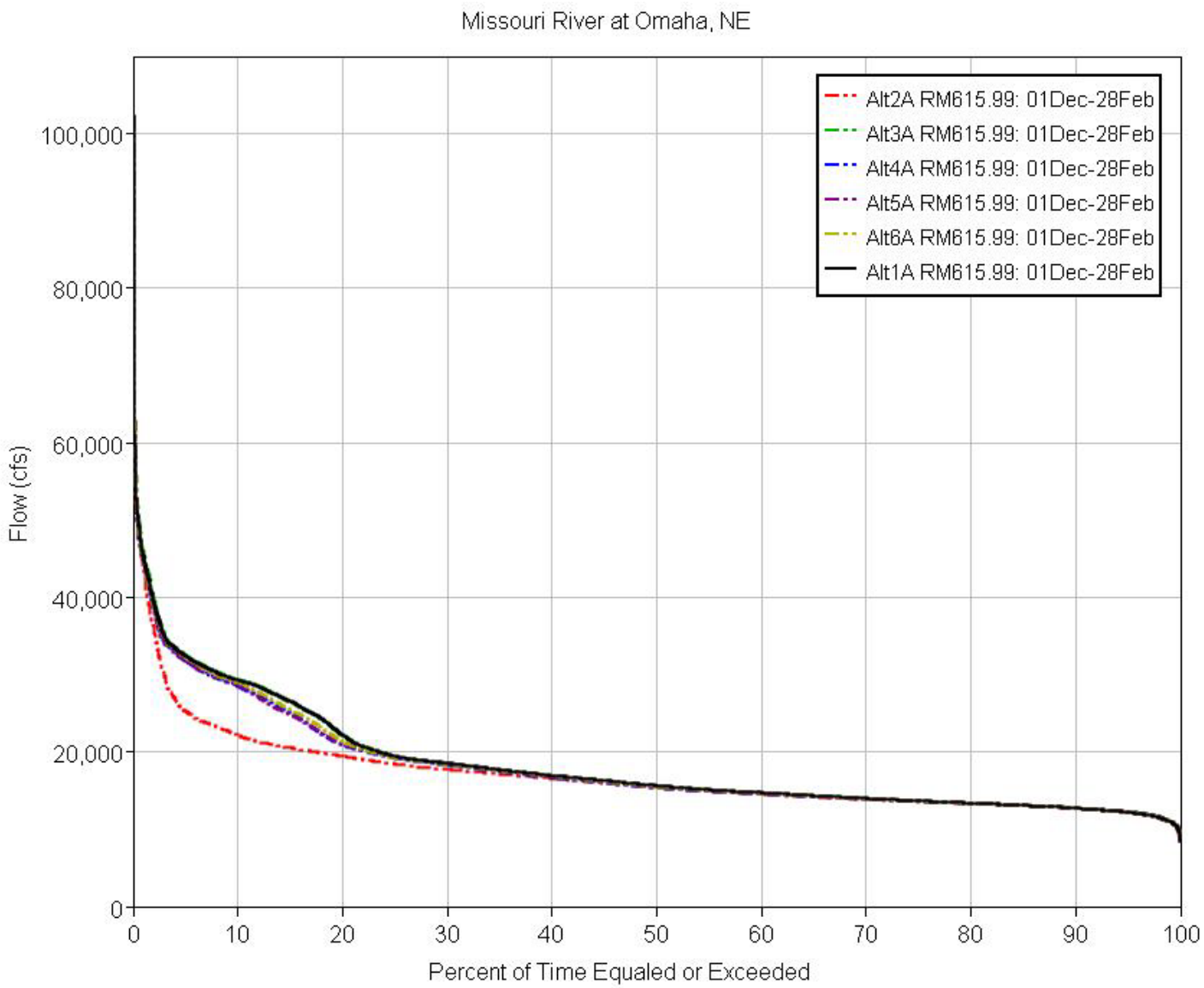


Plate 15: Omaha Winter Duration

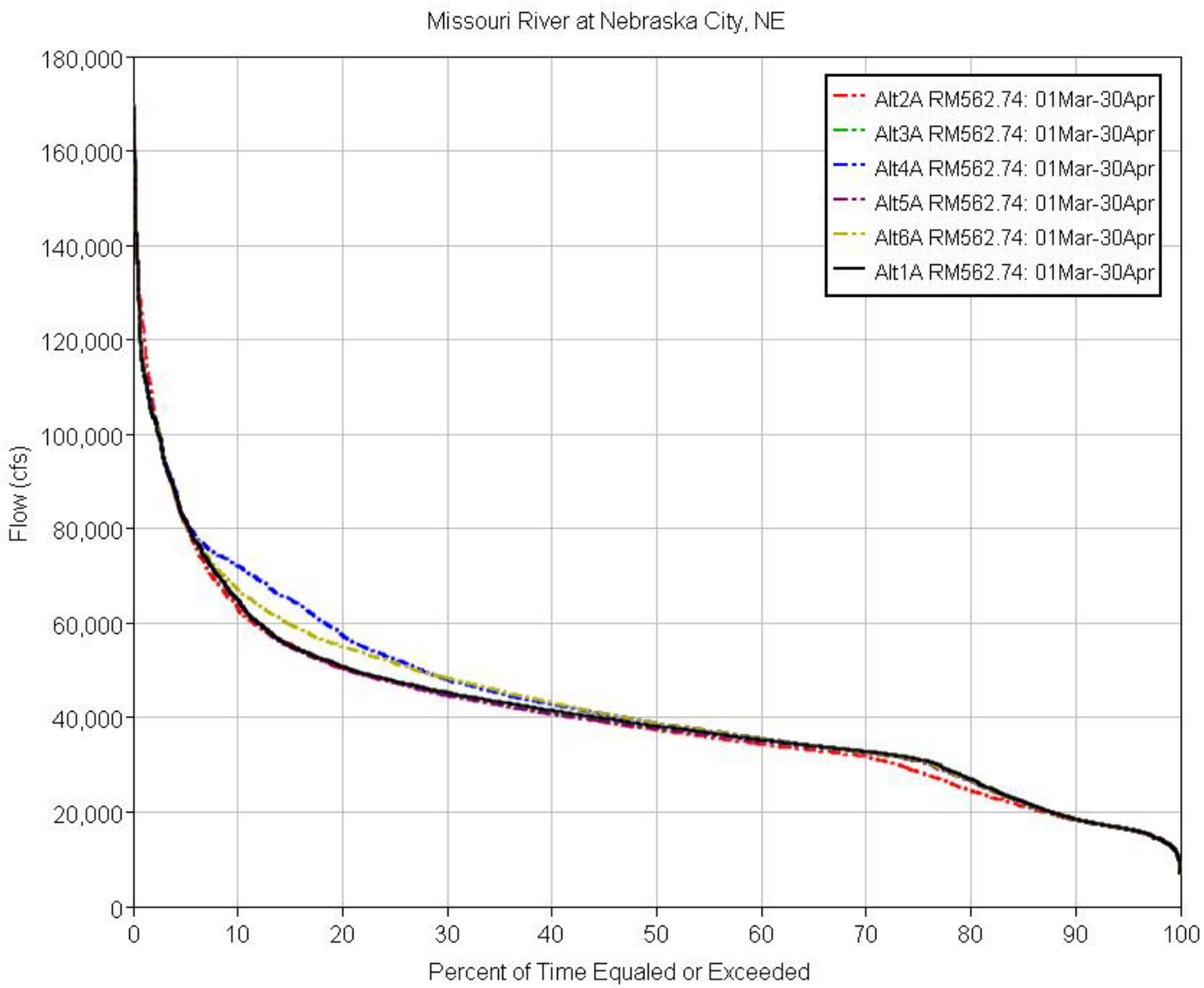


Plate 16: Nebraska City Spring Duration

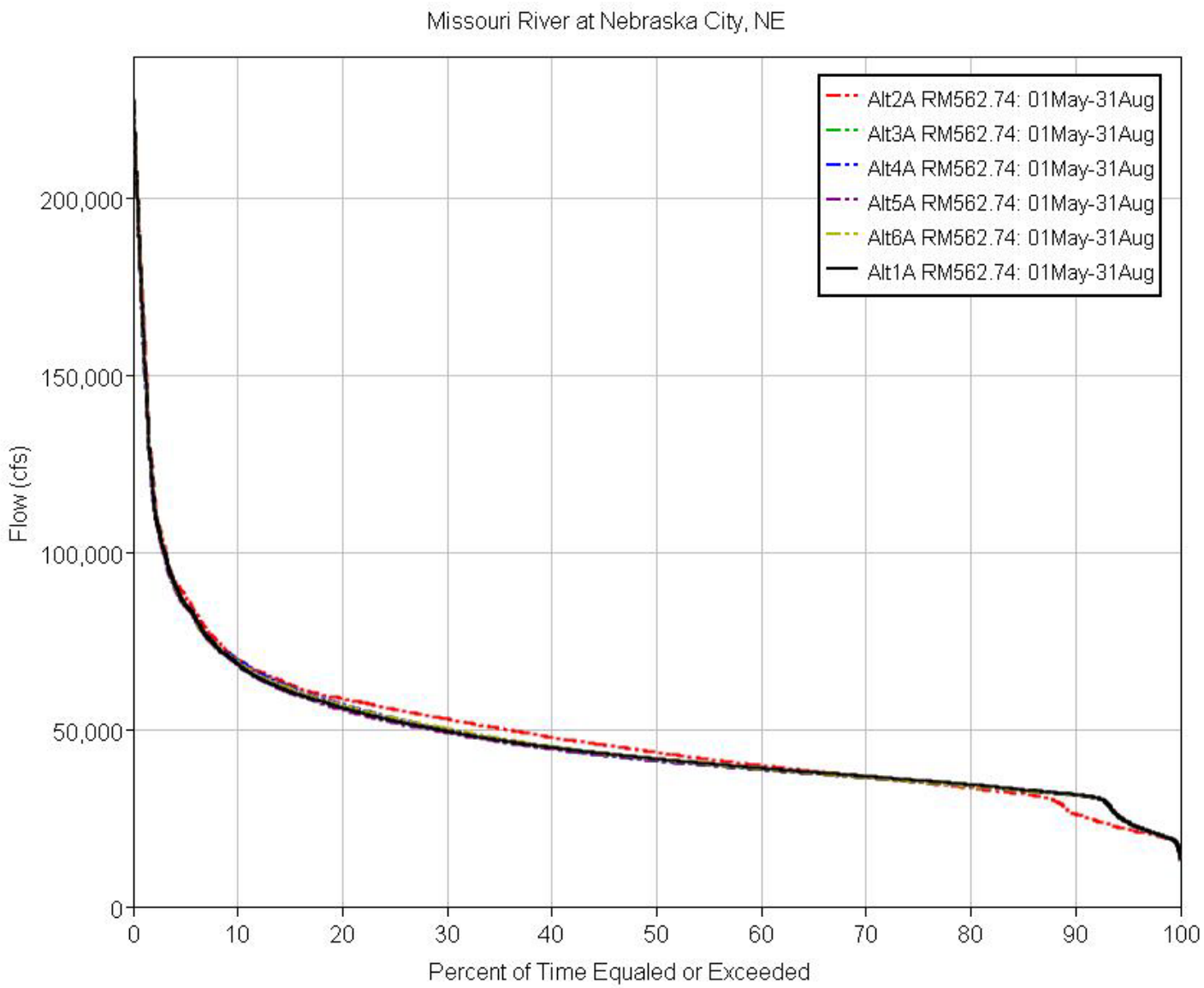


Plate 17: Nebraska City Summer Duration

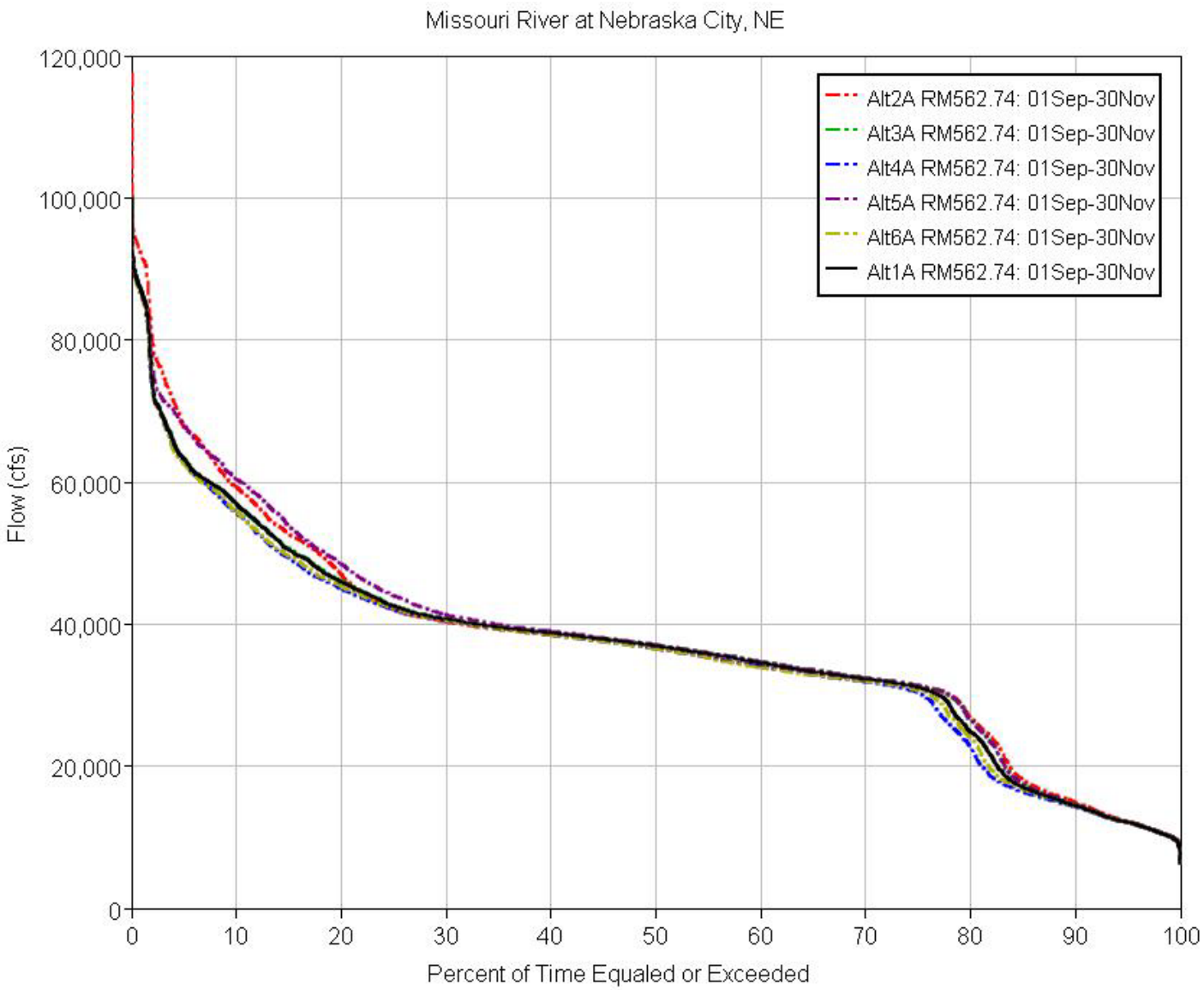


Plate 18: Nebraska City Fall Duration

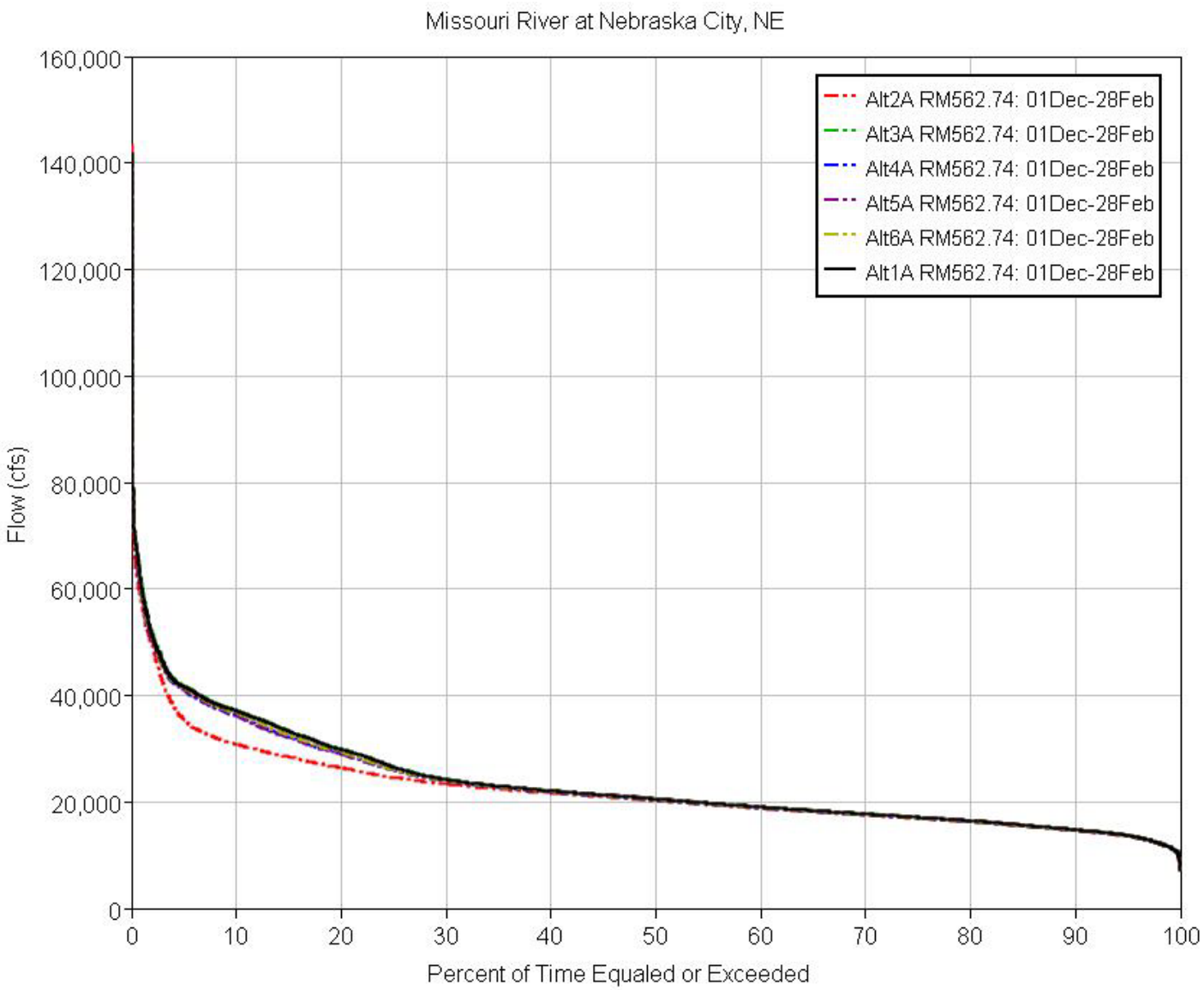


Plate 19: Nebraska City Winter Duration

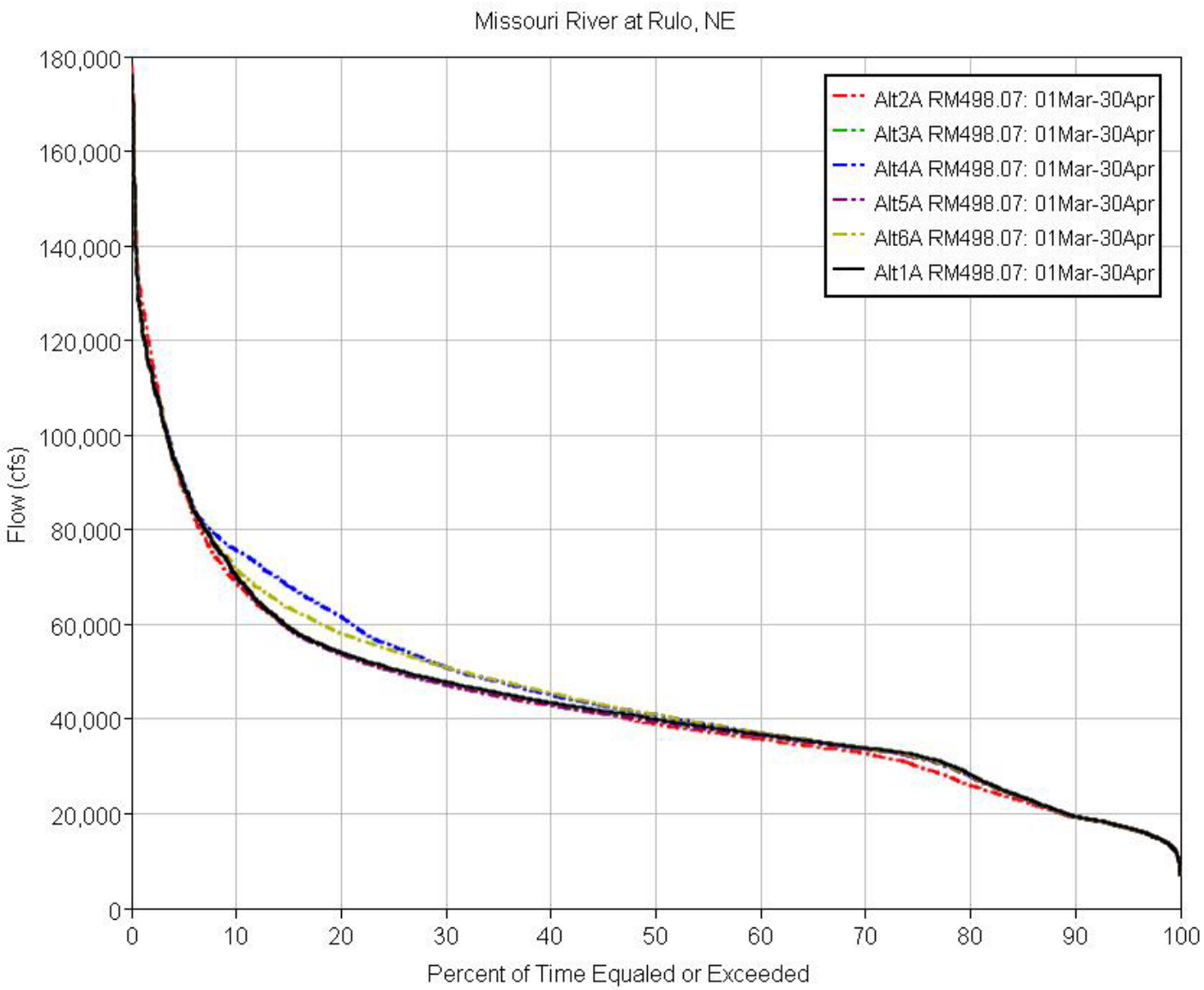


Plate 20: Rulo Spring Duration

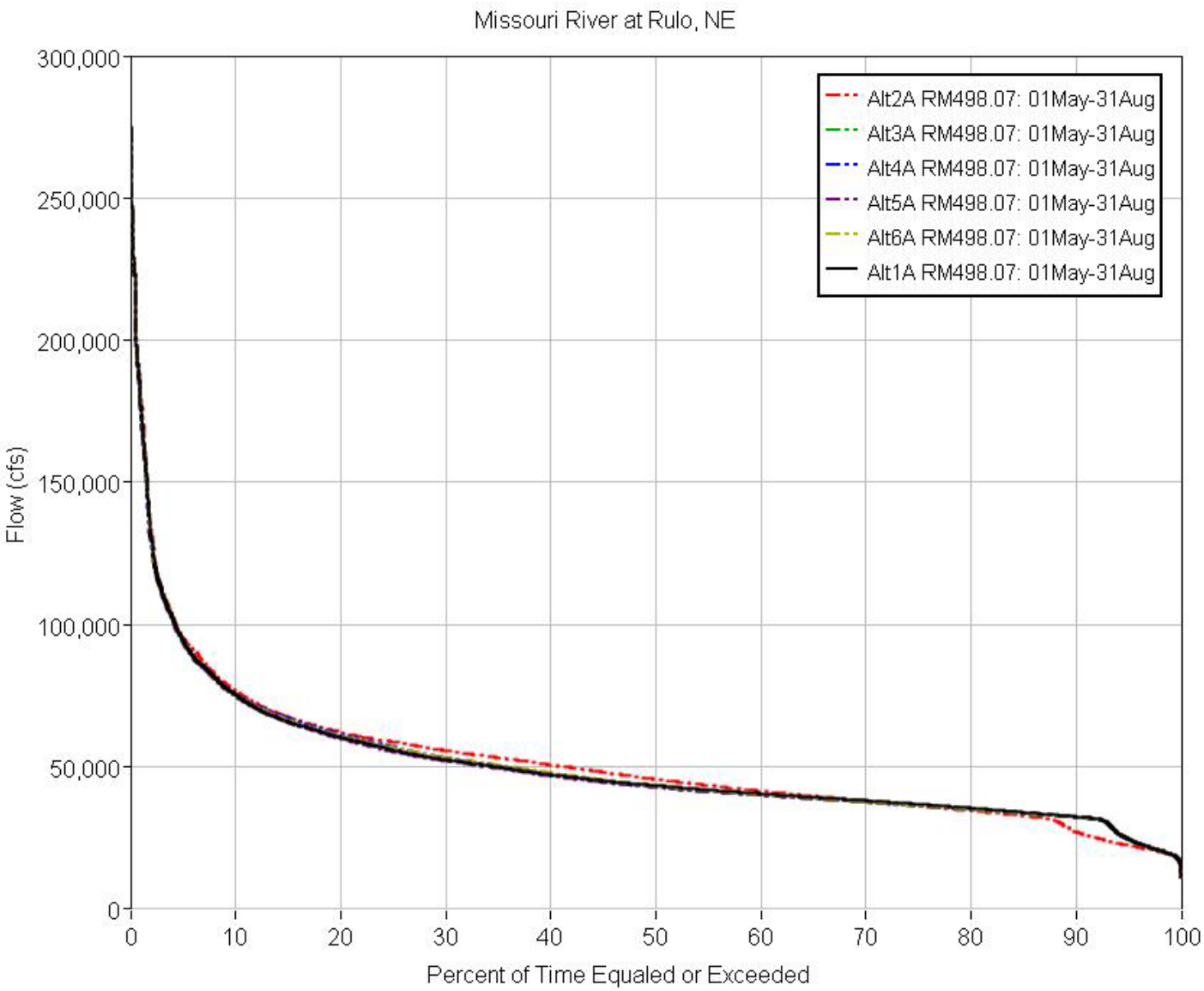


Plate 21: Rulo Summer Duration

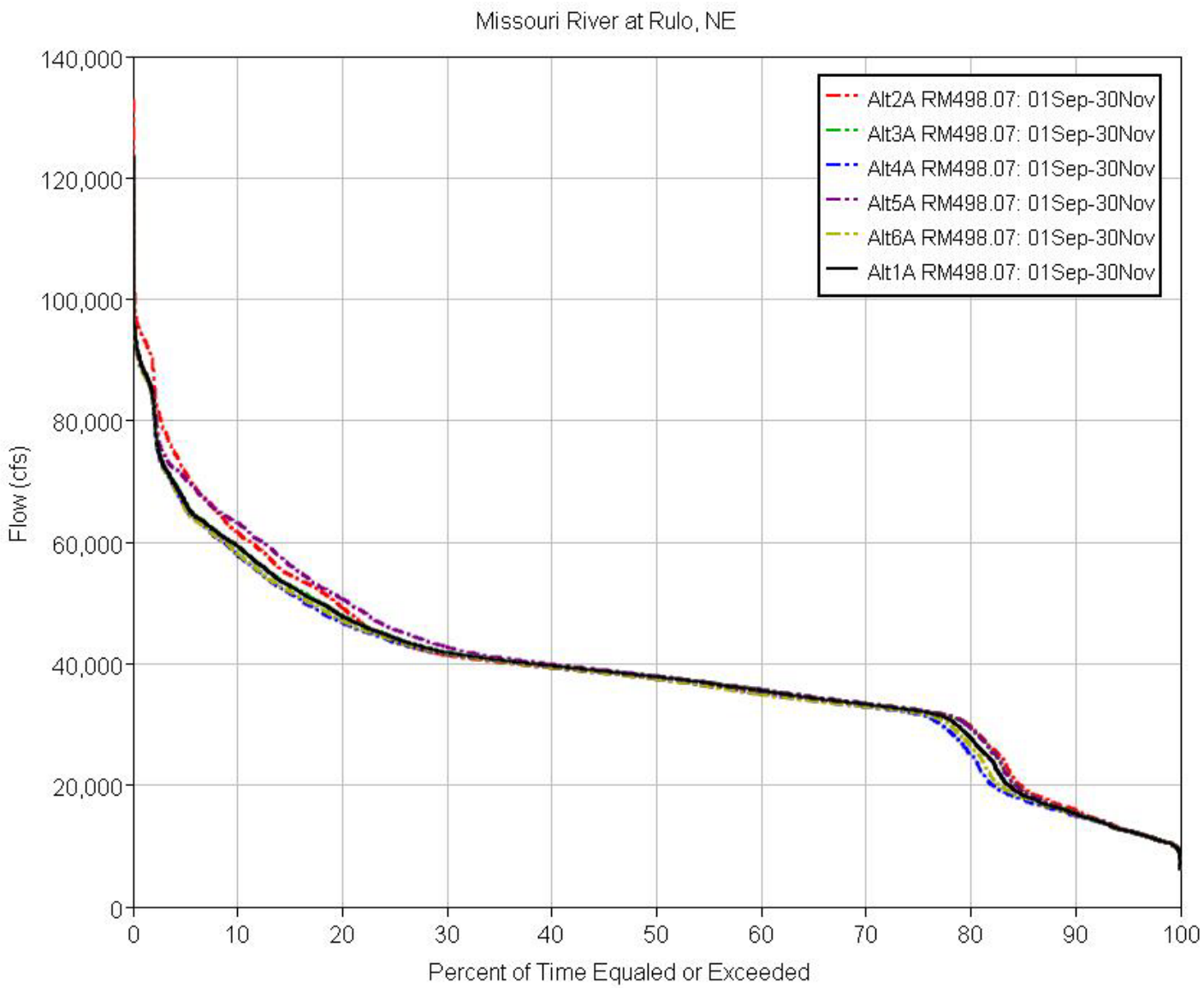


Plate 22: Rulo Fall Duration

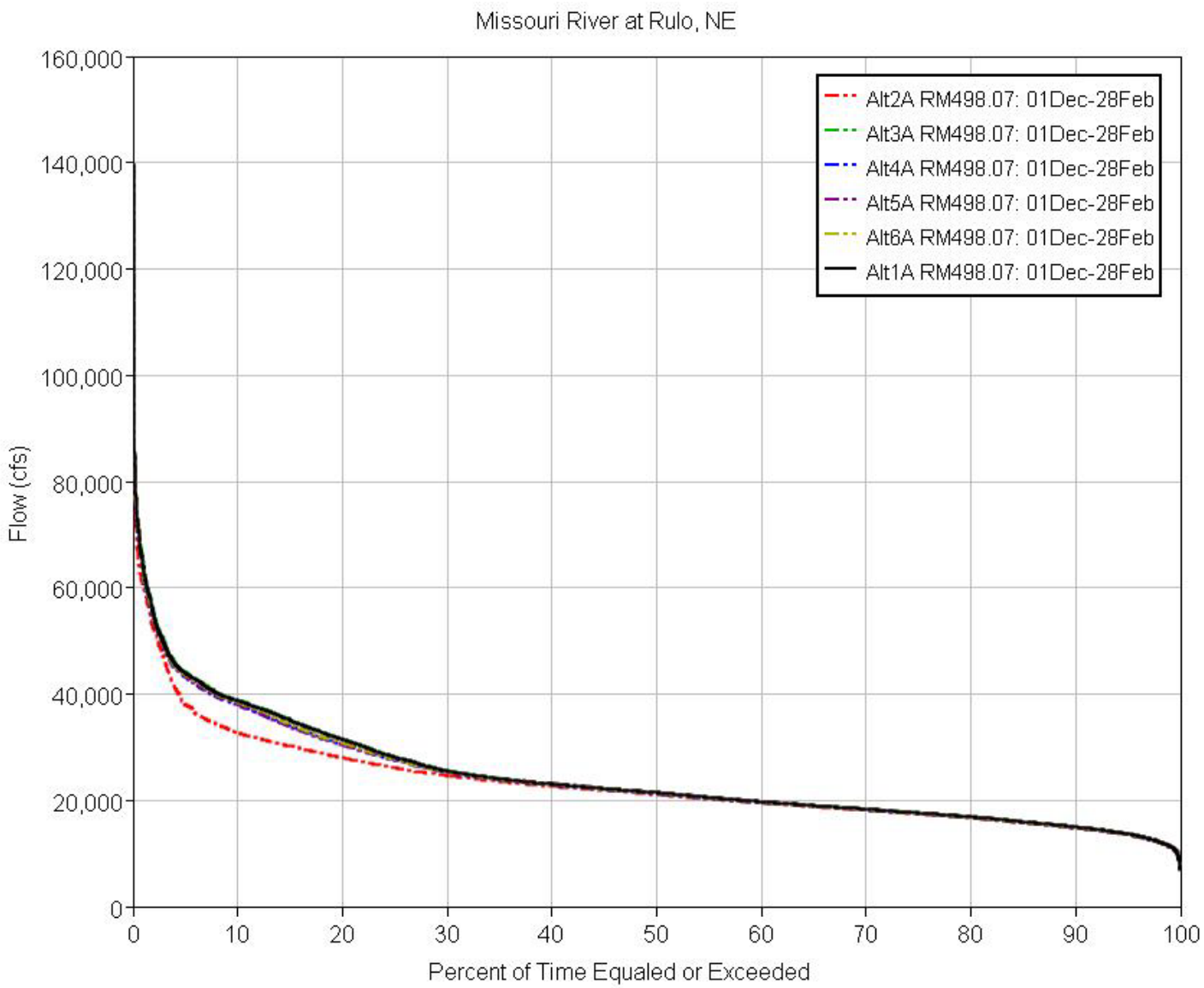


Plate 23: Rulo Winter Duration

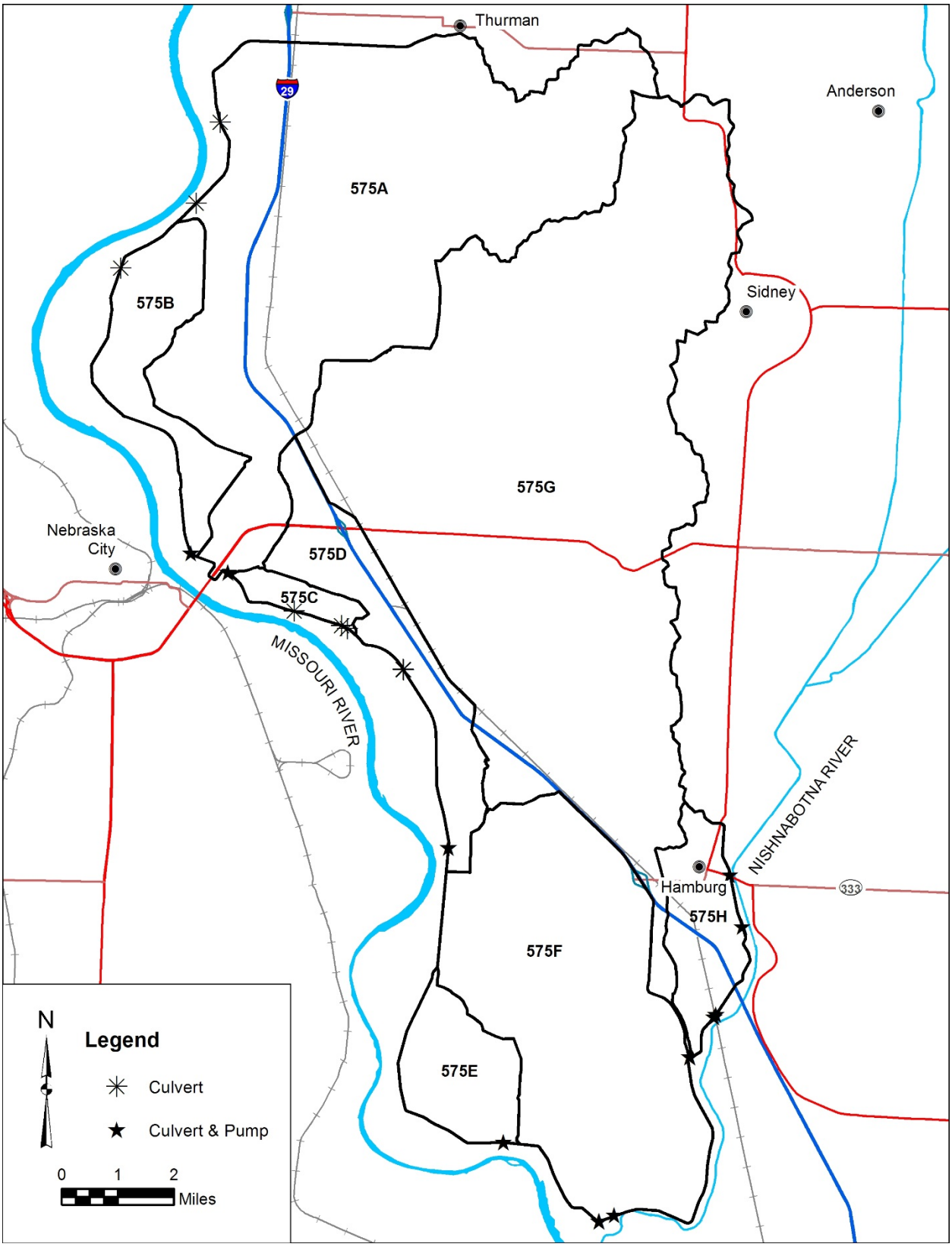


Plate 24: Levee Unit L-575 Basin Map

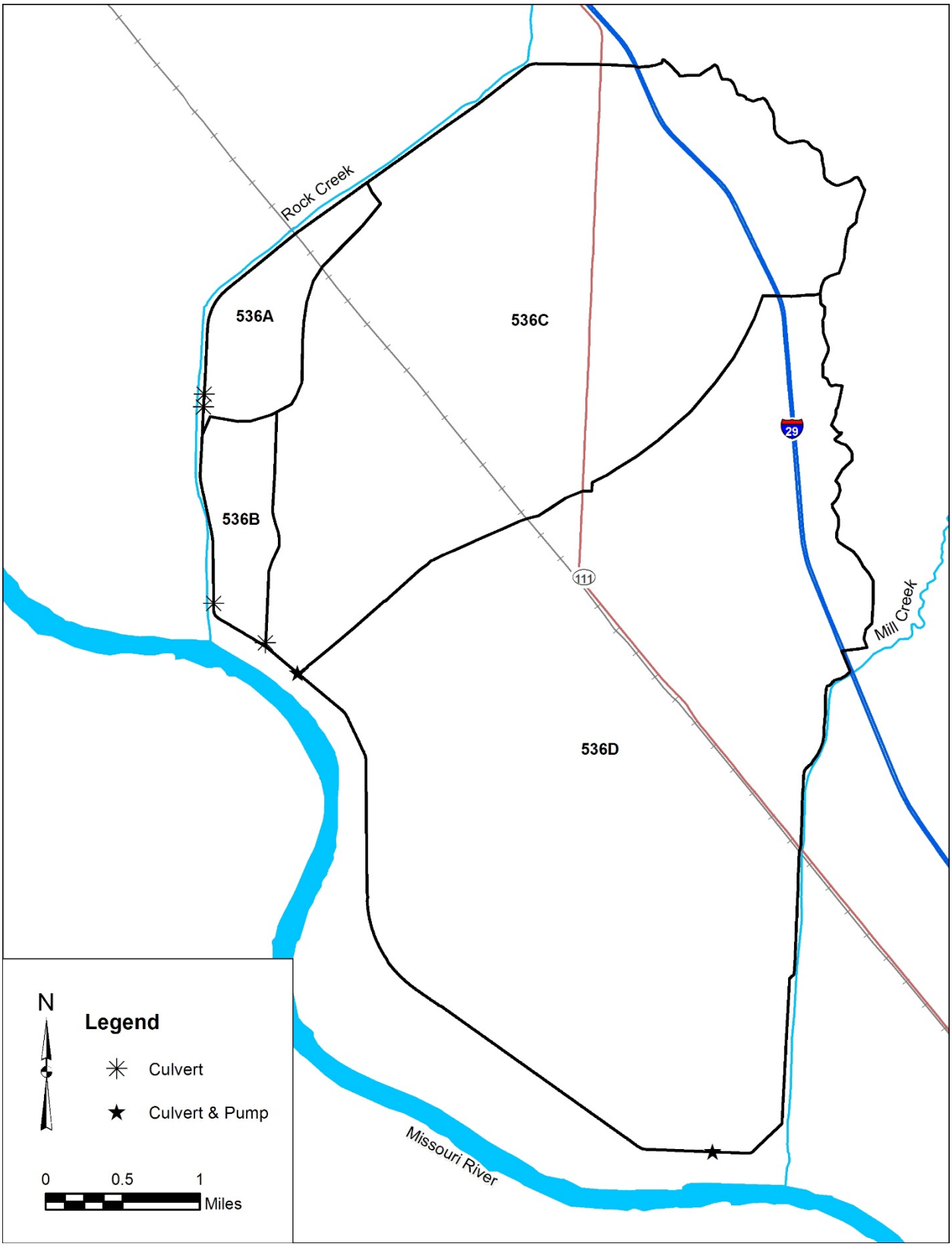


Plate 25: Levee Unit L-536 Basin Map

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575A							
Alt 1A	913.43	913.52	913.81	914.61	916.36	912.28	921.36
Alt 2A	913.42	913.52	913.80	914.70	916.50	912.28	921.36
Change from Alt 1A	0.00	-0.01	-0.01	0.10	0.14	0.00	0.00
Alt 3A	913.43	913.52	913.81	914.59	916.37	912.28	921.36
Change from Alt 1A	0.00	0.00	0.00	-0.02	0.01	0.00	0.00
Alt 4A	913.42	913.52	913.81	914.58	916.34	912.28	921.36
Change from Alt 1A	0.00	0.00	0.00	-0.03	-0.02	0.00	0.00
Alt 5A	913.42	913.52	913.81	914.58	916.36	912.28	921.36
Change from Alt 1A	0.00	0.00	0.00	-0.02	0.00	0.00	0.00
Alt 6A	913.42	913.52	913.81	914.61	916.35	912.28	921.36
Change from Alt 1A	0.00	0.00	0.00	0.00	-0.01	0.00	0.00
Storage Area 575B							
Alt 1A	914.35	914.40	914.63	915.57	917.52	912.94	922.61
Alt 2A	914.35	914.40	914.62	915.75	917.64	912.94	922.61
Change from Alt 1A	0.00	0.00	-0.01	0.18	0.12	0.00	-0.01
Alt 3A	914.35	914.40	914.62	915.56	917.53	912.94	922.62
Change from Alt 1A	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00
Alt 4A	914.35	914.40	914.62	915.58	917.58	912.94	922.62
Change from Alt 1A	0.00	0.00	-0.01	0.01	0.06	0.00	0.00
Alt 5A	914.35	914.40	914.62	915.57	917.54	912.94	922.61
Change from Alt 1A	0.00	0.00	-0.01	-0.01	0.02	0.00	0.00
Alt 6A	914.35	914.40	914.62	915.61	917.53	912.94	922.62
Change from Alt 1A	0.00	0.00	0.00	0.04	0.00	0.00	0.00
Storage Area 575C							
Alt 1A	913.83	913.85	913.91	914.02	914.75	912.26	919.70
Alt 2A	913.83	913.85	913.91	914.04	914.94	912.26	919.70
Change from Alt 1A	0.00	0.00	0.00	0.02	0.19	0.00	0.00
Alt 3A	913.83	913.85	913.91	914.02	914.76	912.26	919.70
Change from Alt 1A	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Alt 4A	913.83	913.85	913.91	914.03	914.73	912.26	919.70
Change from Alt 1A	0.00	0.00	0.00	0.01	-0.02	0.00	0.00
Alt 5A	913.83	913.85	913.91	914.02	914.72	912.26	919.70
Change from Alt 1A	0.00	0.00	0.00	0.00	-0.03	0.00	0.00
Alt 6A	913.83	913.85	913.91	914.03	914.69	912.26	919.70
Change from Alt 1A	0.00	0.00	0.00	0.00	-0.06	0.00	0.00

Plate 26: Storage Area Alternative Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575D							
Alt 1A	907.36	907.42	907.65	908.41	910.15	905.63	911.98
Alt 2A	907.36	907.42	907.65	908.58	910.40	905.63	911.98
Change from Alt 1A	0.00	0.00	0.00	0.17	0.25	0.00	0.00
Alt 3A	907.36	907.42	907.65	908.40	910.16	905.63	911.98
Change from Alt 1A	0.00	0.00	0.00	-0.01	0.01	0.00	0.00
Alt 4A	907.36	907.42	907.65	908.42	910.39	905.63	911.98
Change from Alt 1A	0.00	0.00	0.00	0.01	0.24	0.00	0.00
Alt 5A	907.36	907.42	907.65	908.40	910.22	905.63	911.98
Change from Alt 1A	0.00	0.00	0.00	0.00	0.07	0.00	0.00
Alt 6A	907.36	907.42	907.66	908.47	910.19	905.63	911.98
Change from Alt 1A	0.00	0.00	0.00	0.06	0.05	0.00	0.00
Storage Area 575E							
Alt 1A	896.29	896.31	896.41	896.96	898.81	895.18	904.72
Alt 2A	896.29	896.31	896.40	897.05	899.03	895.18	904.72
Change from Alt 1A	0.00	0.00	0.00	0.10	0.22	0.00	0.00
Alt 3A	896.29	896.31	896.40	896.95	898.82	895.18	904.73
Change from Alt 1A	0.00	0.00	0.00	-0.01	0.01	0.00	0.01
Alt 4A	896.29	896.31	896.40	896.95	898.70	895.18	904.73
Change from Alt 1A	0.00	0.00	0.00	0.00	-0.11	0.00	0.00
Alt 5A	896.29	896.31	896.40	896.94	898.73	895.18	904.72
Change from Alt 1A	0.00	0.00	0.00	-0.02	-0.08	0.00	0.00
Alt 6A	896.29	896.31	896.40	896.98	898.76	895.18	904.73
Change from Alt 1A	0.00	0.00	0.00	0.02	-0.05	0.00	0.00
Storage Area 575F							
Alt 1A	893.54	893.62	893.80	894.32	895.94	892.00	904.72
Alt 2A	893.54	893.62	893.81	894.40	896.15	892.00	904.73
Change from Alt 1A	0.00	0.00	0.01	0.08	0.21	0.00	0.00
Alt 3A	893.54	893.62	893.80	894.32	895.95	892.00	904.73
Change from Alt 1A	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Alt 4A	893.54	893.62	893.80	894.36	896.16	892.00	904.73
Change from Alt 1A	0.00	0.00	0.00	0.04	0.21	0.00	0.00
Alt 5A	893.54	893.62	893.80	894.33	896.05	892.00	904.73
Change from Alt 1A	0.00	0.00	0.00	0.01	0.10	0.00	0.00
Alt 6A	893.54	893.62	893.80	894.35	895.96	892.00	904.73
Change from Alt 1A	0.00	0.00	0.01	0.03	0.01	0.00	0.00

Plate 26 cont'd: Storage Area Alternative Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575G							
Alt 1A	898.09	898.17	898.39	899.68	901.55	890.61	909.79
Alt 2A	898.09	898.17	898.39	899.72	901.55	890.61	909.80
Change from Alt 1A	0.00	0.00	0.00	0.03	0.01	0.00	0.00
Alt 3A	898.09	898.17	898.39	899.69	901.54	890.61	909.79
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alt 4A	898.09	898.17	898.39	899.70	901.56	890.61	909.79
Change from Alt 1A	0.00	0.00	0.00	0.01	0.02	0.00	0.00
Alt 5A	898.09	898.17	898.39	899.69	901.54	890.61	909.79
Change from Alt 1A	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Alt 6A	898.09	898.17	898.39	899.69	901.54	890.61	909.79
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Storage Area 575H							
Alt 1A	898.26	898.42	899.14	900.37	900.81	896.86	906.81
Alt 2A	898.26	898.43	899.15	900.37	900.81	896.86	906.83
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Alt 3A	898.26	898.42	899.15	900.37	900.81	896.86	906.82
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alt 4A	898.26	898.42	899.15	900.37	900.82	896.86	906.82
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alt 5A	898.26	898.42	899.15	900.37	900.81	896.86	906.81
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alt 6A	898.26	898.42	899.15	900.37	900.81	896.86	906.82
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Storage Area 536A							
Alt 1A	875.92	875.93	875.96	876.03	876.28	874.00	883.55
Alt 2A	875.92	875.93	875.96	876.04	876.35	874.00	883.55
Change from Alt 1A	0.00	0.00	0.00	0.00	0.07	0.00	0.00
Alt 3A	875.92	875.93	875.96	876.03	876.28	874.00	883.55
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alt 4A	875.92	875.93	875.96	876.04	876.34	874.00	883.55
Change from Alt 1A	0.00	0.00	0.00	0.00	0.06	0.00	0.00
Alt 5A	875.92	875.93	875.96	876.04	876.31	874.00	883.55
Change from Alt 1A	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Alt 6A	875.92	875.93	875.96	876.04	876.29	874.00	883.55
Change from Alt 1A	0.00	0.00	0.00	0.00	0.01	0.00	0.00

Plate 26 cont'd: Storage Area Alternative Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 536B							
Alt 1A	873.07	873.08	873.12	873.27	873.82	871.12	882.82
Alt 2A	873.07	873.08	873.13	873.29	873.88	871.12	882.43
Change from Alt 1A	0.00	0.00	0.00	0.02	0.06	0.00	-0.39
Alt 3A	873.07	873.08	873.12	873.27	873.83	871.12	882.87
Change from Alt 1A	0.00	0.00	0.00	0.00	0.01	0.00	0.05
Alt 4A	873.07	873.08	873.12	873.27	873.85	871.12	882.87
Change from Alt 1A	0.00	0.00	0.00	0.00	0.03	0.00	0.05
Alt 5A	873.07	873.08	873.13	873.27	873.81	871.12	882.87
Change from Alt 1A	0.00	0.00	0.00	0.00	-0.01	0.00	0.05
Alt 6A	873.07	873.08	873.13	873.27	873.82	871.12	882.87
Change from Alt 1A	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Storage Area 536C							
Alt 1A	871.42	871.44	871.59	872.32	874.43	869.20	882.82
Alt 2A	871.42	871.44	871.59	872.50	874.62	869.20	882.43
Change from Alt 1A	0.00	0.00	0.00	0.19	0.19	0.00	-0.39
Alt 3A	871.42	871.44	871.59	872.31	874.45	869.20	882.87
Change from Alt 1A	0.00	0.00	0.00	-0.01	0.01	0.00	0.05
Alt 4A	871.42	871.44	871.59	872.35	874.56	869.20	882.87
Change from Alt 1A	0.00	0.00	0.00	0.04	0.13	0.00	0.05
Alt 5A	871.42	871.44	871.59	872.31	874.47	869.20	882.87
Change from Alt 1A	0.00	0.00	0.00	-0.01	0.04	0.00	0.05
Alt 6A	871.42	871.44	871.59	872.38	874.45	869.20	882.87
Change from Alt 1A	0.00	0.00	0.00	0.07	0.02	0.00	0.05
Storage Area 536D							
Alt 1A	866.58	866.61	866.72	866.98	867.92	864.58	882.82
Alt 2A	866.58	866.61	866.73	867.01	868.10	864.58	882.43
Change from Alt 1A	0.00	0.00	0.00	0.03	0.17	0.00	-0.39
Alt 3A	866.58	866.61	866.72	866.98	867.94	864.58	882.87
Change from Alt 1A	0.00	0.00	0.00	0.00	0.02	0.00	0.05
Alt 4A	866.58	866.61	866.72	866.99	868.11	864.58	882.87
Change from Alt 1A	0.00	0.00	0.00	0.02	0.18	0.00	0.05
Alt 5A	866.58	866.61	866.72	866.98	868.00	864.58	882.87
Change from Alt 1A	0.00	0.00	0.00	0.00	0.08	0.00	0.05
Alt 6A	866.58	866.61	866.72	866.99	867.96	864.58	882.87
Change from Alt 1A	0.00	0.00	0.00	0.01	0.04	0.00	0.05

Plate 26 cont'd: Storage Area Alternative Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575A							
Alt 1	913.43	913.52	913.81	914.61	916.36	912.28	921.36
Alt 1: C[1]	915.40	915.46	915.63	915.91	916.55	912.28	921.36
Change from Alt 1	1.98	1.94	1.81	1.30	0.19	0.00	0.00
Alt 1: P[2]	913.43	913.52	913.81	914.61	916.45	912.28	921.47
Change from Alt 1	0.00	0.00	0.00	0.00	0.09	0.00	0.11
Alt 1: C + P	915.40	915.46	915.63	915.92	916.82	912.28	921.47
Change from Alt 1	1.98	1.94	1.82	1.31	0.46	0.00	0.11
Alt 2	913.42	913.52	913.80	914.70	916.50	912.28	921.36
Alt 2: C + P	915.40	915.47	915.63	915.97	916.99	912.28	921.47
Change from Alt 2	1.98	1.95	1.83	1.26	0.49	0.00	0.11
Alt 3	913.43	913.52	913.81	914.59	916.37	912.28	921.36
Alt 3: C + P	915.40	915.46	915.63	915.92	916.84	912.28	921.47
Change from Alt 3	1.98	1.94	1.82	1.33	0.47	0.00	0.11
Alt 4	913.42	913.52	913.81	914.58	916.34	912.28	921.36
Alt 4: PEY[3]	913.43	913.53	913.85	914.96	916.52	912.28	921.36
Change from Alt 4	0.00	0.01	0.04	0.38	0.17	0.00	0.00
Alt 4: C + PEY	915.41	915.47	915.65	916.03	916.71	912.28	921.36
Change from Alt 4	1.98	1.95	1.84	1.45	0.36	0.00	0.00
Alt 4: C + P	915.40	915.46	915.63	915.93	916.81	912.28	921.47
Change from Alt 4	1.98	1.94	1.82	1.35	0.47	0.00	0.11
Alt 4: C + P + PEY	915.41	915.47	915.65	916.07	917.21	912.28	921.47
Change from Alt 4	1.98	1.95	1.84	1.49	0.87	0.00	0.11
Alt 5	913.42	913.52	913.81	914.58	916.36	912.28	921.36
Alt 5: C + P	915.40	915.47	915.63	915.92	916.81	912.28	921.47
Change from Alt 5	1.98	1.94	1.82	1.34	0.46	0.00	0.11
Alt 5: C + P + PEY	915.41	915.48	915.67	916.04	916.97	912.28	921.47
Change from Alt 5	1.99	1.96	1.86	1.45	0.61	0.00	0.11
Alt 6	913.42	913.52	913.81	914.61	916.35	912.28	921.36
Alt 6: C + P	915.40	915.47	915.63	915.93	916.80	912.28	921.47
Change from Alt 6	1.98	1.94	1.82	1.32	0.45	0.00	0.11

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575B							
Alt 1	914.35	914.40	914.63	915.57	917.52	912.94	922.61
Alt 1: C	916.35	916.37	916.44	916.65	917.57	912.94	922.61
Change from Alt 1	2.00	1.96	1.81	1.07	0.05	0.00	0.00
Alt 1: P	914.35	914.40	914.63	915.58	917.71	912.94	922.81
Change from Alt 1	0.00	0.00	0.00	0.01	0.19	0.00	0.19
Alt 1: C + P	916.35	916.37	916.44	916.66	918.11	912.94	922.81
Change from Alt 1	2.00	1.96	1.81	1.09	0.59	0.00	0.19
Alt 2	914.35	914.40	914.62	915.75	917.64	912.94	922.61
Alt 2: C + P	916.35	916.37	916.45	916.71	918.29	912.94	922.81
Change from Alt 2	2.00	1.97	1.83	0.96	0.65	0.00	0.20
Alt 3	914.35	914.40	914.62	915.56	917.53	912.94	922.62
Alt 3: C + P	916.35	916.37	916.44	916.66	918.12	912.94	922.81
Change from Alt 3	2.00	1.96	1.82	1.10	0.59	0.00	0.19
Alt 4	914.35	914.40	914.62	915.58	917.58	912.94	922.62
Alt 4: PEY	914.35	914.41	914.68	916.11	917.75	912.94	922.61
Change from Alt 4	0.00	0.01	0.06	0.53	0.17	0.00	0.00
Alt 4: C + PEY	916.35	916.37	916.45	916.80	917.84	912.94	922.61
Change from Alt 4	2.00	1.97	1.84	1.22	0.26	0.00	0.00
Alt 4: C + P	916.35	916.37	916.44	916.68	918.09	912.94	922.81
Change from Alt 4	2.00	1.96	1.82	1.10	0.50	0.00	0.19
Alt 4: C + P + PEY	916.35	916.37	916.46	916.85	918.82	912.94	922.81
Change from Alt 4	2.00	1.97	1.84	1.27	1.23	0.00	0.19
Alt 5	914.35	914.40	914.62	915.57	917.54	912.94	922.61
Alt 5: C + P	916.35	916.37	916.44	916.67	918.11	912.94	922.81
Change from Alt 5	2.00	1.96	1.82	1.10	0.56	0.00	0.19
Alt 5: C + P + PEY	916.35	916.37	916.46	916.80	918.37	912.94	922.81
Change from Alt 5	2.00	1.97	1.84	1.24	0.83	0.00	0.19
Alt 6	914.35	914.40	914.62	915.61	917.53	912.94	922.62
Alt 6: C + P	916.35	916.37	916.44	916.67	918.04	912.94	922.81
Change from Alt 6	2.00	1.96	1.82	1.06	0.51	0.00	0.19

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575C							
Alt 1	913.83	913.85	913.91	914.02	914.75	912.26	919.70
Alt 1: C	915.29	915.31	915.34	915.40	915.66	912.26	919.70
Change from Alt 1	1.46	1.45	1.43	1.38	0.91	0.00	0.00
Alt 1: P	913.83	913.85	913.91	914.02	914.75	912.26	919.75
Change from Alt 1	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Alt 1: C + P	915.29	915.31	915.34	915.40	915.66	912.26	919.75
Change from Alt 1	1.46	1.45	1.43	1.38	0.91	0.00	0.05
Alt 2	913.83	913.85	913.91	914.04	914.94	912.26	919.70
Alt 2: C + P	915.29	915.31	915.34	915.41	915.71	912.26	919.75
Change from Alt 2	1.46	1.45	1.43	1.36	0.77	0.00	0.05
Alt 3	913.83	913.85	913.91	914.02	914.76	912.26	919.70
Alt 3: C + P	915.29	915.31	915.34	915.40	915.66	912.26	919.75
Change from Alt 3	1.46	1.45	1.43	1.38	0.90	0.00	0.05
Alt 4	913.83	913.85	913.91	914.03	914.73	912.26	919.70
Alt 4: PEY	913.83	913.86	913.92	914.09	915.15	912.26	919.70
Change from Alt 4	0.00	0.00	0.01	0.06	0.42	0.00	0.00
Alt 4: C + PEY	915.29	915.31	915.35	915.43	915.99	912.26	919.70
Change from Alt 4	1.46	1.46	1.44	1.40	1.26	0.00	0.00
Alt 4: C + P	915.29	915.31	915.34	915.40	915.67	912.26	919.75
Change from Alt 4	1.46	1.45	1.43	1.38	0.94	0.00	0.05
Alt 4: C + P + PEY	915.29	915.31	915.35	915.43	915.99	912.26	919.75
Change from Alt 4	1.46	1.46	1.44	1.40	1.27	0.00	0.05
Alt 5	913.83	913.85	913.91	914.02	914.72	912.26	919.70
Alt 5: C + P	915.29	915.31	915.34	915.40	915.66	912.26	919.75
Change from Alt 5	1.46	1.45	1.43	1.38	0.94	0.00	0.05
Alt 5: C + P + PEY	915.29	915.31	915.35	915.42	915.73	912.26	919.75
Change from Alt 5	1.46	1.46	1.45	1.40	1.01	0.00	0.05
Alt 6	913.83	913.85	913.91	914.03	914.69	912.26	919.70
Alt 6: C + P	915.29	915.31	915.34	915.40	915.65	912.26	919.75
Change from Alt 6	1.46	1.45	1.43	1.37	0.96	0.00	0.05

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575D							
Alt 1	907.36	907.42	907.65	908.41	910.15	905.63	911.98
Alt 1: C	909.88	909.91	909.99	910.14	910.65	905.63	911.98
Change from Alt 1	2.52	2.49	2.33	1.73	0.50	0.00	0.00
Alt 1: P	907.36	907.42	907.65	908.41	910.15	905.63	912.02
Change from Alt 1	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Alt 1: C + P	909.88	909.91	909.99	910.14	910.65	905.63	912.02
Change from Alt 1	2.52	2.49	2.33	1.73	0.50	0.00	0.04
Alt 2	907.36	907.42	907.65	908.58	910.40	905.63	911.98
Alt 2: C + P	909.88	909.91	909.99	910.16	910.71	905.63	912.02
Change from Alt 2	2.52	2.49	2.34	1.58	0.31	0.00	0.04
Alt 3	907.36	907.42	907.65	908.40	910.16	905.63	911.98
Alt 3: C + P	909.88	909.91	909.99	910.14	910.65	905.63	912.02
Change from Alt 3	2.52	2.49	2.34	1.74	0.49	0.00	0.04
Alt 4	907.36	907.42	907.65	908.42	910.39	905.63	911.98
Alt 4: PEY	907.36	907.43	907.70	908.96	910.74	905.63	911.98
Change from Alt 4	0.00	0.01	0.05	0.54	0.36	0.00	0.00
Alt 4: C + PEY	909.88	909.92	910.00	910.22	910.81	905.63	911.98
Change from Alt 4	2.52	2.50	2.35	1.80	0.43	0.00	0.00
Alt 4: C + P	909.88	909.91	909.99	910.15	910.66	905.63	912.02
Change from Alt 4	2.52	2.49	2.34	1.73	0.28	0.00	0.04
Alt 4: C + P + PEY	909.88	909.92	910.00	910.22	910.82	905.63	912.02
Change from Alt 4	2.52	2.50	2.35	1.80	0.43	0.00	0.04
Alt 5	907.36	907.42	907.65	908.40	910.22	905.63	911.98
Alt 5: C + P	909.88	909.91	909.99	910.15	910.64	905.63	912.02
Change from Alt 5	2.52	2.49	2.34	1.74	0.42	0.00	0.04
Alt 5: C + P + PEY	909.88	909.92	910.01	910.20	910.73	905.63	912.02
Change from Alt 5	2.53	2.50	2.36	1.79	0.51	0.00	0.04
Alt 6	907.36	907.42	907.66	908.47	910.19	905.63	911.98
Alt 6: C + P	909.88	909.91	909.99	910.15	910.63	905.63	912.02
Change from Alt 6	2.52	2.49	2.33	1.68	0.44	0.00	0.04

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575E							
Alt 1	896.29	896.31	896.41	896.96	898.81	895.18	904.72
Alt 1: C	898.53	898.53	898.55	898.61	899.09	895.18	904.73
Change from Alt 1	2.24	2.22	2.15	1.65	0.28	0.00	0.01
Alt 1: P	896.29	896.31	896.41	896.96	898.82	895.18	908.60
Change from Alt 1	0.00	0.00	0.00	0.00	0.01	0.00	3.88
Alt 1: C + P	898.53	898.53	898.55	898.61	899.14	895.18	909.03
Change from Alt 1	2.24	2.22	2.15	1.65	0.33	0.00	4.31
Alt 2	896.29	896.31	896.40	897.05	899.03	895.18	904.72
Alt 2: C + P	898.53	898.53	898.55	898.62	899.30	895.18	909.03
Change from Alt 2	2.24	2.22	2.15	1.57	0.27	0.00	4.31
Alt 3	896.29	896.31	896.40	896.95	898.82	895.18	904.73
Alt 3: C + P	898.53	898.53	898.55	898.61	899.14	895.18	909.03
Change from Alt 3	2.24	2.22	2.15	1.66	0.33	0.00	4.30
Alt 4	896.29	896.31	896.40	896.95	898.70	895.18	904.73
Alt 4: PEY	896.29	896.31	896.42	897.28	899.24	895.18	904.72
Change from Alt 4	0.00	0.00	0.01	0.32	0.53	0.00	0.00
Alt 4: C + PEY	898.53	898.53	898.55	898.65	899.57	895.18	904.70
Change from Alt 4	2.24	2.22	2.15	1.69	0.86	0.00	-0.02
Alt 4: C + P	898.53	898.53	898.55	898.61	899.16	895.18	909.03
Change from Alt 4	2.24	2.22	2.15	1.66	0.45	0.00	4.30
Alt 4: C + P + PEY	898.53	898.53	898.55	898.65	899.62	895.18	909.03
Change from Alt 4	2.24	2.22	2.15	1.70	0.91	0.00	4.30
Alt 5	896.29	896.31	896.40	896.94	898.73	895.18	904.72
Alt 5: C + P	898.53	898.53	898.55	898.61	899.12	895.18	909.03
Change from Alt 5	2.24	2.22	2.15	1.67	0.39	0.00	4.31
Alt 5: C + P + PEY	898.53	898.53	898.56	898.65	899.29	895.18	909.03
Change from Alt 5	2.24	2.22	2.15	1.70	0.56	0.00	4.31
Alt 6	896.29	896.31	896.40	896.98	898.76	895.18	904.73
Alt 6: C + P	898.53	898.53	898.55	898.61	899.12	895.18	909.03
Change from Alt 6	2.24	2.22	2.15	1.64	0.36	0.00	4.30

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575F							
Alt 1	893.54	893.62	893.80	894.32	895.94	892.00	904.72
Alt 1: C	895.73	895.76	895.82	895.94	896.47	892.00	904.73
Change from Alt 1	2.19	2.14	2.02	1.62	0.53	0.00	0.01
Alt 1: P	893.54	893.62	893.80	894.32	895.97	892.00	908.60
Change from Alt 1	0.00	0.00	0.00	0.00	0.03	0.00	3.87
Alt 1: C + P	895.73	895.76	895.82	895.95	896.70	892.00	909.03
Change from Alt 1	2.19	2.14	2.02	1.63	0.75	0.00	4.31
Alt 2	893.54	893.62	893.81	894.40	896.15	892.00	904.73
Alt 2: C + P	895.73	895.76	895.82	895.95	896.78	892.00	909.03
Change from Alt 2	2.19	2.14	2.01	1.55	0.63	0.00	4.31
Alt 3	893.54	893.62	893.80	894.32	895.95	892.00	904.73
Alt 3: C + P	895.73	895.76	895.82	895.95	896.70	892.00	909.03
Change from Alt 3	2.19	2.14	2.02	1.63	0.75	0.00	4.30
Alt 4	893.54	893.62	893.80	894.36	896.16	892.00	904.73
Alt 4: PEY	893.54	893.63	893.84	894.62	896.87	892.00	904.72
Change from Alt 4	0.00	0.01	0.03	0.26	0.72	0.00	0.00
Alt 4: C + PEY	895.73	895.77	895.83	896.01	897.05	892.00	904.70
Change from Alt 4	2.19	2.15	2.03	1.65	0.90	0.00	-0.02
Alt 4: C + P	895.73	895.76	895.82	895.95	896.78	892.00	909.03
Change from Alt 4	2.19	2.15	2.02	1.59	0.62	0.00	4.30
Alt 4: C + P + PEY	895.73	895.77	895.83	896.02	898.04	892.00	909.03
Change from Alt 4	2.19	2.15	2.03	1.66	1.88	0.00	4.30
Alt 5	893.54	893.62	893.80	894.33	896.05	892.00	904.73
Alt 5: C + P	895.73	895.76	895.82	895.95	896.72	892.00	909.03
Change from Alt 5	2.19	2.14	2.02	1.62	0.67	0.00	4.31
Alt 5: C + P + PEY	895.73	895.77	895.84	896.01	897.22	892.00	909.03
Change from Alt 5	2.19	2.15	2.04	1.68	1.17	0.00	4.31
Alt 6	893.54	893.62	893.80	894.35	895.96	892.00	904.73
Alt 6: C + P	895.73	895.76	895.82	895.95	896.68	892.00	909.03
Change from Alt 6	2.19	2.14	2.02	1.60	0.73	0.00	4.30

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575G							
Alt 1	898.09	898.17	898.39	899.68	901.55	890.61	909.79
Alt 1: C	901.05	901.08	901.14	901.28	901.98	890.61	909.79
Change from Alt 1	2.96	2.92	2.75	1.59	0.44	0.00	0.00
Alt 1: P	898.09	898.17	898.39	899.69	901.56	890.61	910.14
Change from Alt 1	0.00	0.00	0.00	0.00	0.01	0.00	0.35
Alt 1: C + P	901.05	901.08	901.14	901.28	902.01	890.61	910.17
Change from Alt 1	2.96	2.92	2.75	1.59	0.47	0.00	0.38
Alt 2	898.09	898.17	898.39	899.72	901.55	890.61	909.80
Alt 2: C + P	901.05	901.08	901.14	901.28	902.02	890.61	910.17
Change from Alt 2	2.96	2.92	2.75	1.56	0.46	0.00	0.38
Alt 3	898.09	898.17	898.39	899.69	901.54	890.61	909.79
Alt 3: C + P	901.05	901.08	901.14	901.28	902.01	890.61	910.17
Change from Alt 3	2.96	2.92	2.75	1.59	0.47	0.00	0.38
Alt 4	898.09	898.17	898.39	899.70	901.56	890.61	909.79
Alt 4: PEY	898.10	898.17	898.42	899.76	901.61	890.61	909.79
Change from Alt 4	0.00	0.01	0.03	0.06	0.05	0.00	0.00
Alt 4: C + PEY	901.05	901.08	901.14	901.28	902.01	890.61	909.79
Change from Alt 4	2.96	2.92	2.75	1.58	0.45	0.00	0.00
Alt 4: C + P	901.05	901.08	901.14	901.28	902.01	890.61	910.17
Change from Alt 4	2.96	2.92	2.75	1.58	0.45	0.00	0.38
Alt 4: C + P + PEY	901.05	901.08	901.14	901.28	902.05	890.61	910.18
Change from Alt 4	2.96	2.92	2.75	1.59	0.49	0.00	0.39
Alt 5	898.09	898.17	898.39	899.69	901.54	890.61	909.79
Alt 5: C + P	901.05	901.08	901.14	901.28	902.01	890.61	910.17
Change from Alt 5	2.96	2.92	2.75	1.58	0.46	0.00	0.38
Alt 5: C + P + PEY	901.05	901.08	901.14	901.28	902.02	890.61	910.17
Change from Alt 5	2.96	2.92	2.75	1.59	0.47	0.00	0.38
Alt 6	898.09	898.17	898.39	899.69	901.54	890.61	909.79
Alt 6: C + P	901.05	901.08	901.14	901.28	902.01	890.61	910.17
Change from Alt 6	2.96	2.92	2.75	1.59	0.47	0.00	0.38

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 575H							
Alt 1	898.26	898.42	899.14	900.37	900.81	896.86	906.81
Alt 1: C	899.72	899.89	900.24	900.62	900.97	896.86	906.81
Change from Alt 1	1.46	1.47	1.09	0.25	0.15	0.00	0.00
Alt 1: P	898.26	898.42	899.15	900.62	902.61	896.86	910.15
Change from Alt 1	0.00	0.00	0.00	0.25	1.80	0.00	3.34
Alt 1: C + P	899.72	899.90	900.36	901.41	903.25	896.86	910.18
Change from Alt 1	1.46	1.48	1.21	1.04	2.43	0.00	3.37
Alt 2	898.26	898.43	899.15	900.37	900.81	896.86	906.83
Alt 2: C + P	899.72	899.90	900.36	901.41	903.25	896.86	910.18
Change from Alt 2	1.46	1.48	1.21	1.04	2.44	0.00	3.35
Alt 3	898.26	898.42	899.15	900.37	900.81	896.86	906.82
Alt 3: C + P	899.72	899.90	900.36	901.41	903.25	896.86	910.18
Change from Alt 3	1.46	1.48	1.21	1.04	2.43	0.00	3.37
Alt 4	898.26	898.42	899.15	900.37	900.82	896.86	906.82
Alt 4: PEY	898.26	898.44	899.17	900.38	900.82	896.86	906.81
Change from Alt 4	0.00	0.01	0.03	0.01	0.01	0.00	0.00
Alt 4: C + PEY	899.72	899.89	900.24	900.62	900.97	896.86	906.80
Change from Alt 4	1.46	1.47	1.10	0.25	0.15	0.00	-0.02
Alt 4: C + P	899.72	899.90	900.36	901.41	903.25	896.86	910.18
Change from Alt 4	1.46	1.48	1.21	1.04	2.43	0.00	3.37
Alt 4: C + P + PEY	899.72	899.90	900.37	901.43	903.28	896.86	910.19
Change from Alt 4	1.46	1.48	1.22	1.06	2.46	0.00	3.38
Alt 5	898.26	898.42	899.15	900.37	900.81	896.86	906.81
Alt 5: C + P	899.72	899.90	900.36	901.41	903.25	896.86	910.18
Change from Alt 5	1.46	1.48	1.21	1.04	2.44	0.00	3.37
Alt 5: C + P + PEY	899.72	899.90	900.36	901.42	903.25	896.86	910.18
Change from Alt 5	1.46	1.48	1.22	1.05	2.44	0.00	3.37
Alt 6	898.26	898.42	899.15	900.37	900.81	896.86	906.82
Alt 6: C + P	899.72	899.90	900.36	901.41	903.25	896.86	910.18
Change from Alt 6	1.46	1.48	1.21	1.04	2.44	0.00	3.37

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 536A							
Alt 1	875.92	875.93	875.96	876.03	876.28	874.00	883.55
Alt 1: C	877.42	877.42	877.42	877.46	877.55	874.00	883.55
Change from Alt 1	1.50	1.49	1.46	1.43	1.27	0.00	0.00
Alt 1: P	875.92	875.93	875.96	876.04	876.28	874.00	883.55
Change from Alt 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alt 1: C + P	877.42	877.42	877.42	877.46	877.55	874.00	883.55
Change from Alt 1	1.50	1.49	1.46	1.43	1.27	0.00	0.00
Alt 2	875.92	875.93	875.96	876.04	876.35	874.00	883.55
Alt 2: C + P	877.42	877.42	877.42	877.46	877.56	874.00	883.55
Change from Alt 2	1.50	1.49	1.46	1.42	1.21	0.00	0.00
Alt 3	875.92	875.93	875.96	876.03	876.28	874.00	883.55
Alt 3: C + P	877.42	877.42	877.42	877.46	877.55	874.00	883.55
Change from Alt 3	1.50	1.49	1.46	1.43	1.27	0.00	0.00
Alt 4	875.92	875.93	875.96	876.04	876.34	874.00	883.55
Alt 4: PEY	875.92	875.93	875.97	876.08	877.07	874.00	883.55
Change from Alt 4	0.00	0.00	0.01	0.04	0.73	0.00	0.00
Alt 4: C + PEY	877.42	877.42	877.42	877.48	877.94	874.00	883.55
Change from Alt 4	1.50	1.49	1.46	1.44	1.59	0.00	0.00
Alt 4: C + P	877.42	877.42	877.42	877.46	877.56	874.00	883.55
Change from Alt 4	1.50	1.49	1.46	1.42	1.21	0.00	0.00
Alt 4: C + P + PEY	877.42	877.42	877.42	877.48	877.94	874.00	883.55
Change from Alt 4	1.50	1.49	1.46	1.44	1.59	0.00	0.00
Alt 5	875.92	875.93	875.96	876.04	876.31	874.00	883.55
Alt 5: C + P	877.42	877.42	877.42	877.46	877.55	874.00	883.55
Change from Alt 5	1.50	1.49	1.46	1.43	1.25	0.00	0.00
Alt 5: C + P + PEY	877.42	877.42	877.42	877.47	877.74	874.00	883.55
Change from Alt 5	1.50	1.49	1.46	1.44	1.43	0.00	0.00
Alt 6	875.92	875.93	875.96	876.04	876.29	874.00	883.55
Alt 6: C + P	877.42	877.42	877.42	877.46	877.55	874.00	883.55
Change from Alt 6	1.50	1.49	1.46	1.43	1.26	0.00	0.00

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 536B							
Alt 1	873.07	873.08	873.12	873.27	873.82	871.12	882.82
Alt 1: C	874.79	874.79	874.80	874.84	875.10	871.12	882.82
Change from Alt 1	1.72	1.71	1.68	1.57	1.28	0.00	0.00
Alt 1: P	873.07	873.08	873.12	873.27	873.82	871.12	883.08
Change from Alt 1	0.00	0.00	0.00	0.00	0.00	0.00	0.26
Alt 1: C + P	874.79	874.79	874.80	874.84	875.11	871.12	883.08
Change from Alt 1	1.72	1.71	1.68	1.57	1.29	0.00	0.26
Alt 2	873.07	873.08	873.13	873.29	873.88	871.12	882.43
Alt 2: C + P	874.79	874.79	874.80	874.84	875.11	871.12	882.69
Change from Alt 2	1.72	1.71	1.67	1.56	1.23	0.00	0.25
Alt 3	873.07	873.08	873.12	873.27	873.83	871.12	882.87
Alt 3: C + P	874.79	874.79	874.80	874.84	875.11	871.12	883.12
Change from Alt 3	1.72	1.71	1.68	1.57	1.28	0.00	0.25
Alt 4	873.07	873.08	873.12	873.27	873.85	871.12	882.87
Alt 4: PEY	873.07	873.08	873.13	873.33	874.10	871.12	882.87
Change from Alt 4	0.00	0.00	0.00	0.06	0.25	0.00	0.00
Alt 4: C + PEY	874.79	874.79	874.80	874.86	875.31	871.12	882.87
Change from Alt 4	1.72	1.71	1.68	1.59	1.47	0.00	0.00
Alt 4: C + P	874.79	874.79	874.80	874.84	875.10	871.12	883.12
Change from Alt 4	1.72	1.71	1.68	1.58	1.26	0.00	0.25
Alt 4: C + P + PEY	874.79	874.79	874.80	874.86	875.32	871.12	883.12
Change from Alt 4	1.72	1.71	1.68	1.59	1.47	0.00	0.25
Alt 5	873.07	873.08	873.13	873.27	873.81	871.12	882.87
Alt 5: C + P	874.79	874.79	874.80	874.84	875.10	871.12	883.12
Change from Alt 5	1.72	1.71	1.68	1.58	1.29	0.00	0.25
Alt 5: C + P + PEY	874.79	874.79	874.80	874.85	875.16	871.12	883.12
Change from Alt 5	1.72	1.71	1.68	1.58	1.34	0.00	0.25
Alt 6	873.07	873.08	873.13	873.27	873.82	871.12	882.87
Alt 6: C + P	874.79	874.79	874.80	874.84	875.11	871.12	883.12
Change from Alt 6	1.72	1.71	1.68	1.57	1.28	0.00	0.25

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 536C							
Alt 1	871.42	871.44	871.59	872.32	874.43	869.20	882.82
Alt 1: C	874.42	874.42	874.45	874.54	874.95	869.20	882.82
Change from Alt 1	3.00	2.98	2.86	2.22	0.51	0.00	0.00
Alt 1: P	871.42	871.44	871.59	872.32	874.43	869.20	883.08
Change from Alt 1	0.00	0.00	0.00	0.00	0.00	0.00	0.26
Alt 1: C + P	874.42	874.42	874.45	874.54	874.95	869.20	883.08
Change from Alt 1	3.00	2.98	2.86	2.22	0.52	0.00	0.26
Alt 2	871.42	871.44	871.59	872.50	874.62	869.20	882.43
Alt 2: C + P	874.42	874.42	874.45	874.55	875.04	869.20	882.69
Change from Alt 2	3.00	2.98	2.86	2.04	0.43	0.00	0.26
Alt 3	871.42	871.44	871.59	872.31	874.45	869.20	882.87
Alt 3: C + P	874.42	874.42	874.45	874.54	874.95	869.20	883.12
Change from Alt 3	3.00	2.98	2.86	2.23	0.51	0.00	0.25
Alt 4	871.42	871.44	871.59	872.35	874.56	869.20	882.87
Alt 4: PEY	871.42	871.44	871.61	873.02	875.70	869.20	882.87
Change from Alt 4	0.00	0.00	0.03	0.67	1.14	0.00	0.00
Alt 4: C + PEY	874.42	874.42	874.46	874.60	876.08	869.20	882.87
Change from Alt 4	3.00	2.98	2.87	2.25	1.51	0.00	0.00
Alt 4: C + P	874.42	874.42	874.45	874.55	875.03	869.20	883.12
Change from Alt 4	3.00	2.98	2.86	2.19	0.47	0.00	0.25
Alt 4: C + P + PEY	874.42	874.42	874.46	874.60	876.09	869.20	883.12
Change from Alt 4	3.00	2.98	2.87	2.25	1.52	0.00	0.25
Alt 5	871.42	871.44	871.59	872.31	874.47	869.20	882.87
Alt 5: C + P	874.42	874.42	874.45	874.54	874.99	869.20	883.12
Change from Alt 5	3.00	2.98	2.86	2.23	0.52	0.00	0.25
Alt 5: C + P + PEY	874.42	874.42	874.46	874.60	875.65	869.20	883.12
Change from Alt 5	3.00	2.98	2.87	2.29	1.18	0.00	0.25
Alt 6	871.42	871.44	871.59	872.38	874.45	869.20	882.87
Alt 6: C + P	874.42	874.42	874.45	874.54	874.97	869.20	883.12
Change from Alt 6	3.00	2.98	2.86	2.16	0.52	0.00	0.25

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

Water Surface Elevation (ft, NAVD88)							
	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	Min	Max
Storage Area 536D							
Alt 1	866.58	866.61	866.72	866.98	867.92	864.58	882.82
Alt 1: C	869.58	869.59	869.63	869.73	869.97	864.58	882.82
Change from Alt 1	3.00	2.98	2.91	2.75	2.04	0.00	0.00
Alt 1: P	866.58	866.61	866.72	866.98	867.93	864.58	883.08
Change from Alt 1	0.00	0.00	0.00	0.00	0.01	0.00	0.26
Alt 1: C + P	869.58	869.59	869.63	869.73	869.98	864.58	883.08
Change from Alt 1	3.00	2.98	2.91	2.75	2.06	0.00	0.26
Alt 2	866.58	866.61	866.73	867.01	868.10	864.58	882.43
Alt 2: C + P	869.58	869.59	869.63	869.73	870.01	864.58	882.68
Change from Alt 2	3.00	2.98	2.90	2.72	1.91	0.00	0.25
Alt 3	866.58	866.61	866.72	866.98	867.94	864.58	882.87
Alt 3: C + P	869.58	869.59	869.63	869.73	869.98	864.58	883.12
Change from Alt 3	3.00	2.98	2.91	2.75	2.04	0.00	0.25
Alt 4	866.58	866.61	866.72	866.99	868.11	864.58	882.87
Alt 4: PEY	866.58	866.61	866.74	867.16	869.37	864.58	882.87
Change from Alt 4	0.00	0.00	0.02	0.16	1.27	0.00	0.00
Alt 4: C + PEY	869.58	869.59	869.64	869.77	870.40	864.58	882.87
Change from Alt 4	3.00	2.98	2.92	2.77	2.29	0.00	0.00
Alt 4: C + P	869.58	869.59	869.63	869.73	869.99	864.58	883.12
Change from Alt 4	3.00	2.98	2.91	2.73	1.89	0.00	0.25
Alt 4: C + P + PEY	869.58	869.59	869.64	869.77	870.44	864.58	883.12
Change from Alt 4	3.00	2.98	2.92	2.78	2.33	0.00	0.25
Alt 5	866.58	866.61	866.72	866.98	868.00	864.58	882.87
Alt 5: C + P	869.58	869.59	869.63	869.73	869.98	864.58	883.12
Change from Alt 5	3.00	2.98	2.91	2.74	1.98	0.00	0.25
Alt 5: C + P + PEY	869.58	869.59	869.64	869.77	870.25	864.58	883.12
Change from Alt 5	3.00	2.98	2.92	2.78	2.24	0.00	0.25
Alt 6	866.58	866.61	866.72	866.99	867.96	864.58	882.87
Alt 6: C + P	869.58	869.59	869.63	869.73	869.98	864.58	883.12
Change from Alt 6	3.00	2.98	2.91	2.74	2.02	0.00	0.25

1) C = Culverts filled half-full of sediment sensitivity
2) P = Pumps removed sensitivity
3) PEY = Simulated pulse every year sensitivity

Plate 27 cont'd: Interior Drainage Sensitivity - Storage Area Statistics

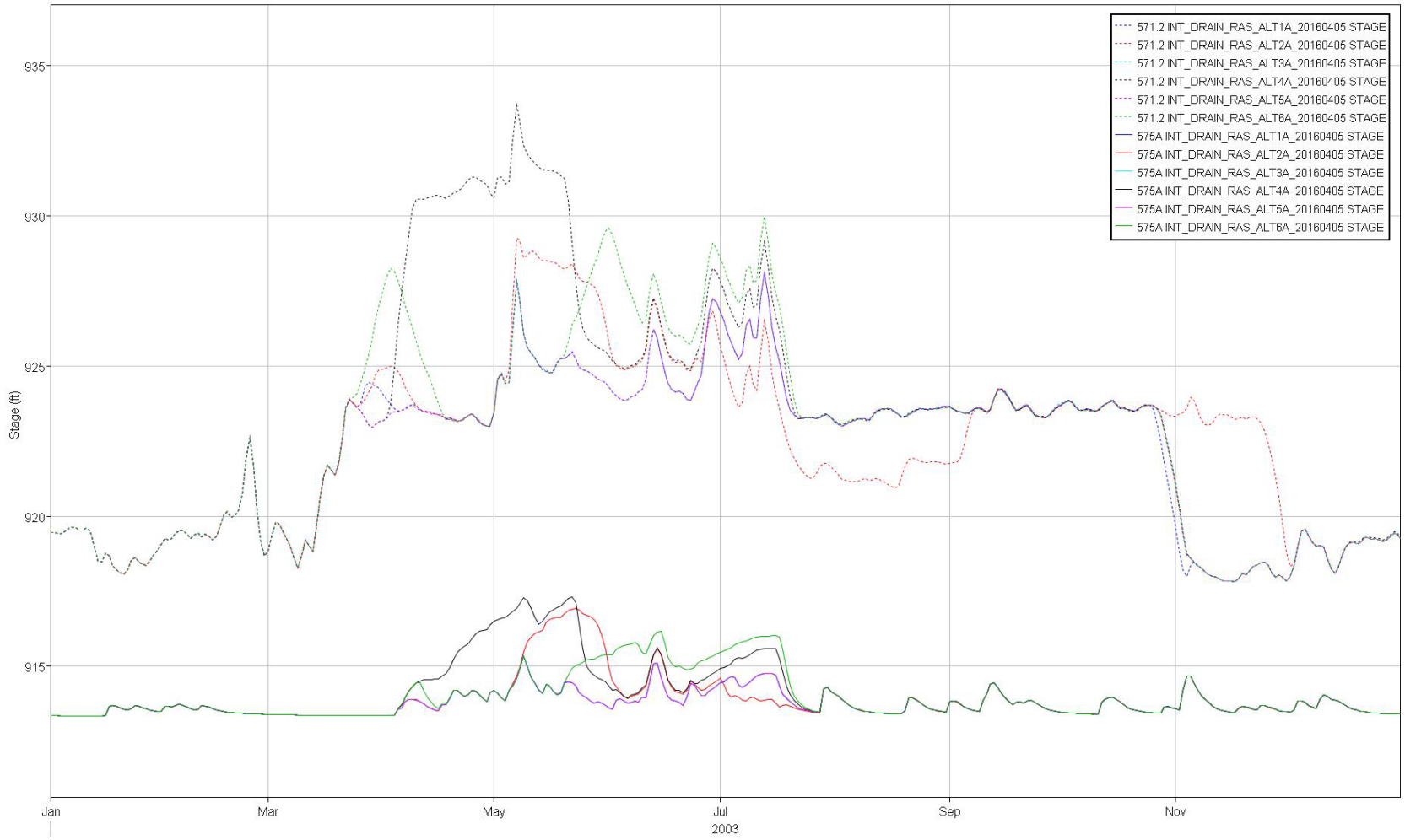


Plate 28: Interior Drainage Example Output

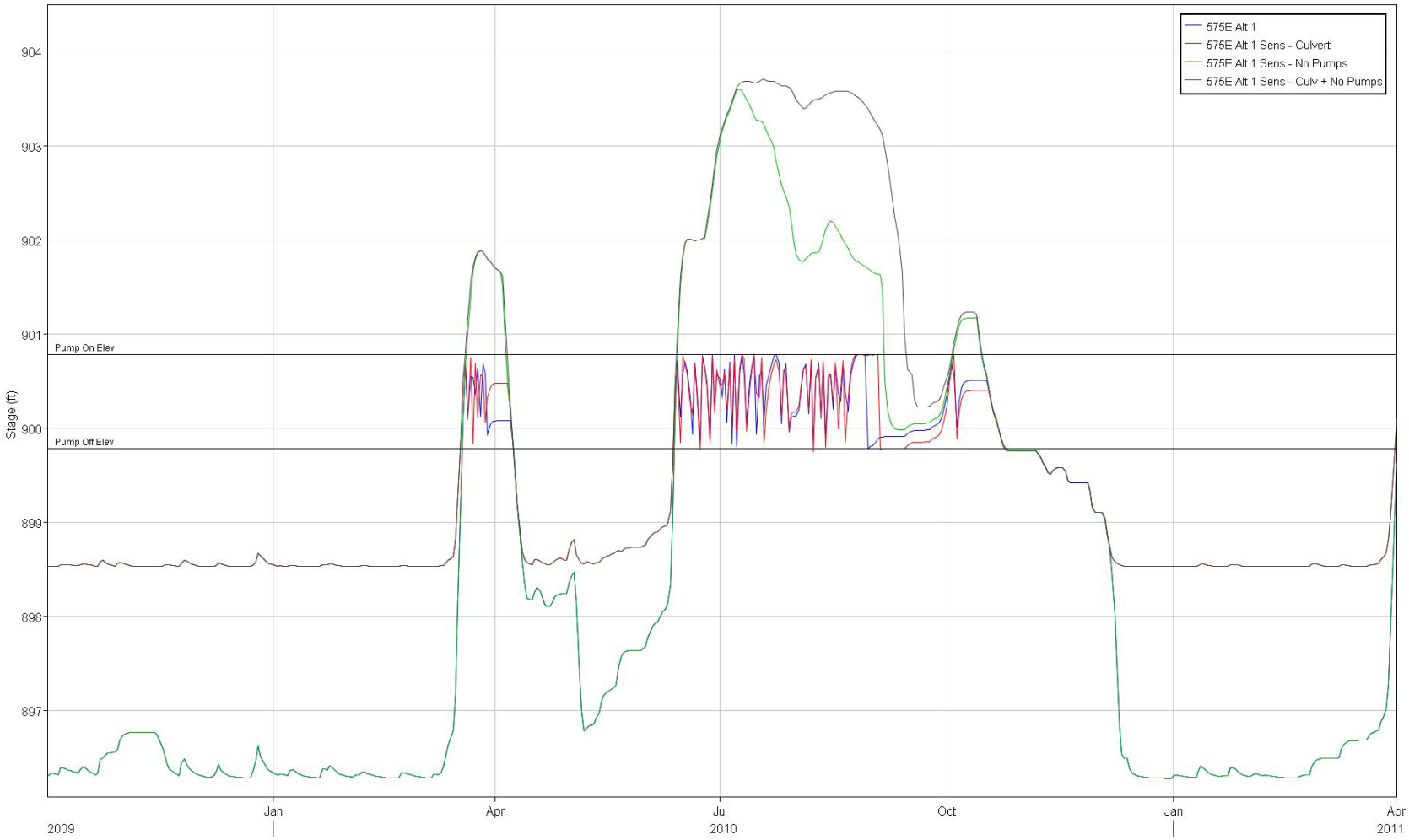


Plate 29: Interior Drainage Sensitivity Example Output

Levee Station	Lateral Structure/ Storage Area Connection	Lateral Structure Station(s)	# of Pipes	Solution Criteria	Diameter (ft)	Chart	Scale #	US Invert Elev (NAVD88, ft)	DS Invert Elev (NAVD88, ft)	Culvert Length (ft)	Entrance Loss Coefficient	Exit Loss Coefficient	N-Value for Top	N-Value for Bottom	Depth to Use Bottom	Depth Blocked
495+35	575a1-m	5565	1	Highest US EG	4	2	1	930.09	928.84	135	0.5	1	0.024	0.024	0	0
24+91	575a1-m	14560	1	Highest US EG	4	1	1	928.95	927.05	374	0.5	1	0.013	0.013	0	0
684+80	575b1-m	7105	1	Highest US EG	3.5	2	1	924.42	922.74	169	0.5	1	0.024	0.024	0	0
172+00	575b2-m	29510	1	Highest US EG	4	1	1	914.35	912.81	309	0.5	1	0.013	0.013	0	0
320+35 - #1	575a2-m	5491	1	Highest US EG	4	1	1	913.35	912.21	237	0.5	1	0.013	0.013	0	0
320+35 - #2	575a2-m	5500	1	Highest US EG	5	1	1	913.35	912.21	237	0.5	1	0.013	0.013	0	0
320+35 - #3	575a2-m	5509	1	Highest US EG	4	1	1	913.35	912.21	237	0.5	1	0.013	0.013	0	0
1114+50	575c-m	7475	1	Highest US EG	3	2	1	915.35	913.86	153	0.5	1	0.024	0.024	0	0
1161+40	575c-m	12165	1	Highest US EG	3	2	1	913.79	912.27	153	0.5	1	0.024	0.024	0	0
1167+50	575c-m	12775	1	Highest US EG	4	2	1	914.80	913.71	143	0.5	1	0.024	0.024	0	0
450+00	575d-m	5950 5980	2	Highest US EG	5	1	1	910.45	909.33	238	0.5	1	0.013	0.013	0	0
1404+00	575d-m	23708 23698	2	Highest US EG	5	2	1	907.34	905.59	159	0.5	1	0.024	0.024	0	0
NR 2165+00 R	575g-t	324 335 347 359 373	5	Highest US EG	6	2	1	898.05(1)	896.69(1)	173	0.5	1	0.024	0.024	0	0
NR 2213+54 R	575h-t	14890	1	Highest US EG	4	2	1	902.35	900.98	113	0.5	1	0.024	0.024	0	0
NR 254+30 R	575h-t	14590	1	Highest US EG	3	2	1	898.22	897.51	116	0.5	1	0.024	0.024	0	0
1769+35	575e-m	24370 34380	2	Highest US EG	4.5	2	1	896.28	895.11	179	0.5	1	0.024	0.024	0	0
NR 1900+32 R	575f-t	25500 25510	2	Highest US EG	4	2	1	893.81	892.61	126	0.5	1	0.024	0.024	0	0
NR 1915+30 R	575f-t	24005 24015	2	Highest US EG	4.5	2	1	893.47	892.50	141	0.5	1	0.024	0.024	0	0
NR 155+40 R	575h-t	5000	1	Highest US EG	3	2	1	901.39(1)	900.82(1)	574	0.5	1	0.024	0.024	0	0
NR 102+29 R	575h-t	5	1	Highest US EG	4.5	2	1	907.09	902.94	294	0.5	1	0.024	0.024	0	0

(1) - Inverts were shifted up 5 feet because they were near or below the Nishnabotna River invert.

Plate 30: L-575 Culvert Information

Levee Station	Lateral Structure/ Storage Area Connection	Lateral Structure Station(s)	# of Pipes	Solution Criteria	Diameter (ft)	Chart	Scale #	US Invert Elev (NAVD88, ft)	DS Invert Elev (NAVD88, ft)	Culvert Length (ft)	Entrance Loss Coefficient	Exit Loss Coefficient	N-Value for Top	N-Value for Bottom	Depth to Use Bottom	Depth Blocked
RC 412+70 L	536a-t	9850	1	Highest US EG	3	2	1	875.92	875.37	90	0.5	1	0.024	0.024	0	0
RC 417+00	536a-t	10285	1	Highest US EG	3	2	1	876.32	875.49	88	0.5	1	0.024	0.024	0	0
RC 485+00 L	536b-t	5851	1	Highest US EG	3.5	2	1	873.04	871.95	112.5	0.5	1	0.024	0.024	0	0
520+80(1)	536b-c	8031	1	Highest US EG	2.5	2	1	877.77	877.29	48	0.5	1	0.024	0.024	0	0
535+10	536c-m	1420 1430	2	Highest US EG	6	2	1	871.42	869.41	128.5	0.5	1	0.024	0.024	0	0
777+20	536d-m	24120 24130	2	Highest US EG	6	2	1	866.58	865.24	118.5	0.5	1	0.024	0.024	0	0

(1) - 520+80 is a culvert under an interior road (G Ave) adjacent to the levee.

Plate 31: L-536 Culvert Information

				Pump Connection Data			Pump Group Data					
Levee Station	Pump Line Size and Type	Curve # Used	Culvert Length (ft)	Pump From (SA)	Pump To (XS)	Distance from US RS to the pump outlet	Group Name	# of Pumps in Group	Startup (min)	Shutdown (min)	WS Elev On (ft)	WS Elev Off (ft)
L-575												
172+00	30" INLINE WATER HOG	3	309	575B	562.35	835	Group #1	1	0	0	918.35	917.35
320+35	2-30" INLINE WATER HOG	3	237	575A	561.4	700	Group #1	2	0	0	917.35	916.35
1404+00	24" STEEL	2	159	575D	554.7	870	Pump Group #1	1	0	0	912.34	911.34
1404+00	48" STEEL	4	159	575D	554.7	922	Pump Group #2	1	0	0	912.34	911.34
NR 2165+00 R	24" STEEL	2	173	575F	41975	600	Pump Group #1	1	0	0	904.05	903.05
NR 2165+00 R	30" STEEL	3	173	575F	41975	575	Pump Group #2	1	0	0	904.05	903.05
NR 2165+00 R	2-48" STEEL	4	173	575G	41975	340	Group #1	2	0	0	904.05	903.05
NR 2213+54 R	18" STEEL	1	113	575H	45994	170	Pump Group #1	1	0	0	906.35	905.35
NR 2213+54 R	24" STEEL	2	113	575H	45994	170	Pump Group #2	1	0	0	906.35	905.35
NR 254+30 R	18" STEEL	1	116	575H	46284	50	Group #1	1	0	0	901.22	900.22
1769+35	2-24" STEEL	2	179	575E	546.15	1837	Group #1	2	0	0	900.78	899.78
NR 1900+32 R	24" STEEL	3	126	575F	14635	130	Group #1	1	0	0	897.81	896.81
NR 1915+30 R	36" STEEL	4	141	575F	18586	1700	Group #1	1	0	0	897.97	896.97
NR 155+40 R	18" STEEL	1	574	575H	56606	165	Group #1	1	0	0	904.39	903.39
NR 102+29 R	15" STEEL	1	294	575H	61096	0	Group #1	1	0	0	911.59	910.59
L-536												
535+10	18" STEEL	1	128.5	536C	521.85	1260	Group #1	1	0	0	877.42	876.42
777+20	24" STEEL	2	118.5	536D	516.3	604	Pump Group #1	1	0	0	872.56	871.56
777+20	30" STEEL	3	118.5	536D	516.3	639	Pump Group #2	1	0	0	872.56	871.56

Plate 32: Pump Data

Curve #1		Curve #2		Curve #3		Curve #4	
Fairbanks Morse - 18”		Fairbanks Morse - 24”		Cascade 24P - 24”		Cascade 42P - 42”	
Head (ft)(1)	**Flow (cfs)**	**Head (ft)(1)**	**Flow (cfs)**	**Head (ft)(1)**	**Flow (cfs)**	**Head (ft)(1)**	**Flow (cfs)**
30.94	12.71	25.29	21.08	27.00	21.54	28.18	48.09
29.86	13.15	23.93	22.45	25.67	22.77	27.76	52.58
27.28	14.23	22.57	23.54	24.10	24.22	27.07	57.09
24.63	15.29	20.98	24.64	22.26	25.70	26.18	62.17
21.90	16.28	19.05	25.73	19.72	27.57	24.86	68.18
19.20	17.16	17.13	26.82	17.35	29.40	23.32	74.09
16.50	17.98	14.92	27.91	14.49	31.30	20.52	82.29
13.76	18.67	12.47	29.00	11.76	33.10	17.72	88.52
11.00	19.31	9.99	30.06	9.04	34.71	14.01	94.56
8.28	19.90	7.25	31.01	6.32	36.01	10.62	99.69
5.52	20.41	4.62	31.81	3.60	36.96	6.85	104.27
2.84	20.89	1.98	32.46	1.11	37.62	3.97	106.84
0.16	21.37					1.32	109.18

(1) Head values include friction and minor losses.

Plate 33: Pump Curve Data

	Curve #1	Curve #2	Curve #3	Curve #4
Average Pipe Length (ft)	245.1	148.5	192.7	157.7
N-Value	0.012	0.012	0.012	0.012
Diameter (ft)	1.5	2	2	3.5
Friction Head Loss (ft)	0.01887	0.00247	0.00320	0.00013
Sum of Loss Coefficients, K	1.5	1.5	1.5	1.5

Plate 34: Pump Curve Loss Parameters

L575 AND L536 SEEPAGE FLOW DETERMINATIONS

MISSOURI RIVER LEVEE SYSTEM

U.S. ARMY CORPS OF ENGINEERS

OMAHA DISTRICT

1616 CAPITOL AVENUE

OMAHA, NEBRASKA 68102-4901

DRAFT

December 2016

LEVEE UNDERSEEPAGE AND RELIEF WELL FLOWS.

1. General. CENWO-ED-GA was tasked with determining seepage flows from underseepage through the levee foundation, and from relief wells. This was performed for levee systems L575 and L536.

1.1. Underseepage Flows. The underseepage flows were determined from flows in SEEP/W models created after the 2011 flood. SEEP/W is a numerical model that was developed by GEO-SLOPE International Ltd. These models were chosen because they are recent and developed from recent soil investigations (MER, CPT, borings). The flows were obtained from within the model at the flux boundary and location at the levee centerline. This is discussed in detail in later paragraphs.

1.2. Relief Well Flows. The relief wells flows were determined using USACE Mobile District spreadsheet developed from equations in EM 1110-2-1914 Design, Construction, and Maintenance of Relief Wells. Soil parameters, stratigraphies, and geometries were obtained from the SEEP/W models. The river level elevations were varied from the top of levee to the toe of levee and relief well flows recorded.

L536 DETERMINATION.

1. Project Description. Levee System L-550/536 is located in Atchison and Holt Counties in Missouri along the left (east) bank on the Missouri River. The total length of the system is 15.8 miles. The system extends from the Rock Creek tieback south of Rock Port, Missouri down the Missouri River and Mill Creek tieback to high ground west of Corning, Missouri. The county line is located near the southern end of the mainline levee being Holt 100/Atchison Holt Road located about one mile north of Corning, Missouri. The Rock Creek tieback segment is 5.5 miles long and is officially part of the L-550 levee even though it is part of the L-536 system. The length of the L-536 segments of the system is 10.3 miles as described below: L-536 begins at Station 503+45 where it continues stationing from L-550 at the Rock Creek tieback, approximately six miles south of Rock Port, Missouri. L-536 runs downstream along the Missouri River for a distance of 8.1 miles (Station 801+00) where it joins the right bank of the Mill Creek tieback. The levee continues up the Mill Creek right bank for a distance of 2.2 miles where the system ties into high ground. This upstream tieback is located just west of Corning, Missouri. See Figure 1 for a partial map of L536, mainly the area of seepage during 2011 flooding.

2. Underseepage Berms. Landside and riverside underseepage berms were constructed along the entire reach of the Missouri River levee. It was determined that no berms were needed along the tiebacks. The landside berms generally extend 100 feet from the centerline of the levee with the exception of the berm between Station 503+45-535+50 which extended 20'. The thickness of the berms, measured at the berm shoulders, vary from 2.5 to 4.5 feet. Additional underseepage control methods (relief wells) were required at various reaches of the levee where conditions of relatively large, thin blanket on the landward side, or close proximity of the levee to the river bank, or a combination of these, render inadequate the use of berms alone. Riverside berms extend 25' from the centerline of the levee along the below intervals. All berms were sloped at 1:50. The table below describes locations of landside and riverside berms.

3. Relief Wells. Fifty-seven pressure relief wells were installed along the landside toe of the Missouri River reach of the levee system. Relief wells were constructed with 8-inch inside diameter slotted wood stave screens. An 8-inch inside diameter plastic riser pipe extends from the screens to slightly above the surrounding natural ground. A relief valve assembly (check valve) was attached to the top of each riser pipe to prevent ponded water from entering the well. At the surface, the wells were finished in a concrete well pit with a landside opening at the ground line and a trash guard in the opening. Some wells had shallow excavations adjacent to the overflow opening to facilitate flow into ponding areas.

Phase 1 repairs were considered time critical and needed to be completed prior to the 2012 flood season. The Phase 1 construction contract was awarded on February 21, 2012. The Phase 1 design was based upon engineering judgment without the aid of additional field surveys or geotechnical data. Concurrent with the construction of the Phase 1 repairs, extensive geotechnical investigations were conducted. The investigations included profiling the levee embankment ant foundation stratigraphy with geophysics, specifically multiple point electric resistivity. Cone penetrometers were then pushed to target areas of concern and to correlate the MER data. Borings were then drilled to target areas of concern and to correlate the CPT data. All components of the geotechnical investigations were then surveyed to locate the horizontal location and vertical elevation of the data points. The purpose of the study was to assess the need for, and the design of, additional seepage control measures in areas that sustained damages during the flood event. The purpose of the underseepage report was to utilize the completed geotechnical investigation data to evaluate the adequacy of the Phase 1 repairs and to design the Phase 2 repairs.

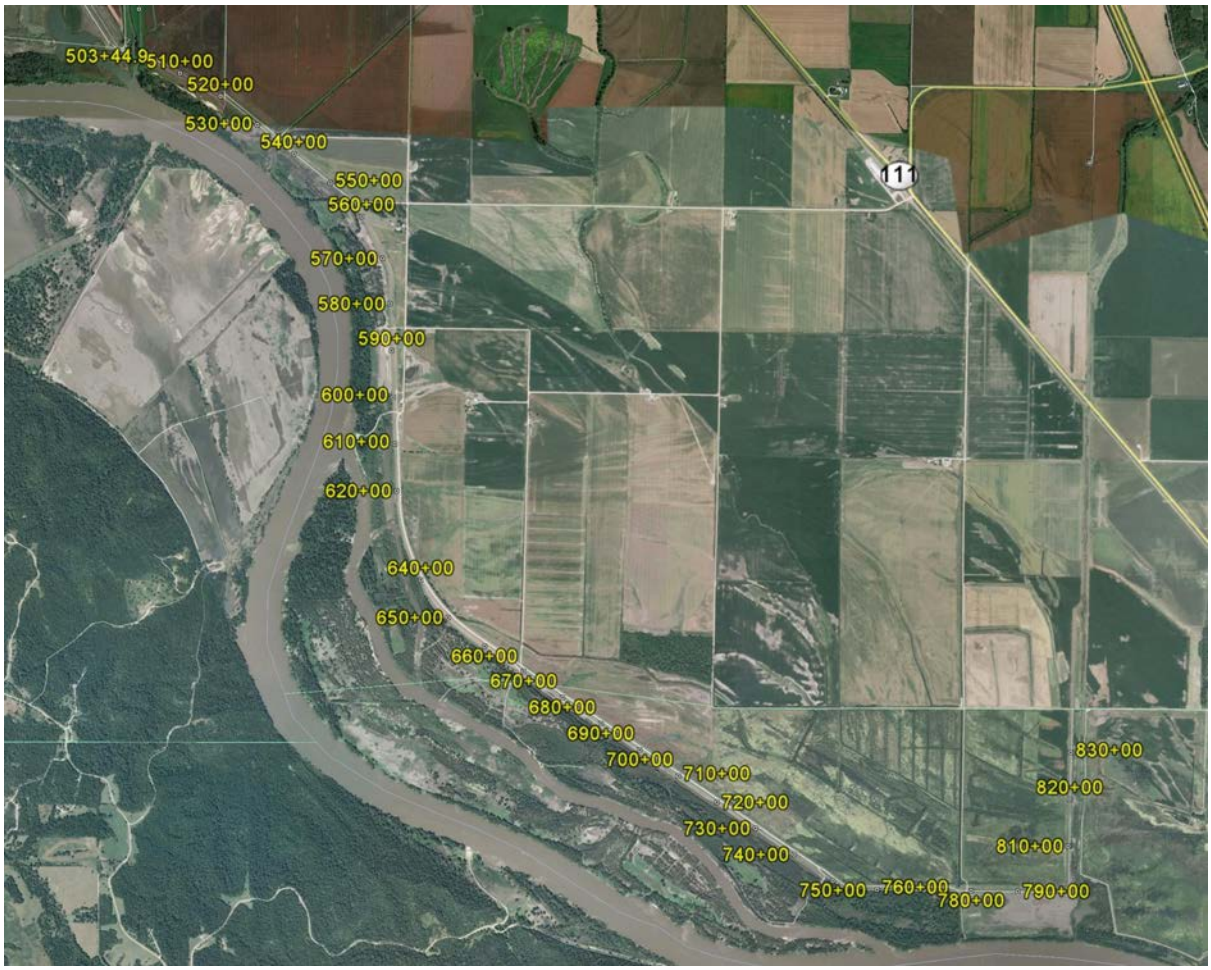


Figure 1. L536 South Portion Along Missouri River

4. Flow Determination. The underseepage and relief flow determination, and the values to use are discussed in the following paragraphs. The L536 boundary was divided into four areas by ED-H and designated as 536A, 536B, 536C and 536D. Areas 536B, 536C and 536D bound the levee along the Missouri River. Areas 536A, 536B and 536C bound the Rock Creek tieback levee. Area 536D bound the Mill Creek tieback levee.

4.1. Underseepage Flow Determination. The underseepage flows, as stated earlier, were determined from existing recent post-2011 Flood SEEP/W modeling. L536 models were performed at Stations 568+00, 677+25, 728+25, and 800+00. The areas were designated in the modeling as, and to cover Area 1 between Stations 790+00 and 810+00, Area 2A between Stations 730+00 and 747+00, Area 2B between Stations 647+00 and 690+00, and Area 2C between Stations 555+00 and 570+00.

Landside seepage berms are located from Stations 555+00 to 570+00, 601+45, 640+00 to 642+00, 647+00 to 690+00, and 710+00 to 809+00. The four seepage models all yielded a similar flow rate and it was decided to use one value. A seepage rate with the river at the levee crest for the tiebacks and berm-only areas was obtained from the SEEP/W model as 0.24 gallons per minute/linear foot of levee for the river level at the crest. The seepage rate with river levels at the toe would be 0 and any seepage rates for other river levels should be determined by interpolating between the crest and toe values. This rate should be used for berm-only areas station 555+00 to 565+50, 710+20 to 776+45, and 777+40 to 809+00; and the tieback levees (stationing adjusted for areas containing both wells and berms). Table 1 and the succeeding three paragraphs should be used for flows for the entire system.

Table 1 – L536 Seepage Flow Rates

Stationing Range		Reach Length	Q_{BERM} gpm/lf	Q_{WELL}
535+10	555+00	[2]1990	0.24	0
555+00	565+50	[2]1050	0.24	0
565+50	710+20	[1]14470	0	See Table 2
710+20	776+45	[2]6625	0.24	0
776+45	777+40	[1]95	0	See Table 2
777+40	809+00	[2]3160	0.24	0

[1]Use curve provided, should use desired stage and pick rate from curve and multiply by number of wells. The duration of the event should be considered by ramping up to a peak, using the peak length, and ramping down from peak. There are a total of 68 wells in these two station groups.

[2]A linear curve of 0.24 gpm/linear foot of levee at the crest to 0 at the levee toe should be used for these station reaches. The rate should be picked using desired stage and multiplied by the total linear feet of levee. The duration of the event should be considered by ramping up to a peak, using the peak length, and ramping down from peak.

The other three drainage boundaries would use just the berm seepage rates and methodology as in note [2]. Two of the drainage boundaries border the Missouri River and should use the berm seepage rates.

4.2. Relief Well Flow Determination. The relief well flows, as stated earlier, were determined using a USACE Mobile District spreadsheet. There are a total of 68 wells in the reach along the Missouri River, the south drainage Area 536D. The next two northern drainage area boundaries (536B & 536C) that are along the Missouri River are from station 503+45 to 520+80, and 520+80 to 535+10; these do not have wells. One well flow rate analysis was used for L536, see Table 2 and Figure 2 for the values. It should be noted that the flows are linear for the range of elevations presented.

Table 2 Relief Well Flow Rates	
Elev.	**GPM**
887*	93.3
885	76.6
883	61.3
880	36.8
878	20.4
876	4.1
875.5	0
873**	0

*Crest of Levee
**Base of Levee

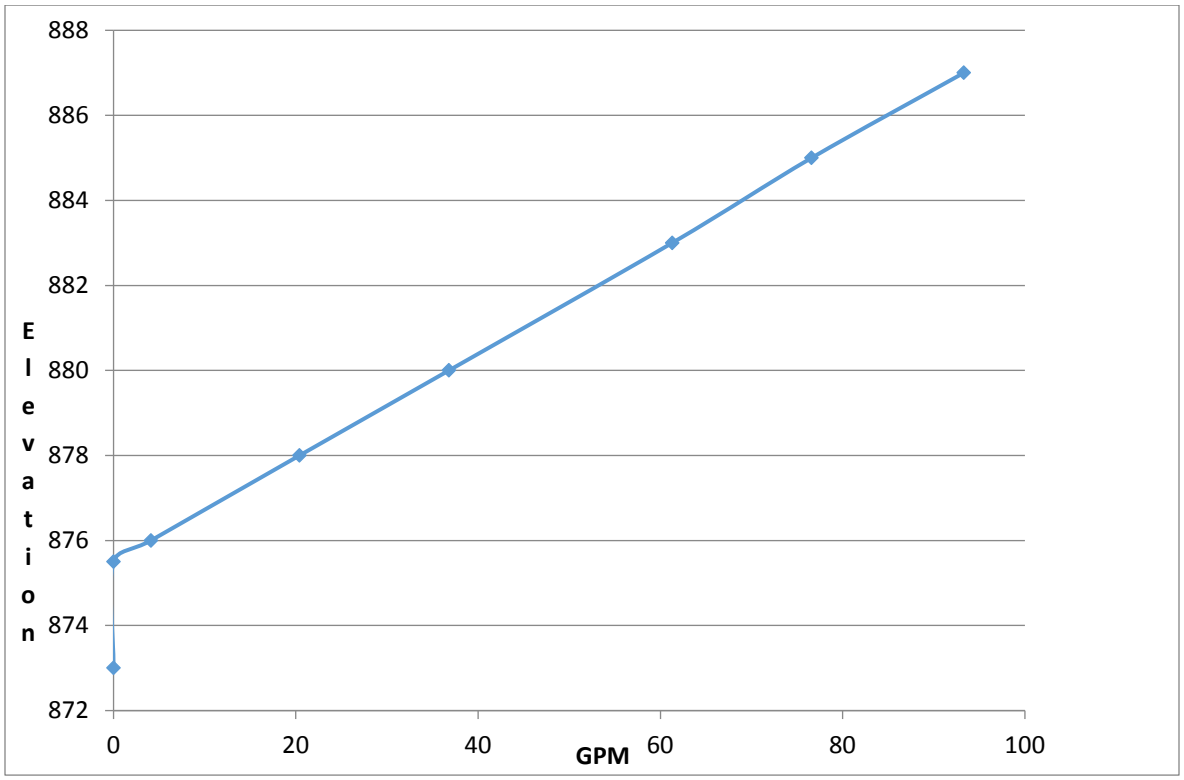


Figure 2. Chart of Relief Well Flows

L575 DETERMINATIONS.

1. Project Description. The L-575 levee system consists of five segments totaling approximately 41.8 miles in length which protects nearly 70,000 acres of land within the flood plain of the Missouri River. The system protects small communities and agricultural land against high stages of the Missouri River, Plum Creek, and the Nishnabotna River. The construction of the levees began May 1947 and was completed in August 1949, while the installation of the underseepage control facilities continued until November 1950. All five levee segments were originally designed to provide flood risk protection for a two percent annual chance (50 year return period) flood with two feet of freeboard.

The Plum Creek and Missouri River (Benton-Washington) levee segment stretches approximately 24.5 miles along the left descending bank of Plum Creek and the Missouri River. The levee embankment

begins on the left bank of Plum Creek at Station 222+90 near the town of Thurman, Iowa, extends west to Station 445+00, near Missouri River mile 573.5, and continues south along the left bank of the Missouri River to Station 1490+00.

The Missouri River and Nishnabotna River (NW Atchison) levee segment includes four separate sections of the Missouri River and the Nishnabotna River levees. The Northwest Atchison County Levee District includes segments along the Missouri River between approximate Stations 1490+00 to 40+43 (on the Middle Breach Setback levee) and 1783+00 to 1834+50. The district also controls segments along the Nishnabotna River between approximate Stations 1960+00 to 2069+67, 2126+13 to 2213+80, and 260+20 to 176+75 (Note that levee stationing changes at 2213+80 to 260+20, at which point stationing decreases upstream toward Hamburg). Overall, the district controls 7.4 miles of levee.

The Missouri River (Buchanan) levee segment begins at approximate Station 40+43 on the Middle Breach Setback and extends south approximately 4.4 miles to Station 1783+00.

The Nishnabotna River (McKissock Island) levee segment includes two separate sections of levee totaling approximately 3.1 miles. The district controls levee along the right bank of the Nishnabotna River from approximate Station 1834+50 to 1960+00 and from Station 2069+67 to Station 2126+13.

The Nishnabotna River (Hamburg) levee segment begins at Station 177+00 and extends north for approximately 2.3 miles to tie-in to high ground at Station 49+96 in Hamburg, Iowa.

See Figure 3 for a map of L575.

2. Underseepage Berms. Landside seepage berms were constructed as part of the original levee design along portions of the Missouri River in the Benton-Washington, NW Atchison, Buchanan, and McKissock Island districts. Flooding in 2011 caused breaches on portions of the levee system, and the levee embankments and seepage berms in these areas were abandoned. Repairs to the damage occurred in 2012 and 2013 and included new setback levees constructed in breach locations and new underseepage control systems, including landside seepage berms, relief wells, and toe drain systems. Landside and riverside underseepage berms were constructed along the entire reach of the Missouri River levee. It was determined that no berms were needed along the tiebacks. Additional underseepage control methods (relief wells) were required at various reaches of the levee where conditions of relatively large, thin blanket on the landward side, or close proximity of the levee to the river bank, or a combination of these, render inadequate the use of berms alone.

3. Relief Wells. There were originally 230 relief wells installed on the L-575 levee system. Several relief wells located in areas that were breached and damaged in the 2011 flood event were abandoned or unable to be located and new relief wells were installed.

On the Benton-Washington levee segment, there were originally 128 relief wells. During the 2012-2013 repairs, 84 of these wells were abandoned, 19 wells were replaced, and 39 new wells were installed. Currently there are 83 relief wells on this segment. There were 17 new relief wells installed on the NW Atchison segment on the new setback levee and seepage berm constructed during the 2012-2013 repairs. On the Buchanan segment, there were originally 42 relief wells. During the 2012-2013 repairs, 13 of these wells were abandoned, 11 wells were replaced, and 15 new wells were installed. Currently there are 44 relief wells on this segment. On the McKissock Island levee segment, there were originally 60 relief wells. During the 2012-2013 repairs, 23 of these wells were abandoned or not found, 22 wells were replaced, and 14 new wells were installed. Currently there are 51 relief wells on this segment. There are no relief wells located on the Hamburg segment.

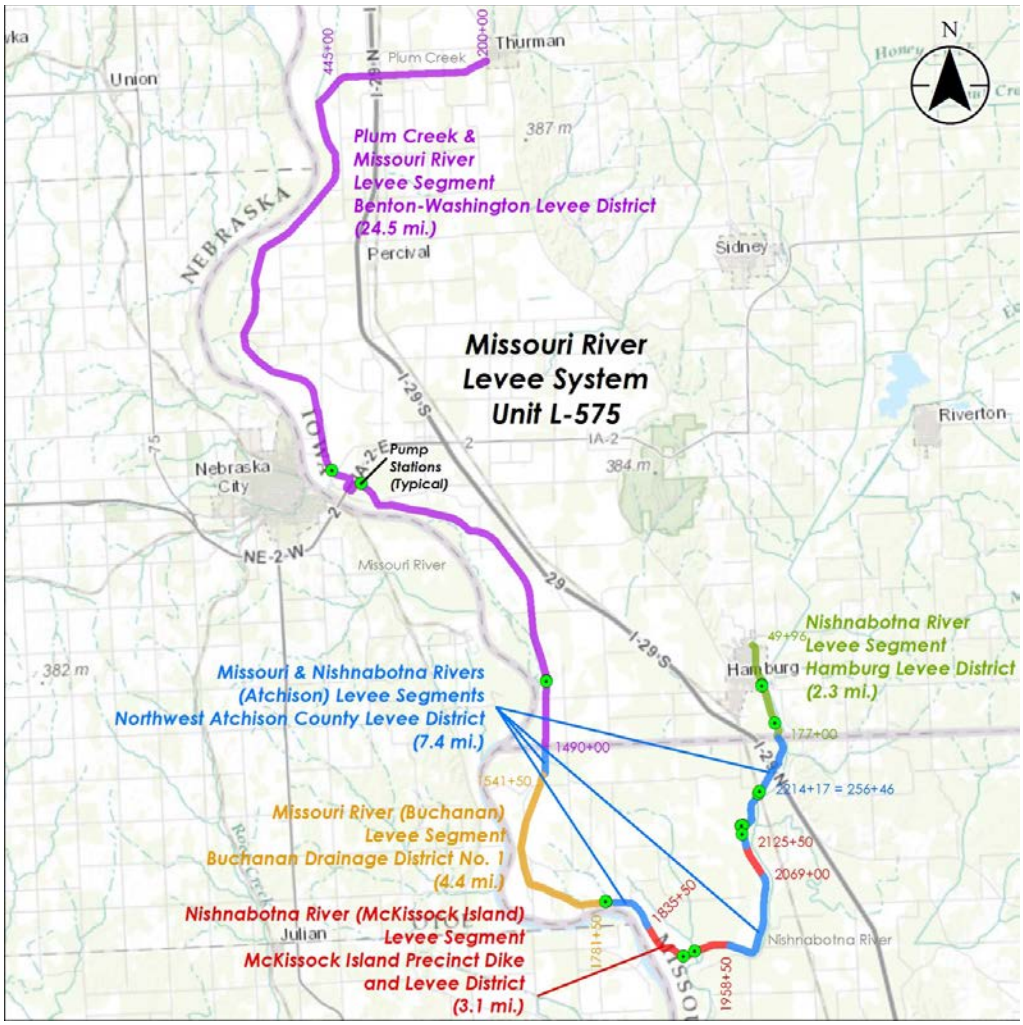


Figure 3. L536 South Portion Along Missouri River

4. Flow Determination. The underseepage and relief flow determination, and the values to use are discussed in the following paragraphs. The L575 boundary was divided into eight areas by ED-H and designated as 575A, 575B, 575C, 575D, 575E, 575F, 575G and 575H. Areas 575B, 575C, 575D, 575E and 575F bound the levee along the Missouri River. Areas 575A and 575B bound the Plum Creek tieback levee. Areas 575F and 575H bound the Nishnabotna River tieback levee.

4.1. Underseepage Flow Determination. The underseepage flows, as stated earlier, were determined from existing recent post-2011 Flood SEEP/W modeling. L575 models were performed at the 1185, Upper Breach, Middle Breach and Lower Breach Setbacks. 1185 was modeled at four locations, the Upper Breach at three locations, the Middle Breach at three locations, and the Lower Breach at two locations. The flows through the aquifer at the centerline of levee with the river level at the crest for each location is shown in Table 3.

Table 3 – Underseepage Flows per SEEP/W			
	Stations	**cfs/lf**	**gpm/lf**
1185 Setback			
	405+00	0.00007537	0.034
	435+00	0.00007372	0.033
	470+00	0.00004378	0.020
	496+00	0.00005070	0.023
Upper Breach			
	34+00	0.00717000	3.218
	34+00	0.00680200	3.053
	34+00	0.00676700	3.037
	40+00 to 65+00	0.00242700	1.089
	40+00 to 65+00	0.00260700	1.170
	40+00 to 65+00	0.00298700	1.341
	52+00	0.00169500	0.761
	52+00	0.00141400	0.635
	52+00	0.00169500	0.761
Middle Breach			
	19+00	0.00800300	3.592
	19+00	0.00800900	3.595
	35+00	0.00441100	1.980
	35+00	0.00442500	1.986
	37+00 to 63+00	0.00331600	1.488
Lower Breach			
	10+00	0.00637000	2.859
	10+00	0.00821500	3.687
	22+50	0.00423700	1.902
	22+50	0.00583200	2.618

4.2. Relief Well Flow Determination. The relief well flows, as stated earlier, were determined using a USACE Mobile District spreadsheet. There are a total of 191 wells in the L575 system. Relief wells are located between Stations 55+200 and 600+00, 734+00 and 743+80, 984+00 and 1044+00, 1111+00 and 1162+40, 1384+00 and 1404+50, 1424+75 and 1425+00, 1530+00 and 1592+00, 1596+45 and 1646+00, 1687+90 and 1703+00, 1756+15 and 1758+85, 1857+00 and 1864+50, 1866+00 and 1900+00, 1903+90 and 1951+80, and 661+00. Each location was analyzed with one relief well flow spreadsheet specifics reflective of the reach. Fourteen well locations were analyzed in L575 due to scoping changes after the L536 determinations. Table 4 lists the relief well reaches and the flow determined for all wells in the reach.

Table 4 – Relief Well Flow Rates	
Station Reach	**gpm/well**
535+00 to 620+00	77.0
656+50 to 665+50	67.4
725+00 to 751+78	124.3
837+00 to 1072+00	98.6
1072+00 to 1170+00	118.4
1344+00 to 1422+00	64.1
1422+00 to 1482+00	64.1
1525+00 to 1592+00	79.1
1592+00 to 1646+00	79.1
1651+00 to 1729+90	115.7
1750+00 to 1783+00	115.7
1834+52 to 1864+90	47.7
1864+90 to 1900+00	63.7
1900+00 to 1933+00	47.0

Table 5 presents the seepage flow values to be used for both relief well reaches and non-well reaches; the values presented are maximum values. The seepage rate with river levels at the toe would be 0 and any seepage rates for other river levels should be determined by interpolating between the crest and toe values as was done for L536; this would also apply to the relief well values. This is considered reasonable and proper because the resulting flow functions are linear. In relief well reaches, the relief well value would be used in lieu of the underseepage value. For stations 837+00 to 1072+00, 1072+00 to 1170+00 and 1185+00 to 1344+00, where there are no wells, a berm value of 2.197 should be used instead of the listed non-berm value of 0.034. Final underseepage flow rates shown in Table 5 were adjusted from those presented in Table 4, the low values were usually ignored and an average of the remaining values were used and some adjusted up or down using engineering judgement. The underseepage flow values presented in Table 4 may have been high being they were obtained beneath the levee centerline, and actual flow exiting the ground surface would be reduced to loss of head. Values outside of the seepage model areas were selected based on foundation stratigraphy.

Table 5 – Underseepage and Relief Well Flows

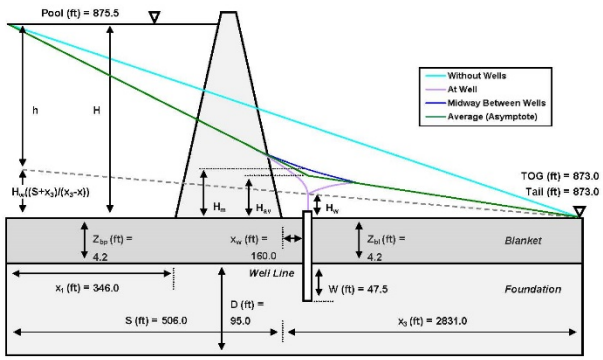
Berm Locations-sta		Reach length	Actual length	Berm width				well start station	well end statiion	No. of Wells	Q_{berm}	Q_{rw}	
											gpm/LF	gpm/well	
22290	44000	21710			No Berm						0.034		
44000	44700	700		80							2.197		
44700	45400	700			No Berm						0.034		
45400	46000	600		80							2.197		575a
46000	49000	3000			No Berm						0.034		
49000	49750	750		90							2.197		
49750	53500	3750			No Berm						0.034		
53500	62000	8500	6454	150	Upper Breach Setback			55200	60000	32	2.197	77.0	
62000	63800	1800			No Berm						0.034		
63800	65450	1650		90							2.197		
65450	65650	200		90-105							2.197		
65650	66550	900		105				66100		1	2.197	67.4	
66550	68750	2200		105-90							2.197		
68750	69050	300		90							2.197		
69700	72500	2800		75-110							2.197		575b
72500	75178	2678		110				73400	74380	7	2.197	124.3	
75178	77000	1822		110							2.197		
77000	80300	3300		110-75							2.197		
80300	83700	3400		75-100							2.197		
83700	107200	23500	34645	150	Highway 2 Setback			98400	104400	4	0.034	98.6	575a
107200	117000	9800		100				111100	116240	26	0.034	118.4	
117000	118500	1500			No Berm						0.034		575d
118500	134400	15900	16764	150	1185 Setback						0.034		
134400	142200	7800		100				138400	140450	9	2.965	64.1	
142200	148200	6000		100				142475	142500	2	2.965	64.1	
148200	149005	805		150							2.965		575c
149005	152200	3195		90-70							2.965		
152200	152500	300		100							2.965		
152500	159200	6700	6262	150	Middle Breach Setback			153000	159200	32	2.965	79.1	
159200	164600	5400		95				159645	164600	16	2.965	79.1	575e
164600	165100	500		95-100							2.673		
165100	172990	7890		100				168790	170300	10	2.673	115.7	
172990	175000	2010		105-110							2.673		
175000	178300	3300		110-90				175615	175885	3		115.7	
178300	180000	1700		110-90							2.673		
180000	183452	3452		90-110							2.673		
183452	186490	3038		90-110				185700	186450	6	2.380	47.7	
186490	190000	3510	3424	150	Lower Breach Setback			186600	190000	14	2.380	63.7	575f
190000	193300	3300			No Berm			190390	195180	29	0.034	47	
193300	195800	2500		100							2.380		
195800	221354	25554			No Berm						0.034		
													575g
5000	25634	20634			No Berm						0.034		575h

APPENDIX A

USACE Mobile District Relief Well Spreadsheet

Relief Well System Design and Analysis Program				*vs 9.8.09*
Project	L536			
Program is Applicable for Blanket Aquifer Foundation Case with an Infinite Line of Wells Parallel to an Infinite Line Source				
Parameter	*Expected Value*	*Units*	*Definition*	
Load and Underseepage Geometric Parameters				
Pool	875.50	ft	Pool elevation	
Tail	873.00	ft	Landside tail water elevation	
H	2.50	ft	Net head on well system	
TOG	873.00	ft	Landside top of ground elevation	
L_1	1275.0	ft	Distance from poolside embankment toe to an open seepage entrance; enter "NA" if not applicable	
	NA	ft	Distance from poolside embankment toe to a seepage block; enter "NA" if not applicable	
L_2	160.0	ft	Base width of impervious embankment	
L_3	NA	ft	Distance from landside embankment toe to an open seepage entrance; enter "NA" if not applicable	
	NA	ft	Distance from landside embankment toe to a seepage block; enter "NA" if not applicable	
x_w	160.0	ft	Line of wells distance downstream from the embankment toe; if line of wells is located at the embankment toe enter "0.0"	
x_1	346.0	ft	Distance from poolside embankment toe to effective seepage entry	
	346.0	ft	x_1 determined from hydraulic grade line measured by aquifer foundation piezometeric data; enter "NA" if not applicable	
S	506.0	ft	Distance from effective source of seepage entry into foundation to the landside embankment toe (fig. 11, TM 3-424)	
x_3	2831.0	ft	Distance from landside embankment toe to effective seepage exit	
	NA	ft	x_3 determined from hydraulic grade line measured by aquifer foundation piezometric data; enter "NA" if not applicable	
Blanket Strata Parameters				
Z_{bp-1}	4.2	ft	Actual thickness of poolside blanket stratum 1	*Classification: Sandy Silt*
Z_{bp-2}	0.0	ft	Actual thickness of poolside blanket stratum 2	*Classification: -*
Z_{bp}	4.2	ft	Total actual thickness of poolside blanket strata	
K_{bp-1}	8.60E-03	ft/d	K_y (vertical hydraulic conductivity) of poolside blanket stratum 1	
$\underline{K}_{bp}$	8.6E-03	ft/d	Effective K_y of poolside blanket strata (eq. 3, TM 3-424)	
c_{bp}	0.0004		Constant for poolside blanket strata (eq. B-4, EM 1110-2-1914)	
Z_{bl-1}	4.2	ft	Actual thickness of landside blanket stratum 1	*Classification: Sandy Silt*
Z_{bl}	4.2	ft	Total actual thickness of landside blanket strata	
K_{bl-1}	8.60E-03	ft/d	K_y (vertical hydraulic conductivity) of landside blanket stratum 1	
$\underline{K}_{bl}$	8.6E-03	ft/d	Effective K_y of landside blanket strata (eq. 3, TM 3-424)	
c_{bl}	0.0004		Constant for landside blanket strata (eq. B-4, EM 1110-2-1914)	
$\gamma_{sat-bl-1}$	115.0	pcf	Saturated unit weight (γ_{sat}) of landside blanket stratum 1	
$\underline{\gamma}_{sat-bl}$	115.0	pcf	Effective saturated unit weight of landside blanket strata	
$\underline{\gamma}_{b-bl}$	52.6	pcf	Effective buoyant unit weight (γ_b) of landside blanket strata	
Aquifer Foundation Strata Parameters				
D_1	95.0	ft	Actual thickness of foundation stratum 1	*Classification: Sand*
D_2	0.0	ft	Actual thickness of foundation stratum 2	*Classification: -*
D_3	0.0	ft	Actual thickness of foundation stratum 3	*Classification: -*
D_4	0.0	ft	Actual thickness of foundation stratum 4	*Classification: -*
D_5	0.0	ft	Actual thickness of foundation stratum 5	*Classification: -*
D_6	0.0	ft	Actual thickness of foundation stratum 6	*Classification: -*
D_7	0.0	ft	Actual thickness of foundation stratum 7	*Classification: -*
D_8	0.0	ft	Actual thickness of foundation stratum 8	*Classification: -*
D_9	0.0	ft	Actual thickness of foundation stratum 9	*Classification: -*
D	95.0	ft	Total actual thickness of foundation strata	
$\underline{D}$	95.0	ft	Thickness of transformed (homogeneous, isotropic) foundation (eq. 4-19, EM 1110-2-1914)	
K_{x-1}	1.73E+02	ft/d	K_x (horizontal hydraulic conductivity) of foundation stratum 1	
K_{y-1}	1.73E+02	ft/d	K_y (vertical hydraulic conductivity) of foundation stratum 1	
K_{x-2}	0.00E+00	ft/d	K_x of foundation stratum 2	
K_{y-2}	0.00E+00	ft/d	K_y of foundation stratum 2	
K_{x-3}	0.00E+00	ft/d	K_x of foundation stratum 3	
K_{y-3}	0.00E+00	ft/d	K_y of foundation stratum 3	
K_{x-4}	0.00E+00	ft/d	K_x of foundation stratum 4	
K_{y-4}	0.00E+00	ft/d	K_y of foundation stratum 4	
K_{x-5}	0.00E+00	ft/d	K_x of foundation stratum 5	
K_{y-5}	0.00E+00	ft/d	K_y of foundation stratum 5	
K_{x-6}	0.00E+00	ft/d	K_x of foundation stratum 6	
K_{y-6}	0.00E+00	ft/d	K_y of foundation stratum 6	
K_{x-7}	0.00E+00	ft/d	K_x of foundation stratum 7	
K_{y-7}	0.00E+00	ft/d	K_y of foundation stratum 7	
K_{x-8}	0.00E+00	ft/d	K_x of foundation stratum 8	
K_{y-8}	0.00E+00	ft/d	K_y of foundation stratum 8	
K_{x-9}	0.00E+00	ft/d	K_x of foundation stratum 9	
K_{y-9}	0.00E+00	ft/d	K_y of foundation stratum 9	
$\underline{K}_x$	1.73E+02	ft/d	Effective horizontal hydraulic conductivity of foundation	
$\underline{K}_y$	1.73E+02	ft/d	Effective vertical hydraulic conductivity of foundation	
$\underline{K}_x/\underline{K}_y$	1.0		Ratio of effective horizontal and vertical hydraulic conductivity of foundation	
$\underline{K}_e$	1.73E+02	ft/d	Effective hydraulic conductivity of transformed (homogenous, isotropic) foundation (eq. 4-20, EM 1110-2-1914)	
Relief Well System Design and Analysis Program				*vs 9.8.09*

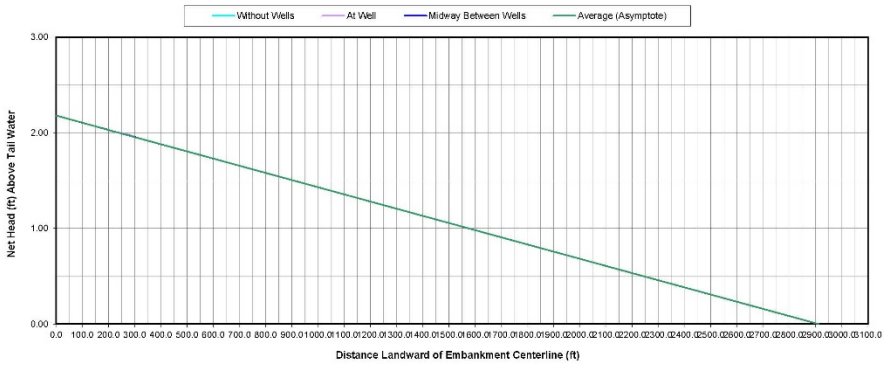
Well Parameters			
d_w	0.667	ft	Diameter of screen for relief wells
T_{fp}	0.500	ft	Thickness of filter pack (between outside of well screen and natural formation) for relief wells
r_w	0.833	ft	Effective well radius (well screen radius plus filter pack thickness)
W/D	50.0%		Effective well screen penetration into transformed foundation
If continuous well screen is not used, manually adjust below values for W_1, W_2, and ... W_9 until the calculated W/D ' is equal to the above user specified W/D			
W/D '	50.0%		Effective well screen penetration into transformed foundation (eq. 4-21, EM 1110-2-1914)
W_1	47.5	ft	Actual screen length of well screen in foundation stratum 1
W_2	0.0	ft	Actual screen length of well screen in foundation stratum 2
W_3	0.0	ft	Actual screen length of well screen in foundation stratum 3
W_4	0.0	ft	Actual screen length of well screen in foundation stratum 4
W_5	0.0	ft	Actual screen length of well screen in foundation stratum 5
W_6	0.0	ft	Actual screen length of well screen in foundation stratum 6
W_7	0.0	ft	Actual screen length of well screen in foundation stratum 7
W_8	0.0	ft	Actual screen length of well screen in foundation stratum 8
W_9	0.0	ft	Actual screen length of well screen in foundation stratum 9
W	47.5	ft	Total actual screen length of well in foundation strata
W/D	50.0%		Actual penetration into foundation strata of well screen
$RW_{TOR/TOW}$	875.00	ft	Relief well riser elevation (or elevation of backed-up well discharge water in well housing if > than the riser elevation)
	No		Will discharge ($RW_{TOR/TOW}$) elevation remain constant for all tail water elevations below TOG via pumping of discharge line?
H_{el}	2.00	ft	Elevation head loss
E_w	80.0%		Well efficiency (theoretical/actual drawdown) for projected Q_w *0.0 gpm = projected Q_w*
Enter E_w measured from pump-testing existing system, or E_w to be maintained if designing new system; alternatively, E_w can be adjusted to yield estimated H_n value			
H_n	0.00	ft	Equivalent well (e.g. entrance, friction, and velocity) losses (excluding potential partial penetration losses) for specified E_w
Input Parameters Conceptual Diagram			



Drawing not to scale; head curves shown for illustrative purposes, calculated values based on all inputs are given below; under certain conditions H_{av} may exceed H_m

Deterministic Design Requirements			
$h_{excess\text{-}base\ (ft)}$	2.12	0.50	Base condition excess head (at embankment toe) above TOG (or tail water elevation if > than TOG)
FS_{base}	1.67		Base condition (effective stress) factor of safety against uplift (heave) at embankment toe
$FS_{required\text{-}HHD}$	1.57		Required (effective stress) factor of safety against uplift (heave) at well line (based on 6/11/09 HHD criteria for 25 and 30 pools)
$FS_{required}$	1.00		User-specified design (effective stress) factor of safety against uplift (heave) at well line
$h_{excess\text{-}allowed}$	3.54	ft	Allowable excess head above TOG (or tail water elevation if > than TOG) at well line
$i_{v\text{-}bl\text{-}allowed}$	0.84		Allowable vertical gradient through blanket at well line
Well Spacing Parameters			
$a_{approximate}$	771430.0	ft	Well spacing predicted from automated trials to approximately meet $FS_{required}$ (if prediction result is an error, increase W/D)
a	75.0	ft	Final design well spacing; enter value which yields adequate $FS_{uplift\text{-}a}$ and reliability if designing a new well system
a/r_w	90.0		Ratio used for determination of θav and θm parameters
D/a	1.27		Ratio used for determination of θav and θm parameters
θav	1.001		Average uplift parameter (derived from table 5-1, EM 1110-2-1914; based on theoretical well factors solutions)
$h_{n\ (iteration\ 1)}$	0.00	ft	Net head on well system corrected for elevation head loss (iteration 1)
$h_{av\ (iteration\ 1)}$	0.00	ft	Average net head in plane of wells corrected for elevation loss (derived from fig. 5-4b, eq. 5-23, EM 1110-2-1914); (iteration 1)
$H_{w\ (iteration\ 1)}$	2.00	ft	Total well losses (elevation and efficiency); (iteration 1)
$h_{n\ (iteration\ 2)}$	0.00	ft	Net head on well system corrected for total well losses (iteration 2)
$h_{av\ (iteration\ 2)}$	0.00	ft	Average net head in plane of wells corrected for total well losses (derived from fig. 5-4b, eq. 5-23, EM 1110-2-1914); (iteration 2)
$H_{w\ (iteration\ 2)}$	2.00	ft	Total well losses (elevation and efficiency); (iteration 2)
$h_{n\ (iteration\ 3)}$	0.00	ft	Net head on well system corrected for total well losses (iteration 3)
$h_{av\ (iteration\ 3)}$	0.00	ft	Average net head in plane of wells corrected for total well losses (derived from fig. 5-4b, eq. 5-23, EM 1110-2-1914); (iteration 3)
$H_{w\ (iteration\ 3)}$	2.00	ft	Total well losses (elevation and efficiency); (iteration 3)
H_{av}	2.00	ft	Average net head in plane of wells (eq. 43, TM 3-424)
θm	0.982		Midwell uplift parameter (derived from table 5-1, EM 1110-2-1914; based on theoretical well factors solutions)
h_m	0.00	ft	Net head midway between wells corrected for total well losses (derived from fig. 5-4b, eq. 5-22, EM 1110-2-1914)
H_m	2.00	ft	Net head midway between wells (eq. 45, TM 3-424)
> H_{av},H_m	875.00	ft	Total head elevation equivalent of the greater of H_{av} and H_m at well line resulting from well spacing (a)
Relief Well System Design and Analysis Program			*vs 9.8.09*

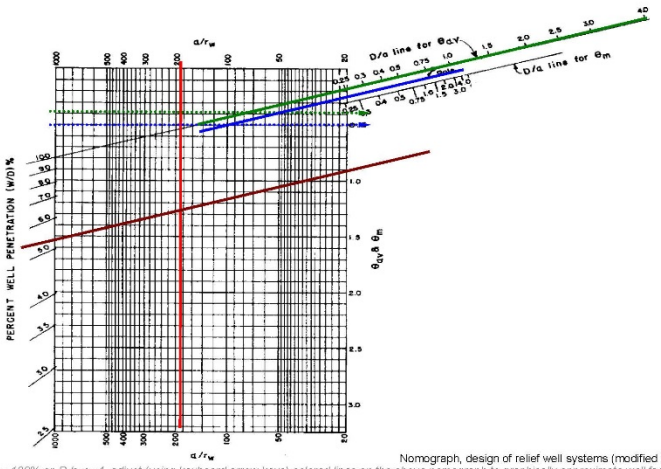
Deterministic Design Results			
$FS_{uplift-a}$	1.77		Effective stress factor of safety against uplift (heave) at well line resulting from well spacing (a)
Check to ensure $FS_{uplift-a}$ is close to, but >= to $FS_{required}$, which indicates well system design is appropriate; if not, then adjust well system design			
$h_{excess-a}$	2.00	ft	Excess head above TOG (or tail water elevation if > than TOG) at well line
i_{v-bl-a}	0.48		Vertical gradient through blanket at well line
ΔM	0.00000		Net seepage gradient toward the well line (eq. 7-6, EM 1110-2-1914; Darcy's law eq.)
Q_w	2.1	ft^3/d	Discharge from a single well (eq. 7-7, EM 1110-2-1914)
	0.0	gpm	



Plot assumes Midway and Average curves converge U/S & D/S from well line at a distance equal to well spacing; At Well curve U/S & D/S projections are approximate

H_{av}, $H_{hr(D/S\ Toe)}$	875.12	ft	Projected total head elevation at the downstream (D/S) embankment toe resulting from well spacing (a)
$x_{-D/S}$	0.0	ft	Specified distance landward of well line to project total head elevation; enter value between 0 and (x_3 - x_w)
H_{av}, $H_{hr(x-D/S)}$	875.00	ft	Projected total head elevation at specified distance ($x_{-D/S}$) downstream of well line
Check to ensure projected heads are tolerable; if not then adjust well system design or implement additional necessary seepage control measure(s)			

Theoretical Uplift Parameters Check



Nomograph, design of relief well systems (modified fig. 60, TM 3-424)

If W/D = 100% or D/a <= 4, adjust (using keyboard arrow keys) colored lines on the above nomograph to graphically approximate well factors solutions

W/D	50%		Design value for effective well screen penetration into transformed foundation (maroon line on nomograph)
a/r_w	90.0		Ratio used for determination of θav and θm parameters (red line on nomograph)
D/a	1.27		Ratio used for determination of θav and θm parameters
θav	1.001		Average uplift parameter (derived from table 5-1, EM 1110-2-1914; based on theoretical well factors solutions)
$θav_{nomograph}$	1.10		Average uplift parameter (estimated graphically/manually from above nomograph - green lines; fig. 60, TM 3-424)
θm	0.982		Midwell uplift parameter (derived from table 5-1, EM 1110-2-1914; based on theoretical well factors solutions)
$θm_{nomograph}$	1.20		Midwell uplift parameter (estimated graphically/manually from above nomograph - blue lines; fig. 60, TM 3-424)
Comparison can be made (if W/D = 100% or D/a <= 4) between well factors estimated from above nomograph to those calculated from theoretical solutions			

Relief Well System Design and Analysis Program *vs 9.8.09*

Summary of Well Installation Parameters			
W	47.5	ft	Screen length (in foundation strata) for each well
d_w	0.67	ft	Diameter of each well screen
T_f	0.50	ft	Thickness of filter pack (between outside of well screen and natural foundation) for each well
a	75.0	ft	Spacing for wells
E_w	75%		Well efficiency (theoretical/actual drawdown) for projeced Q_w *0.0 gpm = projected Q_w*

Notes

1. Relief well system analysis completed by Erich D. Guy, USACE Huntington District
2. Program applicable for blanket aquifer foundation case with an infinite line of wells parallel to an infinite line source. It is based on methods contained in:
   U.S. Army Corps of Engineers (USACE), 1992, Design, Construction, and Maintenance of Relief Wells (Engineer Manual 1110-2-1914)
   USACE, 1956, Investigation of Underseepage and its Control: Lower Mississipp River Levees (Technical Memorandum 3-424)
   Mansur and Kaufman, 1962, Dewatering, in Foundation Engineering edited by Leonards, McGraw-Hill Book Company
   Department of The Army, 1983, Dewatering and Groundwater Control (Army Technical Manual 5-818-5)
3. Program modifications to/advancements beyond existing methods include: stratified blanket and foundation consideration, well losses (elevation, efficiency) consideration, automated uplift parameters solution and appropriate well spacing prediction, variable tail water (i.e. not necessarily at prevailing ground surface elevation) consideration, variable well line position (e.g. downstream of toe) consideration, well discharge backup/discharge line pumping considerations, and automated reliability module inclusion.
4. Program assumes laterally continuous strata, and doesn't account for topographical variations along the analysis cross-section (e.g. low-lying areas downstream of the well line which may affect projected stability, nor does it account for possible well spacing adjustments necessary to account for ends of reach and/or finite reach length effects.

Relief Well System Design and Analysis Program *vs 9.8.09*

USACE MOBILE DISTRICT RELIEF WELL SPREADSHEET

SEEP/W TYPICAL SECTION

US Army Corps of Engineers ®
Omaha District

Missouri River Interior Drainage Hydrologic Analysis

DRAFT

USACE Omaha District
Hydrologic Engineering Branch
November 2016

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OVERVIEW

An interior drainage analysis was performed as part of the Missouri River Recovery Program (MRRP). Two levee units within the Omaha District were analyzed, L536 and L575. The purpose of the interior drainage hydrologic analysis was to model flows at each outlet structure to be used in assessing flood damage. L575 and L536 are about 10 miles apart on the left bank of the Missouri River. Both interior drainage basins are shown in Figure 1.

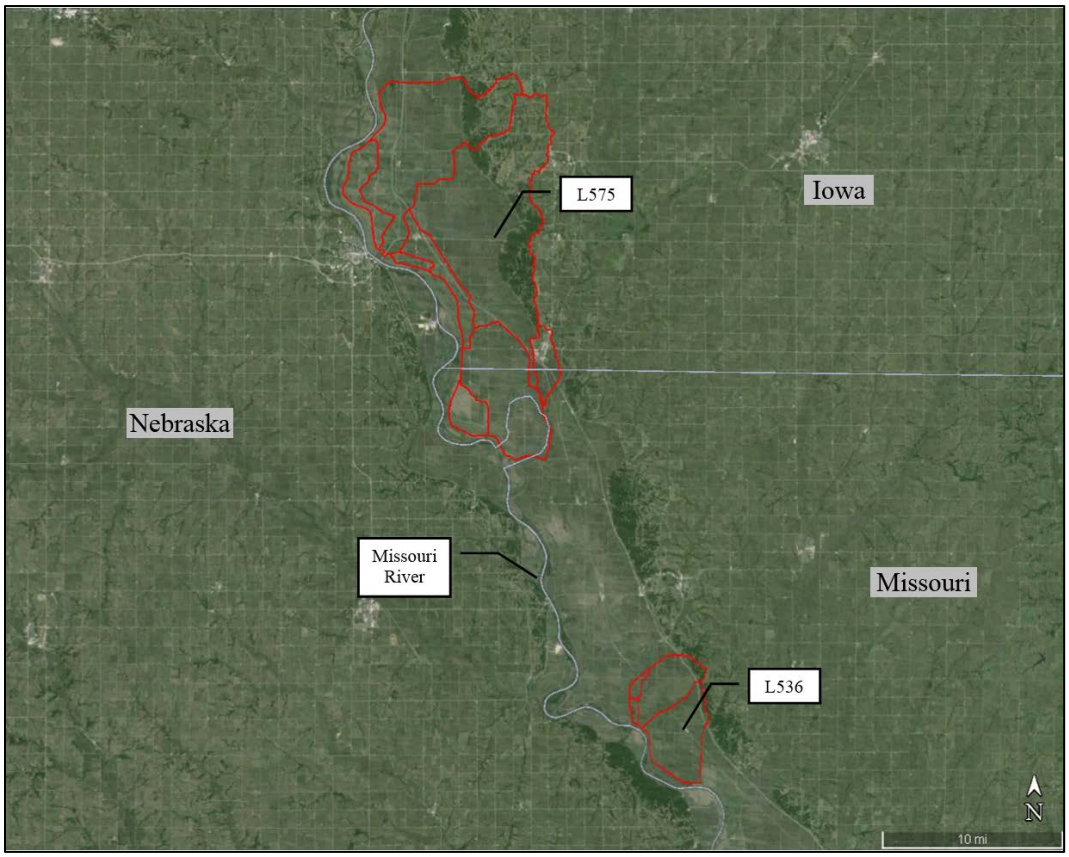


Figure 1. L536 and L575 basins modeled in the interior drainage basin hydrologic analysis.

The Missouri River Master Water Control Manual (USACE, 1998) included a volume about the Interior Drainage Study performed on both levee basins. Much of the information in that study was used to create the new interior drainage analysis with updated hydrologic modeling methods. Subbasin delineation was updated based on changes in the outlets of each drainage basin.

Calibration of both levee interior drainage basin models was limited due to availability of data. Therefore, a pilot study, within close proximity and with similar basin characteristics, was utilized in calibration. Several small basins with similar characteristics were considered for calibration, but, ultimately, Mill Creek, near Oregon, MO, was used. Mill Creek is relatively small in drainage area and has similar basin characteristics to those of both interior drainage basins. The intent of the Mill Creek pilot study was to calibrate that model with available streamgage data and apply the same parameter estimation techniques and adjustments to each interior drainage model. Details of the Mill Creek pilot study are provided in Attachment A.

LEVEE UNIT L536

SITE DESCRIPTION

Levee Unit L536 is located in Atchison and Holt Counties in northwestern Missouri. The levee unit spans along the left bank of the Missouri River. Rock Port and Langdon, Missouri are located just north of the basin, and Corning, Missouri is located south of the basin. Bluffs are located in the northeastern section of the basin that are approximately 1.2 mi^2 in area. The L536 drainage basin is approximately 22 mi^2 in area and composed of 4 subbasins. The L536 drainage basin is shown in Figure 2 below.

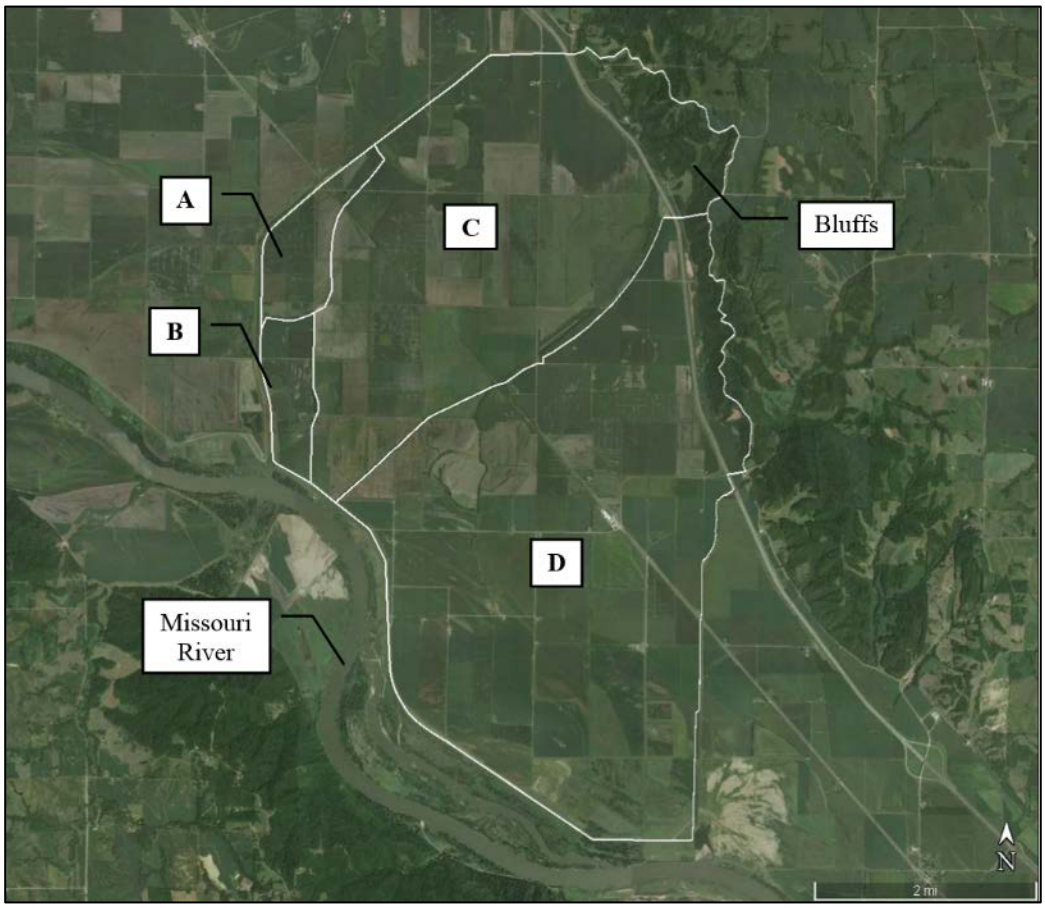


Figure 2. L536 drainage basin.

A site visit to the L536 interior drainage basin was used to obtain hydrologic information about the watershed. The primary purpose of the visit was to determine the location of streams and the amount of baseflow in the streams. Streams A and B were not accessible because of their locations. The following photos show streams in the L536 drainage basin.

Figure 3. Flow path in basin C with very little flow. (40.337402°N, 95.540044°W)

Figure 4. Main flow path in basin C looking east. (40.316878°N, 95.521348°W)

Figure 5. Stream D looking east. (40.290419°N, 95.502614°W)

Figure 6. Basin D flow path in the bluffs. (40.345658°N, 95.506015°W)

HYDROLOGIC MODEL

Hydrologic modeling was performed using HEC-HMS version 4.1 developed by the US Army Corps of Engineers Hydrologic Engineering Center (USACE, 2015). A continuous simulation was created from 1930-2012 with an hourly time step in order to obtain period of record flow at various outlets. Precipitation was combined at Nebraska City, Nebraska, and Hamburg, Iowa, to create an hourly rainfall record from 1930-2012. The hydrologic model utilized the deficit and constant loss method, Snyder's unit hydrograph runoff transformation, and recession baseflow. Parameter estimates were made based on techniques used in the Mill Creek pilot study in Attachment A and adjusted based on calibration of the Mill Creek model.

Precipitation

Hourly precipitation data was obtained from NCDC Climate Data Online (2016) at Hamburg, Iowa, from 1948-2009. In order to complete the hourly precipitation record from 1930-2012, daily precipitation at Nebraska City, Nebraska, was converted to hourly precipitation using hourly rainfall distributions computed using Hamburg hourly data. Hourly factors were computed by dividing the rainfall in one hour by the cumulative daily rainfall at the observed rain gage. This technique was used so the daily precipitation distribution would mimic that of the available hourly data. Hourly distributions were determined for the following four types of precipitation.

1. No precipitation the day before or after
2. Precipitation the day before but not the day after
3. Precipitation the day after but not the day before
4. Precipitation the day before and the day after

Each precipitation type produced a different hourly distribution to be used in the conversion of daily precipitation. The hourly distributions for each daily precipitation type are shown in Figure 7 below.

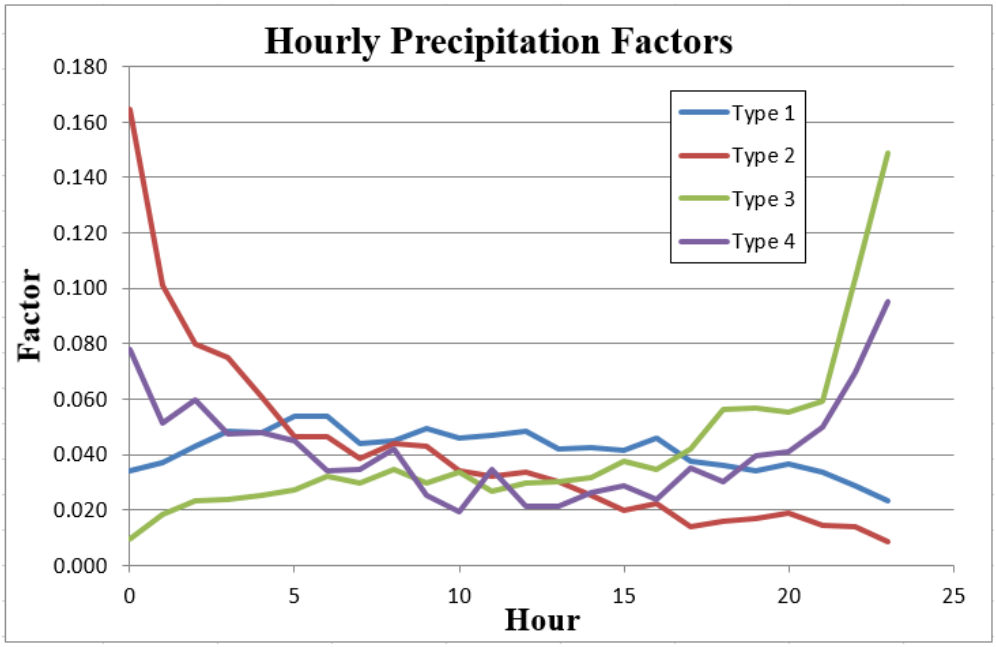


Figure 7. Hourly precipitation factor for each daily precipitation type.

Daily precipitation was then distributed over each day based of the type of precipitation and the calculated average hourly factors. Converted daily Nebraska City precipitation was used in place of any missing data in the Hamburg precipitation period of record.

Although the Hamburg and Nebraska City precipitation records are different, they were compared to check for any large discrepancies. In August 1987 the Hamburg rainfall record showed 6.6 inches of rainfall in one hour. The Nebraska City record showed no rainfall at that time. It was assumed that the 6.6 inches was recorded incorrectly and that there was no rainfall because it is a very large amount of precipitation (larger than a 1000-year frequency storm) in one hour and there was no precipitation the day before or after. In March 1987, 5.5 inches of precipitation were recorded at Hamburg. Again, there was no precipitation recorded in Nebraska City on that day, and there was no precipitation recorded the day before or after at Hamburg, so it was again assumed that there was no rainfall in the time period. There were no other large discrepancies between the two rainfall records. The final precipitation used in the levee unit L536 model is shown in Figure 8 below.

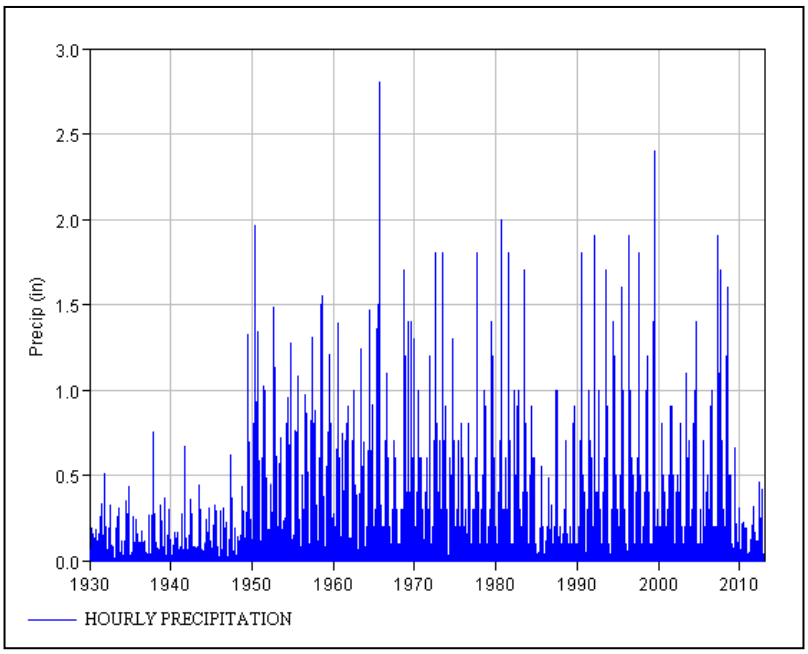


Figure 8. Hourly precipitation at Hamburg, Iowa combined with converted daily precipitation at Nebraska City, Nebraska.

Meteorologic Model

The meteorologic model utilized the described precipitation from 1930-2012.The hourly precipitation used in the hydrologic model is shown in Figure 8. The monthly average method was used to model evapotranspiration in conjunction with the meteorologic model. The monthly average method combines monthly average pan evaporation and a coefficient to convert to evapotranspiration. Monthly average pan evaporation was estimated using evaporation data from NCDC Climate Data Online (2016) at Shenandoah, Iowa, which was the closest available evaporation data from NCDC Climate Data Online (2016). Determination of the coefficient, 0.75, is described in more detail in the Mill Creek Pilot Study in Attachment A. Monthly pan evaporation is shown in Table 1.

Table 1. Monthly average evaporation at Shenandoah, IA. A factor of 0.75 was used.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (in)	0	0	0	5.19	5.96	7.06	7.76	6.42	5.04	3.54	0	0

Delineation

Levee unit L536 subbasins were delineated based on the drainage basins in the Master Manual Interior Drainage Study (1998). Basin delineations were updated based on changes to outlets in the levee, which resulted in the merging of two subbasins into subbasin A. Subbasin delineations are shown in Figure 2. The HEC-HMS schematic is shown in Figure 9 below. Subbasin areas are shown in Table 2.

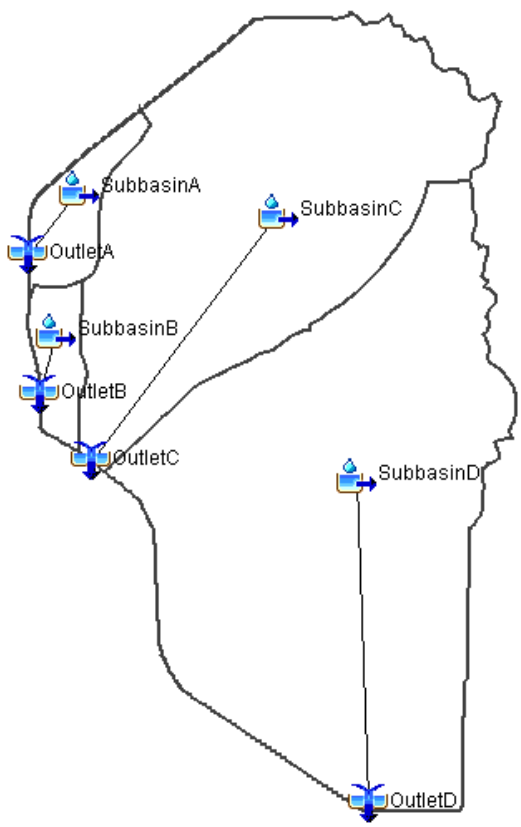


Figure 9. HEC-HMS L536 basin schematic.

Table 2. Subbasin areas computed using HEC-GeoHMS processing.

Subbasin	**A**	**B**	**C**	**D**
Area (mi^2)	0.75	0.58	8.47	12.11

Canopy

The simple canopy method was used in conjunction with monthly average evapotranspiration and rainfall loss methods. The canopy method models the interception of rainfall by plants in the landscape (USACE, 2013). It was assumed that the interception of rainfall by plants is negligible in the L536 drainage basin. The simple uptake method was required by HMS in order to properly model evapotranspiration losses in the basin.

Rainfall Losses

The deficit and constant method was used to model rainfall losses. Parameters of the deficit and constant method are initial deficit, maximum storage, constant loss rate, and percent imperviousness. The initial deficit is an estimate of the moisture required to saturate the soil at the start of the simulation. The maximum deficit represents the maximum amount of water it would take to saturate the soil. The constant loss is represented by the hydraulic conductivity of the soil. Soil properties were determined based on gridded SSURGO soils data (NRCS, 2012) and associated properties from Rawls, et al (1999). L536 is composed mostly of clay soils with silt loam soils in the bluffs. Soil parameter maps are shown in Figure 10 below.

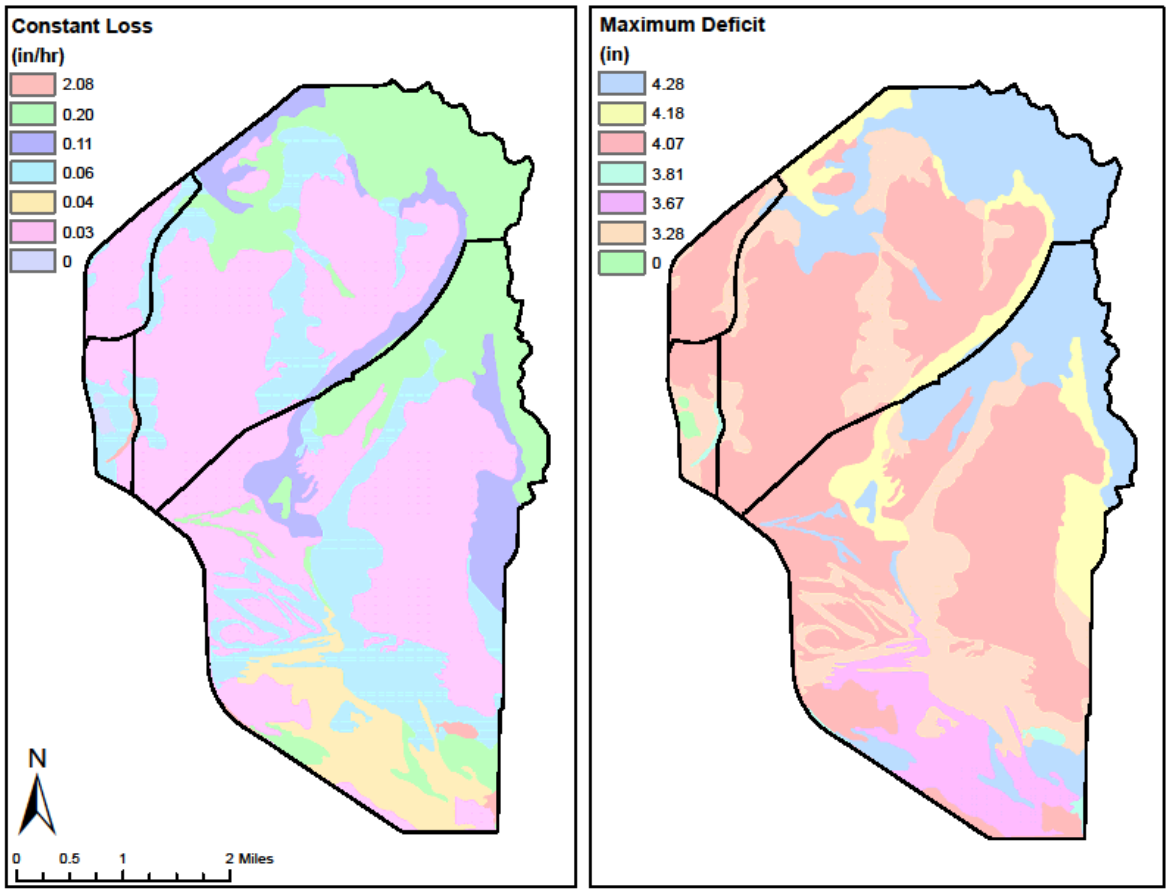


Figure 10. Deficit and constant rainfall loss parameters used to find subbasin average parameters.

Percent imperviousness was determined from the National Land Cover Database, which assigns an average percent imperviousness to each 100' x 100' grid cell (NLCD, 2011). The average percent imperviousness of each subbasin was calculated using HEC-GeoHMS processing. Deficit and constant loss parameters are shown in Table 3.

Table 3. Deficit and constant loss parameters.

Subbasin	Initial Deficit (in)	Maximum Storage (in)	Constant Loss (in/hr)	Impervious (%)
A	1.5	4.0	0.10	0.54
B	1.5	4.0	0.10	0.38
C	1.5	4.1	0.15	1.01
D	1.5	4.0	0.15	1.13

Runoff Transformation

Snyder's unit hydrograph method was used to model runoff transformation for L536. Snyder's utilizes lag time and a peaking coefficient (C_p). Lag time (t_l) is calculated from a lag time coefficient (C_t), the longest flowpath, and the centroidal longest flowpath. Flowpath measurements were estimated using Google Earth Pro and HEC-GeoHMS processing. C_t was estimated at 0.6 based on Veismann and Lewis (2002) and the Mill Creek pilot study. The peaking coefficient was estimated at 0.5 based on the Mill Creek pilot study. Parameters used in the Snyder's unit hydrograph runoff transform are shown in Table 4 below.

Table 4. Snyder's unit hydrograph runoff transform parameters.

Subbasin	C_p	C_t	Centroidal Longest Flowpath (mi)	Length (mi)	Lag Time (hr)
A	0.5	0.6	0.65	1.92	0.64
B	0.5	0.6	0.65	1.25	0.56
C	0.5	0.6	2.16	5.70	1.27
D	0.5	0.6	2.58	6.24	1.38

Baseflow

The recession baseflow method was used in modeling L536. The recession method utilizes an initial discharge, threshold discharge, and recession constant. The initial discharge and threshold discharge were estimated based on flow observations on the site visit. The recession constant was estimated at 0.34 for the two smaller subbasins, A and B, and 0.4 for the two larger subbasins, C and D. Recession baseflow parameters used to model L536 are shown in Table 5 below.

Table 5. Recession baseflow parameters used to model L536.

Subbasin	Initial Discharge (cfs)	Recession Constant	Threshold Flow (cfs)
A	10	0.34	15
B	5	0.34	10
C	15	0.4	30
D	15	0.4	30

CALIBRATION

Calibration of the L536 interior drainage model was completed using the Mill Creek pilot study described in Attachment A and a USGS runoff publication. The intent of the Mill Creek pilot study was to determine how calibration altered the starting parameter estimates, and to use the same parameter adjustments as calibration for the interior drainage hydrologic model. Calibration of the Mill Creek pilot study included adjustments of the monthly average evapotranspiration coefficient, baseflow recession constant, and the runoff transformation peaking and lag time coefficients. Parameters that were not adjusted in the Mill Creek pilot study were estimated using the same methods and were not adjusted, in order to parallel calibration techniques. For example, the deficit and constant loss parameters were not adjusted in calibration of the Mill Creek pilot study; therefore, those same parameters were estimated using the same technique as the Mill Creek pilot study and were not adjusted from original estimates.

In the Mill Creek pilot study, the monthly average evapotranspiration coefficient was initially estimated to be 0.6 and adjusted in calibration to 0.75. Because the same monthly average evaporation values were used in the L536 model, the same coefficient, 0.75, was used, as well.

The baseflow recession constant for Mill Creek was initially estimated to be 0.5 and reduced to 0.34 for each subbasin to decrease runoff volume per unit area, and to account for the very small area of each subbasin. The same initial estimate was used for the L536 subbasin because the two basins are very similar. The recession constant for the two smaller subbasins, A and B, was reduced to 0.34. Subbasins C and D were assigned a recession constant of 0.4 to account for the larger area which usually results in a higher recession constant.

The peaking coefficient was initially estimated at 0.8 in the Mill Creek pilot study and was adjusted to 0.6 in calibration. L536 is in the same region as Mill Creek, so the initial estimate was the same for Mill Creek and L536; however, the final calibrated peaking coefficient was 0.5 to account for much flatter slopes. The lag time coefficient for Mill Creek was initially estimated at 0.4 and adjusted to 0.6 in calibration. The same starting parameter value and final calibrated value were used for L536 because of the basin similarities.

The L536 model was also calibrated using the USGS published document showing average annual runoff throughout the United States from 1951 to 1980 in the form of a contour map (Gebert, 1987). According to the map of average annual runoff, L536 would produce approximately 7 inches of runoff, which is similar to results of the L536 hydrologic model. Overall the L536 basin averages about a 3% higher runoff volume per unit area (7.2 inches) over the USGS observation period. Subbasin runoff volumes per unit area and USGS runoff publication volume are shown in Table 6.

Table 6. Comparison of runoff volume per unit area from 1951-1980.

Source	Runoff Volume per unit area (inches)
Subbasin A	9.7
Subbasin B	10.3
Subbasin C	4.5
Subbasin D	4.2
USGS Runoff Publication	7.0

RESULTS

The L536 interior drainage basin was calibrated based on parameter adjustments of the Mill Creek pilot study. Runoff volumes per unit area were compared to USGS average runoff volumes (Gebert, 1987) as another method of calibration. Flows at each one of the outlets are shown in Figure 11, Figure 12, Figure 13, and Figure 14. Yearly runoff volume per unit area, the total runoff from each subbasin over each year in the period of record, at each outlet as well as a period of record annual average are shown in Table 7. Higher runoff volume per unit area in subbasins A and B are the results of lower constant loss rates of those basins.

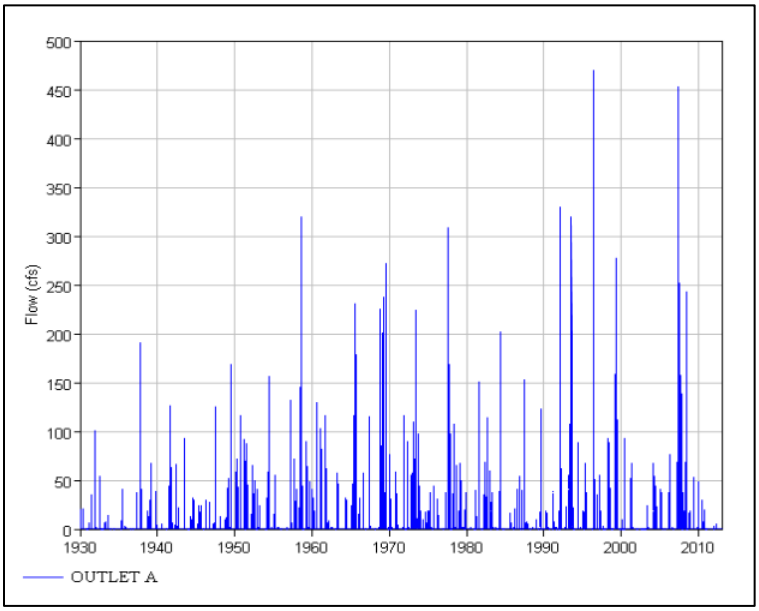


Figure 11. Outflows from L536 outlet A.

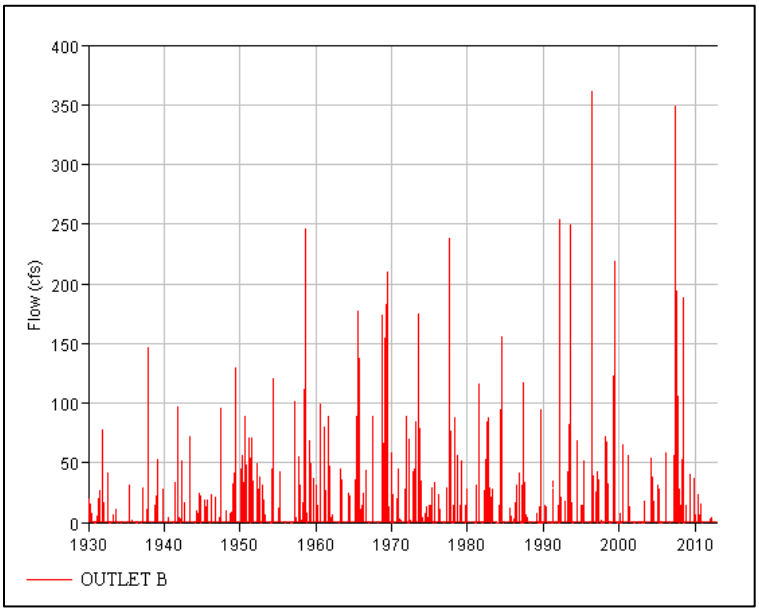


Figure 12. Outflows from L536 outlet B.

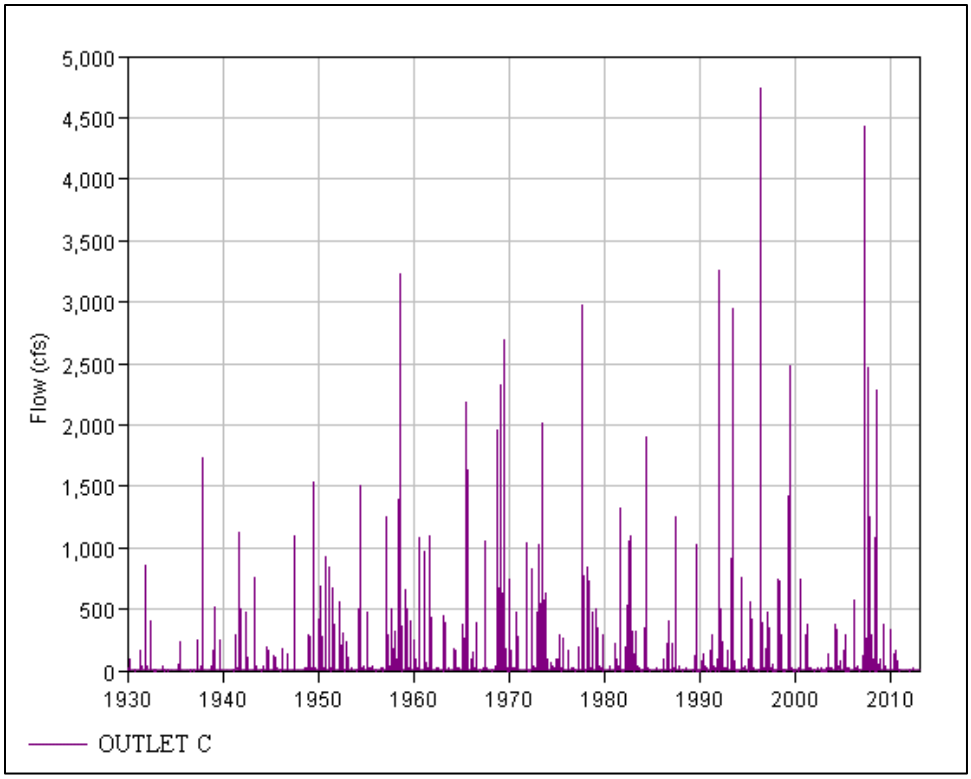


Figure 13. Outflows from L536 outlet C.

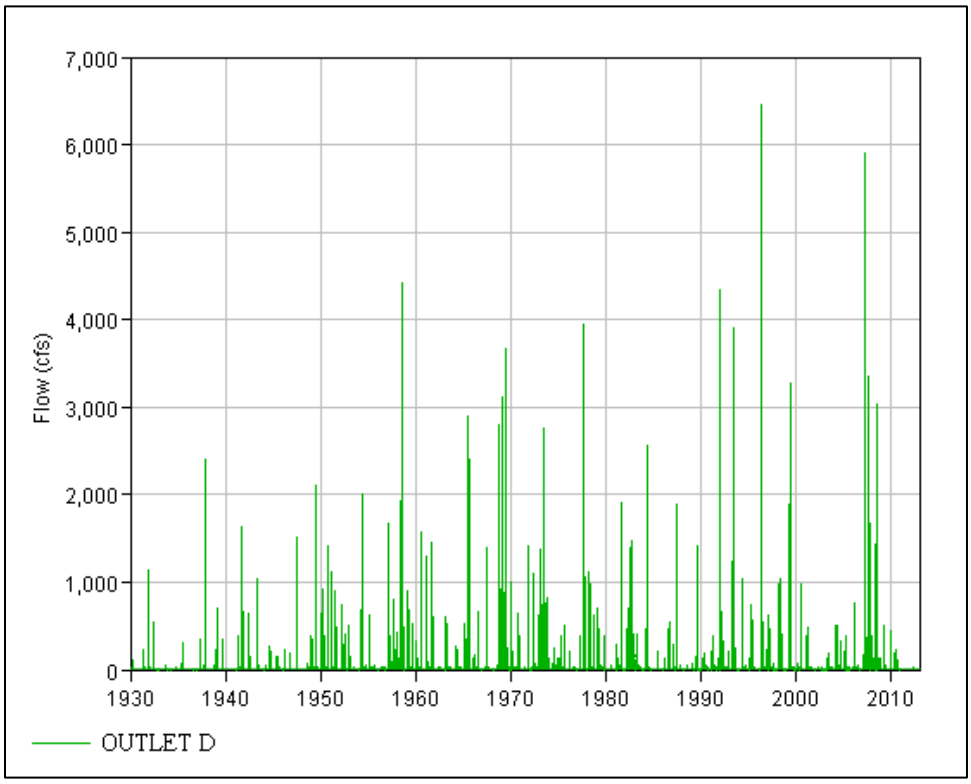


Figure 14. Outflows from L536 outlet D.

Table 7. Yearly runoff volume per unit area, in inches, at each outlet in L536. Yearly averages are also shown.

Year	A	B	C	D	Year	A	B	C	D
1930	1.5	1.8	0.9	0.9	**1972**	7.4	8.4	3.7	3.4
1931	5.0	3.8	2.6	2.3	**1973**	25.9	30.0	10.4	9.5
1932	2.2	2.6	1.1	1.0	**1974**	1.7	1.4	1.5	1.8
1933	0.3	0.2	0.6	0.6	**1975**	3.6	1.8	2.0	2.1
1934	0.2	0.1	0.5	0.5	**1976**	5.7	5.5	1.8	1.7
1935	2.4	2.7	1.2	1.2	**1977**	27.3	30.9	14.1	13.2
1936	0.3	0.3	0.4	0.5	**1978**	11.4	12.8	5.4	4.9
1937	9.8	7.6	3.9	3.6	**1979**	11.9	13.4	4.5	4.1
1938	0.6	0.5	1.0	1.0	**1980**	0.8	0.5	1.3	1.4
1939	4.1	3.0	1.4	1.3	**1981**	7.6	8.6	3.4	3.2
1940	0.3	0.2	0.5	0.6	**1982**	16.2	14.7	6.4	5.9
1941	6.3	7.6	2.2	2.1	**1983**	4.8	3.0	2.6	2.3
1942	4.5	4.8	1.7	1.6	**1984**	16.4	15.9	7.6	6.7
1943	3.6	3.9	1.5	1.5	**1985**	0.9	0.8	0.7	0.8
1944	3.9	2.2	1.8	1.7	**1986**	3.8	4.1	1.6	1.6
1945	4.7	4.5	1.7	1.5	**1987**	5.6	6.3	2.6	2.6
1946	0.8	0.7	1.5	1.4	**1988**	0.4	0.3	0.7	0.7
1947	6.2	6.7	2.6	2.5	**1989**	3.0	3.3	1.8	1.7
1948	0.4	0.3	0.6	0.7	**1990**	1.9	1.6	1.9	1.9
1949	11.6	13.1	4.9	4.5	**1991**	9.5	8.0	3.6	3.2
1950	10.8	12.0	4.3	4.3	**1992**	10.6	11.1	6.4	6.0
1951	19.2	20.7	7.5	6.6	**1993**	33.5	35.1	15.7	14.7
1952	7.6	6.7	2.9	2.7	**1994**	2.9	3.1	1.9	1.9
1953	2.7	2.5	1.4	1.4	**1995**	14.3	16.0	5.9	5.0
1954	6.4	7.1	3.4	3.3	**1996**	18.4	18.7	9.6	9.1
1955	2.6	2.9	1.7	1.6	**1997**	4.5	5.3	2.4	2.2
1956	0.8	0.6	1.4	1.5	**1998**	9.5	10.9	4.7	4.3
1957	10.3	11.5	4.4	4.2	**1999**	18.6	19.7	8.5	7.8
1958	20.9	23.5	10.6	9.9	**2000**	2.8	3.1	1.8	1.9
1959	20.0	20.4	6.7	6.0	**2001**	9.1	8.3	3.5	3.2
1960	13.7	15.1	4.8	4.4	**2002**	0.7	0.5	1.1	1.2
1961	14.6	13.1	5.6	5.3	**2003**	1.6	1.3	1.5	1.6
1962	2.0	1.7	1.6	1.7	**2004**	9.6	10.7	3.8	3.5
1963	4.8	5.5	2.3	2.2	**2005**	4.3	5.0	1.6	1.5
1964	2.8	2.5	1.8	1.9	**2006**	6.1	6.5	2.6	2.6
1965	20.5	23.3	9.1	8.5	**2007**	28.3	32.2	14.6	14.0
1966	2.8	1.9	2.0	1.8	**2008**	14.9	16.9	6.7	6.1
1967	7.4	8.4	3.8	3.6	**2009**	5.1	5.8	1.8	1.7
1968	5.6	6.2	3.2	3.2	**2010**	5.0	4.9	2.1	1.9
1969	18.6	21.4	9.4	8.8	**2011**	0.3	0.2	0.6	0.7
1970	7.2	6.2	3.7	3.2	**2012**	0.5	0.4	0.6	0.6
1971	3.6	3.8	2.6	2.6	**Yearly Average**	**7.7**	**8.1**	**3.6**	**3.4**

LEVEE UNIT L575

SITE DESCRIPTION

The L575 drainage basin is located in parts of Montgomery County in southwestern Iowa, Atchison County in northwestern Missouri, and Nemaha County in southeastern Nebraska. Hamburg, Iowa is located in the southeastern part of the drainage basin in subbasin H. Nebraska City, Nebraska, is located just west of L575 and the Missouri River. The L575 basin is approximately145 mi^2 in area and broken up into 10 subbasins ranging in size from 1.2 mi^2 to 36 mi^2. The L575 interior drainage basin and its subbasins are shown in Figure 15 below.

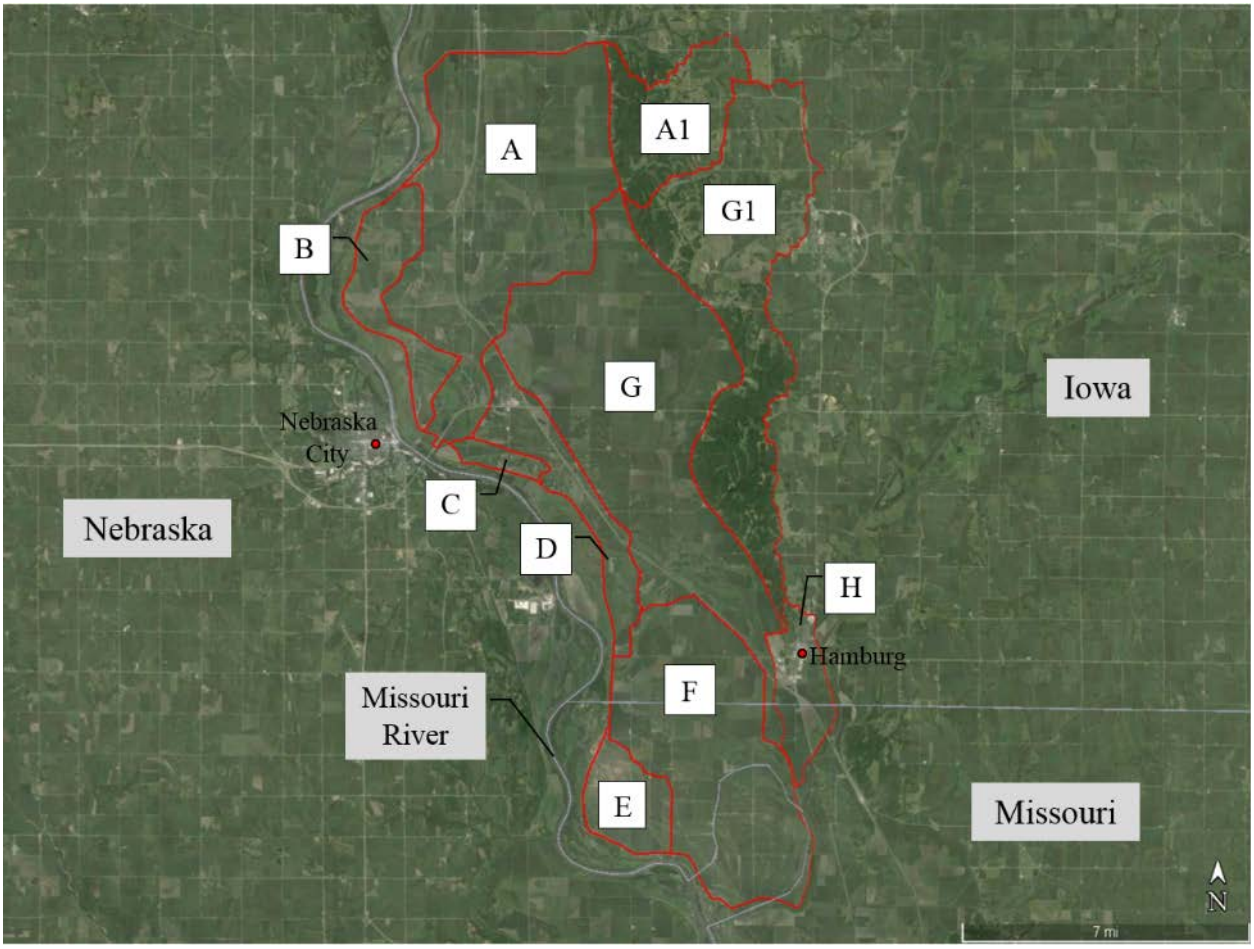


Figure 15. L575 drainage basins.

Hydrologic information about the watershed was obtained on a site visit to the interior drainage basin. The purpose of the site visit was to observe the location of the streams and the amount of baseflow, and to make general observations of the basin. Eight point cross-sections were observed in basins A and G. The following photos show observations of streams in the L575 drainage basin.

Figure 16. Basin G flow path west of Hamburg. (40.60086°N, 95.674128°W)

Figure 17. Basin A1 flow path looking north from Bluff Rd. (40.766921°N, 95.70520°W)

Figure 18. Basin A flow path looking south. (40.758872°N, 95.771166°W)

Figure 19. Basin B flow path looking south. There was no flow in this particular flow path location. (40.758336°N, 95.838822°W)

HYDROLOGIC MODEL

Hydrologic modeling of basin L575 was performed using HEC-HMS version 4.1 developed by the US Army Corps of Engineers Hydrologic Engineering Center (USACE, 2015). A continuous simulation was created from 1930-2012 with an hourly time step. Precipitation used for basin model L536 was also used for L575 due to the proximity of the basins to each other and the precipitation gages. Parameters values were estimated based on estimation and calibration of the Mill Creek pilot study parameters.

Precipitation

The same precipitation used to model L536 was also used to model L575. It is the best available data for the basin location. Hourly precipitation at Hamburg, IA and converted hourly precipitation at Nebraska City, NE were combined and are shown in Figure 20.

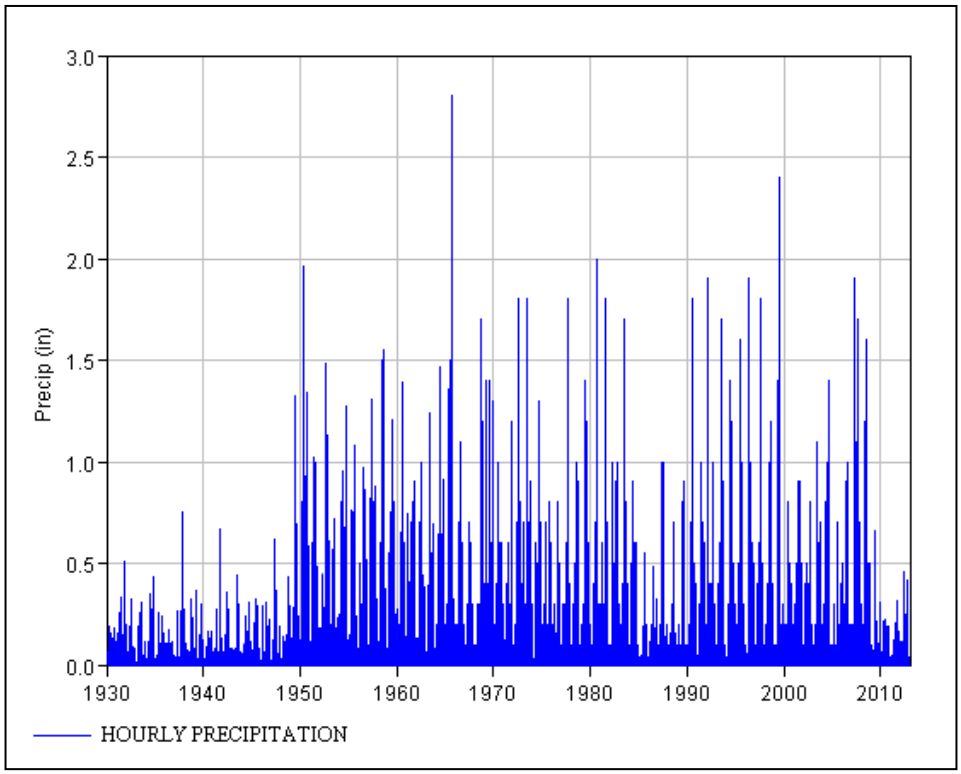


Figure 20. Hourly precipitation combined at Nebraska City and Hamburg.

Meteorologic Model

The meteorologic model utilized the described precipitation, also used in the L536 model, from 1930 through 2012. The hourly precipitation used in the hydrologic model is shown in Figure 20. The monthly average evapotranspiration method was used in conjunction with the meteorologic model. The monthly average method combines monthly average pan evaporation and a coefficient that converts pan evaporation to evapotranspiration. Monthly average evaporation was estimated using pan evaporation data from NCDC Climate Data Online (2016) at Shenandoah, Iowa, which was the closest available data. A coefficient of 0.75 was estimated based on the pilot study. Determination of evapotranspiration parameters is described in more detail in the Mill Creek pilot study in Attachment A. Monthly pan evaporation is shown in Table 8.

Table 8. Monthly average pan evaporation at Shenandoah, IA. A factor of 0.75 was used.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (in)	0	0	0	5.19	5.96	7.06	7.76	6.42	5.04	3.54	0	0

Delineation

Levee unit L575 subbasins were delineated based on the drainage basins in the Master Manual Interior Drainage Study (USACE, 1998). Updates were made to the delineations based on changes to levee outlets. The delineations are shown in Figure 15. The HEC-HMS schematic is shown in Figure 21. Levee unit L575 subbasin areas were determined using HEC-GeoHMS processing and are shown in Table 9.

Table 9. L575 subbasin areas.

Subbasin	A	A1	B	C	D	E	F	G	G1	H
Area (mi^2)	30.82	9.37	5.88	1.21	6.85	4.46	23.19	35.29	23.92	4.25

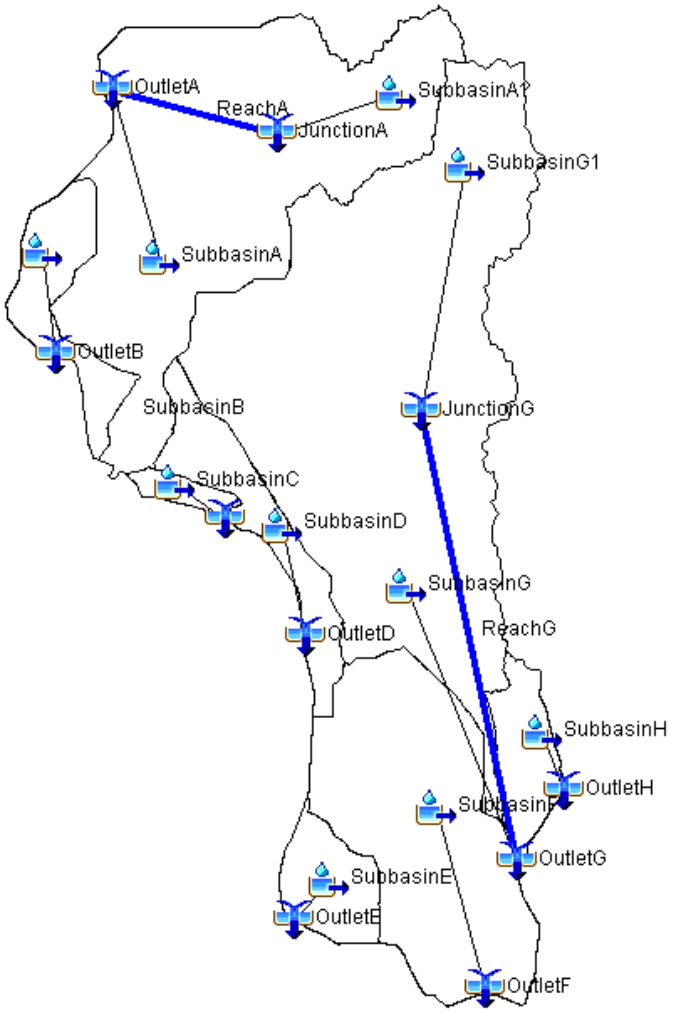


Figure 21. L575 HEC-HMS schematic.

Canopy

The simple canopy method was used in conjunction with monthly average evapotranspiration and rainfall loss methods. The canopy method models the interception of rainfall by plants in the landscape (USACE, 2013). It was assumed that there is no canopy storage in the L575 interior drainage basin. The simple uptake method was required by HMS in order to properly model evapotranspiration losses in the basin.

Rainfall Losses

The deficit and constant method was used to model rainfall losses. Parameters used to model deficit and constant losses are initial deficit, maximum storage, constant loss rate, and percent imperviousness. The initial deficit is an estimate of the moisture required to saturate the soil at the start of the simulation. The maximum deficit represents the maximum amount of moisture it would take to saturate the soil. The constant loss is represented by the hydraulic conductivity of the soil. Soil properties were determined based on gridded SSURGO soils data from NRCS (2012) and associated properties from Rawls, et al (1999). L575 is composed of a mix of clay loam and sandy soils, which accounts for higher constant loss rates than the L536 interior drainage basin. Soil parameter maps are shown in Figure 22 below.

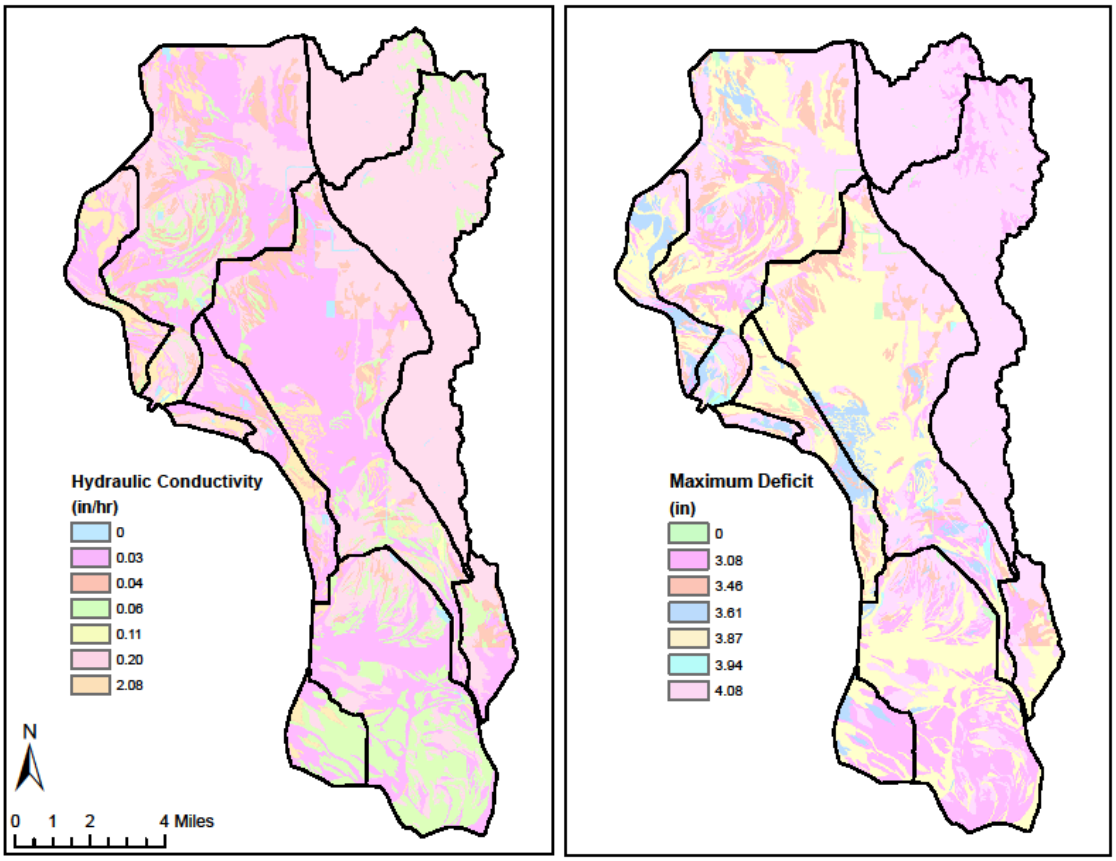


Figure 22. Deficit and Constant rainfall loss parameters used to find average subbasin parameters.

Percent imperviousness was determined from the National Land Cover Database, which assigns an average percent imperviousness to each 100’ x 100’ grid cell (NLCD, 2011). Percent imperviousness was calculated using HEC-GeoHMS processing. Hamburg is located in subbasin H, which accounts for the higher percent imperviousness. The Mill Creek pilot study indicated no change in rainfall loss parameters

from initial estimates, so L575 deficit and constant parameters were not adjusted from the initial estimates. Deficit and constant loss parameters are shown in Table 10 below.

Table 10. Deficit and constant loss parameters. Hamburg is located in subbasin H, which accounts for the higher percent impervious of that subbasin.

Subbasin	Initial Deficit (in)	Max Deficit (in)	Constant Rate (in/hr)	Impervious (%)
A	1.5	3.8	0.60	1.24
A1	1.5	3.8	0.30	0.26
B	1.5	3.9	0.60	1.09
C	1.5	3.9	0.48	0.85
D	1.5	3.8	0.32	2.54
E	1.5	3.8	0.32	0.37
F	1.5	3.8	0.32	0.60
G	1.5	3.9	0.48	0.71
G1	1.5	3.9	0.32	0.25
H	1.5	3.8	0.48	7.91

Runoff Transformation

The Snyder unit hydrograph method was used to model the runoff transformation for L575. Snyder's utilizes lag time and a peaking coefficient (C_p). Lag time (t_l) is calculated from a lag time coefficient (C_t), the longest flowpath, and the centroidal longest flowpath. Flowpath measurements were estimated using Google Earth Pro and HEC-GeoHMS. C_t was estimated at 0.6 based on Veismann and Lewis (2002) and the Mill Creek pilot study. The peaking coefficient was estimated at 0.55 for subbasins A1 and G1 in the bluffs, and 0.5 for all other subbasins, because the subbasins have flatter slopes than the Mill Creek basin. Parameters used to model the Snyder unit hydrograph runoff transformation are shown in Table 11 below.

Table 11. Snyder unit hydrograph transform parameters.

Subbasin	C_p	C_t	Length (mi)	Centroidal Longest Flowpath (mi)	Lag Time (hr)
A	0.50	0.6	9.7	7.3	2.2
A1	0.55	0.6	4.8	2.4	1.3
B	0.50	0.6	7.5	4.6	1.7
C	0.50	0.6	2.3	1.1	0.8
D	0.50	0.6	5.0	1.3	1.1
E	0.50	0.6	3.1	1.7	1.0
F	0.50	0.6	7.8	3.9	1.7
G	0.50	0.6	18.5	8.1	2.7
G1	0.55	0.6	4.9	2.6	1.3
H	0.50	0.6	2.3	1.0	0.8

Channel Routing

The Muskingum-Cunge method was used to model channel routing in the L575 interior drainage basin. Two channels, A and G, were modeled in the L575 basin. Channel length, slope, shape, and Manning's n roughness coefficient are used in channel routing. Channel length and slope were determined using Google Earth Pro and HEC-GeoHMS. An eight-point cross-section was used to model both streams. The shape was estimated based on observations from the site visit. The observed shape of each channel is shown in Figure 23. Manning's n roughness coefficient was estimated at 0.04 for the channel and 0.045 for each bank of the channel based on the channel type (Gupta, 2008). The streams and overbank areas in basin A and basin G are very similar in roughness, so the same Manning's n coefficients were used for each. Muskingum-Cunge channel routing parameters are shown in Table 12.

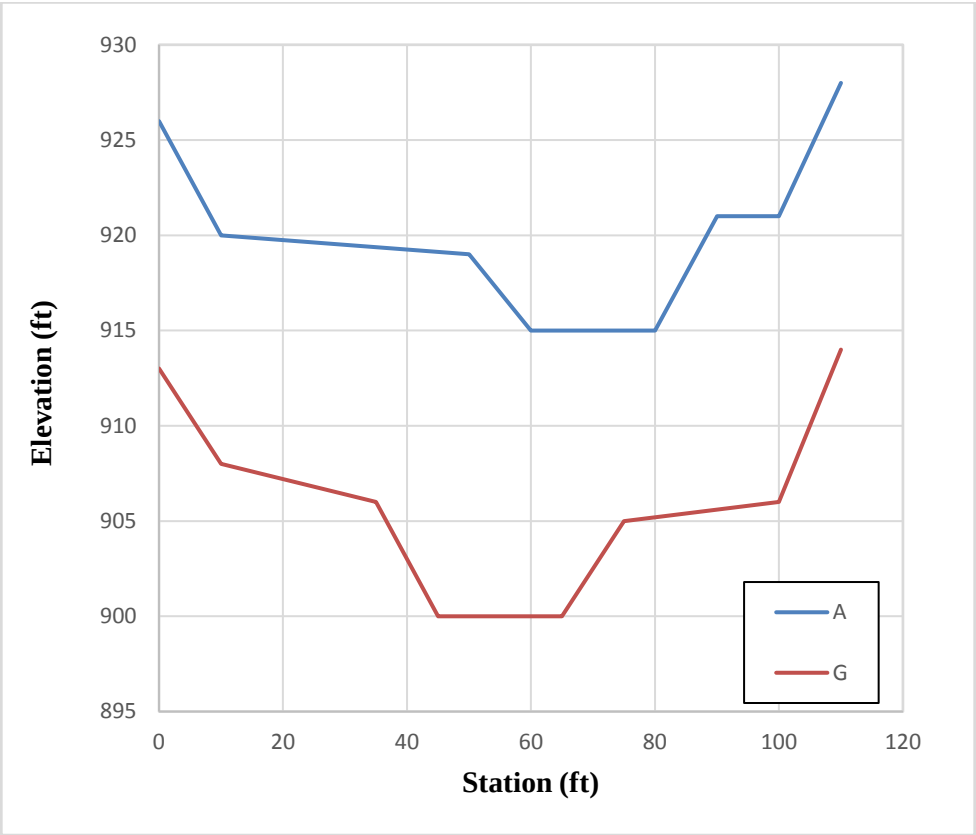


Figure 23. Channel cross-sections used in Muskingum-Cunge routing. Shapes were determined from observations of each channel.

Table 12. Muskingum-Cunge channel routing parameters.

Reach	Length (ft)	Slope (ft/ft)	Manning's n	Right Bank Manning's n	Left Bank Manning's n
A	25524	0.002	0.04	0.045	0.045
G	97908	0.001	0.04	0.045	0.045

Baseflow

The recession baseflow method was used in modeling L575. The recession method utilizes an initial discharge, threshold flow, and recession constant. The initial discharge and threshold discharge were estimated based on flow observations from the site visit. The recession constant was estimated based on the Mill Creek pilot study. Because the L575 drainage basin is much larger in area and has flatter slopes than the Mill Creek basin, it was assumed that the recession constant would be greater than that of the Mill Creek model. Recession baseflow parameters used to model L575 are shown in Table 13 below.

Table 13. Recession baseflow parameters

Subbasin	Initial Discharge (cfs)	Recession Constant	Threshold Flow (cfs)
A	20	0.50	35
A1	10	0.45	20
B	5	0.45	15
C	5	0.40	15
D	10	0.45	20
E	10	0.45	20
F	10	0.50	20
G	20	0.50	35
G1	5	0.50	15
H	10	0.45	20

CALIBRATION

Calibration of the L575 interior drainage basin was completed using the Mill Creek pilot study in Attachment A, the USGS runoff volume publication, and spring pulse gage data. The intent of the Mill Creek pilot study was to determine how calibration altered the starting parameter estimates and to use the same parameter adjustments as calibration for the interior drainage hydrologic model. Calibration of the Mill Creek pilot study included adjustments of the monthly average evapotranspiration coefficient, baseflow recession constant, and the runoff transformation peaking and lag time coefficients. Parameters that were not adjusted in the Mill Creek pilot study were estimated using the same methods and were not adjusted from initial estimates so calibration was paralleled in the L575 model.

In the Mill Creek pilot study, the monthly average evapotranspiration coefficient was initially estimated to be 0.6 and adjusted in calibration to 0.75. Because the same monthly average evaporation values were used in the L575 model, the same coefficient, 0.75, was used, as well.

The baseflow recession constant for Mill Creek was initially estimated to be 0.5 and reduced to 0.34 for each subbasin to decrease runoff volume per unit area, and to account for the very small area of each subbasin. The same initial estimate was used for the L575 subbasins because the two basins are very similar. L575 subbasin areas are much larger than the Mill Creek and L536 subbasins, so the recession constant was reduced to 0.4 for subbasin C, 0.45 for subbasins A1, B, D, E, and H, and 0.5 for the rest of the subbasins.

The peaking coefficient was initially estimated at 0.8 in the Mill Creek pilot study and was adjusted to 0.6 in calibration. L575 is in the same region as Mill Creek, so the initial estimate is the same; however, the final calibrated peaking coefficient was adjusted to 0.5 to account for flatter slopes in the basin. A peaking coefficient of 0.55 was used for the two subbasins in the bluffs, A1 and G1, to account for steeper slopes. The lag time coefficient for Mill Creek was initially estimated at 0.4 and adjusted to 0.6 in calibration. The same starting lag time coefficient estimate and calibration adjustment were applied to the L575 model.

The L575 model was also calibrated using the USGS published document showing average annual runoff throughout the United States from 1951 to 1980 (Gebert, 1987). According to the map of average annual runoff, L575 would produce approximately 6.5 inches of runoff volume per unit area from 1951-1980. Over the same observation period, the L575 HMS model produced approximate 3.5 inches of runoff volume per unit area, which is significantly less than the USGS publication. The significant difference can be attributed to the higher loss rates in the basin. Loss parameters could be adjusted to better calibrate runoff volumes to USGS estimates; however, the USGS document generalized runoff amounts for large areas and variability at a watershed scale is to be expected, so loss parameters were not altered from original estimates. Table 14 shows a comparison of runoff volume per unit area over the USGS publication observed period of 1951-1980.

Table 14. Comparison of runoff volume per unit area from 1951-1980.

Source	Runoff Volume per unit area (inches)
Subbasin A	1.9
Subbasin B	2.0
Subbasin C	2.5
Subbasin D	5.2
Subbasin E	2.0
Subbasin F	1.9
Subbasin G	1.4
Subbasin H	11.3
USGS Runoff Publication	6.5

The final method of calibration of the L575 interior drainage basin utilized spring pulse gage data. Spring pulse data was available in 2008, 2009, and 2010. Spring pulse data was compared to modeled data resulting from the L575 hydraulic model. The original estimates of loss rates, as well as alternatives of 75%, 50%, and 25% of original estimates, were analyzed. The results of the comparison showed that, while there were peak flows that were better modeled using one of the three alternatives, initial loss rate estimates ultimately provided the most valuable results, in terms of runoff volume, over the entire modeled period of record (1930-2012).

RESULTS

The L575 interior drainage basin was calibrated based on parameter adjustments of the Mill Creek pilot study and runoff volumes per unit area from 1951-1980 provided in the USGS runoff publication. Results are shown from 1930-2012. Flows at each one of the outlets are shown in Figure 24 to Figure 31. Yearly runoff volume per unit area, the total runoff from each subbasin over each year in the period of record, at each outlet as well as a period of record annual average are shown in Table 15. Yearly averages are much lower in the L575 subbasins than in L536, which can be attributed to higher constant losses. Subbasin H produced a higher runoff volume per unit area because Hamburg is located in that subbasin which resulted in a higher percent imperviousness and greater direct runoff.

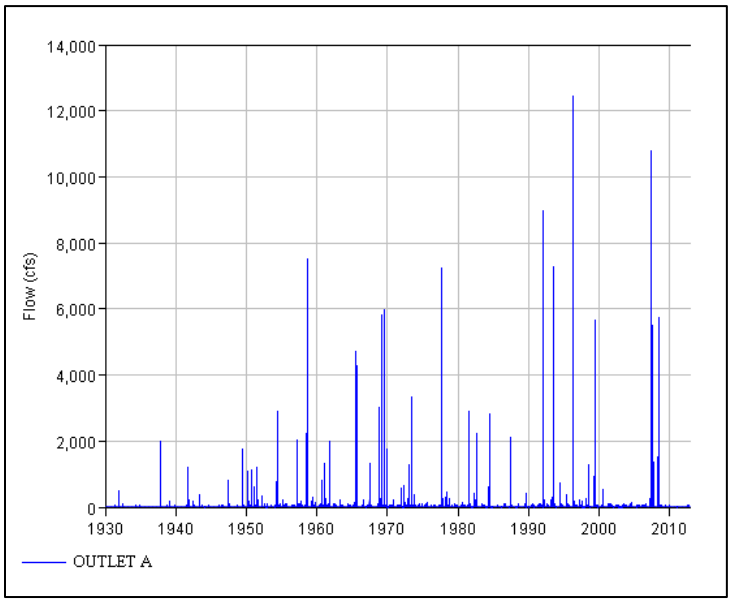


Figure 24. Subbasin A outflow.

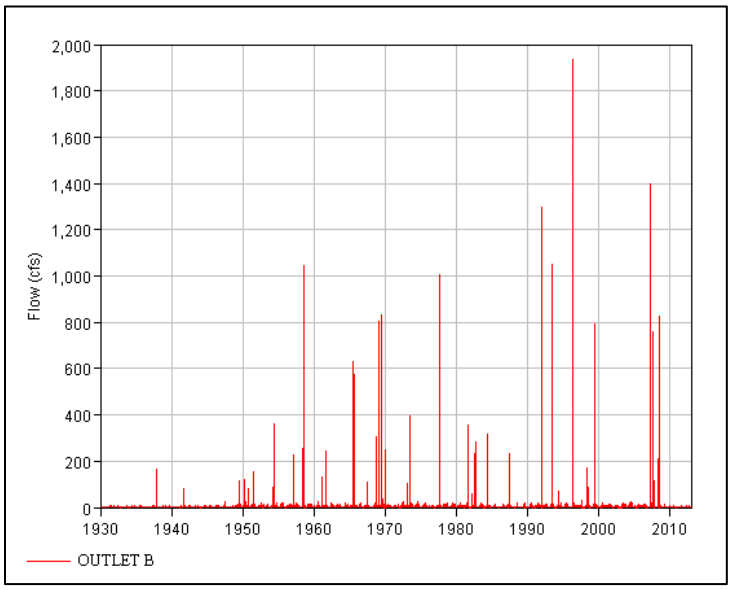


Figure 25. Subbasin B outflow.

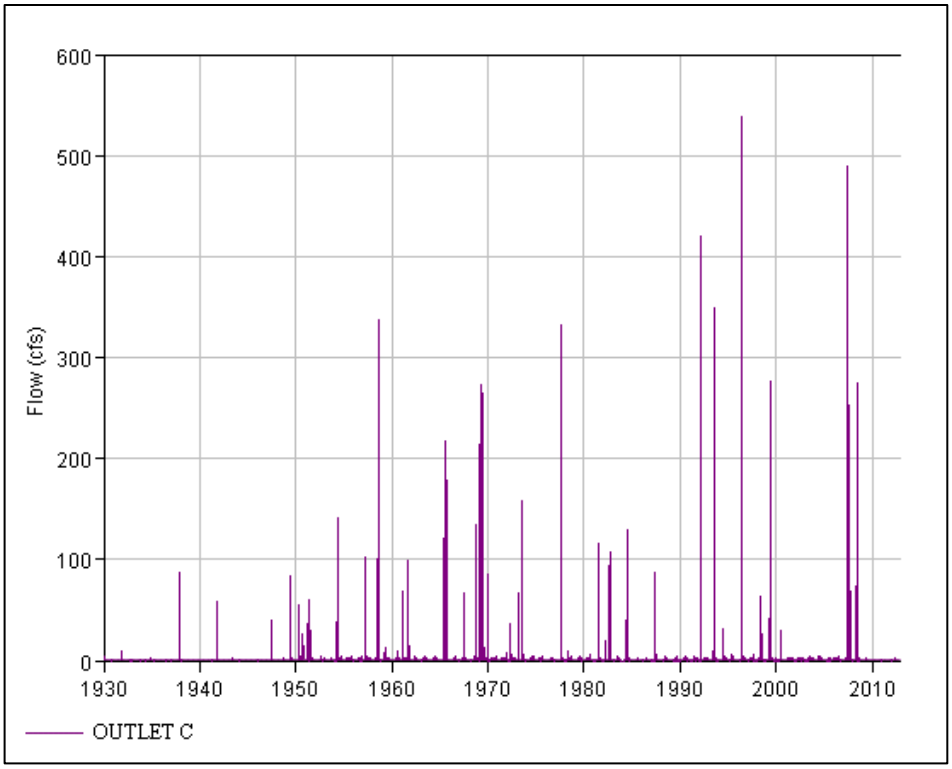


Figure 26. Subbasin C outflow.

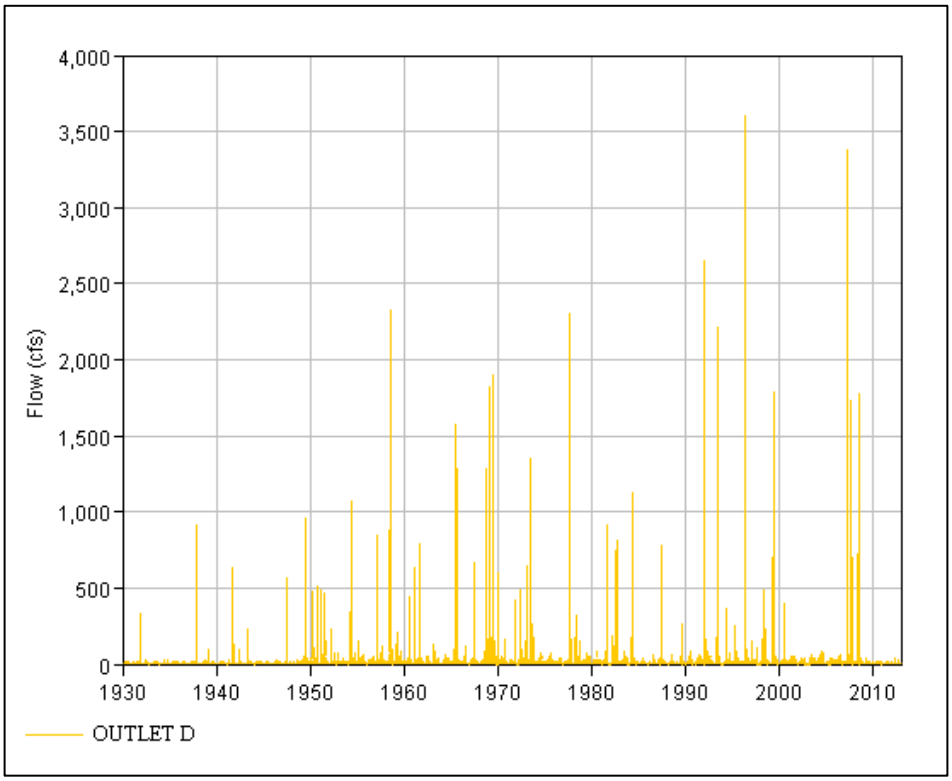


Figure 27. Subbasin D outflow.

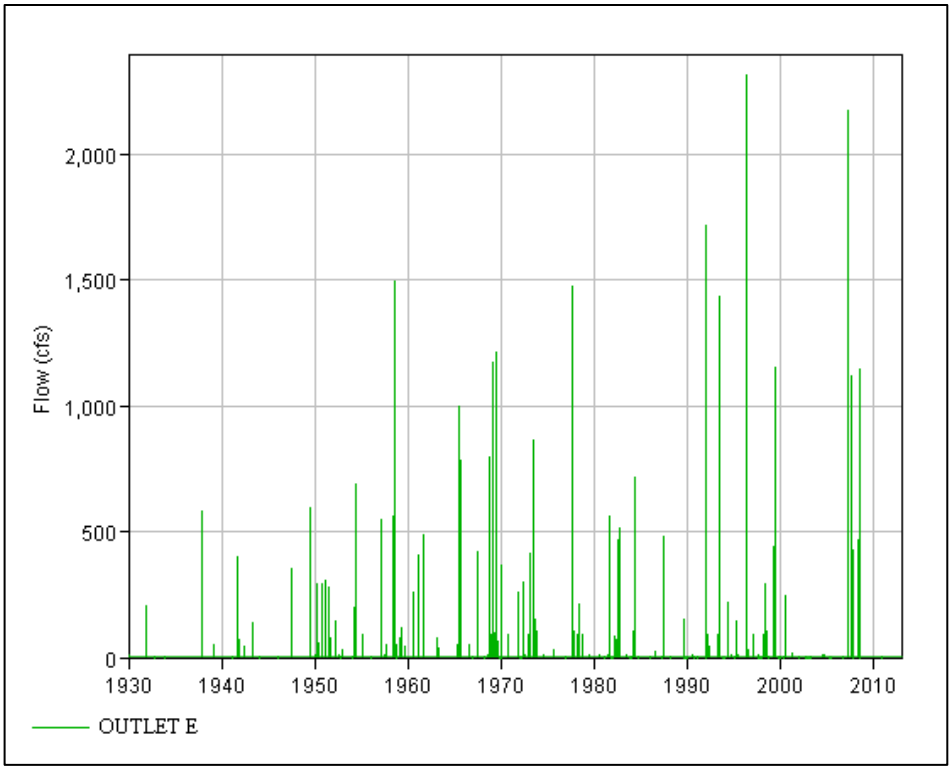


Figure 28. Subbasin E outflow

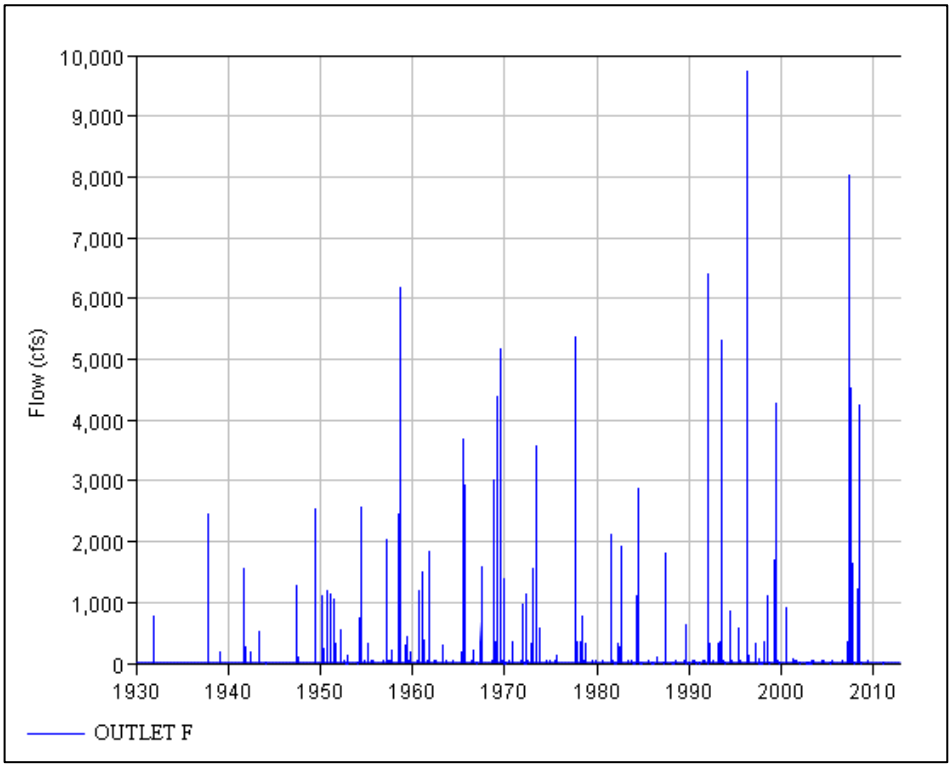


Figure 29. Subbasin F outflow.

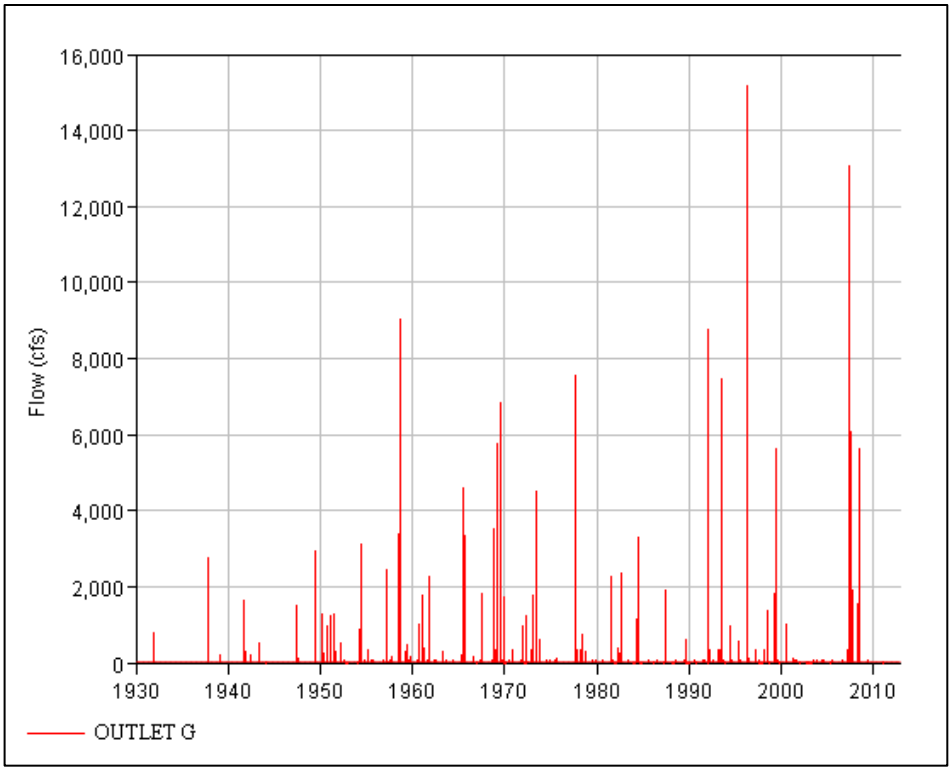


Figure 30. Subbasin G outflow.

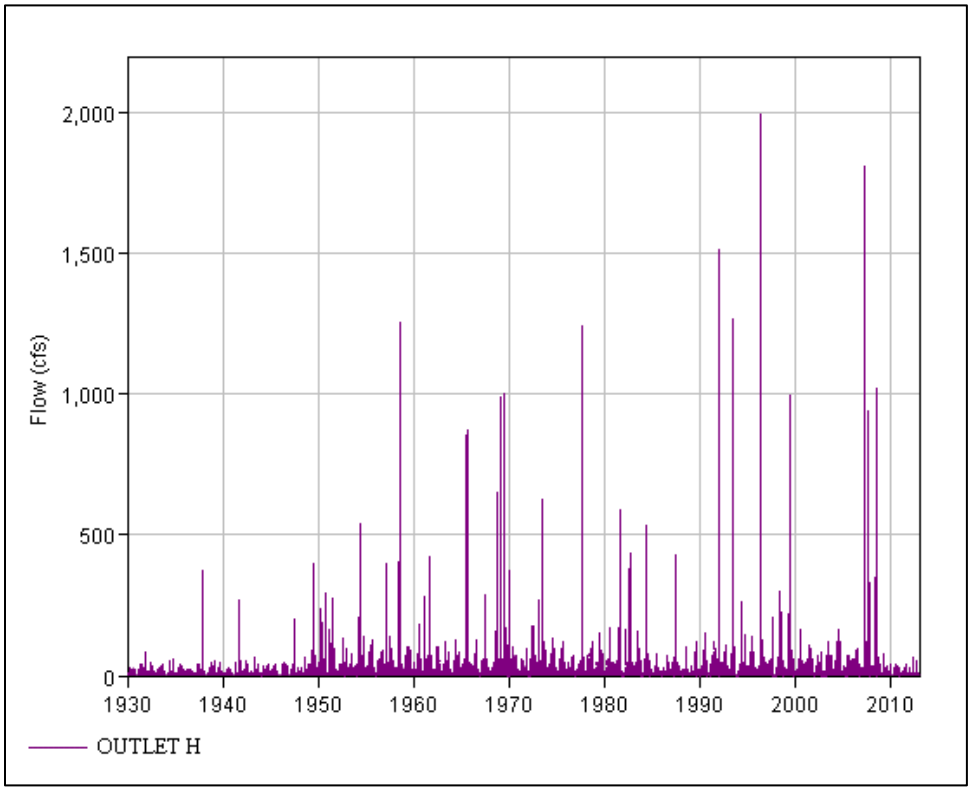


Figure 31. Subbasin H outflow.

Table 15. Runoff volume per unit area, in inches, at each outlet in the L575 interior drainage basin. A yearly average for each outlet is also provided. Higher constant loss rates account for much lower yearly average runoff volume than that of L536.

Year	A	B	C	D	E	F	G	H
1930	0.65	0.66	0.55	1.31	0.29	0.40	0.33	4.45
1931	0.94	0.93	0.85	2.07	0.63	0.75	0.54	6.10
1932	0.61	0.62	0.35	1.22	0.17	0.38	0.29	3.85
1933	0.64	0.67	0.42	1.41	0.19	0.41	0.32	4.37
1934	0.49	0.53	0.29	1.12	0.14	0.33	0.26	3.30
1935	0.72	0.75	0.45	1.58	0.22	0.46	0.36	5.26
1936	0.49	0.49	0.36	1.17	0.17	0.30	0.24	3.77
1937	1.02	0.98	1.22	2.23	1.03	1.11	0.82	5.33
1938	0.62	0.65	0.38	1.31	0.18	0.40	0.31	4.23
1939	0.62	0.61	0.37	1.47	0.41	0.42	0.33	4.00
1940	0.59	0.61	0.43	1.38	0.20	0.37	0.30	4.47
1941	0.92	0.90	1.15	2.11	1.05	0.94	0.67	5.17
1942	0.88	0.89	0.54	1.88	0.49	0.59	0.45	5.75
1943	0.72	0.72	0.46	1.79	0.54	0.56	0.40	4.75
1944	1.00	1.04	0.66	2.25	0.31	0.64	0.50	7.03
1945	0.83	0.84	0.57	1.89	0.28	0.51	0.41	5.64
1946	0.79	0.82	0.47	1.65	0.22	0.50	0.39	5.04
1947	0.91	0.88	1.10	2.19	0.98	0.88	0.63	5.41
1948	0.71	0.72	0.44	1.55	0.22	0.43	0.36	4.94
1949	1.90	2.02	2.74	5.64	1.92	1.97	1.43	12.74
1950	2.14	2.30	2.83	5.75	2.12	1.88	1.29	11.66
1951	2.42	2.48	3.86	6.87	2.85	2.42	1.72	14.14
1952	1.33	1.40	1.11	3.55	1.08	1.01	0.68	8.82
1953	1.00	1.06	1.02	3.33	0.50	0.67	0.49	8.68
1954	1.83	1.93	2.61	4.83	1.73	1.75	1.30	10.33
1955	1.08	1.32	1.11	3.43	0.81	0.85	0.62	8.40
1956	1.20	1.40	1.32	3.85	0.65	0.88	0.65	8.83
1957	1.93	2.14	2.33	5.20	1.67	1.63	1.24	11.34
1958	4.50	4.37	6.42	9.11	6.01	5.49	4.42	14.43
1959	2.14	2.18	2.65	6.16	2.31	1.74	1.22	13.79
1960	1.77	1.90	1.65	5.30	1.49	1.49	0.96	11.92
1961	2.08	2.37	2.90	5.65	2.18	2.09	1.58	12.02
1962	1.39	1.71	1.53	4.20	0.76	1.01	0.75	10.10
1963	1.31	1.46	1.36	4.24	1.09	1.01	0.69	9.70
1964	1.33	1.44	1.34	4.30	0.66	0.90	0.68	10.40
1965	4.23	4.17	6.39	8.68	5.30	4.56	3.69	15.75
1966	1.21	1.32	1.19	3.75	0.81	0.91	0.61	9.48
1967	1.76	1.79	2.36	5.44	1.63	1.65	1.14	12.10
1968	1.61	1.62	2.18	4.64	1.87	1.69	1.23	11.13
1969	4.59	4.70	6.74	8.46	5.98	5.12	4.34	13.20
1970	1.46	1.47	1.50	4.57	1.12	1.12	0.78	11.13

1971	1.18	1.11	1.35	3.67	0.98	0.99	0.68	9.17
1972	1.48	1.47	1.93	4.70	1.40	1.28	0.92	11.23
1973	2.72	2.87	3.91	7.69	3.49	3.03	2.21	16.04
1974	1.13	1.37	1.24	3.73	0.61	0.82	0.60	8.82
1975	1.26	1.51	1.26	4.11	1.02	0.97	0.68	10.89
1976	0.87	0.88	0.70	2.45	0.34	0.58	0.43	6.60
1977	5.13	4.71	7.06	10.86	7.38	6.53	5.09	16.76
1978	1.66	1.83	1.69	5.25	1.77	1.50	0.97	12.36
1979	1.55	1.78	1.71	4.97	0.84	1.14	0.82	11.90
1980	1.15	1.25	1.20	3.65	0.59	0.79	0.54	9.59
1981	1.84	2.06	2.36	4.82	1.69	1.58	1.17	10.61
1982	2.56	2.56	4.18	6.44	2.98	2.54	2.01	13.70
1983	1.13	1.23	1.17	3.68	0.58	0.79	0.57	9.97
1984	2.10	1.96	3.09	5.77	3.30	2.58	1.79	11.08
1985	0.74	0.81	0.50	1.68	0.24	0.48	0.38	5.16
1986	0.95	0.96	0.54	1.89	0.46	0.60	0.46	5.74
1987	1.40	1.56	1.90	3.67	1.34	1.34	1.00	8.95
1988	0.57	0.69	0.57	1.57	0.27	0.41	0.31	4.32
1989	0.76	0.86	0.79	2.29	0.70	0.70	0.49	5.38
1990	1.39	1.72	1.55	4.53	0.76	1.02	0.69	11.85
1991	1.28	1.45	1.27	3.95	0.62	0.92	0.66	9.58
1992	3.00	3.16	3.65	6.97	3.12	2.87	2.36	13.92
1993	6.16	5.61	7.96	12.01	8.52	7.40	6.10	18.36
1994	1.18	1.30	1.70	3.59	1.13	1.01	0.69	8.62
1995	1.56	1.80	1.78	5.12	1.33	1.28	0.84	13.10
1996	4.46	4.34	5.58	9.27	5.21	4.88	4.03	15.61
1997	0.97	0.95	0.97	3.04	0.75	0.72	0.49	7.46
1998	1.73	1.95	2.65	5.03	1.71	1.42	1.08	11.93
1999	3.23	3.12	5.65	7.26	4.61	3.81	2.99	13.13
2000	1.02	1.15	1.47	3.33	0.86	0.90	0.67	8.63
2001	1.28	1.57	1.38	4.24	0.84	0.94	0.70	10.58
2002	0.91	1.06	1.03	3.14	0.51	0.69	0.49	8.07
2003	1.23	1.36	1.19	3.83	0.58	0.90	0.61	9.66
2004	1.28	1.64	1.55	3.99	0.76	0.92	0.70	10.05
2005	0.74	0.81	0.74	2.43	0.36	0.52	0.40	6.46
2006	1.30	1.41	1.29	4.30	0.63	0.90	0.66	11.03
2007	5.61	5.30	8.37	11.38	8.21	7.39	5.79	17.30
2008	3.10	3.26	5.46	6.78	3.91	3.34	2.74	12.87
2009	0.80	0.82	0.50	1.72	0.24	0.49	0.40	5.40
2010	0.87	0.90	0.56	1.83	0.27	0.55	0.42	6.09
2011	0.68	0.69	0.43	1.45	0.21	0.41	0.33	4.85
2012	0.60	0.67	0.41	1.38	0.18	0.40	0.31	4.10
Yearly Average	**1.60**	**1.67**	**1.96**	**4.12**	**1.54**	**1.50**	**1.14**	**9.28**

REFERENCES

Feldman, A.D. (2000). Hydrologic Modeling System HEC-HMS Technical Reference Manual. Washington, DC: United States Army Corps of Engineers.

Gebert, W.G. (1987). Average Annual Runoff in the United States, 1951-1980. U.S. Geological Survey. Madison, WI.

National Climate Data center. (2016, February 9). *Climate Data Online*.

National Land Cover Data (NLCD). (2016, January 8). *Multi-Resolution Land Characteristics Consortium.* Retrieved February 11, 2016.

Rawls, WJ, Brakensiek, DL, & Miller, N (1983). Green-Ampt Infiltration Parameters from Soils Data. *Journal of Hydraulic Engineering*, 62-70.

Scharffenberg, WA (2015, July). Hydrologic Modeling System HEC-HMS User's Manual. Davis, California: U.S. Army Corps of Engineers Hydrologic Engineering Center.

United States Department of Agriculture National Resources Conservation Service. (2013, December 6). Web Soil Survey. Retrieved January 22, 2016.

USACE (August 1998). Master Water Control Manual Missouri River Volume 11: Interior Drainage Study. Northwestern Division.

US Geological Survey. (2016, January 6). *USGS 06816000 Mill Creek at Oregon, MO*.

Viesmann Jr., W., & Lewis, G.L. (2002). *Introduction to Hydrology*. Upper Saddle River: Prentice Hall.

ATTACHMENT A: MILL CREEK PILOT STUDY

BACKGROUND

The Mill Creek pilot study was used in calibration of the levee unit interior drainage models. The intent of the pilot study was to use the same parameter estimation techniques and calibration adjustments for each levee unit model. There are no gages located in the interior drainage basins, so Mill Creek was selected to calibrate the levee unit models. After considering several different stream locations, Mill Creek near Oregon, MO was selected because of its similarities to the interior drainage basins and relatively small size (5.2 mi^2). USGS operated a gage (6816000) on Mill Creek from 1950-1976. Gage records include yearly peak flows and average daily flows. The hydrologic model was calibrated based on runoff volume per unit area over the USGS gage period of record.

HYDROLOGIC MODEL

Meteorologic Model

The Mill Creek meteorologic model was developed using hourly precipitation at St. Joseph, Missouri, and daily precipitation at Oregon, Missouri. Hourly precipitation was available at St. Joseph, MO, and daily precipitation was available at Oregon, MO. Each hour of the St. Joseph precipitation record was assigned a factor, which is the precipitation in one hour divided by the cumulative precipitation over that day. Those factors were then multiplied by the daily precipitation at Oregon, MO to convert to hourly precipitation. On days when there was precipitation in Oregon and none in St. Joseph, average hourly factors, computed from hourly factors at St Joseph over the gage period of record, were used to convert daily precipitation to hourly precipitation. The converted hourly precipitation at Oregon is shown in Figure 32 below.

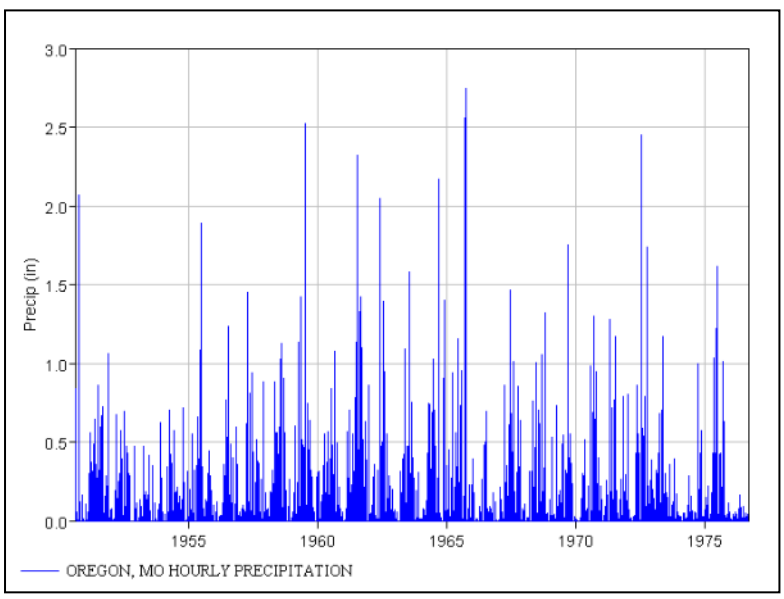


Figure 32. Oregon hourly precipitation converted using hourly factors from St. Joseph.

The monthly average method was used to model evapotranspiration in the Mill Creek drainage basin. The monthly average method uses a monthly pan evaporation rate and a pan coefficient to convert pan evaporation to evapotranspiration. Coefficients to convert pan evaporation to evapotranspiration can range from 0.6 to 0.8 for a Class A land pan (Gupta, 2008). An initial estimate of 0.6 was assumed. Runoff volume per unit area prior to calibration was too high, so the coefficient was adjusted to 0.75 to account for more losses in the basin. Evaporation was estimated using monthly pan evaporation at

Shenandoah, Iowa from 1966-1986, and monthly averages were calculated. Shenandoah provided the closest available data obtained from NCDC Climate Data Online (2016). The monthly average pan evaporation at Shenandoah, Iowa is shown in Table 16 below.

Table 16. Monthly evaporation at Shenandoah, Iowa used to model monthly average evapotranspiration.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (in)	0	0	0	5.19	5.96	7.06	7.76	6.42	5.04	3.54	0	0

Delineation

Mill Creek subbasins were delineated using HEC-GeoHMS. The Mill Creek basin delineation and the HEC-HMS schematic are shown in Figure 33 below. Subbasin areas are shown in Table 17.

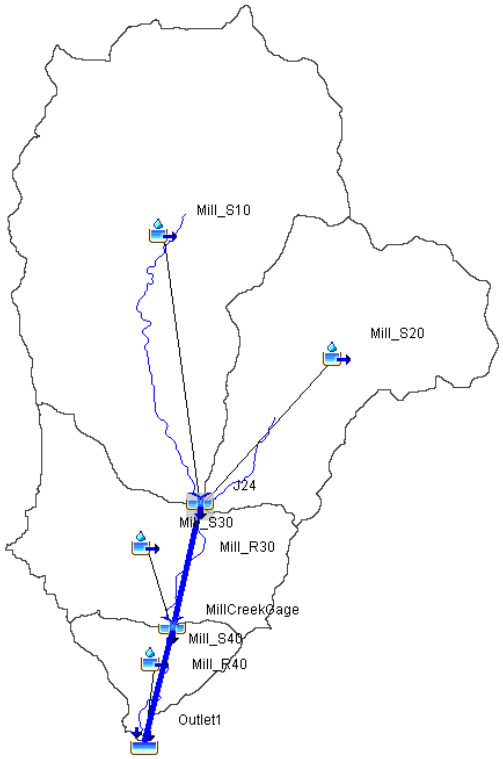


Figure 33. Mill Creek HEC-HMS schematic.

Table 17. Mill Creek subbasin areas.

Subbasin	**Mill_S10**	**Mill_S20**	**Mill_S30**	**Mill_S40**
Area (mi2)	2.70	1.28	0.90	0.28

Canopy

The simple canopy method was used in conjunction with monthly average evapotranspiration and rainfall loss methods. The canopy method models the interception of rainfall by plants in the landscape (USACE, 2013). It was assumed that there is no canopy storage in the Mill Creek basin; however, the simple uptake method was required by HMS in order to properly model evapotranspiration losses in the basin.

Rainfall Losses

The deficit and constant loss method was used to model rainfall losses. The method uses an initial deficit, maximum deficit, constant loss rate, and percent imperviousness. Gridded SSURGO soils data was used to determine soil properties (NRCS, 2012). The starting loss parameters were determined based on soil type, mostly silt loam soils, and the associated deficit and constant parameters (Rawls, et al, 1983). The National Land Cover Database (NLCD) was used to determine average percent imperviousness for each subbasin (2012). There was no adjustment of rainfall loss parameters during calibration of the Mill Creek model. Deficit and constant parameters are shown in Table 18 below.

Table 18. Deficit and constant loss parameters used in the Mill Creek model.

Subbasin	Initial Deficit (in)	Maximum Storage (in)	Constant Rate (in/hr)	Impervious (%)
Mill_S10	1.0	3.6	0.20	0.2
Mill_S20	1.0	3.6	0.20	0.3
Mill_S30	1.0	3.4	0.16	3.9
Mill_S40	1.0	3.6	0.20	2.3

Runoff Transformation

Snyder's unit hydrograph method was used to model the runoff transformation. This method utilizes a peaking coefficient (C_p) and a lag time coefficient (C_t). According to Viesmann and Lewis (2002), the lag time coefficient for the area of Mill Creek usually ranges from 0.2 to 0.6, with an average value of 0.4. Data was not available for the specific location of Mill Creek, so it was assumed that parameters would be similar to those of Western Iowa, which is the location of the provided range of values. The starting value was assumed to be 0.4 for all subbasins. That lag time coefficient was adjusted to 0.6 to account for relatively mild slopes and to reflect the timing of flows at the USGS streamflow gage. The lag time was calculated using the coefficient, longest flowpath, and centroidal longest flowpath.

Peaking coefficients in the Mill Creek region, again assumed to be similar to those of Western Iowa, are generally in the range of 0.7 to 1.0, with an average value of 0.8 (Viesmann & Lewis, 2002). A starting value of 0.8 was chosen for the Mill Creek basin. During calibration, that value was adjusted to 0.6 to account for milder slopes and the relatively small size of the basin. Although 0.6 is slightly outside the suggested range, it produces the most accurate results in respect to volume per unit area. Snyder's unit hydrograph parameters are shown in Table 19 below.

Table 19. Snyder's unit hydrograph parameters used to Mill Creek runoff transformation. Initial and final calibrated parameters are shown.

Iteration	Parameter	Mill_R10	Mill_R20	Mill_R30	Mill_R40
Initial	**C_t**	0.4	0.4	0.4	0.4
	Lag Time (hrs)	0.57	0.38	0.31	0.30
	C_p	0.8	0.8	0.8	0.8
Final	**C_t**	0.6	0.6	0.6	0.6
	Lag Time (hrs)	0.85	0.57	0.47	0.46
	C_p	0.6	0.6	0.6	0.6

Channel Routing

The Muskingum-Cunge method was used to route flow through channels. The method uses channel shape, slope, length, and Manning's n roughness coefficient. Lengths, slopes, and channel shapes were determined using Google Earth Pro and ArcMap 10.0. The Manning's n roughness coefficient used in modeling channel routing was 0.04 (Gupta, 2008). Channel routing parameters were not adjusted during calibration. Muskingum-Cunge parameters are shown below in Table 20.

Table 20. Muskingum-Cunge channel routing parameters.

Reach	Length (ft)	Slope (ft/ft)	Manning's n	Width (ft)	Side Slope (H:V)
Mill_R30	3800	0.002	0.04	12	4
Mill_R40	4020	0.002	0.04	12	4

Baseflow

The recession method was used to model baseflow. Baseflow parameters were estimated using the USGS streamflow gage. Initial discharge, recession constant, and threshold flow are used in the recession baseflow method. According to the HEC-HMS technical reference manual, the recession constant for surface runoff can range from 0.3 to 0.8 with smaller watersheds generally producing lower values. The starting value for the recession constant was estimated as 0.5. Through calibration, the value was adjusted to 0.34. The small value is justified by the very small size of the watershed and its subbasins. The initial discharge and threshold flows were adjusted to match flows at the USGS streamgage. Baseflow parameters are shown in Table 21 below.

Table 21. Recession baseflow parameters.

Subbasin	Initial Recession Coefficient	Final Recession Coefficient	Initial Discharge (cfs)	Threshold Flow (cfs)
Mill_S10	0.5	0.34	10	18
Mill_S20	0.5	0.34	10	18
Mill_S30	0.5	0.34	10	18
Mill_S40	0.5	0.34	10	18

CALIBRATION

The Mill Creek pilot study was calibrated using runoff volumes from the HMS model, the USGS Mill Creek streamflow gage, and the USGS runoff publication. In calibration, the recession baseflow constant, Snyder's Unit Hydrograph peaking and lag time coefficients, and monthly average evapotranspiration coefficient were all adjusted. Average yearly runoff volume per unit area, determined prior to any calibration adjustments, was approximately 7.2 inches. After adjustments of the aforementioned parameters, the resulting yearly average runoff volume per unit area was approximately 5.8 inches.

Runoff volumes in acre-feet were calculated using HEC-DSSVue 2.0.1 and were converted to inches of runoff based on the area of the basin. The USGS streamflow gage produced an average annual runoff of 5.7 inches during the observation period of 1950-1976 (2016). USGS published a document that provides average annual runoff throughout the United States in the form of a contour map from 1951-1980 (Gebert, 1987). The runoff publication showed a runoff volume per unit area of approximately 7.5 inches in the area of Mill Creek. The adopted Mill Creek HMS model produced an average annual runoff volume per unit area of 5.8 inches, which is about 2% greater than the USGS streamflow gage and about 30% less than the USGS runoff publication. That significant difference in runoff volumes between the USGS runoff publication and the HMS runoff can be attributed to using varying periods of record and also that the USGS document generalized runoff amounts for large areas and variability at a watershed scale is to be expected. Runoff volumes per unit area in inches are shown in Table 22.

Table 22. Runoff volumes of the Mill Creek HMS model and calibration sources.

Source	Observation Period (yrs)	Runoff Volume (in)
HMS Model	1950-1976	5.8
USGS Gage	1950-1976	5.7
USGS Runoff Publication	1951-1980	7.5

RESULTS

The Mill Creek pilot study was calibrated based on runoff volumes of the HMS model, the streamflow gage, and the USGS runoff publication. Table 23 shows the yearly runoff volume per unit area of the Mill Creek pilot study. The yearly average runoff volume per unit area of Mill Creek is approximately 5.8 inches, which is about 2% greater than the 5.7 inches of average yearly runoff volume of the USGS streamflow gage. The USGS runoff publication showed approximately 7.5 inches of runoff. The difference can be attributed to reducing the significant scale of the publication to a watershed scale. Flows resulting from the HMS model are shown in Figure 34.

Table 23. Yearly runoff volume per unit area of the Mill Creek pilot study.

Year	Runoff Volume (in)
1950	1.7
1951	13.7
1952	4.2
1953	1.9
1954	4.0
1955	2.9
1956	1.3
1957	5.7
1958	9.2
1959	9.6
1960	3.9
1961	12.5
1962	4.8
1963	2.6
1964	10.1
1965	14.3
1966	0.7
1967	8.3
1968	2.7
1969	4.5
1970	5.1
1971	4.0
1972	5.3
1973	8.6
1974	2.1
1975	8.3
Yearly Average	**5.8**

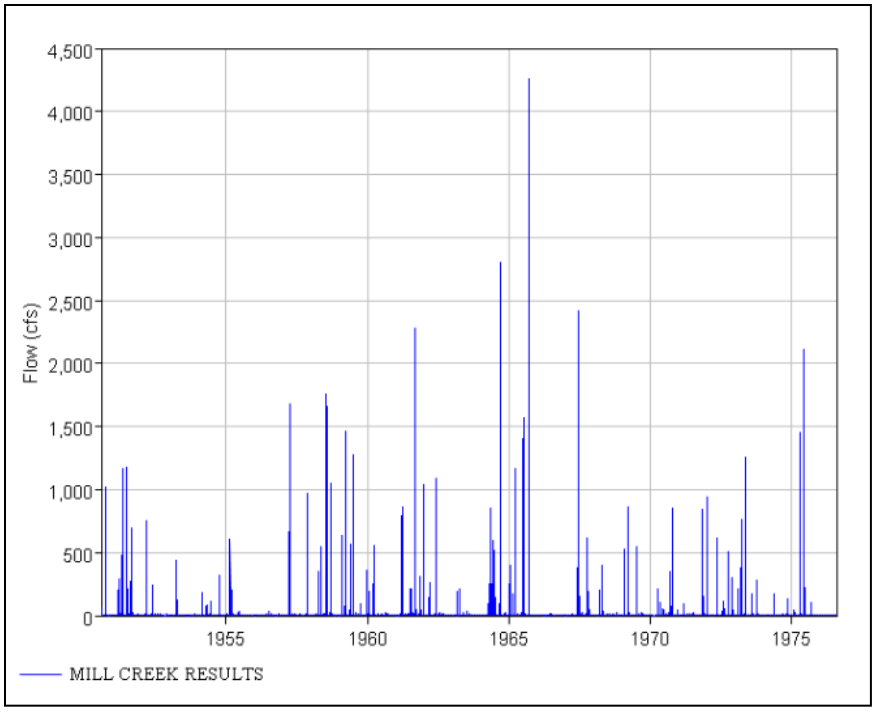


Figure 34. Mill Creek HMS flow results shown from 1950 to 1976.

CONCLUSIONS

The intent of the Mill Creek pilot study was to use the described methods to determine initial parameter values and adjust the values for each levee unit according to the adjustments made in calibration. Calibration of the Mill Creek pilot study included adjusting Snyder's Unit Hydrograph runoff transformation and recession baseflow parameters; therefore, those same parameters should be adjusted in the levee unit studies. In the case of Snyder's Unit Hydrograph parameters, the interior drainage basins have milder slopes than that of Mill Creek so the peaking coefficient and lag time coefficients should be adjusted accordingly. Baseflow parameter adjustments should be similar, and the same method of initial estimation should be used. Because there was no adjustment in deficit and constant loss parameters calculated using gSSURGO soils data, it can be assumed that no adjustments need to be made to levee unit loss parameters calculated using the same method.

Missouri River Unsteady HEC-RAS Models
Alternatives Analysis

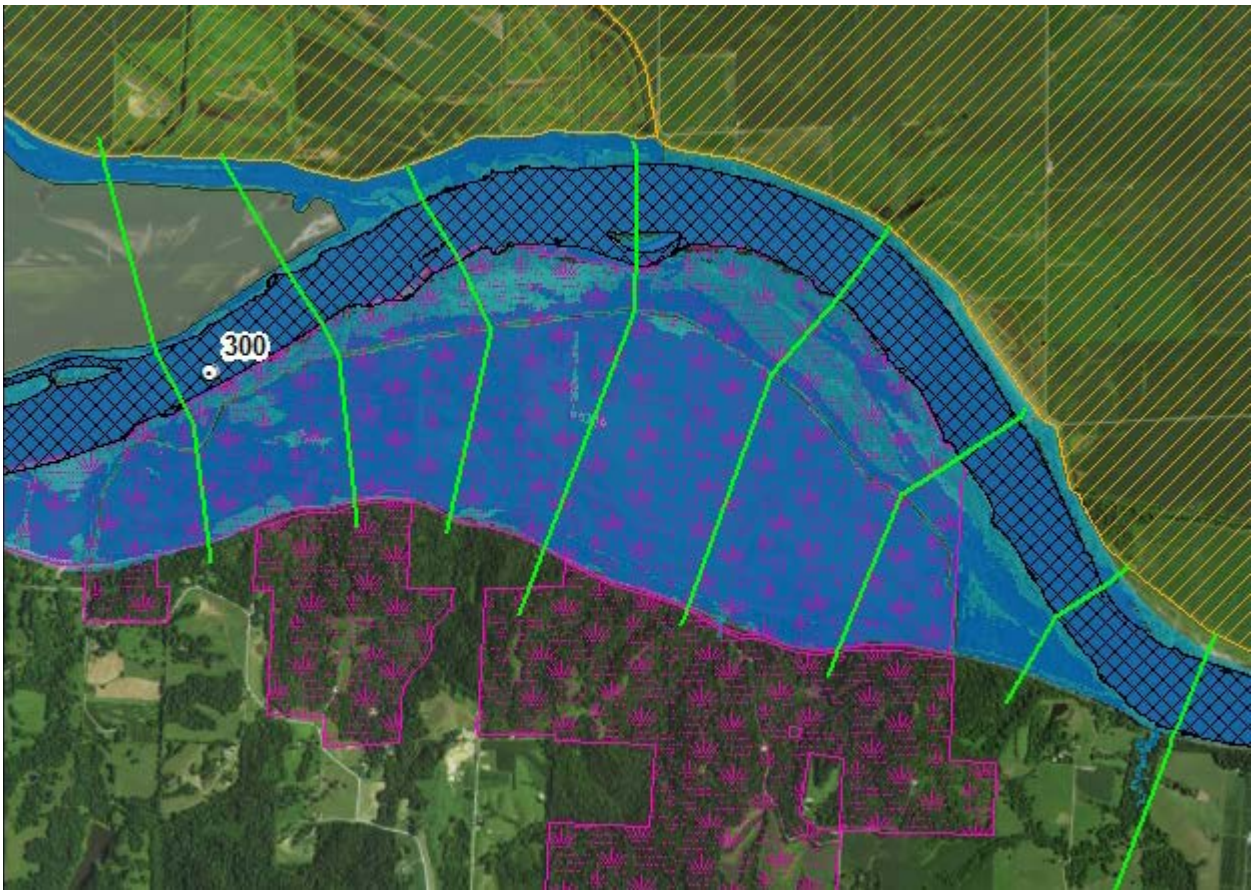
DRAFT

US Army Corps of Engineers ®

Kansas City District

Appendix E

Rulo to Mouth



December 2016

COVER PHOTO:

Baltimore Bend, the site of an interception habitat project currently undergoing design as a part of the Missouri River Recovery Program (MRRP).

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Attachment 2 – Floodplain Connectivity Metadata

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ACRONYMS

2003 BiOp……2003 Amendments to the 2000 Biological Opinion

DRM……..Daily Routing Model

HAMP..... Habitat Assessment Monitoring Program

MRBWMD……Missouri River Basin Water Management Division

NWK…… Northwest Division Kansas City District

NWO…… Northwest Division Omaha District

RAS..... Hydrologic Engineering Center River Analysis System Software

ResSim……..... Hydrologic Engineering Center Reservoir Simulation Software

SWH..... Shallow Water Habitat

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

USACE…… United States Army Corps of Engineers

USFWS…….United States Fish and Wildlife Service

USGS..... United States Geological Survey

1 INTRODUCTION

The Missouri River unsteady HEC-RAS model was created as a base model for planning studies which could be used to simulate and analyze broad scale watershed alternatives. Model geometry development and calibration for the existing conditions is documented in *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix E Rulo to the Mouth* (USACE, May 2015). The objective of the HEC-RAS modeling documented in this Appendix is to simulate the Management Plan alternatives which include both geometry and flow changes relative to the No Action alternative for the reach of the Missouri River in Kansas City District extending from Rulo, NE to the Mississippi River. Model extents overlap with the Omaha District on the Missouri River upstream of Rulo, Nebraska to Nebraska City, Nebraska, and with St. Louis District on the Mississippi River from L&D 25 to the St. Louis, Missouri gage.

Six alternatives, including the No Action alternative, were simulated in HEC-RAS from March 1930 to December 2012, however the HC team only used complete year data for their analysis from January 1, 1931 to December 31, 2012. Development of inflow records at current depletion levels to use as boundary conditions for the Res-Sim and HEC-RAS models is documented in *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling Report* (USACE, 2016a). Each alternative has unique flow releases from the reservoirs, as simulated by the Res-Sim models. Output flow hydrographs from Res-Sim were routed through the Gavins to Rulo HEC-RAS model, and then passed to the Rulo to Mouth model. Refer to **Appendix D** for details regarding the upstream model between Gavins Point Dam and Rulo, Nebraska. Three HEC-RAS geometries were developed, representing three proposed habitat construction configurations on the river. See Table 1-1 for a complete list of the geometry and flow pairings for each alternative. No Action Alternative 1 is the baseline simulation to which all other Alternatives will be compared for evaluation.

Table 1-1. Alternative Geometry and Flow Pairings

Alternative	River Geometry (RAS)	Reservoir Flow (Res-Sim)	Adopted Alternative Short Name
Alternative 1	No Action	No Action	No Action
Alternative 2	BiOp	BiOp	BiOp
Alternative 3	IRC	All Mechanical	Mech
Alternative 4		Spring Bird Flow 2, 42 MAF	Spring 2
Alternative 5		Fall Bird Flow 5, 35kcfs service level	Fall 5
Alternative 6 *		Pallid Spawning Cue	Spawn Cue

* Former name was Alternative 7, which corresponds to all HEC-RAS model runs and file names

Refer to Section 2 for detailed descriptions of the geometries, and Section 3 for a summary of the flows.

2 GEOMETRY

Three geometry configurations were developed in HEC-RAS. Modifications generally included the addition of shallow water habitat (SWH) in the form of river widening at a specified reference flow plus the addition of a few chutes. Backwaters and modifications to previously constructed projects were accounted for by the Omaha District only. Assumptions for each individual geometry, as well as assumptions that apply to all three are detailed in the following subsections.

2.1 MODIFICATIONS TO CALIBRATION MODEL

The starting point for all alternative geometry changes was the calibrated geometry documented in the *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix E Rulo to the Mouth* (USACE, May 2015). From hereafter this geometry will be referred to as Existing Conditions 2012 geometry because it generally represents river conditions and calibrated water surface elevations as of the year 2012.

A handful of geometry changes had to be made to run the period of record. All changes from the Existing Conditions 2012 geometry and calibration runs are documented in **Attachment 1 – Revision Log**. Many of the modifications were small corrections to mistakes found later and adjustments to weir coefficients for stability that are not likely to impact water surfaces significantly. Significant modifications that are worth mentioning include:

1) **Hydrosurvey data corrected** – Bed data was corrected to account for Temporary Bench Mark (TBM) errors discovered during a spring 2015 quality control check of the hydrosurvey spreadsheet. 8 TBMs were found to be in error, impacting 64 model cross sections. The maximum positive shift in bed data was 1.27 ft and the maximum negative shift was -1.31 ft. Cross sections were only modified if the impact was greater than two tenths of a foot. Modifications were between the upstream limit of cross section 449.44 near the St. Joseph gage, and downstream limit of cross section 286.16 near Waverly. Calibration was checked at each gage from St. Joseph to Waverly. Calibration at St. Joseph was improved after the changes, calibration at Kansas City remained unchanged, and at Waverly the flow varied factors were adjusted to return the calibration to Post-ATR model accuracy. Calibration metrics were not re-calculated because the changes were so small it is not likely to significantly change the calibration precision of the model.

2) **RAS version** – Calibration was performed in the 01-Oct-2014 version of HEC-RAS 5.0 Beta. All alternatives runs were performed in HEC-RAS 5.0 Release Candidate 2 (21-August-2015). Modifications to the model for the upgrade from 5.0 Beta to Release Candidate 2 included tweaking the lateral structures so they did not extend into junction zones and removing initial conditions on most storage areas, these are now automatically calculated. HEC-RAS 5.0 Release Candidate 2 (21-August-2015) is the recommended version for running the alternative runs. The alternative runs were tested in HEC-RAS 5.0.1 and 5.0.3, however result differences and stability issues were experienced relating to HTAB tables and pilot channels. These issues would need to be resolved before upgrading to a newer version of HEC-RAS.

3) **Mechanism to drain storage areas** – In HEC-RAS once a storage area is overtopped it holds water until the end of the simulation, unless a mechanism is implemented to drain the water from the area. This weakness was acknowledged in the calibration report. Possible solutions were to add pumps, add breaches, or add culverts.

   Pumps were tested, but were tedious to input into the model and had stability challenges. Additionally, pumps were inadvertently left out of the import wizard, making them difficult to transfer between geometries.

   Breaches were also tested but not ultimately used for multiple reasons. First and foremost, due to a coding oversight in HEC-RAS the breach and repair function only occurs one time per run. Many levees on the lower river have breached dozens of times over the period of record, making this option only feasible to implement if the period of record simulations were re-started after any levee breach, which is not practical for running multiple alternatives. Also, breach variability in the real world would make it very difficult to pick one location and one overtopping depth per unit that would appropriately replicate the breach process for 300 different leveed areas over 82 years of simulated record.

   Culverts with flap gates were quick to input, easy to stabilize, and easily transferable from geometry to geometry. Culverts input into the model to drain storage areas was an independent and simplified effort as compared to the detailed interior drainage modeling analysis. Refer to Section 5 for full documentation of the site-specific analysis performed to evaluate interior flooding from rainfall runoff and seepage. For the primary model runs, actual on the ground culvert configuration at each levee was not input into the model, instead a blanket assumption for number and size of culverts was made based on protected area size. For areas less than 5,000-acres, one pipe per 700-acres was created in the model, with a minimum of at least 1-36” pipe. For areas over 5,000 acres 1-60” pipe was created per 1,100-ac of protected area. Culverts were created at or slightly above the lowest elevation in the storage area curve. Leaving a little room at the bottom provided stability on the receding limb and left a small amount of water in the area for stability on the next overtopping event. Water remaining in the areas was checked to make sure it was an insignificant amount and was contained in ditch areas. The flap gate option was used in HEC-RAS to prevent river water from entering the area prior to overtopping, but allowed water from levee overtopping to drain from the area after the river receded.

2.2 ALTERNATIVE GEOMETRY OVERVIEW

Each of the three geometries created for alternatives analysis has a unique set of assumptions and goals with regard to SWH. Target acres, distribution on the river, and depth criteria at a specified statistical reference flow were defined for each geometry. Geometries were constructed to represent the end state at the completion of the ROD implementation period. Table 2-1 summarizes the descriptions below.

1) **No Action** – Assumes habitat construction activities follow current practices to achieve 20 acres/mile of SWH, the minimum target specified within the 2003 Amendments to the 2000 Biological Opinion (2003 BiOp) of 20 – 30 ac/mi (USFWS, Dec 2003). Habitat was

distributed by 2003 BiOp reaches, and the 2014 *Shallow Water Habitat Accounting Report* (USACE, Sept 2014) was used to determine the acreage deficit within each reach to attain the 20 ac/mi goal. Habitat was placed to provide 0 – 5 ft of depth at August 50% exceedance flows. Most of the SWH added to the geometry was in the form of top width widening, the remainder accomplished with chutes.

2) **BiOp As Written/ As Projected (BiOp)** – Guidance from the US Fish & Wildlife (USFW) documented in *Planning Aid Letter Regarding the Missouri River Recovery Management Plan-EIS: USFWS 2003 BiOp Projected Alternative* was provided to create a geometry which represents an ideal implementation of the 2003 BiOp. It assumes habitat construction accomplishes 30 ac/mi of SWH, and performs at a wider range of flows. Similar to the No Action geometry, habitat was distributed by 2003 BiOp reaches, and the 2014 *Shallow Water Habitat Accounting Report* was used to determine the acreage deficit within each reach to attain the 30 ac/mi goal. One third of the habitat was set provide shallow water at summer low flows, one third at median August, and one third at a spring pulse flows. Most of the SWH added to the geometry was in the form of top width widening, the remainder accomplished with chutes. Part of the BiOp requirement was maximizing floodplain connectivity, and a separate analysis was conducted as documented in Section 2.8 to ensure the requirements were met, although no changes to the HEC-RAS model were necessary.

3) **Interception Rearing Complex (IRC)** – Assumes SWH construction activities proceed based on findings made by the Effects Analysis (Jacobson, et al., 2016). Total amount of habitat was based on a current annual SWH implementation rate of about 130 ac/year per district for a total of 260 ac/year for 13 years. Distribution was based on conversations with the Effects Analysis team, who specified upper and lower boundaries based on their knowledge of larval pallid spawning locations, drift rates, and timing of interception. Sioux City is the upstream threshold for IRC placement, with the area between the Nebraska Platte River and the Osage River more likely to be successful. Chutes and existing habitat may be modified to meet IRC habitat criteria, but for purposes of HEC-RAS modeling these were not counted toward the target acreage. Habitat was placed to provide 0 – 6 ft of depth at median June flows. All of the SWH goal acreage was accomplished by top width widening.

Table 2-1. Geometry Summary

	No Action	BiOp	IRC
Target acres of SWH	20 ac/mi	30 ac/mi	260 ac/yr for 13 years
Basis for SWH target	minimum 2003 BiOp target	full 2003 BiOp target	current annual SWH implementation rate
Existing Habitat	counted, used 2014 SWH Report	counted, used 2014 SWH Report	not counted
Chutes[1]	Modeled & counted	Modeled & counted	Modeled but not counted
Distribution	20 ac/mi per BiOp reach	30 ac/mi per BiOp reach	Located for optimal interception/retention
Reference flow	August 50% Exceedance	1/3 Summer low, 1/3 median August, and 1/3 spring pulse	Median June
SWH depth criteria	0 – 5 ft	0 – 5 ft	0 – 6 ft
Additional requirements	-	Floodplain connectivity	-

Note:
1) All three geometries include the same 5 chute projects that were in construction or were completed soon after the calibration period (Benedictine Bottoms, Dalbey, Cranberry Bend, Jameson Extension, and Cora Island).

2.3 Acres of Habitat

Breakdown of target acres of SWH by reach and by habitat type for each geometry is summarized below. No Action and BiOp targets take into account existing acres of SWH on the river, whereas IRC only considered new construction. Two types of SWH construction in the Kansas City District were added, top width widening and chutes. Emphasis was heavy on top width widening. Chutes added were the same for all geometries, but were only counted toward the target acres for the No Action and BiOp geometries.

Widening and chutes were accumulated by a length along the river in miles, and then converted to acres by multiplying by a uniform top width and converting units to acres. For widening, the length measurement started and ended about halfway between cross sections, since this most appropriately reflects the interpolation between cross sections made by HEC-RAS during computations.

2.3.1 *No Action*

Acres of SWH added to HEC-RAS to meet 20 ac/mi for the No Action geometry were broken down by 2003 BiOp segment for even distribution of habitat along the river. Table 2-2 shows the acres added to HEC-RAS by segment. Total acres added to the Rulo to Mouth HEC-RAS model was 2,380 acres.

For the Kansas City District, the No Action acreage was achieved by widening and chutes only. The breakdown of habitat type for Rulo to the mouth is shown in

Table 2-3 and is equivalent to 13% chutes and 87% top width widening. Total number of cross sections modified downstream of Rulo, Nebraska was 128 (94 for widening and 34 for chutes) of the 879 Missouri River cross sections.

Table 2-2. Acres of SWH – No Action Geometry

Reach	Segment	RM Start	RM End	Miles	Required Acres (20 ac/mi)	Existing Acres of SWH (2014 SWH Report)	SWH Acres Needed to Reach Goal
Ponca to Sioux City	11	753	735	18	360	120	240
Sioux City to Platte River	12	735	595	140	2,800	1,682	1,118
Platte River to Rulo (Omaha)	13	595	498	97	1,940	1,290	650
Rulo to Kansas River (KC)	13	498	367	131	2,620	1,270	1,350
Kansas River to Osage River	14	367	130	237	4,740	3,710	1,030
Osage River to Mouth	15	130	0	130	2,600	2,600 [1]	0
Omaha District				255	5,100	3,092	2,008
Kansas City District				498	9,960	7,580	2,380
Total				753	15,060	10,672	4,388

Note:

1) Existing acres for segment 15 (3,253 acres) exceeds 20 ac/mi. For purposes of Alternative 1 No Action, no new SWH will be added to this segment with the exception of Cora Island Chutes A & C which are currently under construction (summer/fall 2015). Cora Island was not shown to be counted toward the target acres in this table.

2) No SWH will be added to reaches upstream of Gavins, these calculations only apply to the Gavins to Rulo and Rulo to the Mouth HEC-RAS models.

Table 2-3. SWH Type – No Action Geometry

Reach	Segment	Widening (acres)	Widening (miles) [1]	Number of Widening Projects	Chutes (acres)	Chutes (miles)[2]	Number of Chute Projects
Rulo to Kansas R	13	1,129	31.1	14	221	6.1	2
Kansas R to Osage R	14	937	25.8	10	93	2.6	2
Osage R to Mouth	15	0	0	0	0	0	1[3]
Total		2,066	57	24	314	9	5

Note:

1) Assumes approx widening width on average of 300-ft in the Kansas City district.

2) Assumes ultimate chute width of approximately 300-ft in the Kansas City district.

3) Even though the target acres to accomplish 20 ac/mi = 0, Cora Island was still added to the No Action geometry because it is currently under construction.

2.3.2 *BiOp*

Acres of SWH added to HEC-RAS to meet 30 ac/mi for the BiOp geometry were broken down by 2003 BiOp segment, same as the No Action, for even distribution of habitat along the river.

Table 2-4 shows the acres added to HEC-RAS by segment. Total acres added to the Rulo to Mouth HEC-RAS model was 6,707 acres.

For the Kansas City District, the BiOp acreage was achieved by widening and chutes only. The breakdown of habitat type for the Rulo to the mouth only is shown in Table 2-5 and is equivalent to 6% chutes and 94% top width widening. Total number of cross sections modified downstream of Rulo, Nebraska was 222 (188 for widening and 34 for chutes) of the 879 Missouri River cross sections.

Table 2-4. Acres of SWH – BiOp Geometry

Reach	Segment	RM Start	RM End	Miles	Required Acres (30 ac/mi)	Existing Acres of SWH (2014 SWH Report)	SWH Acres Needed to Reach Goal
Ponca to Sioux City	11	753	735	18	540	120	420
Sioux City to Platte River	12	735	595	140	4,200	1,682	2,518
Platte River to Rulo (Omaha)	13	595	498	97	2,910	1,290	1,620
Rulo to Kansas River (KC)	13	498	367	131	3,930	1,270	2,660

Kansas River to Osage River	14	367	130	237	7,110	3,710	3,400
Osage River to Mouth	15	130	0	130	3,900	3,253	647
Omaha District				255	7,650	3,092	4,558
Kansas City District				498	14,940	8,233	6,707
Total				753	22,590	11,325	11,265

Table 2-5. SWH Type – BiOp Geometry

Reach	Segment	Widening (acres)	Widening (miles) [1]	Number of Widening Projects	Chutes (acres)	Chutes (miles)[2]	Number of Chute Projects
Rulo to Kansas R	13	2,439	44.7	19	221	6.1	2
Kansas R to Osage R	14	3,307	60.6	25	93	2.6	2
Osage R to Mouth	15	529	9.7	4	118	3.2	1
Total		6,275	115	48	432	12	5

Note:

1) Assumes approx widening width on average of 450-ft in the Kansas City district.

2) Assumes ultimate chute width of approximately 300-ft in the Kansas City district.

2.3.3 *IRC*

Total acres of SWH added to HEC-RAS to meet 260 ac/yr for the IRC geometry were calculated by assuming a 13 year construction window. This is based on a 15-year implementation period, and the assumption that habitat construction will begin no more than 2 years after the ROD is signed. Distribution was based on conversations with the Effects Analysis team. The highest density of habitat was located between the Nebraska Platte River and Osage Rivers (RM 595 to 130), with the remainder spread between the Sioux City to the Platte River and Osage to the Mouth Reaches. Table 2-6 shows the acres added to HEC-RAS by BiOp segment, for easy comparison to the other two geometries. Between both districts, the total target acres of habitat for the IRC configuration is about 1,000 acres less compared to the No Action, but the distribution is more heavily targeted on the lower river. For the Kansas City district, total acres added to the Rulo to Mouth HEC-RAS model was 2,519 acres, slightly more than the No Action geometry and with more habitat downstream of Kansas City.

For both districts, the IRC target SWH acreage was achieved by widening only. The breakdown of habitat type for the Rulo to the mouth only is shown in Table 2-7. Chutes are still shown in the table because they were added to the HEC-RAS geometry, even though they were not counted toward the target acreage. The total number of cross sections modified downstream of Rulo, Nebraska was 148 (114 for widening and 34 for chutes) of the 879 Missouri River cross sections.

Table 2-6. Acres of SWH – IRC Geometry

Reach	Segment	RM Start	RM End	Miles	Acres of SWH added to HEC-RAS
Ponca to Sioux City	11	753	735	18	0
Sioux City to Platte River	12	735	595	140	276
Platte River to Rulo (Omaha)	13	595	498	97	585
Rulo to Kansas River (KC)	13	498	367	131	670
Kansas River to Osage River	14	367	130	237	1,389
Osage River to Mouth	15	130	0	130	460
			Omaha District	255	861
			Kansas City District	498	2,519
			Total	753	3,380

Table 2-7. SWH Type – IRC Geometry

Reach	Segment	Widening (acres)	Widening (miles) [1]	Number of Widening Projects	Chutes (acres)	Chutes (miles)[2]	Number of Chute Projects
Rulo to Kansas R	13	670	18.4	8	221	6.1	2
Kansas R to Osage R	14	1,389	38.2	15	93	2.6	2
Osage R to Mouth	15	460	12.7	6	118	3.2	1
Total		2,519[3]	69	29	432	12	5

Note:

1) Assumes approx widening width on average of 300-ft in the Kansas City district.

2) Assumes ultimate chute width of approximately 300-ft in the Kansas City district.

3) Target acres entirely accomplished by top width widening, even though chutes were still added to the model.

2.3.4 *Public Ownership Acreage Analysis*

To assist the economic analysis team, an analysis was performed to calculate the amount of existing publicly owned lands available for new habitat construction. This information was used to determine the amount and cost of additional lands that would need to be purchased. Existing public lands includes USACE, USFWS, and state conservation owned lands suitable for habitat development, and was accumulated by counting publicly owned river front acres available in each BiOp segment, so existing public land availability is a constant between alternatives. Values in the table were

capped at the target. Suitability of particular sites for the type of habitat to be constructed was not considered. Furthermore, the additional lands required acreage is habitat only, a factor would need to be used to convert from habitat land to total real estate tract purchase size. See Table 2-8,

Table 2-9, and

Table 2-10 for a listing of public ownership acreage availability for each alternative geometry.

Table 2-8: Public Ownership Acreage - No Action Alternative

		Widening (ac)			Backwaters (ac)			Total
Reach	**Seg**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Addt'l Lands Req'd (ac)[1]**
Ponca to Sioux City	11	180	0	180	60	0	60	**240**
Sioux City to Platte River	12	601	601	0	420	420	0	**0**
Platte River to Rulo (NWO)	13	672	672	0	0	0	0	**0**
Rulo to Kansas River (NWK)	13	1,129	454	675	-	-	-	**675**
Kansas River to Osage River	14	937	937	0	-	-	-	**0**
Osage River to Mouth	15	0	0	0	-	-	-	**0**
Omaha District		1,453	1,273	180	480	420	60	**240**
Kansas City District		2,066	1,391	675	-	-	-	**675**
Total		3,519	2,664	855	480	420	60	**915**
Total Percentage		-	76%	24%	-	87.5%	12.5%	**-**

Note:

1) Note that chutes (NWK) and changes to existing SWH (NWO) are not shown because they reside on existing public lands.

2) Includes existing public lands that are available for habitat placement. This number is capped at the target acres and is not the total acres of existing public lands.

Table 2-9: Public Ownership Acreage - BiOp Alternative

		Widening (ac)			Backwaters (ac)			Total
Reach	**Seg**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Addt'l Lands Req'd (ac)[1]**
Ponca to Sioux City	11	240	0	240	180	0	180	**420**
Sioux City to Platte River	12	1,761	836	925	660	660	0	**925**
Platte River to Rulo (NWO)	13	1,582	907	675	60	60	0	**675**
Rulo to Kansas River (NWK)	13	2,439	454	1,985	-	-	-	**1,985**
Kansas River to Osage River	14	3,307	1,375	1,932	-	-	-	**1,932**
Osage River to Mouth	15	529	529	0	-	-	-	**0**
Omaha District		3,583	1,743	1,840	900	720	180	**2,020**
Kansas City District		6,275	2,358	3,917	-	-	-	**3,917**
Total		9,858	4,101	5,757	900	720	180	**5,937**
Total Percentage		-	42%	58%	-	80%	20%	**-**

Note:

1) Note that chutes (NWK) and changes to existing SWH (NWO) are not shown because they reside on existing public lands.

2) Includes existing public lands that are available for habitat placement. This number is capped at the target acres and is not the total acres of existing public lands.

Table 2-10: Public Ownership Acreage - IRC Alternative

		Widening (ac)			Backwaters (ac)			Total
Reach	**Seg**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Target (ac)**	**Exist Public Lands (ac)[2]**	**Addt'l Lands Req'd (ac)**	**Addt'l Lands Req'd (ac)[1]**
Ponca to Sioux City	11	0	0	0	-	-	-	**0**
Sioux City to Platte River	12	276	276	0	-	-	-	**0**
Platte River to Rulo (NWO)	13	585	585	0	-	-	-	**0**
Rulo to Kansas River (NWK)	13	670	454	216	-	-	-	**216**
Kansas River to Osage River	14	1,389	1,375	14	-	-	-	**14**
Osage River to Mouth	15	460	460	0	-	-	-	**0**
Omaha District		861	861	0	-	-	-	**0**
Kansas City District		2,519	2,289	230	-	-	-	**230**
Total		3,380	3,150	230	-	-	-	**230**
Total Percentage		-	93%	7%	-	-	-	**-**

Note:

1) Note that chutes (NWK) and changes to existing SWH (NWO) are not shown because they reside on existing public lands.

2) Includes existing public lands that are available for habitat placement. This number is capped at the target acres and is not the total acres of existing public lands.

2.4 EXCLUDED AREAS

Locations selected for habitat construction in the HEC-RAS model are theoretical and do not reflect actual locations of future mitigation projects. However, the following areas were intentionally avoided when making modifications to HEC-RAS models:

1) Reaches of river within a 10,000-ft radius of an airport (FAA, Aug 2007)

2) Areas within 1/4 mile upstream or downstream of small town infrastructure along the river bank, on that side of the river only

3) Areas within 1/4 mile upstream or downstream of power plant or municipal water intakes, on both sides of the river

4) Areas within 1/4 mile upstream or downstream of barge loading facilities and other river related industrial infrastructure along the river bank, on that side of the river only

5) Areas within 1/4 mile upstream or downstream of bridges, on both sides of the river

6) Riverfront property near Federal/PL 84-99 levees within 1,000-ft of the river bank, on that side of the river only.

7) Reaches adjacent to larger cities where the channel is confined by urban levees

8) The outside edge of river bends, because based on past experience most widening and or chute projects in the Kansas City District have been constructed on the inside of river bends.

9) Widening projects were not located in the same bend as new or existing chutes or widening to avoid excessive navigation channel flow loss.

2.5 Reference Flows

Reference flows were used to set construction elevations for SWH and chutes added to the geometries. Reference flows were run through the 2012 existing condition geometry in steady flow, and the resulting water surface profile along with the specified depth was used to set the invert for added SWH.

2.5.1 *No Action*

Reference flow for the No Action geometry was the 50% exceedance flow in the month of August. August 50% exceedance was evaluated for the *2014 Shallow Water Accounting Report* at mainstem Missouri River gages as well as the Kansas River at DeSoto and the Osage River at St. Thomas (USACE, Sept 2014). Flow changes in HEC-RAS were made at major tributaries based on the *Upper Mississippi River System Flow Frequency Study* (UMRSFFS) accumulated basin size to the confluence (USACE, 2003). Table 2-11 lists the flows used by reach.

Table 2-11. Reference Flows – No Action

From	To	Gage Evaluated	From (RM)	To (RM)	August 50% Exceedance Flow (cfs)
Tarkio	Big Nemaha	Rulo	507	495	41,900
Big Nemaha	Nodaway		495	463	43,000
Nodaway	Platte	St Joseph	463	391	44,800
Platte	Kansas		391	367	45,200
Kansas	Waverly	Kansas River at DeSoto / Kansas City	367	293	52,500
Waverly	Grand	Waverly	293	250	52,900
Grand	Chariton		250	239	53,500
Chariton	Lamine		239	202	55,300
Lamine	Moreau	Boonville	202	138	57,700
Moreau	Osage		138	130	58,100
Osage	Gasconade	Osage at St Thomas	130	104	60,300
Gasconade	Mouth	Hermann	104	0	66,900

2.5.2 *BiOp*

Three different reference flows were used for the BiOp geometry: 1) summer low, 2) median August, and 3) spring pulse. Flows were calculated by starting with the Gavins Point release and adding incremental flows at major tributaries. Incremental flows were calculated by the MRBWMD in the *Missouri River Incremental Flows Below Gavins Point Technical Report* (USACE, July 2014) for the pre-dam and post-dam time periods, at statistical levels of minimum, median, and maximum, lower and upper decile and quartiles. Median pre-dam records were used because they incorporate the drought of the 30's and are therefore slightly lower than the post-dam statistic. Incremental flows for the months of July, August, and May, were used for summer low, median August, and spring pulse, respectively. July incremental flows were added downstream to the summer low Gavins Release, because the summer low condition centers primarily on this month. May incremental flows were added downstream to the spring pulse because the second spring pulse specified occurs during this month. Changes to the reservoir operations for each alternative as modeled in Res-Sim are discussed in more detail in Section 3.

Release from Gavins for the summer low and spring pulse were selected to be in concert with the Res-Sim model rules, with the intention of constructing habitat at an effective level for those conditions. Release from Gavins for the Median August reference flow was pulled from the

MRBWMD *Hydrologic Statistics Technical Report* (USACE, Sept 2013). Table 2-12 lists the Kansas City District flows by reach, as well as the release from Gavins for reference.

Table 2-12. Reference Flows – BiOp

From	To	USGS Gage Location	Summer Low [1] (cfs)	Median August [2] (cfs)	Spring Pulse [3] (cfs)
Gavins Release			21,000	36,900	48,800
Tarkio	Big Nemaha	Rulo	32,700	45,000	63,900
Big Nemaha	Nodaway		33,553	45,594	64,790
Nodaway	Platte	St Joseph	35,000	46,600	66,300
Platte	Kansas		35,451	46,890	66,777
Kansas	Crooked	Kansas City	43,700	52,200	75,500
Crooked	Grand	Waverly	44,000	52,400	75,900
Grand	Chariton		45,929	54,037	80,577
Chariton	Lamine		46,505	54,525	81,973
Lamine	Moreau	Boonville	47,300	55,200	83,900
Moreau	Osage		48,223	55,823	85,868
Osage	Gasconade		53,958	59,692	98,098
Gasconade	Mouth	Hermann	55,600	60,800	101,600

Note:
1) Flows for summer low were increased downstream of Gavins by adding median July incremental flows as calculated by the MRBWMD
2) Flows for Median August were increased by adding median August
3) Flows for Spring Pulse were increased by adding median May

Median August differs slightly from the August 50% exceedance used for No Action, this is because August 50% exceedance was based off an independent evaluation of daily flow records at each major gage location, whereas the incremental flows used to for the median August flow were produced by the Daily Routing Model (DRM), applying a routing coefficient to daily flow records and comparing two different major gage locations.

2.5.3 *IRC*

Reference flow for the IRC geometry was the median June, with release from Gavins and incremental flows as calculated in the MRBWMD technical reports (USACE, July 2014) (USACE,

Sept 2013). Median June flows in the Kansas City reaches tend to be higher compared with July and August. Table 2-13 lists the Kansas City District flows by reach and the release from Gavins.

Table 2-13. Reference Flows – IRC

From	To	USGS Gage Location	Median June Flow (cfs)
Gavins Release			32,200
Tarkio	Big Nemaha	Rulo	49,800
Big Nemaha	Nodaway		50,802
Nodaway	Platte	St Joseph	52,500
Platte	Kansas		53,158
Kansas	Crooked	Kansas City	65,200
Crooked	Grand	Waverly	65,600
Grand	Chariton		69,517
Chariton	Lamine		70,686
Lamine	Moreau	Boonville	72,300
Moreau	Osage		73,923
Osage	Gasconade		84,012
Gasconade	Mouth	Hermann	86,900

2.6 Top Width Widening

Some form of top width widening was the primary means of adding SWH to all three geometries. Widening width, depth, and design invert elevation varied by alternative and by position on the river.

Widening areas offer full conveyance for flow in the model. This impacted three model parameters: overbank ineffective areas, levee points, and permanent ineffective areas in the channel. 1) Ineffective areas in the overbank impacted by the widening were moved back to the limit of widening at the same elevation, making the assumption that the widening would not affect the elevation at which the overbank conveys flow. 2) If there were levee points in the overbank impacted by the widening, these were also moved back to the limit of widening and left at the same elevation, making the assumption that any minor agricultural levees (levees not modeled using lateral weirs and storage areas) impacted by the widening would be set back. 3) Permanent Ineffective flow areas in the channel that represent navigation structures (only applies to the Rulo

to Mouth model) were truncated, assuming that during construction navigation structures would be modified to provide some level of conveyance through the widening area. An example cross section where all three parameters were adjusted is shown in Figure 2-1. These assumptions were carried through all three geometries.

Widened areas in all three geometries were assigned a Manning's n-value of 0.035, which is rougher than the main channel because it accounts for structure modifications that may be necessary to maintain the habitat and adjacent navigation channel to the desired dimensions. This assumed Manning's n-value is lower than the roughness in the overbanks.

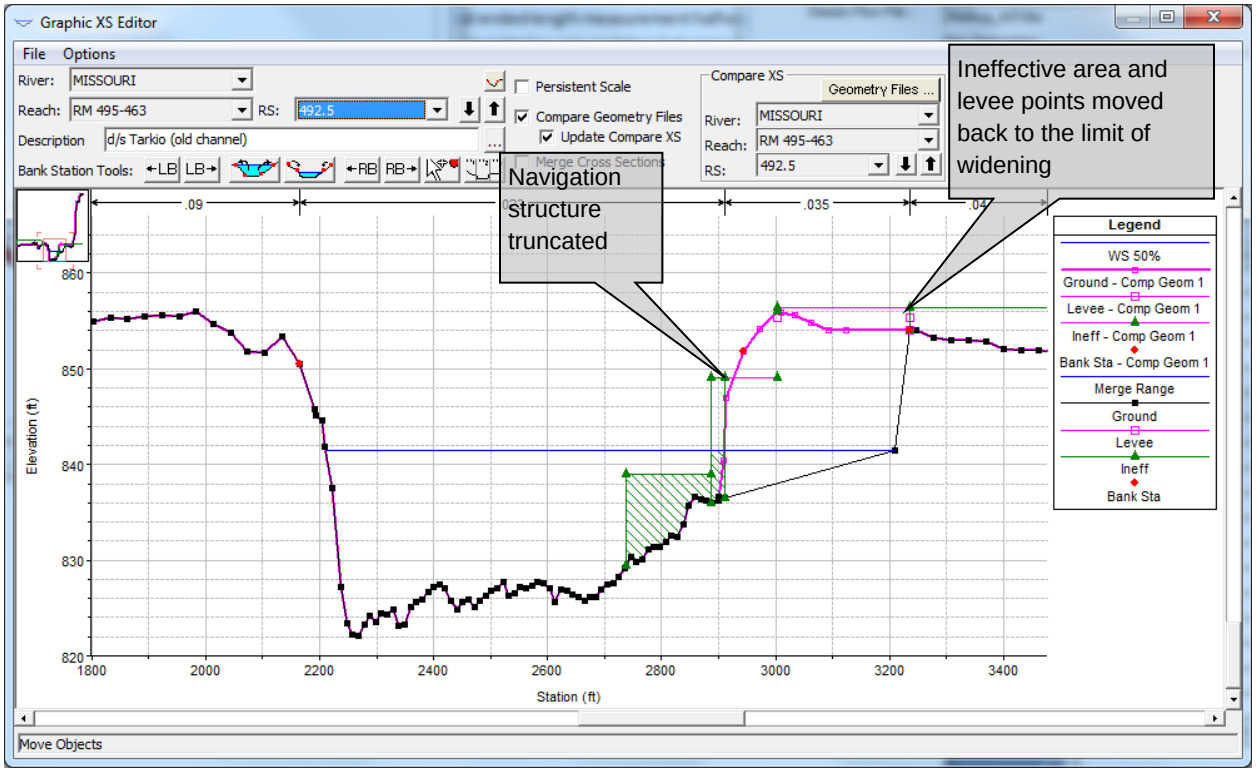


Figure 2-1. Ineffective flows and levee points in widened cross section

Preliminary modeling suggests widening could cause local aggradation in the main channel. This potential localized aggradation of the bed, if it occurred, could be a concern if it results in the loss of the authorized channel dimensions or was significant enough to offset the added flow conveyance from the river widening during flood flows. However, this would be prevented on a project by project basis with detailed hydraulic modeling and adjustments to structures incorporated into the design. A full geomorphic sediment model would be necessary to determine if considerable widening could cause system wide changes.

Example widened cross sections for each geometry are shown in the following sections.

2.6.1 *No Action*

Top width widening for the No Action geometry was added to the HEC-RAS model in each affected cross section as shown in Figure 2-2. Cross sections were widened 300-ft

downstream of Rulo (Kansas City District). Depths range from 5 to 0-ft with respect to the August 50% water surface elevation at each cross section.

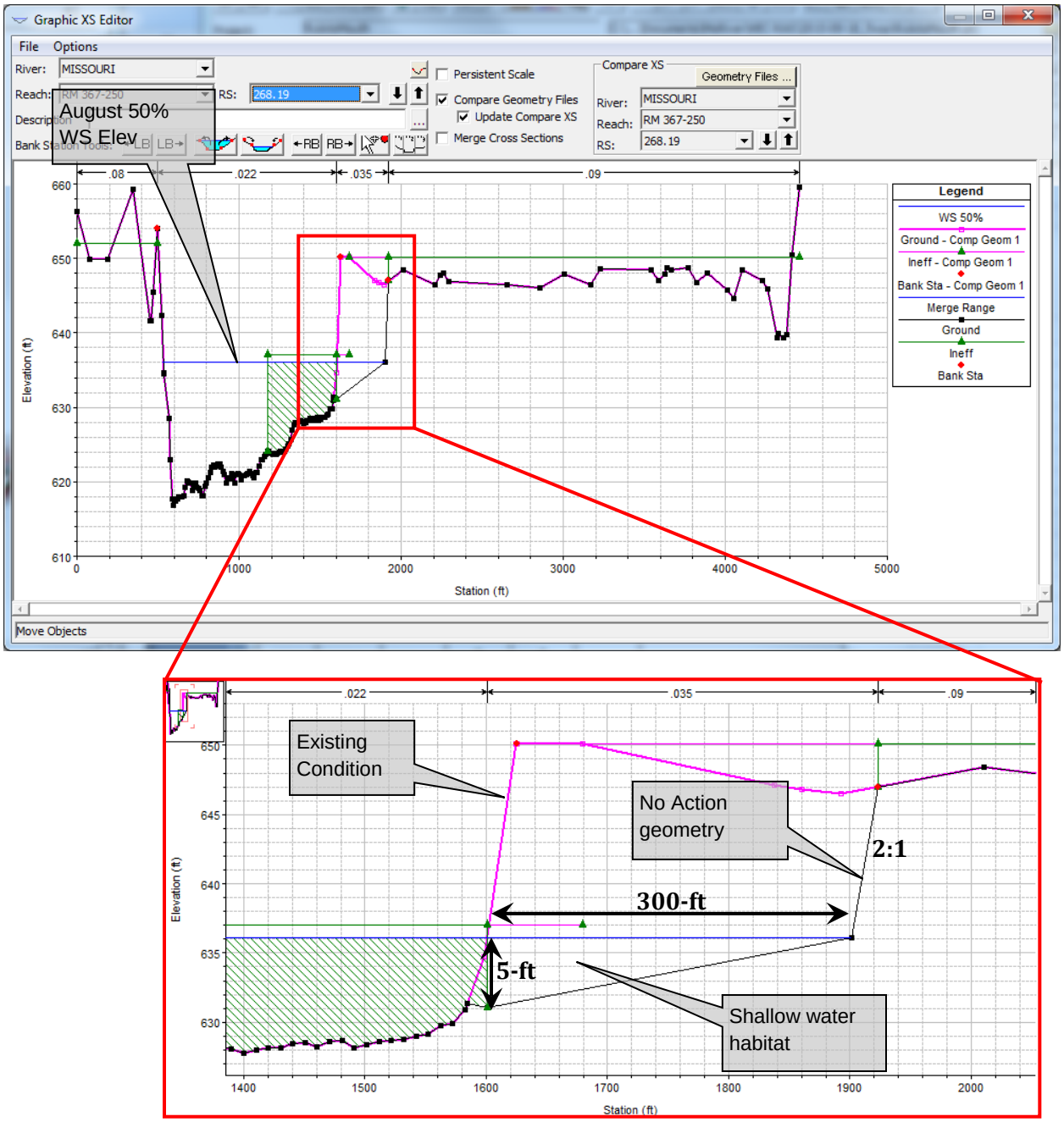


Figure 2-2. Widened cross section – No Action

2.6.2 *BiOp*

Top width widening for the BiOp geometry was added to the HEC-RAS model in each affected cross section as shown in Figure 2-3. Downstream of Rulo (Kansas City District), cross sections

were widened a total of 450-ft, allowing for three 150-ft benches of SWH for each of the three flow regimes. Depths range from 0 to no more than 5-ft on each bench with respect to the reference water surface elevation.

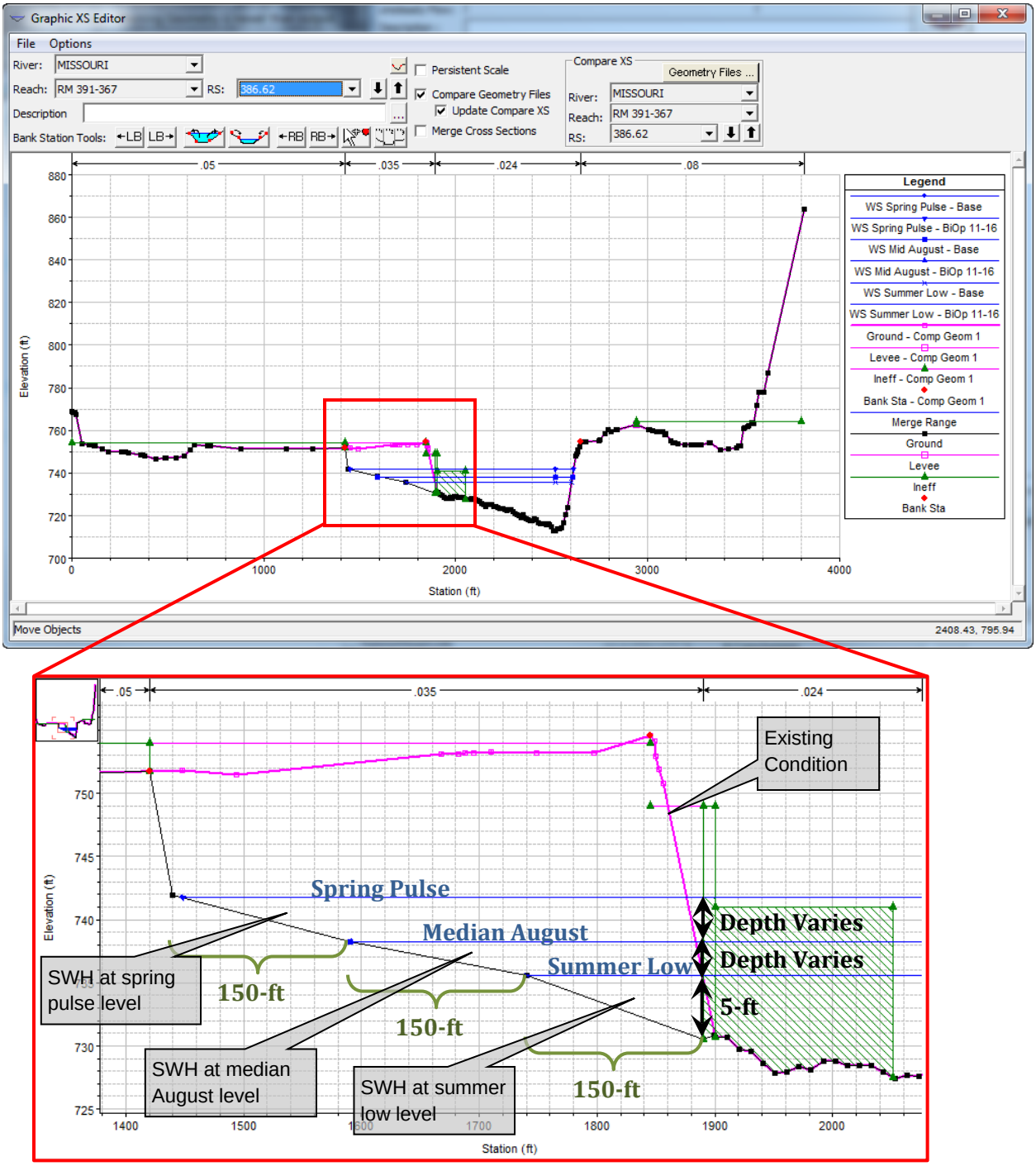


Figure 2-3. Widened cross section – BiOp

Water surface profiles for each of the three reference flows did not exactly parallel each other due to the variability of cross section shape and flow changes. HEC-RAS's template tool was used to

add the widening to the model, so it was necessary to select a uniform template with identical widths and depths, even though the depths between profiles vary. After examining the difference between profiles, shown in Figure 2-4, three different templates were created for each BiOp reach. Depth selected were based on the average distance between profiles.

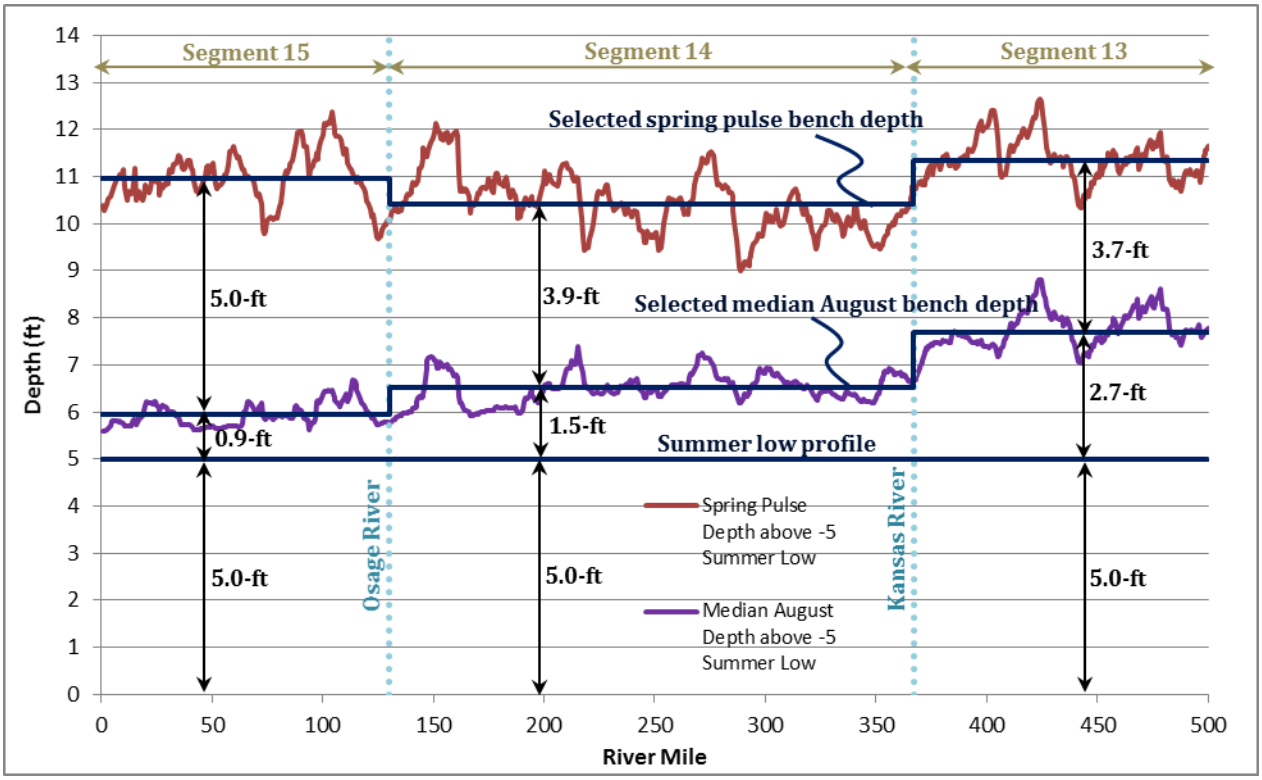


Figure 2-4. Widening Depths - BiOp

An average bench depth for each BiOp reach means that sometimes the reference profile was shallower than the top of bench and sometimes deeper than the top of bench. An exact method would have been time intensive, requiring manual editing of each of the 188 cross sections by hand to exactly match the reference profile. Considering the natural variability of the flows seen by the Missouri River from year to year, an exact methodology would not necessarily add value to the analysis. Summer low, median August, and spring profiles themselves are based on a statistical approximation of median flow conditions, any given year the actual flows for the specified time period could be higher or lower than the statistic. The methodology chosen should hit the average of conditions over the period of record.

Each habitat bench is sloped, so the depth over the 150-ft width varies from 0-ft to the depth shown in Figure 2-4 and repeated in tabular form in Table 2-14.

Table 2-14. Widening Depths - BiOp

	Segment 13		Segment 14		Segment 15	
	Width (ft)	**Depth (ft)**	**Width (ft)**	**Depth (ft)**	**Width (ft)**	**Depth (ft)**
Spring pulse bench	150	3.7	150	3.9	150	5.0
Median August bench	150	2.7	150	1.5	150	0.9
Summer low bench	150	5	150	5	150	5
Total	**450**	**11.4**	**450**	**10.4**	**450**	**11.0**

2.6.3 *IRC*

Top width widening for the IRC geometry was added to the HEC-RAS model in each affected cross section as shown in Figure 2-5. Cross sections were widened 300-ft downstream of Rulo (Kansas City District). Depths range from 6 to 0-ft with respect to the Median June water surface elevation at each cross section.

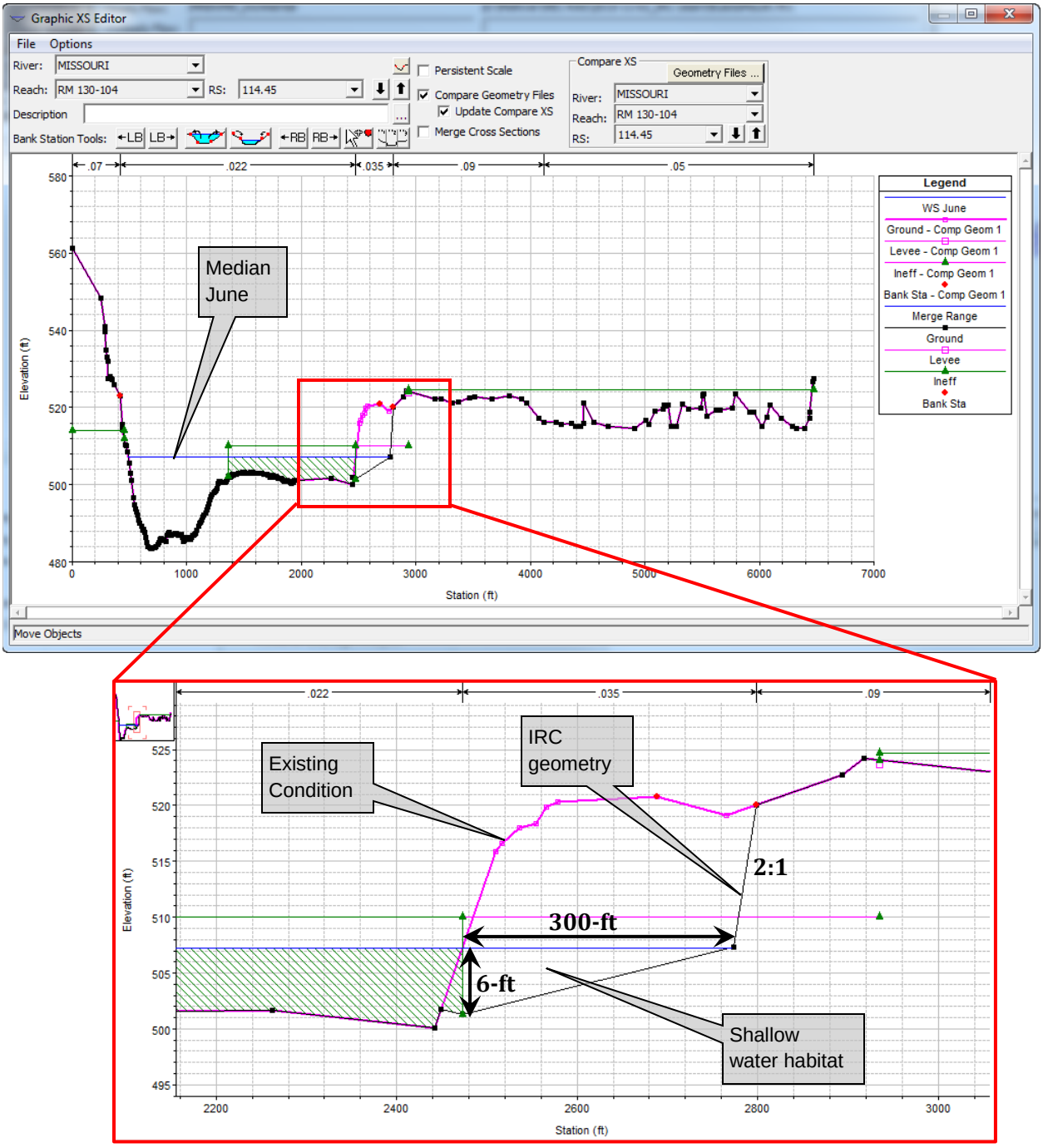


Figure 2-5. Widened cross section – IRC

2.7 CHUTES

Changes to chutes in the HEC-RAS models were identical for all three geometries. Only chutes constructed or awarded to construction between the existing condition 2012 geometry and present day 2015 were added to HEC-RAS, because recent emphasis has been on top width

widening projects rather than chute projects. Table 2-15 lists all known chutes in the Kansas City District. The list includes natural chutes, constructed chutes, chutes that have been designed but may never be constructed, as well as the modeling approach selected for alternatives.

Table 2-15. Chutes

Chute	Origin		Modeling Approach				Notes
	Natural	USACE Project	In Existing Condition 2012 Geometry	Added new chute in Alter-natives Geometry	Evolved in Alter-natives Geometry	Did not Add	
Wolf Creek		x				x	Design is on hold as of Fall 2015
Worthwine		x	x		x		
Benedictine		x		x			Under construction 2015 - 2016
Dalbey		x		x			Constructed 2013
Baltimore		x				x	Design is on hold as of Fall 2015
Cranberry		x		x			Under construction 2015 - 2016
Cranberry (existing)	x		x				
Lisbon	x		x				
Jameson		x	x		x		
Jameson Extension		x		x			
Franklin Island	x		x				Chutes have partially silted in
Overton North		x	x		x		
Tadpole		x	x		x		
Smokey Waters		x	x				No future development anticipated
St Aubert	x		x				
Tate Island	x		x				
Lunch Island	x		x				
No name (RM 60)	x		x				
No name (RM 57)	x		x				

Howell Island/Centaur Chute	x		x				
Johnson Island	x		x				
Bonhomme Chute	x		x				
No name (RM 36)	x		x				
Bryan Island	x		x				
Pelican	x		x				
Littles	x		x				
Cora Island		x		x			Under construction 2015 - 2016

New chutes that were added to the Rulo to Mouth reach for all alternatives included: Benedictine, Dalbey, Cranberry, the Jameson Extension, and Cora Island. Wolf Creek and Baltimore have some level of design completed but are currently on hold (as of fall 2015) and therefore were not included. Dalbey was added because construction was completed in 2013 so it was not included in the 2012 existing condition geometry.

Chutes are represented in the HEC-RAS model as added overbank conveyance in cross sections that intersect the chute alignment. A single chute shows up in anywhere from 1 to 6 cross sections, depending on the length of the chute and cross section arrangement. Chutes were given a triangular shaped channel bottom 300-ft wide ranging in depth from 0 to 5-ft at August 50% for all three geometries as shown in Figure 2-6. Chute areas were assigned a Manning's n-value of 0.028, which is generally slightly rougher than the main channel, but not as rough as the 0.035 selected for widened habitat.

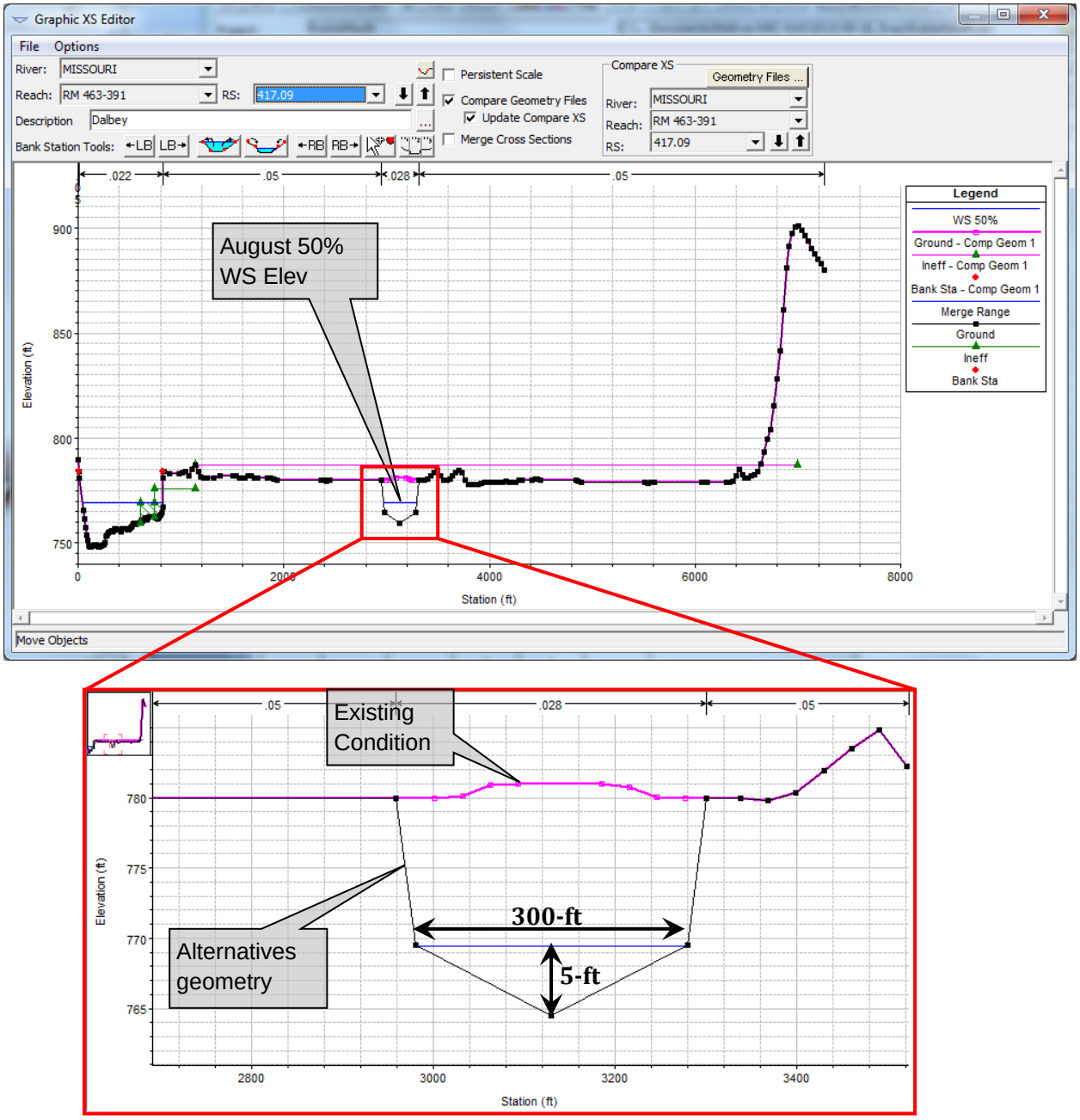


Figure 2-6. Chute cross section

Assumptions with regards to levee points and ineffective areas at cross sections where chutes were added were site specific and reflect best as possible the on-the-ground post construction conditions.

All previously constructed chutes that are in the baseline geometry were widened to the same fully developed dimensions as the new chutes, 300-ft wide, triangular shaped channel bottom with depths ranging from 0-ft to 5-ft. This only applies to four chutes from Rulo to the Mouth: Worthwine, Jameson, Overton North, and Tadpole. All three are in the existing conditions geometry with inverts at -10 CRP, based on approximations from surveyed depths. However, the

assumption was still made to essentially raise the bottom of the chutes by 5-ft, assuming that the chutes will be continue to be managed until they achieve the original design goal of shallower depths on average.

Natural chutes on the river (21 total represented in existing conditions model) were not evolved because future conditions would be difficult to forecast or they are assumed to have already reached a relatively stable state.

2.8 FLOODPLAIN CONNECTIVITY

Floodplain connectivity at a 20% annual chance exceedance (ACE) (or 5-yr) was assessed as a requirement of Alternative 2. A mapping analysis was conducted, although no changes to the HEC-RAS model were necessary.

Coordination with the USFWS produced a Planning Aid Letter detailing the modeling assumptions for the BiOp alternative. Per the criteria set forth in the 2003 Amended BiOp (USFWS, Dec 2003), the total authorized acreage for the Missouri River Fish and Wildlife Mitigation Program is 166,750-ac. In the 2003 BiOp and Planning Aid Letter, it was assumed that 100,000 of the 166,750-ac would be utilized for SWH and floodplain connectivity. Per the USFWS Draft Program Management Plan (USACE, Apr 2007), the total authorized acreage was split by state, and as applied to floodplain connectivity numbers are reported in the first column of Table 2-16.

Mapping of existing floodplain connectivity was performed in HEC-GeoRAS. A steady profile was run in HEC-RAS for the 20% ACE (5-yr), and also for the 50% ACE (2-yr) for comparison, using flows from UMRSFFS (USACE, 2003). GIS data was exported from HEC-RAS, and Geo-RAS was used to create an inundation boundary. The bounding polygon had to be edited for a clean mapping product, and other manual edits were made to exclude areas that could not be counted as floodplain connectivity. Full procedure followed to count acres of floodplain connectivity is included in **Attachment 2 – Floodplain Connectivity Metadata**. Calculated floodplain connectivity acres by state are listed for each district and total in Table 2-16. Existing floodplain connectivity acres of 147,650-ac surpasses the 100,000-ac goal of floodplain connectivity, therefore no changes were made to the HEC-RAS model.

Table 2-16. Acres of Floodplain Connectivity by State Downstream of Sioux City, IA

State	Portion of authorized acres available for floodplain connectivity and SWH [1]	Existing Acres of floodplain connectivity (20% ACE inundation) [2, 3]			Additional acres of floodplain habitat to add to HEC-RAS models
		NWO	NWK	Total	
Nebraska	15,983	31,550	270	31,820	0
Iowa	14,228	16,120	-	16,120	0
Kansas	6,976	-	8,560	8,560	0
Missouri	62,813	8,020	83,130	91,150	0
Total	100,000[1]	55,690	91,960	147,650	0

Note:

1) The 100,000 authorized acreage goal includes both SWH and floodplain connectivity.

2) Does not imply ownership, includes both public and private land.

3) The calculated acres of floodplain connectivity shown in the table above includes chutes but excludes main channel acres defined by median August flows, both defined as SWH. Because of this inconsistency, the calculated acres were compared to the full portion of authorized acres, rather than trying to separate SWH from floodplain connectivity, and was considered acceptable because existing exceeded authorized even without counting some of the SWH acres.

In the Kansas City district, total floodplain connectivity at the 5-yr was calculated at 91,960 acres. For comparison, the floodplain connectivity at 2-yr is 32,050-ac in the Kansas City District, approximately one third of the 5-yr inundation acres.

The calculated acres of existing floodplain inundation with connectivity includes:

- Areas lower in elevation than the computed 5-yr water surface and judged to be connected to the main channel
- Private lands not protected by levees, including fringe areas between levees and river bank and areas without any discernable protection that would be inundated at the reference flow.
- Existing chutes as of the year 2012

Areas excluded from the existing floodplain connectivity acres:

- Area behind all active/maintained levees, including federal levees, levees in the PL84-99 program and smaller agricultural levees often found between the federal/ program levees and the river bank. No distinction was made as to levee reliability or performance risk.

- Disconnected areas and areas judged not to have obvious connection to the main channel at the 5-yr
- Inundated area well outside the bluff line or in tributary backwater areas
- Missouri River main channel as determined by the boundary of the August 50% duration flow extent shapefile obtained from the *2014 HAMP SWH Accounting Report* (USACE, Sept 2014). The total amount of existing habitat for the Kansas City District alone is 8,232-ac, which does include chutes. Chute acres were added by hand for the report, and this calculation was not easily transferable to the floodplain analysis.
- Current BSNP mitigation land behind levees, namely the downstream portion of Eagle Bluffs, where the site is actively managed to provide connectivity via structures.

Selected locations that demonstrate the inundation mapping as well as included and excluded areas are shown in the following figures.

Figure 2-7 is the area at and just upstream of the Nodaway River confluence at where Federal levees 482-R and 488-L are located. The area has a mix of both major and minor levees that were excluded, and also demonstrates that the Nodaway River backwater area was not included beyond the bluff line.

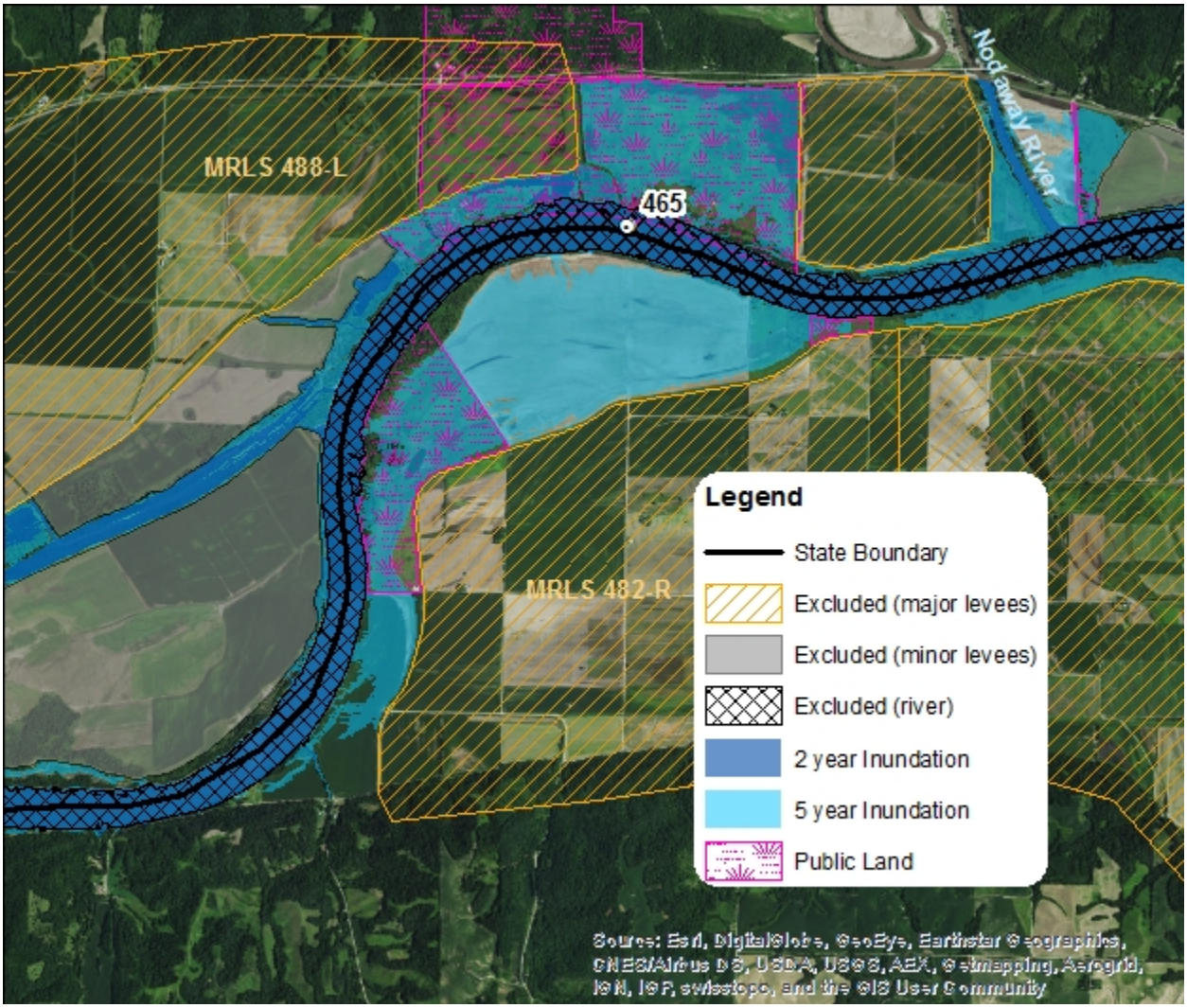


Figure 2-7. Floodplain Connectivity

Figure 2-8 shows the Baltimore Bottoms Unit of the Big Muddy National Fish and Wildlife Refuge, an area owned by the USFWS. At this location the old levees surrounding the refuge have been cut or left unrepaired following the May 2007 flood event to allow for floodplain connectivity. This area appears to be inundated at a 2-yr level with slivers of connection to the main channel.

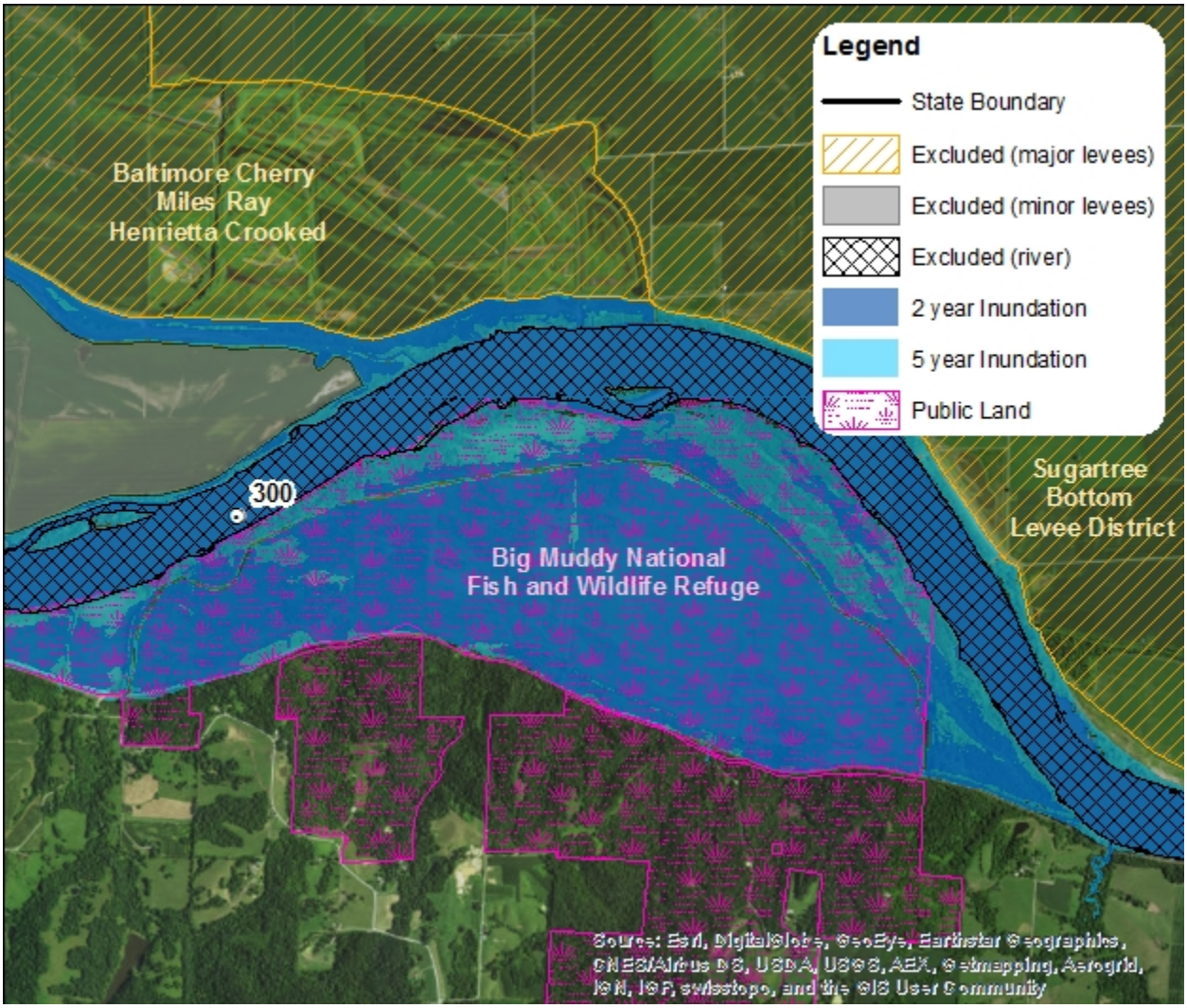


Figure 2-8. Floodplain Connectivity

Figure 2-9 shows the Lisbon (north / left bank) and Jameson Island (south / right bank) Units of the Big Muddy National Fish and Wildlife Refuge. A naturally formed chute is present at Lisbon, whereas USACE constructed a chute at Jameson Island. Note that while the river was excluded in the floodplain calculation, the chute areas were counted. Also note the tieback area between the two Howard County PL84-99 program leveed areas was excluded and is labeled as a major levee. All tiebacks between levees were modeled as storage areas, and to simplify the floodplain calculation no storage areas were included in the inundation mapping, even though these tieback areas are technically connected to the river.

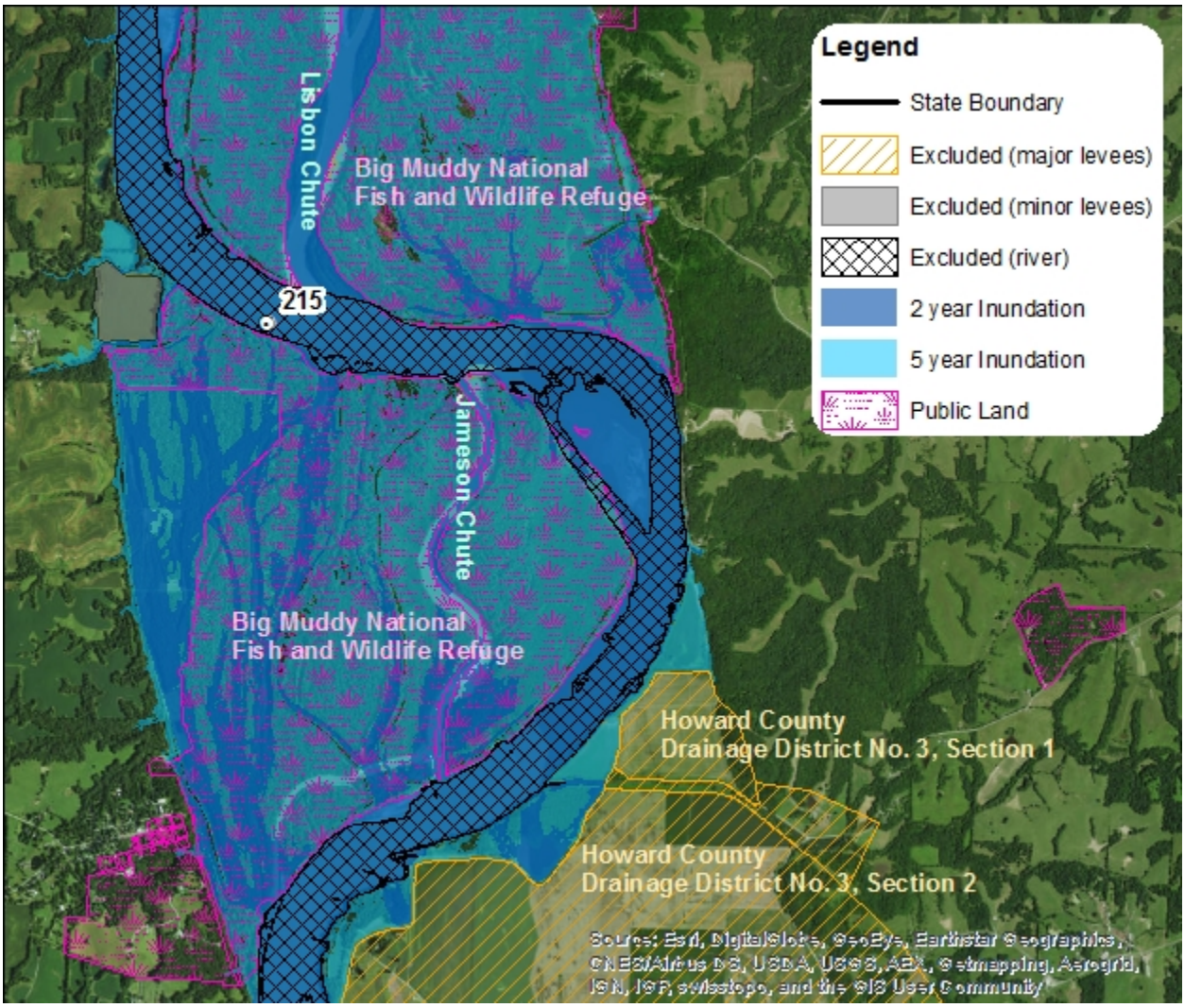


Figure 2-9. Floodplain Connectivity

Figure 2-10 is at Pelican Island (right bank state owned Conservation Area) and Little's chutes (left bank in private ownership). There is an unintentional mapping gap over Pelican Island, due to a gap in the terrain data. This figure provides another example of where the chute areas were included while the river was excluded.

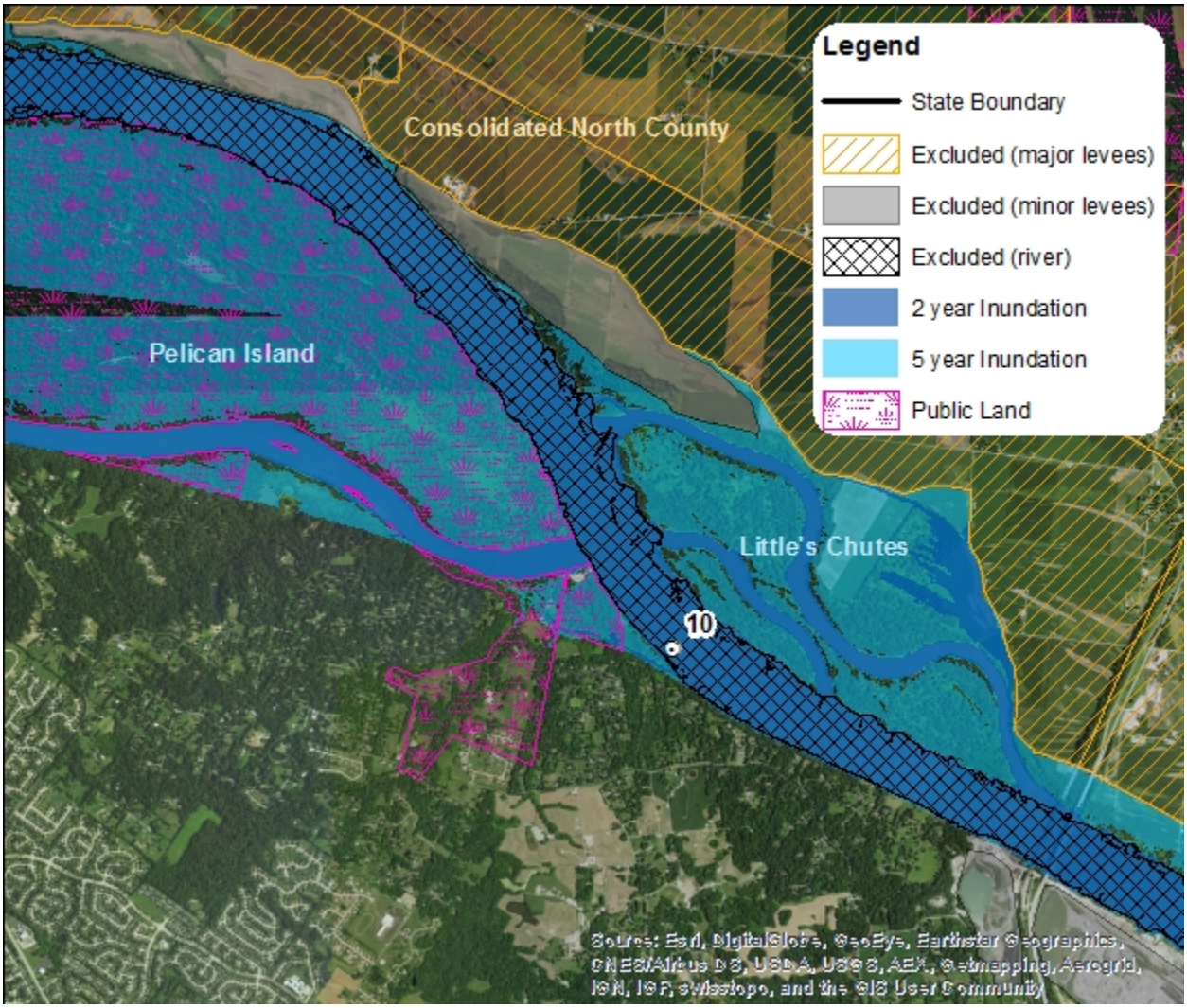


Figure 2-10. Floodplain Connectivity

The full 5-yr and 2-yr inundation boundaries are available in the electronic files accompanying the report.

3 FLOW CHANGES

Changes to the reservoir operations for each alternative were modeled using rule changes in the Res-Sim model(s). The resulting daily flow hydrograph out of Gavins was then run through the appropriate Gavins to Rulo HEC-RAS model for each alternative before being run though the corresponding Rulo to Mouth model. The hydrograph handoff location was at Nebraska City because of the overlap between the two districts. One period of record run was made for each model for each of the six alternatives. Refer to *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report* (USACE, 2016b) for details regarding the Res-Sim modeling.

For quick reference, the following list and table summarizes the flow releases/pulses as they impact the lower river and the Kansas City district reaches. The full Res-Sim document should be referenced for complete details as there are many complexities and layers to the Res-Sim rules. Each simulation makes specific checks on system storage, runoff forecasts, flood control targets, navigation targets, navigation season length, water supply targets, and other parameters, all of which can limit or eliminate the releases/pulse in any given year. Table 3-1 summarizes the ranges of releases from Gavins point, as well as the number of years in which the release was eliminated, partially or fully completed.

1) **Alt 1 No Action** – Master Manual flows including a plenary bimodal spawning cue attempted each year, one in March and one in May

2) **Alt 2 BiOp** – two spawning cues attempted each year, one in March and one in May, plus a summer low flow from June 23 lasting as late as September 1 that only occurs in the two years following complete March & May pulses

3) **Alt 3 Mech** – same rules as No Action except no plenary bimodal spawning cue (no pulse)

4) **Alt 4 Spring 2** – high spring release starting in April to create sandbar habitat, duration ranging from 35 to 175 days depending on release magnitude

5) **Alt 5 Fall 5** – high fall release starting October 15 to create sandbar habitat, duration ranging from 35 to 175 days depending on release magnitude

6) **Alt 6 Spawn Cue** – two spawning cutes attempted every 3 years, one in March and one in May

Table 3-1. Gavins Releases per Alternative

Alternative	Start Month	Release from Gavins (kcfs) [1]	Eliminated (# of years)	Partial (# of years)	Full/ completed (# of years)	
Alt 1 No Action	March	23 – 35	49	4	30	16
	May	25 – 41	54	8	21	
Alt 2 BiOp	March	31	40	25	18	10
	May	38 – 56	43	25	15	
Alt 3 Mech	-	-	-	-	-	
Alt 4 Spring 2	April	45 – 60	64	9	18	
Alt 5 Fall 5	October	45 – 60	74	2	15	
Alt 6 Spawn Cue	March	39 – 61	40	26	17	11
	May	50 – 67	66	6	11	

Note:
1) Based on Res-Sim POR simulations

4 RESULTS

All alternatives runs were performed in HEC-RAS 5.0 Release Candidate 2 (21-August-2015) because that was the most current version as of October and November 2015, when most of the runs were completed. Official release of HEC-RAS 5.0 was on 4-March-2016 and 5.0.1 on 22-Apr-2016, at which point evaluation of results by the economists and human considerations teams was well underway and it would have unnecessarily compromised schedule to re-run the simulations.

Model output contains a considerable amount of information, not easily condensed to simple conclusions. Each of the six alternative runs produced 82 years (March 1930 – December 2012) of stage and flow hydrographs at 1,192 cross sections and stage hydrographs at 338 storage areas between Rulo and the Mouth. Responses to the Res-Sim flow changes in combination with habitat geometry changes are complex.

To express the changes compared with the No Action alternative, the model results were evaluated by 1) statistical evaluation comparing min, max, and percentiles, and 2) duration analysis plots. Statistical and duration evaluations were made at five locations along the river, the Missouri at St. Joseph, Kansas City, Boonville, and Hermann, and the Mississippi River at St. Louis. Each is fairly representative of hydraulic reaches bounded by the major tributaries to the Missouri. St Joseph represents the reach upstream of the Kansas River, Kansas City

represents downstream of the Kansas River, Boonville captures the effects of flow out of the Grand/Chariton Rivers, and Hermann is representative of the lower river, below the Osage and Gasconade Rivers.

Stage and flow hydrographs at all cross sections and all storage areas were passed to economists and biologists for evaluation of impacts to human considerations and habitat interests.

4.1 STATISTICS

Tables comparing min, max, and percentile flows and stages at the five major locations are provided in **Attachment 3 – Rulo to Mouth Alternative Statistics**. Significance of the statistics are explained below using St. Joseph as an example. St. Joseph statistics are repeated in the body of the text and in the attachment.

In the attachment, the top two tables provide the minimum, maximum, 10, 25, 50, 75 and 90 percentile statistical flows on the period of record hydrographs. Flow statistics are on the left, stage statistics are on the right. Table 4-1 and

Table 4-2 show the statistics at St. Joseph.

Table 4-1. Flow (cfs) statistics on the period of record at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	7,416	7,537	7,416	7,416	7,416	7,416
10%	18,181	18,170	18,250	18,020	18,231	18,094
25%	26,258	25,180	26,443	25,719	26,317	25,931
50%	39,282	38,478	39,156	38,950	39,046	38,988
75%	50,589	52,358	50,527	51,032	50,703	51,328
90%	68,612	69,893	68,614	70,557	69,439	69,001
Max	292,224	293,577	297,961	297,991	297,994	297,977

Table 4-2. Stage (ft) statistics on the period of record at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	787.8	787.8	787.8	787.8	787.8	787.8
10%	791.3	791.3	791.3	791.2	791.3	791.3
25%	793.8	793.4	793.8	793.6	793.8	793.7
50%	797.4	797.1	797.4	797.3	797.4	797.3
75%	799.6	799.7	799.6	799.7	799.7	799.8
90%	802.6	802.4	802.6	802.9	802.8	802.6
Max	820.3	819.2	820.8	820.8	820.8	820.8

Min and max are the lowest daily flow and the highest daily flow output by the model in each alternative over the period of record. Calculated minimum and maximums do not necessarily occur on the same date from alternative to alternative. For example, at St. Joseph the minimum flow is 7,416-cfs for Alternatives 1, 3, 4, 5, and 6. In the model output, this occurred on 3-Dec-1955, as shown by the hydrograph output in

Figure 4-1. For Alternative 2, the minimum flow of 7,537-cfs occurred on 26-Apr-1935, rather than in 1955. In this example, the low summer flow Gavins Point release rule during the months of July and August allowed the navigation season to extend one to two weeks longer in Alternative 2 than the other Alternatives, with the result of covering the lowest few days of flow at St. Joseph. The next lowest day in the period of record occurred for all alternatives on 26-Apr-1935, unchanged from alternative to alternative, but reported as the minimum only for Alternative 2.

Figure 4-1. Alternatives Flows at St. Joseph - 1955

The lowest flow/stage in the period of record, and how the alternatives may impact this for the better or worse is an important result for several interest groups, including navigation and water supply. The highest flood flow/stage, and how the alternatives may impact these at various locations along the river is of interest as well. However, caution should be used when trying to draw conclusions from this statistics table alone, especially for maximum and peak flood flows in the Rulo to Mouth reach because of the interaction of river flow with leveed areas. The FIA models produced by the economists that compute structural and agricultural damages from flood events will provide a more complete picture of how the alternatives impact the lowest and highest flows/stages because they incorporate all cross sections and all storage areas along the river, whereas these tabular statistics only capture one location.

Flow and stage changes between alternatives at a certain location are influenced by an array of variables. From alternative to alternative the two primary changes to the hydraulic model were 1) flow out of the Mainstem Missouri River reservoir system as calculated by HEC-ResSim, and 2) the habitat additions to the river geometry. Flow calculated by the HEC-RAS model at a downstream location not only depends on how the Gavins Point release changed, but also how those changes carry downstream. Even when the Gavins Point release has no change, the flow or stage calculated from alternative to alternative at a downstream location may change because of the habitat additions to the river geometry.

There is evidence that habitat construction on a reach of river tends to lower the river stages in the vicinity and slightly upstream of the habitat location and generally have a minor dampening

effect on the hydrograph, lowering peak flows downstream of the habitat location (Jacobson, Linder, & Bitner, 2015). Differences in the overall amount of constructed habitat is the most likely explanation for the increase in the maximum flow and stage at St. Joseph in Alternatives 3-6 compared to Alternative 1, as shown in Table 4-1 and

Table 4-2. The maximum flow for the period of record at St. Joseph occurred in all Alternatives during the great flood of 1993. Releases out of Gavins from the Res-Sim model are identical for all the alternatives during this year, which means all differences observed at downstream locations are due to habitat additions to the river geometry. Alternatives 3-6 all utilize the IRC geometry configuration, whereas Alternative 1 uses the No Action geometry configuration. From Rulo to Kansas City, less habitat overall was added to the IRC geometry, 670-ac, than the No Action geometry, 1,129-ac (1,350-ac minus 221-ac for chutes). Additionally, the total amount of habitat in the IRC geometry for the Omaha District was 861-ac verses 1,453-ac (2,008-ac minus 555-ac for backwaters and changes to existing) in the No Action geometry. It appears in this case that the greater amount of habitat upstream and in this reach may result in a lower peak flow and lower peak stage at St. Joseph in the No Action compared to the Alternatives that utilize the IRC habitat configuration.

However, this simple correlation between habitat and flow/stage does not always hold exactly true, both because of the complexities of the Missouri River system and the nature of unsteady HEC-RAS modeling. Flow changes appear in the results in unexpected and often unexplainable ways. For example, the BiOp geometry had the most habitat added, both upstream of St. Joseph and in the Rulo to Kansas City reach. The maximum stage for Alternative 2 at St Joseph, as shown in

Table 4-2, was significantly lower than the other alternatives, however the flow was slightly increased, see Table 4-1. One factor that influences the timing and magnitude of flows at all levels is the interaction of downstream conveyance features that represent storage. Storage interacts with the conveyance in the main river by taking on water when the river is rising, and returning water when the river is falling. At low flows, this interaction happens with the navigation structures represented by permanent ineffective areas in the channel. At bank full flows, this interaction happens with storage areas that represent tributaries and tiebacks with low lying connection to the river. And at the highest of flows, this interaction happens at a more extreme magnitude with large protected areas behind levees modeled in HEC-RAS with storage areas. River widening for habitat may seem small compared to a fully inundated floodplain, but even slight differences in the river water surface elevation could change the interaction of the river with the storage areas, and alter the timing and magnitude of water to reach a certain location. Without extensive testing and sensitivity runs it is difficult to get a handle on the magnitude of influence of storage on the system.

It is also important to note that the HEC-RAS alternative models have been configured to report one value per 24 hour period, and unfortunately that one value is not a daily average as in HEC-ResSim. The HEC-RAS model computes stage and flow every ten minutes for the entire period of record, but only reports the value that lands on 2400 of each day. The most reasonable output interval was chosen as daily due to the size of watershed being modeled, POR length, and the number of hydrograph locations necessary for HC analysis. This means that slight shifts in timing from alternative to alternative can carry over into the results as small fluxuations in the reported peak flow. Changes in timing are a small factor, not likely to significantly impact any results evaluation, but should be kept in mind when making comparison at a precise level such as in the statistics tables.

In the attachment, the second table down for each gage calculates the difference between the alternative and the No Action Alternative 1 for each statistic. As an example, the difference tables for St. Joseph are shown below as Table 4-3 and Table 4-4. If the value in this table is positive, the alternative resulted in an increase from No Action. If the value in this table is negative, the alternative resulted in a decrease from No Action. To use the minimum flow example at St. Joseph, Alts 3, 4, 5, and 6 showed no change from Alternative 1, whereas Alternative 2 showed an increase of 121-cfs from No Action.

Table 4-3. Change in Flow (cfs) statistic compared to No Action at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	121	0	0	0	0
10%	-	-11	69	-162	49	-87
25%	-	-1,078	185	-539	60	-326
50%	-	-804	-126	-332	-236	-294
75%	-	1,769	-62	443	114	739

90%	-	1,282	2	1,945	827	389
Max	-	1,353	5,738	5,768	5,770	5,754

Table 4-4. Change in Stage (cfs) statistic compared to No Action at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	-0.3	0.1	-0.2	0.0	-0.1
50%	-	-0.2	0.0	0.0	0.0	0.0
75%	-	0.1	0.0	0.1	0.1	0.2
90%	-	-0.2	0.1	0.3	0.2	0.1
Max	-	-1.1	0.4	0.4	0.4	0.4

Stage statistics have been rounded to the nearest tenth of a foot, which is equivalent to 1.2 inches. This helps demonstrate how flow changes impact river elevations, which is the more tangible result. For example, even though the minimum flow in Alternative 2 was 121-cfs higher than in Alternative 1, there is less than an inch of impact to the water surface elevation of the river, and therefore zero reported change.

The third and last table for each gage is quite a bit different than the first two tables. For the entire period of record, the difference from alternative to No Action on each day was calculated, and then the statistics were calculated on that new dataset. As an example, same day change tables are shown for St. Joseph as Table 4-5 and

Table **4-6**. The minimum and maximum in this table should be thought of as the biggest 1 day reduction or 1 day increase in flow or stage over the period of record.

Table 4-5. One day change in Flow (cfs) at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-31,105	-29,178	-22,895	-45,342	-29,282
10%	-	-2,958	-126	-1,975	-439	-1,200
25%	-	-261	-26	-115	-45	-138
50%	-	0	0	-1	0	-3
75%	-	182	27	15	24	10

90%	-	3,480	134	128	170	130
Max	-	39,822	17,417	39,022	42,389	34,299

Table 4-6. One day change in Stage (ft) at St. Joseph

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-7.4	-3.1	-6.8	-4.0	-5.4
10%	-	-1.0	0.0	-0.4	-0.1	-0.2
25%	-	-0.3	0.0	0.0	0.0	0.0
50%	-	-0.1	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.3	0.1	0.1	0.1	0.1
Max	-	6.5	3.0	7.5	7.2	5.9

The magnitudes of the maximum and minimum flows in the one day change tables look extreme compared to the period of record statistics, but the numbers alone are almost meaningless without knowledge of where in the spectrum of low to high these flows occurred. As an example, both Alternatives 4 & 5 had daily changes in flow compared with Alternative 1 of magnitudes exceeding 20-30,000-cfs for many days during the year 1994. Flow hydrograph output at St. Joseph in 1994 are presented in Figure 4-2.

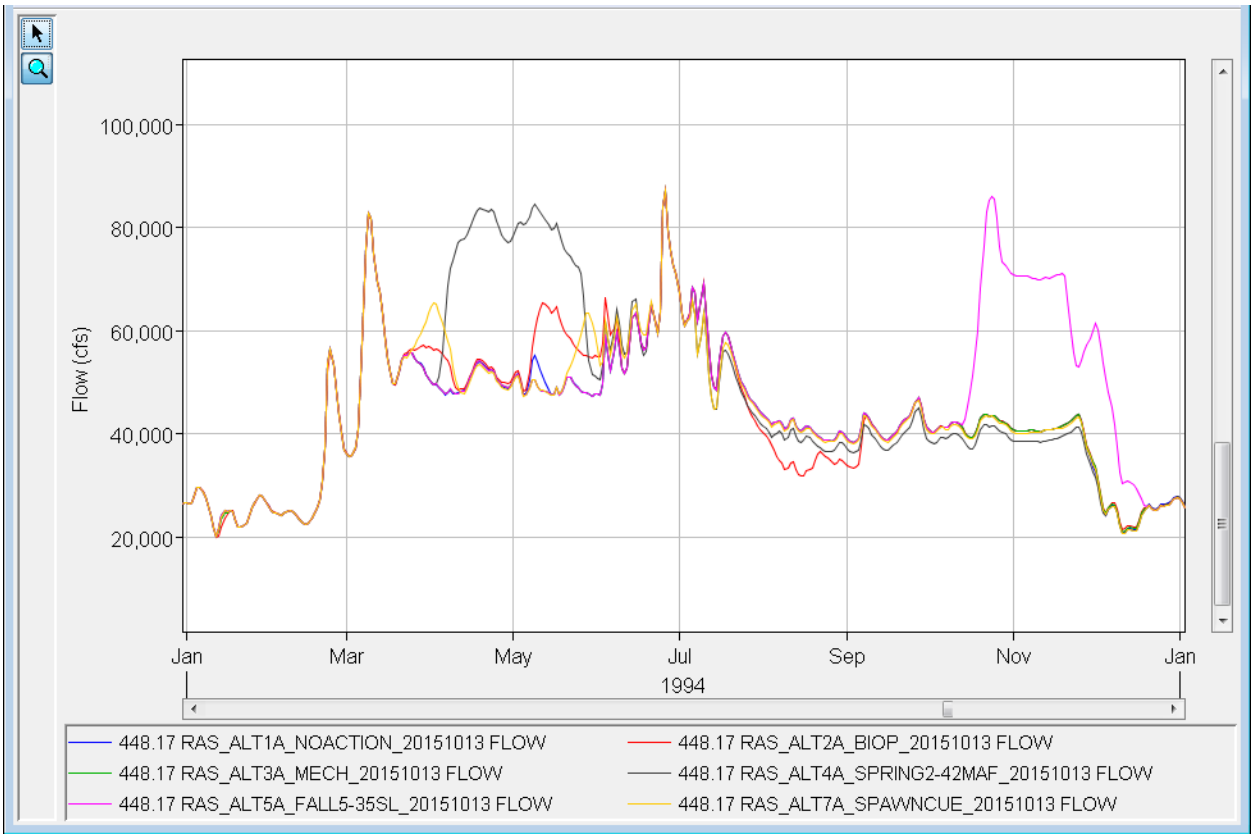


Figure 4-2. Alternatives Flows at St. Joseph - 1994

For context, at St. Joseph the 2-yr flow from UMRSFFS is 109,000-cfs, which is about bank full, and 50% exceedance during the month of August is 44,800-cfs. The 20-30,000-cfs flow changes during 1994 seen in Alternatives 4 & 5 occur well within the confines of the bank of the river. Significance of these changes with regards to stakeholders is addressed within the economic evaluations.

4.2 Seasonal Duration Plots

Plots comparing percent of time alternative flows and stage equal or exceed a range of values are provided in **Attachment 4 – Rulo to Mouth Alternative Flow Duration Plots** and **Attachment 5 – Rulo to Mouth Alternative Stage Duration Plots**. Plots compare alternatives at the five major locations by season. Seasons are defined as spring (01-Mar to 30-Apr), summer (01-May to 31-Aug), fall (01-Sep to 30-Nov), and winter (01-Dec to 28-Feb), and coincide with the seasons as defined for the reservoir system operational rules.

For the flow plots, the difference between the alternative curves and No Action are the largest at St. Joseph, and become smaller moving downstream as the effects of release changes out of Gavins Point are masked by incremental flows from tributaries. Winter flows decrease in the alternatives with respect to the No Action, whereas spring and summer seasons see increases, and fall has a little bit of both.

There is more variability in the stage plots, as this incorporates both flow timing/ magnitude changes intertwined with river widening habitat changes. However, a similar trend was observed as flows with the largest variability between alternatives being at the upstream gage and decreasing with distance downstream from Gavins Point.

4.3 LIMITATIONS

The analysis relies on the simulation of the 82 year period of record using daily average outflows from a HEC-ResSim model input into fixed bed HEC-RAS models, with stage and flow values pulled at the same time each day from 10 minute computation. While the analysis coupled with species and human considerations models can be used to show relative benefits and potential impacts based on historic flows, there are limitations in the conclusions that can be drawn based on some of the simplifying assumptions.

1) **Uncertainty Analysis –** A probabilistic risk and uncertainty assessment was not performed on the combined HEC-ResSim and HEC-RAS model output. Pulses and release changes only occur in 12% of the years on the low end (Alternative 2) to 21% of the years on the high end (Alternative 4) in the period of record, as noted in Table 3-1. The potential flood damages from coincident downstream flows occurring during the spring or fall pulses can only be considered for this smaller subset of the period of record of 10 to 18 years. Without a Monte Carlo type 1,000-year plus simulation, it is difficult to express with even moderate confidence the risk associated with the flow and river geometry changes made for the alternatives. Statistics and percentages calculated based on the 82 years of record should therefore be used with caution, and with the understanding of the consequences of using only a small sample of years.

2) **Stationarity of the flow record –** The period of record ranges from the extreme drought of the 1930s, to the floods of 1993 and 2011, however, it's unknown what the flow conditions of the next 50-years will bring, and whether or not they will be comparable to the conditions experienced over the last 82 years. Climate change analysis performed for the Missouri River basin indicates that earlier snowmelt can be expected along with increasing trends in extreme floods and droughts (USACE, 2016c). Given the same criteria for releasing a spring or fall pulse, the percentage of years in which a pulse is released could be quite different, and in turn the economic impact could be quite different as well.

3) **Stable Bed and Floodplain –** The hydraulic modeling to date is based on revisions to the existing conditions hydraulic model to account for varying amounts and distributions of habitat through river widening and continued development of SWH projects such as chutes. The analysis does not account for how the bed of the Missouri River may respond to river widening activities. Additionally, the analysis does not try to project where sediment may accumulate in the floodplain or include projections of future change in floodplain roughness. This carries with it the necessary assumptions that any bed and floodplain changes would be either negligible, similar between each alternative, or mitigated during more detailed design of river widening projects.

4) **Flood source –** The Missouri River, major tributaries, and ungaged inflows included in the HEC-RAS model are the only flood sources, water only floods areas protected by levees from levee overtopping, and levees do not breach. In reality, flooding can also occur due to localized rainfall and subsequent runoff, through seepage under levee foundations during prolonged high water, or through failure of levees prior to overtopping. Past experience on the Missouri River indicates that a majority of levee breaches occur following levee overtoppings when water flows into or exits the levee system. However, breaches prior to overtopping have occurred and may occur again in the future. Predicting breach formation through the period of record simulation was considered infeasible in part due to ongoing repairs and improvements made by levee sponsors or USACE after each event. Not including breaches can underestimate potential flood damages in some cases. While the level of effort required to model all levees systems with detailed rainfall runoff and underseepage flow calculations was considered prohibitive, more detailed analysis was conducted for four levee systems, two in Omaha District and two in Kansas City District. The two Kanas City District interior drainage models are documented in Section 5.

5) **Level of detail** – The HEC-RAS model is a one dimensional unsteady flow calculation, which means flow only moves in one direction and velocity components in directions other than the direction of flow are not accounted for. Additionally, cross-sections were spaced a half mile apart on the Missouri River. This means any changes in the river between cross-sections is not captured by the model.

5 INTERIOR DRAINAGE ANALYSIS

Crop damage as a result of levee overtopping was accounted for in the primary modeling effort, but damage to crops behind levees can be caused by other mechanisms. Typical Missouri River levee systems have culverts to allow local drainage to exit the interior of the levee and drain to the river. Each culvert typically would include one or more closures, such as a flap gate or sluice gate, to prevent river water from backing up into the leveed area. When river levels are higher than the culvert outlets and this coincides with heavy local rainfall, ponding water can cause flooding on the interior of the levee. Additionally, when river levels are above the interior ground level, seepage through the ground under the levee can also cause flooding on the interior.

To simulate these types of flooding, and measure differences between the proposed alternatives and the No Action alternative, a sub-set of the seven sites evaluated for the Master Manual (USACE, Aug 1998) were modeled in detail. Four sites were selected, L-575 and L-536 in the Omaha district and L-488 and L-246 in the Kansas City district. Figure 5-1 shows an area map with the locations of the four sites on the river.

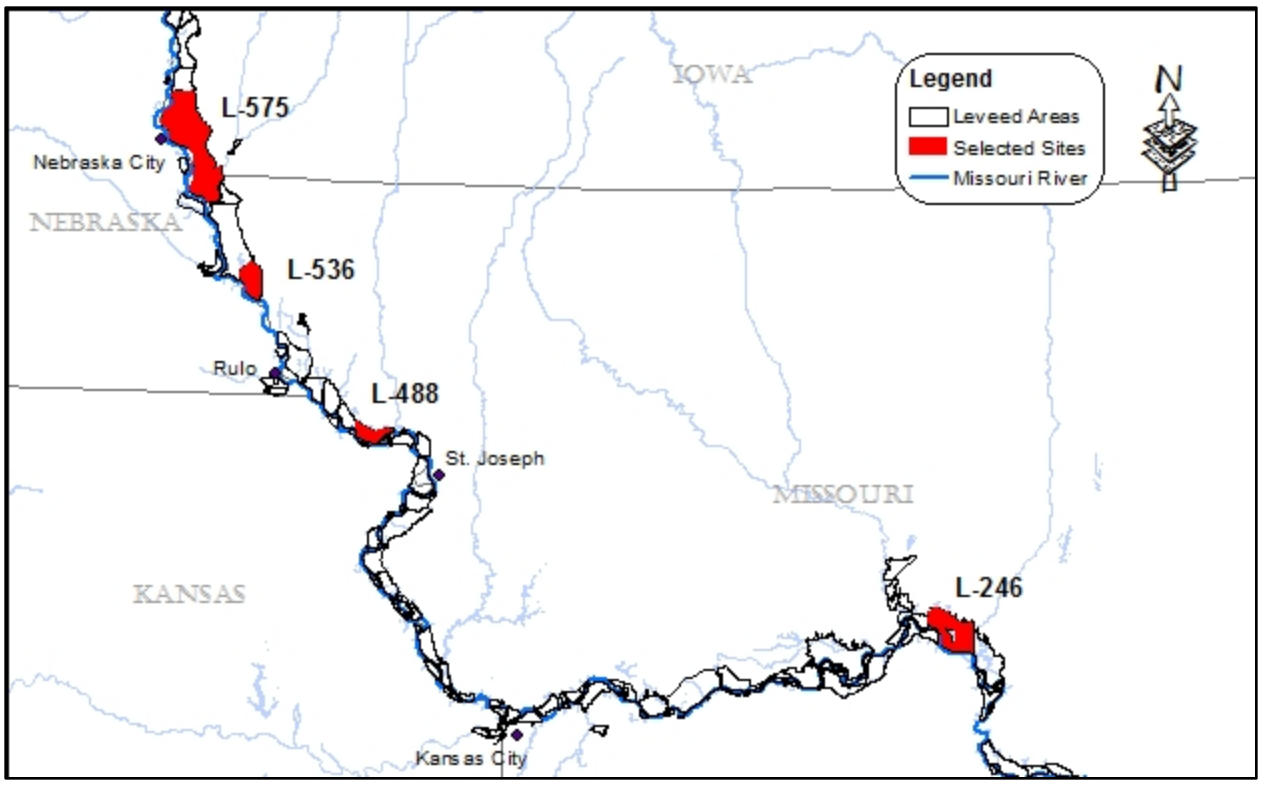


Figure 5-1. Interior Drainage Sites

Detailed modeling included a HEC-HMS model to simulate runoff, a HEC-RAS model to simulate the water surface profile of the river and water elevation on the levee interior, and a HEC-FIA model to calculate damages. Because the models are quite complex and time consuming to set up, it was not feasible to model every levee on the Missouri River to this level of detail. HEC-HMS model documentation can be found in **Attachment 6 – Interior Drainage HMS Model Documentation**. Construction, calibration, and results of HEC-RAS model are documented in the following sections.

5.1 Model Construction

Two smaller trimmed HEC-RAS models were created to model L-488 and L-246. The boundaries were selected to be well upstream and downstream of the zone of influence on the levee of concern, as well as at a clean boundary condition with regard to floodplain flow through storage areas. Upstream flow boundary conditions, and the downstream stage boundary condition were taken from the primary models for each alternative period of record run. Cross sections in the trimmed models are from each of the alternative geometries, No Action, BiOp and IRC, and reflect the habitat assumptions in that reach per each alternative geometry.

To accurately model the changing stage on the interior of the levee with regard to local rainfall, culvert drainage, and seepage, the protected area behind L-488 and L-246 were delineated into multiple independent pooling areas. Area delineation considered the route of rainfall runoff from the bluffs into ditches in the floodplain, the most dominate culvert outlet locations, and natural high ground divisions between pooling areas. Each area has at least one associated lateral

structure, to which was added the corresponding culvert(s) that primarily drain the area. No pumps were considered in the models at this time.

5.1.1 *L-488*

Delineation of the protected area behind L-488 is shown in Figure 5-2. The area was subdivided into five storage areas based on the five primary culvert outlets. Selected delineation is very comparable to the delineation in the Master Manual, with the exception of 448c and 448d, which were combined in the old evaluation, and a few slight differences on the high ground division which can be attributed to better quality present day terrain data.

New storage area curves for the five areas were cut from 1-meter LiDAR data flown in the winter of 2011-2012. Storage area curves were created in HEC-GeoRAS using 0.1 slice density and 50 points, capped at an elevation of 855-ft. Observed data from spring pulse monitoring conducted in 2009 was available for model calibration at one of the culverts in L-488. Figure 5-2 presents a schematic of the L-488 detailed hydraulic model including the locations of the observed stage hydrographs.

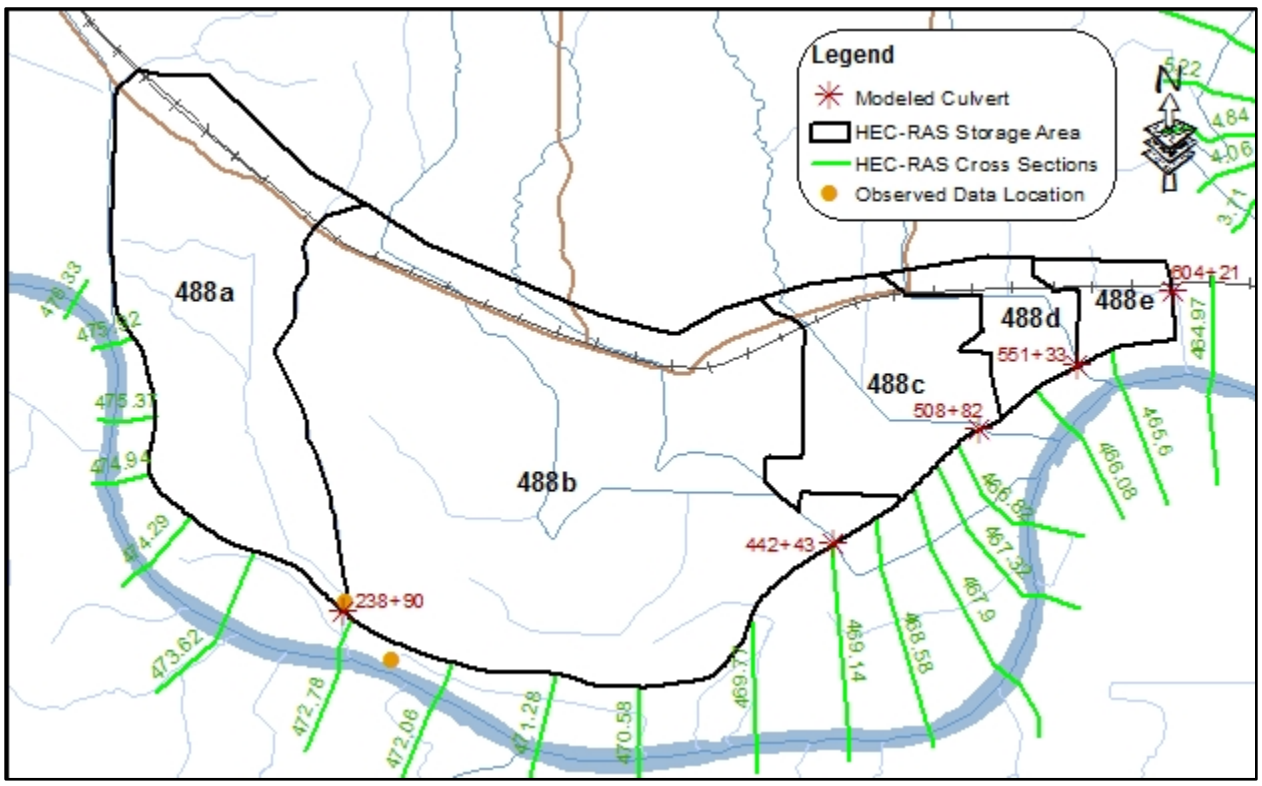


Figure 5-2. L-488 Layout

An HEC-HMS model was created to simulate the localized runoff to each culvert using hourly rainfall data assembled from nearby available precipitation gages for the full period of record. Details of the HEC-HMS model set up and calibration are contained in **Attachment 6**.

Each area in HEC-RAS was paired with a flow hydrograph produced by HEC-HMS, representing the rainfall runoff from the bluffs and over the floodplain area, routed to the respective outlet location, identified by a node name. Pairings, as well as drainage area and floodplain areas are in Table 5-1. Flow hydrographs from HEC-HMS were input as a flow boundary condition to each storage area in HEC-RAS.

Table 5-1. L-488 Links

Storage Area	Storage Area Size (sq mi)	Associated HMS Node	Drainage Area (sq mi)
488a	3.66	30c	4.02
488b	8.47	24c	18.34
488c	1.71	25c	1.92
488d	0.64	4c	2.52
488e	0.43	28c	0.63

One lateral structure representing the levee was associated with each storage area. There are nine total drainage structures on the levee system, however only one primary outlet location was added to each lateral structure. Secondary culvert outlets were all small and appeared to prevent localized ponding on the floodplain rather than provide a drainage path for bluff rainfall. Including these may have actually over-represented the ability of the interior drainage system to exit water from the interior, as ponding water would have to be high enough to spill over high ground on the interior to utilize these outlets. Selected culverts and their key hydraulic parameters are listed in Table 5-2. All pipe information was taken from the Missouri River Levee System Unit 488-L 2010 Periodic Inspection Report.

Table 5-2. L-488 Culverts

Levee Station	Associated Storage Area	Size and Conduit	Manning's n-value	Gates	Entrance Type	Ent Loss Coeff	Length (ft)	Inlet Elev (NAVD 88)	Outlet Elev (NAVD 88)
238+90	488a	2-72" RCP*	0.013	Sluice	Headwall	0.5	116	825.39	823.94
442+43	488b	5-72"CMP	0.024	Sluice	Headwall	0.5	102	821.32	819.84
508+82	488c	5-72" CMP	0.024	Sluice	Headwall	0.5	124	821.31	819.70
551+33	488d	3-54" CMP	0.024	Sluice	Projected	0.9	132	819.80	817.62
604+21	488e	1-48" CMP	0.024	Sluice	Headwall	0.5	134	820.80	818.86

Notes
* Original pipe was two CMPs, replaced by two RCPs

5.1.2 *L-246*

Delineation of the protected area behind L-246 is shown in Figure 5-3. The area is significantly more complicated than L-488, with a ring of levees surrounding an interior lake and drainage ditch called Palmer Creek. Storage area delineation went through several different versions, with the final configuration based on the best match to observed data. Selected delineation is comparable to the delineation in the Master Manual, but with the addition of 246n.

New storage area curves for the five areas were cut from 1-meter LiDAR data flown in 2006, the most recent available at this time. Storage area curves were created in Geo-RAS using slice density of 0 and 50 points, capped at an elevation of 645-ft. Observed data from spring pulse monitoring conducted between 2008 and 2010 was available for model calibration at three of the culverts in L-246. Figure 5-3 presents a schematic of the L-246 detailed hydraulic model including the locations of the observed stage hydrographs.

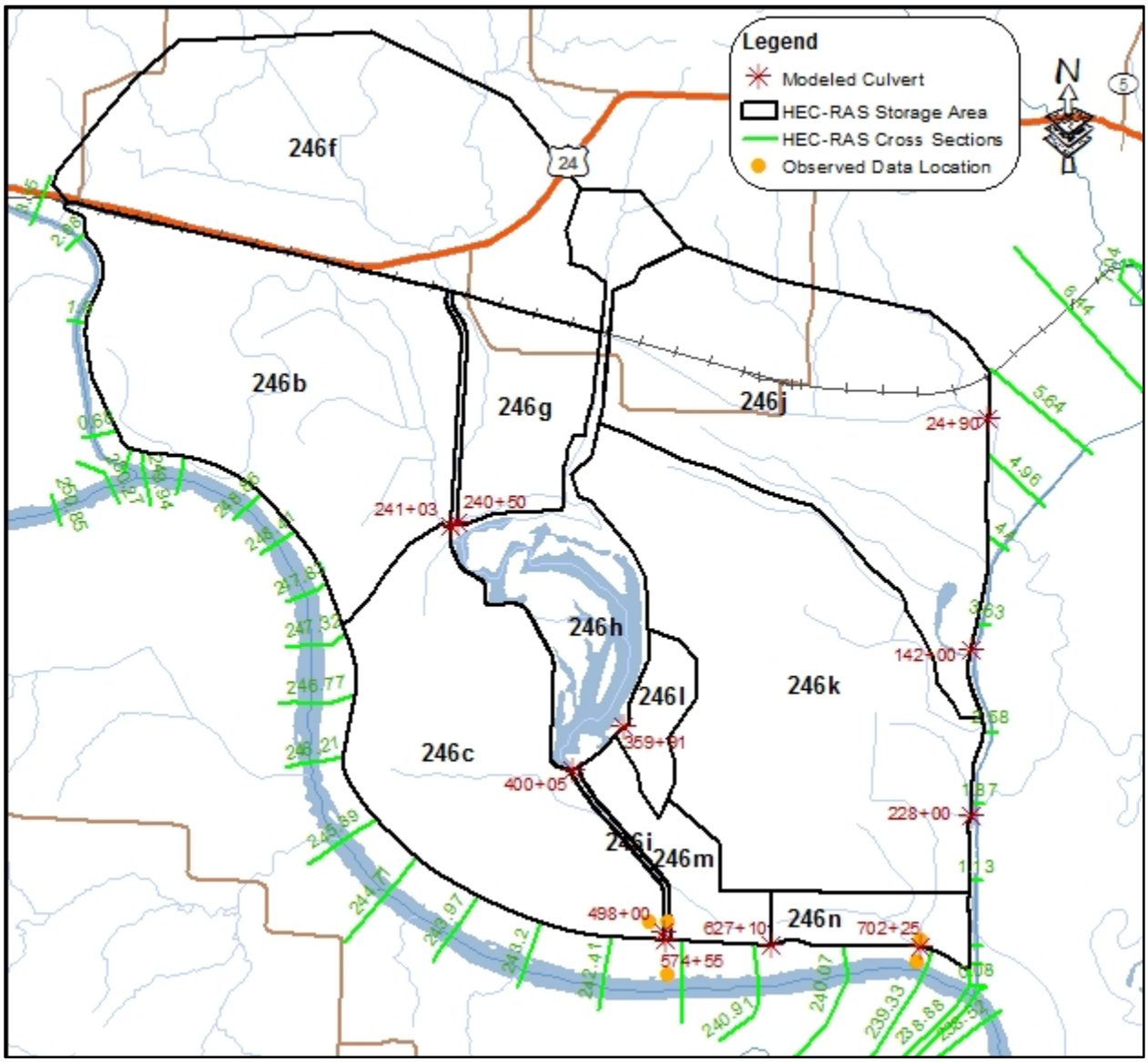


Figure 5-3. L-246 Layout

An HEC-HMS model was created to simulate the localized runoff to each culvert using hourly rainfall data assembled from nearby available precipitation gages for the full period of record. Details of the HEC-HMS model set up and calibration are contained in **Attachment 6**.

Each area in HEC-RAS was paired with a flow hydrograph produced by HEC-HMS, representing the rainfall runoff from the bluffs and over the floodplain area, routed to the respective outlet location, identified by a node name. Pairings, as well as drainage area and floodplain areas are in Table 5-3. Flow hydrographs from HEC-HMS were input as a flow boundary condition to each storage area in HEC-RAS.

Table 5-3. L-246 Links

Storage Area	Storage Area size (sq mi)	Associated HMS Node	Drainage Area (sq mi)
246b	8.55	29c + 34c	9.9
246c	6.52	49c + 36c + 47c	6.7
246f	8.93	-	-
246g	2.22	32c	2.2
246h	3.72	45c + 41c	47.7
246i	0.12	-	-
246j	8.35	27c + 25c	10.5
246k	10.02	33c	10.1
246l	0.72	40c	0.42
246m	1.29	39c	1.91
246n	0.98	-	-

One lateral structure representing the exterior levee was associated with each storage area. Interior levees and high ground divisions between areas were represented by storage area connections. There are thirty eight total drainage structures on the levee system, providing drainage from the interior to the Grand, Chariton, and Missouri Rivers, as well as through the interior levees to the lake, and from the lake to the Missouri River. One drainage structure was identified as the controlling structure for each storage area and added to either the relevant lateral structure or storage area connection, with the exception of 246j for which there were two fairly large structures. Selected culverts and their key hydraulic parameters are listed in Table 5-4. All pipe information was taken from the Missouri River Levee System Unit 246-L 2013 Periodic Inspection Report.

Table 5-4. L-246 Culverts

Levee Station	Alignment	Associated Storage Area	Size and Conduit	Manning's n-value	Gates	Entrance Type	Ent Loss Coeff	Length (ft)	Inlet Elev (NAVD 88)	Outlet Elev (NAVD 88)
241+03	Palmer RB	246b	1-60" CMP	0.024	sluice	headwall	0.5	53.6	621.19	620.60
			1-48" CMP	0.024	sluice	headwall	0.5	53.6	621.28	620.65
498+00	Palmer RB	246c	1-36" CMP	0.024	flap	headwall	0.5	124.7	616.08	615.50
240+50	Palmer ULB	246g	2-42" CMP	0.024	flap	headwall	0.5	56.5	621.23	620.84
400+05	Palmer RB	246h	3-6'x6' RCB	0.013	sluice	wingwall, square	0.5	68.7	619.10	613.60
574+55	Main	246i	1-5'x10' RCB	0.013	sluice/ flap	wingwall, rounded	0.2	122.3	611.85	610.10
			2-5'x5' RCB	0.013	sluice/ flap	wingwall, rounded	0.2	122.4	616.90	614.97
24+90	Chariton RB	246j	2-5'x5' RCB	0.013	sluice/ flap	headwall	0.5	94	621.84	620.51
142+00	Chariton RB	246j	1-72" CMP	0.024	sluice/ flap	headwall	0.5	164	614.10	612.47
228+00	Chariton RB	246k	2- 5'x5' RCB	0.013	sluice/ flap	wingwall, rounded	0.2	176	613.80	612.44
702+25	Main	246n	1-54" CMP	0.024	sluice/ flap	headwall	0.5	170.69	613.02	-
627+10	Main	246m	1-30" CMP	0.024	flap	headwall	0.5	125.2	613.89	-
359+91	Palmer LLB	246l	1-36" CMP	0.024	flap	headwall	0.5	75.9	620.45	620.00

5.2 SIMULATION AND CALIBRATION

All calibration and alternative period of record runs were made in HEC-RAS version 5.0 Release Candidate 2 (21 August 2015) for consistency with the primary alternative runs. Before running the alternatives the models were calibrated using data collected by the MRRP in 2008, 2009, and 2010 to evaluate the impacts of the spring pulse and rises on interior drainage (USACE, Jan 2011). Calibration data included riverside and landside stages that were compared to model calculations.

5.2.1 *Seepage*

Seepage was incorporated for both the calibration and alternative runs. To calculate seepage the models were run twice. In the first run, ponding on the interior was simulated based only on the contribution of rainfall runoff from HMS routed through the culverts in HEC-RAS. Seepage rate estimates from the Master Manual were reviewed by the Geotechnical Engineering Section and were deemed reasonable for this purpose. Recent seepage studies at L-497 showed slightly lower seepage rates than those utilized in the Master Manual study. The seepage rates vary, increasing proportionally with river head, and are expressed in units of cfs per foot of

levee. Results of the first model run were used to estimate the driving head as a difference between the interior ponding elevation and the river elevation, and a daily average seepage rate was then calculated for the length of the levee corresponding to each storage area. For each area the levee length along the river was measured, as seepage is identified as a flow rate per unit levee length. A representative cross section was selected near the mid-point of the levee length for comparison to the landside ground and ponding elevation. Each day the head difference between river and landside was calculated. Head was defined as the river stage compared to the ground or ponded water on the landside, whichever was higher. If the head was negative, meaning the river was lower than the ponded water on the landside, or lower than the lowest point on the landside, seepage was set to zero. If the head was positive, a daily seepage rate was calculated based on the values in Table 5-5 and Table 5-6. The models were then run again incorporating the seepage as inflow into the area. No further iterations were performed, as these would have only served to slightly reduce the seepage contribution.

Table 5-5. L-488 Seepage

	Storage Area	448a	448b	448c	448d	448e
	Levee Length [1] (ft)	23,964	23,022	4,688	3,353	5,556
Head (ft)	**Seepage per unit length [2] (cfs/ft)**	**Seepage applied to HEC-RAS Storage Areas per Head per Day (cfs)**				
0	0	0.0	0.0	0.0	0.0	0.0
2	0.00048	11.5	11.1	2.3	1.6	2.7
4	0.00096	23.0	22.1	4.5	3.2	5.3
6	0.00144	34.5	33.2	6.8	4.8	8.0
8	0.00192	46.0	44.2	9.0	6.4	10.7
12.5	0.003	71.9	69.1	14.1	10.1	16.7
15	0.00359	86.0	82.6	16.8	12.0	19.9
	Representative River Cross Section	474.94	470.58	467.32	466.08	465.6

Notes
1 Levee length calculated in GIS
2 Seepage per unit length as per Master Manual values

Table 5-6. L-246 Seepage

	Storage Area	246b	246c	246m	246n	246k	246j
	Levee Length [1] (ft)	28,089	26,713	5,181	13,921	9,000	17,512
Head (ft)	Seepage per unit length [2] (cfs/ft)	Seepage applied to HEC-RAS Storage Areas per Head per Day (cfs)					
0	0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.00047	13.2	12.6	2.4	6.5	4.2	8.2
4	0.00093	26.1	24.8	4.8	12.9	8.4	16.3
6	0.0014	39.3	37.4	7.3	19.5	12.6	24.5
8	0.00187	52.5	50.0	9.7	26.0	16.8	32.7
15	0.0035	98.3	93.5	18.1	48.7	31.5	61.3
	Representative River Cross Section	248.86	244.71	241.63	240.07	1.87[3]	4.4[3]

Notes
1 Levee length calculated in GIS
2 Seepage per unit length as per Master Manual values
3 Chariton River cross-section

On L-246, seepage was only calculated along the exterior levee units along the Grand, Missouri, and Chariton Rivers. Seepage from the Missouri River to the lake, or from the lake to the fields was not accounted for.

5.2.2 *L-488*

Observed data for calibration at L-488 was available at the locations identified in Figure 5-2 near culvert 238+90. Measurements were only taken in the year 2009, on the landside and riverside near the culvert. HEC-RAS results for this year are plotted verses the observed data in Figure 5-4 and Figure 5-5.

Although model results don't match observed data exactly, the interior ponding generally reaches similar depths at a similar occurrence frequency. The Spring Pulse report (USACE, Jan 2011) recognized that there was considerable noise/chatter in the landside dataset compared to measured data at other units. The variability at L-488 may be influenced by the sponsors pumping activities at this location, which was not accounted for in this analysis due to not enough information on how pumps are operated during events. River stage computed by HEC-RAS could be tracking a little low because the NoAction rather than the existing condition cross section geometry was used for calibration runs. Downstream habitat placement may have a general lowering effect on the water surface profile in this vicinity.

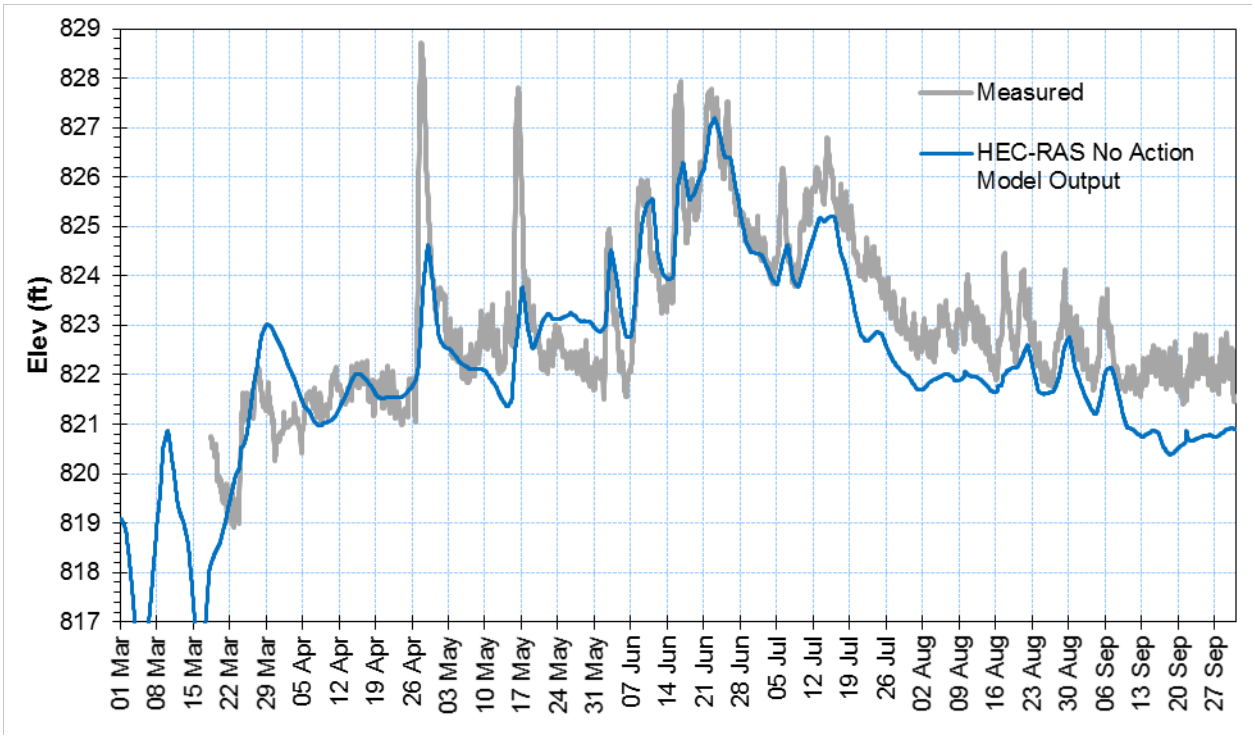


Figure 5-4. L-488 River Stage 2009 – measured vs modeled

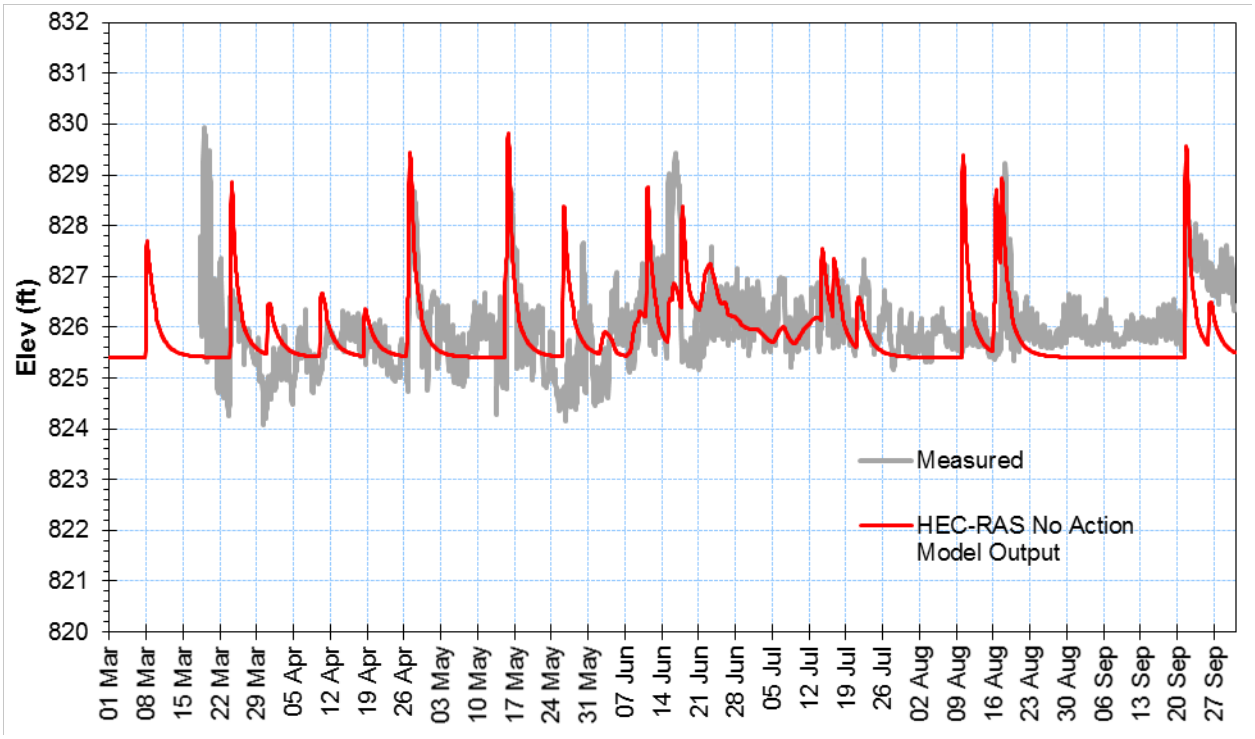


Figure 5-5. L-488 Interior Stage 2009 – measured vs modeled

As an additional validation, 2011 and 1993 floods were run through the model and RAS mapper inundation extents were compared to actual inundation extents.

Figure 5-6 shows the aerial photography collected during the 2011 flood event with HEC-RAS storage areas at L-488 outlined in black. Figure 5-7 overlays model results for comparison. L-488 did not overtop or breach during the 2011 flood, which means all of the ponding on the landside of the levee is due to seepage and/or bluff rainfall runoff that was unable to drain through the culvert because of high river profiles all summer long. Model results generally appear to overestimate the ponding in the interior during 2011, but not by much. The aerial photography was collected at the end of August, when flood waters were beginning to recede. Inundation shown in Figure 5-7 represents the inundation at the maximum ponding depth experienced during the 2011 flood simulation. The gap between water in the photo and maximum inundation is large, but the match between the brown areas that indicate dead crops and the maximum inundation is much closer.

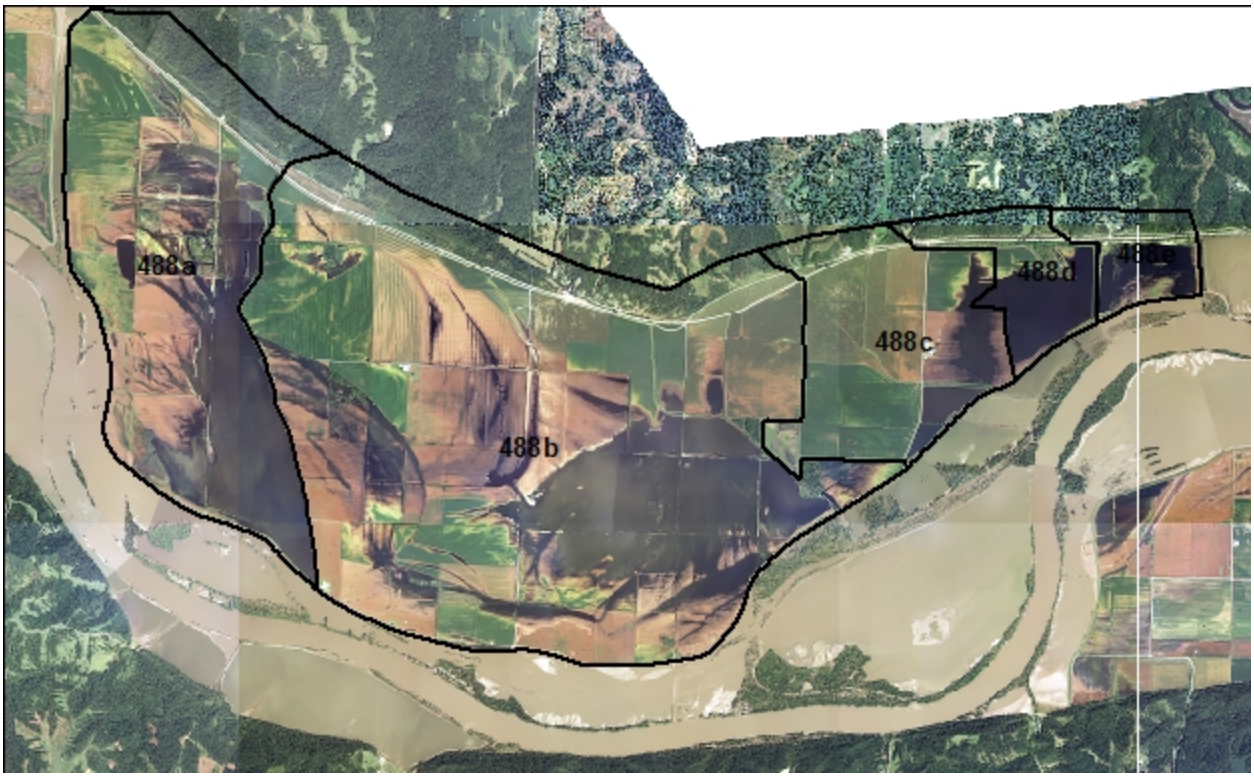


Figure 5-6. Flood inundation in 2011 at L-488

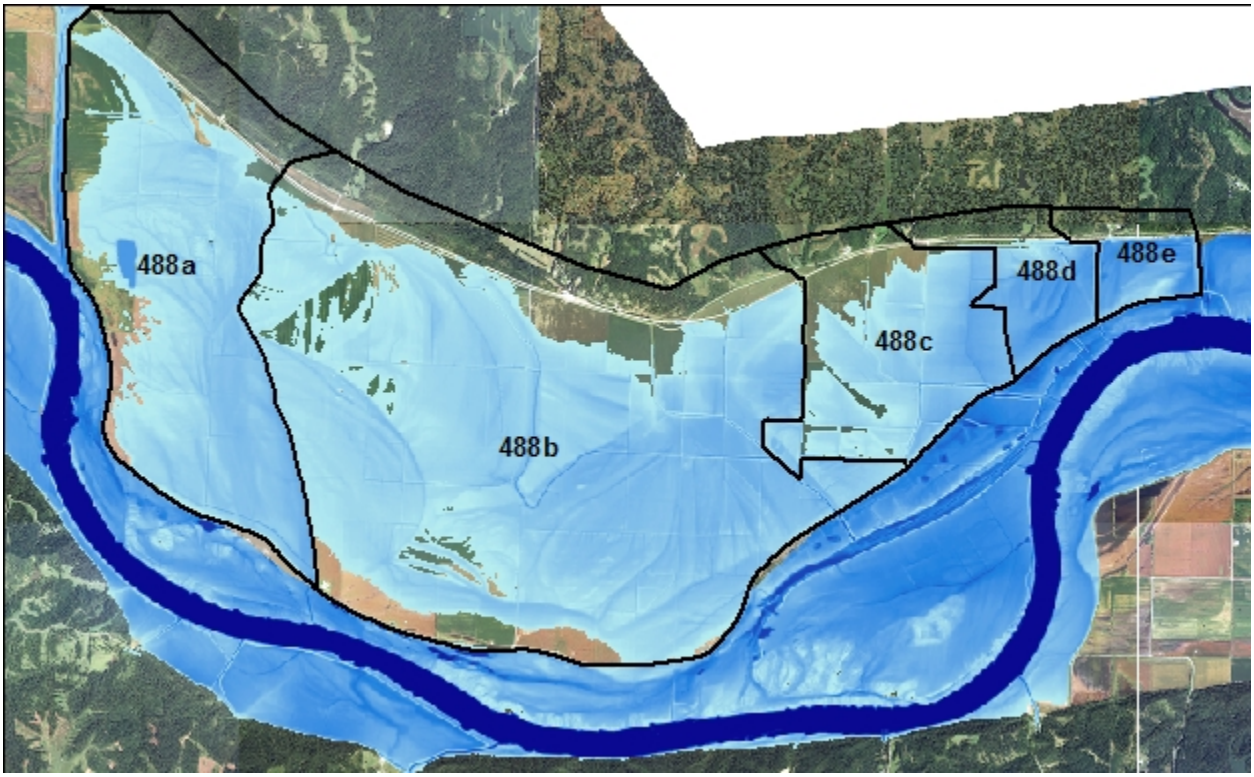


Figure 5-7. Flood inundation in 2011 at L-488 – model results

Figure 5-8 overlays the model results with the 1993 flood extents digitized during the post flood report from aerial photography. L-488 was reported as overtopped but not breached in the 1993 post flood report (USACE, 1994). However, the profile of the river at the maximum moment of the 1993 flood is about 2-ft lower than the L-488 top of levee in the No Action alternative model run. Reasons for this were discussed in the calibration report, the use of daily data and the ungaged flow methodology made it difficult to match annual peaks in all years in all locations. Regardless, the model results still overestimate the interior flooding during 1993 based on local rainfall and seepage contributions alone.

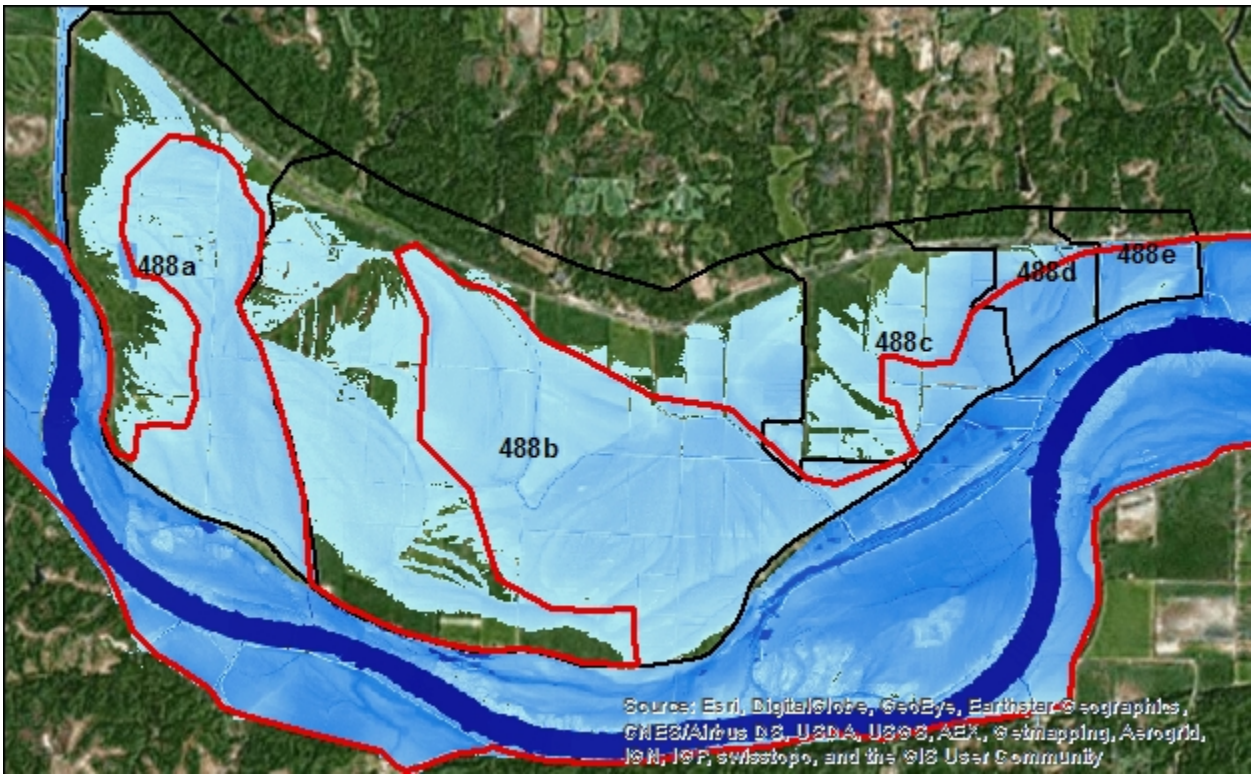


Figure 5-8. Flood inundation in 1993 at L-488 – model results

Overall, calibration and validation of the L-488 interior drainage model indicates that the model is acceptable for re-producing pooling water in the interior of the levee due to high river stages, seepage, and local bluff rainfall.

5.2.3 *L-246*

Observed data for calibration at L-246 was available for the locations identified in Figure 5-3. Measurements were taken in 2008 and 2009 on the riverside and landside at culvert 574+55 where Palmer Ditch drains water from the lake to the Missouri River. In 2009 an additional data collector was added in the landside fields to the west of the ditch at the inlet of culvert 498+00. In 2010, stages were collected at culvert 702+25 known as Dalton Ditch, instead of at the Palmer Ditch outlet. HEC-RAS results for 2008, 2009, and 2010 are plotted verses the observed data in Figure 5-9 through Figure 5-13. Model results track well with the peak ponding recorded by the instrumentation both in frequency and magnitude.

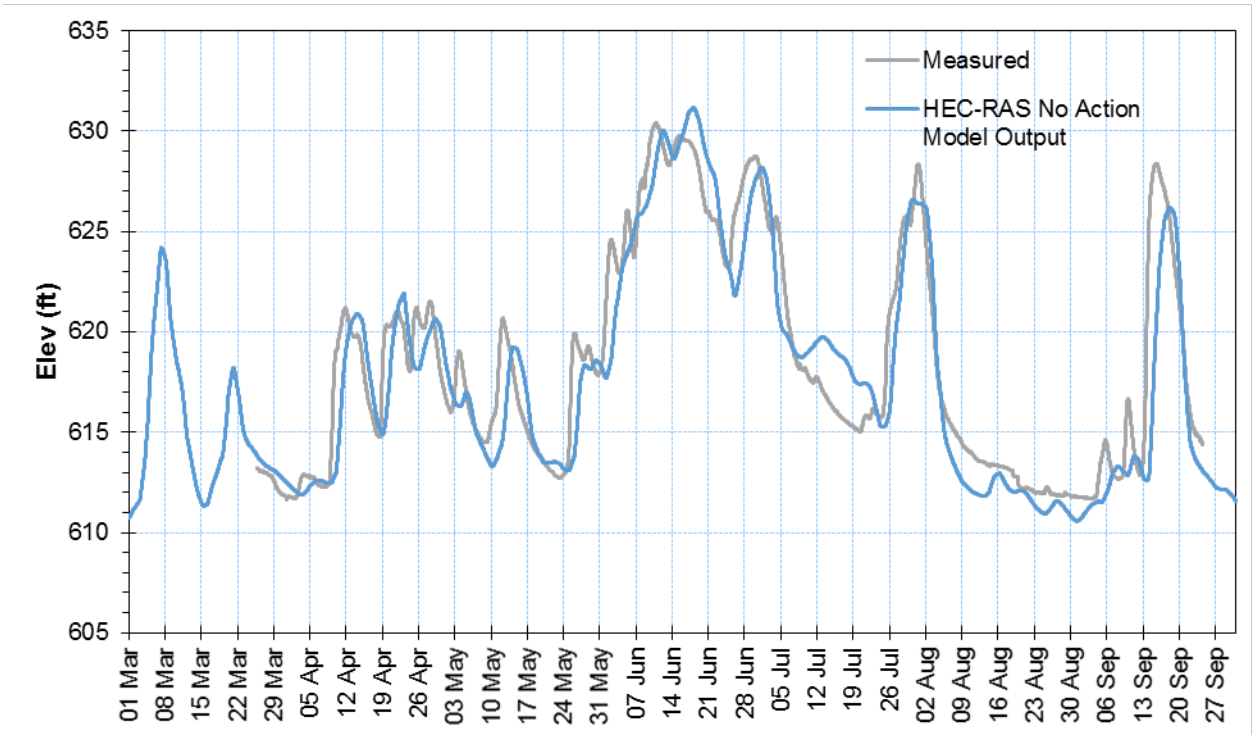


Figure 5-9. L-246 River Stage 2008 – measured vs modeled

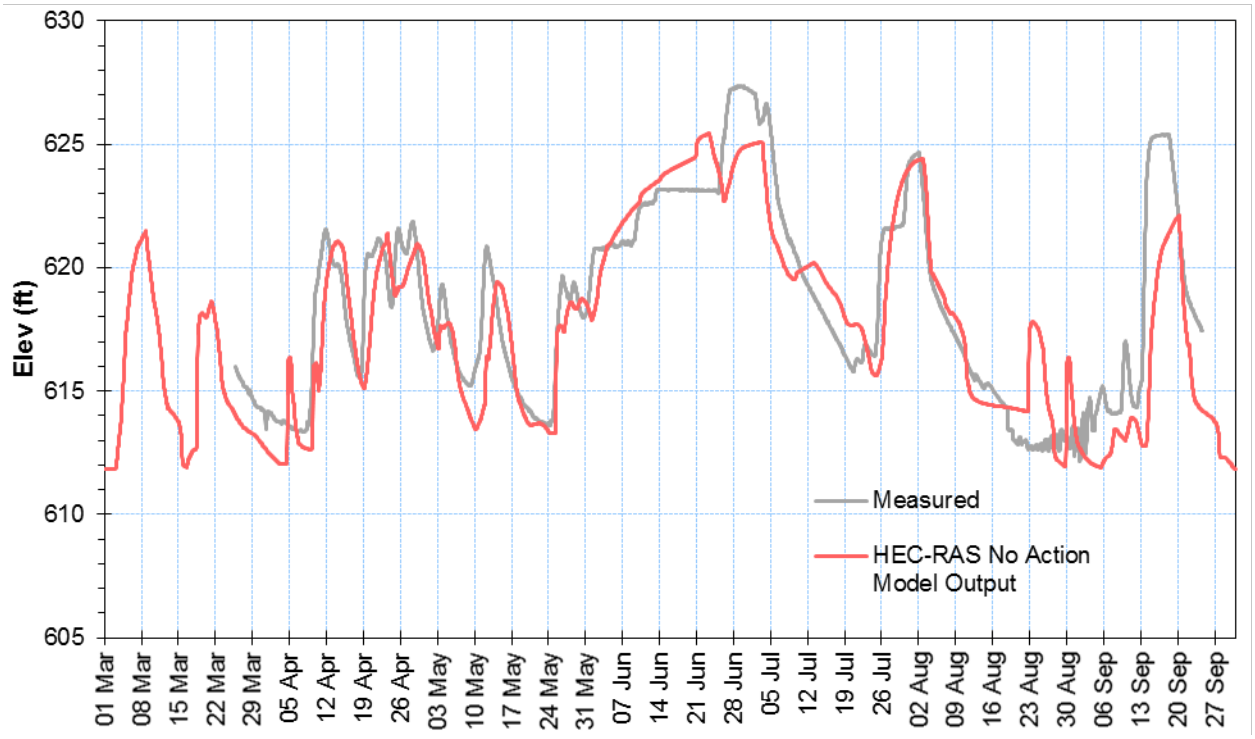


Figure 5-10. L-246 Palmer Ditch Stage 2008 – measured vs modeled

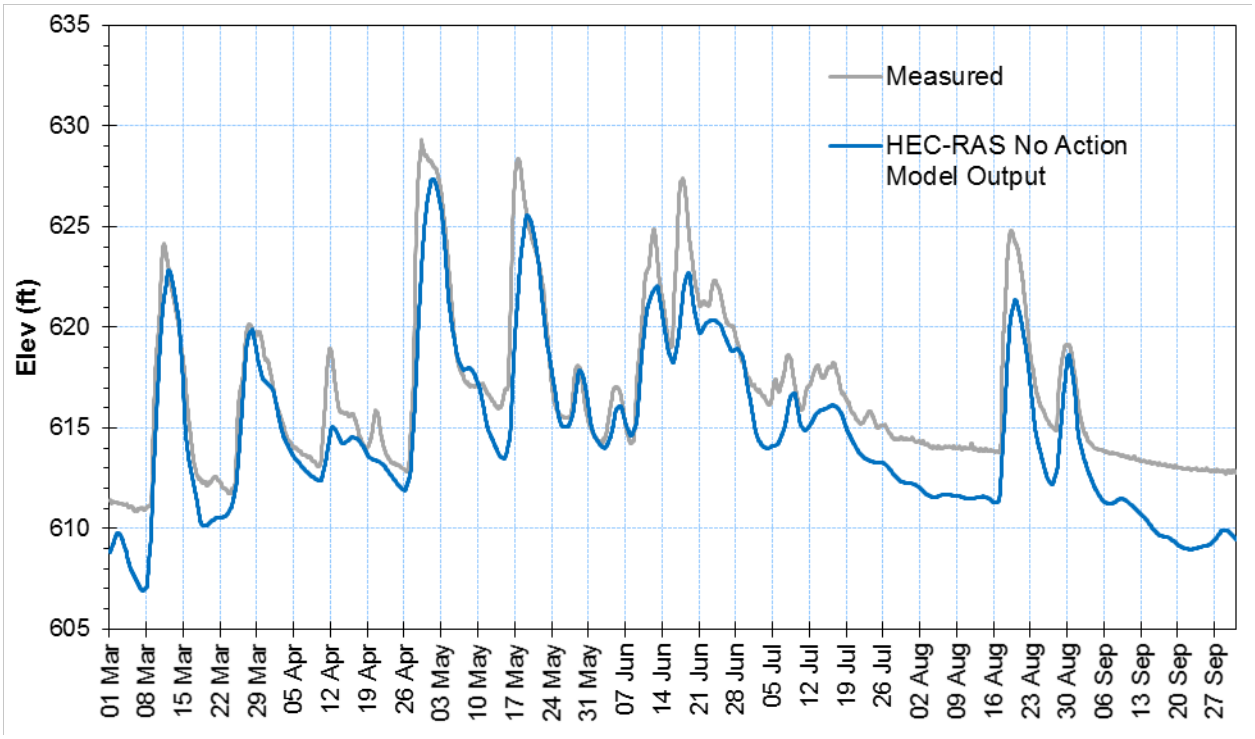


Figure 5-11. L-246 River Stage 2009 – measured vs modeled

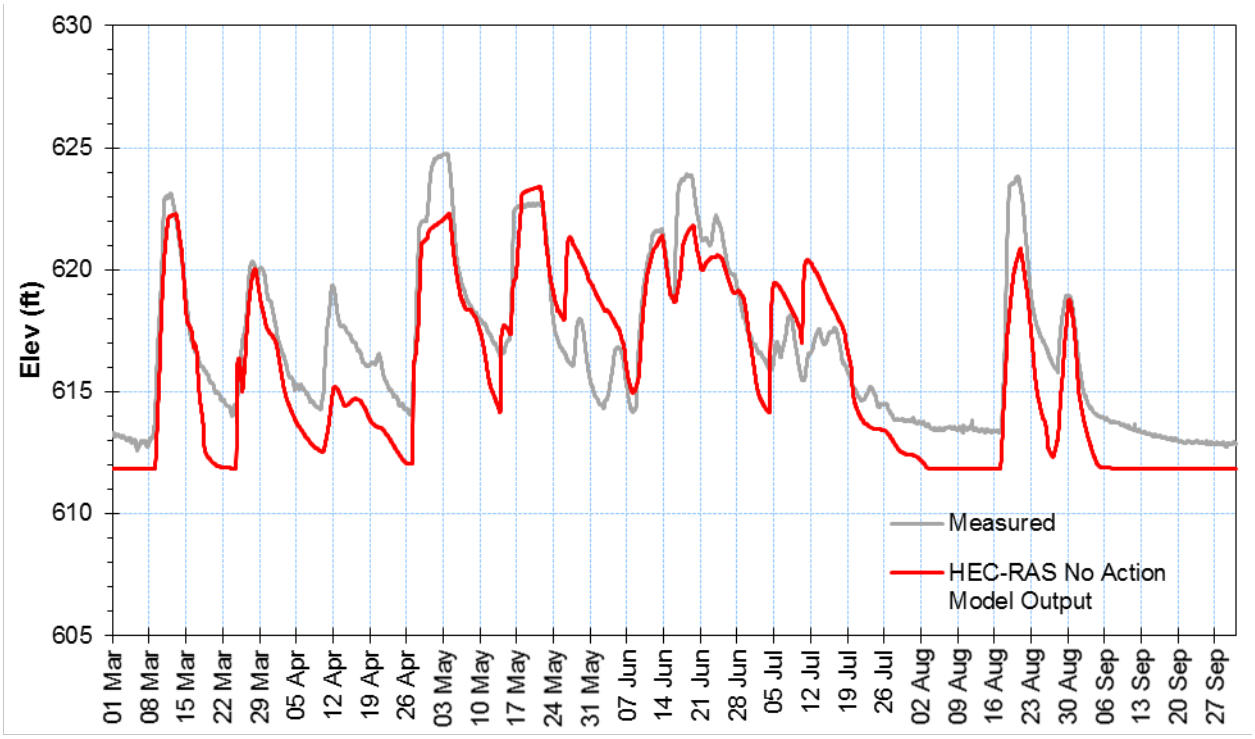


Figure 5-12. L-246 Palmer Ditch Stage 2009 – measured vs modeled

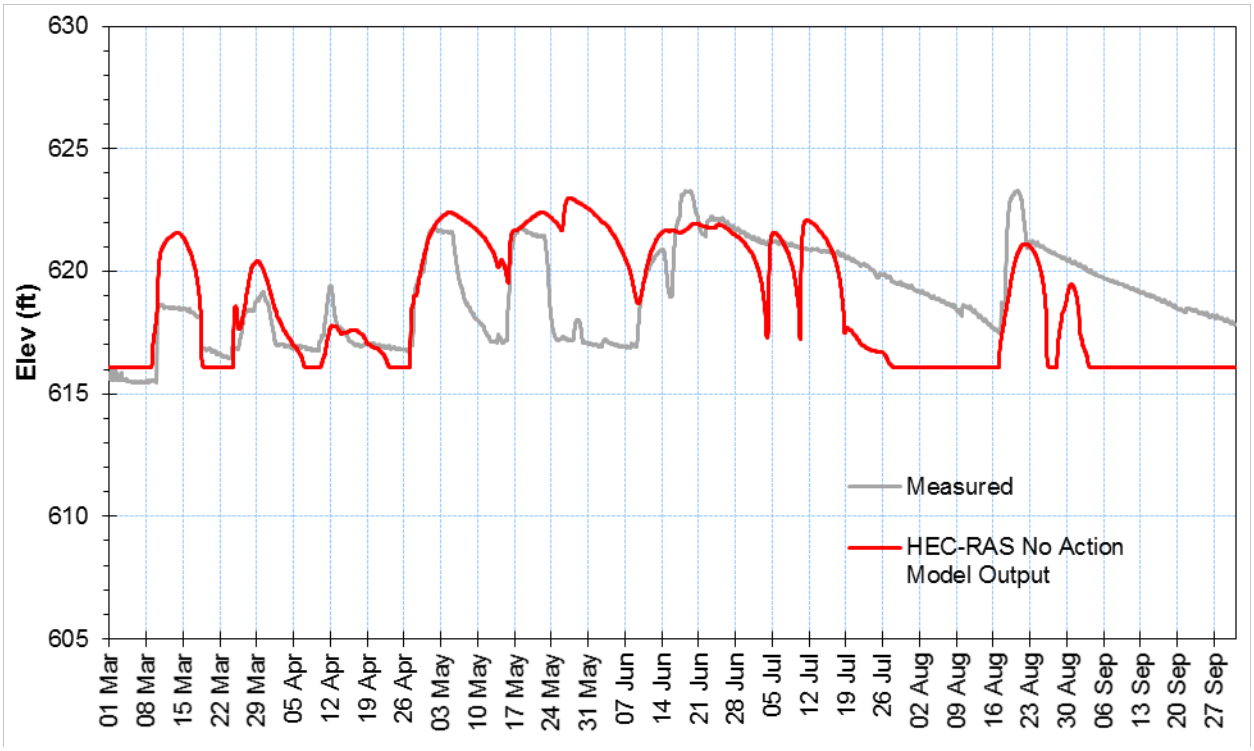


Figure 5-13. L-246 West of Palmer Ditch Stage 2009 – measured vs modeled

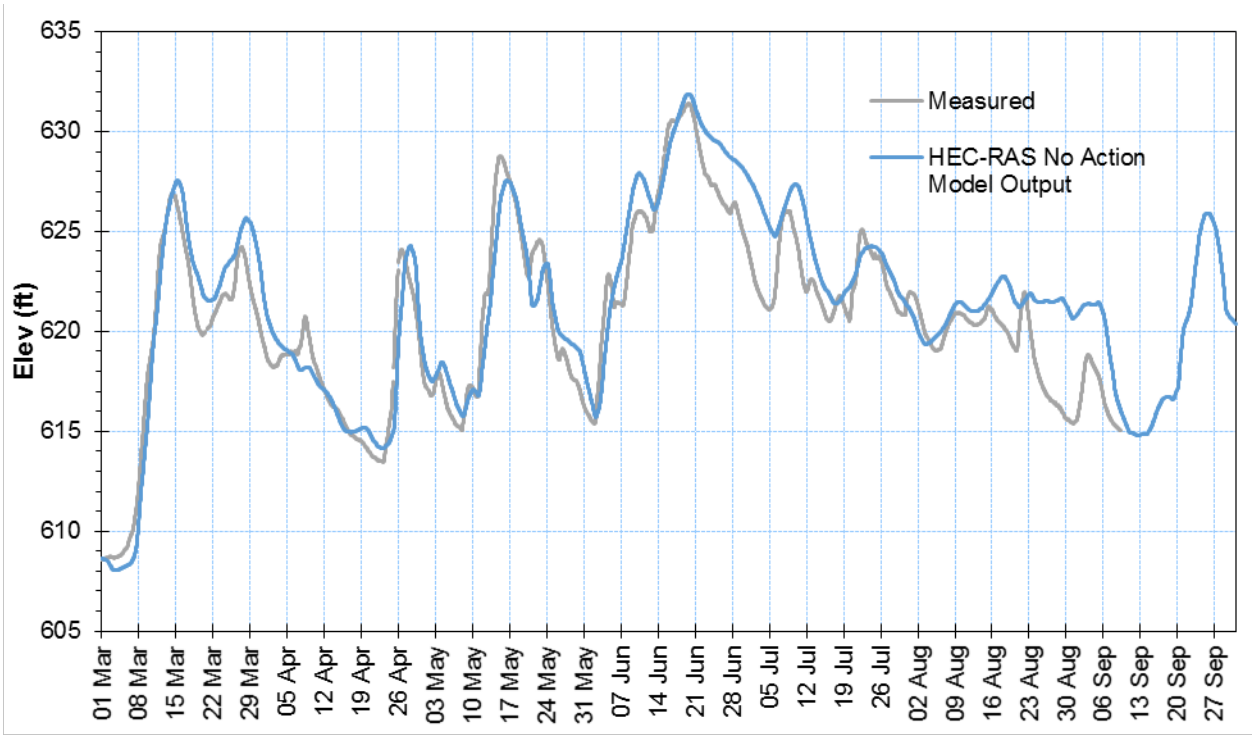


Figure 5-14. L-246 River Stage 2010 – measured vs modeled

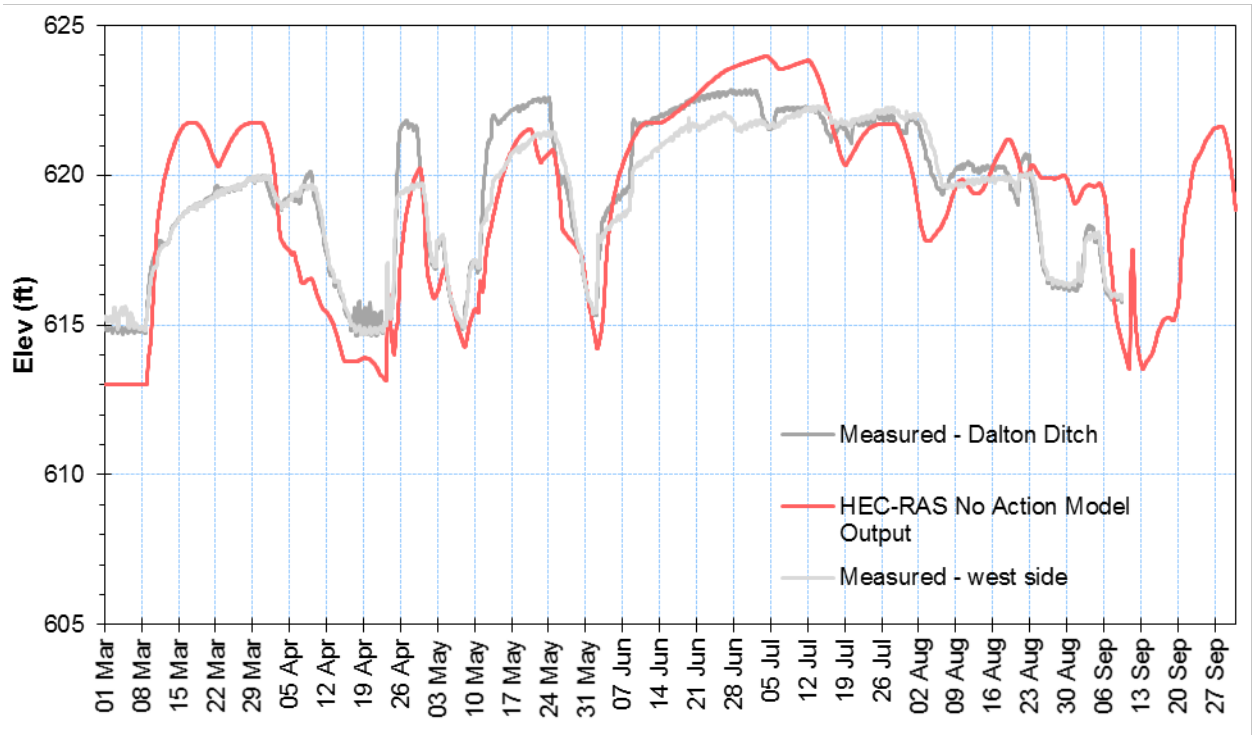


Figure 5-15. Dalton Ditch Stage 2010 – measured vs modeled

Note that in 2009, Figure 5-13, the model drains the area west of Palmer ditch too efficiently in June and August events. River stages on the Missouri, and correspondingly in Palmer ditch are also several feet too low during this same timeframe, which could be contributing to the discrepancy.

As an additional validation, 2011 and 1993 floods were run through the model and RAS mapper inundation extents were compared to actual inundation extents.

Figure 5-16 shows the aerial photography collected during the 2011 flood event with HEC-RAS storage areas at L-246 outlined in black. Figure 5-17 overlays model results for comparison. The 2011 event was not as severe on the lower river downstream of Kansas City. Interior flooding shown in the image is due to prolonged high river stages preventing rainfall runoff from draining out culverts, as well as the contribution of seepage. Model results overestimate the ponding in the interior during 2011. However, this could partially be from the model not accounting for pumping done by local land owners during the 2011 flood.

Figure 5-16. Flood inundation in 2011 at L-246

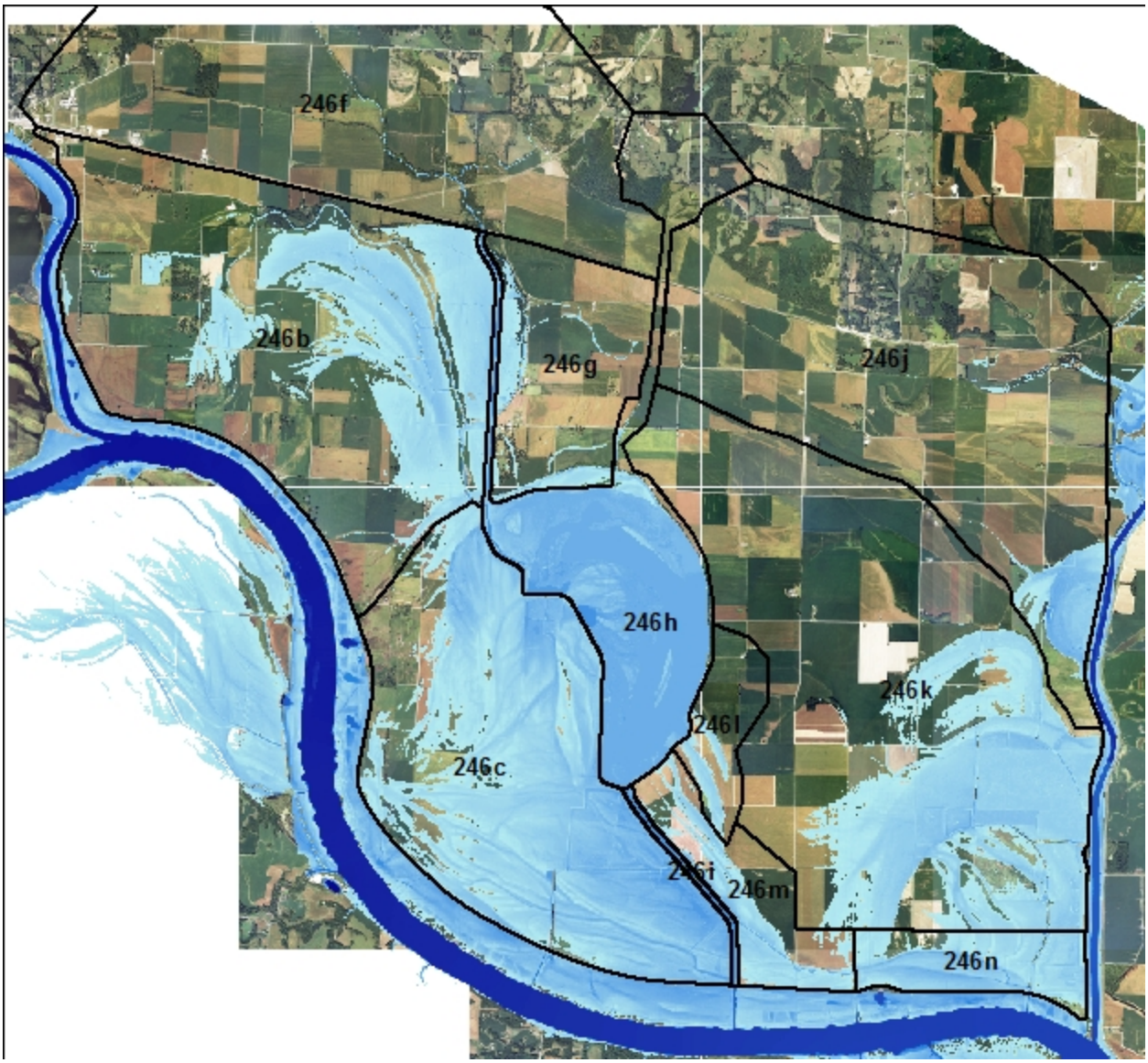


Figure 5-17. Flood inundation in 2011 at L-246 – model results

As at L-488, the aerial photography is from late August and the model results shown are the inundation at the maximum ponding depth experienced during the 2011 flood simulation. At this location on the river it is possible that the duration of time that flood waters were at a level high enough to cause crop damage on the levee interior was significantly less than on the upper river.

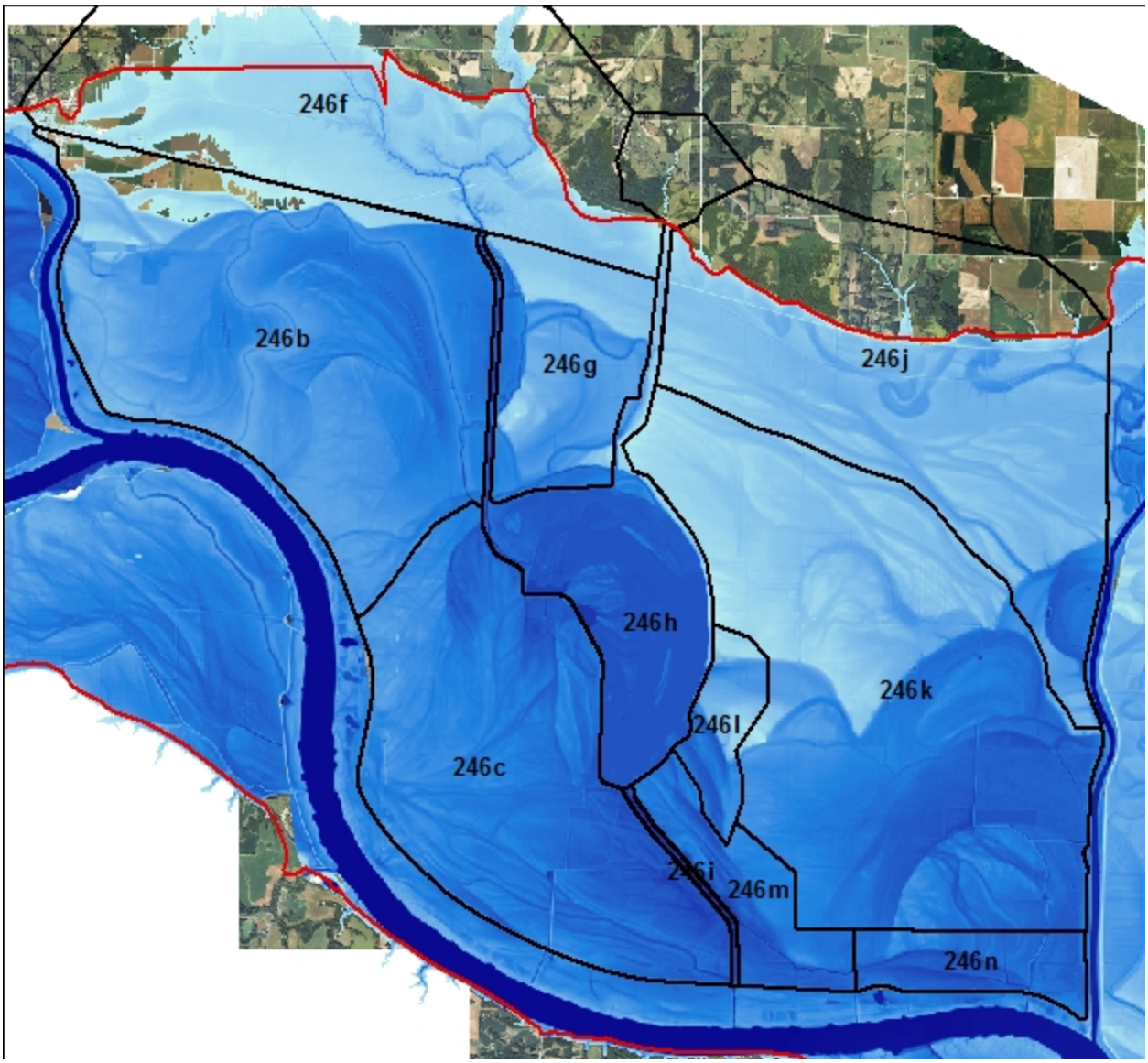


Figure 5-18. Flood inundation in 1993 at L-246 – model results

Figure 5-18 overlays the model results with the 1993 flood extents digitized during the post flood report from aerial photography. L-246 overtopped and breached at half a dozen locations, therefore validation from this particular event does not inform much about the performance of seepage and runoff calculations. However, as explained in the calibration report and in section 2.1, breaches were not accounted for in the model simulations, only overtopping. Validation of the 1993 inundation demonstrates that the model produces a realistic maximum inundation boundary with overtopping alone.

Overall, calibration and validation of the L-246 interior drainage model indicates that the model is acceptable for re-producing pooling water in the interior of the levee due to high river stages, seepage, and local bluff rainfall.

5.3 RESULTS

All interior drainage runs were performed in HEC-RAS 5.0 Release Candidate 2 (21-August-2015), the same version of the software used for the full Rulo to Mouth alternative runs. Period of record for the interior drainage models was limited by availability of rainfall data for the HMS models. For L-488 the record length was 64 years, from Aug 1948 to Dec 2012. For L-488 the record length was 63 years from Aug 1948 to Dec 2011. Stage and flow hydrographs for the interior areas of L-488 and L-246 were input into HEC-FIA models for evaluation of impacts to agricultural damage. Results are documented in the Environmental Consequences section of the EIS and the Flood Risk Management Technical Report.

To express the changes compared with the No Action alternative, the model results were evaluated by the same statistical evaluations made on the full models. Tables comparing min, max, and percentiles for each individual storage area are provided in **Attachment 7 – L-488 Interior Drainage Alternative Statistics** and **Attachment 8 – L-246 Interior Drainage Alternative Statistics**.

Most of the time the interior areas do not have water, as shown by the 10, 25, 50, and sometimes 75 percentile statistics being equal to the minimum elevation. Additionally, it appears that most of the time the alternatives didn't cause any change to the interior ponding compared to No Action, as shown by the 10 through 90 percentile daily change being equal to zero as well.

Seepage appears to be a large factor in changes from No Action. Take for example the year 1982. Alternative 4 had a complete pulse released during the month of April, which caused river stages near the mouth of the Chariton to increase by about five feet, as shown in Figure 5-19. The result was an increase of 3-4 feet of ponding depth on the interior of area 246K as shown in Figure 5-20, one of the larger increases over the period of record, and entirely due to seepage as there was no rainfall inflow from HMS during the month of August in this year. While this increase was modeled during April for Alternative 4, the interior flooding was modeled to have been higher than that in March and again in May and multiple other times during the same year.

Figure 5-19. Alternatives Flows at L-246 – 1982

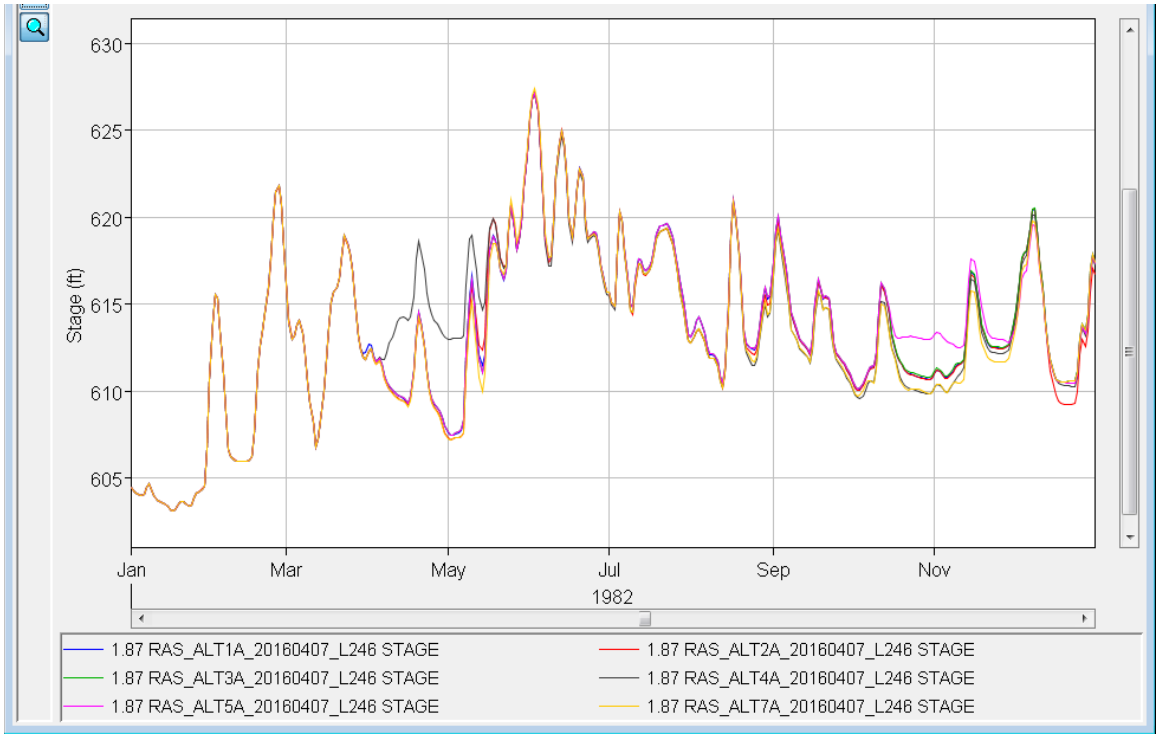
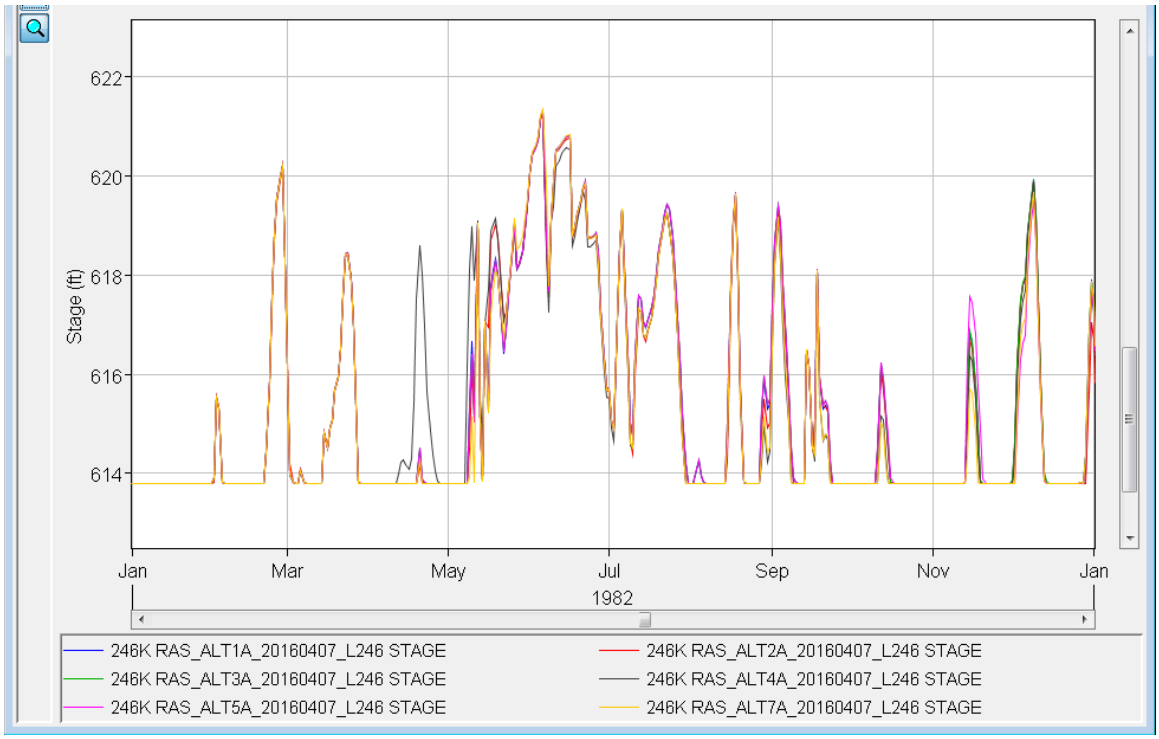


Figure 5-20. Alternative Stages in 246K – 1982



The interior drainage models provide a powerful tool to assess the complicated interaction between reservoir releases hundreds of miles upstream of a levee unit on interior ponding resulting from rainfall and/or seepage. However, limited conclusions can be extrapolated to the entire river. With such slight differences compared to No Action, it is difficult to separate the impact of flow changes from the reservoirs from the impact of added habitat to make global conclusions. Changes are highly localized, depending upon factors such as how low the culvert outlet is and the interior area available for ponding before damages occur.

The Omaha district ran a handful of sensitivity simulations at L-575 and L-536, comparing pumps to no pumps, half clogged culverts, and pulse level water surface elevations along the levee every single year. For results refer to the Gavins to Rulo **Appendix D**. An additional sensitivity simulation would be to hold the river geometry at the constant baseline condition, instead of accounting for habitat. Omaha used the No Action river geometry for all simulations, while the Kansas City district varied the river geometry according to the alternative assumptions. These sensitivity runs help separate the influence of the many contributing factors, as well as identify an upper threshold of influence based on the release rules of the pulses given the 62-years of downstream rainfall conditions.

6 CONCLUSIONS

The unsteady HEC-RAS model analysis gives a means to systematically evaluate differences in river elevations for various reservoir and habitat alternatives given the limitations presented in Section 4.3. These results can be fed into additional species and human considerations models, such as HEC-FIA, to screen alternatives for relative benefits and potential economic impacts. The outputs should be carefully examined with an eye towards the model limitations and judgement applied where needed to mitigate any potential pitfalls of the hydraulic analysis. An advantage to the alternative modeling in this current study compared to the Master Manual is the ability to account for differences in flow routings and river stages with varying amounts and distributions of habitat.

Flow change alternatives show the largest change in flow and stage duration statistics relative to No Action in upstream reaches. Downstream reaches, such as downstream of major tributaries such as the Kansas, Grand, Chariton, Osage and Gasconade Rivers show increasingly less change as drainage area increases. If flow change alternatives are considered for implementation, additional risk and uncertainty analysis is recommended to more comprehensively quantify risk of spring or fall pulse flows.

The analysis presented in this report is based off of alterations to the existing conditions HEC-RAS models. The steps of this analysis could be repeated if predictions of bed change are made for any of the alternatives. Having both analysis completed would provide a range of reasonable results throughout the planning horizon.

7 REFERENCES

FAA. (Aug 2007). *Advisory Circular No 150/520-33B Hazardous Wildlife Attractants on or Near Airports.* U.S. Department of Transportation Federal Aviation Administration.

Jacobson, R. B., Linder, G., & Bitner, C. (2015). *The Role of Floodplain Restoration in Mitigating Flood Risk, Lower Missouri River, USA.* Springer New York.

Jacobson, R., Annis, M., Colvin, M., James, D., Welker, T., & Parsley, M. (2016). *Missouri River Scaphirhynchus albus (pallid sturgeon) effects analysis—Integrative report 2016.* Columbia, MO: U.S. Geological Survey Scientific Investigations Report 2016–5064. Retrieved from http://dx.doi.org/10.3133/sir20165064

USACE. (1994). *The Great Flood of 1993 Post-Flood Report, Lower Missouri River Basin.* Kansas City, MO: U.S. Army Corps of Engineers Kansas City District.

USACE. (2003). *Upper Mississippi River System Flow Frequency Study - Hydrology and Hydraulics Appendix E.* Kansas City, MO: U.S. Army Corps of Enginers.

USACE. (2016a). *Missouri River Recovery Management Plan Time Series Data Development for Hydrologic Modeling.* U.S. Army Corps of Engineers, Northwestern Division, Omaha and Kansas City Districts.

USACE. (2016b). *Mainstem Missouri River Reservoir Simulation Alternatives Technical Report.* Omaha, NE: U.S. Army Corps of Engineers.

USACE. (2016c). *Missouri River Recovery Management Plan - Climate Change.* Omaha, NE: U.S. Army Corps of Engineers.

USACE. (Apr 2007). *Missouri River Fish and Wildlife Mitigation Program Draft Program Managment Plan.* U.S. Army Corps of Engineers.

USACE. (Aug 1998). *Missouri River Master Water Control Manual Review and Update Study Volume 11.* U.S. Army Corps of Engineers, Northwestern Division.

USACE. (Jan 2011). *Missouri River Recovery Program 2009 Spring Pulse and Rises Drainage Monotoring and Evaluation.* Omaha, NE: U.S. Army Corps of Engineers, Omaha District.

USACE. (July 2014). *Missouri River Incremental Flows Below Gavins Point Technical Report.* Omaha, NE: US Army Corps of Engineers Missouri River Basin Water Managment Division.

USACE. (May 2015). *Missouri River Unsteady HEC-RAS Model Calibration Report Appendix E Rulo to the Mouth.* Kansas City, MO: U.S. Army Corps of Engineers Kansas City District.

USACE. (Sept 2013). *Hydrologic Statistics Technical Report.* Omaha, NE: US Army Corps of Engineers Missouri River Basin Water Managment Division.

USACE. (Sept 2014). *Shallow Water Habitat Accounting Report.* Kansas City and Omaha: U.S. Army Corps of Engineers.

USFWS. (Dec 2003). *U.S. Fish and Wildlife Service 2003 Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project.* U.S. Fish and Wildlife Service.

Missouri River Unsteady HEC-RAS Model
Revision Log

Revision Number	Date	Description of changes	Distribution
Rev 1	6/9/2015	Bed data was corrected to account for Temporary Bench Mark (TBM) errors discovered during a spring 2015 quality control check of the hydrosurvey spreadsheet. 8 TBMs were found to be in error, impacting 64 model cross sections. The maximum positive shift in bed data was 1.27 and the maximum negative shift was -1.31. Cross sections were only modified if the impact was greater than two tenths of a foot. Modifications were between the upstream limit of cross section 449.44 near the St. Joseph gage, and downstream limit of cross section 286.16 near Waverly. Calibration was checked at each gage from St. Joseph to Waverly. Calibration at St. Joseph was improved after the changes, calibration at Kansas City remained unchanged, and at Waverly the flow varied factors were adjusted to return the calibration to Post-ATR model accuracy. Calibration Metrics were not re-calculated because the changes were so small it is not likely to significantly change the calibration precision of the model. Calibration of the Mississippi River at gage locations was re-evaluated and slightly improved. Lateral structure and storage area connection weir coefficients in the crossover area were double checked for consistency and revised. All SAC weir coefficients were lowered to 0.3, except the railroad (1.5) and the interstate (2). All lateral structure weir coefficients on the crossover reach were lowered to 0.3, except a few that were obviously high ground (0.5). Storage area connections at Rulo representing the Railroad and Highway 159 have been renamed to: rr1, rr2, rr3, rr4 and hwy1-2, hwy3, hwy4, and hwy5. Corrections made to SAs/LSs/SACs after examining period of record leveed area flooding: removed closure gaps on lateral structures: 455a, 385q, 385r, arm, cid-k, sal making the assumption that the gaps will be closed properly prior to flooding. Connected LS 220.1 how3 to the proper SA. Fixed bogus low spot at the beginning of how4. Corrections made to bank sta xsec 14.01 and 15.1. Discovered while making modifications to base model for alternatives evaluation.	(1) National Weather Service, (2) Riverside for IDEKER lawsuit
Rev 2	9/11/2015	Lateral Structures were tweaked so that they did not extend into junction zones, which are downstream of the last cross section in a reach. This was necessary for the upgrade to the new version of RAS 5.0. Corrections to cross sections 479.8, 479.09, 478.4, first ineffective area representing navigation structure was switched from temporary to permanent. Correction to cross section 472.06, ineffective & levee point stationing were not aligned. Adjusted levee point at cross section 311.07 to elev 690.6	None
	10/21/2015	Confirmed run compatibility with RAS 5.0 Release Candidate 2	

Revision Number	Date	Description of changes	Distribution
Rev 2 (cont'd)		Removed initial conditions on all SAs, except a few leveed areas that need a starting water surface for stability at initial overtopping. In previous versions of HEC-RAS, if a lateral structure had an open connection to the river (such as a storage area that represents a tieback) the initial water surface in the receiving storage area had to be close to the water surface in the river or the model would go unstable in the first timestep. A spreadsheet was developed to auto populate the initial conditions. However, in the new version of RAS 5.0, if a SA initial condition is left blank the default starting water surface is equal to the river if water is over the lateral structure (if not, the default starting water surface is set to empty). Therefore, the model is more versatile for distribution with the initial conditions set to blank.	
Rev 3	10/28/2015	Added culverts with flap gates to drain the storage areas post floods SAC chrt-tuqt was accidently connected to tuq not tuqt LS blt1 and crk swapped river stationing on blt1 and crk lateral structures SAC sug1-2 removed ditch that was draining sug1 out the north side	
	11/4/2015	xsec 177.28 repaired at sandbar LS wol3 and wol3-t lowered weir coeffs from 1.5 to 1 LS cnc01 lowered weir coeff from 2 to 1.5 raised culverts to be equal to starting ws elev in wol3 (745.5), gr03 (651), gr04 (650), gr05 (649.7), cnc07 (427.6)	(1) Final Run of No Action Alternative for Draft EIS
	11/16/2015	SAC capt-2 lowered weir coeff from 1.5 to 1 LS cnc01 lowered first weir coeff (27.871) from 1.5 to 1 SAC gr09 and gr08 lowered weir coeffs from 1.5 to 1 SAC ckl lowered weir coeff from 1.5 to 1 SAC teb3-mokt lowered weir coeff (0.75 to 0.5) SAC mokt-mok lowered weir coeff (2 to 1.5) LS teb3 lowered weir coeff from 0.75 to 0.5 LS mok lowered weir coeff from 2 to 1.5	(2) Final Run BiOp and IRC Alternatives for Draft EIS (3) Year 15 (2032deg) runs

Process:

1. Run HEC-RAS steady flow plan for 2-yr and 5-yr UMRSFFS flows
2. Export GIS data for GeoRAS: cross sections and profiles only, not including storage areas
3. In GIS, using GeoRAS commands, follow the steps to create inundation area for 5-yr
4. Widened bounding polygon to include areas that did not get captured by cross section extents only, but should be mapped as wet in the 5-yr [boundary.shp]
5. Identified (excluded) areas that should not be counted as floodplain connectivity (even though they may be inundated at the 5-yr level) [excluded.shp]
6. Re-computed inundation area for 5-yr and computed inundation area for 2-yr with new bounding polygon

   Repeat steps 7-16 for both 5-yr and 2-yr:

7. Create a new file geodatabase [Math5yr.gdb] and import inundation boundary [b5yr_raw]
8. Use Repair Geometry tool on boundary [b5yr_raw]
9. Erase SAs (SAs included tributaries/tiebacks, however, when mapping for future purposes may actually want to create a new SA set for this step without tribs and high ground connections so these areas are mapped … wish list item) [b5yr_eraseSA]
10. Erase Excluded areas [b5yr_eraseExcluded]
11. Select the largest polygon (assume this represents all inundation areas with connectivity to the river) and export to new shapefile [b5yr_one]
12. Import state boundaries [states.shp] and BiOp segment boundaries [biopsegments.shp] into the file geodatabase
13. Split by state [Kansas, Missouri, Nebraska] and split by BiOp Segment [segment13, segment14, segment15]
14. Combine split feature classes into one and compute acres [b5yr_acres]
15. Export to final directory [5yr_existing.shp]
16. Subtract acres of river [River.gdb] (see next process) in each state for final acres of floodplain connectivity
17. To view in Google Earth use the dice tool (20,000 verticies) and then in Google Earth select File > Import [5yr_dice]

Process for calculating river:

1. Obtained depth grid of August 50% from RAS Mapper computed as a part of the HAMP SWH accounting effort (three segments, all .vrt file type) [1Depth (50%).vrt, 2Depth (50%).vrt, 3Depth (50%).vrt]
2. Used Reclassify tool in GIS to make an img with cell value of 1 where there was water and cell value of NoData where there was no water (one for each segment) [reclass1, reclass2, reclass3]
3. Used Raster to Polygon tool to create polygon with a perimeter at the bounds of the img (one for each segment) [poly1, poly2, poly3]
4. Merge the polygons into one shapefile [poly_all]

5. Use the clip tool to get rid of extra stuff (started with Ben's HAMP clip polygon and modified it to also remove all wet areas in chutes and Omaha area) [poly_all_clip]
6. Select the largest shapefile(s) to minimize size and complexity and hopefully remove some of the SWH areas
7. Created a new file geodatabase [River.gdb] and imported the largest shapefile from previous step for the split calculation [poly_one]
8. Import state boundaries [states.shp] and BiOp segment boundaries [biopsegments.shp] into the file geodatabase
9. Split by state [Kansas, Missouri, Nebraska] and split by BiOp Segment [segment13, segment14, segment15]
10. Combine split feature classes into one and compute acres [river]
11. Use dice tool for viewing in google earth [river_dice]

St. Joseph, MO

Flow **Stage**

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	7,416	7,537	7,416	7,416	7,416	7,416
10%	18,181	18,170	18,250	18,020	18,231	18,094
25%	26,258	25,180	26,443	25,719	26,317	25,931
50%	39,282	38,478	39,156	38,950	39,046	38,988
75%	50,589	52,358	50,527	51,032	50,703	51,328
90%	68,612	69,893	68,614	70,557	69,439	69,001
Max	292,224	293,577	297,961	297,991	297,994	297,977

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	787.8	787.8	787.8	787.8	787.8	787.8
10%	791.3	791.3	791.3	791.2	791.3	791.3
25%	793.8	793.4	793.8	793.6	793.8	793.7
50%	797.4	797.1	797.4	797.3	797.4	797.3
75%	799.6	799.7	799.6	799.7	799.7	799.8
90%	802.6	802.4	802.6	802.9	802.8	802.6
Max	820.3	819.2	820.8	820.8	820.8	820.8

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	121	0	0	0	0
10%	-	-11	69	-162	49	-87
25%	-	-1,078	185	-539	60	-326
50%	-	-804	-126	-332	-236	-294
75%	-	1,769	-62	443	114	739
90%	-	1,282	2	1,945	827	389
Max	-	1,353	5,738	5,768	5,770	5,754

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	-0.3	0.1	-0.2	0.0	-0.1
50%	-	-0.2	0.0	0.0	0.0	0.0
75%	-	0.1	0.0	0.1	0.1	0.2
90%	-	-0.2	0.1	0.3	0.2	0.1
Max	-	-1.1	0.4	0.4	0.4	0.4

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-31,105	-29,178	-22,895	-45,342	-29,282
10%	-	-2,958	-126	-1,975	-439	-1,200
25%	-	-261	-26	-115	-45	-138
50%	-	0	0	-1	0	-3
75%	-	182	27	15	24	10
90%	-	3,480	134	128	170	130
Max	-	39,822	17,417	39,022	42,389	34,299

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-7.4	-3.1	-6.8	-4.0	-5.4
10%	-	-1.0	0.0	-0.4	-0.1	-0.2
25%	-	-0.3	0.0	0.0	0.0	0.0
50%	-	-0.1	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.3	0.1	0.1	0.1	0.1
Max	-	6.5	3.0	7.5	7.2	5.9

Kansas City, MO

Flow **Stage**

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	8,277	8,279	8,278	8,278	8,278	8,278
10%	21,119	21,171	21,204	20,916	21,145	20,972
25%	32,300	30,388	32,520	31,715	32,361	31,905
50%	43,796	43,134	43,664	43,510	43,611	43,699
75%	62,062	63,520	62,052	63,303	62,753	63,201
90%	88,931	89,820	89,022	89,509	88,806	88,864
Max	485,993	485,144	489,166	489,198	489,199	489,176

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	706.6	706.6	706.6	706.6	706.6	706.6
10%	711.3	711.3	711.3	711.2	711.3	711.2
25%	714.2	713.7	714.2	714.0	714.2	714.1
50%	717.0	716.8	716.9	716.9	716.9	716.9
75%	720.3	720.5	720.3	720.5	720.4	720.5
90%	724.3	724.3	724.3	724.3	724.2	724.2
Max	750.5	750.5	750.6	750.6	750.6	750.6

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	2	1	1	1	1
10%	-	52	86	-203	26	-147
25%	-	-1,913	220	-585	61	-395
50%	-	-662	-131	-286	-185	-97
75%	-	1,458	-10	1,242	691	1,139
90%	-	889	91	579	-124	-66
Max	-	-849	3,173	3,205	3,206	3,183

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	-0.1	0.0	0.0
25%	-	-0.5	0.1	-0.1	0.0	-0.1
50%	-	-0.2	0.0	-0.1	0.0	0.0
75%	-	0.2	0.0	0.2	0.1	0.1
90%	-	0.1	0.0	0.0	-0.1	0.0
Max	-	0.0	0.1	0.1	0.1	0.1

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-30,814	-28,546	-30,738	-41,073	-30,742
10%	-	-2,942	-161	-1,965	-470	-1,184
25%	-	-310	-41	-147	-71	-170
50%	-	0	0	-3	0	-5
75%	-	234	37	21	34	15
90%	-	3,483	176	157	220	176
Max	-	40,971	17,889	40,715	42,346	34,283

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-6.3	-3.6	-6.3	-4.2	-4.7
10%	-	-0.6	0.0	-0.4	-0.1	-0.2
25%	-	-0.1	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.5	0.0	0.0	0.0	0.0
Max	-	6.4	2.6	6.9	6.8	6.0

Boonville, MO

Flow **Stage**

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	9,517	9,578	9,517	9,517	9,517	9,517
10%	23,769	23,838	23,872	23,632	23,853	23,677
25%	36,849	35,517	36,935	36,422	36,796	36,528
50%	49,428	49,140	49,291	49,157	49,326	49,366
75%	75,456	76,426	75,416	77,050	76,432	76,444
90%	112,936	113,594	112,792	113,707	112,562	112,964
Max	654,938	626,469	654,804	655,142	655,125	654,963

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	564.2	564.2	564.2	564.2	564.2	564.2
10%	568.1	568.1	568.1	568.0	568.1	568.0
25%	571.2	570.9	571.2	571.1	571.1	571.1
50%	573.5	573.5	573.5	573.5	573.5	573.5
75%	577.5	577.5	577.6	577.6	577.6	577.6
90%	581.6	581.7	581.7	581.8	581.7	581.7
Max	602.6	602.3	602.6	602.6	602.6	602.6

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	61	0	0	0	0
10%	-	69	103	-137	84	-92
25%	-	-1,332	86	-426	-53	-321
50%	-	-289	-137	-271	-102	-62
75%	-	970	-39	1,594	976	988
90%	-	658	-144	771	-374	28
Max	-	-28,470	-135	204	187	25

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	-0.3	0.0	-0.1	0.0	-0.1
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.1	0.2	0.1	0.1
90%	-	0.0	0.1	0.2	0.1	0.1
Max	-	-0.3	0.1	0.1	0.1	0.1

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-49,054	-25,928	-31,383	-45,156	-31,385
10%	-	-3,170	-183	-1,922	-542	-1,184
25%	-	-457	-40	-168	-74	-191
50%	-	2	0	-2	0	-3
75%	-	427	49	30	46	24
90%	-	3,514	199	177	246	202
Max	-	37,211	17,270	46,093	42,237	36,262

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-5.3	-2.3	-5.3	-3.3	-4.0
10%	-	-0.5	0.0	-0.2	0.0	-0.2
25%	-	-0.1	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.1	0.1	0.1	0.1
90%	-	0.5	0.2	0.2	0.2	0.2
Max	-	5.5	2.1	6.1	6.0	5.6

Hermann, MO

Flow **Stage**

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	11,158	11,156	11,158	11,158	11,158	11,158
10%	29,553	29,291	29,784	29,338	29,785	29,442
25%	43,218	42,180	43,275	42,929	43,093	42,895
50%	59,963	60,130	59,806	59,695	59,859	60,070
75%	97,843	98,447	97,795	98,159	97,938	98,022
90%	151,469	151,722	151,337	152,104	151,355	151,577
Max	646,417	613,212	640,265	640,730	640,821	640,004

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	479.7	479.7	479.7	479.7	479.7	479.7
10%	483.6	483.6	483.7	483.6	483.7	483.6
25%	486.5	486.3	486.5	486.4	486.4	486.4
50%	489.2	489.3	489.2	489.2	489.2	489.2
75%	494.0	494.1	494.0	494.0	494.0	494.0
90%	499.6	499.6	499.5	499.6	499.5	499.5
Max	519.8	519.6	519.7	519.7	519.7	519.7

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-2	0	0	0	0
10%	-	-262	231	-214	232	-111
25%	-	-1,038	57	-289	-126	-323
50%	-	167	-157	-268	-104	107
75%	-	604	-48	316	95	179
90%	-	253	-131	636	-114	109
Max	-	-33,205	-6,153	-5,688	-5,597	-6,413

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	-0.2	0.0	0.0	0.0	-0.1
50%	-	0.1	0.0	-0.1	0.0	0.0
75%	-	0.1	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	-0.3	-0.1	-0.1	-0.1	-0.1

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-67,618	-24,872	-28,542	-50,560	-28,545
10%	-	-3,183	-236	-1,850	-655	-1,207
25%	-	-504	-50	-204	-92	-220
50%	-	3	0	-1	0	-3
75%	-	483	72	48	68	42
90%	-	3,521	266	238	318	286
Max	-	62,321	17,923	51,790	41,833	36,972

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-5.3	-3.1	-4.5	-3.4	-3.6
10%	-	-0.4	0.0	-0.2	-0.1	-0.2
25%	-	-0.1	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.4	0.0	0.0	0.0	0.0
Max	-	6.1	2.1	5.7	5.9	5.4

St Louis, MO

Flow **Stage**

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	44,420	44,213	44,421	44,421	44,420	44,421
10%	94,077	94,153	94,298	93,860	94,277	93,908
25%	122,418	121,689	122,487	122,291	122,470	122,414
50%	167,124	167,013	167,025	166,959	167,571	167,047
75%	245,980	247,085	245,861	246,330	245,955	246,705
90%	370,674	371,027	370,328	372,553	369,788	371,059
Max	1,060,881	1,037,179	1,055,878	1,056,156	1,056,190	1,055,883

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	372.3	372.3	372.3	372.3	372.3	372.3
10%	379.8	379.8	379.8	379.8	379.8	379.8
25%	383.1	383.0	383.1	383.0	383.1	383.1
50%	387.6	387.6	387.6	387.5	387.6	387.6
75%	394.0	394.1	394.0	394.1	394.0	394.1
90%	402.3	402.3	402.3	402.4	402.3	402.3
Max	428.3	427.7	428.2	428.2	428.2	428.2

Min, max, percentile change from No Action

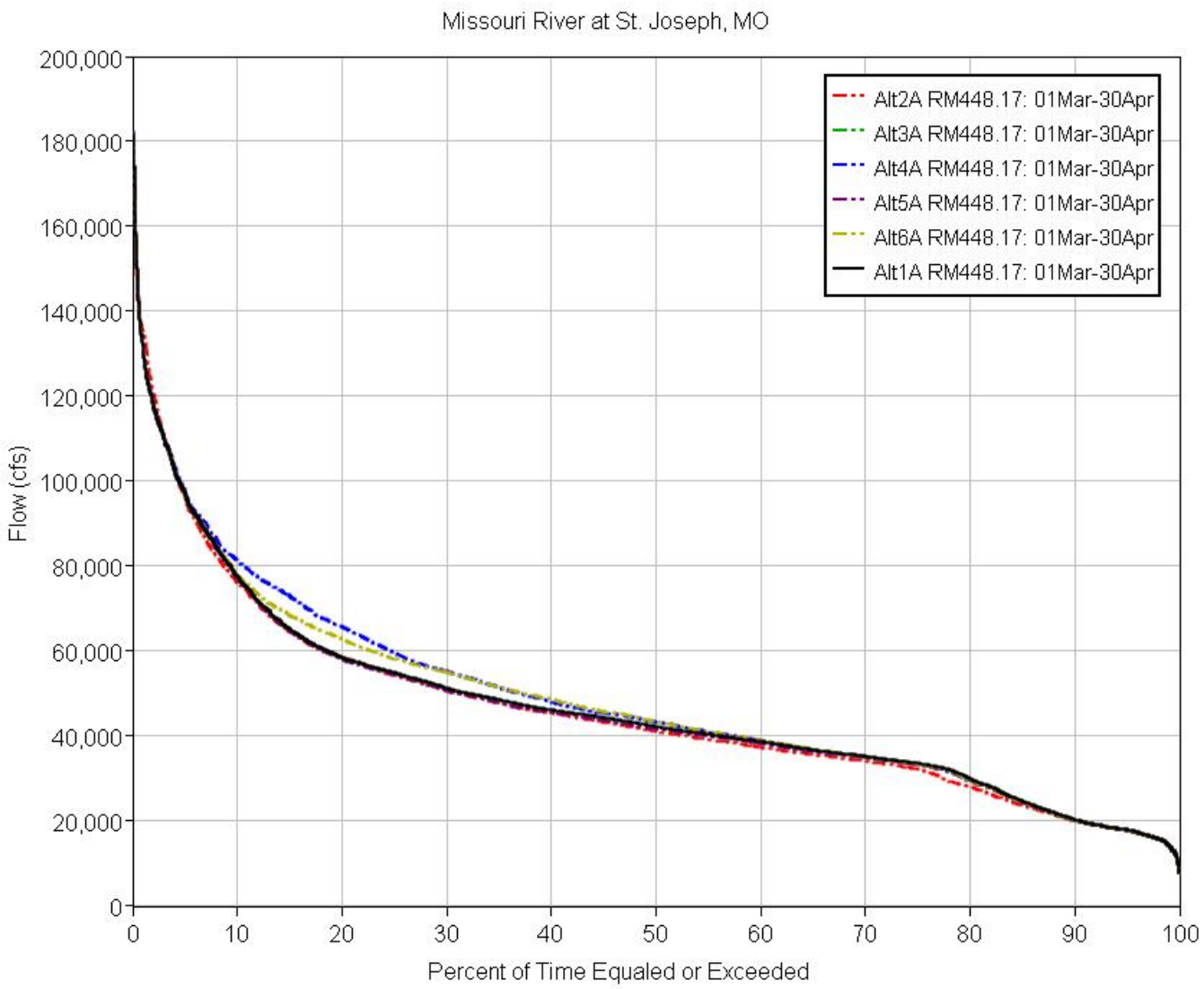
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-207	0	0	0	0
10%	-	76	221	-218	200	-169
25%	-	-729	69	-127	51	-5
50%	-	-111	-99	-165	447	-77
75%	-	1,105	-119	349	-25	725
90%	-	353	-345	1,879	-886	385
Max	-	-23,702	-5,003	-4,725	-4,691	-4,998

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	-0.1	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.1	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.1	0.0	0.0
Max	-	-0.7	-0.1	-0.1	-0.1	-0.1

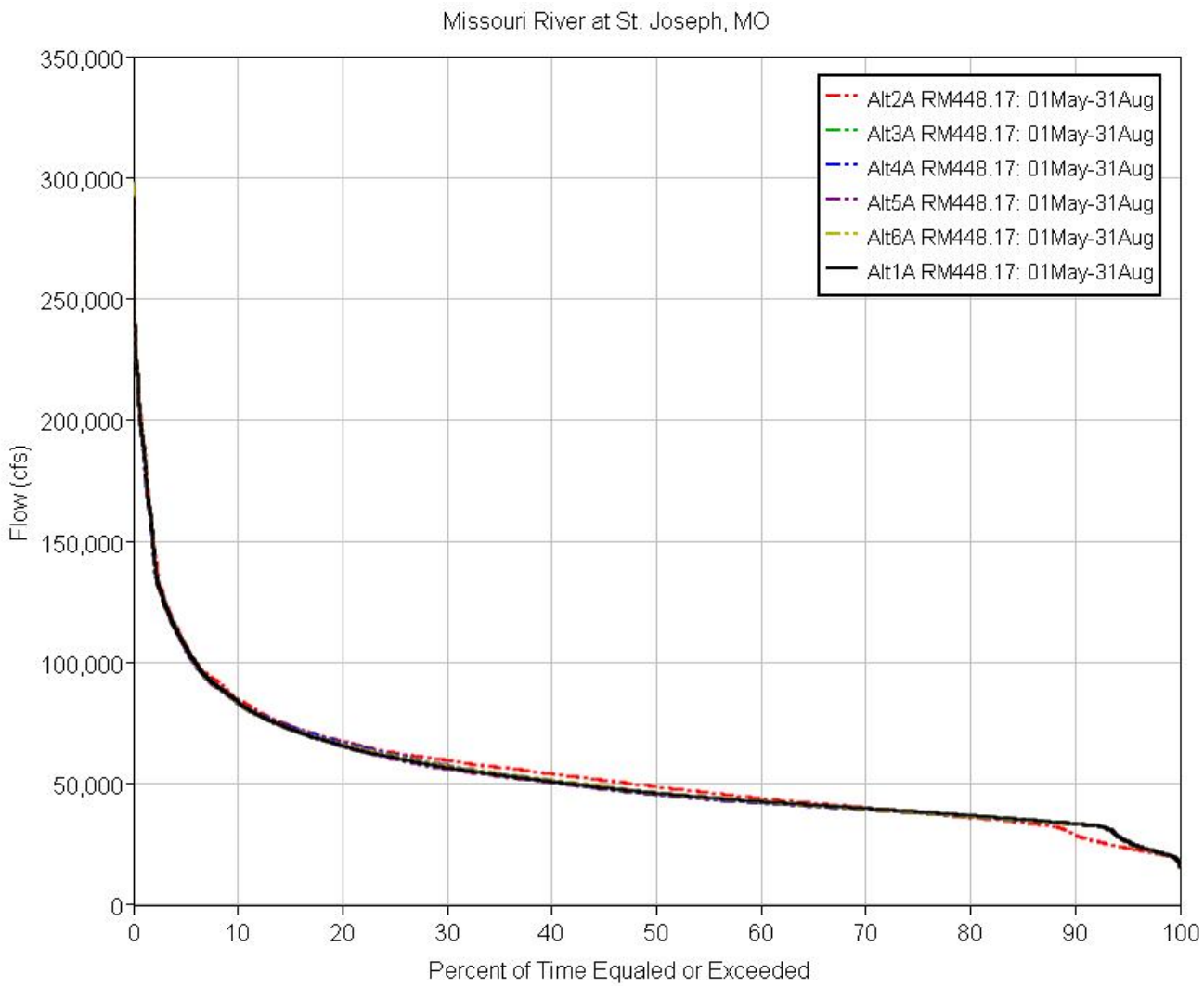
Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-29,382	-24,296	-25,831	-44,581	-25,880
10%	-	-3,146	-311	-1,814	-690	-1,197
25%	-	-527	-83	-271	-142	-272
50%	-	5	1	-6	0	-10
75%	-	515	106	75	105	72
90%	-	3,493	324	315	381	350
Max	-	102,322	17,806	50,207	42,837	39,593

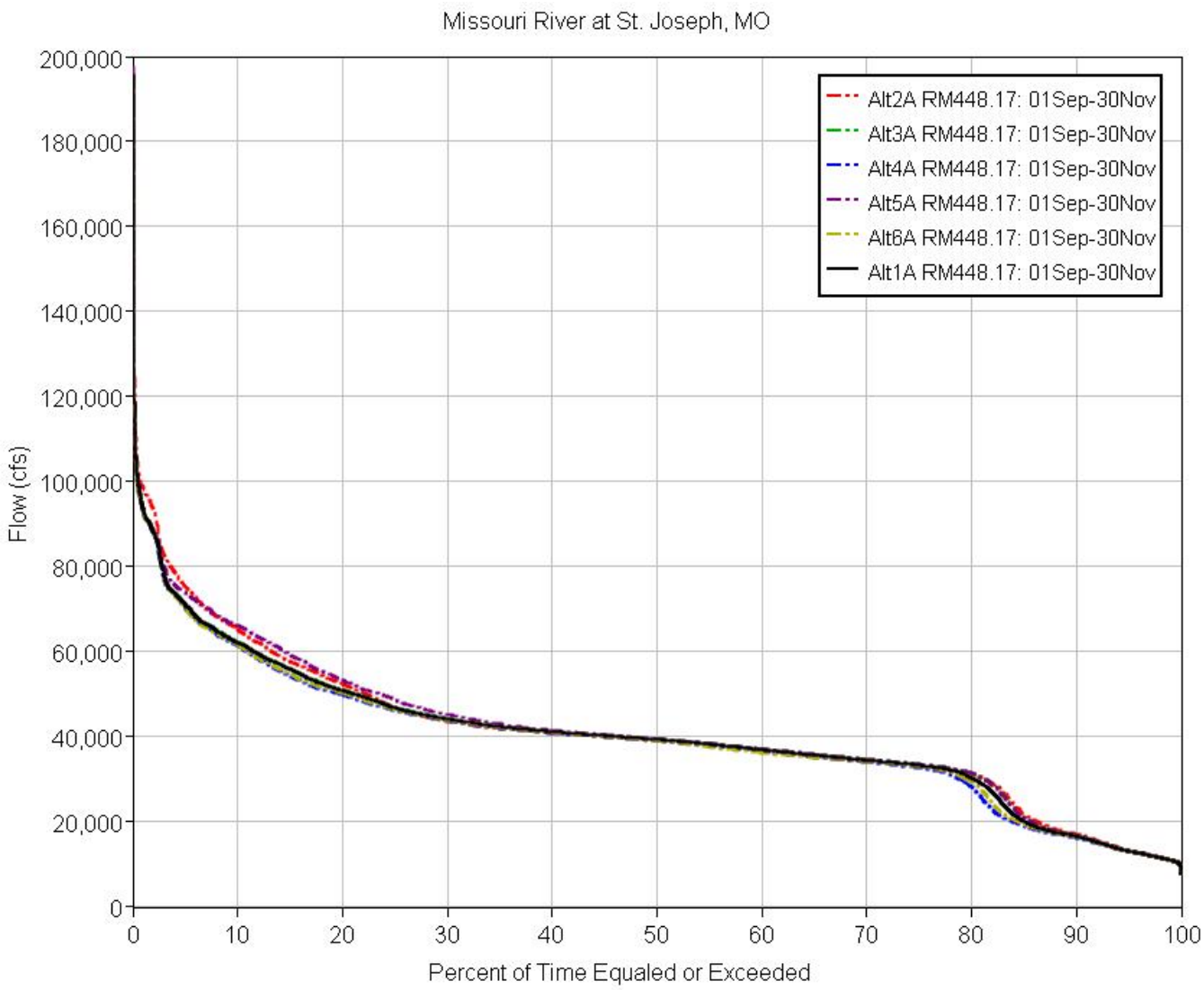
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-3.0	-2.0	-3.5	-2.5	-2.3
10%	-	-0.3	0.0	-0.2	-0.1	-0.1
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.3	0.0	0.0	0.0	0.0
Max	-	7.0	1.2	4.0	4.0	3.7



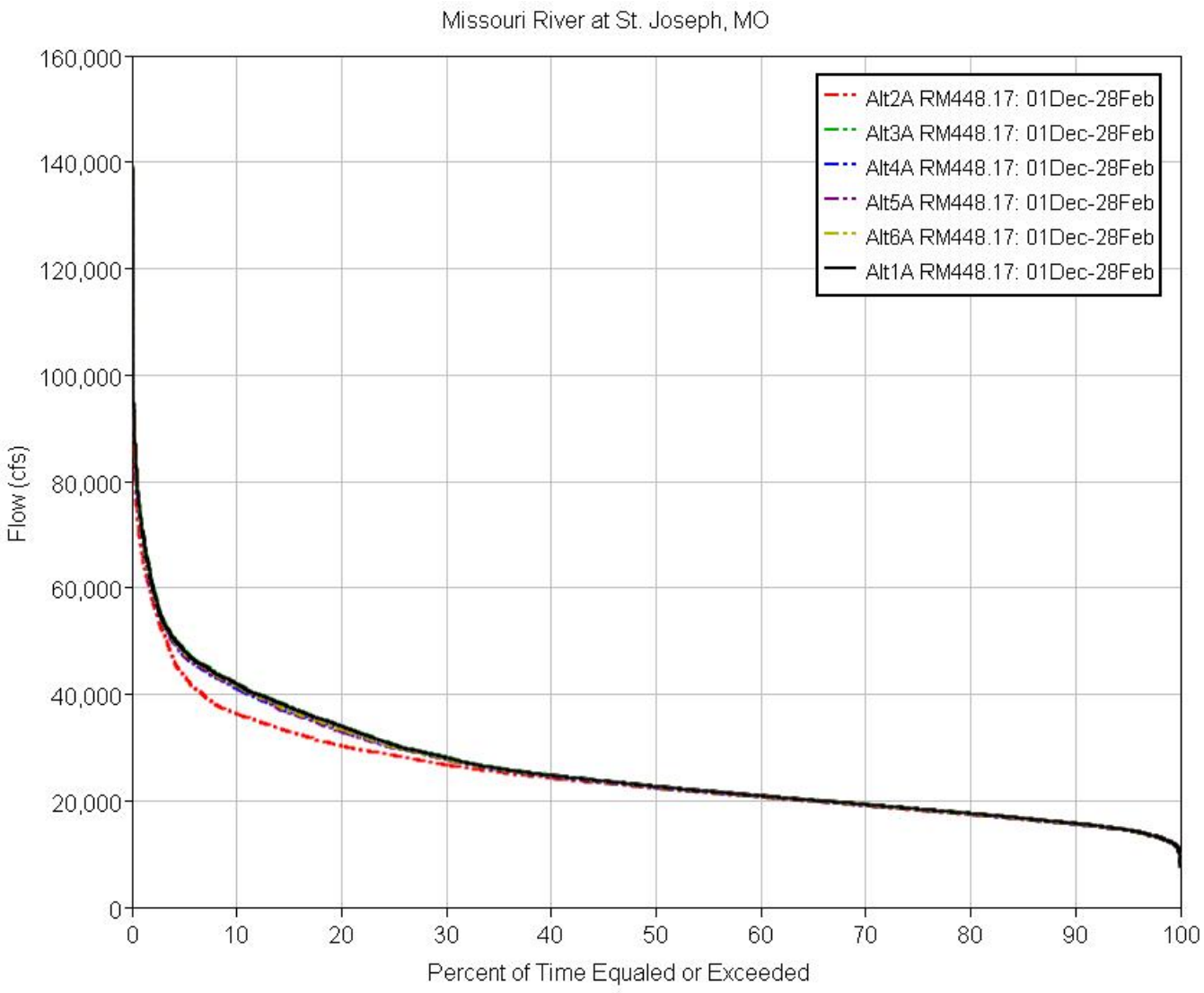
St. Joseph Spring Duration



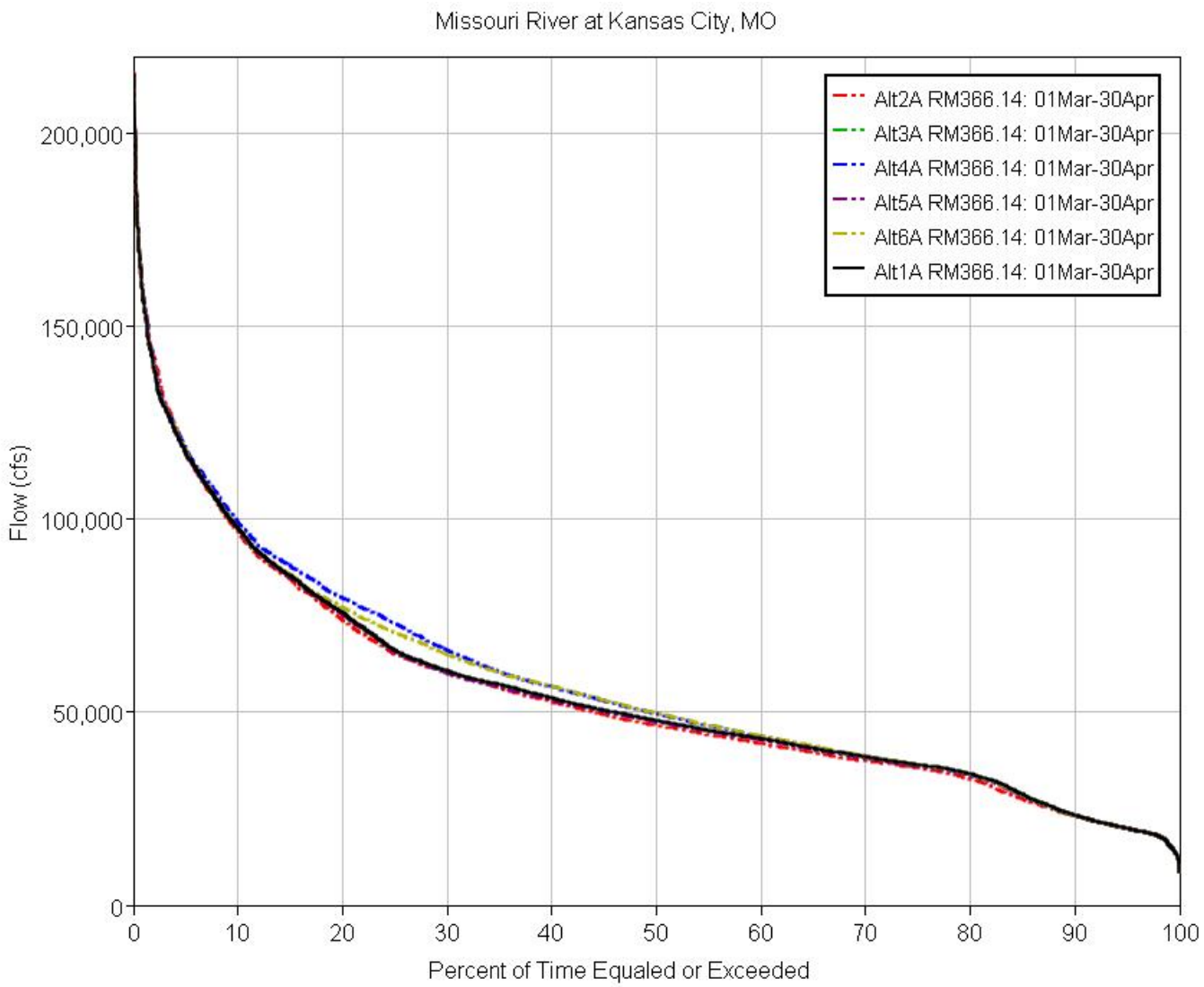
St. Joseph Summer Duration



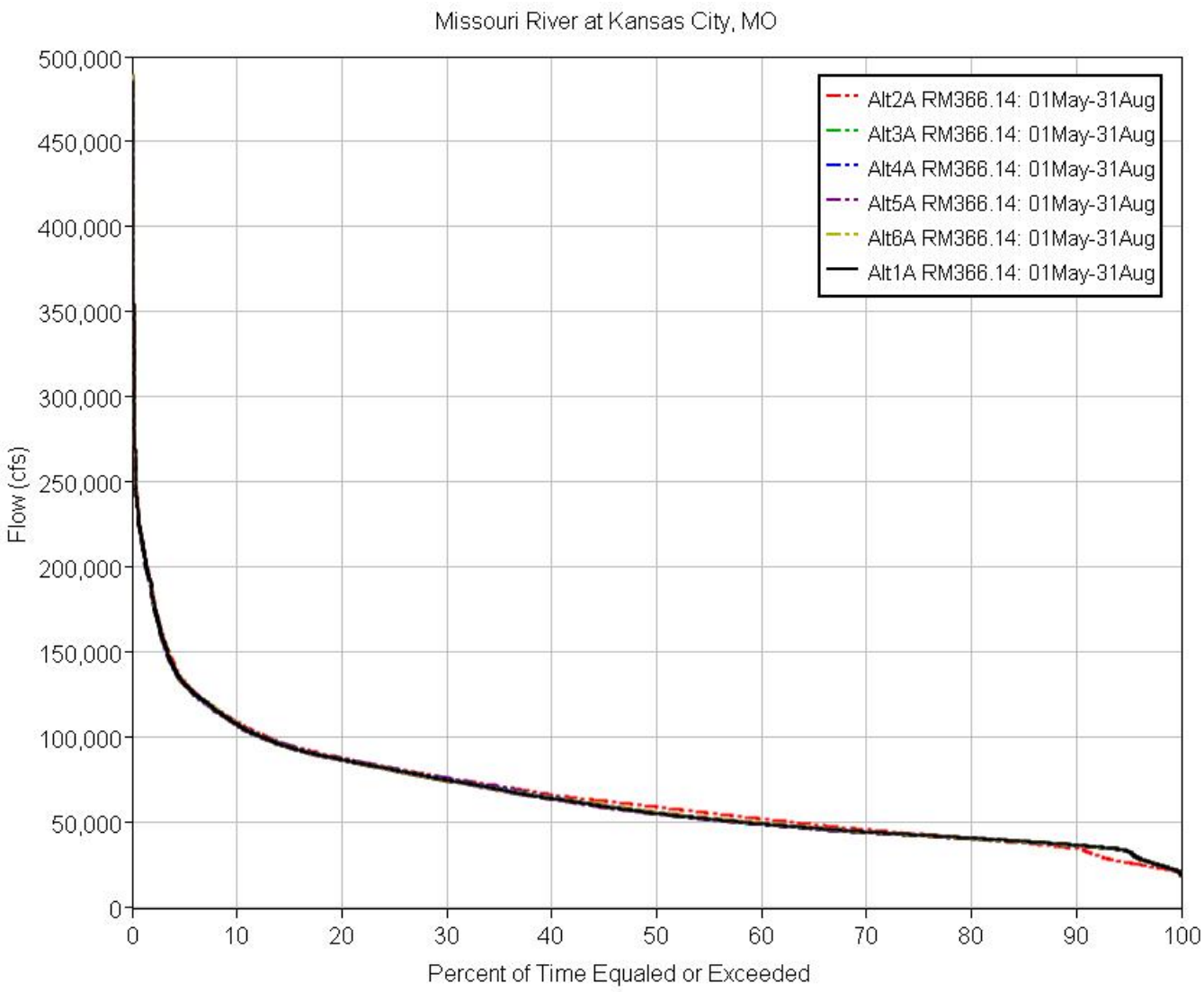
St. Joseph Fall Duration



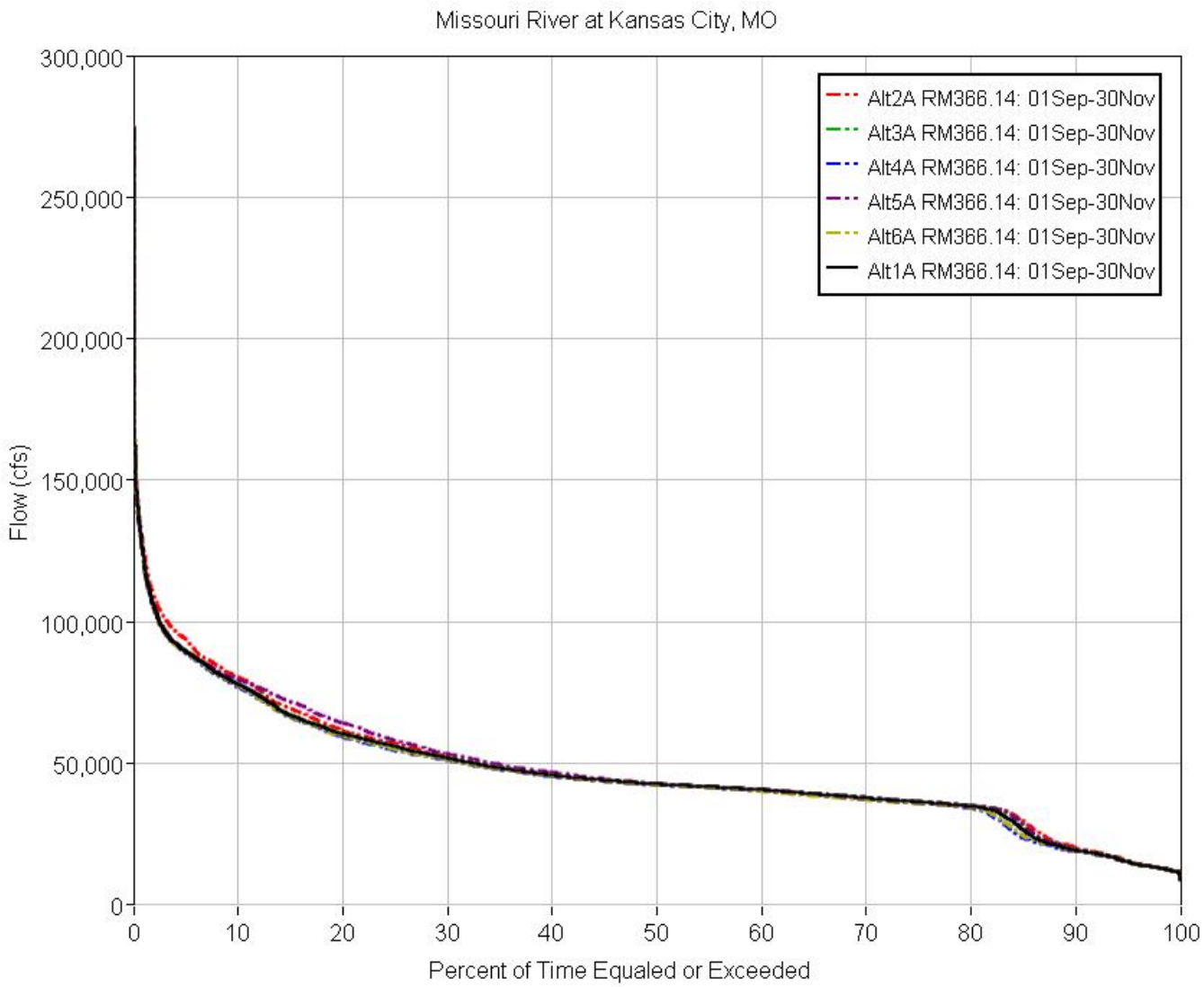
St. Joseph Winter Duration



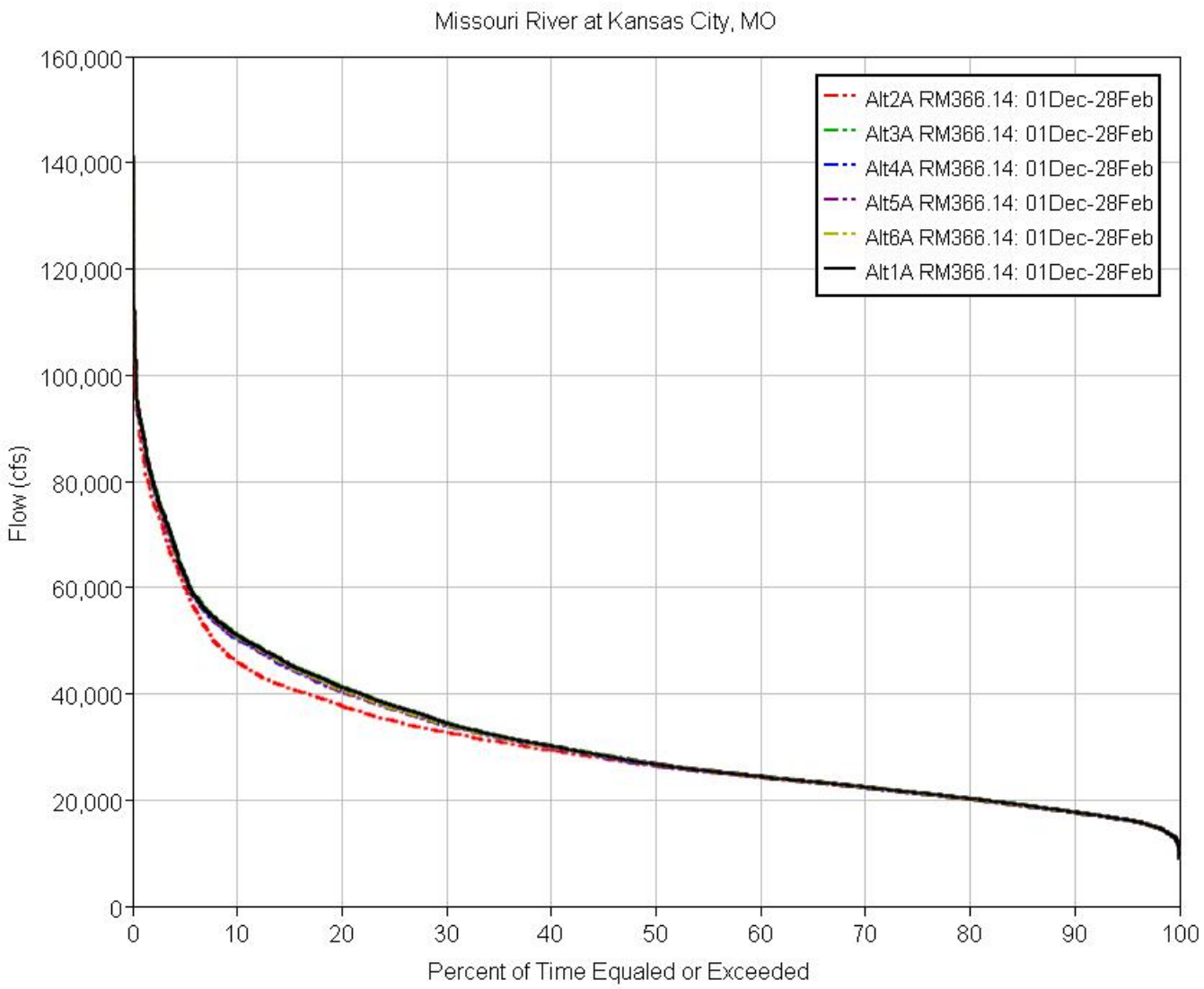
Kansas City Spring Duration



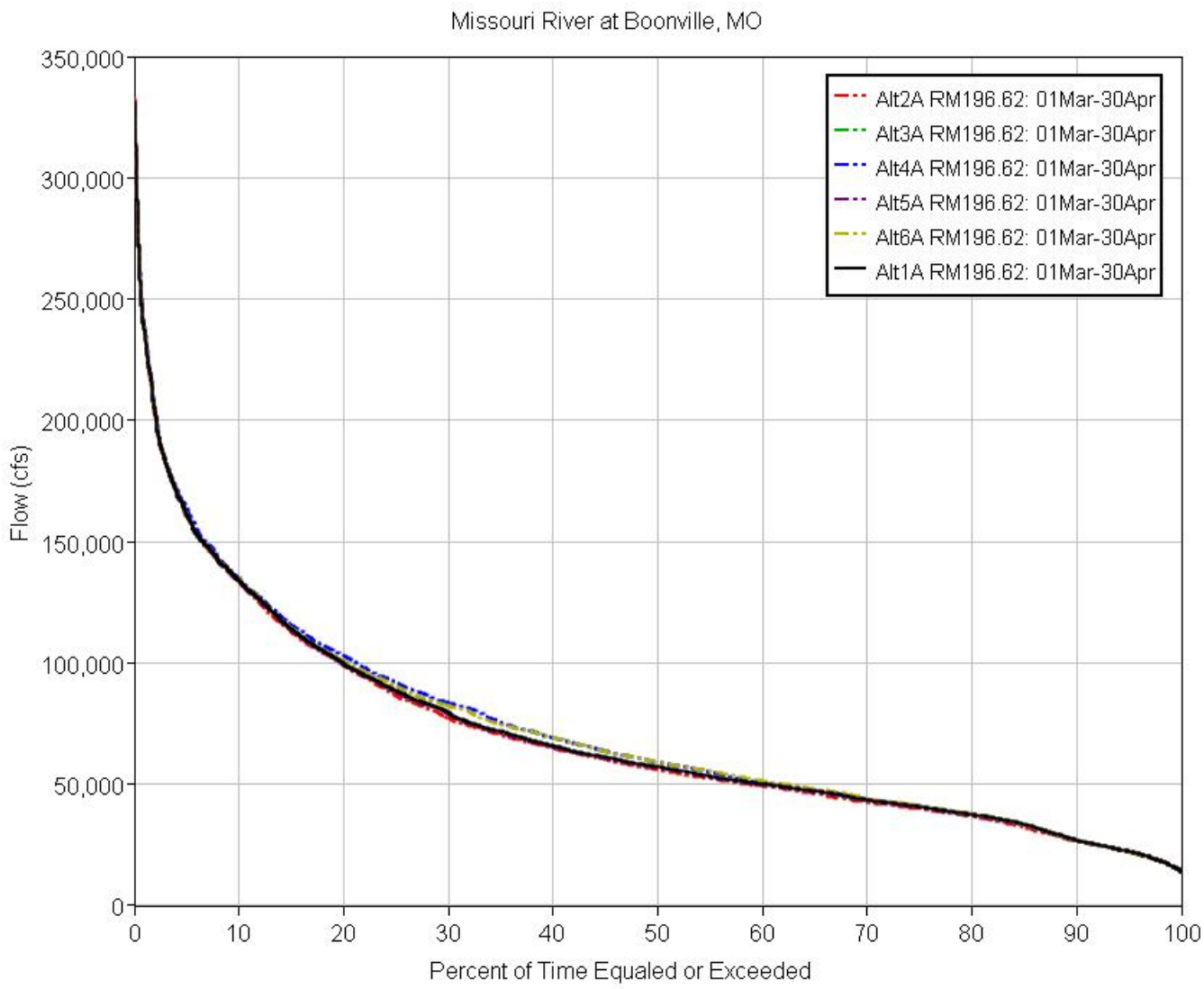
Kansas City Summer Duration



Kansas City Fall Duration



Kansas City Winter Duration



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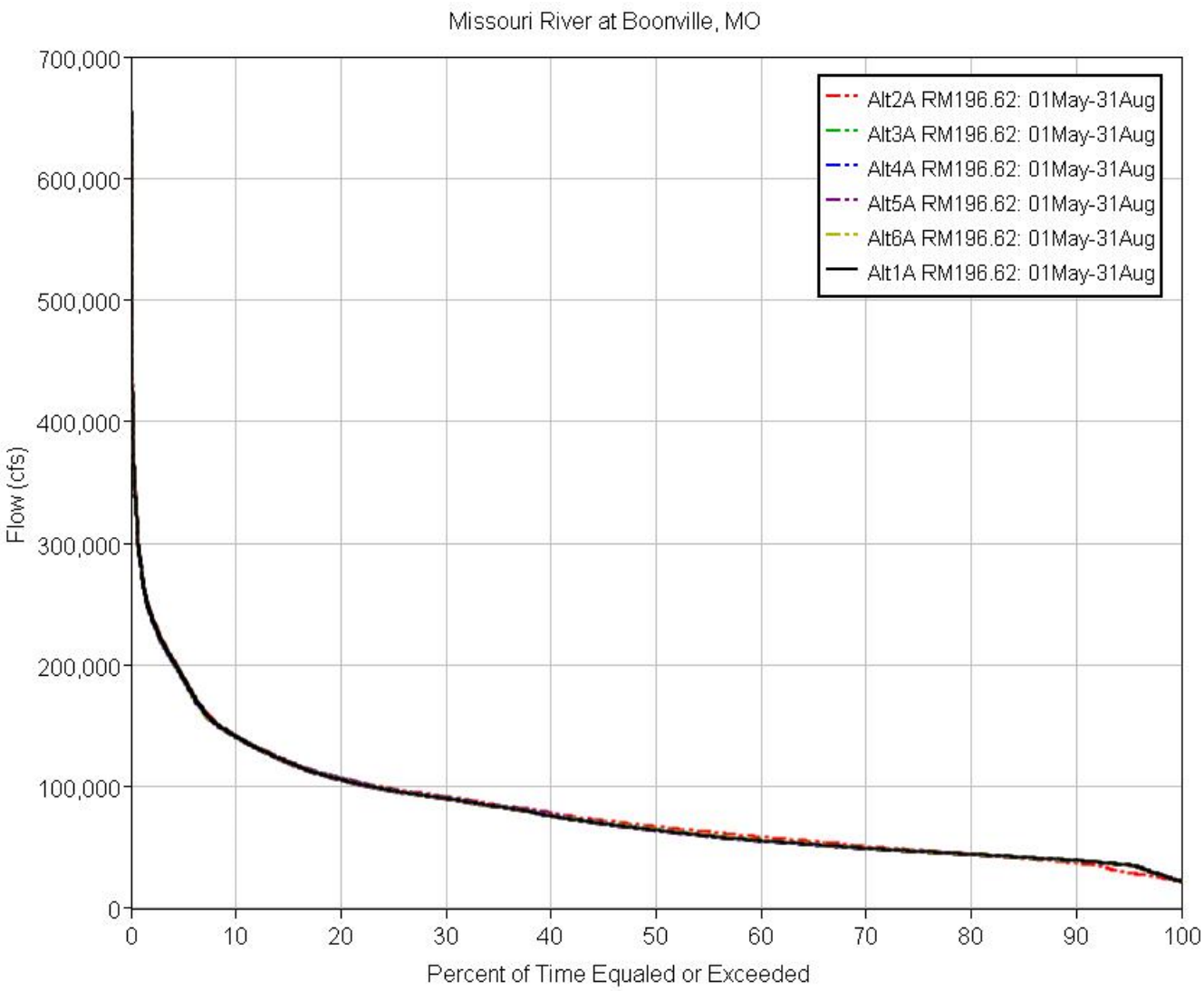

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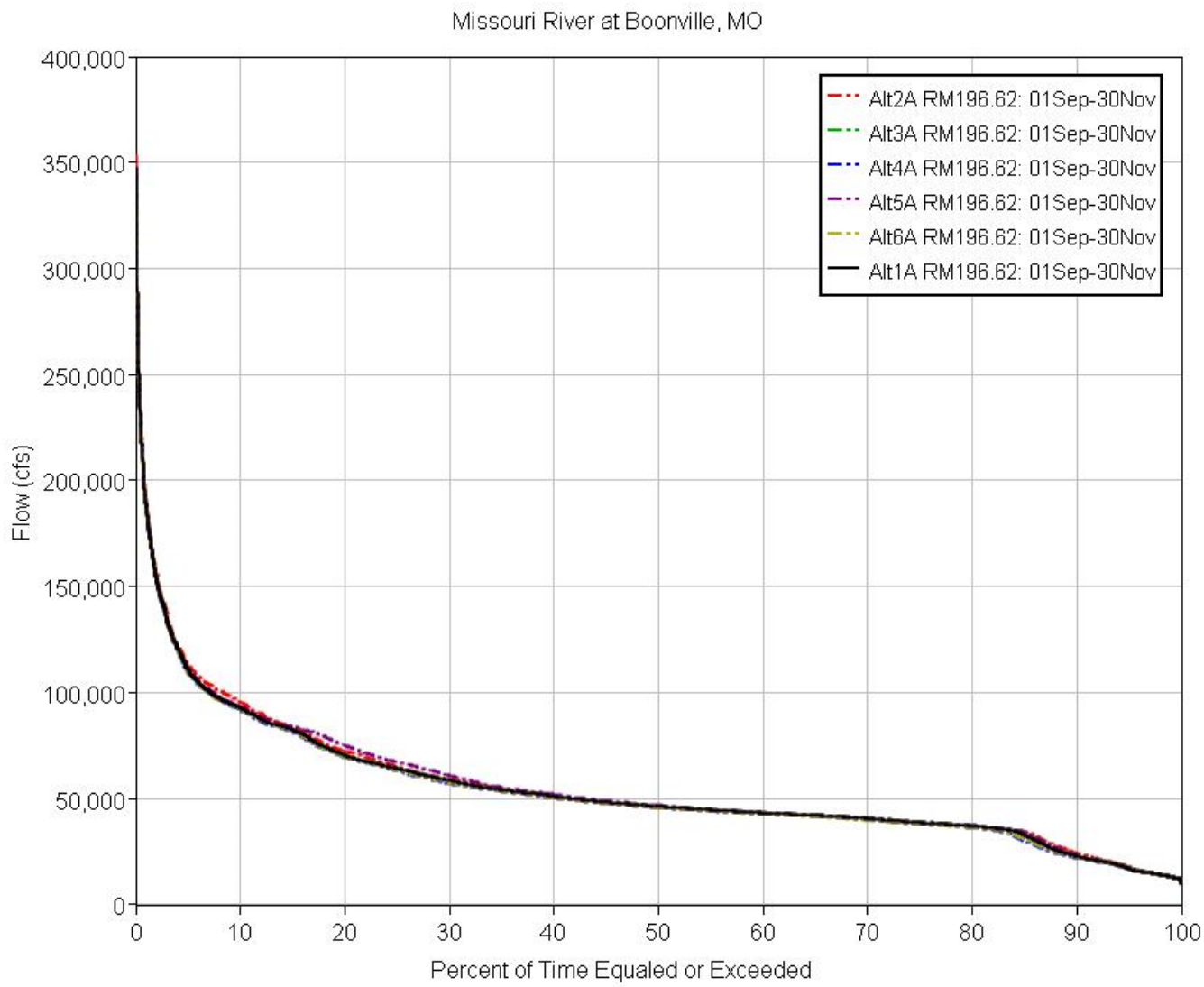

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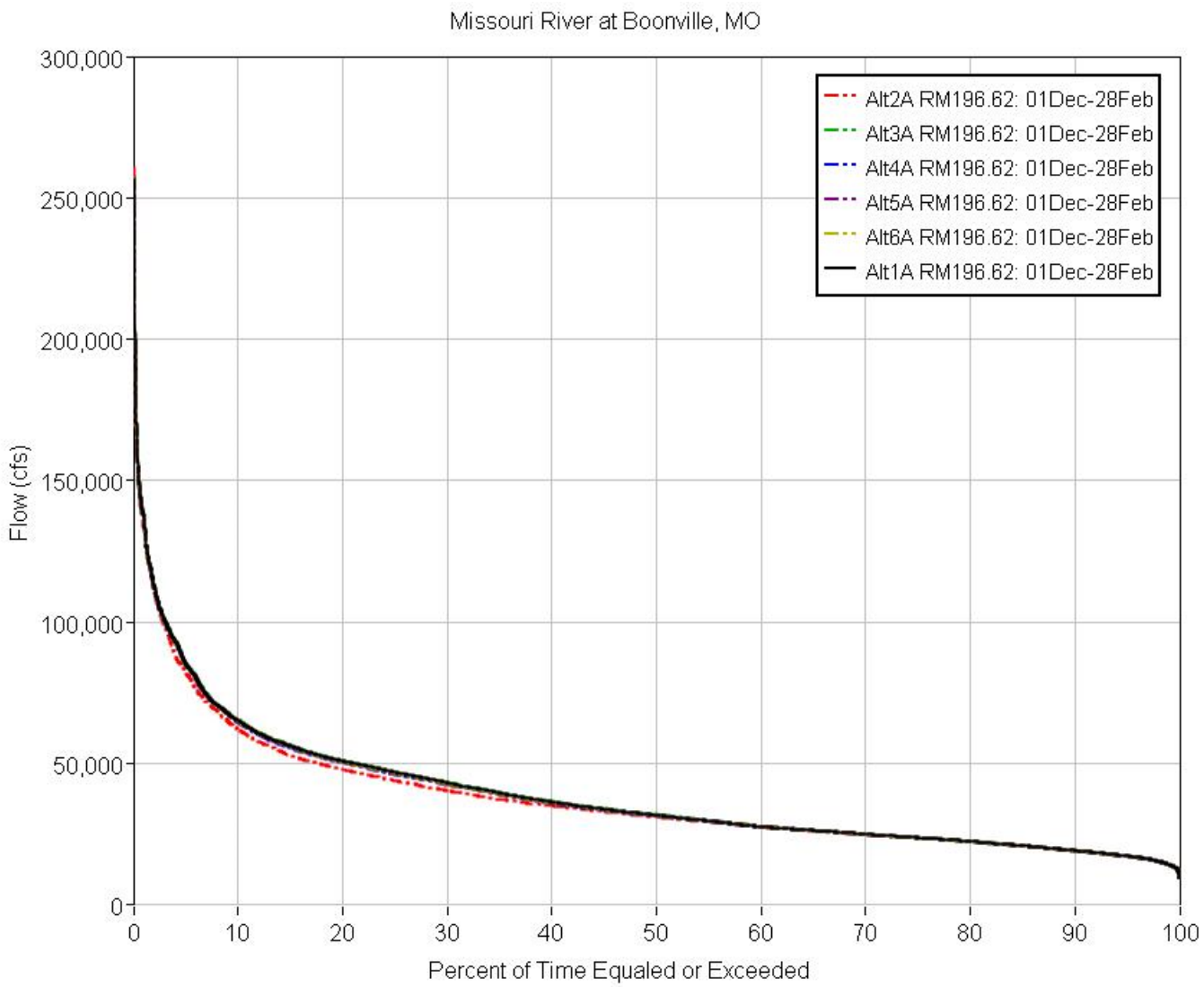

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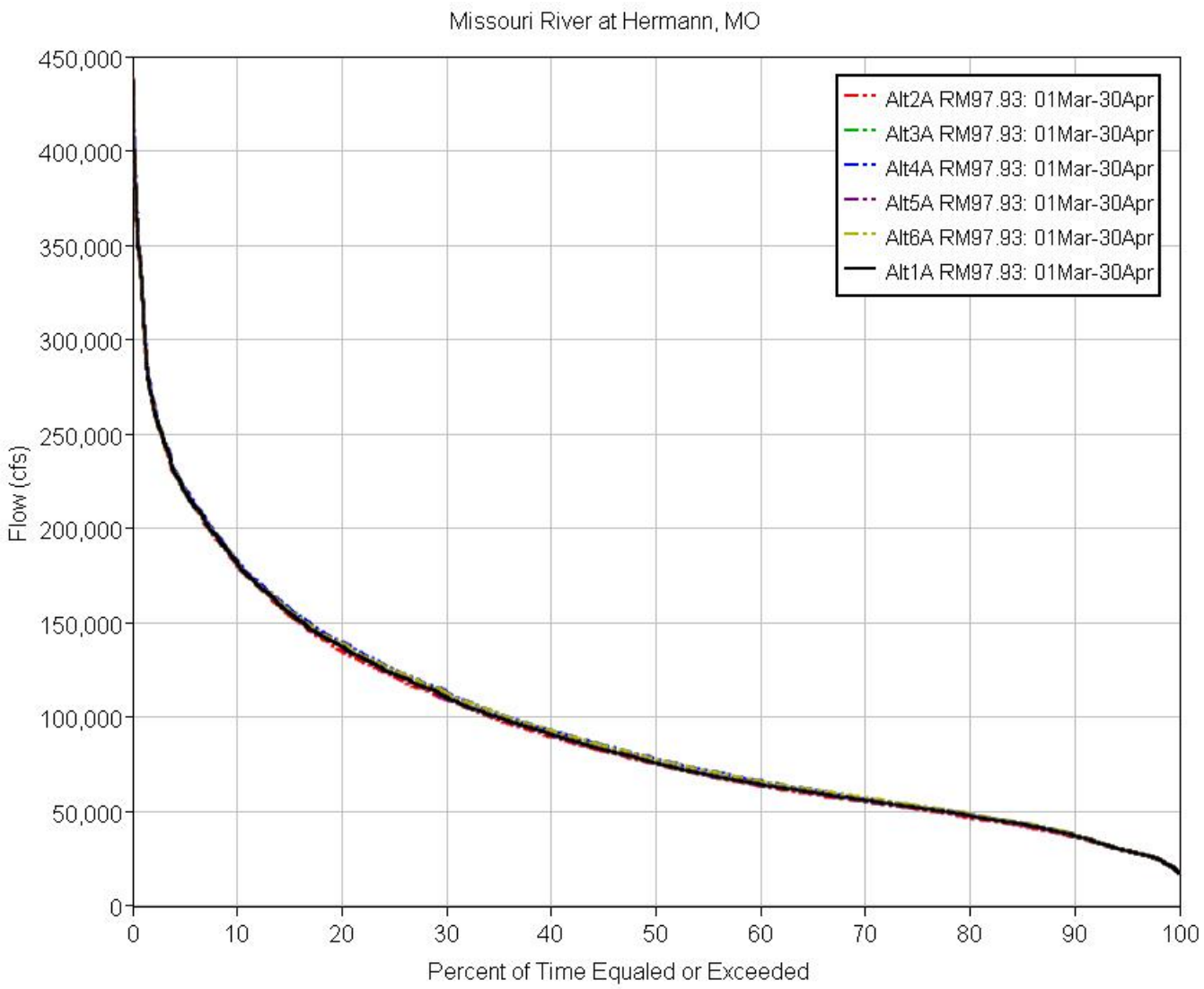

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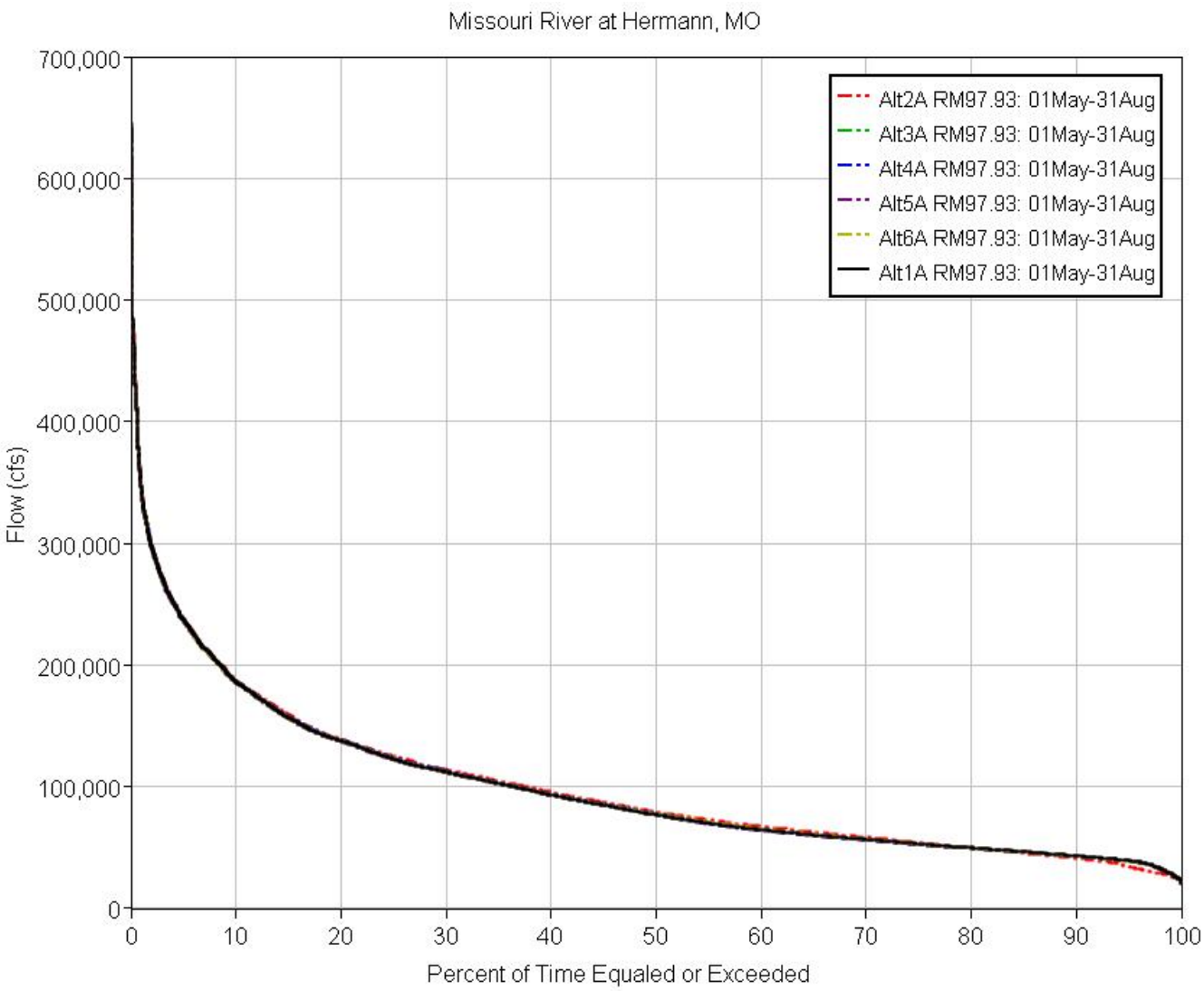

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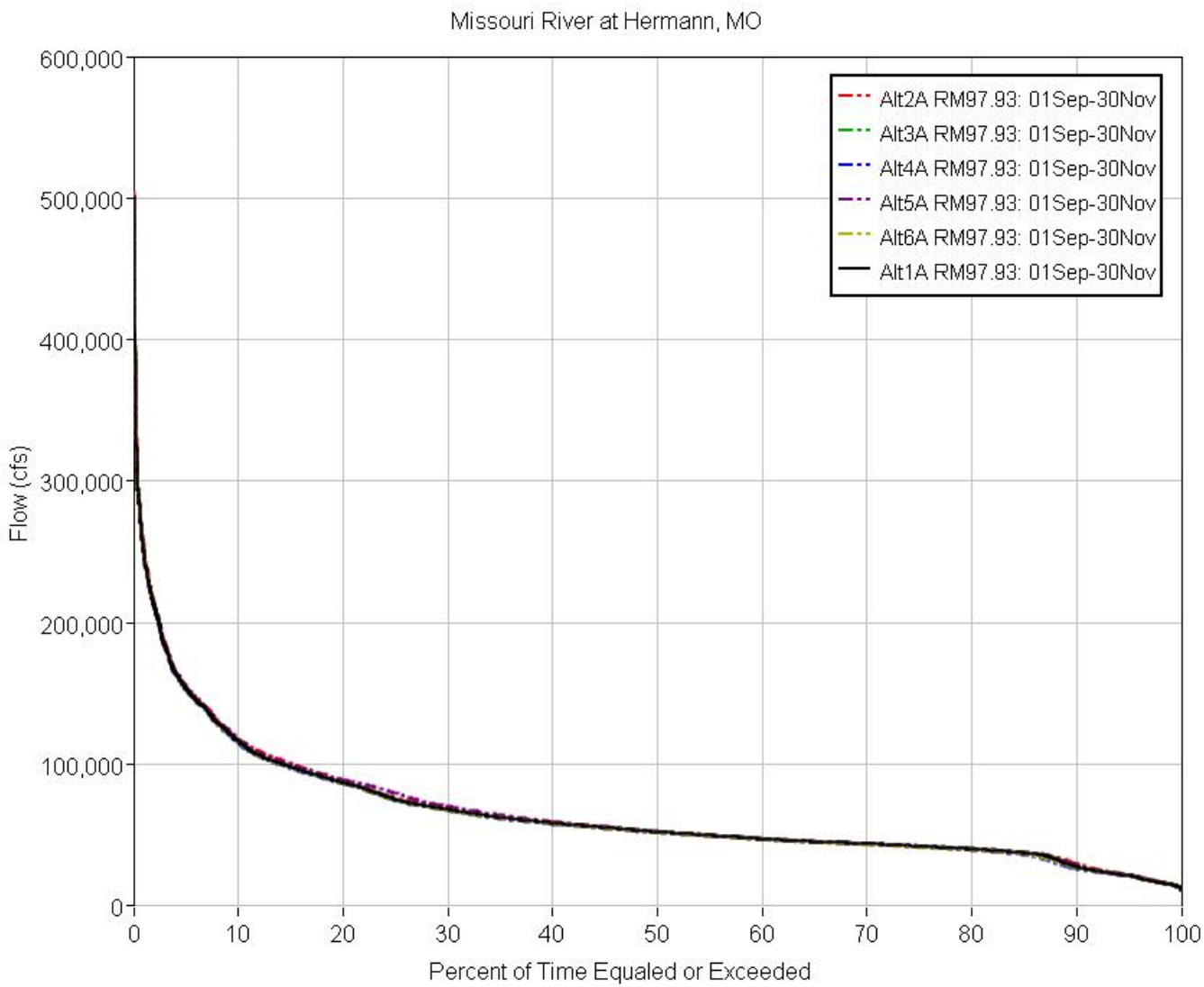

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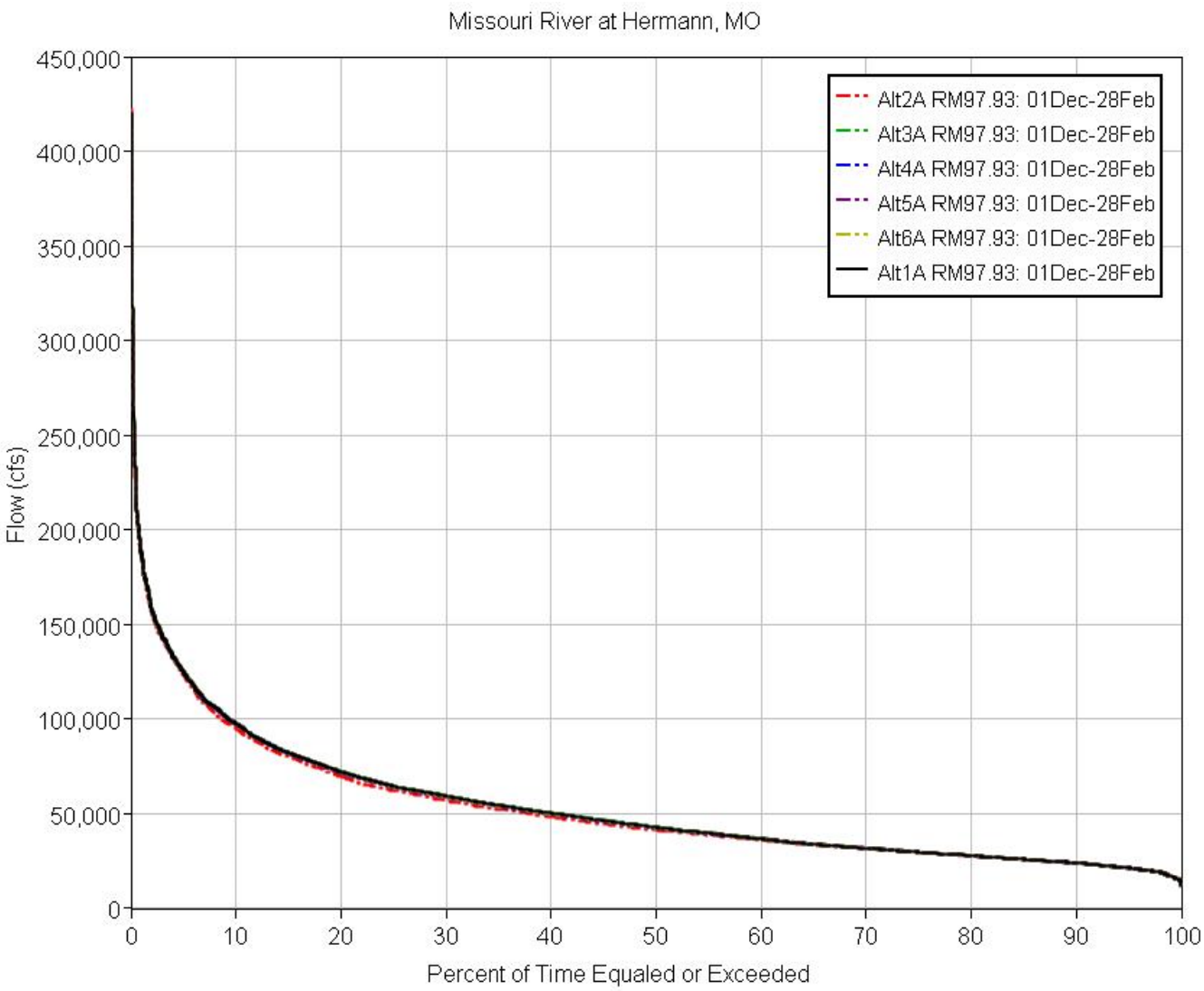

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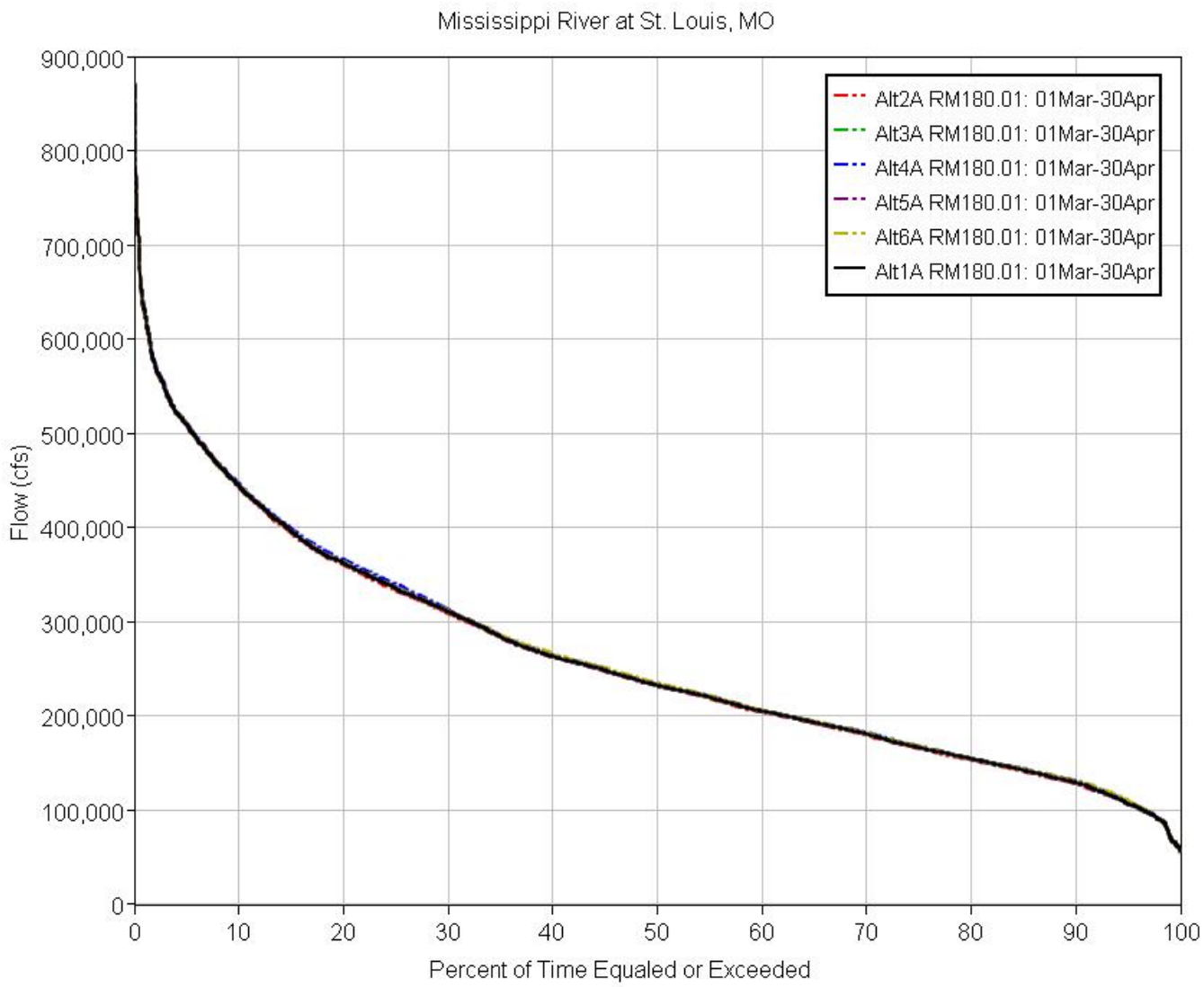

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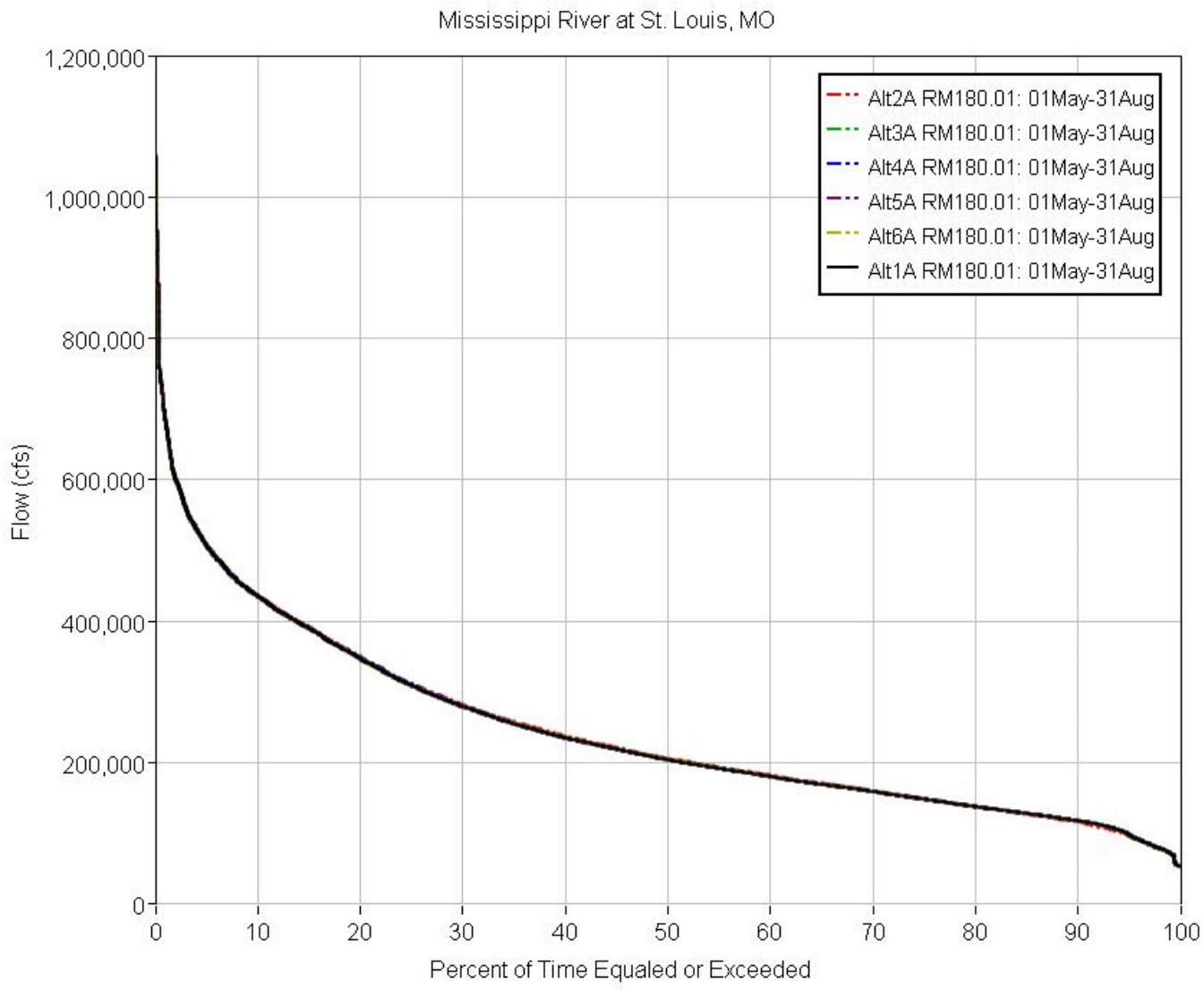

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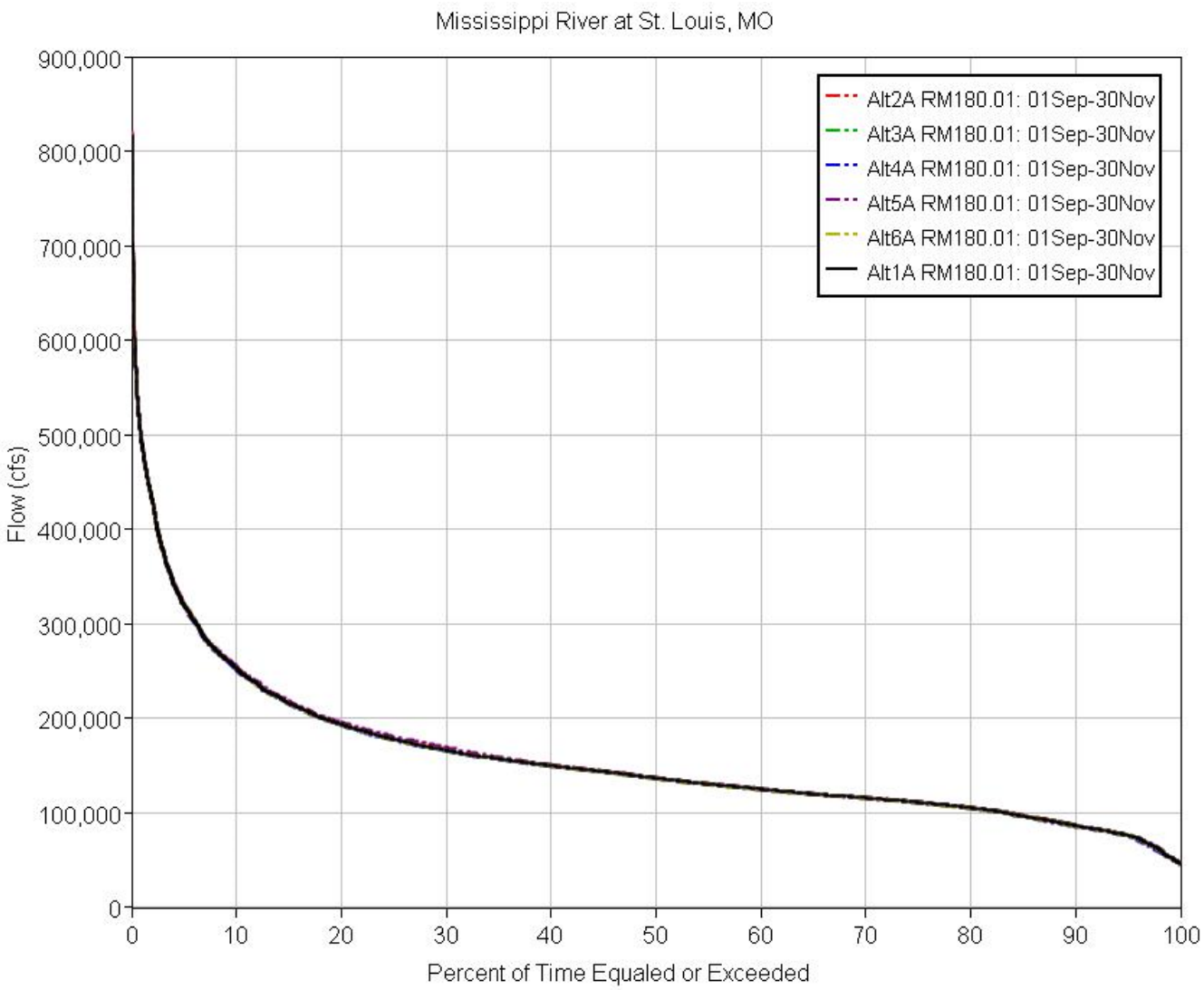

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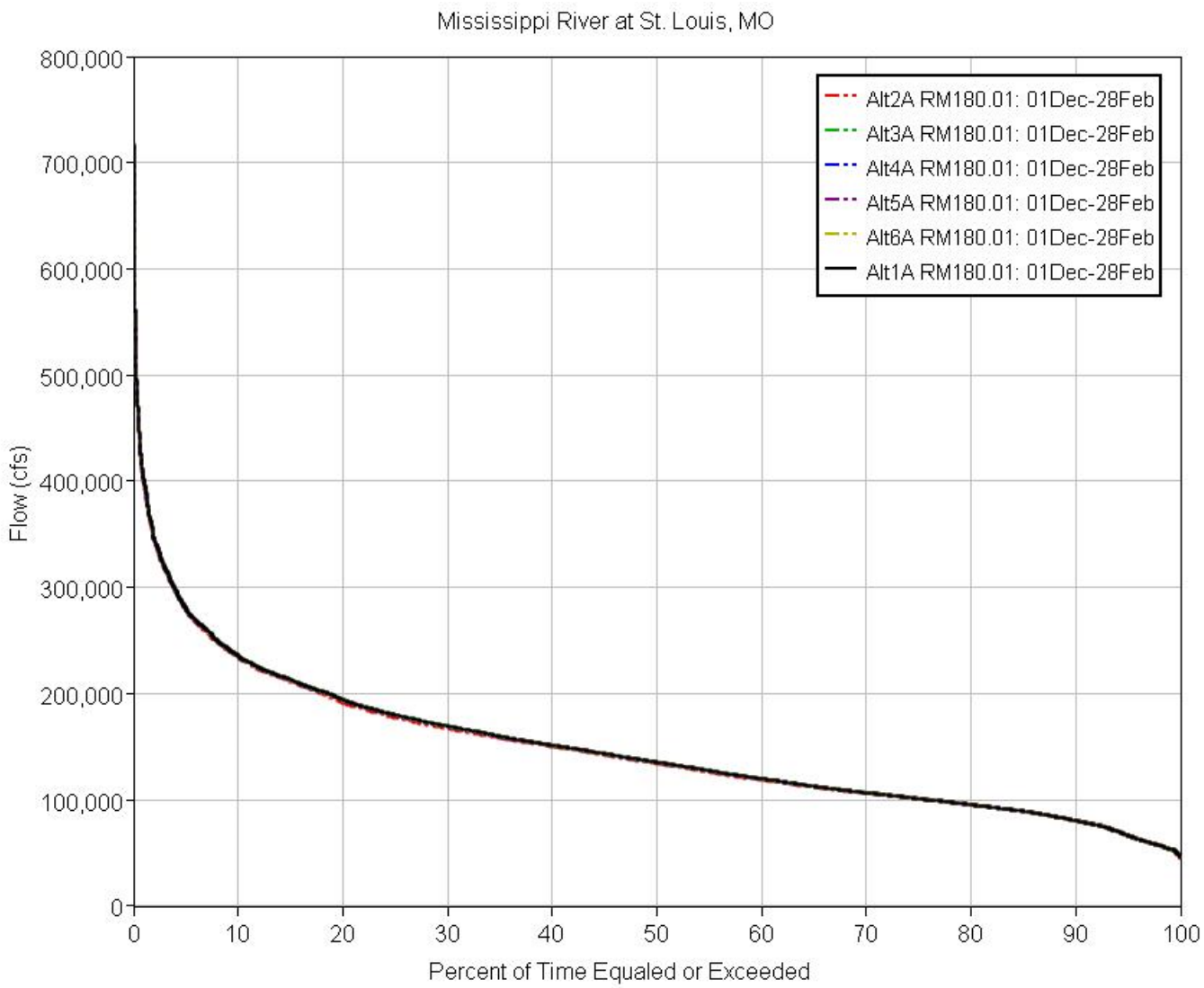

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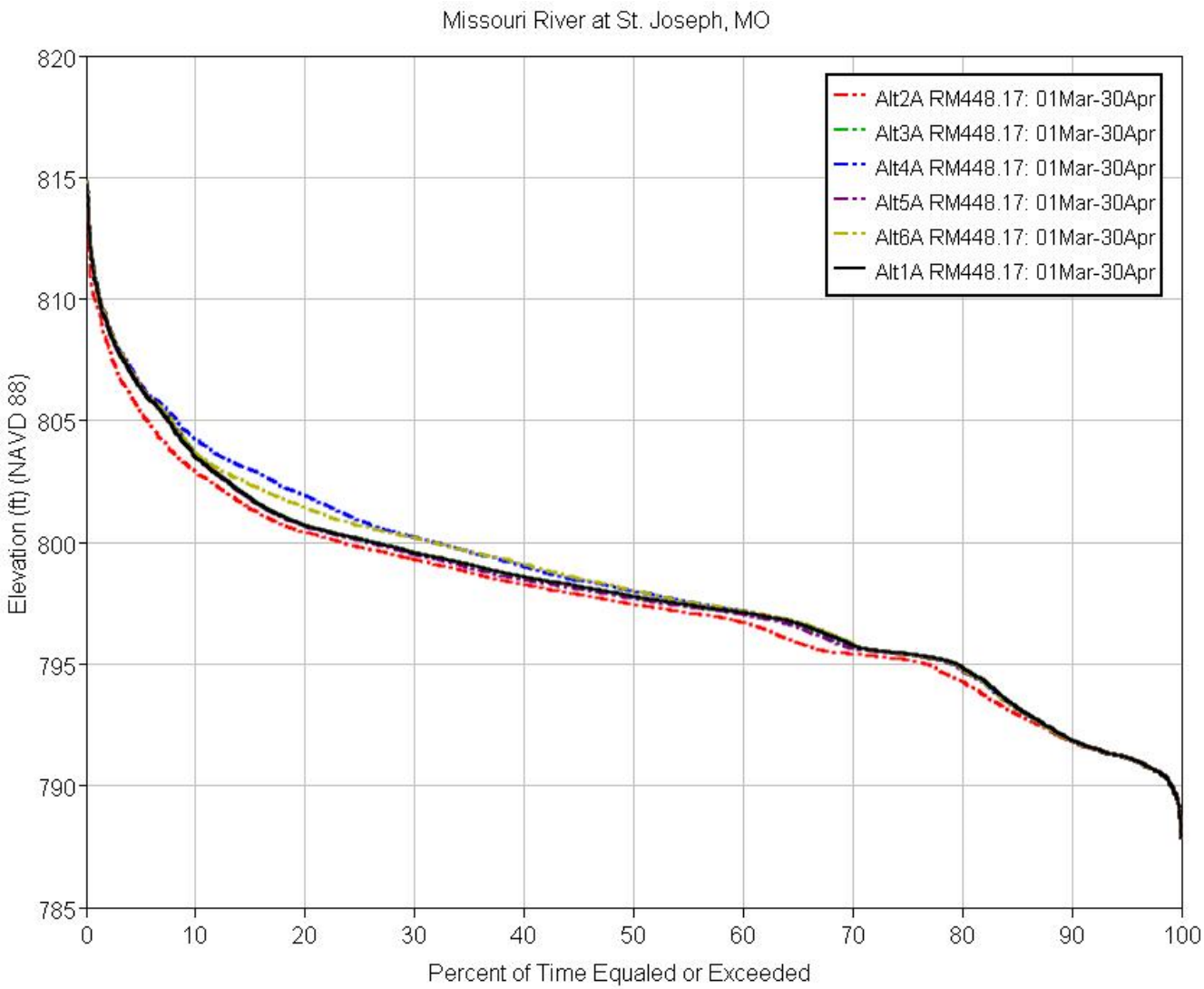

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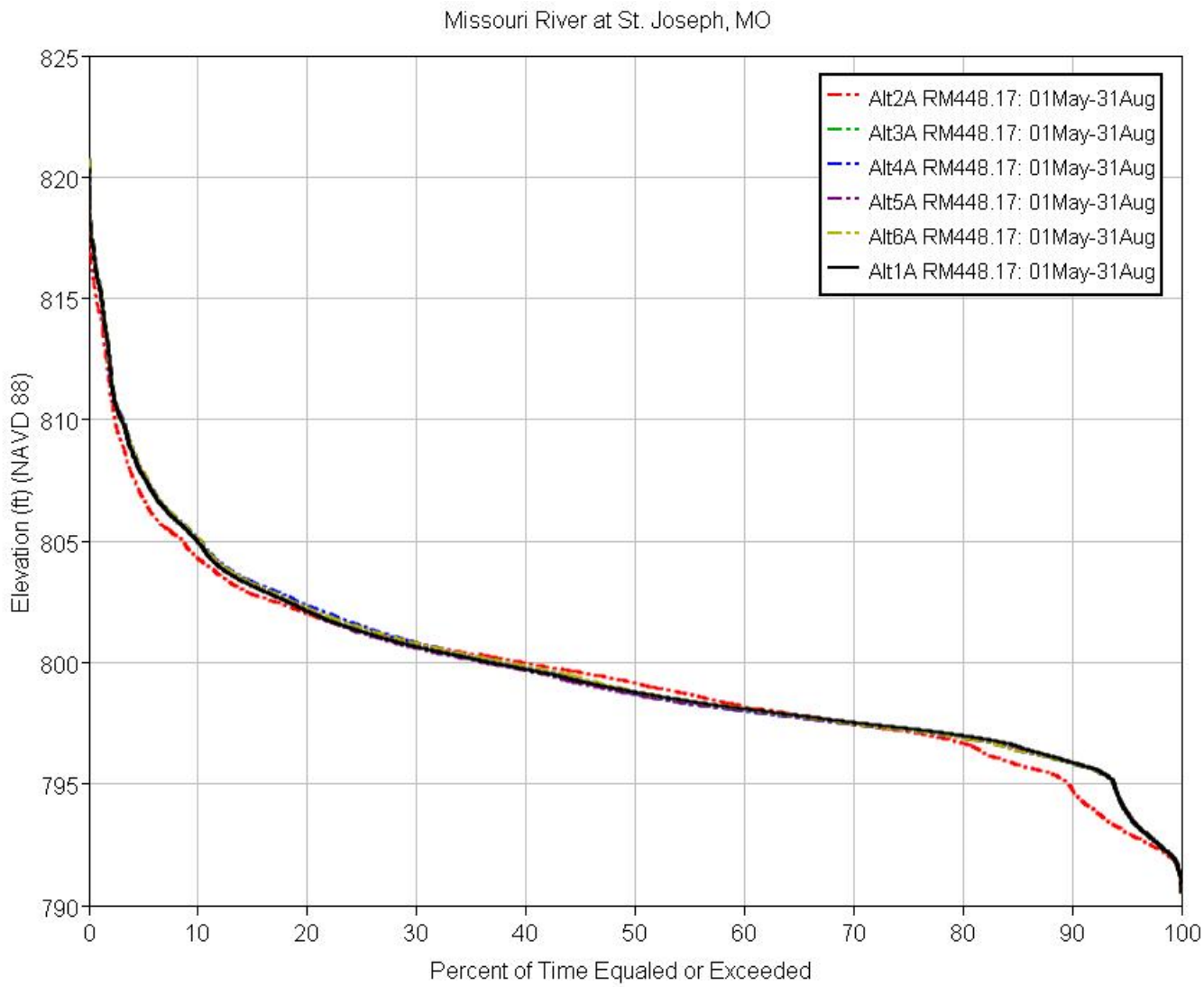

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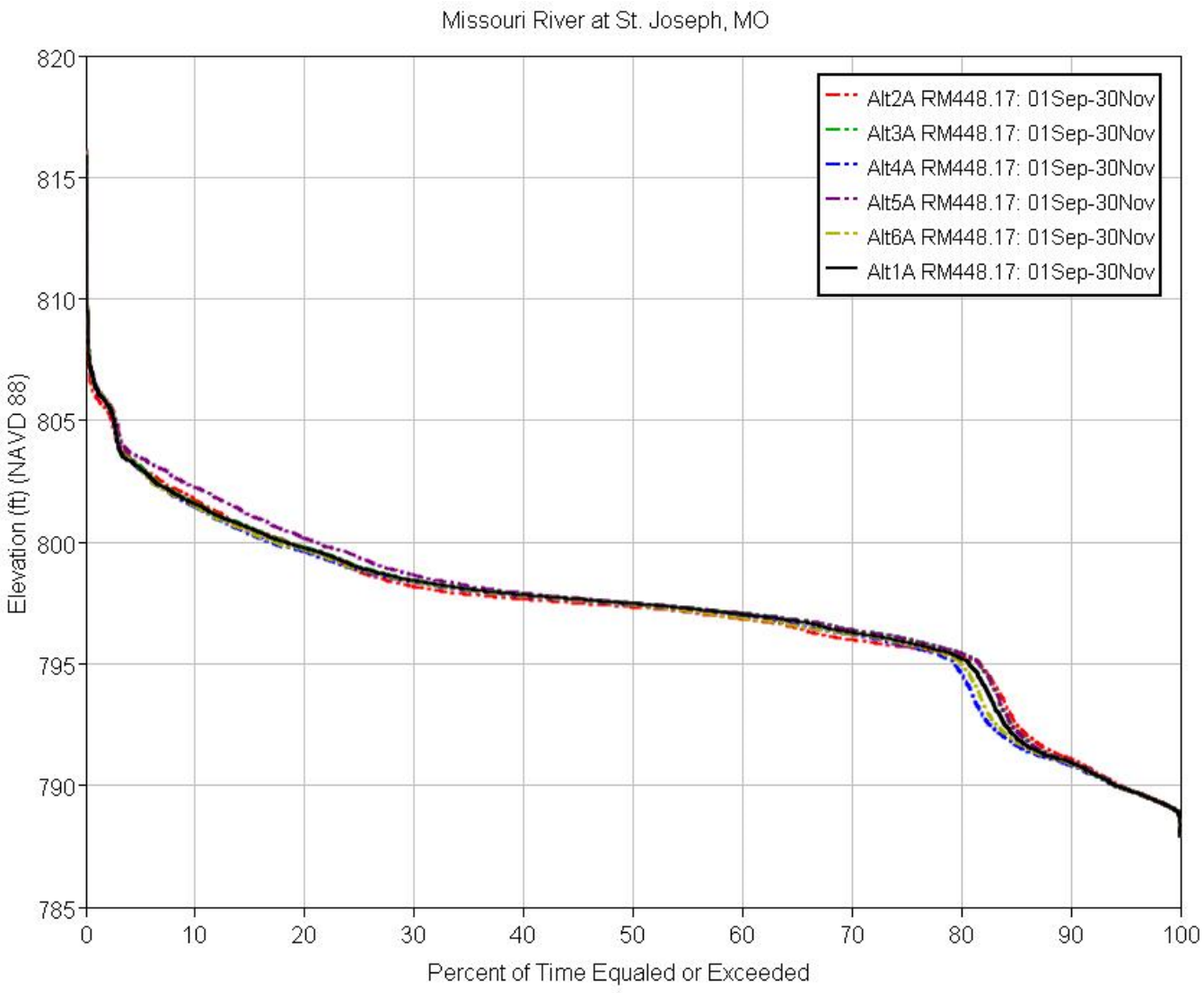

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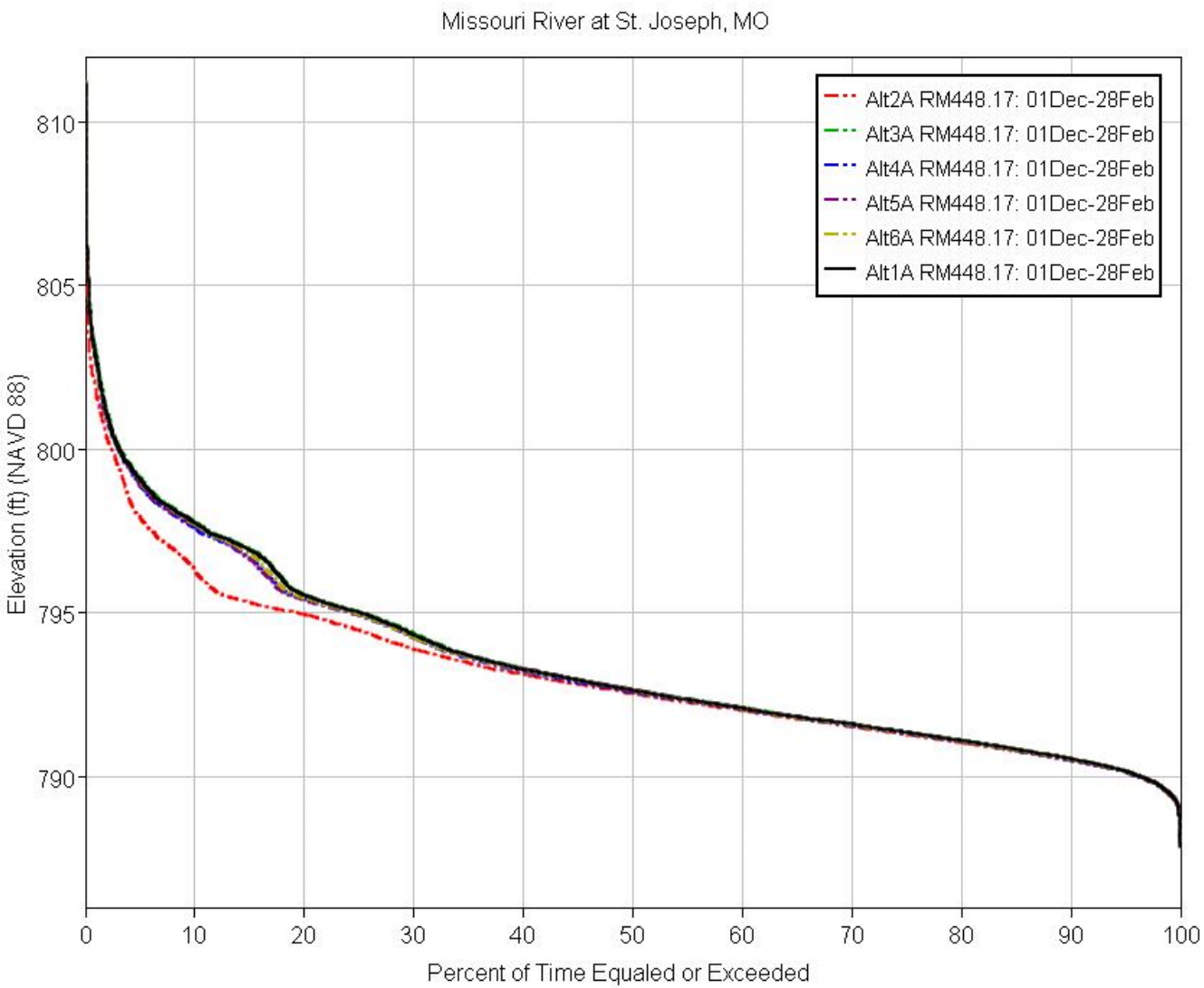

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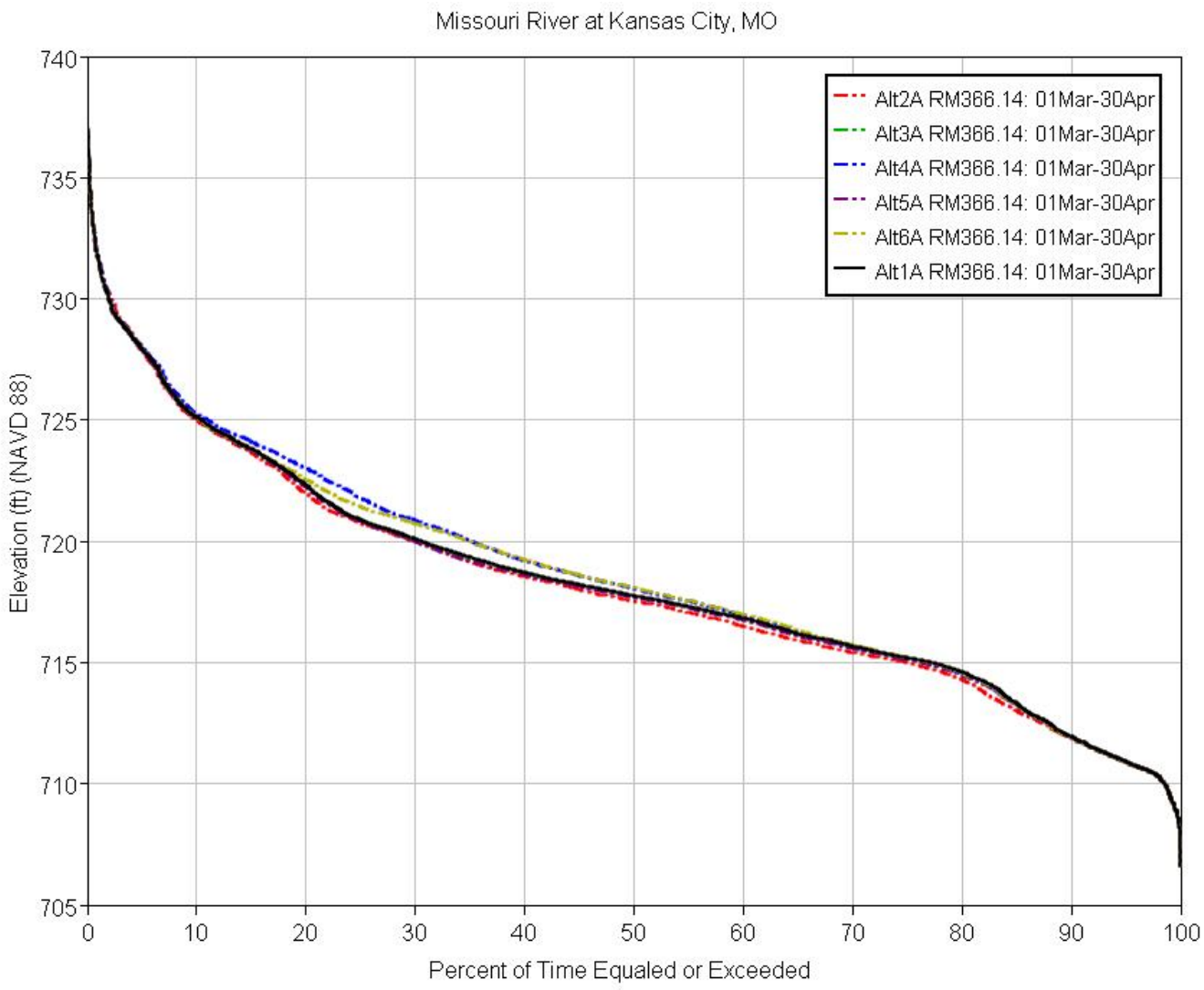

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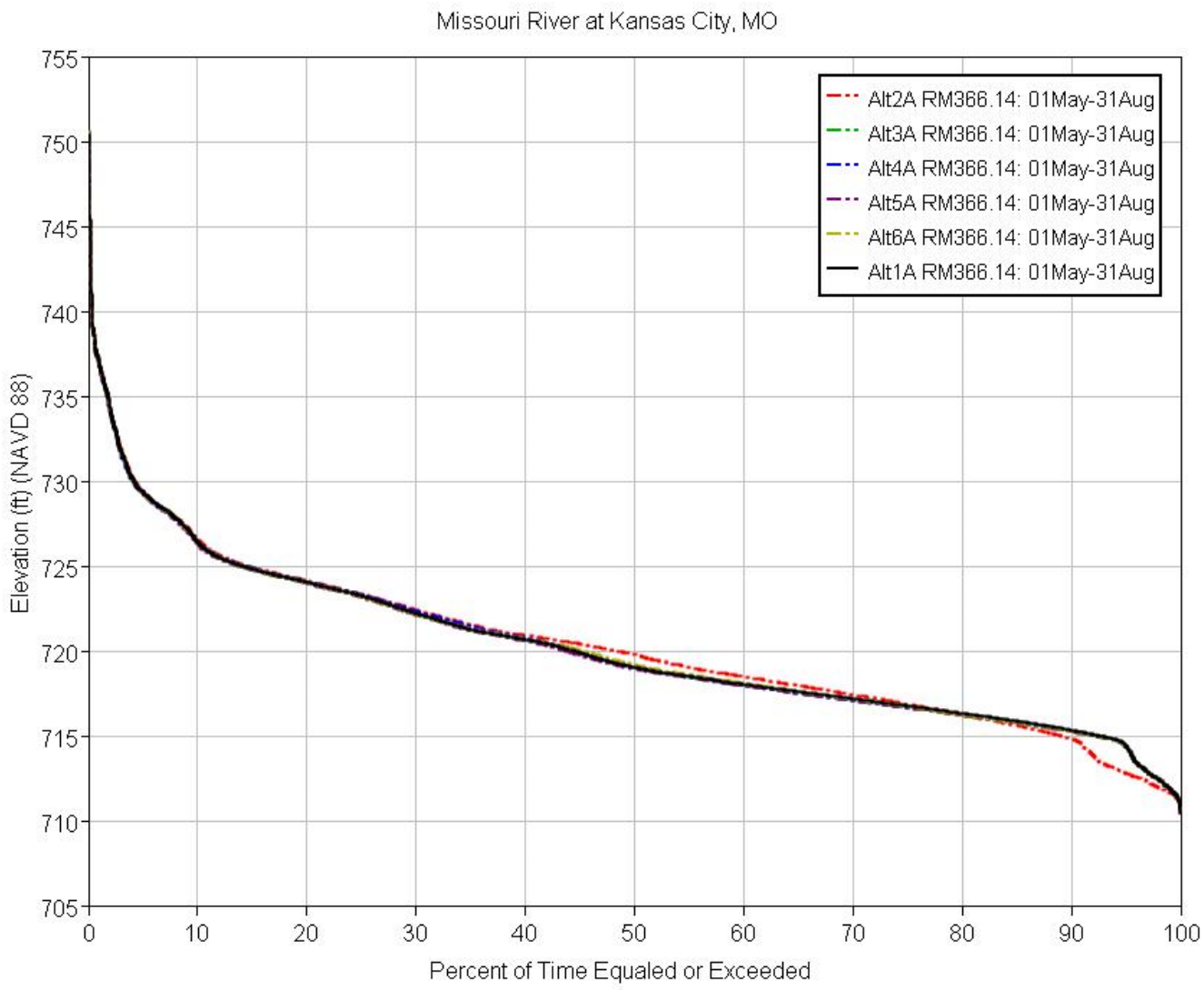

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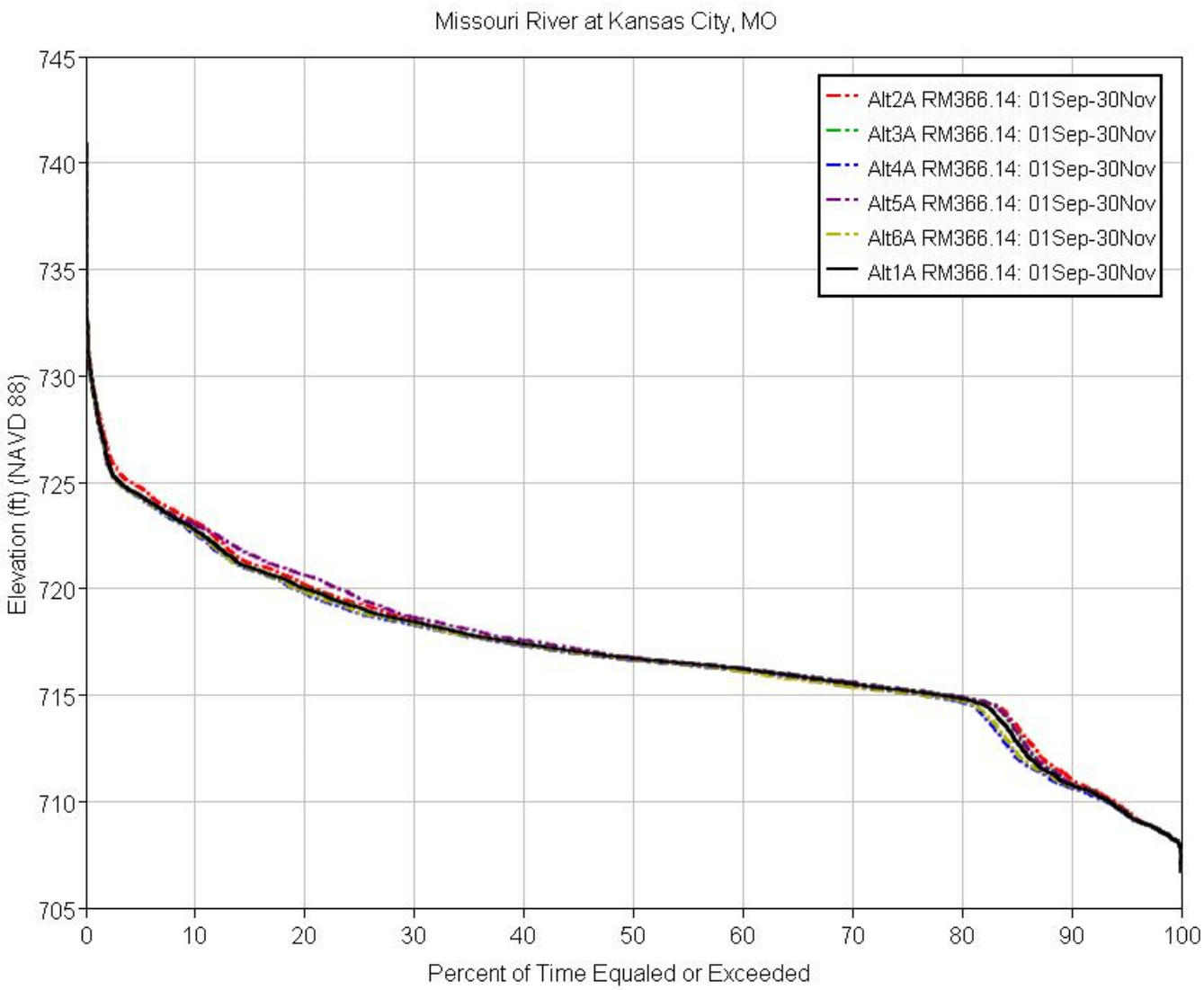

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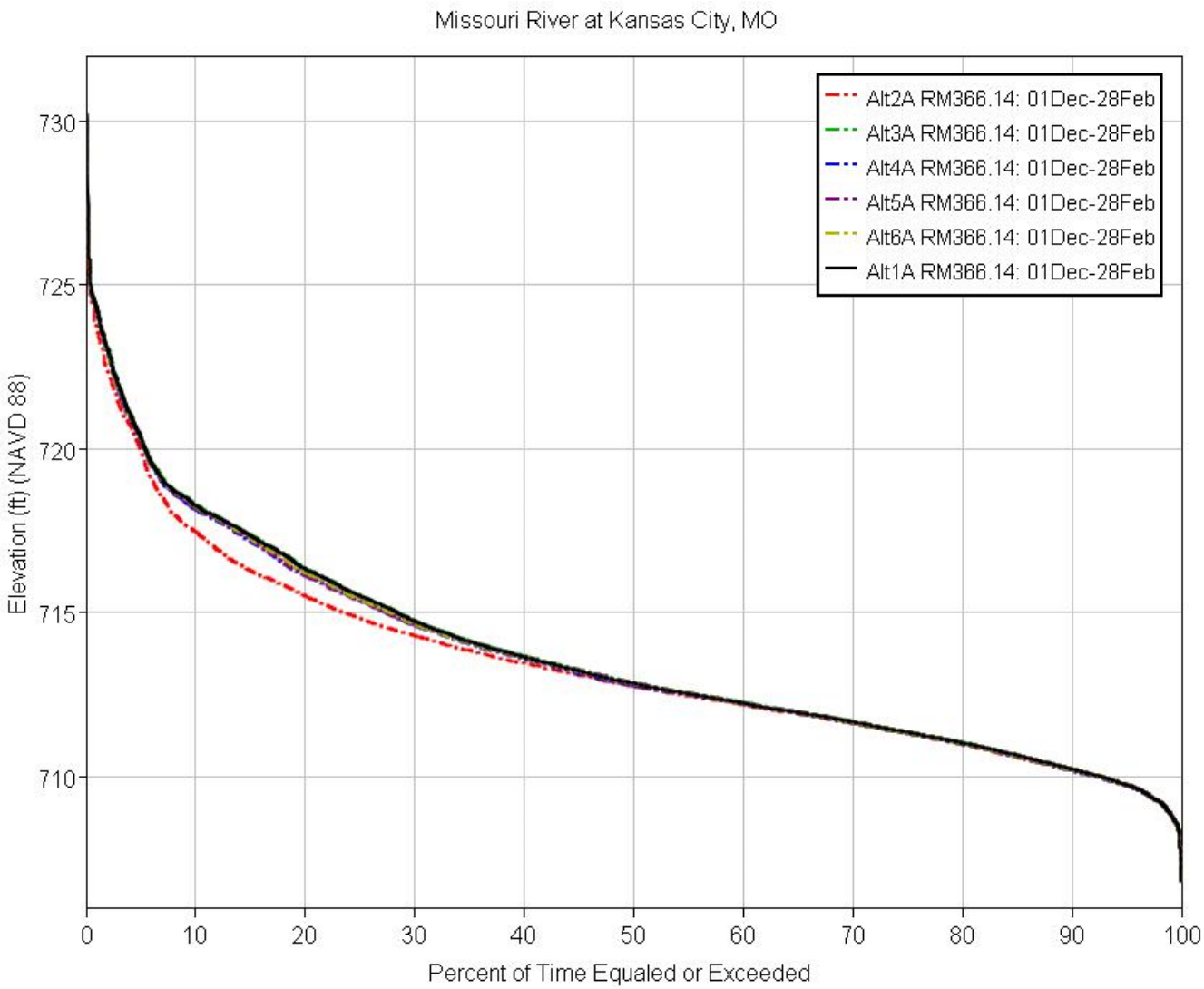

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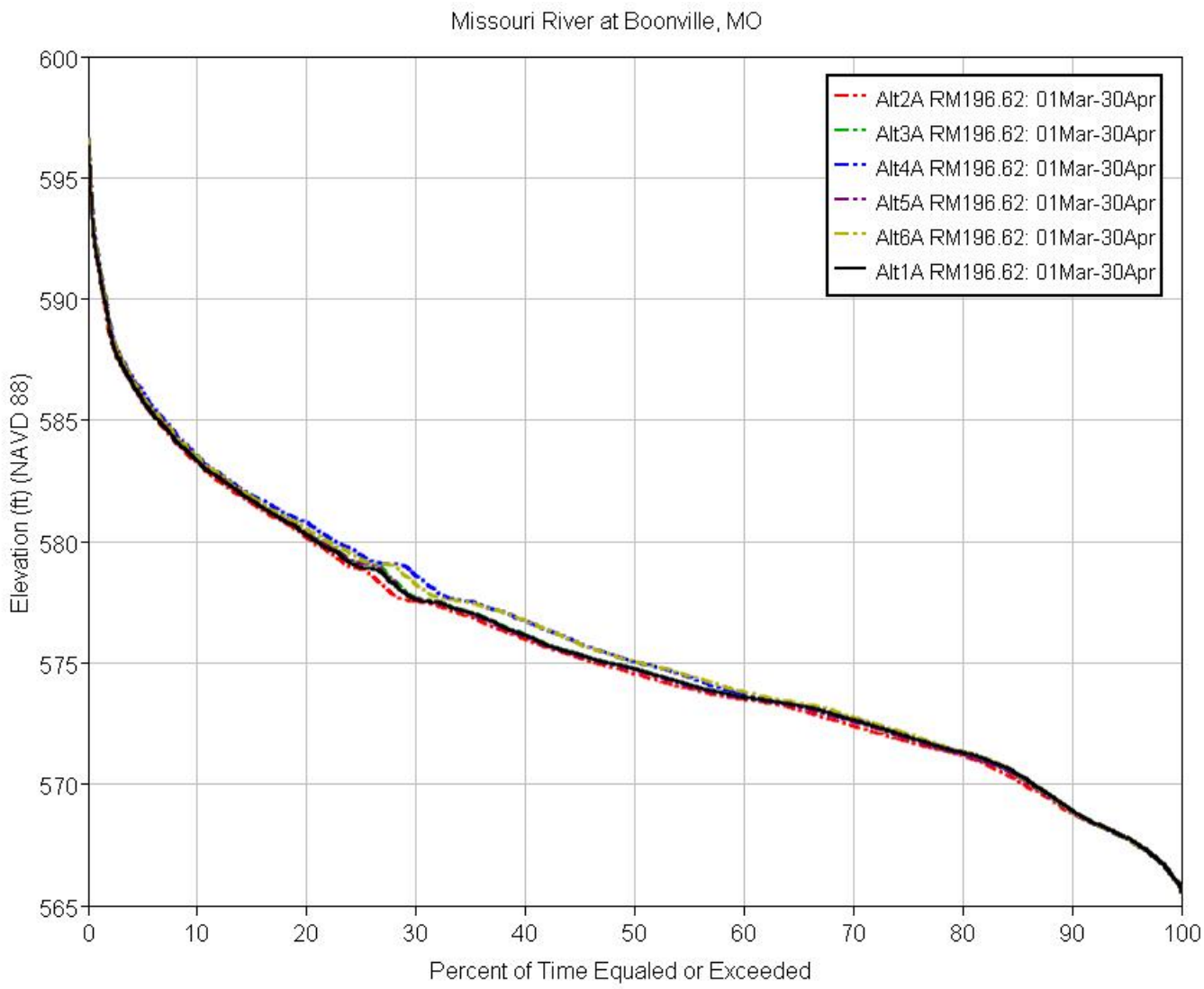

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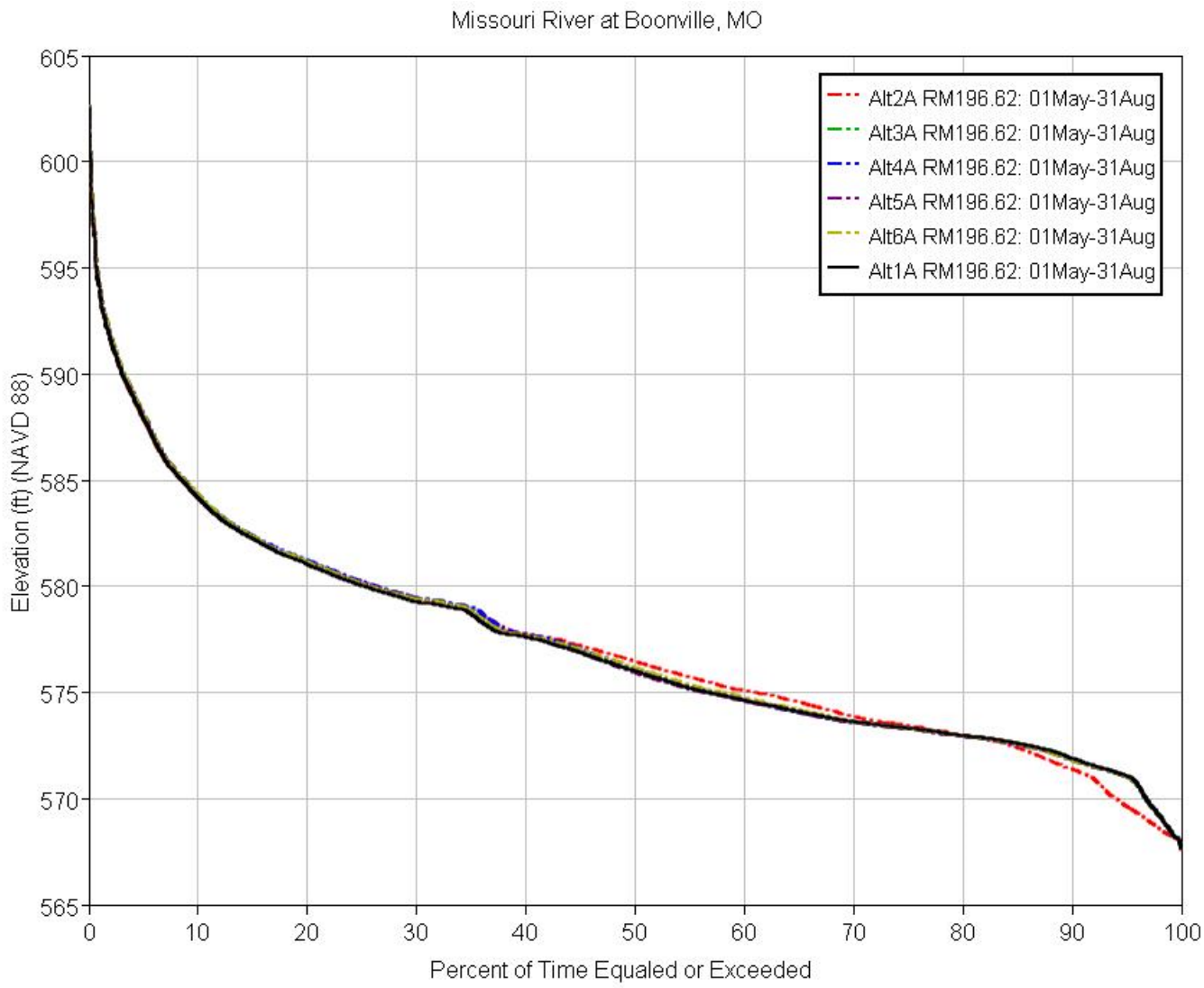

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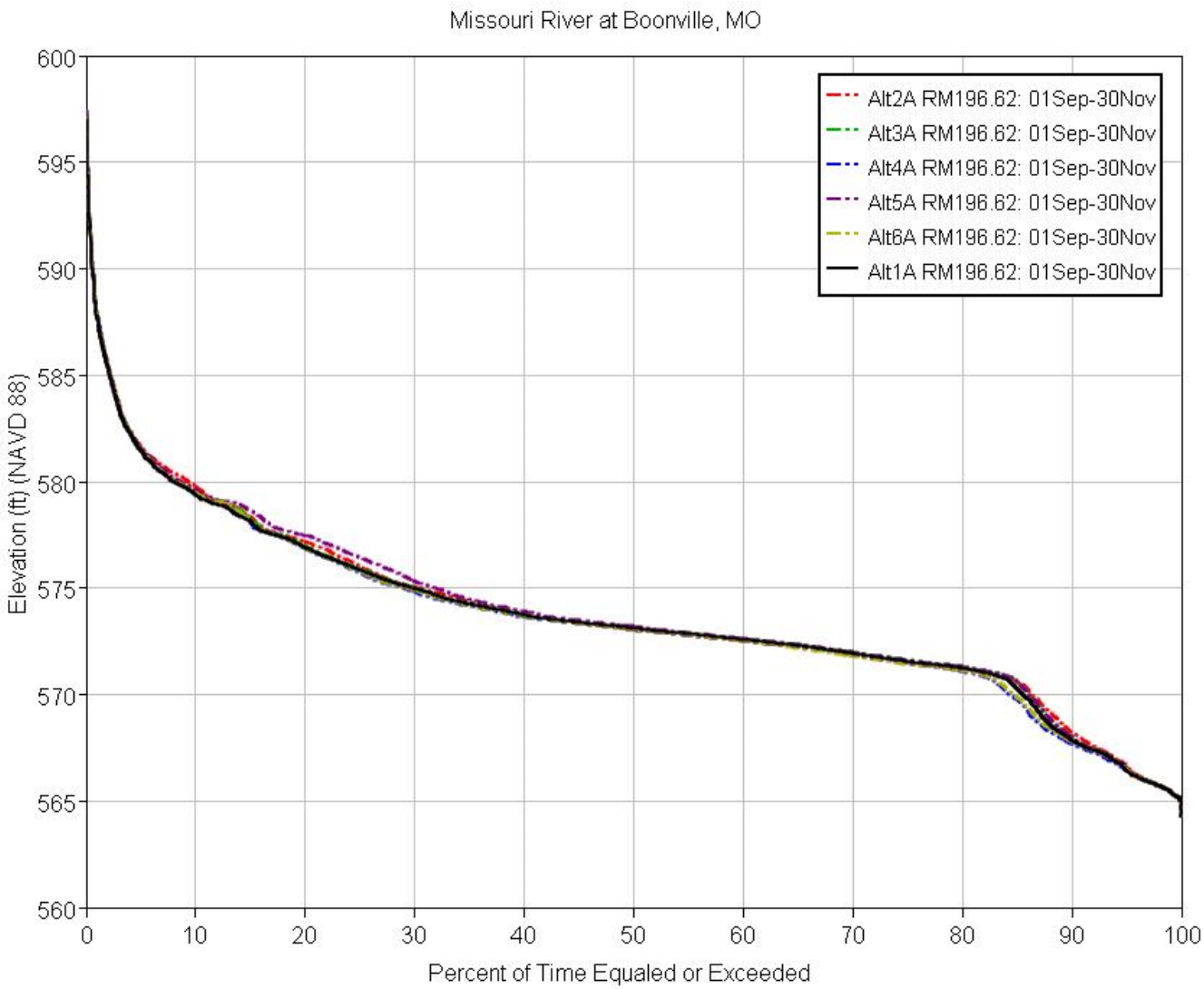

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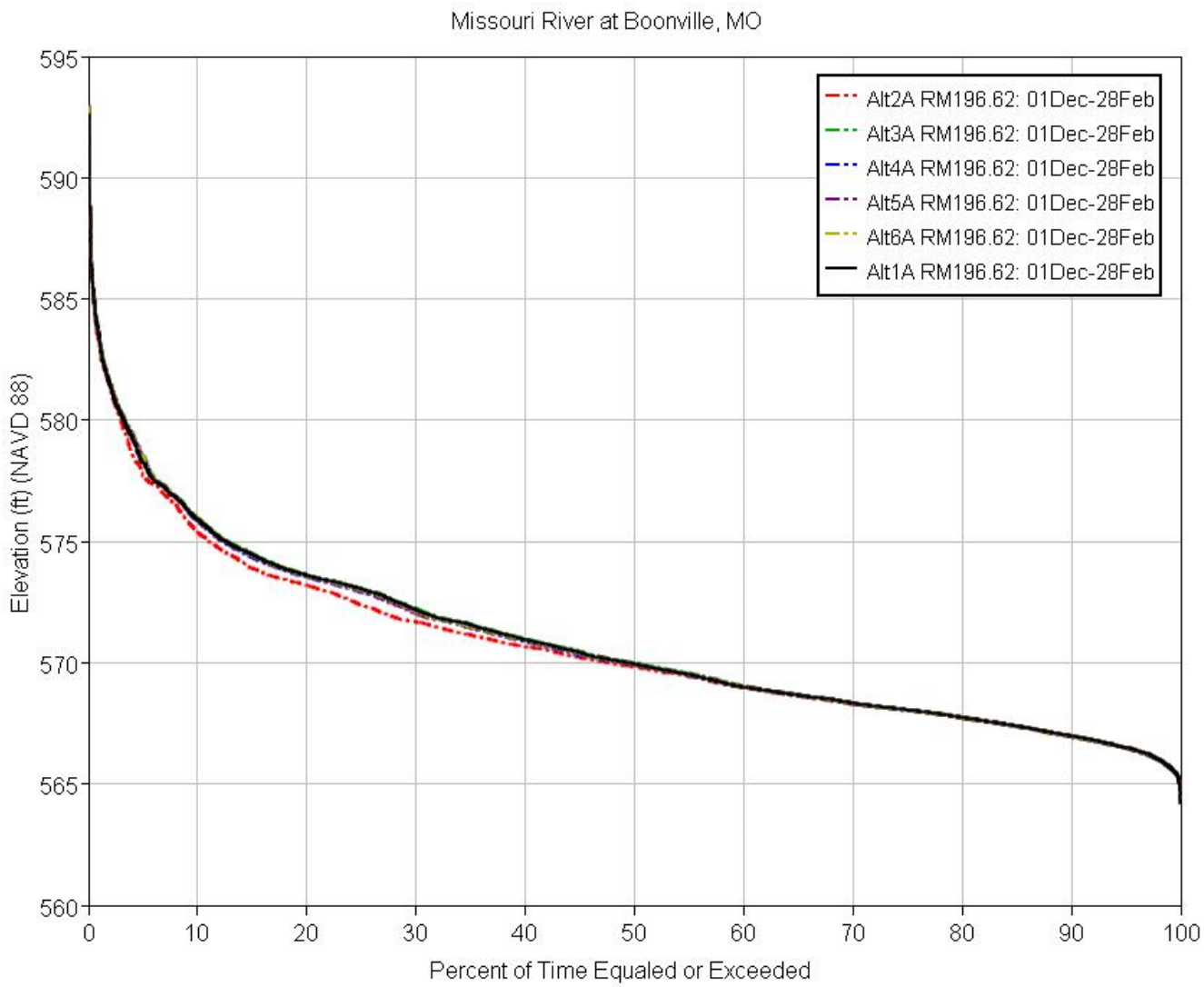

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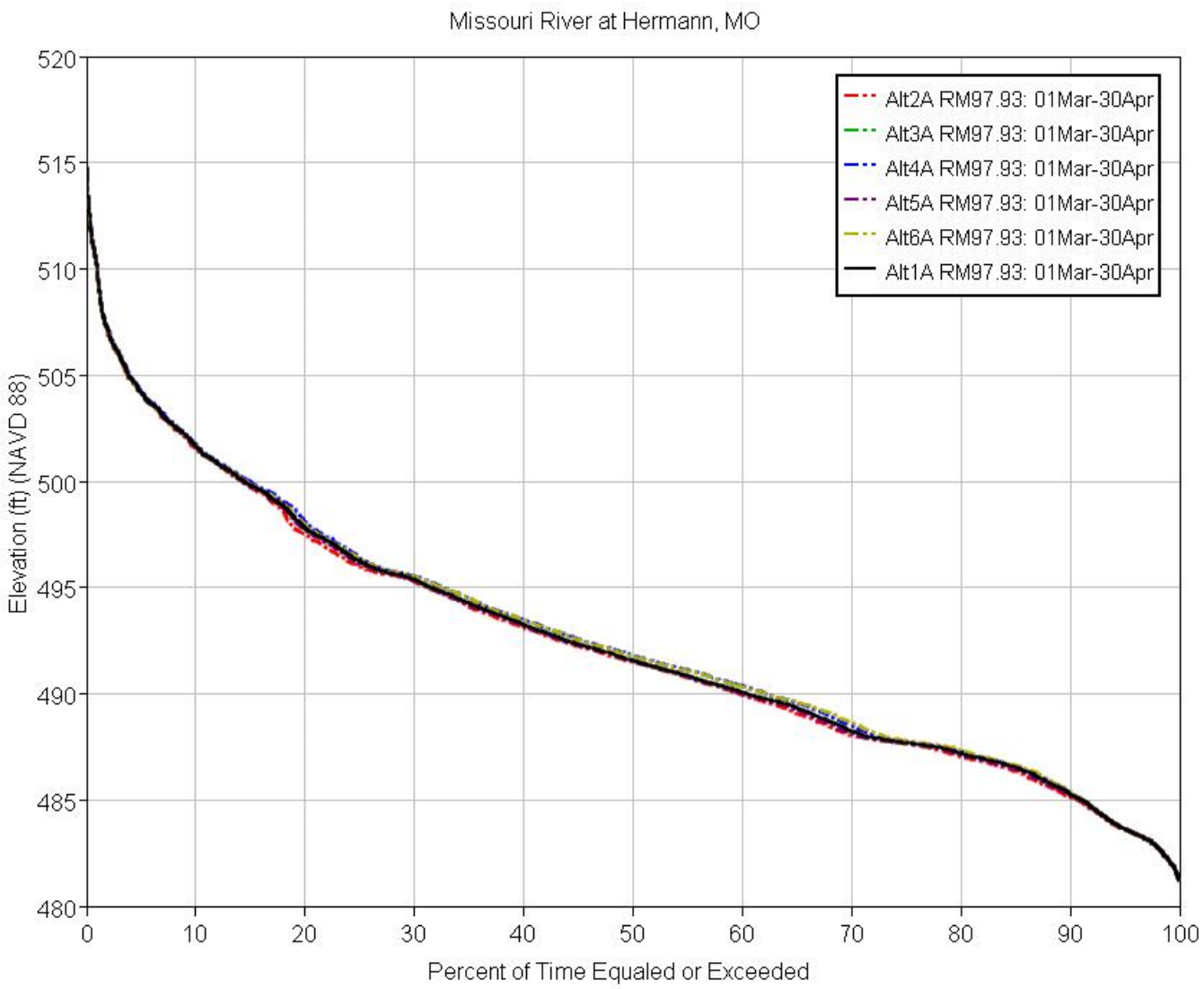

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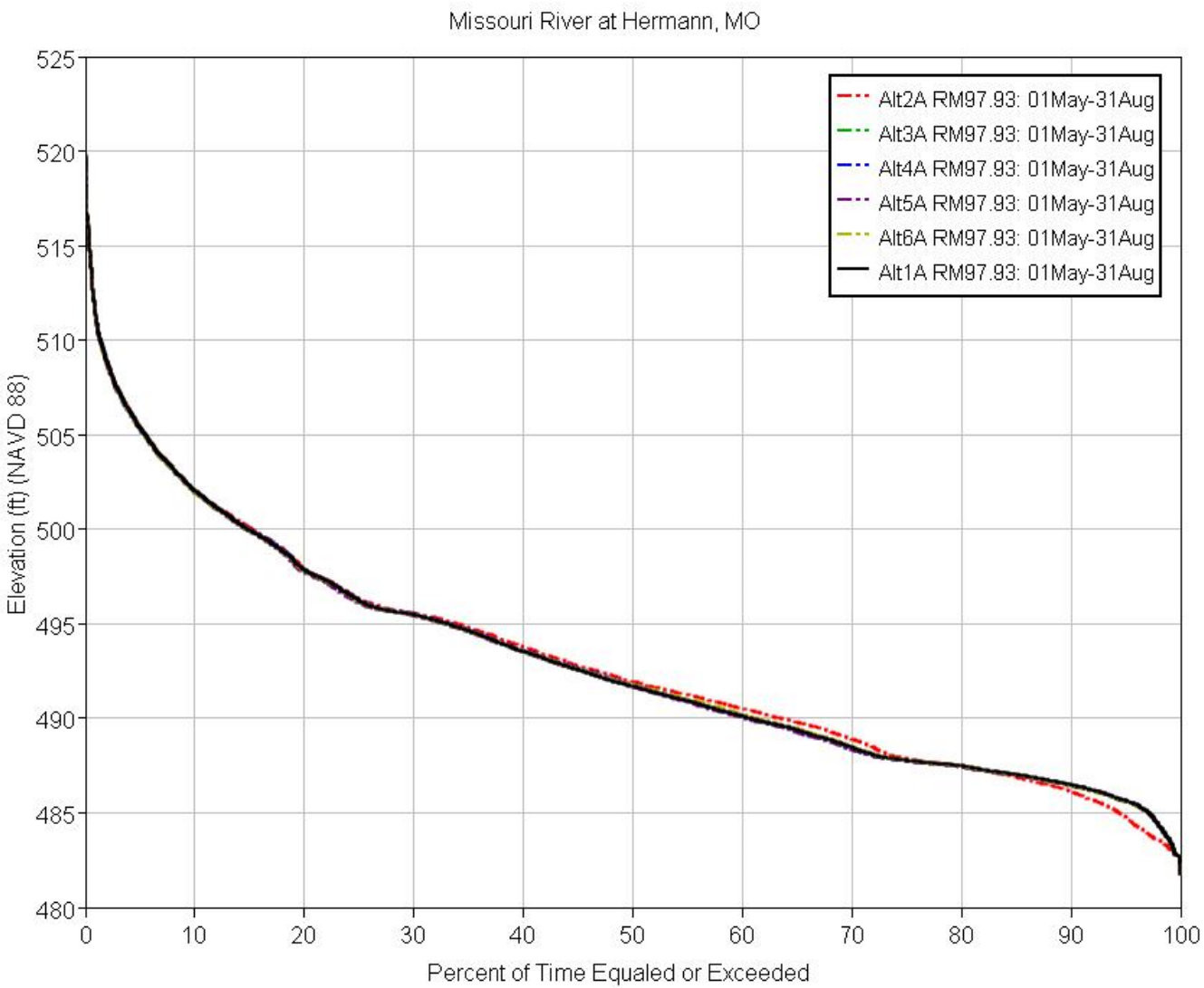

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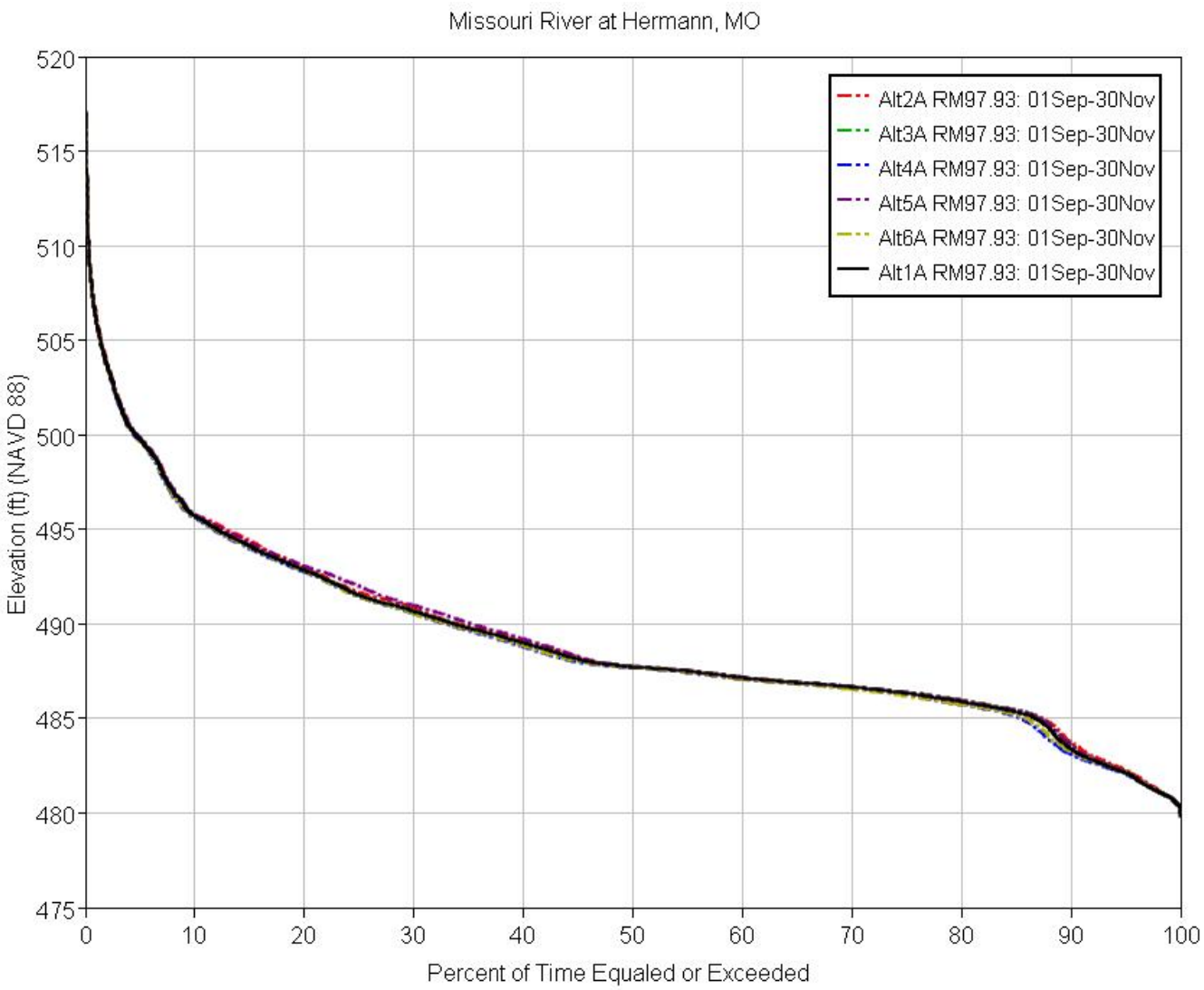

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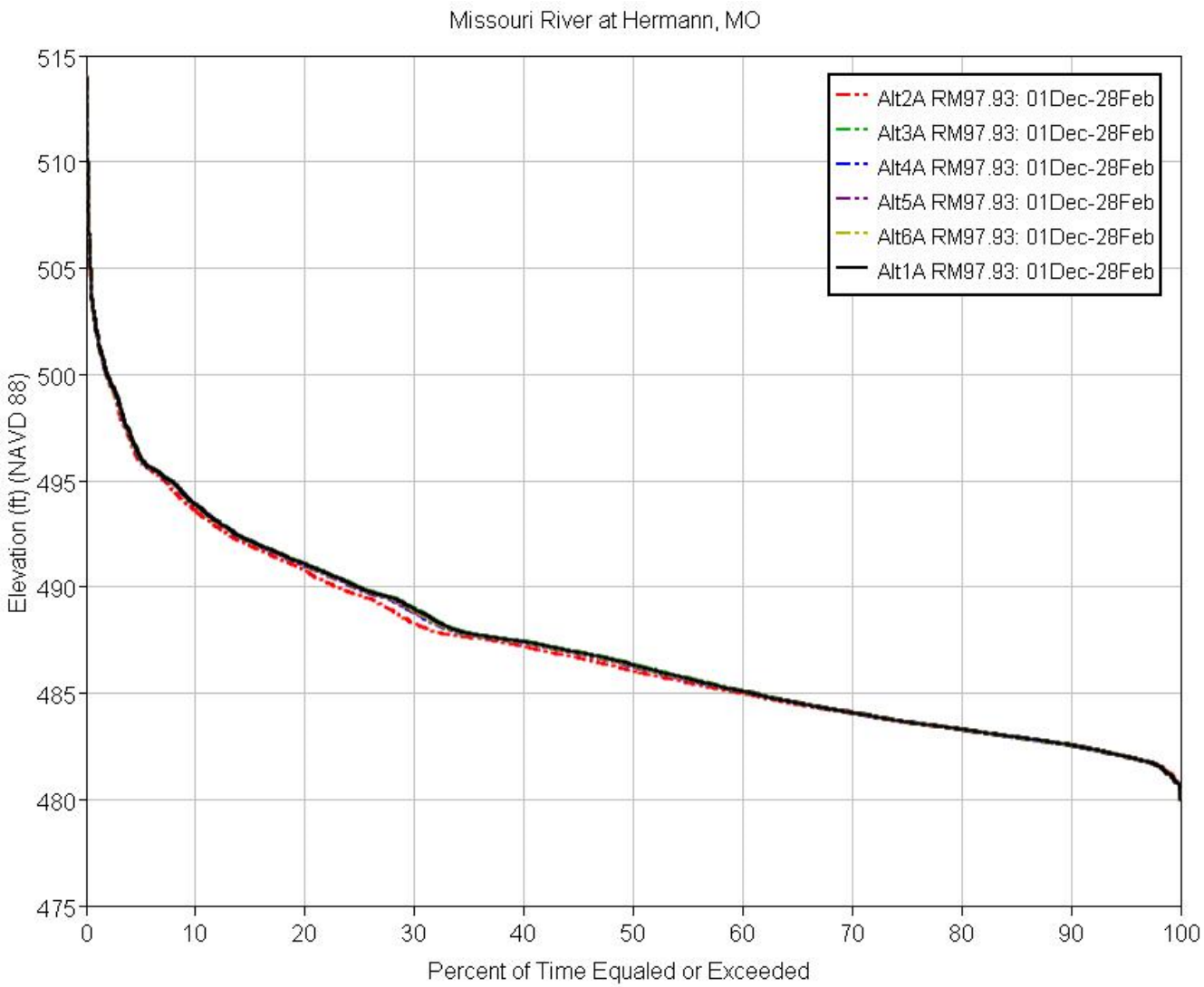

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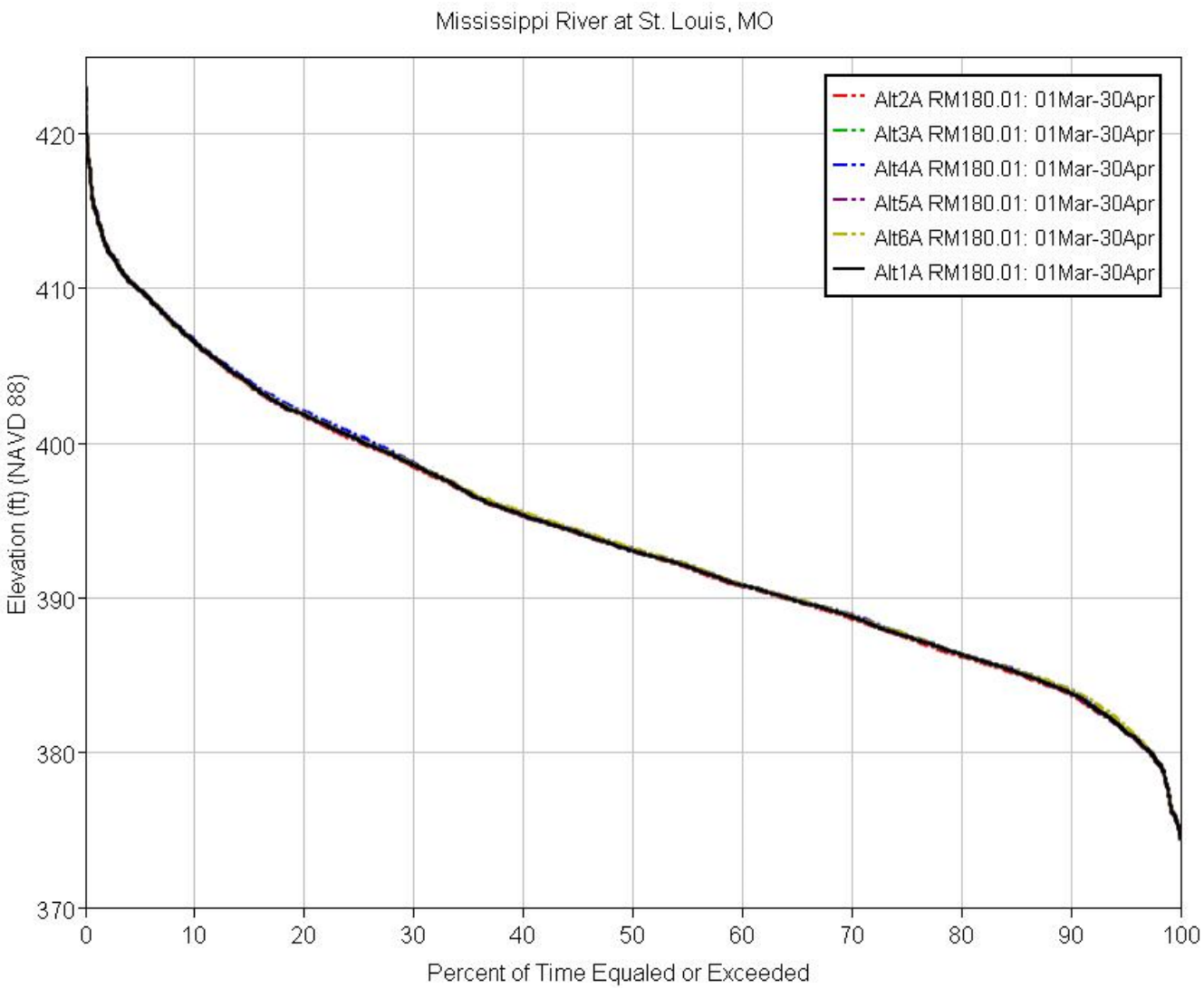

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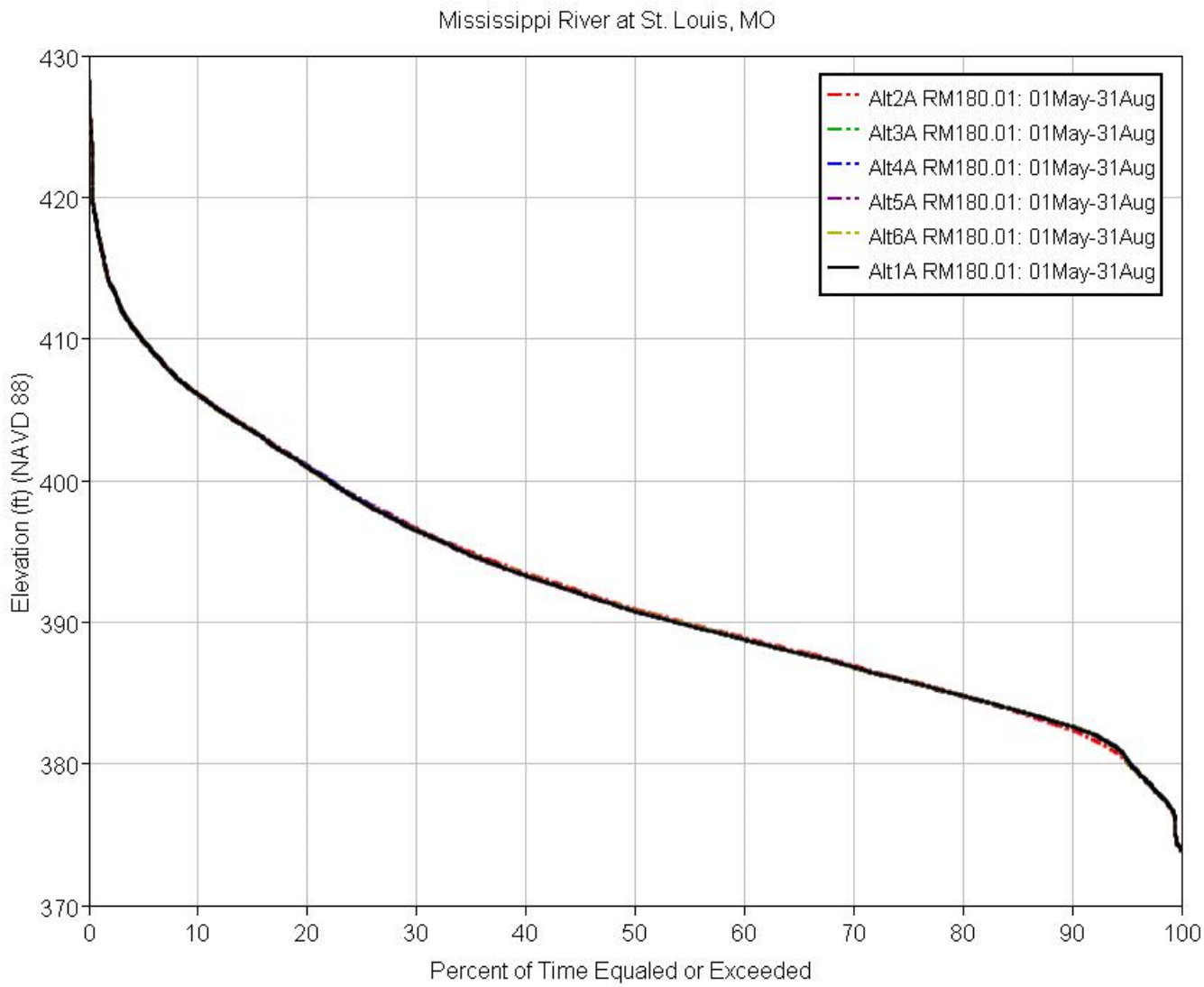

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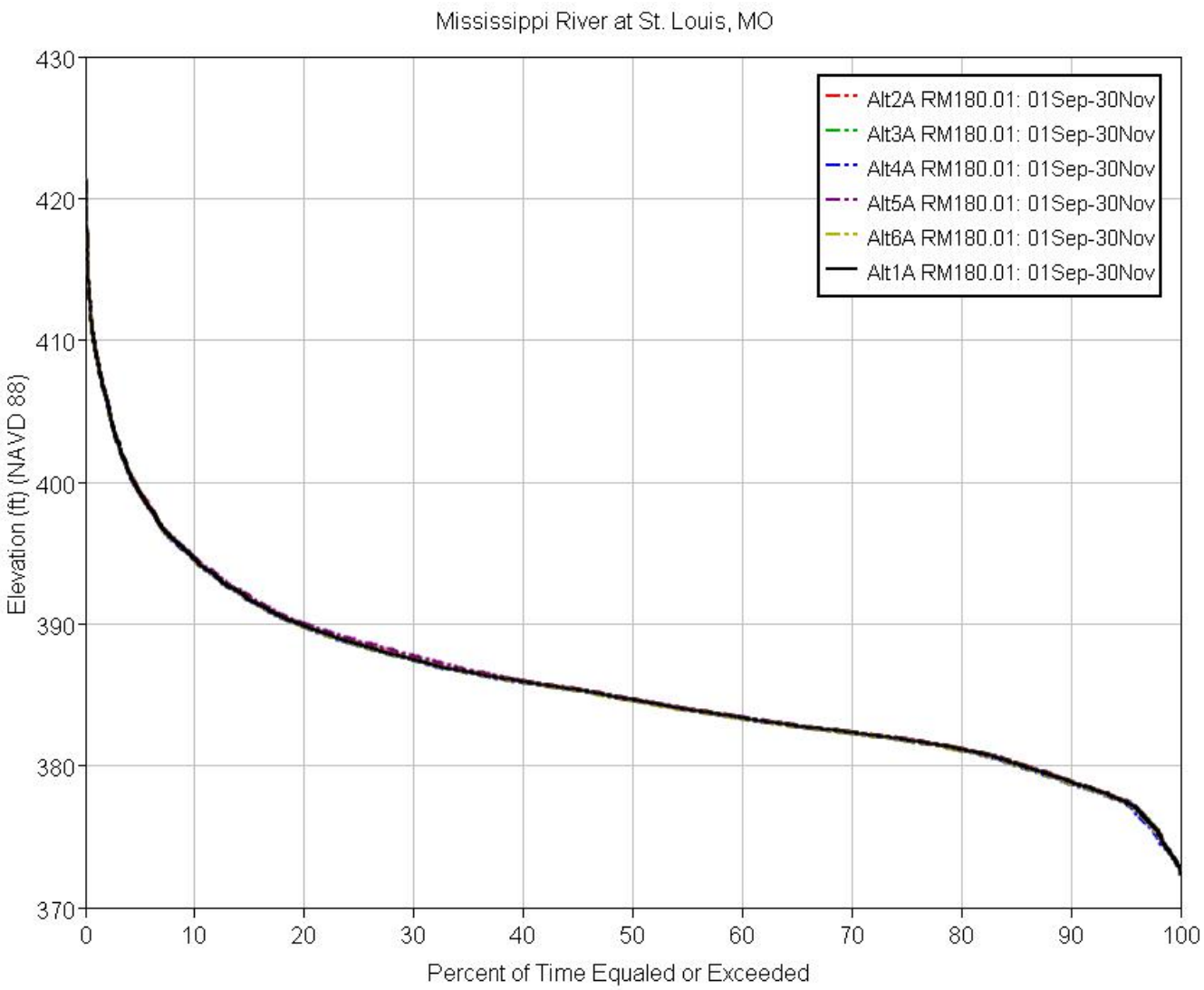

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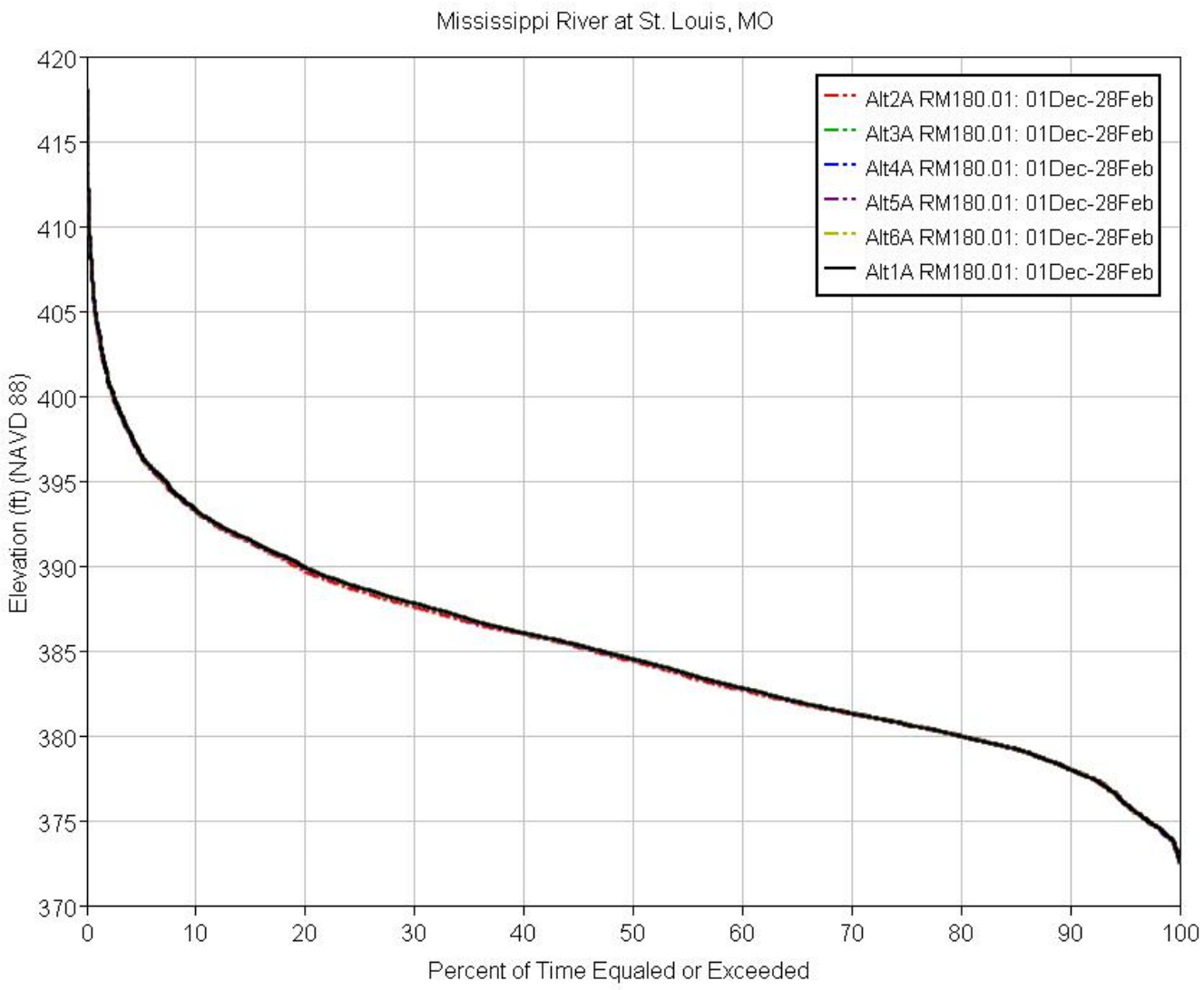

St. Louis Winter Duration

Attachment 6

Interior Drainage Hydrologic Analysis

Missouri River Recovery Program Management Plan

United States Army Corps of Engineers

Kansas City District

DRAFT – December 2016

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Acronyms

DEM	Digital Elevation Model
ET	Evapotranspiration
HSG	Hydrologic Soil Group
Ksat	Saturated Hydraulic Conductivity
LIDAR	Light Detection and Ranging
MRLS	Missouri River Levee System
NAIP	National Agricultural Imagery Program
NED	National Elevation Database
POR	Period of Record
USGS	United States Geological Survey
WMS	Watershed Modeling System

1 INTRODUCTION

Interior drainage analyses for four Missouri River levee systems, two in Omaha District and two in Kansas City District, were conducted as part of the Missouri River Recovery Program's Management Plan. The selected sites represent a sub sample of locations modeled in 1998 during the Master Manual review and update (REF). The interior drainage analysis involved simulating period of record (POR) inflows using a rainfall runoff model to provide flow inputs to an unsteady hydraulic analysis to simulate inundation in leveed areas. Hourly rainfall-runoff hydrologic simulations between 1948-2012 was conducted for the interior drainage at the Missouri River Levee System (MRLS) L488 and the MRLS L246 levee systems. This work was conducted in general accordance with USACE Engineering Manual (EM) 1110-2-1413 "Hydrologic Analysis of Interior Areas" and EM 1110-2-1417 "Flood-Runoff Analysis." The purpose of this report is to document the supporting engineering analyses of the interior drainage hydrologic modeling for the two levee systems in the Kansas City District. Close coordination of the modeling was conducted with Omaha District to ensure reasonably consistent methodology, including both districts utilizing model calibration of a historic stream gage on Mill Creek to inform the model development for the interior drainage sites (USACE, 2016).

2 MRLS L488 INTERIOR DRAINAGE

The MRLS L488 levee, described as L488, interior drainage analysis has been developed to provide POR runoff estimates that are produced by the contributing drainage basin of the levee system. The leveed area generally surrounds Forbes, Missouri and protects agricultural lands along the Missouri River floodplain. The contributing drainage area consists of about 15 square miles of flood plain and about 13 square miles of area above the bluff line. Figure 1 shows a general layout of the interior drainage area.

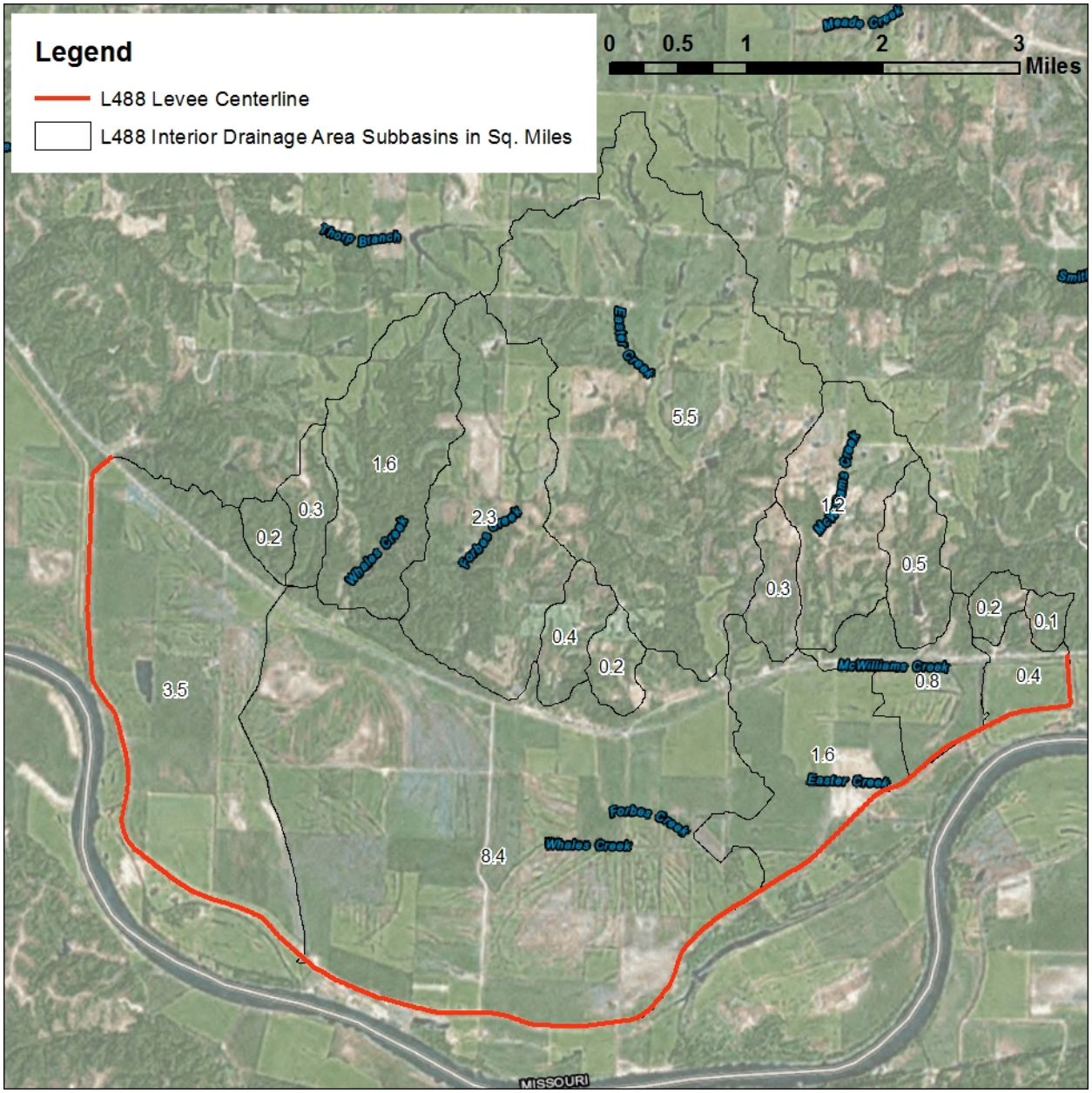

Figure 1: L488 Interior Drainage Area and Subbasin Boundaries

2.1 HYDROLOGIC MODEL DEVELOPMENT

A hydrologic analysis was developed with parameters shown in Table 1. The basin model development involved estimating terrain, soil, and land use properties as well as calibrating the basin to meet the objectives of the study.

Table 1: L488 Hydrologic Model Parameters

Model Parameter	Adopted Method
Hydrologic Modeling Software	HEC-HMS v 4.2
Basin delineation and physical terrain analysis	A 10-meter terrain grid obtained from the USGS National Elevation Database (NED) was processed with Aquaveo WMS software with refinements based on 1-meter LIDAR and recent NAIP aerial photography
Precipitation Data	Hourly point precipitation data at several gages
Loss Methods	Deficit and Constant
Routing Methods	Muskingum-Cunge
Transform methods	Snyder Unit Hydrograph
Canopy Methods	none
Calibration approach	Adapted from the Mill Creek pilot study basin parameters, input flows into the hydraulic analysis and compared results to modeled interior ponding elevations
HEC-HMS working File Location	K:\MissionProjects\sec\ed-h\MoRiver_Models\500_Rivers\592_Alternatives_HC\Interior Drainage\L488\HMS

Basin delineations and river centerlines were first established from a 10-meter digital elevation model (DEM) and refined in the floodplain with a higher definition 1-meter DEM that is based on light detection and ranging (LIDAR) data collected in 2012. These refinements were needed because many drainage boundaries and canals within the floodplain were not adequately represented in the 10-meter DEM. In many floodplain locations with a relatively small amount of elevation relief, the relatively coarse terrain data in the 10-meter LIDAR did not adequately represent the hydraulic parameters needed to route discharge to each outlet. Historical National Agriculture Imagery Program (NAIP) aerial photography was also used to verify the delineations and river centerlines. The basin model layout is shown in Figure 2.

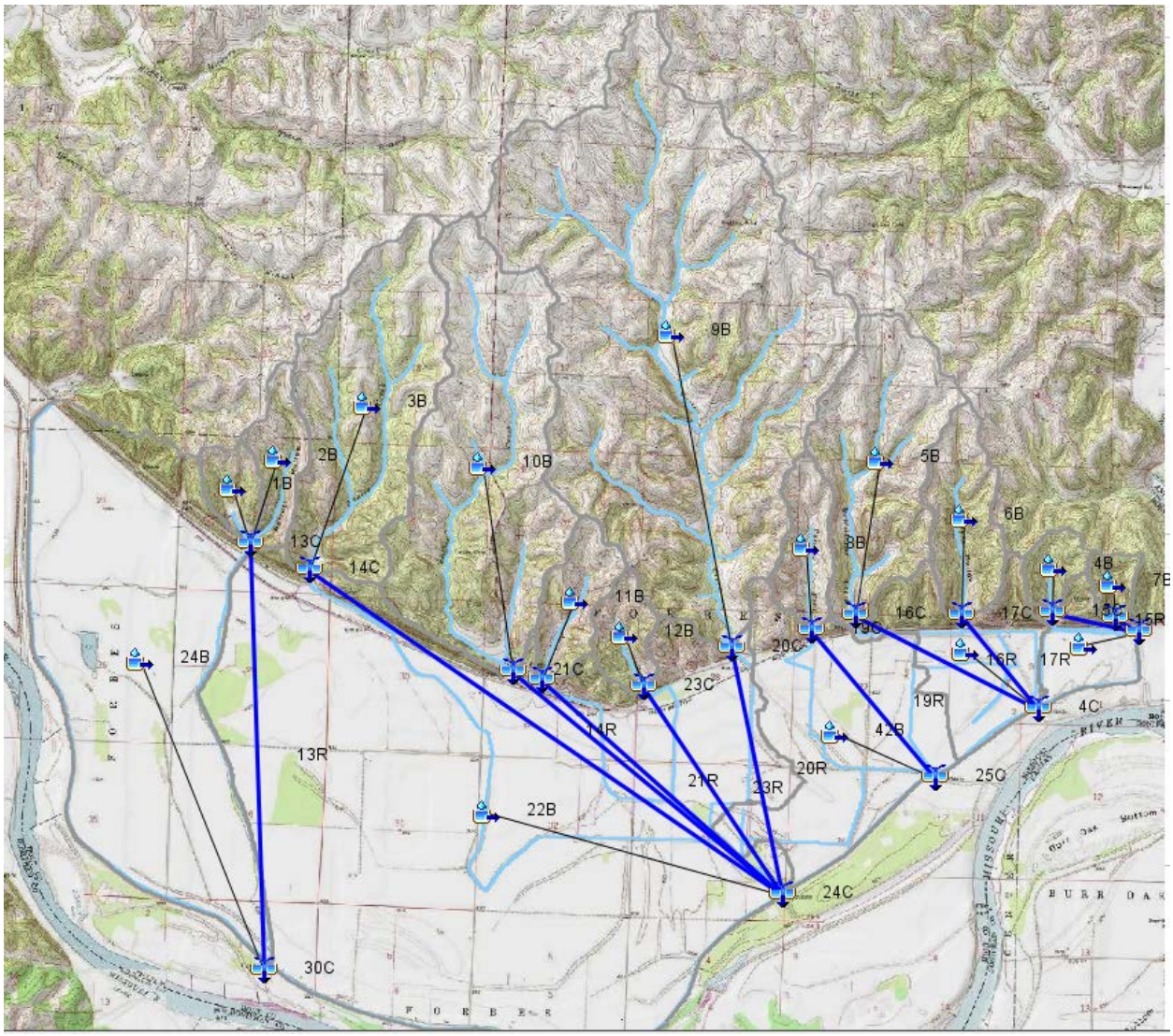

Figure 2: L488 Basin Schematic

2.2 BASIN MODEL COMPONENTS

The basin model consisted of estimating several parameters that were required to route flow to each outlet structure in the levee. Five outlet structures are shown in Table 2 that have contributing subbasins summarized in Table 2.

Table 2: L488 Hydrologic Index for each Outlet

Outlet Levee Station	Junction	Cumulative Drainage Area (mi^2)
442+43	24C	18.34
508+82	25C	1.92
604+21	28C	0.63
238+90	30C	4.02
551+33	4C	2.52

Hydrologic parameters of each subbasin are shown in Table 3 that include hydrologic connections, outlets through the levee, basin area, and lag time. Uniform parameters for all basins included the Snyder's transform method with a peaking coefficient of 0.6, the recession baseflow initial discharge of 0.5 cfs/square mile, and initial/constant loss methods with an initial deficit of 1-inch. Basins located in the floodplain do not have downstream reaches because they are directly connected to the outlet structures. Variation of parameters such as loss rates and recession constants is discussed in the subsequent sections.

Table 3: L488 Subbasin Parameters

Basin Name	Downstream Reach	Outlet Structure	Basin Location	Basin Area (mi^2)	Lag Time (hours)	Recession Constant	Threshold Flow (cfs)	Maximum Storage (in)	Constant Rate (in/hr)
6B	17R	4C	above bluffs	0.515	0.67	0.4	0.515	4.1	0.21
5B	16R	4C	above bluffs	1.207	0.92	0.45	1.207	4.1	0.24
44B	--	4C	Floodplain	0.800	0.96	0.4	0.8	3.9	0.27
2B	13R	30C	above bluffs	0.298	0.57	0.4	0.298	4.0	0.26
1B	13R	30C	above bluffs	0.183	0.37	0.4	0.183	4.0	0.23
24B	--	30C	Floodplain	3.536	3.51	0.45	3.536	3.6	0.41
7B	18R	28C	above bluffs	0.112	0.27	0.4	0.112	3.9	0.22
4B	15R	28C	above bluffs	0.154	0.35	0.4	0.154	4.0	0.20
17B	18R	28C	Floodplain	0.360	0.67	0.4	0.36	4.0	0.25
8B	19R	25C	above bluffs	0.326	0.46	0.4	0.326	4.3	0.34
42B	--	25C	Floodplain	1.593	2.08	0.45	1.593	3.5	0.21
12B	23R	24C	above bluffs	0.232	0.45	0.4	0.232	4.1	0.21
11B	22R	24C	above bluffs	0.350	0.59	0.4	0.35	4.1	0.25
10B	21R	24C	above bluffs	2.258	1.46	0.45	2.258	4.1	0.23
9B	20R	24C	above bluffs	5.493	1.66	0.45	5.493	4.1	0.26
3B	14R	24C	above bluffs	1.620	1.15	0.45	1.62	4.1	0.29
22B	--	24C	Floodplain	8.385	4.86	0.45	8.385	3.3	0.20

2.2.1 Loss methods

Hydrologic losses were established with considerations to published saturated hydraulic conductivity (Ksat) and hydrologic soil groups (HSGs) estimates within the modeled basins. These values were compared to the Mill Creek pilot study parameters to identify possible differences in runoff losses between each basin. The comparison of soil properties for the two basins was used to improve the site investigations for the L488 basin, which has no gaged information with which could be used for calibration. Aquaveo's Watershed Modeling System (WMS) v 10.0 software was used to acquire geospatial layers of soil parameters from the SSURGO database that are shown in Figure 3 and Figure 4. The analysis indicates the Mill Creek basins have Ksat values of of 2-4 um/sec and mostly soil types B. For comparison purposes it is noted that 1um/sec = 0.142inches/hour. The L488 basins above the bluff line had KSAT values of 1-3 um/sec and soil types B&C with some D. The L488 flood plain basins have lower values of KSAT no more than 1 um/sec with soil types D&C.

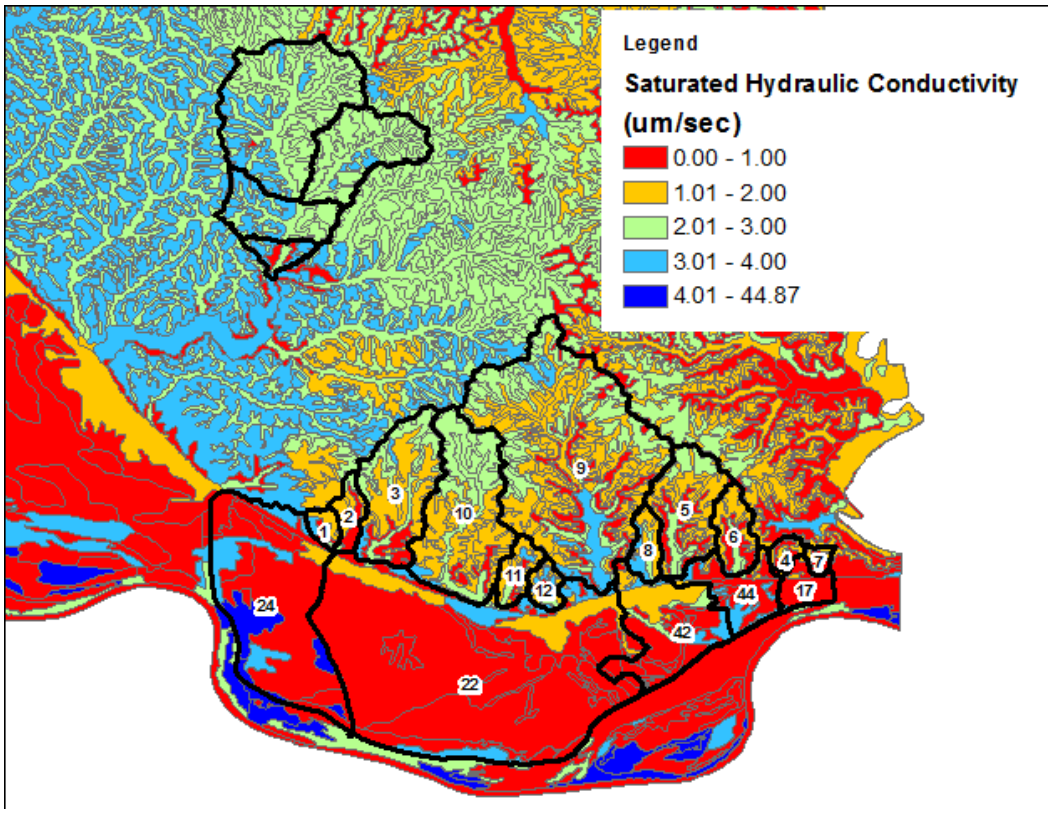

Figure 3: SSURGO Saturated Ksat in each sub-basin of L488 and Mill Creek Basins

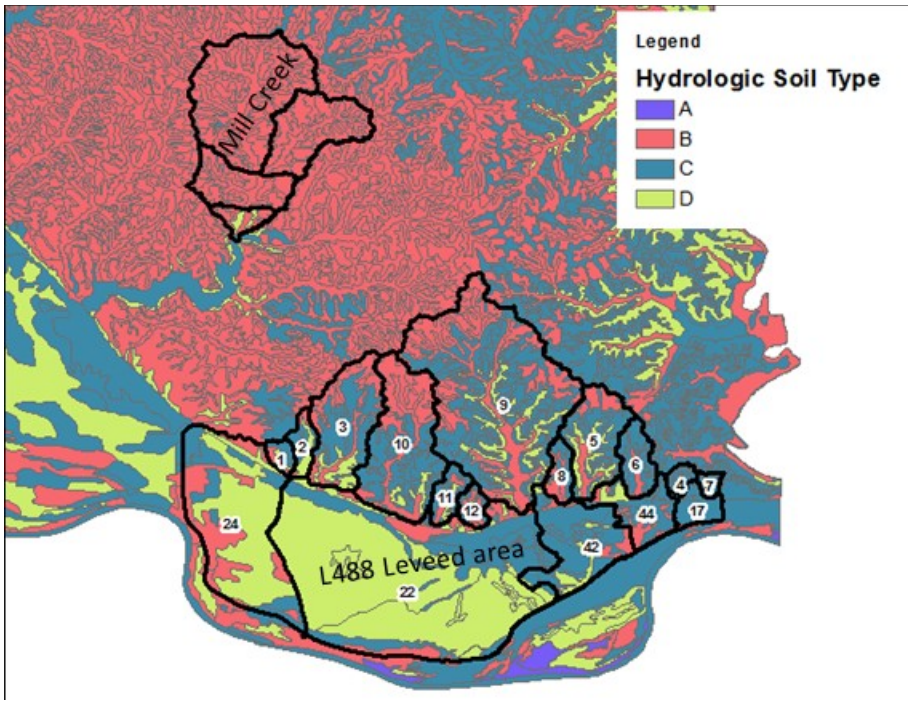

Figure 4: SSURGO Hydrologic Soils in each sub-basin of Mill Creek and L488

Rainfall losses were modeled using the deficit and constant loss method. This method uses the following parameters: initial deficit, maximum storage, constant rate, and percent impervious. The initial deficit is an estimate of the moisture required to saturate the soil at the start of the simulation. The maximum storage (or maximum deficit) is the amount of moisture needed to saturate the soil. The constant loss rate is similar to the hydraulic conductivity of the soil and is an important calibration parameter. Soil properties were determined based on the SSURGO soils data and associated properties from Rawls, et al (1983). L488 is composed of mostly silt loam and silty clay soils. The percent impervious was left at zero as it was considered negligible due to this being mostly agriculture land.

2.2.1 Baseflow

Baseflow was modeled by scaling the baseflow as a function of the basin area for each subbasin. A baseflow of 0.5 cfs per square mile was used. This compares to the Mill Creek pilot study, where the median flow from the gage was 0.53 cfs per square mile. The recession constant was also estimated as a function of basin area. Recession constants of 0.4, 0.45, and 0.5 were applied to basins with less than 1 square mile, 1-10 square miles, and 10-20 square miles, respectively.

2.2.2 Routing Reaches

Routing reaches were modeled using the Muskingum-Cunge method with an automatic fixed interval, a manning's n-value of 0.035, and a trapezoidal channel shape with 40-ft widths and 2H:1V side slopes. Computed values of slope and length for each modeled reach is shown in Table 4.

Table 4: L488 Routing Reach Parameters

Routing Reach	Final Outlet	Length (ft)	Slope (ft/ft)
17R	4C	6577.478	0.00319
16R	4C	10154.31	0.00251
13R	30C	15540.52	0.00136
18R	28C	1067.984	0.00763
15R	28C	3383.138	0.00383
19R	25C	9778.543	0.00169
23R	24C	9918.963	0.00186
22R	24C	12493.28	0.00153
21R	24C	13362.53	0.00146
20R	24C	11032.43	0.00076
14R	24C	26089.8	0.00096

2.3 METEOROLOGICAL MODEL COMPONENTS

2.3.1 Evapotranspiration and Canopy Loss Considerations

The meteorological model considered the Mill Creek study's evapotranspiration (ET) with a monthly average rate and coefficient as shown in the Table 5. Efforts to model ponding area elevations during the calibration process resulted in not modeling ET or canopy losses.

Table 5: Evapotranspiration Rates and Coefficients

Month	Average Rate (inches/month)	Coefficient
January	0	0.75
February	0	0.75
March	0	0.75
April	5.19	0.75
May	5.96	0.75
June	7.06	0.75
July	7.76	0.75
August	6.42	0.75
September	5.04	0.75
October	3.54	0.75
November	0	0.75
December	0	0.75

2.3.2 Precipitation

Hourly precipitation since 1948 was assembled and reviewed at the nearest 7 weather stations to L488 from the NCDC – CDO database to ensure the best quality precipitation dataset could be adopted for the study. Since continuous coverage was not available at any of the stations, the measurement coverage in each year at each gage was evaluated. Precipitation data input to the HEC-HMS model was assembled into a single time series by prioritizing measurement coverage and minimizing station distance from L488 and shown in Figure 5. Gage data sources are shown in Exhibit 1.

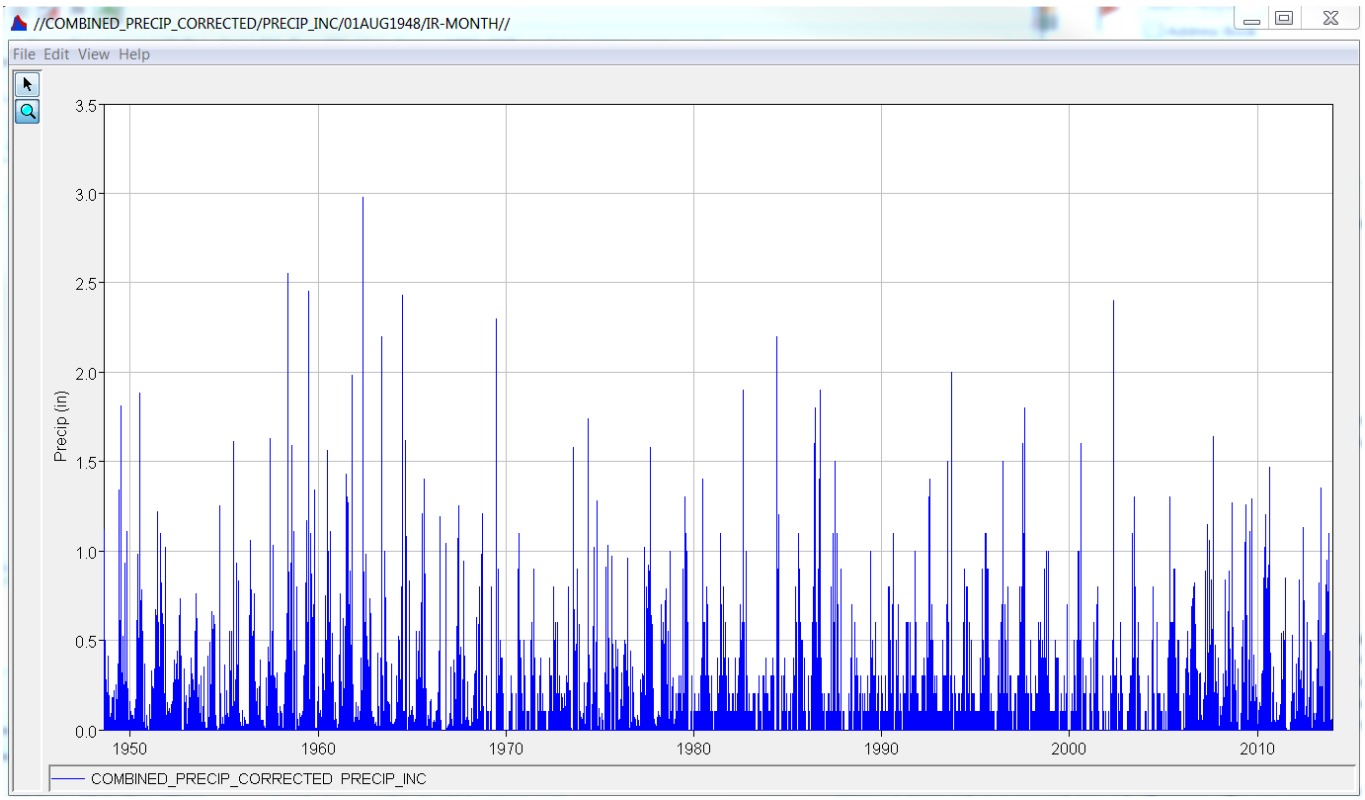

Figure 5: Adopted L488 Hourly Rainfall Period of Record

2.4 MODEL CALIBRATION AND VALIDATION

Model calibration involved comparing computed interior drainage pool elevations produced with modeled inflows within the hydraulic analysis to observations. This is described in detail in Section 5.2 in Appendix E of the Missouri River Unsteady HEC-RAS Models Alternative Analysis. Other calibration analysis involved the Mill Creek pilot study that included calibration to a stream gage within the basin. Several basin parameters from the Mill Creek pilot study were used as a starting point for the L488 analysis.

Additional site specific analysis was conducted to validate that the model was generating reasonable long-term runoff volumes and peak flows. Annual computed runoff in the L488 basin

was accumulated and plotted against 25 years of available records at the USGS Mill Creek streamgage as shown in Figure 6. A USGS (1987) analysis that developed runoff estimates between 1951-1980 was compared to the modeled annual runoff for validation. The 1987 USGS publication estimated an average annual runoff of 7.5 to 8 inches of runoff during these years, whereas the HEC-HMS analysis produced a slightly higher estimate with an average of 8.6 inches. Canopy and ET losses affected these results by reducing the average modeled annual runoff to about 2.4 inches. This unrealistically low estimate of computed average annual runoff resulted in not including canopy or ET losses into the adopted modeling.

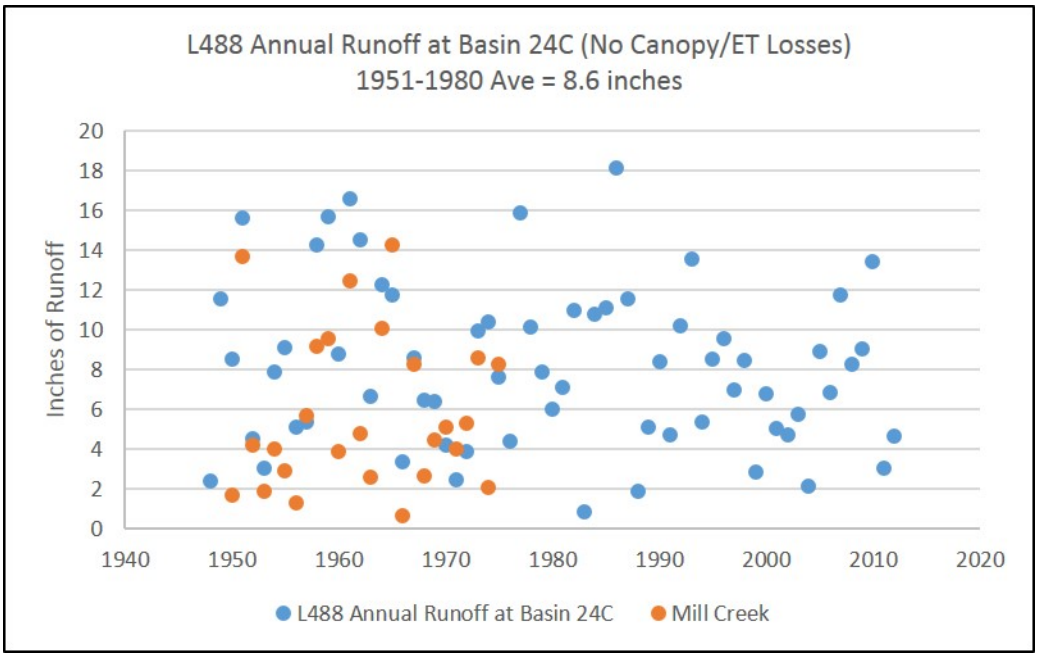

Figure 6: Annual Computed Runoff Volume

Additional analysis was conducted to validate the reasonableness of the results by comparing the frequency of annual peak flows from the HEC-HMS model to USGS regional streamflow statistic equations. Annual peak hourly inflows from HEC-HMS were used in the analysis, which would be expected to somewhat underestimate frequency event values derived from instantaneous flow records. Regression analysis inputs included a 4.8 mile longest flow path, 5.49 square mile basin, and a B-shape of 4.188. The Weibull positioned computed annual peak streamflow from Basin 9B are plotted, both with and without canopy and ET losses, along with the results of USGS regional streamflow regression equations in Figure 7. The annual peak streamflow with canopy and ET losses more closely matches the USGS regression equations than the annual peak streamflow without canopy and ET losses. However, it was determined to not include canopy and ET in the adopted modeling since neglecting these losses more reasonably matched long term runoff volumes. Additionally, the impact of the modeling producing large peak flows more often than expected would likely produce conservative results in the alternative analysis.

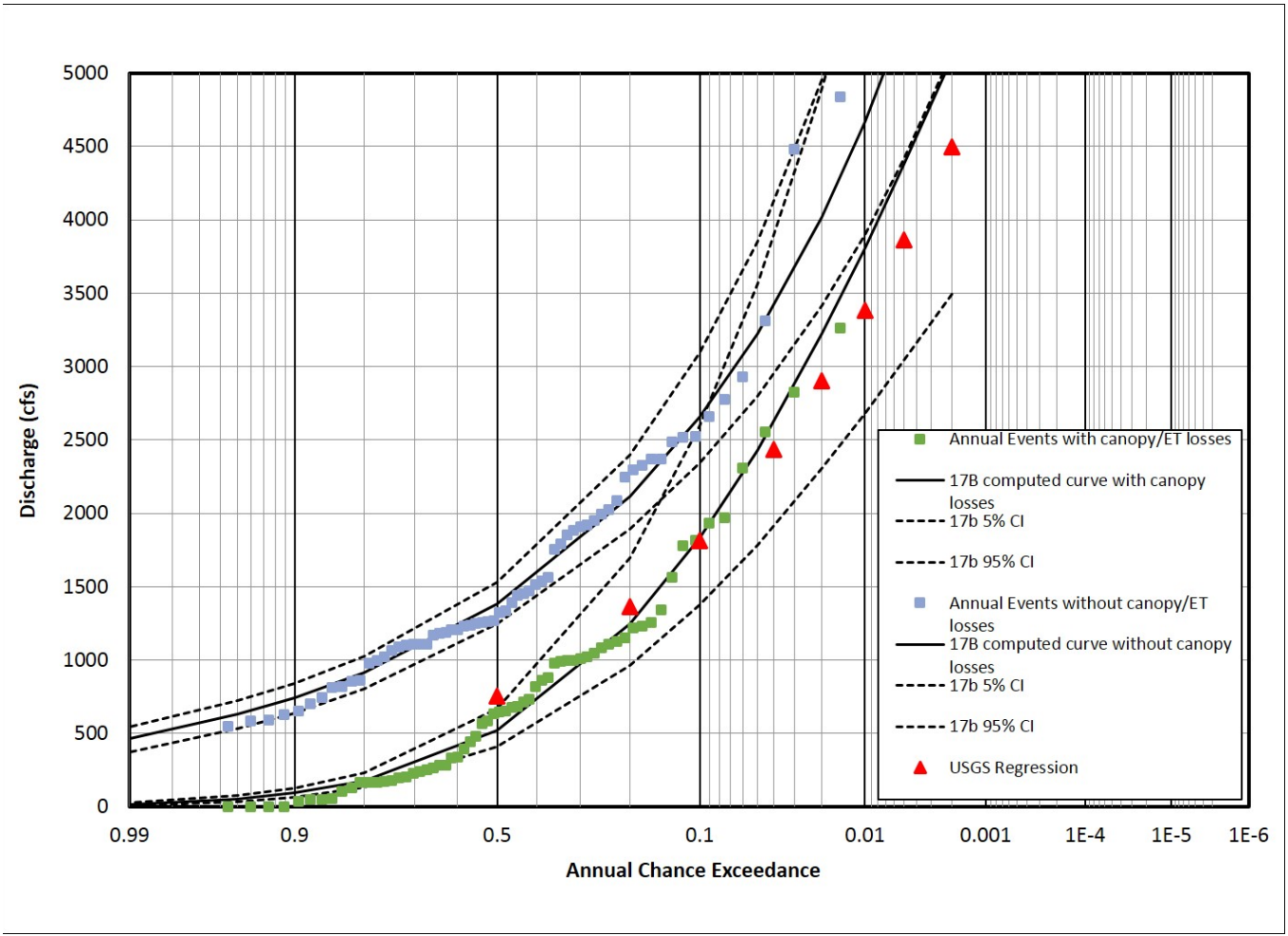

Figure 7: L488 Flow Frequency Comparison on Normal Probability Plot

2.5 RESULTS

Hourly discharge data was input to the unsteady hydraulic analysis to simulate interior drainage ponding and interactions with the Missouri River system. Typical results from HEC-HMS that were used as flow input to the HEC-RAS model is shown for the L488 levee at the station 442+43 outlet in Figure 8.

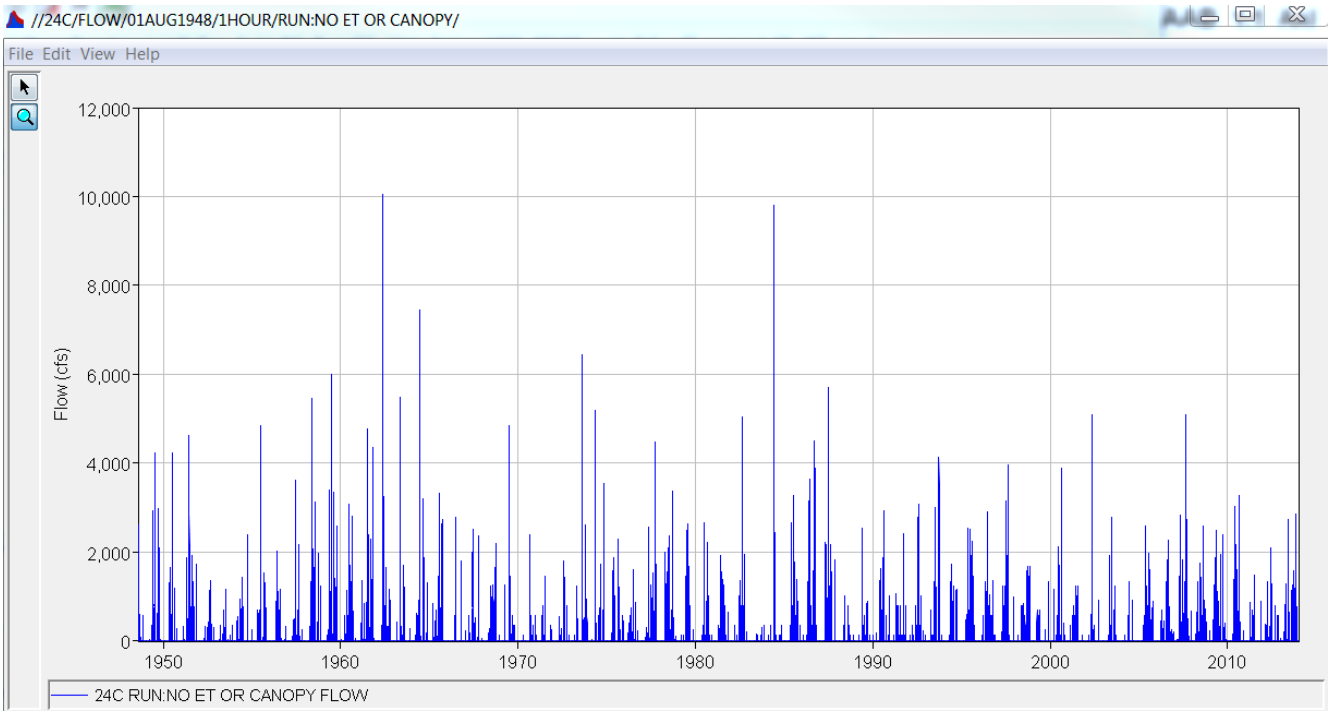

Figure 8: Hourly Computed Discharge at the 442+43 Outlet Structure at the L488 Levee

3 MRLS L246 INTERIOR DRAINAGE

The MRLS L246 levee, noted throughout the report as L246, interior drainage analysis has been developed to provide period of record runoff estimates that are produced by the contributing drainage basin of the levee system. The leveed area is generally east of Brunswick, Missouri and protects several agricultural lands along the Missouri River floodplain. The contributing drainage area consists of about 46 square miles of flood plain and about 44 square miles of area above the bluff line. Figure 9 shows a general layout of the interior drainage area.

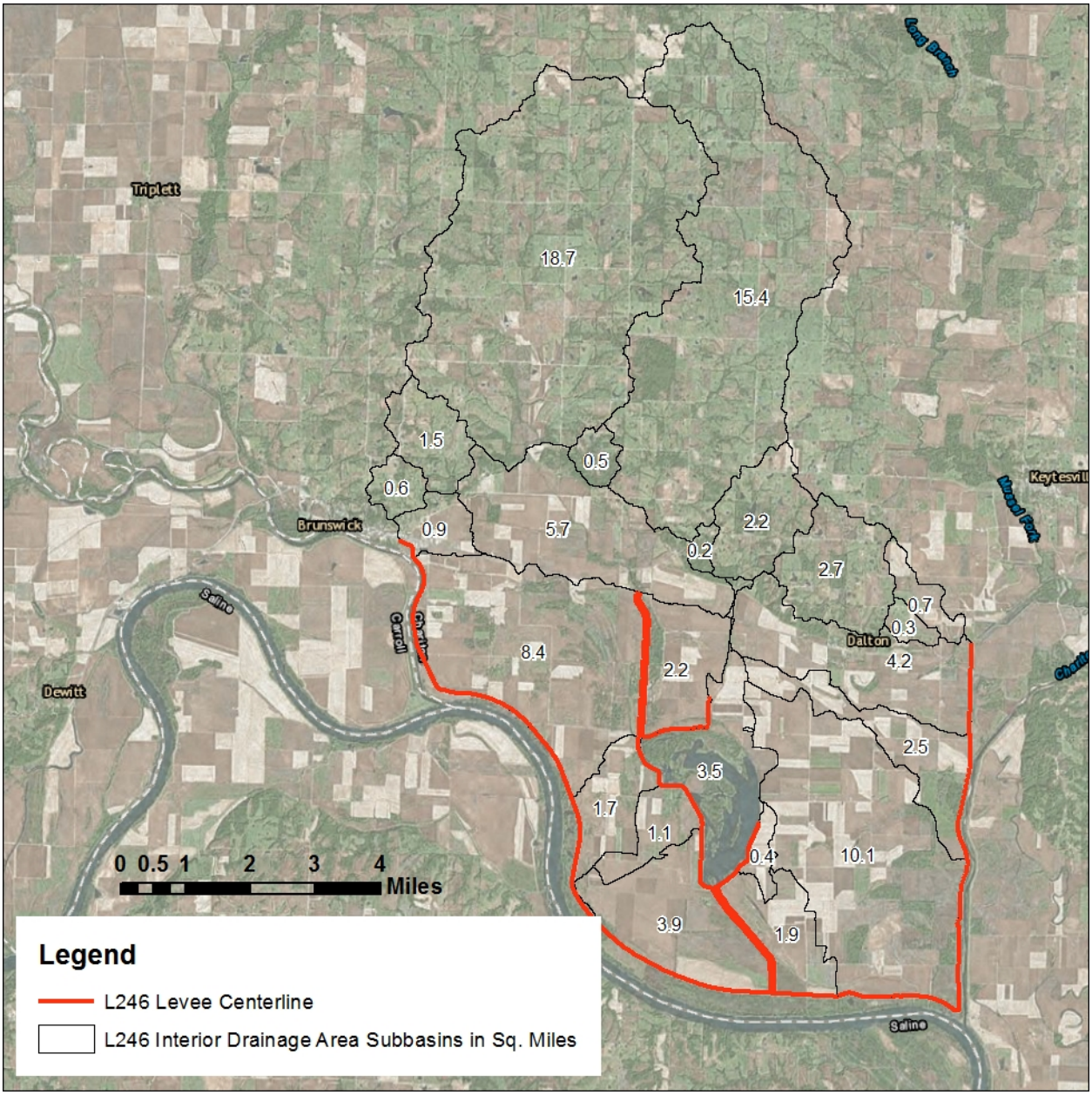

Figure 9: L246 Interior Drainage Layout and Subbasin Boundaries

3.1 HYDROLOGIC MODEL DEVELOPMENT

A hydrologic analysis was developed with parameters shown in Table 6. The basin model development involved estimating terrain, soil, and land use properties as well as calibrating the basin to meet the objectives of the study.

Table 6: L246 Hydrologic Model Parameters

Model Parameter	Adopted Method
Hydrologic Modeling Software	HEC-HMS v 4.2
Basin delineation and physical terrain analysis	A 10-meter terrain grid obtained from the USGS National Elevation Database (NED) was processed with Aquaveo WMS software.
Precipitation Data	Hourly point precipitation data at several gages
Loss Methods	Deficit and Constant (initial deficit of 1-inch, maximum storage of 3.6 inches, and constant rate of 0.2 inches/hour)
Routing Methods	Muskingum Cunge (0.024 manning's n)
Transform methods	Snyder Unit Hydrograph (0.6 peaking coefficient, computed lag time for each subbasin)
Canopy Methods	none
Hydrologic model calibration approach	Adapted from the Mill Creek pilot study basin parameters
HEC-HMS working File Location	K:\MissionProjects\sec\ed-h\MoRiver_Models\500_Rivers\592_Interior-Drainage\HMS

The hydrologic model was developed so that much of the basin could estimate runoff that were routed to Cutoff Lake. These Cutoff Lake inflows were then modeled as storage area inflows within the HEC-RAS analysis and routed to the mainstem Missouri River through a lateral connection. Flows were also modeled to three outlet structures on the Chariton River tieback, which were inflows to the Chariton River reach of the hydraulic model. One outlet structure on the Grand River was modeled which provided inflow to the Grand River reach of the hydraulic model. Two outflows from the leveed area to the Missouri River were modeled and connected as inflows to the Missouri River reach of the hydraulic model. The hydrologic basin schematic is shown in Figure 10.

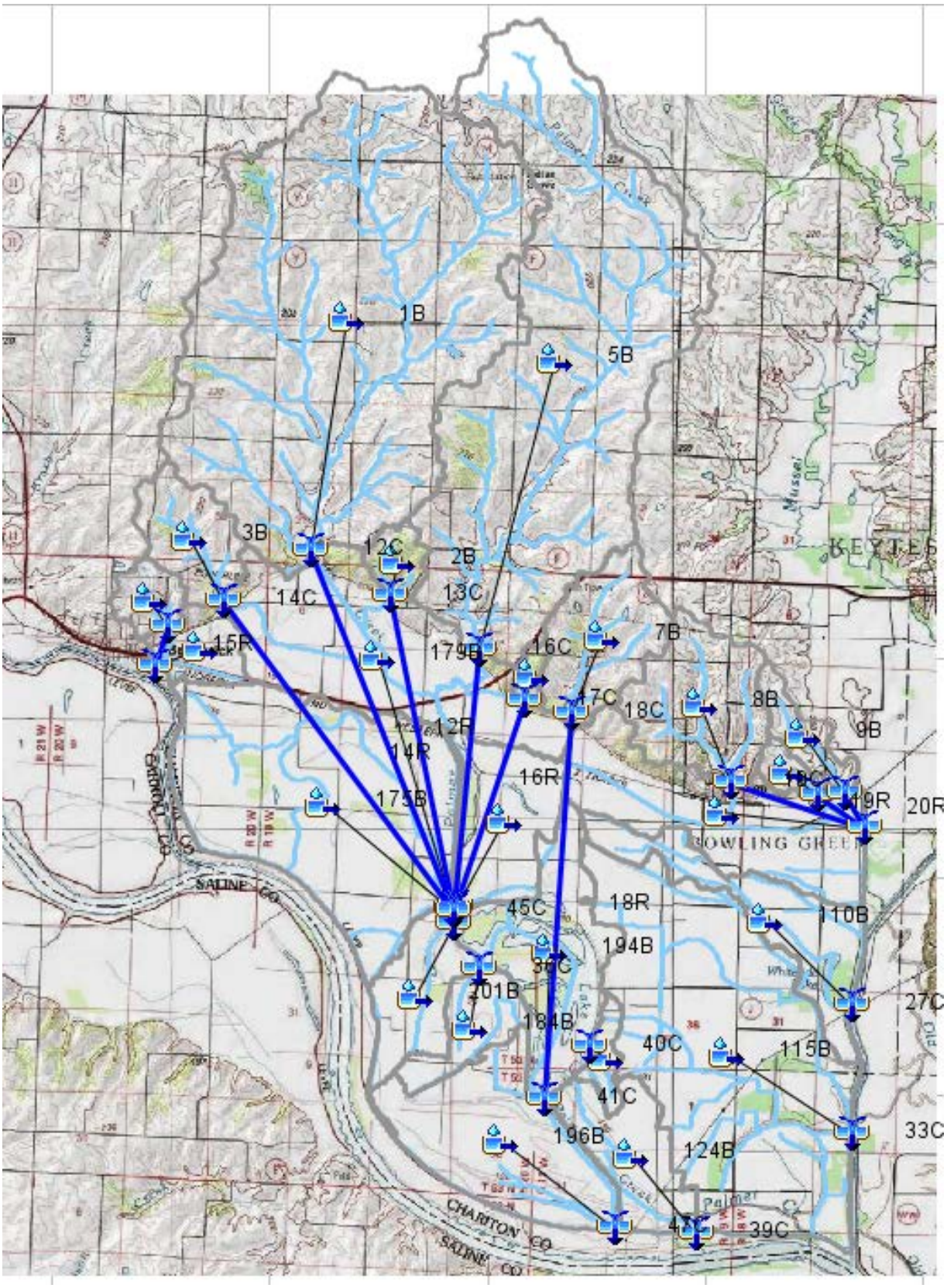

Figure 10: L246 Hydrologic Basin Schematic

3.2 BASIN MODEL COMPONENTS

The basin model consisted of estimating several parameters that were required to route flow to each outlet structure in the levee. Outlet structures and Cutoff Lake inflows are shown in Figure 10 with contributing subbasins summarized in Table 7.

Table 7: L246 Hydrologic Index for each Outlet

Outlet Levee Station	HEC-HMS Junction	Cumulative Drainage Area (mi^2)
241+03	29C	8.37
498+00	47C	3.89
240+50	32C	2.2
288+68	36C	1.11
400+05	41C	5.71
327+27	40C	0.42
17+75	34C	1.54
24+90	25C	7.96
142+00	27C	2.49
228+00	33C	10.1
627+00	39C	1.91
Palmer Creek inflows to Cutoff Lake	45C	41.95
288+68	49C	1.65

Hydrologic parameters of each subbasin are shown in Table 8 that include hydrologic connections, outlets through the levee, basin area, and lag time. Uniform parameters for all basins included the Snyder's transform method with a peaking coefficient of 0.6, the recession baseflow initial discharge of 0.5 cfs/square mile, and initial/constant loss methods with an initial deficit of 1-inch. Basins located in the floodplain do not have downstream reaches because they are directly connected to the outlet structures. Variation of parameters such as loss rates and recession constants is discussed in the subsequent sections.

Table 8: L246 Subbasin Parameters

Basin Name	Downstream Reach	Outlet Structure	Basin Location	Basin Area (mi^2)	Lag Time (hours)	Recession Constant	Threshold Flow (cfs)	Maximum Storage (in)	Constant Rate (in/hr)
201B	--	49C	floodplain	1.65	6.47	0.45	1.65	4.0	0.33
196B	--	47C	floodplain	3.89	8.85	0.45	3.89	3.6	0.12
191B	--	40C	floodplain	0.42	1.75	0.4	0.42	3.8	0.22
4B	15R	34C	above bluffs	0.63	0.58	0.4	0.63	3.9	0.24
181B	--	34C	floodplain	0.91	1.06	0.4	0.91	3.7	0.23
180B	--	32C	floodplain	2.20	4.52	0.45	2.2	3.7	0.15
175B	--	29C	floodplain	8.37	11.25	0.45	8.37	3.3	0.27
6B	17R	45C	above bluffs	0.23	0.42	0.4	0.23	4.1	0.32
5B	16R	45C	above bluffs	15.38	3.68	0.5	15.38	3.5	0.18
3B	14R	45C	above bluffs	1.51	1.00	0.45	1.51	3.8	0.21
2B	13R	45C	above bluffs	0.52	0.70	0.4	0.52	4.1	0.25
1B	12R	45C	above bluffs	18.65	2.61	0.5	18.65	3.5	0.17
179B	--	45C	floodplain	5.66	3.40	0.45	5.66	3.7	0.19
184B	--	36C	floodplain	1.11	8.82	0.45	1.11	3.2	0.11
7B	18R	41C	above bluffs	2.21	1.22	0.45	2.21	4.2	0.24
194B	--	41C	floodplain	3.50	16.14	0.45	3.5	3.2	0.21
124B	--	39C	floodplain	1.91	6.07	0.45	1.91	4.3	0.34
110B	--	27C	floodplain	2.49	7.87	0.45	2.49	3.7	0.22
115B	--	33C	floodplain	10.10	9.41	0.5	10.1	3.6	0.38
10B	21R	25C	above bluffs	0.34	0.82	0.4	0.34	4.0	0.29
9B	20R	25C	above bluffs	0.71	1.56	0.4	0.71	4.1	0.29
8B	19R	25C	above bluffs	2.69	1.26	0.45	2.69	4.0	0.26
143B	--	25C	floodplain	4.22	2.34	0.45	4.22	3.6	0.24

3.2.1 Loss Methods

Saturated hydraulic conductivity (Ksat) and hydrologic soil groups (HSGs) were evaluated at each subbasin of the L246 hydrologic model and compared to the Mill Creek pilot study parameters to identify reasons why possible differences in runoff might occur between each basin. The comparison of soil properties for the two basins was used to improve the site investigations for the L246 basin, which has no gaged information with which could be used for calibration. Aquaveo's Watershed Modeling System (WMS) v 10.0 software was used to develop geospatial layers of both soil parameters that are shown in Figure 11 and Figure 12. The analysis indicates the Mill Creek basins have Ksat values of 2-4 um/sec and mostly soil types B. For comparison purposes, it is noted that 1um/sec = 0.142inches/hour. The L246 basins have Ksat values that range between 0-3 um/sec with soil types D&C.

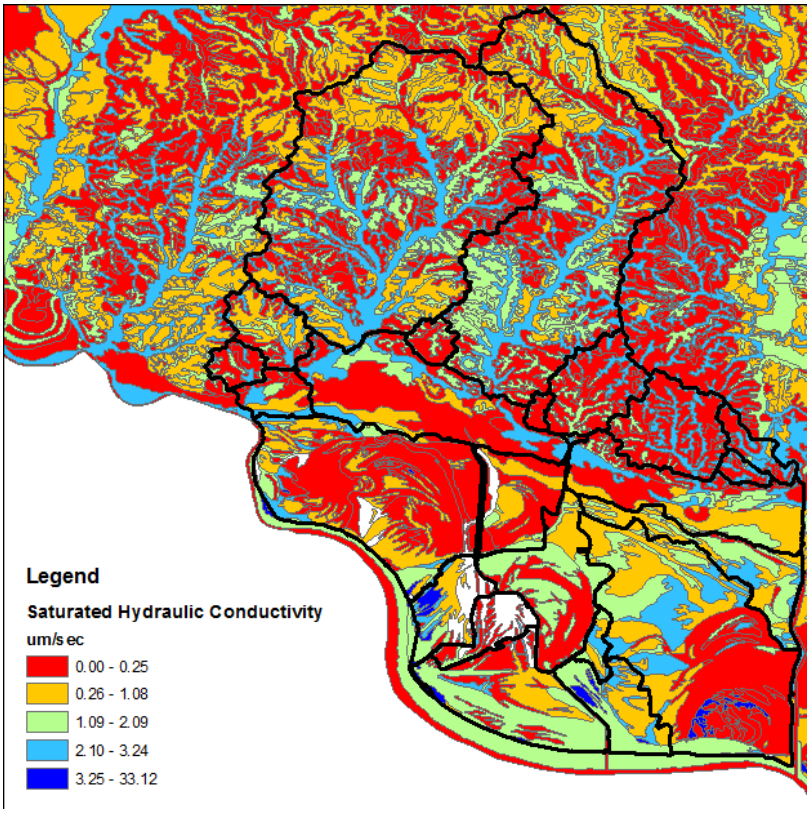

Figure 11: SSURGO Saturated Ksat in each sub-basin of L246

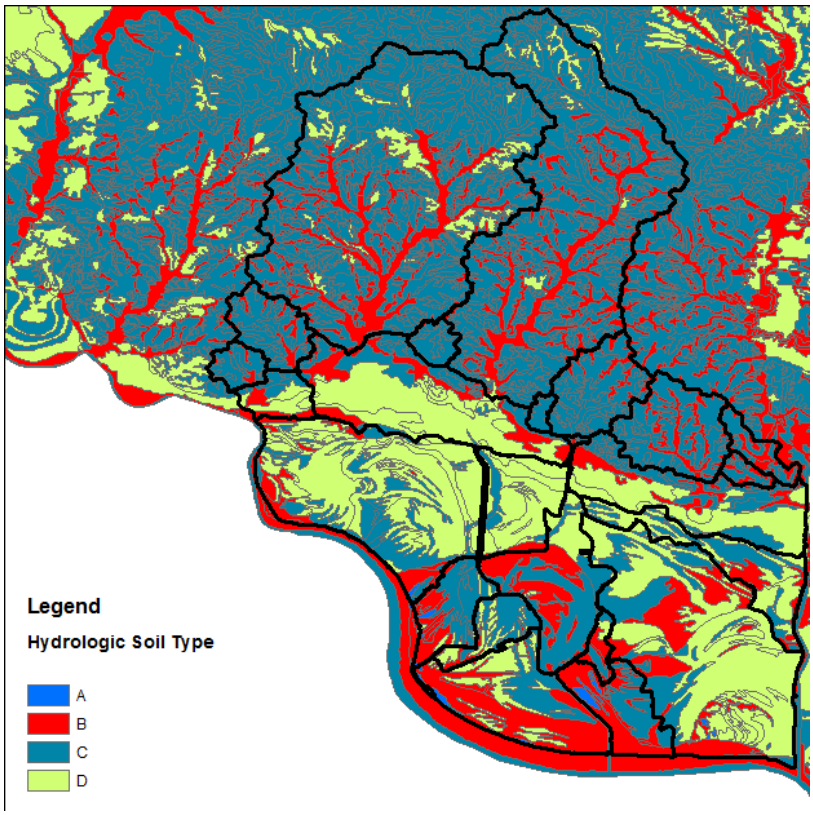

Figure 12: SSURGO Hydrologic Soils in each sub-basin of L246

Rainfall losses were modeled using the deficit and constant loss method. This method uses the following parameters: initial deficit, maximum storage, constant rate, and percent impervious. The initial deficit is an estimate of the moisture required to saturate the soil at the start of the simulation. The maximum storage (or maximum deficit) is the amount of moisture needed to saturate the soil. The constant loss rate is similar to the hydraulic conductivity of the soil and is an important calibration parameter. Soil properties were determined based on the SSURGO soils data and associated properties from Rawls, et al (1983). L246 is composed of mostly silt loam, clay, clay loam, and silty clay soils. The percent impervious was left at zero as it was considered negligible due to this being mostly agriculture land.

3.2.1 Baseflow

Baseflow was modeled by scaling the baseflow as a function of the basin area for each subbasin. A baseflow of 0.5 cfs per square mile was used. This compares to the Mill Creek pilot study, where the median flow from the gage was 0.53 cfs per square mile. The recession constant was also estimated as a function of basin area. Recession constants of 0.4, 0.45, and 0.5 were applied to basins with less than 1 square mile, 1-10 square miles, and 10-20 square miles, respectively.

3.2.2 Routing Reaches

Routing reaches were modeled using the Muskingum-Cunge method with an automatic fixed interval, a manning's n-value of 0.035, and a trapezoidal channel shape. Computed values of slope and length and adopted channel widths and side slopes for each modeled reach are shown in Table 9.

Table 9: L246 Routing Reach Parameters

Routing Reach	Final Outlet	Length (ft)	Slope (ft/ft)	Channel Width (ft)	Side Slope
15R	34C	3149.1	0.003176	10	2
17R	45C	22991.2	0.001156	80	3
16R	45C	21450.5	0.000382	80	3
14R	45C	31964.3	0.00085	50	2
13R	45C	25647.7	0.001011	80	3
12R	45C	28368.2	0.000647	80	3
18R	41C	31526.7	0.000614	30	2
21R	25C	4873.0	0.002565	20	2
20R	25C	3606.7	0.001802	20	2
19R	25C	12054.6	0.00083	30	2

3.3 METEOROLOGICAL MODEL COMPONENTS

3.3.1 Evapotranspiration and Canopy Loss Considerations

The meteorological model considered the Mill Creek study's evapotranspiration (ET) with a monthly average rate and coefficient as shown in Table 5. Efforts to model ponding area elevations during the calibration process resulted in not modeling ET or canopy losses.

3.3.2 Precipitation

Hourly precipitation since 1948 was assembled and reviewed at the nearest 8 weather stations to L246 from the NCDC – CDO database to ensure the best quality precipitation dataset could be adopted for the study. Since continuous coverage was not available at any of the stations, the measurement coverage in each year at each gage was evaluated. Precipitation data input to the HEC-HMS model was assembled into a single time series by prioritizing measurement coverage and minimizing station distance from L246 and shown in Figure 13. Gage data sources are shown in Exhibit 2**Error! Reference source not found.**.

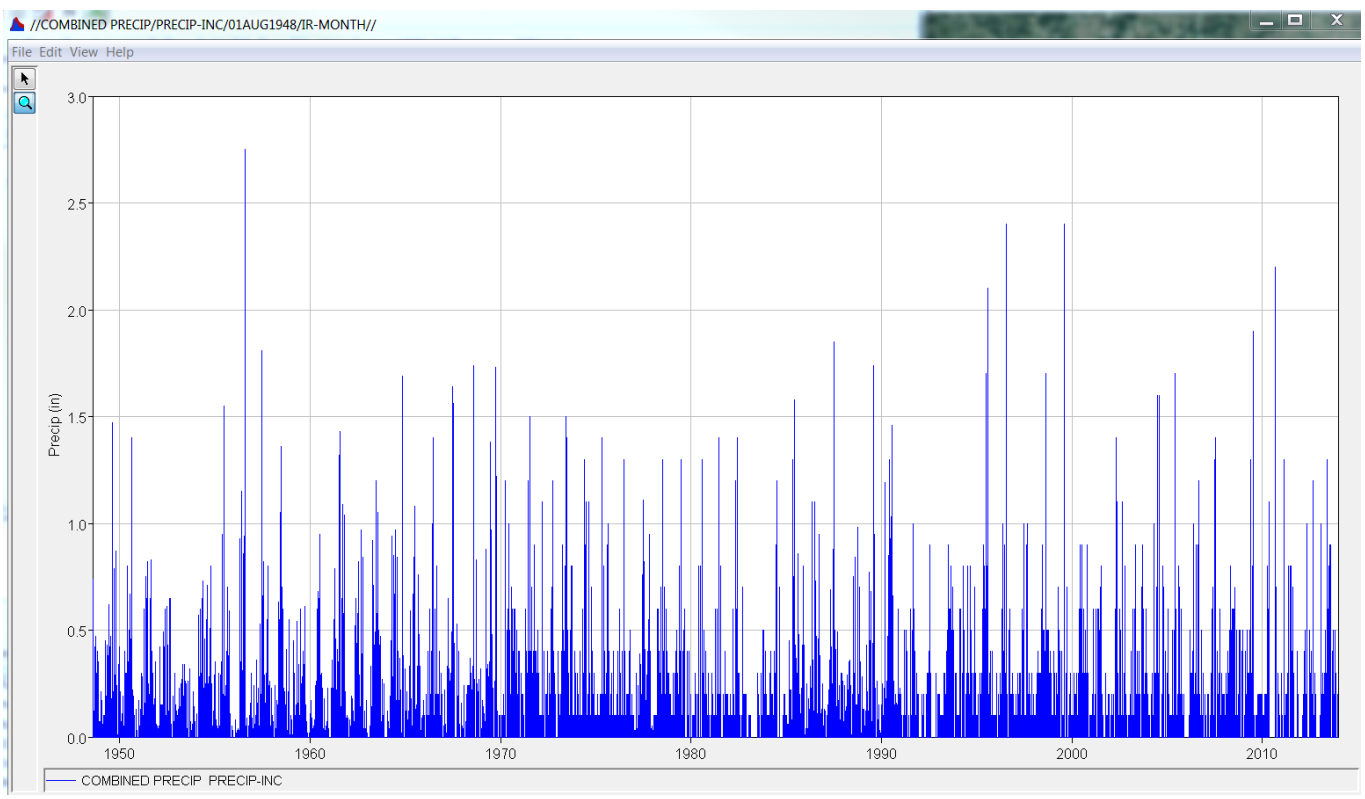

Figure 13: Adopted L246 Hourly Rainfall Period of Record

3.4 MODEL CALIBRATION AND VALIDATION

Model calibration involved comparing computed interior drainage pool elevations produced with modeled inflows within the hydraulic analysis to observations. This is described in detail in

Section 5.2 in Appendix E of the Missouri River Unsteady HEC-RAS Models Alternative Analysis. Other calibration analysis involved the Mill Creek pilot study that included calibration to a stream gage within the basin. Several basin parameters from the Mill Creek pilot study were used for the L246 analysis.

Additional site specific analysis was conducted to validate that the model was generating reasonable long-term runoff volumes and peak flows. Annual computed runoff in the L246 basin was accumulated and shown in Figure 14. A USGS (1987) analysis that developed runoff estimates between 1951-1980 was compared to the modeled annual runoff for validation. The 1987 publication estimated an average annual runoff of 8 to 9 inches of runoff during these years, whereas the HEC-HMS analysis produced a slightly higher estimate with an average of 10.1 inches. Canopy and ET losses affected these results by reducing the average modeled annual runoff to about 2.5 inches. This unrealistically low estimate of computed average annual runoff resulted in not including canopy or ET losses into the adopted modeling.

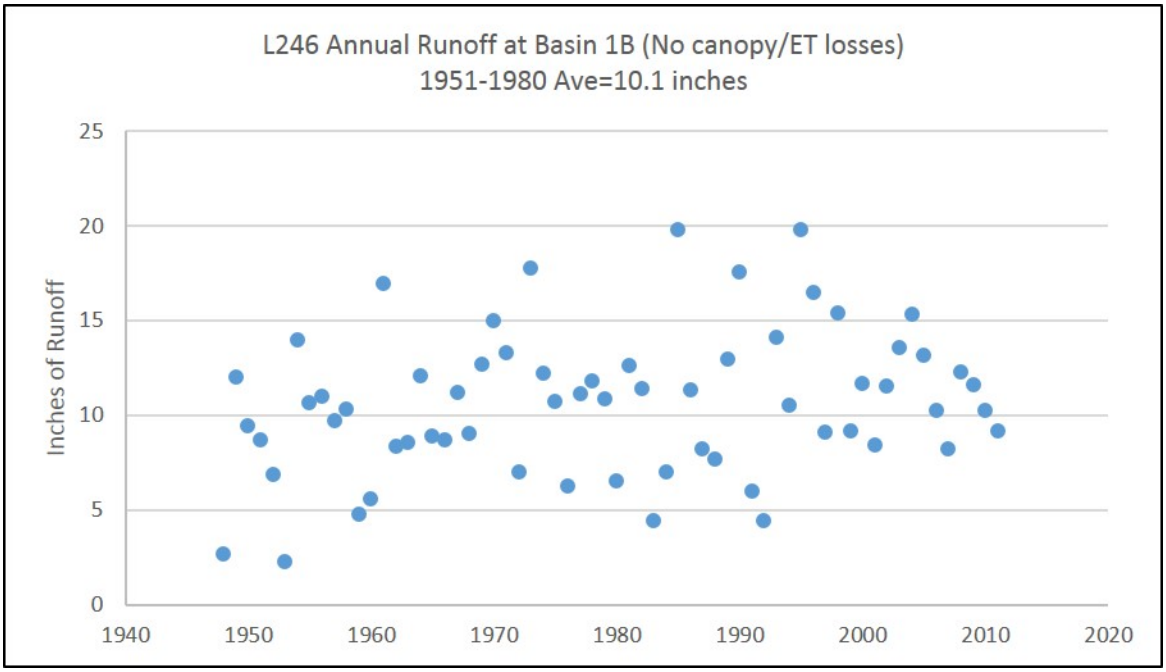

Figure 14: Annual Computed Runoff Volume

Additional analysis was conducted to validate the reasonableness of the results by comparing the frequency of annual peak flows from the HEC-HMS model to USGS regional streamflow statistic equations. Annual peak hourly inflows from HEC-HMS were used in the analysis, which would be expected to somewhat underestimate frequency event values derived from instantaneous flow records. Regression analysis inputs included a 7.8 square mile longest flow path, 18.65 square mile basin, and a B-shape of 3.266. The Weibull positioned computed annual peak streamflow from Basin 1B are plotted, both with and without canopy and ET losses, along with the results of USGS regional streamflow regression equations in Figure 15. The annual peak streamflow with canopy and ET losses more closely matches the USGS regression equations than the annual peak streamflow without canopy and ET losses. However, it was determined to not include

canopy and ET in the adopted modeling since neglecting these losses more reasonably matched long term runoff volumes. Additionally, the impact of the modeling producing large peak flows more often than expected would likely produce conservative results in the alternative analysis.

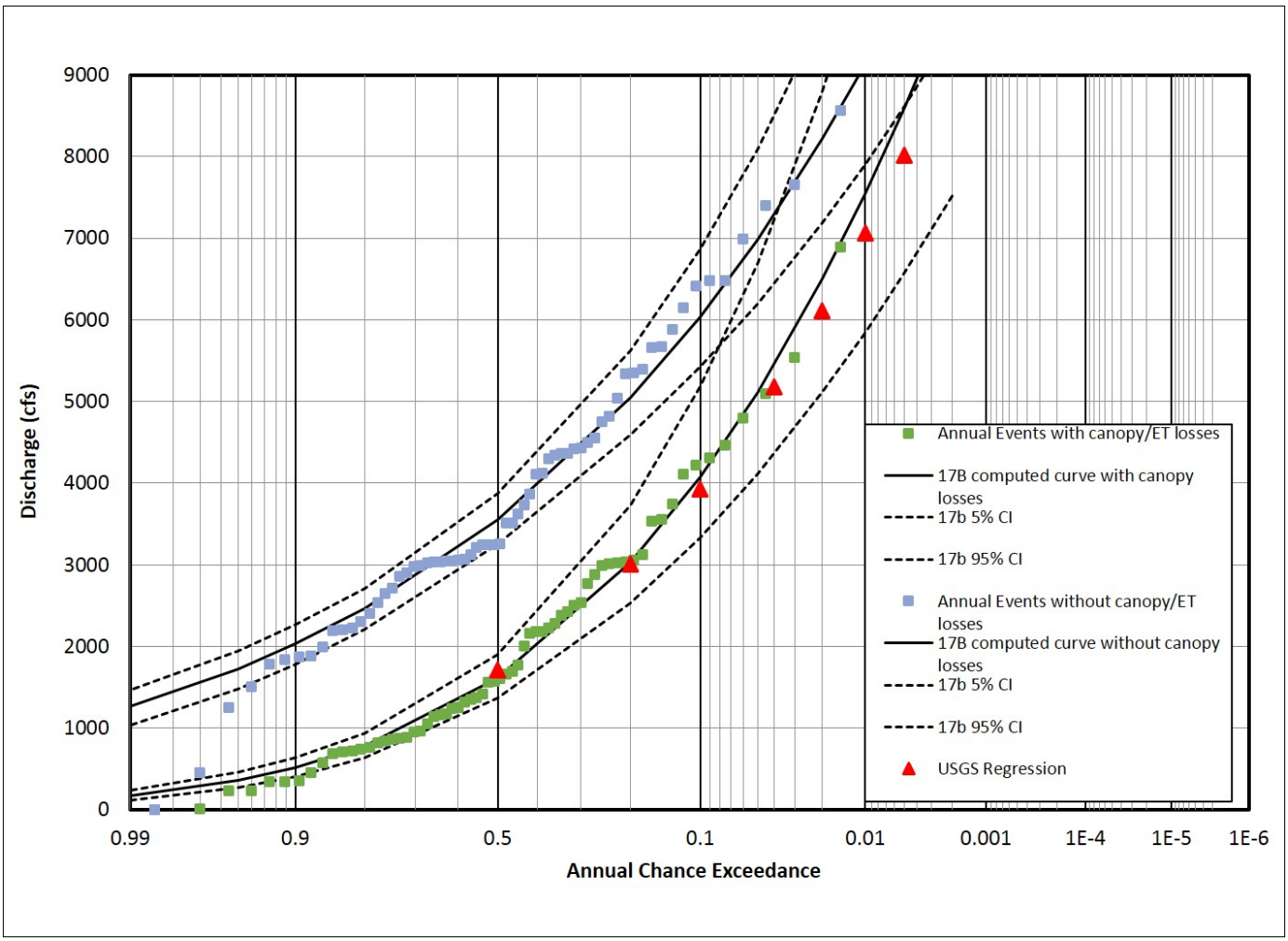

Figure 15: L246 Flow Frequency Comparison on Normal Probability Chart

3.5 RESULTS

Hourly discharge data was input to the unsteady hydraulic analysis to simulate interior drainage ponding and interactions with the Missouri River system. Typical output from the analysis is shown for the L488 levee at the station 442+43 outlet in Figure 16.

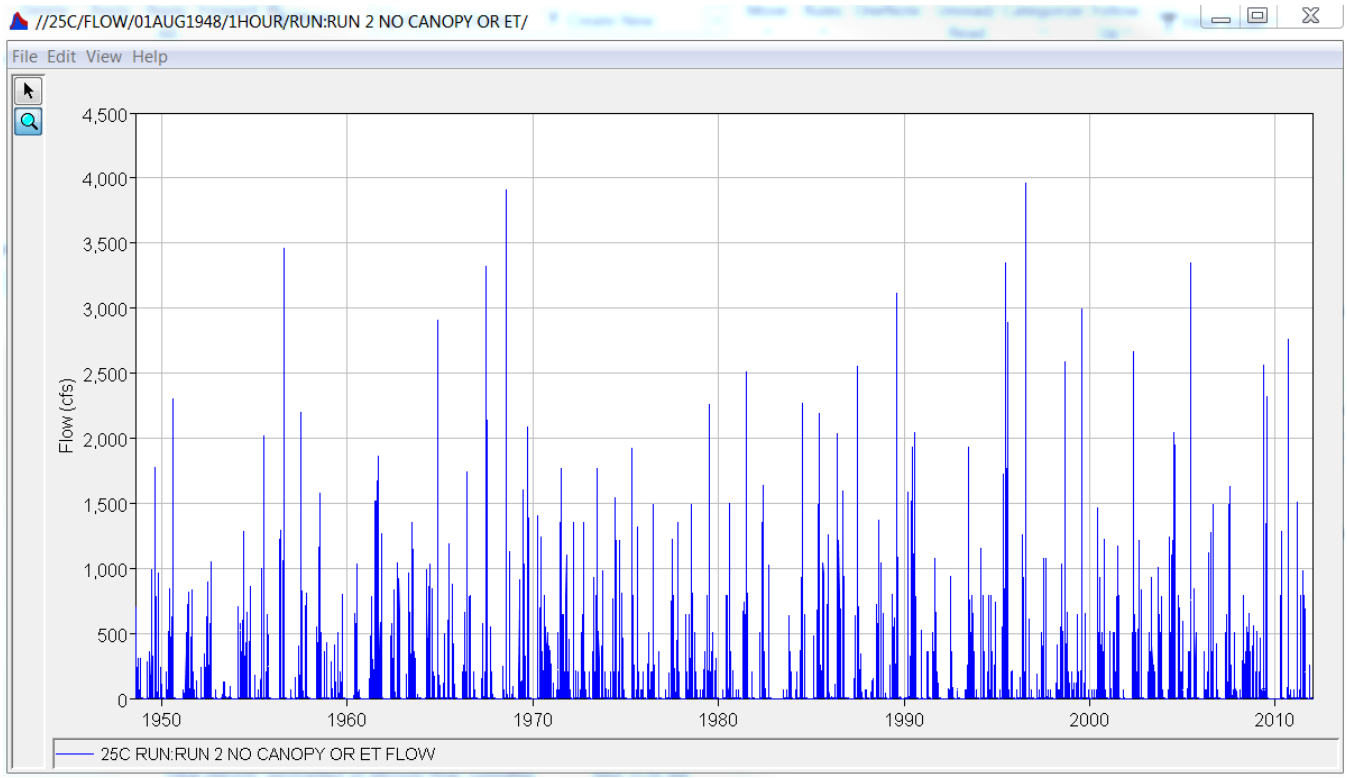

Figure 16: Hourly Computed Discharge at the 24+90 Outlet Structure at the L246 Levee

4 MODEL NOTES AND LIMITATIONS

Several model limitations were identified for this study that are listed below:

1. Routings in the floodplain are approximate and would be improved with a 2-dimensional hydraulic model because many channels and overland flow areas have very mild slopes and extensive overbanks.

2. The Mill Creek Pilot study's model calibration focused on matching daily volumes. Since these models adopt several hydrologic parameters from that study, they are not intended to be used to estimate peak discharge during flood events.

3. Historic precipitation data used in this study was selected based on the best nearby gage vs trying to Thiessen weight hourly data that is not continuous and applied this precipitation evenly across each drainage sub basin. Actual precipitation would have likely varied across the sub basins and would not have exactly matched the records of nearby precipitation gages. Additionally, some of the years had to use gages that were 46 miles away for L488 and 58 miles away for L246, as all the other nearby gages had little to no precipitation data. This distance creates some uncertainty in the precipitation that would have occurred at the study areas.

4. Many assumptions were made to develop each hydrologic analysis that are documented throughout this report. These assumptions were required to address issues associated with uncertain basin and meteorological conditions because of a general lack of observed hydrologic data at each site. However, these assumptions are considered reasonable for the purposes and scope of this study.

5 REFERENCES

Gebert, W.A., Graczyk, D.J., and Krug, W.R., 1987 “Average annual runoff in the United States, 1951-80”. U.S. Geological Survey, Madison, WI. http://water.usgs.gov/GIS/metadata/usgswrd/XML/runoff.xml.

National Oceanic and Atmospheric Administration (NOAA) National Centers or Environmental Information. Climate Data Online (CDO). <https://www.ncdc.noaa.gov/cdo-web/datasets> Hourly Precipitation data accessed January 2016.

Rawls, WJ, Brakensiek, DL, & Miller, N (1983). Green-Ampt Infiltration Parameters from Soils Data. *Journal of Hydraulic Engineering*, 62-70.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [03/01/2016].

Southard, R.E., and Veilleux, A.G., 2014, Methods for estimating annual exceedance-probability discharges and largest recorded floods for unregulated streams in rural Missouri: U.S. Geological Survey Scientific Investigations Report 2014–5165, 39 p., http://dx.doi.org/10.3133/sir20145165.

USACE, 1987, Engineering Manual (EM) 1110-2-1413, Hydrologic Analysis of Interior Areas. US Army Corps of Engineers, Washington, DC 20314-1000.

USACE, 2013, Hydrologic Modeling System (HMS) User Manual. Version 4.0. US Army Corps of Engineers, Hydrologic Engineering Center, Institute of Water Resources, 609 Second Street, Davis, CA 95616. http://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Users_Manual_4.0.pdf

USACE, 2016, Missouri River Interior Drainage Hydrologic Analysis, Attachment A: Mill Creek Pilot Study. Omaha, NE: US Army Corps of Engineers Omaha District.

6 EXHIBITS

Exhibit 1: L488 Precipitation Station Summary

Gage Location	Troy3	Troy2	Oregon	Oregon1	Rosecrans Airport	StJoseph	KCI	
Gage Name	COOP:148250	COOP:148252	COOP:236357	COOP:236359	COOP:237440, COOP:237435	COOP:237445	COOP:234358	
distance from center of L488	5 miles S	9 miles S	10 miles NW	10 miles NNW	15 miles SE	20 miles SE	46 miles SE	
latitude (degrees)	39.8283	39.78333	39.9807	39.98333	39.7736	39.7533	39.2972	
longitude (degrees)	-95.088	-95.1	-95.1465	-95.13333	-94.9233	-94.8577	-94.7306	
Period of record	03/01/1988-12/25-2013	01/01/1971-04/01/1988	06/01/1979-12/22-2013	01/01/1951-01/01/1978	COOP:237440: 08/01/1948-01/01/1965 COOP:237435: 09/01/1974-12/29/2013	01/01/1965-1/1/1993	11/1/1972-12/29/2013	Adopted Gage for analysis
Year	Measurement coverage in each year							
1948	--	--	--	--	42%	--	--	Rosecrans Airport
1949	--	--	--	--	100%	--	--	Rosecrans Airport
1950	--	--	--	--	100%	--	--	Rosecrans Airport
1951	--	--	--	99%	100%	--	--	Rosecrans Airport
1952	--	--	--	99%	100%	--	--	Rosecrans Airport
1953	--	--	--	100%	100%	--	--	Rosecrans Airport
1954	--	--	--	100%	97%	--	--	Rosecrans Airport
1955	--	--	--	100%	100%	--	--	Rosecrans Airport
1956	--	--	--	100%	100%	--	--	Rosecrans Airport
1957	--	--	--	100%	100%	--	--	Rosecrans Airport
1958	--	--	--	99%	100%	--	--	Rosecrans Airport
1959	--	--	--	99%	100%	--	--	Rosecrans Airport
1960	--	--	--	98%	100%	--	--	Rosecrans Airport
1961	--	--	--	98%	100%	--	--	Rosecrans Airport
1962	--	--	--	99%	100%	--	--	Rosecrans Airport
1963	--	--	--	100%	100%	--	--	Rosecrans Airport
1964	--	--	--	98%	100%	--	--	Rosecrans Airport
1965	--	--	--	98%	100%	97%	--	St. Joseph
1966	--	--	--	99%	--	83%	--	St. Joseph
1967	--	--	--	99%	--	100%	--	St. Joseph
1968	--	--	--	91%	--	90%	--	St. Joseph
1969	--	--	--	95%	--	87%	--	St. Joseph
1970	--	--	--	100%	--	84%	--	St. Joseph
1971	--	56%	--	78%	--	84%	--	St. Joseph
1972	--	38%	--	73%	--	89%	17%	St. Joseph
1973	--	10%	--	87%	--	36%	100%	Oregon 1
1974	--	0%	--	61%	100%	42%	100%	KCI
1975	--	5%	--	84%	61%	100%	100%	Oregon 1
1976	--	11%	--	44%	17%	100%	100%	KCI
1977	--	0%	--	0%	0%	100%	100%	KCI
1978	--	36%	--	0%	68%	100%	100%	KCI
1979	--	64%	25%	--	100%	88%	100%	StJoseph
1980	--	100%	70%	--	100%	76%	100%	Troy 2
1981	--	100%	75%	--	100%	17%	100%	Troy 2
1982	--	98%	14%	--	100%	38%	100%	Troy 2
1983	--	67%	42%	--	100%	8%	100%	Troy 2
1984	--	79%	13%	--	100%	25%	100%	Troy 2
1985	--	92%	8%	--	100%	55%	100%	Troy 2
1986	--	92%	100%	--	100%	52%	100%	Troy 2
1987	--	89%	100%	--	100%	84%	100%	Troy 2
1988	78%	3%	100%	--	100%	35%	100%	Troy 3
1989	100%	--	100%	--	100%	0%	100%	Troy3
1990	100%	--	100%	--	100%	0%	100%	Troy3
1991	100%	--	77%	--	100%	0%	100%	Troy3
1992	100%	--	0%	--	100%	0%	100%	Troy3
1993	99%	--	24%	--	100%	0%	100%	Troy3
1994	100%	--	0%	--	100%	--	100%	Troy3
1995	100%	--	19%	--	100%	--	100%	Troy3
1996	91%	--	50%	--	100%	--	100%	Troy3
1997	100%	--	5%	--	100%	--	100%	Troy3
1998	99%	--	58%	--	100%	--	100%	Troy3
1999	82%	--	57%	--	100%	--	100%	Troy3
2000	81%	--	57%	--	100%	--	100%	Troy3
2001	50%	--	78%	--	100%	--	100%	Troy3
2002	99%	--	72%	--	100%	--	100%	Troy3
2003	68%	--	68%	--	16%	--	100%	Troy3
2004	43%	--	75%	--	0%	--	100%	Oregon
2005	79%	--	51%	--	0%	--	100%	Troy3
2006	28%	--	48%	--	100%	--	100%	Rosecrans Airport
2007	50%	--	57%	--	100%	--	100%	Rosecrans Airport
2008	100%	--	68%	--	100%	--	100%	Rosecrans Airport
2009	94%	--	94%	--	100%	--	100%	Rosecrans Airport
2010	74%	--	99%	--	100%	--	100%	Rosecrans Airport
2011	100%	--	80%	--	100%	--	100%	Rosecrans Airport
2012	99%	--	90%	--	100%	--	100%	Rosecrans Airport
2013	77%	--	92%	--	99%	--	99%	Rosecrans Airport

Exhibit 2: L246 Precipitation Station Summary

MO Gage Location	Marshall	Bynumville	Hamden	New Franklin	Higbee	Bedford	Sweet Springs	Columbia Regional Airport	
Gage Name	COOP:235298	COOP:231156	COOP:233565	COOP:236012	COOP:233835	COOP:230503	COOP:238223	COOP:231791	
Distance from Cutoff Lake	19 miles SSW	19 miles NE	21 miles NE	28 miles SSE	29 miles SEE	29 miles NW	35 miles SSW	58 miles SE	
Latitude (degrees)	39.1341	39.58333	39.6	39.0172	39.2415	39.68333	38.9663	38.81667	
Longitude (degrees)	-93.2225	-92.81667	-92.78333	-92.7558	-92.5068	-93.38333	-93.4195	-92.21667	
Period of record	07/31/1948-12/26/2013	05/31/1980-02/28/1990	07/31/1948-04/30/1980	07/31/1957-12/25/2013	4/30/1949-08/31/1992	07/31/1948-01/31/1965	06/30/1992-12/31/2013	10/1/1969-12/23/2013	Adopted Gage for analysis
Year	Measurement coverage in each year								
1948	42%	--	42%	--	--	42%	--	--	Marshall
1949	99%	--	97%	--	56%	99%	--	--	Marshall
1950	99%	--	100%	--	100%	99%	--	--	Marshall
1951	52%	--	95%	--	97%	97%	--	--	Hamden
1952	64%	--	99%	--	99%	98%	--	--	Hamden
1953	39%	--	100%	--	99%	99%	--	--	Hamden
1954	18%	--	100%	--	100%	100%	--	--	Hamden
1955	50%	--	99%	--	99%	100%	--	--	Hamden
1956	83%	--	99%	--	99%	99%	--	--	Hamden
1957	100%	--	99%	42%	100%	100%	--	--	Marshall
1958	100%	--	100%	99%	99%	100%	--	--	Marshall
1959	99%	--	99%	98%	100%	99%	--	--	Marshall
1960	89%	--	99%	98%	100%	98%	--	--	Hamden
1961	99%	--	100%	100%	100%	99%	--	--	Marshall
1962	99%	--	100%	99%	99%	98%	--	--	Marshall
1963	98%	--	99%	99%	99%	100%	--	--	Marshall
1964	98%	--	99%	98%	99%	100%	--	--	Marshall
1965	91%	--	100%	91%	100%	2%	--	--	Hamden
1966	100%	--	95%	67%	97%	--	--	--	Marshall
1967	83%	--	99%	58%	91%	--	--	--	Hamden
1968	71%	--	99%	100%	97%	--	--	--	Hamden
1969	86%	--	100%	82%	99%	--	--	25%	Hamden
1970	81%	--	92%	42%	91%	--	--	100%	Hamden
1971	100%	--	93%	67%	100%	--	--	100%	Marshall
1972	94%	--	92%	82%	76%	--	--	100%	Marshall
1973	88%	--	99%	13%	96%	--	--	100%	Hamden
1974	89%	--	99%	72%	82%	--	--	100%	Hamden
1975	56%	--	99%	100%	92%	--	--	100%	Hamden
1976	72%	--	78%	100%	97%	--	--	100%	New Franklin
1977	84%	--	64%	86%	95%	--	--	100%	Higbee
1978	54%	--	92%	100%	82%	--	--	100%	New Franklin
1979	8%	--	79%	100%	53%	--	--	100%	New Franklin
1980	0%	39%	26%	83%	0%	--	--	100%	New Franklin
1981	0%	5%	--	88%	13%	--	--	100%	New Franklin
1982	0%	21%	--	83%	59%	--	--	100%	New Franklin
1983	100%	17%	--	66%	36%	--	--	100%	New Franklin
1984	8%	0%	--	76%	13%	--	--	100%	New Franklin
1985	3%	0%	--	41%	5%	--	--	100%	Columbia Regional Airport
1986	9%	0%	--	17%	0%	--	--	100%	Columbia Regional Airport
1987	0%	0%	--	3%	0%	--	--	100%	Columbia Regional Airport
1988	0%	0%	--	0%	0%	--	--	100%	Columbia Regional Airport
1989	2%	8%	--	0%	0%	--	--	100%	Columbia Regional Airport
1990	31%	0%	--	14%	0%	--	--	100%	Columbia Regional Airport
1991	28%	--	--	76%	0%	--	--	100%	New Franklin
1992	8%	--	--	61%	0%	--	50%	100%	New Franklin
1993	69%	--	--	67%	--	--	100%	100%	Sweet Springs
1994	17%	--	--	80%	--	--	100%	100%	Sweet Springs
1995	1%	--	--	95%	--	--	100%	100%	Sweet Springs
1996	3%	--	--	91%	--	--	100%	100%	Sweet Springs
1997	52%	--	--	24%	--	--	100%	100%	Sweet Springs
1998	85%	--	--	49%	--	--	100%	100%	Sweet Springs
1999	75%	--	--	87%	--	--	94%	100%	Sweet Springs
2000	64%	--	--	98%	--	--	82%	100%	New Franklin
2001	23%	--	--	88%	--	--	80%	100%	New Franklin
2002	40%	--	--	55%	--	--	97%	100%	Sweet Springs
2003	75%	--	--	100%	--	--	96%	100%	New Franklin
2004	88%	--	--	83%	--	--	74%	100%	Marshall
2005	70%	--	--	88%	--	--	52%	100%	New Franklin
2006	80%	--	--	83%	--	--	93%	100%	Sweet Springs
2007	59%	--	--	95%	--	--	94%	100%	New Franklin
2008	65%	--	--	79%	--	--	91%	100%	Sweet Springs
2009	80%	--	--	88%	--	--	90%	100%	Sweet Springs
2010	69%	--	--	35%	--	--	46%	100%	Marshall
2011	71%	--	--	33%	--	--	41%	100%	Marshall
2012	8%	--	--	24%	--	--	63%	100%	Sweet Springs
2013	0%	--	--	97%	--	--	57%	98%	New Franklin

448A
Stage

448B
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	825.4	825.4	825.4	825.4	825.4	825.4
10%	825.4	825.4	825.4	825.4	825.4	825.4
25%	825.4	825.4	825.4	825.4	825.4	825.4
50%	825.4	825.4	825.4	825.4	825.4	825.4
75%	826.1	826.1	826.1	826.2	826.1	826.2
90%	827.2	827.2	827.2	827.3	827.2	827.2
Max	834.3	834.2	834.3	834.3	834.3	834.3

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	821.3	821.3	821.3	821.3	821.3	821.3
10%	821.3	821.3	821.3	821.3	821.3	821.3
25%	821.3	821.3	821.3	821.3	821.3	821.3
50%	821.3	821.3	821.3	821.3	821.3	821.3
75%	821.8	821.8	821.8	821.8	821.8	821.8
90%	823.3	823.2	823.3	823.5	823.4	823.4
Max	834.3	834.2	834.3	834.3	834.3	834.3

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.1	0.0	0.1	0.0	0.1
90%	-	0.0	0.0	0.1	0.0	0.0
Max	-	-0.2	0.0	0.0	0.0	0.0

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	-0.1	0.0	0.2	0.1	0.1
Max	-	-0.2	0.0	0.0	0.0	0.0

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-3.8	-2.5	-3.1	-3.6	-3.1
10%	-	-0.1	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	4.2	2.3	3.9	3.3	3.8

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-3.8	-2.5	-3.1	-3.6	-3.1
10%	-	-0.1	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	4.2	2.3	3.9	3.3	3.8

448C
Stage

448D
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	821.3	821.3	821.3	821.3	821.3	821.3
10%	821.3	821.3	821.3	821.3	821.3	821.3
25%	821.3	821.3	821.3	821.3	821.3	821.3
50%	821.3	821.3	821.3	821.3	821.3	821.3
75%	821.4	821.4	821.4	821.4	821.4	821.4
90%	822.0	822.0	822.0	822.0	822.0	822.0
Max	833.3	832.7	833.4	833.4	833.4	833.4

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	819.8	821.4	821.4	821.4	821.4	821.4
10%	821.3	821.3	821.3	821.3	821.3	821.3
25%	821.3	821.3	821.3	821.3	821.3	821.3
50%	821.3	821.3	821.3	821.3	821.3	821.3
75%	821.3	821.3	821.3	821.3	821.3	821.3
90%	821.3	821.3	821.3	821.3	821.3	821.3
Max	821.3	821.3	821.3	821.3	821.3	821.3

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.1	0.0	0.0
Max	-	-0.6	0.1	0.1	0.1	0.1

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	-0.1	0.0	0.0	0.0	0.0
Max	-	-0.6	0.1	0.1	0.1	0.1

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-3.7	-2.2	-2.6	-3.6	-2.6
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	4.2	3.0	4.3	2.7	4.8

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-4.0	-3.9	-4.1	-4.3	-4.1
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	4.4	2.5	5.6	2.4	3.9

448E
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	820.8	820.8	820.8	820.8	820.8	820.8
10%	820.8	820.8	820.8	820.8	820.8	820.8
25%	820.8	820.8	820.8	820.8	820.8	820.8
50%	820.8	820.8	820.8	820.8	820.8	820.8
75%	820.9	820.9	820.9	820.9	820.9	820.9
90%	822.1	822.1	822.1	822.1	822.1	822.1
Max	833.3	832.7	833.4	833.4	833.4	833.4

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	-0.1	0.0	0.0	0.0	0.0
Max	-	-0.6	0.1	0.1	0.1	0.1

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-4.0	-3.9	-4.1	-4.3	-4.1
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	4.4	2.5	5.6	2.4	3.9

246B
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	621.2	621.2	621.2	621.2	621.2	621.2
10%	621.2	621.2	621.2	621.2	621.2	621.2
25%	621.2	621.2	621.2	621.2	621.2	621.2
50%	621.2	621.2	621.2	621.2	621.2	621.2
75%	622.3	622.2	622.3	622.3	622.3	622.3
90%	623.3	623.2	623.3	623.3	623.3	623.3
Max	642.5	642.5	642.5	642.6	642.6	642.6

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	-0.1	0.0	0.0	0.0	0.0
Max	-	-0.1	0.0	0.0	0.0	0.0

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-1.3	-0.9	-1.4	-0.9	-0.9
10%	-	-0.1	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	1.4	0.5	1.6	1.3	1.2

246C
Stage

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	616.1	616.1	616.1	616.1	616.1	616.1
10%	616.1	616.1	616.1	616.1	616.1	616.1
25%	616.1	616.1	616.1	616.1	616.1	616.1
50%	616.1	616.1	616.1	616.1	616.1	616.1
75%	619.2	619.1	619.2	619.3	619.2	619.2
90%	622.4	622.3	622.5	622.5	622.4	622.4
Max	642.5	642.4	642.5	642.5	642.5	642.5

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	-0.1	0.0	0.1	0.0	0.0
90%	-	-0.1	0.0	0.0	0.0	0.0
Max	-	-0.1	0.0	0.0	0.0	0.0

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-4.7	-2.9	-4.7	-4.2	-4.3
10%	-	-0.2	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	4.9	2.2	4.7	3.1	4.5

246F
Stage

246G
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	619.1	619.1	619.1	619.1	619.1	619.1
10%	619.1	619.1	619.1	619.1	619.1	619.1
25%	619.1	619.1	619.1	619.1	619.1	619.1
50%	619.1	619.1	619.1	619.1	619.1	619.1
75%	619.8	619.8	619.8	619.8	619.8	619.8
90%	621.8	621.8	621.8	621.8	621.8	621.8
Max	641.8	641.8	641.8	641.8	641.8	641.8

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	620.8	620.8	620.8	620.8	620.8	620.8
10%	620.8	620.8	620.8	620.8	620.8	620.8
25%	620.8	620.8	620.8	620.8	620.8	620.8
50%	620.8	620.8	620.8	620.8	620.8	620.8
75%	621.0	621.0	621.0	621.0	621.0	621.0
90%	621.9	621.9	621.9	621.9	621.9	621.9
Max	642.5	642.4	642.5	642.5	642.5	642.5

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	0.0	0.1	0.1	0.1	0.1

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	-0.1	0.0	0.0	0.0	0.0

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-1.6	-0.5	-1.2	-1.1	-1.2
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	2.2	1.4	1.9	0.7	1.5

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-0.7	-0.4	-0.6	-0.9	-0.6
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	0.8	0.5	0.9	0.2	0.6

246H
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	619.1	619.1	619.1	619.1	619.1	619.1
10%	619.1	619.1	619.1	619.1	619.1	619.1
25%	619.1	619.1	619.1	619.1	619.1	619.1
50%	619.1	619.1	619.1	619.1	619.1	619.1
75%	619.8	619.8	619.8	619.8	619.8	619.8
90%	621.8	621.8	621.8	621.8	621.8	621.8
Max	642.5	642.4	642.5	642.5	642.5	642.5

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	-0.1	0.0	0.0	0.0	0.0

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-1.6	-0.5	-1.2	-1.1	-1.2
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	2.2	1.4	1.9	0.7	1.5

246I
Stage

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	611.8	611.8	611.8	611.8	611.8	611.8
10%	611.8	611.8	611.8	611.8	611.8	611.8
25%	611.8	611.8	611.8	611.8	611.8	611.8
50%	612.3	612.3	612.3	612.2	612.3	612.3
75%	616.8	616.9	616.8	616.9	616.8	616.8
90%	619.9	619.9	619.9	619.9	619.8	619.9
Max	642.5	642.4	642.5	642.5	642.5	642.5

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.1	0.0	0.0	0.0	0.0
75%	-	0.1	0.0	0.1	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	-0.1	0.0	0.0	0.0	0.0

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-4.1	-1.7	-2.9	-3.3	-2.9
10%	-	-0.1	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.3	0.0	0.0	0.0	0.0
Max	-	3.6	2.2	5.9	4.5	5.2

246J
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	614.1	614.1	614.1	614.1	614.1	614.1
10%	614.1	614.1	614.1	614.1	614.1	614.1
25%	614.1	614.1	614.1	614.1	614.1	614.1
50%	614.1	614.1	614.1	614.1	614.1	614.1
75%	615.0	615.1	615.0	615.0	615.0	615.0
90%	618.8	618.8	618.8	618.8	618.8	618.8
Max	641.2	641.2	641.2	641.2	641.2	641.2

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	0.0	0.0	0.0	0.0	0.0

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-2.6	-3.1	-2.3	-3.1	-3.1
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	3.8	1.9	3.9	2.8	2.8

246K
Stage

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	612.8	612.8	612.8	612.8	612.8	612.8
10%	613.8	613.8	613.8	613.8	613.8	613.8
25%	613.8	613.8	613.8	613.8	613.8	613.8
50%	613.8	613.8	613.8	613.8	613.8	613.8
75%	614.2	614.2	614.2	614.2	614.2	614.2
90%	617.6	617.7	617.6	617.7	617.6	617.7
Max	641.2	641.1	641.2	641.2	641.2	641.2

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.1	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	0.0	0.0	0.0	0.0	0.0

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-2.9	-2.2	-2.8	-3.2	-2.8
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	3.8	2.0	4.2	2.8	3.3

246L
Stage

246M
Stage

Min, Max, Percentile Statistics on the period of record (March 1930 - Dec 2012) hydrographs

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	620.5	620.5	620.5	620.5	620.5	620.5
10%	620.5	620.5	620.5	620.5	620.5	620.5
25%	620.5	620.5	620.5	620.5	620.5	620.5
50%	620.5	620.5	620.5	620.5	620.5	620.5
75%	620.5	620.5	620.5	620.5	620.5	620.5
90%	621.7	621.7	621.7	621.7	621.7	621.7
Max	642.4	642.3	642.4	642.4	642.4	642.4

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	613.9	613.9	613.9	613.9	613.9	613.9
10%	613.9	613.9	613.9	613.9	613.9	613.9
25%	613.9	613.9	613.9	613.9	613.9	613.9
50%	613.9	613.9	613.9	613.9	613.9	613.9
75%	614.9	614.9	614.9	614.9	614.9	614.9
90%	619.2	619.2	619.2	619.2	619.1	619.2
Max	642.4	642.4	642.5	642.5	642.5	642.5

Min, max, percentile change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	-0.1	0.0	0.0	0.0	0.0

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	0.0	0.0	0.0	0.0	0.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.1	0.0	0.1	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	-0.1	0.0	0.0	0.0	0.0

Min, max, percentile on the daily change from No Action

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-1.2	-1.0	-1.0	-1.0	-1.0
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.0	0.0	0.0	0.0	0.0
Max	-	1.0	0.7	1.2	0.3	0.7

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Min	-	-3.8	-1.9	-3.6	-3.3	-3.6
10%	-	0.0	0.0	0.0	0.0	0.0
25%	-	0.0	0.0	0.0	0.0	0.0
50%	-	0.0	0.0	0.0	0.0	0.0
75%	-	0.0	0.0	0.0	0.0	0.0
90%	-	0.1	0.0	0.0	0.0	0.0
Max	-	5.1	2.1	5.2	3.5	3.8