Mississippi Valley Division,

Regional Planning and Environment Division South

Yazoo Backwater Area Water Management

APPENDIX A -ENGINEERING SUMMARY

November 2024

APPENDIX A
ENGINEERING SUMMARY

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SECTION 1 GENERAL

AUTHORIZATION

PROJECT AUTHORIZATION

The Yazoo Basin Reformulation Study was an evaluation of a remaining unconstructed feature of the authorized Federal flood control project for the Yazoo Basin. The Reformulation Study was divided into four major features and included a thorough analysis of engineering, economic, and environmental aspects of project alternatives. The Reformulation Study included the following features: (1) Upper Steele Bayou Project, (2) Upper Yazoo Projects (UYP), (3) Yazoo Backwater Project, and (4) Headwater Tributaries Project. Reports for project features (1) and (2) were completed in 1993 and 1994, respectively. This Engineering Summary discusses and documents the plan for Feature 3 – Yazoo Backwater Project. The Headwater Tributaries Project Study has not been completed.

REPORT AUTHORITY

The Flood Control Act (FCA) of 1941, dated 18 August 1941 (House Document (HD)/359/77/1), as amended by FCAs of 22 December 1944 and 27 October 1965 (HD/308/88/2), and the Water Resources Development Act of 1986 and 1996, authorized the Yazoo Backwater Project. The FCA of 1941 provided for the extension of a levee along the west bank of the Yazoo River from the Mississippi River levee to Yazoo City, Mississippi. Also included in the authorized plan of 1941 was a structure at Little Sunflower River and a combination structure and pump station at Big Sunflower River, Deer Creek, and Steele Bayou with a total pumping capacity of 14,000 cubic feet per second (cfs).

The FCAs of 1944 and 1965 extended the project to include approximately 38 miles of levee on the east bank of the Yazoo River and features for fish and wildlife.

PURPOSE OF REPORT

This Engineering Summary documents engineering studies performed on the design, operation, maintenance, and their associated costs for the plan.

PRIOR STUDIES, REPORTS, AND EXISTING WATER PROJECTS

MISSISSIPPI RIVER LEVEES

The Mississippi River Levees project was authorized by the Flood Control Act (FCA) of 15 May 1928, as modified and amended in subsequent Acts of 23 April 1934, 15 June 1936, 18 August 1941, 24 July 1946, and 27 October 1965. The Mississippi River levees prevent inundation of the alluvial valley of the lower Mississippi River which begins at Cape Girardeau, Missouri and gently slopes to the Gulf of Mexico. The main stem levees protect a number of major cities and towns as well as industrial areas, farmland, and wildlife habitats of woodlands and marshes. The Mississippi River levees protect the alluvial valley against the flooding from the Mississippi River by confining flow to the leveed channel except where it enters natural backwater areas or is diverted purposely into floodway areas.

A major Mississippi River flood in 1973 led to the development of the Refined 1973 Mississippi River and Tributaries (MR&T) Project Flood Flowline, which enabled levee deficiencies along the main stem levees to be identified. An Environmental Impact Statement (EIS) was prepared in 1976 to address environmental impacts of the work needed to address the identified deficiencies. A reevaluation of the project was completed in 1998 on the remaining work along with a Supplement to the final EIS. This report documented that of the 460.4 miles of levee in the Vicksburg District, 216.8 miles need to be enlarged and raised to grade with placement of approximately 57.4 miles of seepage control measures. Of these amounts, 69.4 miles of levee enlargement and approximately 30 miles of associated seepage control are required in Mississippi generally in the area south of Greenville, Mississippi. This work is ongoing. During high stages on the Mississippi River, seepage enters into the Yazoo Backwater Study Area from beneath the Mississippi River levee. Although the U.S. Army Corps of Engineers cannot prevent the seepage, it is managing it by the construction of relief wells and seepage berms to protect the integrity of the Mississippi River levee.

PRIOR STUDIES AND REPORTS IN THE YAZOO BACKWATER STUDY AREA

Previous reports and studies that are pertinent to the Yazoo Basin Reformulation Study and the current plan are listed below:

Big Sunflower, Little Sunflower, Hushpuckena, and Quiver Rivers, and their Tributaries, and Deer Creek, Steele Bayou, and Bogue Phalia, Mississippi, General Design Memorandum (GDM) No. 1, September 1955. This report proposed a system of channel improvement along these area rivers and tributaries.

Annex M to the Mississippi River and Tributaries, Comprehensive Review Report, Big Sunflower River Basin, 16 November 1959. This report recommended that the scope of the existing authorized project for the Big Sunflower River Basin be increased to provide greater channel capacity on Steele Bayou and its tributaries.

Big Sunflower, Little Sunflower, Hushpuckena, and Quiver Rivers, and their Tributaries, and Deer Creek, Steele Bayou, and Bogue Phalia, Mississippi, Supplement A (to GDM No. 1), April 1962. This report recommended modifications to project streams as proposed in GDM No. 1.

Supplement B (to GDM No. 1), October 1963. Prompted by local interests, this report modified GDM No. 1 to add channel improvement to a reach of Quiver River.

Steele Bayou, Main Canal - Riverside Drainage District (Canal No. 9) and Black Bayou, Supplement C (to GDM No. 1), February 1964. This supplement recommended more extensive improvement on Steele Bayou, Main Canal, and Black Bayou than those proposed in GDM No. 1 and modified in Annex M.

Muddy Bayou Report (Eagle Lake), December 1969, was prepared in response to requests by the Warren County Board of Supervisors, the Mississippi Game and Fish Commission, and other local interests. As a result of the report, the Yazoo Backwater Project was modified to include the Muddy Bayou Control Structure. The water control structure, approved and completed in 1970 and 1977, respectively, allows manipulation of lake levels between Eagle Lake and Steele Bayou for improvement of water quality and fishery resources in the lake. The structure also provides incidental flood protection for properties along Eagle Lake.

Yazoo Basin, Yazoo Backwater Area, Fish and Wildlife Mitigation Plan Report, dated July 1976, and approved by the Chief of Engineers on 03 December 1976, authorized construction of nine greentree reservoirs and nine slough control structures in the Delta National Forest. These features as proposed would mitigate the fish and wildlife losses caused by the Yazoo Backwater Project. Six greentree reservoirs

and five slough control structures have been completed. The others were eliminated due to unsuitable site conditions and problems with existing easement.

Steele Bayou Basin, Plan Formulation, GDM No. 18, August 1976. This report recommended modifying the authorized project to provide additional channel improvements on Steele Bayou and Black Bayou.

Yazoo Basin, Yazoo Backwater Area Pump Project Report, July 1982, presented a reevaluation of the economic feasibility of the pumping stations features of the backwater project. This report recommended installation of a 17,500-cfs pumping station at Steele Bayou. In December 1985, the plan changed because budgetary guidance directed by the Work Allowance of 1986 did not provide funds for the 17,500-cfs pumping station. Instead, the allowance provided funds for Engineering and Design for a 10,000-cfs capacity pumping station to be located approximately one mile west of the existing Steele Bayou structure.

Fish and Wildlife Mitigation Report, July 1982, was prepared in conjunction with the reevaluation efforts of the Yazoo Area Pump Project, Yazoo Area, and the Satartia Area Backwater levee Projects. This report was used as a basis for determining the modifications that should be made to achieve a balance in the use of the backwater area's natural resources. The report included the mitigation analyses for the construction and operation of the Yazoo Area and Satartia Area Backwater Levee Projects, including the connection channel, structures, the recommended Yazoo Area Pump Project, and other appurtenances. The Fish and Wildlife Mitigation Report recommended the acquisition of 40,000 acres of woodlands through perpetual easements in the project area.

Yazoo Basin, Yazoo Study Area, Mississippi, Mississippi Mitigation Plan Report, October 1989, presented a proposal for mitigation implementation to compensate for terrestrial wildlife losses incurred during construction and operation of the Yazoo Area and Satartia Area levees. This report recommended the purchase of 8,400 acres of frequently flooded cleared farmland to be reforested for terrestrial wildlife habitat through the acquisition of fee title. In 1990, the U.S. Army Corps of Engineers, Vicksburg District, purchased a tract of land containing 8,800 acres – this property is referred to as the Lake George Property. It is located in Yazoo County between the Delta National Forest and the Panther Swamp National Wildlife Refuge.

Upper Steele Bayou Reformulation Report, December 1992. Recommendations were made in this report for additional flood control improvements in the upper Steele Bayou Basin for Black Bayou, Main Canal, Ditch 6, and Robertshaw Ditch.

Memorandum for President, Mississippi River Commission, 02 December 1993, subject: FC/MR&T, Yazoo Basin, Mississippi, Big Sunflower, Bogue Phalia, Little Sunflower, Holly Bluff Cutoff, Bogue Phalia Cutoff, and Dowling Bayou Channel Maintenance Project. This memorandum outlined the plan for preparing the Supplement D (to GDM No. 1) report.

Flood Control, Mississippi River and Tributaries, Yazoo Basin, Big Sunflower River Basin Channel Maintenance, November 1994, Supplement D to GDM No. 1. Supplement D was approved by Mississippi River Commission 1st endorsement, 1 February 1995, subject to resolution of comments.

Flood Control, Mississippi River and Tributaries, Yazoo Basin, Yazoo Backwater Area, Draft Reformulation Report and SEIS, September 2000.

Flood Control, Mississippi River and Tributaries, Yazoo Basin, Yazoo Backwater Area, Final Reformulation Report and SEIS, November 2007.

EXISTING WATER PROJECTS

There are five existing projects within the subarea of the Yazoo Backwater Area: Yazoo area, Satartia area, Satartia Extension area, Rocky Bayou, and Carter area. Although these projects are separate elements of the Yazoo Basin Backwater Project, they are part of the flood control measures authorized in 1941, 1944, 1965, and 1986. A brief description of the authorized improvements for these existing projects follows:

Yazoo Area (926,000 acres). This project area is located between the east bank Mississippi River levee and the Will M. Whittington Auxiliary Channel. The area extends north from Vicksburg, Mississippi, a distance of approximately 60 miles to Belzoni, Mississippi. Authorized work in the Yazoo Area consists of a levee system 30.5 miles long, extending from the end of the east bank Mississippi River levee, generally along the west bank of the Yazoo River to a connection with the west levee of the Will M.

Whittington Auxiliary Channel. This levee system includes two structures, one at Steele Bayou with a design capacity of 19,000 cfs and one at Little Sunflower River with a design capacity of 8,000 cfs, and a channel between the Sunflower River and Steele Bayou to connect the upper and lower ponding areas within the Yazoo Study Area. The levee system is completed to an interim grade of 107.0 feet, National Geodetic Vertical Datum (NGVD 29). The work also includes 24 miles of channel work, two major structures, and two river closures. This work is complete and now operational.

Satartia Area (28,800 acres). The Satartia area is located south of Satartia, Mississippi, between the Yazoo River on the west and the hill line on the east. Authorized work in the area consists of 20 miles of levee and one major structure. Protection of this area was completed in November 1976.

Satartia Extension Area (3,200 acres). This area is located south of the Satartia area, and protection includes 8.2 miles of levee and floodgate for drainage. Currently, no flood control features are authorized for the Satartia Extension Project.

Rocky Bayou (14,080 acres). The Rocky Bayou area is located south of the city of Yazoo City, Mississippi, between the Yazoo River on the west and the hill line on the east. Authorized improvements consist of about 19 miles of levee and one major structure. Levee Item 1, which is the reach along O'Neal Creek, was separated into two construction contracts: Items 1A and 1B. Item 1A, a 3.0-mile levee item, was awarded 25 March 1985 and Item 1B, a 0.7-mile reach and a small structure, was awarded on 12 November 1986, and both are complete.

Carter Area (102,400 acres). The Carter Area is bounded by the Yazoo River on the east and the Will M. Whittington Auxiliary Channel on the west. The area begins upstream of the confluence of the Big Sunflower and the Yazoo Rivers and extends northward to the latitude of Yazoo City. Improvements authorized for the Carter area consist of about 29 miles of levee and one major structure. No work has been initiated on this project.

PROJECT LOCATION

This appendix is concerned specifically with the Yazoo Backwater Study Area for the current plan. The area, as depicted in Figure 1-1, lies in west-central Mississippi between the Mississippi River east bank levee and the Will Whittington Channel on the east. The triangular-shape area extends northward approximately 60 miles to the latitude of Hollandale and Belzoni, Mississippi, and comprises about 926,000 acres. Big Sunflower and Little Sunflower Rivers, Deer Creek, and Steele Bayou flow through the project area. Interior drainage of the area is provided by structures at Little Sunflower River (upper ponding area) and Steele Bayou (lower ponding area).

Figure 1-1. The Yazoo Backwater Study Area for the current plan.

ALTERNATIVES

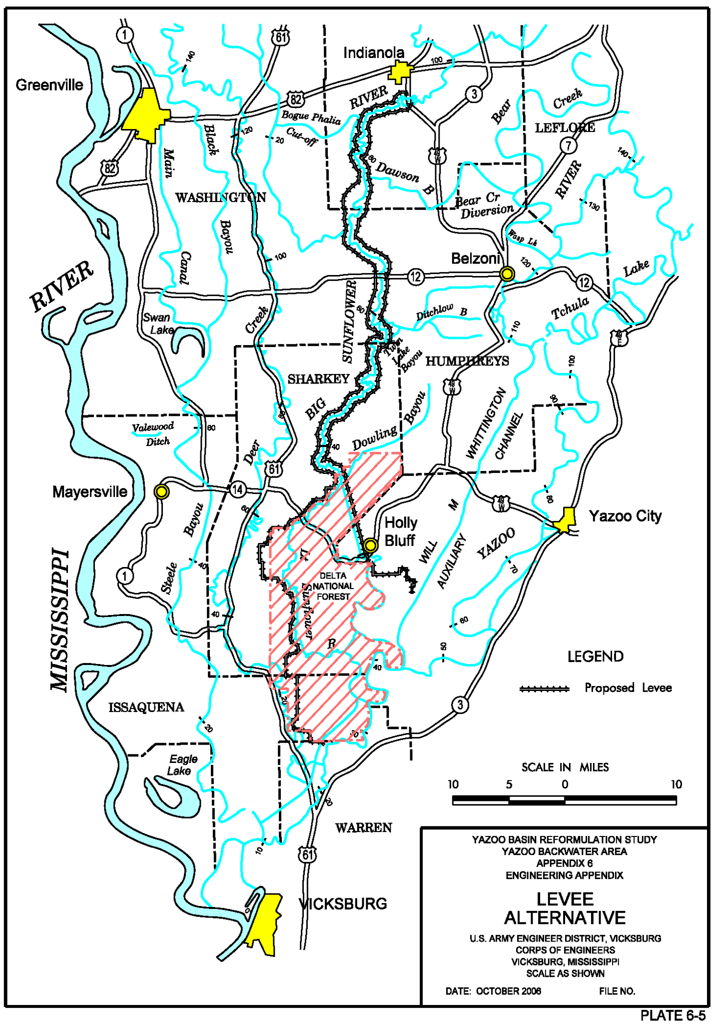
GENERAL

There were many alternative plans considered during the evaluation of the Yazoo Backwater Reformulation Study. A brief synopsis of past alternatives is given in the following paragraphs.

PAST ALTERNATIVES

The Yazoo Backwater Reformulation Study began by analyzing structural flood control features consisting of five pump size alternatives and a levee alternative. The five pump alternatives that were originally analyzed in the 1982 Reevaluation Report were reanalyzed. The 10,500, 14,000, 17,500, 21,000, and 24,500 cfs pumping stations were reanalyzed, and their location was to be adjacent to the Steele Bayou structure.

A levee alternative was developed to basically open the Big Sunflower River Basin back to Mississippi River Backwater flooding. The Yazoo Backwater levee would be realigned along the Big Sunflower and Little Sunflower Rivers to a point near Highway 49 West, where it would tie back into natural ground as shown in Figure 1-2. The levee alignment was designed to skirt the wildlife management forested areas along the Big and Little Sunflower Rivers such that minimal damage to the environment would occur. Approximately 61 structures would be required to protect the landside areas of the levee and some lengthy landside drainage ditches would also be required. The connecting channel between the Big Sunflower Basin and the Steele Bayou Basin would be closed off, thereby establishing a drainage divide between the two basins and the closure at Big Sunflower River opened to pass flows and protected to serve as a



way to maintain low water levels. The Little Sunflower structure would be modified to maintain a minimum ponding area for waterfowl and aquatic habitat.

Figure 1-2. The previous levee alternative for the Yazoo Basin Reformulation Study.

Through the scoping and review process for the 2007 FSEIS, a 14,000 cfs pump was selected. This plan had a pump on/off elevation of 85.0 feet (NGVD 29) from December through February and an on/off elevation of 80.0 feet (NGVD 29) from March through November. Shortly after this, several workshops were held, and a consensus group was formed with interested Federal agencies, state agencies, wildlife interests, environmental agencies, and other groups. After the workshops and consensus group meetings, a large array of alternatives was considered. These 30 alternatives (Figure 1-3) included not only structural flood control measures, but also the combination of structural and nonstructural flood control. Nonstructural flood control measures include reforestation by buying easements on open lands, nontraditional operation of the pumping station to include various ponding levels and pump on/off operation, and the purchasing of lands below the 100-year frequency flood level.

Plan	Construction Cost												Average Annual Benefit	Excess Benefits
	Easements				Reforestation	Reforestation	Environmental Impacts	Mititgation Cost	Structural Modifications	Pump	Total	Average Annual Cost		
	Conservation Woodlands	Reforestation Open Lands a/	Flow/Water Management	Total ($ Million)	Acres	($ Million)	(HU)	($ Million)	($ Million)	($ Million)	($ Million)	$000	$000	$000
1	Preserve Below 100.3	Use Retained	N/A	261.4	0	0	0	0	0	0	261	19,238	0	-19,238
2	Preserve Below 100.3	Reforest Below 90.0	N/A	307.8	101,800	14.3	80,070	0	0	0	330	24,265	-4,452	-28,717
	NONSTRUCTURAL PLANS													
3	Preserve Below 85.0	Use Retained Below 85.0	N/A	42.1	0	0	-49,151	31.3	0	120	193	16,365	16,242	-123
4	Preserve Below 85.0	Use Retained Below 85.0	Below 80.0 b/	63.5	0	0	-41,104	26.2	0.35	120	210	17,548	16,242	-1,306
5	Preserve Below 85.0	Use Retained Below 85.0	Below 85.0 c/	81.7	0	0	-41,200	26.2	0.35	120	228	18,890	16,242	-2,648
6	Preserve Below 85.0	Reforest Below 85.0	N/A	56.0	53,000	7.4	10,608	0	0	120	187	15,574	16,900	1,326
7	Preserve Below 85.0	Reforest Below 85.0	Below 80.0 b/	70.2	53,000	7.4	21,533	0	0.35	120	202	16,654	16,900	246
8	Preserve Below 85.0	Reforest Below 85.0	Below 85.0 c/	81.7	53,000	7.4	21,390	0	0.35	120	213	17,503	16,900	-603
9	Preserve Below 90.0	Use Retained Below 90.0	N/A	85.2	0	0	-30,927	19.1	0	120	224	18,522	13,387	-5,135
10	Preserve Below 90.0	Use Retained Below 90.0	Below 80.0 b/	102.0	0	0	-9,232	5.8	0.35	120	228	18,675	13,387	-5,288
11	Preserve Below 90.0	Use Retained Below 90.0	Below 85.0 c/	117.0	0	0	-9,223	5.8	0.35	120	243	19,783	13,387	-6,396
12	Preserve Below 90.0	Reforest Below 90.0	N/A	135.0	101,800	14.3	36,022	0	0	120	276	22,155	13,883	-8,272
13	Preserve Below 90.0	Reforest Below 90.0	Below 80.0 b/	139.0	101,800	14.3	66,607	0	0.35	120	280	22,466	13,883	-8,583
14	Preserve Below 90.0	Reforest Below 90.0	Below 85.0 c/	141.0	101,800	14.3	66,616	0	0.35	120	282	22,615	13,883	-8,732
	COMBINATION PLANS - 14,000 CFS PUMP a/													
15	Preserve Below 85.0	Use Retained Below 85.0	N/A	42.1	0	0	-53,614	34.2	0	143	219	18,562	18,052	-510
16	Preserve Below 85.0	Use Retained Below 85.0	Below 80.0 b/	63.5	0	0	-45,832	29.2	0.35	143	236	19,756	18,052	-1,704
17	Preserve Below 85.0	Use Retained Below 85.0	Below 85.0 c/	81.7	0	0	-45,828	29.2	0.35	143	254	21,097	18,052	-3,045
18	Preserve Below 85.0	Reforest Below 85.0	N/A	56.0	53,000	7.4	3,932	0	0	143	210	17,532	18,159	627
19	Preserve Below 85.0	Reforest Below 85.0	Below 80.0 b/	70.2	53,000	7.4	14,414	0	0.35	143	225	18,612	18,159	-453
20	Preserve Below 90.0	Reforest Below 85.0	Below 85.0 c/	81.7	53,000	7.4	14,417	0	0.35	143	236	19,461	18,159	-1,302
21	Preserve Below 90.0	Use Retained Below 90.0	N/A	85.2	0	0	-35,692	22.8	0	143	251	20,783	14,794	-59,889
22	Preserve Below 90.0	Use Retained Below 90.0	Below 80.0 b/	102.0	0	0	-11,473	7.3	0.35	143	253	20,763	14,794	-5,969
23	Preserve Below 90.0	Use Retained Below 90.0	Below 85.0 c/	117.0	0	0	-11,469	7.2	0.35	143	268	21,855	14,794	-7,061
24	Preserve Below 90.0	Reforest Below 90.0	N/A	135.0	101,800	14.3	29,534	0	0	143	299	24,113	14,917	-9,196
25	Preserve Below 90.0	Reforest Below 90.0	Below 80.0 b/	139.0	101,800	14.3	63,519	0	0.35	143	303	24,424	14,917	-9,507
26	Preserve Below 90.0	Reforest Below 90.0	Below 85.0 c/	141.0	101,800	14.3	63,523	0	0.35	143	305	24,573	14,917	-9,656
	STRUCTURAL PLANS a/													
27 (14K P) d/	N/A	N/A	N/A	0.0	0.0	0.0	-63,743	40.5	0	120	161	13,990	17,539	3,549
28 (17.5K P) d/	N/A	N/A	N/A	0.0	0.0	0.0	-75,884	48.2	0	143	191	16,636	19,664	3,028
29(LEV)	N/A	N/A	N/A	0.0	0.0	0.0	-30,081	19.1	0	215	234	19,552	15,102	-4,450
30 (14K P)	Preserve Below 100.3	N/A	N/A	73.3	0.0	0.0	-63,743	39.4	0	120	233	19,348	17,539	-1,809

a/ Pump would be operated to provide flood damage reduction for cleared lands above easement elevation.
b/ 1 December - 1 March.
c/ 80 feet, NGVD, 1 December - 1 January and 15 February - 1 March; 85 feet, NGVD, 1January - 15 February.
d/ Pump would be operated to provide flood damage reduction for cleared lands above elevation 80 feet except during 1 December - 1March when pump would be operated at 85.0 feet, NGVD.
e/ Does not reflect cost of pump but of the levee.

PLATE 6-6

Figure 1-3. The 30 previous alternatives for the Yazoo Backwater Reformulation Study.

FINAL ARRAY

This analyze will involve a new plan in light of new environmental data. The plan addressed in this document is the remaining flood damage reduction feature of the Yazoo Basin, Yazoo Backwater, Mississippi, Project, which will include both structural (construction and operation of a pump station) and nonstructural alternatives.

SECTION 2 HYDROLOGY AND HYDRAULICS

PURPOSE OF HYDROLOGIC ANALYSIS

The purpose of these hydrologic analyses is to identify the base hydrologic conditions in the Yazoo Backwater Study Area and estimate the changes to those conditions resulting from various flood control alternatives. Hydrologic information summarized in this appendix has been used in other analyses, including the economic and environmental analyses of the DEIS.

This section presents the methodology used in the hydrologic analyses and explains the types of data used in the analysis which support the formulation of the various plans. Engineer Manual (EM) 1110-2-1413 was used as guidance and criteria for the hydrologic analyses.

OBJECTIVE

This report will provide new information for completion of the Yazoo Backwater flood protection.

INTRODUCTION

There are several areas with updated or completely new information that will be discussed in this Hydrology Section. This information would result in significant changes since prior analysis. Updated information includes flooding since 1997, revising the period-of-record (POR) used in the hydrologic analysis of the project, the acquisition of a higher resolution digital elevation model (DEM) using an airplane based LIDAR, the application of the HEC-RAS 2D to model the POR to provide daily stages for the base and with-pump condition, the determination of the areal extent of floods (frequency and duration) based on the new POR utilizing the LIDAR DEM, and finally obtaining new land-use/land-cover information using the NASS-2022 coverage. Each of these topics will be covered in a sub-section below.

BACKGROUND

The U.S. government operates flood control reservoirs across the country. Three agencies are responsible for their operation: the U.S. Army Corps of Engineers, the Bureau of Reclamation, and the Tennessee Valley Authority. The flood control reservoirs fall into two basic categories dry dams and wet dams. Dry dams do not have a minimum, or base pool, while wet dams have a minimum pool. The Yazoo Study Area acts like a dry dam, as it only stores water during flood events. While the U.S. has with many lakes and reservoirs that can provide flood storage, many of the country’s largest lakes have been modified to provide flood damage reduction. Lake Okeechobee in Florida is an example of a natural lake that has been modified by the addition of levees and flood control gates to provide downstream flood damage reduction. Where natural lakes do not exist, the government has constructed large reservoirs to provide flood damage reduction. Many of these man-made reservoirs are among the largest lakes in the country (Fort Peck, Lake Oahe, Lake Sakakawea, and Toledo Bend). Wikipedia provides a list of the 100 largest lakes and reservoirs in the U.S. Both Grenada (90) and Sardis (98) Lakes in Mississippi are on that list. If the Yazoo Backwater Study Area was treated as a lake or reservoir, it would rank as the 23rd largest when the Steele Bayou landside gage is at elevation 87 feet (NGVD 29). In 2019, the Steele Bayou landside gage reached 98.2 feet (North American Vertical Datum [NAVD 88]), and the Yazoo Backwater Study Area would have jumped to 9th on the list of largest water bodies. The only lakes larger than the Yazoo Backwater Study Area Lake, would be the five Great Lakes, Great Salt Lake (Utah), Lake-of the Woods (Minnesota and Canada), and Iliamna Lake (Alaska), which are all natural lakes. The Yazoo Backwater Study Area Lake would be larger than all the man-made reservoirs in the U.S. at that time. When the Yazoo Backwater Study Area is at 87 feet (NGVD 29) on the Steele Bayou landside gage, the area flooded is as great as the sum of the four Yazoo Basin flood control reservoirs when they are at their maximum capacity. This capacity was achieved 21 times in the 21 years that have elapsed since 1997. As another indication of the scale of flooding in the basin, the 2019 flood covered an area equal to two-thirds of the area of the State of Rhode Island.

DESCRIPTION OF YAZOO BACKWATER STUDY AREA

The Mississippi River Mainline Levees are designed to protect the alluvial valley from extreme flood events by confining flow to the leveed floodway, except where it enters the natural backwater areas or is diverted intentionally into floodway areas. When major floods occur and the carrying capacity of the Mississippi River leveed channel is threatened, additional conveyance through the Birds Point-New Madrid Floodway and relief outlets through the Atchafalaya Basin Floodway, Morganza Floodway, and Bonnet Carre Floodways are utilized as well as the storage capacity of flat lowlands at the junctions of tributaries with the Mississippi River. These tributary areas are commonly referred to as backwater areas. The Yazoo River tributary area is commonly known as the Yazoo Backwater Area, or the Yazoo Study Area. The Yazoo Backwater levees were built to protect a major portion of the Mississippi Delta from major Mississippi River floods and are primarily designed to overtop prior to the MR&T Project Design Flood (PDF) peak such that storage is made available to reduce the level of the PDF, thus resulting in a lesser levee grade along the mainline levees.

DRAINAGE AREAS

The Yazoo Backwater Study Area has a drainage area comprised of the Little Sunflower River, Big Sunflower River, Deer Creek, and Steele Bayou Basins as shown in Figure 1. These streams have a total drainage area of 4,093 square miles of the alluvial valley of the Mississippi River commonly called the Mississippi Delta. The area extends from the confluence of Steele Bayou with the Yazoo River north to the vicinity of Clarksdale, Mississippi, and has an average width of approximately 30 miles. The Mississippi Delta alluvial plain is generally flat with slopes averaging 0.3 to 0.9 feet per mile. Drainage areas of the four basins can be seen in

Table 1.

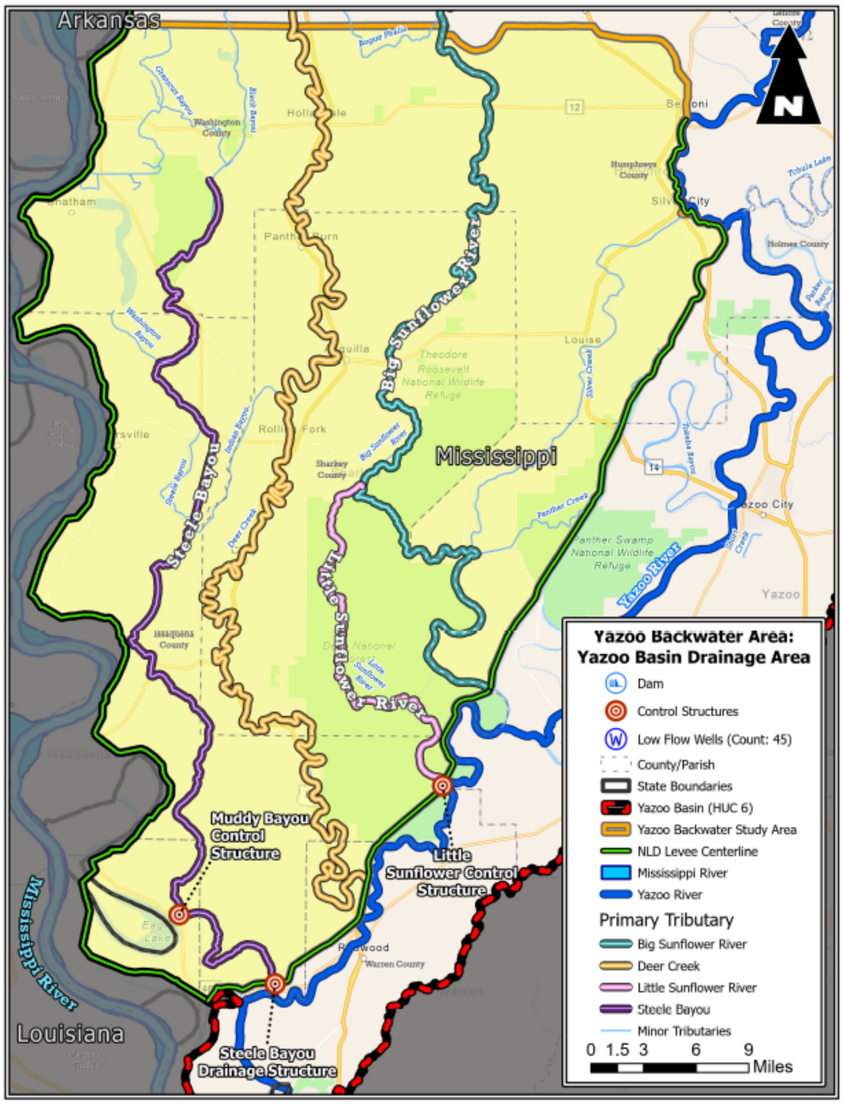


Figure 1-1. The drainage areas within the Yazoo River Basin.

Table 1-1. Yazoo Area Drainage Basin Area

Stream	Drainage Area (sq mi)
Big Sunflower River	2,832
Little Sunflower River	309
Deer Creek	200
Steele Bayou	752
Total	4,093

CLIMATE

The climate of the Yazoo Backwater Study Area is primarily humid, subtropical with abundant precipitation. The summers are long and hot; the winters are short and mild. According to the 2017 Climatological Data Annual Summary for Mississippi, the average annual temperature for the Lower Mississippi Delta was about 66.5 degrees Fahrenheit in 2017. Additionally, during 2017, the average monthly temperatures for the Lower Mississippi Delta ranged from 46.9 degrees Fahrenheit in December to 82.2 degrees Fahrenheit in July (NCEI 2017). During 2018, the Lower Mississippi Delta experienced an average annual temperature of 64.3 degrees Fahrenheit, with average monthly temperatures ranging from 39.1 degrees Fahrenheit in January to 81.7 degrees Fahrenheit in July (NCEI 2018). The average annual temperature for the Lower Mississippi Delta during 2019 was 64.9 degrees Fahrenheit. Monthly average temperatures during 2019 range from 45.0 degrees Fahrenheit in January to 83.0 degrees Fahrenheit in September (NCEI 2019). Temperature extremes ranged from about 10 degrees Fahrenheit to 100 degrees Fahrenheit for 2017 and 2018 (NCEI 2017, NCEI 2018). Temperature extremes during 2019 ranged from 20 degrees Fahrenheit to 100 degrees Fahrenheit (NCEI 2019).

PRECIPITATION

According to the 2017 Climatological Data Annual Summary for Mississippi, the annual rainfall over the Lower Mississippi Delta was approximately 53.9 inches. During 2017, normal monthly rainfall for the Lower Mississippi Delta varied from 6.4 inches in April to 1.5 inches in October (NCEI 2017). In 2018, the Lower Mississippi Delta had an annual rainfall of 68.2 inches, with a normal monthly rainfall ranging from 2.3 inches in October to 13.3 inches in February (NCEI 2018). In 2019, the Lower Mississippi Delta had an annual rainfall of 77.9 inches, with a normal monthly rainfall ranging from 0.7 inches in September to 13.9 inches in February (NCEI 2019). The Lower Mississippi Delta generally receives more rainfall during winter and spring months than summer or fall months due to the intrusion and retreat of polar air across the region that creates frontal boundaries and widespread and persistent rainfall. Snowfall occurs about once a year with an average of approximately two inches.

CLIMATE CHANGE

This section summarizes the conclusions of an analysis of potential climate change vulnerabilities for the Yazoo Backwater Area Water Management Project. The full *ECB 2018-14 Analysis of Potential Climate Change Vulnerabilities,* including a table summarizing the residual risks due to climate change, can be found in Annex A to this Engineering Appendix.

The purpose of the Yazoo Backwater Area Water Management Project is to reduce flood risk within the YSA caused by high Mississippi River levels coincident with interior flooding within the YSA basin that often occurs during the spring. Additionally, the project seeks to improve aquatic habitat within the Big Sunflower River, a primary tributary of the YSA, by augmenting low flow conditions that typically occur during the fall through groundwater pumping. The project includes a 25,000 cfs pump station, structure and land acquisition through voluntary buyout, and installation of groundwater wells. Output based on both historic, observed hydrometeorological data and projected, climate-changed hydrometeorological data is reviewed to support qualitative statements about how to incorporate resilience to climate change impacts over the project's lifecycle.

Based on the weight of evidence presented in this assessment, climate change impacts are anticipated to affect the study area's hydrology over the project's 50-year life cycle. Findings from available climate change literature indicate the Lower Mississippi River Region has experienced an increasing trend in streamflow during the last century, a similar trend observed for the entire Mississippi River Basin. Trend analysis of the Mississippi River at Vicksburg, MS supports this increasing trend in streamflow, whereas analysis of the Big Sunflower River near Merigold, MS identified no significant trends in annual maximum or spring and fall mean streamflow. Regarding future streamflow, the literature lacks consensus in projected trends for the Lower Mississippi River Region (USACE, 2015). However, a 2019 study (USACE) analyzing climate model projections suggests future increasing streamflow and flow frequency on the Lower Mississippi River main stem at Vicksburg. The CHAT output for the Mississippi River main stem stream segment indicates a statistically significant increasing trend in high streamflow under RCP 8.5, but no statistically significant trends under RCP 4.5. No significant trends in future high streamflow were identified for the Big Sunflower stream segment.

Precipitation projections for the Lower Mississippi River Region suggest a mild increase in annual precipitation, but a strong consensus is lacking (USACE, 2015). Projected seasonal changes in precipitation are weak and vary. There is greater consensus that observed increases in the number of extreme precipitation events are projected to continue increasing in frequency and intensity for the study area. A projected increase in the magnitude of annual maximum 3-day precipitation is identified in the CHAT analysis for the Lower Mississippi-Greenville and Big Sunflower watersheds under both RCPs. Increased magnitude and/or frequency of extreme precipitation suggests the potential for increased frequency of flooding both on the Mississippi River and on the Big Sunflower. Although there is not strong consensus in projections of increasing streamflow on the Mississippi River main stem, the consensus in projections of increased magnitude and frequency of extreme precipitation provides more evidence of the potential for increased high streamflow on the Mississippi main stem, and on Big Sunflower, which could increase the number of days the Steele Bayou WCS is closed, resulting in an increased number of pump days in order to keep interior water levels at or below elevation 93' NGVD29.

The current pump design and operation considered extreme flooding events for the Yazoo Backwater Area, both in magnitude and duration, including 2019, the current flood of record that reached just below the Mississippi River 0.5% AEP elevation. The 2019 flood was driven by both backwater and headwater flooding. Modeling of the proposed pump capacity and pump-on elevation constraint required 158 days of pump operation to maintain the interior WSEL objective during the 2019 flood, demonstrating the design is robust in handling higher magnitude and longer duration floods. The proposed pump operation further demonstrates climate change resilience by a capacity to manage interior water levels to accommodate an earlier crop season start date (March 16-October 15), influenced by warming temperatures. A robust pump station design demonstrates some resilience in the voluntary buyout footprint, defined based on the managed WSELs of 90' and 93' (NGVD29). Furthermore, adaptive management and monitoring will be conducted to evaluate changes in flow frequency that subsequently inform wetland delineation and managed interior water levels. The project's Operation and Maintenance Manual will be adapted to reflect changing hydrologic conditions.

Since the cooling trend of 1960-1970, the YSA is now warming at an accelerated rate, and there is strong agreement in climate model projections that: air temperatures will increase; summer months will experience the greatest increase in air temperature; and daily minimum temperatures will also increase. In addition to projected increased extreme precipitation, there is also consensus in projected increased drought intensity driven by increased temperatures, ET rates, and soil moisture loss rates. CHAT results for annual mean daily temperature for both the Lower Mississippi-Greenville and Big Sunflower watersheds support these findings, indicating strong historic and future warming trends with a median change between the base epoch (1950-2005) and the mid-century epoch (2035-2064) means of 3.47-4.25 °F. Drought index (maximum number of consecutive dry days) results also show future increasing trends in the number of consecutive dry days for both watersheds. Increased ET rates and drought intensity driven by increased temperatures are likely to increase agricultural irrigation demands in the YSA. Increased withdrawals from the MRVAA to support rice and catfish production will further reduce baseflow conditions in the Yazoo Backwater Area tributaries as well as groundwater elevations.

Final sighting and design of low flow augmentation wells can incorporate resilience by locating wells close to the Mississippi River, a regional source of aquifer recharge. However, implementation of groundwater conservation efforts in the region, the need for which is well recognized, requires action beyond the scope of this project and are needed to ensure resilience of this project feature and resource. Final design of the low flow augmentation wells should consider results from recent MRVAA groundwater modeling efforts. Resilience can be incorporated into the conservation and reforestation efforts on acquired lands subject to frequent flooding by selecting species with tolerance to flooding and drought, both of which are projected to occur within the YSA.

INFILTRATION AND RUNOFF

When precipitation falls, some is stored as infiltration and some leaves as runoff. The runoff coefficient is the percentage of precipitation that leaves. Runoff coefficients vary from 10 percent in the summer months to 70 percent in the spring and winter months, depending on antecedent conditions, rainfall distribution, and rainfall intensity. Observed rainfall is obtained from the National Weather Service River Forecast Center and the runoff coefficient applied to determine average runoff. Data on the Big Sunflower River at Sunflower, Mississippi, show that annual runoffs vary from about six to 41 inches and average about 24.5 inches over the drainage area. The runoff coefficients are average values that reflect conditions in the basin. Seasonal variations in runoff coefficients are shown by the monthly-generalized values in Table 1.

Table 1-2. Average Monthly Percent Runoff

Month	Runoff Coefficients (%)
January	60
February	60
March	70
April	70
May	60
June	40
July	25
August	10
September	10
October	25
November	25

December	60

FLOODING SINCE 1979

The Yazoo Basin experiences headwater floods, backwater floods, or both simultaneously. Generally, whenever the basin receives more than 0.5 inches of precipitation, there will be some run-off. This run-off will cause the basin's rivers to rise. When they rise enough, water will start to fill off-channel storage areas. At this point, the event is classified as a flood. Flooding throughout the basin begins at different frequency intervals. For most gages, flooding begins for events greater than the 1.25-year frequency event, but flooding may not begin in some areas until the 5-year event is achieved. These events are called headwater floods. Another aspect of headwater floods is that there is typically more than one foot of slope between gages. There are six gages that were in operation for the entire 43 years of the POR, and another six with partial records. Of the six with partial records, only two are within the 100-year floodplain. Backwater floods occur when a downstream river experiences higher stages than the tributary. When this occurs, the water surface on the tributary rises towards the elevation of the downstream river. Backwater floods can affect large areas and extend many miles upstream. During the 2011 Mississippi River flood, the Yazoo River backed up all the way to Belzoni, which is a distance of 116 river miles upstream of the confluence of the Yazoo River with the Mississippi River in Vicksburg. A true backwater flood will have a flat or nearly flat surface. A backwater flood in the Yazoo Backwater Study Area is defined by two conditions. First, the water surface at the Steele Bayou landside gage is above 80 feet (NGVD 29), and second, the water surface elevation for the Steele Bayou riverside gage is higher than the landside gage. This means the structures gates are closed. At 80 feet (NGVD 29) on the Steele Bayou landside gage, off-channel storage areas start to fill. The backwater flood persists until the gates are open and the water surface has returned to 80 feet (NGVD 29). A backwater flood is seldom caused by a single precipitation event. During a backwater flood there is generally several precipitation events, some or all may induce some headwater flooding. All these events contribute to the total volume of water stored within the backwater area. Figure 12 provides the hydrographs from several gages for the first few months of 1994, and it identifies several headwater flood events and a backwater event. The gages at Holly Bluff, Anguilla, and Little Callao reside on the Big Sunflower River. The many precipitation events that cause headwater flooding will not be affected by the pump station. These flood pulses will continue to occur after the project is completed.

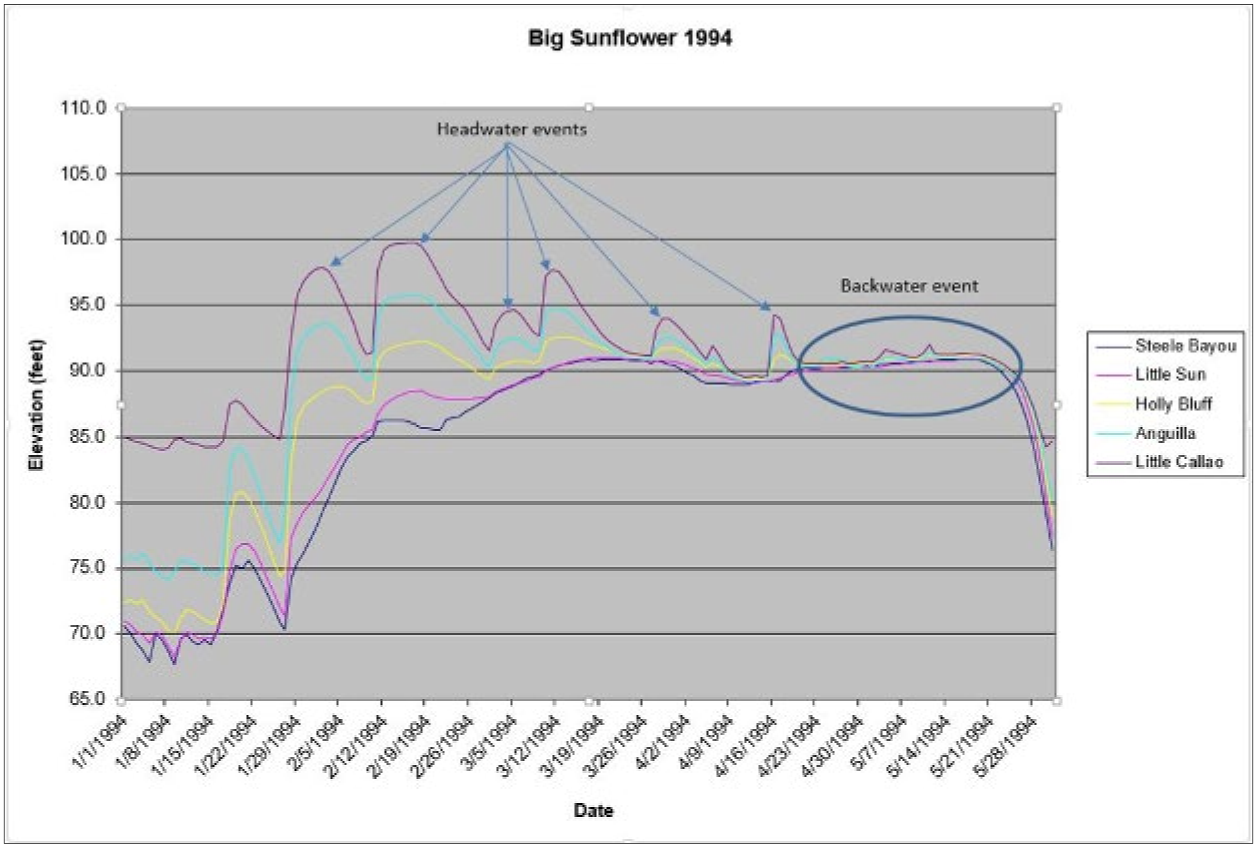


Figure 1-2. 1994 hydrograph for several Yazoo Study Area gages.

As previously stated, the Yazoo Basin experiences a backwater-driven flood when the riverside of the Steele Bayou flood control structure exceeds the landside and when the landside is above 80.0 feet (NGVD 29). 80.0 feet is roughly top bank for the rivers in the lower backwater. When these conditions are met, the Steele Bayou flood control structure gates are closed. Should the Yazoo Backwater receive rain events over time while the gates are closed, the Yazoo Backwater begins to experience flooding since flood waters are unable to drain from the region through the Steele Bayou structure. The following paragraphs describe backwater-driven flood events from 1978 through 2019 and provides graphics that illustrate when these backwater conditions are met. The new period-of-record encompasses 1978 through 2020.

MAJOR BACKWATER FLOOD EVENTS

FLOOD OF 1979

The flood of 1979 occurred after the Yazoo Backwater levee was completed and began as the Mississippi River started to rise early in 1979. By 01 March, due to a combination of rainfall in the Yazoo Backwater Study Area and high Mississippi River stages, Steele Bayou began to rise above elevation 80 feet (NGVD 29). On 04 March, as water reached an elevation of 82.5 feet (NGVD 29) in the Yazoo Backwater Study Area, the Steele Bayou gates were closed to prevent the Mississippi and Yazoo Rivers from flowing into the Yazoo Backwater Study Area. The Little Sunflower River structure was closed on 05 March as water reached 85.05 feet (NGVD 29). Water in the Yazoo Backwater Study Area continued to rise throughout March. However, from 08 April through 14 April, the Steele Bayou gates were momentarily opened as the Mississippi River at Vicksburg briefly fell from 90.0 feet (NGVD 29) on 24 March to 88.3 feet (NGVD 29) on 03 April and Steele Bayou riverside fell below Steele Bayou landside.

After this brief recession of water, both the river and landsides of the Backwater levees began to experience an increase in water elevations, resulting in the closure of the Steele Bayou gates on 14 April. Steele Bayou riverside and Little Sunflower riverside then reached peak elevations of 97.2 and 97.6 feet (NGVD 29) on 28 April. Despite the large amount of rainfall in the Yazoo Backwater Study Area, Little Sunflower landside did not reach its peak of 96.6 feet (NGVD 29) until 05 May. The Mississippi and Yazoo Rivers, which had begun their fall several days before, fell low enough for the floodgates to be opened at Steele Bayou on 04 May at elevation 96.3 feet (NGVD 29) and Little Sunflower River on 05 May at elevation 96.6 feet (NGVD 29). The peak elevations in the Yazoo Backwater Study Area, during this backwater-driven flood event, were the annual peak elevations during 1979. This decline continued until water fell below elevation 80.0 feet (NGVD 29) in the Steele Bayou area on 14 June and the Little Sunflower area on 15 June 1979 ending a flood which lasted 104 days and flooded a maximum of 350,400 acres.

Without the Yazoo Backwater levees and structures, approximately 400,000 acres would have been flooded. Many homes in the Eagle Lake area were threatened with major flooding as water levels were within inches of the natural ridge protecting the area adjacent to the Muddy Bayou structure. Emergency efforts to raise the ridge by USACE were successful during this event; however, lake water levels were raised to elevation 90.0 feet (NGVD 29), with flow through the Muddy Bayou structure, in preparations to lessen catastrophic damage, which would have occurred had Steele Bayou stages risen another inch or two. Because the Yazoo Backwater exceeded an elevation of 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on to alleviate the high water within the Yazoo Backwater Study Area.

In Figure 13, the top graph illustrates the Yazoo Backwater elevations for the gages at Steele Bayou landside, Little Sunflower landside, Holly Bluff (Big Sunflower River), Anguilla (Big Sunflower River), and Little Callao (Big Sunflower River) during the 1979 Yazoo Backwater flood. The bottom graph depicts the difference in elevation between Steele Bayou landside and riverside during the 1979 Yazoo Backwater flood. When

Steele Bayou landside is lower than Steele Bayou riverside, i.e., the difference in elevation is negative, and Steele Bayou landside is above 80.0 feet (NGVD 29), the gates of the Steele Bayou water control structure are closed. The closure of the Steele Bayou gates keeps high water from draining from the Yazoo Study Area. The Yazoo Backwater elevations and Steele Bayou landside and riverside elevation difference graphics are provided for each following historical Yazoo Backwater flood event.

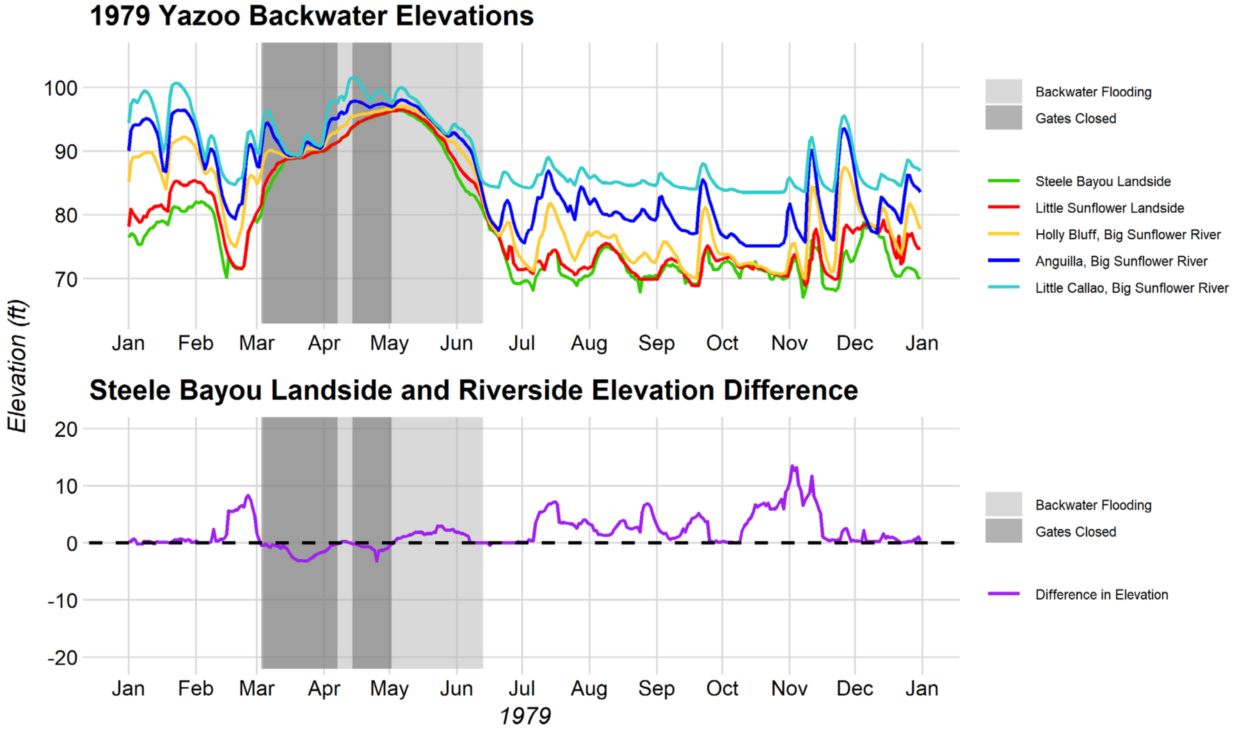


Figure 1-3. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1979 Yazoo Backwater flood.

FLOOD OF 1983

Headwater flooding in the Yazoo Backwater Study Area began in December 1982 and peaked at 92.0 feet (NGVD 29) on 11 January 1983 before falling below an elevation of 80.0 feet (NGVD 29) on 19 February 1983 (Figure 14). During March, the Yazoo Backwater Study Area experienced another headwater flood, but during April, stages on the Mississippi River began to increase after three storms, occurring from late April and throughout May, produced rainfall totals up to 16 inches in the lower Ohio and Mississippi River Basins. The excessive rainfall resulted in the Mississippi River beginning to experience dramatic increases in elevation during April and resulted in the closure of the Steele Bayou gates on 19 April. On 27 May, the Mississippi River at Vicksburg peaked at 95.5 feet (NGVD 29). On 28 May, the Steele Bayou riverside peaked at 98.5 feet (NGVD 29) and on 09 June, the Steele Bayou landside peaked at 95.8 feet (NGVD 29). After the Yazoo Backwater Study Area crested, the gates at Steele Bayou were opened on 11 June, and the Yazoo Backwater Study Area flood waters receded below an elevation of 80 feet (NGVD 29) on 30 June 1983. Overall, the Yazoo Backwater Study Area experienced backwater-induced flooding for 73 days from 19 April until 30 June during 1983. Because the Yazoo Backwater Study Area exceeded 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on during this flood event.

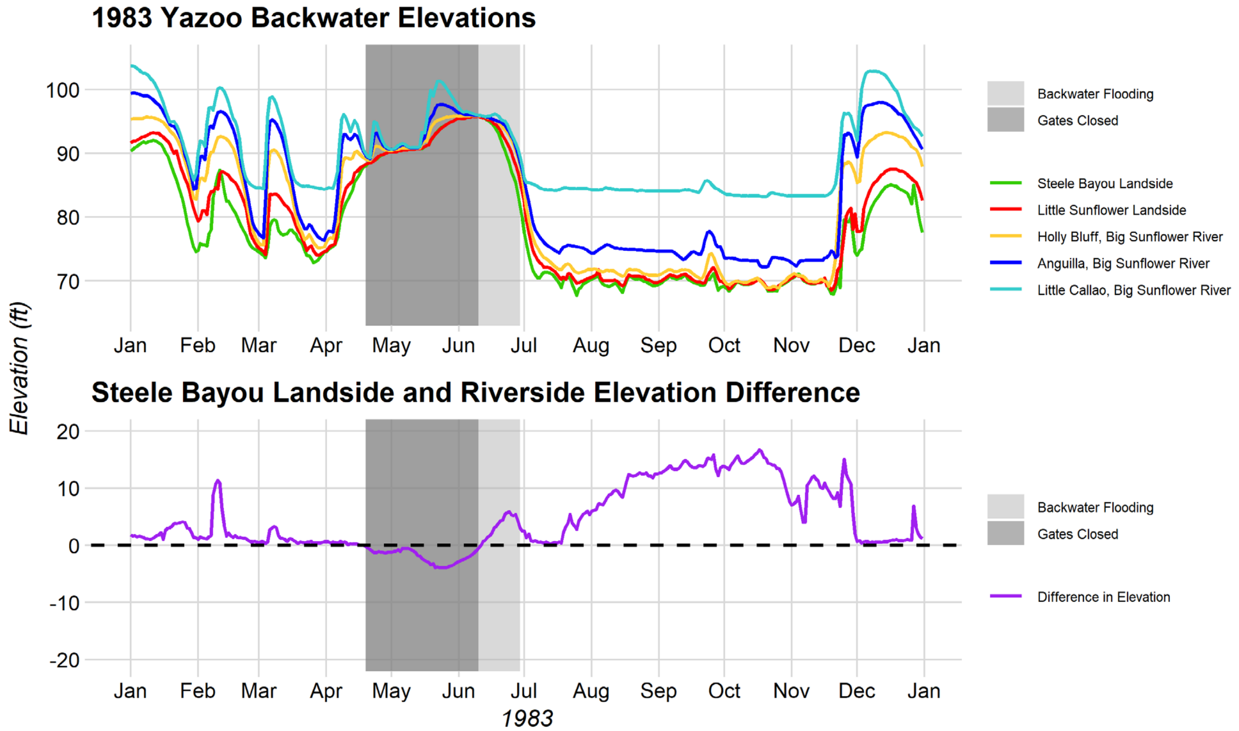


Figure 1-4. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1983 Yazoo Backwater flood.

FLOOD OF 1984

The 1984 Yazoo Backwater Study Area flood began on 27 March when the gates at Steele Bayou were forced to close due to a rising Mississippi River and Steele Bayou riverside (Figure 15). As the Mississippi River at Vicksburg began to experience increasing stages, water backed up into the Yazoo Backwater Study Area. The Mississippi River at Vicksburg peaked on 26 May at 92.0 feet (NGVD 29). Then the Steele Bayou riverside crested at 94.5 feet (NGVD 29) on 27 May, and the Steele Bayou landside crested at 92.0 feet (NGVD 29) on 29 May. The flood receded below an elevation of 80.0 feet (NGVD 29) on 15 June. The Yazoo Backwater Study Area experienced backwater-induced flooding for 81 days from 27 March to 15 June during 1984. Additionally, because the Yazoo Backwater Study Area exceeded 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on during this flood event.

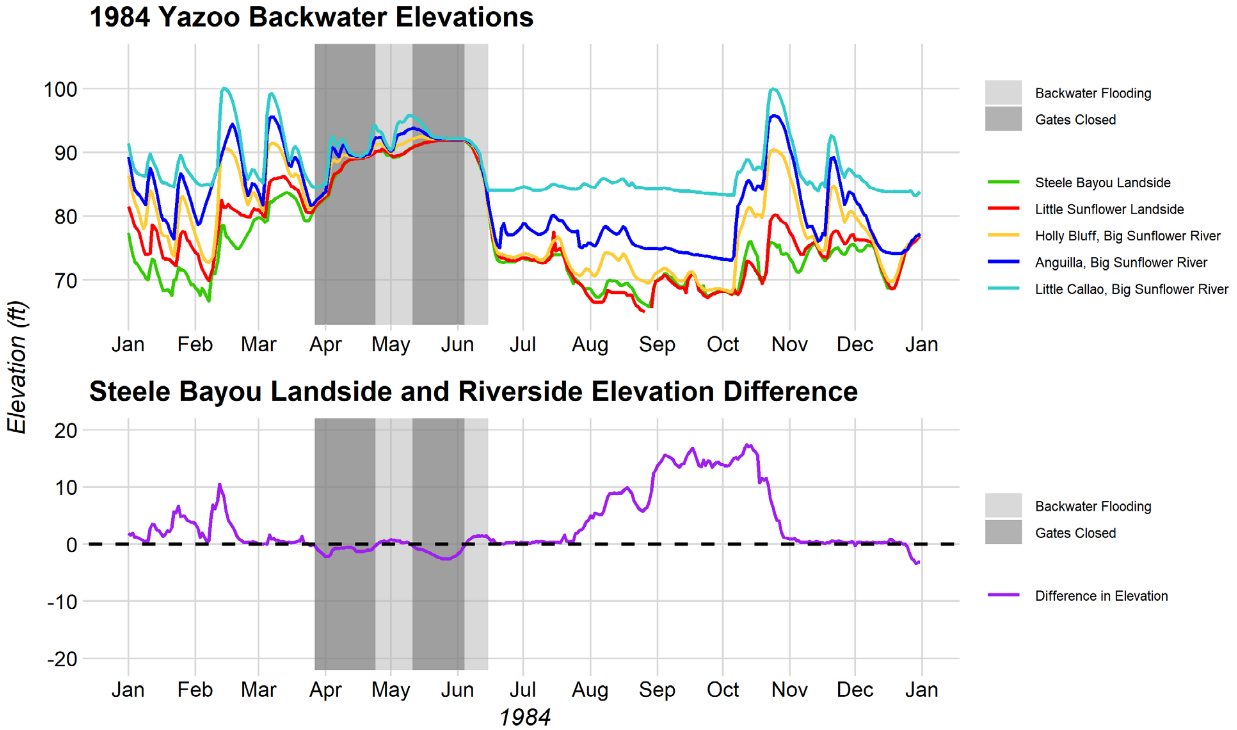


Figure 1-5. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1984 Yazoo Backwater flood.

FLOOD OF 1991

During January of 1991, the Yazoo Backwater Study Area experienced backwater-induced flooding that resulted in the closure of the Steele Bayou gates (Figure 16). The Mississippi River at Vicksburg began to rise on 20 December 1990 and crested at 90.6 feet (NGVD 29) on 20 January 1991. Due to the increasing stages on the Mississippi River, the Steele Bayou riverside began to increase and surpassed the landside elevation, resulting in the closure of the Steele Bayou gates on 07 January and remained closed until 27 January. The Steele Bayou riverside peaked at 91.7 feet (NGVD 29) on 28 January and the Steele Bayou landside crested at 93.1 on 22 January. Because the Steele Bayou landside barely surpassed an elevation of 93.0 feet (NGVD 29) during non-crop season of this backwater-induced flood event, the proposed pumps would have been turned on for a short period of time.

From April through June, the Yazoo Backwater Study Area was flooded by a headwater flood due to tremendous amounts of rainfall in the Upper Yazoo Area (Figure 16). The flooding in the Yazoo Area peaked at elevation 92.4 feet (NGVD 29) on 06 May. Because this flood event was a headwater flood, the Steele Bayou riverside elevation reached a peak of 90.8 feet (NGVD 29) on 04 May, roughly 1.5 feet lower than the landside elevation. The Steele Bayou and Little Sunflower River structure gates only briefly closed at the beginning of this flood event as the Steele Bayou riverside momentarily exceeded the Steele Bayou landside.

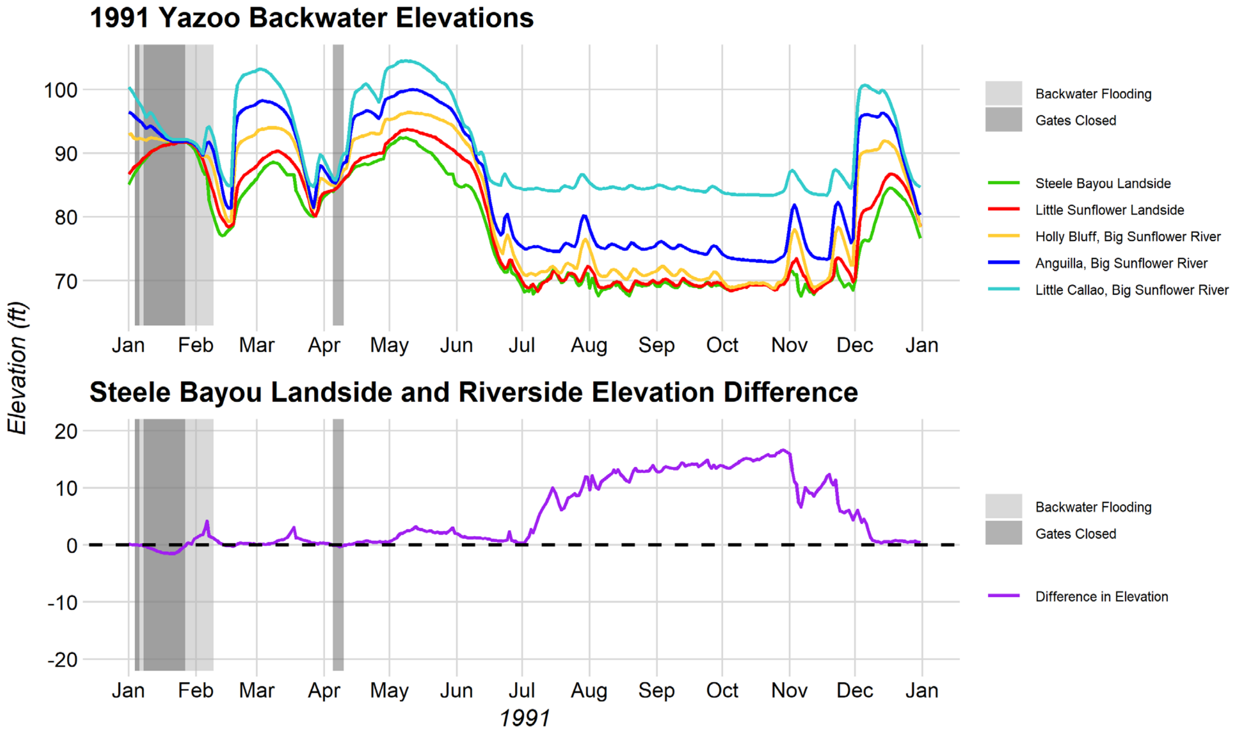


Figure 1-6. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1991 Yazoo Backwater flood.

FLOOD OF 1993

The flood of 1993 primarily affected the Upper Mississippi River and its tributaries. High antecedent soil moisture followed by persistent, heavy rainfall from April through September produced extensive flooding in the Upper Mississippi Basin. The effect on the Lower Mississippi River was passed without major flooding. The flood of 1993 demonstrated that during high Upper Mississippi River discharges, flooding on the Upper Mississippi River alone would not produce a major flood event on the Lower

Mississippi River. However, the Yazoo Backwater Study Area still experienced backwater-induced flooding as a result of the major flooding in the Upper Mississippi Basin. On 10 March, the gates at Steele Bayou were closed as the Steele Bayou riverside exceeded the Steele Bayou landside (Figure 17). The gates at Steele Bayou were briefly able to open from 30 March to 07 April before closing again. The Mississippi River at Vicksburg peaked at 89.9 feet (NGVD 29) on 18 May. Then, both the Steele Bayou landside and riverside reached an elevation of 91.5 feet (NGVD 29) on 19 May. The flood receded below elevation of 80 feet (NGVD 29) on 07 June. The Mississippi River at Vicksburg rose again on 16 July, due to the Upper Mississippi River flooding, and reached an elevation of 85.2 feet (NGVD 29) on 12 August. The Steele Bayou gates were closed from 23 July to 10 August, and the Steele Bayou riverside and landside gages both crested at 86.5 feet (NGVD 29) on 12 August. The flood receded below 80.0 feet (NGVD 29) on 02 September (Figure 17). Overall, the Yazoo Backwater Study Area was flooded for 130 days in 1993. The proposed pumps would have been turned on during the flood event in May since high water elevations in the Yazoo Backwater Study Area exceeded 90.0 feet (NGVD 29) during crop season. However, the proposed pumps would not have been turned on for the August flood event since water elevations did not exceed 90.0 feet (NGVD 29).

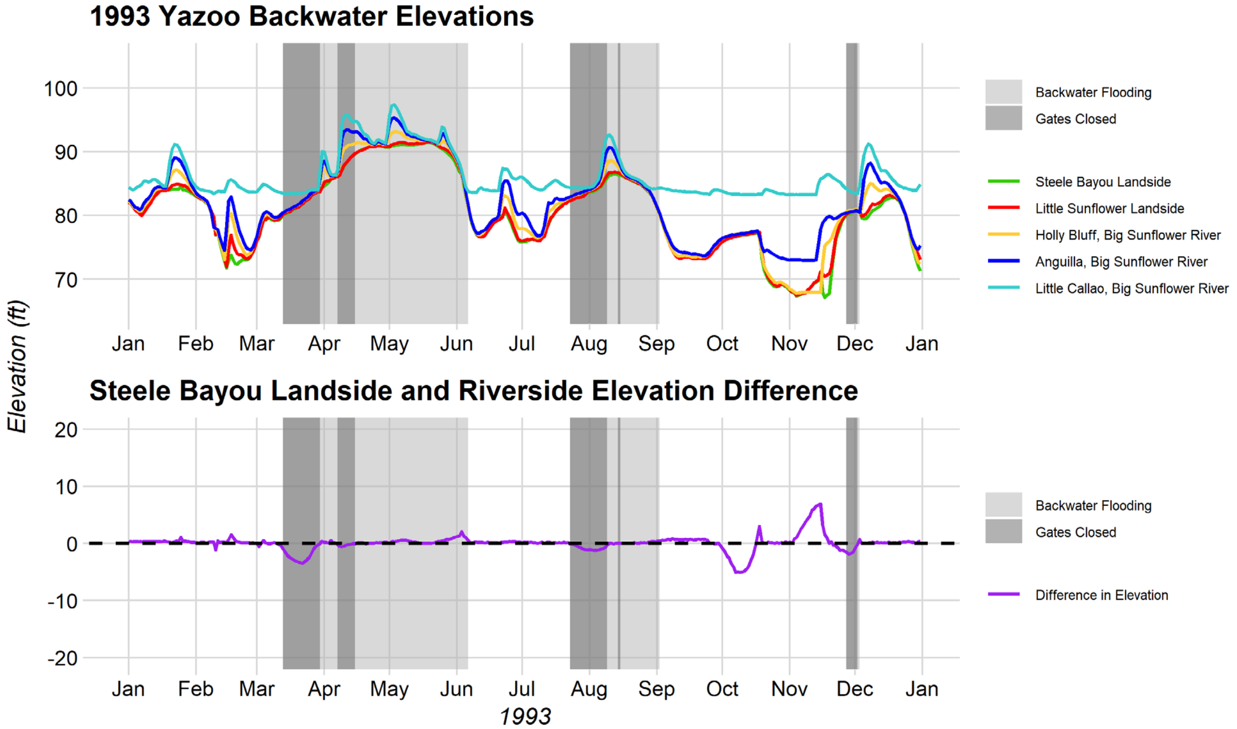


Figure 1-7. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1993 Yazoo Backwater flood.

FLOOD OF 1997

The flood of 1997 began with the Mississippi River reaching the highest flood levels experienced at Arkansas City, Arkansas, and Natchez, Mississippi, since 1973 and the highest at Greenville and Vicksburg, Mississippi, since 1983.The 1997 Mississippi River flood was the fourth highest of record at Natchez and Cairo, following close behind 1927, 1937, and 1973.The Mississippi River at Vicksburg began to experience significant increases in stage in early March (Figure 18). On 09 March, the gates at Steele Bayou were closed as the riverside exceeded the landside elevation. The Mississippi River at Vicksburg crested at 95.3 feet (NGVD 29) on 23 March. The Steele Bayou riverside peaked at 98.2 feet (NGVD 29) on 24 March, and the Steele Bayou landside peaked at an elevation of 93.3 feet (NGVD 29) on 08 April. The Steele Bayou gates remained closed until 12 April. The Yazoo Backwater Study Area did not recede below 80.0 feet (NGVD 29) until 19 May. The Yazoo Backwater Study Area experienced another brief backwater-induced flood from 08 June through 08 July and peaked at 85.0 feet (NGVD 29) on 28 June. Because the Yazoo Backwater Study Area experienced high water above an elevation of 90.0 feet (NGVD 29) in late March and April, the proposed pumps would have been turned on during this flood event. The proposed pumps would have been turned on during the minor flood event in June as high-water elevations exceeded 90.0 feet (NGVD 29) during crop season. Overall, the Yazoo Backwater Study Area was flooded for 101 days in 1997.

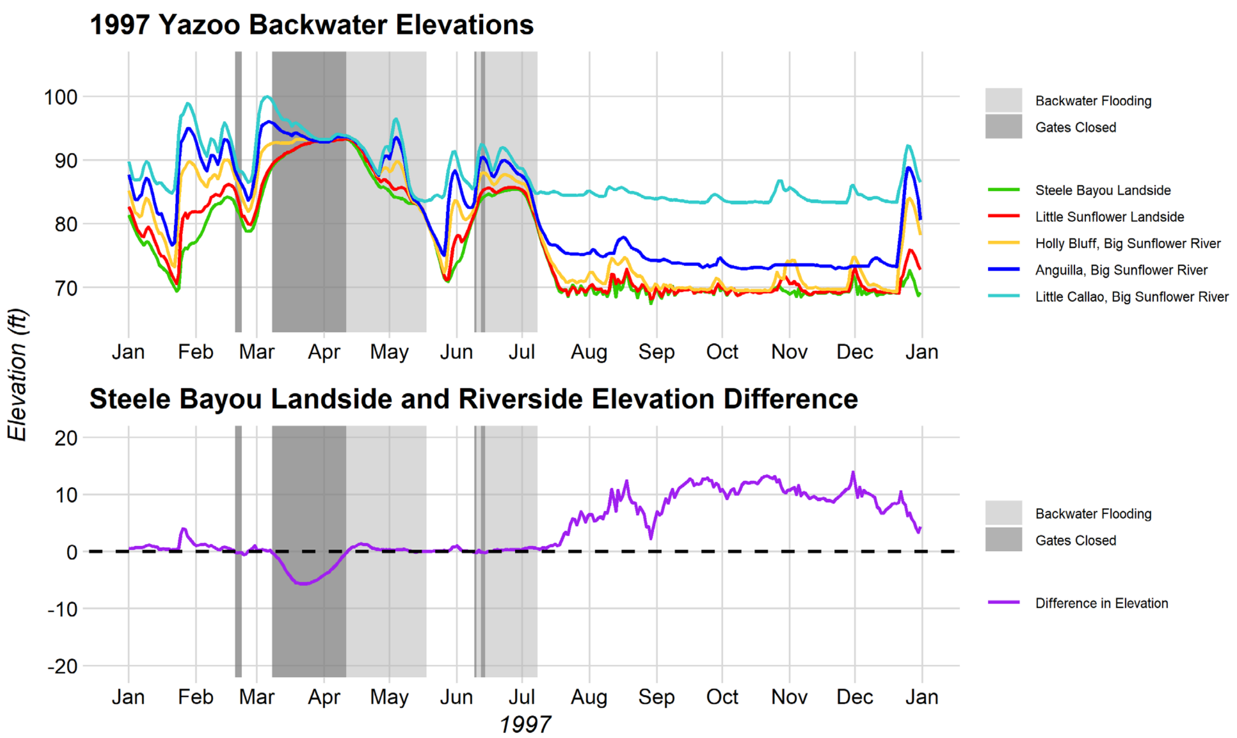


Figure 1-8. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1997 Yazoo Backwater flood

FLOOD OF 1998

The 1998 Yazoo Backwater flood began on 29 March due to a rising Mississippi River. The increases in elevation on the Mississippi River resulted in Steele Bayou riverside exceeding the landside elevation, and the landside elevation surpassing 80.0 feet (NGVD 29). Consequently, the gates were closed on 29 March, which is depicted in Figure 19. The Steele Bayou gates were closed from 29 March through 11 April, 25 April through 25 May, and 29 June through 09 July. The second closure of the Steele Bayou gates corresponded to the peak of the 1998 flood event, when the Steele Bayou landside crested on 11 May at 88.3 feet (NGVD 29). Around this time, more upstream river gages within the Yazoo Backwater (Little Callao, Anguilla, and Holly Bluff on the Big Sunflower River) began to equalize with the downstream gages (Little Sunflower landside and Steele Bayou landside). The Mississippi River at Vicksburg and the riverside elevation of Steele Bayou peaked shortly after at 89.8 feet (NGVD 29) and 91.6 feet (NGVD 29), respectively, on 14 May. Although the Steele Bayou gates were opened after the peak of the Yazoo Backwater flood, from 26 May through 28 June, the elevation of the Yazoo Backwater remained above an elevation of 80.0 feet (NGVD 29), prolonging the backwater flood until 05 June when the elevation fell below 80.0 feet (NGVD 29). Similarly, the third gate closure from 29 June through 09 July, resulted in the Yazoo Backwater flooding again, with high water elevations remaining above 80.0 feet (NGVD 29) until 18 July. Overall, the Yazoo Backwater was flooded for 89 days from 29 March through 18 July during 1998, and the highest Yazoo Backwater elevation for 1998 was associated with the backwater flood. Although this was considered a flood event, this event would not have required the proposed pumps to be turned on since the Yazoo Backwater elevations did not exceed 93.0 feet (NGVD 29) during non-crop season or 90.0 feet (NGVD 29) during crop season.

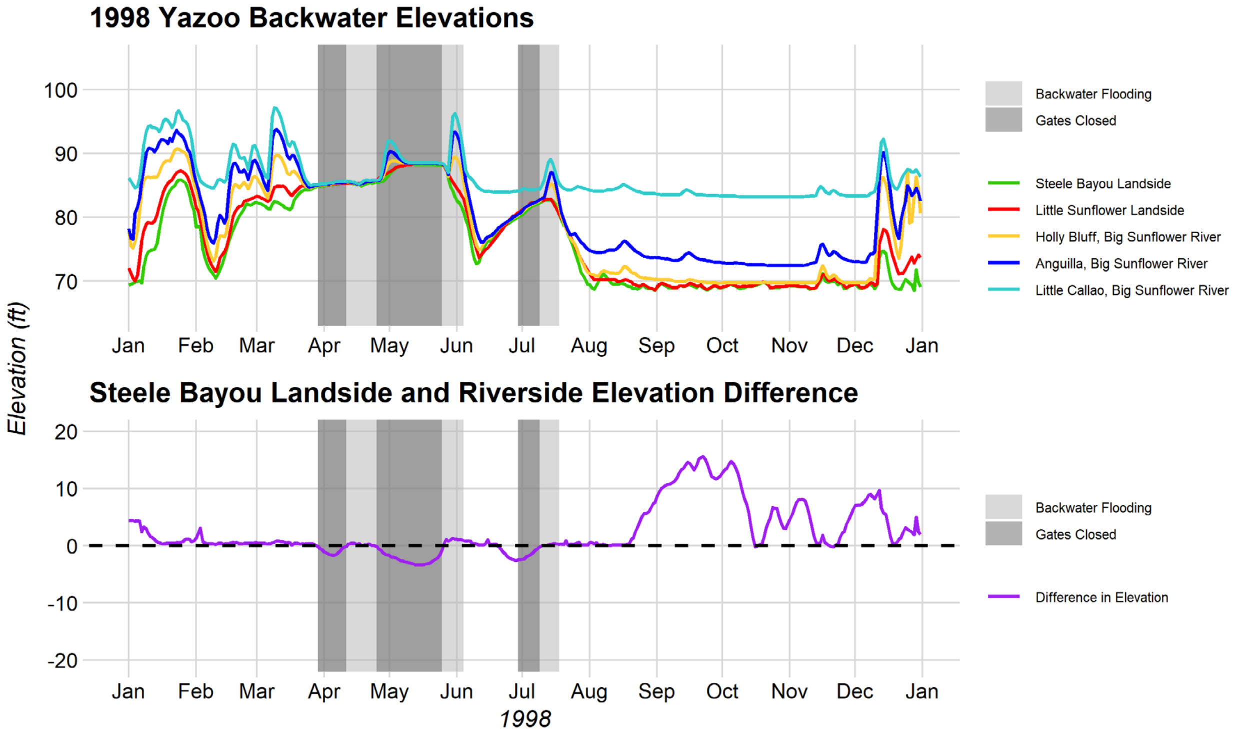


Figure 1-9. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1998 Yazoo Backwater flood.

FLOOD OF 1999

During 1999, the Yazoo Backwater Study Area experienced numerous heavy rainfall events from January through April that resulted in the Yazoo Backwater having prolonged headwater-driven flooding. The highest elevation the Yazoo Backwater experienced during 1999 was 90.3 feet, which occurred on 15 February due to the headwater flooding. Then, on 02 May, the Yazoo Backwater began to experience backwater-driven flooding due to a rising Mississippi River. The Steele Bayou gates were closed from 02 May through 06 May (

Figure 10). The Steele Bayou riverside elevation peaked at 85.0 feet (NGVD 29) on 13 May, and the Steele Bayou landside elevation peaked at 85.2 feet (NGVD 29) on 14 May. The Mississippi River at Vicksburg peaked at 83.5 feet (NGVD 29) on 19 May. Although the Steele Bayou gates were only closed from 02 May through 06 May, the Yazoo Backwater continued to experience backwater-driven flood conditions until 27 May when the Yazoo Backwater was able to recede below an elevation of 80.0 feet (NGVD 29). Overall, the Yazoo Backwater was flooded for 26 days during the 1999 backwater-driven flood event. Additionally, the backwater-driven flood event would be considered minor since the Yazoo Backwater elevation did not exceed 90.0 feet (NGVD 29), and the proposed pumps would not have been turned on.

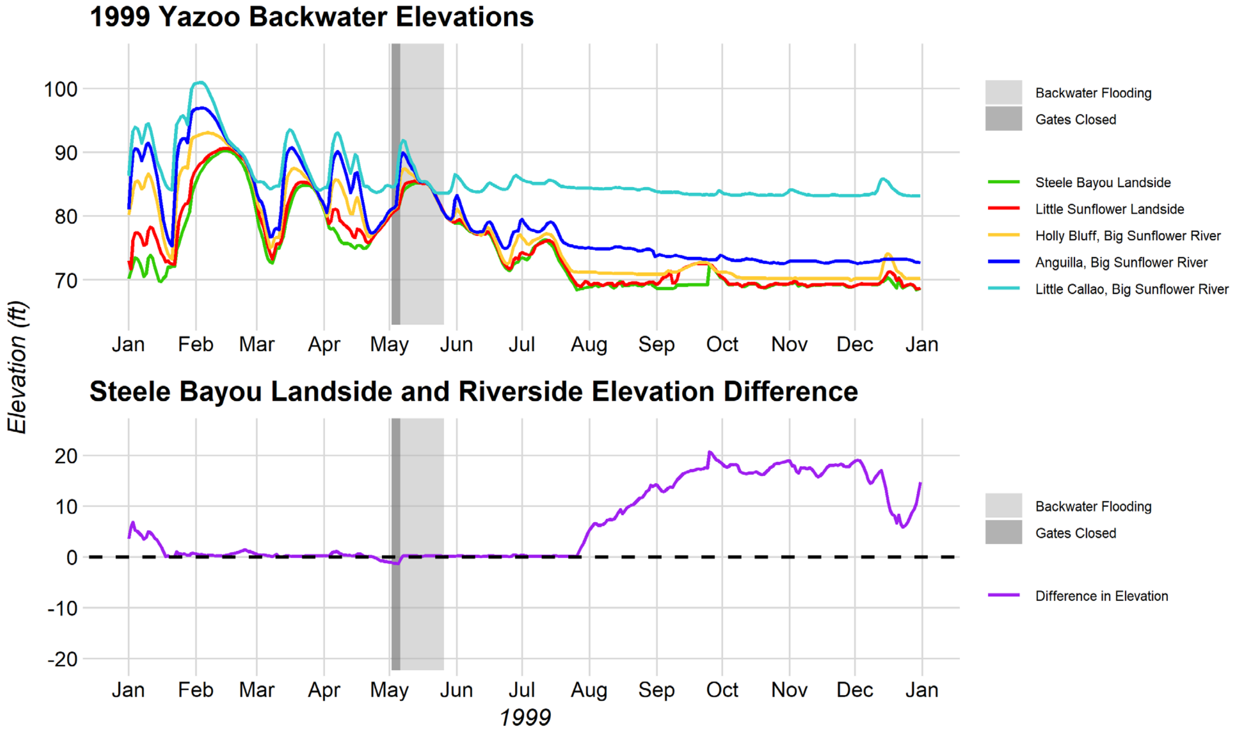


Figure 1-10. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 1999 Yazoo Backwater flood.

FLOOD OF 2002

During 2002, the Yazoo Backwater experienced numerous heavy rainfall events from January through April that resulted in headwater flooding in the Yazoo Basin. The Yazoo Backwater experienced an annual crest at 90.0 feet (NGVD 29) on 13 April during the headwater-driven flooding. Then, on 04 May, the Yazoo Backwater began to experience backwater-driven flooding due to a rising Mississippi River. Both the Mississippi River at Vicksburg and the Steele Bayou riverside peaked at 91.6 and 93.7 feet (NGVD 29), respectively, on 03 June. Thus, the Steele Bayou gates were closed briefly from 04 May through 06 May to mitigate backwater flow into the Yazoo Backwater Study Area (

Figure 11). The gates were then opened from 07 May through 14 May, before closing from 15 May through 11 June. The Steele Bayou landside crested 12 June at 88.0 feet (NGVD 29), during the second closure of the Steele Bayou gates, and elevations in the Yazoo Backwater began to equalize. Although the Steele Bayou gates were reopened on 12 June, the flood waters within the Yazoo Backwater did not recede below 80.0 feet (NGVD 29) until 21 June. The Yazoo Backwater was flooded for a total of 49 days during the backwater-driven flood event of 2002. The backwater-driven flood event would not have resulted in the proposed pumps being turned on since the Yazoo Backwater did not exceed an elevation of 90.0 feet (NGVD 29).

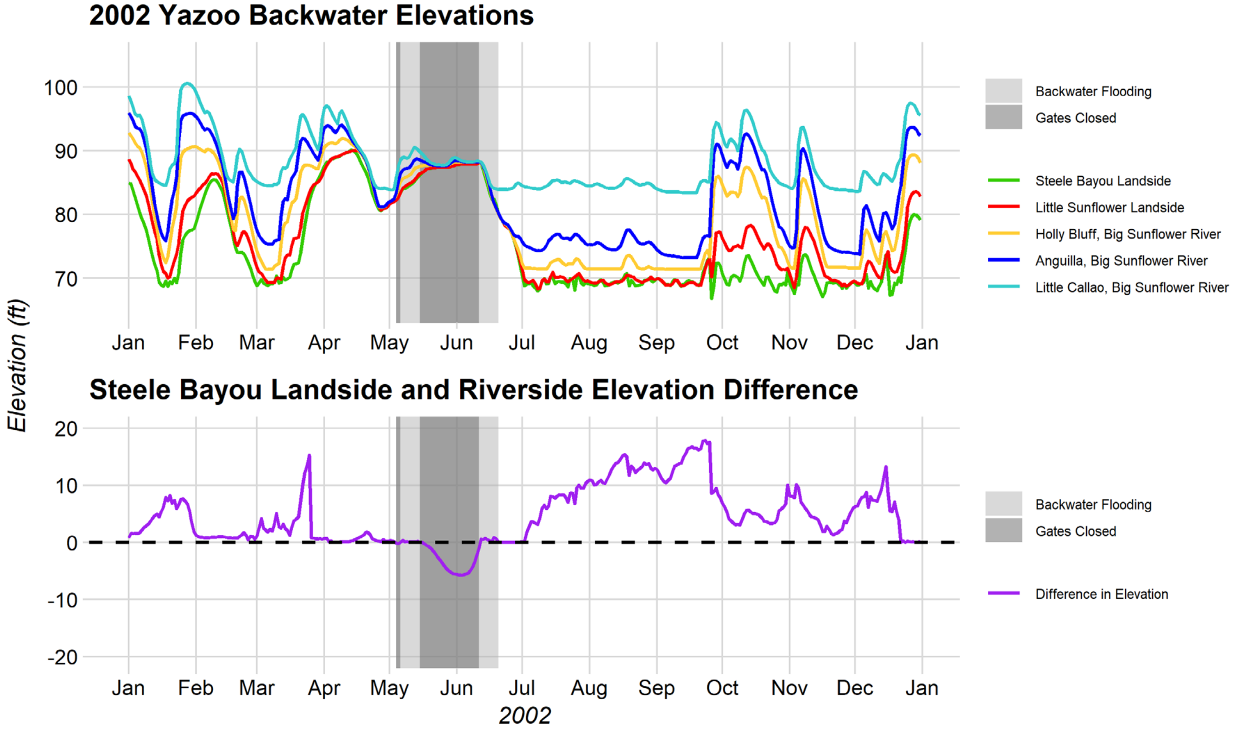


Figure 1-11. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2002 Yazoo Backwater flood.

FLOOD OF 2003

The 2003 Yazoo Backwater flood began on 19 May when the Yazoo Backwater elevation exceeded 80.0 feet (NGVD 29) and Steele Bayou landside had a lower elevation than the riverside (Figure 12). To reduce backwater flow into the Yazoo Backwater Study Area, the Steele Bayou gates were closed from 19 May through 04 June. The Steele Bayou riverside elevation peaked at 91.0 feet (NGVD 29), on 29 May, and the Mississippi River at Vicksburg crested at 89.2 feet (NGVD 29) on 30 May. The Steele Bayou landside peaked on 05 June at 88.3 feet (NGVD 29), and river gages within the Yazoo Backwater began to equalize as flood waters reached their maximum depth. The Yazoo Backwater flood waters were able to recede below an elevation of

80.0 feet (NGVD 29) on 10 June following the decline of elevations on the Mississippi River. The Yazoo Backwater Study Area experienced flood conditions for 23 days during 2003, and the annual peak elevation for the Yazoo Backwater Study Area occurred during this backwater flood. This flood event would not have resulted in the proposed pumps being turned on since the Yazoo Backwater did not exceed an elevation of 90.0 feet (NGVD 29).

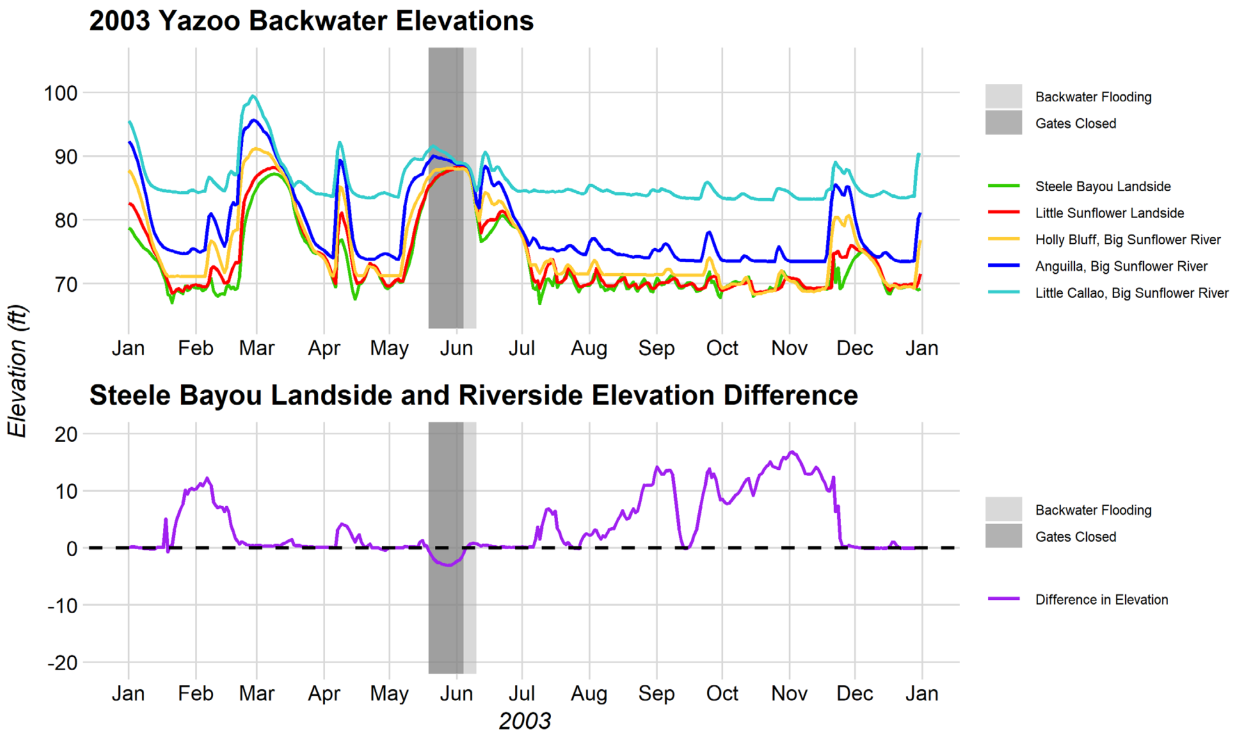


Figure 1-12. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2003 Yazoo Backwater flood.

FLOOD OF 2004

During 2004, the Yazoo Backwater experienced headwater flooding from February through March and again from November through December as storm events deposited copious amounts of rainfall across the Yazoo Basin. In fact, the highest annual elevation the Steele Bayou landside reached was 87.6 feet (NGVD 29) on 20 December, during the second headwater flood. In addition to the headwater floods, the Yazoo Backwater experienced two backwater-driven floods during 2004. The Yazoo Backwater briefly flooded from 15 March through 27 March due to rising elevations on the Mississippi River. The Steele Bayou gates were closed from 15 March through 24 March as a result (

Figure 13). During this brief backwater-driven flood event, the Mississippi River at Vicksburg crested at 83.6 feet (NGVD 29) on 21 March, the Steele Bayou riverside elevation peaked at 84.9 feet (NGVD 29) on March 21, and the Steele Bayou landside peaked on 25 March at 83.2 feet (NGVD 29). The Steele Bayou gates were then opened on 25 March, and the Yazoo Backwater receded below the elevation of 80.0 feet (NGVD 29) on 27 March. The Yazoo Backwater was flooded for a total of 13 days during March. The Yazoo Backwater briefly flooded again for 36 days due to backwater conditions from 06 June through 11 July, when the Yazoo Backwater fell below an elevation of 80.0 feet (NGVD 29). The Steele Bayou gates were closed from 06 June until 18 June. The Steele Bayou landside peaked at 84.7 feet (NGVD 29) on 02 July, and the Steele Bayou riverside elevation peaked at 84.0 feet (NGVD 29) on 15 June.

Figure 1 illustrates the Yazoo Backwater elevations from the most downstream station at Steele Bayou landside to the most upstream station at Little Callao (Big Sunflower River). The cresting of the Yazoo Backwater occurred on 25 March and 02 July. Around the time of both crests, Steele Bayou, Little Sunflower, Holly Bluff (Big Sunflower River) and Anguilla (Big Sunflower River) elevations converged. In contrast to other major flood events, not all Yazoo Backwater stations equalized in the 2004 flood. The Yazoo Backwater did not exceed 90.0 feet (NGVD 29) during either of these backwater-driven flood events. Therefore, the proposed pumps would not have been turned on.

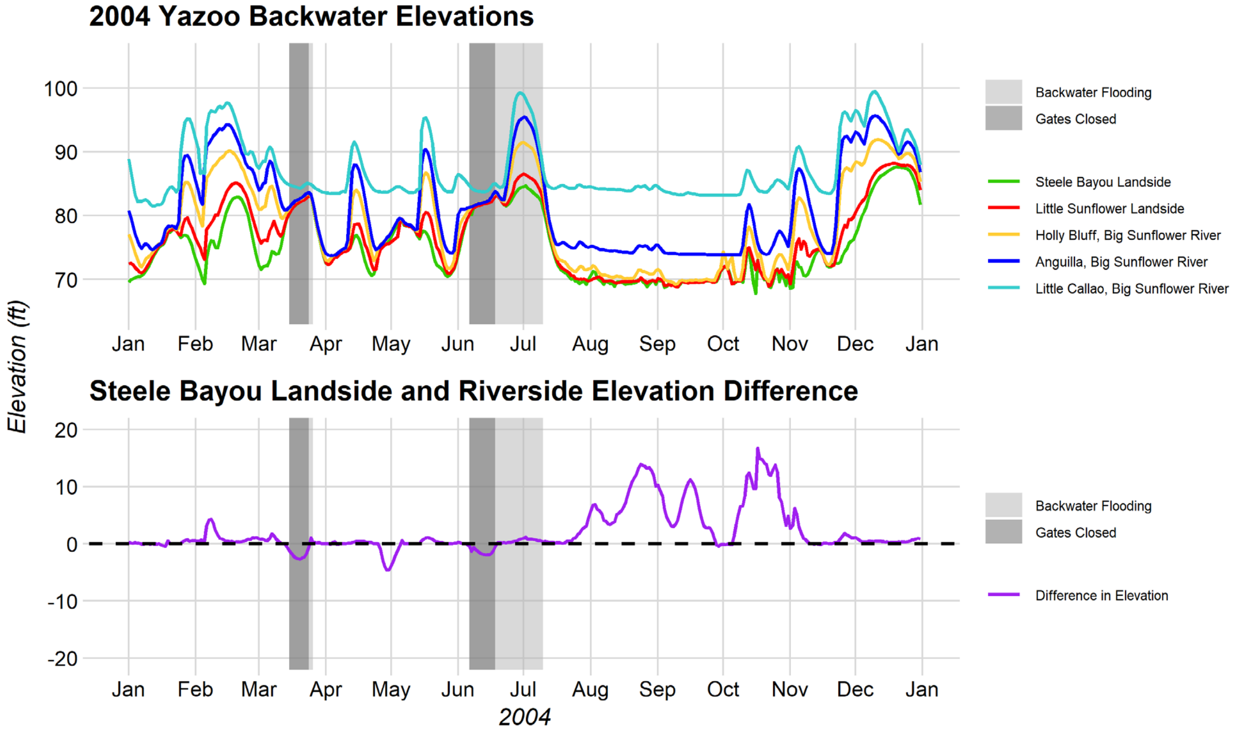


Figure 1-13. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2004 Yazoo Backwater flood.

FLOOD OF 2005

The 2005 Yazoo Backwater flood began on 14 January due to a rising Mississippi River. The Mississippi River at Vicksburg crested at 90.7 feet (NGVD 29) on 30 January. The Steele Bayou gates were closed from 15 January through 06 February (

Figure 14). The Steele Bayou riverside elevation peaked at 92.8 feet (NGVD 29) on 29 January, and roughly a week later, the Steele Bayou landside peaked at 90.0 feet (NGVD 29) on 07 February. The Yazoo Backwater was flooded for 57 days before the flood waters receded below an elevation of 80.0 feet (NGVD 29) on 11 March.

Figure 14 illustrates the Yazoo Backwater elevations from the most downstream station at Steele Bayou landside to the most upstream station at Little Callao (Big Sunflower River). When the Yazoo Backwater reached a maximum in high water, the elevations at the upstream river gages began to equalize with the elevations at the downstream river gages. Because the Yazoo Backwater did not surpass 90.0 feet (NGVD 29), the proposed pumps would not have been turned on during this flood event.

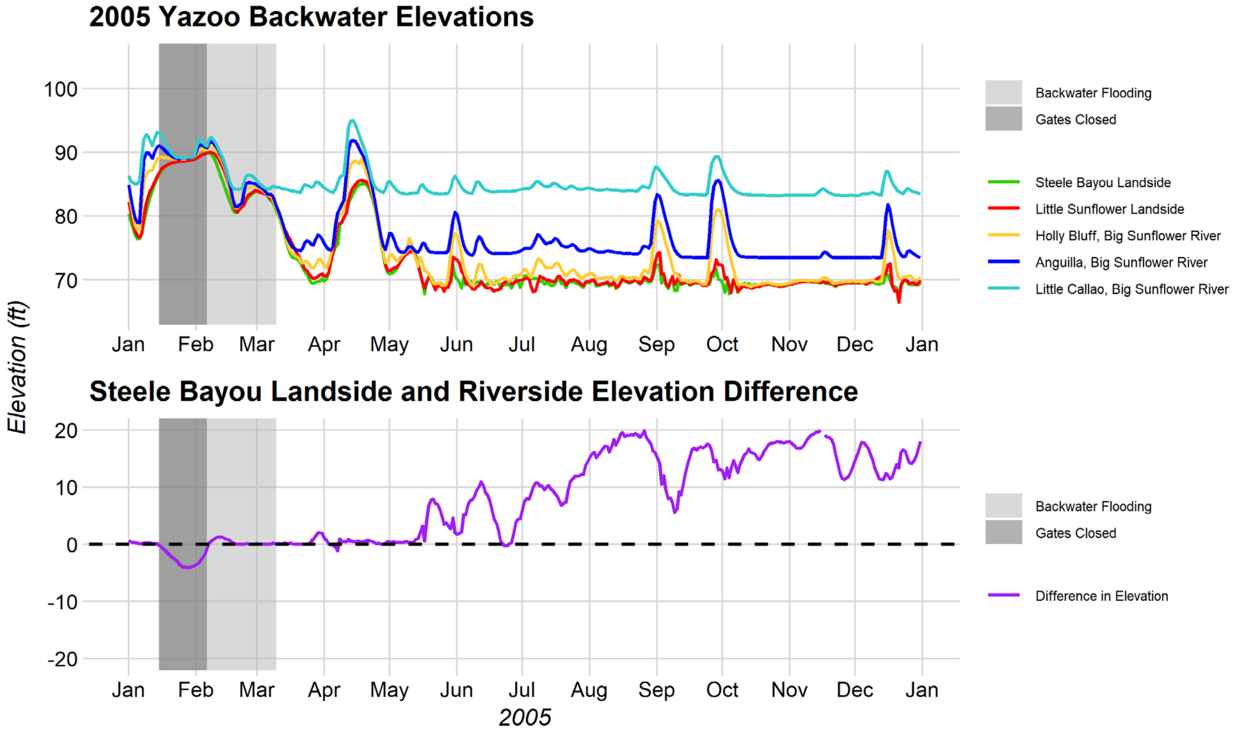


Figure 1-14. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2005 Yazoo Backwater flood.

FLOOD OF 2007

During 2007, the Yazoo Backwater experienced headwater flooding during the beginning of January from heavy rainfall. The headwater flooding amplified water levels in the Yazoo Backwater Study Area; and when the Mississippi River began to rise, the Yazoo Backwater Study Area began to flood from backwater conditions. The backwater flooding began 19 January, and the Steele Bayou gates were closed to prevent backwater flow into the Yazoo Backwater from 19 January through 21 January (

Figure 115). The Mississippi River at Vicksburg crested at 83.9 feet on 26 January. Consequently, the riverside elevation of the Steele Bayou crested at 85.4 feet (NGVD 29), on 26 January. The Steele Bayou landside elevation peaked at 85.4 feet (NGVD 29), on 25 January, which is the annual peak elevation the Yazoo Backwater experienced during 2007. The elevation of the Yazoo Backwater then fell below 80.0 feet (NGVD 29) on 07 February. The Yazoo Backwater was flooded for 20 days during 2007. Because the Yazoo Backwater did not exceed 90.0 feet (NGVD 29), the proposed pumps would not have been turned on during this flood event.

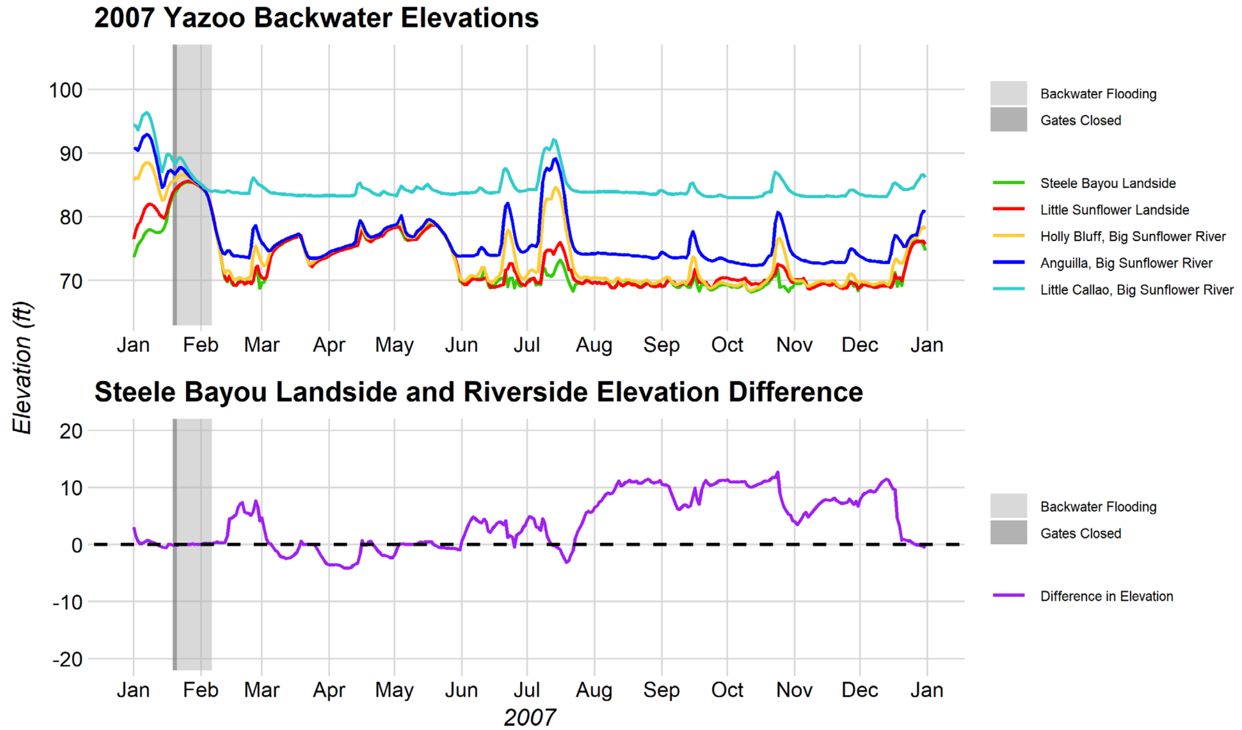


Figure 1-15. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2007 Yazoo Backwater flood.

FLOOD OF 2008

The 2008 Yazoo Backwater flood began 18 February due to a rising Mississippi River. After above normal rainfall across the Mississippi River Valley during February and March, the Mississippi River at Vicksburg started rising and crested at 97.1 feet (NGVD 29) on 20 April. The Steele Bayou gates were closed from 18 February through 04 March when the riverside exceeded the landside and when the landside surpassed 80.0 feet (NGVD 29) (

Figure 1-16). The gates were then briefly opened before being closed again from 06 March through 09 June and 11 June through 22 July. During the second closure of the gates, the riverside elevation of the Steele Bayou crested at 100.0 feet (NGVD 29) on 23 April, and the landside peaked at 92.2 feet (NGVD 29) on 08 May. The Steele Bayou landside elevation of 92.2 feet (NGVD 29) was the annual peak elevation for the Yazoo Backwater Study Area during 2008. After the crest on the Mississippi River, elevations began to fall, allowing the high water within the Yazoo Backwater to recede below an elevation of 80.0 feet (NGVD 29) on 22 July. Overall, the Yazoo Backwater experienced high water above 80.0 feet (NGVD 29) for 156 days during 2008.

Figure 1-16 illustrates the Yazoo Backwater elevations from the most downstream station at Steele Bayou landside to the most upstream station at Little Callao (Big Sunflower River). The Yazoo Backwater peaked on 08 May as flood waters reached their maximum level, resulting in the elevation at all river gages within the Yazoo Backwater equalizing soon after. The Yazoo Backwater elevation exceeded 90.0 feet (NGVD 29) during crop season. Therefore, the proposed pumps would have been turned on during this flood.

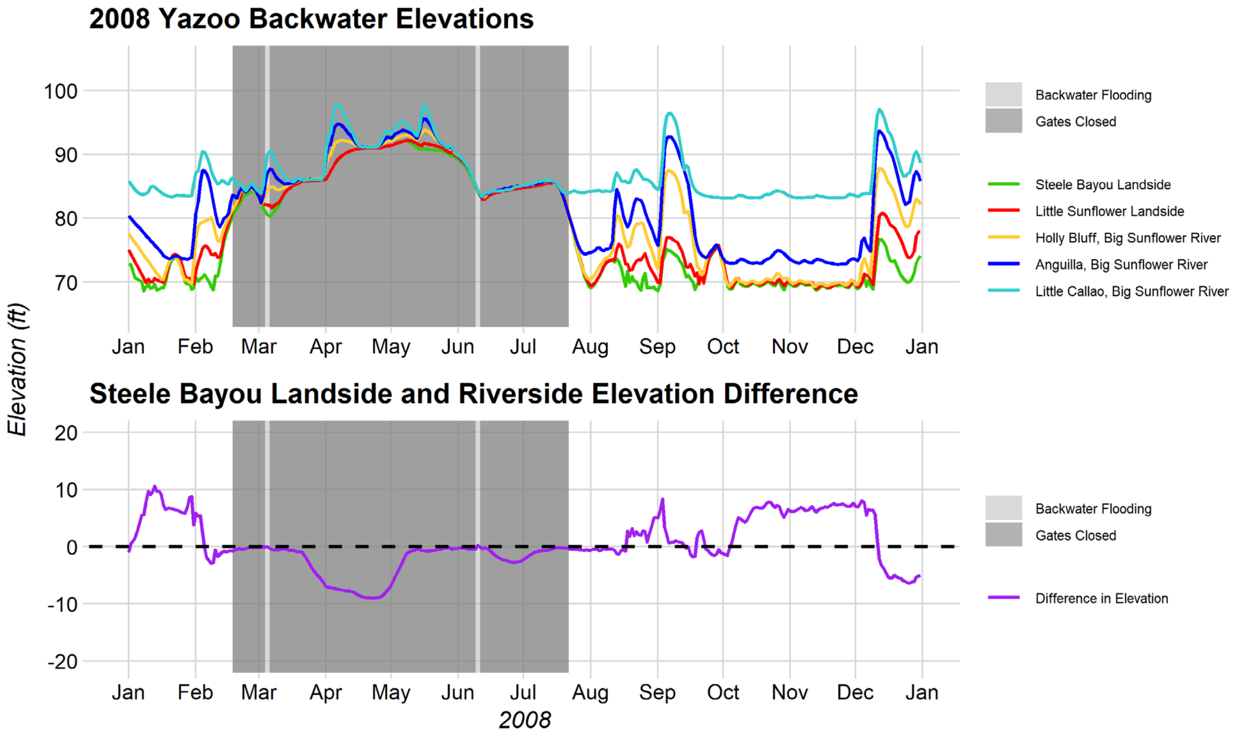


Figure 1-16. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2008 Yazoo Backwater flood.

FLOOD OF 2009

During 2009, the Yazoo Backwater experienced numerous flood events due to a rising Mississippi River. The first flood event occurred briefly from 07 January through 12 January after localized heavy rainfall occurred across the Lower Mississippi Valley during December 2008. The Steele Bayou gates were closed from 07 January through

11 January (Figure 117). The Mississippi River at Vicksburg peaked at 79.4 feet (NGVD 29) on 08 January, and the Steele Bayou riverside elevation crested at 85.7 feet (NGVD 29) on 09 January. Due to the increasing elevations on the Mississippi River, the Steele Bayou landside peaked at 81.8 feet (NGVD 29) on 09 January, before falling below 80.0 feet (NGVD 29) on 12 January. Because the Yazoo Backwater elevation did not exceed 90.0 feet (NGVD 29), the proposed pumps would not have been turned on during this flood event.

The second flood event began in March when the Mississippi River at Vicksburg once again began to experience increasing elevations. The Steele Bayou gates were closed 28 March through 30 March and again from 04 April through 01 July (Figure 1). The elevation of the flood waters within the Yazoo Backwater exceeded 80.0 feet (NGVD 29) on 28 March. Then the Mississippi River at Vicksburg crested at 93.8 feet (NGVD 29) on 28 May. Similarly, the Steele Bayou riverside elevation peaked at 96.6 feet (NGVD 29) on 28 May. As a result of the increasing backwater, the Yazoo Backwater peaked on 04 June at 93.7 feet (NGVD 29), which was the annual peak elevation for the Yazoo Backwater Study Area during 2009. The second flood event receded below an elevation of 80.0 feet (NGVD 29) on 01 July. Because the Yazoo Backwater elevation exceeded 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on during this flood event.

The third Yazoo Backwater flood began 15 October, which consisted of backwater fluctuating above and below 80.0 feet (NGVD 29) throughout the remainder of the year (Figure 117). The downstream United States received anywhere from 200 to more than 300 percent of normal precipitation during October. Specifically, Mississippi received almost 10 inches of rainfall, making it the second wettest October from 1895 through 2009. The influx of copious rainfall led to high water conditions on the Mississippi River and within the Yazoo Backwater Study Area. The Yazoo Backwater elevation experienced significant fluctuations resulting from the opening and closing of the Steele Bayou gates in an attempt to release flood waters. The Steele Bayou gates were closed eight times during this flood event with the periods from 16 October through 28 October and 31 October through 12 November being the longest consecutive periods the gates were closed. During the flood event, on 12 November, the Mississippi River at Vicksburg, the Steele Bayou riverside, and the Steele Bayou landside crested at 86.3, 88.2, and 88.1 feet (NGVD 29), respectively. The third flood event receded below an elevation of 80.0 feet (NGVD 29) on 29 November. The Yazoo Backwater was above an elevation of 80.0 feet (NGVD 29) for 148 days during 2009. Because the Yazoo Backwater elevation did not exceed 90.0 feet (NGVD 29), the proposed pumps would not have been turned on during this flood event.

Figure 117 illustrates the Yazoo Backwater elevations from the most downstream river gage at Steele Bayou landside to the most upstream river gage at Little Callao (Big Sunflower River). The cresting of the Yazoo Backwater is indicated by the majority of the gages equalizing around 09 January, 04 June, and 12 November.

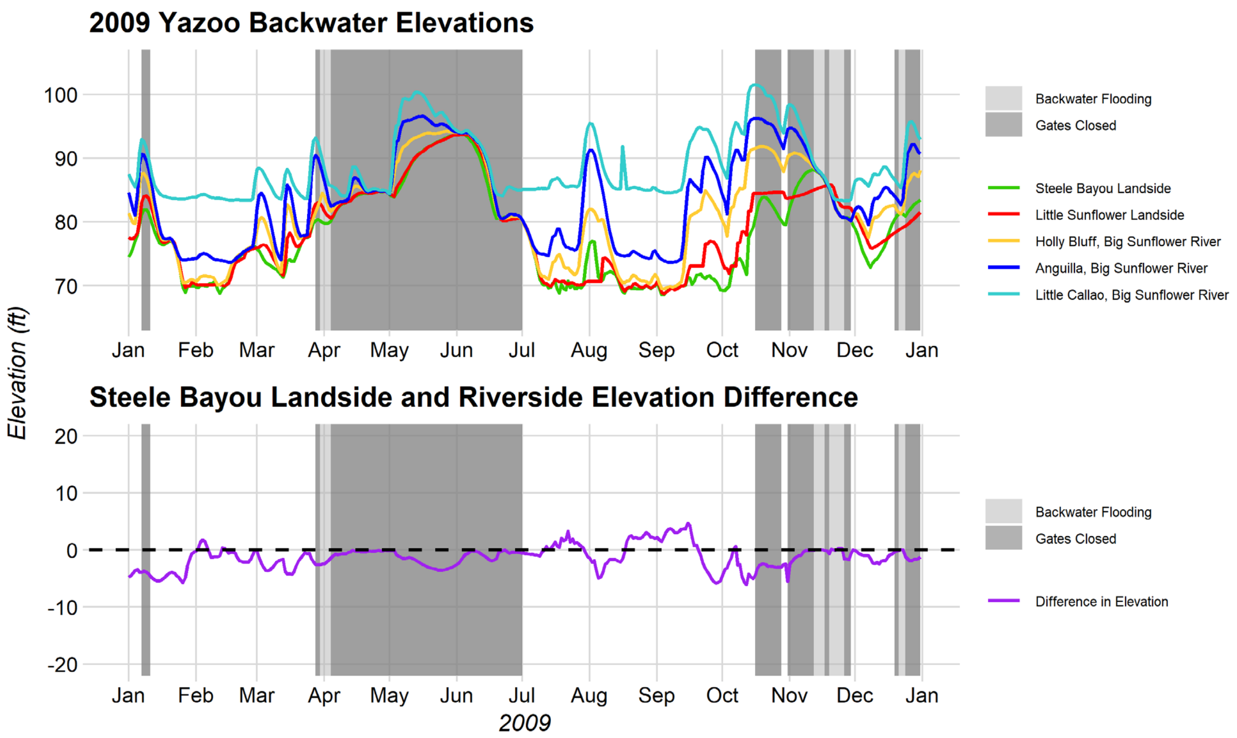


Figure 1-17. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2009 Yazoo Backwater flood.

FLOOD OF 2010

The 2010 Yazoo Backwater flood event began as a continuation of the third 2009 Yazoo Backwater flood. The Yazoo Backwater continued to fluctuate above and below 80.0 feet (NGVD 29) from January through July. These fluctuations were driven by heavy rainfall events and backwater flow into the Yazoo Backwater, resulting in the opening and closing of the Steele Bayou flood control structure. The Steele Bayou gates were closed seven times during 2010, with 15 February through 01 March being the longest, consecutive closure (

Figure 118). The Steele Bayou landside elevation exceeded 80.0 feet (NGVD 29) on 18 December 2009 and remained above 80.0 feet (NGVD 29) through January 2010. The Steele Bayou landside then peaked on 06 January at 85.6 feet (NGVD 29) and the riverside elevation peaked at 85.6 feet (NGVD 29) on 05 January. Because the Yazoo Backwater elevation did not exceed 93.0 feet (NGVD 29), the proposed pumps would not have been turned on during this flood event. The flood receded below elevation of 80.0 feet (NGVD 29) on 12 January.

A second Yazoo Backwater flood event then began on 28 January. The Steele Bayou landside crested at 89.8 feet (NGVD 29) on 13 February and the riverside elevation peaked at 89.9 feet (NGVD 29) on 13 February. The Yazoo Backwater elevation of 89.8 feet (NGVD 29) was the annual peak elevation the Yazoo Backwater Study Area experienced during 2010. Because the Yazoo Backwater elevation did not exceed 93.0 feet (NGVD 29), the proposed pumps would not have been turned on during this flood event. The flood receded below an elevation of 80.0 feet (NGVD 29) on 01 March.

Figure 118 illustrates the Yazoo Backwater elevations from the most downstream river gage at Steele Bayou landside to the most upstream gage at Little Callao. The Yazoo Backwater peaked on 13 February and flood waters reached their maximum level resulting in the elevation of all stations equalizing soon after.

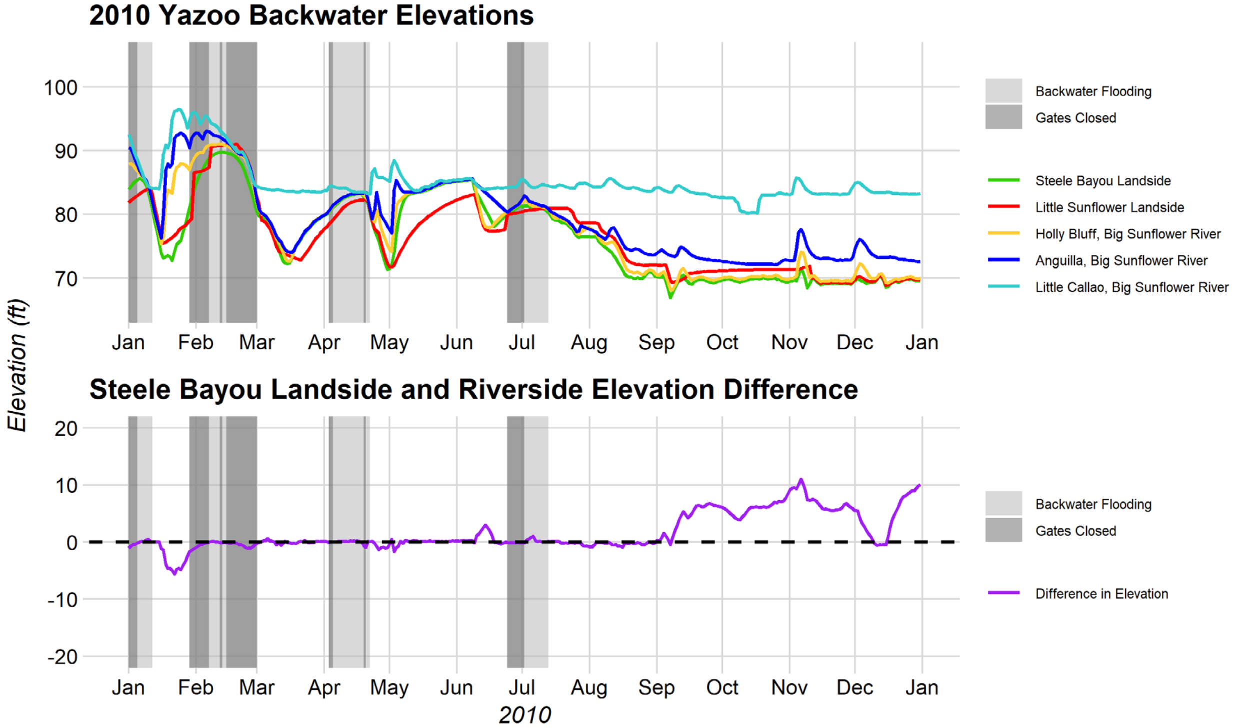


Figure 1-18. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2010 Yazoo Backwater flood.

FLOOD OF 2011

The 2011 Yazoo Backwater flood began on 10 March due to a rising Mississippi River. The Mississippi River began to swell due to two major storm systems that deposited record levels of rainfall over the Mississippi River Valley. Thus, the Mississippi River at Vicksburg peaked at 103.4 feet (NGVD 29) on 18 May. The Steele Bayou landside peaked on 29 May at 90.0 feet, (NGVD 29) and the riverside elevation peaked 106.2 feet (NGVD 29) on 19 May. The Steele Bayou landside elevation of 90.0 feet (NGVD 29) was the annual peak elevation for the Yazoo Backwater during 2011. The flood receded below an elevation of 80.0 feet (NGVD 29) on 19 July. During this flood event, the Steele Bayou gates were closed from 10 March through 20 April and 22 April through 19 July (

Figure 119). The Yazoo Backwater was flooded for a total of 132 days during 2011.

Figure 119 also illustrates the Yazoo Backwater elevations from the most downstream river gage at Steele Bayou landside to the most upstream river gage at Little Callao (Big Sunflower River). The Yazoo Backwater peaked on 29 May, and flood waters reached their maximum level resulting in all stations equalizing. Because the Yazoo Backwater elevation peaked at 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on temporarily during this flood event so that the water surface does not exceed 90.0 feet.

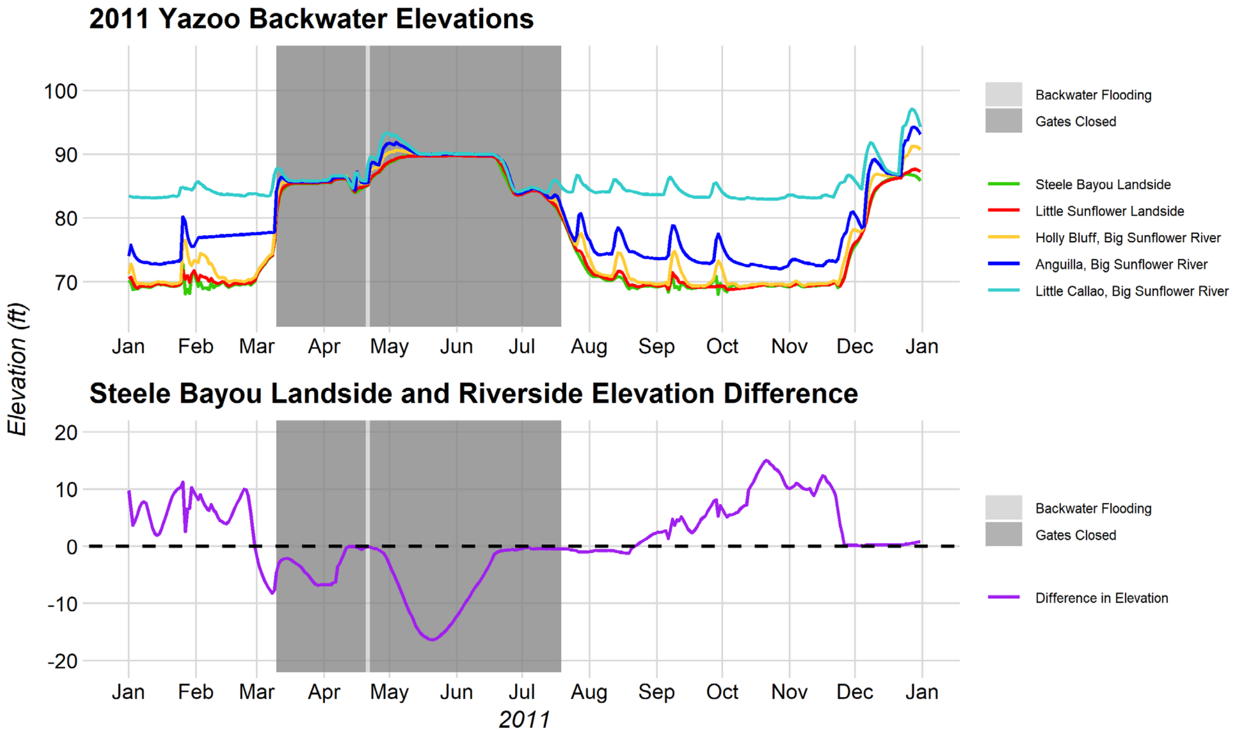


Figure 1-19. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2011 Yazoo Backwater flood.

FLOOD OF 2013

The 2013 Yazoo Backwater flood began on 29 April due to a rising Mississippi River. Heavy rainfall events resulted in the Lower Mississippi Valley receiving more than eight inches above normal monthly precipitation in January and 0.5 to three inches above normal precipitation in February. Because heavy rainfall events occurred earlier in the year, the Mississippi River at Vicksburg began to experience rises in elevations during March. Then above normal rainfall in the Upper Mississippi Valley during April and May further amplified river flow along the Mississippi River downstream. Consequently, the Mississippi River at Vicksburg peaked at 90.5 feet (NGVD 29) on 24 May. The high water on the Mississippi River prompted flood waters to enter the Yazoo Backwater Study Area. As a result, the Steele Bayou gates were closed 29 April through 28 May, 12 June through 22 June, and 15 July through 23 July (Figure 10). The Steele Bayou riverside elevation peaked during the first gate closure at 92.3 feet (NGVD 29) on 22 May, and the Steele Bayou landside peaked on 29 May at 90.9 feet (NGVD 29). The Yazoo Backwater elevation of 90.9 feet (NGVD 29) was the maximum elevation the Yazoo Backwater Study Area experienced during 2013. Flood waters within the Yazoo Backwater finally receded below an elevation of 80.0 feet (NGVD 29) on 26 July. Figure 1 illustrates the Yazoo Backwater elevations equalizing soon after the Yazoo Backwater reached a maximum in high water elevation. Overall, the Yazoo Backwater was above 80.0 feet (NGVD 29) for 79 days during the 2013 flood event. Because the Yazoo Backwater elevation exceeded 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on during this flood event.

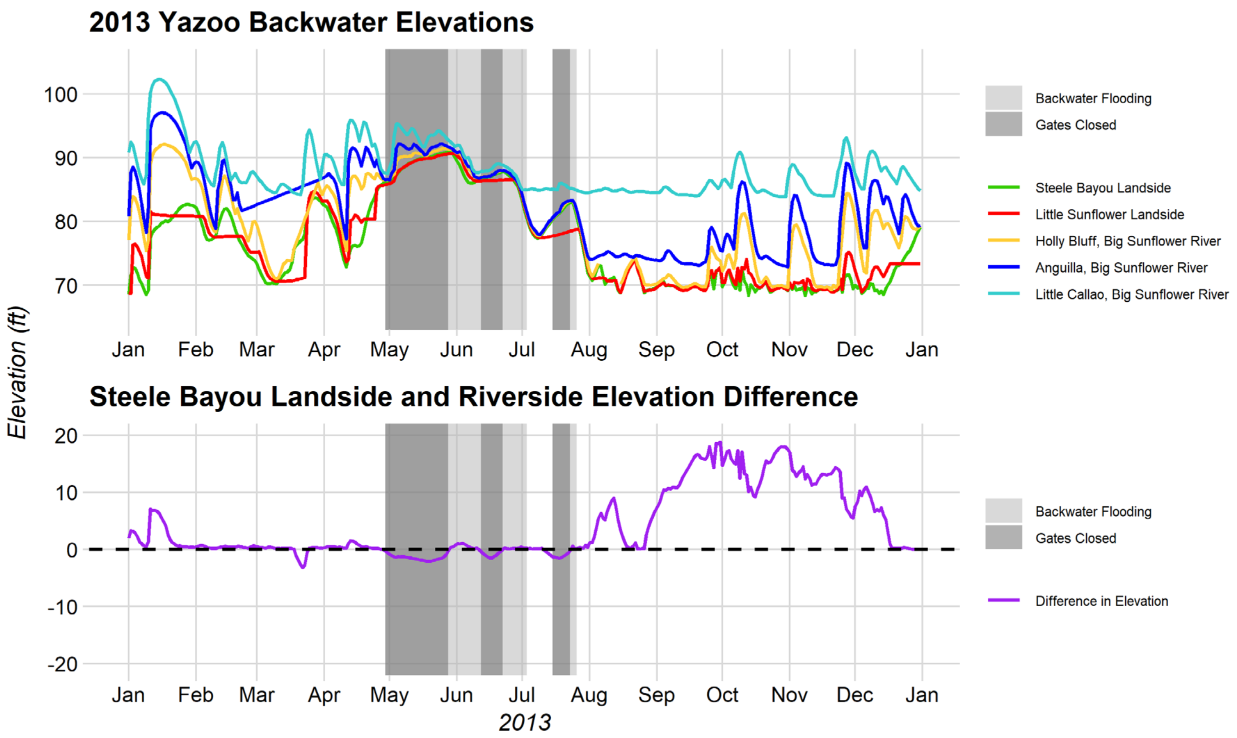


Figure 1-20. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2013 Yazoo Backwater flood.

FLOOD OF 2014

The Yazoo Backwater also experienced flood conditions during 2014. The Steele Bayou gates were closed twice, from 04 January through 07 January and from 10 May through 12 May, due to a rising Mississippi River (Figure 11). In between these backwater-driven flood events, the Yazoo Backwater Study Area experienced an annual peak elevation of 86.8 feet (NGVD 29) on 20 April due to a headwater-driven flood event. The backwater-driven flood event that occurred during May was more significant than the backwater-driven flood event that occurred during January. The Mississippi River at Vicksburg peaked on 21 April at 84.7 feet (NGVD 29) after receiving more than eight inches above monthly normal precipitation. The Steele Bayou riverside elevation peaked at 81.2 feet (NGVD 29) on 12 May, and the Steele Bayou landside elevation peaked at 81.2 feet (NGVD 29) on 13 May. The Yazoo Backwater was flooded for 23 days before the flood receded below an elevation of 80.0 feet (NGVD 29) on 02 June. Because the Yazoo Backwater elevation did not exceed 90.0 feet (NGVD 29), the proposed pumps would not have been turned on during this flood event.

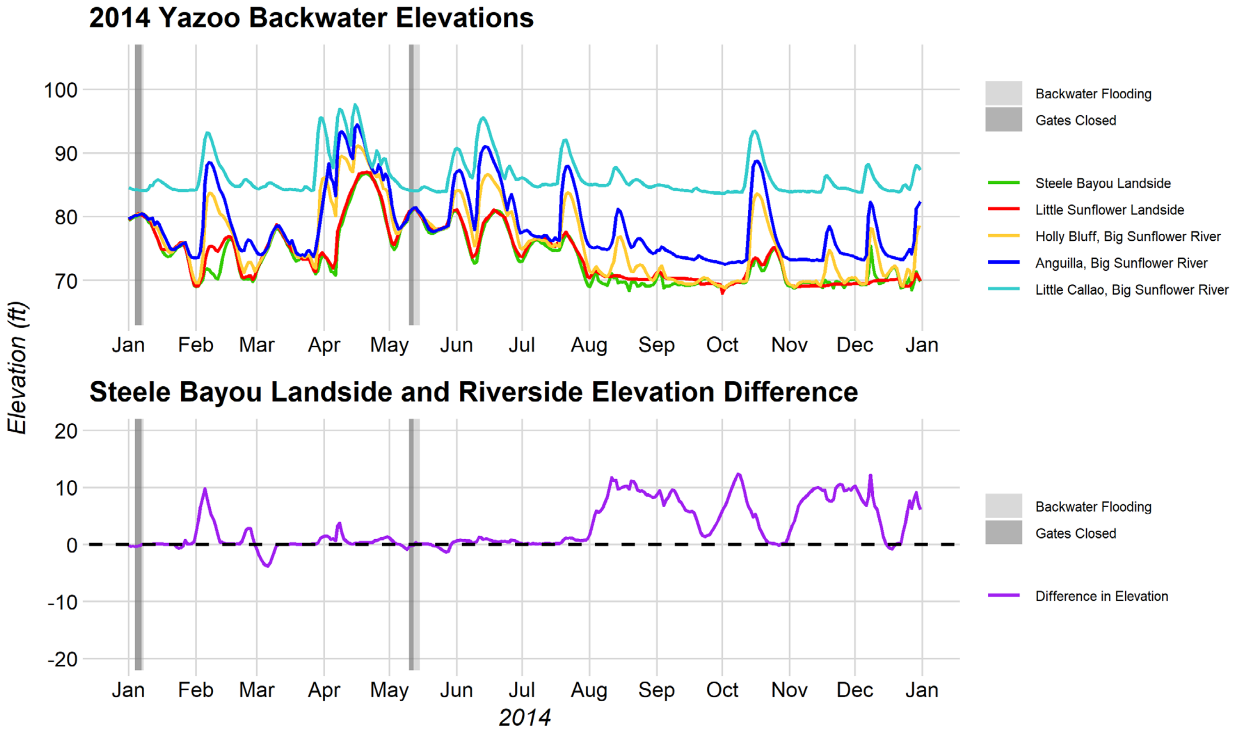


Figure 1-21. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2014 Yazoo Backwater flood.

FLOOD OF 2015

During 2015, the Yazoo Backwater began to experience increases in elevations due to headwater flooding at the beginning of March. Then, the Yazoo Backwater began to experience backwater-driven flooding on 22 March due to a rising Mississippi River. The Upper Mississippi Valley received above normal precipitation for March, April, June and July, which consequently increased elevations on the Mississippi River downstream. The Mississippi River at Vicksburg began to experience dramatic increases in elevations in March and remained elevated before cresting at 92.2 feet (NGVD 29) on 29 July. The Steele Bayou landside peaked on 04 April at 90.6 feet (NGVD 29), which was the maximum elevation for 2015. Because the Yazoo Backwater elevation exceeded 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on during this flood event. The Steele Bayou riverside elevation peaked at 94.1 feet (NGVD 29) on 27 July. Because the Mississippi River at Vicksburg crested later than the Yazoo Backwater, the Yazoo Backwater was unable to drain and experienced prolonged flooding. In addition, the Steele Bayou gates were closed five times, with 23 June through 07 August being the longest, consecutive closure (

Figure 12). Flood conditions existed within the Yazoo Backwater for 145 days before high water receded below an elevation of 80.0 feet (NGVD 29) on 13 August.

Figure 12 also illustrates the elevations at all Yazoo Backwater river gages equalizing as flood waters peaked.

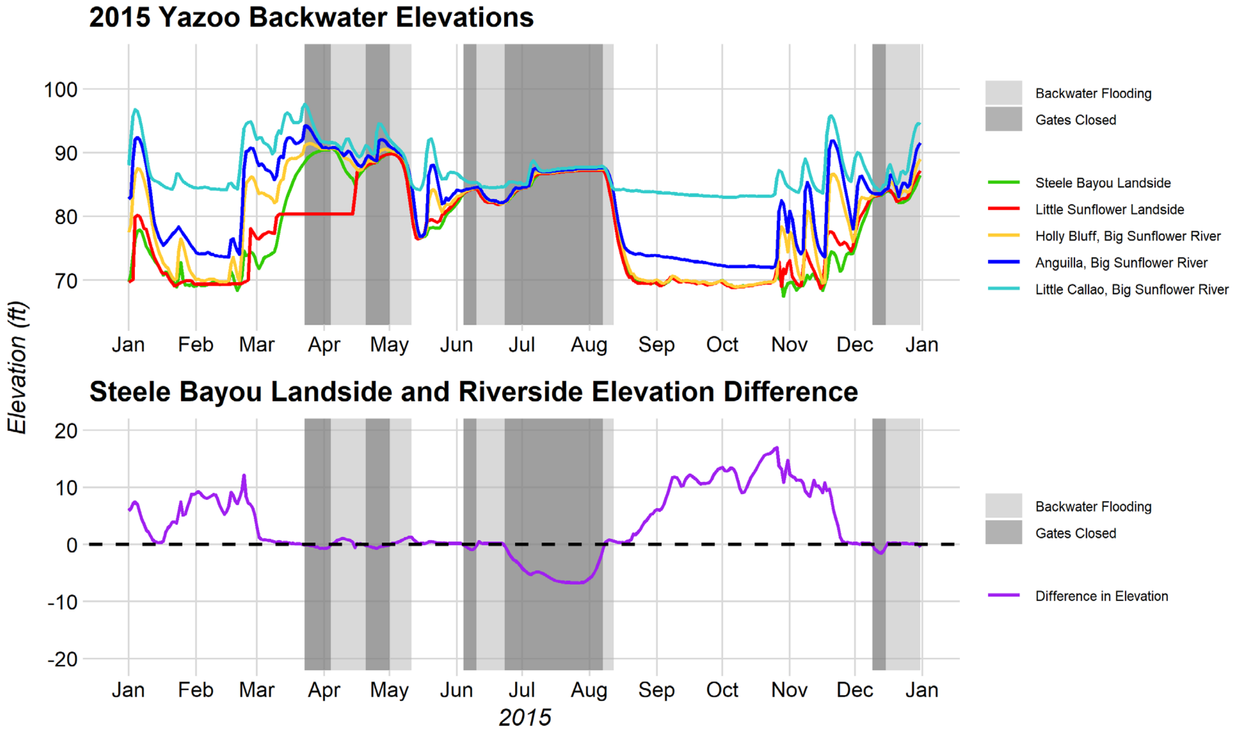


Figure 1-22. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2015 Yazoo Backwater flood.

FLOOD OF 2016

The 2016 Yazoo Backwater flood began on 05 December 2015 due to a rising Mississippi River. After an abnormally wet fall and significant rainfall events in December 2015, the Mississippi River at Vicksburg was roughly 86.3 feet (NGVD 29) on 01 January before increasing 10 feet to 96.4 feet (NGVD 29) on 16 January. Similarly, the Steele Bayou riverside also crested on 16 January at 99.3 feet (NGVD 29). The Steele Bayou landside did experience a minor crest at 91.4 feet (NGVD 29) on 29 January. However, the major crest occurred on 21 March at 92.0 feet (NGVD 29) due to a secondary rise in elevation of the Steele Bayou riverside and the Mississippi River at Vicksburg. This crest was the highest elevation the Yazoo Backwater experienced during 2016 and was associated with the backwater flood conditions but was further amplified from significant headwater-driven flooding, which occurred concurrent to the backwater-driven flooding. Because the Yazoo Backwater elevation exceeded 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on during this flood event. Flood waters receded below elevation of 80.0 feet (NGVD 29) on 09 June, 202 days after the start of flood conditions within the Yazoo Backwater. During this flood event, the Steele Bayou gates were closed five times, with 01 January through 28 January being the longest, consecutive closure (

Figure 13).

Figure 1 also illustrates the Yazoo Backwater elevations equalizing as flood waters reached their maximum level.

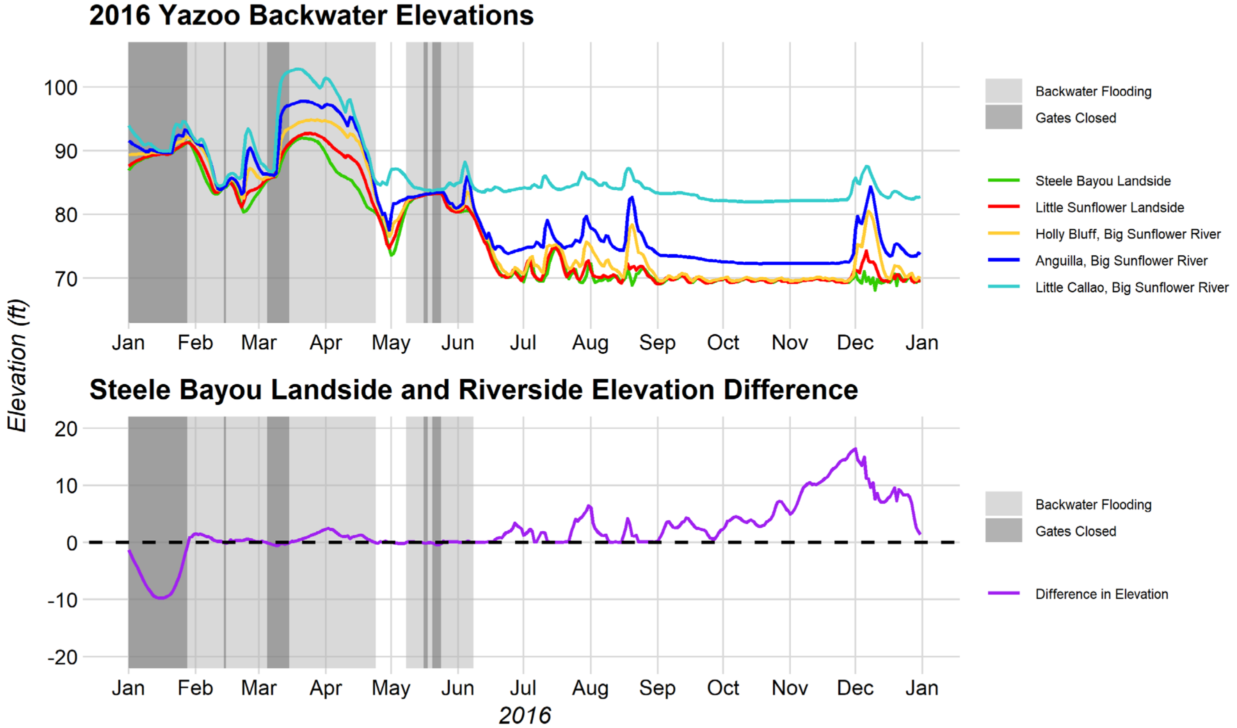


Figure 1-23. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2016 Yazoo Backwater flood.

FLOOD OF 2017

The 2017 Yazoo Backwater flood began on 02 May due to a rising Mississippi River. The Mid-Mississippi Valley received more than eight inches above normal monthly precipitation during April 2017. As a result of the abundant rainfall upstream, the

Mississippi River at Vicksburg peaked on 26 May at 94.6 feet (NGVD 29). The Steele Bayou riverside elevation crested at 97.1 feet (NGVD 29) on 27 May, and the Steele Bayou landside elevation peaked on 16 June at 88.5 feet (NGVD 29), which was the maximum annual elevation for the Yazoo Backwater during 2017. Because the Yazoo Backwater elevation exceeded 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on during this flood event. The Yazoo Backwater experienced flood conditions for 53 days, before the high-water elevation fell below 80.0 feet (NGVD 29) on 23 June. In addition, the Steele Bayou gates were closed from 02 May through 15 June, during this event (Figure 1-44). Figure 1-44 illustrates the Yazoo Backwater elevations from the most downstream station at Steele Bayou landside to the most upstream station at Little Callao (Big Sunflower River). The Steele Bayou landside structure crested on 16 June when the Yazoo Backwater reached a maximum in high water elevation. Around this time, more upstream river gages were also experiencing rises in elevation and began to equalize with the downstream river gages.

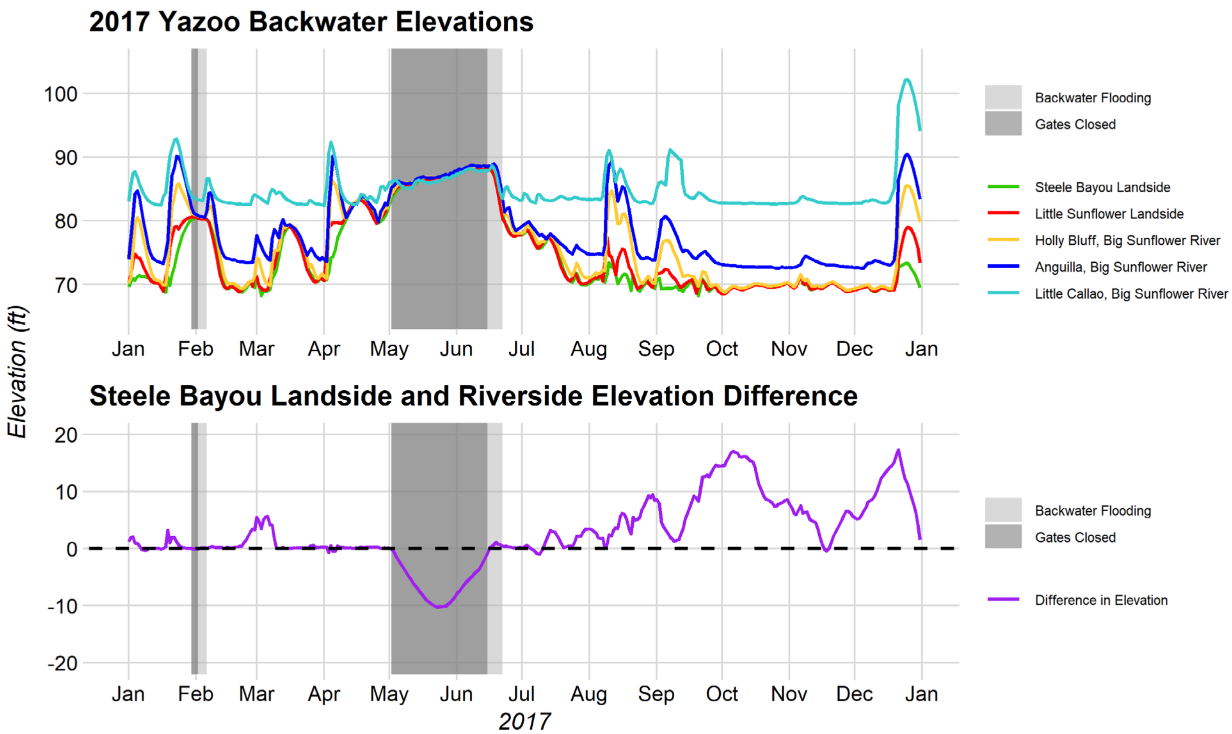


Figure 1-44. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2017 Yazoo Backwater flood.

FLOOD OF 2018

During 2018, the Yazoo Basin received significant rainfall and headwater flooding began during February as the Lower Mississippi Valley received more than eight inches above normal monthly precipitation during February. The Steele Bayou landside reached a maximum annual elevation of 95.1 feet (NGVD 29) on 25 March due to the headwater-driven flooding. The above normal rainfall also resulted in elevations on the Mississippi River at Vicksburg increasing during February, which initiated backwater-driven flooding. As a result of the backwater-driven flooding, the gates at the Steele Bayou control structure were closed 01 March through 25 March (

Figure 1-25). The Mississippi River at Vicksburg peaked at 96.1 feet (NGVD 29) on 15 March. As a result, the Steele Bayou riverside elevation peaked at 99.0 feet (NGVD 29) on 16 March, and the Steele Bayou landside elevation peaked at 95.1 feet (NGVD 29) on 25 March. Because the Steele Bayou elevation exceeded both 93.0 feet (NGVD 29) during non-crop season and 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on for a long period of time during this backwater-driven flood event. The Yazoo Backwater was above an elevation of 80.0 feet (NGVD 29) for a total of 81 days during 2018 before receding on 20 May. In addition, two minor backwater events occurred during November and December, forcing the Steele Bayou gates closed for four days (

Figure 1-25).

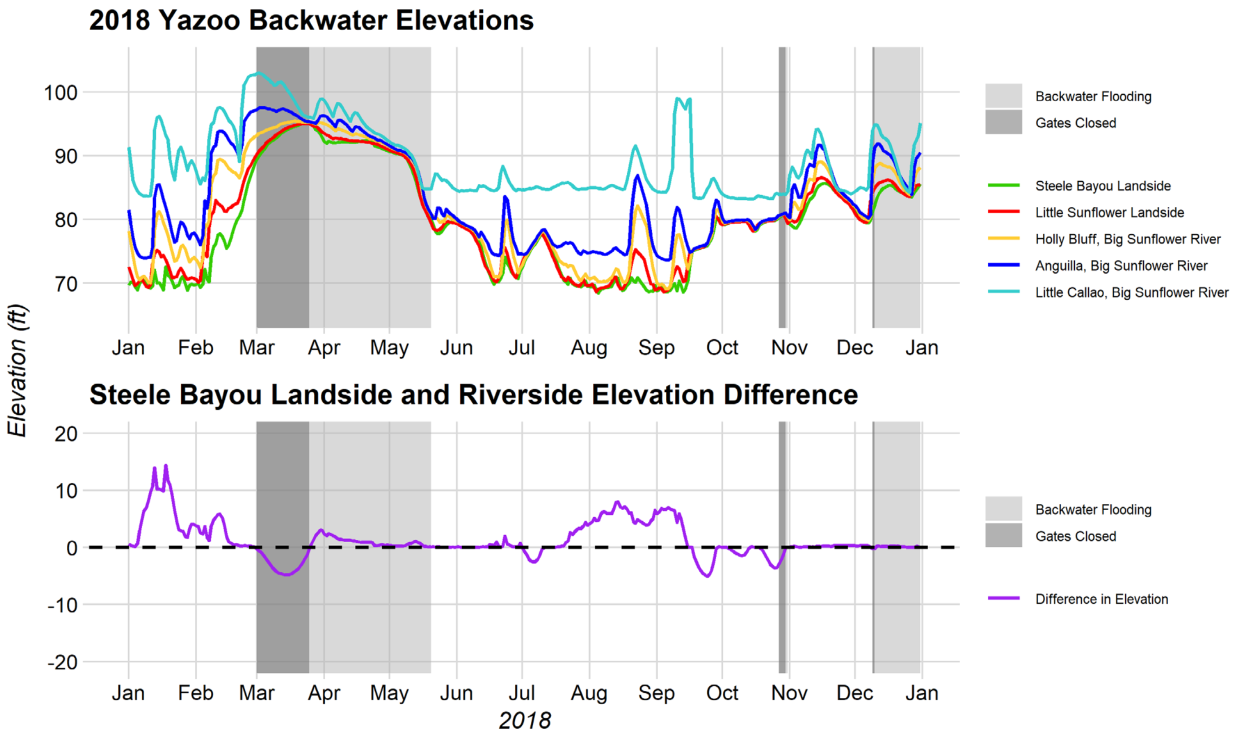


Figure 1-25. The Yazoo Backwater elevations and the Steele Bayou landside and

riverside elevation differences for the 2018 Yazoo Backwater flood.

FLOOD OF 2019

The 2019 Yazoo Backwater flood began in the fall of 2018 due to an abnormally wet season. Frequent rain events from January through July, resulted in persistent, increased elevations on the Mississippi River. Additionally, an extended closure of the Steele Bayou gates further amplified flood conditions. Steele Bayou was closed five times during 2019, with 15 February through 01 April being the longest, consecutive closure (Figure 1-26). In addition, the steady spring rainfalls occurred subsequent to an abnormally wet winter season, which further amplified the above normal stream flow during the spring months. Flood conditions within the Yazoo Backwater began 09 January, when the Steele Bayou riverside exceeded the Steele Bayou landside, and the Steele Bayou landside was above an elevation of 80.0 feet (NGVD 29). The last week in February, multiple storm systems propagated across the Lower Mississippi Valley and deposited more than 10 inches of rainfall across the region. As a result, the Mississippi River at Vicksburg increased from an elevation of 90.3 feet (NGVD 29) on 20 February to a peak elevation of 97.6 feet (NGVD 29) on 13 March. The increased elevations on the Mississippi River resulted in water backing up to the Steele Bayou Control Structure. Thus, the Steele Bayou riverside peaked on 12 March at 100.0 feet (NGVD 29). The Steele Bayou landside experienced a minor crest on 31 March at 97.2 feet (NGVD 29). After the significant rainfall in the last week of February, elevations on the Mississippi River at Vicksburg and the Steele Bayou riverside started to fall. However, the Steele Bayou flood control structure gates remained closed throughout March, preventing the Yazoo Backwater to drain.

On 01 April, the control structure was opened, allowing the Yazoo Backwater to drain slightly. However, multiple heavy rainfall events throughout May produced increases in elevation on the Mississippi River at Vicksburg and the Steele Bayou riverside, forcing the Steele Bayou gates closed. This second closure resulted in the Steele Bayou landside experiencing its primary crest at 98.2 feet (NGVD 29) on 23 May. This crest was the maximum elevation the Yazoo Backwater obtained during 2019. After the crest within the Yazoo Backwater, the Steele Bayou gates were opened, but were closed on 07 June to prevent backflow into the Yazoo Backwater. The closure of the control structure kept the Steele Bayou landside at an elevation around 97.0 feet (NGVD 29), for May, June, and most of July. It was not until the third week in July when the Yazoo Backwater began to experience significant declines in elevation.

From 1973 through 2018, the Steele Bayou landside elevation exceeded 95.0 feet (NGVD 29) for 124 days, with the longest duration above 95.0 feet (NGVD 29) being 68 days from 09 April 1973 through 15 June 1973. During 2019, the Yazoo Backwater was above an elevation of 80.0 feet (NGVD 29) from 09 January to 16 August, or 219 days, and was above 95.0 feet (NGVD 29) for 145 days from 05 March through 27 July. The duration of high water, above 95.0 feet (NGVD 29), during 2019 was more than twice the longest duration of high water that occurred in 1973. Because the Steele Bayou elevation exceeded both 93.0 feet (NGVD 29) during non-crop season and 90.0 feet (NGVD 29) during crop season, the proposed pumps would have been turned on for a long period of time during this backwater-driven flood event. Figure 1-26 illustrates the Yazoo Backwater elevations from the most downstream station at Steele Bayou landside to the most upstream station at Little Callao (Big Sunflower River). In contrast to other major flood events, all of the Yazoo Backwater gages converged in the 2019 flood and remained equalized for the majority of the flood event due to the extreme, prolonged high-water conditions.

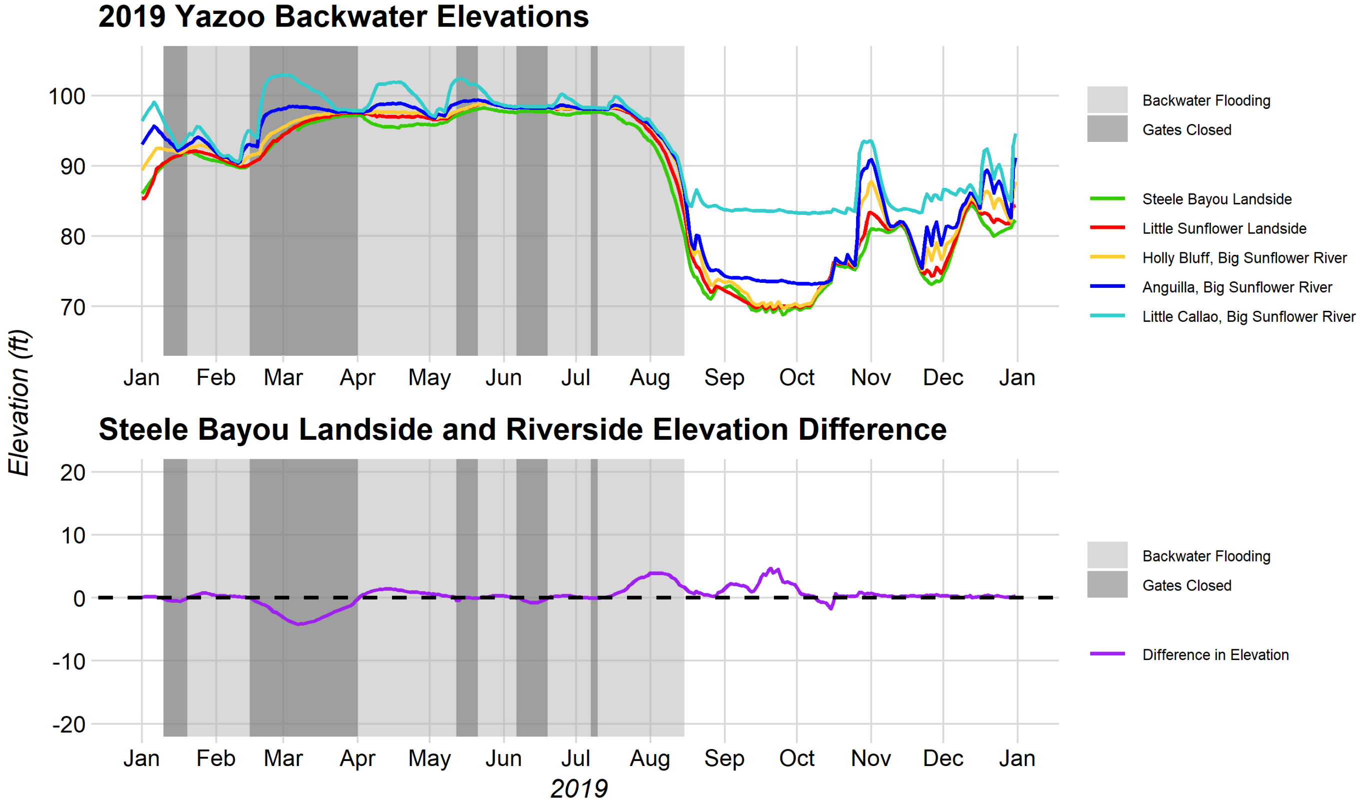


Figure 1-26. The Yazoo Backwater elevations and the Steele Bayou landside and riverside elevation differences for the 2019 Yazoo Backwater flood.

FLOOD CONTROL

PROJECT FEATURES

Completed flood control projects in the Yazoo Backwater Area, or the Yazoo Backwater Study Area, are shown in

Figure 1-27. These features include the following:

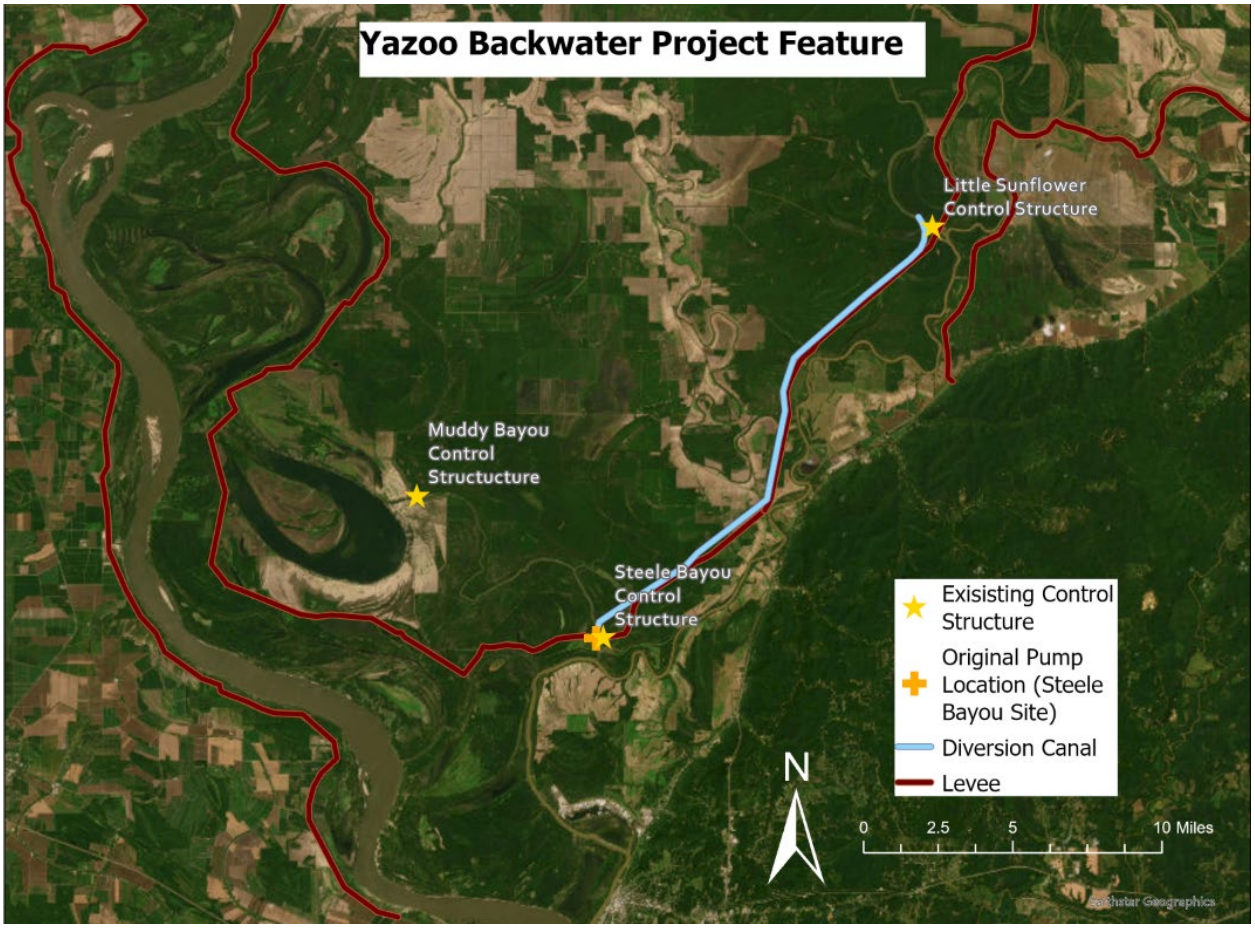


Figure 1-27. The flood control projects in the Yazoo Backwater Area.

Yazoo Backwater Levee connects to the end of the east bank Mississippi River levee just north of Vicksburg and extends north eastward to the downstream end of the west bank Will M. Whittington Lower Auxiliary Channel Levee. The Yazoo Backwater levee has a net levee grade of elevation 107.0 feet (NGVD 29). The Yazoo Backwater levee is considered an overtopping section to the mainline levee of the Mississippi River, except for 1,000 feet on each side of the Steele Bayou and Little Sunflower structures. These 30.5 miles of overtopping levee ensure that in case of the MR&T Project Design Flood (PDF), the storage in the Yazoo Backwater Study Area will be utilized to reduce the risk of overtopping the main stem levee.

Steele Bayou structure is located 3,200 feet upstream of the confluence of Steele Bayou and the Yazoo River. The structure consists of four vertical lift gates 30 by 22.5 feet, concrete-paved approach channel, and a stilling basin. The Steele Bayou ponding area is connected by a 200-foot bottom width channel to the Little Sunflower ponding area. Construction of the Steele Bayou structure was begun on 22 July 1965 and completed 17 January 1969.

Two connecting channels play a vital part in the operation of the current plan. One is a 200-foot bottom width channel between the Big and Little Sunflower Rivers. The Little Sunflower River is enlarged between this connecting channel and the Little Sunflower Structure. The other connecting channel is a 200-foot bottom width channel between the Little Sunflower River and Steele Bayou, which also intercepts Deer Creek flow. The purpose of the channel connecting the Sunflower ponding area with the lower and larger Steele Bayou ponding area is to make the most efficient and economical use of the pumping capacity.

Little Sunflower structure is located opposite Yazoo River Mile 32.6, approximately 21 miles northeast of Vicksburg. The structure consists of two vertical lift gates 25.0 by 22.5 feet, concrete-paved approach channel, and a stilling basin. Construction of the structure was completed 28 July 1975.

Muddy Bayou control structure is located 13 miles northwest of Vicksburg in the Yazoo Study Area on Muddy Bayou a tributary of Steele Bayou approximately 1,300 feet from its mouth at RM 11.4 of Steele Bayou. The control structure consists of two 20 by 12-foot vertical lift gates the Muddy Bayou Channel (a cutoff dam adjacent to the structure) and an access road from Mississippi Highway 465. The control structure was completed 18 August 1977, controls all water flowing in or out of Eagle Lake through Muddy Bayou, provides flood protection to the Eagle Lake area during periods of moderately high stages (elevation 95.0 feet [NGVD 29]) on Steele Bayou, and provides the means of regulating pool stages in Eagle Lake.

EXISTING PROJECT OPERATION

The primary purpose of the Yazoo Backwater Project is to provide flood protection from the Mississippi and Yazoo Rivers to areas in the Lower Mississippi Delta. During periods of high-water stages on the Mississippi and Yazoo Rivers, the Steele Bayou and Little Sunflower Structures are closed, necessitating storage of interior drainage within the ponding areas. The interior areas will pond up until the riverside tailwater subsides and the interior water can be released through the floodgates.

The Steele Bayou Structure is the principal structure for the Yazoo Backwater Project. Any time the stage on the landside of the Steele Bayou and Little Sunflower Structures is higher than the riverside and above 70 feet the gates are opened. With a rising river, the current water control manual allows the interior ponding areas are allowed to rise to an elevation of 75.0 feet. The structures are closed when the river elevation is higher than the interior ponding levels. Currently interior ponding areas are managed in the 68.5 feet to 70.0 feet range. The backwater project is not complete without a pump in place and having interior ponding to 75.0 without a pump creates an almost bank full scenario in the lower Yazoo Backwater as most top banks in the lower portion of the backwater are in the 78.0-80.0 feet range. Without a pump to evacuate ponded waters, letting water in the interior to a 75.0 feet elevation would lead to sooner flooding of homes and lands in the lower backwater. With the proposed pump in place, the interior ponding areas will be allowed to rise to 75.0 feet from the opening of Steele Bayou Structure but not higher because Eagle Lake operations call for, at certain times of the year, for the Muddy Bayou Control Structure at Eagle Lake to be opened to draw down the elevations of Eagle Lake from 76.0 feet to 75.0 feet in order to meet guidelines and purposes for Wildlife, Fisheries, and Parks. Should the Yazoo Backwater Area be higher than 75.0 feet then this operation at Muddy Bayou Control Structure could not be made due to higher stages in the river outside of Eagle Lake.

The interior ponding areas are primarily agricultural and forested lands. Several developed areas exist in the Yazoo Backwater Study Area. Although the interior area is protected from the high stages of the Mississippi and Yazoo Rivers, it is subject to flooding resulting from inflow into the ponding areas from Steele Bayou, Deer Creek, Little Sunflower River, and Big Sunflower River.

INTERIOR HYDROLOGIC AND HYDRAULIC ANALYSES

HYDROLOGIC MODEL SETUP

DATA COMPILATION

This section describes the data collected and reviewed for this modeling effort, which includes geographic and climatic information, field observations, and previous reports for the Yazoo Backwater Study Area.

Streamflow Data

The two main sources of stream data used within this modeling effort were from the USGS National Water Information System (NWIS)[1] and the Mississippi Valley Division (MVD) Corps Water Management System (CWMS) database[2]. All data was downloaded as daily average discharges, and this daily data was used to calibrate the HEC-HMS model. The stream gages, identified as inputs or used to calibrate the HEC-HMS model, are listed in

Table 1-1.

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[1] https://waterdata.usgs.gov/nwis

[2] https://www.mvk-wc.usace.army.mil/watercontrol.html

Table 1-1. Streamflow Gages

ID	Gage Description	Type	Latitude	Longitude
Anguilla*	Sunflower @ Anguilla	Flow***	32° 58’ 19” N	90° 46’ 40” W
Doddsville*	Quiver @ Doddsville	Flow***	33° 38' 25" N	90° 24' 5" W
Grace*	Steele Bayou @ Grace	Flow***	32° 55' 3" N	90° 57' 45" W
Leland**	Bogue Phalia @ Leland	Flow	33° 23' 48" N	90° 50' 51" W
Sunflower**	Sunflower @ Sunflower	Flow	33° 32' 50" N	90° 32' 35" W
Swan Lake**	Tallahatchie @ Swan Lake	Flow	33° 51' 35" N	90° 16' 35" W

*These gages were used as computation points for calibration

**These gages were model inputs

***These flows are based on rating curves at the gage locations

Precipitation Data

Precipitation data was collected from gaging stations and gridded precipitation data files. The gaging stations are owned and operated by the National Centers for Environmental Information (NCEI) National Climatic Data Center (NCDC) for the National Oceanic and Atmospheric Administration (NOAA)[3]. The precipitation gages were then used as input for the HEC’s GageInterp program. GageInterp can be used to estimate spatially distributed values of precipitation, temperature, or other parameters. The program reads values from a HEC-DSS file and interpolates between and around those points, at the center of cells in a grid. The program then writes the resulting grids to new records in one or more DSS files. In order for the program to run, the user specifies the input gages as locations given by longitude, latitude, optional elevation, and DSS path names from which the values at the gages will be read, and also specifies the type and extent of the grid to be used. The user can select an interpolation method from several options, and interpolated values may be adjusted by specifying a bias grid, or by using a lapse computation on temperature measurements, based on a user-supplied elevation grid (USACE 2016). For the precipitation data, a Standard Hydrologic Grid (SHG) with a 2,000-meter cell size was chosen. The Inverse distance squared (ID2W) interpolation method was utilized along with a 100,000-meter range. The range sets a maximum distance between the cell center and gage contributing to cell precipitation estimate.

Due to the given NCDC precipitation gages having data until the middle of 2013, a Stage IV precipitation grid was used from January 2013 through December 2019. This

[3] https://www.ncdc.noaa.gov/cdo-web/

Stage IV grid is produced by the University Corporation for Atmospheric Research (UCAR)[4].

Table 1-2 identifies the precipitation stations and

Figure 1-28 locates the precipitation stations within the Yazoo River watershed.

Table 1-2. Precipitation Gages

State/County	Gage Description	Latitude	Longitude
MS Desoto	Arkabutla Dam*	34° 45’ 0” N	90° 8’ 0” W
MS Marshall	Byhalia*	34° 52’ 0” N	89° 41’ 0” W
MS Coahoma	Clarksdale	34° 12’ 0” N	90° 34’ 0” W
MS Bolivar	Cleveland	33° 51’ 46” N	90° 6’ 12” W
AR Desha	Dumas*	33° 53’ 19” N	91° 31’ 54” W
LA West Carroll	Epps*	32° 36’ 14” N	91° 28’ 40” W
MS Leflore	Greenwood*	33° 31’ 0” N	90° 10’ 0” W
MS Carroll	Greenwood AP*	33° 30’ 0” N	90° 5’ 0” W
MS Grenada	Grenada Dam*	33° 48’ 0” N	89° 46’ 0” W
MS Rankin	Jackson Int. AP*	32° 18’ 52” N	90° 4’ 43” W
MS Holmes	Lexington*	33° 7’ 0” N	90° 3’ 0” W
AR Drew	Monticello*	33° 38’ 3” N	91° 45’ 17” W
MS Marshall	Mount Pleasant*	34° 54’ 20” N	89° 33’ 43” W
MS Lafayette	Oxford*	34° 23’ 0” N	89° 32’ 0” W
AR Jefferson	Pine Bluff*	34° 15’ 0” N	92° 0’ 0” W
MS Sharkey	Rolling Fork	32° 55’ 0” N	90° 52’ 0” W
MS Panola	Sardis Dam*	34° 24’ 0” N	89° 47’ 25” W
MS Washington	Stoneville	33° 25’ 0” N	90° 55’ 0” W
AR Arkansas	Stuttgart*	34° 29’ 0” N	91° 32’ 0” W
LA Madison	Tallulah*	32° 20’ 53” N	91° 1’ 48” W
MS Warren	Vicksburg*	32° 23’ 0” N	90° 52’ 0” W

[4] https://data.eol.ucar.edu/dataset/21.093

MS Yazoo	Yazoo City*	32° 51' 0" N	90° 26' 0" W

*These gages are outside the Yazoo Study Area boundary but are used in the precipitation grid

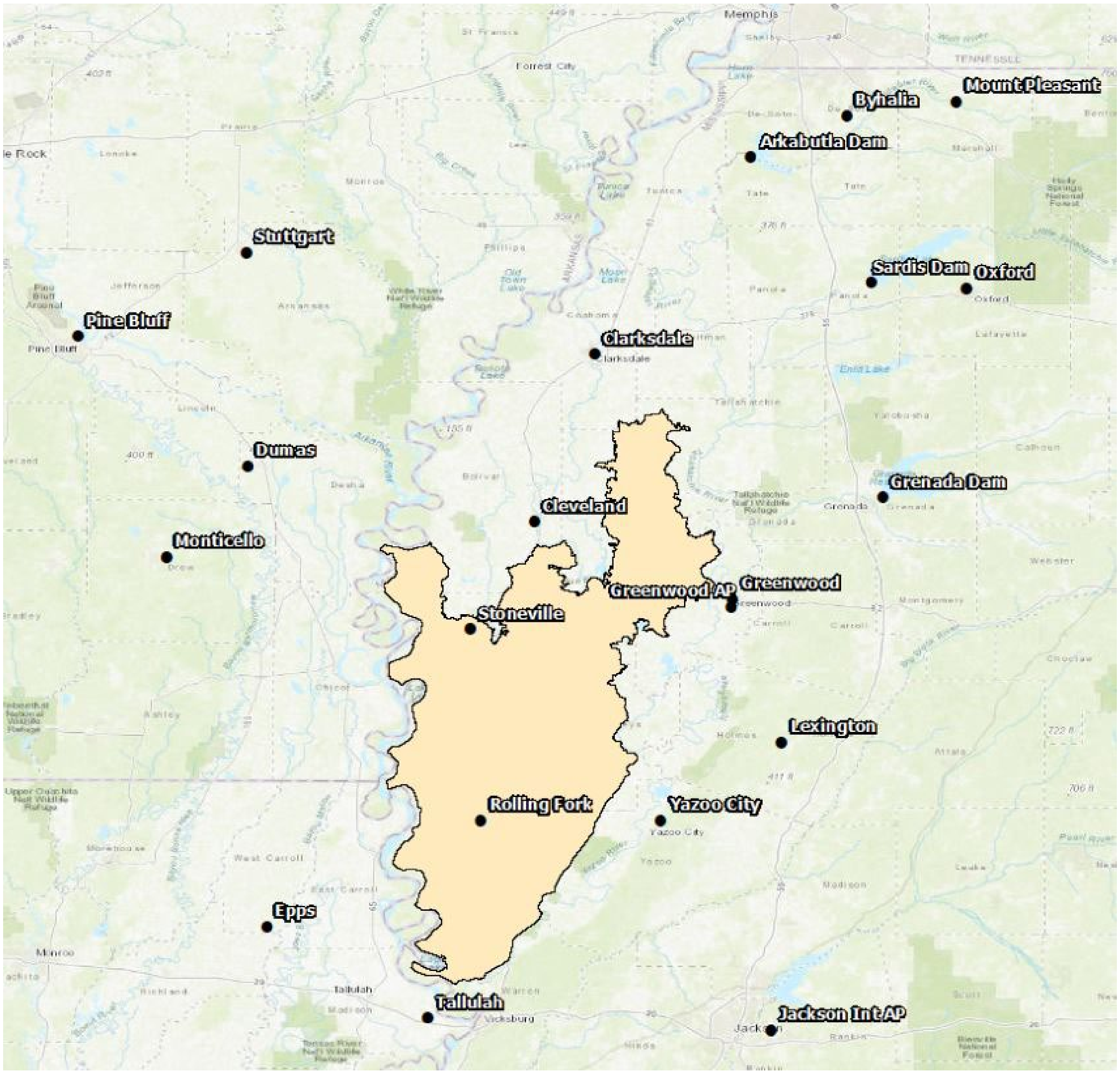


Figure 1-28. The precipitation gages within the Yazoo River watershed.

Temperature Data

Temperature data that was used within this modeling effort was also generated from the HEC GageInterp program. The 43-year period-of-record was used to retrieve data from the NOAA Climate Data Online (CDO)[5]. The maximum and minimum temperature were used to calculate the average temperature, and then the average temperature HEC-DSS file was used in GageInterp to generate a spatially interpolated grid set. Within the GageInpterp program, the temperature grid was a SHG with a 2,000-meter cell size. The inverse distance (IDW) interpolation method was chosen with an unlimited range of temperature gage influence.

SOFTWARE AND DOCUMENTATION

Table 1-3 provides a summary of the computer programs and versions used in development of the HEC-HMS model.

Table 1-3. Computer Programs Utilized

Program	Version	Capability	Developer
ArcGIS	10.4.1	Geographical Information System	ESRI
HEC-DSSVue	3.0	Plot, tabulate, edit, and manipulate data in HEC-DSS files	HEC
HEC-HMS	4.4.1	Rainfall-runoff simulation	HEC
HEC GageInterp	1.6	Create a sequence of HEC-DSS grids from time-series measurements	HEC

HEC-HMS MODEL DEVELOPMENT

To develop a continuous simulation model that computed volumetric flow rates necessary for use in the Yazoo Backwater Study Area over a 43-year period, a hydrologic model was needed. HEC-HMS 4.4.1 was the hydrologic model used to develop the runoff. The precipitation and temperature data were utilized in the HEC-HMS model. The following sections detail model-specific processes that were used to create and calibrate the HEC-HMS model.

Status of the Vicksburg District's Existing HEC-HMS Model(s)

The USACE Vicksburg District had a completed HEC-HMS model for the Yazoo River watershed, which includes the Yazoo Backwater Study Area. This model was used as a basis for the new Yazoo Backwater Study Area HEC-HMS model. The original Yazoo River watershed covered a total area of 13,480 square miles and consisted of 110

[5] https://www.ncdc.noaa.gov/cdo-web/

subbasins. The model domain was reduced to only 2,687 square miles and thirteen subbasins for this study. The Yazoo River Corps Water Management System (CWMS) and Yazoo Backwater Study Area are shown in

Figure 1-29. The subbasins for the Yazoo River CWMS model are shown in orange and the subbasins for the Yazoo Backwater Study Area are shown in light green.

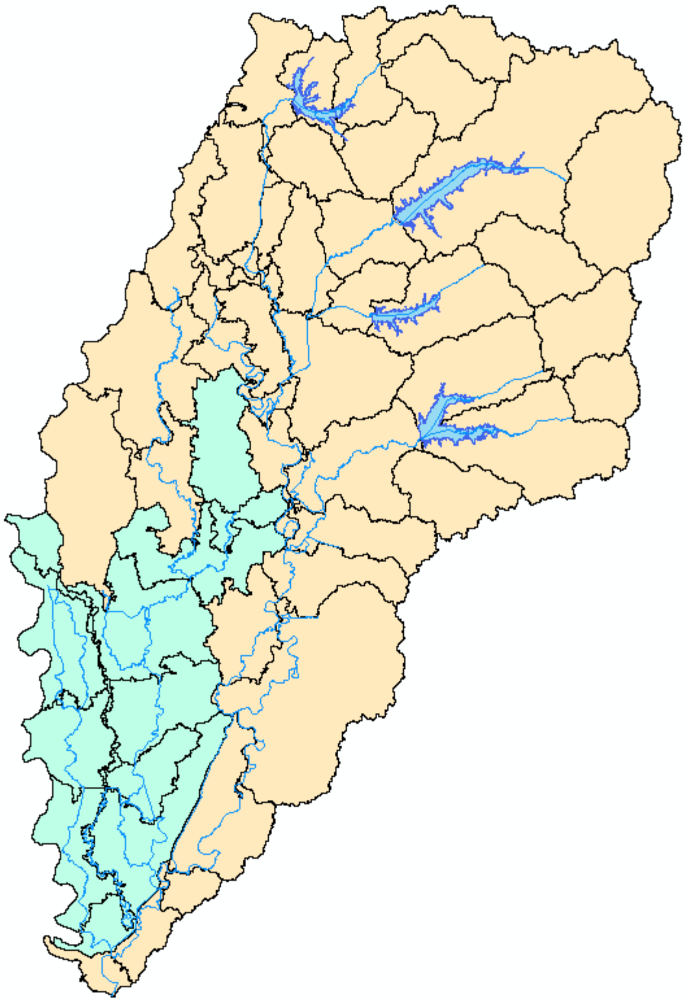


Figure 1-29. Yazoo River CWMS and Yazoo Study Area Comparison

Yazoo Backwater Study Area

A list of subbasins used in the Yazoo Backwater Study Area modeling and their sizes can be found in

Table 1-4.

Table 1-4. Subbasin Summary

Subbasin Name	Area (sq. mi.)
SF Doddsville Loc	258
SF QuiverSunflower	81
SF BigSunatQuiver	302
SF LittleCalleo	379
SF Anguilla Loc	268
DB DeerCreekN	113
SF HollyBluff	150
SF LittleSunflower	331
DB DeerCreekS	28
SB Longwood	259
SB SteeleGrace	224
SB MuddyBayou	212
SB SteeleMouth	82

Precipitation

A gridded precipitation file was initially used to estimate rainfall in the HEC-HMS model. Once the initial 43-year simulation was run, the output HEC-DSS file included hourly precipitation that was associated with each subbasin. All data used for the study including precipitation data, temperature data, flow data, etc. covered the 43-year period of record for the study. The 43-year period of record spans from 1978, when the Yazoo Backwater Levee was complete, to 2020. In order to cut down on run times, the hourly precipitation from the gridded precipitation run was converted to specified hyetographs at each subbasin. These hyetographs were linked to their respective precipitation gages from the output of the gridded precipitation run.

Evapotranspiration

A modified, gridded version of the Hamon method was used initially to estimate potential evapotranspiration (ET) losses using the previously mentioned daily average temperature grid set and a coefficient (Harwell 2012). The output from the gridded Hamon method consisted of HEC-DSS files that had the average temperature associated with each subbasin. Later, the Hamon method was utilized by linking temperature gages for each subbasin to the HEC-DSS file that had the gridded Hamon output. The Hamon method was used to simulate evapotranspiration (ET) losses throughout the model. Within the Hamon method, ET losses are directly proportional to the daily average temperature and related to the location of interest and time of year (Hamon 1961). The Hamon coefficient for the Yazoo Backwater Study Area was set as the default of 0.0065.

Infiltration

Infiltration computations were executed using the Deficit and Constant Loss method. Initial estimates of initial deficit, maximum deficit, and constant loss rate were based upon surficial soil texture estimates done in the Yazoo River CWMS model. These textures were acquired from the NRCS gSSURGO soil coverage. These values were later set to a similar range for consistency across all subbasins for the 43-year period.

Unit Hydrograph Transform

The modified Clark (ModClark) unit hydrograph transform was used to route excess precipitation to the subbasin outlet within each subbasin. This linear, quasi-distributed transform method uses a set of grid cells to represent travel times within a subbasin to the outlet point. As such, it explicitly accounts for variations in travel time from all areas within a subbasin through the use of a time travel index for each grid cell. As previously stated, these grid cells were laid out using the Standard Hydrologic Grid (SHG) system with a 2,000 meter by 2,000-meter resolution and then placed over the modeling domain using tools available through HEC.

The Yazoo Backwater Study Area HEC-HMS model stayed fairly consistent with the original estimates from the Yazoo River CWMS model. These initial estimates were conducted using the TR55 method in HEC-GeoHMS and the Travel Time Tool (TTT) in ArcGIS.

Much like in the Yazoo River CWMS model, the time of concentration (Tc) and storage coefficient (R) values were adjusted as necessary to calibrate at stream gages.

Baseflow

The Linear Reservoir method was used to transform water which was infiltrated into interflow and baseflow and add these components to any direct runoff generated within each subbasin. For this modeling effort, the storage and movement of infiltrated water was simulated using two layers. The layers are considered “linear” due to the fact that the outflow at each time step of the simulation is a linear function of the average storage during the time step. Due to the use of the Deficit and Constant Loss method, the volume of infiltrated water was evenly divided between the two layers. The resultant outflow from both layers was combined to compute the total baseflow for each subbasin. Finally, within this method, only infiltrated water is available, which allows for mass to be conserved. This was essential due to the long simulation windows used during model calibration.

The two baseflow layers were conceptualized to differentiate between short and long baseflow responses; the upper layer was parameterized to respond faster than the lower layer. Initial parameter estimates of a storage coefficient for both layers were based upon the previously mentioned unit hydrograph transform parameters. Initially, the groundwater one storage coefficient was set to two times the subbasin ModClark storage coefficient and the groundwater two coefficient was set to one hundred times the groundwater one storage coefficient. This was done in an effort to preserve the expected physical relationships between subbasin size, slope, land use, and geology (amongst other factors) when estimating the movement of water as baseflow. Lastly, the number of reservoirs was initially set to one in both layers. These values were adjusted during the calibration phase to calibrate at stream gages. More details on the groundwater numbers can be found in Table 2-8 on pages 72-73.

Streamflow Routing

The routing methods used in the Yazoo River CWMS model were also used in the Yazoo Backwater Study Area model. The two methods used were Lag and Modified Puls routing. The Lag routing was kept consistent with the Yazoo River CWMS model as well as most the Modified Puls reaches. However, a few Modified Puls reaches were modified to simulate more attenuation on the Big Sunflower River. The routing reaches used within the HEC-HMS model are detailed in Table 1-5 below.

Table 1-5. Routing Reach Summary

Name	Method*
SFR QuivDodd_QuivSun	L
SFR QuiverSun_BigSun	L
SFR SunSunfl_SunQuiv	M-P
SFR SunQuiv_HollyInd	M-P
SFR HollyInd_BPhalia	M-P
SFR Leland_BPhalia	M-P
SFR BPhalia_LCallio	M-P
SFR LCallio_AnguiGag	M-P
SFR AnguiGag_AnguMth	M-P

Name	Method*
SFR AnguMth_SunLow	L
DBR DeerN_LSunfl	L
SFR LittleSun_BigSun	L
SFR SunHollyB_East	L
SFR SunHollyE_LtlSun	L
SFR SunLSun_SFCntrl	L
SFR SFCntrl_DBDeer	L
SBR SBSteeleConnect	L
SBR BlkLong_SBGrace	M-P
SBR SBOtter_SBOnward	M-P
SBR SBOnward_SBMuddy	M-P
SBR SBMuddy_SBCntrl	L

*M-P = Modified Puls, L = Lag

Diversions

There were several diversions used in the Yazoo River CWMS HEC-HMS model. However, the diversions were removed from the Yazoo Backwater Study Area HEC-HMS model for simplicity as the breakouts would not significantly affect the timing component. The Swan Lake diversion was added into the model as a source because it directly adds flow into the system. The flow was calculated based on a diversion rating curve; flows greater than 7,500 cfs at Tallahatchie River at Swan Lake begin to cross basins to the Quiver River basin thus entering the Yazoo Backwater Study Area.

Precipitation-Runoff Calibration/Validation

Multiple years were chosen ranging from high precipitation years to low precipitation years in order to determine one set of parameters to represent conditions over the 43-year simulation. These years include:

Calibration Events

1991 – High Precipitation

2004 – Average Precipitation

2011 – Low Precipitation

2019 – High Precipitation

Validation Events

1983 - High Precipitation

1997 – Average Precipitation

2005 – Low Precipitation

2010 – Low Precipitation

Calibration/Validation Parameters and Approach

Table 1-6 shows the calibration and validation parameter and approach.

Table 1-6. Calibration and Validation Parameters and Approach

Process	Parameter	Calibration/Validation Approach
Evapotranspiration	Hamon Coefficient	This parameter is used by the Hamon routine to compute the amount of potential ET. This parameter was not varied from the default during model calibration.
	Crop Coefficient	This parameter is specified for each subbasin and is used to adjust the amount of potential ET at a subbasin-scale. The Dynamic Canopy method was used to allow a variable crop coefficient. This parameter was decreased by 0.5 times the calibrated crop coefficient and was increased up to a maximum of 1.5 depending upon the vegetative cover and/or the amount of active irrigation within each subbasin.
Infiltration	Initial Deficit	This parameter is event specific and represents the moisture conditions in the watershed at the beginning of a simulation. This parameter has very little impact on a continuous simulation as the model “warms up” after simulating the first couple of events.
	Maximum Deficit	This parameter sets an upper limit to the moisture deficit. This parameter was adjusted during calibration to three or four inches across all subbasins.
	Constant Loss Rate	The constant loss rate represents the basin average infiltration rate when the soil has reached a saturated state. This parameter varied from the Yazoo River CWMS model in that a range of 0.2 to 0.3 was chosen to represent the subbasins.
	Percent Impervious Cover	The percent impervious area parameter represents the percentage of the watershed where impervious land is directly connected to the stream network. This parameter was not varied from the Yazoo River CWMS model during model calibration.
Runoff Transform	Time of Concentration (T_c)	This parameter was varied slightly from the original Yazoo River CWMS estimates. The changes were to better match the unit hydrographs at stream gages.
	Storage Coefficient (R)	This parameter was set to two times the time of concentration across each subbasin.
Baseflow	GW 1 Initial Discharge	The initial discharge represents the flow rate contribution from ground water 1 at the beginning of the simulation. Initial discharge from GW 1 was set to zero.
	GW 1 Fraction	This parameter determines how the percolation is split to the reservoirs. In this case, it is how much of that percolation goes into the GW 1 reservoir. The fraction must be greater than zero and less than or equal to one. When the sum of the fractions is exactly one then there will be no aquifer recharge. When the sum is less than one, the remainder of the percolation becomes aquifer recharge.

Process	Parameter	Calibration/Validation Approach
	GW 1 Storage Coefficient	GW 1 was conceptualized to represent the fast-responding portion of baseflow. Therefore, this coefficient was set to a smaller value than the GW 2 storage coefficient. This value was altered to best match the observed hydrograph shape and flow volumes. Efforts were made to develop a single value or acceptable range for each subbasin and/or zone regardless of the time of year.

Table 1-8. (Cont.) Calibration and Validation Parameters and Approach.

Process	Parameter	Calibration/Validation Approach
	GW 1 # of Reservoirs	This parameter sets the number of linear reservoirs within layer 1 which directly affects the attenuation and timing of computed runoff. This parameter was set to 3 reservoirs during model calibration.
	GW 2 Initial Discharge	Initial discharge is event specific and can vary throughout the year within a single subbasin. Therefore, this parameter was set to 0.1 cfs/sq. mi to match the initial flow at the beginning of each simulation.
	GW 2 Fraction	This parameter determines how the percolation is split to the reservoirs. In this case, it is how much of that percolation goes into the GW 1 reservoir. The fraction must be greater than zero and less than or equal to one. When the sum of the fractions is exactly one then there will be no aquifer recharge. When the sum is less than one, the remainder of the percolation becomes aquifer recharge.
	GW 2 Storage Coefficient	GW 2 was conceptualized to represent the slow responding portion of baseflow. Therefore, this coefficient was set to a larger value than the GW 1 storage coefficient. This value was altered to best match the observed hydrograph shape and flow volumes. Efforts were made to develop a single value or acceptable range for each subbasin and/or zone regardless of the time of year.
	GW 2 # of Reservoirs	This parameter sets the number of linear reservoirs within layer 2 which directly affects the attenuation and timing of computed runoff. This parameter was set to 3 reservoirs during model calibration.
Streamflow Routing	Lag Time	This parameter was not varied during model calibration.
	Storage-Discharge Function	This parameter was adjusted because preliminary results showed reach routing needed more attenuation in the Big Sunflower River. These adjustments were needed because the HEC-RAS model used storage areas for the overbank area, water in the overbank was not accounted for when storage-discharge information was originally computed in the HEC-RAS model.
	Number of Sub reaches	This parameter was not varied during model calibration.

Final Parameters

After completing the calibration for the years noted in section 92.a., efforts were made to come up with a single parameter set to represent the 43-year continuous simulation. Once a single parameter set was chosen, several validation events were run. This would turn out to be an iterative process, and the parameters were adjusted until there was a comfortable balance (optimally 0.5’-1.0’ difference) between the calibration and validation results. In the following tables (

Table 1-7, Table 1-8, Table 1-9, and Table 1-10), the final model parameters for evapotranspiration, infiltration, unit hydrograph transform, and baseflow are represented.

Table 1-7. Evapotranspiration (Dynamic Canopy)

Subbasin	Initial Storage (%)	Max Storage (IN)	Crop Method	Crop Gage
SF Doddsville Loc	0	0.01	Time-Series Gage	SF Doddsville Loc
SF QuiverSunflower	0	0.01	Time-Series Gage	SF QuiverSunflower
SF BigSunatQuiver	0	0.01	Time-Series Gage	SF BigSunatQuiver
SF LittleCalleo	0	0.01	Time-Series Gage	SF LittleCalleo
SF Anguilla Loc	0	0.01	Time-Series Gage	SF Anguilla Loc
DB DeerCreekN	0	0.01	Time-Series Gage	DB DeerCreekN
SF HollyBluff	0	0.01	Time-Series Gage	SF HollyBluff
SF LittleSunflower	0	0.01	Time-Series Gage	SF LittleSunflower
DB DeerCreekS	0	0.01	Time-Series Gage	DB DeerCreekS
SB Longwood	0	0.01	Time-Series Gage	SB Longwood
SB SteeleGrace	0	0.01	Time-Series Gage	SB SteeleGrace
SB MuddyBayou	0	0.01	Time-Series Gage	SB MuddyBayou
SB SteeleMouth	0	0.01	Time-Series	SB SteeleMouth

			Gage	

Table 1-8. Infiltration (Deficit and Constant)

Subbasin	Initial Deficit (IN)	Maximum Storage (IN)	Constant Rate (IN/HR)	Impervious (%)
SF Doddsville Loc	0	4	0.2	18.6
SF QuiverSunflower	0	3	0.2	4.6
SF BigSunatQuiver	0	3	0.2	3
SF LittleCalleo	0	3	0.2	21.9
SF Anguilla Loc	0	3	0.3	11.4
DB DeerCreekN	0	4	0.2	2.9
SF HollyBluff	0	4	0.2	1.4
SF LittleSunflower	0	4	0.3	3.3
DB DeerCreekS	0	4	0.2	3.1
SB Longwood	0	3	0.2	4.9
SB SteeleGrace	0	3	0.3	5.6
SB MuddyBayou	0	4	0.3	2
SB SteeleMouth	0	4	0.3	3.2

Table 1-9. Transform (ModClark)

Subbasin	Time of Concentration (HR)	Storage Coefficient (HR)
SF Doddsville Loc	60	120
SF QuiverSunflower	60	120
SF BigSunatQuiver	75	150
SF LittleCalleo	50	100
SF Anguilla Loc	115	230
DB DeerCreekN	175	350
SF HollyBluff	30	60
SF LittleSunflower	15	30

DB DeerCreekS	75	150
SB Longwood	50	100
SB SteeleGrace	50	100
SB MuddyBayou	50	100
SB SteeleMouth	25	50

Table 1-10. Baseflow (Linear Reservoir)

Subbasin	GW1				GW2			
	Initial Q (cfs)	Fraction	Coeff (hrs)	# of Res	Initial Q (cfs)	Fraction	Coeff (hrs)	# of Res
SF Doddsville Loc	0	0.95	60	3	0.1	0.05	600	3
SF QuiverSunflower	0	0.8	120	3	0.1	0.2	1200	3
SF BigSunatQuiver	0	0.7	150	3	0.1	0.2	1500	3
SF LittleCalleo	0	0.7	100	3	0.1	0.2	1000	3
SF Anguilla Loc	0	0.7	115	3	0.1	0.2	1150	3
DB DeerCreekN	0	0.4	350	3	0.1	0.05	3500	3
SF HollyBluff	0	0.4	60	3	0.1	0.05	600	3
SF LittleSunflower	0	0.4	30	3	0.1	0.05	300	3
DB DeerCreekS	0	0.4	150	3	0.1	0.05	1500	3
SB Longwood	0	0.4	30	3	0.1	0.3	300	3
SB SteeleGrace	0	0.5	60	3	0.1	0.2	600	3
SB MuddyBayou	0	0.4	150	3	0.1	0.05	1500	3
SB SteeleMouth	0	0.4	50	3	0.1	0.05	500	3

HEC-HMS Model Metrics

Model performance was evaluated by comparing computed results against observed results at numerous locations. Model parameters were altered to minimize the differences between computed and observed discharge at each streamflow gage. When available, summary statistics were used to quantify model performance compared to observations (Moriasi et al. 2007). Statistics include Nash-Sutcliffe Efficiency (NSE), Ratio of the Root Mean Square Error to the Standard Deviation Ratio (RSR), and Percent Bias (PBIAS).

NSE measures the relative magnitude of the residual variance compared to the measured data variance. NSE ranges between negative infinity and one, where an NSE equal to one is optimal. Values of NSE less than or equal to zero indicate the mean observed value is a better predictor than the simulated value. More information on NSE can be found in the Journal of Hydrologic Engineering, Volume 13, Issue 10 from 1 October 2008. NSE is computed using the following equation:

$$NSE = 1 - \left[\frac{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\Sigma_{i=1}^{n}(Y_i^{obs} - \bar{Y}^{obs})^2}\right]$$

Where n is the number of observed values compared to computed over the duration of the simulation, Y_i^{obs} is the observed values, Y_i^{sim} is the computed values, and $\bar{Y}^{obs}$ is the average of observed values.

RSR normalizes the root mean square error by using the standard deviation of the observations, incorporating the benefits of error index statistics so that the resulting statistic can be applied to various constituents. RSR is computed using the following equation:

$$RSR = \frac{RSME}{STDEV_{obs}} = \frac{\left[\sqrt{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\Sigma_{i=1}^{n}(Y_i^{obs} - \bar{Y}_i^{sim})^2}\right]}$$

Where RSME is the root mean square error, STDEVobs is the standard deviation of the observations, and $\bar{Y}_i^{sim}$ is the average of simulated values.

PBIAS measures the average tendency of the simulated data to be larger or smaller than the observed data. The optimal value for PBIAS is zero, with low absolute PBIAS indicating accurate model simulation. PBIAS is computed using the following equation:

$$PBIAS = \left[\frac{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim}) \times 100}{\Sigma_{i=1}^{n}(Y_i^{obs})}\right]$$

Summary statistic performance ratings are presented in Table 1-11.

Table 1-11. Performance Rating for Summary Statistics

Performance Rating	NSE	RSR	PBIAS
Very Good	0.65<NSE≤1.00	0.00<RSR≤0.60	$PBIAS$< ±15
Good	0.55<NSE≤0.65	0.60<RSR≤0.70	±15≤$PBIAS$<±20
Satisfactory	0.40<NSE≤0.55	0.70<RSR≤0.80	±20≤$PBIAS$<±30
Unsatisfactory	NSE≤0.40	RSR>0.80	$PBIAS$≥±30

Model Results and Performance

The section below shows the model results from the submission of the model. While the HEC-HMS (hydrologic) model was used as inputs in the HEC-RAS (hydraulic) model, the hydraulic model results took precedent over the hydrologic model results. The Big Sunflower River at Anguilla and Steele Bayou at Grace observed flow data were developed from a backwater rating curve. Due to the complexity and uncertainty of a backwater rating, these two gage locations were primarily used as a visual check to calibrate the shape of the hydrograph. Furthermore, these two gages are the primary source of available flow data within the backwater area. With that in mind, the HEC-HMS model calibration contained more uncertainty, and thus more emphasis was placed on the HEC-RAS results, especially considering HEC-RAS results produced stage data which was easily checked with observed stage data at multiple locations. The results from the hydraulic model showed that the computed volume at Steele Bayou control structure was closer to the observed volume with the hydrologic model results shown in this section. With that being said, edits have already been made to the HEC-HMS model to improve results at the computation points.

Figure 1-50 through Figure 1-36 show several calibration/validation events for the stream gages that the model was calibrated to. All of the calibration/validation events are not shown due to the fact that the model is being judged on an overall performance for the 43-year simulation. However, these figures demonstrate the uncertainties within the model; including uncertainties in the boundary conditions and process parameters defined in HEC-HMS.

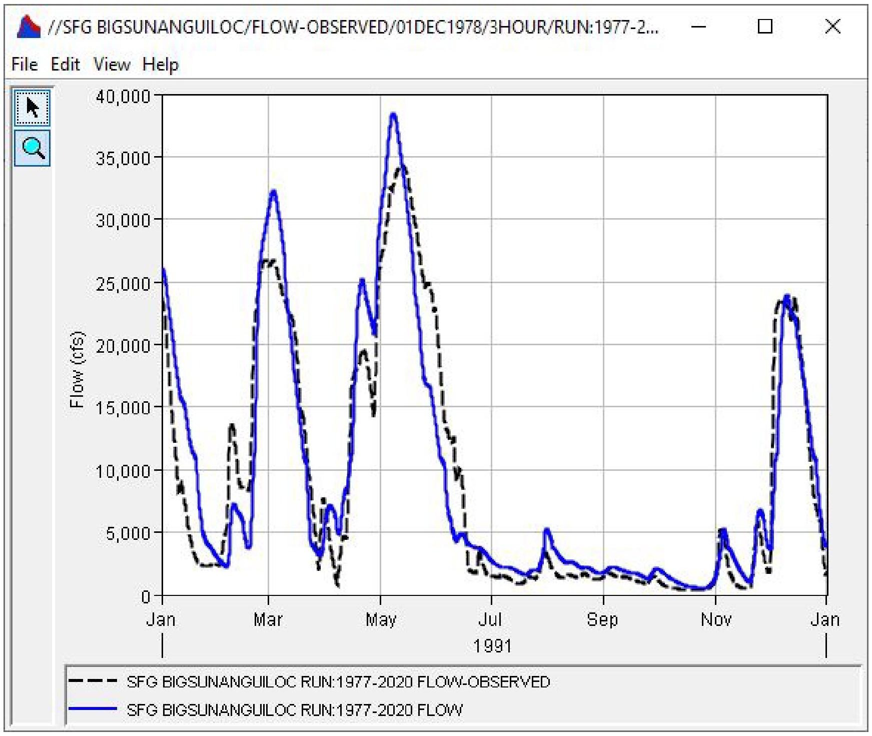


Figure 1-50. Big Sunflower River at Anguilla – 1991.

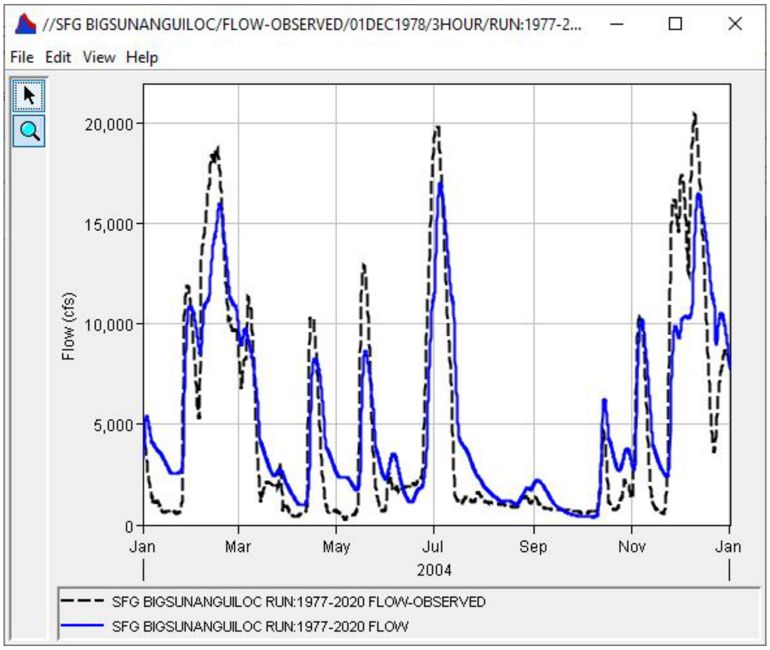


Figure 1-61. Big Sunflower River at Anguilla – 2004.

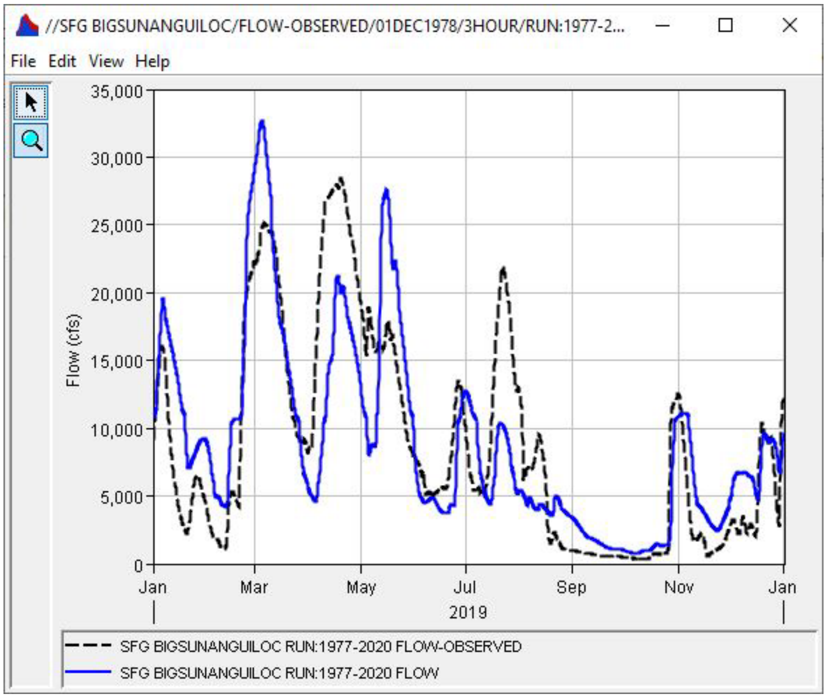


Figure 1-72. Big Sunflower River at Anguilla – 2019.

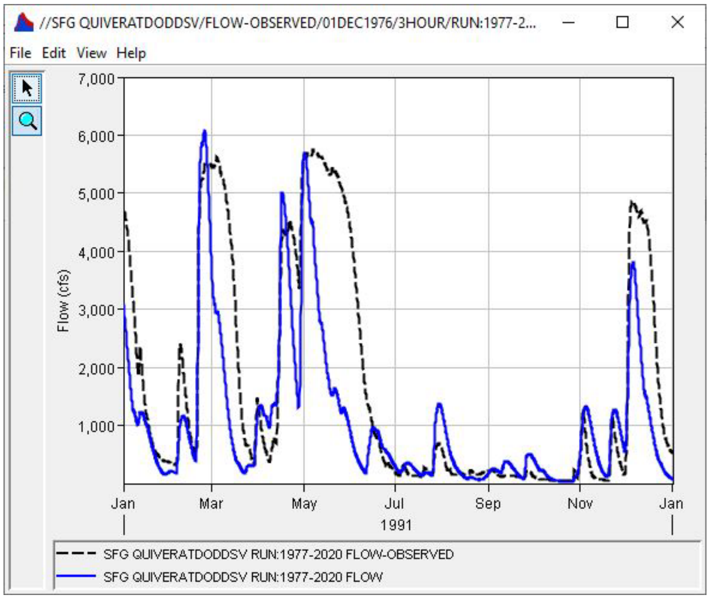


Figure 1-83. Quiver River at Doddsville – 1991.

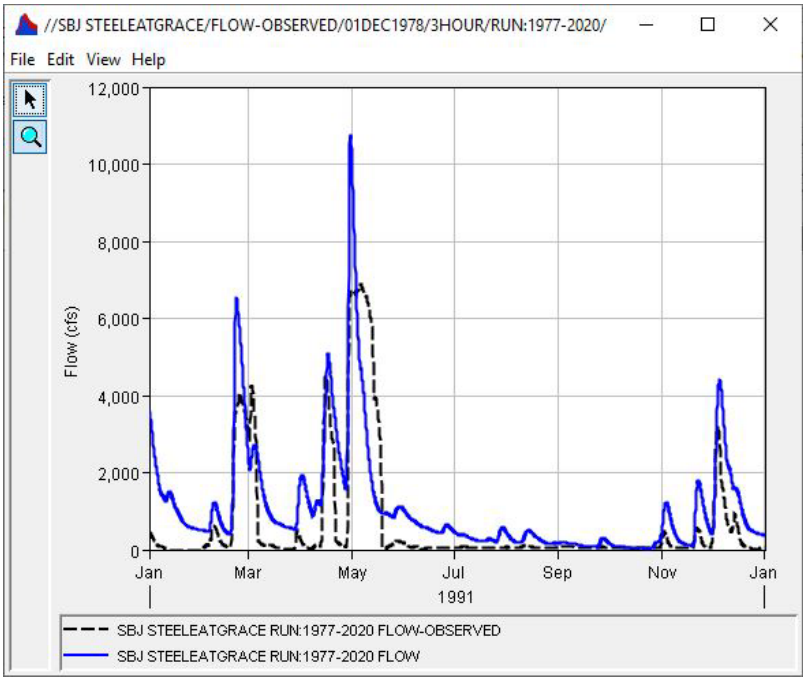


Figure 1-94. Steele Bayou at Grace – 1991.

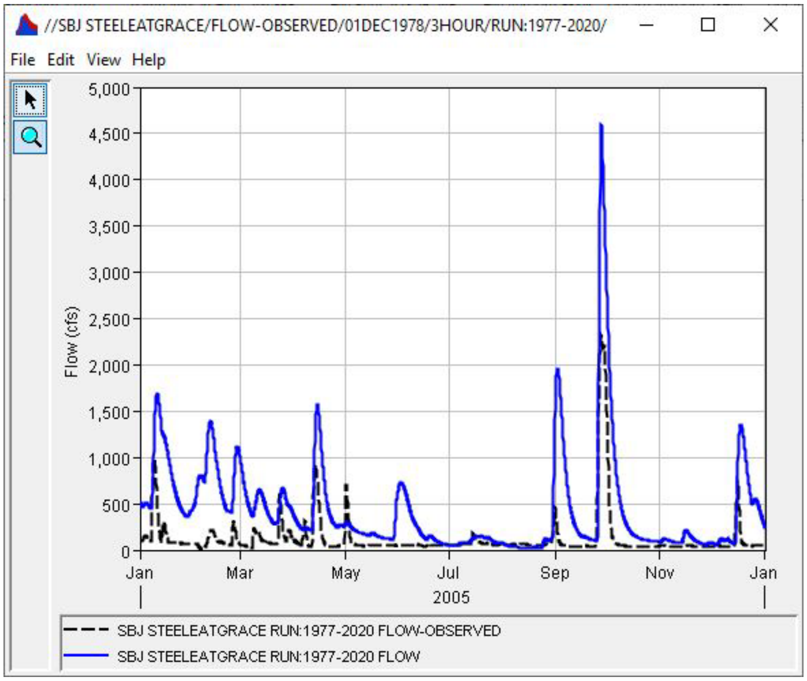


Figure 1-35. Steele Bayou at Grace – 2005.

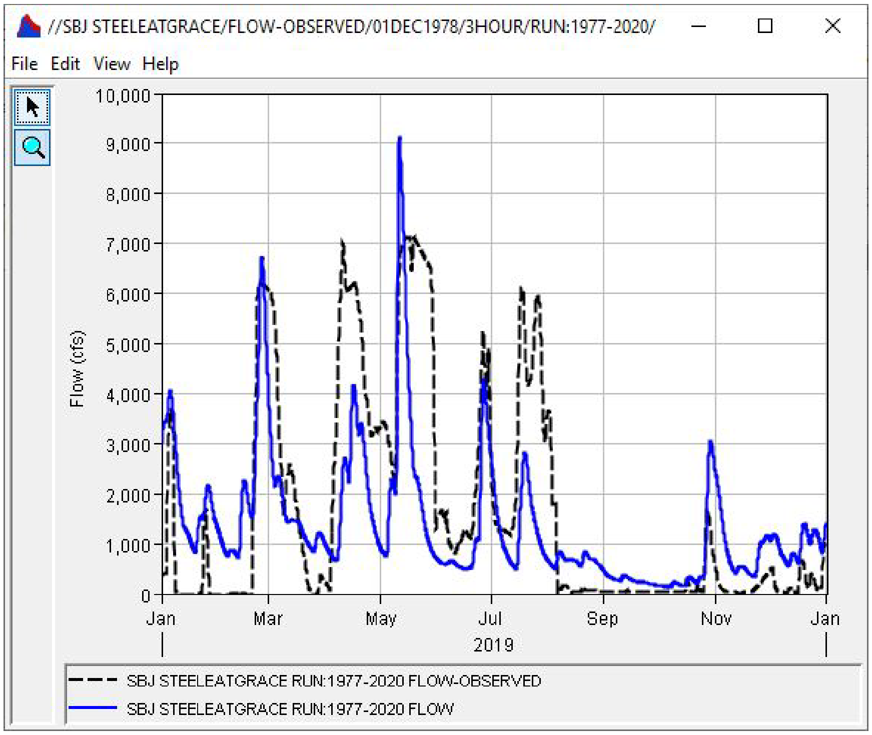


Figure 1-36. Steele Bayou at Grace – 2019.

Figure 1-37 through Figure 1-39 shows the average computed monthly flows compared against the average observed monthly flows at the three computation points for the 43-year period. The monthly plots help demonstrate the volumetric water balance throughout the year. While the model can more effectively capture flows for certain years compared to other years, the average monthly flows help to balance out model performance over the 43-year period. The figures shown below display that, in general, the average computed monthly flows are higher than the average observed monthly flows. As previously stated, changes to the model have already been made to eliminate bias from the HEC-HMS model. These modified results will be shown in a later section.

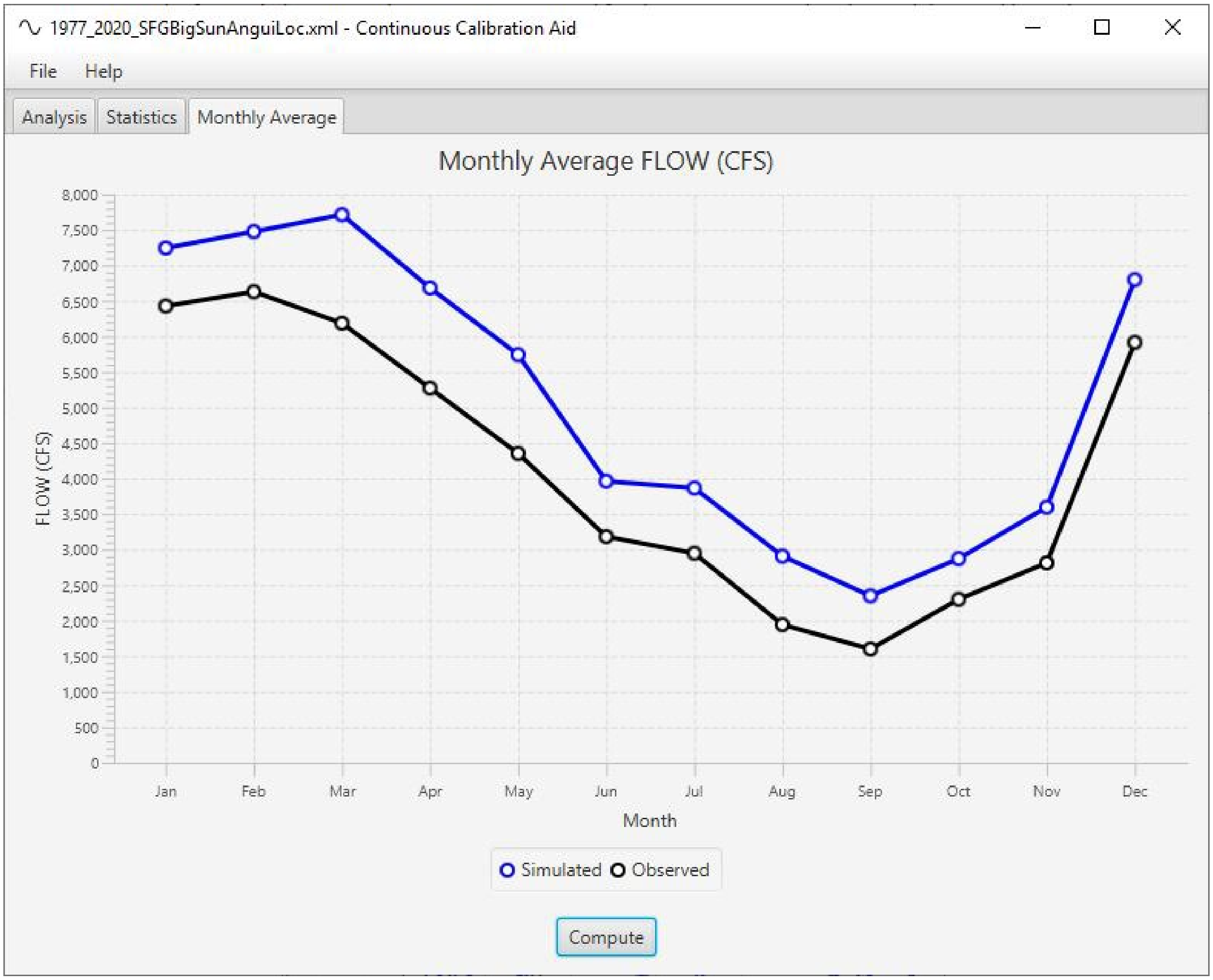


Figure 1-37. Big Sunflower River at Anguilla Monthly Flow Comparison.

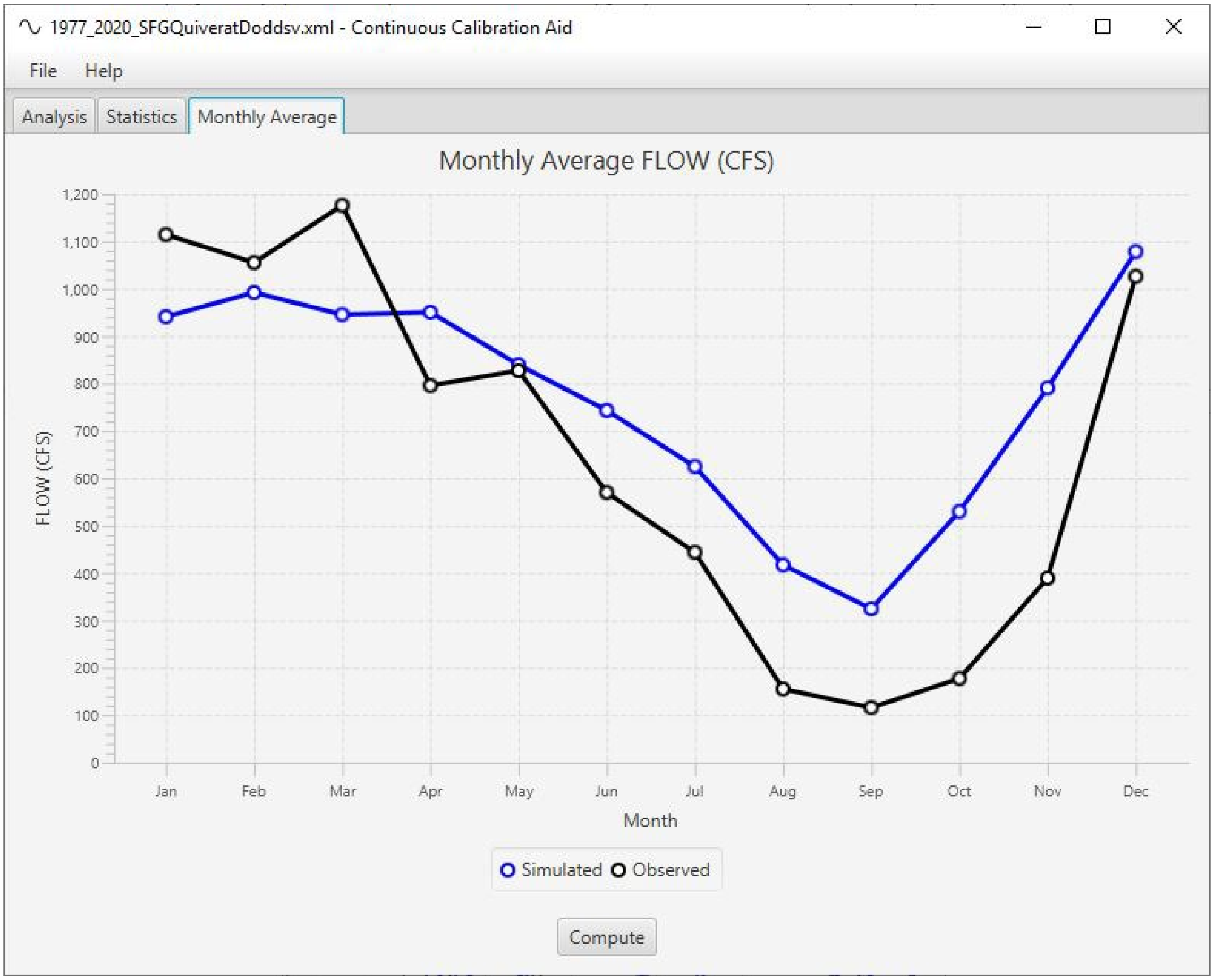


Figure 1-38. Quiver River at Doddsville Monthly Flow Comparison.

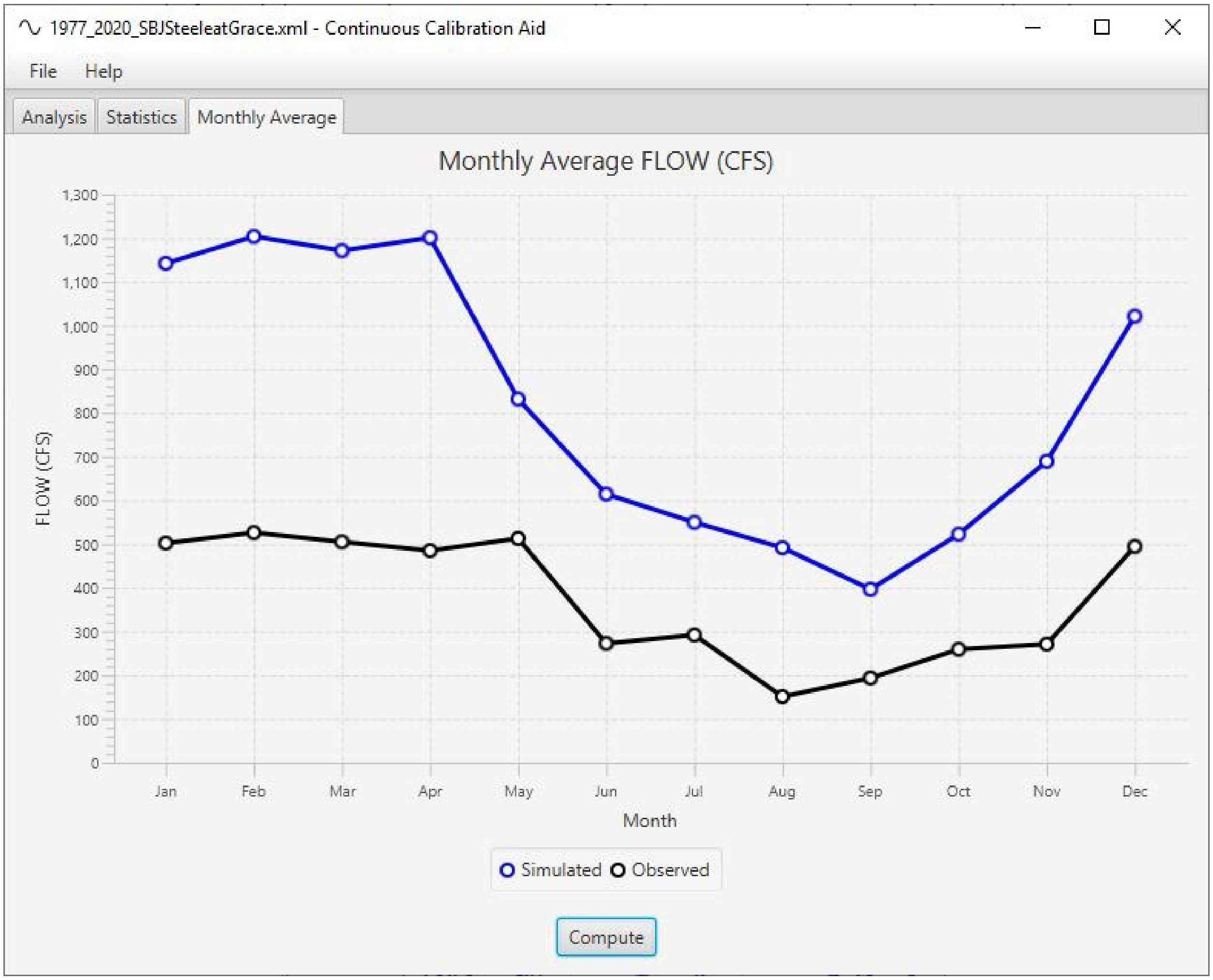


Figure 1-39. Steele Bayou at Grace Monthly Flow Comparison.

In Table 1-12, the model performance at each computation point is shown for the 43-year simulation. The performance ratings table can be found in the 'HEC-HMS Model Metrics' section above.

Table 1-12. Model Performance at Computation Points for Forty-Three Year Simulation

Computation Point	NSE	RSR	PBIAS	R2
Anguilla	0.70	0.55	-23.56	0.74
Doddsville	0.55	0.67	-17.10	0.56
Grace	0.01	1.00	-120.02	0.43

Based on Table 1-12, the Big Sunflower River at Anguilla had a performance rating of 'very good', the Quiver River at Doddsville had a performance rating of 'good' (the Quiver River at Doddsville only had data from 1997 to 1998), and Steele Bayou at Grace had a performance rating of 'unsatisfactory'. While Steele Bayou at Grace had an 'unsatisfactory' rating, it should be noted that Steele Bayou at Grace only represents a small portion of the model so the model results should not completely be thrown out due to the poor performance at one computation point. Any computation point could have not performed as well as it should have due to uncertainties within the model. As stated before, in the monthly flow comparison figure, it is noticeable that the average computed monthly flows are higher than the average observed monthly flows. Another reason for the substandard performance is the uncertainty with the precipitation grid. Efforts were made to incorporate a scaled version of the USGS Soil Water Balance (SWB) model that used DayMet precipitation data; however, there was not enough confidence to use this method. Also, many different iterations were run in GageInterp that used different precipitation gages, interpolation methods, and ranges to come up with the best precipitation grid from the given data.

Conclusions and Recommendations for Future Improvements

A HEC-HMS model was developed for the Yazoo Backwater Study Area for a 43-year period. The model utilized continuous simulation. Several calibration/validation events were chosen in order to come up with a single parameter set to represent the simulation window. Multiple statistical metrics were used to determine the model performance. Overall, the model performed well with the exception of Steele Bayou at Grace. Although Steele Bayou at Grace had an 'unsatisfactory' performance, this gage only represents a small portion of the watershed compared to the Big Sunflower River at Anguilla.

Several recommendations for future improvements to the Yazoo Backwater Study Area HEC-HMS model are provided below:

Develop or locate a more consistent precipitation dataset.

Reduce the baseflow in the streams while maintaining the peak flows through a reduction of the groundwater one coefficient and/or a reduction in the ModClark storage coefficient.

Integrate the gain/loss method for routing reaches to account for the flow loss.

Incorporate 'Save States' in HEC-HMS that would allow for the model to be calibrated to each individual year.

IMPROVED HEC-HMS MODEL RESULTS

Figure 1-100 through Figure 1-122 shows 1991 at Anguilla, 1991 at Grace, and 2005 at Grace with comparison of observed flow with computed (modeled) flow. It should be noted that the computed flows are adjusted down to better match those of the observed flows. This model was not chosen because the flows match the lower flows well, instead the model was chosen because the model was overall low on the higher flow peaks in both the HEC-HMS and HEC-RAS models.

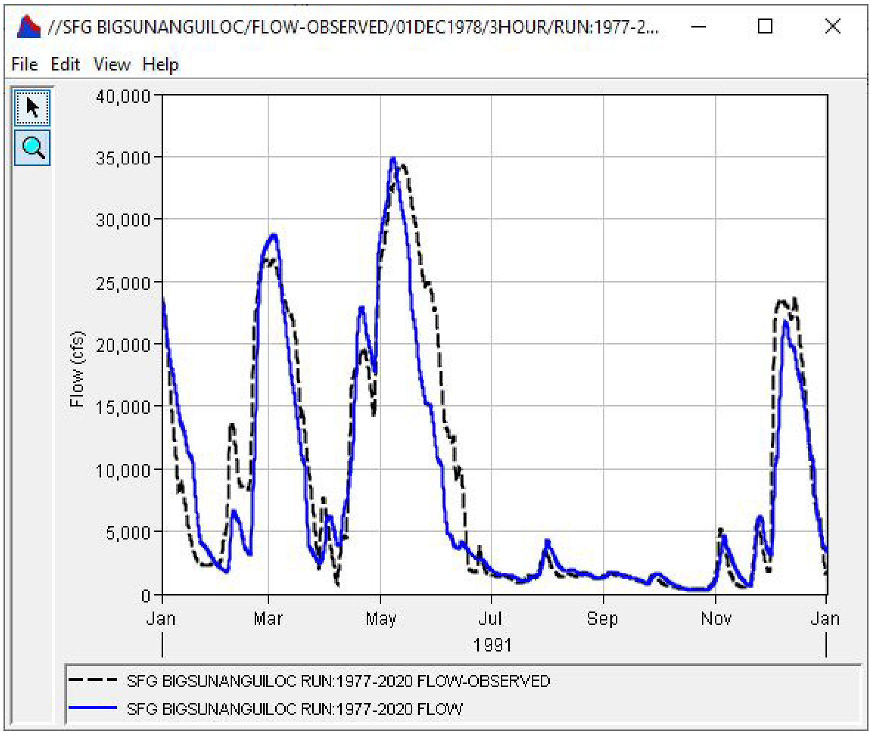


Figure 1-100. Improved Model - Big Sunflower River at Anguilla – 1991.

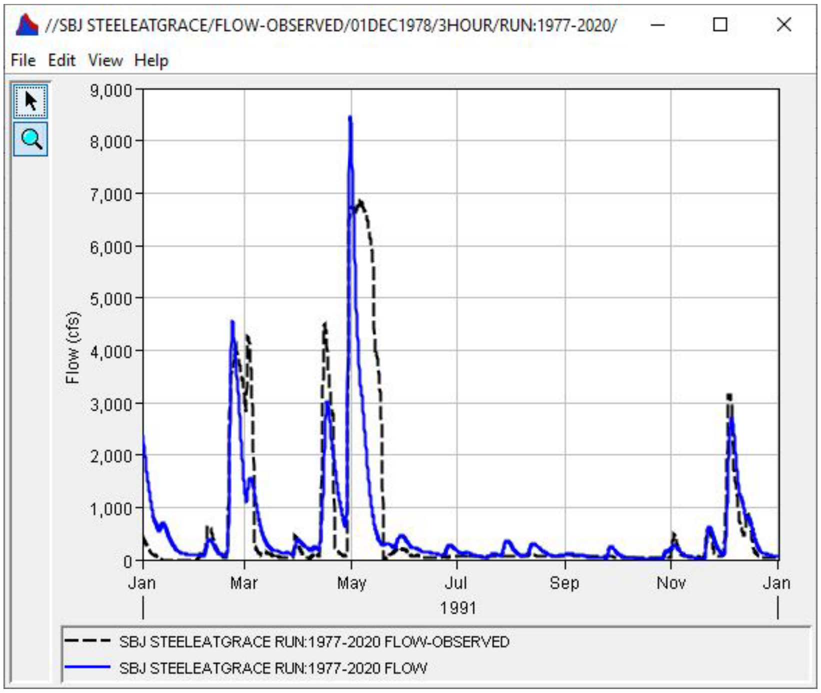


Figure 1-111. Improved Model – Steele Bayou at Grace – 1991.

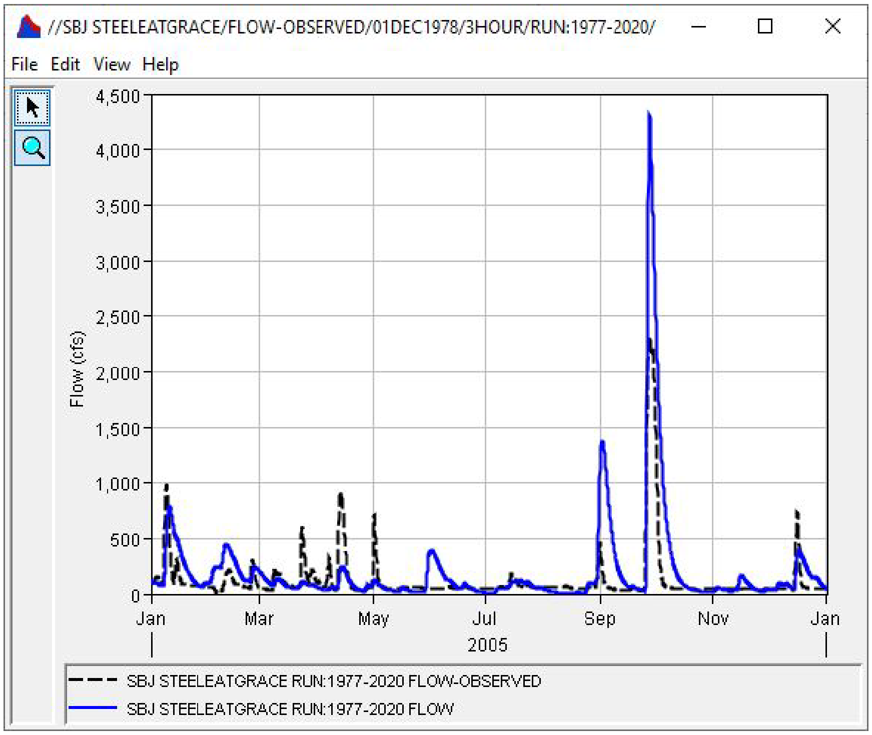


Figure 1-122. Improved Model - Steele Bayou at Grace – 2005.

In Figure 1-133 through Figure 1-, the improved average computed monthly flows are compared against the average observed monthly flows at the three computation points for the 43-year period. As stated before, the monthly plots help demonstrate the volumetric water balance throughout the year. In general, the monthly flow comparison did improve for the Big Sunflower River at Anguilla and Steele Bayou at Grace when comparing the 2023 HEC-HMS model against the 2020 HEC-HMS model. However, they did not improve for the Quiver River at Doddsville. This is due to a consistent change that was made to the linear reservoir baseflow parameter. This parameter will be further changed in the future to ensure there is no bias within the model.

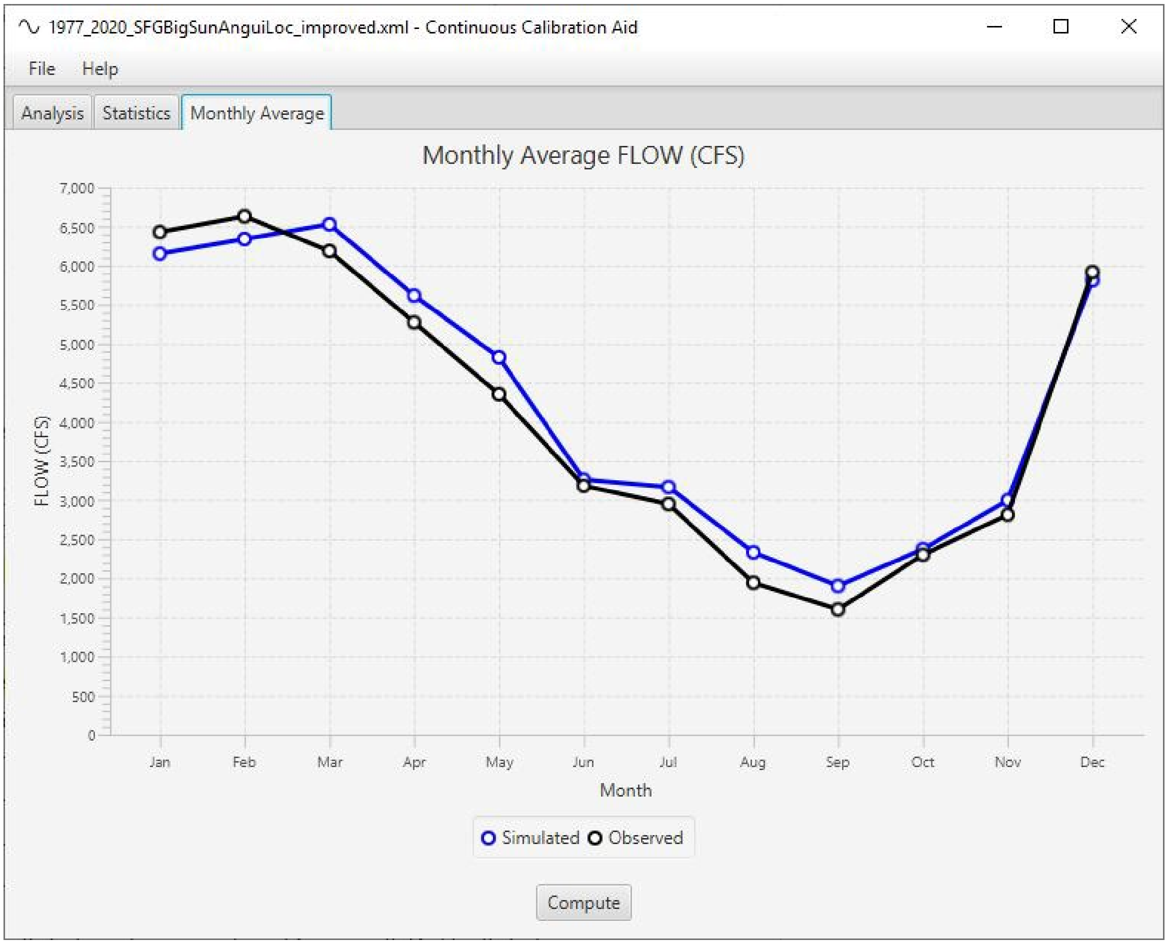


Figure 1-133. Improved Model - Big Sunflower River at Anguilla Monthly Flow Comparison.

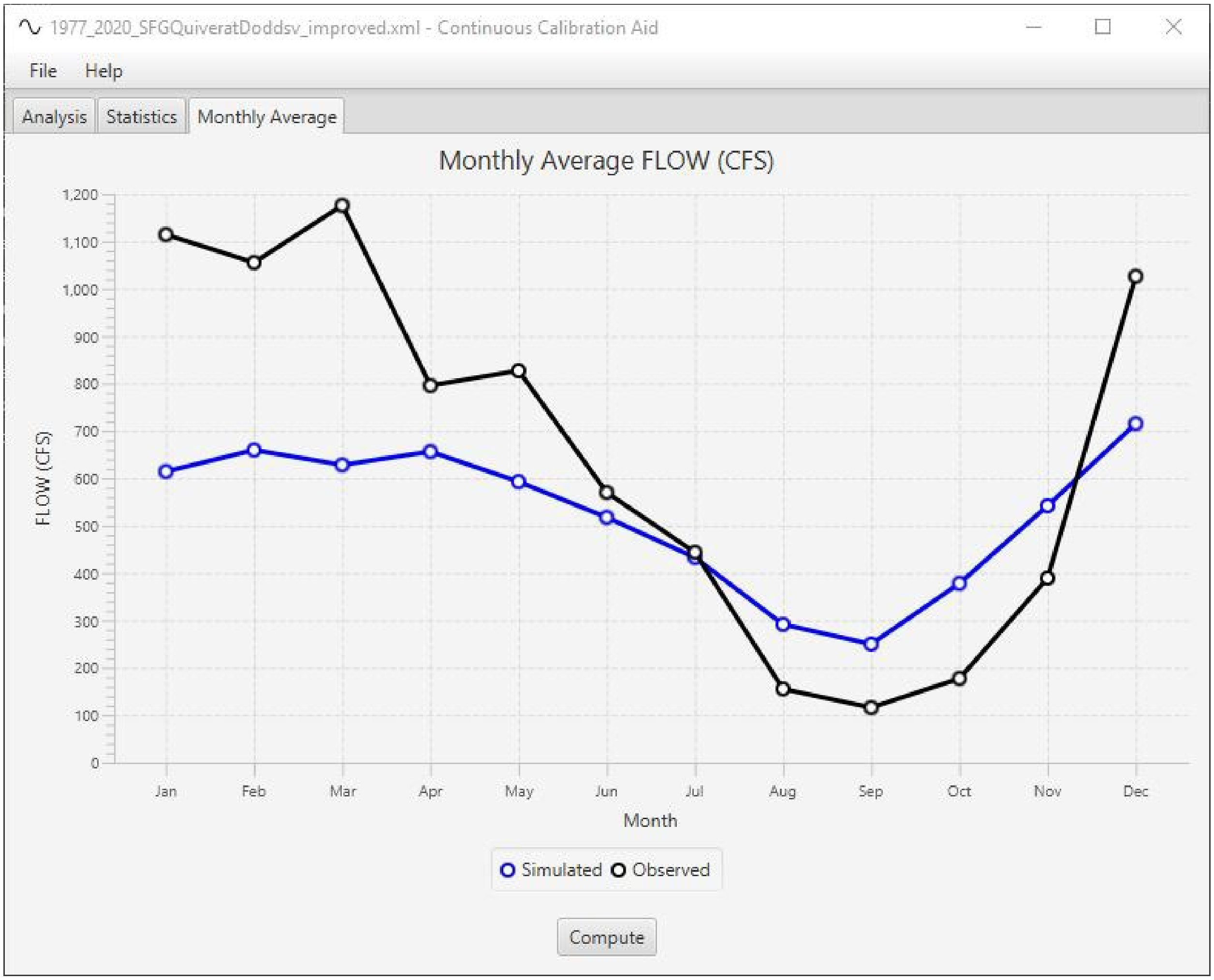


Figure 1-144. Improved Model - Quiver River at Doddsville Improved Monthly Flow Comparison.

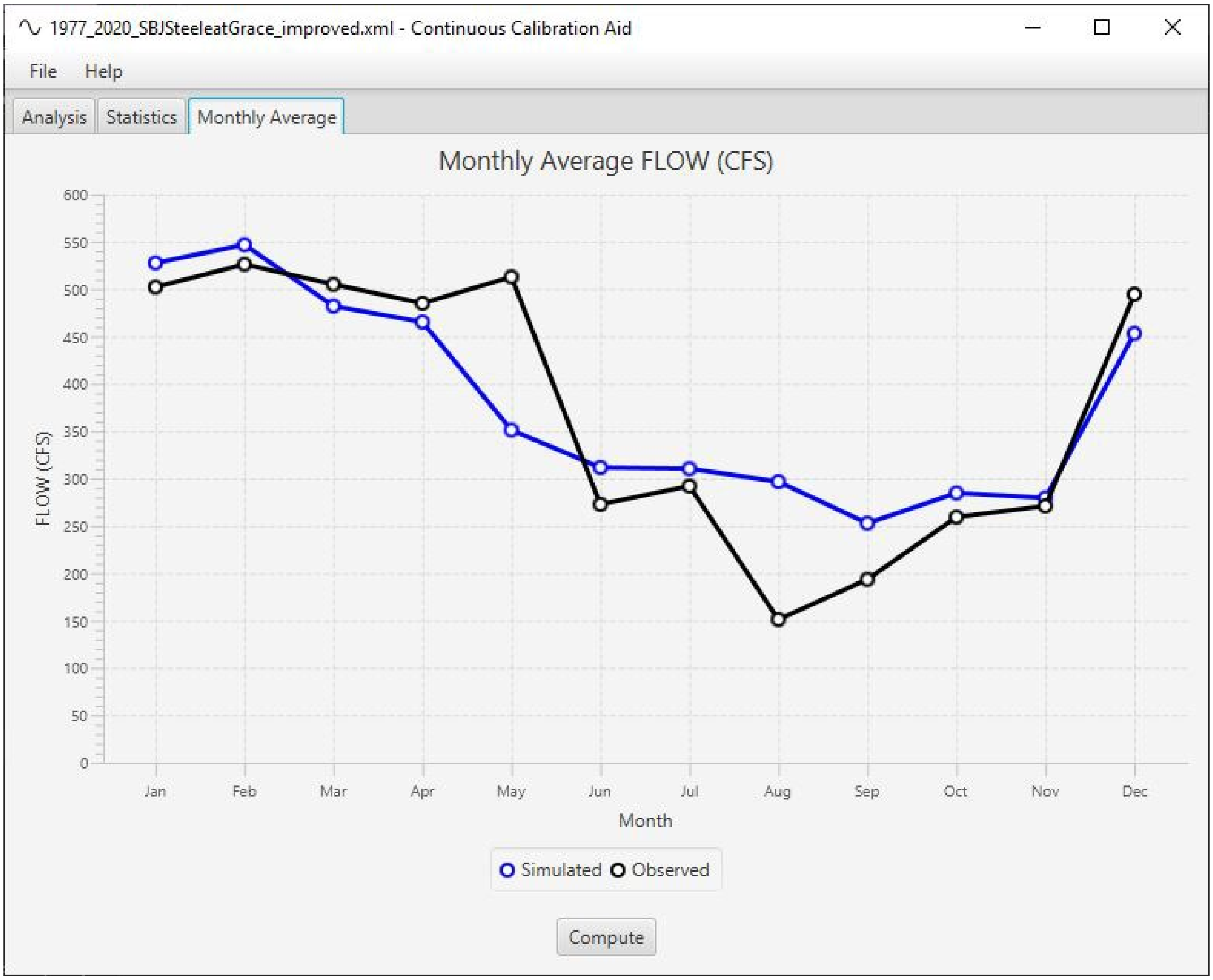


Figure 1-45. Improved Model - Steele Bayou at Grace Improved Monthly Flow Comparison.

In Table 1-13, below, the model performance at each computation point is shown for the 43-year simulation. The performance ratings table can be found in the 'HEC-HMS Model Metrics' section above.

Table 1-13. Improved Model - Performance at Computation Points for Forty-Three Year Simulation

Computation Point	NSE	RSR	PBIAS	R2
Anguilla	0.75	0.50	-3.55	0.75
Doddsville	0.46	0.74	19.88	0.53
Grace	0.43	0.76	-2.08	0.43

Based on Table 1-13, the Big Sunflower River at Anguilla still had a performance rating of ‘very good’, the Quiver River at Doddsville dropped down to a performance rating of ‘satisfactory’ (Doddsville only had data from 1997 to 1998 and represents a very small portion of the watershed), and Steele Bayou at Grace improved to a performance rating of ‘satisfactory’.

HYDRAULIC MODEL SETUP

OVERVIEW

The updated hydraulic modeling was developed using the HEC-RAS (Hydraulic Engineering Center- River Analysis System) computer program, version 6.3.1. HEC-RAS takes the flows computed in HEC-HMS and develops a river profile for various flood events or frequency events. These profiles from HEC-RAS can then be used to create an inundation shapefile showing extents of a flood event and depth of flooding. The updated HEC-RAS model utilizes a 2D flow area that extends from the Yazoo Backwater Levee System at the southern and eastern boundaries to Mississippi Highway 82 at the northernmost boundary, and it extends to the Mississippi River Mainline Levee System to the west. The unsteady flow model incorporates and routes the variable flows with adjustments for channel roughness, geometry, and bathymetric data. The unsteady model’s ability to simulate changes to the flow and water surface over time allows for a more accurate representation of hydraulic routing of water through the watershed. An existing model was updated by incorporating channels using surveyed bathymetric data, adding hydraulic structures to represent weirs, and revising channel roughness.

STUDY REACHES

The 2D flow area representing the Yazoo Backwater Study Area extends from the Yazoo Backwater Levee System as the downstream boundary and northward to Mississippi Highway 82. This area includes Steele Bayou, Little Sunflower, Big Sunflower, Bogue Phalia, and Deer Creek channels. Bridges that cross these channels were not modeled because they are considered to have no impact on water surface elevation. Three bridges were overtopped during the 2019 event and were considered for addition. However, these bridges were deemed to have little to no impact on the model results and were removed to improve stability and accuracy. Manning’s override regions were created to adjust the Manning’s “n” values within the channels. Thus, the model “reaches” used for calibration are the override regions within the Yazoo Backwater 2D flow area. The model reach extents are defined below. The Big Sunflower and Little Sunflower River names were shortened in the model as “Big Sun” and “Little Sun” accordingly.

Steele Bayou extends from the Steele Bayou Control Structure to the confluence of the Main Canal and Black Bayou. These channels extend further upstream to their intersection with MS Highway 82. The Little Sunflower/Steele Bayou connecting channel extends from the Steele Bayou Control Structure to the Little Sunflower Control Structure.

Little Sunflower River extends from the Little Sunflower Control Structure to the confluence with the Old Sunflower Channel. Old Sunflower River extends downstream to its confluence with the Big Sunflower River and the Holly Bluff Cut-off channel and upstream to the confluence of the Big Sunflower River and the upstream end of the Holly Bluff Cut-off.

The Big Sunflower River extends from the confluence with the Little Sunflower River at the downstream end to Mississippi Highway 82 at the upstream end. The Big Sunflower River includes the Holly Bluff Cut-off, which is a 6.5-mile channel that was built to bypass the Old Sunflower Bend reach.

Deer Creek North extends from the confluence with Little Sunflower River at the downstream end to Hollandale, Mississippi at the upstream end. Deer Creek South extends from the confluence with the Little Sunflower/ Steele Bayou Connecting Channel at the downstream end to Rolling Fork, Mississippi at the upstream end. Deer Creek South does not have bathymetric data and is considered to have little effect on the area since it runs dry for most of the year, and rain that falls within its banks is the only contribution to its flow. Deer Creek North and South are separated by a cut off at Rolling Fork that diverts the water from Deer Creek North into the Little Sunflower River.

TERRAIN

Topographic data for the hydraulic model is primarily based on airborne light detection and ranging (LiDAR) data. The LiDAR data is a 3-meter DEM from the seamless USGS National Elevation Dataset. The vertical elevation units were converted from meters to feet, and the dataset was projected into the Albers Projection, using the North American 1983 Datum. All elevations are listed as NAVD 88. The vertical error in the 3-meter DEM is shown in Figure 2-46 below to be a mean of 0.23’ and this was verified by 400 known survey benchmarks through the Yazoo Backwater area. These benchmarks were located near bridges, roadways, and near property lines. This vertical error would be representative for water bodies, roads, pastureland, personal property, and crop land. There were no survey benchmarks in or near wooded or forested areas so the vertical area of the DEM in these areas (woods and forest) is unknown.

Figure 1-46. Vertical Error of 3-meter LiDAR dataset.

Because LiDAR data does not capture elevations below the water surface, bathymetric data was burned into the terrain using a 1D model with cross sections and surveys taken in 1991, 1992, 2001, 2009, 2010, 2014, and 2020 in support of the 2011 Big Sunflower Maintenance Project and various projects associated with the Steele Bayou Sediment Reduction Project. Additional surveys were conducted along Steele Bayou in March 2020. The surveys were conducted in collaboration with the Vicksburg District Geospatial Data Section and ERDC CHL survey personnel. The team surveyed 18 cross sections in various locations within Steele Bayou basin. The cross sections were conducted using the U.S. State Plane NAD83 Mississippi West FIPS 2302 coordinate system and the NAVD 88 Geoid-18 vertical datum. Measurements were all taken in U.S. Survey feet. The survey team ran single beam cross sections in the survey areas within Steele Bayou Basin and took real-time Kinematic (RTK) data where the top bank was accessible. Figure 2-47 identifies the general areas within Steele Bayou that were surveyed during March 2020.

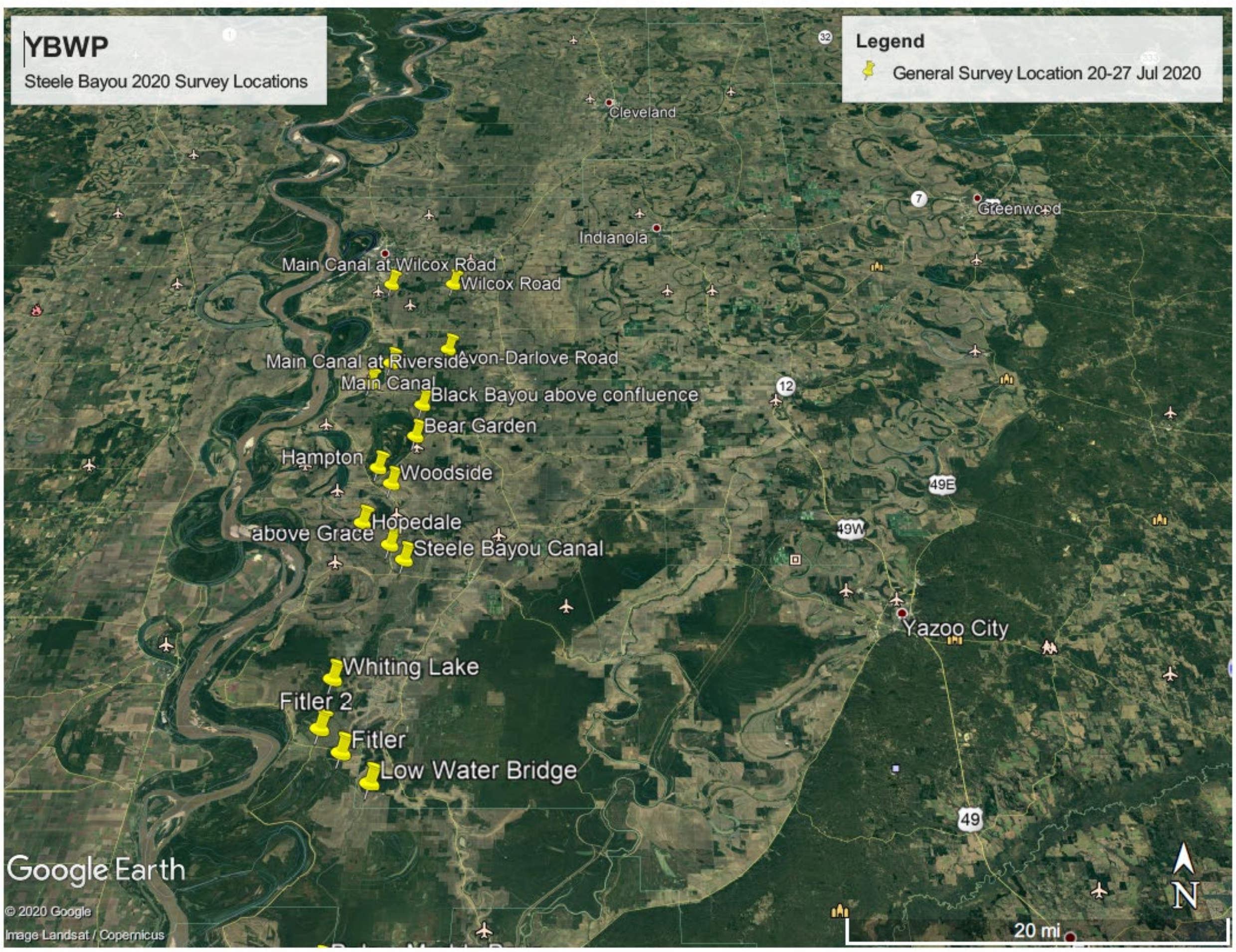


Figure 1-47. Locations within Steele Bayou that were surveyed during March 2020.

Cross-sections were drawn where survey data was available. In areas where survey data was unavailable, cross-sections were interpolated. Interpolation was either performed by HEC-RAS or by adjusting the upstream cross section to match the slope of the existing cross-sections. The eastern side of the basin had more extensive cross section coverage though segments had to be stitched together from multiple years. Interpolation was only needed around complex curves on the eastern side of the model due to more available cross sections. On the western side of the model, which included Steele Bayou and Deer Creek, cross-sections were more widely spaced with some being as far apart as 15 miles. Multiple cross-sections were interpolated in these areas, which could lead to a high level of uncertainty in channel geometry.

Aerial imagery was used to determine where weirs and other hydraulic structures were located to ensure they were properly represented. Any man-made or dredged channels were estimated in the model using as-built plans or surveyed channel thalwegs.

Once cross-sections were determined to be a proper representation of the channel, RASMapper was used to create a channel terrain file. The channel terrain files were merged in ESRI ARC-Map. By merging the channels into the LiDAR, bridge decks, or other features misrepresenting the channel, could be removed and a more accurate channel volume could be determined. Figure 1-48 shows the cross section for the Yazoo Backwater Study Area, indicated in red, along the centerlines of rivers modeled, indicated in blue. Some cross sections within the figure have been lengthened so they are more visible from this extent.

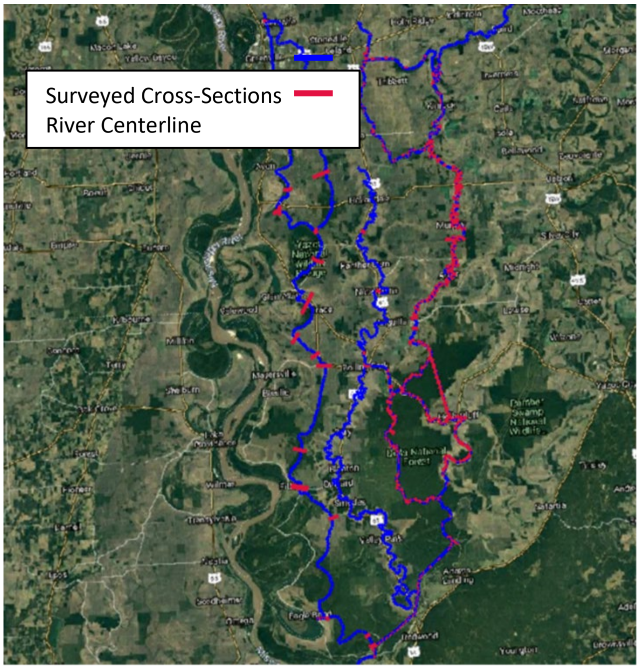


Figure 1-48. The cross sections for the Yazoo Backwater Study Area, indicated in red, along the centerlines of the rivers modeled, indicated in blue.

TWO-DIMENSIONAL FLOW AREAS

Overview

This model utilizes three 2D flow areas, including one for the Yazoo Backwater Study Area, named "Yazoo Backwater" in the model, one for the Tara overflow area, and one for the Yazoo River. The 2D flow area for the Yazoo River was used to input riverside stage boundaries for the Little Sunflower and Steele Bayou Control Structures. The Yazoo River was temporarily placed into the model as a 1D reach; however, 1D was determined to be too unstable to accurately model the flow leaving the control structures. The 1D geometry also proved to be a less accurate calibration for the riverside stages, which led to the control structure gates not being opened at appropriate times.

The cell size throughout most of the 2D flow area is 2000 feet. Refinement regions were created around the channels, with cell sizes ranging from 200 feet to 500 feet. Channels not represented by refinement regions are represented using break lines, due to lack of channel terrain survey information in some locations. Break lines were utilized to represent roads and other high ground in the 2D flow area. Cells enforcing the break lines are as small as 50 feet.

Internal Hydraulic Structures

Internal hydraulic structures were used to represent structures that cross the channel. The coordinates and elevations of structures were provided in a KMZ file. Structures and their information are listed in Table 1-14.

Table 1-14. Coordinates and Elevations of Internal Hydraulic Structures

Name	Latitude	Longitude	Elevation
Weir E	33.1316883342	-90.9972838539	97.0
Mai[illegible]	[illegible]683542	-91.0005132539	103.5
Blac[illegible]	[illegible]64546	-90.9545944169	107.0
Black Bayou Weir 3	33.2823493887	-90.9246694127	101.5
Black Bayou Weir 2	33.1576412193	-90.9248162494	96.0
Black Bayou Weir 1	33.1219421683	-90.9584477152	93.0
SB Weir Rolling Fork	32.9076077378	-90.9533827388	86.0
Steele Bayou Weir 1	32.7494575452	-91.0282707263	78.0
Bogue Phalia Weir 1	33.2355860402	-90.8106721248	92.0
Big Sun Lock 1 Weir	33.1731825829	-90.6836090928	82.5
SB Lafayette Weir	32.995854	-90.973170	90.15

- Surveyed Cross-

Storage Areas (SA)/2D Connection

Multiple SA/2D connections were used to connect 1D and 2D flow areas to one another (Table 1-15). Connections were used at Muddy Bayou control structure, Steele Bayou Control Structure, and Little Sunflower Control Structure; all three were controlled via gate rules. The Muddy Bayou Structure includes the gates as well as a roughly 0.6-foot gap between the gates and the top of the bridge that was discovered during the 2019 flood event.

Table 1-15. SA/2D Connections Used to Connect 1D and 2D Flow Areas

Name	**Connections**	**Gates**	**Gate Invert (feet, MSL)**
Steele	Yazoo Backwater – Yazoo River	4 sluices: 30x22.5 feet	60
Little Sunflower	Yazoo Backwater – Yazoo River	2 sluices: 30x22.5 feet	60
Muddy Bayou	Eagle Lake – Yazoo Backwater	2 sluices: 12x20 feet	65
	*Note: This structure also contains a 270x0.6 feet overflow area with an invert elevation of 96.6 feet, MSL		
48” Culvert	Eagle Lake – Tara Overflow	N/A	N/A
EL_5000	Tara Overflow – Yazoo Backwater	N/A	N/A
Eagle Lake Connection	Eagle Lake – Yazoo Backwater	N/A	N/A
	*Elevations along this ridge beside Eagle Lake were taken from a previous survey		
Muddy_ROB	Eagle Lake – Yazoo Backwater	N/A	N/A
Muddy_LOB	Eagle Lake – Yazoo Backwater	N/A	N/A

Manning’s “n” Roughness for 2D

The roughness of the 2D flow area was based off the 2016 National Land Cover Database (NLCD) for the Contiguous U.S. Table 1-16 shows the values used for the 2D land cover data. The Manning’s “n” value for cultivated crops was used as a calibration point, since much of the land in the Yazoo Backwater Study Area is used for crop cultivation. High water events most frequently occur during crop season. Thus, it was assumed that the increase in vegetation would increase the overbank roughness during this time of year. HEC-RAS does not currently allow the Manning’s “n” value to be changed throughout the year in a 2D flow area, as a result, the cultivated crop value remains high even during non-crop seasons.

Table 1-16. Manning's n-Values used for 2D Flow Areas in the Yazoo Backwater Study Area HEC-RAS Model

Name	Manning's "n"	Override Values
Woody wetlands	0.08	----
Developed, open space	0.04	----
Open water	0.02	----
Cultivated crops	0.03	0.05
Barren land rock/sand/clay	0.025	----
Emergent herbaceous wetlands	0.065	----
Developed, medium intensity	0.095	----
Evergreen forest	0.12	----
Developed, low intensity	0.08	----
Developed, high intensity	0.15	----
Deciduous forest	0.13	----
Grassland/herbaceous	0.04	----
Mixed forest	0.12	----
Pasture/hay	0.03	----
Shrub/scrub	0.1	----

Manning's override regions were created to adjust the Manning's "n" values within the channels. These regions were created using banklines exported from the cross-sections that were used to create the channel terrain. Manning's "n" values within channels were calibrated with observed stage data from gages that model data could be compared to. Manning's "n" values used for each channel are provided in Table 1-17.

Table 1-17. Manning's n-Values Used in Channel Override Regions

River	Reach	Manning's "n"
Bogue Phalia	Reach 1	0.032
Bogue Phalia	Cut-off	0.035
Bogue Phalia	Reach 2	0.035
Big Sun	Reach 1	0.038
Big Sun	Reach 2	0.035
Big Sun	Reach 3	0.035
Big Sun	Reach 4	0.03
Holly Bluff	Cut-off	0.03
Old Sun Bend	Reach 1	0.03
Old Sun Bend	Reach 2	0.03
Little Sun	Reach 1	0.03
Little Sun	Reach 2	0.03
Little Sun	Reach 3	0.03
Steele Bayou	Reach 1	0.04
Steele Bayou	Reach 2	0.035
Black Bayou	Reach 1	0.035
Little Sun – Steele Bayou	Connection	0.03
Deer Creek	Reach 1	0.035

Boundary Conditions

Calibrated flows from the HEC-HMS model were used throughout the HEC-RAS model. An observed stage hydrograph served as the boundary condition for the riverside of the Little Sunflower and Steele Bayou Control Structures, and the structures were operated using basic rules set. The structures were opened when the landside water surface elevation was above 70 feet, MSL, and the landside water surface elevation is higher than the riverside water surface elevation. Only historic events were modeled as the observed data could be used to assess model accuracy.

Additional boundary conditions were used within the 2D flow area to represent flows at critical locations. All flows were calibrated using HEC-HMS local inflow points, except for the Phalia at Leland boundary, which is an observed flow that was input into HEC-HMS. HEC-HMS would rewrite this data as an output that was used as an input in HEC-RAS. Big Sun at Quiver was also based on observed data. A gage exists upstream of the HEC-RAS input location at Big Sunflower at Sunflower with observed flow. Then, flow was routed through HEC-HMS on the Quiver River. These two flows were combined and output from HEC-HMS on the Big Sunflower River at Highway 82. Precipitation inflow was added to Eagle Lake to prevent the pool from remaining stagnate throughout the model run. The same boundary conditions were used in the "With-Pump" and "Without-Pump" scenarios; the only difference between the "With-Pump" and "Without-Pump" scenarios was the addition of the pump station within the geometry. Table 1-18 provides information on each of the boundary conditions.

Table 1-18. Boundary Conditions for the Yazoo Backwater Study Area HEC-RAS Model

2D Flow Area	**HEC-RAS Location**	**Boundary Condition Type**	**HEC-HMS Connection**	**HEC-HMS Data Type**
Yazoo Backwater	Phalia at Leland	Observed Flow Hydrograph	PHALIAATLELAND	FLOW
Yazoo Backwater	Main Canal at Longwood – 4	Flow Hydrograph	LONGWOOD	FLOW
Yazoo Backwater	Main Canal at Longwood – 3	Flow Hydrograph	LONGWOOD	FLOW
Yazoo Backwater	Main Canal at Longwood – 2	Flow Hydrograph	LONGWOOD	FLOW
Yazoo Backwater	Steele at Grace	Flow Hydrograph	STEELEGRACE	FLOW
Yazoo Backwater	Deer Creek North	Flow Hydrograph	DEERCREEKN	FLOW
Yazoo Backwater	Big Sun at Little Callao	Flow Hydrograph	LITTLECALLEO	FLOW
Yazoo Backwater	Big Sun at Holly Bluff – 2	Flow Hydrograph	HOLLYBLUFF	FLOW
Yazoo Backwater	Steele Mouth	Flow Hydrograph	STEELEMOUTH	FLOW
Yazoo Backwater	Big Sun at Quiver	Flow Hydrograph	BIGSUNATQUIVER	FLOW
Yazoo Backwater	Little Sun -2	Flow Hydrograph	LITTLESUNFLOWER	FLOW
Yazoo Backwater	Little Sun – 1	Flow Hydrograph	LITTLESUNFLOWER	FLOW
Yazoo Backwater	Steele at Muddy Bayou	Flow Hydrograph	MUDDYBAYOU	FLOW
Yazoo Backwater	Main Canal at Longwood – 1	Flow Hydrograph	LONGWOOD	FLOW

2D Flow Area	HEC-RAS Location	Boundary Condition Type	HEC-HMS Connection	HEC-HMS Data Type
Yazoo Backwater	Deer Creek South	Flow Hydrograph	DEERCREEKS	FLOW
Yazoo Backwater	Big Sun at Holly Bluff – 1	Flow Hydrograph	HOLLYBLUFF	FLOW
Yazoo Backwater	Big Sun at Anguilla	Flow Hydrograph	ANGUILLA LOC	FLOW
Yazoo River	Little Sun RS	Stage Hydrograph	N/A	N/A
Yazoo River	Steele Riverside	Stage Hydrograph	N/A	N/A
N/A	Eagle Lake	Lateral Inflow	EAGLELAKE	FLOW

Pumping Station

For the “With-Pump” scenarios, a pump station was added to the base geometry. The pumping station was added at the sump, or the lowest point of the Steele Bayou Basin area. The location of the proposed pump station is approximately 2,500 feet west of the Steele Bayou Control Structure. Twenty-two pumps were modeled with a combined capacity of 25,674 cfs. Each pump has an 1,167 cfs capacity. All pumps will not be turned on at the same time. Pumps will be staggered on and off as defined by the pump curve developed during the modeling to ensure that the backwater is allowed to reach 90 feet during crop season and 93 feet during non-crop season. Figure 2-49 shows the pump activation curve for the Yazoo Backwater Pump Project. The curve was developed looking at the upstream most gage in the Steele Bayou Basin, Anguilla, and the upstream most gage in the Little Sunflower Basin, Grace. The flow for each of these two gages were added and used for the development of this curve. The higher the inflow into the backwater area, the sooner the pumps will need to activate to reduce the risk of exceeding 93 feet.

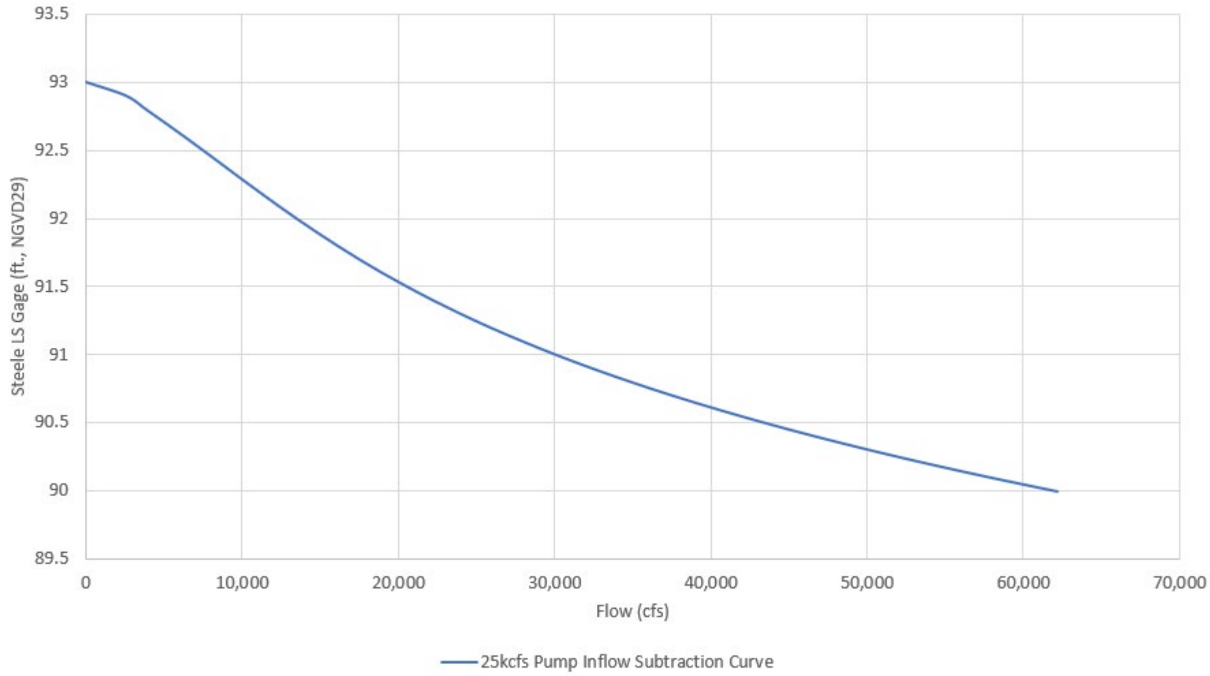


Figure 2-49. Pump activation curve developed for the Yazoo Backwater Study Area

To help develop this pump curve, two lower events (1997 and 2009) and two higher events (2019 and 2020) were used to develop the pump curve. The "with pump" runs for those events are shown in Figures 2-50 through 2-53 below. The top half of the figure shows the stage with the bottom half of the figure showing the flow. The pump outflow is depicted by the red line in the bottom half of the figure. For the figures shown on the following pages, each event has the stages peaking at 93 feet as shown by the purple line in the top half of each figure.

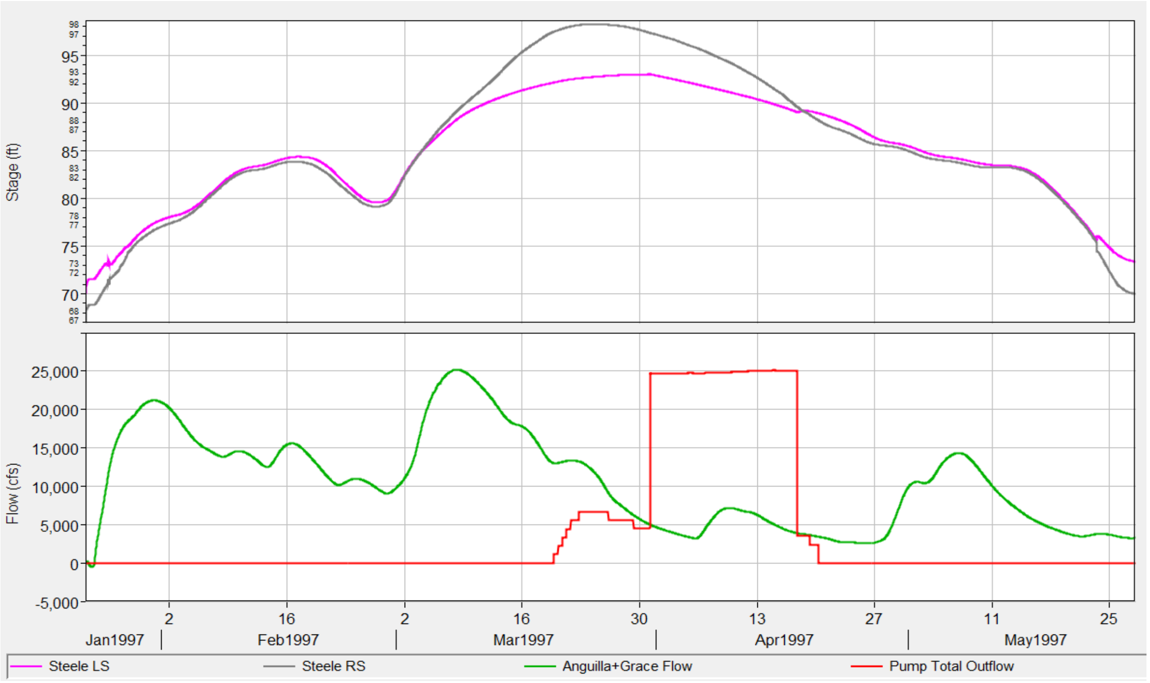


Figure 2-50. Hydrograph at Steele Bayou for 1997

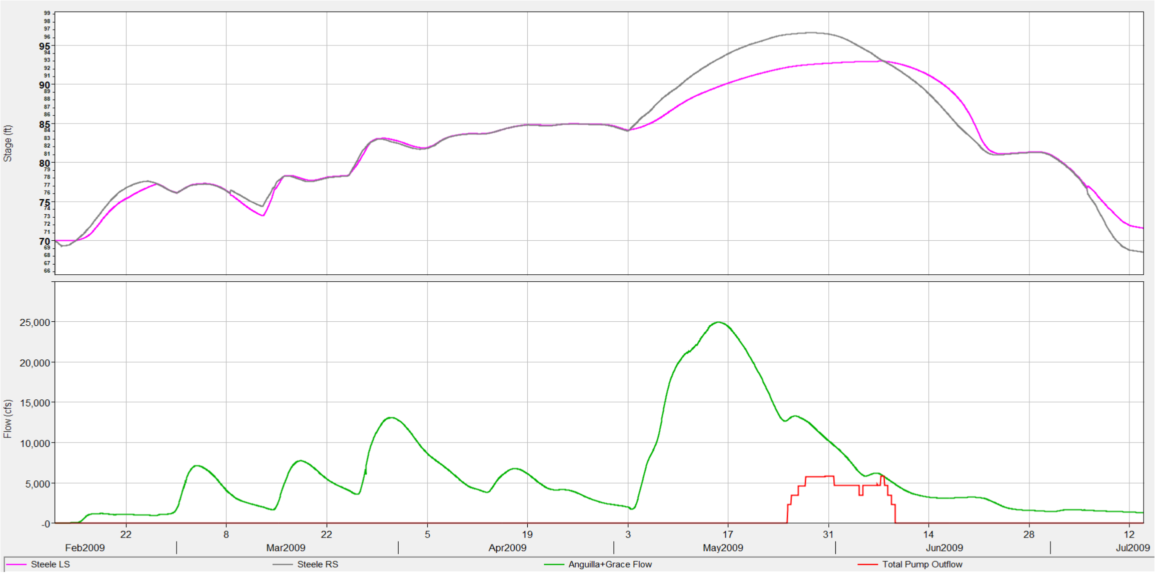


Figure 2-51. Hydrograph at Steele Bayou for 2009

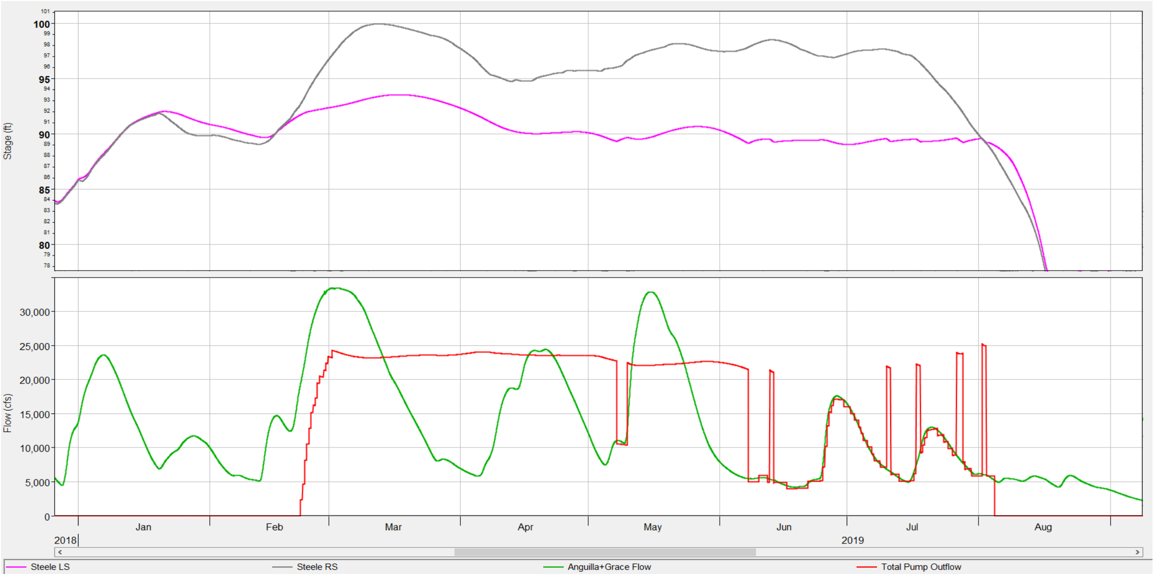


Figure 2-52. Hydrograph at Steele Bayou for 2019

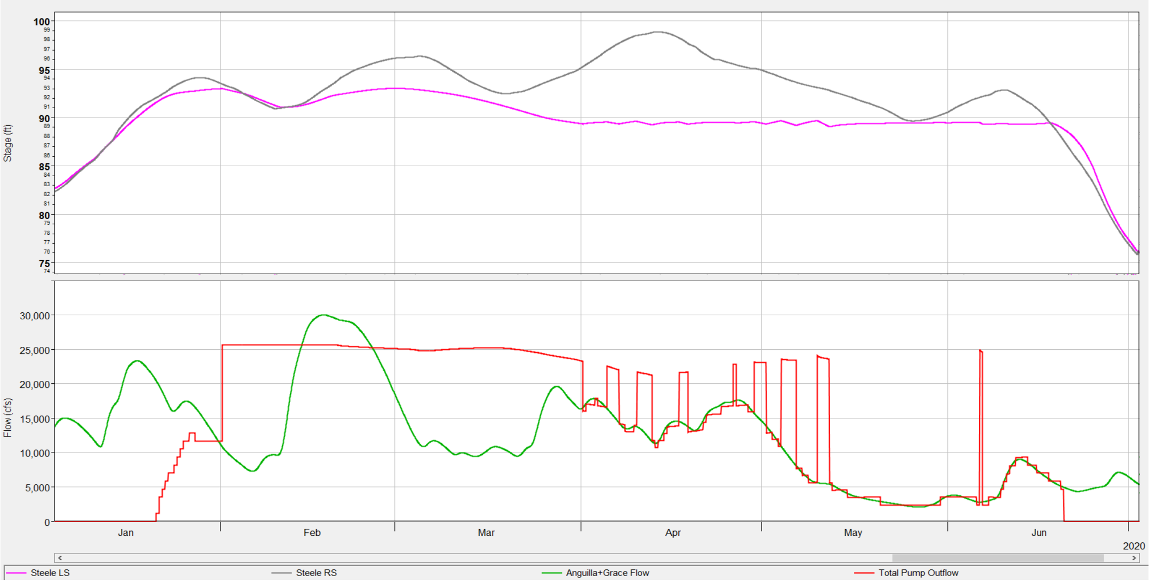


Figure 2-53. Hydrograph at Steele Bayou for 2020

Table 2-21 shows the first calibration runs of trying to develop the pump curve and get all events to peak at the 93 feet elevation. This table compiles all data from Figure 2-49 through Figure 2-53 as well as the pump curve data all in one easy to read table. This was developed to verify that our model was calibrated to the observed gage data, and that the pump curve in the model was working correctly to where the pumps would turn on at the correct time and would allow the flood event to reach 93 feet without greatly exceeding it. These values do not include any seasonal crop rules but are results directly from utilizing the pump inflow curve. The model was modified later to be better refined and also to include the crop season and non-crop season dates.

Table 2-21. Steele Bayou Pump Operation Data

Steele Bayou – Pump Operations				
Scenario	1997	2009	2019	2020
Observed Gage Elevation	93.3	93.7	98.2	96.8
Without Pump Model Elevation	93.6	93.5	98.5	96.9
Pump-On Elevation	92.1	92.2	91.7	91.6
Maximum Elevation with 25,000cfs Pumps	93.0	93.0	93.6	93.0

CALIBRATION AND WITHOUT-PUMP SCENARIO

Overview

Four events were provided for calibration of the model. These years represented different event conditions on the Yazoo River and in the Yazoo Backwater Study Area. The entire year was examined to monitor how the model handled both high water events and low water periods since the goal was to run the entire period-of-record. Calibration years were 1991, 2004, 2011, and 2019. The 1991 and 2019 calibration years represented high Yazoo Backwater and high Mississippi River events. The 2004 calibration year represented an average Yazoo Backwater and Mississippi River event. The 2011 calibration year represented a low Yazoo Backwater and high Mississippi River event.

The starting elevation of the 2D flow area was entered as the elevation of Steele Bayou landside on the beginning date of the model run. In order to establish an accurate starting elevation for the upper parts of the region, the HEC-RAS model was run from 01 December of the previous year. For the 2019 calibration event, a restart file beginning at the start of the high-water event in September of 2018 was created. This hot start file prevented running additional months each time, eliminating any unnecessary run times.

With a 43-year period-of-record, it was assumed that all events would not calibrate with the same level of accuracy due to silt buildup and erosion throughout the basin over the period-of-record. With that in mind, the calibration for the period-of-record is not perfect, but rather the best model representation for such a long duration.

Calibration

The HEC-RAS calibration was originally completed primarily in HEC-RAS. However, after it was determined uncertainty existed within the precipitation data, the calibration focus shifted to the precipitation data and HEC-HMS parameters. The HEC-HMS parameters were adjusted and then re-integrated into the HEC-RAS model. This back-and-forth calibration between the HEC-HMS and HEC-RAS model was performed iteratively to determine the best parameters for calibration. This calibration approach also allowed for more variables, in addition to the roughness factor in the 2D flow areas, to be modified simultaneously.

The calibration events and the “Without-Pump” scenario used the same geometry. Results of calibration were compared at six gage locations: Steele Bayou landside, Little Sunflower landside, Steele Bayou at Grace, and Big Sunflower at Little Calleo, Holly Bluff, and Anguilla. Stage outputs at these locations were obtained by inserting reference points in the 2D flow area.

Figure 14 through Figure 1-59 shows some of the calibration run results versus the observed data. It is evident in the figures below that some years resulted in hydrographs that were much closer to the observed information than other years. Additionally, gages in the upper portion of the basin experienced higher degrees of error compared to gages at Little Sunflower and Steele Bayou Control Structures. Calibration runs also showed that stages were consistently too high during low flow periods, but it was deemed more important to accurately portray peaks over low flow since the modeling effort was primarily concerned with higher events in which pumps would operate. The discrepancies between years at a single gage could have resulted from using one set of channel data for the entire period-of-record or from inherent errors within the precipitation data.

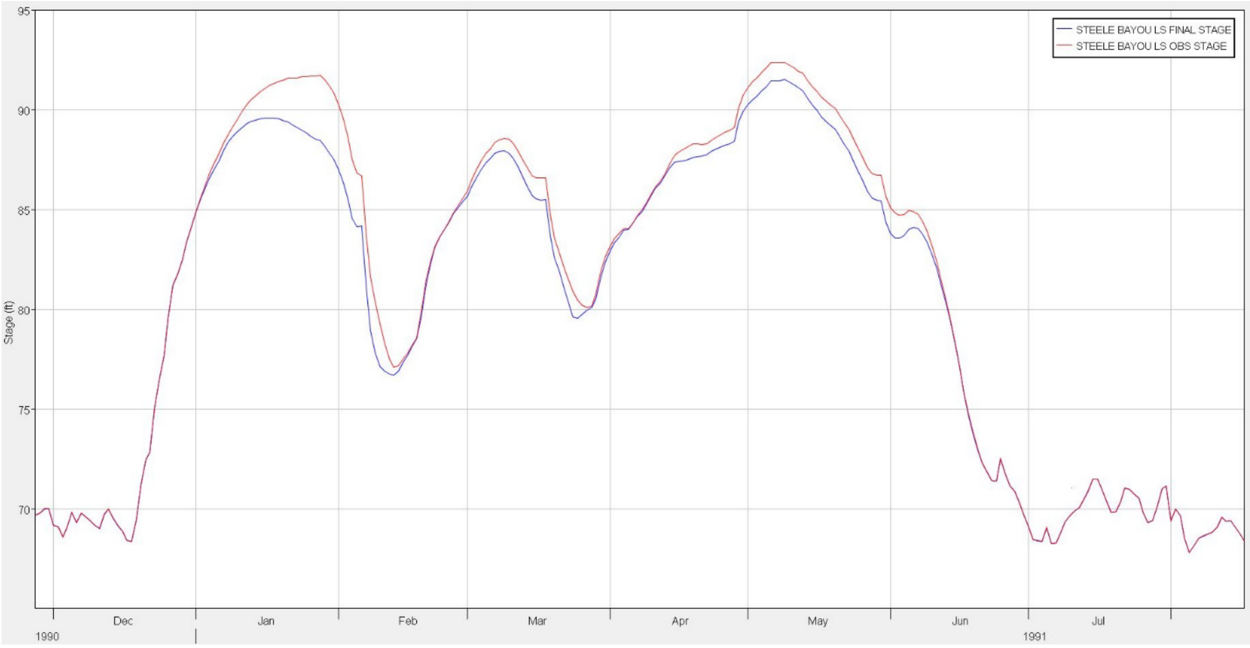


Figure 1-54. Steele Bayou Landside 1991 Calibration.

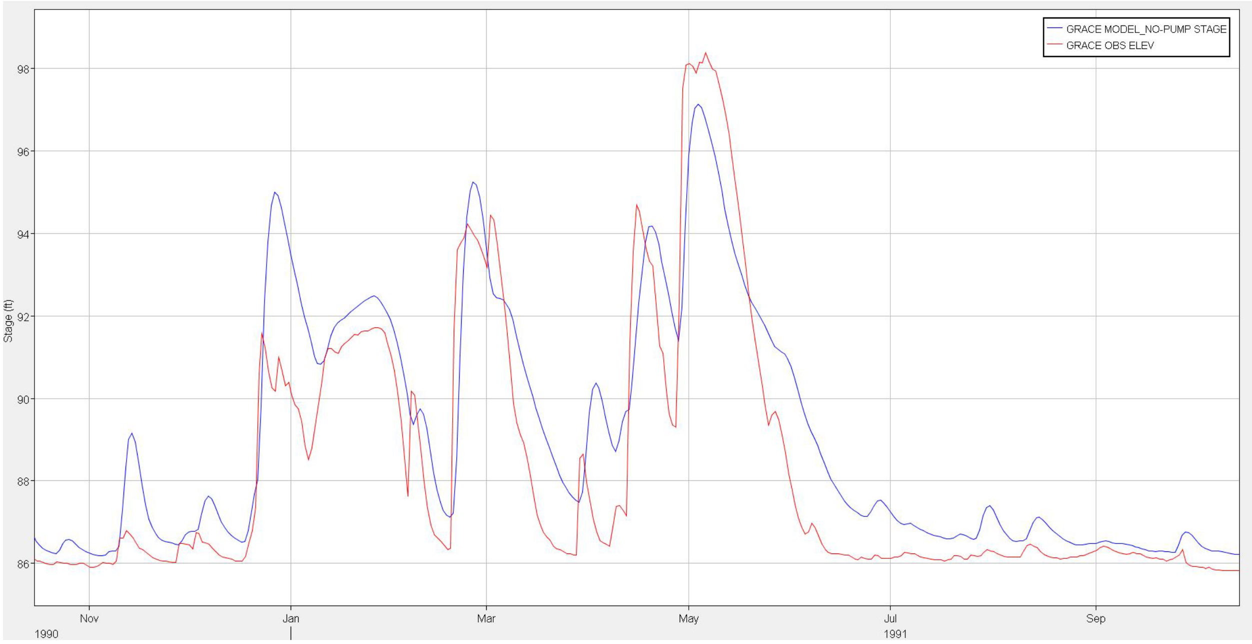


Figure 1-55. Steele Bayou at Grace 1991 Calibration.

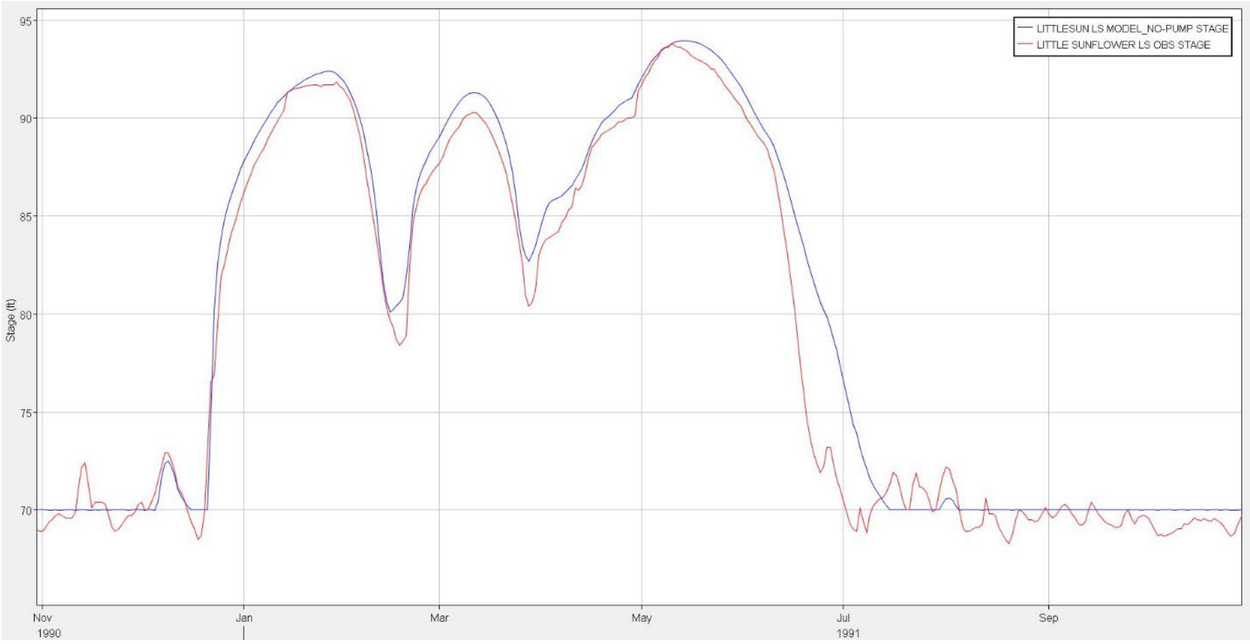


Figure 1-56. Little Sunflower Control Structure 1991 Calibration.

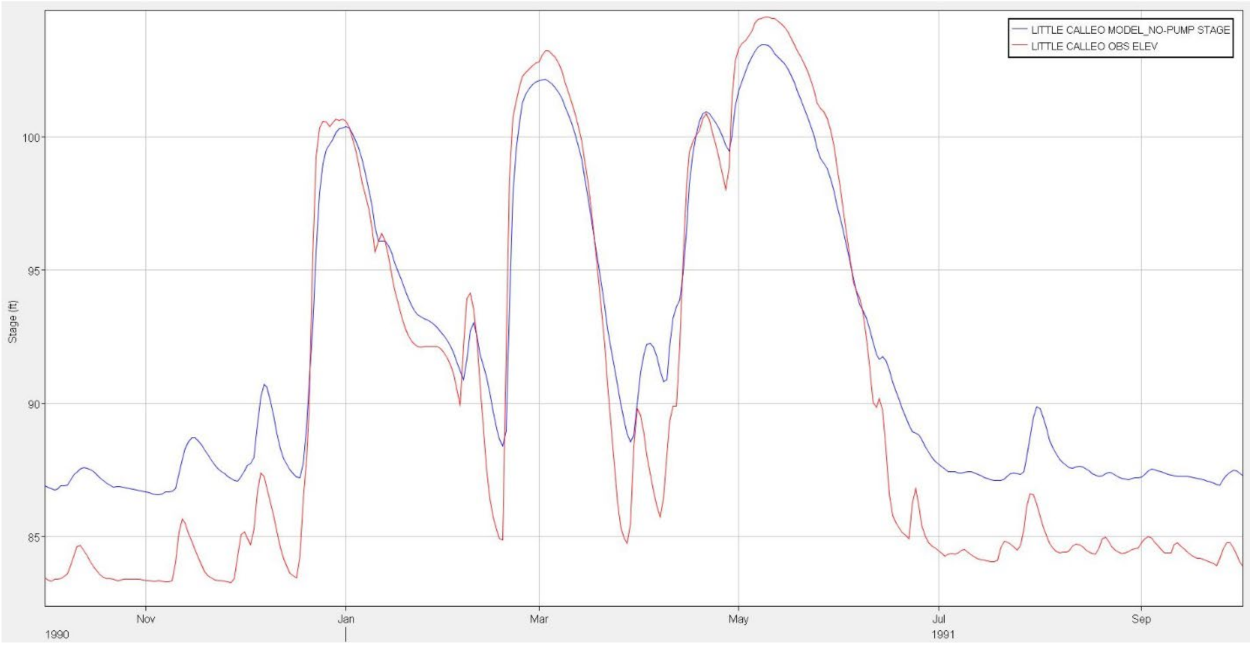


Figure 1-57. Big Sunflower at Little Calleo 1991 Calibration.

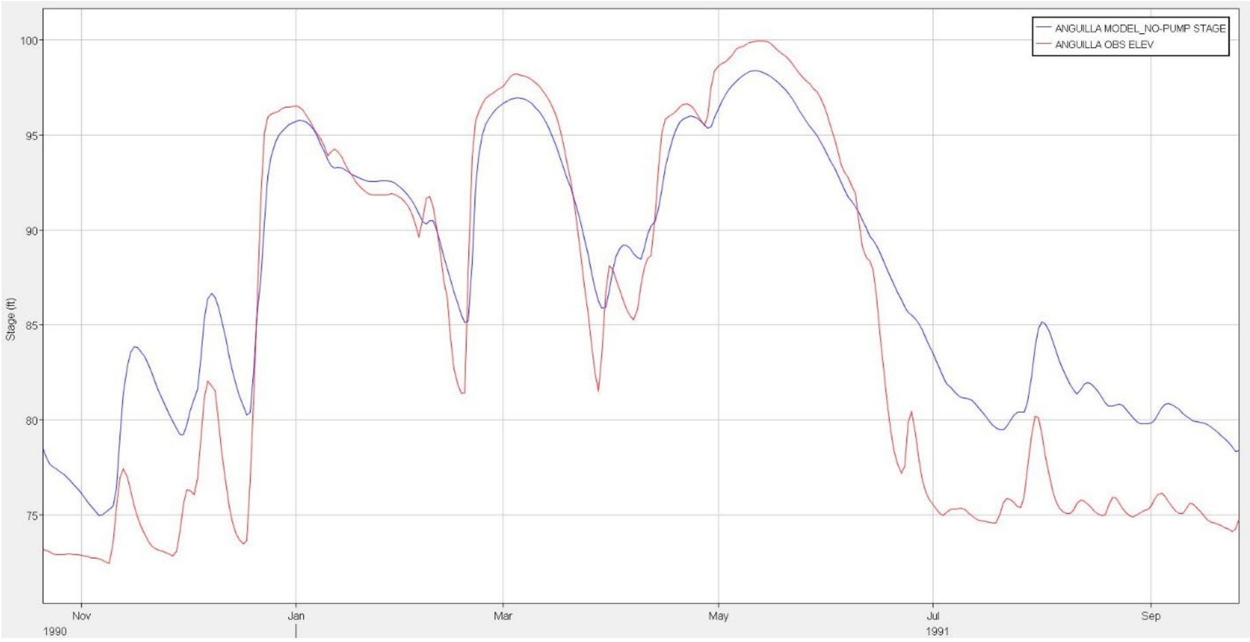


Figure 1-58. Big Sunflower at Anguilla 1991 Calibration.

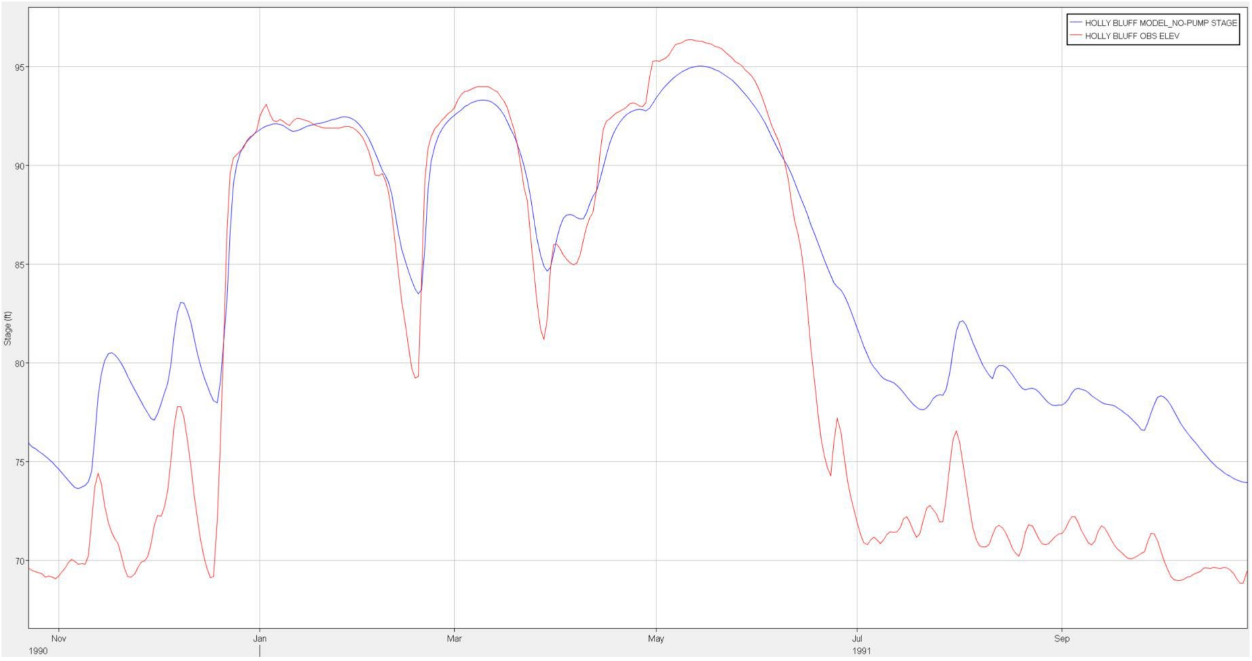


Figure 1-59. Big Sunflower at Holly Bluff Calibration 1991.

Figure 1-6-60 through Figure 1-7-71 shows the 2004 calibration. The 2004 calibration had the highest uncertainty with the precipitation data. The peaks for this year were lower than the observed data, and the timing was off at certain gages. Changing calibration parameters drastically to correct for the high level of uncertainty in years, such as 2004, would have decreased the level of accuracy seen in years that the precipitation had less uncertainty.

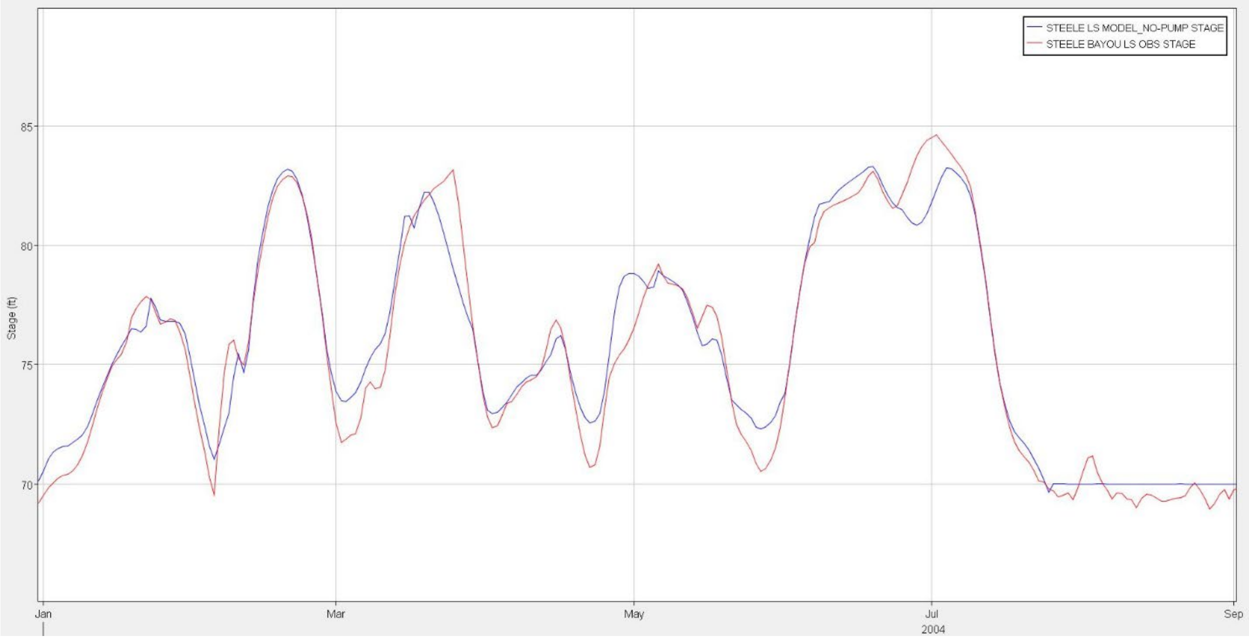


Figure 1-60. Steele Bayou Landside 2004 Calibration.

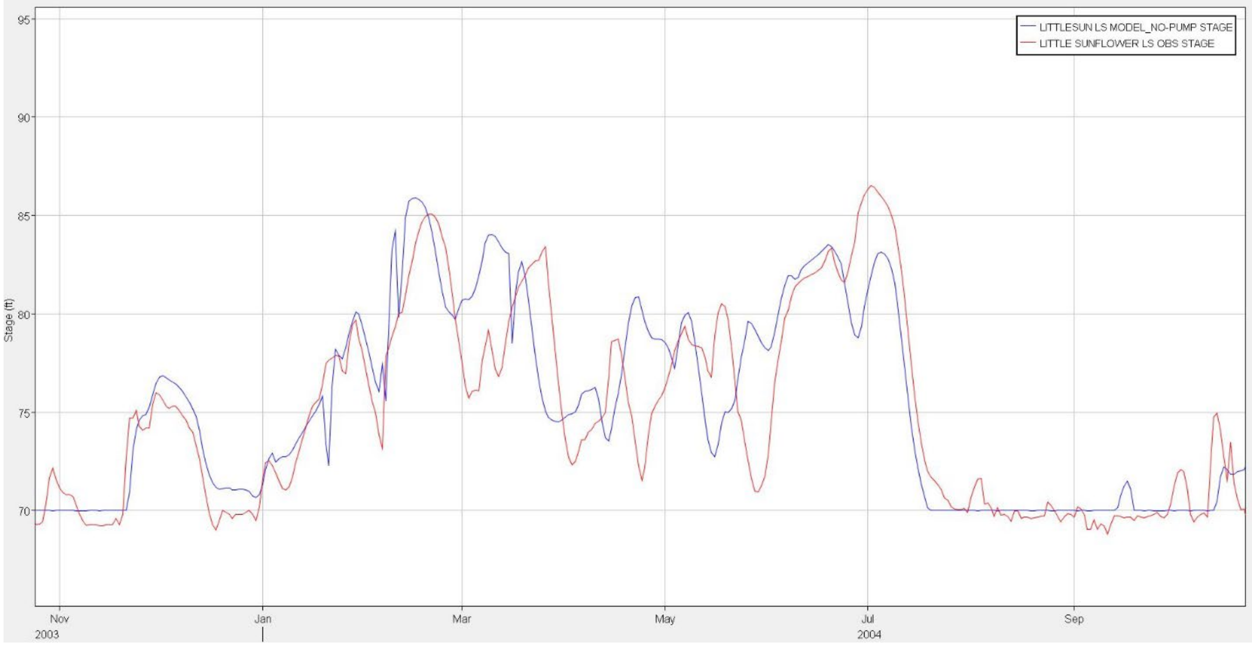


Figure 1-61. Little Sunflower Control Structure 2004 Calibration.

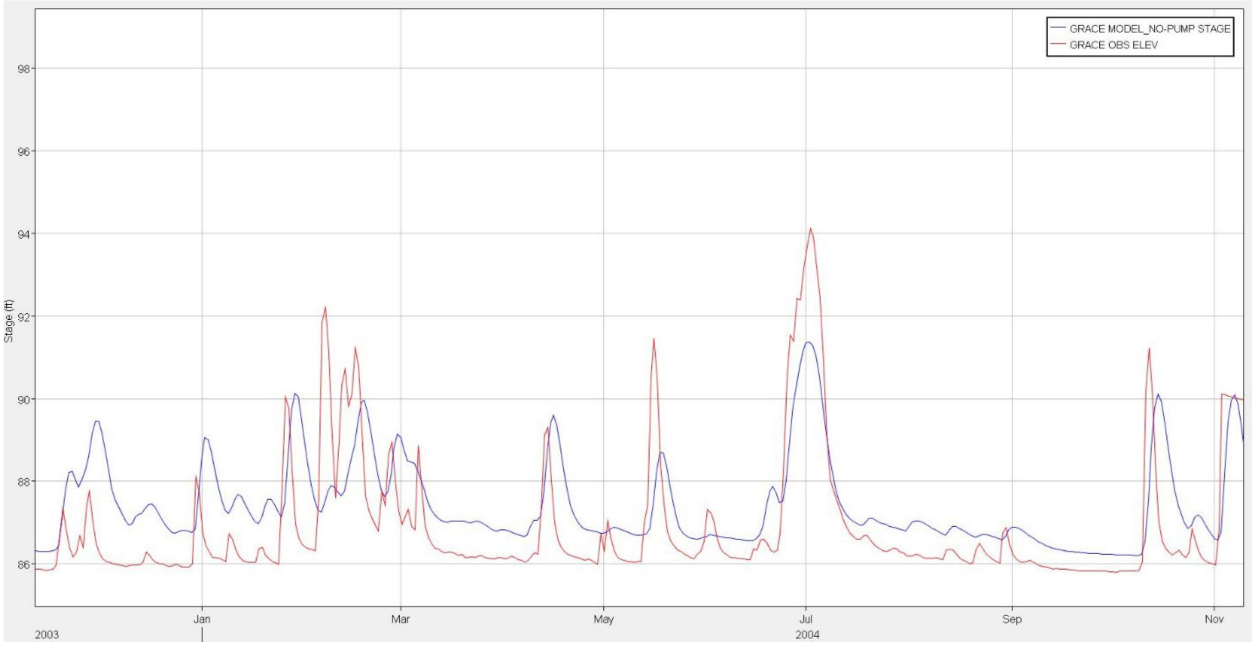


Figure 1-62. Steele Bayou at Grace 2004 Calibration.

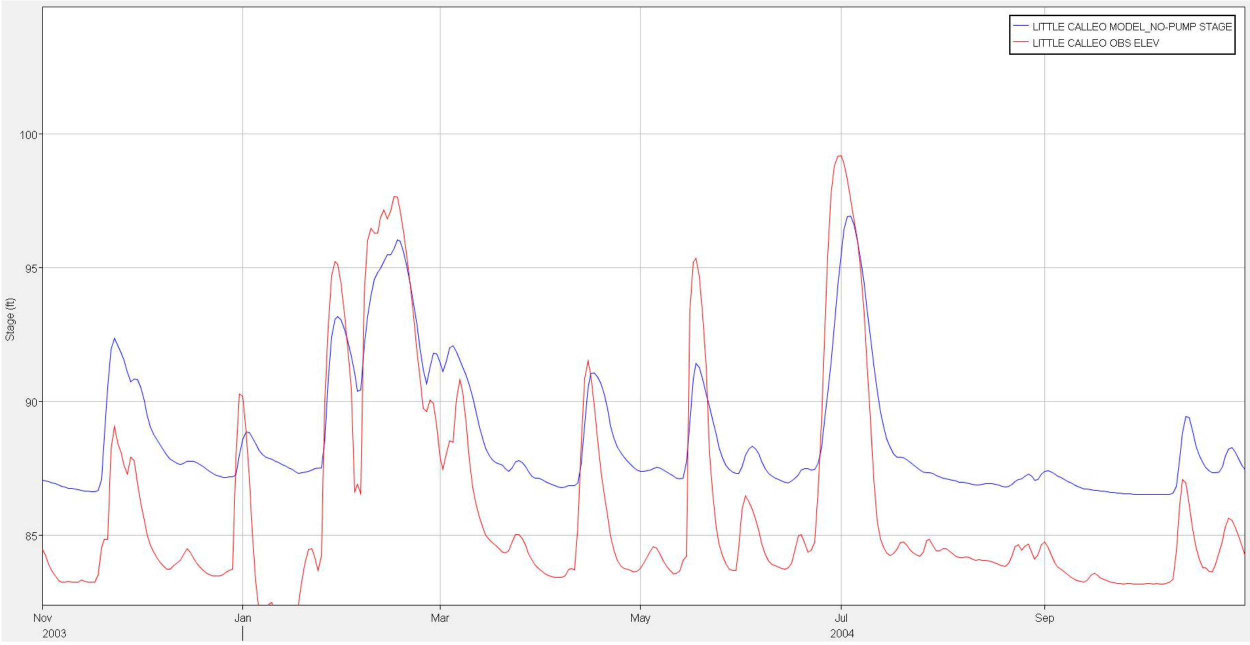


Figure 1-63. Big Sunflower at Little Calleo 2004 Calibration.

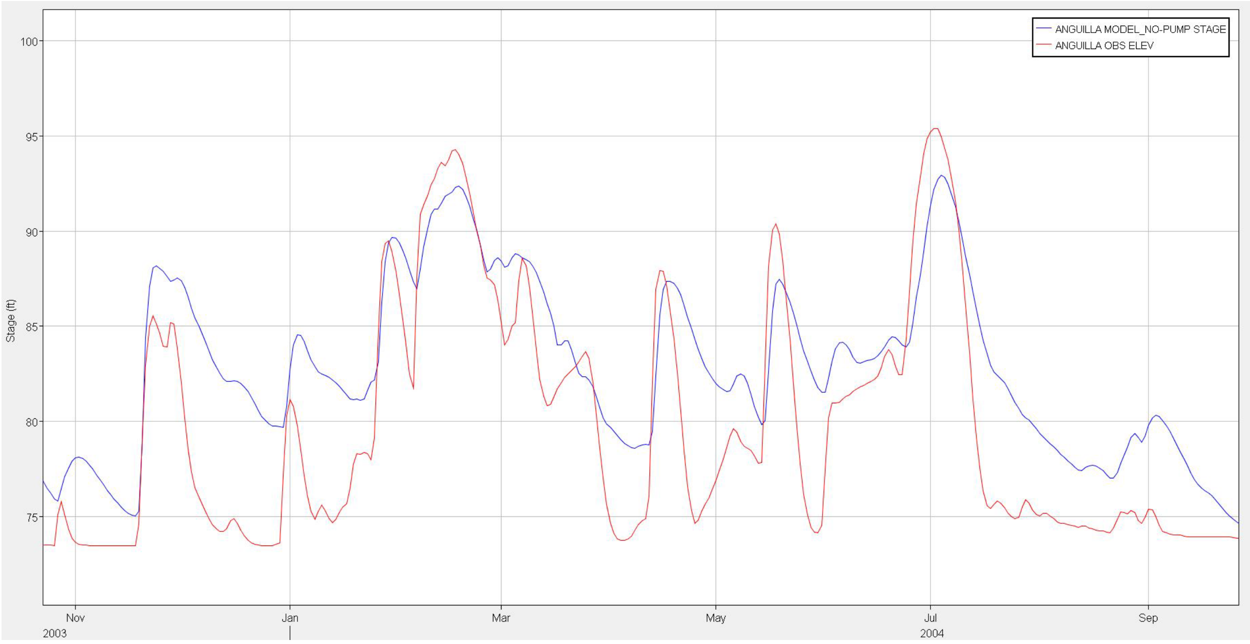


Figure 1-64. Big Sunflower at Anguilla 2004 Calibration.

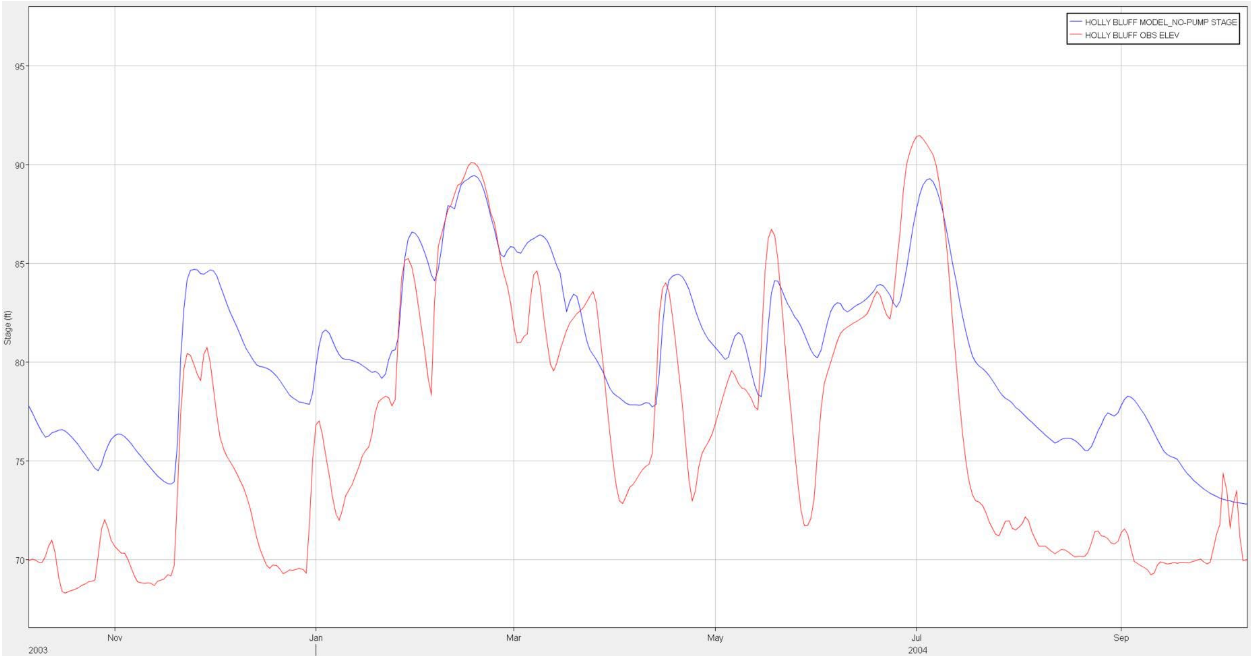


Figure 1-65. Big Sunflower at Holly Bluff 2004 Calibration.

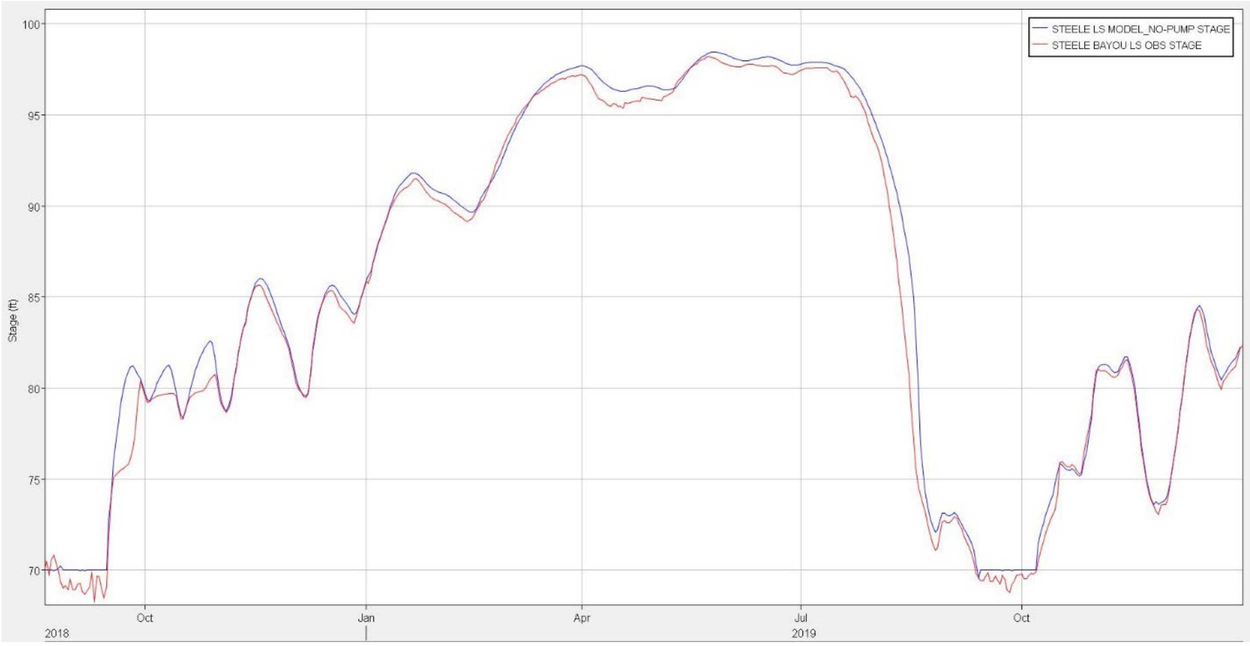


Figure 1-66. Steele Bayou Landside 2019 Calibration.

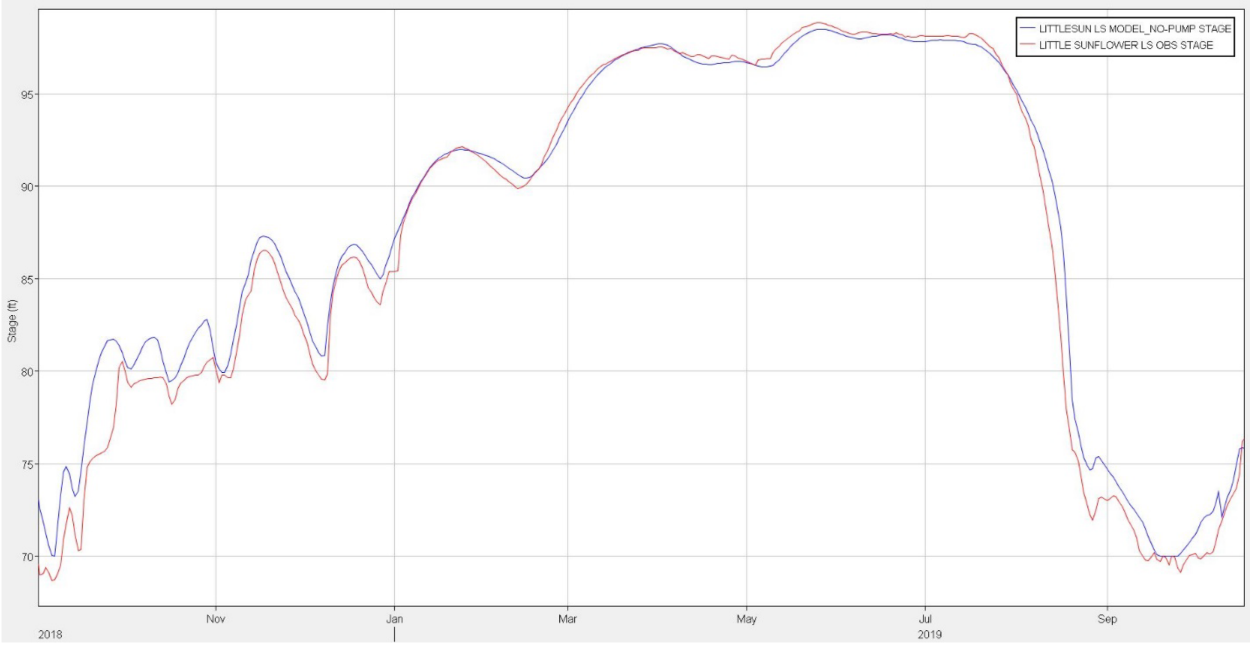


Figure 1-67. Little Sunflower Control Structure Landside 2019 Calibration.

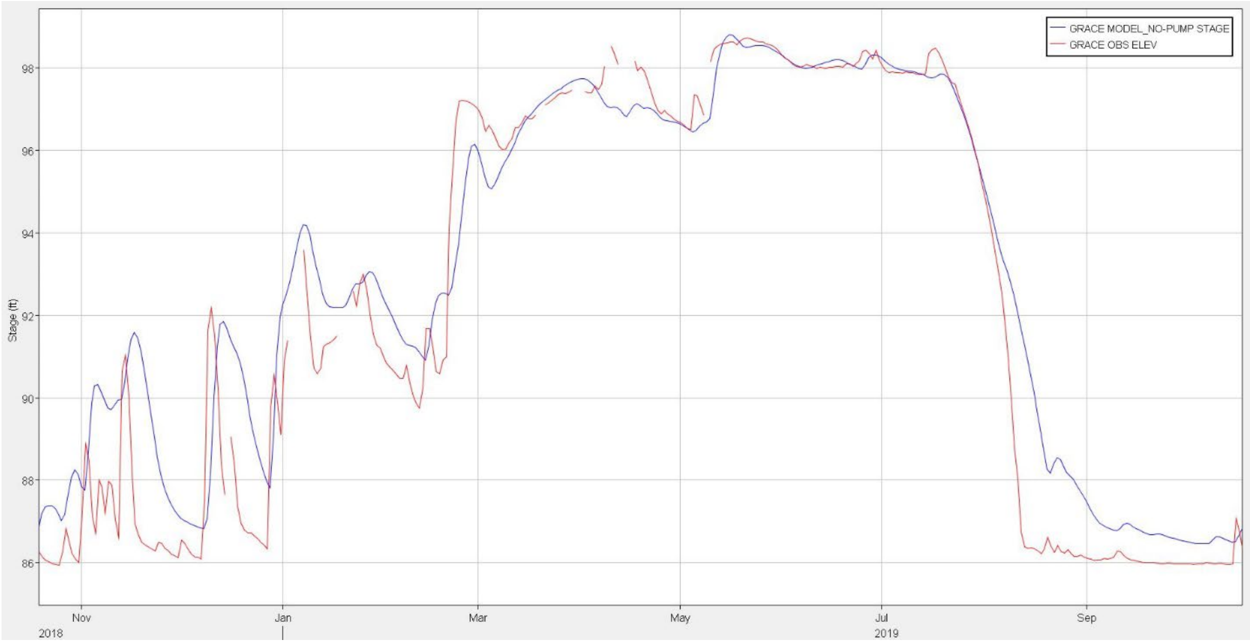


Figure 1-68. Steele Bayou at Grace 2019 Calibration.

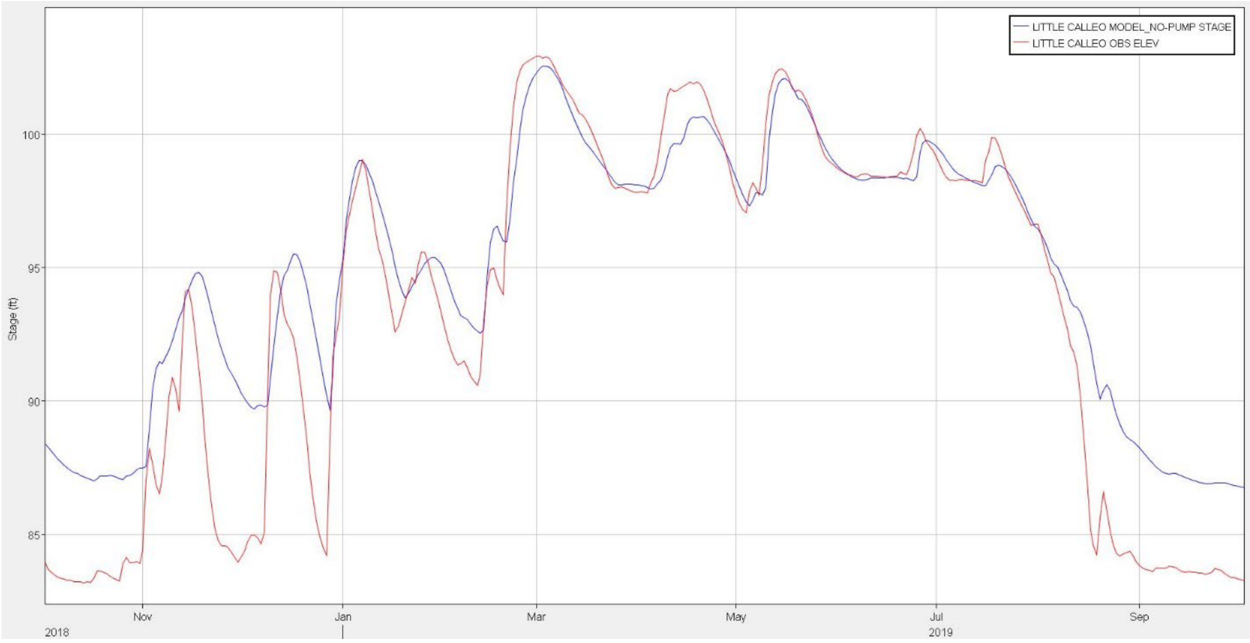


Figure 1-69. Big Sunflower at Little Calleo 2019 Calibration.

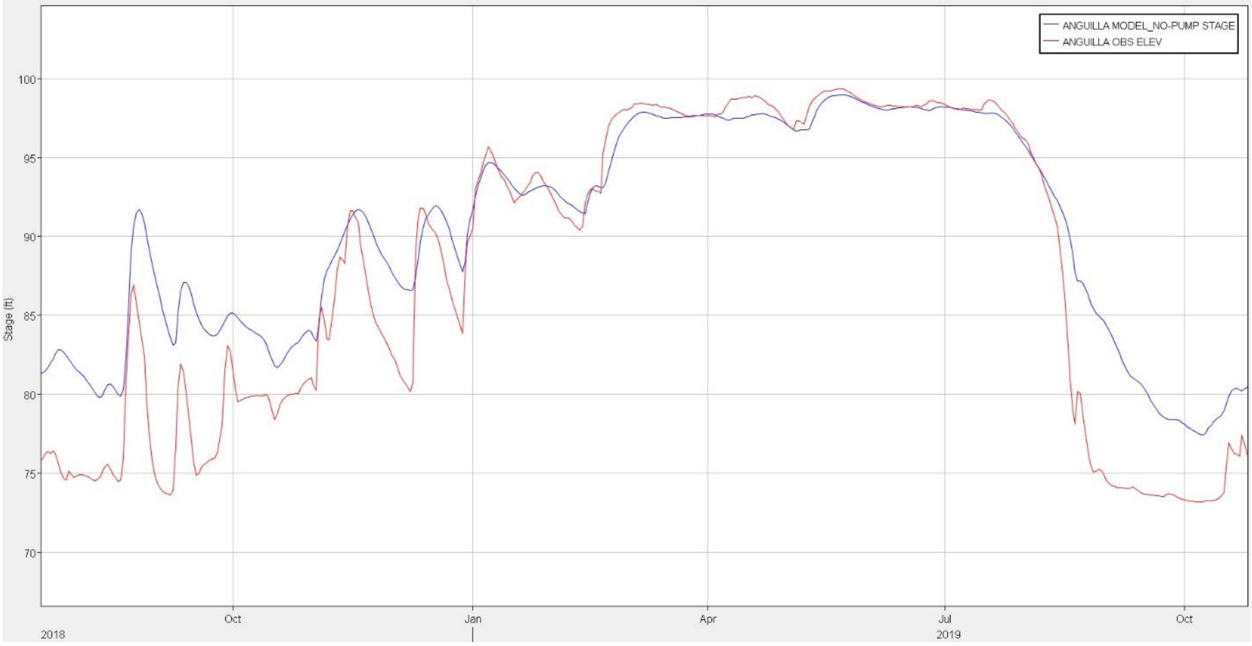


Figure 1-70. Big Sunflower at Anguilla 2019 Calibration.

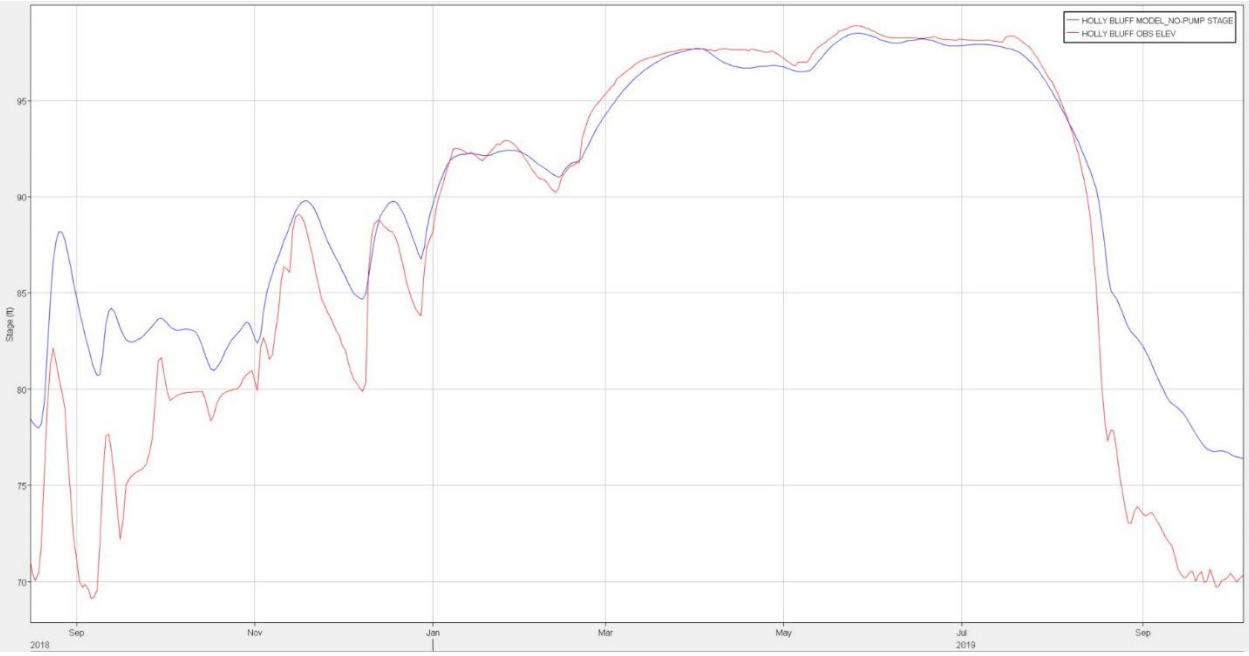


Figure 1-71. Big Sunflower at Holly Bluff 2019 Calibration.

Validation

Validation runs were performed on four years in addition to the calibration runs. These years included 1983, 1997, 2005, and 2010, and were years that experienced similar flooding to the years used for calibration. These runs ensured the calibration parameters were not falsely skewing the data to appear accurate. Once the model was calibrated and verified, the "Period-of-record" run was made.

Figure 1-72 to Figure 1-83 shows some of the validation run results. The result from the verification runs show similar discrepancies to those that were identified from the calibration runs. However, validation was considered to be appropriate because the results at Steele Bayou and Little Sunflower showed the same level of accuracy as the calibration runs. The timing between the calibration and validation results did slightly differ at Steele Bayou at Grace. However, after changing parameters in both the HMS and RAS models, it was concluded that the difference in timing was caused by errors in the timing of the precipitation data.

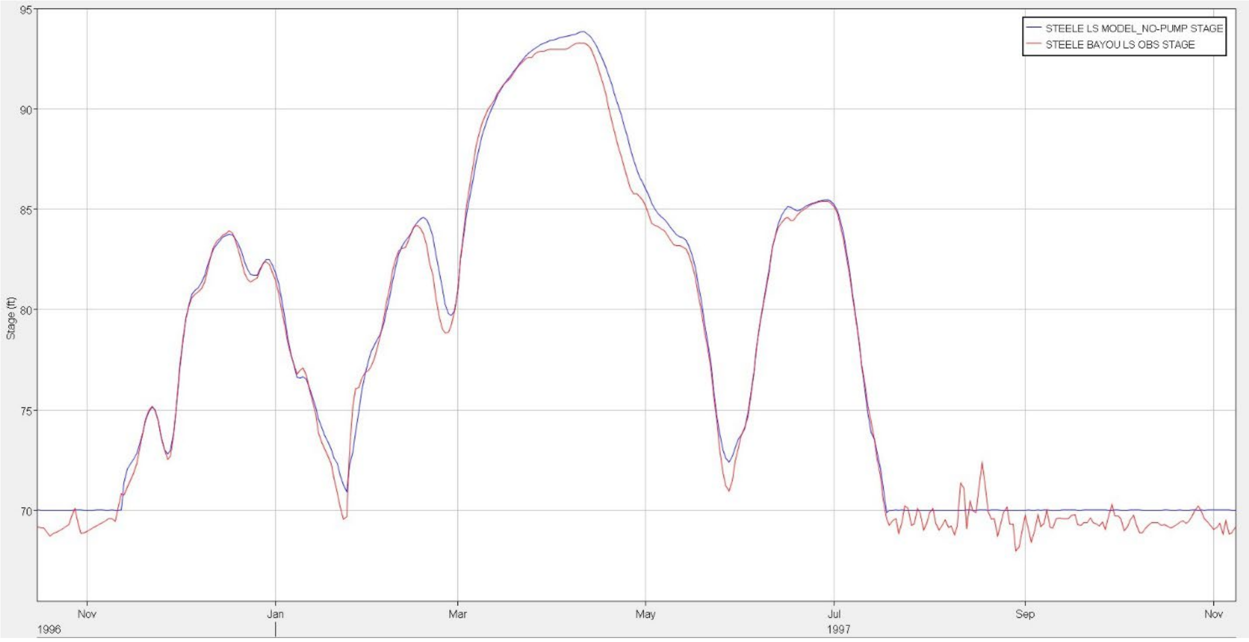


Figure 1-72. Steele Bayou Landside 1997 Validation.

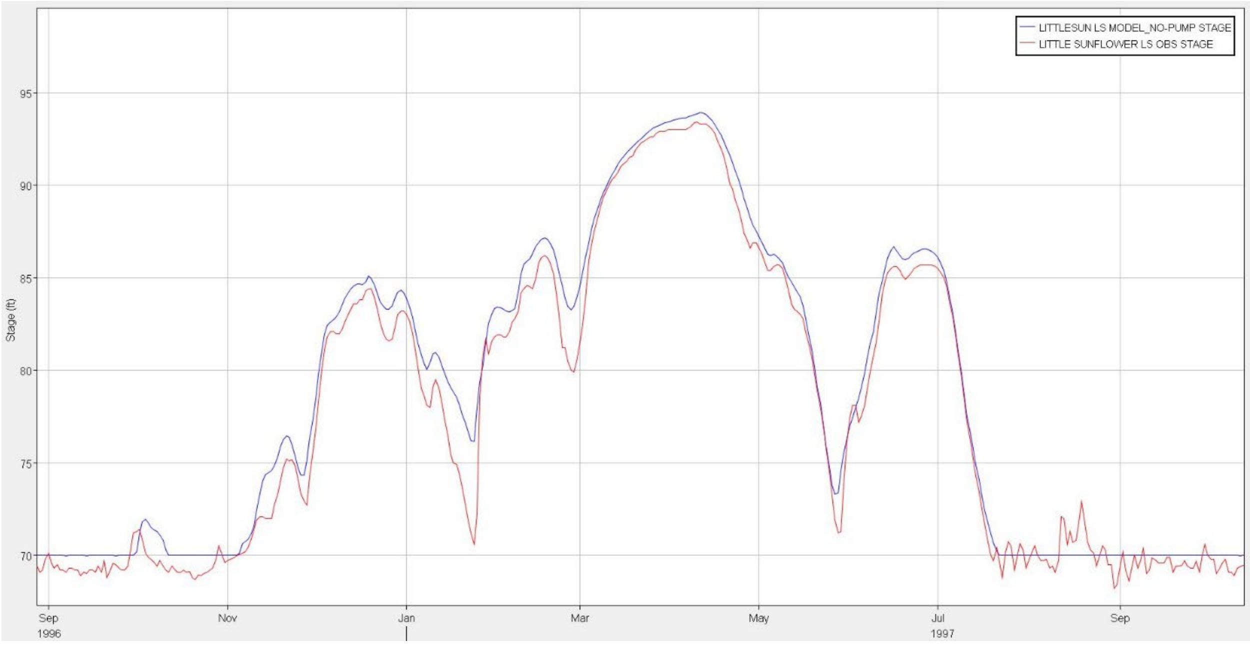


Figure 1-73. Little Sunflower Control Structure 1997 Validation.

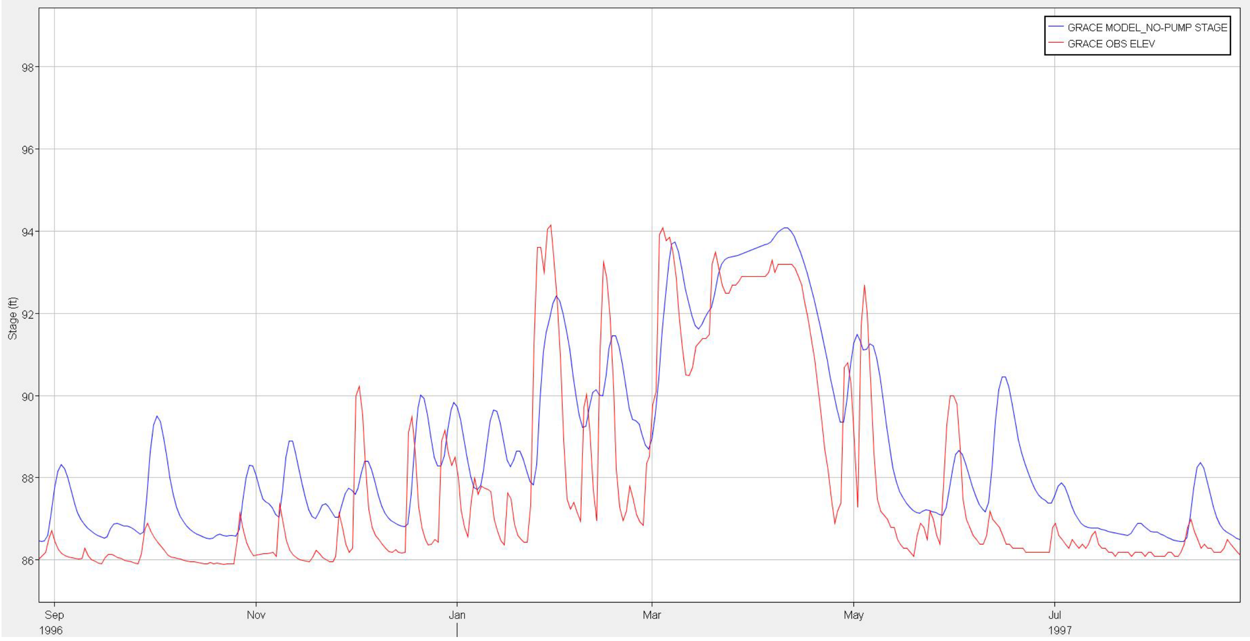


Figure 1-74. Steele Bayou at Grace 1997 Validation.

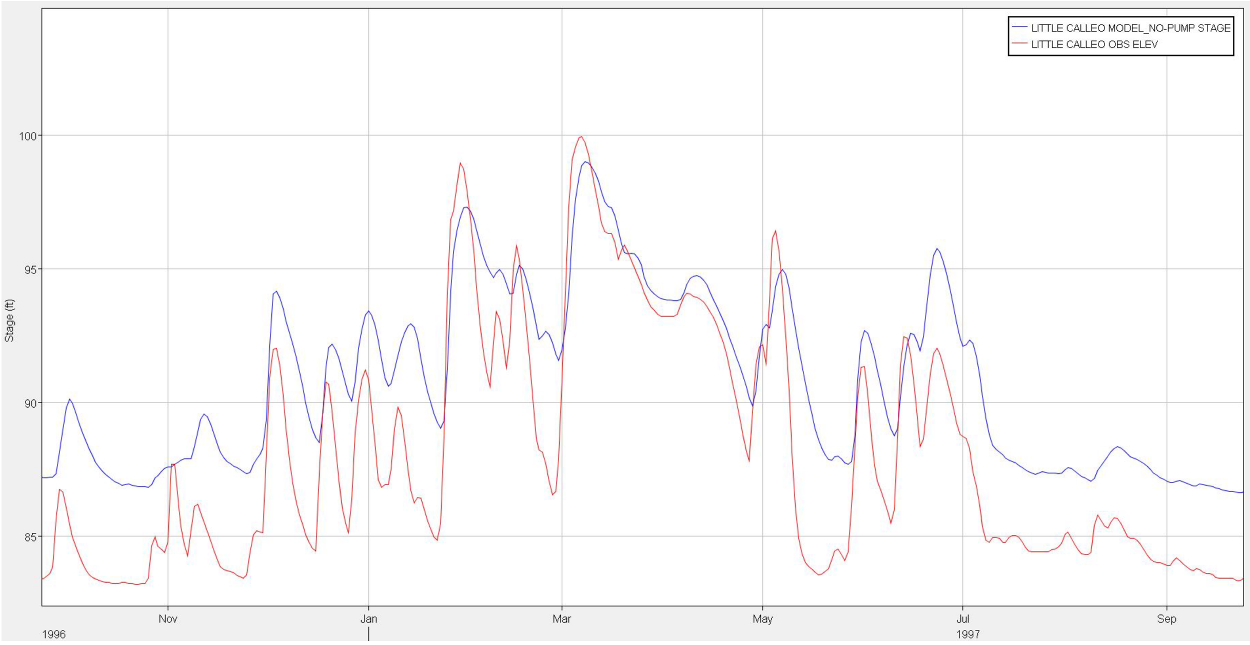


Figure 1-75. Big Sunflower at Little Calleo 1997 Validation.

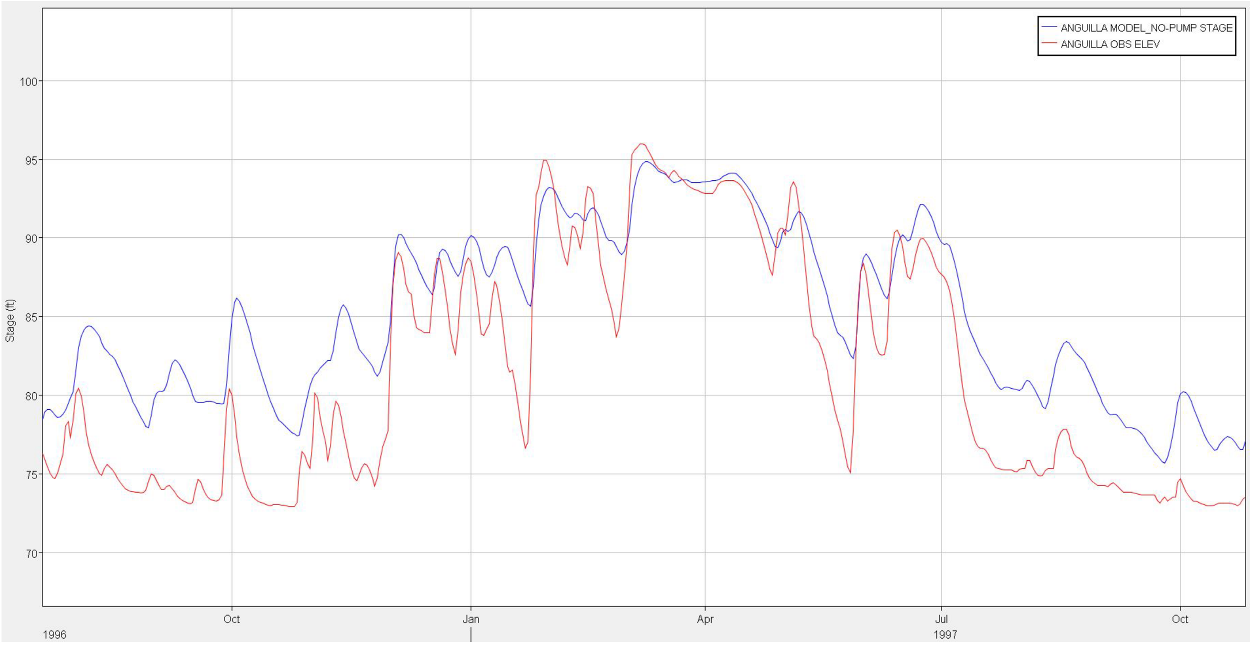


Figure 1-76. Big Sunflower at Anguilla 1997 Validation.

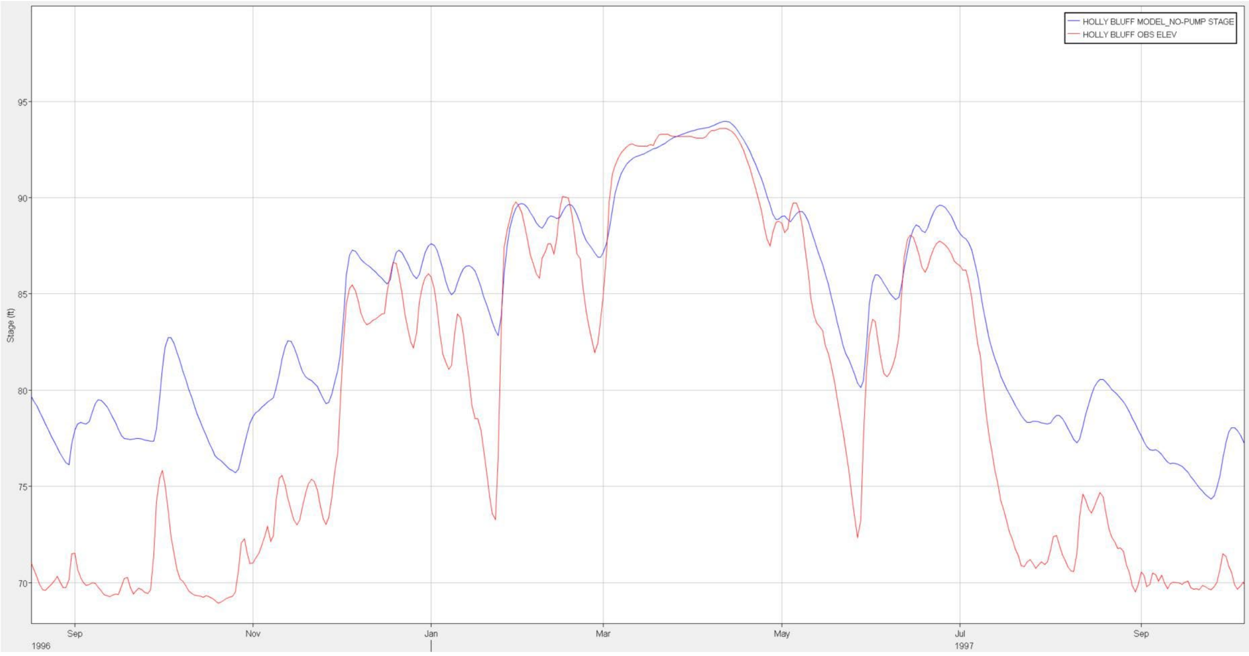


Figure 1-77. Big Sunflower at Holly Bluff 1997 Validation.

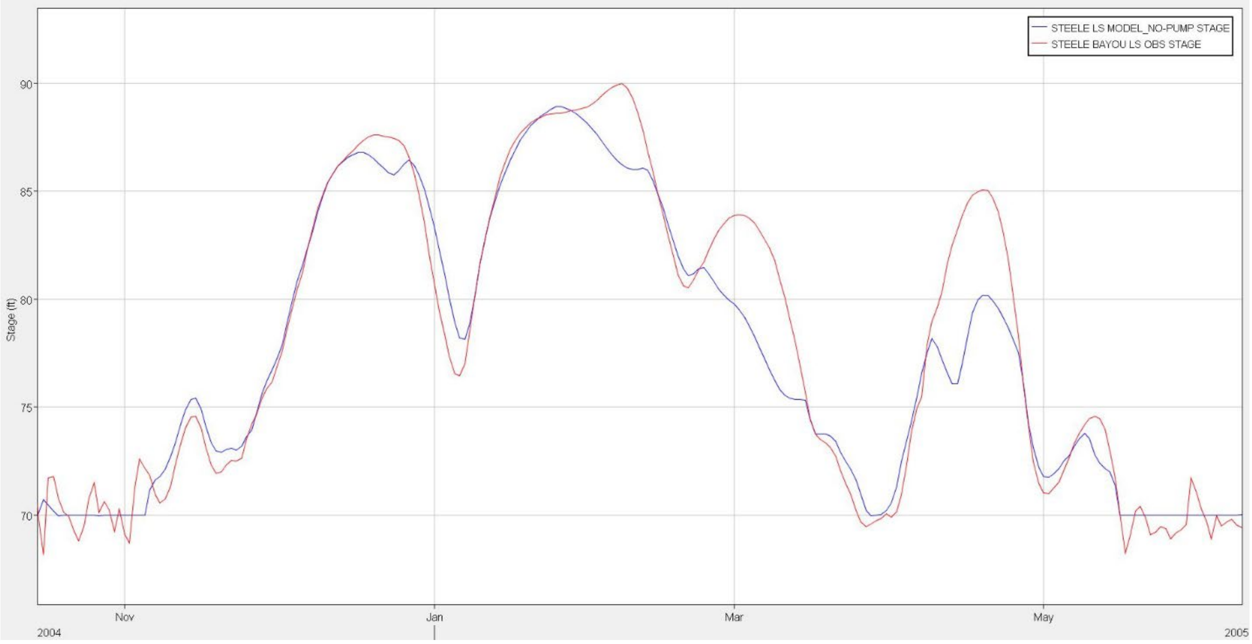


Figure 1-78. Steele Bayou Landside 2005 Validation.

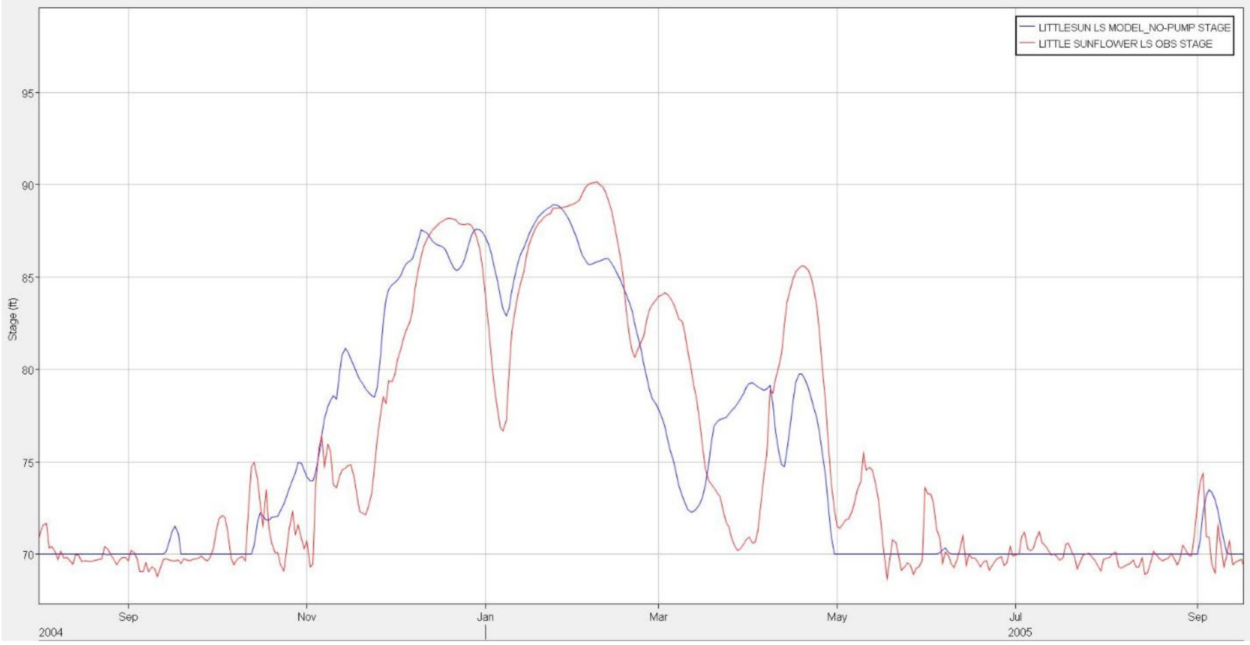


Figure 1-79. Little Sunflower Control Structure 2005 Validation.

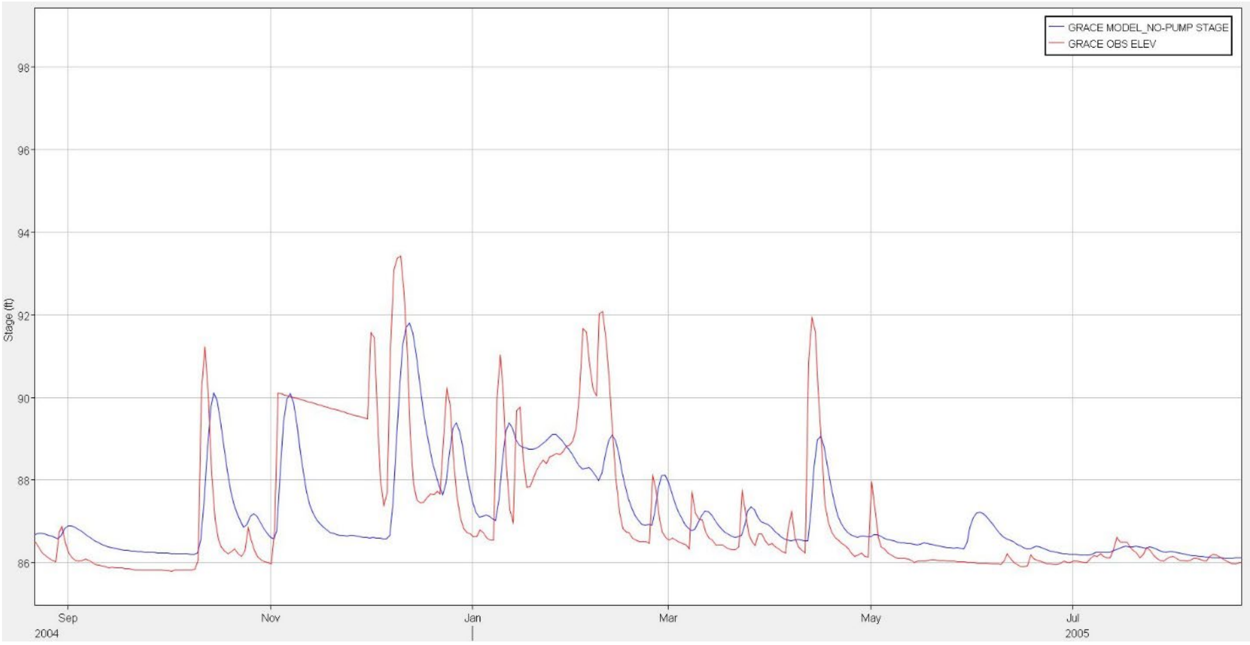


Figure 1-80. Steele Bayou at Grace 2005 Validation.

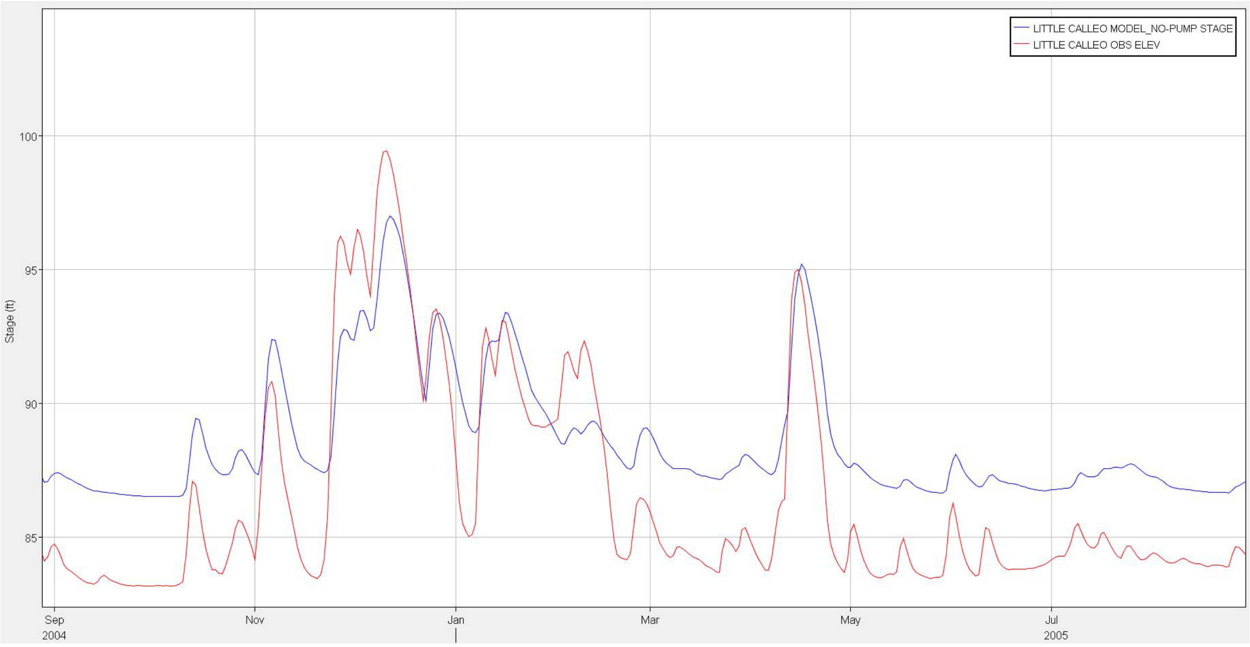


Figure 1-81. Big Sunflower at Little Calleo2005 Validation.

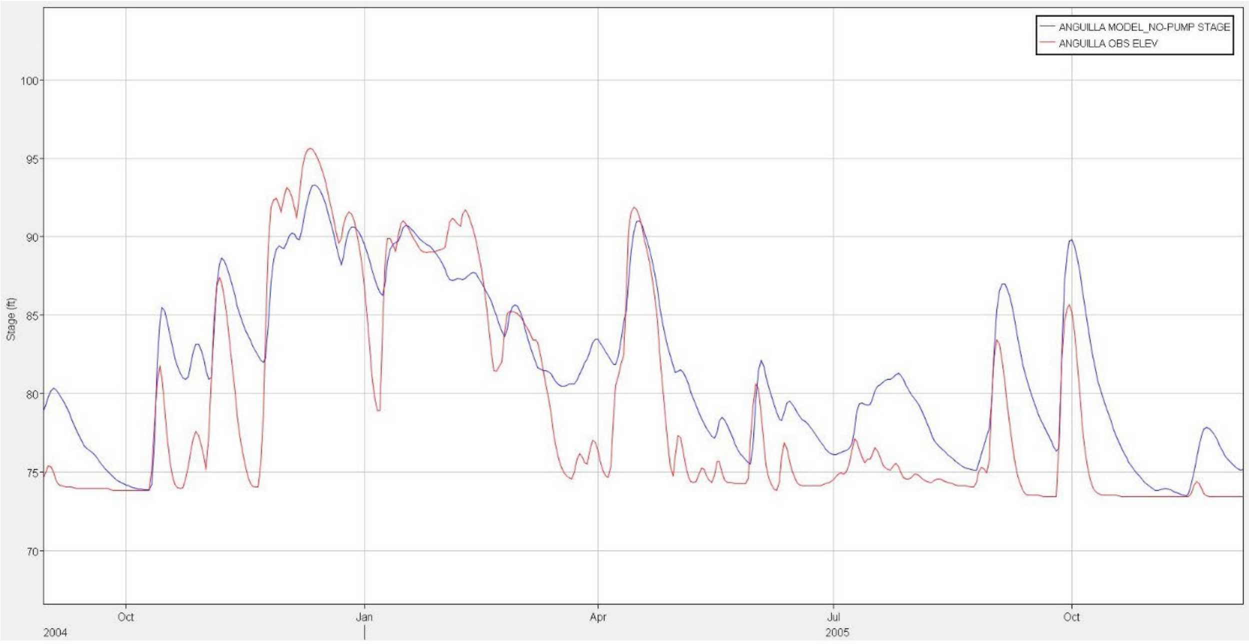


Figure 1-82. Big Sunflower at Anguilla 2005 Validation.

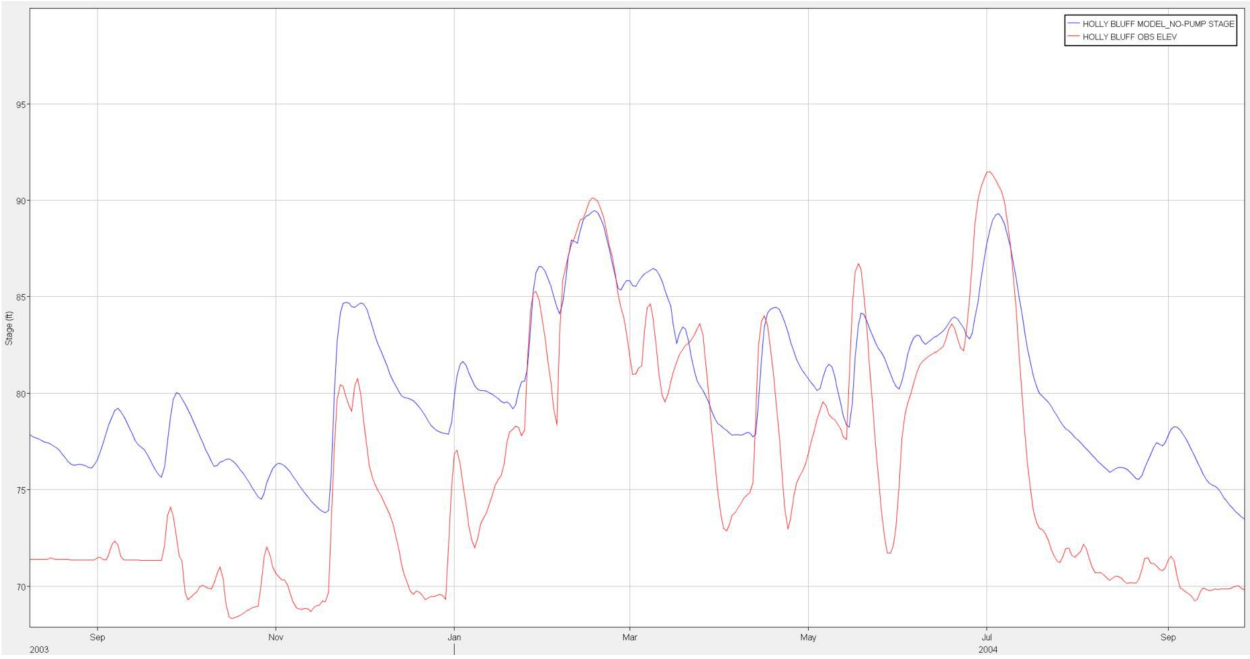


Figure 1-83. Big Sunflower at Holly Bluff 2005 Validation.

Sensitivity

The sensitivity of the model to Manning's "n" values and precipitation inputs were tested to determine which had more of an impact on calibration. The Manning's "n" value for cultivated crop had the largest impact on results, relative to other Manning's values because it is the most prevalent value throughout the area. The Manning's "n" value for cultivated crop was increased from an original value of 0.03 to 0.05 to slow the flow of water after it overtopped the main channel area. The Manning's "n" of the channels was also tested. These values did not significantly impact calibration results and were rarely changed after initial runs.

The precipitation data had a more significant impact on calibration results. Much of the precipitation data was obtained with a degree of uncertainty. The high level of uncertainty, associated with the precipitation data, made model calibration more difficult to recreate observed stages, particularly for the 2004 event. Due to this level of uncertainty, the period-of-record was run using results based on two different precipitation datasets, precipitation from gages stations from NCEI and gridded Stage IV precipitation from UCAR. Refer to the 'Hydrologic Model Setup' section above for more information on precipitation calculations. In some cases, weekly precipitation values showed as much as a 40% variation between the two precipitation datasets. These results proved the model was more sensitive to the change in precipitation data than the Manning's "n" values when tested. However, the level of uncertainty between the two precipitation datasets is unknown.

Period-of-record Runs

The period-of-record (POR) was considered to be the 43 years from 01 January 1978 to 31 December 2020. The POR began on 01 January 1978, after the Yazoo Backwater Levee System and the Little Sunflower Control System was completed, which eliminated the need to use simulated data for base conditions. To decrease the run time and the possibility of data loss, the POR was divided into 5-year sections, with the beginning of each section including the last two months of the previous section to allow the model to properly warm-up.

RESULTS

Water surface elevations (WSEL) were taken from six gage locations throughout the basin: Steele Bayou at Grace, Steele Bayou Control Structure landside, Little Sunflower Control Structure landside, Big Sunflower at Little Calleo, Anguilla, and Holly Bluff. The Figure 1-84 through Figure 1-101 shows a comparison of the without-pump dataset and the with-pump (alternative 2) dataset. For the model runs shown on the following figures, the pump on is March 16 and pump off is October 15. Gages further upstream experienced less of a difference from the pump station than the gages at the control structures. Upstream gages also experienced less of an impact when the flooding was primarily headwater flooding versus backwater flooding.

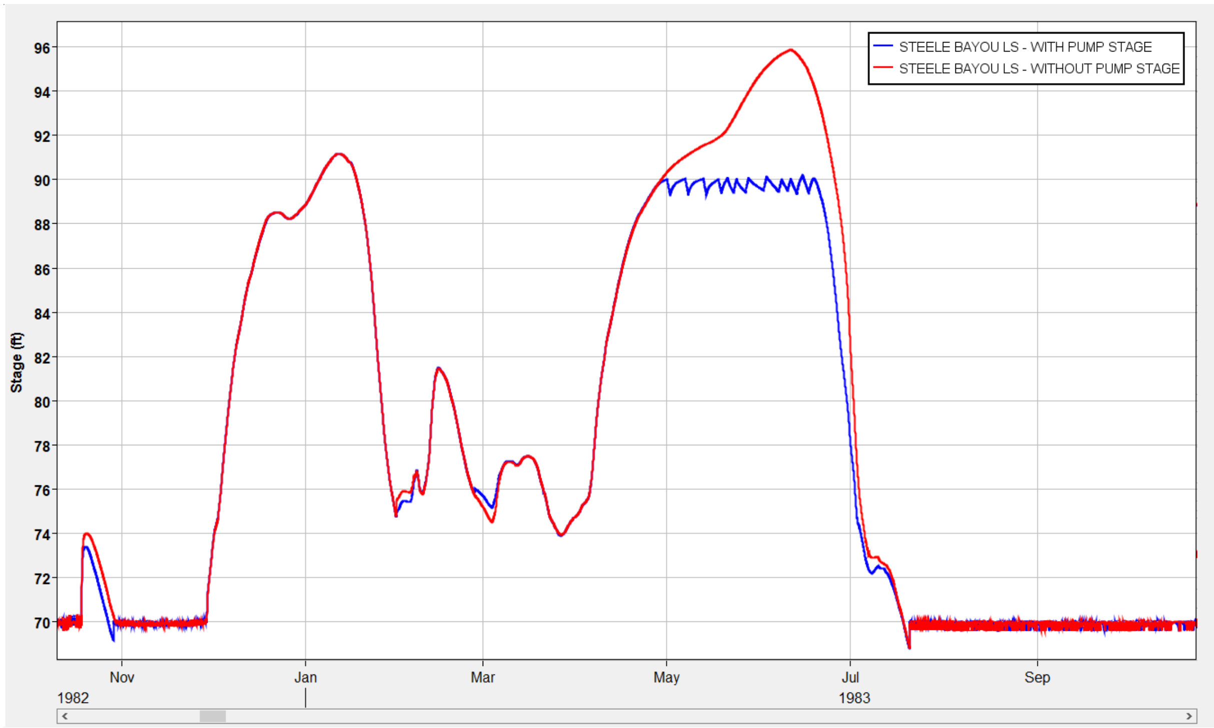


Figure 1-84. Steele Bayou Control Structure Landside 1983 Comparison.

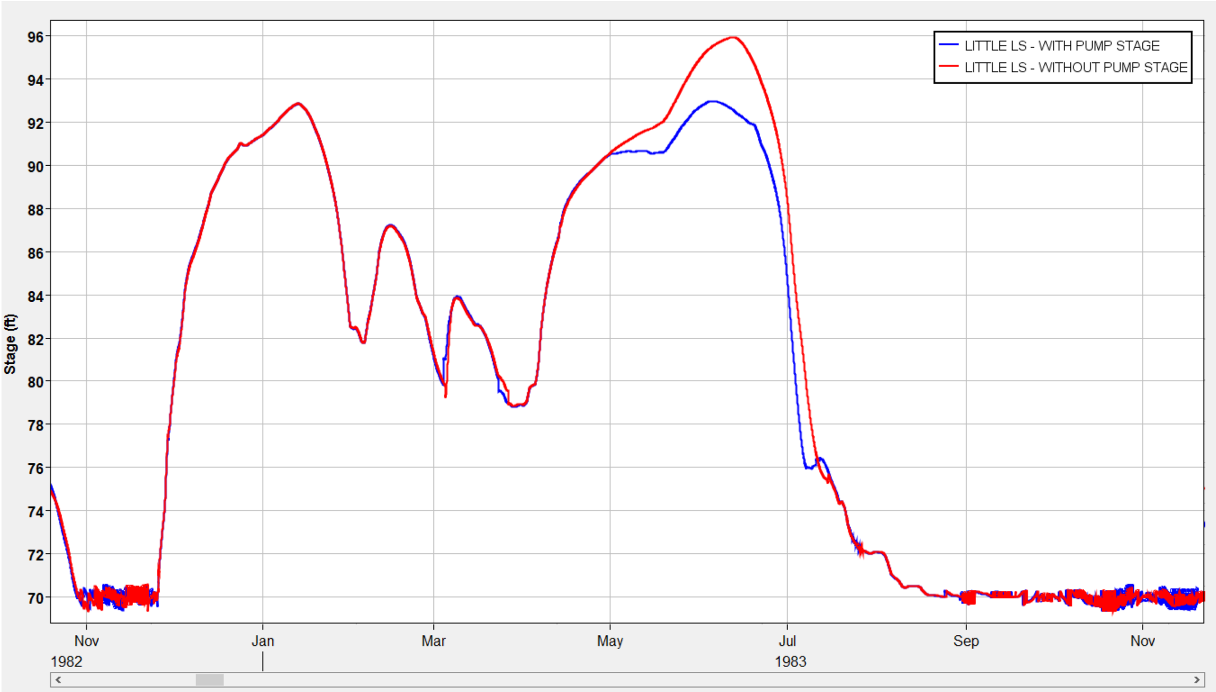


Figure 1-85. Little Sunflower Control Structure Landside 1983 Comparison.

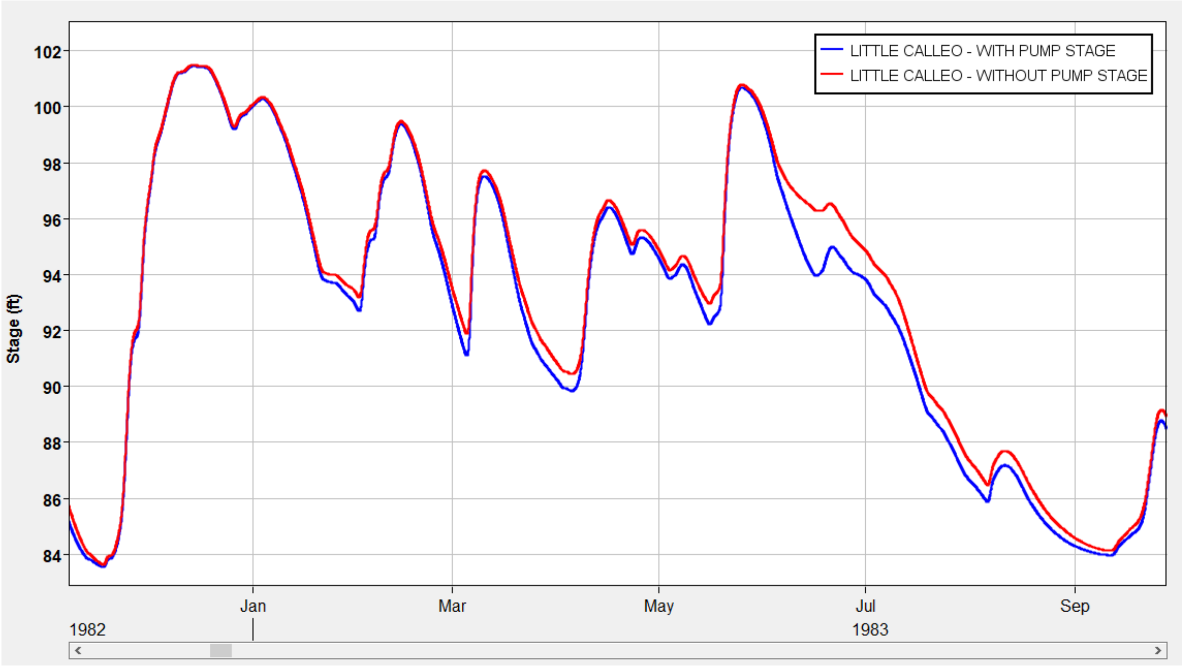


Figure 1-86. Big Sunflower at Little Calleo 1983 Comparison.

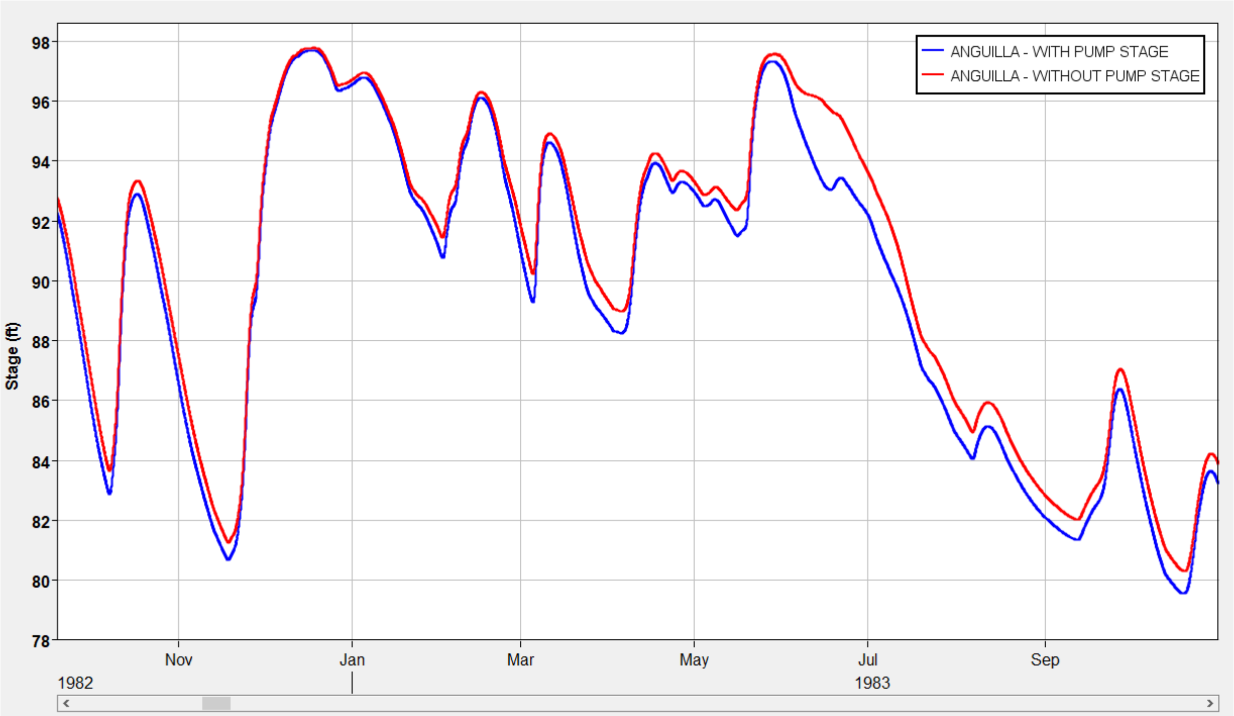


Figure 1-87. Big Sunflower at Anguilla 1983 Comparison.

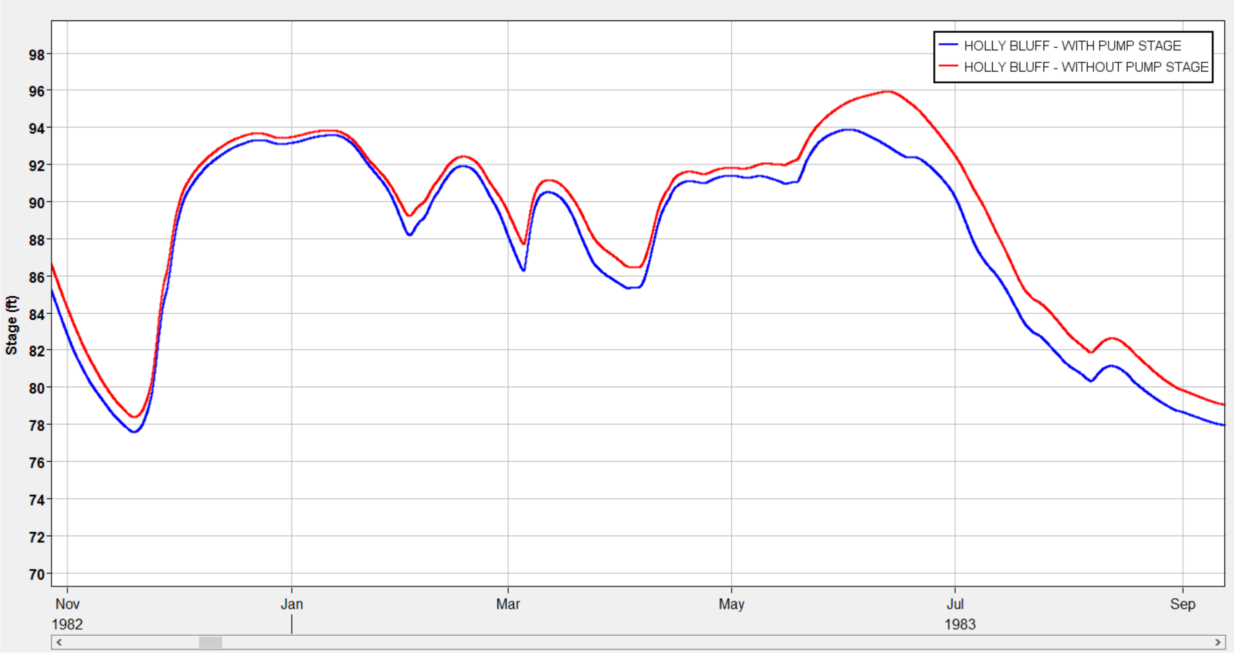


Figure 1-88. Big Sunflower at Holly Bluff 1983 Comparison.

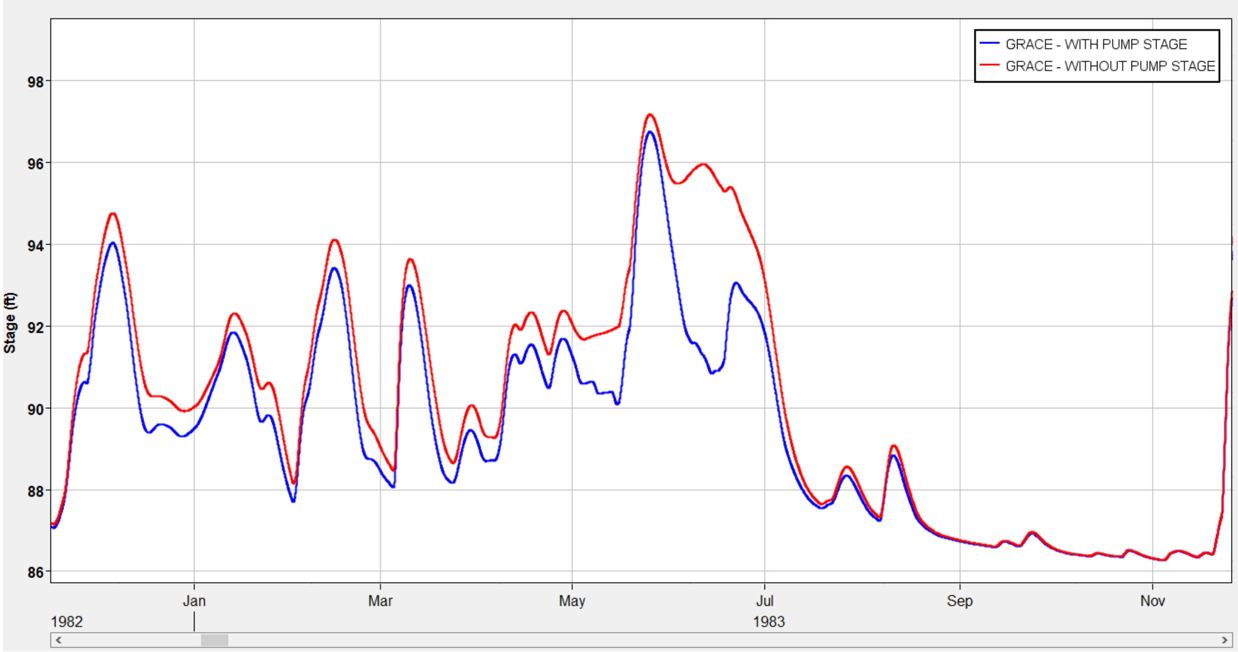


Figure 1-89. Steele Bayou at Grace 1983 Comparison.

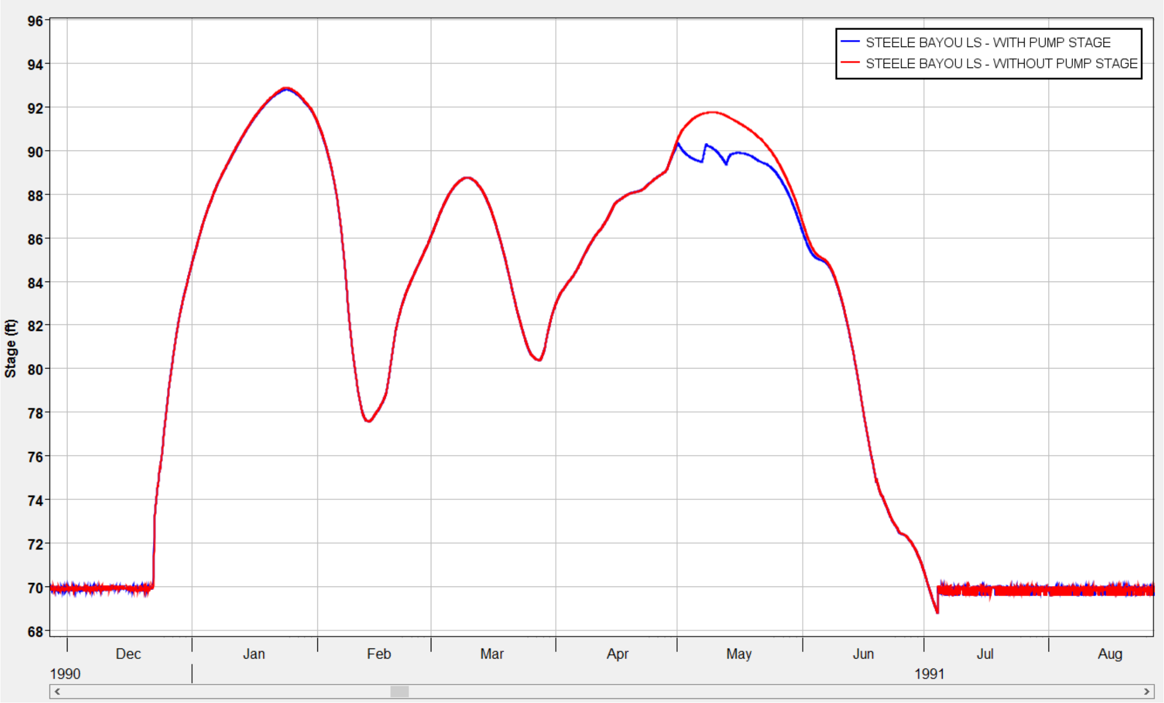


Figure 1-90. Steele Bayou Landside 1991 Comparison.

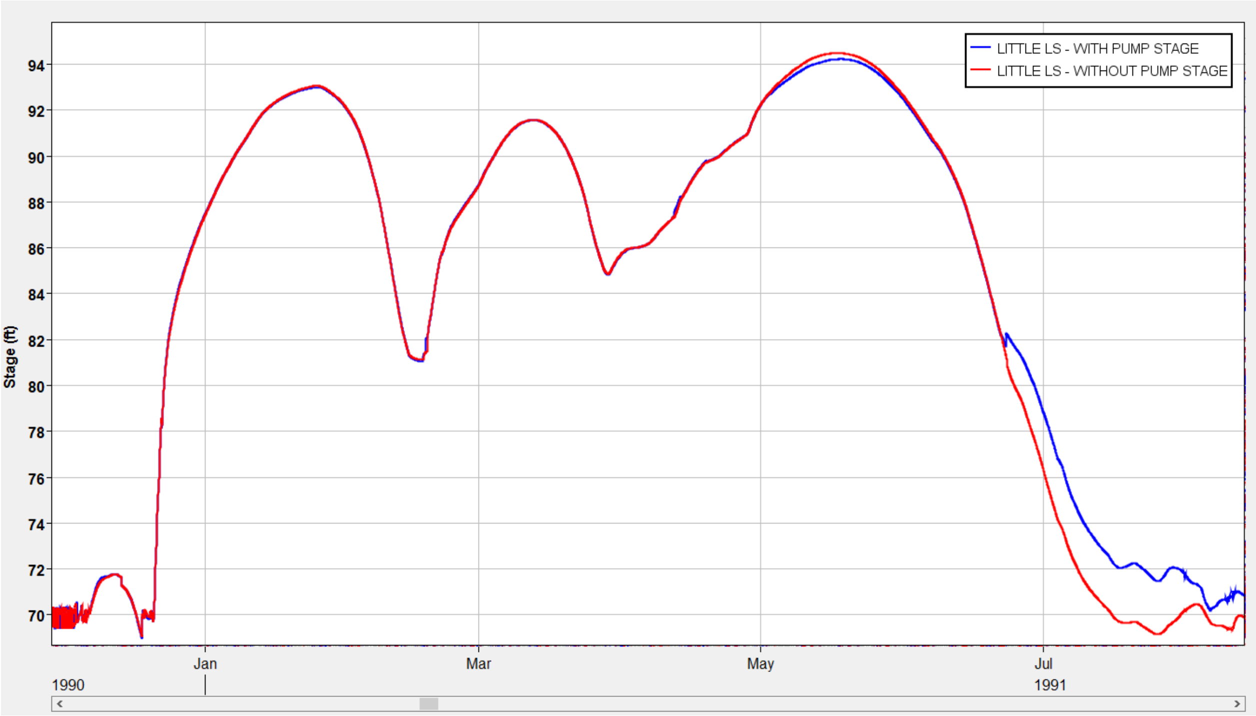


Figure 1-91. Little Sunflower Landside 1991 Comparison.

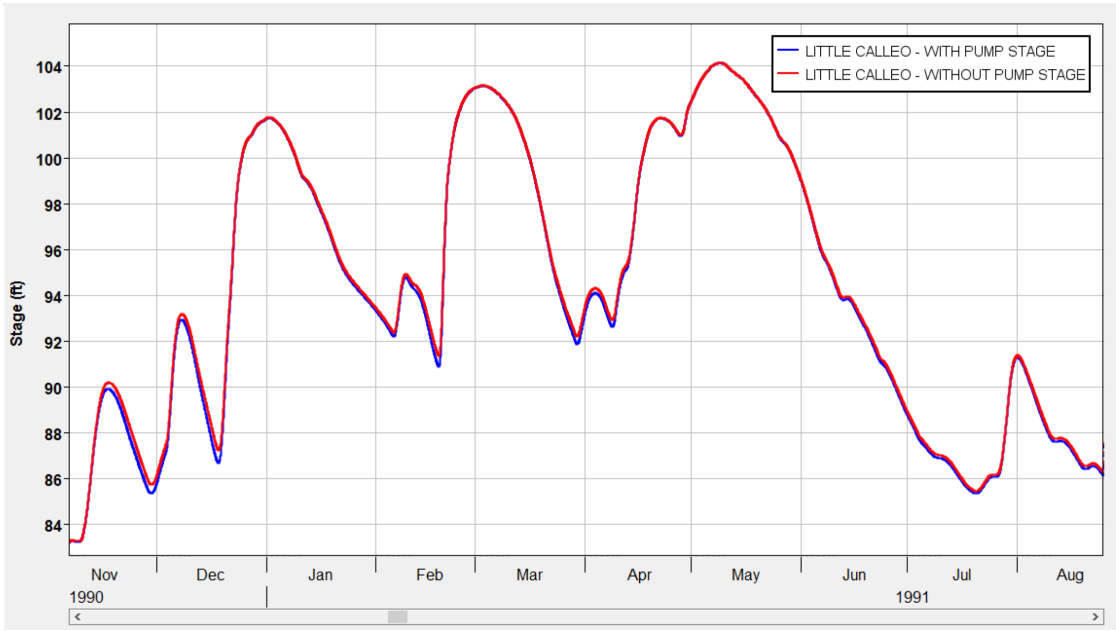


Figure 1-92. Big Sunflower at Little Calleo 1991 Comparison.

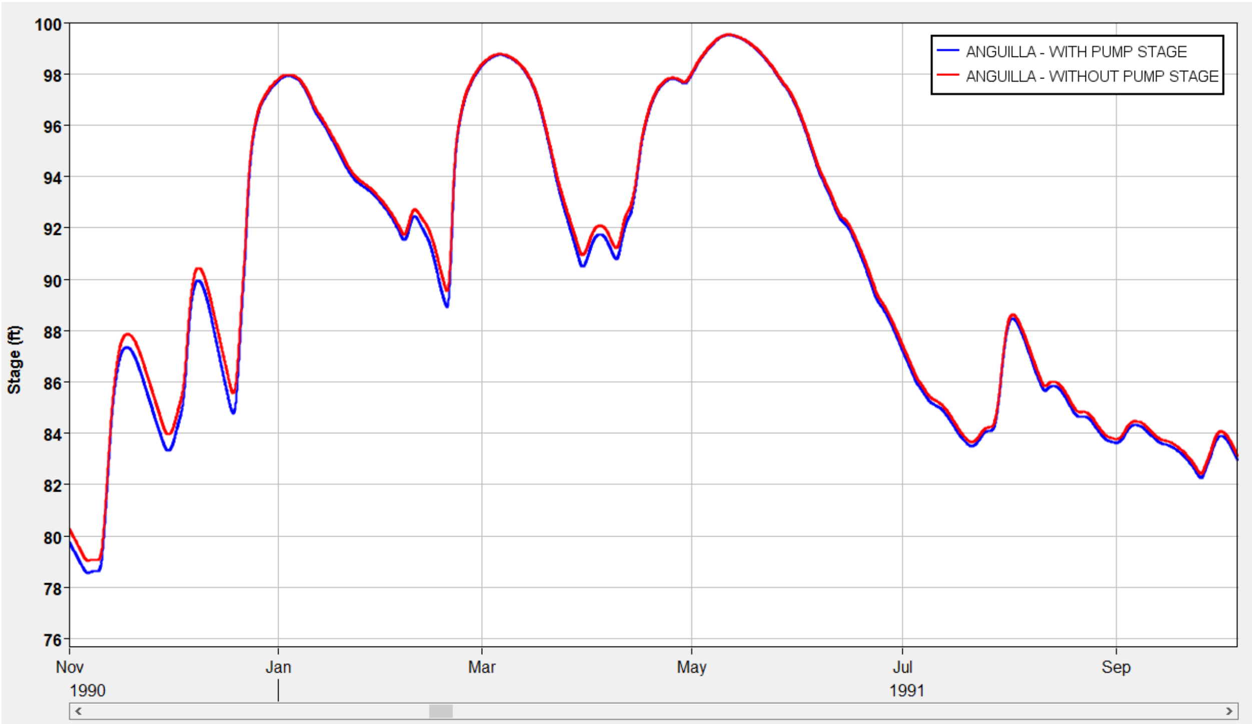


Figure 1-93. Big Sunflower at Anguilla 1991 Comparison.

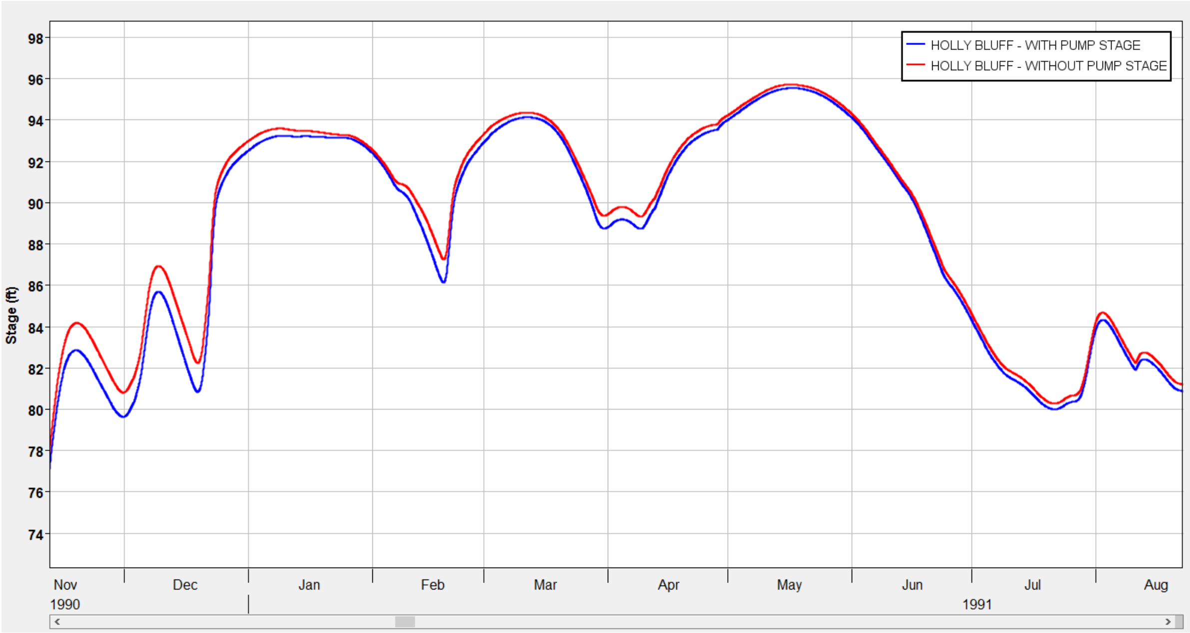


Figure 1-94. Big Sunflower at Holly Bluff 1991 Comparison.

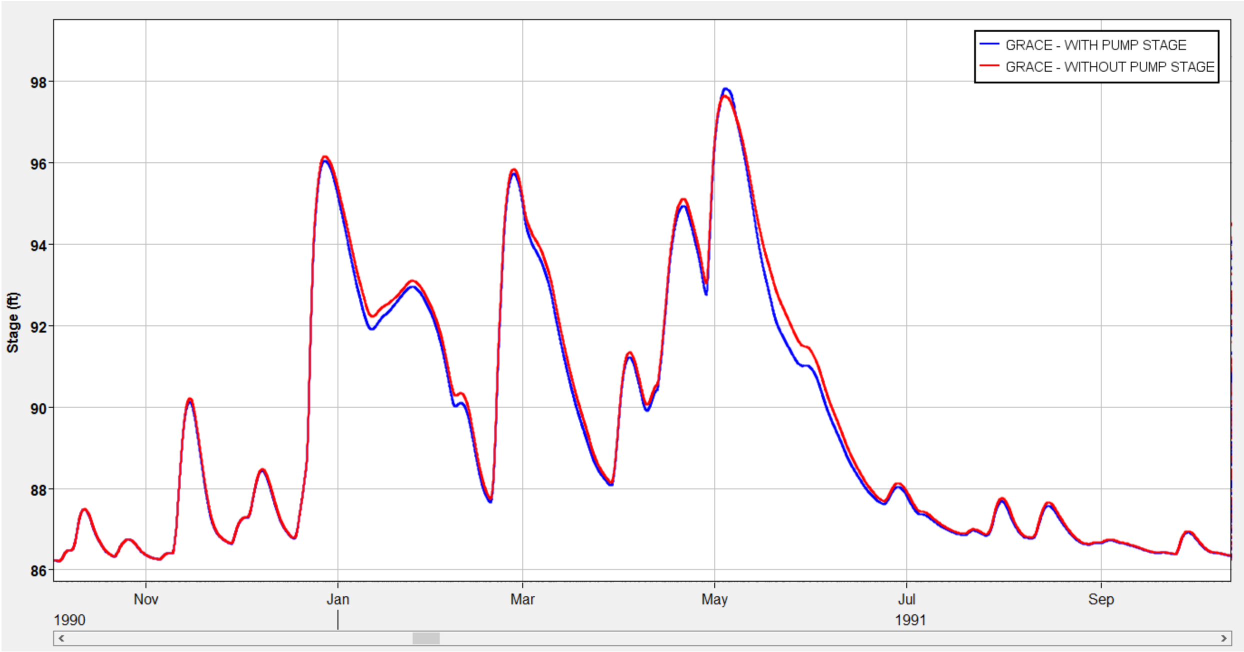


Figure 1-95. Steele Bayou at Grace 1991 Comparison.

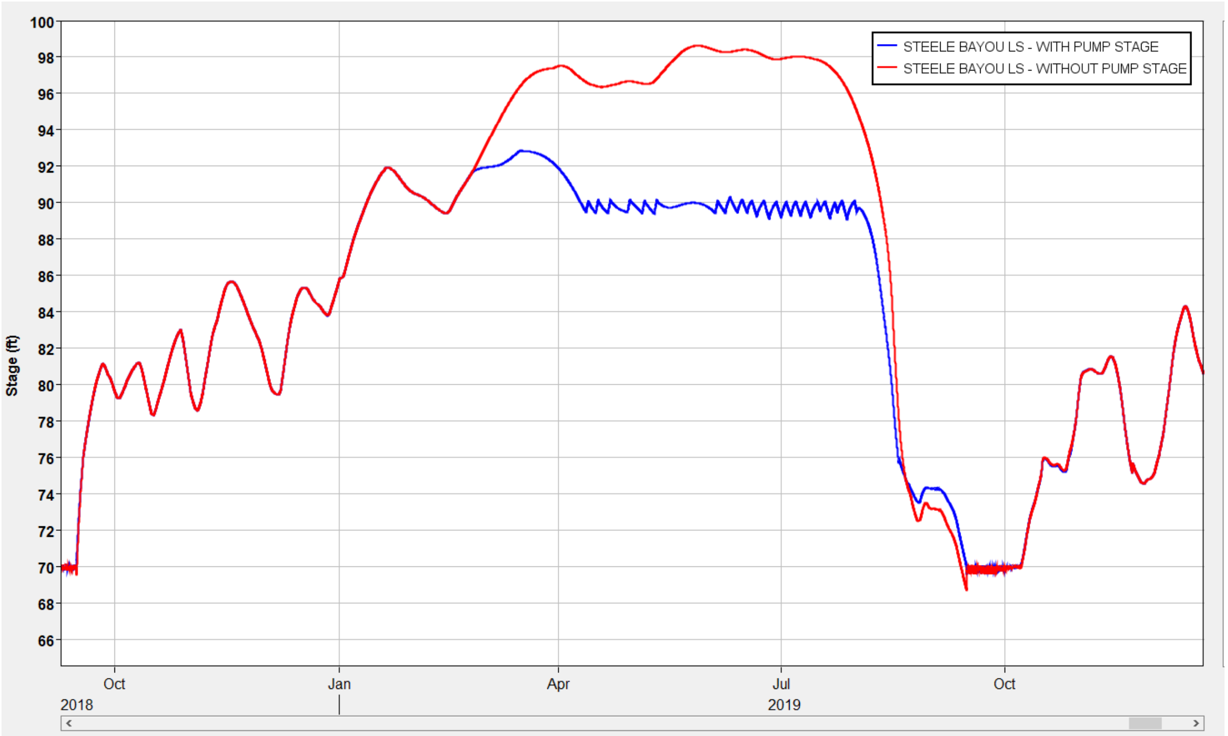


Figure 1-96. Steele Bayou Landside 2019 Comparison.

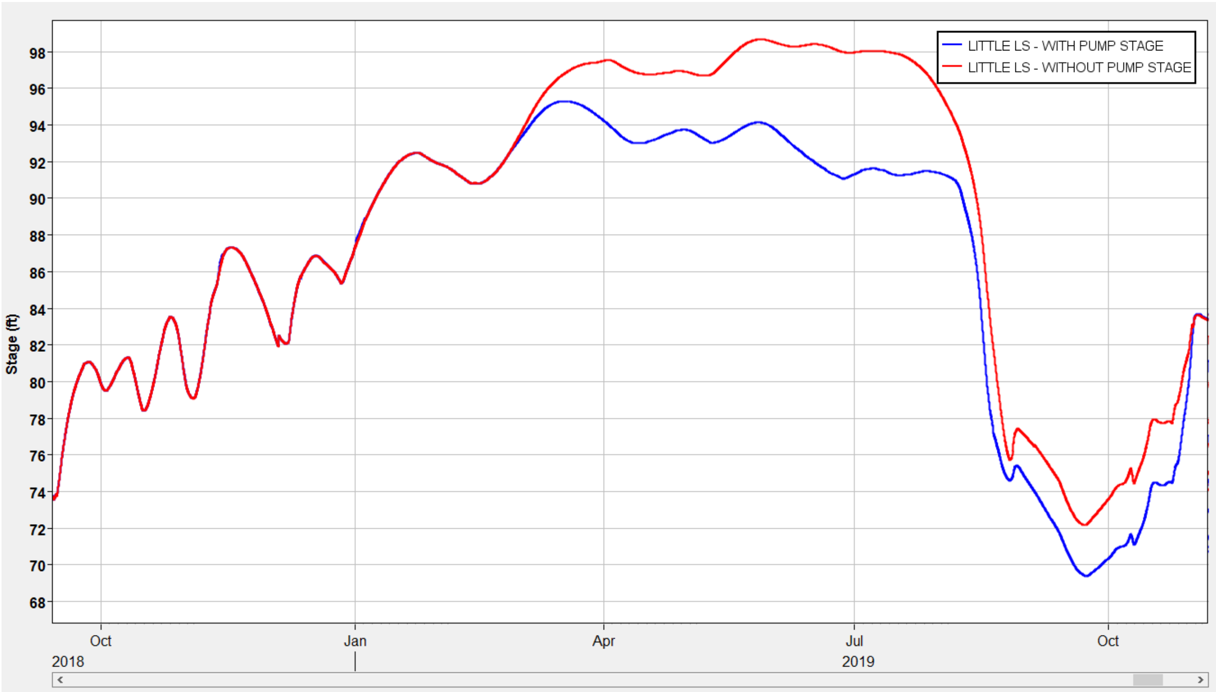


Figure 1-97. Little Sunflower Landside 2019 Comparison.

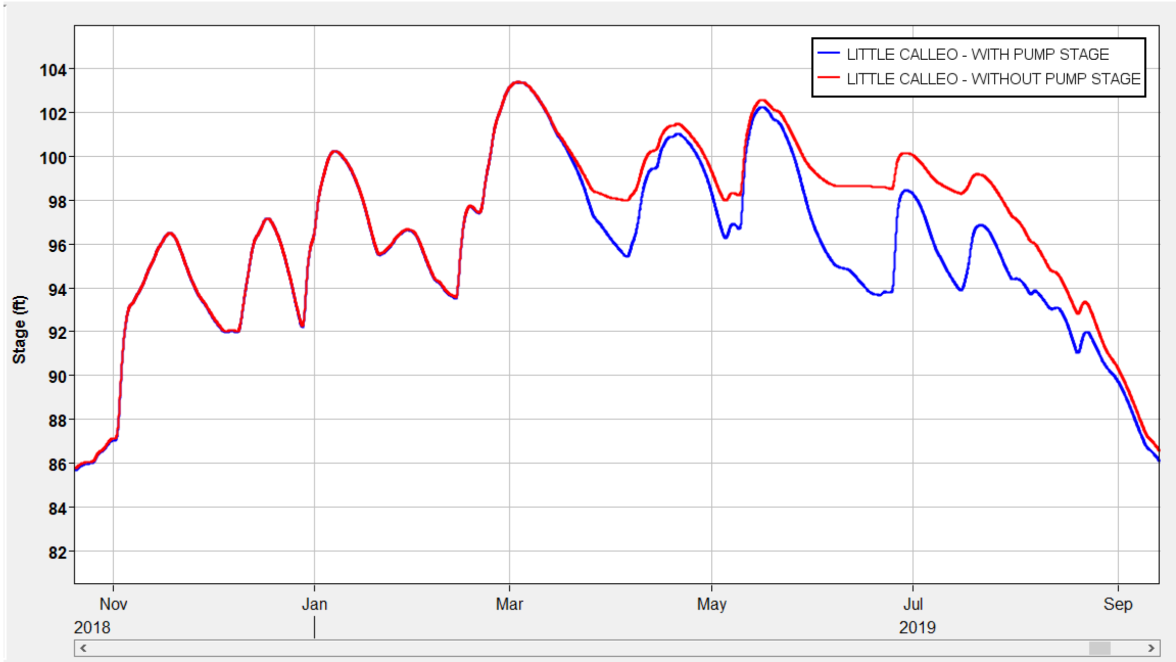


Figure 1-98. Big Sunflower at Little Calleo 2019 Comparison.

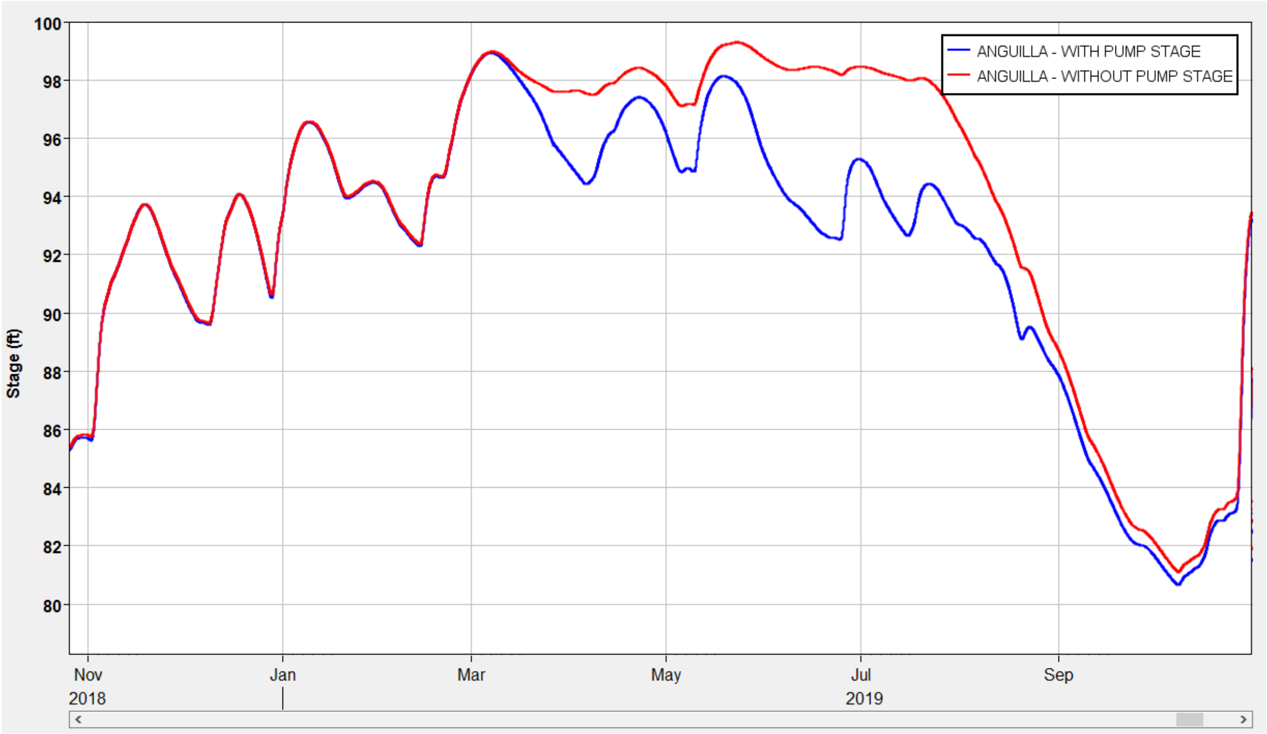


Figure 1-99. Big Sunflower at Anguilla 2019 Comparison.

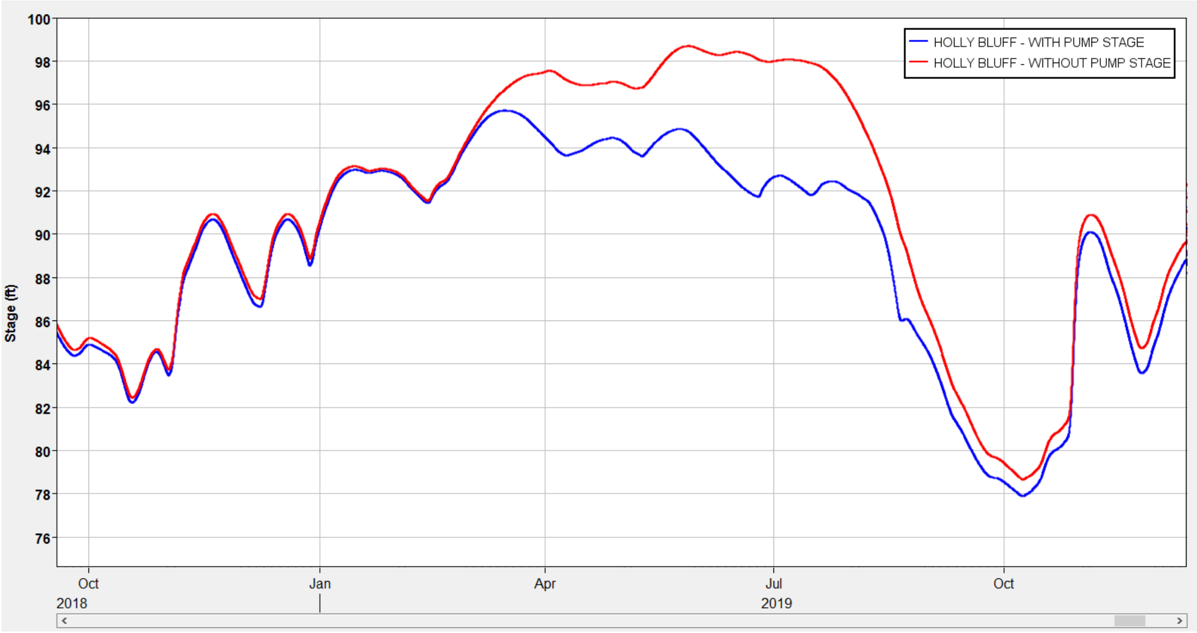


Figure 1-100. Big Sunflower at Holly Bluff 2019 Comparison.

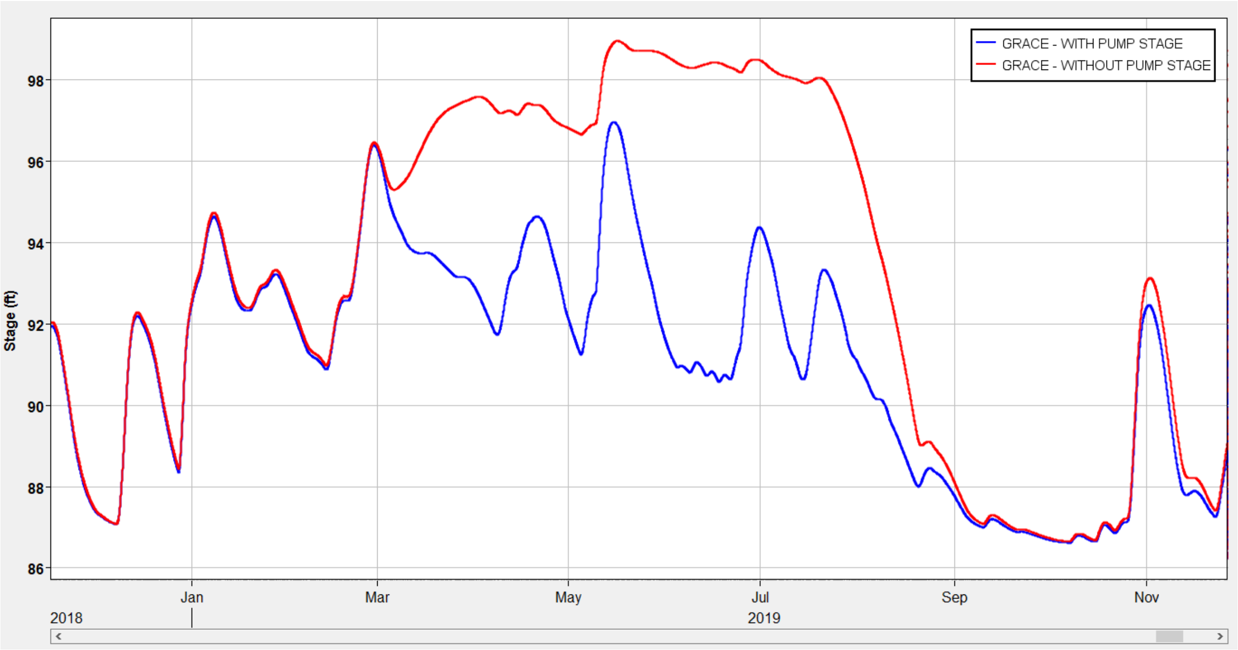


Figure 1-101. Steele Bayou at Grace 2019 Comparison.

FLOOD FREQUENCY ANALYSIS

Flood frequencies can be calculated with two different methods, annual and partial series. Both methods give similar results for the low frequency events like the 25- or 50-year floods, but the partial series give a higher elevation estimate of high frequency events like the 1- and 2-year floods. The annual method uses the single highest peak from each year in the period of record (POR). The partial series method utilizes the peaks over threshold method to filter the POR to obtain all of the peaks which exceed the threshold requirements. The threshold values used is this study were: the minimum peak elevation was greater than or equal to the annual series 1 year elevation, a minimum of 14 days between the peaks, and a minimum change in elevation of three feet. This provided a partial series of 59 to 76 peaks and the top 43 (number of years in the POR) peaks were used to calculate the flood frequency elevations. The Hydrologic Engineering Center (HEC) Statistical Software Package (SSP) Version 2.2 was used to calculate the annual and partial series flood frequency elevations. SSP uses the methods outlined in Bulletin 17C, Guidelines for Determining Flood Flow Frequency, May 2019. The annual stage frequencies were calculated with the General Frequency Analysis module; while the partial frequencies were calculated with the Distribution Fitting Analysis module after the POR stages were filtered using the threshold values listed above. The annual series method was used in development of the operation plan which includes the elevations that the pumps will be operated to. The annual series is the most common method used for

USACE studies. The partial series method will be used in development of the mitigation plan. Since the partial series method gives a more conservative number compared to the annual series method, this will provide a “buffer” for all mitigation analysis. The results of both the annual and partial series flood frequency analyses are provided in Tables 2-22 and 2-23.

It is important to note that the peaks from the without pump RAS model were utilized for this flood frequency analysis instead of the observed peaks. The RAS model was calibrated to observed data, but the peaks averaged out to be slightly higher, 0.125 feet, in the RAS model when compared to observed data. Table 2-21 on page 101 shows the observed and modeled peaks for the 4 events used in calibration. By using the modeled stages in the annual frequency analysis, the computed flood frequencies are slightly more conservative had this analysis been completed using the observed period of record data.

Table 1-22. Annual Series Method (Used for Operational Analysis - Pumps)

Annual Frequency Analysis – No Pump						
Flood Frequency	Little **Callao**	Anguilla	Holly **Bluff**	Little Sunflower Landside	Grace	Steele Bayou Landside
0.2 (500 yr)	106.07	---	---	100.32	---	102.32
0.5 (200 yr)	105.92	---	97.33	99.98	100.22	100.62
1 (100 yr)	104.72	100.83	97.22	99.68	99.09	99.07
2 (50 yr)	104.49	100.49	96.97	98.50	98.55	97.84
5 (20 yr)	103.85	99.46	95.87	96.63	97.65	96.36
10 (10 yr)	103.15	98.94	94.95	94.97	96.90	94.63
20 (5 yr)	102.06	98.50	94.15	93.55	96.07	92.79
50 (2 yr)	100.31	96.96	92.85	90.31	94.64	89.30
80	98.79	95.71	91.60	87.97	93.46	85.18
90	98.08	94.95	90.43	86.06	92.71	82.50
95	97.59	94.34	89.66	84.44	92.26	81.05
99 (1 yr)	96.36	93.79	88.74	81.30	91.42	79.15

Table 1-23. Partial Series Method (Used for Mitigation Analysis)

Partial Frequency Analysis – No Pump						
Flood Frequency	**Little Callao**	**Anguilla**	**Holly Bluff**	**Little Sunflower Landside**	**Grace**	**Steele Bayou Landside**
0.2 (500 yr)	104.47	99.85	99.22	102.14	100.15	102.14

Partial Frequency Analysis – No Pump						
Flood Frequency	**Little Callao**	**Anguilla**	**Holly Bluff**	**Little Sunflower Landside**	**Grace**	**Steele Bayou Landside**
0.5 (200 yr)	104.39	99.81	99.06	101.14	99.06	101.14
1 (100 yr)	104.25	99.53	99.70	99.62	98.97	99.62
2 (50 yr)	103.74	99.39	98.17	98.08	98.81	98.00
5 (20 yr)	103.16	99.08	96.93	96.40	97.90	96.38
10 (10 yr)	102.75	98.86	95.28	95.25	96.94	95.22
20 (5 yr)	102.21	98.34	94.33	93.70	96.12	93.27
50 (2 yr)	101.02	97.39	92.97	91.25	94.91	90.61
80	100.30	96.54	92.28	89.63	94.05	89.16
90	100.07	96.30	92.08	89.17	93.88	88.72
95	99.95	96.17	91.89	88.91	93.76	88.43
99 (1 yr)	99.75	95.99	91.70	88.68	93.58	87.93

RISK AND UNCERTAINTY

A risk-based analysis was performed on the computed stage-frequency curves developed at the Steele Bayou structure as outlined in EC 1105-2-205. This gage was used in the period-of-record-routing analysis from which stage-frequency curves were developed and utilized in the Economic Analysis of the SEIS.

The General Frequency Analysis (GF) module of the SSP software that was used to calculate the stage frequencies allows the user to select either a graphical or an analytical fit. The analytical method was used in this study. The GF module calculates the 95 percent confidence interval for each frequency. The 95 percent confidence intervals for the without project conditions at the Steele Bayou gage were computed. The results of both the annual and partial series flood frequency analyses are provided in Table 2-24 and 2-25 respectively below. Table 1-24. Annual Series Method Confidence Intervals for Steele Bayou

Probability	**Return Period**	**Expected Probability (feet)**	**Confidence Limits**	
			0.05	**0.95**
			Elevation (feet)	
0.2	500	102.32	105.13	99.87
0.5	200	100.62	103.52	98.70
1	100	99.07	102.19	97.73

Probability	**Return Period**	**Expected Probability (feet)**	**Confidence Limits**	
			0.05	**0.95**
			Elevation (feet)	
2	50	97.84	100.75	96.67
5	20	96.36	98.60	95.06
10	10	94.63	96.71	93.61
20	5	92.79	94.47	91.81
50	2	89.30	90.40	88.13
80	1.25	85.18	86.73	84.07
90	1.12	82.50	84.93	81.83
95	1.06	81.05	83.48	79.94
99	1	79.15	80.80	76.34

Table 1-25. Partial Series Method Confidence Intervals for Steele Bayou

Probability	Return Period	Expected **Probability** (feet)	Confidence Limits	
			0.05	0.95
			Elevation (feet)	
0.2	500	102.14	105.41	96.57
0.5	200	101.14	102.95	96.34
1	100	99.62	101.72	96.11
2	50	98.00	100.26	95.63
5	20	96.38	98.31	94.72
10	10	95.22	96.34	93.54
20	5	93.27	94.54	92.12
50	2	90.61	91.51	90.10
80	1.25	89.16	89.51	88.80
90	1.12	88.72	89.08	88.34
95	1.06	88.43	88.90	88.13
99	1	87.93	88.78	87.94

RISK program, and an HEC-DSS output file. The ASCII output data were provided to Economics and used in their risk analysis as described in Appendix R.

PUMP MANAGEMENT ELEVATIONS

From the above sections, it was noted that the annual series method would be used for the operational analysis of the pump. In previous sections of this document 90 feet and 93 feet have been referenced as the elevations to which the pump would be managed. HGM guidance states the usage of the 2 year and 5-year elevations for wetland management and mitigation purposes. From Table 2-22 on page 128, the 2 year and 5-year elevations were computed to be 89.30 feet and 92.79 feet respectively. With the way that water travels down Steele Bayou and the Little Sunflower River to the structures and connecting channel and then backs up in the Steele Bayou area, it was desirable to manage the pumps to a level above the 2 year and 5 year, the 90 feet and 93 feet, to provide a “buffer” and ensure that all lands within the 2 year and 5 year footprint have a chance to be inundated because of the way the backwater operates.

PUMP CAPACITY SELECTION

Several different pump capacities were evaluated for the current plan. The 2019 flood is the current flood of record for the Yazoo Backwater which had a peak elevation at Steele Bayou of 98.2 feet. The calibrated RAS model has a peak elevation of 98.6 feet at Steele Bayou for the 2019 flood event. From the previous section, 90 feet and 93 feet, depending on if it was cropping season or non-crop season, are the elevations to manage the floodwaters during a flood event. For non-crop season, it is more desirable that the pumps turn on above 90 feet, preferably in the 91 feet to 92 feet range, to allow more land to be inundated prior to the pumps being activated. To determine what pump capacity would be optimal in order to manage water elevations to 93 feet, four different pump capacities were evaluated with four different pumps on elevations. In addition to the 25,000 cfs, this analysis evaluated pump capacities of 14,000 cfs, 17,500 cfs, 20,000 cfs, and 22,100 cfs. Pump on elevations of 87 feet, 88 feet, 89 feet, and 90 feet were evaluated to determine the maximum water surface elevation for these combinations of pump capacity with pump on elevations. Table 2-26 shows the results of this analysis with the pump on elevation in the first column, the pump capacity in the second column, and the maximum water surface elevation in the third column.

Table 1-26. Peak Water Surface Elevations Utilizing Different Pump Sizes and Pump On Elevations

Scenario		2019
Observed		98.2 ft
RAS Model with No Pump		98.6 ft
Pump On at 87’	14,000 cfs Pump	95.6 ft
	17,500 cfs Pump	93.7 ft
	20,000 cfs Pump	92.2 ft
	22,100 cfs Pump	91.0 ft
Pump On at 88’	14,000 cfs Pump	95.8 ft
	17,500 cfs Pump	93.9 ft
	20,000 cfs Pump	92.5 ft
	22,100 cfs Pump	91.6 ft
Pump On at 89’	14,000 cfs Pump	96.1 ft
	17,500 cfs Pump	94.2 ft
	20,000 cfs Pump	92.8 ft
	22,100 cfs Pump	92.1 ft
Pump On at 90’	14,000 cfs Pump	96.4 ft
	17,500 cfs Pump	94.5 ft
	20,000 cfs Pump	93.2 ft
	22,100 cfs Pump	92.7 ft

From Table 2-26, the 14,000 cfs and 17,500 cfs pumps would not adequately manage floodwaters to 93.0 feet regardless of the pump on elevation. The 20,000 cfs pump could only manage floodwaters to 93.0 feet if the pump on elevation is set below 90 feet. The 22,100 cfs pump can manage floodwaters below 93 feet at any pump on elevation with 90 feet pump on being the highest the pumps could turn on without managing to a level above 93.0 feet. Based on requirements to manage floodwaters to 93.0 feet or below as well as requirements to have the pump on elevation much higher than 90 feet, a higher pump capacity is needed. 25,000 cfs pump was selected and modeled through the 2019 event. The desired requirements were achieved so the 25,000 cfs pump was modeled through other flood events to ensure that the requirements were achieved. Table 2-27 shows the results of this analysis and verifies that 25,000 cfs pump is the best pump capacity to manage floodwaters to 90 feet or 93 feet while allowing the pumps to turn on at higher elevations. Note that the 1997 and 2009 events occurred during crop season, so the pumps were managed to 90 feet while the 2019 and 2020 events occurred during non-crop season, so the pumps were managed to 93 feet.

Table 1-27. 25,000 cfs Pump Analysis

Flood Year	1997	2009	2019	2020
Observed	93.3	93.7	98.2	96.8
RAS Model with No Pump	93.9	93.5	98.6	97.0
25,000 cfs Pump On Elevation	90.2	89.7	91.6	91.9
25,000 cfs Pump Modeled Elevation	90.3	90.3	92.9	93.0

PROPOSED PLANS

The three alternatives utilized included: alternative 1 – no action (without a pump), alternative 2 – 25,000 cfs pump station with the March 16 start of crop season date, and alternative 3 - 25,000 cfs pump station with March 25 start of crop season date. These were analyzed using the HEC-RAS model for the 43-year period of record. The modeled pump station utilized the inflow curve to determine pump outflows. Tables 2-28 and 2-29 highlight the reduction in water levels at key gages in the basin for alternatives 2 and 3. The two-crop season pump alternative results were subtracted from the without pump alternative results. Figures 102-105 highlight the HEC-RAS model inundation results for the 1997-, 2009-, 2019-, and 2020-year events, comparing the alternative 1 (no action or without pump) and alternative 2 (25,000 cfs pump station with the March 16 start of crop season date). No figures are provided for alternative 3 because the small difference noted between Table 2-28 and Table 2-29 cannot be visualized at the scale shown on the flood maps (Figures 2-107 to 2-110). Note no modeling was completed for alternative 4 as this was a structural alternative.

Table 2-28 – Alternative 2 reduction in water surface elevations at key gage locations

Alternative 2 – 25,000cfs pump with crop season dates of (March 16 - Oct 15)				
Gage	Flood Year			
	1997	2009	2019	2020
	Reduction in water levels compared to Without Pump Alternative (ft.)			
Steele Bayou LS	3.6	3.2	5.7	4.0
Little Sun LS	1.6	1.3	3.4	2.0
Holly Bluff	0.7	0.4	3.0	1.7
Anguilla	0.1	0.1	0.4	0.1
Little Calleo	0	0	0	0
Grace	0.1	0.1	2.0	0.9

Table 2-29 – Alternative 3 reduction in water surface elevations at key gage locations

Alternative 3 - 25kcfs Pump with alternative 1 crop season dates (March 25 - Oct 15)				
Gage	Flood Year			
	1997	2009	2019	2020
	Reduction in water levels compared to Without Pump Alternative (ft.)			
Steele Bayou LS	1.4	3.2	5.6	4.0
Little Sun LS	0.9	1.3	3.4	2.0
Holly Bluff	0.5	0.4	3.0	1.7
Anguilla	0.1	0.1	0.4	0.1
Little Calleo	0	0	0	0
Grace	0.1	0.1	2.0	0.9

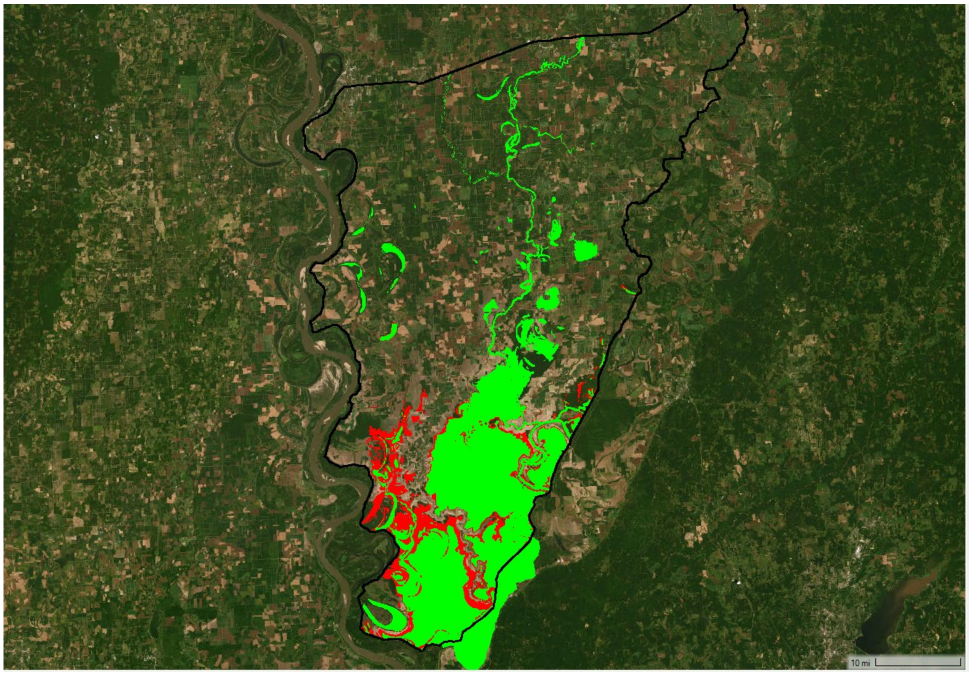


Figure 2-102 – 1997 Event HEC-RAS inundation coverage with alternative 1 (no pump station) in red color and alternative 2 (25,000 cfs pumps with March 16 start of crop season date) in green color

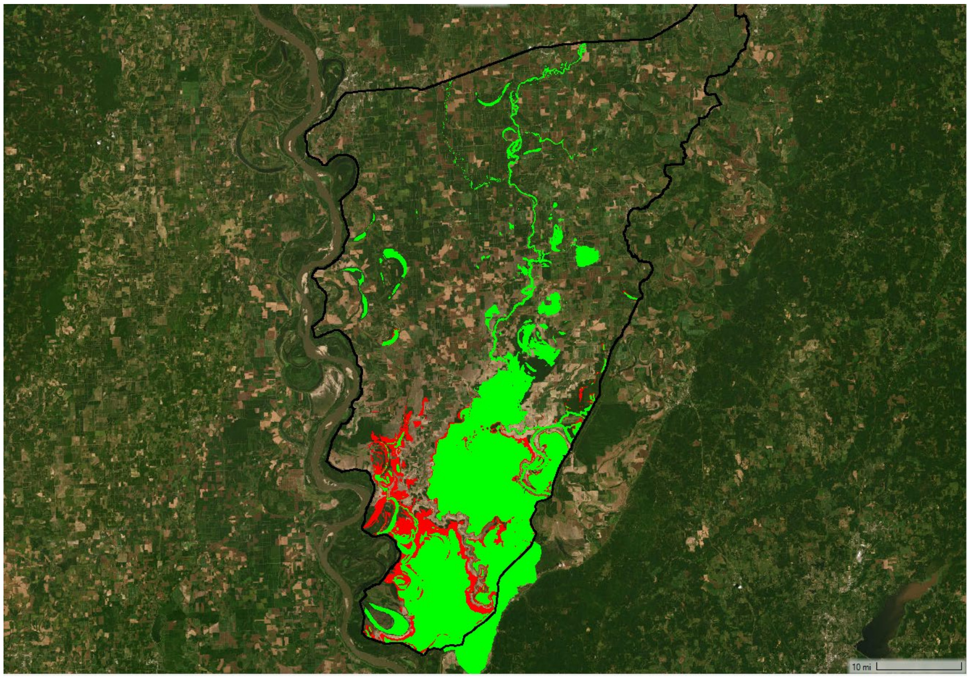


Figure 2-103 – 2009 Event HEC-RAS inundation coverage with alternative 1 (no pump *station) in red color and alternative 2 (25,000 cfs pumps with March 16 start of crop season date) in green color*

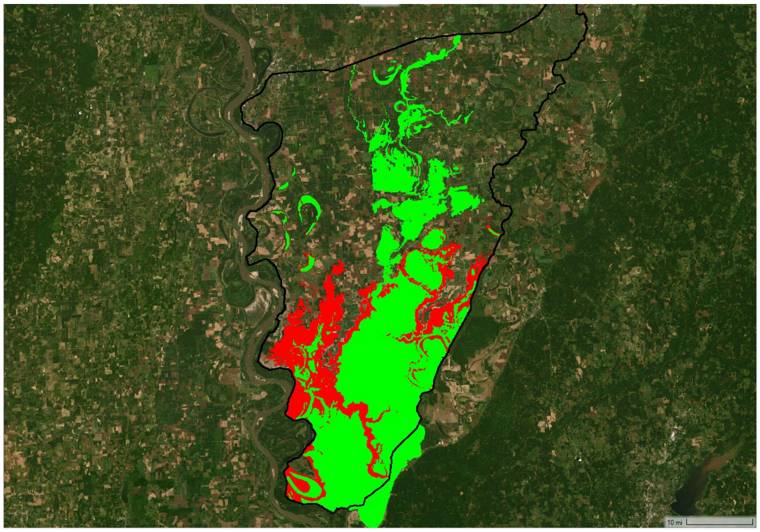


Figure 2-104 – 2019 Event HEC-RAS inundation coverage with alternative 1 (no pump station) in red color and alternative 2 (25,000 cfs pumps with March 16 start of crop season date) in green color

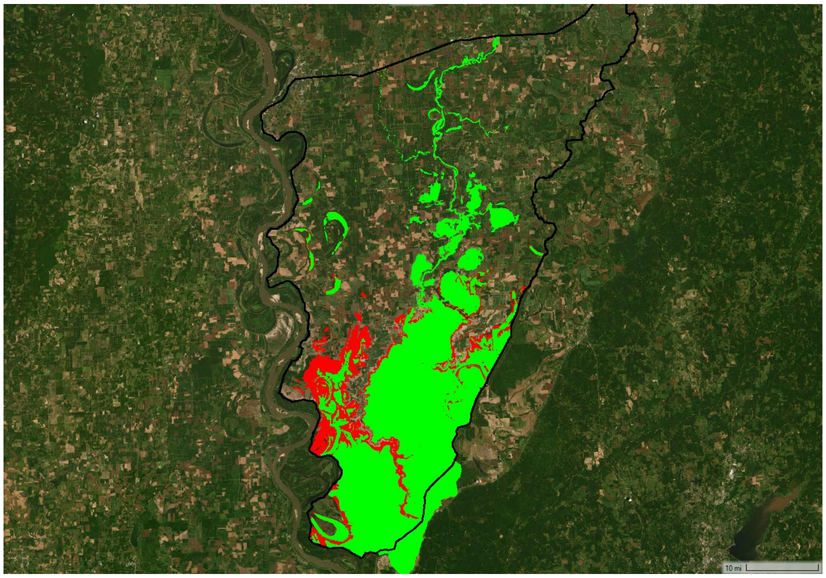


Figure 2-105 – 2020 Event HEC-RAS inundation coverage with alternative 1 (no pump station) in red color and alternative 2 (25,000 cfs pumps with March 16 start of crop season date) in green color

PUMP OPERATIONAL DATA

The period-of-record routing results were used to develop the data required to determine the pump energy requirements. The data used to calculate the energy requirements included average head, average annual number of days of pump operation, and discharge duration. The recommended plan yearly pumping data which show the periods of continuous flood event, number of days pumped per year, and some pumping statistics are found in the tables below. Alternative 2 is crop season dates from March 16 to October 15 while alternative 3, is crop season dates from March 25 to October 15. Both alternatives were calculated for this analysis. Figure 2-106 shows the number of times, with corresponding years, that the pumps would have activated during each of the half a foot increments provided. Alternative 2 data is on the left-hand side of the figure and alternative 3 data is on the right-hand side of the figure. Figure 2-107 shows the maximum elevation each year through the period of record, if the pumps would have activated during that year, and if the pumps would have activated during crop season or non-crop season. Alternative 2 was analyzed in this figure when looking at which events would have activated the pumps in crop and non-crop season. Figure 2-108 shows pump on data, pump off date, elevation the pumps turned on, and number of days pumping for each year that the pumps would have operated. Both alternative 2 and alternative 3 were calculated for this analysis. Table 2-30 shows the pump operation days by month for both alternative 2 and alternative 3. This is the total number of days the pump would have been operated during that month for the entire period of record. The bottom of the table shows the total number of days the pump would have operated over the entire period of record. With a total of 851 days of pump operation over the 43-year period of record with alternative 2, the pumps would have operated 5.4% of the time over the period of record. Prior to the 2019 and 2020 floods, which each would have had operations exceeding 140 days per year, the pumps would have operated 3.7% from 1978 to 2018. If necessary, further refinements to the pumping station will be evaluated in depth following the approval of the current plan.

Period of Record: 1978 - 2020 (43 Years)

Non-Crop Season (16 Oct - 15 Mar)	Occurances	Year
Years Pump Does Not Cut On:	40	
Years Pump Cuts On Between 92.5'-93.0'	0	
Years Pump Cuts On Between 92.0'-92.5'	0	
Years Pump Cuts On Between 91.5'-92.0'	2	2019, 2020
Years Pump Cuts On Between 91.0'-91.5'	1	2018
Years Pump Cuts On Between 90.5'-91.0'	0	
Years Pump Cuts On Between 90.0'-90.5'	0	

Non-Crop Season (16 Oct - 24 Mar)	Occurances	Year
Years Pump Does Not Cut On:	40	
Years Pump On Between 92.5'-93.0':	0	
Years Pump On Between 92.0'-92.5':	0	
Years Pump On Between 91.5'-92.0':	2	2019, 2020
Years Pump On Between 91.0'-91.5':	1	2018
Years Pump On Between 90.5'-91.0':	0	
Years Pump On Between 90.0'-90.5':	0	

Crop Season (16 Mar - 15 Oct)	Occurances	Year
Years Pump Does Not Cut On:	23	
Years Pump On Between 90.5'-91.0':	1	** 1994
Years Pump On Between 90.0'-90.5':	1	** 1997
Years Pump On Between 89.5'-90.0':	15	* Below
Years Pump On Between 89.0'-89.5':	0	

* 1979, 1980, 1983, 1984, 1990, 1991, 1993, 2002, 2008, 2009, 2011, 2013, 2015, 2016, 2017

** Pump cut on the first day of crop season

Crop Season (25 Mar - 15 Oct)	Occurances	Year
Years Pump Does Not Cut On:	23	
Years Pump On Between 90.5'-91.0':	3	** 1994, 1997, 2016
Years Pump On Between 90.0'-90.5':	1	** 1979
Years Pump On Between 89.5'-90.0':	13	* Below
Years Pump On Between 89.0'-89.5':	0	

* 1980, 1983, 1984, 1990, 1991, 1993, 2002, 2008, 2009, 2011, 2013, 2015, 2017

** Pump cut on the first day of crop season

Figure 2-106. Pump-on Ranges with Corresponding Years

Year	Max. Elevation	Year	Max. Elevation
1978	85.73	2000	78.86
1979	96.32	2001	87.34
1980	89.79	2002	90.02
1981	80.08	2003	89.05
1982	85.42	2004	83.56
1983	95.87	2005	89.33
1984	92.88	2006	79.48
1985	88.59	2007	85.57
1986	86.98	2008	92.08
1987	84.62	2009	93.49
1988	84.69	2010	89.82
1989	89.74	2011	91.28
1990	89.98	2012	86.60
1991	92.88	2013	91.52
1992	84.27	2014	86.78
1993	91.53	2015	90.52
1994	91.52	2016	91.31
1995	88.47	2017	89.80
1996	88.69	2018	95.27
1997	93.89	2019	98.62
1998	89.08	2020	96.99
1999	90.23		

(red text) - pump would have cut on

(black text) - pump would not have cut on

(green highlight) - pump activates during crop season

(yellow highlight) - pump activates during non-crop season

Figure 2-107. Peak Annual Elevation and Pump Operation

Year	Alternative 2 Date of Pump-On	Alternative 3 Date of Pump-On	Alternative 2 Date of Pump-Off	Alternative 3 Date of Pump-Off	Elevation of Pump-On		Total Days Pumping	
					Alternative 2	Alternative 3	Alternative 2	Alternative 3
1979	21-Mar-79	25-Mar-79	22-May-79	22-May-79	89.6	90.2	62	58
1980	15-Apr-80	15-Apr-80	21-Apr-80	21-Apr-80	89.5	89.5	6	6
1983	27-Apr-83	27-Apr-83	18-Jun-83	18-Jun-83	89.7	89.7	52	52
1984	23-Apr-84	23-Apr-84	7-Jun-84	7-Jun-84	89.5	89.5	45	45
1990	12-Jun-90	12-Jun-90	17-Jun-90	17-Jun-90	89.6	89.6	5	5
1991	21-Jan-91	21-Jan-91	25-Jan-91	25-Jan-91	92.5	92.5	4	4
1991	29-Apr-91	29-Apr-91	22-May-91	22-May-91	89.6	89.6	23	23
1993	22-Apr-93	22-Apr-93	28-May-93	28-May-93	89.7	89.7	36	36
1994	16-Mar-94	25-Mar-94	23-May-94	23-May-94	90.7	91	68	59
1997	16-Mar-97	25-Mar-97	19-Apr-97	19-Apr-97	90.2	92.4	34	25
2002	11-Apr-02	11-Apr-02	17-Apr-02	17-Apr-02	89.6	89.6	6	6
2008	14-Apr-08	14-Apr-08	2-Jun-08	2-Jun-08	89.6	89.6	49	49
2009	18-May-09	18-May-09	14-Jun-09	14-Jun-09	89.7	89.7	27	27
2011	19-May-11	19-May-11	20-Jun-11	20-Jun-11	89.5	89.5	32	32
2013	15-May-13	15-May-13	2-Jun-13	2-Jun-13	89.6	89.6	18	18
2015	31-Mar-15	31-Mar-15	8-Apr-15	8-Apr-15	89.6	89.6	8	8
2015	1-May-15	1-May-15	5-May-15	5-May-15	89.6	89.6	4	4
2016	19-Mar-16	23-Mar-16	29-Mar-16	29-Mar-16	89.8	91.2	10	6
2017	11-Jun-17	11-Jun-17	16-Jun-17	16-Jun-17	89.6	89.6	5	5
2018	9-Mar-18	9-Mar-18	7-May-18	7-May-18	91.3	91.3	59	59
2019	24-Feb-19	24-Feb-19	1-Aug-19	1-Aug-19	91.6	91.6	158	158
2020	25-Jan-20	25-Jan-20	17-Jun-20	17-Jun-20	91.8	91.8	144	144

Figure 2-108. Pump Operation Details

Table 2-30. Pump Operation Days by Month over the Period of Record

Month	**Alternative 2**	Alternative **3**
January	7	7
February	32	32
March	134	108
April	224	224
May	302	302
June	120	120
July	31	31
August	1	1
September	0	0
October	0	0
November	0	0
December	0	0
Total Days Pumping over Period of Record	851	825

PROPOSED PLAN PUMP OPERATION

For the HEC-RAS modeled proposed pump plan, the period-of-record-routing models pump operation included 22 pumps at 1,167 cfs each with a pump on/off elevation that varies depending on the combined inflow from the Grace and Anguilla gages. The developed pump curve in Figure 2-49 on page 98 shows the corresponding stages and flow for the pump on elevations. The model operated the number of pumps based on managing the floodwaters to the 90 feet or 93 feet elevations depending on crop season and non-crop season time respectively. Since the natural gas-driven pumps cannot be instantaneously turned on at the same time, a pump operation scheme was developed to achieve a pumping capability and floodwater management. Any specific refinements to the pump operation sequence will be developed as part of the water control plan for the project. The current plan pumping units and pump station layout are designed for a nominal pump on elevation to manage to 90 feet and 93 feet. To provide for a margin of safety, the discharge pipe maximum elevation was set at 106.0 feet. This design allows for the pumps to operate efficiently and without damage down to elevation 89.0 feet. Operation below 89.0 feet is outside of the design requirements for the pumping units and could damage the natural gas engines and/or pumps. Note that Design Branch might choose to look at larger pumps during the design. It might be that they recommend fewer pumps with a larger capacity for each pump. If that is what is recommended during design, the modeling will be updated to reflect the number of pumps and capacity of each pump. This will not impact the current results, or the sequencing in which the pumps will activate.

STANDARD PROJECT FLOOD

The Standard Project Flood (SPF) represents the flood that can be expected from the most severe combination of meteorologic and hydrologic conditions that are considered reasonably characteristic of the geographic region involved, excluding extremely rare combinations. Procedures for estimating the SPF involve a single storm event – the Standard Project Storm (SPS). However, with base conditions, flooding in the Yazoo Backwater Study Area generally results from several storm events occurring over a period of several months.

Assuming a condition when the floodgates are closed and the SPF event occurs over the Yazoo Backwater Study Area, the inflows are of such magnitude that the 25,000 cfs pumping station capacity is greatly exceeded and the interior ponding area would rise significantly where the floodgates would likely be operated for an extended period to evacuate the interior ponding for this headwater-type event. A similar but smaller event by comparison was the 1991 flood event, which was a headwater-type event with a low tailwater condition on the Mississippi River.

Should this condition occur with a high Mississippi River tailwater and an SPF event over the Yazoo Backwater Area, the pump would shorten the duration of the rising leg of the hydrograph and slightly reduce the peak stage. The extent and magnitude of flooding with the SPF would not be greatly affected by the 25,000 cfs pumping station because the storm was a very intense, short duration event with inflow rates much in excess of the pump capacity.

DOWNSTREAM IMPACTS OF THE PROPOSED PUMP

Here we describe our analysis of the potential for increased flooding to downstream communities that would result from the proposed project. This analysis utilized a Mississippi River model that included the lower part of the Yazoo River. The model analyzed the volume of water that the 25,000cfs pump station would add to the Yazoo River during the peak of the 2011 Mississippi River flood to see the increase stage at the Vicksburg gage. The 2011 Mississippi River flood was selected for this model, because it quantifies the maximum possible increase to downstream communities under a historical extreme event.

During the 2011 Mississippi River flood event, there were several homes in the Ford Subdivision and Chickasaw Rd areas that flooded. John Elfer, Warren County Emergency Management Director, described in a November 27, 2023, email the homes in the Ford Subdivision and Chickasaw Rd areas that were impacted from previous floods. Following the series of significant Mississippi River flood events, some homes in the Ford Subdivision and Chickasaw Rd areas were bought out and demolished while other homes were raised. According to the Flood Science Center and the Vicksburg Post, buyouts of flood prone homes have been conducted multiples times in Vicksburg. The first purchase of 50 homes occurred in 1990 under the 1362 FEMA flood buyout program. In 1993 another 28 homes were purchased under the same program. After the 2011 flood, as many as 13 additional homes were purchased. To confirm the current conditions and future potential impacts, the USACE hydraulics team visited the community on August 21, 2024, to survey the ground elevations and finish floor elevations of the homes to develop an inventory for the homes still in place. The inventory found seven primary residences still in place with one of the seven having a tree through the roof and currently uninhabitable. The locations of these remaining homes and the surveyed finished floor elevations are shown in the last paragraph of this section.

Analysis of the consequential 2011 Mississippi River Flood**:**

During the 2011 Mississippi River flood, the USGS measured 2,300,000cfs passing the Vicksburg gage during the peak of the flood in May. The model analyzed the impact of the 25,000cfs pump flow added to the Mississippi River at the 2011 peak stage. The model and rating curves showed a maximum of 0.30-0.40-foot increase at the Vicksburg gage if the proposed 2024 pump was in-place. Similarly, the expected increase in stage would return to normal once at the Natchez gage, 71 miles downstream of Vicksburg. To ensure accuracy in the model, the results were compared to the Mississippi River rating curve at the Vicksburg gage which has been maintained using measured data since the 1960s. Figure 2-109 shows the rating curve for the Mississippi River at Vicksburg. The rating curve estimates that a 0.25-foot increase would equate to an additional 23,500cfs in the river validating the model results with decades of measured data.

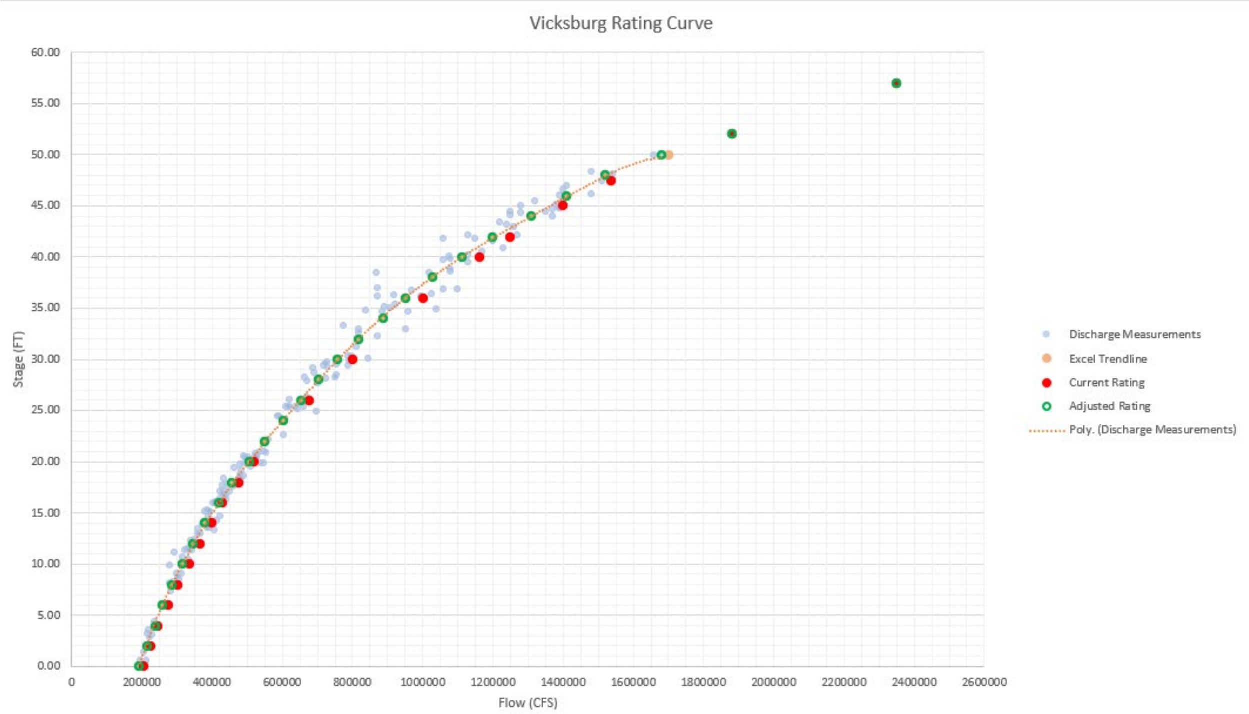


Figure 2-109. Rating Curve for Mississippi River at Vicksburg

Impact to the Ford Subdivision and Chickasaw Rd areas:

With an estimate of up to 0.30-0.40-foot increase at the Vicksburg gage, the Ford Subdivision and Chickasaw Rd areas would also expect to have an observed increase in flood elevations. Model results were compared for several MS River frequency floods and noted the increase that the pumps would have on the elevation at the Ford Subdivision and Chickasaw Rd areas. Below is a list of past flood events, what frequency event the past flood most closely equates to, the elevation of the flood elevation at the Ford Subdivision and Chickasaw Rd without the pumps, and the flood elevation with the pump in place.

MS River Frequency	Elevation* Flood Event	Elevation without Pump	with Pump
~ 2-year	Jan 1983	94.12’	94.65’
~ 5-year	Jun 1995	94.80’	95.38’
~ 10-year	Jan 2016	100.40’	100.78’
~ 10-year	Mar 2018	99.58’	99.97’
~ 25-year	Mar 2019	101.40’	101.70’
~ 50-year	NONE		
~ 100-year	NONE		
~ 200-year	May 2011	107.83’	108.05’

*Elevations shown above are elevations at Ford Subdivision and Chickasaw Rd

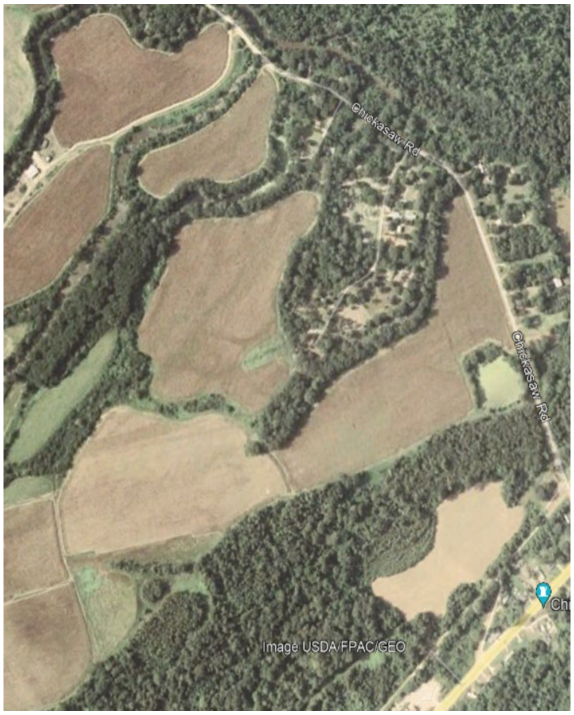
Since the construction of the Yazoo Backwater Levee in 1978, there have been no Mississippi River floods that equate to a 50-year or 100-year event. According to Flood Science Center multiple homes were elevated or purchased in 1990, 1993, and 2011. Seven homes remain in the Ford Subdivision and Chickasaw Rd areas. FEMA, along with most city and county regulations, require flood protection of homes to a 100-year event. At the time of elevation of the remaining seven homes, those elevations range between 100.84ft – 105.97ft.

Climate models indicate that the Lower Mississippi River region will experience warmer temperatures, more drought conditions, and less precipitation days within the coming decades. This paired with the historic gage data analysis, indicates the Ford Subdivision and Chickasaw Rd areas are not expected to experience an increase in flood stage in the future. Below is a collection of Google Earth images of the Ford Subdivision and Chickasaw Rd areas from November 2005 and January 2023 to visually see the change in number of homes in this area. Also below are the same 2023 images with the survey information of ground elevation and finished floor elevation for each home within these areas. The homes are elevated 8 to 10 feet above natural ground elevation.

Ford Subdivision – Jan 2023 (Google Earth) Ford Subdivision – Nov 2005 (Google Earth)

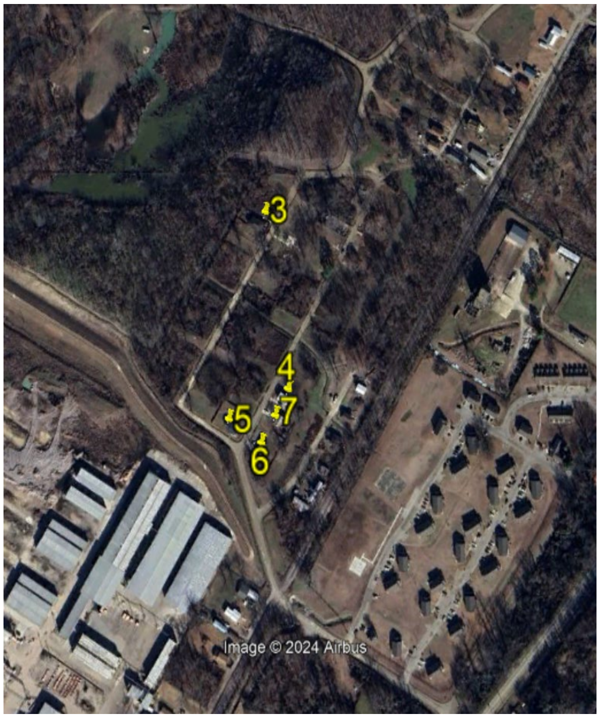
Chickasaw Rd – Jan 2023 (Google Earth)

Chickasaw Rd – Nov 2005 (Google Earth)



Chickasaw Rd – Home Elevations

Ford Subdivision – Home Elevations



Home	Existing Ground Elevation	Finished Floor Elevation
1	92.84	101.29
2	90.04	105.97
3	92.90	100.84
4	94.34	105.34
5	94.34	104.08
6	94.34	104.29
7	94.34	102.49

HYDRAULIC DESIGN

INLET AND OUTLET CHANNELS

The inlet channel will carry water from the lower Steele Bayou basin to the pumping plant. The inlet channel construction will require a section of the existing backwater levee to be removed. A new bridge will be constructed over the inlet channel to provide access up and down the existing backwater levee. The 3,000-foot-long inlet channel will have a bottom elevation of 71 feet (NGVD 29). The flared inlet channel entrance will have a 100-foot radius on both the banks entering into the 450-foot-wide inlet channel. The first 2,500 feet of inlet channel will be 450 feet wide followed by a transition from 450 feet to 475 feet. The last 100 feet of inlet channel will be 475 feet wide as it arrives at the pumping plant.

The outlet channel will carry water from the pumping plant to the Yazoo River. The 2,200-foot-long outlet channel will have a bottom elevation of 76 feet (NGVD 29). The outlet channel for the first 200 feet, as it leaves the pumping plant, will be 475 feet wide followed by a transition to 1,500-foot channel length with width of 425 feet. The remaining 500 feet of outlet channel will be 525 feet wide as it enters the Yazoo River. The north bank will have a 100-foot radius and the south bank will have a 150-foot radius.

The inlet channel will have 1V:4H side slopes lined with engineering fabric, 24” of small stone, and 48” of riprap for the 100 feet leading up to the pumping station. The outlet channel will have 1V:4H side slopes lined with engineering fabric, 24” of small stone, and 48” of riprap for the 200 feet leaving the pumping plant.

PUMP DESIGN

The pumping station was designed and modeled prior to the cancellation of the project in 1986. Reference Technical Report HL-88-2, "Pumping Station Inflow-Discharge Hydraulics, Generalized Pump Sump Research Study," ERDC, February 1988.

ENVIRONMENTAL ANALYSIS

WATERFOWL

Waterfowl feeding habitat is defined as areas that are inundated by up to 18 inches of water. The Yazoo Backwater stages generally increase during the waterfowl season of 01 November to 28 February. Mean monthly stages increase by 10 or more feet at most gaging locations during this period. The maximum and minimum stages during the winter waterfowl season were determined by the computer program ENVIRO-DUCK. The ENVIRO-DUCK program was initially developed by the Vicksburg District with the cooperation of the U.S. Fish and Wildlife Service (USFWS). It was based on a food energy model developed by the USFWS. ENVIRO-DUCK was later updated and modified by Dr. Mickey Heitmeyer for the Memphis District. For input, the program requires the beginning and ending dates of the waterfowl season and the period-of-record to be used in the analysis. The program also requires a stage-area curve for every gage, which it uses to calculate the daily acres inundated (resting) and the daily acres of feeding habitat. Using this information, the program calculates the daily resting and feeding acres available, sums these for each year, and calculates the average acres available during each year. The program also calculates the annual mean, minimum, and maximum stages during the waterfowl season. Finally, it calculates the mean, minimum, and maximum stages during the entire period-of-record during the waterfowl season.

The areal extent of available waterfowl habitat was determined with the FESM flood mapping tool. The FESM tool produces a Geo-TIFF file. Water surface profiles for the minimum and maximum stages were used to map the upper and lower bounds of the waterfowl habitat. The land use of the project area was determined using NASS Crop Data Layer (CDL) for 2022, which was clipped to the project area.

FISHERIES

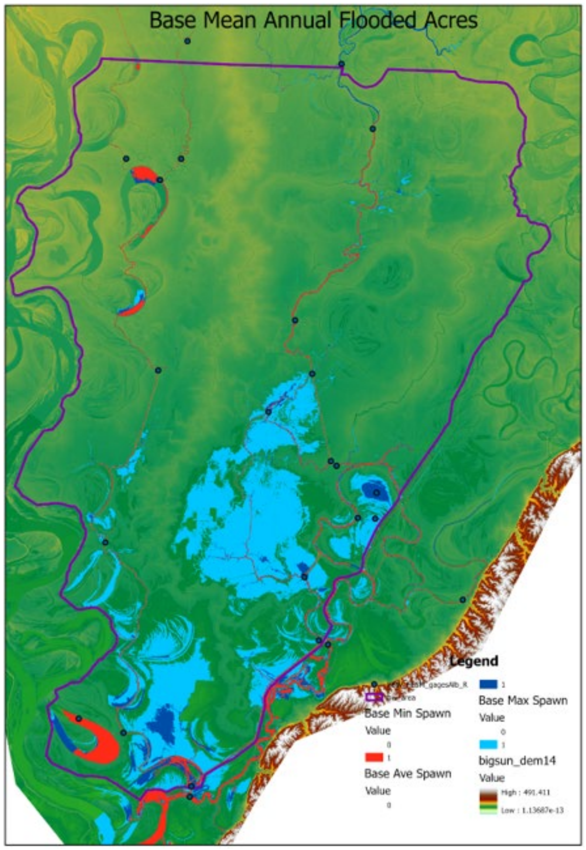
In the late 1980's the USACE Vicksburg District and the Fish and Wildlife Service (FWS) jointly worked to devise a method to assess the impact of flood control projects on the fishery resources of the Yazoo Basin. The two agencies agreed that the loss of spawning and rearing habitat during the spring floods was the likely cause of the decline of the basin's fishery resources. The EnviroFish program was the result of the cooperative effort. The original program was written in Fortran and required several external text files to supply the required input data. The program was updated in the late 1990s. The updated program was written in "C++" and interfaced directly with the HEC Data Storage System (HEC-DSSVUE) hydrologic database. HEC-DSS stores the daily stage and discharge data at all gage locations. The stage-area curves required by the EnviroFish program are also maintained in DSSVUE.

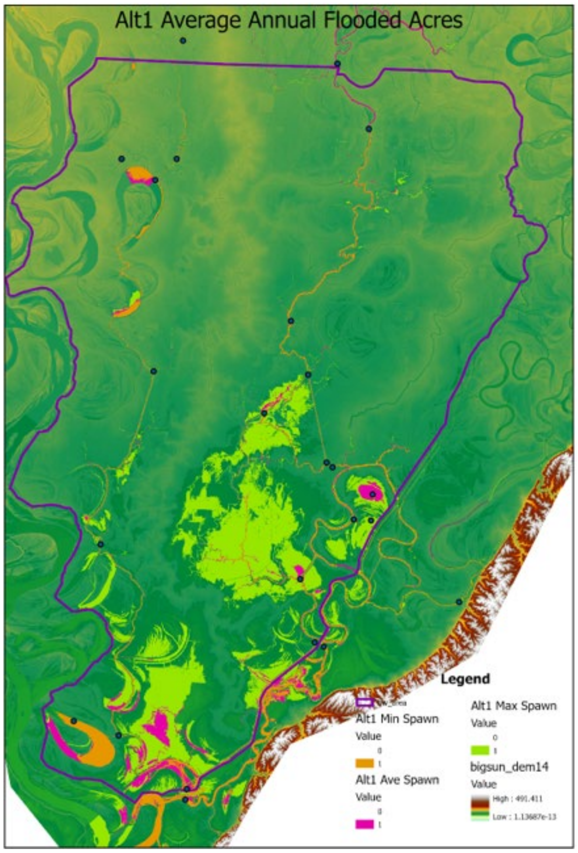
The EnviroFish Program provides two output files, but the main goal is to determine the Average Daily Flooded Acres (ADFA) for the period of record (POR). Fishery biologists can compare the ADFA of the base condition and with project alternatives to calculate the impact of the flood control projects to the fishery resources. The two output files are a summary file of the ADFA by year and a file of the daily acres flooded. The daily file provides five columns of data. The data fields are stage, total rearing acres, restricted rearing acres and spawning acres. There are separate output files for cleared and forested areas. The program allows the user to establish some restricting parameters on the calculation of the daily acres. Total rearing is unrestricted and provides the total area flooded for each day. Restricted rearing can establish minimum and/or maximum depths for rearing. For this project the rearing area had no minimum depth, but the maximum depth was restricted to 10 feet, due to low dissolved oxygen (DO) levels observed in deeper areas. The spawning areas had two restrictions. The minimum depth was one foot, and the spawning duration was set at eight days. The spawning activity includes nest building, egg laying, and hatching. The average duration of these activities is eight days, thus the minimum elevation in each 8-day period was used to calculate the spawning acreage. This calculation was accomplished with a moving window. The program determines the minimum elevation in an 8-day period, then the window is moved forward one day, and the calculation is repeated.

The second output file is the summary statistics file. This file has 13 output statistics, which are: year, mean-stage, total rearing, restricted rearing, and spawning area, maximum-stage, total rearing, restricted rearing, and spawning area, and minimum-stage, total rearing, restricted rearing, and spawning area. Finally, the program calculates the POR values for the previously listed statistics. In all previous studies, the Corps used a spawning and rearing season from 1 March to 30 June of each year. For this study, the spawning and rearing season was subdivided into three sub-seasons. The sub-seasons were: 1, March; 2, April and May; and 3, June. The EnviroFish program was not designed to have sub-seasons, so the program was run for the entire year, and SAS was used to calculate the statistics for each sub-season. Because the entire year was processed, three additional seasons were established. Those seasons were: 4, summer (July and August); 5, fall (September – November); and 6, winter (December – February). The additional three seasons were not used in the analysis of the impacts to fisheries, but the data are included in the Excel spreadsheet of the EnviroFish output. The additional seasons allow interested readers the opportunity to observe how the available habitat vary throughout the entire year.

The EnviroFish analyses were performed on six hydrologic reaches. There are four reaches in the Big Sunflower Basin and two in the Steele Bayou Basin. The four Big Sunflower reaches from upstream to downstream are: Little Callao, Anguilla, Holly Bluff and Little Sunflower. The two Steele Bayou reaches are: Grace and Steele Bayou. The average annual duration of flooding varies from upstream to downstream, with the downstream stations experiencing the greatest duration of flooding. A common misconception about the spawning and rearing season is that there is out-of-channel flooding every day during this season. This is not true, and for some of the upstream stations the average annual days with stages equal to or greater than the 1-year frequency flood elevation is less than 10 days. In contrast, for the most downstream station, the average annual days with flooding greater than or equal to the 1-year frequency event is 28 days. The spawning season lasts for 122 days each year; thus, most days have less flooding than the 1-year frequency event. The graph and maps below show the average annual mean, min and max ADFA. The average minimum shows flooding only within the channel areas. The mean annual ADFA has some breakout from the channels but is still within the channels in most places. The average maximum ADFA has significant out of channel flooding, but the extent is less than the 1-year frequency flood.

Mean Annual Fisheries Habitat			
	Min	Mean	Max
Base	14,512.5	28,152.8	137,157.5
Alt1	13,538.5	25,829.9	114,559.7
Change	-974.0	-2,322.9	-22,597.8





TERRESTRIAL

The ERDC Wildlife Team requested the analysis of Period-of-Record (POR) hydrology for three different wildlife associations. The three associations were: Great Blue Herons (GBH), wading shore birds (spring and fall), and waterfowl. The seasons were based on the primary annual periods that these associations are present in the Yazoo Backwater Project Area. The season for GBH is 15 March through 31 July (Terrestrial Season 1 – TS1). Shore birds had two seasons each year. The spring season is 15 April through 15 June (Terrestrial Season 2 – TS2) and fall season 1 July through 15 October (Terrestrial Season 3 – TS3). The final terrestrial association is for dabbling ducks, and they are generally present from 1 November through the end of February (Terrestrial Season 4 – TS4).

This is the first study the Vicksburg District has performed using GBH and shore birds, and no models have been established to perform these analyses. The EnviroFish model can provide the necessary information. The EnviroFish model calculates four daily statistics, which are water depth (water surface elevation), total rearing area, restricted rearing area, and spawning area. The restricted rearing bin of the EnviroFish model allows the user to establish minimum and maximum water depths. The GBH's require a water depth range of 0 to 1.5 feet, and shorebirds require a depth range of 0 to 0.67 feet (8 inches). Thus, when examining the Excel tables of EnviroFish results, the restricted rearing (r-rearing) column is the appropriate column to use. The Excel file with the GBH data is GBH_EFoutput.xlsx.

The preferred habitat for Great Blue Herons is water with a depth up to 18 inches. The EnviroFish model calculates the daily acres of habitat available during the spring GBH season. The hydrologic analysis then provides statistics summarizing the range of habitat available. The first value is the “average daily flooded acres” (ADFA). In addition to the mean (ADFA), the minimum, maximum, and 75th percentile values for daily stage and habitat area are provided. ARC-Map coverages of the mean and 75th percentile elevations were created with the FESM mapping tool for the Base, Alternative 1, and Alternative 2.

The preferred habitat for Shore Birds is water up to 8 inches (0.67 feet) in depth. The EnviroFish model calculated the daily acres of habitat available during the spring and fall shore bird seasons (TS2 and TS3 respectively). The daily acres of habitat available for each day of the POR are available in an Excel spreadsheet (ShoreB_EnviroF_Sep2023.xlsx). The spreadsheet provides statistics for the POR for the two seasons. The statistics are the mean daily habitat (ADFA), and the minimum, maximum, the 25th and 75th percentiles of both the daily stages and the habitat acres.

Waterfowl will feed in water up to 18 inches in depth and utilize deeper water for resting. EnviroFish was used to determine the available feeding and resting habitats. The feeding depth (1.5 feet) for the maximum restricted rearing depth and 0 feet was used as the minimum. The total rearing area minus the restricted rearing area would be the resting area. The results of the analyses are provided in the Waterfowl_EnvF_1.5.xlsx spreadsheet.

OFFSITE WETLAND DELINEATION

INTRODUCTION

For this study the Vicksburg District is considering all lands within the 5-year flood plain as wetlands. This is different from previous studies, but it is consistent with the Yazoo Basin HGM Manual which considers all lands within the 5-year flood plain as riverine wetlands. The offsite wetland delineation described in this appendix is different from the method used in the 2007 SEIS and the 2020 Report. For an area to be a federally defined wetland, it must have all three of the following components: (a) hydrophytic vegetation, (b) hydric soils, and (c) current wetland hydrology. In this study it is assumed that all areas in the 5-year flood plain meet these three criteria. To meet the hydrology requirement, an area must be inundated or saturated to the surface continuously for 12.5 percent (46 days for a 365-day growing season) of the growing season in most years (5 years in 10).

However, in some cases that requirement can be met with inundation or saturation to the surface continuously for as little as 5 percent of the growing season (18 days in the project area). Areas above the 2-year flood plain cannot meet this requirement with inundation, but they may be saturated in the top twelve inches in most years. The HGM

Wetland Assessment Protocol assigns wetland values using (6 or 8) metrics. Several of those metrics use the duration and frequency of flooding to determine the metric value. Therefore, the wetlands in the 5-year flood plain have been delineated based on flood duration and frequency. Assuming all lands within the 5-year flood plain are wetlands will provide a larger estimate of wetland extent and will offset the error induced by the method's inability to consider wetlands sustained by soil saturation. This method provides a means to determine wetland extent during periods when the required hydrologic conditions are no longer being met. The preferred method of the WDM of determining the hydrology of wetlands is visual observation of flooding. For this offsite estimation of wetland extent, the FESM flood extent mapping tool will be used to determine the various flood frequency and flood duration zones within the 5-year flood plain.

Offsite Wetland Delineation Methodology

The Vicksburg District (CEMVK) has been utilizing and perfecting a GIS-based off-site wetland delineation method since 1990. This method is called the 5 percent Duration Flood Method or sometimes it is shortened to the Flood Method. The first use of satellite imagery of floods and GIS to delineate wetlands was made for the Yalobusha-Tallahatchie River Maintenance Project in 1990. The method has subsequently been utilized in several other studies including Upper Steele Bayou; Upper Yazoo Projects; Shreveport, Louisiana, to Daingerfield, Texas; Big Sunflower River Maintenance; Sicily Island; and Mississippi River Levees (1997 and 2020). Each application has included some refinements to the basic concept of utilizing a combination of satellite imagery and GIS to delineate the areal extent of wetlands. The basic process in the 2007 Report involves these four steps:

Wetland elevation development. Analyze stage data to determine the 5 percent duration elevation at each gage. Daily gage records from six gage locations within the study area were used. Stage records from 1943 to 1997 were used, when available.

Satellite imagery. Find and classify a satellite image (or images) where the observed stages are approximately equal to the 5 percent duration elevation for each gage. (Note: in many of the studies this was the most imprecise step. Flood scene elevations differed as much as four feet from the 5% duration elevation).

Verify flood extent. Verify that the flooded areas on the classified satellite images accurately reflect the stages on the date of the flood scene.

Field Verification of wetland delineation. Field verification of the wetland delineation using onsite methods by wetland experts.

Wetland Delineation in the 2020 and 2023 reports.

Wetland elevation development. Analyze stage data to determine the 5 percent duration elevation at each gage. Daily gage records from six gage locations within the study area were used. Stage records from 1997 to 2020 were used, when available.

FESM Duration Extent. Use the five sets of wetland duration elevations and the four sets of flood frequency elevations from above to model the wetland extent for each duration and frequency.

Verify flood extent. Use LANDSAT satellite imagery of flood events to calibrate the FESM flood extent tool.

Field Verification of wetland delineation. This step was dropped in the 2020 study. The 2003 EMAP study which determined the jurisdictional wetland status of more than 150 sites in three tiers established the credibility of the FESM 5% duration wetland extent.

Assumptions

All areas flooded in the 5-year flood plain are either permanent waters or wetlands.

Areas flooded by the 5-year flood event will meet the three (hydrologic, vegetative and hydric soils) criteria of wetlands.

RESULTS OF OFFSITE WETLAND DELINEATION

Wetland Elevation Development

As was previously noted, the Corps WDM defines wetland hydrology as: “An area may have wetland hydrology if it is inundated or saturated to the surface for at least 5 percent of the growing season in most years.” The Vicksburg District interprets the “in most years” as the median (50th percentile) annual 5 percent duration for a period-of-record. The median elevation was used for all five duration intervals. The median duration elevations were developed from the dix recording gage locations throughout the study. These gages, along with other pertinent data, are listed in Table 2-31. The period-of-record for most gage locations was 43 years. The 1978 to 2020 POR was utilized because it represents the period after the Backwater Levee was completed. HEC-RAS water surface elevation data were utilized at all gages locations for all alternatives. Observed data is available for Alt1 (no pump) but is not available for the other alternatives. These computed period-of-record elevation data are also utilized for economic, terrestrial, waterfowl, and aquatic analyses.

Table 2-31. Stage Data Period-of-Record by Gage

Gage	Period-of-Record Available	Period-of-Record Used
Steele Bayou Landside at the Steele Bayou Structure	21 October 1968 to Present	1978 to 2020

Steele Bayou at Rolling Fork	22 September 1955 to Present	1978 to 2020
Little Sunflower Landside at the Little Sunflower Structure	April 1978 to Present	1978 to 2020
Big Sunflower at Holly Bluff	28 August 1910 to Present	1978 to 2020
Big Sunflower at Anguilla	18 February 1949 to Present	1978 to 2020
Big Sunflower at Little Callao	3 February 1948 to Present	1978 to 2020

WETSORT

Wetland elevations were developed using the Vicksburg District WETSORT computer program. WETSORT statistically analyzes the period-of-record stage data and computes the annual stages for the 2.5, 5, 7.5, 10, and 12.5 percent duration events during the growing season; sorts the data by stage; and calculates the median elevation for each duration event. Other durations can be added such as the 25% and 50% durations. Required inputs are the beginning and ending dates of the growing season and period-of-record stage data. An example of the output for the 5 percent duration event at the Steele Bayou structure is provided in Table 2-32. For the 2007 and 2020 studies a 270-day growing season was used. For the 2023 study both the 270- and a 365-day growing season duration elevations were calculated. Only the 365-day elevations were used in the HGM analysis of wetland values.

Table 2-32. Example of WETSORT for 5% duration – 18 days (365 season)

	Alt1 - No Pump			**Alt2 - 25Mar**		**Alt3 - 15Mar**	
Rank	**Value**	**Start Date**	**End Date**	**Value**	**Start Date**	**Value**	**Start Date**
1	98.27	21-May-19	8-Jun-19	92.44	21-Feb-20	92.44	21-Feb-20
2	96.55	14-Apr-20	2-May-20	92.4	11-Mar-19	92.35	11-Mar-19
3	95.6	27-Apr-79	15-May-79	91.88	12-Mar-18	91.25	15-Jan-91
4	94.75	31-May-83	18-Jun-83	91.25	15-Jan-91	91.11	8-Mar-18
5	93.4	15-Mar-18	2-Apr-18	90.22	16-Mar-97	89.85	20-Apr-94
6	93.18	28-Mar-97	15-Apr-97	89.96	10-Mar-94	89.77	13-May-84
7	92.03	20-May-84	7-Jun-84	89.77	13-May-84	89.75	8-May-93
8	91.97	26-May-09	13-Jun-09	89.75	8-May-93	89.74	16-Jan-16
9	91.61	6-May-08	24-May-08	89.74	16-Jan-16	89.73	20-May-11
10	91.28	15-Jan-91	2-Feb-91	89.73	20-May-11	89.66	14-Apr-08
11	91.07	2-Jun-11	20-Jun-11	89.68	1-Apr-79	89.65	21-Mar-79

	Alt1 - No Pump			Alt2 - 25Mar		Alt3 - 15Mar	
Rank	**Value**	**Start Date**	**End Date**	**Value**	**Start Date**	**Value**	**Start Date**
12	90.97	3-May-94	21-May-94	89.66	14-Apr-08	89.64	27-Apr-83
13	90.91	7-May-93	25-May-93	89.64	27-Apr-83	89.59	15-May-13
14	89.91	16-May-13	3-Jun-13	89.59	18-May-09	89.59	18-May-09
15	89.73	16-Jan-16	3-Feb-16	89.59	15-May-13	89.59	14-Mar-97
16	89.01	10-Apr-80	28-Apr-80	89	10-Apr-80	89	10-Apr-80
17	88.58	31-May-17	18-Jun-17	88.58	31-May-17	88.58	31-May-17
18	88.48	22-Jul-15	9-Aug-15	88.48	22-Jul-15	88.48	22-Jul-15
19	88.46	5-Mar-89	23-Mar-89	88.45	5-Mar-89	88.45	5-Mar-89
20	88.41	21-Jan-05	8-Feb-05	88.41	21-Jan-05	88.41	21-Jan-05
21	88.38	6-Feb-99	24-Feb-99	88.38	6-Feb-99	88.38	6-Feb-99
22	88.33	23-Feb-90	13-Mar-90	88.32	23-Feb-90	88.32	23-Feb-90
23	88.24	26-May-02	13-Jun-02	88.23	26-May-02	88.23	26-May-02
24	88.12	10-May-98	28-May-98	88.13	10-May-98	88.13	10-May-98
25	87.81	9-Jun-96	27-Jun-96	87.8	7-Feb-10	87.8	7-Feb-10
26	87.78	7-Feb-10	25-Feb-10	87.79	9-Jun-96	87.8	9-Jun-96
27	87.49	14-Mar-85	1-Apr-85	87.46	14-Mar-85	87.46	14-Mar-85
28	87.39	12-Jun-95	30-Jun-95	87.39	12-Jun-95	87.39	12-Jun-95
29	86.29	14-Dec-82	1-Jan-83	86.27	14-Dec-82	86.27	14-Dec-82
30	85.68	23-May-03	10-Jun-03	85.69	23-May-03	85.69	23-May-03
31	85.47	11-Dec-04	29-Dec-04	85.47	11-Dec-04	85.47	11-Dec-04
32	84.1	28-Feb-01	18-Mar-01	84.1	28-Feb-01	84.1	28-Feb-01
33	84.01	16-May-78	3-Jun-78	84.01	16-May-78	84.01	16-May-78
34	83.09	18-Jan-07	5-Feb-07	83.09	18-Jan-07	83.09	18-Jan-07
35	81.35	11-Apr-14	29-Apr-14	81.36	7-Mar-87	81.36	7-Mar-87
36	81.35	7-Mar-87	25-Mar-87	81.35	11-Apr-14	81.35	11-Apr-14
37	81.06	17-Mar-12	4-Apr-12	81.06	17-Mar-12	81.06	17-Mar-12
38	79.14	9-Dec-86	27-Dec-86	79.13	9-Dec-86	79.13	9-Dec-86
39	78.36	8-Jun-81	26-Jun-81	78.36	8-Jun-81	78.36	8-Jun-81
40	77.83	21-Mar-92	8-Apr-92	77.82	21-Mar-92	77.82	21-Mar-92
41	76.48	2-Apr-00	20-Apr-00	76.46	2-Apr-00	76.46	2-Apr-00
42	76.21	8-Apr-88	26-Apr-88	75.9	7-Apr-88	76.29	8-Apr-88
43	74.21	27-Jan-06	14-Feb-06	74.11	28-Jan-06	74.5	29-Jan-06

The WETSORT program was run for Alt1, Alt2, and Alt3 at the six gage locations listed in Table 2-32 above. The results of the WETSORT runs are available in “Wetsort_RAS_Sep2023.xlsx”. It was also run for the Big Sunflower gage at Sunflower, the Quiver River gages at Sunflower and Doddsville, and the Bogue Phalia gage at Leland. These four gages provided the upstream input for the RAS model. WETSORT was only run for the observed stages at these gages using the 1978 to 2020 POR. Observed data was also used for the external gages on the Yazoo River (Satartia, Little Sunflower RS, Steele Bayou RS, and Mississippi River at Vicksburg). The riverside WETSORT results are found in “Wetsort_78POR_RAS.xlsx”. Figures 2-110 – 2-112 show the five duration profiles for Alternatives 1 to 3, respectively. Figure 2-113 plots the 5% duration profiles for all three alternatives, and Figure 2-114 plots the 12.5% duration profiles. The y-axis is elevation, and the x-axis is distance in miles from the Steele Bayou gage.

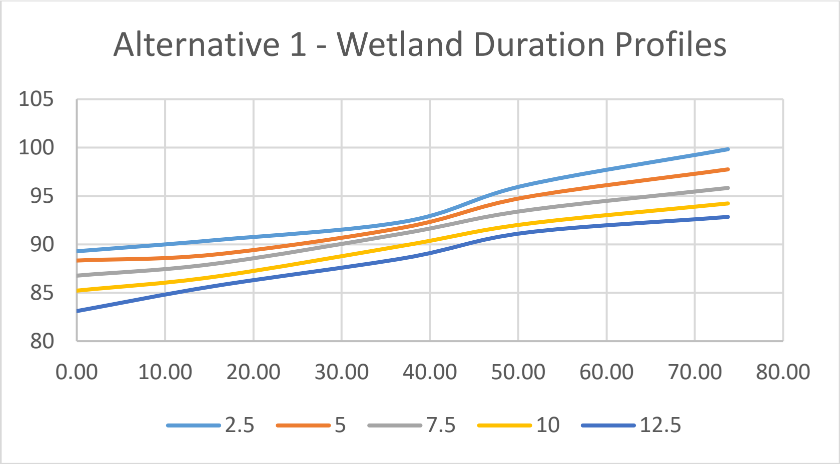


Figure 2-110. Alternative 1 Wetland Duration Profiles

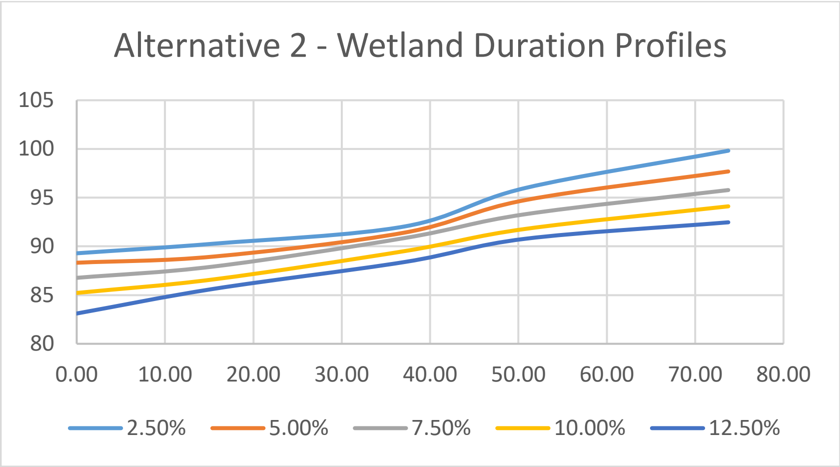


Figure 2-111. Alternative 2 Wetland Duration Profiles

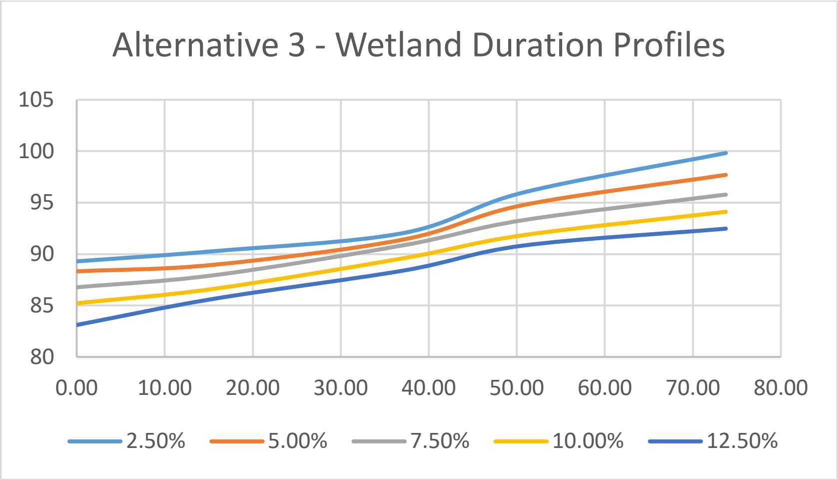


Figure 2-112. Alternative 3 Wetland Duration Profiles

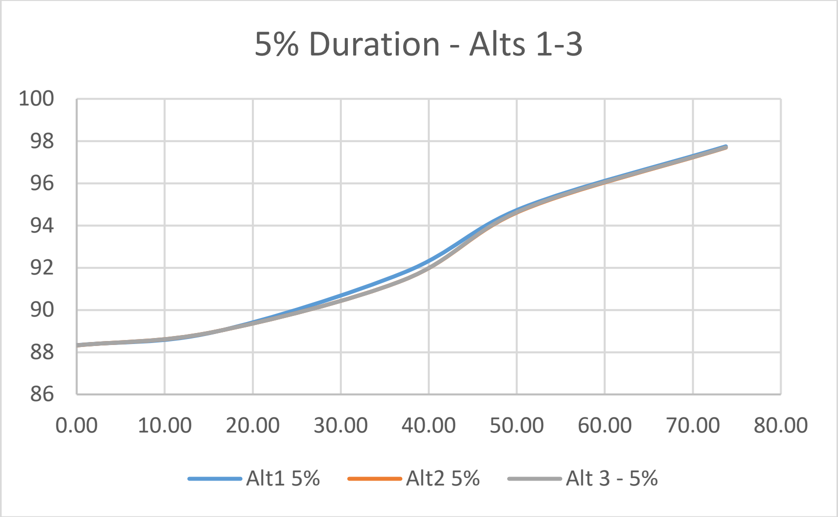


Figure 2-113. Duration Profiles for Alternatives 1-3

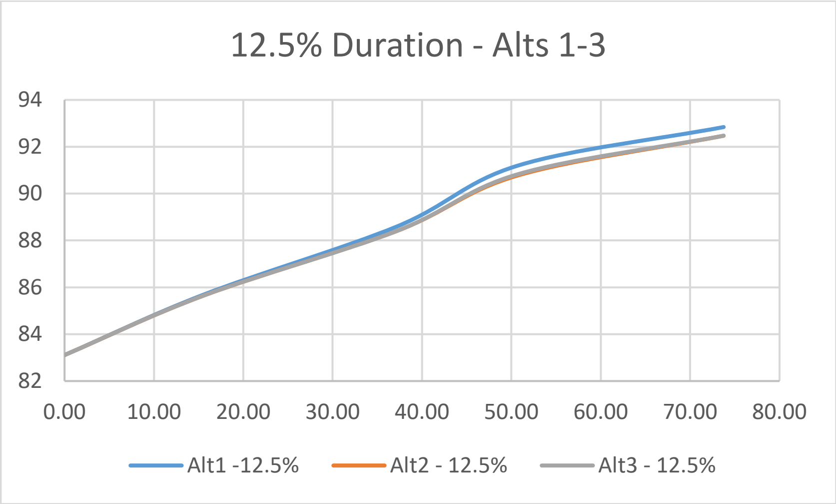


Figure 2-114. 12.5% Duration Profiles for Alternatives 1-3

FLOOD EVENT SIMULATION MODEL (FESM)

Flood Event Simulation Model (FESM) is not a model but rather a GIS mapping tool that displays inundation for a given flood event. FESM utilizes river alignment and river profile elevations at USACE gage locations from a hydraulic model. HEC-RAS was the hydraulic model utilized for this study. FESM then floods from the river profile elevations at gage locations vertically downward to the digital elevation model (DEM). The DEM is a representation of bare earth topographic surface excluding trees, building, and other surface objects. FESM is used by USACE to balance precision and speed in providing acreage used for mitigation impacts while providing a more conservative estimate of the impacts. FESM results can be verified by aerial photography from the flood event or other readily available H&H tools.

FESM used the five profiles to determine the areal extent of each of the duration intervals. The FESM tool uses three GIS data layers. The first layer is a point file with the gage or pseudo-gage locations and their respective water surface elevations for the five duration intervals. Pseudo-gages are point locations, such as stream intersections, where there are no water surface elevations available. The elevations for these points are calculated by linear interpolation from the upstream and downstream gages. The second layer is a polyline file, which connects the 25 gage locations. The last data layer is a DEM. A 10-foot DEM was used in this study. The DEM used for the RAS model was modified by removing some bridge decks on secondary roads. The FESM tool was run five times for each alternative, once for each duration interval, and the five resultant files were merged to form a composite wetland zone map. The required fields for the gage file are shown in Table 2-33 below. The first two fields (FID and Shape) are ArcMap required fields. The next four fields are FESM required fields (ID, Name, Type and Meta). The
“type” field informs the model if the water surface elevations are supplied (obs) or need to be calculated (calc). If the model is required to calculate the surface, the equation is provided in the “Meta” field. The last two fields (“D 35” and “D 28”) are event water surface elevations for a model run. The file can have any number of event fields, with a requirement that the name is unique. The required fields for the channels file are shown in Table 2-34. As in the Gages file the first two fields are required by ArcMap. The remaining five fields are required by FESM. The “From G-ID” and the “To G-ID” fields reference the downstream and upstream gages, respectively, from the Gages file for each stream segment. The final field “length” is the length of the stream segment. The units of length are dependent on the projection of the files. The FESM “project” file has a field requesting the units used for distance and elevation. Tables 2-33 and 2-34 do not show the complete shapefiles. The complete files are in Gage_Calculator_YBW2023.xlsx (the file is available on the project website). The model starts by reading the gage and channel input files. Next, the model calculates the slope of each segment length (Upstream gage elevation minus downstream gage elevation / segment length). The model then creates additional stream nodes along the centerline of the channel. The distance between nodes is equal to the size of the DEM pixels. The elevation of these nodes is equal to the product of the slope*pixel + downstream node elevation. This creates a starting centerline elevation for each stream segment. The model then compares the centerline elevation to the pixel elevation. If the water surface elevation is greater than the DEM elevation, the pixel (grid cell) is marked as “1”. If the water surface elevation is less than the land surface elevation, the pixel is marked as “0”. The computation line moves to the newly created pixels marked with a “1”, and the next iteration of comparisons begins. The iterations continue until no more pixels are marked as “1”. The output file is a geo-tiff file with pixel dimensions equal to the DEM, and pixel values of 0 or 1.

FESM Assumptions

The water surface elevation of the streams diminishes in a linear fashion from upstream to downstream.

When modeling flood duration events, the flood extent is at its' maximum. The flood surface is neither rising nor falling (lateral slope = 0).

When modeling flood frequency events, the flood stage is at its' maximum, but the extent will be subject to frictional losses (lateral slope = 1).

The DEM provides an accurate description of the land-surface elevation.

Table 2-33. FESM Gage File Required Fields

FID	Shape	ID	Name	Type	Meta	D_35	D_28
0	Point	101	Little Sunflower-L	obs		84.45	86.3
22	Point	102	juncLs_SixM	calc	4,0.302*(g103-g101)+g101	0	0
1	Point	103	Holly Bluff	obs		85.42	87.27
24	Point	104	Junc_lowHBCutoff	calc	5,0.0408*(g107-g103)+g103	0	0
23	Point	105	junc_BS_LS	calc	6,0.4692*(g107-g103)+g103	0	0
25	Point	106	Upper_HBcut	calc	7,0.5428*(g107-g103)+g103	0	0
2	Point	107	Anguilla	obs		86.14	87.24
3	Point	108	Little Calleo	obs		86.72	88.02
4	Point	109	Mouth of BogueP	calc	1,0.139*(g112-g108)+g108	0	0
5	Point	110	Mouth of Bogue C	calc	2,0.3094*(g112-g108)+g108	0	0
6	Point	111	Mouth of Quiver	calc	3,0.6706*(g112-g108)+g108	0	0

7	Point	112	Sunflower	obs		96.25	97.07

Table 2-34. FESM Channel File Required Fields

FID	Shape	ID	Name	From G-ID	To G-ID	Length
11	Polyline	41	Bogue_Phalia1	116	117	244465.7
10	Polyline	42	Bogue_Phalia2	109	116	114072.2
19	Polyline	43	BogueP_Cutoff	118	116	7929.256
12	Polyline	44	BogueP_Cutoff	110	118	58747.94
4	Polyline	46	BigSunflower8	113	114	189684.4
0	Polyline	47	BigSunflower7	112	113	221998.5
16	Polyline	48	BigSunflower6	111	112	86989.58
1	Polyline	49	BigSunflower5	110	111	94529.85
15	Polyline	50	BigSunflower4	109	110	47796.8
14	Polyline	51	BigSunflower3	108	109	36907.44
2	Polyline	52	BigSunflower2	107	108	120699.7
30	Polyline	53	BigSunflower1	106	107	32672.39

The FESM mapping tool has a couple of options available to adjust the output extent. These options involve adjusting the lateral slope. During a flood, as water moves away from the channel the water surface generally decreases slowly due to friction. To account for the lateral change in the water surface, the modeler can adjust the lateral slope. The model can be run either using a constant lateral slope or can use a slope factor to adjust the calculated slope for each reach. If the modeler selects, constant slope, the model defaults to a slope of zero (no change in the water surface), but the modeler can input a value for the constant slope. The average north to south slope of the Big Sunflower Basin is 1 foot in two miles, this is approximately one foot in 10,000 feet or 0.0001 foot/foot. The second option, for adjusting the lateral slope, is to select the calculated slope option. For this option, the calculated slope for each channel segment will be multiplied by the slope factor. The default slope factor is “1”, which would then use the calculated slope for each segment as the lateral slope. The frequency model runs used a slope factor of “1”, and duration model runs used a slope factor of “0”.

SLOPE ADJUSTMENT

As discussed above there are two ways to adjust the lateral slope. Using a constant slope or a slope factor. The flood frequency model runs were run with a slope factor of “1”, which means the lateral slope is the same as the river slope for each segment. Table 2-35 shows the slopes between the gages in the project area for the seven frequency flood events. The range of slope values is 0.000001 to 0.000039 feet/foot. Converting these slope values to feet/mile yields slopes of 0.00528 and 0.20592 feet/mile. The smallest slopes were calculated between Holly Bluff and Little Sunflower LS and between Little Sunflower LS and Steele Bayou LS during the 50 and 100-year flood frequency events. These gages are in the upper and lower storage areas. The greatest slopes were observed between the Little Callao and Anguilla gages and the Anguilla and Holly Bluff gages. These gages are in the upper part of the basin, which is subject to more frequent headwater flood events. Table 2-36 shows the channel slopes between the gages for the duration events. Because a constant slope of zero was used, there was no reduction in the water surface elevation as the flood progressed laterally away from the channel centerline. The observed range of values was less than the range for the frequency events (0.000008 to 0.000033), but they were on the same order of magnitude. The slopes generally increased from downstream to upstream. These tables can be viewed in Gage_calculator_YBW2023.xlsx, which is available on the Project Website.

Table 2-35. FESM Channel Slopes between Gages by Frequency Event (no pump alt.)

Slope between gages by frequency (Feet/Foot)					
Dist. Feet	121363.0	114101.0	113975.7	82184.9	240511.9
Interval	Lc-An	An-HB	HB-LS	LS-SB	Gr-SB
500	0.000038	0.000006	-0.000026	0.000008	-0.000006
200	0.000038	0.000007	-0.000018	0.000031	0.000002
100	0.000039	-0.000002	0.000001	0.000015	0.000002
50	0.000036	0.000011	0.000001	0.000001	0.000003
20	0.000034	0.000019	0.000005	0.000000	0.000006
10	0.000032	0.000031	0.000000	0.000000	0.000007

5	0.000032	0.000035	0.000006	0.000005	0.000012
2	0.000030	0.000039	0.000015	0.000008	0.000018
1.25	0.000031	0.000037	0.000023	0.000006	0.000020
1.11	0.000031	0.000037	0.000026	0.000005	0.000021
1.05	0.000031	0.000038	0.000026	0.000006	0.000022
1.01	0.000031	0.000038	0.000026	0.000009	0.000023

Table 2-36. FESM Channel Slopes between Gages by Duration (no pump alt.)

Slope between gages by duration (Feet/Foot)					
Dist. Feet	121363	114101	113975.7	82184.86	240511.9
Duration	Lc-An	An-HB	HB-LS	LS-SB	Gr-SB
2.50%	0.000031	0.000033	0.000017	0.000014	0.000017
5.00%	0.000024	0.000027	0.000025	0.000008	0.000013
7.50%	0.000019	0.000020	0.000028	0.000015	0.000018
10.00%	0.000018	0.000019	0.000029	0.000017	0.000021
12.50%	0.000014	0.000023	0.000025	0.000031	0.000025

FESM OUTPUT

The FESM model is used to simulate both frequency and duration events for all alternatives (Alt1, Alt2 and Alt3). The 1, 2, 5, 10, 20, 50, and 100-year frequency events and the 2.5, 5.0, 7.5, 10.0, and 12.5% duration events. The first step in the modeling is collecting the elevation data at the gage locations used in the modeling. The model has 34 nodes which require elevation data. Nineteen are actual gage locations, 9 are stream junctions, the remaining sites are old gage locations where daily data is no longer collected. Six of the gage locations are in the backwater area of the project area. Four are in the Upper Steele Bayou basin above the 100-year flood elevation. Four are headwater locations that provide upstream conditions. The locations for the gages are in Figure 2-115. The remaining locations are riverside locations on the Yazoo River. At the 15 sites without daily data, the elevations are calculated by linear interpolation. The interpolation can be either done within the FESM model or externally with a spreadsheet. Flood frequency elevations for all gages are determined by the HEC-SSP program, and the duration elevations are determined with WETSORT.

GIS SCENE PROCESSING

FESM produces a geo-tiff file, which must be processed for analysis with ArcMap. The raw TIFF file has two values 0 and 1. The 0 value is for unflooded areas and the 1 value is for flooded areas. Each scene is reclassified (the grid cell values are changed). The 0 values are eliminated, and the flood or duration is given a unique value. Flood scenes are reclassed to a value equal to their flood return interval (1, 2, 5, 10, 20, 50 and 100). The reclassification of the flood duration TIFFs is more complicated. Base (Alt1-no pump) are given values of 10, 20, 30, 40 and 50 for the 2.5, 5.0, 7.5, 10.0 and 12.5 % durations respectively. The pump alternatives are given values of 1, 2, 3, 4 and 5 for the 2.5, 5.0, 7.5, 10.0 and 12.5% durations respectively. The pump alternatives (Alt2 and Alt3) are given values of 1, 2, 3, 4 and 5 for the 2.5, 5.0, 7.5, 10.0 and 12.5% durations respectively. The numerical values of the base and flood durations are carefully selected, such that when the two scenes are added only unique values are produced. The next step is making composite flood or duration scenes for each alternative (ArcMap-Data Management Tools/Raster/Raster Dataset/Mosaic to New Raster). The composite flood scenes display all flood frequencies as nested grid values. The 100-year scene extent contains all the individual flood scene values, and the 50-year extent is represented by all values except ‘100.’ The composite scenes are useful in viewing the change in extent with flood frequency. The process for making composite wetland scenes is similar. In the 2007 and 2020 studies the composite base (without pump) map contained the 2-year frequency flood with the 2.5, 5.0, 7.5, 10.0 and 12.5% duration floods. This creates 6 wetland zones. The zones represent these duration intervals: 1 to <7 days, 7 to <14 days, 14 to < 21 days, 21 to <28 days, 28 to <35 days, and >34 days. The composite for the with-pump alternative contained the base 2-year, the with pump 2-year and the five duration floods. The inclusion of the base 2-year with the alternative’s floods was necessary to create the wetland mosaic map with the above layers for both the base and with-pump alternatives. The Wetland mosaic maps are created in ArcMap (Spatial Analyst Tools/Map Algebra/Raster Calculator). Table 2-37 below shows how the mosaic files are created. Table 2-37, part A provides a sample area of Alt1 wetlands, and Table 2-37, part B provides a sample area of the same area for Alt2 wetlands. Table 2-37, part C then shows the mosaic product that would be produced by the Map Algebra tool. The sample areas in Table 4 represent an area with 40 grid cells. The 5-year flood plain contains 152,879,530 grid cells. The number and size of the FESM grid cells are determined by the DEM. All FESM runs were performed with the same DEM, thus ensuring that the number grid cells, and extent of the output files are identical. The vertical accuracy of the DEM is discussed earlier in this appendix, but that determination used only cleared sites. (Note: When this LiDAR DEM was first introduced in 2010, the USGS contractor that developed the DEM provided these estimates of the vertical elevation accuracy based on land-cover: cleared lands, herbaceous cover, and forested land).

Table 2-37. Mosaic File Development

Table																		
A- Alt1 – no-pump						B- Alt2 - Mar25						C-Alt1 + Alt2					
Row	A	B	C	D	E	Row	A	B	C	D	E	Row	A	B	C	D	E
1	50	50	50	40	40	1	5	5	4	4	4	1	55	55	54	44	44
2	50	50	40	40	40	2	5	5	4	4	3	2	55	55	44	44	43
3	50	40	40	40	30	3	4	4	3	3	3	3	54	44	43	43	33
4	40	40	30	30	30	4	4	3	3	3	2	4	44	43	33	33	32
5	40	30	30	30	20	5	3	3	3	2	2	5	43	33	33	32	22
6	30	30	20	20	20	6	3	2	2	2	2	6	33	32	22	22	22
7	20	20	20	20	10	7	2	2	2	1	1	7	22	22	22	21	11
8	10	10	10	10	10	8	1	1	1	1	1	8	11	11	11	11	11

The resulting grid file's extent is the lesser of the two input files. Having the base 2-year in both composite files ensures that the areal extent is the same, which means nothing will be clipped. For the 270-day growing season in the current study, the mosaic map was created as above. When the mosaic map was created for the 365-day growing season (the map used for wetland impact analysis), several additional layers were added to the composite maps. The additional layers were the 3, 4, and 5-year flood extents. The 365-day growing season also included six duration zones within the 2-year floodplain. Those zones represented these duration intervals: 1 to <9 days, 9 to <18 days, 18 to <27 days, 27 to < 37 days, 37 to < 46 days, and >45 days. The background layer for the with-pump alternatives (Alts 2 and 3) used the Alt1 (no-pump) 5-year flood. The grid values for the Alt1 map were 60, 70, 80, and 90, for the 2, 3, 4, and 5-year floods respectively. For Alts 2 and 3, the additional grid values were 6, 7, 8, and 9 respectively for the 2, 3, 4, and 5-year floods respectively. Tables 2-38 and 2-39 provide the matrix of grid cell values for the 270-day and the 365-day wetland mosaic maps respectively.

Table 2-38. Wetland 270 Mosaic Grid Value Matrix

Alternative	No-pump	2-year	2.50%	5.00%	7.50%	10%	12.50%
Pump Alts	Grid Value	100	10	20	30	40	50
2-year	0	100	10	20	30	40	50
2.50%	1	101	11	21	31	41	51
5.00%	2	102	12	22	32	42	52
7.50%	3	103	13	23	33	43	53
10.00%	4	104	14	24	34	44	54
12.50%	5	105	15	25	35	45	55

The Table 2-38 matrix has 36 unique values. Six of those (11, 22, 33, 44, 55, and 100) indicate grid locations with no change in hydrology. These cells have dark highlights. There are 15 cells where the units value is less than the ten's value. These cells have lighter highlights are cell values, which indicate a change in hydrology where the duration or frequency changes to a drier condition. There are also 15 cells where the hydrology is getting wetter, but these values are unlikely to occur. The 365-day wetland mosaic is considerably more complicated. The addition of three flood frequencies (3, 4, and 5-year) increases the matrix from 36 to 90 unique values. There are 9 values (11, 22, 33, 44, 55, 66, 77, 88, and 99), which indicate no change in the duration or frequency of the events. There are 45 potential grid cell values, that indicate a negative change in hydrology (shaded light grey), and there are 36 potential grid cell values which indicate an increase in hydrology (no shading). The grid values in Table 2-39 that are in **bold** typeface**,** are the values that are found in the mosaic file (Figures 2-118 and 2-119). For Alternative 2 (Mar25) the sum of the acres for the nine grid values with no change in hydrology is 258,925, which is 73.8% of the total area. There are 22 grid values with a decline in hydrology (less duration or frequency). The sum of acres is 86,026, which is 24.5% of the total area. There are 15 grid values with an increase in duration or frequency, and their total area is 6,056 acres (1.7% of the total). For the group of grid values with a decline in hydrology, 67,295 acres had a change in flood frequency, and 18,731 experienced a change in duration. For Alt3 (Mar15) the sums of the three groups are similar. The area with no change is 255,542 acres (72.8%), the sum with a decrease in hydrology is 83,419 acres (23.8%), and the increase in hydrology is 12,236 acres (3.5%). For Alt3, 62,549 acres show a decline in flood frequency, and 20,870 acres experience a decline in flood duration. Figure 2-115 Alt1 Wetlands shows the wetland areas developed using the 6 duration intervals and the 4 flood frequencies. The figure has 9 classes (Table 2-39, grid value row), which are: durations 9 to 17 days, 18 to 26 days, 27 to 36 days, 36 to 45 days, and greater than 45 days, 1 to 8 days (2-year frequency), 3-year, 4-year, and 5-year frequencies. The figures for alternatives 2 (Figure 2-116) and 3 (Figure 2-117), have an additional class (Alt1 5-year) (Grid column in Table 2-39). This layer is needed to maintain the same extent of the flooded area, which is necessary for the Raster Calculator function in ArcMap. The wetland extents for Alternatives 1 -3 are shown in Figure 2-115 to Figure 2-117 respectively. The composites created by adding the grid values of the Alt1 file to those of alternatives 2 (Mar15) and 3 (Mar25) (Raster Calculator) are shown in Figures 2-118 and 1-119, respectively. Due to the high number of classes, it is difficult to observe changes to individual classes. The five duration classes greater than 9 days (2.5%) with no change in duration are shown in shades of blue (classes 11, 22 ,33, 44, and 55). These five classes represent approximately 67% of the 2-year frequency wetland area. The area and landcover of the GIS layers described above are in NASS22_SepWetlands_revised.xlsx, which is available on the Corps website for this project.

Table 2-39. 5-Year Wetland Grid Value Matrix

		5-year	4-Year	3-Year	2-year	2.50%	5.00%	7.50%	10%	12.50%
Alternative	Grid Value	90	80	70	60	10	20	30	40	50
Base 5-yr	90	180	170	160	150	100	110	120	130	140
5-year	9	99	89	79	69	19	29	39	49	59
4-Year	8	98	88	78	68	18	28	38	48	58
3-Year	7	97	87	77	67	17	27	37	47	57
2-Year	6	96	86	76	66	16	26	36	46	56
2.50%	1	91	81	71	61	11	21	31	41	51
5.00%	2	92	82	72	62	12	22	32	42	52
7.50%	3	93	83	73	63	13	23	33	43	53
10.00%	4	94	84	74	64	14	24	34	44	54
12.50%	5	95	85	75	65	15	25	35	45	55

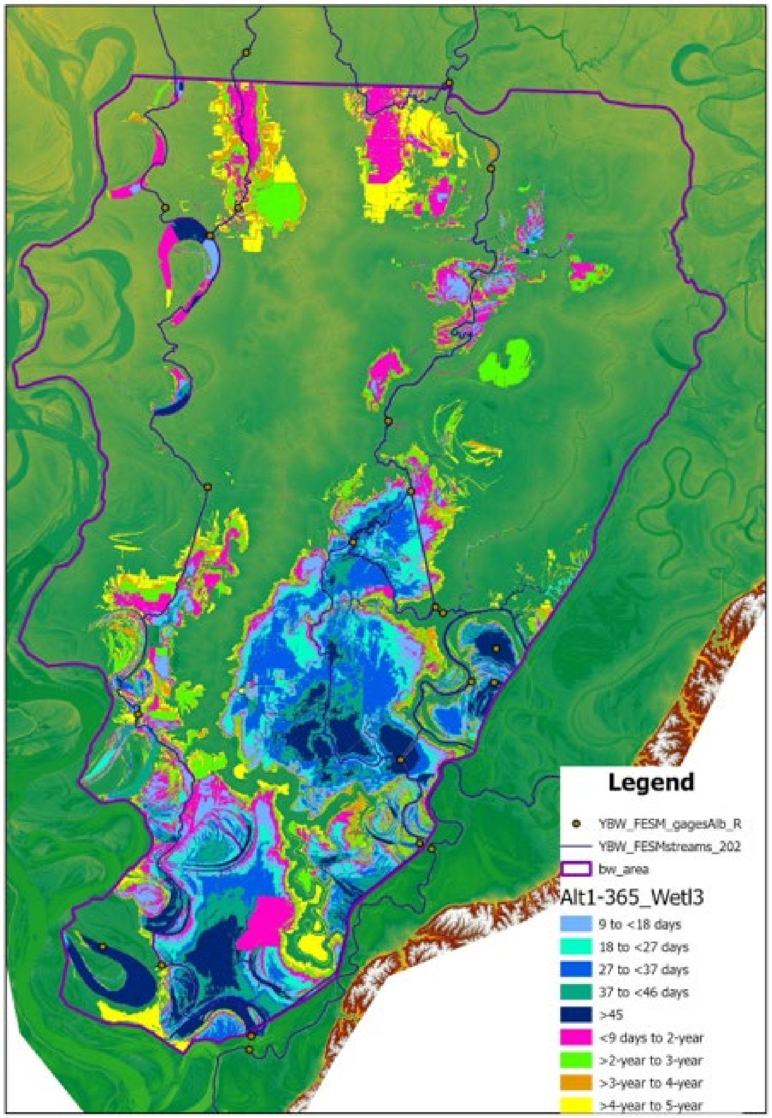


Figure 2-115. Alternative 1 365 Composite Wetlands

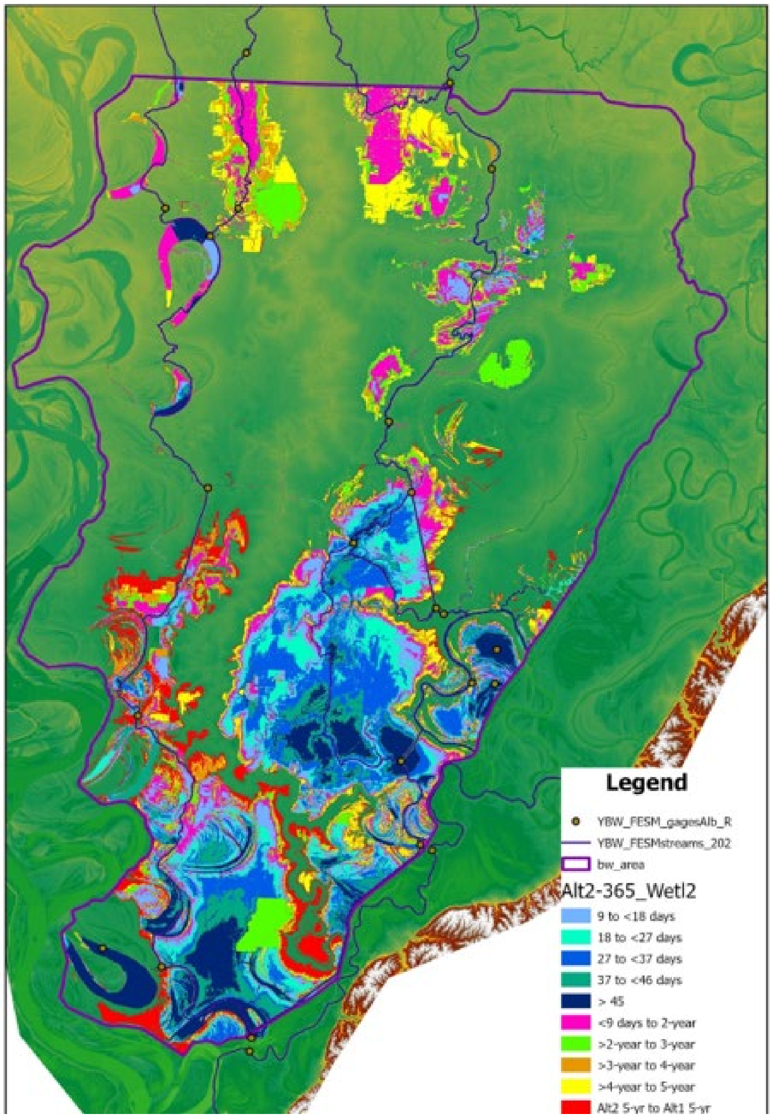


Figure 2-116. Alternative 2 365 Composite Wetlands

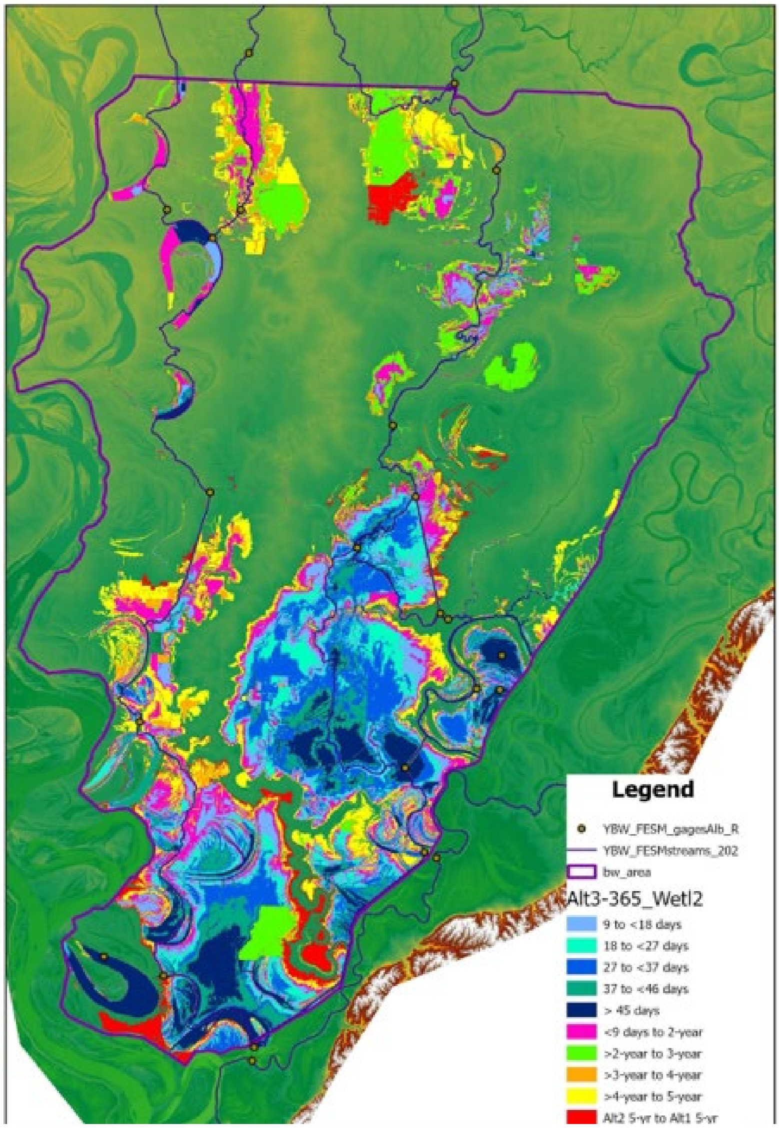


Figure 2-117. Alternative 3 365 Composite Wetlands

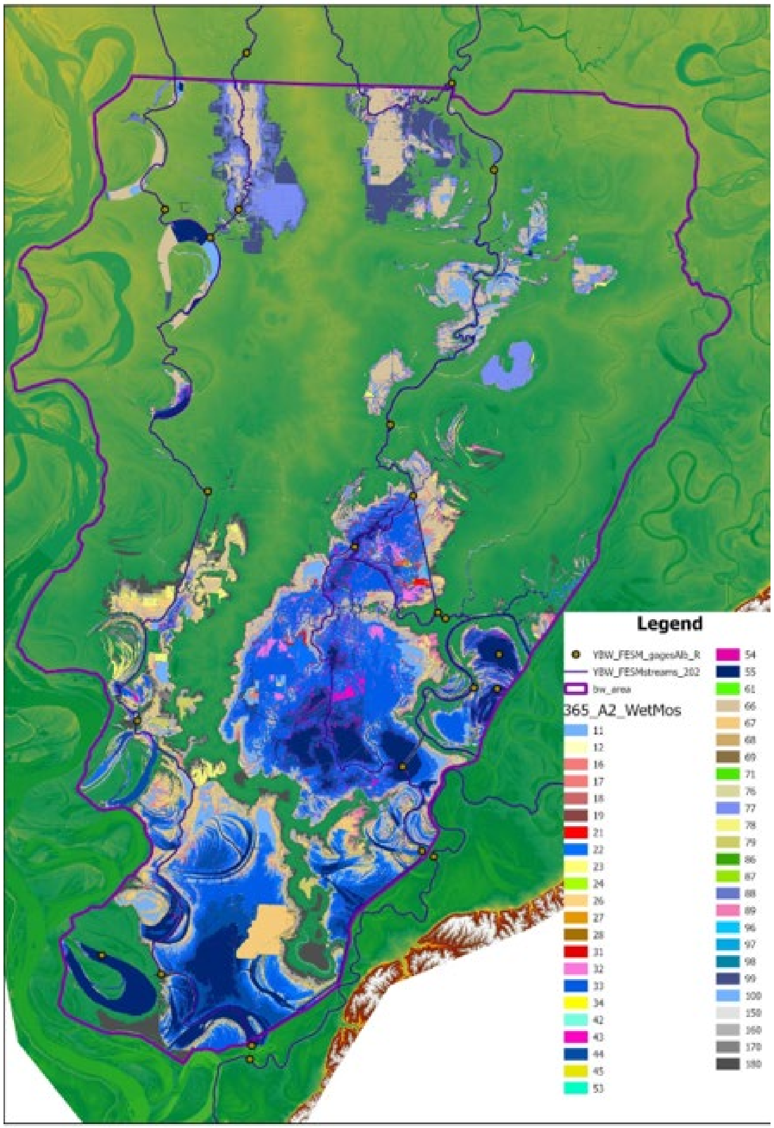


Figure 2-118. Mosaic of Alternative 1 and Alternative 2 Composite Wetlands

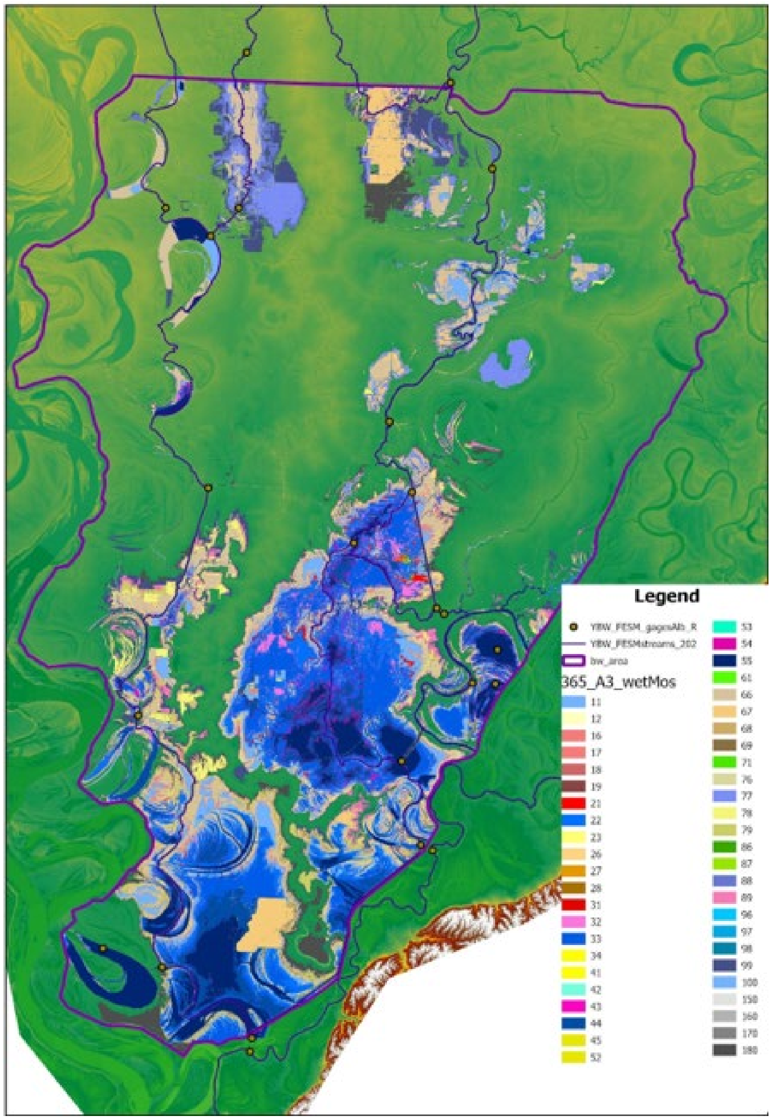


Figure 2-119. Mosaic of Alternative 1 and Alternative 3 Composite Wetlands

Figures 2-118 and 2-119 are quite complicated and are dominated by classes with no change in wetland status (Alt2 no change = 72.6%, Alt3 no change = 73.8%). To make it easier for the reader to visualize where changes are occurring additional figures that show only the changes are below. Figure 2-120 shows the changes in flood duration for Alt2, and Figure 2-121 shows the changes in flood frequency for Alt2. Figures 2-122 and 2-123 show the same respective changes in duration and frequency for Alt3. Table 2-40 shows the changes in acreage for the Alt2 mosaic for flood duration and frequency, and Table 2-41 provides the same information for Alt3.

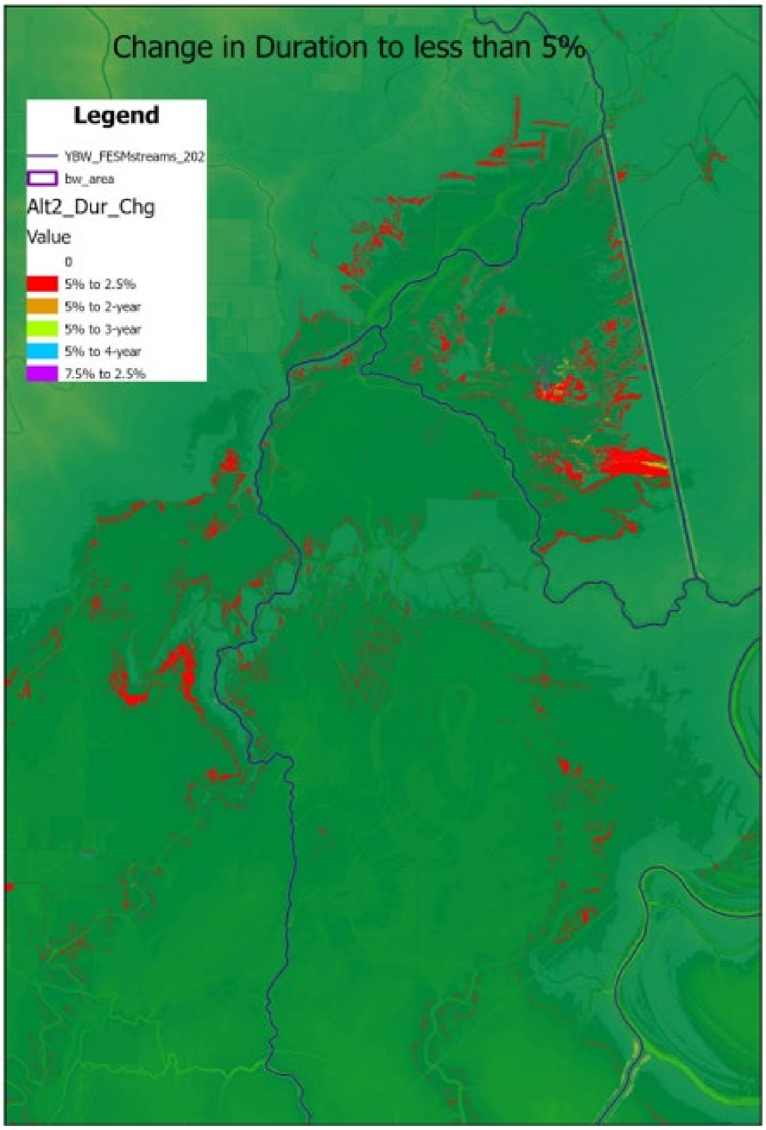


Figure 2-120. Alternative 2 Change in Duration

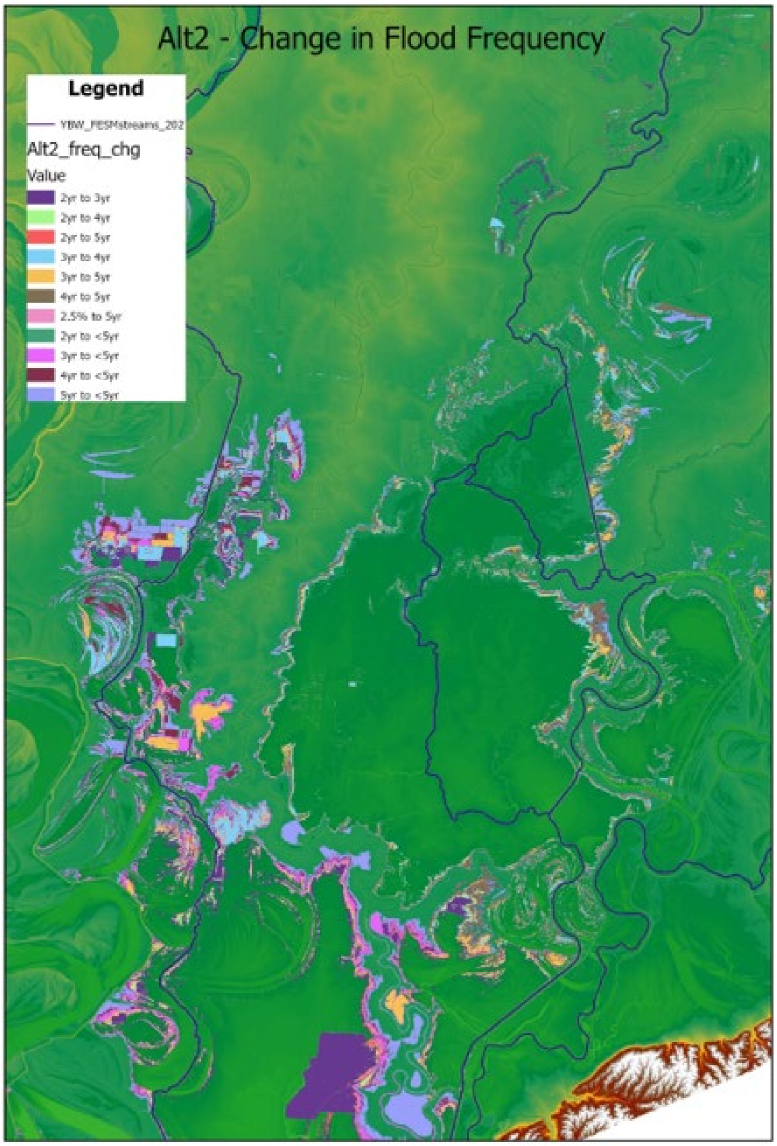


Figure 2-121. Alternative 2 Change in Flood Frequency

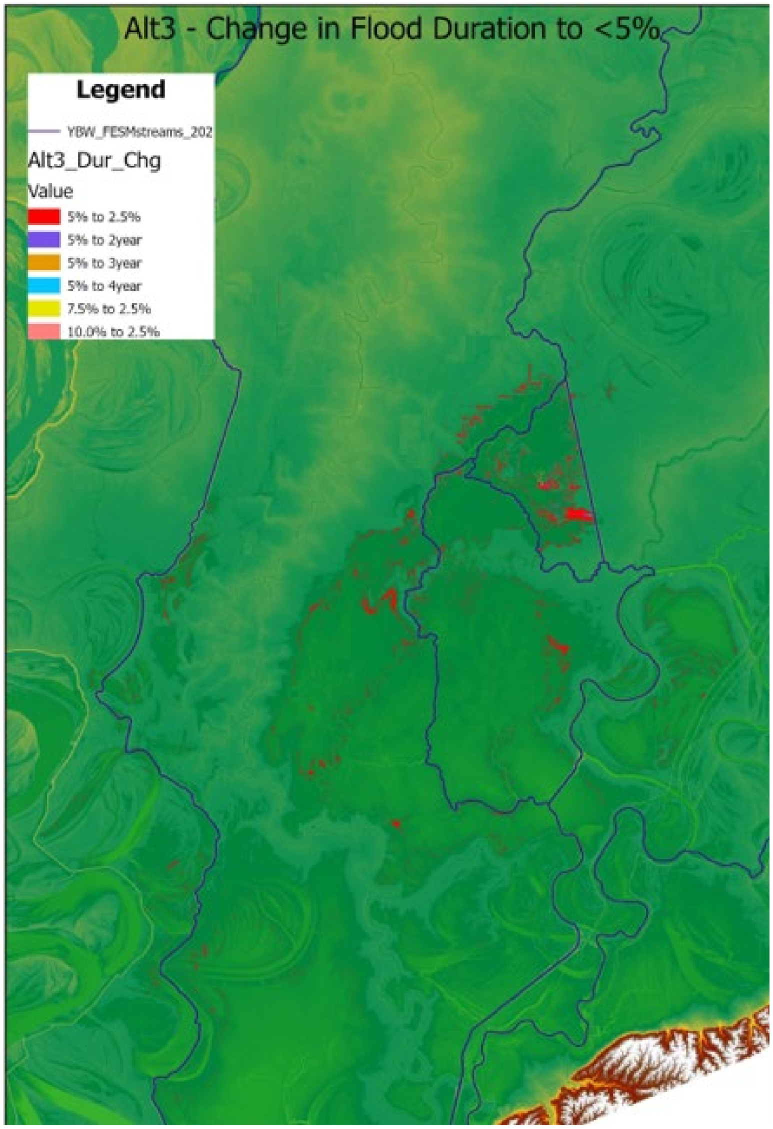


Figure 2-122. Alternative 3 Change in Flood Duration

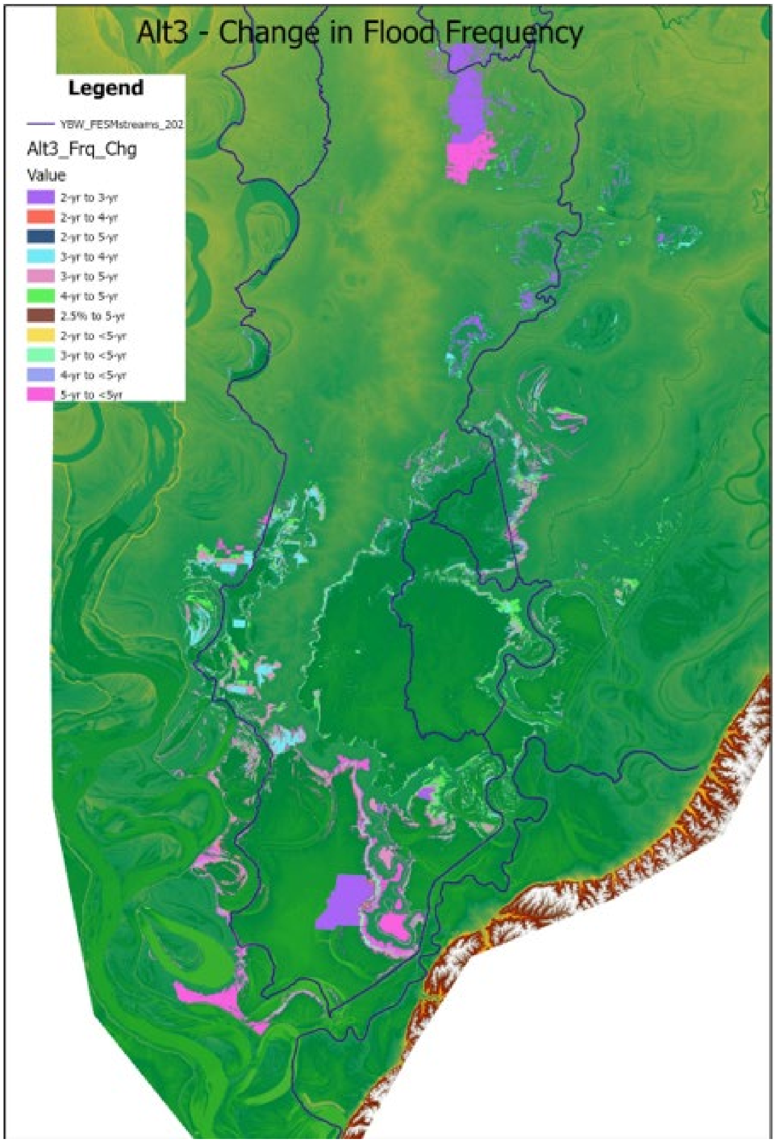


Figure 2-123. Alternative 3 Change in Flood Frequency

Table 2-40. Alt2 changes in wetland acreage based on flood duration and frequency.

Alt2 - Change in Duration			Alt2 - Change in **Frequency**		
Class	Label	Acres	Class	Label	Acres
21	5% to 2.5%	3988.1	67	2-yr to 3-yr	13083.6
26	5% to 2-year	52.5	68	2-yr to 4-yr	1522.0
27	5% to 3-year	1.8	69	2-yr to 5-yr	907.6
28	5% to 4-year	0.9	78	3-yr to 4-yr	9037.9
31	7.5% to 2.5%	11.8	79	3-yr to 5-yr	8780.0
			89	4-yr to 5-yr	8926.5
			150	2-yr to <5-yr	42.0
			160	3-yr to <5-yr	5731.2
			170	4-yr to <5-yr	5163.5
			180	5-yr to <5-yr	21562.0
Total		4055.1			74756.4

Table 2-41. Alt3 changes in wetland acreage based on flood duration and frequency.

Alt3 - Change in Duration			Alt3 - Change in Frequency		
Class	Label	Acres	Class	Label	Acres
21	5% to 2.5%	3963.4	67	2-yr to 3-yr	15295.8
26	5% to 2-year	42.9	68	2-yr to 4-yr	1521.6
27	5% to 3-year	2	69	2-yr to 5-yr	704.5
28	5% to 4-year	0.7	78	3-yr to 4-yr	9190.3
31	7.5% to 2.5%	30.5	79	3-yr to 5-yr	12476.5
			89	4-yr to 5-yr	12215.4
			100	2.5% to 5-yr	18.9
			150	2-yr to <5-yr	25.8
			160	3-yr to <5-yr	982.3
			170	4-yr to <5-yr	1036.6
			180	5-yr to <5-yr	15892.9
Total		4039.5			69360.5

SATELLITE IMAGERY

The areal extent of wetlands for the early studies using the “flood” method were based on a satellite image which approximated the 5 percent duration flood. Although the 2007 initial wetland extent was based on the 10Mar89 flood scene, FESM modeled extents were used for the HGM analysis of wetland impacts. This is mainly due to the small differences between the base – without pump alternative and the with pump alternatives wetland elevations. Figures 2-113 and 2-114 illustrate the small differences in the 5 and 12.5% durations, as the lines plot nearly on top of each other for some gage locations. In the current study, the change in elevation at several of the gage sites is 0.1 foot or less. Finding satellite images with such a small change is extremely difficult. Instead, the current study used satellite imagery to calibrate the FESM mapping tool. The Vicksburg District has a library of approximately 50 satellite images in the south Delta. Several scenes are selected with a range of flood extent, simulated with the FESM model, and the extents are visually inspected for accuracy. Observed water surface elevations for the FESM model gages on the date of the flood scene are used in the FESM model to simulate the flood extent. The FESM results are compared to the flood scenes in Arc-MAP. In addition to visual inspection, some satellite scenes were classified, and the classified scene extents were compared to the FESM flood extents. Calibration is not a simple process. There are many factors which affect the calibration process. One of the factors is whether the water surface is rising, falling or stable. A stable surface is best. Changing stages produce changing flood extents. Stable implies that the water surface elevation and the flood extent are in equilibrium. The flood extent can lag behind the stage by two or more days, during rising and falling stages. Another factor is the cloud cover on the date of the acquired scene. The amount of precipitation on the days preceding the acquisition date can also affect the classification of the satellite scene. The satellite sensors can detect water or saturated soil, but those sensors cannot determine if the water present is due to ponded precipitation or flooding. Saturated soil, particularly in forested areas, often appear flooded. Saturated soil, in the areas adjacent to ponded waters due to falling stages, make the determination of the edge of the flooded area more difficult. An ideal flood scene for use in comparing FESM to a satellite image would have no clouds, stable stages, and leaf-off conditions. Such scenes are difficult to obtain. Permanent water bodies such as lakes and catfish ponds will be registered as flooded in the satellite scene, but not by the FESM model. During the winter months, some landowners intentionally flood fields to attract waterfowl. There are also several green-tree reservoirs (GTR) in the project area that are flooded in Winter to attract waterfowl.

Semi-quantitative Calibration

The use of satellite imagery is no longer an essential element of the off-site wetland delineation. The extent of the duration and frequency layers are determined with FESM. The question then becomes “does the FESM flood extent tool provide a good estimate of these extents”. The next two sections will provide information to support the use of the FESM tool. When calibrating FESM to a flood scene, the goal is not an exact fit, but instead FESM should match or slightly exceed the area within the two primary storage areas, within the Big Sunflower and Steele Bayou sub-basins. Then the FESM output should be close to the satellite scenes in the upper reaches. The two primary storage areas are relatively shallow bowls, with the rivers running through the bowls. In the upper reaches, the river's natural levee prevents over-bank flooding, and flooding is through tributary channels. These off-channel storage areas can be several miles away from the main channel. This distance increases the frictional losses. These off-channel storage areas are depressional areas that are often surrounded by the natural levees of abandoned river channels. These natural levees can be as high or higher than the natural levee of the current main channel. As such, these areas can directly store precipitation. The 2005 land-use/landcover layer used in the 2007 SEIS identified over 30,000 acres of catfish ponds in the project area, and ~10,000 acres of lakes. These ponds are surrounded by levees, which are normally constructed to the 50 or 100-year flood elevation. When the ponds receive rain, these ponds store precipitation. The catfish industry reached its' peak in 2011. At that time there were 110,000 acres of catfish ponds in the Delta. The industry crashed shortly after that time and only 30 to 40 thousand acres of ponds are still in production. Due to the expense of removing the levees, they are mostly still present. Many of the abandoned ponds are used to attract waterfowl and are flooded or allowed to store precipitation during the waterfowl season. These ponds and other permanent waterbodies complicate the determination of floodwater. The classification programs cannot easily separate one type of water from another. A semi-quantitative calibration can be obtained by measuring the distance between the edge of the flood and the FESM model output. In Arc-Map the FESM output is made transparent (~50%). Then the edge of both scenes is visible, and the measuring tool can be used to determine the distance between the edges. Figure 2-124 shows the FESM output overlaying the satellite image for 13 Jan 1983. Several places where the FESM results exceed the satellite flood are highlighted. Overall, it is clear that the FESM tool using a calculated slope factor met or exceeded the flood extent. There are some swales on the left side of the image that were not flooded by FESM, but it unknown if these swales have a direct connection to a river. There are also several blocks of catfish ponds, which are not flooded, but these are protected by levees. This method can also be used to select which FESM slope adjustment provides a better fit. The FESM tool has a slope function, with two possible values, which are: Constant or Calculated. When "Constant" is selected, the user inputs a slope to use for all lateral slope adjustments. When "Calculated" is selected, the user inputs a value for the "Lateral Slope Scale". Slope is calculated by FESM for each segment of the stream channels file. The elevation of the downstream gage is subtracted from the elevation of the upstream gage, then the result is divided by the segment length in feet. A Lateral Slope Scale of 1, applies the stream slope laterally away from the channel. For example, on 28 Feb 2020, the total difference in the water surface between the Steele Bayou LS gage (downstream gage) and the Little Callao gage was 3.4 feet. The distance between the gage locations is 22.7 miles. This yields an average slope of 0.0436 feet per mile, or 8.26E-6 feet/foot. The DEM has 10 by 10 feet pixels, with a Lateral Slope Scale of 1, the water surface would be reduced by 8.26E-5 feet/pixel. A Lateral Slope Scale of 2, multiplies the stream slope by 2 and applies the calculated slope laterally away from the channel. Figure 2-125 has two FESM runs for 13 Jan 1983. One run used a calculated slope function of 1, and the other used a slope function of 2. There is very little difference between the areal extent of the floods in the lower (Steele Bayou sump) or in the upper (Big Sunflower sump) in the two model runs. The greatest area of difference occurs in the Dowling Bayou area, which is northeast of DNF. The area is above the Little Sunflower ponding area and has point bar surface geology. This type of geology forms ridges and swales, as the river channel meanders across the landscape. The swales are depressional areas and frequently pond precipitation. The second area with large differences between the two FESM runs is in the Lake George area. The Lake George area is protected by an NRCS flood control project. The area has a levee at elevation 95, an outlet pipe equipped with a flap gate and a pump. The area ponds rainwater when the Big Sunflower stages are greater than the interior water surface. In 2019 the levee was over topped, and the area was flooded. When the interior of the Lake George project was draining, in August of 2019 the high discharges tore the flap gate from its' hinges. The water surface for the interior is either estimated from the satellite scene or calculated from the Big Sunflower channel nodes upstream and downstream of the exit channel. The two model runs used different methods and the observed differences are due to the modeler's error.

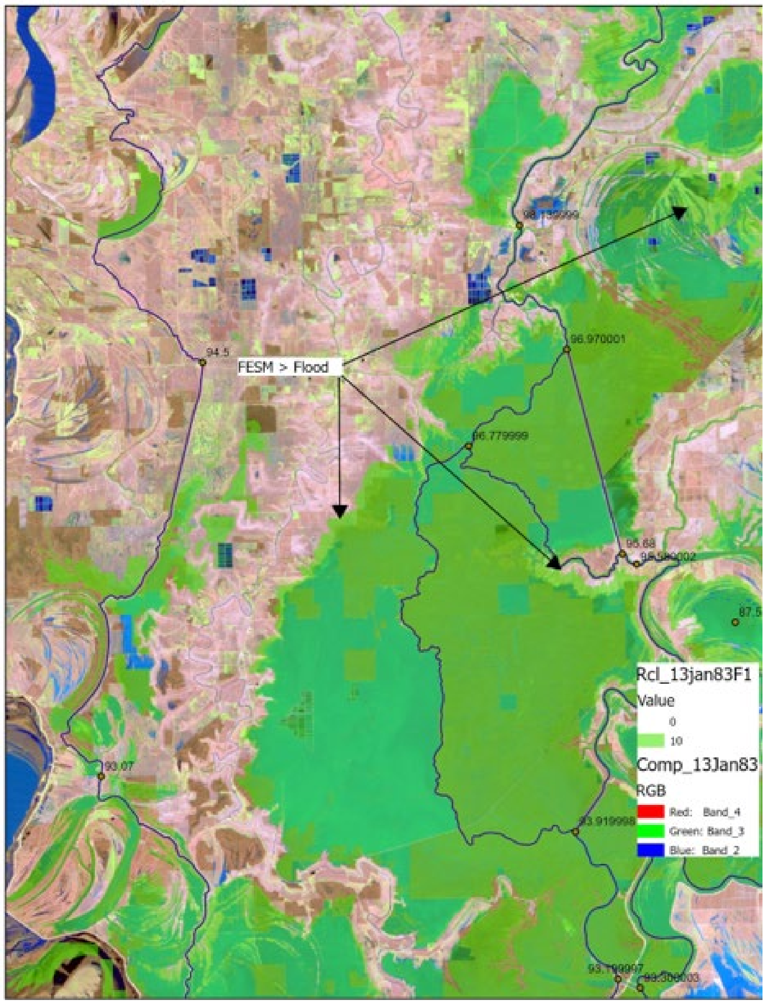


Figure 2-124. Composite with FESM Overlaying Satellite Flood – 13Jan1983

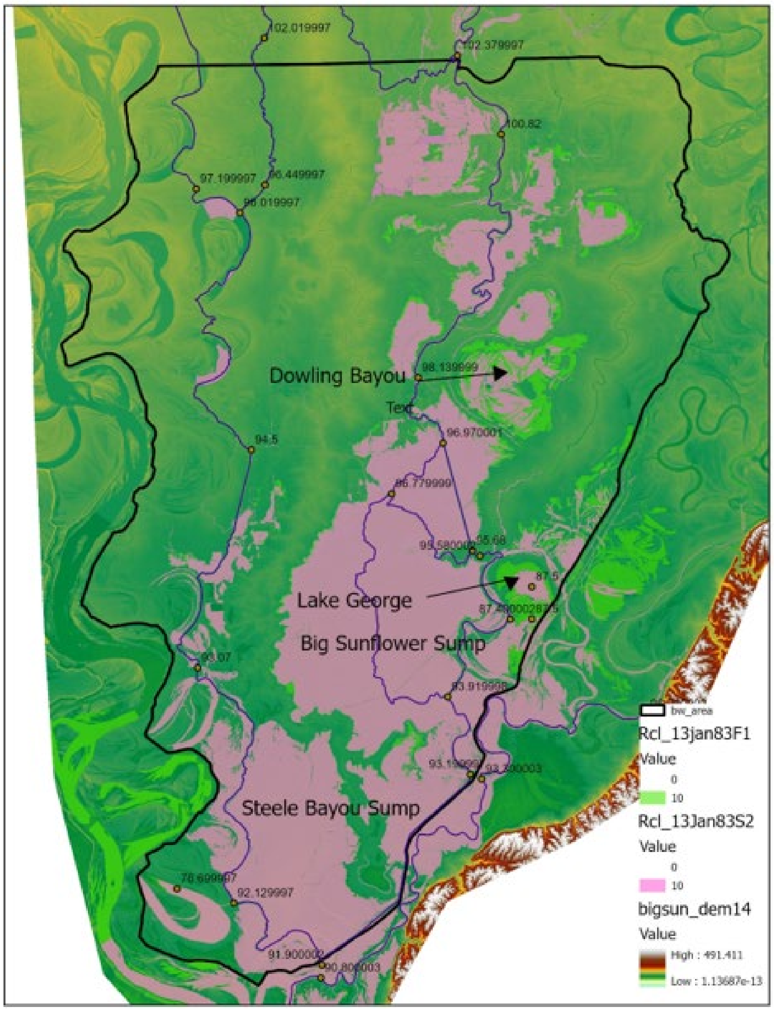


Figure 2-125. FESM Runs Using Calculated Slope Factors of 1 and 2

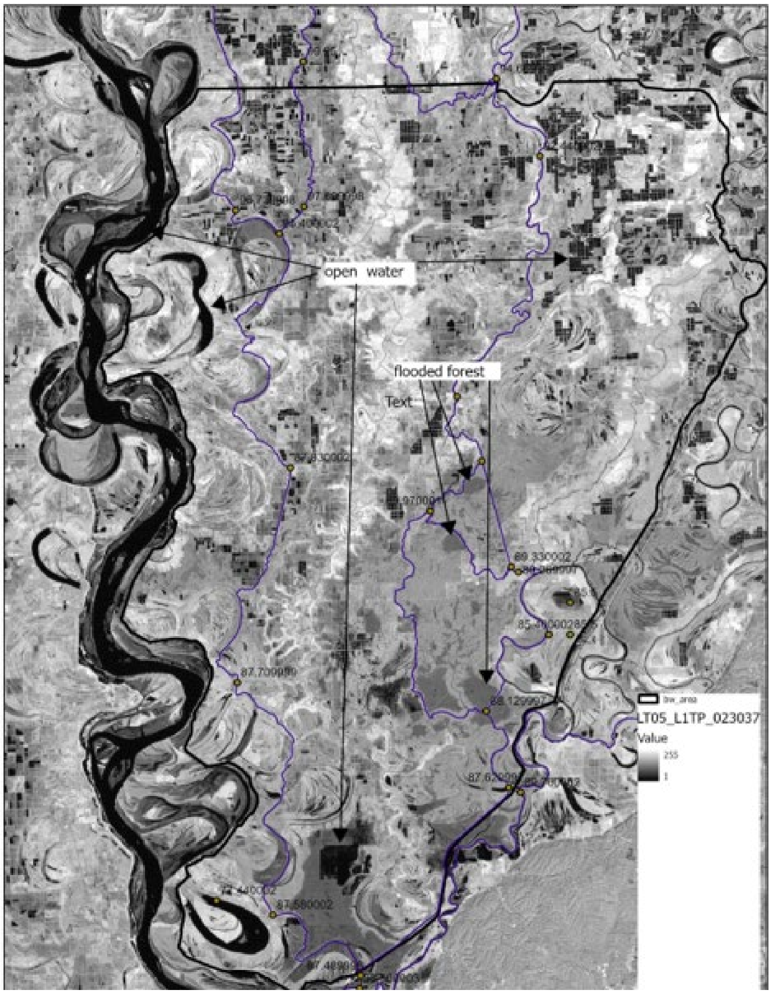


Figure 2-126. Landsat Shortwave Infrared Band - 17Jan2005

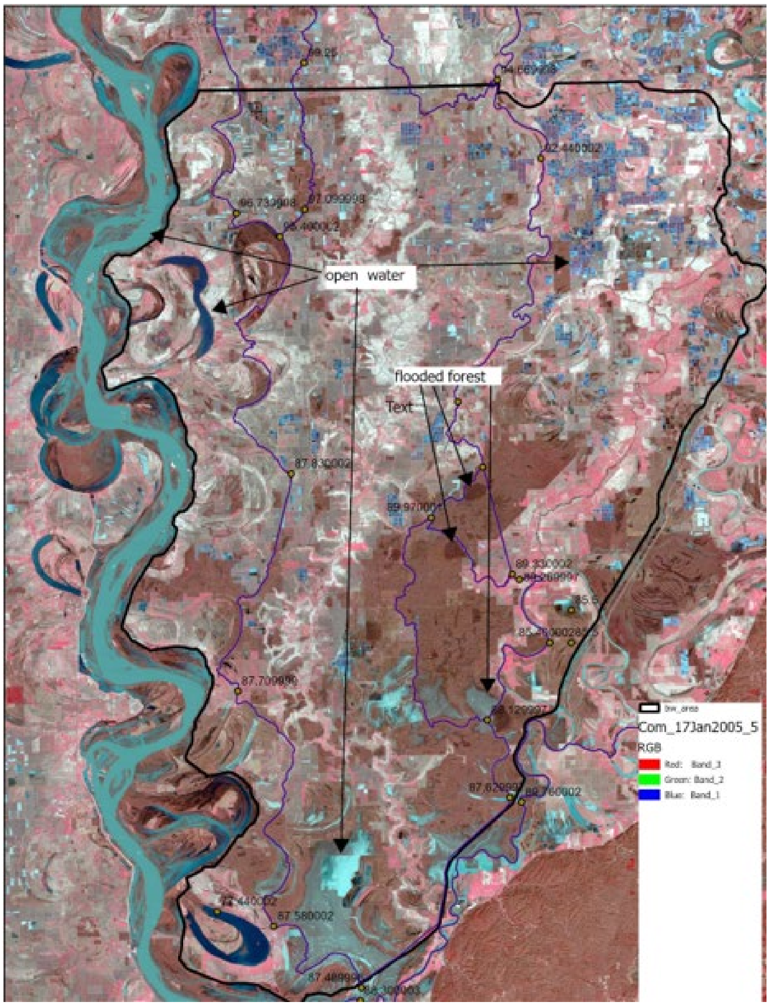


Figure 2-127. Landsat False Color Infrared – 17Jan2005

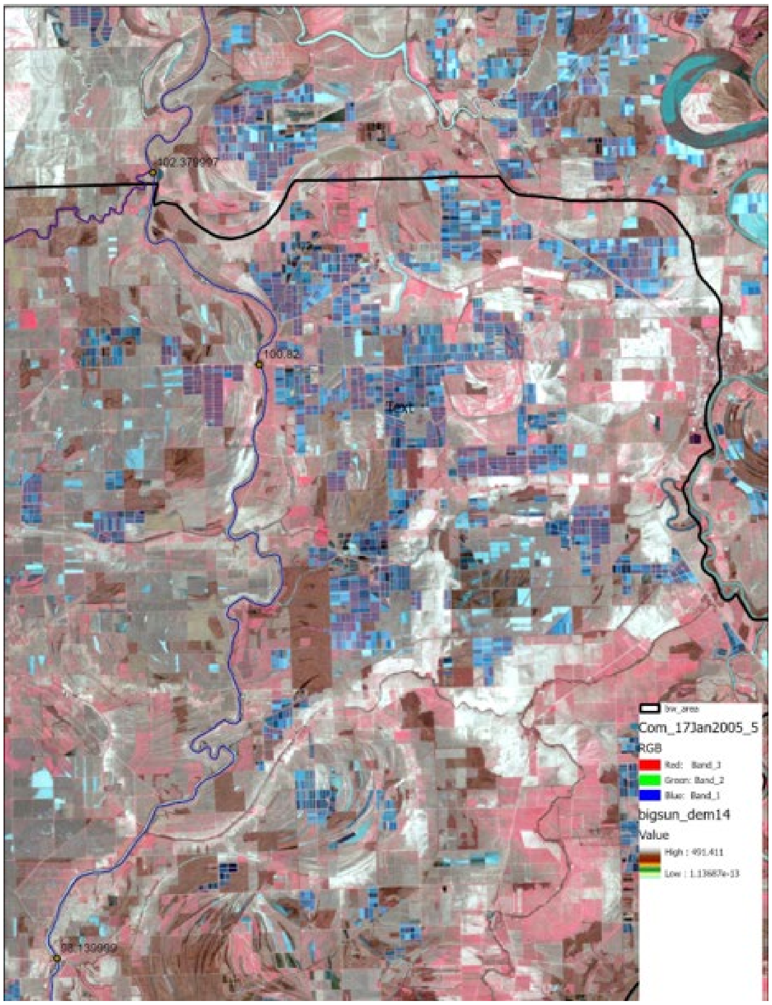


Figure 2-128. Landsat False Color Infrared Catfish Ponds – 17Jan2005

Satellite Image CLASSIFICATION

The satellite imagery was obtained from the USGS EROS Data Center. Imagery from Landsat satellites 4, 5, 7, and 8, were used. The number of available bands varies by satellite. The Thematic Mapper on Landsat satellites 4 and 5 has seven bands of data (bands 1-7). These include three visible bands (1-blue, 2-green, and 3-red), three infrared bands (4-near IR, 5-Shortwave IR, and 7-SWIR), and one thermal IR (6). Landsat 7 has 8 bands. The first seven are the same as 4 & 5, and a panchromatic band was added. Landsat 8 has eleven bands. For the classifications five bands were used. Those bands were: green, red, NIR, and two SWIR. The IR bands provide a good distinction for water, as water absorbs IR and appears black. The red and green bands help identify vegetation and help separate different types of water bodies based on turbidity. Figure 2-126 shows a single IR band (band 5, 17Jan20005) and Figure 2-127 is a false color IR (FCIR) image (green, red, and NIR from 17Jan2005) respectively. Pointers are used to indicate several waterbodies in the IR image. All four appear black. The four waterbodies are the Mississippi River, Lake Washington, a block of catfish ponds, and a moist soil management area in Mahana WMA. Several tracts of flooded forest are also indicated. These appear medium gray. The upper two flooded forest tracts are the Green Ash GTR and the Sunflower GTR. The bottom area is a wildlife area in DNF flooded by a weir. The false-color image (Figure 2-128) covers the same area, but the four water bodies now are different colors. Lake Washington is deep blue indicating low turbidity. The Mississippi River is a medium blue indicating moderate turbidity. The catfish ponds range from dark blue or purple to cyan. The lighter the color the greater the turbidity. The Mahana area is a light cyan, indicating high turbidity. The Mahana area is surrounded by a levee and has a water control structure in the southwest corner of area. The Mahana moist soil management area is surrounded by flooded forest. These two figures show that the IR bands do a good job of isolating water, while the FCIR image shows that waterbodies have a very high range of color. This range of color often leads to some miss sorting of the three water categories. Figure 2-128 is a close-up of the catfish ponds in the upper northeast quadrant of the FCIR image. It is much easier to see the wide range of colors in the catfish ponds in this figure. You can also see the individual levees around the ponds.

Arc-Map's Iso-cluster unsupervised classifier was used to classify satellite images. ArcMap used the reflectance values from the five bands of each image to place the pixels in the bins. The sorting uses the Iso-cluster and Maximum Likely Hood classification tools to do the sorting. Sixty bins were used for most of the classifications, but a few needed more classes (80). The 60 or 80 bins of the classified images were sorted into these categories: floodwater, flooded-forest, unflooded forest (BLH), cleared lands, permanent water bodies (ponds and lakes), saturated soil, edge, clouds and cloud shadow. Not every scene had all these classes. Sometimes the edges of the satellite scenes had reflectance values, which classed as a separate category. These generally were unique and did not interfere with the image classification. These pixels were put in a separate bin for classification (edge). Occasionally, image pixels were classified with the edge pixels, but the quantity of these pixels is generally very small. Another problem was separating floodwater from permanent waters. It is generally easy to identify the catfish ponds, because they are small waterbodies with square edges. However, the classifier uses five bands to sort the pixels into bins. If the color of the water in the pond is similar to the floodwaters, then the pond is included in the floodwater class.

24 Jan 2019

1. The first classified satellite scene is from 24Jan2019. The scene depicts a backwater flood, with a stage exceeding a 2-year frequency flood at the Steele Bayou LS gage. From the 2019 hydrograph (Figure 2-129) below, you can see that the Steele Bayou Riverside elevation is greater than the landside elevation on this date. The stages for the upstream gages are falling after a significant precipitation event (approximately 3 inches in the last 8 days and >6 inches since 1Jan, NWS precipitation data). The heavy rain has left much of the cleared lands with saturated soil. Figure 2-130 shows that the major areas of difference between the satellite and FESM flooded areas are catfish ponds and lakes. Lakes Washington and Swan Lake (Yazoo NWR) account for almost 5,000

acres. There are several isolated agricultural fields that are flooded as well (flooded rectangular blocks isolated from other flooded areas). These were likely flooded to attract waterfowl but haven't been drained. Table 2-42 has summation of acres within the classes of the composite scene created by adding the classified satellite image and the FESM model output. The satellite column tabulates acres flooded in the classified satellite scene, while the FESM column has the acres unique to the FESM flooded area. The shared area is the sum of the FESM floodwater and flooded forest classes. The total flood is the sum of those two classes by the satellite. The flooded acres unique to the satellite are the difference between the satellite flooded classes and the FESM flooded classes (floodwater and flooded forest). Areas unique to the FESM model are the sum of the FESM classes less to the two flooded classes. Flooded acres unique to the satellite would constitute errors of exclusion by the FESM model, while areas unique to the FESM model would constitute errors of inclusion. The satellite flood covers 243,095 acres, and the FESM output covers 203,326 acres. The FESM output extent is 83.6% of the satellite’s extent. The area shared by both is 177,286 acres (72.9% of satellite extent). The areas in the floodwater class include all permanent water (lakes and ponds) and intentionally flooded agricultural fields. The Backwater Project Area includes more than 30,000 acres of catfish ponds, and 14,000 acres of permanent water. To illustrate the importance of separating permanent water from floodwater, a polygon file was created that included the catfish ponds, lakes, and some agricultural fields ponding water to attract waterfowl. Because the acres of catfish ponds vary over time, the ponds were digitized from several satellite images from 1983 to 2020. The polygon file contained a grid-value field, which was used to create a raster file with permanent waters. A grid-value of 20 was used for catfish ponds, a value of 40 was used for lakes, and a value of 60 was used for flooded agricultural fields. The grid-value field was given a value of zero, if the catfish pond or agricultural field was not flooded in each satellite image. The polygon file was then converted to a grid file with values of 0, 20, 40 and 60. This file was then added to the composite file of the flood and the FESM flooded area (such as 24Jan2019, Figure 2-130). These new composite files were then reclassified, and the lakes were given a grid-value of 5, catfish ponds were given a grid-value of 6, and agricultural fields were given a grid-value of 8. The modified composite flood scene is below as Figure 2-131. The revised tabulation is provided in Table 2-43. The inclusion of permanent water decreases the total flooded areas, decreases the difference in the acres flooded by satellite and FESM, and increases the %shared area by seven percent (72.9 to 79.9%).

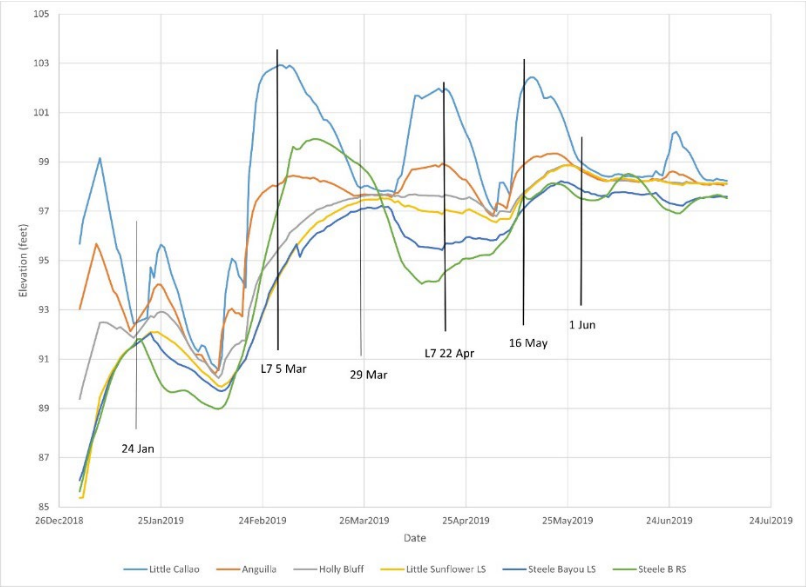


Figure 2-129. 2019 Hydrograph

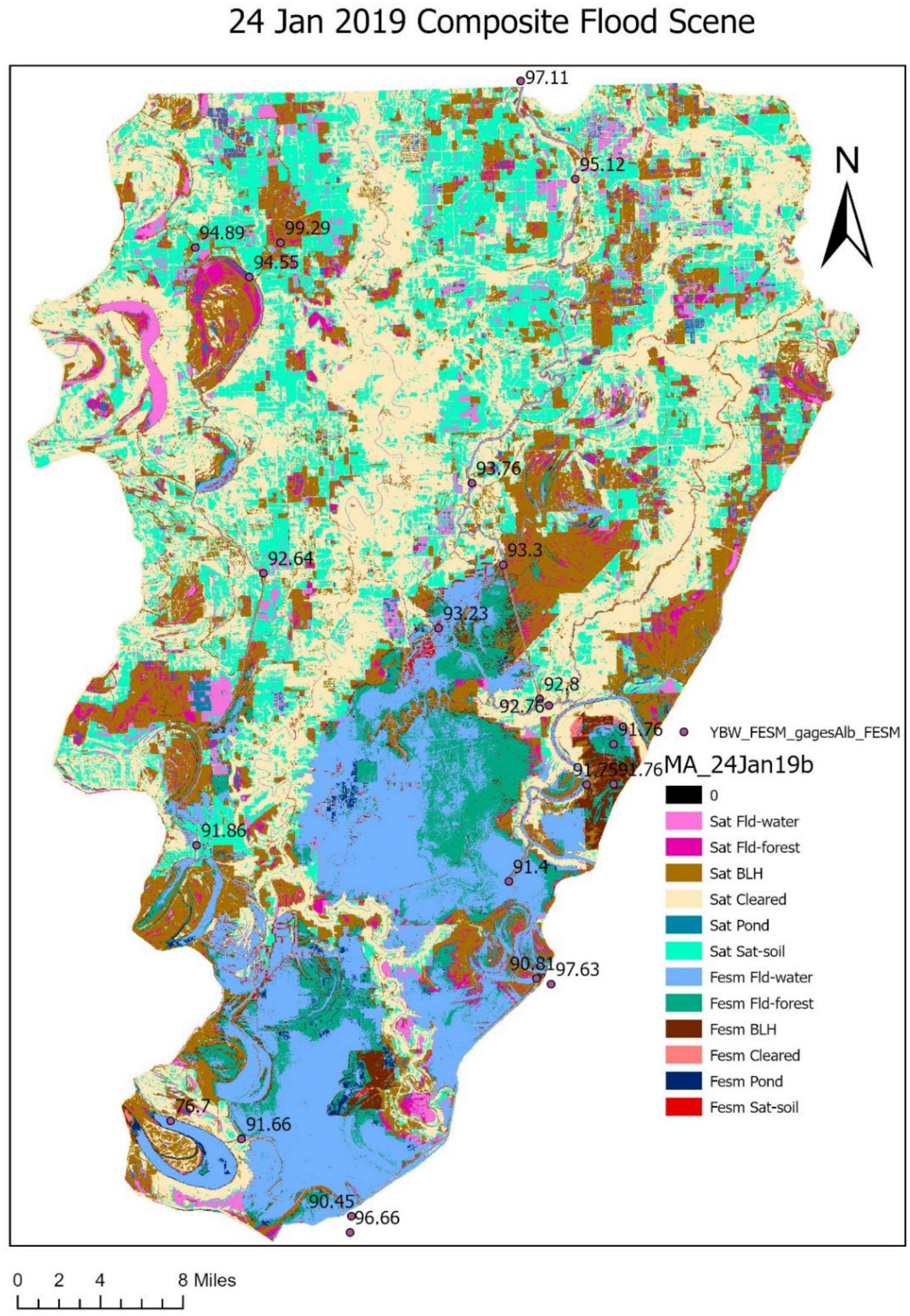


Figure 2-130. Raster Calculator composite of classified 24 Jan 2019 and FESM

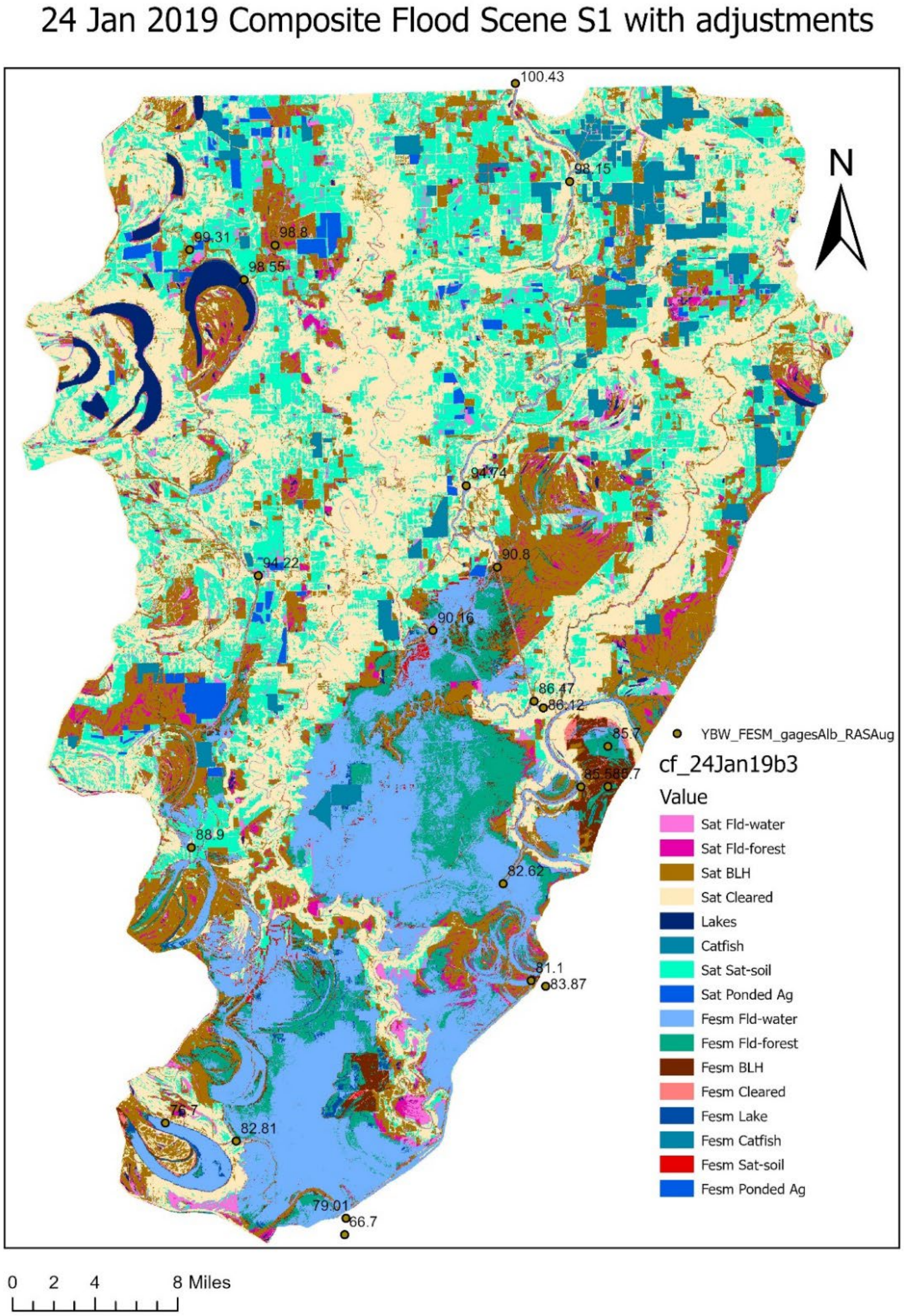


Figure 2-131. Raster Calculator composite of 24 Jan 2019 and FESM with adjusted ponds

Table 2-42. Summation of area flooded on 24Jan2019 by satellite and FESM

Class	Satellite	FESM	Label	Satellite	FESM
Floodwater	167173.3	128900.9	Total Flood	243095.5	203325.9
Flooded Forest	75922.2	48385.6	Shared Area	177286.5	177286.5
Unflooded BLH	174153.8	14294.4	Satellite Only	65809.0	
Cleared	314505.3	2141.9	FESM Only		26039.4
Pond - Lake	12613.7	4477.0	% Total Flood	100	83.6%
Saturated Soil	181028.5	5126.2	% Shared	72.9%	87.2%
Total Acres	925396.8	203325.9			

Table 2-43. Summation of area flooded on 24Jan2019 adjusted for permanent water

Class	Satellite	FESM	Label	Satellite	FESM
Floodwater	150206.2	127465.9	Total Flood	219970.6	203062.3
Flooded Forest	69764.4	48315.3	Shared Area	175781.3	175781.3
Unflooded BLH	163528.3	14290.1	Satellite Only	44189.3	
Cleared	309978.3	2140.3	FESM Only		22007.3
Pond - Lake	17452.7	4168.9	% Total Flood	100	92.3%
Catfish	33046.0	1408.0	% Shared	79.9%	86.6%
Saturated Soil	170750.2	5034.5			
Ponded Ag	10978.9	239.3			
Total Acres	925705.0	203062.3			

29 Mar 2019

Figure 2-129 is a hydrograph of the elevations at six gages in the project area during 2019. On the hydrograph the dates of the available satellite scenes are shown as vertical lines. Several of these scenes were used for FESM calibration. The Mar-29 scene depicts a major backwater flood. The image has nearly perfect conditions for model calibration. The water surface elevations for the gages in the project interior are within a range of one foot (Little Callao 97.9 – Steele Bayou 97.1), the forested areas do not have leaves, but the scene has some high clouds. The FESM model is in near perfect agreement with the satellite scene.

If you zoom in on the image, you can measure the difference between the edge of the flooded area in the satellite image and the FESM model. This gives a semi-quantitative evaluation of the FESM model. For a more quantitative evaluation, the satellite image must be classified. Arc-Map's Iso-cluster unsupervised classifier was used to classify the images. Sixty bins were used for most of the classifications, but a few needed more classes (80). The satellite images were classified into these categories: floodwater, flooded-forest, unflooded forest (BLH), cleared lands, permanent water bodies (ponds and lakes), saturated soil, clouds and cloud shadow. Not every scene had all these classes. It was often difficult to separate floodwater from permanent waters. When the category was in doubt, the floodwater class was used. The grid values for these categories were 1 to 8. The FESM model produces two classes, unflooded and flooded with values of 0 and 1 respectively. The FESM output was re-classed to values of 0 and 10, with 10 assigned to the flooded class. The final step in this process was adding the classified Satellite scene with the FESM scene, using the Raster Calculator (Arc-Map, Spatial Analyst, Raster Calculator). The resulting grid file had grid values of 1 to 8 and 11 to 18. All values less than 10 were unflooded in FESM, while values above 10 were flooded in FESM. Table 2-44 below contains the results of the comparison of the 29May2019 flood to the FESM modeled results for that date. Figure 2-132 shows the combined flood scene (MA 29Mar2019). The image was created in ArcMap, Spatial Analyst/Raster Calculator. The classified satellite scene (Iso_29Mar19) was added to the reclassified FESM output (recl_29Mar19). The color table used for the classes is in the lower righthand corner. The same color table is used for all "MA" (MA=Map Algebra, an old name for Raster Calculator) scenes created with Raster Calculator. Areas, in shades of pink, are flooded in the satellite scene, but not by the FESM model. These areas represent errors of exclusion by the FESM model. Areas, in shades of red, are flooded by FESM but not by satellite. These represent errors of inclusion by the FESM model. The FESM Fld-water and FESM Fld-forest are the two flood classes shared by both the satellite and FESM.

The total area flooded in the satellite scene was 422,960 acres, while the FESM model flooded 414,576 acres. The FESM model flooded 98% of the area that was identified as water in the satellite scene. There are 376,055 acres that were common to both scenes, which is 88.9% of the water area in the satellite scene. There are 46,900 acres of water that are not flooded in the FESM scene. This area could be permanently flooded areas such as lakes or catfish ponds. It could also contain intentionally flooded agricultural lands to attach waterfowl. To clarify the amount of the satellite scene in permanent water, the catfish ponds and lakes present in the satellite scene on 29Mar19 were digitized, the polygons were converted to a grid file, and the MA_29Mar19 raster image was merged with the permanent waters into a new grid file (CF_29Mar19). The tabulation of that file is presented in Table 2-45 below. This increases the percentage of the satellite scene shared flooded area from 88.9 to 91.3 and reduces the Satellite only class from 46,900 to 34,800 acres. The tabulation presented for the other scenes will be treated in the same fashion as this scene.

Table 2-44. Tabulation of acres flooded on 29Mar2019 by satellite and FESM

Class	**Satellite**	**FESM**	**Label**	**Satellite**	**FESM**
Floodwater	218961.0	200577.1	Total Flood	422960.2	414576.5
Flooded Forest	203999.2	175478.4	Shared Area	376055.5	376055.5
Unflooded BLH	53928.2	10817.5	Satellite Only	46904.7	
Cleared	379329.3	13311.4	FESM Only		38521.1
Pond - Lake	23311.4	6042.8	% Total Flood	100.0%	98.0%
Saturated Soil	46053.4	8349.4	% Shared	88.9%	90.7%
Total Acres	925582.5	414576.5			

Table 2-45. Tabulation of acres flooded on 29Mar2019 adjusted for permanent waters

Class	**Satellite**	**FESM**	**Label**	**Satellite**	**FESM**
Floodwater	208558.4	193884.8	Total Flood	400159.2	414249.7
Flooded Forest	191600.8	171466.9	Shared Area	365351.7	365351.7
Unflooded BLH	47033.9	10402.9	Satellite Only	34807.5	
Cleared	380567.4	13006.0	FESM Only		48898.0

Pond - Lake	9485.3	6774.6	% Total Flood	100.0%	103.5%
Catfish	30000.9	5288.8	% Shared	91.3%	88.2%
Saturated Soil	42798.6	7369.5			
Cloud	15757.9	6056.2			
Total Acres	925803.3	414249.7			

In Figure 2-132 below, the observed classes were adjusted as with the 24 Jan 2019 scene in Figure 2-130. The permanent waters catfish ponds and lakes have been added, but most of the intentionally flooded agricultural fields have been drained, because the waterfowl season is closed. The largest areas, that are flooded by satellite and not by FESM, are areas under high clouds. This area is the pink shaded area between the two large storage areas (sumps). The high clouds change the reflectance value of the ground below the clouds, making an accurate classification of the land-surface difficult. The acres flooded in the adjusted composite scene for 29Mar2019 are presented in Table 2-45. The adjustments reduce the total flooded areas by both satellite and FESM and increase the shared area by 2.4%. The 29Mar2019 is an almost perfect example of a classic backwater flood. The elevation difference between the six gage locations is less than 1-foot, and the backwater flood has delayed the trees from leafing out (see A.I. summary of the impacts of flooding on leaf phenology; similar information can be found in most textbooks on Forestry). The scene does have some cloud cover. Areas flooded by FESM and not the satellite scene are shown in shades of red. These show that the model slightly overestimated the flood extent, by extending the edge beyond the satellite images flooded area. The major difference in flooded areas between the classified satellite scene and the FESM model is from catfish ponds, other permanent water, and some interference from cloud cover. The adjusted scene reduces the total flooded area by removing permanent waters such as lakes and catfish ponds.

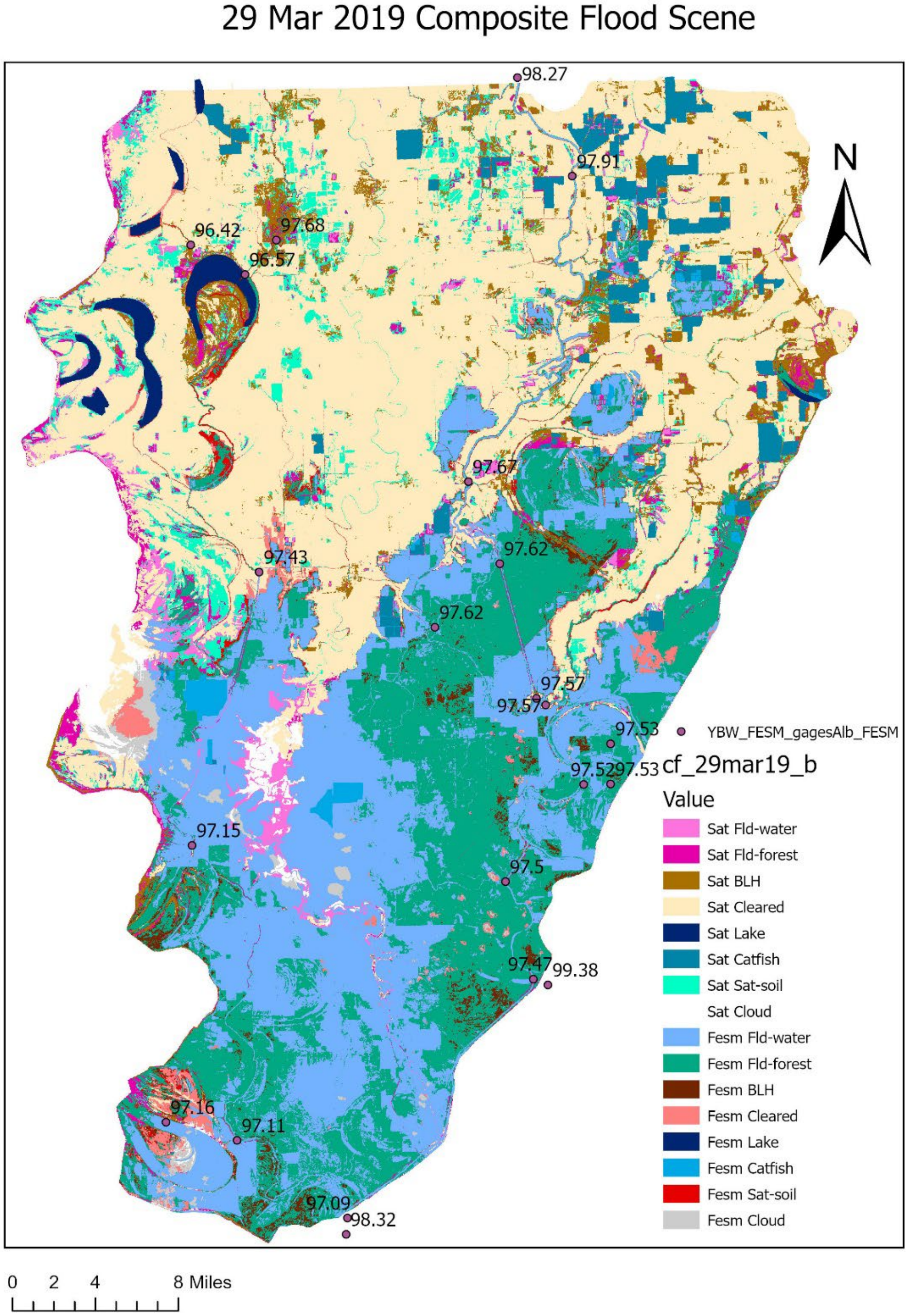


Figure 2-132. CF 29Mar2019 - Composite Classified Sat 29Mar2019 and FESM

28 Feb 2020

The 2020 backwater flood is like the 2019 flood. The stage at the Steele Bayou gage exceeded 80 feet (NAVD) in December 2019 and remained above that stage until late June of 2020. Out of channel flooding starts around elevation 80. The basin received from 7 to 12 inches of rain from 9 Feb to 27 Feb. Figure 2-133, 2020 Hydrograph shows that two storm events in February caused the stages to rise at the gage locations inside the project area. On 28 February, the upper gages (Little Callao and Anguilla) had falling stages, while the lower gages were still rising. On the date of the satellite scene, there was 3.4 feet of slope between the Steele Bayou LS gage and the Little Callao gage. The average slope calculates to 0.04 feet/mile. The stage at Steele Bayou was 95.97, which is greater than the 10-year frequency flood elevation for that gage, while the stage at Little Callao was 99.32 is a 50-year event. The total area flooded in the satellite scene is 375,169 acres compared to 378,509 acres by the FESM model. There are 338,644 acres flooded shared by both. This represents 90.3% of the total for the satellite scene and 89.5% of the total for the FESM model. Figure 2-134 shows the composite flood scene. As with other composite scenes, most of the areas flooded only by the satellite are permanent waterbodies (lakes and catfish ponds). Figure 2-135, Catfish Ponds, is a FCIR satellite image from the upper Northeast portion of the project area, where the catfish ponds are concentrated. In the figure you can see the individual levees separating the ponds. Table 2-46 below shows the summation of the tabulation of the composite flood scene for 28 Feb 2020. Permanent waters were added to the scene and the values were retabulated. The retabulated values are presented in Table 2-47 below. The permanent waters decreased the Satellite total flooded acres, while the shared acres remained nearly constant. This increased the percentage shared by both scenes 4 percent.

Table 2-46. Tabulation of Acres by Class for 28Feb2020

Label	Satellite	FESM		Satellite	FESM
Flood Water	169642.43	150038.53	Total Flood	375169.48	378509.56
Flooded Forest	205527.06	188605.85	Shared Acres	338644.4	338644.4
Unflooded BLH	105797.59	17666.44	Satellite Only	36525.1	
Cleared	331347.31	10210.37	FESM Only		39865.2
Saturated Soil	113268.12	11988.38	%Total	100.0%	100.9%
Total Acres	925582.51	378509.56	%Shared	90.3%	89.5%

Table 2-47. Tabulation of Acres by Class for 28Feb2020 with permanent waters

Label	Satellite	FESM		Satellite	FESM
Flood Water	154975.6	147025.4	Total Flood	353011.66	378263.82
Flooded Forest	198036.1	186217.4	Shared Acres	333242.74	333242.7
Unflooded BLH	98378.0	16764.87	Satellite Only	19768.9	
Cleared	327742.1	10171.9	FESM Only		45021.1
Lake	10149.0	2256.814	%Total	100.0%	107.2%
Catfish	27507.4	3831.78	%Shared	94.4%	88.1%
Saturated Soil	108477.6	11803.13			
Flooded-Ag	697.4	192.5897			
Total Acres	925963.2	378263.8			

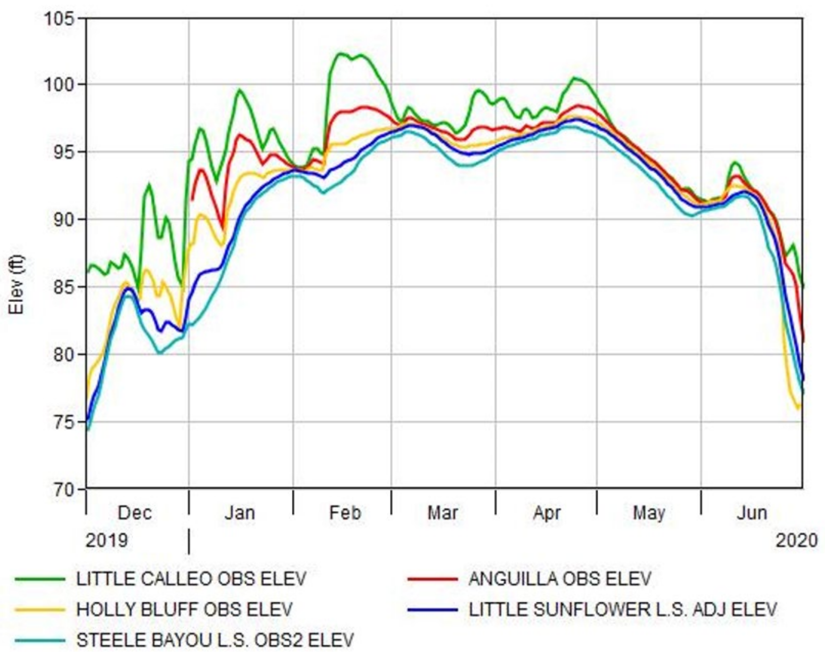


Figure 2-133. 2020 Hydrograph

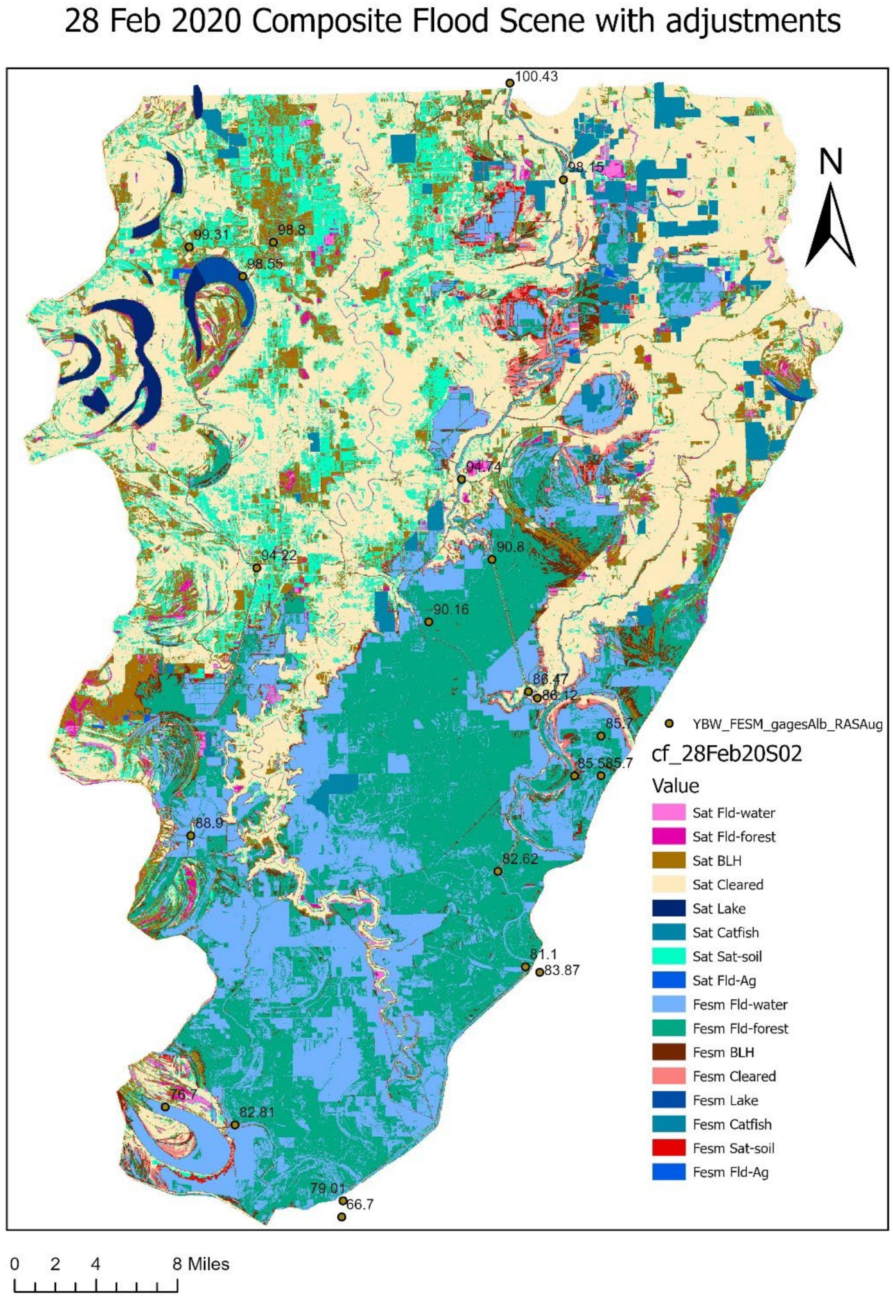


Figure 2-134. CF 28Feb2020 Constant Slope 0.00002

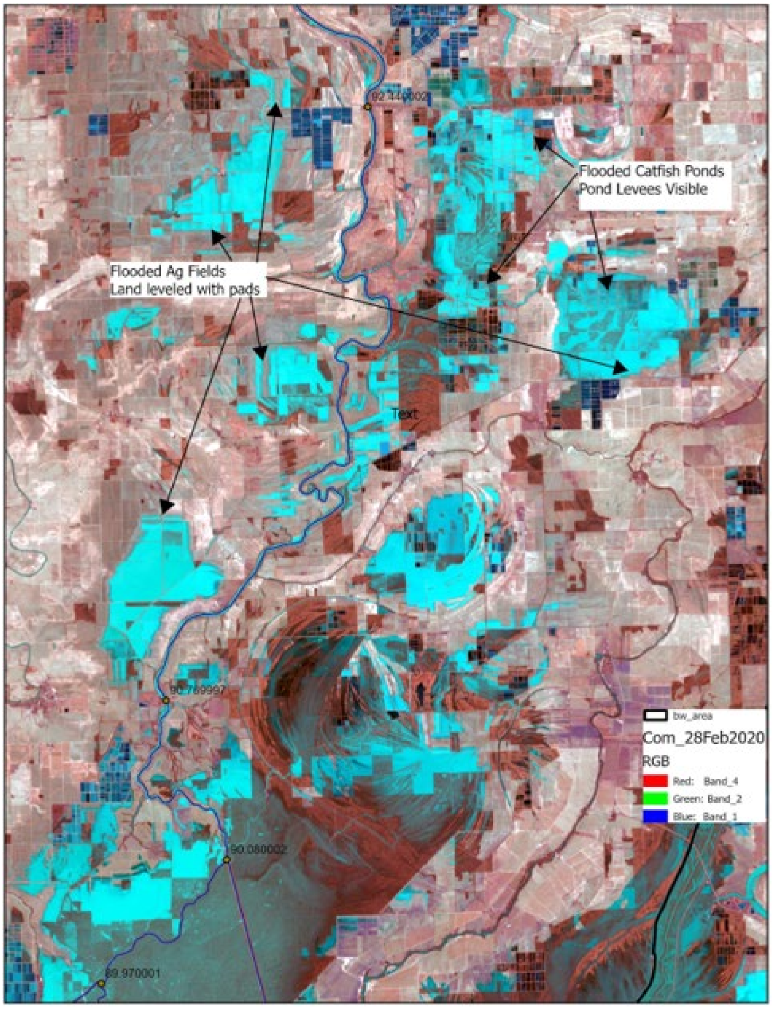


Figure 2-135. FCIR 28Feb2020 Catfish Ponds and Flooded Agriculture Fields

17Jan 2005

The satellite scene from Jan 2005 comes after the accumulation of 3 to 4 inches of rain over most of the Big Sunflower Basin. There were two precipitation events. The first started on 1 Jan and ended 7 Jan. The second started on 11 Jan and ended on the 14^{th}. Approximately 1 inch of rain came from the 11 to 14 of January. Figure 2-136 (2005_Hydrograph), shows the 2005 hydrograph. Stages are falling at the Little Callao and Anguilla gages on 17 Jan. Holly Bluff is relatively constant, while the Little Sunflower and Steele Bayou water surfaces are rising. The flood is an example of a minor backwater flood. The water surface elevation at Steele Bayou and Little Sunflower gages is at the 1-year flood frequency. The water surface elevations at the three upstream gages are less than the 1-year event. The permanent water adjusted classified satellite scene has approximately 210,000 acres of saturated soil, which indicates that the soil has not dried since the precipitation. The total extent of the floodwaters in the satellite scene is 131,350 acres, and the total flooded area by FESM is 89,070 acres. Less than 58,000 flooded acres are shared between the two images. Figure 2-137 (MA_17Jan2005) shows that the difference in flooded area is primarily due to permanent waters (lakes and catfish ponds) and temporary water bodies managed for waterfowl (green-tree reservoirs and ag fields managed for waterfowl). Table 2-48 below summarizes the area flooded by the two scenes.

Table 2-48. Summation of the 17Jan2005 Flood Scenes by Satellite and FESM

Class	**Satellite**	**FESM**	**Label**	**Satellite**	**FESM**
Floodwater	50085.8	16959.0	Total Flood	131346.0	89070.5
Flooded Forest	81260.2	40829.5	Shared	57788.5	57788.5
Unflooded BLH	226222.9	13661.2	Satellite only	73557.5	
Cleared	286648.7	480.1	FESM only		31282.0
Lake	19543.0	6442.2	%Total	100.0%	67.8%
Catfish	40389.1	127.2	%Shared	44.0%	64.9%
Sat-Soil	209975.3	10513.9			
Ponded ag	11838.3	57.4			
Total	925963.2	89070.5			

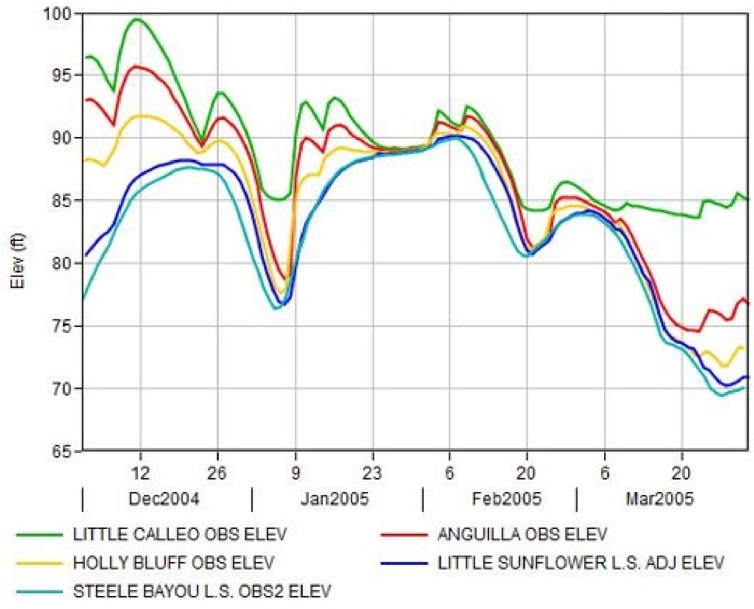


Figure 2-136. 2005 Hydrograph

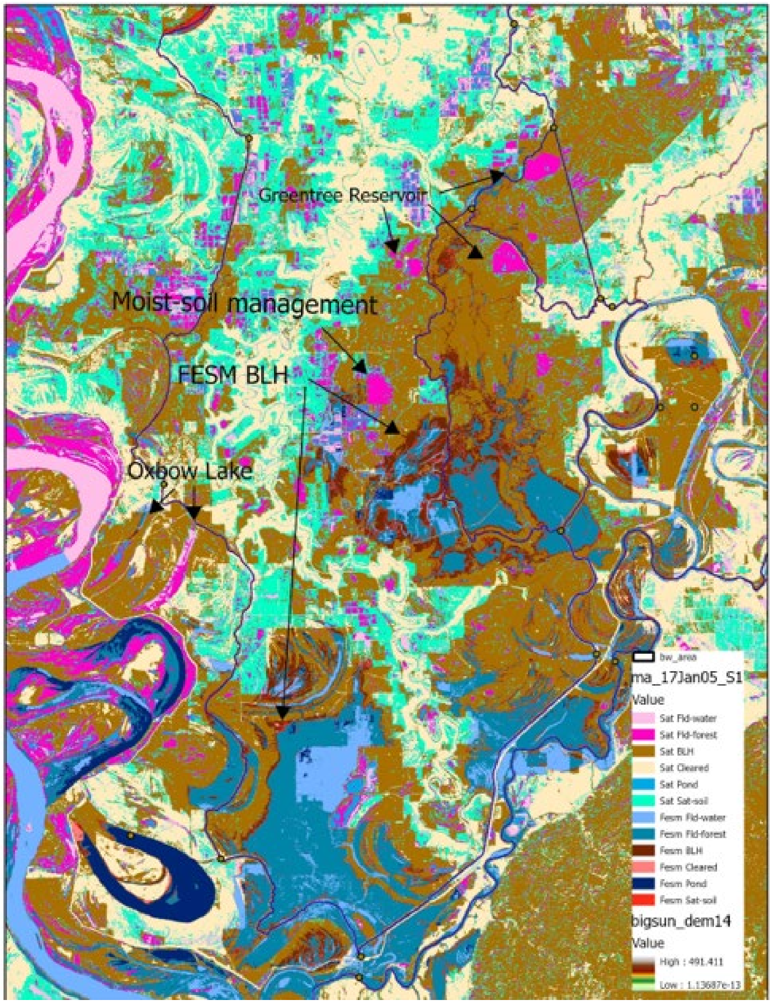


Figure 2-137. MA 17Jan 2005

22Jan2001

The satellite scene from 22 Jan 2001 is an example of a minor headwater flood. The scene was captured after the project area experienced 3 to 6 inches of rain in the previous 4 days. The water surface elevation at the Steele Bayou gage was 75 feet NAVD, which is less than the 1-year frequency event. There is 23 feet of slope between the Steele Bayou gage and the Little Callao gage. Little Callao is approximately 80 miles upstream of Steele Bayou. The stages at all gages in the project area are rising. Figure 2-138, 2001_Hydrograph illustrates the large and rapid change in stage at all gages. Figure 2-139, CF_22Jan01, points out several large areas of managed ponding for waterfowl or localized ponding of precipitation. The ground surface in these areas is greater than the gage elevations. Several of the green-tree reservoirs in DNF are holding water, and other areas are holding water due to water control structures installed by Ducks Unlimited. Many agricultural fields in the upper portion of the basin are also holding water, which is due to intentional ponding for waterfowl, or ponded rainwater which has not had a chance to drain. Table 2-49 below shows the results of the tabulation of the combined classified flood scene modified for permanent water and the corresponding FESM model output.

Table 2-49. Summation of the 22Jan2001 Flood Scenes

Class	**Satellite**	**FESM**	**Label**	**Satellite**	**FESM**
Floodwater	49424.2	13447.7	Total Flood	72121.1	42506.5
Flooded Forest	22696.9	1809.1	Shared	15256.8	15256.8
Unflooded BLH	233166.6	11927.9	Satellite only	56864.2	
Cleared	341064.9	2741.2	FESM only		27249.7
Lake	10149.0	2484.5	%Total	100.0%	58.9%
Catfish	52660.4	5406.5	%Shared	21.2%	35.9%
Sat-Soil	200835.7	4533.4			
Ponded ag	15753.9	155.7			
Edge	10.0	0.4			
Total	925761.5	42506.5			

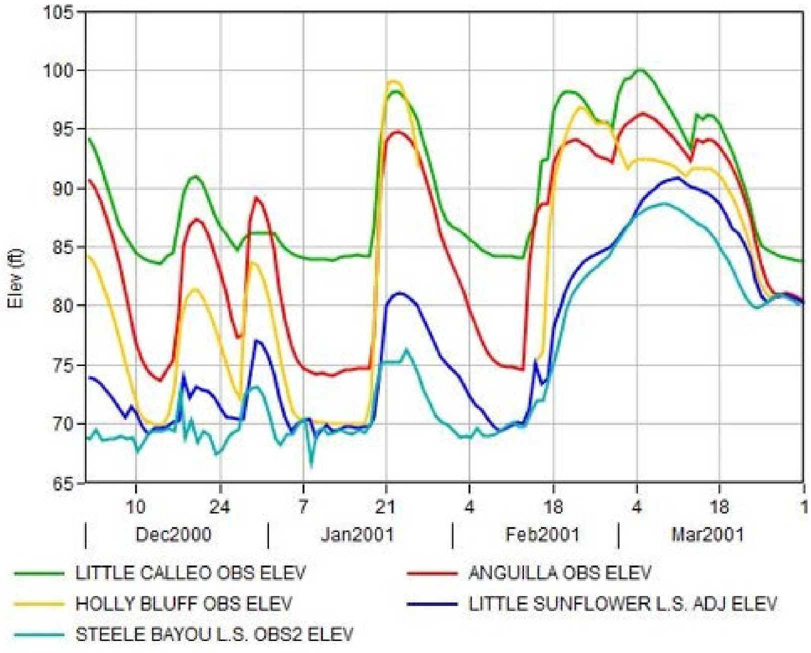


Figure 2-138. 2001 Hydrograph

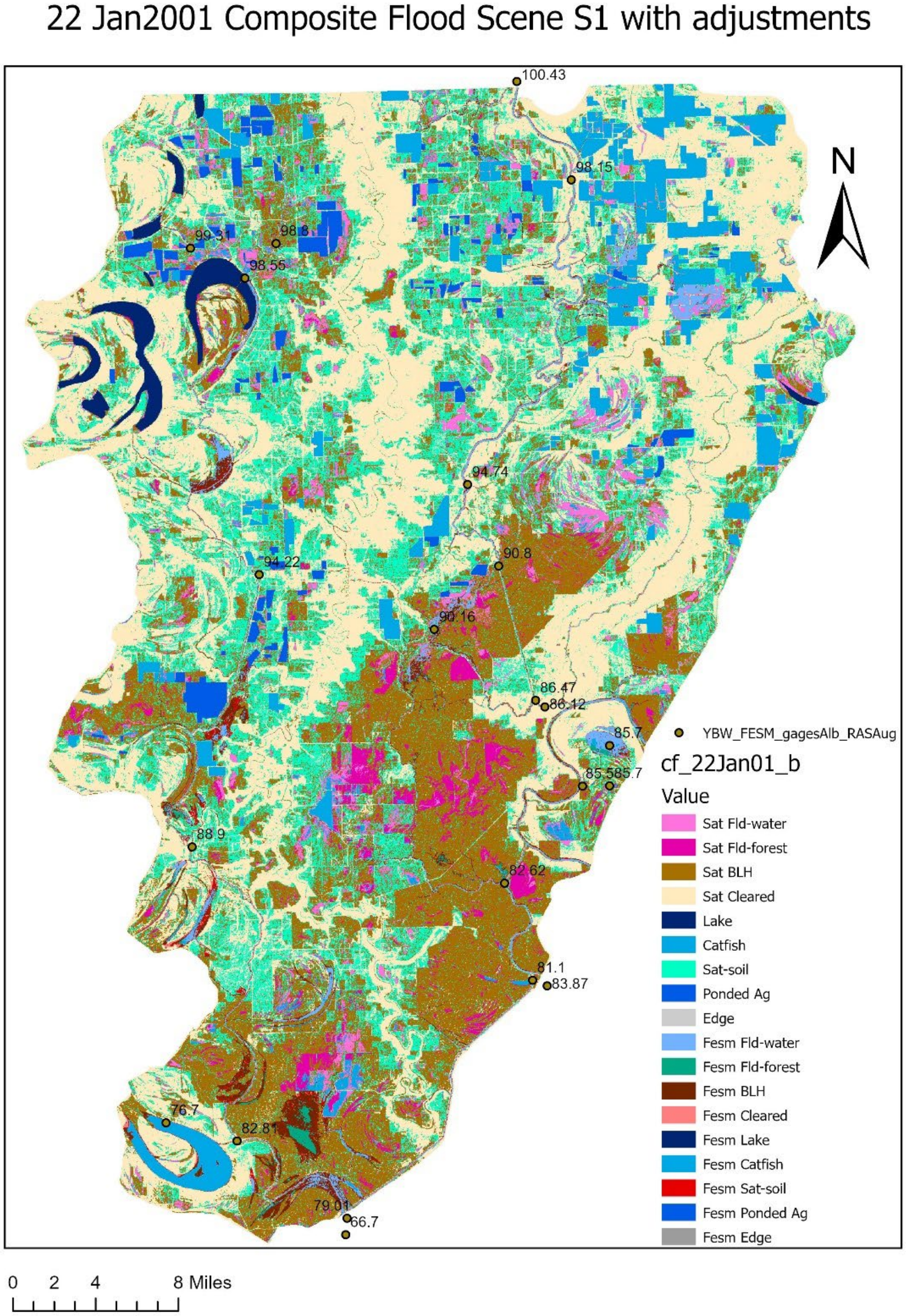


Figure 2-139. CF 22Jan2001

13 Jan 1983

The 13Jan83 flood is a headwater flood during high backwater stages. The scene was acquired following heavy rains across the basin (7-12 inches between 24Dec82 and 10Jan83, NWS gages). Figure 2-140 1983_Hydrograph shows the stages at the interior gages during the event. A previous storm raised the Steele Bayou gage from <75 feet (NAVD) to 88 feet. The second storm raised the stage at Steele Bayou to 92 feet. There is nearly 9 feet of slope between the Steele Bayou gage (91.9) and the Little Callao gage (100.82). This amount of slope indicates a headwater flood. The upstream gages peaked on 31Dec82 (Little Callao, 104.8) and 2Jan83 (Anguilla, 99.4). The Holly Bluff gage peaked on 9Jan83 and was slowly falling. Both the Little Sunflower and the Steele Bayou gages peaked the day prior to the satellite image. Figures 2-141 (Composite 13Jan1983 with FESM Slope = 1) and 2-142 (Composite 13Jan1983 with FESM Slope = 2) show the composite satellite and FESM images for this flood event. In the first composite the FESM model used a calculated Slope Factor of 1, and in the second figure the model used a Slope Factor of 2. In both Figures, the total area flooded by the FESM tool exceeds the total flooded by the satellite. Tables 2-50 and 2-51 provide the tabulation of the acres flooded for the two scenes, respectively (corrected for catfish and lakes). The area shared by the satellite and FESM with a slope factor of 1 is 89.7%, while the percentage is 85.2% with a slope factor of 2.

Table 2-50. Tabulation of acres flooded by the satellite and FESM (slope factor 1)

Class	**Satellite**	**FESM**	**Label**	**Satellite**	**FESM**
Floodwater	141936.2	125900.1	Total Flood	291128.7	338224.1
Flooded Forest	149192.6	135337.9	Shared	261238.0	261238.0
Unflooded BLH	101376.5	17715.8	Satellite only	29890.8	
Cleared	446214.0	32298.6	FESM only		76986.1
Lake	17550.8	7703.6	%Total	100.0%	116.2%
Catfish	24655.9	3292.0	%Shared	89.7%	77.2%
Sat-Soil	44884.5	15972.7			
Ponded ag	152.8	3.3			
Total	925963.2	338224.1			

Table 2-51. Tabulation of acres flooded by the satellite and FESM (slope factor 2)

Class	Satellite	FESM	Label	Satellite	FESM
Floodwater	142029.8	117335.4	Total Flood	291238.8	308900.4
Flooded Forest	149209.0	130794.2	Shared	248129.6	248129.6
Unflooded BLH	101362.2	14402.0	Satellite only	43109.2	
Cleared	446110.1	23386.5	FESM only		60770.7
Lake	11561.4	1321.7	%Total	100.0%	106.1%
Catfish	30653.6	8017.4	%Shared	85.2%	80.3%
Sat-Soil	44884.3	13620.5			
Ponded ag	152.8	22.7			
Total	925963.2	308900.4			

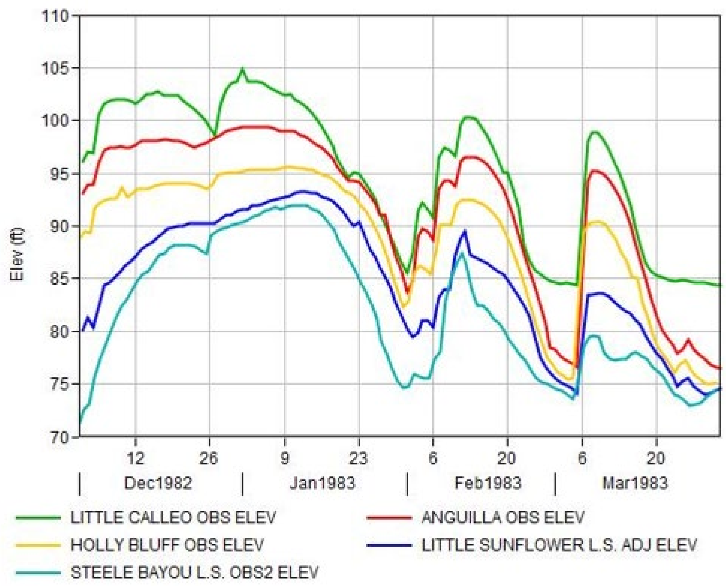


Figure 2-140. 1983 Hydrograph

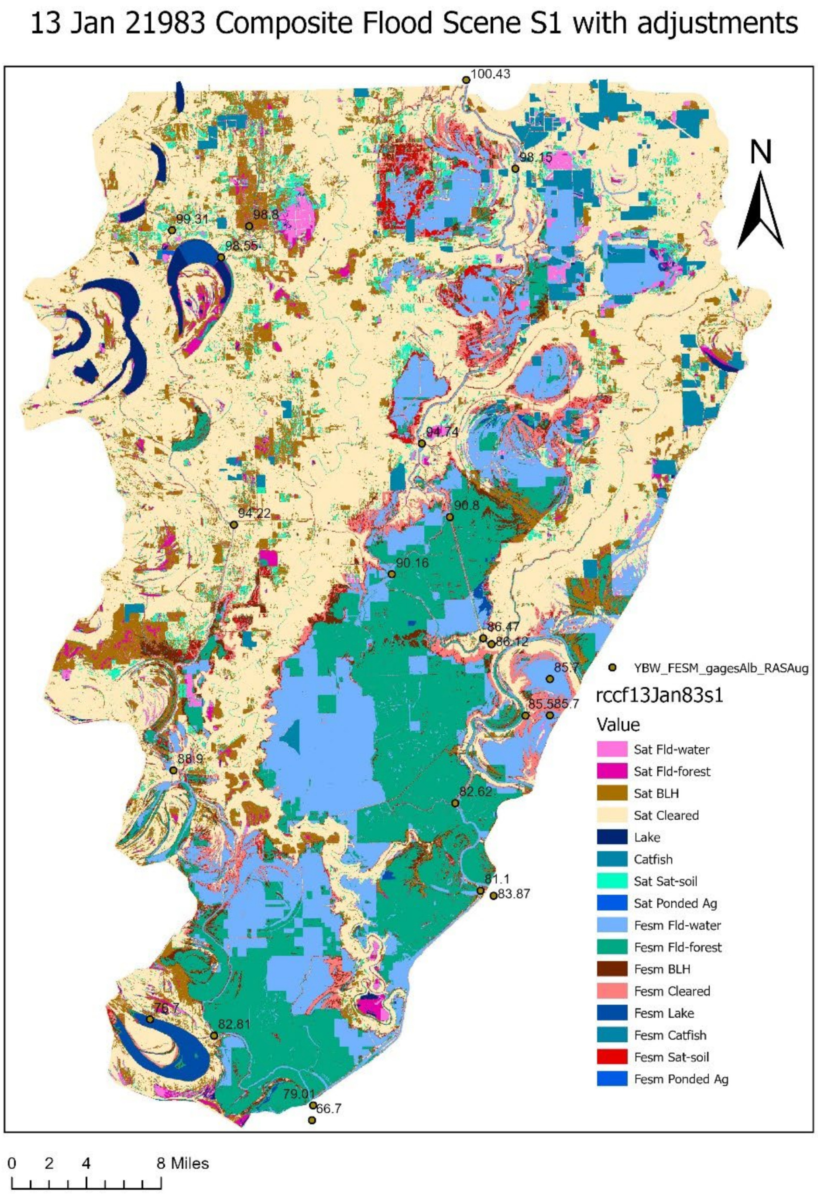


Figure 2-141. Composite 13Jan1983 with FESM Slope = 1

13 Jan 21983 Composite Flood Scene S2 with adjustments

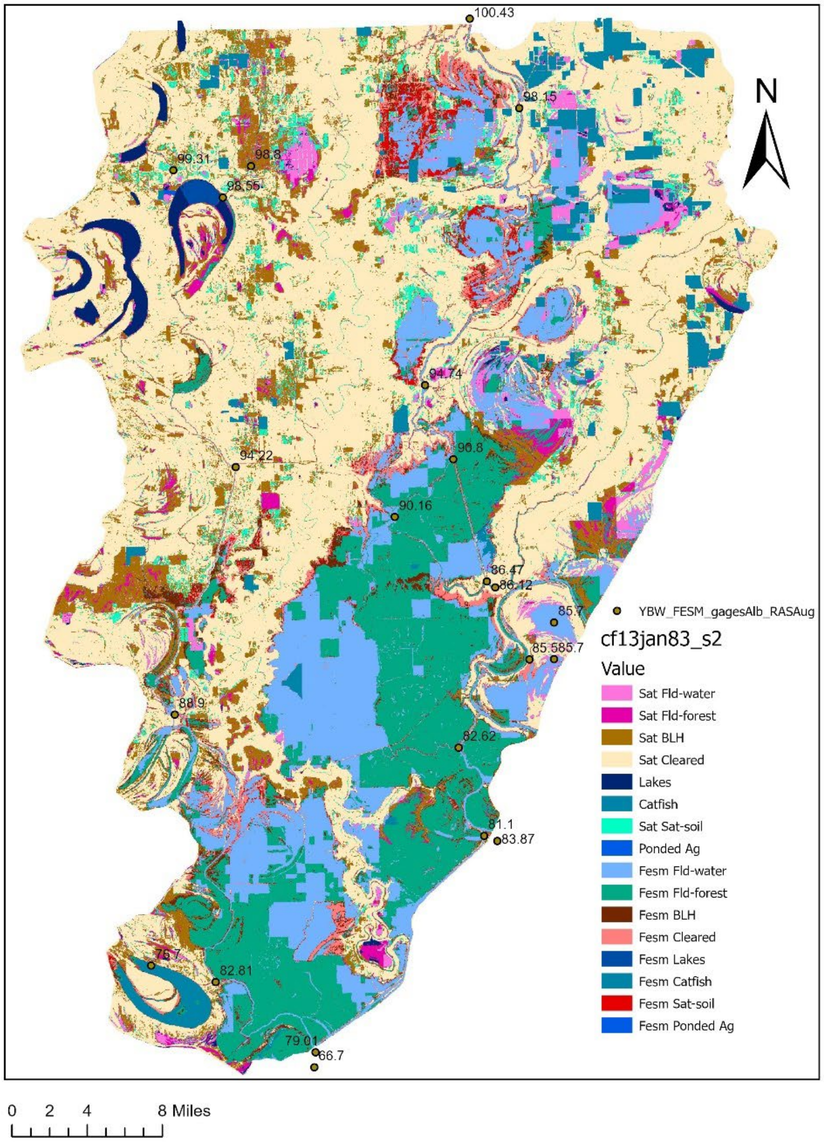


Figure 2-142. Composite 13Jan1983 with FESM Slope = 2

17 Apr 1997

This satellite scene was captured after a moderate rainstorm in early April (5-6), which deposited one to two inches across most of the basin. The range of stages (91.2- Steele Bayou to 92.8- Little Callao) was nearly flat, with only a 1.6 feet elevation change from upstream to downstream. This nearly flat-water surface makes this a classic backwater flood. The 1983 EIS used flat water surface areas based on the Steele Bayou LS gage, because backwater floods are supposed to have flat surfaces. Figure 2-143 (1997 Hydrograph) shows how the water surface at the five gages in the Big Sunflower varied during the winter and spring of 1997. The date of the satellite scene capture is marked by a vertical line in the figure. At the time of capture, the flood surfaces at all five gages are starting to fall. Figure 2-144 (MA_17Apr1997) is a composite of the classified satellite scene and the FESM model. The HUC-10 sub-reaches are shown in the figure. Table 2-52 is a tabulation of the acres flooded by HUC-10 sub-reach. At the two most downstream gages (Steele Bayou LS and Little Sunflower LS), the FESM flood extent covers more than 100% of the satellite flooded area (127 and 118%, respectively). These two reaches encompass most of the two primary storage areas. In the next two upstream reaches (SB-Onward and BS-Holly Bluff) the FESM model covers 57 and 78% of the satellite's flooded area within their reaches. Some of the permanent waters in the upstream reaches are marked in Figure 2-144. Most of the catfish ponds in the project area are found in the Anguilla and Little Callao reaches. Based on the elevations in the DEM, the water surface elevations within the catfish ponds range from 98 to 106 feet NAVD (Anguilla) and 100 to 109 feet NAVD (Little Callao). The pond levees are normally two-feet higher than the pond water surface, which would make the pond levees higher than the 100-year flood stages for those reaches. The winds, that often accompany storms, create waves within the ponds and cause minor erosion of the pond levees. This leads to increased turbidity, which makes the pond's reflectance similar to floodwaters. Although there is no observed floodwater in those reaches, the catfish ponds classed the same as floodwaters. The 17Apr97 flood scene was adjusted for permanent waters in the same manner as floodwaters. Figure 2-145 (FESM overlaid on the 17Apr97 Satellite image) shows that the only areas flooded by FESM in the Anguilla and Little Callao Reaches are the mainline channel and some tributary mouths. Figure 2-146 shows FESM for 17Apr97 overlaid on 2-year frequency with polygons for two major storage areas.

FESM, when compared to satellite imagery of a similar time frame most accurately estimates flood extent in the southern portion of the YSA, especially during low frequency events (high and prolonged stages) such as those observed in 1983, 2019, and 2020. The estimation of flood extent is more challenging when assessed during more high frequency events where FESM may underestimate flooding, especially upper portion of the watershed where interactions of hydrology, land-use, and topography are more complex and not accounted for in the FESM visualization tool.

Table 2-52. Tabulation of Composite Satellite & FESM by HUC10 Reach

	Class	Little Sun	Holly Bluff	Anguilla	Little Callao	Steele Bayou	Onward	Grace
Sat Fld-water	1	751.0	1987.9	1749.5	248.4	1861.4	781.3	1083.9
Sat Fld-forest	2	3309.2	7427.6	4169.6	295.3	4371.1	5490.6	5018.9
Sat BLH	3	11105.9	33698.8	18181.5	1680.6	15099.8	20782.3	20415.2
Sat Cleared	4	28318.9	102125.0	121132.1	9281.7	21733.7	56061.2	97057.0
Lakes	5	0.0	319.4	0.0	0.0	0.0	0.0	7157.8
Catfish	6	1002.8	7175.9	19255.2	3899.6	0.0	1904.1	2035.8
Ponded Ag	8	0.0	0.0	92.1	0.0	0.0	0.0	143.2
FESM Fld-water	11	35526.4	3844.9	971.4	230.6	29166.0	2235.9	487.0
FESM Fld-forest	12	37314.4	6264.3	521.1	84.3	22561.9	2205.2	922.3
FESM BLH	13	24632.6	4840.8	243.5	40.3	14261.6	1503.4	560.2
FESM Cleared	14	322.9	263.3	20.9	1.1	2347.8	134.1	74.5
Fesm Lakes	15	0.0	0.0	0.0	0.0	0.0	0.0	1329.0
Fesm Catfish	16	572.9	0.0	1.6	0.0	0.0	2.0	0.4
Fesm Ponded Ag	18	0.0	0.0	60.9	0.0	0.0	0.0	0.0
Total Acres		142856.9	167947.8	166399.3	15761.89	111403.4	91100.06	136285.3
Total Sat Flood		76900.9	19524.7	7411.6	858.6	57960.4	10713.0	7512.1
Total Fesm Fld		98369.1	15213.3	1819.4	356.3	68337.3	6080.6	3373.4
%Fesm/Sat		127.9%	77.9%	24.5%	41.5%	117.9%	56.8%	44.9%
%Shared/TotSat		94.7%	51.8%	20.1%	36.7%	89.2%	41.5%	18.8%

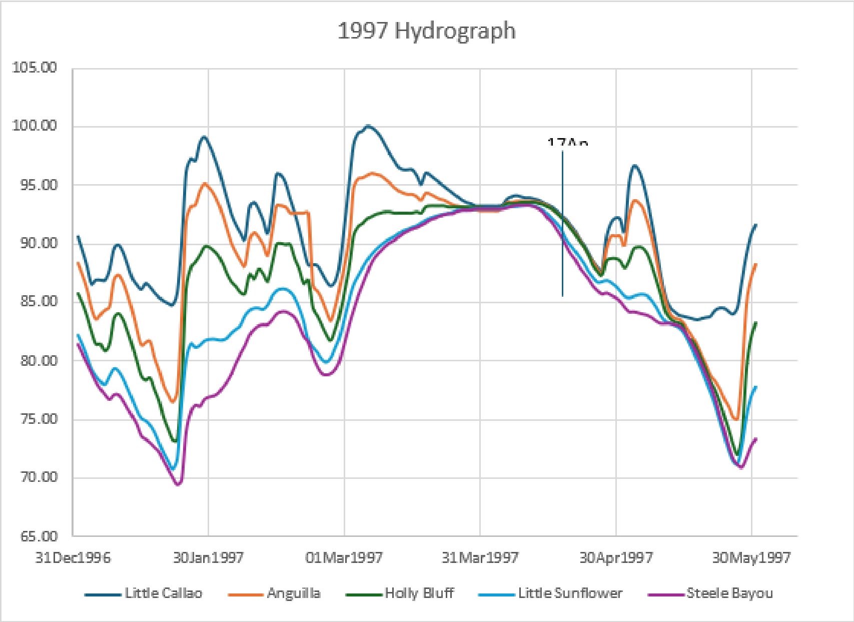


Figure 2-143. 1997 Hydrograph

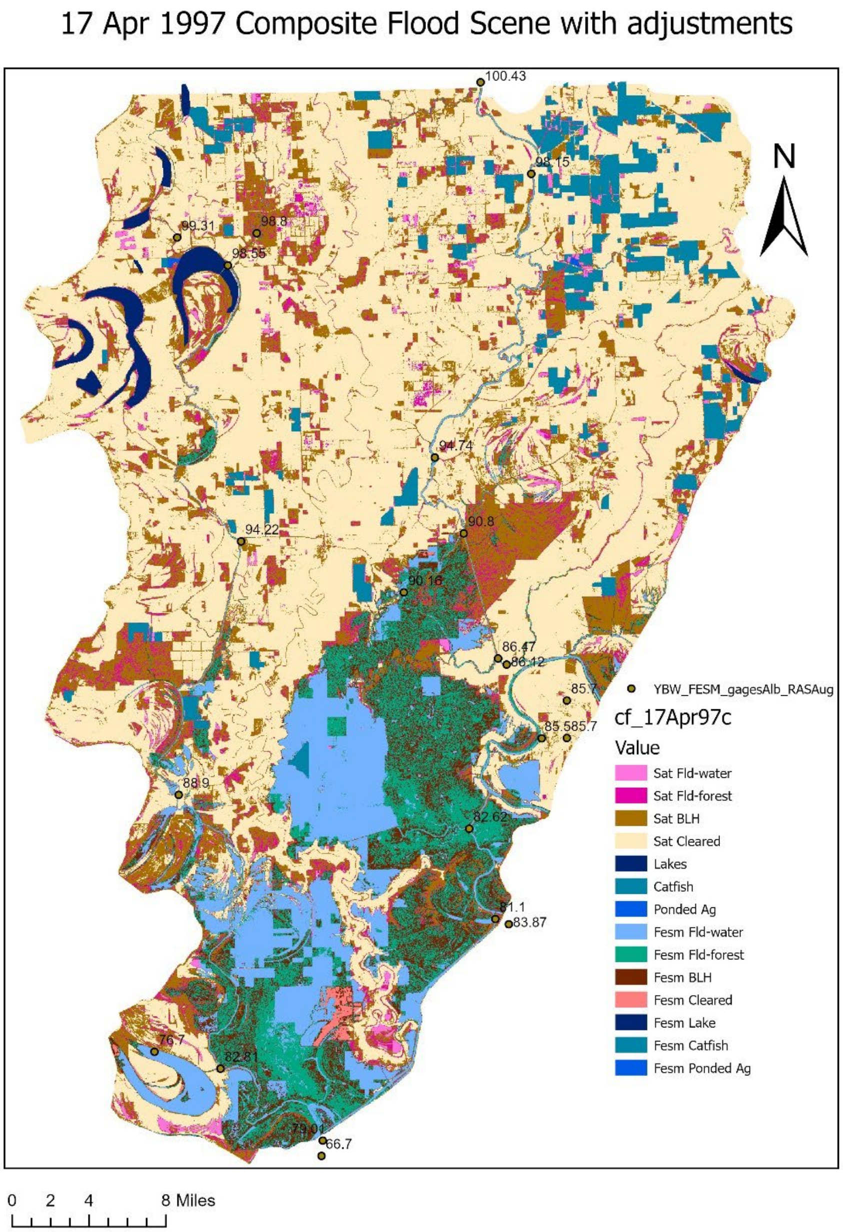


Figure 2-144. Composite Satellite and FESM for 17Apr1997 adjusted for permanent waters

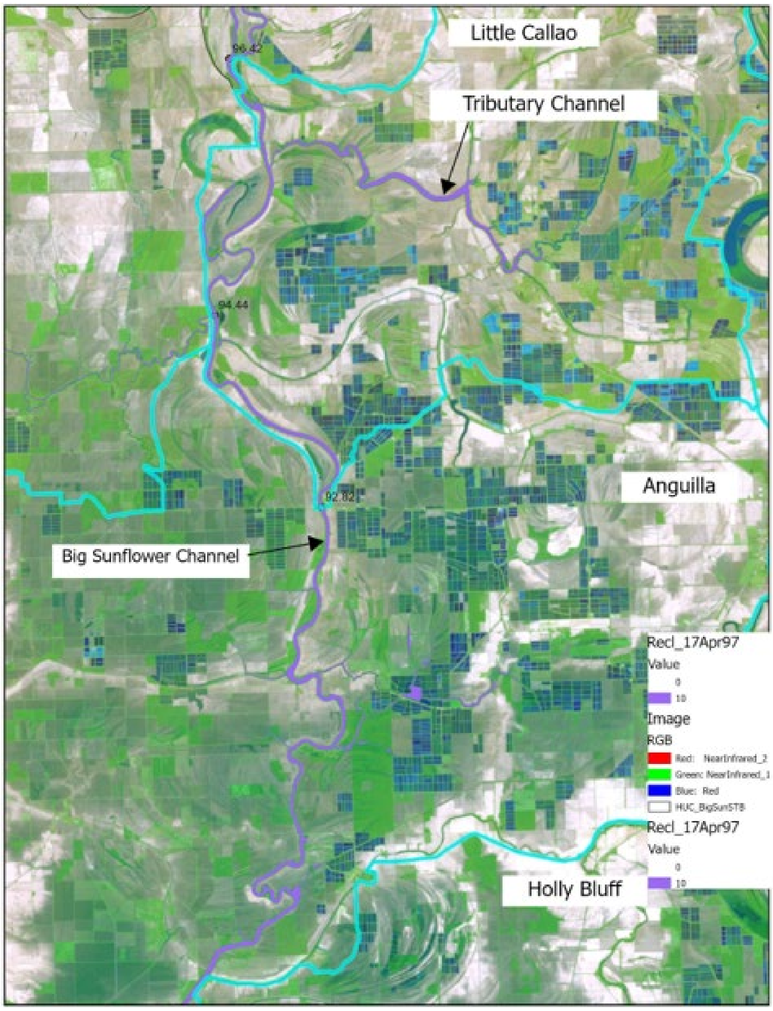


Figure 2-145. 17Apr1997 Satellite Scene with FESM Overlay

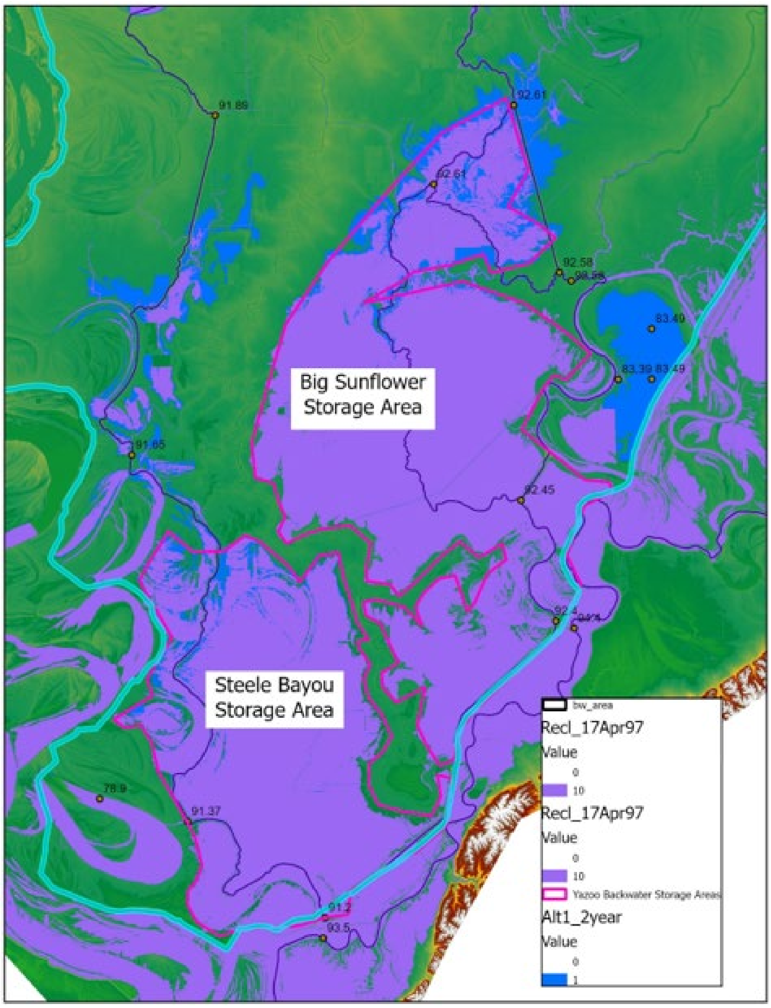


Figure 2-146. 17Apr1997 Satellite Scene with FESM Overlay

EFFECTS OF THE CURRENT PLAN

NAVIGATION

Alternative 2 will not impact any stages on the Yazoo River until the elevation at Steele Bayou landside is 90.0 feet in crop season or 93.0 feet in non-crop season. Therefore, the navigation depth under low-flow conditions would not be impacted. The pump outlet channel was designed to minimize crosscurrents in the navigation channel when the pumping station would be operating. Reference Technical Report HL-90-4, "Yazoo Backwater Pumping Station Discharge Outlet," ERDC, May 1990.

SEDIMENTATION

During certain prolonged periods when the pumps are not in operation and river stages are at moderate levels, some minor sedimentation is expected to occur in the approach to the inlet channel of the pumps and in the outlet channel near the confluence with the Yazoo River. While sedimentation is not expected to be of any major concern, the control of vegetation in the deposited areas will need to be pursued possibly on an annual basis. It is likely after the project is complete, that removal of sediment accumulations (averaging about 1 foot in depth over the extent of the channels which is approximately 80,000 cubic yards) once or twice in the life of the project may be necessary depending upon the sequence of hydrologic events which could result in deposition in the channels as described above. Material deposited in the outlet channel by the secondary currents of the Yazoo River may be returned to the Yazoo River without any significant impacts. That material deposited in the inlet channel will likely be disposed in upland areas available within the pumping station property.

ENDANGERED SPECIES

Possible impacts to habitat of endangered species, such as pondberry, were analyzed using hydrologic data and the FESM model. Endangered species analysis is found in the Threatened and Endangered Species section of the SEIS.

YAZOO BACKWATER PUMP ENTRAINMENT AND IMPINGEMENT

The proposed project would install and operate fourteen pumps with an overall capacity of approximately 25,000 cubic feet per second in the Yazoo Basin to reduce seasonal flood elevations above 90 feet and 93 feet depending on crop and non-crop seasons. Fish approaching the intakes are susceptible to entrainment by the pumps, which have axial flow impellers operate at 145 to 151 RPM’s creating intake velocities of 1.7 feet per second increasing to 2.3 feet per second at the trash rack, and 5.8 feet per second at the formed suction intake. The trash racks are spaced approximately 5.5 inches apart preventing larger fish from entering the intakes, although adult fish could become trapped against the racks (i.e., impingement). Small-bodied fish could be entrained and are susceptible to physical strike of the impeller and can be subjected to rapid changes in shear stress, pressure, acceleration, and turbulence.

To evaluate species composition of potentially entrained fish, the outlet below Steele Bayou Structure was sampled with paired "bongo" nets (0.75-meter diameter, 4.5-meter long, 505-micrometer mesh) during August 2019 and May through June 2020 after the Steele Bayou gates were open following impoundment. The Yazoo River above the Steele Bayou outlet and the outlet of Forest Home Chute, a natural backwater draining into the Yazoo River, were also sampled for comparison. Net samples were taken below the water surface and each sample was of 5-minute duration fished from a stationary boat. A General Oceanics Model 2035-B flow meter was mounted in the mouth of each net to measure velocity of water passing through the net. Meter readings and duration of sampling were converted to an estimate of water volume filtered for each sample. Samples were fixed and preserved in five percent buffered formalin. In the laboratory, fishes were identified to the lowest practical taxon and enumerated. Catch was expressed as density (e.g., number of larval fishes per 100 cubic meters of water filtered) and used to describe temporal patterns in occurrence and relative abundance.

USACE acknowledges that entrainment may occur during operation of the pumps, but does not anticipate significant impacts to fish populations in the study area based on the following reasons:

Over 98 percent of the fishes collected with bongo nets were either Gizzard or Threadfin Shad, and of these individuals, 99 percent were larvae or juveniles (Table 1-53). Gizzard and Threadfin Shad are ubiquitous throughout the lower Mississippi Valley and are often the most abundant fish species in lakes and rivers. No protected or rare species were collected.

Table 1-53. Abundance of fish species collected in bongo nets during summer 2019 and spring-summer 2020 after the Steele Bayou structure was opened following impoundment. Abundance is expressed as number of fish/100 cubic meters of water filtered.

Scientific Name	Common Name	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Clupeidae	Shad	1643.0	47.4	1643.0	47.4
Dorosoma sp.	Shad (either Gizzard or Threadfin)	1101.6	31.8	2744.6	79.1
Dorosoma cepedianum	Gizzard Shad	673.6	19.4	3418.2	98.6
Pomoxis nigromaculatus	Black Crappie	19.0	0.6	3437.2	99.1
Lepisosteus oculatus	Spotted Gar	10.8	0.3	3448.0	99.4
Hypophthalmichthys molitrix	Silver Carp	4.7	0.1	3452.7	99.6
Pomoxis annularis	White Crappie	3.8	0.1	3456.4	99.7
Ictiobus sp.	Buffalo	3.7	0.1	3460.2	99.8
Micropterus salmoides	Largemouth Bass	2.2	0.1	3462.4	99.8
Centrarchus macropterus	Flier	1.7	0.1	3464.1	99.9
Morone chrysops	White Bass	1.4	0.0	3465.5	99.9
Gambusia affinis	Mosquitofish	1.2	0.0	3466.7	100.0
Aphredoderus sayanus	Pirate Perch	0.7	0.0	3467.5	100.0

Lepomis sp.	Sunfish	0.7	0.0	3468.2	100.0

The pump station will draw water near the bottom of the inlet channel, which is approximately 27 feet in total depth. Based on the Water Quality and Aquatic Appendix, deeper water during impoundment is hypoxic (less than three milligrams per liter of dissolved oxygen) and avoided by fish.

Most adult fish, including minnows, have burst speeds of three feet per second or greater that can be maintained for at least 30 seconds, which exceeds the water velocity at the trash intake but not the formed intake. Most fish avoid moving backwards in a current (at the point of entrainment) and will exhibit burst swimming speeds to move out of the intake area if possible. Fish entrained and not injured would move through the outlet into the Yazoo River where access to floodplain and riverine habitat is widely available.

Most studies of fish entrainment through power plant turbines concluded that overall mortality is less than five percent (Cada 1990).

LOW FLOW IN DELTA STREAMS

Rivers and streams in most of the country are in equilibrium with the surficial aquifer. During periods of heavy rainfall, water moves from the rivers into storage in the surficial aquifer. On the other hand, water moves from the aquifer into the stream during periods of less rainfall. The water that moves into streams from the aquifer is called base flow. Base flow is essential to maintaining good aquatic life communities in streams and rivers. However, when the surficial aquifer is heavily utilized for irrigation or some other consumptive use, the water level in the aquifer can fall below the stream bed, inhibiting the stream from receiving base flow from the aquifer. Figure 1-15147 shows the flow duration profiles of the Big Sunflower River at Sunflower, Mississippi. The period-of-record flows have been divided into five periods to illustrate how the flow has changed over time. More insight into this problem can be obtained from the USGS Circular 1376, “Streamflow Depletion by Wells—Understanding and Managing the Effects of Groundwater Pumping on Streamflow.” Figure 1-1547 shows that the minimum flow was around 200 cfs in the 1930s through the 1940s, but, during the next three decades, the minimum flow diminished to just under 100 cfs. By the 1980s and 1990s, the minimum flow (one percent duration) had diminished to around 20 cfs, which is a 90 percent reduction from when it was first measured in the mid-1930s.

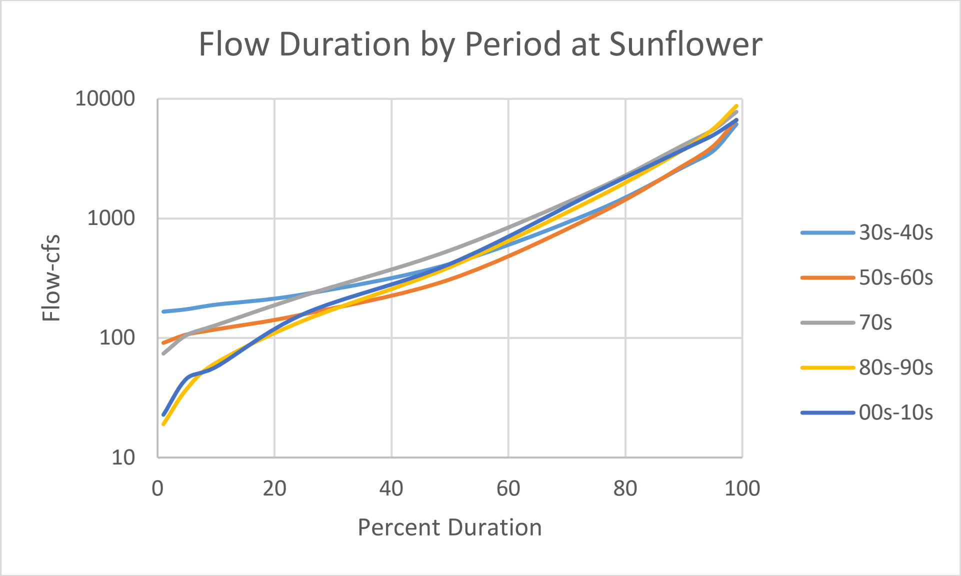


Figure 1-1547. Flow Duration by period in the Big Sunflower River at Sunflower, Mississippi.

The observed flow depletion is most severe during the fall months, which historically receive less rainfall. Figure 1-1648, Figure 1-1749, and Figure 1-1850 show the flow duration by period for the spring, fall, and summer months respectively. The flow data was sorted by periods, where a single period represents two decades. The exception to this is the 1970s, which are treated as one period. The 1970s was the period when flows were changing from pre-irrigation to full irrigation. In addition, the 1970s represent a very high flow decade. The 1970s experienced four major flood years, which were 1973, 1974, 1975, and 1979. The two highest floods in the POR occurred in 1973 and 1979. From Figure 1-1648 and Figure 1-1749, it is evident the spring and fall flow duration profiles were nearly identical, but flows were much lower during the fall months. The spring and fall profiles show that the two most recent periods (1980 to 1999, and 2000 to 2020) have lower profiles from the one percent through the 50 percent duration. Although, the median value for spring in the most recent period (826 cfs) is only slightly less than the median for the period from 1950 to 1969 (866 cfs).

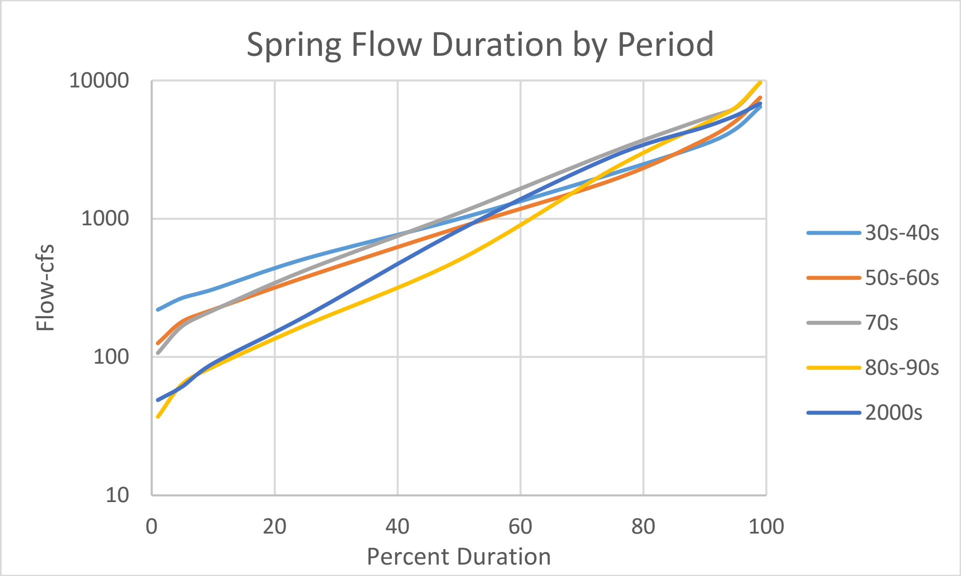


Figure 1-1648. Flow duration profile for the spring months (March, April, and May).

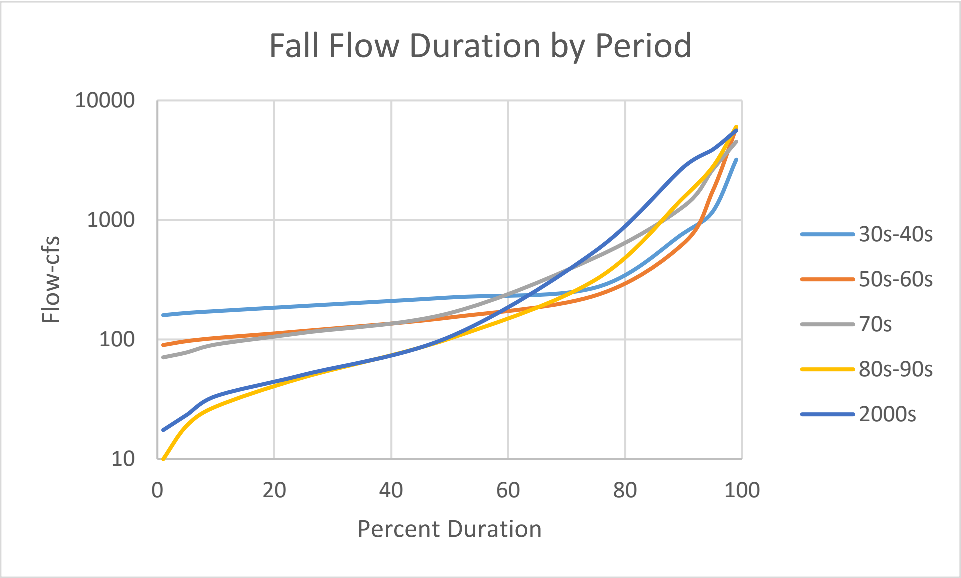


Figure 1-1749. Flow Duration for the fall months (September, October, November).

The median flows in the two most recent fall periods are 102 and 106 cfs and are substantially less than the previous three periods, which had median fall flows ranging from 153 to 225 cfs. As low as the median flows have become, it is the one percent fall flow, which has seen the most significant declines. The one percent flow in the 1980s and 1990s was only 10 cfs. This increased slightly during the last period (2000 to 2020) to 18 cfs. In the first period (1930 to 1949) the one percent flow was 160 cfs, but this declined to 90 cfs in the next period (1950-1969) then to 71 cfs during the 1970s. The summer flow duration profile is quite different. During the summer, the more recent periods showed increased flow instead of decreased flow (Figure 1-1850). This increase is due to irrigation return flow. The median flows for the five periods are respectively: 287, 202, 458, 440, and 370 cfs. Although there were small amounts of irrigation in the late 1960s, irrigation became widespread in the 1970s and has been steadily increasing since then. The entire flow profile during the summer period for the last three periods lies above the profiles for the first two periods, except for the one percent duration. These observed changes in flow are not restricted to the Big Sunflower River. Figure 1-1951 shows the annual flow duration profile by decade for Bogue Phalia. It should be noted that Bogue Phalia only has six decades of flow data, which is displayed by decade instead of by period. As was observed in the Big Sunflower, the low flow end of the profiles declined by decade, with the exception of the 1970s. Again, the fall flow duration profiles for the last 40 years lie below the profiles for the 1960s and 1970s from the median (50 percent duration) to the one percent duration (Figure 1-2052). The fall one percent duration by decade in Bogue Phalia were 35, 53, 7, 6.4, 4.9, and 0.3 cfs respectively. These low flows represent a 90 percent reduction in fall low flow for Bogue Phalia.

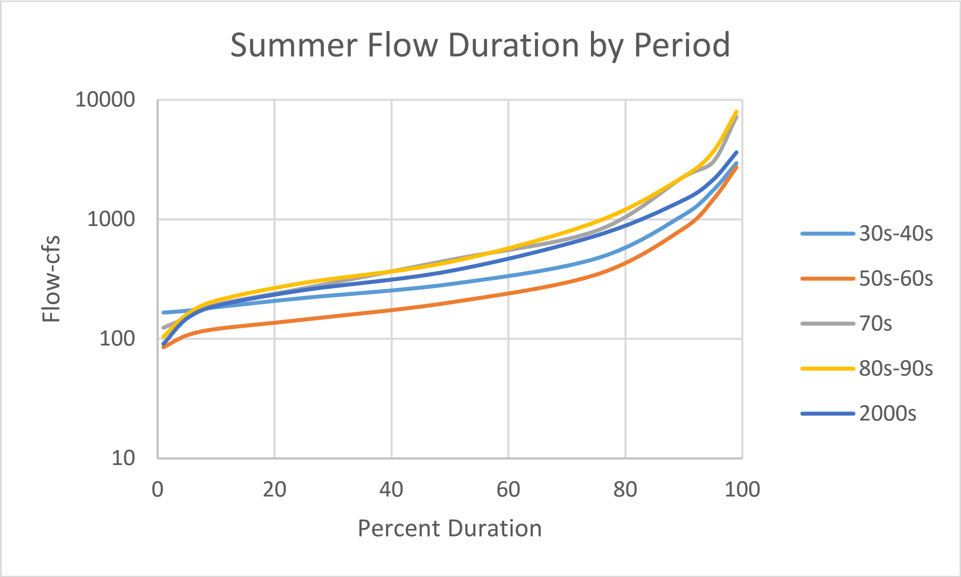


Figure 1-1850. Flow duration profile for the summer months (June, July, and August).

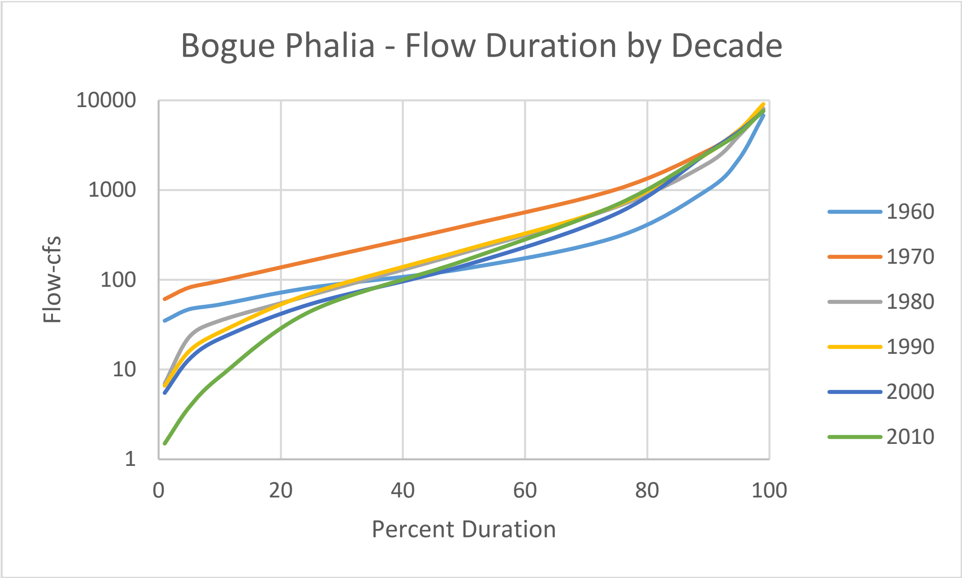


Figure 1-1951. Annual flow duration profile for Bogue Phalia.

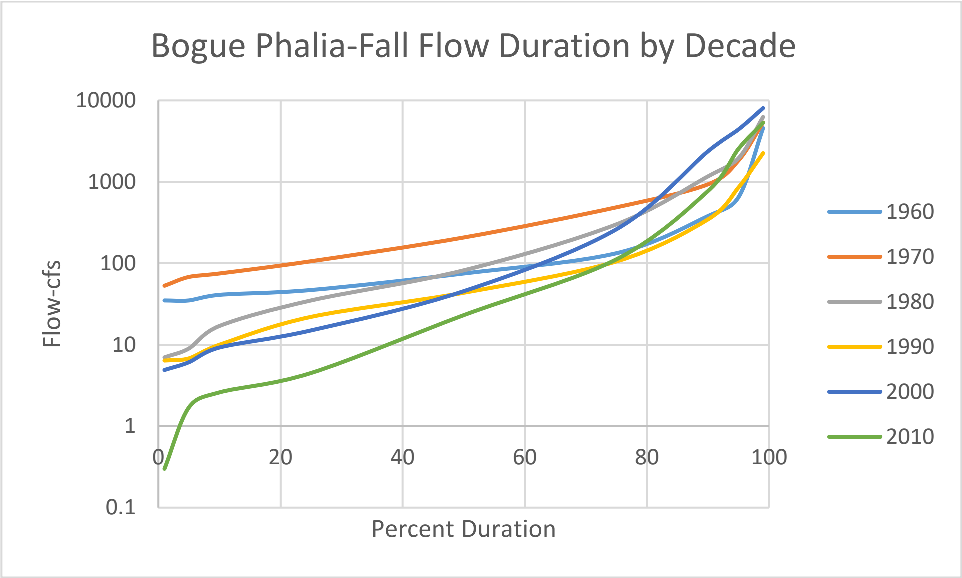


Figure 1-2052. Fall flow duration for Bogue Phalia by decade.

Two of the goals of the Clean Water Act were to make America's surface waters swimmable and fishable. It is hard to imagine how this goal can be accomplished, when a fifth order river has less than a foot of water in the channel.

HYDROLOGIC ALTERATION

The previous paragraphs have described the hydrologic alterations that have occurred in Delta streams over the past forty to fifty years. These alterations are not limited to Bogue Phalia and the Big Sunflower River. These streams were highlighted because long term flow data is available with which to describe the alterations. Many smaller streams have been adversely affected by flow alteration, such that once perennial streams have become ephemeral or intermittent. The EPA has identified hydrologic alteration as a major water quality problem. The EPA's Watershed Academy Web series has a good introduction to flow alteration entitled "How much water does a river need?" This article was provided by Brian Richter of the Nature Conservancy and is a condensed version of an article published in Freshwater Biology (Richter et al. 1997) by the same name. The second section of the EPA Watershed Web Academy paper is essential for the understanding of the low flow problem in the Big Sunflower Basin.

WATER QUALITY AND WATER QUANTITY

"Watershed management focuses mostly on **water quality** issues, but **water quantity** is extremely important in its own right". Writing for the U.S. Supreme Court in the case *Jefferson City Public Utility District v. Ecology Dept. of Washington,* Justice Sandra Day O'Conner said that the separation of water quality from water quantity was an artificial distinction that had no place in a law intended to give broad protection to the physical and biological integrity of water. Further, she claimed that reducing water quantity (or flow) was capable of destroying all designated uses for a given body of water, and that the Clean Water Act's definition of pollution was broad enough to encompass the effects of reduced water flow. This Supreme Court decision upheld the State of Washington's right to require a minimum water flow necessary to protect salmon and steelhead and to disapprove a hydroelectric plant application that would have diminished the existing flow.

The EPA recognizes the essential need for minimum flows, as illustrated by the many reports published on the subject. A recent study which was conducted with the USGS was jointly published by the agencies in 2016. The report is the "Final EPA-USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration, EPA Report 822-R-16-007 or USGS Scientific Investigation Report 2016-5164 (Novak, et al. 2016). There are many activities that alter the flow in streams including: impoundments, channelization, diversions, groundwater pumping, wastewater discharges, urban development, thermoelectric power generation, and agricultural practices (EPA-USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration). Although the direct withdrawal of water for irrigation may have been the original source of flow alteration in the basin, the withdrawal of groundwater for irrigation is the primary cause of flow alteration in the Big Sunflower Basin. Since 1970, the Mississippi Department of Environmental Quality has approved the installation of more than 20,000 irrigation wells in the Mississippi Delta. The withdrawal of irrigation water over the last forty years has created a cone of depression in the groundwater centered in Sunflower and Leflore counties (Barlow and Clark 2011). The report observes, "Water-level declines also have resulted in decreases in base flow in many Delta streams to the extent that in the absence of rainfall of irrigation return flow, some stream reaches are dry during the summer months." The impact of streamflow depletion due to wells is documented in the report: "Streamflow Depletion by Wells—Understanding and Managing the Effects of Groundwater Pumping of Streamflow" (Barlow and Leake 2012). The problem of low flow or flow alteration is not new to the Mississippi Delta. The USGS first reported on the problem in a report published in 1964 (Low-Flow Characteristics of Streams in the Mississippi Embayment in Mississippi and Alabama; Speer et al. 1964). In this report, the USGS compared the low flows in Delta Streams before and after the initiation of surface withdrawals for irrigation. The report found that the 20 percent recurrence annual low flow for the Big Sunflower River at Sunflower dropped from 138 cfs to 89 cfs after only a few years of irrigation withdrawals. In order to compare the low flows in streams with widely differing drainage areas the low flows were normalized by dividing the observed flows in cfs by the drainage area in square miles, which yields a unit of cfs/mi^2. The baseline 90 percent exceedence flows for several locations in cfs/mi^2 were: Big Sunflower River (BS) at Sunflower, 0.24; BS at Little Callao, 0.22; BS at Holly Bluff, 0.25; Bogue Phalia at Leland, 0.17. The 90 percent exceedence flow after irrigation started yielded these flows (cfs/mi^2.): BS at Sunflower, 0.16; BS at Little Callao, 0.14; BS at Holly Bluff, 0.16; and BP at Leland, 0.11.

There are four major natural sources of water entering streams. They are direct precipitation falling on the stream (relatively small component), overland flow from runoff, interflow from runoff (or subsurface storm flow), and discharge from groundwater (base flow). During wet periods overland flow and interflow are the major contributors to streamflow, but during dry periods, base flow will be dominant or the only source to supply flow to a stream. Most streams are in a case of dynamic equilibrium with the groundwater. During wet periods the water level in the stream is high, and the water surface will be higher than the groundwater. During these periods water will move from the stream into the aquifer (Figure 1-2153, losing stream). During dry periods, the process is reversed. The water level in the water table will be higher than the stream's surface, and water will move from the aquifer into the stream (Figure 1-2254, gaining stream). In some instances, the water table can drop below the bottom of the stream, and stream is now disconnected from the aquifer, and it will lose flow to the aquifer throughout the year (Figure 1-2355, disconnected stream). When a disconnected stream has no flow, it becomes an ephemeral stream. Many of the smaller tributary streams in the Big Sunflower Basin have become ephemeral streams during the fall due to lack of rainfall (these three conditions are described in USGS Circular 1376; Barlow and Leake 2012). These three are simplified examples of the interaction of groundwater and surface water. For a more complete understanding, the reader is directed to read the three reports cited in the previous section. Figure 1-2456 is from the USGS Report 2011-5019 (Simulation of Water-use Conservation Scenarios for the Mississippi Delta Using an Existing Regional Groundwater Flow Model; Barlow and Clark 2011). The figure illustrates the more complex conditions that are observed in the Big Sunflower Basin. The groundwater table is fully charged on both the left and the right of the figure. On the left, the aquifer is in direct connection with the Mississippi River, while on the right side, the aquifer receives inflow from the Bluff Hills to the East and from the Tallahatchie River. The Tallahatchie River receives discharge from the four Corps reservoirs in the Bluff Hills, and generally has ample flows throughout the year. The figure shows examples of both connected and disconnected streams. The center of the zone of depression in the aquifer lies between the Big Sunflower and Quiver Rivers. This area has a thick layer of clays which extend fifty to sixty feet below the surface. The subsurface geology of the area was mapped by Fisk, et al. 1944 and later by Saucier, 1997. Due to the thick layers of clay on the surface the area is dominated by rice and catfish production. Both use much more water than normal crops. Rice uses 36 to 42 inches per acre per year, while catfish uses more than five feet per acre per year. The combination of high-water extraction and low infiltration rates has resulted in a severe drawdown of the alluvial aquifer in that region.

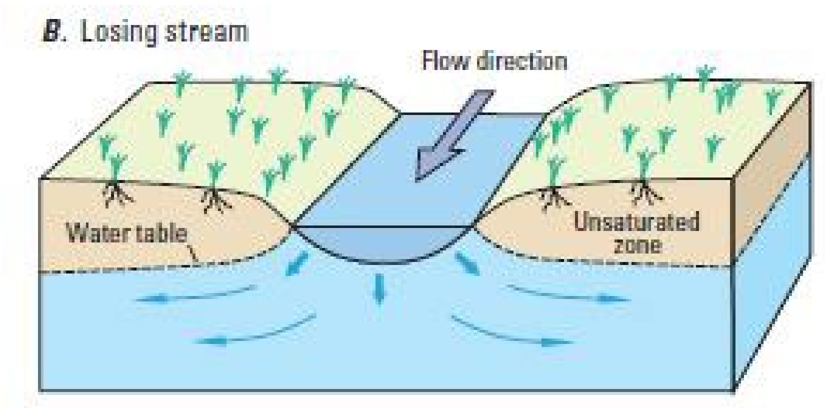


Figure 1-2153. Losing Streams, (USGS, Circular 1376).

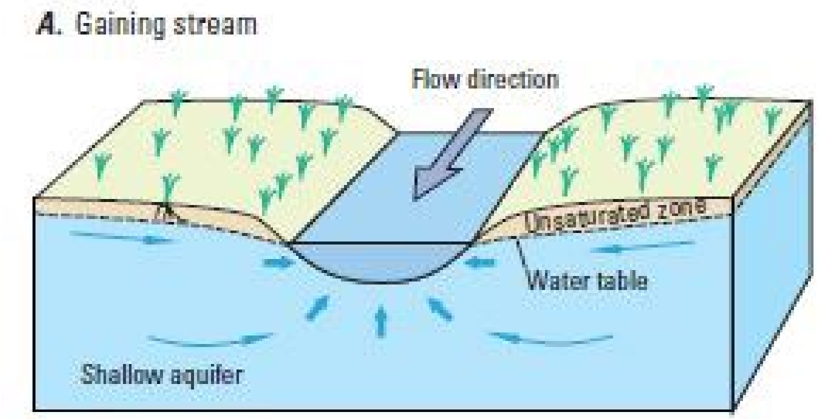


Figure 1-2254. Gaining Streams, (USGS, Circular 1376).

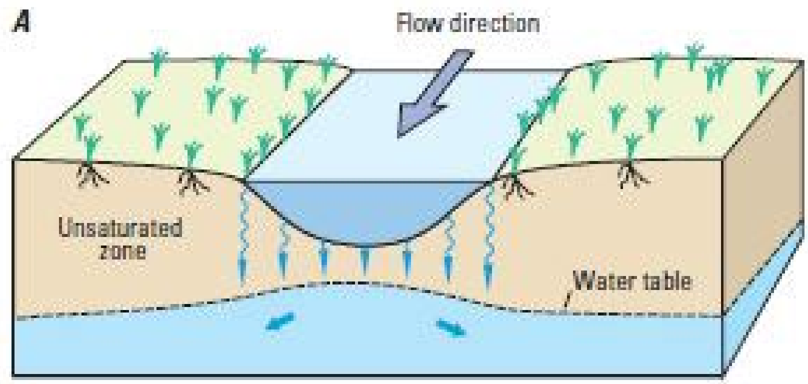


Figure 1-2355. Disconnected Streams (USGS, Circular 1376).

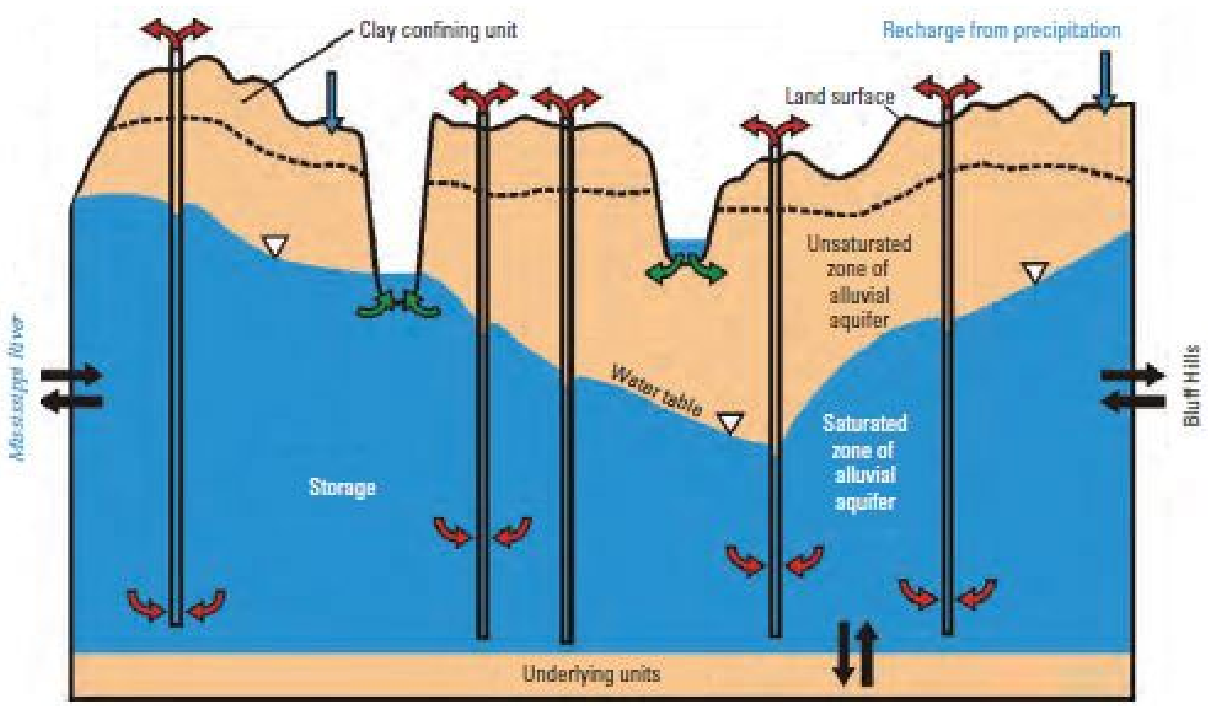


Figure 1-2456. Profile of the Mississippi Alluvial Aquifer in the Mississippi Delta (USGS, SIR 2011-5019).

Several years ago, the USGS and Corps entered into a cooperative agreement to maintain several paired groundwater-surface water gages. These paired gage locations have greatly extended our knowledge of the interactions between the groundwater and surface water in the basin. Seven of these paired gages are located in the Big Sunflower and Steele Bayou Basins. Four gages are located at Big Sunflower River locations, which are from north to south: Clarksdale, Merigold, Sunflower and Anguilla. A fifth gage is located on Bogue Phalia at Leland. Groundwater data from the upper most (Clarksdale, Figure 1-2557) and the lower most (Anguilla, Figure 1-2658) show that the groundwater and surface water are fully connected. When the surface water level increases the groundwater table also rises. During the summer the ground water levels are above the stream levels and the groundwater is discharging into the river maintaining base flow. The paired gages at Sunflower show that the aquifer is below the level of the surface gage, but that it does show increases in the water surface level during periods of high stages. However the Sunflower and Merigold gages (Figure 1-2759 and Figure 1-2860) show an aquifer completely disconnected from the surface stream. The groundwater at these two gages shows increases, when stages are high, but the water surface stays well below the surface of the river. Bogue Phalia is west of the Big Sunflower River and outside of the zone of depression in the alluvial aquifer.

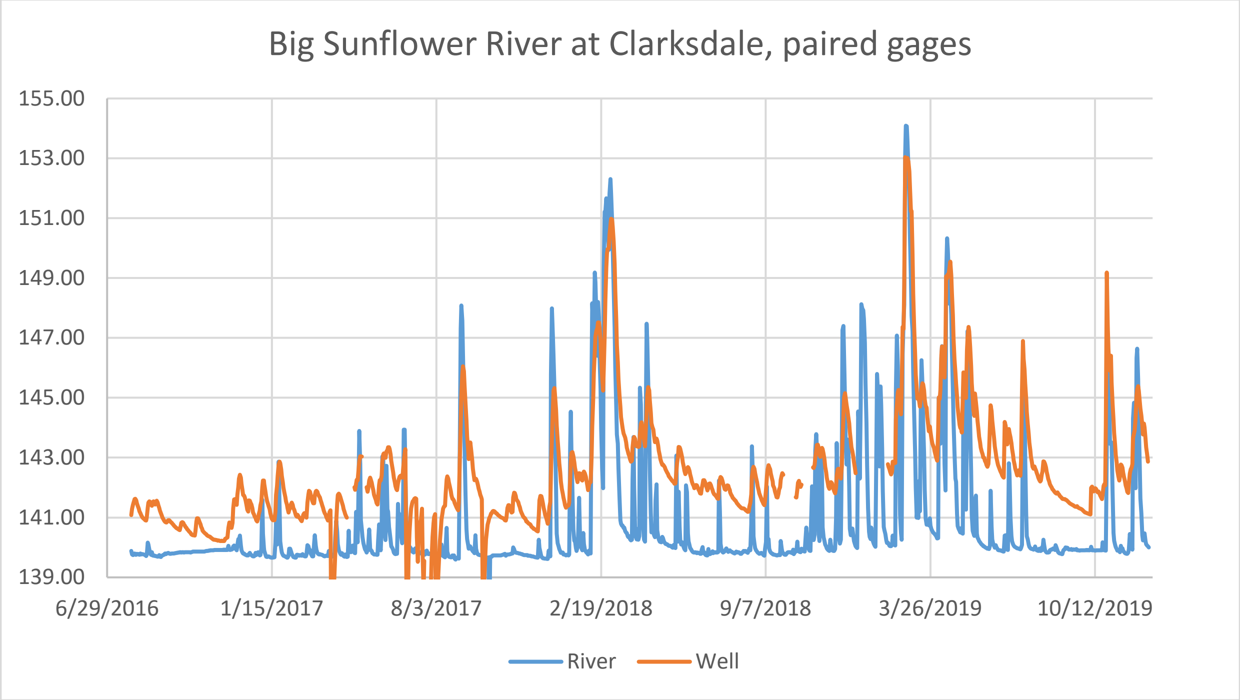


Figure 1-2557. Paired gages for the Big Sunflower River at Clarksdale.

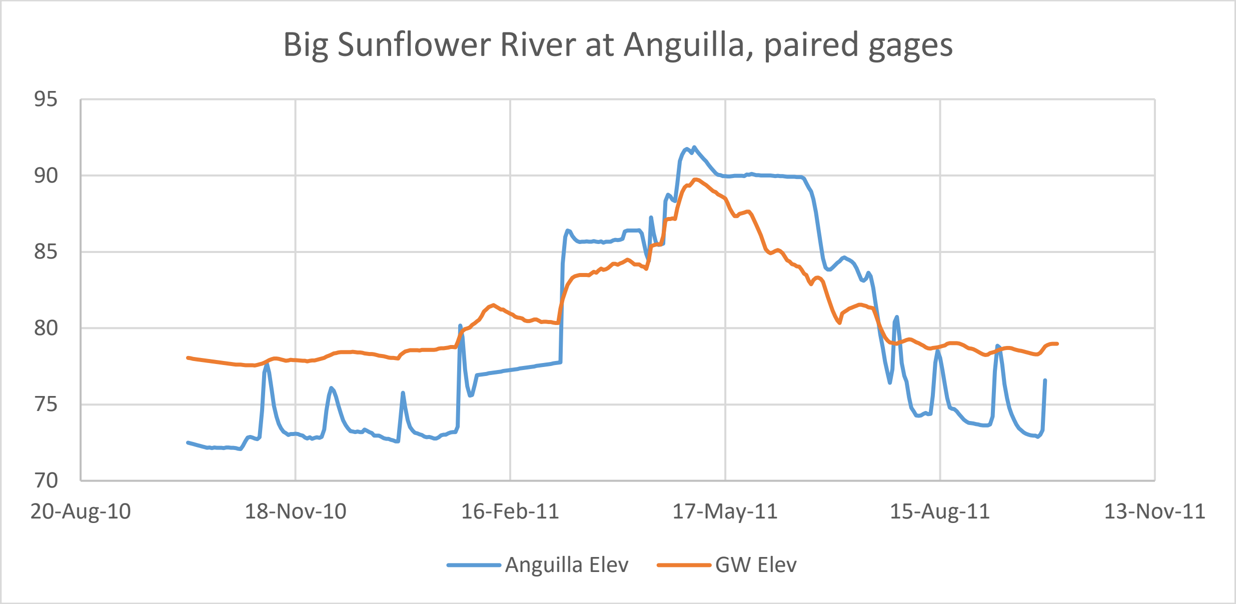


Figure 1-2658. Paired gages for the Big Sunflower at Anguilla.

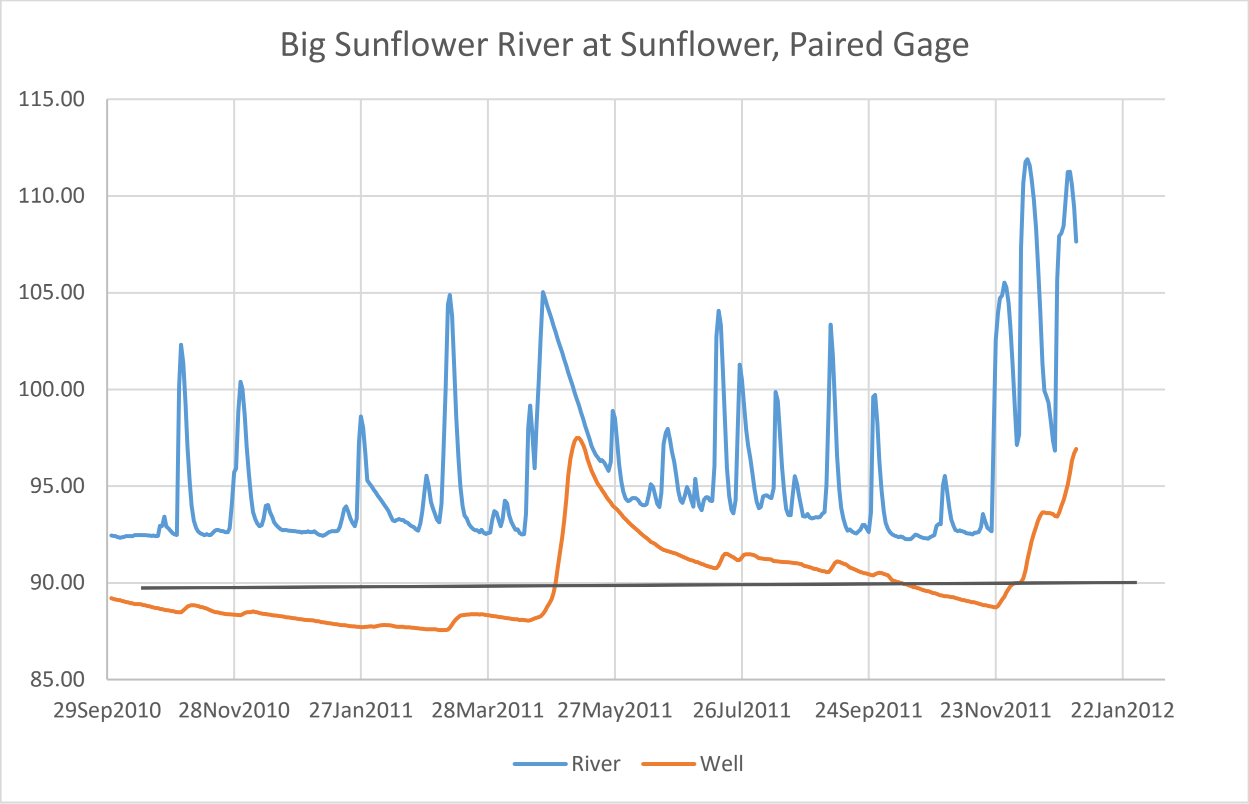


Figure 1-2759. Paired gages for the Big Sunflower River at Sunflower.

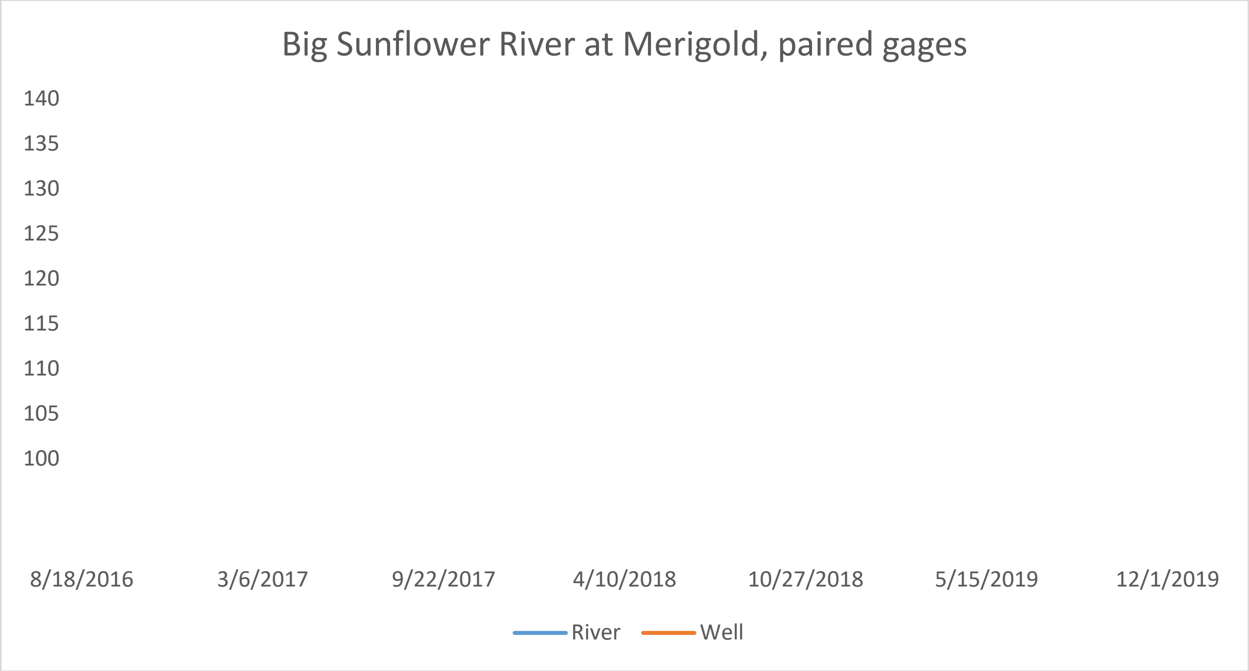


Figure 1-2860. Paired gages for the Big Sunflower River at Merigold.

Figure 1-2961 displays a hydrograph for Bogue Phalia at Leland. It shows that the groundwater water surface is above that of the river during summer and fall, which means that Bogue Phalia is both a losing and gaining stream at some period of each year. These figures illustrate that the conditions within the Big Sunflower Basin are variable. In some locations the rivers and the aquifers are connected, while in other locations they are clearly disconnected.

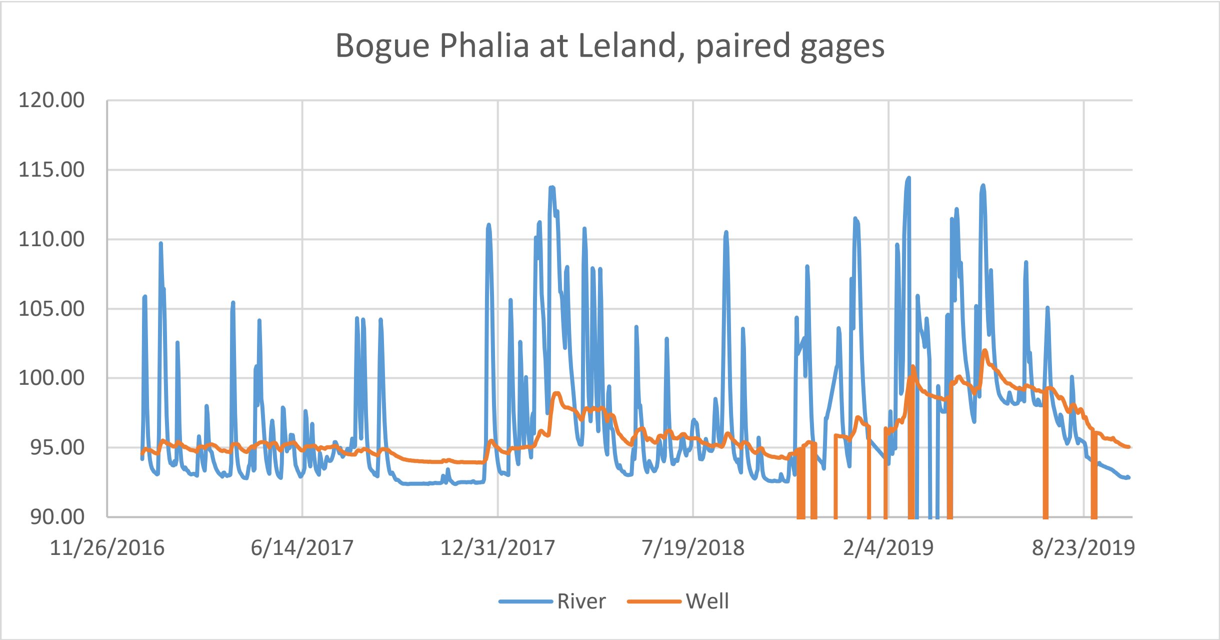


Figure 1-2961. Paired gages for Bogue Phalia at Leland.

The final figure (Figure 1-3062) illustrates the effect that disconnecting the aquifer from the surface stream has impacted flows during the fall low flow season. The median flow has dropped from over 220 cfs in the 1930s and 1940s to around 100 cfs today. The decline in the 90 percent exceedence flow (10-percent duration) is even starker (Note, SAS sorts flows from highest to lowest, thus the percent exceedence flow is obtained by subtracting the percent duration from 100). Initially, the 10 percent duration was around 200 cfs, but it has fallen to between 20 and 30 cfs during the last 40 years.

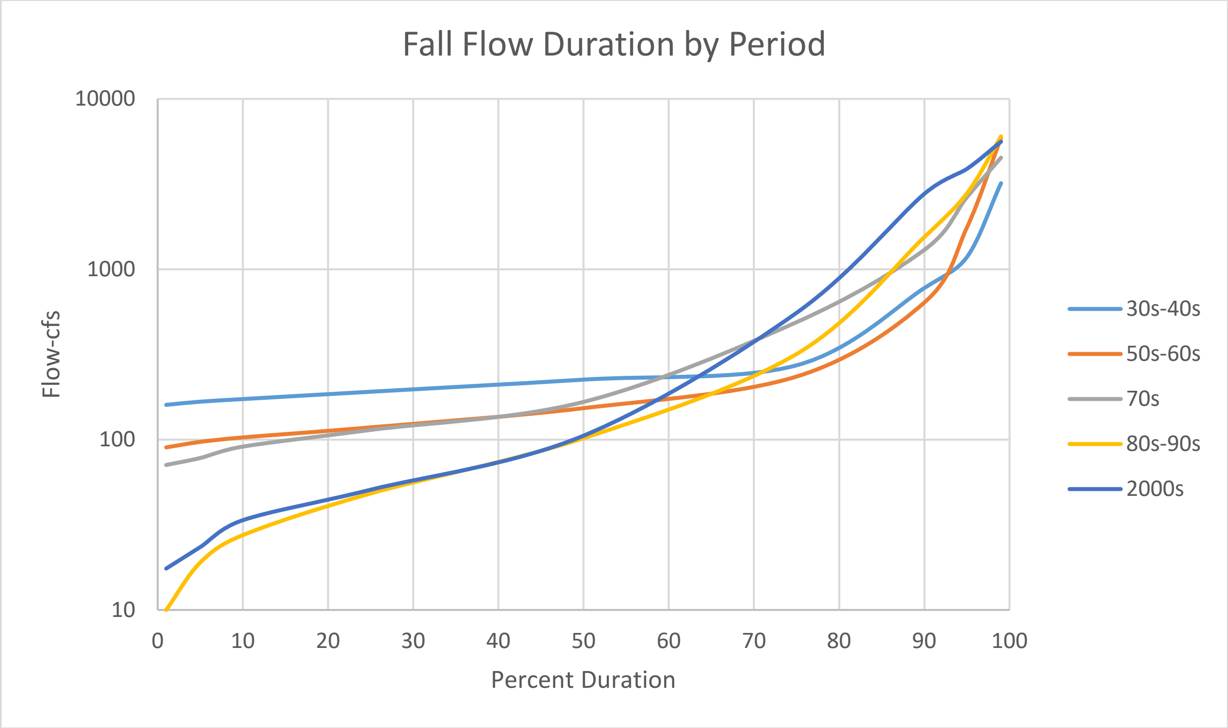


Figure 1-3062. Fall flow duration for the Big Sunflower River at Sunflower.

FLOW AUGMENTATION

Early uses of flow augmentation were to improve water quality or to improve water quantity to ensure the water quality was maintained. The Federal Water Pollution Control Agency, in Atlanta, GA contracted with the University of Florida (Final Report to Southeast Region, FWPCA, Sep 1969, A Model For Quantifying Flow Augmentation Benefits; Pyatt et al. 1969) to examine the cost benefit of augmenting flow compared to the increased costs of wastewater treatment. One of the EPA first reports dealt with flow augmentation, “Water Quality Control Though Flow Augmentation” (Heidelberg College, Biology Department 1971). Again, the emphasis of the study was improving water quality.

The Corps has implemented several programs over the years to try and improve fisheries habitat in the basin, but none have shown any significant improvements. In 1968 the Big Sunflower Lock and Dam upstream of the Little Callao gage on the Big Sunflower River was converted into a weir. The weir increased the minimum water surface by about seven feet. In the early 1980s, the Corps started holding the minimum elevation at the Steele Bayou structure to between 68.5 and 70 feet. This change increased the minimum water level by up to 15 feet in the lower basin. Prior to this change some channels used to go dry during extreme low flow conditions brought on by low flow in the Yazoo and Mississippi Rivers. The Steele Bayou side of the basin has three weirs in the Steele Bayou channel to provide minimum water depths during low flow periods. Finally, the

Upper Steele Bayou Basin has seven additional low flow weirs to improve fisheries habitat and reduce channel maintenance. These weirs have provided some benefit to fisheries in the upper Steele Bayou Basin. There was a measured increase in species richness after project completion. The greatest increase over time occurred in Steele Bayou where species richness was over 50 percent higher post-project. The pre-project fish community consisted of 20 species, whereas 30 species occurred post-project. Increase in richness was due principally to pre-project absence and post-project colonization by intolerant species: threadfin shad, golden topminnow, bantam sunfish, ghost shiner, and speckled chub. Large numbers of inland silverside and threadfin shad indicate substantial zooplankton populations, golden topminnows and bantam sunfish, the availability of structurally complex habitats (vegetation, woody debris) and persistent slack water, and ghost shiner and speckled chub, moderate water velocities. In addition, benthic species such as slough darter were collected for the first time indicating firmer, more stable substrates. Commercial fishes were documented in the system (buffalo) and nest-building sunfishes increased (warmouth, bluegill, dollar sunfish). Largemouth bass were collected only post-project. Largemouth bass are rarely collected in Yazoo delta streams, so their presence in USBS, along with other intolerant species, suggests beneficial effects of increased water levels and more stable substrates. These improvements are presented in a Technical Note (Kilgore et al. 2008). However, weirs do not help solve low DO problems above the weir, but they generally improve DO downstream of the weir. Increased channel depths don't increase DO levels either. Because all of the past attempts to improve fisheries habitat have only led to marginal success, other restoration techniques should be considered, targeting the limiting factor suppressing fisheries improvements – environmental flows. Flow augmentation has been successful in many streams, but flow augmentation is usually done downstream of dams. As there are no dams available, we are suggesting that a series of wells be installed to provide an improved low flow. The Yazoo Mississippi Delta Water Management District (YMD) experiment with flow augmentation during the fall of 1993. That experiment is documented in an article titled, "Augmentation of Low Flows of The Upper Sunflower River," by Dean Pennington (Pennington 1993). YMD later started paying landowners to discharge water from irrigation wells into the upper Big Sunflower River to augment low flows. In 2005, YMD installed eleven wells in the upper Big Sunflower Basin and operated them for many years to augment low flows. They used these wells to augment fall low flow (Sunflower River Low Flow Well Field Project, Pennington, YMD Website). They used these wells for over fifteen years, and they are still using these wells now. These wells increased the base flow to between 35 and 45 cfs during the fall low flow period. Although the increase in base flow at Sunflower is often less due to evaporation and infiltration losses. As mentioned above, many flow augmentation projects have been done downstream of dams. The Upper Snake River watershed in Idaho has several dams operated by the U.S. Bureau of Reclamation due to a court ruling the Bureau of Reclamation has to provide 487,000 acre-feet of water for flow augmentation each year. This water either comes from storage in reservoirs or from landowners from wells. The program was mandated by the Court to offset the incidental take of salmon and steelhead due to low flow. This low flow augmentation program is documented in the report: 2010 Salmon Flow Augmentation Program and Other Activities Associated with the NOAA

Fisheries Service 2008 Biological Opinion and Incidental Take Statement for Operations and Maintenance of Bureau of Reclamation Projects in the Snake River Basin above Brownlee Reservoir, Annual Progress Report (U.S. Department of the Interior 2010). A similar report is available for the Russian River in California (Stream Flow Augmentation Agreements to Benefit Salmonids-A Collaborative Drought Response in the Russian River; National Marine Fisheries Service 2015). Like the Snake River study, this study documented the use of several different methods of flow augmentation, which included flow from reservoirs, flow from wells, and reduced use of water by adjacent vineyards. The actions in this study were initiated during a drought to protect juvenile salmon and steelheads. Another example is in the Spring Creek sub-basin of the Flint River in Georgia. Prolonged droughts and increased water demand were adversely affecting low flow in Spring Creek. The prolonged low flow was affecting mussel populations, and in 2011 a demonstration project was initiated which used flow augmentation from wells to maintain minimum flow in Spring Creek to prevent mussel die off. This project is documented in: “An Evaluation of Streamflow Augmentation as a Short-term Freshwater Mussel Conservation Strategy” (Wisniewski et al. 2015). The internet has hundreds of similar studies, and more can be obtained by querying ‘flow augmentation for fish.’

WELL FIELD AUGMENTATION

In order to improve habitat for fish and mussel, the Corps plans to augment flows in the Big Sunflower and Steele Bayou Basin by withdrawing water from the alluvial aquifer using wells located near the Mississippi River Mainline Levee. The plan would install up to 34 wells in five sub-basins. Figure 1-3163 shows the potential locations of the wells. The final locations cannot be determined until after the project is approved and funds are provided by Congress. Well locations will then be negotiated with the individual landowners. The wells will be sited as close as practicable to the preliminary locations shown in this document. Locations could change depending on cultural and HTRW investigations, minimizing environmental impacts, lack of adequate electrical power at the site, or to facilitate construction. The sub-basins are Harris Bayou, Hushpuckena River, Bogue Phalia, Deer Creek, and Steele Bayou. The wells in the Harris Bayou and Hushpuckena River watersheds would supplement low flows in the upper Big Sunflower River from below Clarksdale to below Indianola. The wells in the Bogue Phalia Basin would augment flows in the middle Big Sunflower River from just above the Little Callao gage to below the Anguilla gage. The wells in the Deer Creek sub-basin would augment flows in the lower Big Sunflower Basin through Rolling Fork Creek. Finally, the wells in the upper Steele Bayou Basin would augment flows in Main Canal, Black Bayou, and Steele Bayou. The wells would only be operated during the fall low flow period after irrigation return flows cease. Depth transducers will be installed in each sub-basin, and pumping would be started and stopped based on observed water surface elevations. The wells will not be operated during medium or high flow events, and they definitely will not be operated during flood events. Minimum flow targets will be established for downstream locations, and the number of wells operated will vary so that the target flows are achieved. The minimum flows will be established through the Adaptive Management Program for this project. The wells will be located near the Mississippi River levee to minimize possible impacts to the alluvial aquifer. The groundwater elevation will be monitored at all sites to evaluate the impact of well usage to the aquifer. All wells will be located outside of the current zone of depression in the groundwater table. Figure 1-3264 and Figure 1-3365 shows the fluctuations in the groundwater elevation at three wells near Greenville, MS, with a hydrograph of the Mississippi River at Greenville for the same period of time. The figure shows that the water surface in the wells goes up and down with the Mississippi River. The water surface of the Mississippi River fluctuates by about 40 feet annually, but the wells water surfaces only change about 10 feet each year. Figure 1-3466, shows the annual fluctuations in the groundwater depth at wells with increasing distance from the Mississippi River. The annual fluctuation decreases with increasing distance from the Mississippi River. The plan places most wells within five miles of the Mississippi River so that the aquifer will be recharged at those locations each year. The planned peak flows for each sub-basin will amount to approximately one to two percent of peak flows. Water depth will be one to two feet at each site, but the ultimate minimum flows and depths will be determined by the Adaptive Management Program.

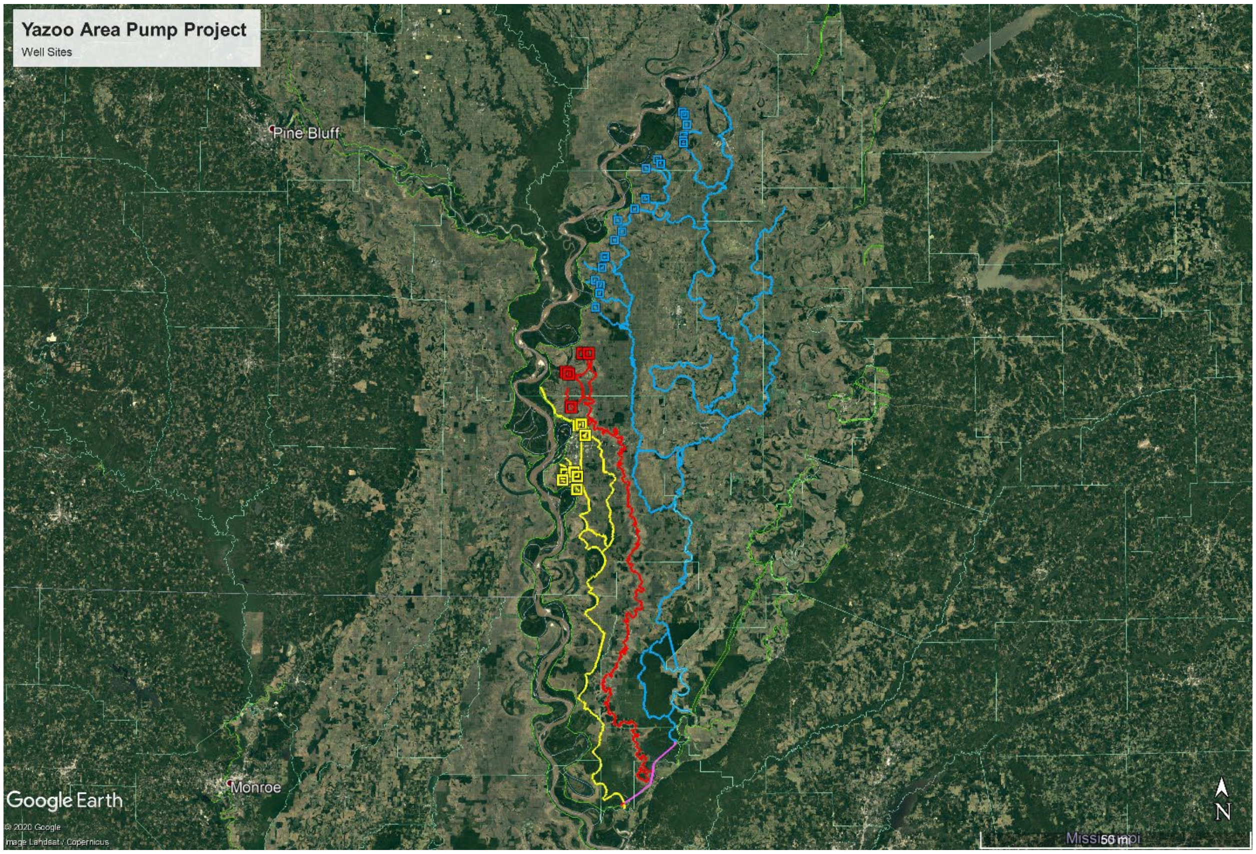


Figure 1-3163. The potential locations of the wells.

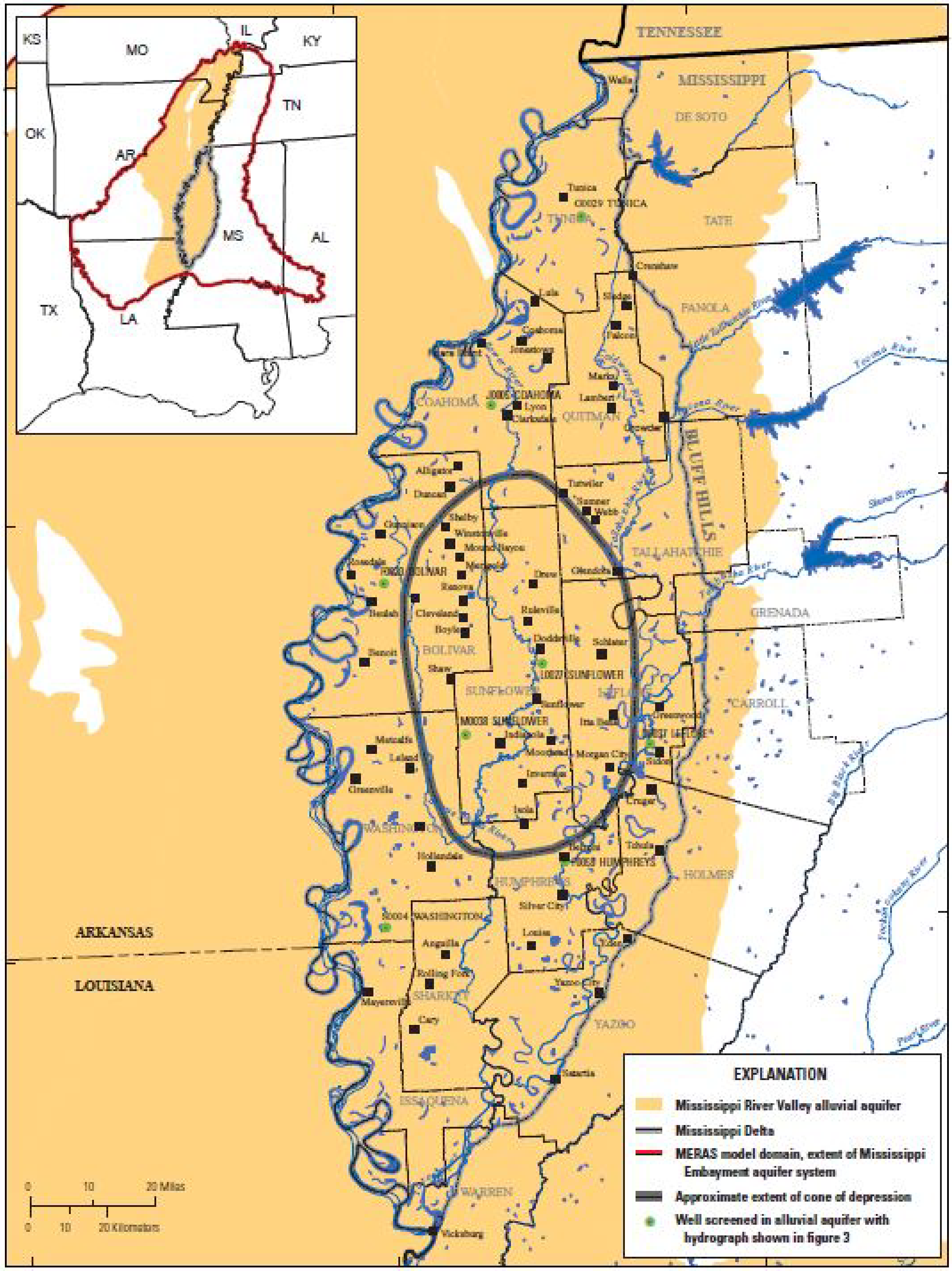


Figure 1-3264. Location of the zone of depression in the alluvial aquifer. From "Simulation of Water-Use Conservation Scenarios for the Mississippi Delta Using an Existing Regional Groundwater Flow Model, USGS Scientific Investigations Report 2011-5019.

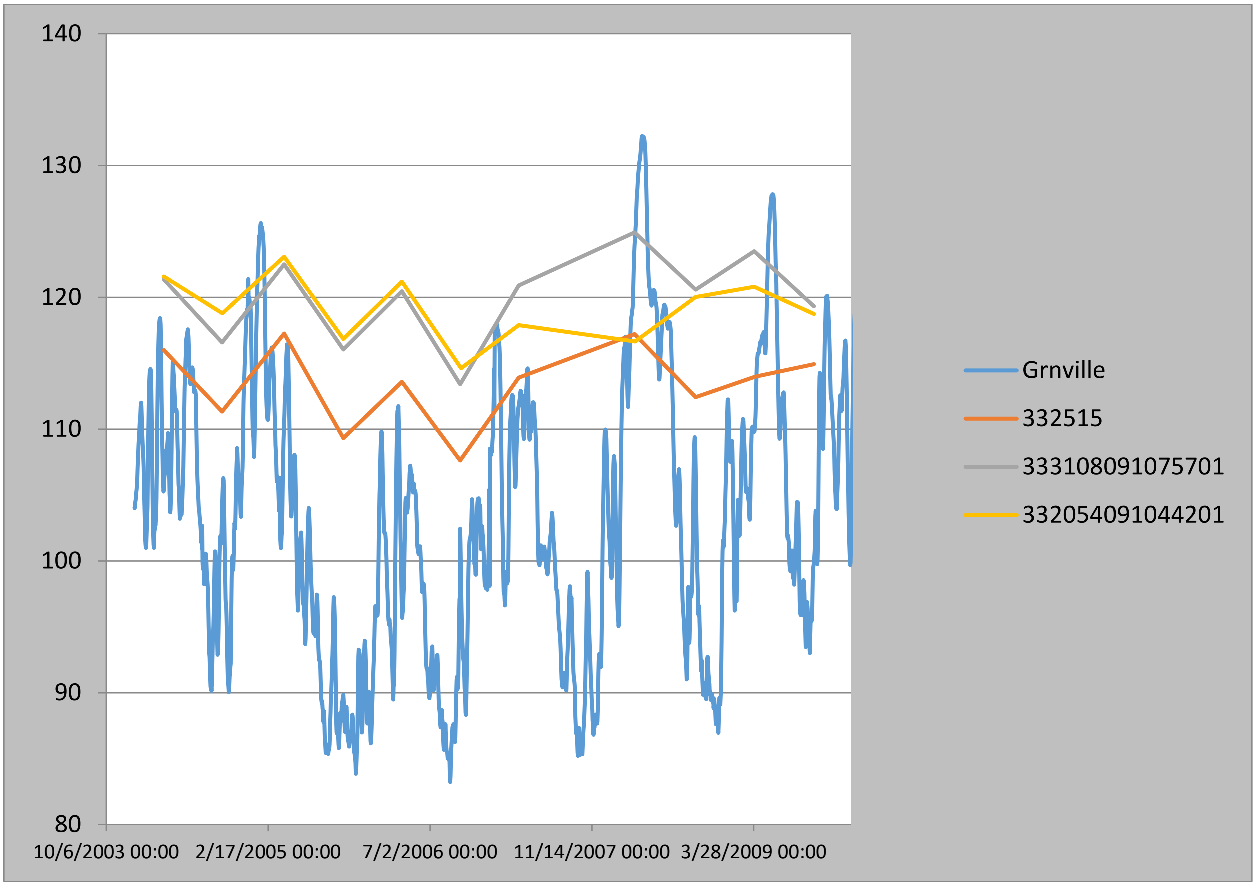


Figure 1-3365. Groundwater elevation compared to the Mississippi River water surface elevation at Greenville, MS.

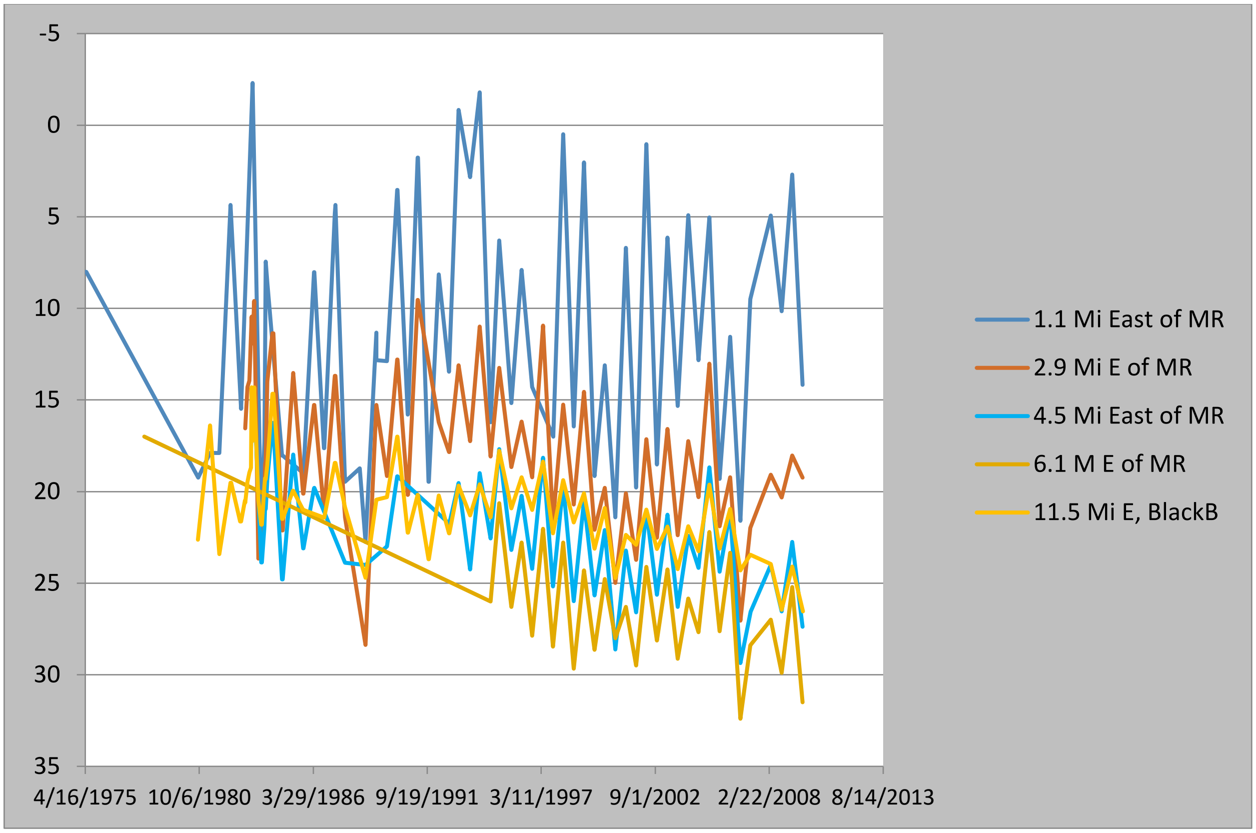


Figure 1-3466. Fluctuations in groundwater surface with distance from the Mississippi River.

Supplemental flows from groundwater wells during low flow conditions would improve water quality, mussel survival, and fish recruitment. Changes from an intermittent condition to perennial flows will increase dissolved oxygen concentrations, biochemical processing, and carbon export. Increases in wetted perimeter due to establishment of environmental flows will provide adequate water to avoid desiccation of established mussel beds and reduced mortality associated with elevated water temperature during low water conditions. Mussels are widespread and abundant in the Big Sunflower-Steele Bayou drainage, and include regional and federally protected species. Elevated flows will facilitate periodic fish passage flows over weirs for spawning movements, recolonization of fish, and an overall increase in fish species richness. Infected mussel host fish could also access new areas of suitable habitat for mussel colonization leading to population expansion. Improvement in water quality and macroinvertebrate production in summer and fall may improve the condition factor of fishes increasing survivorship. Improved health and condition would transfer to the spring spawning period and positively benefit annual recruitment cycles. This approach offsets the high mortality of larvae and juvenile fishes occurring in the spring during hypoxic events with increased survival rates of juvenile and adult fishes during autumn and fall.

SECTION 3 ENGINEERING AND CONSTRUCTION

PURPOSE

The purpose of this Engineering and Construction Section is to provide a site description and document engineering studies performed on the design, operation, and maintenance of the pump station located in Warren County, Mississippi.

PROJECT DESCRIPTION

The Yazoo Backwater Study Area is located in west-central Mississippi and is bordered by the left descending bank of the mainline Mississippi River levee on the west, the west bank levees of the Whittington Auxiliary Channel, the connecting channel, on the east, and the Yazoo River on the south. The area, which includes portion of Humphreys, Issaquena, Sharkey, Warren, Washington, and Yazoo counties, Mississippi and part of Madison Parish, Louisiana, contains approximately 926,000 acres. In addition, this area is subject to headwater flooding from the Yazoo and Sunflower Rivers and backwater flooding from Steele Bayou that is induced from high stages on the Mississippi River. The proposed location of the pump station is located in Warren County, Mississippi. The site lies north of the Yazoo River, west of the Yazoo Diversion Canal, and along the Yazoo Backwater Levee.

REGIONAL GEOLOGY

PHYSIOGRAPHY - TOPOGRAPHY

The Yazoo Backwater Pump Station site is located near the southern limits of the Yazoo Basin, a subprovince of the Mississippi Alluvial Valley. The Yazoo Basin is bounded on the west by the Mississippi River and on the east by the Bluff Hills. The surface of the Yazoo Basin consists mainly of an intricate network of meander belt (point bar, abandoned channel, and natural levee) deposits. The point bar deposits, which form the ground surface at the pump station site, exhibit an undulating surface of ridges and swales partially covered by remnant natural levees. Natural ground surface elevations in the vicinity of the pump station range from approximately 55 feet, NGVD, at Centennial Lake, to more than 100 feet, NGVD, along the base of the Bluff Hills where elevations increase abruptly to 300 feet, NGVD, on the top of the Bluff Hills.

STRATIGRAPHY

The geologic formations present at the project site consist of the Quaternary alluvium, underlain by the Eocene Yazoo Formation. The alluvium is divisible into topstratum deposits, which overlay substratum deposits. The topstratum consists of fine-grained silts, clays, sandy silts, and silty sands deposited by vertical accretion. The substratum is comprised of a thick deposit of fine sands that grade downward to coarse sands and sandy gravel. Lenses of silty sands and clays are occasionally encountered in the substratum. The contact between the topstratum and substratum is highly irregular and reveals channels of topstratum incised into the substratum. The substratum overlies the eroded surface of Tertiary formations within the Mississippi Alluvial Valley. In the study area, the substratum overlies the Yazoo Formation of the Jackson Group. The Yazoo Formation consists of highly plastic, impervious montmorillonitic clay. This formation is a regional aqualude.

STRUCTURE

The study area is situated about 25 miles west of the structural axis of the Mississippi Embayment. Much of the Mississippi Embayment is underlain by extensions of the Ouachita Mountain fold belt of Paleozoic age. Numerous major structures: i.e., fault systems, basins, uplifts, etc., of various ages lie, or partially lie, within the Mississippi Embayment, however, not within the project area. The established trace of the Pickens-Gilbertown Fault System extends from Gilbertown, Alabama, through Pickens, Mississippi, and terminates near the axis of the Mississippi Embayment approximately 30 miles northeast of the study area. The study area is situated a few miles southwest of the Monroe Uplift-Sharkey Platform, along the west limb of the structural embayment, where the formational dip is to the southeast. Surficial evidence of a northwesterly trending fault exists along Bluff Creek, in the Bluff Hills, approximately 4 miles north of Vicksburg and is referred to as the Bliss Creek Fault. The Bliss Creek Fault is reportedly Tertiary in age, i.e., only the Tertiary deposits have been disturbed, whereas the overlying Plio-Pleistocene deposits have not been disturbed. This observation indicates that movement along the fault has not occurred since Tertiary time. The northwesterly extent of the Bliss Creek fault is not known because the Tertiary surface is covered by more than 100 feet of alluvium. A straight-line northwesterly projection of the fault from Bliss Creek places the fault trace about 1 mile northeast of the project site. The questionable extent of the fault, the apparent inactivity of the fault since Tertiary time, and the fact that the Tertiary surface is covered by more than 100 feet of alluvium in the area of the site, are considered sufficient reasons for dismissing the Bliss Creek Fault as a threat to the project.

TECTONICS AND SEISMOLOGY

The New Madrid earthquakes of 1811-1812 are generally considered to be the most powerful earthquakes in United States history and were rated approximately XI on the Modified Mercalli (MM) scale and had a body-wave magnitude of approximately 7.2. Subsequent record keeping and more recent seismic monitoring show that the New Madrid area continues to be an active earthquake area. During the 1950s, more than ten earthquakes were recorded in the New Madrid area, with intensities of MM of V or VI. The numbers and intensities were similar during the 1960s and 1970s. Record keeping, and seismic monitoring led to the development of earthquake zones across the United States, relative to occurrences and intensities of the earthquakes. The generally accepted southern limit of the New Madrid earthquake zone lies near

Marked Tree, Arkansas, northwest of Memphis, Tennessee (about 225 miles from the project site). In the area of the project site, earthquakes should be infrequent and of low intensity if they occur.

HYDROGEOLOGY

The entire study area is ultimately drained into the Mississippi River, which also bounds the region on the west and south. The Yazoo River, locally occupying an abandoned course, traverses the area from the northeast to the southwest and enters the Mississippi River at Vicksburg. The Steele Bayou, Big Sunflower, and Yazoo River drains most of the study area and forms the southern boundary of the project site. The fine-grained topstratum overlies the more permeable sands and gravels of the substratum. The hydraulic connectivity of the topstratum and substratum is dependent on the thickness, lenticularity, and permeability of the topstratum material. Permeable sandy lenses that are overlain and underlain by clay should be considered as hydraulically connected to the substratum during high water and may develop perched water table conditions at low water stages. Piezometers indicate that the water table, as measured by the pressure head in the alluvial aquifer, fluctuates considerably and is primarily controlled by the stages on Steele Bayou and the Yazoo River. It is anticipated that a water table elevation above 100 feet, NGVD, will exist when the Mississippi River stage is at the Project Design Flowline.

SITE GEOLOGY

GENERAL

The Yazoo Backwater Pump station site is located in the alluvial valley of the Mississippi River approximately 8 miles north of Vicksburg. Ground surface elevations vary from 79 to 91 feet, NGVD, and average 85 feet, NGVD. An interpretation of the local geology is presented in ERDC Technical Report 3-480, "Geological Investigations of the Yazoo Basin" (Vicksburg Quadrangle) by F. L. Smith, 1979 (Plate 6-70). Alluvial sediments are generally divisible into a fine-grained upper unit called the topstratum and a coarse-grained lower unit called the substratum. Technical Report 3-480 further classifies topstratum sediments based on their environment of deposits. Each category of sediments contains a suite of material types whose engineering properties vary within known limits. The topstratum deposits present at the pump station site are point bar in origin. Point bar topstratum is deposited on the inside of river bends as a result of meandering of the stream. Point bar deposits consist of an alternating series of ridges and swales. Ridges are elongated silty sandy bars deposited during high river stages. Swales are fine-grained deposits which accumulate between ridges during falling river stages.

TOPSTRATUM

Investigative borings revealed the following subsurface conditions. Point bar topstratum thickness ranges from 13 to 63 feet and averages 37 feet. The topstratum is composed primarily of silt (ML) and silty sand (SM, SP-SM) with subordinate amounts of clay (CH-CL). The silt (ML) is generally gray with sand, silty sand, and clay strata. The silty sands (SM, SP-SM) are brown, fine-grained and contain occasional clay strata. The clays are gray and brown, range from medium to hard in consistency, and contain silt strata, sand strata, and roots. Excavation for the pump station structure will extend through the topstratum materials to approximately elevation 50 feet, NGVD. Plates 6-71 and 6-72 show the relationship between the geology and the structural excavation along the pump station and approach channel centerlines.

SUBSTRATUM

Four of the exploratory borings penetrated through the quaternary alluvium and into the underlying Yazoo Formation. These borings show that the substratum extends to an average elevation of -57 feet, NGVD, and has an average thickness of 103 feet. The substratum is composed of gray sand (SP) with subordinate amounts of silty sand (SM) and silty fine sand (SP-SM). The sand is fine to medium and contains occasional silt strata, lignite, silty sand strata, and a trace of gravel. This unit will form the foundation for the structure and will require dewatering prior to excavation. Dewatering is the temporary drawdown of ground-water levels for construction purposes. The ground-water levels will only be affected during construction of the pump station. After construction, the ground-water levels will return to their natural levels.

TERTIARY

The alluvial sediments are underlain by the Yazoo Formation of the Jackson Group. This formation consists of greenish-gray plastic clay (CH) with silt strata or lenses and scattered shell fragments. This formation is a barrier to ground-water migration (aqualude) and underlies the entire site.

SECTION 4 DESCRIPTION OF THE CURRENT PLAN DESIGN

GENERAL

The Vicksburg District Design Branch has prepared updated planning-level plans and quantities with calculations in order to develop an accurate certified cost estimate for the project. The new plans and quantities include the new pump station located at the Steele Bayou site and all appurtenances, the supplemental low flow groundwater well fields, all required utility connections, and development of the borrow area. The Vicksburg District Design Branch also prepared right-of-way maps to determine environmental and real estate requirements.

The proposed pump station will be constructed at a location approximately 0.5 miles west of the Steele Bayou Drainage Structure. The pumping plant will be approximately 4.75 miles west of Mississippi State Highway 61 and 7.5 miles north of the City of Vicksburg, MS.

For the purposes of this cost estimate geotechnical data was not collected. Additionally, a survey was not conducted. Instead, the ground surface was modeled based on LiDAR data. At the current stage of the planning process detailed investigations of site conditions were not possible.

The updated design is based on the previous pump station design at the Steele Bayou pump site that advanced to approximately 90% complete state. The previous design at Steele Bayou was incomplete and would require redesign in order to meet current USACE guidance and code requirements. For the purposes of this cost estimate the previous design was modified, as described below, for use at the Steele Bayou site.

PREVIOUS DESIGN

The general features of the previous design at the Steele Bayou site included:

A pump station intake structure composed of reinforced concrete monoliths and including a trash rack, a trash raking system, an access bridge, and an intake stoplog system.

A pump station substructure composed of reinforced concrete monoliths and including formed suction intakes, intake and discharge gate systems, a discharge stoplog system, access tunnels, and a floodwall.

A pump station superstructure composed of a reinforced concrete building and truss roof system with exterior brick facade, including a 40-ton bridge crane.

A service bay composed of reinforced concrete monolith and a reinforced concrete building and a truss roof system, stairwell access to tunnels, rolling door, and other maintenance items.

A control building composed of reinforced concrete monolith and reinforced concrete building and truss roof system, stairwell access to tunnels, office and conference room space, control room, storage rooms, restrooms, and elevator.

Reinforced concrete wingwalls on both the intake and discharge sides.

Reinforced concrete floodwalls.

Vertical lift pumps and diesel-fueled engines, including speed reducers and cooling systems.

A fuel transfer dock and fuel storage area composed of two 250,000-gallon diesel fuel tanks.

A highway bridge (Highway 465) that crosses the discharge channel.

A paint, Oil, and Lubrication (POL) storage building composed of concrete masonry unit walls and concrete roof with membrane roofing.

A storage building used to house the pumps prior to installation, which would later be repurposed into a storage facility.

A vehicle garage and associated maintenance and washdown facilities.

A potable water well (40 gallons per minute) with an associated well building and water treatment facilities.

An emergency generator and generator building.

An architectural plaza area, adjacent to the control building, and an overlook park area.

Two access roads, one for the control house and another for the maintenance area.

Table 4-19. Design Elevations for Previous Design

Description	**Elevation (feet, NGVD 29)**
Project Flood – 2-Year	91.0
Project Flood – 100-Year	100.3
Pump Floor	112.8
Top of Structure (Floodwall)	119.0

Pump On/Off	87.0
Inlet Channel Invert	65.0
Discharge Channel Invert	76.0

The previous design included a line of protection across the discharge side of the pump station that consisted of a floodwall at either end of the plant and a floodwall with parapet at the discharge side of the service bay and substructure monoliths. The protection elevation was 119.0 feet (NGVD 29).

Additionally, the previous design included twelve pumps rated at 1,167 cfs for a total plant design capacity of 14,000 cfs. The rated capacity was based on a static (pool-to-pool) head of 3.7 feet. The maximum design static head was 20.0 feet with a capacity of 667 cfs per pump for a total of 8,000 cfs. The pump engines were diesel-fueled engines rated at approximately 2,500 horsepower (hp) each.

The pump station monoliths, from the previous design were approximately 89 feet in length and perpendicular to the channel. Each monolith was proposed to house three pumps.

The intake structure included trash screens and a raking system as well as an access bridge, which allowed vehicles to cross the pump station. The intake structure had a top-of-structure elevation of 107.5 feet (NGVD 29). Additionally, a stoplog system was proposed at the upstream end of the structure and allowed for dewatering.

The substructure from the previous design included the formed suction intake for the pumps, a pump bay to house the pumps, discharge piping, and discharge ports. Two access tunnels above the formed suction intake and upstream of the pump bays allowed for access to and inspection of the pumps. The monoliths included slots for intake and discharge gates located upstream of the formed suction intake and downstream of the discharge ports, respectively. The monoliths included a flood wall with parapet on the discharge side, with a protection elevation of 119.0 feet (NGVD 29). The pump floor elevation was 112.8 feet (NGVD 29), and the engines were located on the pump floor in line with the pumps.

The pump station superstructure was a reinforced concrete building with brick façade and was composed of columns and precast concrete panels. The roof was a steel roof deck overlain with rigid insulation and modified bitumen and was supported on trusses. The building included a 40-ton bridge crane with an auxiliary 10-ton hoist that spanned the entire length of the pump station plus service bay.

The previous design required a highway bridge located at the intersection of the discharge from the pump station and Mississippi Highway 465. The bridge was designed by USACE, but Mississippi Department of Transportation (MDOT) had approval authority of the design. The cost of design and construction of the bridge would be paid for with project funds. The bridge design consisted of two 20-foot lanes on a prestressed concrete girder bridge with 100-foot spans. The total length of the bridge was to be 702 feet.

All structures were soil-founded except for the fuel dock, which was elevated on piling, and the highway bridge, which had pile-founded abutments and piers.

UPDATED DESIGN

The pump station design has been updated based on new directives and changes since the previous design. The following paragraphs describe the major design changes and provide rationale for each change.

The pumping plant capacity was changed to 25,000 cubic feet per second (cfs) total station capacity. In addition, the managed water elevations for the backwater area have been modified:

93.0 feed during non-crop season (16 March to 15 October)

90.0 feet during crop season (16 October to 15 March)

Table 4-2. Design Elevations for Current Design

Description	Elevation (feet, NGVD 29)
Project Flood – 2-Year	90.0*
Project Flood – 100-Year	99.0*
Pump Floor	115.0
Top of Structure (Floodwall)	119.0
Pump On/Off	89.5 or 92.5
Inlet Channel Invert	71.0
Discharge Channel Invert	76.0

*Preliminary elevations still under review

The increase in pumping plant capacity requires an increase in the length of the pump station (perpendicular to flow) from 377 feet to 475 feet. This affects the intake structure, substructure, and superstructure as well as architectural, mechanical, and electrical features.

The pump engines have been changed from diesel-fueled to natural gas-fueled engines. This change will reduce energy costs and emissions. It will also eliminate the need for diesel fuel infrastructure, including the fuel dock and fuel storage tanks.

The service bay and control house structures have been changed from full-depth monoliths to slab-on-grade foundations with grade beams. This change will reduce the overall cost of the structure by reducing the concrete volume and by reducing the total excavation and backfill requirements. The substructure tunnels will be accessed via a reinforced concrete stairwell.

The pump station superstructure has been changed from reinforced concrete with brick façade to a prefabricated metal building. This change will reduce the overall cost of the structure.

The control house has been reduced to eliminate unnecessary facilities. The conference room, multiple restrooms, and elevator have been removed and the overall size of the facility has been reduced.

The potable water well and treatment systems has been removed. It is assumed that potable water will be provided by Valley Park Water District.

As previously stated, the highway bridge across the discharge channel will no longer be required. Instead, a precast concrete girder bridge, with precast deck sections, will be constructed across the intake channel along the levee centerline.

The storage building and vehicle garage have been removed. It is assumed that on-site pump storage will not be required because the project will be solicited under one contract and pumps will be installed upon delivery.

The standby emergency generator building has been removed. The generator will be housed in an enclosure near the service bay.

The pump station will be heated by natural gas unit heaters, eliminating the hydronic heating system, including boilers, pumps, heaters, and piping. Engines will be cooled by remote radiators, one each per engine, eliminating the centralized raw water-cooling system. The bridge crane will be used to provide vertical movement of equipment to the tunnels, eliminating the need for an elevator. The potable water system (exterior hose bibbs and pressure washer) will be used for exterior building maintenance, which eliminates the “fire hose” type wash down system, including the water storage tank.

The architectural plaza area and overlook park area have been removed.

Supplemental low flow groundwater wells will be installed in 34 strategic locations throughout the Mississippi Delta as an environmental feature to the project. Future engineering studies will evaluate the geologic and hydro-geologic conditions of each of the well field sites, and the wells will be pumped to supplement annual low flow conditions. It is estimated that each well site will impact approximately 0.25 to 1.25 acres of land.

Access to the site will be over the Yazoo Backwater Levee. Two embankments will connect the pump station to the levee, one on each side of the intake channel. The

Yazoo Backwater Levee will be enlarged and paved to facilitate access to the pump station.

ASSUMPTIONS

The following assumptions were made in order to produce the required quantities and plans without the detailed site investigation needed to develop precise calculations. These assumptions will be validated during the design phase.

The pump station will be constructed under a single contract.

The original design included several contracts and called for procuring the pumps prior to the completion of the pump station structure. The pumps were to be stored on site in a building specifically designed for storage, which will later be repurposed into a maintenance or storage facility. By assuming a single contract, the designers can remove the storage building and assume that the pumps will be delivered to the site after construction of the pump station structure.

The new pump station will be designed to the required hydraulic criteria, and the major structures of the pump station will be largely unchanged from the previous design.

This assumption allows the designers to quickly determine quantities based on the previous design. At this stage of the planning process, detailed site investigations, required to develop detailed calculations, were not possible. The anticipated changes to the new design will include updated pump curves, updated structural elevations based on new hydraulic modeling, and new soils data from borings. These new criteria are not anticipated to significantly affect the cost of the structure.

Natural gas supply will be provided by the Kinder-Morgan pipeline adjacent to the new site.

This assumption is made because Kinder-Morgan has indicated that they plan to abandon the supply line adjacent to the site. Additionally, they have indicated that they will postpone their decision as of April 2020.

The borrow area identified during the previous design will be used for the new design.

A borrow area residing north of and adjacent to the Steele Bayou structure was identified to provide fill material for the previous design. It is assumed that using this borrow material will be the most cost-efficient method of procuring fill for the new site location. The material will be hauled along Highway 465 to Highway 61, before being transported along the levee to the pump station.

The new pump station will be accessed via the Yazoo Backwater Levee, which will need to be enlarged.

The new location of the pump station is between the Yazoo River and the Yazoo Diversion Canal along the Yazoo Backwater Levee. Enlarging the existing levee and providing surfacing is assumed to produce cost savings versus constructing a new roadway to access the pump station.

Electric power will be provided by the Yazoo Valley Electric Power Association (YVEPA), and a new substation will not be required. Water service will be provided by Valley Park Water District, eliminating the need for installation of a USACE owned and operated new water well and water tank. Wastewater will be treated on site and disposed of in the intake canal.

Based on preliminary estimates of the required power for the site, YVEPA has indicated that a new substation will not be required, and a new distribution line can be installed from existing lines near the pump station. Valley Park has indicated that they have limited capacity for potable water and Valley Park may add an additional well and water tank nearby to provide the required water to the pump station. It is assumed that fire suppression at the new pump station will use stored water.

QUANTITY CALCULATIONS

Quantities were generally taken from Microstation models. Models from the previous design were used and modified for the new location at Deer Creek.

Earthwork quantities are based on Microstation Inroads triangle volume reports. The ground surface was modeled from LiDAR data and surfaces representing the earthwork features were developed. The dimensions for excavation and fill surfaces are based on updates to the previous design. Estimates were received from the three servicing utility companies for potable water, natural gas, and electrical power connections.

Structural quantities are based on three dimensional Microstation models, which were modified from the previous design. New models were developed for the prefabricated metal building, levee bridge, slab on grade foundations, stairwells, and floodwalls. All other structures were taken from the previous design unmodified.

Mechanical quantities are based on three dimensional Microstation models, printed drawings of the previous design, and quoted estimates from manufacturers and local distributers.

Electrical quantities are based on Microstation models and printed drawings of the previous design. Quantities were taken from printed drawings and miscellaneous tables produced during the previous design effort.

Architectural quantities are based on three-dimensional modeling using AutoDesk Revit 2020. The architectural features were modified from the previous design to meet current building and DOD/UFC code and energy requirements. The modified design and quantities assume that no high-sustainability elements will be required but will achieve 30 percent below current ASHRAE requirements. It is also assumed hurricane-related or impact-related items will not be required.

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ANNEX A: ECB 2018-14 ANALYSIS OF POTENTIAL CLIMATE CHANGE VULNERABILITIES

This assessment is performed to highlight existing and future challenges facing the study area due to climate change and is conducted in accordance with United States Army Corps of Engineers' (USACE) Engineering Construction Bulletin (ECB) 2018-14, *Guidance For Incorporating Climate Change Impacts To Inland Hydrology In Civil Works Studies, Designs, and Projects*, revised 19 August 2022. In accordance with ECB 2018-14, this evaluation identifies potential climate change vulnerabilities for the Yazoo Backwater Area Water Management Project Supplemental Environmental Impact Statement (SEIS). The Yazoo Backwater Study Area (YSA) is located in west-central Mississippi immediately north of Vicksburg, Mississippi between the Mississippi River east bank levee on the west and the Yazoo River on the east. The YSA is surrounded by levees and covers around 1,446 square miles, extending north approximately 65 miles to the latitude of Hollandale and Belzoni, Mississippi (Figure A-1). The YSA is located within the 0803-Lower Mississippi-Yazoo 4-digit HUC. Four Yazoo River tributaries, with a total drainage area of 4,093 sq. miles, flow through the YSA including Steele Bayou, Deer Creek, Little Sunflower River and Big Sunflower River (Figure A-1). This assessment highlights existing and future climate change driven risks for the YSA. Study background information can be found in the main report and in *Section 2. Hydrology and Hydraulics* of Appendix A – Engineering Report, and more general background information on climate change driven risk can be found in ECB 2018-14.

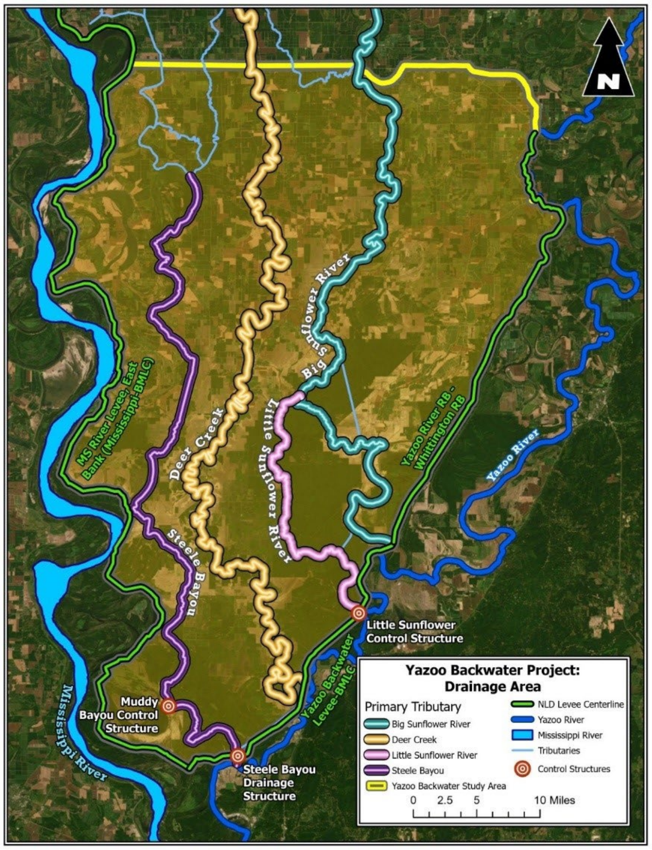


Figure A-1. Map of the Yazoo Backwater Study Area Tributaries and Water Control Structures*STUDY BACKGROUND*

The Yazoo Backwater Area Water Management Project includes both flood risk management and ecosystem restoration features, which will be the focus of the climate assessment contained herein. Construction of a pump station (25,000 cfs capacity) located adjacent to the existing Steele Bayou water control structure (WCS) is planned to manage water levels inside the Yazoo Backwater Area at or below elevation 93.0' NGVD29 (approximately the20% annual exceedance probability (AEP) floodplain elevation) when flooding on the Mississippi and Yazoo Rivers forces closure of the Steele Bayou and Little Sunflower WCS. The proposed plan also includes acquisition of structures and cleared lands in agricultural production vulnerable to frequent interior flooding (below 93' NGVD29), through a voluntary buyout. Reforestation and conservation measures are planned for the acquired lands. Installation of shallow groundwater wells upstream of the YSA is planned to augment low flows within Big

Sunflower River to sustain aquatic habitat during the low flow period occurring during the fall (Figure A-2).

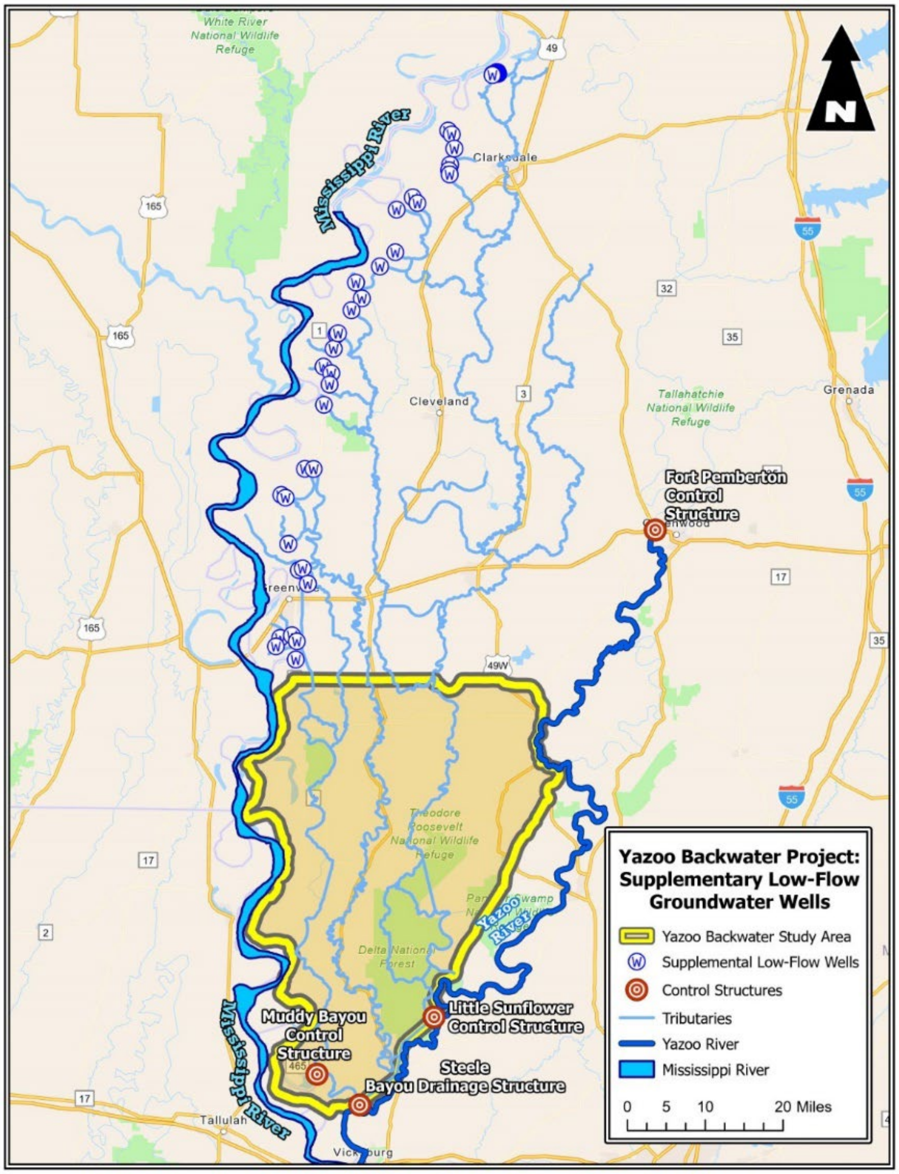


Figure A-2. Proposed Locations for Low Flow Augmentation Groundwater Wells

Flooding within the YSA is influenced by local interior or headwater flooding within the YSA Drainage Area as well as backwater flooding that results from high water on the Mississippi and Yazoo Rivers. When high river stages occur on the Mississippi River and backup the Yazoo River, the gates at Little Sunflower and Steele Bayou WCSs along the Yazoo Backwater Levee System are closed to prevent flood waters from entering the interior of the YSA (Figure A-1). Interior drainage from coincident localized precipitation events within the 4,093 square mile YSA drainage area is unable to drain from behind the Yazoo Backwater Levee System, resulting in historic prolonged flooding that has impacted structures and agricultural land in recent years (Figure A-3). A primary objective of the proposed plan is to provide flood risk management through the construction of a pump station previously authorized as part of the 1941 Flood Control Act (FCA) and acquisition of structures and lands that will remain vulnerable to frequent flooding under the proposed pump operation plan through a voluntary buyout. Another objective of the proposed plan is to augment baseflow in the upper, middle, and lower reaches of Big Sunflower River to support aquatic habitat during the low flow season through the installation and pumping of groundwater wells within the Mississippi River Valley Alluvial Aquifer (MRVAA) (Figure A-2).

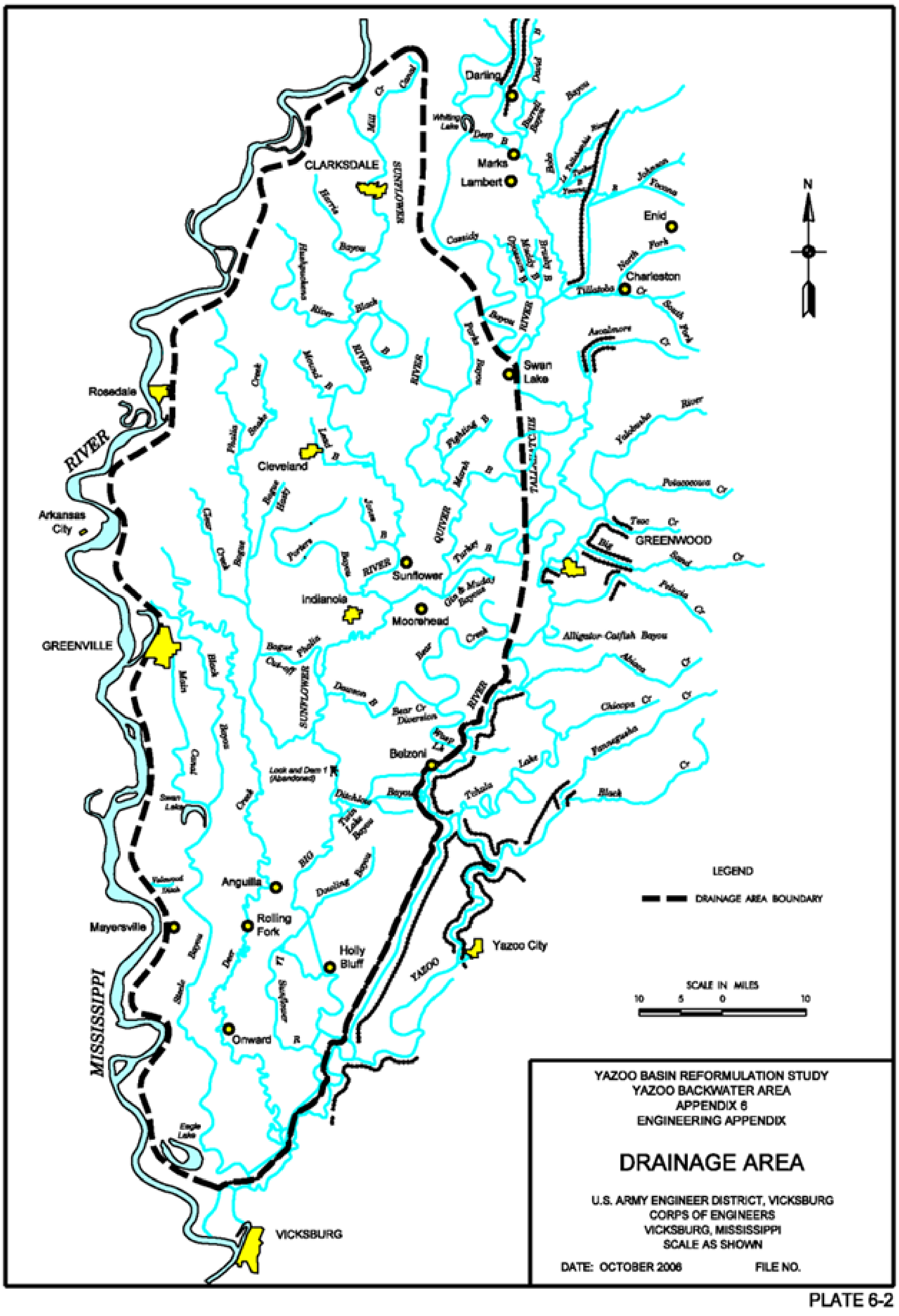


Figure A-3. Streamflow and Meteorologic Gages Analyzed in the Yazoo Backwater Drainage Area

Currently, Mississippi River stages that produce backwater flooding greater than 70’ NGVD29 at the Steele Bayou WCS, (an elevation exceeded approximately 51% of the year), result in gate closure, thereby preventing interior drainage within the YSA to drain outside of the Yazoo Backwater Levee System. High Mississippi River elevations and coincident precipitation within the YSA have produced frequent interior flooding that occurs in different seasons but often during the spring. The proposed plan includes closure of the Steele Bayou WCS at interior elevation 75’ NGVD29 and construction of a 25,000 cfs capacity pump station (22 pumps @ 1,167 cfs fueled by natural gas) to begin evacuating water out of the backwater at an interior elevation (pump-on elevation) above 89.0’ NGVD29 in order to maintain interior ponding elevations of 90’ NGVD29 and 93’ NGVD29 during the crop season (March 16-October 15) and non-crop season, respectively. These managed elevations approximate the 50% and 20% AEP water surface elevations that inform wetland delineation. Interior ponding areas between elevation 90’ - 93’ NGVD 29 within the YSA do impact several developed areas, but most of the land use is agricultural and forested. Structures and cleared agricultural lands with elevations below 93’ NGVD29 (~20% AEP), still vulnerable to frequent flooding under the proposed plan, are eligible for voluntary buyout. Conservation and reforestation measures are planned for the acquired lands.

The number of irrigation wells in support of agriculture within the MRVAA has been increasing since the 1970s. Rice and catfish production are dominant agricultural practices throughout the basin and require significant water resources. Groundwater withdrawals for irrigation throughout the Yazoo Backwater Area contributing to low fall baseflow within the four primary tributaries (Steele Bayou, Deer Creek, Little Sunflower River, and Big Sunflower River) have resulted in impacts to native fisheries and aquatic habitat. The proposed plan will install 34 groundwater wells in the upper portions of the Yazoo Backwater basin to augment fall baseflow (Figure A-2). Future climate conditions may impact the establishment and design of project features. Thus, to analyze the effects of climate change on the flood risk management features for this study, annual maximum 1-day precipitation, as well as annual maximum streamflow and mean spring streamflow records for the Mississippi River at Vicksburg and for the Big Sunflower River near Merigold are evaluated because they are hydrometeorological variables influencing the Project’s flooding condition. Annual mean temperature and mean fall streamflow for the Big Sunflower River near Merigold are evaluated to assess the risk of climate change to the ecosystem restoration features associated with the proposed plan because they represent the low flow conditions of concern to aquatic habitat.

LITERATURE REVIEW

The *Fifth National Climate Assessment* (NCA5), *The Fourth National Climate Assessment* (NCA4), the USACE *Civil Works Technical Report CWTS-2015-13* and Mississippi state and climate division climate summary information published by the National Oceanic and Atmospheric Administration (NOAA) National Centers for

Environmental Information (NCEI) are the basis for this literature review. The focus of these references is on summarizing trends in historic, observed temperature, precipitation, and streamflow records, as well providing an indication of future, climate-changed hydrology based on the outputs from Global Climate Models (GCMs). For this assessment, background on observed and projected temperature and precipitation is provided as context for the impact that they have on observed and projected streamflow.

The NCA5 and NCA4 consider climate change research at both a national and regional scale. *Civil Works Technical Report CWTS-2015-13* was published as part of a series of regional summary reports covering peer-reviewed climate literature. The 2015 USACE Technical Reports cover 2-digit, United States Geological Survey (USGS), hydrologic unit code (HUC) watersheds in the United States. YSA is located in 2-digit HUC 08, the Lower Mississippi River Region and in the NCA5 and NCA4 Southeast climate region.

In many areas, temperature, precipitation, and streamflow have been measured since the late 1800s and provide insight into how the hydrology in the study area has changed over the past century. GCMs are used in combination with different representative concentration pathways (RCPs) reflecting projected radiative forcings up to year 2100 to model future climate. Radiative forcings encompass the change in net radiative flux due to external drivers of climate change, such as, changes in carbon dioxide or land use/land cover. Projected temperature and precipitation results can be transformed to regional and local scales (a process called downscaling) for use as inputs in precipitation-runoff models. Uncertainty is inherent to projections of temperature and precipitation due to the GCMs, RCPs, downscaling methods, and many assumptions needed to create projections (USGCRP, 2017). When applied, precipitation-runoff models introduce an additional layer of uncertainty. However, these methods represent the best available science to predict future hydrologic variables (e.g. precipitation, temperature, streamflow). Many researchers use multiple GCMs and RCPs in their studies to understand how various model assumptions impact results.

Temperature

Based on observed temperature records, the annual, average air temperature in Mississippi has risen only 0.1°F since 1900. Recent years, however, have been warm, with the warmest consecutive 5-year interval of the period being 2016-2020 (Runkle et al., 2022). Temperatures in the Lower Mississippi River Region fluctuated for much of the 20th century, with a warming trend early in the century followed by a cooling trend in the 1960s and 1970s (USACE, 2015). Since the 1970s the Southeast has been warming at an accelerated rate, though overall warming is relatively less than in other regions of the US (USGCRP, 2018). In the state of Mississippi, the number of very warm nights has generally been above average since 2010, with the multi-year average 2010-2014 exceeding all previous multi-year averages. The number of extremely hot days, while still below the warm period early in the 20th century, has risen since the cooling trend of 1960-1970. Minimum daily temperatures in the Southeast for the 2010-2018 period are the warmest they have ever been. For the same period, spring and fall maximum daily temperatures are the warmest they have ever been. The number of warm nights (nights where temperatures remain above 70°F) are increasing, and spring onset is four days earlier in the period 2001-2010 than it was for 1951-1960 (USGCRP, 2018). Increased temperatures have led to an increase in the occurrence of drought and flash drought in the Southeast, an area more prone to drought due to higher rates of evapotranspiration (ET) compared to other parts of the eastern US (USGCRP, 2023).

Although there is not a clear monotonic trend in the long term mean air temperature record in the Lower Mississippi River Region, accelerated warming is now occurring in the Southeast, and there is consensus that temperatures will increase in the future. The Fifth NCA projects the number of extreme heat days in 2050 compared to the period 1991-2020 to increase 30-40 days per year. The Mississippi state climate summary notes that even under a lower emissions pathway, annual average temperatures are expected to exceed record levels in the state by the middle of this century (Runkle et al., 2022). Increased temperatures will increase ET rates and rates of soil moisture loss, which could increase intensity of naturally occurring drought.

Precipitation

For the Lower Mississippi River Region, USACE (2015) cites multiple authors that have identified statistically significant increasing trends in total annual precipitation. The consensus supports a mild increase in annual precipitation in the Lower Mississippi River Region over the past century, with rainfall intensity increasing in the fall and winter months but decreasing in the spring and summer. The Fourth NCA finds that annual precipitation for the Lower Mississippi River Region has increased up to 15 percent by comparing the present-day (1986 through 2015) average to the average for the first half of the last century (1901 through 1960), with the greatest increase in precipitation occurring during fall months. Runkle et al. (2022) find the annual precipitation and number of 3-inch extreme precipitation events for Mississippi to have been above average since the 1970s, and the NCEI (2024) Climate at a Glance Tool shows that Mississippi Climate Division 4, which encompasses the Yazoo Study Area, has experienced an increasingtrend in annual precipitation of ~0.6 inches per decade from 1896 through 2024.

Significant positive linear trends (period 1895-2006) in the soil moisture index for multiple sites within the Lower Mississippi River Region have also been identified. Soil moisture is a function of both supply (precipitation) and demand (ET), and therefore is an effective proxy for both precipitation and ET. Still, agricultural droughts occur frequently during the summer in Mississippi. Since the creation of the United States Drought Monitor Map, Mississippi has been completely drought free 48% of the time (2000-2020) and at least half of the state has been in drought conditions 12% of the time (Runkle et al., 2022).

The 2015 USACE Climate Synthesis concludes that future projections for precipitation in the Lower Mississippi River Region are variable and lacking consensus among studies or across models. In fact, numerous studies project that increases in future drought for the region outweigh increases in precipitation (USACE, 2015). The more recent NCA4 and 2022 Mississippi state climate summary indicates projections show increased frequency and intensity of extreme rainfall events in the future for the Southeast and the state. Additionally, increased frequency and intensity of drought is projected in the Southeast according to the 4th & 5th NCAs and increased ET and soil moisture loss rates leading to increased drought intensity are projected for Mississippi according to the Mississippi state climate summary (Runkle et al., 2022).

Streamflow

Observed streamflow trends are strongly influenced by precipitation, temperature, and other factors such as land use and land cover in a region, groundwater dynamics, drainage patterns, channel geomorphology, and regulation. Because the Proposed Plan for the Yazoo Study Area is dependent upon the conditions of the Mississippi River main stem, stream flow to the Lower Mississippi Region from across the entirety of the upriver Mississippi River Basin is a factor in the local hydrology.

Some studies examined in USACE support a mild upward trend in flow in streams within the Lower Mississippi River Region, other than the Mississippi River main stem, during the last century, but a few authors found no significant trends during the same time period. Thus, a clear consensus is lacking for other streams within the Lower Mississippi River Region (USACE, 2015).

Regarding the Lower Mississippi River main stem, USACE (2020) examined annual water yield trends by performing monotonic trend analysis on mean-daily discharge data for the past century from USGS streamflow gages and USACE river gages. Water yield was derived from the collected data and represents the amount of runoff per unit drainage area. The results indicate the majority of the interior Mississippi River Basin shows increases in annual streamflow emanating from the HUC-4 basins (from 25 percent to more than 100 percent). Some trends of decreasing water yield are exhibited in the upper Missouri and Arkansas river basins. The results indicate the Mississippi River Basin is receiving more rainfall, and is consequentially generating more flow, which is contributing to greater flow in the Lower Mississippi River Basin. The average annual increase in flows in the Lower Mississippi River Basin from the Ohio, Missouri, and Upper Mississippi Rivers was approximately 57.2 million cfs.

As for future projections, USACE (2015) concludes that a small number of reviewed studies indicate a mild decreasing trend in streamflow for the Lower Mississippi River Region through the next century, but a consensus is generally lacking.

For the Mississippi River, USACE (2019) utilized a vector-based continental-scale river routing model to generate daily total runoff for the entire Mississippi River Basin over the time period of 1950 through 2099 under 16 different climate scenarios from the

Coupled Model Intercomparison Project, Phase 5 (CMIP5). The results of this study indicate that many climate models predict extremely high flow events occurring more frequently in the future. In particular, future projections for the recurrence interval for the Mississippi River at Vicksburg estimate the recurrence interval for the 100-year flood will increase from 1.8 million cubic feet per second (cfs) to 2.0 million cfs at Vicksburg based off historical flow observations from 1950 through 2005 and model projections from 2006 through 2099. This increase is an 11.11 percent increase in peak discharge at Vicksburg. Additionally, results illustrate hydrologic conditions of the Mississippi River are not stationary, meaning the statistical characteristics of time series data are changing from 1950 through 2099.

Overall, the literature has lacked consensus in projected streamflow trends throughout the Lower Mississippi River Region (USACE, 2015). A more recent analysis of climate model projections by USACE (2019) suggests streamflow and flood frequency on the Mississippi River main stem are expected to increase, while the 4th & 5th NCAs projected increases in extreme precipitation increase the risk of flooding and projected increased drought intensity can result in low flow conditions in the Southeast. Increased flood magnitude and/or frequency along the Lower Mississippi River main stem could result in more frequent closure of the Steele Bayou WCS and potentially more backwater-induced flooding for the YSA, while increased low flow conditions could impact baseflow conditions within the YSA tributaries.

Summary

Within the literature reviewed, there is evidence that observed temperature, precipitation, and streamflow are increasing within the Lower Mississippi Watershed. Projections of future climate show strong consensus on increases in future temperature, and moderate consensus on increases in future precipitation. There is little consensus related to trends in future streamflow. Figure from the 2015 USACE *Civil Works Technical Report CWTS-2015-01* provides a visual summary of the trends in observed and projected hydrometeorological variables for 2-digit HUC 08, the Lower Mississippi Region.

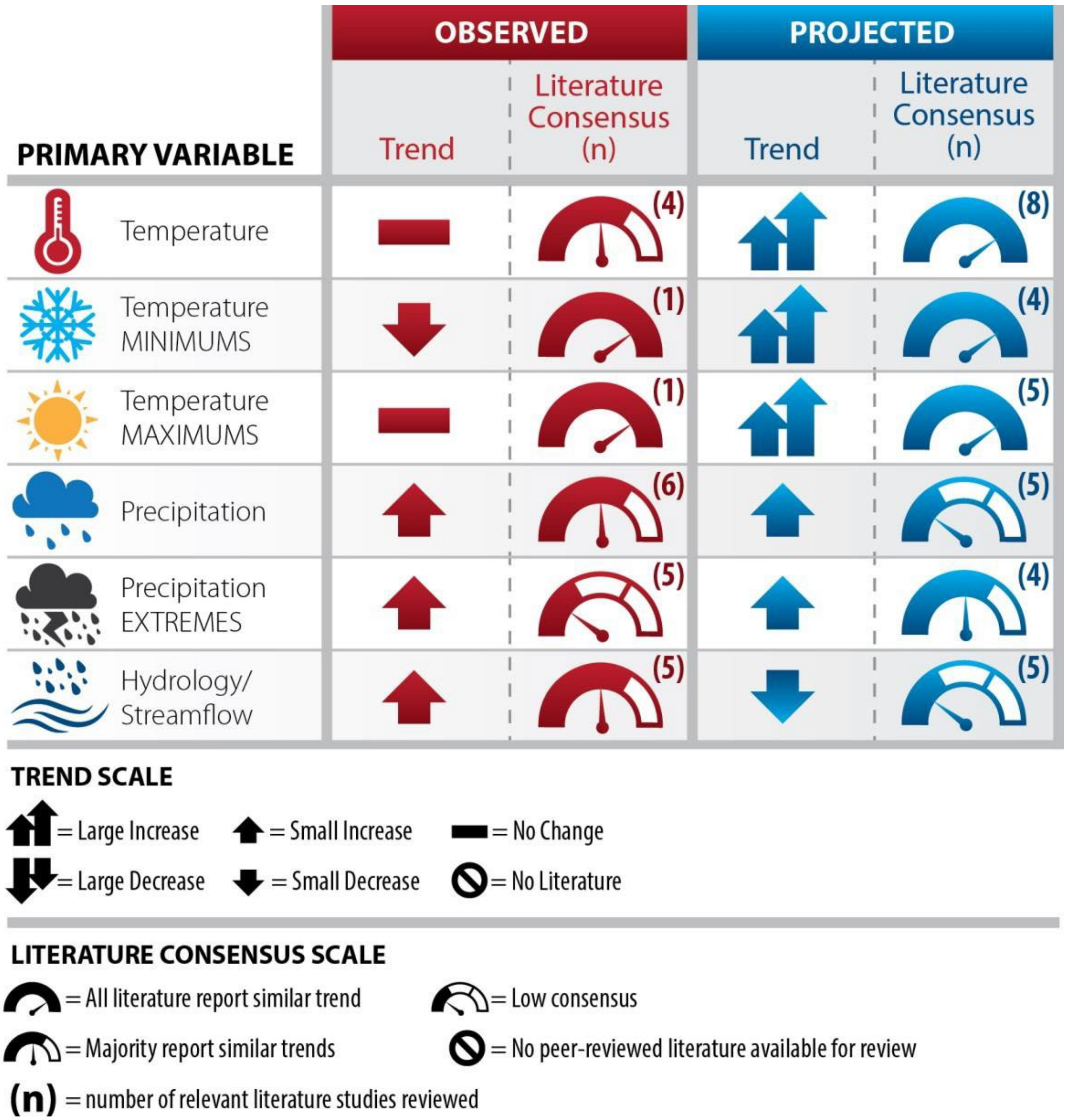


Figure A-4. Summary matrix of LMR (HUC 08) observed and projected climate trends (USACE, 2015)

NONSTATIONARITY DETECTION AND TREND ANALYSIS

The assumption that hydrologic timeseries are stationary (their statistical characteristics are unchanging) in time underlies many traditional hydrologic analyses. Statistical tests can be used to test this assumption using the techniques outlined in USACE Engineering Technical Letter (ETL) 1100-2-3, *Guidance for Detection of*

Nonstationarities (2017). The USACE Time Series Toolbox (TST) tool is a web-based tool that performs the statistical tests described in the guidance. Annual maximum streamflow and mean spring streamflow for both the Mississippi River and the Big Sunflower River, in addition to annual maximum 1-day precipitation for the basin are analyzed for the Yazoo Backwater Area Water Management Project because the Project's flood risk management features are related to high water or flooding on the Mississippi River coincident with interior rainfall and flooding that often occurs during the spring months (March, April and May). The project's ecosystem restoration features are related to low flows and groundwater baseflow during the fall months (September, October and November), thus fall mean streamflow for the Big Sunflower River and annual mean temperature were analyzed. Temperature impacts ET rates that influence rates of groundwater withdrawals for irrigation to support rice and catfish production and other agricultural production throughout the basin. Groundwater withdrawals are resulting in decreased baseflow conditions.

Annual maximum discharge and mean spring discharge for the Mississippi River at Vicksburg, MS were computed in HEC-DSSVue v3.2.3 (HEC, 2021) from instantaneous daily flows provided by the Vicksburg District (MVK). The Mississippi River at Vicksburg gage is located near the confluence with Yazoo River and captures a drainage area of 1,131,145 square miles. This gage is representative of conditions in the Mississippi River that influence operation of the Steele Bayou WCS. Upstream regulation on the Missouri River, lock and dam operation on the Mississippi River, and flood control reservoirs on the Yazoo River influence streamflow at the Vicksburg gage. This distant upstream regulation does not have significant impacts on annual maximum discharge and mean spring discharge records at Vicksburg. As of 1954, all flood control reservoirs on the Yazoo River were operational and construction of the Yazoo Backwater Levee System was completed in 1978. Thus, the TST is applied to detect nonstationarities and trends for the Mississippi River at the Vicksburg gage for the period of record from 1978 to 2023.

Daily discharge and annual maximum discharge records for the Big Sunflower River near Merigold, MS (USGS gage 07288280) were accessed from the USGS (USGS 07288280 BIG SUNFLOWER RIVER NR MERIGOLD, MS). Mean spring discharge and mean fall discharge were computed from the daily records in HEC-DSSVue v3.2.3 (HEC, 2021). The Big Sunflower River near Merigold represents flow conditions in the headwaters of the YSA, on the upper reach of Big Sunflower River and captures a 553 square mile drainage area. The Merigold gage location represents interior flow conditions within the YSA basin that can provide insight into interior flooding and low flow conditions. The TST is applied to detect nonstationarities and trends for the Big Sunflower River near Merigold gage for the period of record from 1993 to 2023.

Daily precipitation and daily mean temperature records for the global historical climate network (GHCN) gage USC00220660 at Belzoni, MS were accessed from the Midwestern Regional Climate Center (cli-MATE: MRCC Application Tools Environment (purdue.edu)). Annual maximum 1-day precipitation and annual mean temperature were computed from the daily records in HEC-DSSVue v3.2.3 (HEC, 2021) for the 1934-2023 period of record. The meteorologic record at Belzoni is considered representative of conditions within the YSA basin to provide insight into interior flows as well as ET and agricultural irrigation.

The TST did not detect any nonstationarities for the Mississippi River at Vicksburg annual maximum streamflow record for the 1978-2023 period. Linear and monotonic trends are evaluated using the t-test, Mann-Kendall and Spearman Rank Order tests. The significance of trends is evaluated using a 0.05 level of significance threshold (p-value<0.05 is considered statistically significant). No statistically significant trends were identified for the 1978-2023 period or record (POR). However, when the period of analysis is extended back to 1955-2023, after all flood control reservoirs on the upstream Yazoo River were operational, still no strong nonstationarities are detected, but the trend analysis indicates a statistically significant, positive trend in annual maximum streamflow by the t-test (p-value=0.0165), Mann-Kendall test (p-value=0.023) and Spearman Rank Order test (p-value=0.0199), see trendline in *Figure A-5*.

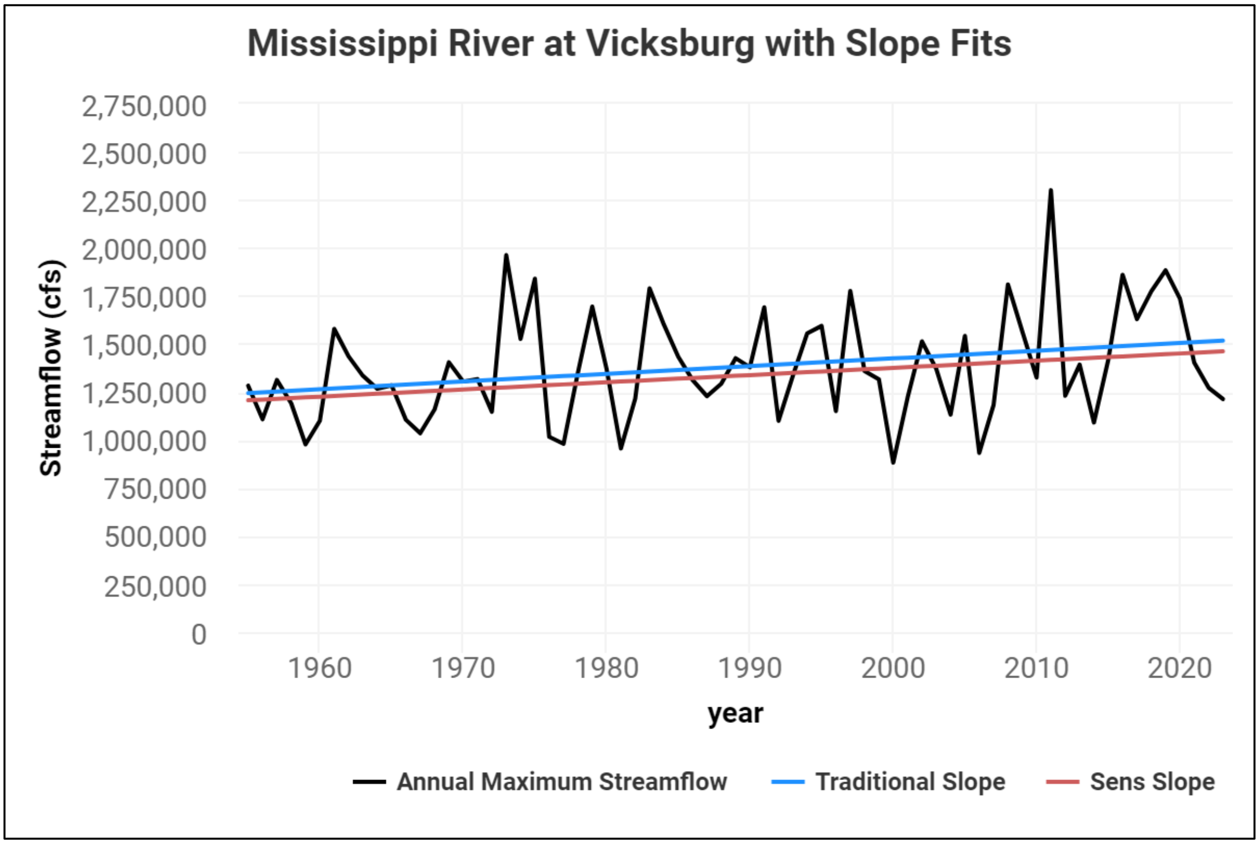


Figure A-5. Trend Analysis for Annual Maximum Streamflow at Vicksburg for 1955-2023.

TST analysis results for the mean spring streamflow at Vicksburg were similar to annual maximum streamflow. No nonstationarities were detected and no statistically significant trends were identified for the 1978-2023 POR. Results for mean spring Mississippi River streamflow at Vicksburg for the 1955-2023 POR indicate no nonstationarities, but the trend analysis indicates a statistically significant, positive trend by the t-test (p-value=0.0274), Mann-Kendall test (p-value=0.0243), and Spearman Rank Order test (p-value=0.0183), see trendline in *Figure A-6*.

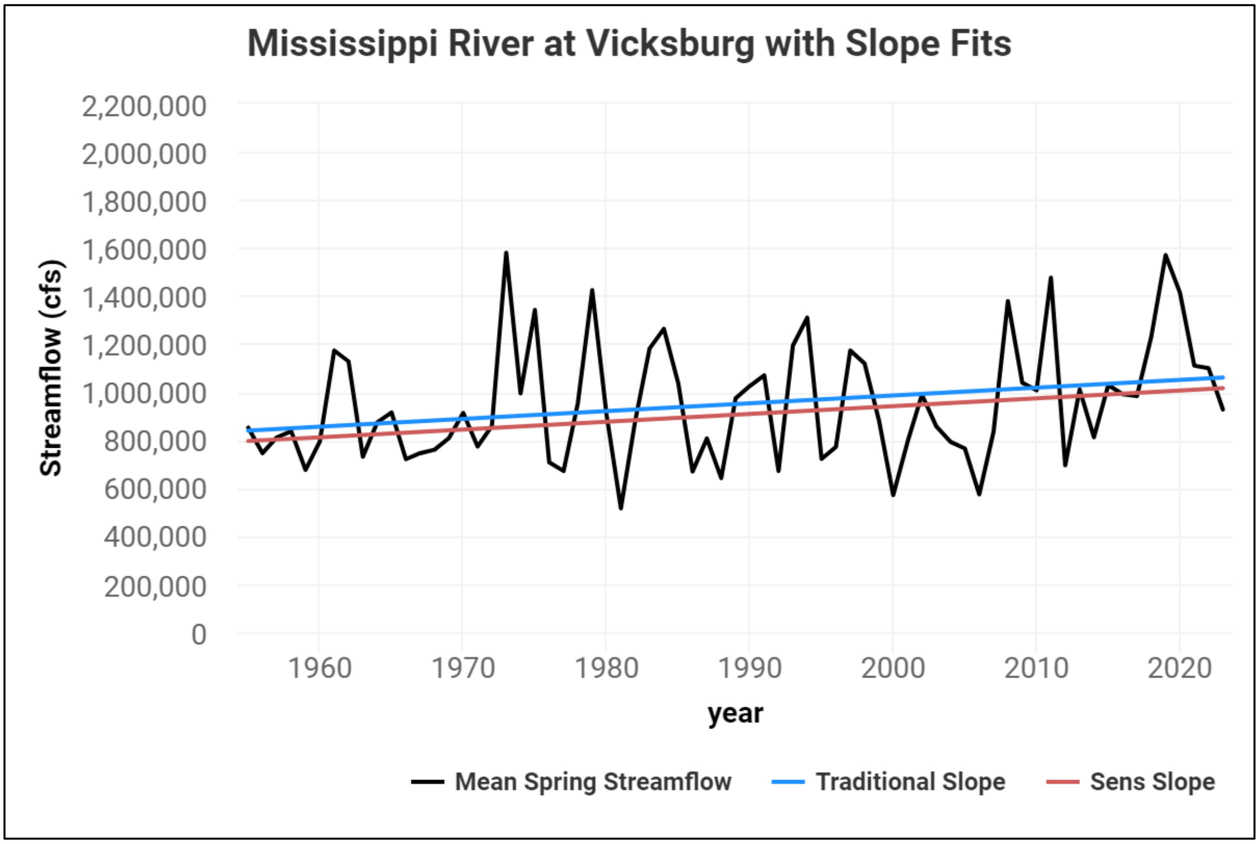
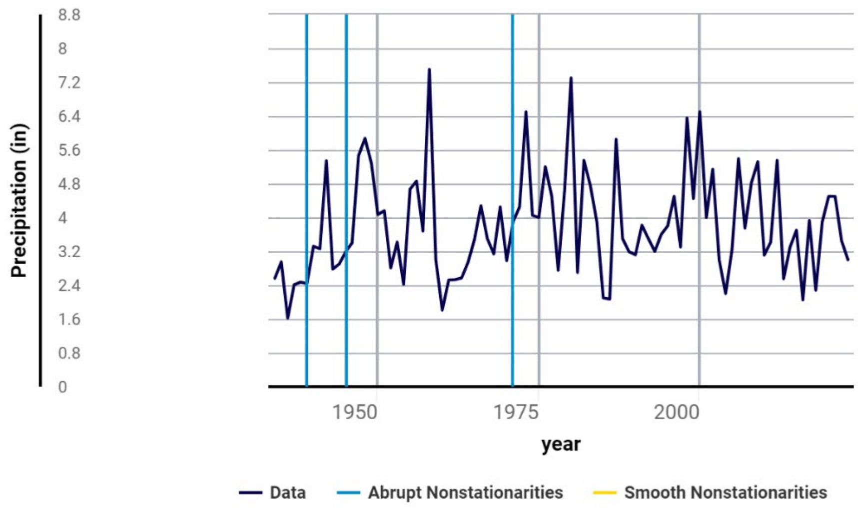


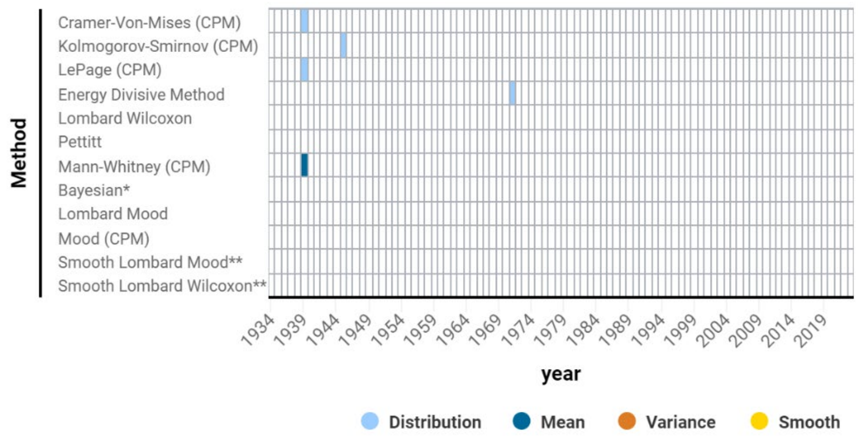
Figure A-6. Trend Analysis for Annual Maximum Streamflow at Vicksburg for 1955-2023.

Big Sunflower River annual maximum flows near Merigold showed no nonstationarities and no statistically significant trends were identified for the 1993-2023 POR. No nonstationarities were detected in the mean spring flows on the Big Sunflower River near Merigold for the 1993-2023 POR. A statistically significant positive trend was identified based on the t-test (p-value=0.0387), but the Mann-Kendall test (p-value=0.0958) and the Spearman Rank-Order test (p-value=0.0657) results did not meet the (p-value<0.05) significance threshold.

As shown in Figure A-7, three tests are indicating evidence of a change point in the annual maximum 1-day precipitation record at Belzoni in 1939, however this is very close to the start of the record (1934). Without more observations preceding the first five years of record it is difficult to determine whether the characteristics of the record truly shifted in 1939, or if there is false evidence of a nonstationarity driven by the limited sample size. There is no statistically significant evidence of an increasing trend in the 1934-2023 POR and when the dataset is truncated to 1939-2023, no further strong nonstationarities or monotonic trends are detected.

No nonstationarities were detected and no statistically significant trends were identified for the mean fall flows on the Big Sunflower River near Merigold for the 1993-2023 POR. As shown in Figure A-8, two strong nonstationarities in the annual mean temperature record at Belzoni are detected in 1956 and 1970. A strong nonstationarity is one that demonstrates a degree of consensus, robustness and a significant increase or decrease in the sample mean and/or variance. The 1956 and 1970 nonstationarities demonstrate consensus because they are identified by multiple tests targeted at identifying a change in the overall statistical distribution (light blue bars in Figure A-8). The 1956 and 1970 nonstationarities can be considered robust because tests targeted at identifying nonstationarities in different statistical properties identify a change in mean (dark blue bars in Figure A-8). The magnitude of the mean, annual, mean daily temperature decreases significantly (by over 2 Degrees Fahrenheit) between 1934-1955 and 1957-1969 and increases significantly (by 1.76 Degrees Fahrenheit between 1957-1969 and 1971-2023. This mid-century cooling and subsequent warming since the 1970’s is supported in the literature review. There are no statistically significant trends in annual mean temperature identified for the 1934-2023 period, nor for the subset period following the 1970 nonstationarity.





* Please see notification in sidebar to check if Bayesian tests have been applied.
** All tests are abrupt except for Smooth Lombard Mood and Smooth Lombard Wilcoxon.

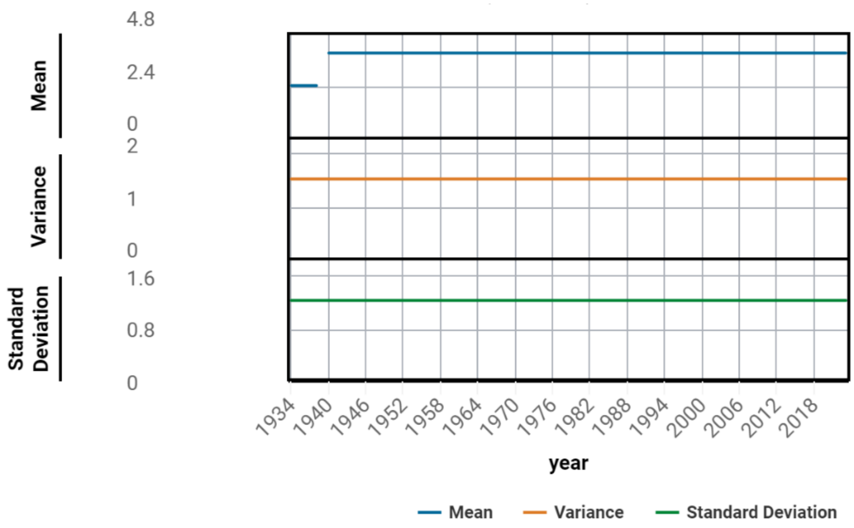
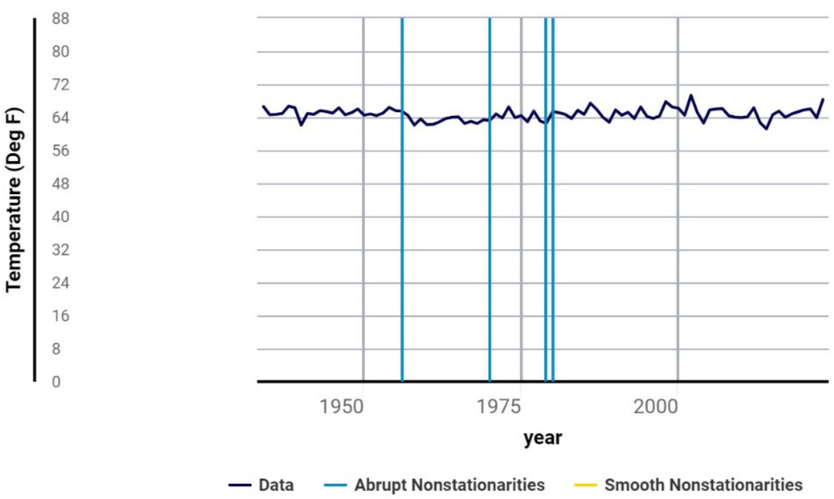
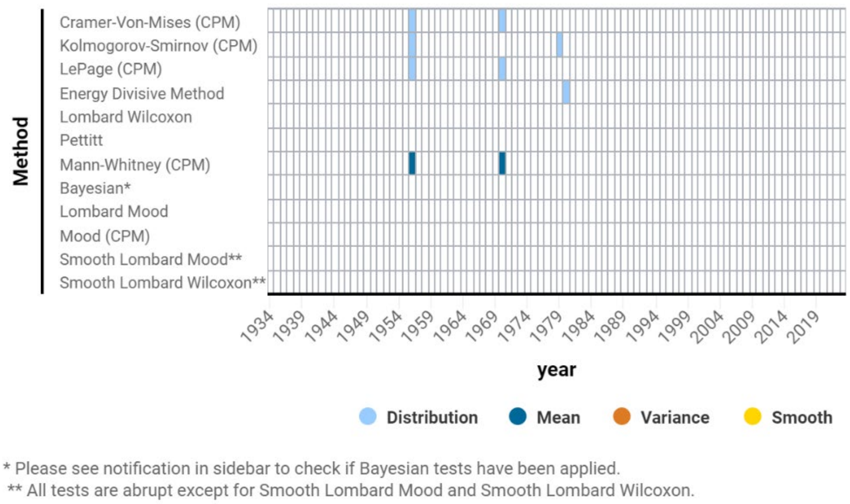


Figure A-7. Time Series Toolbox Output for Annual Maximum 1-day Precipitation for Belzoni, MS.





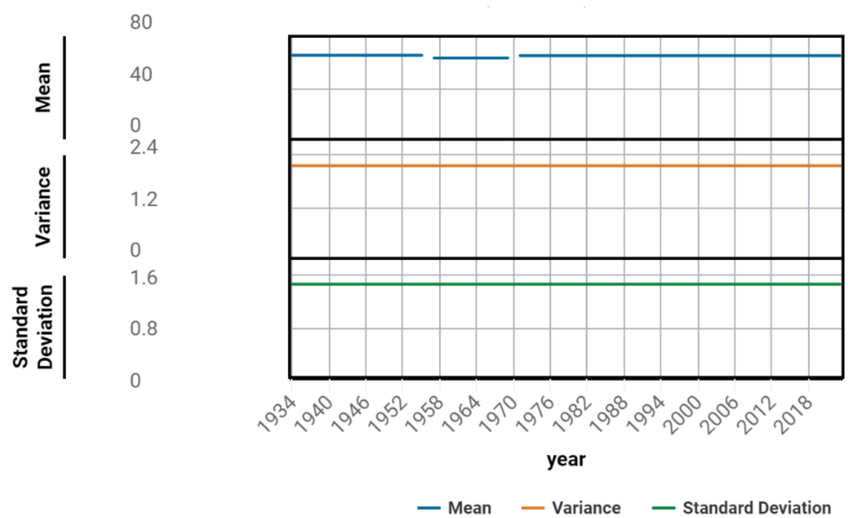


Figure A-8. Time Series Toolbox Output for Annual Mean Temperature for Belzoni, MS.

CLIMATE HYDROLOGY ASSESSMENT TOOL (CHAT)

The USACE Climate Hydrology Assessment Tool (CHAT) displays various simulated, historic and future, climate-changed streamflow, temperature, and precipitation outputs derived from 32 GCMs. The CHAT uses Coupled Model Intercomparison Project Phase 5 (CMIP5) GCM meteorological data outputs that have been statistically downscaled using the Localized Constructed Analogs (LOCA) method. GCMs rely on scenarios representing different pathways to a given atmospheric concentration of greenhouse gas emissions (GHG) referred to as representative concentration pathways (RCPs). RCPs describe the change in radiative forcing at the end of this century, as compared with pre-industrial conditions. Projected hydroclimate data in the CHAT for 2006 to 2099 are produced using two future scenarios: RCP 4.5 (where greenhouse gas emissions stabilize by the end of the century) and RCP 8.5 (where greenhouse gas emissions continue to increase throughout the century). Simulated output representing the historic period of 1951 to 2005 is generated using a reconstitution of historic GHG emissions.

To analyze runoff, LOCA-downscaled GCM outputs are used to force an unregulated, Variable Infiltration Capacity (VIC) hydrologic model. Areal runoff from VIC is then routed through a stream network using MizuRoute. Outputs represent the daily in-channel, routed streamflow for each stream segment – valid at the stream segment endpoint. Since the runoff is routed, the streamflow value associated with each stream segment is a representation of the cumulative flow, including all upstream runoff, as well as the local runoff contributions to that specific segment. Within the CHAT, streamflow output can be selected by stream segment and precipitation/temperature output can be selected for a given 8-digit HUC watershed.

The YSA is in 4-digit HUC 0803 (Lower Mississippi-Yazoo). To investigate simulated trends in hydrometeorological variables relevant to the study, the 8-digit HUC 08030207 (Big Sunflower), stream segment 08001067, was used to understand conditions in the interior YSA basin above the Steele Bayou WCS, and 8-digit HUC 08030100 (Lower Mississippi-Greenville), stream segment 08001476 was used to characterize simulated trends in the Mississippi River itself. Annual maximum of mean monthly streamflow and annual maximum 3-day precipitation are proxies for flooding within the YSA interior because flooding on the Mississippi River results in closure of the Steele Bayou WCS, preventing drainage of the YSA during times of high streamflow and heavy precipitation. The drought indicator variable (annual maximum number of consecutive dry days) and annual mean daily temperature were chosen as proxies for low flow. Temperature and drought impact ET and agricultural irrigation, which impacts fall base flow conditions that are critical to the aquatic habitat of concern. The climate model results for annual maximum 3-day precipitation, the drought indicator, and annual mean daily temperature have similar results for the two 8-digit HUCs evaluated. Therefore, the resulting p-values and trend line slopes for both 8-digit HUCs are shown in a single table and a graphic of the simulated range and mean in climate model output for these variables is provided for the Big Sunflower watershed (HUC 08030207) only. Figures A-9 through A-13 show the range of the modeled output presented for the historic period (1951-2005) and the future period (2006-2099) for the project-relevant hydrometeorological variables identified above. The range of simulated output is indicative of the uncertainty associated with projected, climate-changed streamflow, precipitation, and temperature.

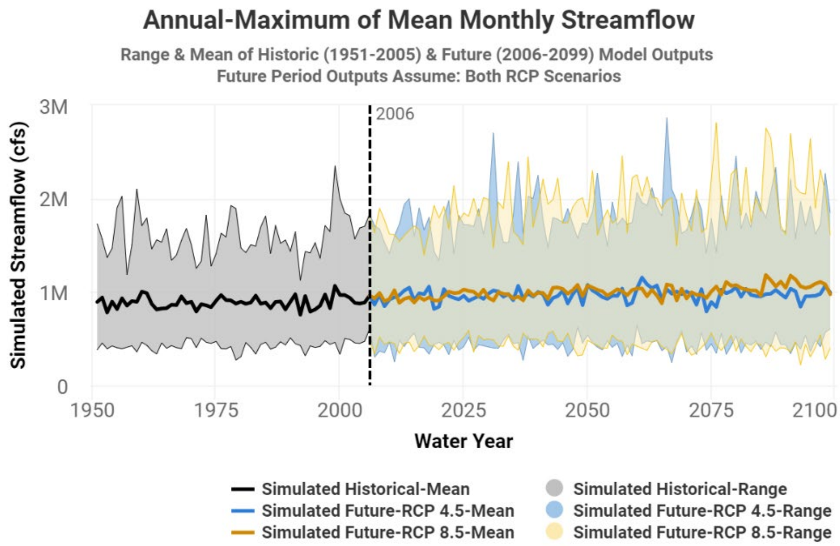


Figure A-9. Range of Annual Maximum of Mean Monthly Streamflow Model Output for the Lower Mississippi-Greenville watershed (HUC 08030100) Stream Segment: 08001476

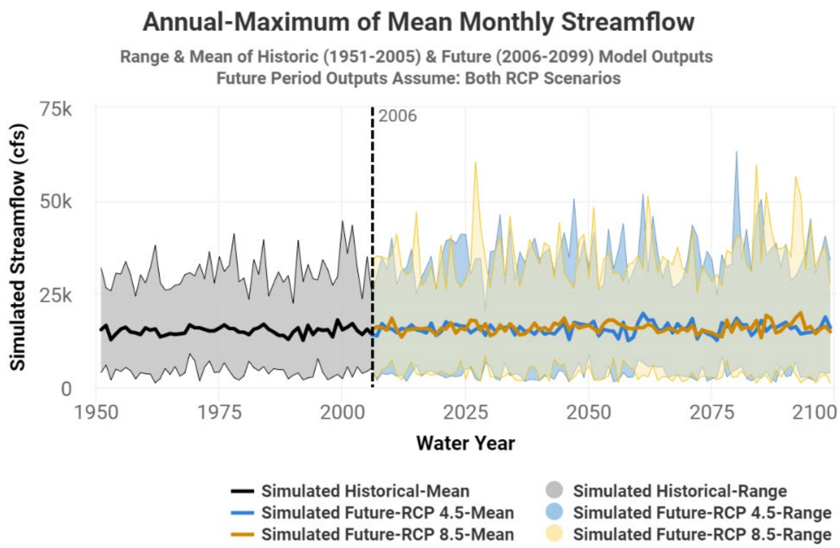


Figure A-10. Range of Annual Maximum of Mean Monthly Streamflow Model Output for the Big Sunflower watershed (HUC 08030207) Stream Segment: 08001067

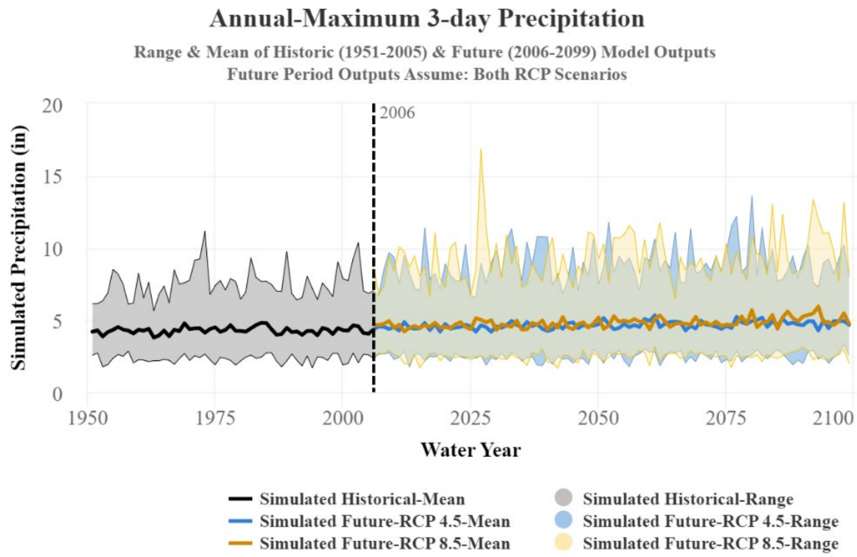


Figure A-11. Range of Annual-Maximum 3-Day Precipitation for the Big Sunflower watershed (HUC08030207)

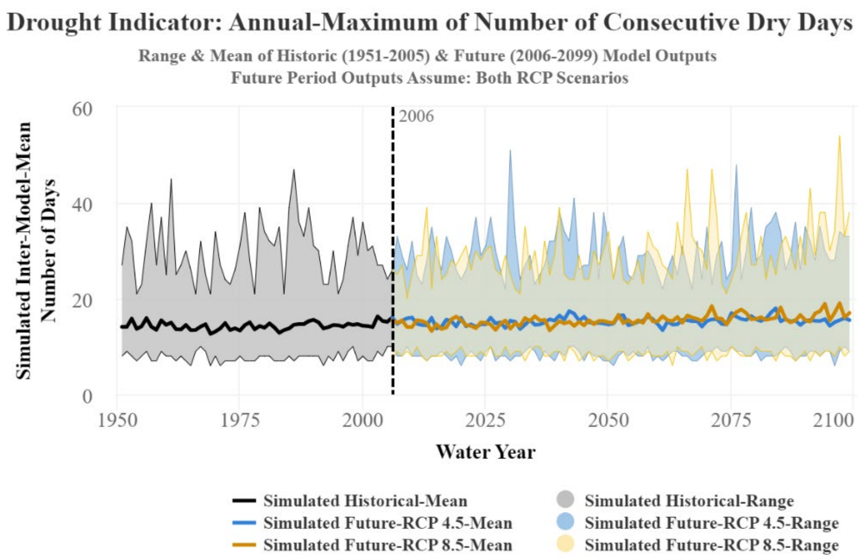


Figure A-12. Range of Annual-Maximum of Number of Consecutive Dry Days for the Big Sunflower watershed (HUC08030207)

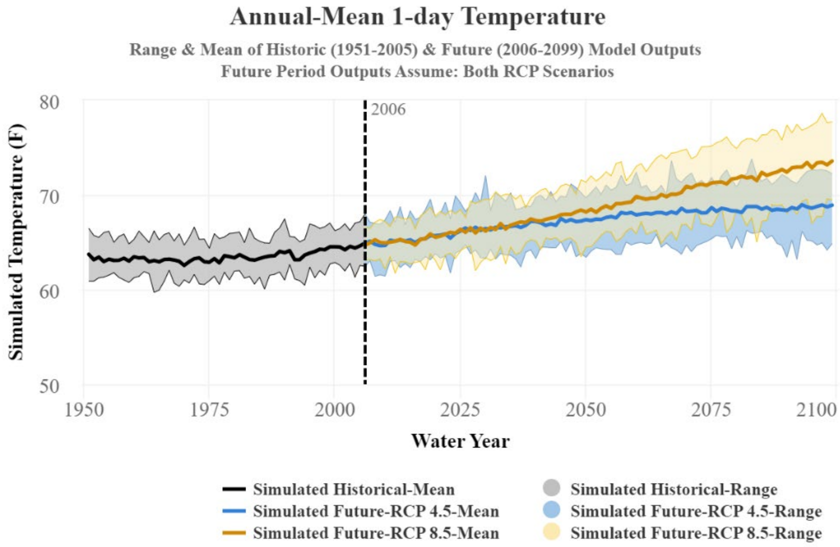


Figure A-13. Range of Annual-Mean 1-Day Temperature for the Big Sunflower watershed (HUC08030207)

The range and mean of GCM-simulated output during the historic and future periods for annual maximum of mean monthly streamflow in the Lower Mississippi-Greenville watershed (HUC 08030100) stream segment 08001476 is shown in Figure A-9. Trends in the simulated mean are evaluated using the t-Test, Mann-Kendall and Spearman Rank-Order tests. All three statistical tests are applied using a 0.05 level of significance (p-values<0.05 are considered statistically significant). As shown in Figure A-14, the directionally and magnitude of change in statistically significant trends in the simulated mean of annual maximum mean monthly streamflow are evaluated using the slope of the fitted linear regression relationship. The results of the three statistical tests and the slopes associated with identified, statistically significant trends are presented in Table A-1. The mean of the 32 projections of simulated, annual maximum of mean monthly streamflow for the future period (2006-2099) shows a statistically significant, positive trend for the Lower Mississippi-Greenville watershed (HUC 08030100) stream segment 08001476 when RCP 8.5 is assumed. The trendline has a slope of 1,459 cfs a year, which equates to a 72,950 cfs change in the average of the 32 projections of annual maximum mean monthly streamflow over a 50-year period. When the CHAT is used to evaluate the change in epoch-mean of simulated annual maximum of mean monthly streamflow it is found that the median change from the base epoch (1950-2005) to the mid-century epoch (2035-2064) is 12.8% when RCP 8.5 is assumed. By the end-century epoch (2070-2099) the median change relative to the base period is 14.5% when RCP 8.5 is assumed. There are no statistically significant trends in simulated annual maximum of mean monthly streamflow for the historic period (1951-2005) or for the future period (2006-2099) when RCP 4.5 is assumed. The statistically significant positive trend identified in the observed annual maximum streamflow record at

Vicksburg is not identified in the simulated annual maximum of mean monthly streamflow for the historical period, which illustrates the differences in temporal scale and source of hydrometeorological forcings between the modeled historical results and the observed records. The modeled historical period is useful for comparisons to the modeled future periods. Projected increases in annual maximum streamflow during the end-century epoch suggests that there could be increased Mississippi River flooding and more frequent closure of the Steele Bayou WCS.

Table A-1. Trend Analysis of Average Model Output: Annual Maximum of Mean Monthly Streamflow for Lower Mississippi-Greenville watershed (HUC 08030100) Stream Segment: 08001476

Trend Analysis	Historic (1951-2005)	Future (2006-2099)		Historic (1951-2005)			Future (2006-2099)					
		RCP 4.5	RCP 8.5				RCP 4.5			RCP 8.5		
	p-values			Statistically Significant? (<0.05)	Slope (cfs/year)	Direction	Statistically Significant? (<0.05)	Slope (cfs/year)	Direction	Statistically Significant? (<0.05)	Slope (cfs/year)	Direction
t-Test	0.368	0.111	<0.001	No	475.88	↑	No	397.73	↑	Yes	1,459	↑
Mann-Kendall	0.433	0.0767	<0.001	No			No			Yes		
Spearman Rank Order	0.473	0.0646	<0.001	No			No			Yes		

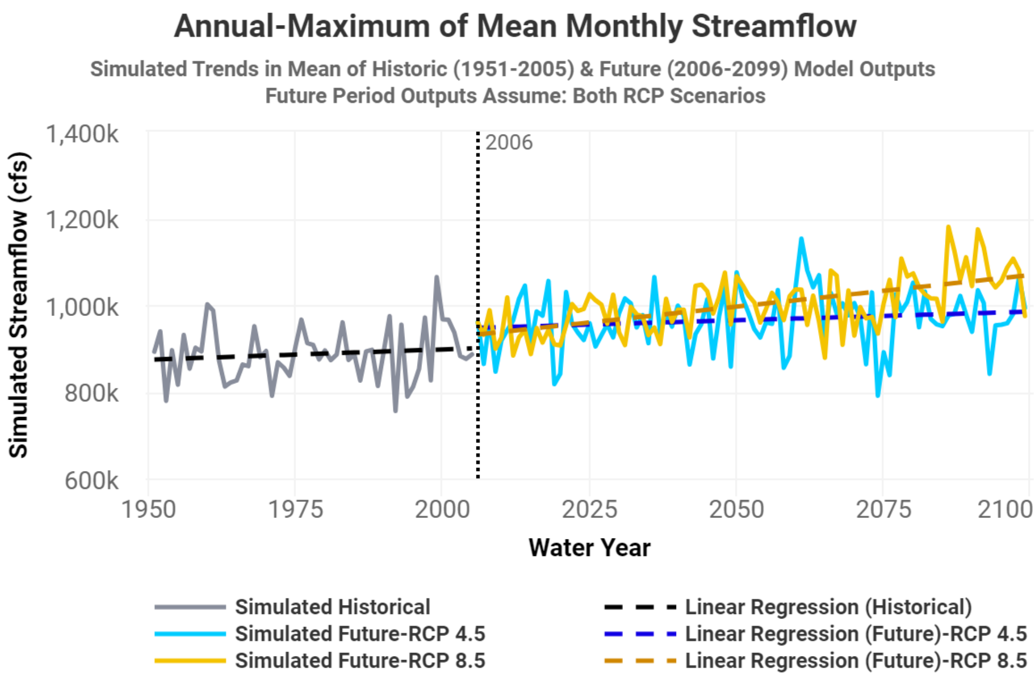


Figure A-14. Trend Analysis of Average Model Output: Annual Maximum of Mean Monthly Streamflow for Lower Mississippi-Greenville watershed (HUC 08030100) Stream Segment: 08001476

For the Big Sunflower watershed (HUC 08030207) Stream Segment: 08001067, the range and mean of simulated output during the historic and future periods for annual maximum of mean monthly streamflow is shown in Figure A-10. The mean of the 32 projections of simulated, annual maximum of mean monthly streamflow show no statistically significant trends for the historic period (1951-2005) or the future period (2006-2099) under both RCP 4.5 and 8.5 (Table A-2 and Figure A-15).

Table A-2. Trend Analysis of Average Model Output: Annual Maximum of Mean Monthly Streamflow for Big Sunflower watershed (HUC 08030207) Stream Segment: 08001067

Trend Analysis	Historic (1951-2005)	Future (2006-2099)		Historic (1951-2005)			Future (2006-2099)					
		RCP 4.5	RCP 8.5				RCP 4.5			RCP 8.5		
	p-values			Statistically Significant? (<0.05)	Slope (cfs/year)	Direction	Statistically Significant? (<0.05)	Slope (cfs/year)	Direction	Statistically Significant? (<0.05)	Slope (cfs/year)	Direction
t-Test	0.42	0.269	0.367	No	7.75	↑	No	6.19	↑	No	4.60	↑
Mann-Kendall	0.581	0.324	0.695	No			No			No		
Spearman Rank Order	0.568	0.265	0.589	No			No			No		

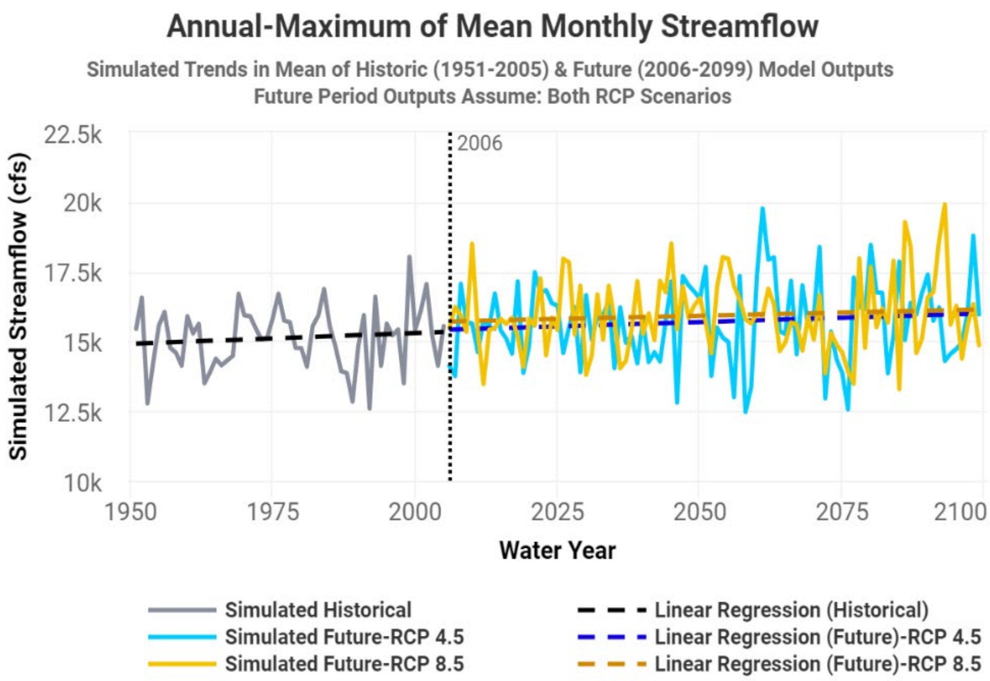


Figure A- 15. Trend Analysis of Average Model Output: Annual Maximum of Mean Monthly Streamflow for Big Sunflower watershed (HUC 08030207) Stream Segment: 08001067

The simulated range and mean of annual maximum 3-day precipitation for the Big Sunflower watershed is shown in Figure A-11. The mean of the 32 projections for both Big Sunflower and Lower Mississippi River-Greenville watersheds show statistically significant positive trends in simulated annual maximum 3-day precipitation for the future period (2006-2099) under both RCP 4.5 and RCP 8.5 (Table A-3 and Figure A-16). There is consensus in the literature that an increase in extreme precipitation events, which can serve as a surrogate for flooding. Under RCP 4.5, the trendline for the Big Sunflower watershed has a slope of 0.004 inches per year, which equates to a 0.2-inch increase in the average of the 32 projections of annual maximum 3-day precipitation over a 50-year period. The trendline for the Lower Mississippi River-Greenville watershed has a very similar slope (0.0047 inches per year) resulting in a similar change (0.235 inch) over the 50-year period. Under RCP 8.5, the trendlines for Big Sunflower and Lower Mississippi River-Greenville watersheds have a slope of 0.0059 inches per year, equating to a nearly 0.3-inch increase in the mean simulated annual maximum 3-day precipitation over 50 years. The median change from the base epoch (1950-2005) to the mid-century epoch (2035-2064) is 0.33 inches for the Big Sunflower watershed and 0.25 inches for the Lower Mississippi River-Greenville watershed when RCP 4.5 is assumed. When RCP 8.5 is assumed, the median change is 0.43 inches and 0.42 inches for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively. By the end-century epoch (2070-2099) the median change relative to the base period is 0.4 inches and 0.43 inches for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively, when RCP 4.5 is assumed. Under RCP 8.5, the end-century epoch median change is 0.64 inches and 0.54 inches for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively. There are no statistically significant trends in simulated annual maximum 3-day precipitation for the historic period (1951-2005) for either watershed. Increases in future maximum precipitation could increase the potential for flooding on both the Mississippi and within the YSA.

Table A-3. Trend Analysis of Average Model Output: Annual Maximum 3-Day Precipitation for Lower Mississippi-Greenville watershed (HUC 08030100) and, in parentheses, for Big Sunflower watershed (HUC 08030207) when results differ

Trend Analysis	Historic (1951-2005)	Future (2006-2099)		Historic (1951-2005)			Future (2006-2099)					
		RCP 4.5	RCP 8.5				RCP 4.5			RCP 8.5		
	p-values			Statistically Significant? (<0.05)	Slope (in/year)	Direction	Statistically Significant? (<0.05)	Slope (in/year)	Direction	Statistically Significant? (<0.05)	Slope (in/year)	Direction
t-Test	0.931 (0.47)	<0.001	<0.001	No	0.0002 (0.0014)	↑	Yes	0.0047 (0.004)	↑	Yes	0.0059	↑
Mann-Kendall	0.954 (0.532)	<0.001	<0.001	No			Yes			Yes		
Spearman Rank Order	0.958 (0.592)	<0.001	<0.001	No			Yes			Yes		

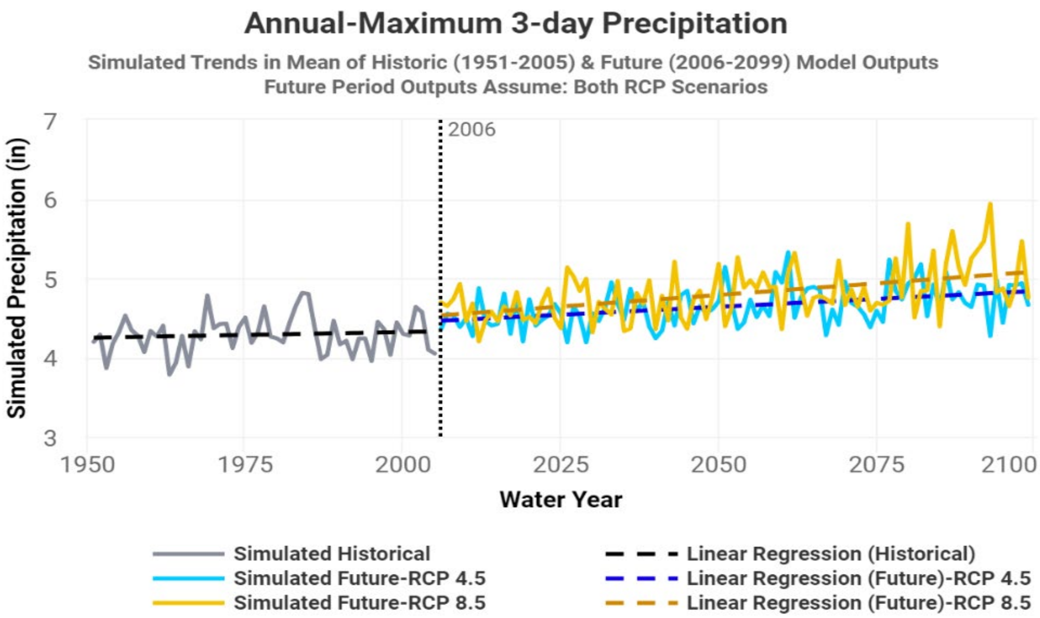


Figure A-16. Trend Analysis of Average Model Output: Annual Maximum 3-Day Precipitation for Big Sunflower watershed (HUC 08030207)

Figure A-12 illustrates the simulated range and mean of annual maximum number of consecutive dry days (or drought indicator) for the Big Sunflower watershed. The mean model output for both Big Sunflower and Lower Mississippi River-Greenville watersheds show statistically significant positive trends in the simulated drought indicator for the future period (2006-2099) under both RCP 4.5 and RCP 8.5 (Table A-4 and Figure A-17). Under RCP 4.5, the trendline for the Big Sunflower watershed has a slope of 0.0072 days per year, which equates to a 0.36 day increase in the average of the 32 projections of annual maximum number of consecutive dry days over a 50-year period. The trendline for the Lower Mississippi River-Greenville watershed has a very similar slope (0.0084 days per year) resulting in a similar change (0.42 days) over the 50-year period. Under RCP 8.5, the trendline for Big Sunflower watershed has a slope of 0.0256 days per year, equating to a 1.3 day increase in the mean simulated annual maximum number of consecutive dry days over 50 years. Again, the trendline for the Lower Mississippi River-Greenville watershed has a very similar slope (0.022 days per year), resulting in a similar change (1.1 days) over the 50-year period, under RCP 8.5. When the CHAT is used to evaluate the change in epoch-mean of simulated annual maximum number of consecutive dry days, the median change from the base epoch (1950-2005) to the mid-century epoch (2035-2064) is 1 day for the Big Sunflower watershed and 1.2 days for the Lower Mississippi River-Greenville watershed when RCP 4.5 is assumed. When RCP 8.5 is assumed, the median change is 0.8 days and 0.9 days for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively. By the end-century epoch (2070-2099) the median change relative to the base period is 1 day and 1.2 days for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively, when RCP 4.5 is assumed. Under RCP 8.5, the end-century epoch median change is 1.95 days and 2.2 days for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively. There are no statistically significant trends in simulated annual maximum number of consecutive dry days for the historic period (1951-2005) for either watershed. Future increased drought could impact demands on the MRVAA that provides baseflow to the YSA tributaries and irrigation to agriculture.

Table A-4. Trend Analysis of Average Model Output: Annual Maximum Number of Consecutive Dry Days for Lower Mississippi-Greenville watershed (08030100) and, in parentheses, for Big Sunflower watershed (08030207) when results differ.

<table>
<tr><td rowspan="3">Trend Analysis</td><td rowspan="2">Historic (1951-2005)</td><td colspan="2">Future (2006-2099)</td><td colspan="3" rowspan="2">Historic (1951-2005)</td><td colspan="6">Future (2006-2099)</td></tr>
<tr><td>RCP 4.5</td><td>RCP 8.5</td><td colspan="3">RCP 4.5</td><td colspan="3">RCP 8.5</td></tr>
<tr><td colspan="3">p-values</td><td>Statistically Significant? (<0.05)</td><td>Slope (days/ year)</td><td>Direction</td><td>Statistically Significant? (<0.05)</td><td>Slope (days/ year)</td><td>Direction</td><td>Statistically Significant? (<0.05)</td><td>Slope (days/ year)</td><td>Direction</td></tr>
<tr><td>t-Test</td><td>0.19 (0.12)</td><td>0.0128 (0.019)</td><td><0.001</td><td>No</td><td rowspan="3">0.0085 (0.0103)</td><td rowspan="3">↑</td><td>Yes</td><td rowspan="3">0.0084 (0.0072)</td><td rowspan="3">↑</td><td>Yes</td><td rowspan="3">0.022 (0.0256)</td><td rowspan="3">↑</td></tr>
<tr><td>Mann-Kendall</td><td>0.0852 (0.074)</td><td>0.0168 (0.02)</td><td><0.001</td><td>No</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Spearman Rank Order</td><td>0.0927 (0.073)</td><td>0.0125 (0.0246)</td><td><0.001</td><td>No</td><td>Yes</td><td>Yes</td></tr>
</table>

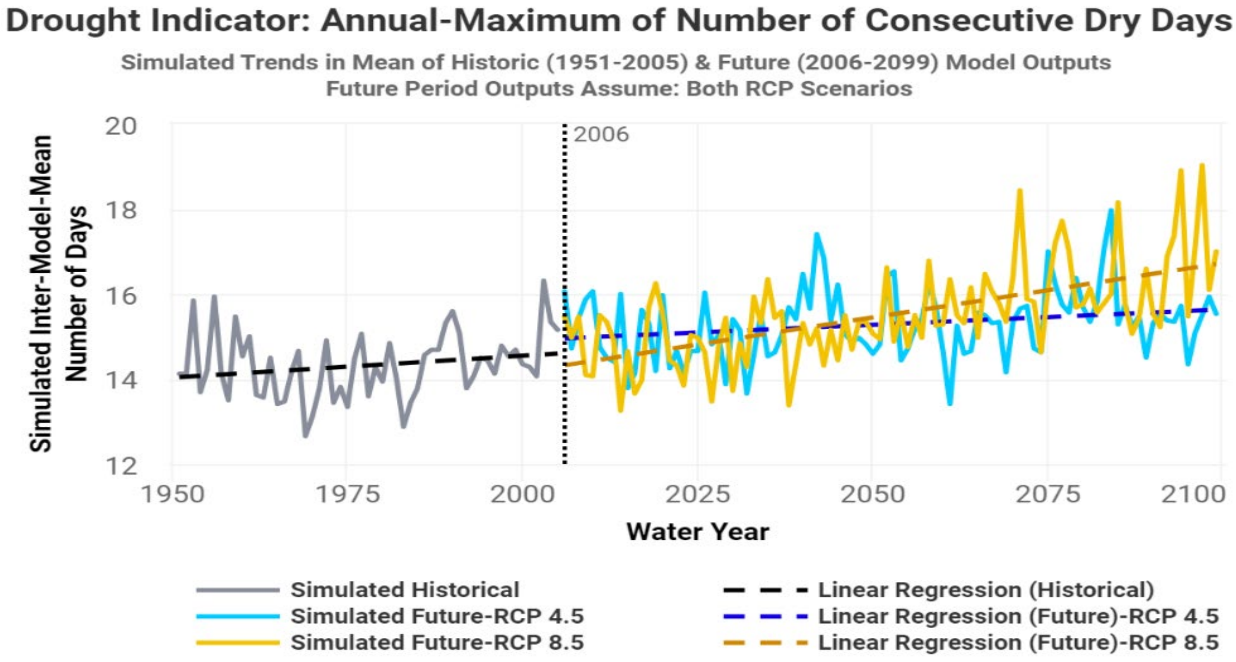


Figure A-17. Trend Analysis of Average Model Output: Annual Maximum Number of Consecutive Dry Days for Big Sunflower watershed (08030207)

The simulated range and mean of annual mean daily temperature for the Big Sunflower watershed is illustrated in Figure A-13. The mean model output for both Big Sunflower and Lower Mississippi River-Greenville watersheds show statistically significant positive trends in the simulated annual mean daily temperature for the historic and future period (2006-2099) under both RCP 4.5 and RCP 8.5 (Table A-5 and Figure A-18). The historic period shows a trendline with a slope of 0.0238 degrees Fahrenheit per year for the Big Sunflower watershed, equating to a 1.19 °F increase over a 50-year period. The historic period trendline for the Lower Mississippi River-Greenville watershed shows a very similar slope (0.0227 °F/year), resulting in a 1.14 °F increase over 50-years. Under RCP 4.5, the trendline for the Big Sunflower watershed has a slope of 0.0443 °F/year which equates to a 2.22 °F increase in the mean simulated annual mean temperature over a 50-year period. The trendline for the Lower Mississippi River-Greenville watershed has a very similar slope (0.0445 °F/year) resulting in a similar change (2.23 °F) over the 50-year period. Under RCP 8.5, the trendline for Big Sunflower watershed has a slope of 0.0991 °F/year, equating to a 4.96 °F increase in the mean simulated annual mean temperature over 50 years. The trendline for the Lower Mississippi River-Greenville watershed has a very similar slope (0.0993 °F/year) resulting in a similar change (4.96 °F) over the 50-year period, under RCP 8.5. The median change from the base epoch (1950-2005) to the mid-century epoch (2035-2064) is 3.47 °F for the Big Sunflower watershed and 3.48 °F for the Lower Mississippi River-Greenville watershed when RCP 4.5 is assumed. When RCP 8.5 is assumed, the median change is 4.25 °F and 4.2 °F for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively. By the end-century epoch (2070-2099) the median change relative to the base period is 4.54 °F and 4.53 °F for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively, when RCP 4.5 is assumed. Under RCP 8.5, the end-century epoch median change is 8.26 °F and 8.21 °F for the Big Sunflower and Lower Mississippi River-Greenville watersheds, respectively. Simulated increasing temperatures in the future can increase ET and consequently irrigation rates, impacting baseflow within the agricultural YSA.

Table A-5. Trend Analysis of Average Model Output: Annual Mean Daily Temperature for Lower Mississippi-Greenville watershed (HUC 08030100) and, in parentheses, for Big Sunflower watershed (08030207) when results differ

<table>
<tr><td rowspan="3">Trend Analysis</td><td rowspan="2">Historic (1951-2005)</td><td colspan="2">Future (2006-2099)</td><td colspan="3" rowspan="2">Historic (1951-2005)</td><td colspan="6">Future (2006-2099)</td></tr>
<tr><td>RCP 4.5</td><td>RCP 8.5</td><td colspan="3">RCP 4.5</td><td colspan="3">RCP 8.5</td></tr>
<tr><td colspan="3">p-values</td><td>Statistically Significant? (<0.05)</td><td>Slope (°F/ year)</td><td>Direction</td><td>Statistically Significant? (<0.05)</td><td>Slope (°F/ year)</td><td>Direction</td><td>Statistically Significant? (<0.05)</td><td>Slope (°F/ year)</td><td>Direction</td></tr>
<tr><td>t-Test</td><td><0.001</td><td><0.001</td><td><0.001</td><td>Yes</td><td rowspan="3">0.0227 (0.0238)</td><td rowspan="3">↑</td><td>Yes</td><td rowspan="3">0.0443 (0.0445)</td><td rowspan="3">↑</td><td>Yes</td><td rowspan="3">0.0993 (0.0991)</td><td rowspan="3">↑</td></tr>
<tr><td>Mann-Kendall</td><td><0.001</td><td><0.001</td><td><0.001</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Spearman Rank Order</td><td><0.001</td><td><0.001</td><td><0.001</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
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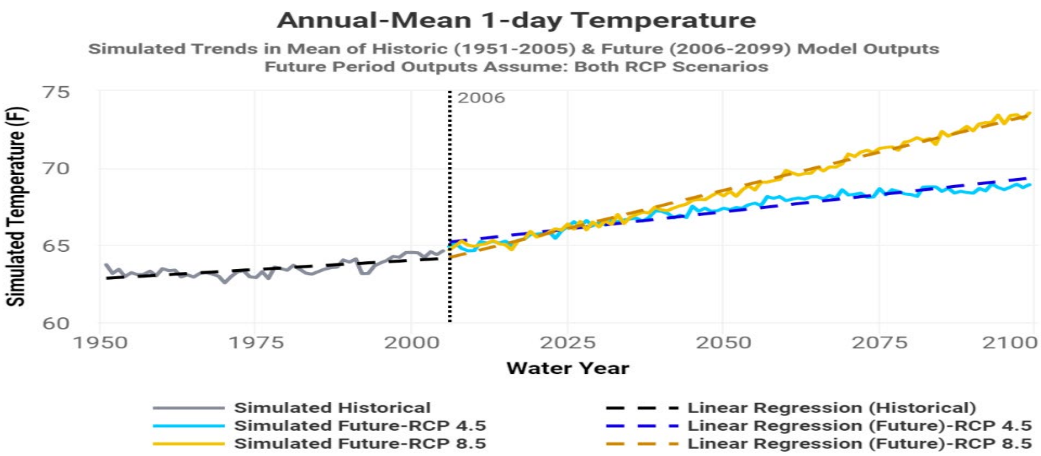

Figure A-18. Trend Analysis of Average Model Output: Annual Mean Daily Temperature for Big Sunflower watershed (08030207)

The CHAT provides streamflow, precipitation and temperature outputs analyzed comparatively by describing simulated changes in monthly output between different epochs (time periods). Monthly streamflow, precipitation and temperature output is analyzed by determining the mean of the monthly value for the variable of interest for each GCM for three epochs: 1950-2005 (baseline), 2035-2064 (mid-century), and 2075-2099 (end of century). The difference between GCM/Month/Epoch means are determined for both the baseline versus mid-century and baseline versus end of century epochs and results are presented as boxplots. These boxplots provide insight into both the range of results and the seasonality of changes in streamflow, precipitation, and temperature over time.

Mean epoch-based changes in simulated monthly mean streamflow for the Lower Mississippi-Greenville watershed (08030100) stream segment 08001476 and Big Sunflower watershed (08030207) stream segment 08001067 are presented in Figure A-19 and A-20, respectively. Model output for RCP 4.5 and 8.5 suggests the median percent change in monthly-mean flows during the spring shows larger increases for the Lower Mississippi-Greenville stream segment than for the Big Sunflower stream segment, for both the mid-century and end-century epochs. Median percent change in spring monthly-mean flows for the Lower Mississippi-Greenville stream segment are consistently positive (ranging from +3.72% to +21.93%) across months, RCPs and epochs, whereas spring median percent change results for the Big Sunflower stream segment vary (ranging from -6.15% to +4.21%) across months, RCPs and epochs. Future increased monthly mean streamflow on the Mississippi could indicate potential for future increased flooding and Steele Bayou gate closures.

Median percent change in monthly-mean flows during the fall for the Lower Mississippi-Greenville stream segment shows consistent relative decreases (ranging from -1.63% to -7.19%) under both RCPs for the end-century epoch, while results for the mid-century epoch show consistent relative decreases in fall monthly mean flows under RCP 4.5 (ranging from -1.19% to -7.94%). Median percent change in fall monthly mean flows for the Big Sunflower stream segment show more variability in magnitude and direction than the Lower-Mississippi-Greenville stream segment, across months, RCPs, and epochs, with the most consistency in monthly results for the late-century epoch across RCPs where September and October show relative increases and November shows a relative decrease. Decreases in fall monthly mean Mississippi River streamflow in the future could impact MRVAA recharge and baseflow within the YSA tributaries.

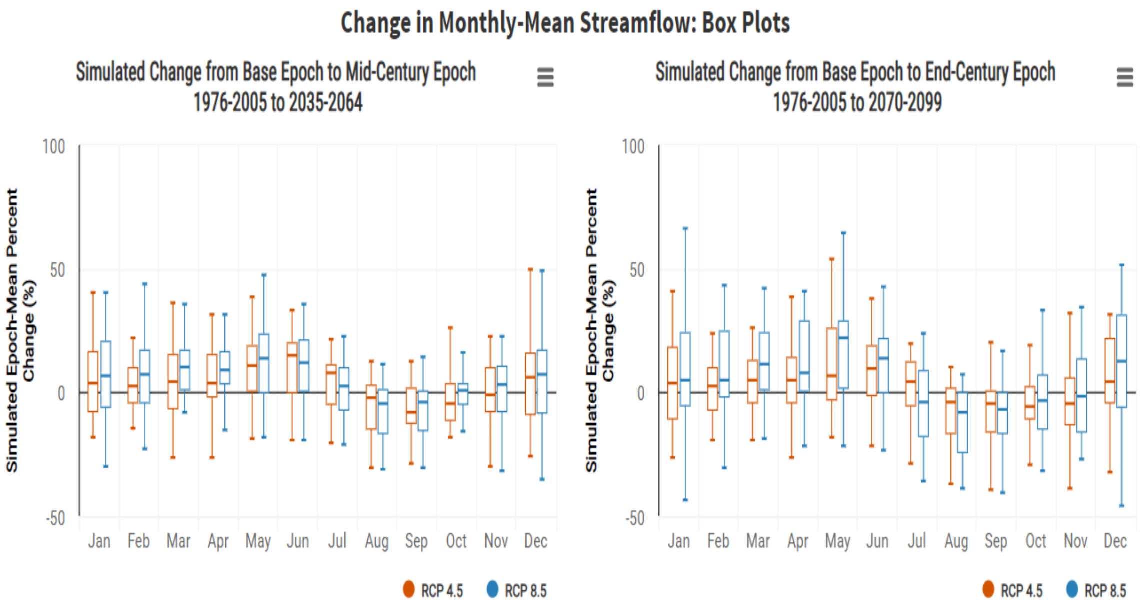

Figure A-19. Change in Epoch-Mean of Simulated Monthly Mean Streamflow - HUC 08030100 – Lower Mississippi-Greenville watershed - Stream segment: 08001476

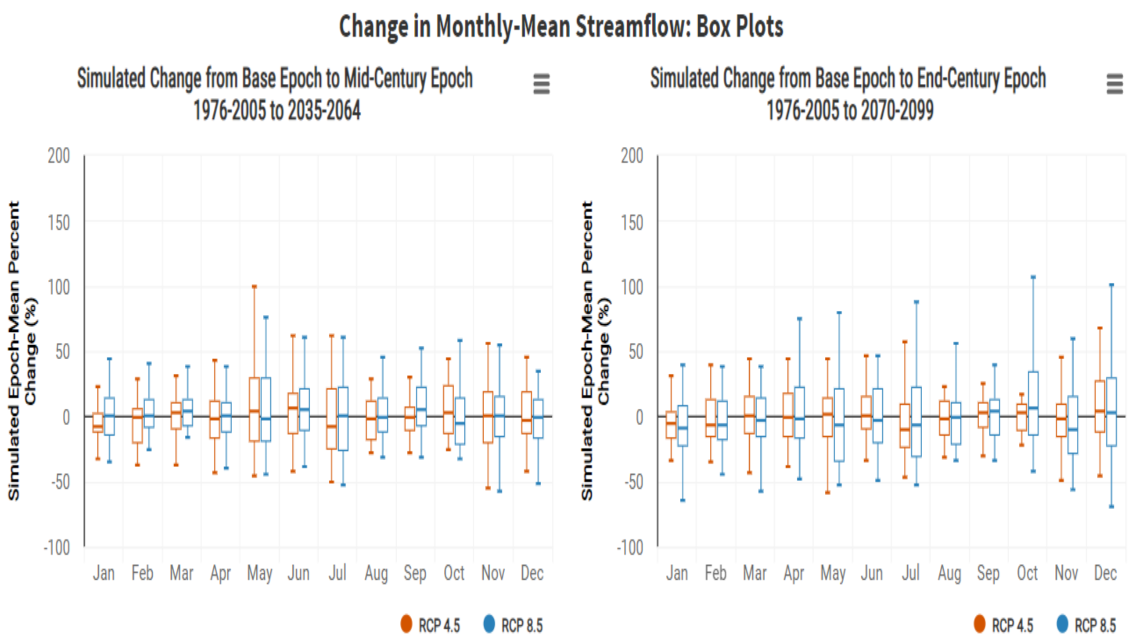

Figure A-20. Change in Epoch-Mean of Simulated Monthly Mean Streamflow - HUC 08030207 – Big Sunflower watershed- Stream segment: 08001067

Mean epoch-based changes in simulated monthly maximum 3-day precipitation for the Lower Mississippi-Greenville watershed (08030100) and Big Sunflower watershed (08030207) are very similar and are presented in Figures A-21 and A-22, respectively. Median results for both watersheds indicate that spring monthly maximum 3-day precipitation will be increased (by 0.007 – 0.26 inches) in the mid-century and late-century epochs relative to the base epoch under both RCPs, with the exception of a relative decrease (-0.03 inches) in April for the mid-century epoch under RCP 8.5 for the Lower Mississippi-Greenville watershed. Future increases in maximum precipitation during the spring could result in increased flooding in both the Mississippi and within the YSA.

Median results for both watersheds indicate that the magnitude of change in fall monthly maximum 3-day precipitation is relatively less than projected change during spring months across RCPs and epochs. Direction of median change in monthly maximum 3-day precipitation (i.e. increasing vs. decreasing) is more variable across months, RCPs, and epochs during the fall than during the spring for both watersheds.

Mean epoch-based changes in simulated monthly mean temperature for the Lower Mississippi-Greenville watershed (08030100) and Big Sunflower watershed (08030207) are very similar and are presented in Figures A-23 and A-24, respectively. Results for both watersheds show monthly mean temperatures for both the mid-century epoch (2035-2064) and the end-century epoch (2070-2099) are increasing relative to historic temperature simulations (1950-2005) for all months and both RCPs. For the mid-century comparisons in both watersheds, median increases of 3.2° F or greater are projected under RCP 8.5 for all months, while median increases of 2.6° F or greater are projected for all months under RCP 4.5. Relative change for the late-century epoch is larger than that for the mid-century epoch and there is much greater difference in relative change depending on which RCP is assumed in the late-century. For example, the median increase in mean monthly temperature in the late century epoch is 8.8° F or greater for May-October under RCP 8.5. Under RCP 4.5, the median increase in mean monthly temperature is 4.6° F or greater for May-October. Increased air temperatures during the growing season can result in increased ET and the need for greater agricultural irrigation, placing further demands on the MRVAA that provides baseflow in the upper reaches of the YSA basin.

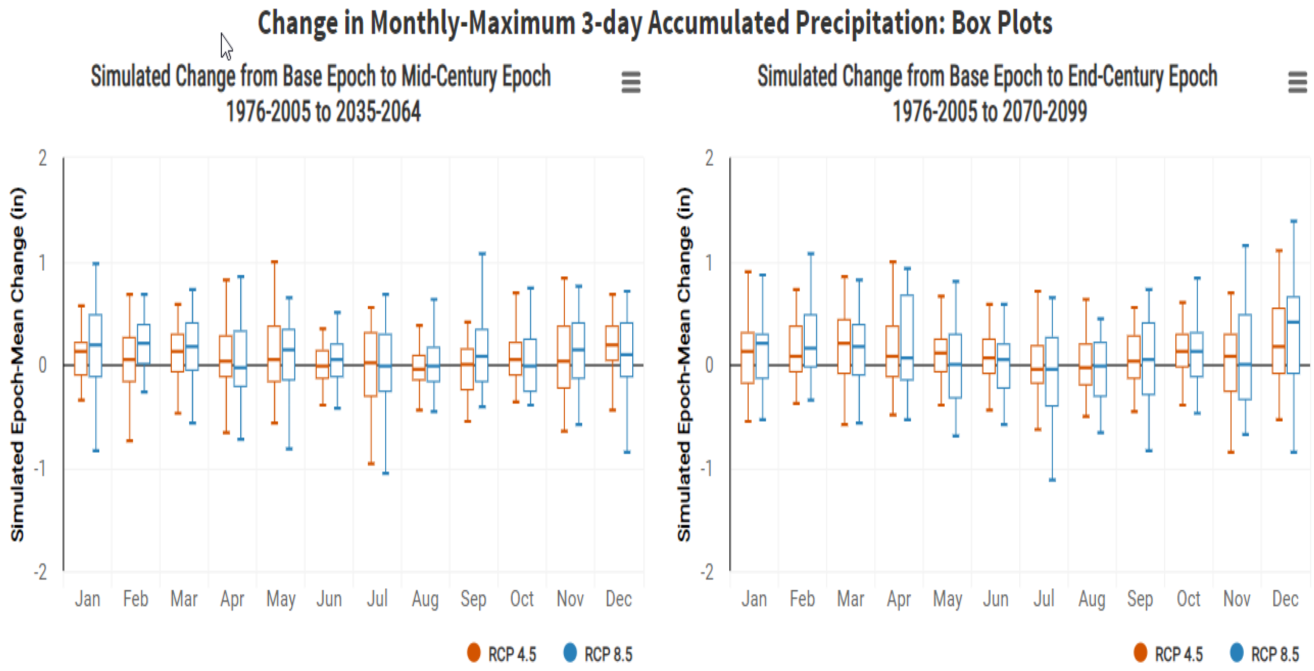

Figure A-21. Change in Epoch-Mean of Simulated Monthly Maximum 3-day Precipitation - HUC 08030100 – Lower Mississippi-Greenville watershed

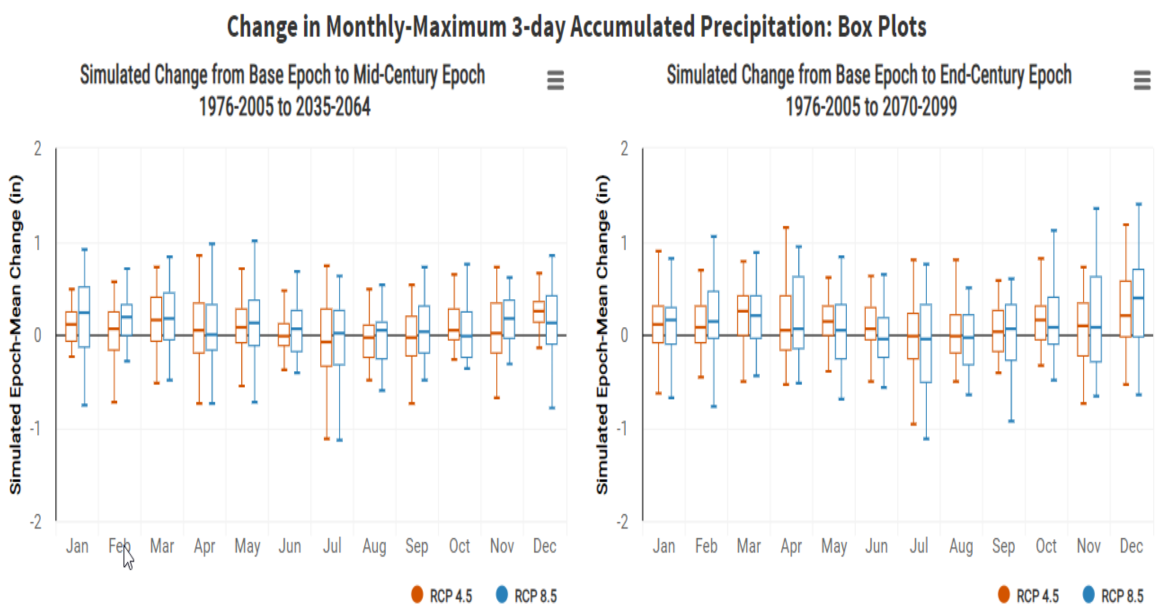

Figure A-22. Change in Epoch-Mean of Simulated Monthly Maximum 3-day Precipitation - HUC 08030207 – Big Sunflower watershed

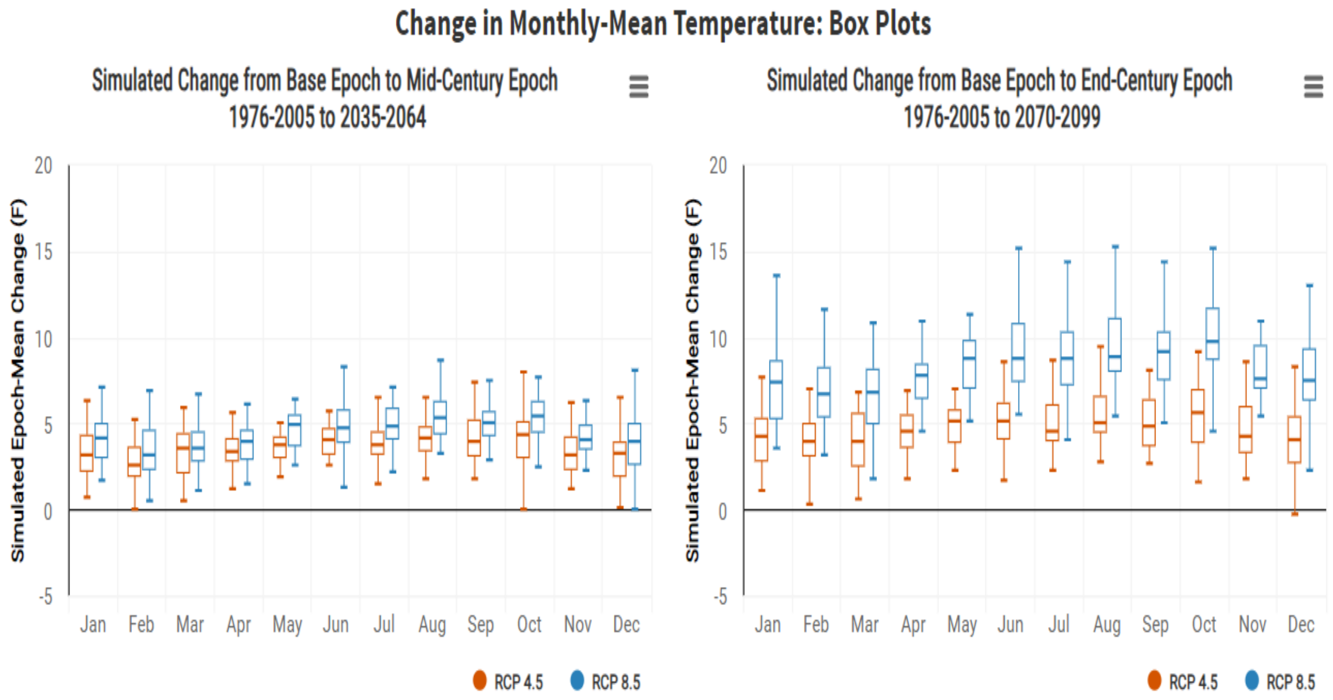

Figure A-23. Change in Epoch-Mean of Simulated Monthly Mean Temperature - HUC 08030100 – Lower Mississippi-Greenville watershed

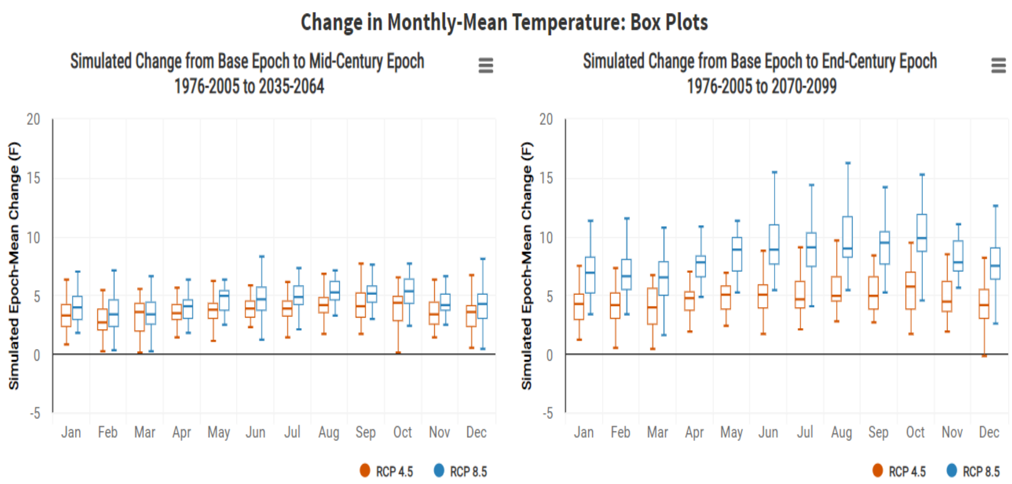

Figure A-24. Change in Epoch-Mean of Simulated Monthly Mean Temperature - HUC 08030207 – Big Sunflower watershed

VULNERABILITY ASSESSMENT

The USACE Climate Change Vulnerability Assessment (VA) Tool facilitates a screening level, comparative evaluation of climate change exposure to projects for a selected USACE business line in a given 4-digit HUC watershed relative to the other 4-digit HUC watersheds within the continental United States (CONUS). A series of indicator variables are computed and aggregated into a vulnerability score using the weighted-order, weighted-average (WOWA) approach. The tool uses the CMIP5 GCM based Bias Corrected, Spatially Disaggregated (BCSD) VIC dataset (2014) to define projected, hydrologic, and meteorologic inputs to the tool's WOWA scores.

The WOWA scores and indicator variable values are available for two subsets of simulations (wet- top 50% by cumulative runoff projections and dry- bottom 50% by cumulative runoff projections). Data are available for three epochs. The epochs include a historic period (Base epoch) and two 30-year, future epochs (centered on 2050 and 2085). The Base epoch is not based on projections and so it is not split into a wet and dry subset. Watersheds with WOWA scores specific to a given business line, that fall within the top 20% of WOWA scores for watersheds in the CONUS are identified as being vulnerable to climate change impacts. The projected datasets incorporated into VA scores contain considerable uncertainty. Some of this uncertainty is reflected by the differences in results for each of the subset-epoch combinations.

The tool is applied using the default, National Standards Settings and for the flood risk management and ecosystem restoration business lines. Indicators used to compute the Flood Risk Management WOWA score include annual coefficient of variation of cumulative runoff, run-off precipitation, local and cumulative flood magnification, and urban area within the 500-year floodplain. The Ecosystem Restoration WOWA score includes: change in sediment load due to change in future precipitation, cumulative monthly runoff variation relative to mean annual runoff, runoff elasticity (ratio of streamflow runoff change to precipitation change), macroinvertebrate index of biotic condition, local mean annual runoff, low flow reduction, percent of freshwater plant communities at risk, and two indicators of flood magnification (indicator of how much high flows are projected to change over time).

The VA Tool provides a scenario comparison over time visualization, which shows the climate risks mapped over time epochs and across scenarios for business lines (USACE, 2016b). Figure A-25 shows the number of vulnerable USACE business lines for each HUC-4 basin within the Vicksburg District under both climate scenarios (dry and wet) and both epochs (2050 and 2085). According to the VA tool, the Yazoo Basin is not identified as having a top 20 percent vulnerability score relative to the other HUC-4 watersheds in the continental United States for the flood risk reduction business line. However, the Yazoo Basin was identified as being vulnerable to the recreation business line for the dry climate scenario during the 2085 epoch and as being vulnerable to the navigation business line for the wet climate scenario during the 2085 epoch.

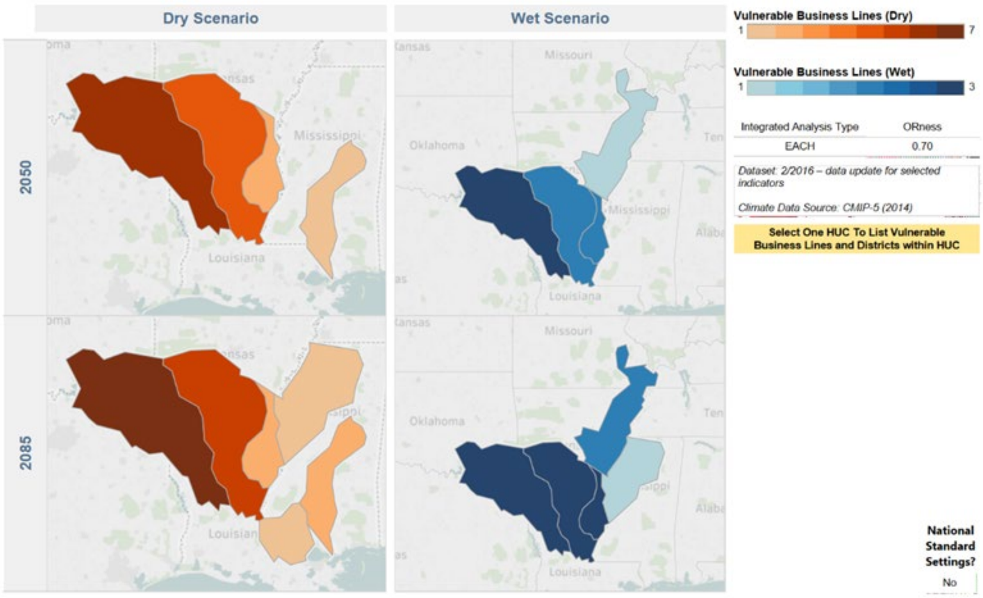

Figure A-25. The scenario comparison over time visualization across all business lines for the Mississippi Valley Division Vicksburg District HUC4s.

Furthermore, the VA Tool assesses the vulnerability score across time epochs and scenarios for given business lines. The WOWA score is used in a comparative sense to help determine if one location is relatively more, or less, exposed than another location. Figure A-26 shows the change in vulnerability scores over time for each HUC-4 in the Vicksburg District for the flood risk reduction business line under the dry climate scenario. Figure A-27 shows the change in vulnerability scores over time for each HUC-4 in the Vicksburg District for the flood risk reduction business line under the wet climate scenario. Relative to other HUC-4 watersheds within the Vicksburg District, the HUC 0803 (Lower Mississippi, Yazoo) has a relatively lower WOWA score and therefore has less exposure to future changes in climate. Table A-6 shows the vulnerability WOWA scores for HUC 0803 for flood risk reduction across each climate scenario and epoch. From Figure A-26, Figure A-27, and Table A-6, it is evident the WOWA vulnerability scores for HUC 0803 do not significantly change over time and that the Yazoo Basin might not experience significant exposure in terms of climate change for the flood risk reduction business line.

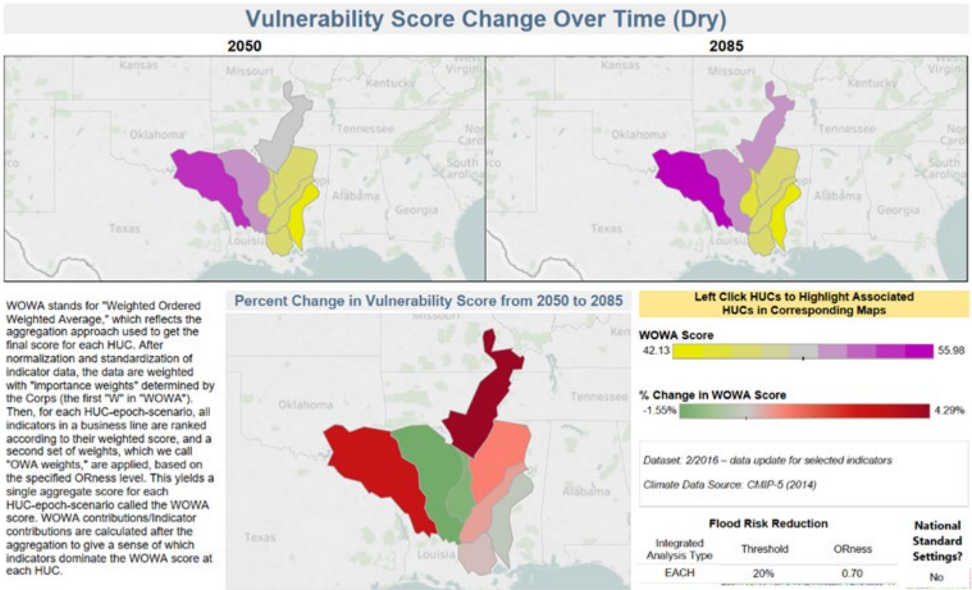

Figure A-26. The vulnerability score change over time for HUC4 watersheds within the Vicksburg District under the dry climate scenario.

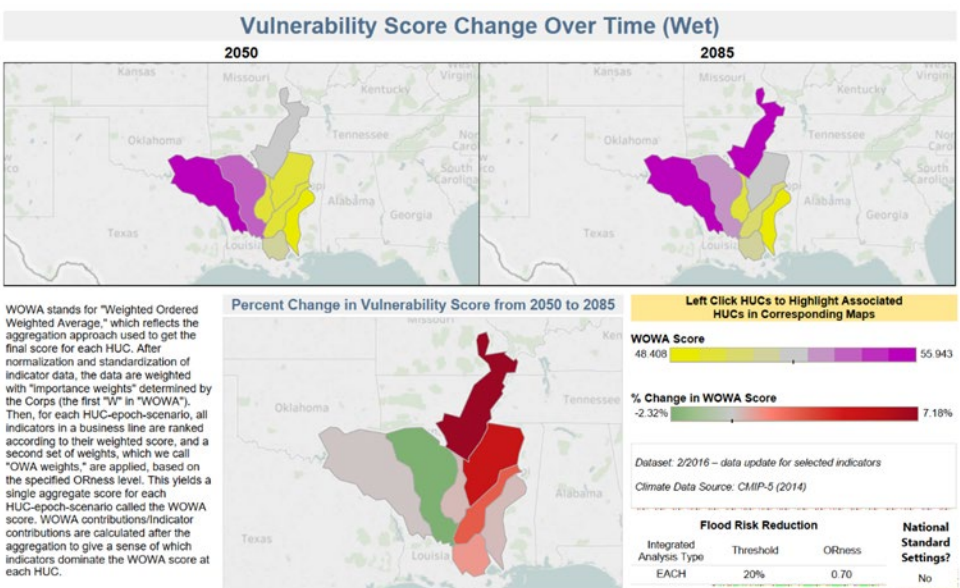

Figure A-27. The vulnerability score change over time for HUC4 watersheds within the Vicksburg District under the wet climate scenario.

Table A-6. The change in WOWA score for the Yazoo Basin (HUC 0803) across epochs and climate scenarios.

	Dry Scenario	Wet Scenario
2050 WOWA Score	46.15	46.65
2085 WOWA Score	46.58	52.09
Percent Change (2050 to 2085)	+0.91%	+4.92%

The HUC Summary from the VA Tool provides a comprehensive summary of the climate risk analysis for a selected business line (USACE, 2021d). The HUC summary results for flood risk reduction do not indicate the Yazoo Basin is significantly vulnerable, when compared to other HUC-4s across the Vicksburg District, under any climate scenario or epoch. The results also provide the dominant indicator, or contributor, for the flood risk reduction business line, which is the 568C flood magnification (Figure A-28). The 568C flood magnification is the change in flood runoff, both cumulative and local, and is the ratio of monthly runoff exceeded 10 percent of the time to monthly runoff during base periods (USACE, 2021d). Thus, the dominant concern in all future scenarios for flood risk is how much magnification does the cumulative (upstream and current basin) and local (current basin) floods experience. The VA Tool also provides the change over time for the indicator value. The indicator value represents the contribution of a single selected indicator to the climate risk score for each watershed for all business line components in which the indicator is used (USACE, 2021d). Table A-7 shows the change in indicator values for the 568C flood magnification from 2050 to 2085. Flood magnification will experience a slight increase for the dry scenario and a greater increase under the wet scenario. This indicates that cumulative and local flood runoff will increase, resulting in larger floods, more so for the wet climate scenario.

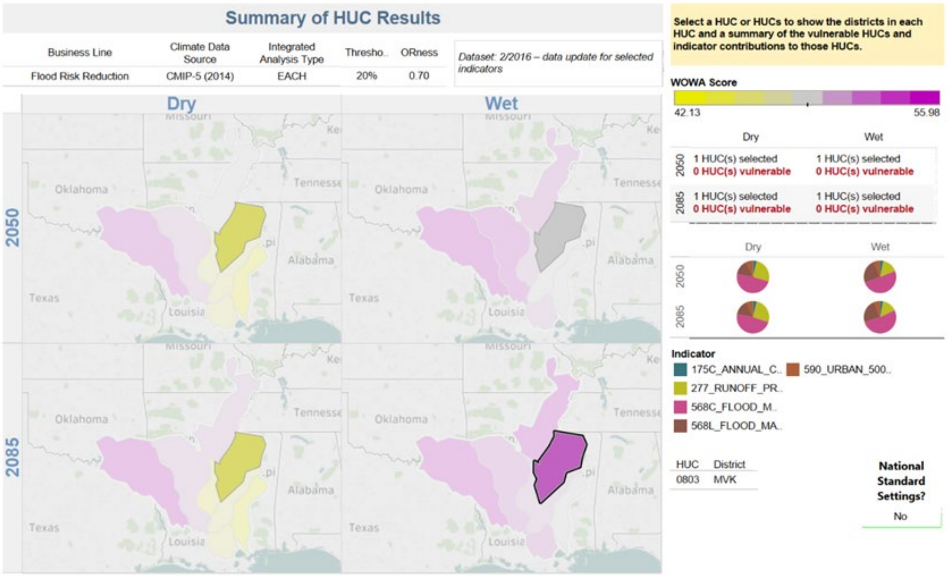

Figure A-28. The 0803 HUC Summary of climate risks for the Flood Risk Reduction business line.

Table A-7. The change in indicator value for the 568C flood magnification indicator from 2050 to 2085.

	Dry Scenario	Wet Scenario
2050	1.08	1.24
2085	1.09	1.35
Percent Change (2050 to 2085)	+1.37%	+9.46%

As shown in Figure A-3529, compared to the other 4-digit HUC watersheds in the CONUS, the Lower Mississippi-Yazoo (HUC 0803) watershed does not have a climate change vulnerability score in the top 20% for the ecosystem restoration business line. This is a comparative evaluation and thus does not imply that the watershed is not vulnerable to future, climate change impacts. Results indicate that for the select metrics incorporated into the tool, this watershed may be less exposed to potential climate change impacts relative to other watersheds in the CONUS. This is true for both the wet and dry subsets and both the 2050 and 2085 epochs. As can be seen in Figure A-3529 and Table A-8, the dominant indicator variable contributing to the Ecosystem Restoration business line VA score for the Lower Mississippi-Yazoo (HUC 0803) watershed is (8) At Risk Freshwater Plants for all epoch and subset combinations. The WOWA score changes by less than 1% between the 2050 and 2085 epochs for both the wet and dry subsets. The percentage by which the indicator variable contributes to the VA score does not significantly change overtime. Because this indicator variable is not dependent on computed, GCM based changes in future hydrology (temperature, precipitation, streamflow), this indicator variable value is constant overtime.

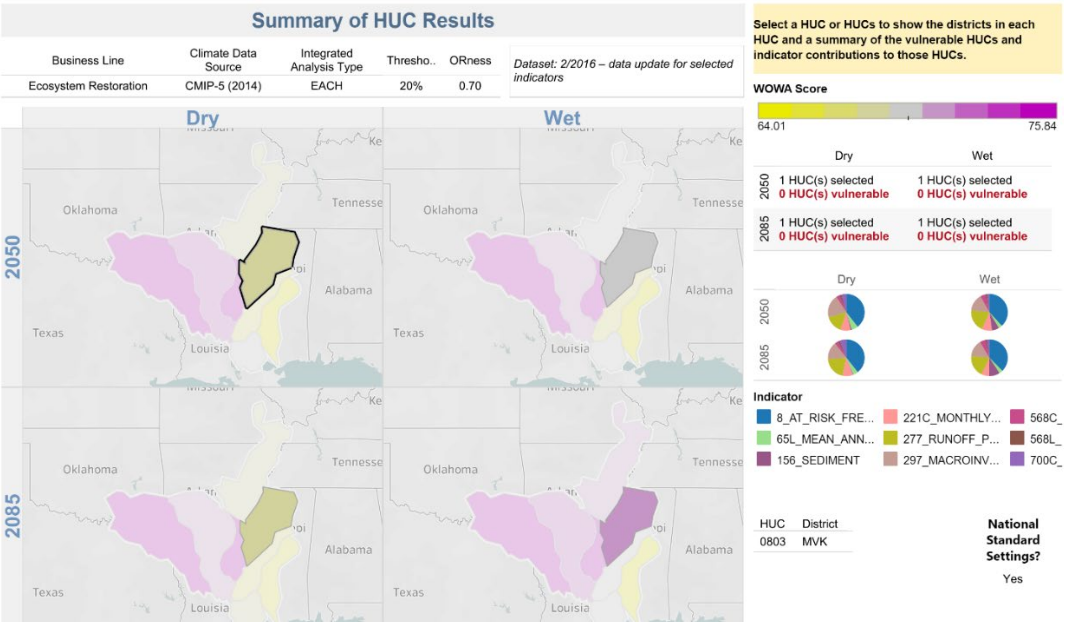

Figure A-35. Output of the Vulnerability Assessment tool - Lower Mississippi-Yazoo watershed

Table A-8. VA Tool Output- HUC 0803 Lower Mississippi-Yazoo Watershed- Ecosystem Restoration

Subset	Epoch	VA Score	% Change in VA Score (2050 to 2085)	Dominant Indicator	Dominant Indicator % Change (2050 to 2085)	
					Contribution to Overall WOWA Score	Indicator Value
WET	2050	69.56	+1.39%	8- At Risk Freshwater Plants	-0.70%	Constant Overtime
	2085	70.95		8- At Risk Freshwater Plants		
DRY	2050	67.97	+0.91%	8- At Risk Freshwater Plants	0%	Constant Overtime
	2085	68.88		8- At Risk Freshwater Plants		

CONCLUSION

The purpose of the Yazoo Backwater Area Water Management Project is to reduce flood risk within the YSA caused by high Mississippi River levels coincident with interior flooding within the YSA basin that often occurs during the spring. Additionally, the project seeks to improve aquatic habitat within the Big Sunflower River, a primary tributary of the YSA, by augmenting low flow conditions that typically occur during the fall through groundwater pumping. The project includes a 25,000 cfs pump station, structure and land acquisition through voluntary buyout, and installation of groundwater wells. Output based on both historic, observed hydrometeorological data and projected, climate-changed hydrometeorological data is reviewed to support qualitative statements about how to incorporate resilience to climate change impacts over the project's lifecycle.

Based on the weight of evidence presented in this assessment, climate change impacts are anticipated to affect the study area's hydrology over the project's 50-year life cycle. Findings from available climate change literature indicate the Lower Mississippi River Region has experienced an increasing trend in streamflow during the last century, a similar trend observed for the entire Mississippi River Basin. Trend analysis of the Mississippi River at Vicksburg, MS supports this increasing trend in streamflow, whereas analysis of the Big Sunflower River near Merigold, MS identified no significant trends in annual maximum or spring and fall mean streamflow. Regarding future streamflow, the literature lacks consensus in projected trends for the Lower Mississippi River Region (USACE, 2015). However, a 2019 study (USACE) analyzing climate model projections suggests future increasing streamflow and flow frequency on the Lower Mississippi River main stem at Vicksburg. The CHAT output for the Mississippi River main stem stream segment indicates a statistically significant increasing trend in high streamflow under RCP 8.5, but no statistically significant trends under RCP 4.5. No significant trends in future high streamflow were identified for the Big Sunflower stream segment.

Precipitation projections for the Lower Mississippi River Region suggest a mild increase in annual precipitation, but a strong consensus is lacking (USACE, 2015). Projected seasonal changes in precipitation are weak and vary. There is greater consensus that observed increases in the number of extreme precipitation events are projected to continue increasing in frequency and intensity for the study area. A projected increase in the magnitude of annual maximum 3-day precipitation is identified in the CHAT analysis for the Lower Mississippi-Greenville and Big Sunflower watersheds under both RCPs. Increased magnitude and/or frequency of extreme precipitation suggests the potential for increased frequency of flooding both on the Mississippi River and on the Big Sunflower. Although there is not strong consensus in projections of increasing streamflow on the Mississippi River main stem, the consensus in projections of increased magnitude and frequency of extreme precipitation provides more evidence of the potential for increased high streamflows on the Mississippi main stem, and on Big Sunflower, which could increase the number of days the Steele Bayou WCS is closed, resulting in an increased number of pump days in order to keep interior water levels at or below elevation 93’ NGVD29.

The current pump design and operation considered extreme flooding events for the Yazoo Backwater Area, both in magnitude and duration, including 2019, the current flood of record that reached just below the Mississippi River 0.5% AEP elevation. The 2019 flood was driven by both backwater and headwater flooding. Modeling of the proposed pump capacity and pump-on elevation constraint required 158 days of pump operation to maintain the interior WSEL objective during the 2019 flood, demonstrating the design is robust in handling higher magnitude and longer duration floods. The proposed pump operation further demonstrates climate change resilience by a capacity to manage interior water levels to accommodate an earlier crop season start date (March 16-October 15), influenced by warming temperatures. A robust pump station design demonstrates some resilience in the voluntary buyout footprint, defined based on the managed WSELs of 90’ and 93’ (NGVD29). Furthermore, adaptive management and monitoring will be conducted to evaluate changes in flow frequency that subsequently inform wetland delineation and managed interior water levels. The project’s Operation and Maintenance Manual will be adapted to reflect changing hydrologic conditions.

Since the cooling trend of 1960-1970, the YSA is now warming at an accelerated rate, and there is strong agreement in climate model projections that: air temperatures will increase; summer months will experience the greatest increase in air temperature; and daily minimum temperatures will also increase. In addition to projected increased extreme precipitation, there is also consensus in projected increased drought intensity driven by increased temperatures, ET rates, and soil moisture loss rates. CHAT results for annual mean daily temperature for both the Lower Mississippi-Greenville and Big Sunflower watersheds support these findings, indicating strong historic and future warming trends with a median change between the base epoch (1950-2005) and the mid-century epoch (2035-2064) means of 3.47-4.25 °F. Drought index (maximum number of consecutive dry days) results also show future increasing trends in the number of consecutive dry days for both watersheds. Increased ET rates and drought intensity driven by increased temperatures are likely to increase agricultural irrigation demands in the YSA. Increased withdrawals from the MRVAA to support rice and catfish production will further reduce baseflow conditions in the Yazoo Backwater Area tributaries as well as groundwater elevations.

Final sighting and design of low flow augmentation wells can incorporate resilience by locating wells close to the Mississippi River, a regional source of aquifer recharge. However, implementation of groundwater conservation efforts in the region, the need for which is well recognized, requires action beyond the scope of this project and are needed to ensure resilience of this project feature and resource. Final design of the low flow augmentation wells should consider results from recent MRVAA groundwater modeling efforts. Resilience can be incorporated into the conservation and reforestation efforts on acquired lands subject to frequent flooding by selecting species with tolerance to flooding and drought, both of which are projected to occur within the YSA.

Table A-Table A-9. Residual Risk Due to Climate Change

Project Feature/s	Trigger	Hazard	Harm	Qualitative Likelihood[1]	Justification of Likelihood Rating
Interior pump station & Structure and land voluntary buyout footprint & Conservation and reforestation plantings on acquired lands	Increased magnitude and frequency of extreme precipitation	Increased extreme precipitation results in Mississippi River backwater flooding and interior/headwater flooding that may produce higher magnitude floods that exceed the pump station capacity.	If pump station capacity is exceeded, interior flooding may exceed the project design elevations of 90' NGVD29 & 93' NGVD29 resulting in flood damages to areas outside of the voluntary buyout footprint.	Unlikely	There is strong evidence of increased frequency and intensity of extreme rainfall events that could increase backwater and headwater flooding in the YSA. However, pump design considered the 2019 flood of record (<0.5% AEP) and adaptive management and monitoring will inform changes to O&M resulting from changing flow frequency. Conservation and reforestation planting efforts select flood tolerant species for resilience.
	Increased (Mississippi River) flood magnitude	More frequent Mississippi River flooding may produce backwater flooding in the YSA and longer periods of gate closure that result in increased interior flooding that exceed the pump station capacity.		Unlikely	There is some evidence of increased Mississippi main stem flood magnitude in the future that could increase backwater flooding in the YSA. However, pump design considered the 2019 flood of record (<0.5% AEP) and adaptive management and monitoring will inform changes to O&M resulting from changing flow frequency. Conservation and reforestation planting efforts should select flood tolerant species for resilience.
	Increased (Big Sunflower) flood magnitude	More frequent interior/headwater flooding may produce higher magnitude floods that exceed the pump station capacity.		Unlikely	There is little to no evidence of increased Big Sunflower streamflow in the future to drive increased interior/headwater flooding in the YSA. Additionally, pump

<table>
<tr><th>Project Feature/s</th><th>Trigger</th><th>Hazard</th><th>Harm</th><th>Qualitative Likelihood[1]</th><th>Justification of Likelihood Rating</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>design considered the 2019 flood of record (<0.5% AEP) and adaptive management and monitoring will inform changes to O&M resulting from changing flow frequency. Conservation and reforestation planting efforts should select flood tolerant species for resilience.</td></tr>
<tr><td>Low flow augmentation groundwater wells</td><td rowspan="2">Increased air temperature and ET rates</td><td rowspan="2">Increased ET rates can increase soil moisture loss rates and result in intensified drought. Drought conditions will result in increased irrigation demands to support rice and catfish production in YSA. This would result in increased withdrawals from the MRVAA.</td><td rowspan="2">Increased withdrawals from the MRVAA could result in further impacts to groundwater levels, exacerbating the low tributary baseflow and impacting pumping rates in the low flow augmentation wells. Drought conditions could impact survivability of conservation and reforestation plantings.</td><td>Somewhat Likely</td><td rowspan="2">There is strong evidence of increasing temperatures that will impact ET rates and drought conditions in the Yazoo Backwater Area basin. This is likely to increase agricultural irrigation demands for rice and catfish production. Final sighting and design of low flow augmentation wells has not been completed, so recent groundwater modeling and projected climate change impacts to the MRVAA can be considered when establishing well locations and depths to improve resilience of this feature (i.e. sighting wells close to the Mississippi River). However, regional groundwater conservation efforts are needed to ensure resilience of the well feature. Conservation and reforestation planting efforts should include drought tolerant species in addition to flood tolerant species for resilience.</td></tr>
<tr><td>Conservation and reforestation plantings on acquired lands</td><td>Somewhat Unlikely</td></tr>
</table>

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