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Technical Assessment of the Old, Mississippi, Atchafalaya, and Red (OMAR) Rivers: Main Report

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Technical Assessment of the Old, Mississippi, Atchafalaya, and Red (OMAR) Rivers

Main Report

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Abstract

This is the main report of Old River, Mississippi River, Atchafalaya River, and Red River (OMAR) Technical Assessment. The primary objective of the OMAR Technical Assessment was to conduct a comprehensive evaluation that aimed to understand the impacts of former and potential changes to the system in the vicinity of the Old River Control Complex (ORCC) over time, the water and sediment delivery regime at the ORCC, and the effects to the river system surrounding the ORCC. Scenarios evaluated in this technical assessment were designed to investigate potential system responses to a wide range of possible operational alternatives and identify knowledge gaps in current understanding of system behavior. This report summarizes and synthesizes the individual reports detailing the investigations into specific aspects of the ORCC and the surrounding region.

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Preface

The investigation documented in this report was conducted for the US Army Corps of Engineers, Mississippi Valley Division (MVD), as part of the Mississippi River and Tributaries Project, under Project Number 478534. and published through the Mississippi River Geomorphology and Potamology (MRG&P) Program. At the time of publication of this report, the MRG&P program director was Dr. James W. Lewis. The MVD commander was MG Diana M. Holland, and the MVD director of programs was Mr. Edward E. Belk.

The work was performed by the Mississippi Valley Division, the New Orleans District, the River and Estuarine Engineering Branch of the Flood and Storm Protection Division, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL), and the Geotechnical Engineering and Geosciences Branch of the Geosciences and Structures Division, US Army Engineer Research and Development Center, Geotechnical and Structures Laboratory (ERDC-GSL). At the time of publication of this report, Mr. David P. May was chief of the River and Estuarine Engineering Branch, and Dr. Cary A. Talbot was chief of the Flood and Storm Protection Division; Mr. Christopher G. Price was chief of the Geotechnical Engineering and Geosciences Branch; Mr. James L. Davis was chief of the Geosciences and Structures Division. The deputy director of ERDC-CHL was Mr. Keith Flowers, and Dr. Ty V. Wamsley was the director. The deputy director of ERDC-GSL was Mr. Charles W. Ertle, II, and the director was Mr. Bartley P. Durst.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

1 Introduction

1.1 Background

1.1.1 Project features

The primary purpose of the Mississippi River and Tributaries (MR&T) Project is to reduce the risk of flooding in the alluvial valley of the Mississippi River. The MR&T features are intended to ensure the safe pass to the Gulf of Mexico of the project design flood, which is a hypothetical flood greater than any recorded flood. An additional purpose is to control the distribution of flow between the Mississippi and Atchafalaya Rivers at the latitude of Red River Landing, Louisiana.

The project design flood above the Old River Control Structure (ORCS) has a flow of 2,720,000 cfs[1,2]. At the latitude of Red River Landing, the project design flood is estimated at 3,030,000 cfs, of which 2,100,000 is being carried by the Mississippi River and 930,000 cfs is being carried by the Atchafalaya Basin. Of the 2,100,000 cfs flowing down the main river channel, 600,000 cfs are to be diverted to the Atchafalaya Basin via the Morganza Control Structure (MCS). Of the remaining 1,500,000 cfs flowing below the MCS in the Mississippi River, 250,000 cfs are to be diverted to Lake Pontchartrain and through the Gulf of Mexico through the Bonnet Carré Spillway (BCS), located approximately 25 mi above New Orleans. Figure 1 shows the map of the area of interest for this assessment.

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[1] For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

[2] For a full list of the unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 345-7, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

Figure 1. Location map.

The ORCS, one component of the MR&T, is a set of flow control structures located on the west bank of the Mississippi River between River Mile (RM) 316 and RM 304 above Head of Passes (HOP), approximately 50 mi northwest of Baton Rouge, LA, and approximately 35 mi southwest of Natchez, MS. The ORCS is made of three federal structures (Low Sill Structure, Overbank Structure, and Auxiliary Structure) and the Old River Lock and Dam, which provides navigation between the Mississippi and Atchafalaya Rivers. The terminology *Old River Control Complex* (ORCC) includes the ORCS plus the Sydney A. Murray, Jr., Hydroelectric Station. The primary purpose of the ORCS is to prevent the Mississippi River from changing its course to that of the Atchafalaya River. The ORCS accomplishes this by controlling the flows from the Mississippi River into the Atchafalaya River and Basin. The Flood Control Act of 1954 requires that the ORCS be operated to maintain the distribution of the total flow and sediment at the latitude of Old River at approximately the same proportions as would have occurred under the natural conditions existing at that time:

> It is equally important that the Atchafalaya receive its share of the sediments in order that scouring of its bed in the upper river will not be increased. The distribution of flow and sediment in the Mississippi and Atchafalaya Rivers is now in desirable proportions and should be so maintained. Control measures which will assure the maintenance of the present water-sediment relationship are needed. (US Congress 1954)

1950 was chosen as a reasonable Base year in evaluating the various interests involved preceding any remedial work and as the last year when stage discharge relations were obtained under high flow conditions. In that year, the total latitude flow was divided between the two rivers as 70% flowing down the Mississippi River and 30% percent down the Atchafalaya River (more information about the historical river behavior can be found in Volume 2 Geomorphic Analysis):

> The percentage of flow from the Mississippi River through Old River has increased from 17.0 percent in 1946 to 21.9 percent in 1950. This flow forms a part of the total flow passing the latitude of Old River, which was 30 percent down the Atchafalaya River and 70 percent down the Mississippi River in 1950 (Table 35, Appendix B). This division of flow is

> essentially constant through all stages. (Latimer and Schweizer 1951)

More information regarding the individual features of the system can be found in Appendix A.

1.1.2 History of significant events

This section provides a brief summary of the most important events that have impacted the interactions between the Old, Mississippi, Atchafalaya, and Red Rivers. For a more detailed account, see the references cited here. Also, these events occurred in the context of other natural and anthropomorphic changes with the watersheds, including tectonic activity, climatic variability, land use change, reservoir and levee construction, etc. Table 1 shows a timeline of the most important events affecting the Old, Mississippi, Atchafalaya, and Red Rivers, in chronological order. History demonstrates multiple adjustments in the management perspective. Some activities limited the amount of flow into the Atchafalaya River, such as the sill dams constructed at Simmesport in the late 1880s and current ORCS regulations. However, other events contributed toward expanding the amount of flow the Atchafalaya River could carry, such as the removal of the Red and Atchafalaya River rafts, major dredging, and the creation of the Whiskey Bay Pilot Channel in the 1930s and the closure of Atchafalaya distributaries in the 1950s and 60s. The 1927 and 1973 flood events are listed in the table due to their importance in influencing management decisions of the system, not because they are the only two significant floods.

Table 1. List of important events.

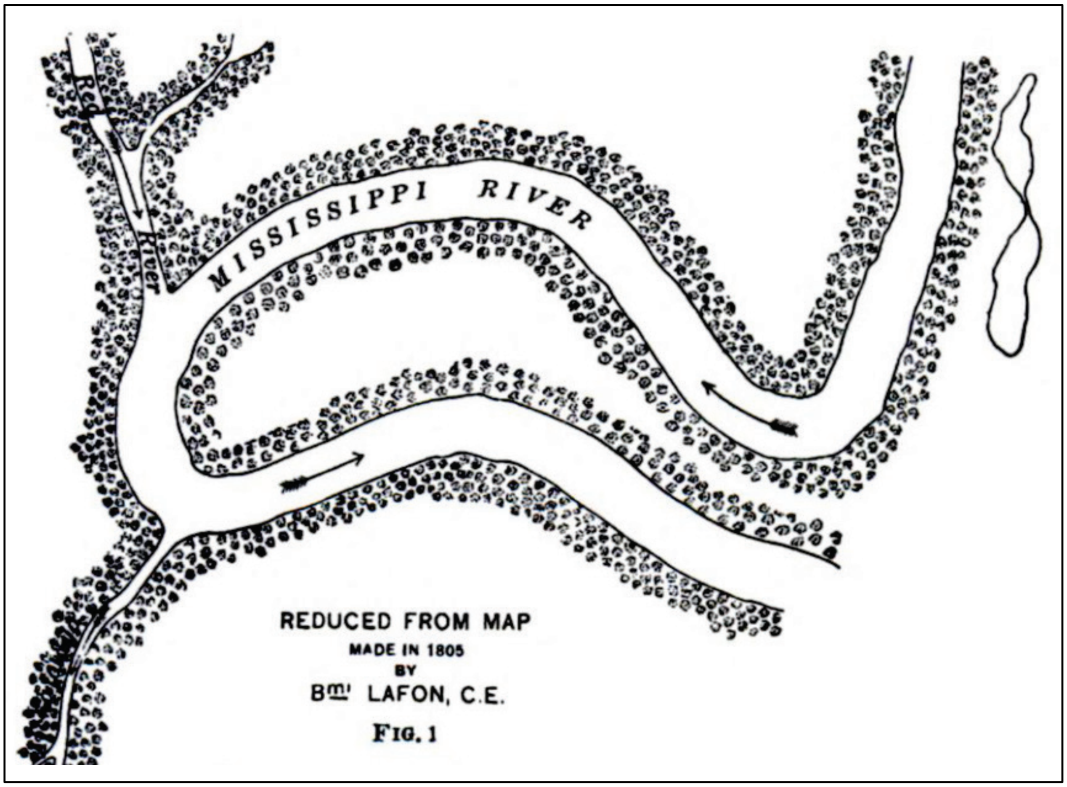
Description	Date	Citation
Atchafalaya River introduced	1500 A.D.	Fisk (1952. p. 58)
Homochitto cutoff on Mississippi River (approximately RM 322[1])	1776	Winkley (1977, p. 25)
Red River raft cleared by Henry M. Shreve (160 mi in length)	1830s	Reuss (1998 p. 26)
Shreve's cutoff on Mississippi River (approximately River Mile 303)	1831	Reuss (1998 p. 26)
Raccourci cutoff on Mississippi River (approximately RM 299)	1848	Winkley (1977, p. 25)
Removal of Atchafalaya River raft	1860	Reuss (1998, p. 33)
Dredging of canal connecting Lower Old and Mississippi Rivers	1878–1937	Mossa (2013)
Construction of two submerged sills at Simmesport (later abandoned)	1887–1888	Reuss (1998, p. 81)
1927 Flood	1927	Barry (2007)
Historical Cutoffs (14 artificial, 2 natural)	1929–1942	Winkley (1977)
Major Atchafalaya River dredging (including Whiskey Bay Pilot Channel and Wax Lake Outlet)	1932–1948	USACE (1982, Vol. 2, p. A-16) Reuss (1998, p. 153) USACE (1952, Vol. 2, p. 28)
Carr Point cutoff	1944–1945	Mossa (2013)
Closure of 22 Atchafalaya distributaries	1954–1968	USACE (1982, Vol. 2, p. A-17)
Low Sill, Overbank, and Lock Structures completed Old River flow moving through new channel Regulated to 1950 distribution (70/30)	1963	Reuss (1998); USACE (1982)
1973 Flood	1973	Reuss (1998); USACE (1982)
J. Bennett Johnston Waterway (series of locks and dams on the Red River)	1977 – 1994	Red River Waterway Commission (2016)[2]
Auxiliary Structure Completed	1986	Reuss (1998)
S. A. Murray, Jr., Hydroelectric Station completed	1990	USACE (MVN)

[1] All references to Mississippi River Miles are 1962 River Miles Above Head of Passes.

[2] https://www.redriverwaterway.com/sites/default/files/pdf/2016snapsotRRWW.pdf

According to Fisk (1952, p. 58), the Atchafalaya River began around 1500 AD as the Turnbull Bend of the Mississippi River migrated to the west. Figure 2 is a map taken from Reuss (1998) showing the Turnbull Bend of the Mississippi River with the Atchafalaya River in the southwest corner.

Figure 2. Map of Turnbull's Bend with Atchafalaya River in southwest corner (from Reuss [1998])



In the 1830s, a 160 mi long raft (a raft is a mass of limbs, tree trunks, and assorted debris bunched together, obstructing the river flow) was cleared from the Red River by Henry M. Shreve (Reuss 1998, p. 26). The clearing of this raft impacted hydraulic conditions, and likely sediment transport, in the Red River.

In 1831, a major cutoff was created in the Mississippi River by Henry M. Shreve (Reuss 1998, p. 26) near RM 303. The newly dredged channel cut off Turnbull Bend, which was a large meander that flowed to the west and back. The top and bottom of this large meander formed Upper Old River and Lower Old River.

In 1848, a manmade cutoff was created at Raccourci near RM 299, reducing the river length by approximately 19 mi (Winkley 1977). According to an 1851 Congressional report (as explained in Winkley 1977), the cutoff at Raccourci took several years to fully develop.

The removal of the Atchafalaya River raft was attempted several times, but it was not until the year 1860 that it was fully accomplished (Reuss 1998, p. 33). According to Reuss (1998, p. 78), this clearing of the Atchafalaya raft caused the river to carry increasing amounts of floodwater from both the Red and Mississippi Rivers.

From 1878 to 1937, dredging took place in the canal connecting the Lower Old River to the Mississippi River (Mossa 2013). Mossa hypothesized that this connection could have been severed by sediment deposition had it not been for maintenance dredging in that canal.

In 1887 and 1888, two submerged sills were constructed on the Atchafalaya River near Simmesport (Reuss 1998), though there is some discrepancy about the exact dates. Latimer and Schweizer (1951) similarly list 1888 and 1889 as the dates of construction completion, but Mossa (2013) stated that the dates of sill construction were 1896 and 1897. Six sills were proposed by MAJ Amos Stickney in 1883 (Reuss 1998, p. 78) to prevent further enlargement of the Atchafalaya River. The crests of Stickney's designed sill dams were just below low water except in the center of the channel where they would be low enough to allow navigation at all stages. The Mississippi River Commission (MRC) recommended the construction of the first two sill dams, and then in the 1890s, the MRC decided not to build the four others (Reuss 1998, p. 82). According to USACE (1982, Volume 2, p. A-16), these two sill dams were maintained until 1920 and then partially maintained until 1934. Latimer and Schweizer (1951) also list 1920 as the final maintenance by the US government, with maintenance of Sill Dam No. 1 continued by the Louisiana and Arkansas Railroad. At the time of the construction of the two sill dams, the MRC had also proposed severing the direct connection between the Red River and the Atchafalaya River with a dam. A sill dam was constructed in 1891 from Turnbull's Island westward to the mainland between the Red and Atchafalaya Rivers, to force low flows from the Red River through Upper Old River to the Mississippi (Latimer and Schweizer 1951). However, crews could not keep up with the dredging in the Old River channel, so the plans for the dam were discontinued, and part of the dam was removed in 1892 (Reuss 1998, p. 83). This structure was in poor condition by 1895 and appears to have been abandoned in 1896 (Latimer and Schweizer 1951).

The 1927 flood is the largest flood of record for many locations on the Mississippi River, producing massive flooding and several large crevasses (Barry 2007). Mossa (2013) hypothesized that the 1927 event enlarged the Lower Old River and resulted in significantly increased flows out of the Mississippi River. Although the data may indicate an acceleration of the proportion of flow through the Atchafalaya River in this time period, it is difficult to determine the amount of contribution from the 1927 flood event because there were several other major changes happening in the rivers at this time as described in the following paragraphs.

The MR&T Project began with the Flood Control Act of 1928, which brought a general shift in management toward increasing the system's efficiency in moving water. This included the efficiency of both the Mississippi and Atchafalaya Rivers as well as an increase in the portion of water that the Atchafalaya River would handle (USACE 1982).

Between 1929 and 1942, 14 cutoffs were constructed, and an additional 2 cutoffs occurred naturally (Winkley 1977; Reuss 1998, p. 149) in the Mississippi River. River cutoffs cause both immediate and long-term changes (Lane 1947), and the associated changes include both positive and negative effects. In general, the positive impacts can include shorter navigation routes and reduced upstream flood water surfaces. However, cutoffs also generally induce erosion upstream and additional sediment deposition downstream (Winkley 1977) along with other negative impacts such as increased risks of bank failure. The 16 cutoffs between 1929 and 1942 shortened the Mississippi River by 151.9 mi in total (Winkley 1977). This resulted in a reduction of the thalweg length from above the Hardin Cutoff to below the Glasscock Cutoff of nearly one-third (540 mi to 340 mi [Winkley 1977]). The Old River location is downstream of all 16 cutoffs, which ranged from RM 343 (Glasscock) to RM 678 (Hardin).

Major Atchafalaya River dredging commenced in the 1930s led by COL Ferguson (Reuss 1998; USACE 1982). This dredging included Whiskey Bay Pilot Channel and Chicot Pass from 1933 to 1937 (Reuss 1998, p. 153). Previously, the lower 70 mi of the Atchafalaya River was a braided network of bayous, lakes, and swamps, which were not very efficient in transporting sediment. Sediment deposition in the lower river caused flood water surfaces in the Atchafalaya River to rise (Reuss 1998, p. 147). More than 100,000,000 cy were dredged between 1932 and 1940 to create a single channel (250 ft bottom width and a bottom elevation of -40 ft NGVD) through the lower Atchafalaya River. In addition, the Wax Lake Outlet channel (15 mi long, 300 ft wide, -45 ft NGVD) was constructed in 1941–1942 (USACE 1982). The dredging of the 1930s also included the removal of the two sill dams near Simmesport (USACE 1982, Volume 2, p. A-16). This dredging represented a change in the management mindset, which had previously been aimed at preventing further Atchafalaya River enlargement. The proportion of flow carried by the Atchafalaya River increased significantly, and the Upper Atchafalaya River stages for a given discharge declined significantly during this time period. This trend of declining stages in the Upper Atchafalaya continued to the 1970s, as shown in more detail in Volume 2 of this report (Lauth et al. 2022).

In 1944, the Carr Point cutoff was constructed to shorten the connection between the Mississippi River and Lower Old River (Mossa 2013). The Carr Point cutoff shortened the local path from 5 km (3.1 mi) to less than 1 km (0.6 mi) (Mossa 2013). Shortly after this, the rapidly enlarging connection required revetments in 1949 and 1950 on both the upstream and downstream banks as the Mississippi River migrated westward (Fisk 1952).

From 1954 to 1968, a systematic program on the Atchafalaya River sought to increase the cross-sectional area of the river by confining the channel. This program closed 22 distributary streams, dredged larger cross-sectional areas, and placed dredged material along the riverbanks. Most of the work through this program was performed in the upper portions of the river, and relatively little work was done in the lower Atchafalaya River where the average channel area remains the smallest (USACE 1982, Vol. 2, p. A-17). Water surface elevations for given discharges in the Upper Atchafalaya River continued their significant decline through this time period and into the 1970s (Lauth et al. 2022, Volume 2 of this report).

Based on changing conditions at Old River and a definitive historical study (Latimer and Schweizer 1951), which concluded that the Mississippi River would shift to the Atchafalaya River, the Old River project was authorized by the Flood Control Act of 1954, Public Law 780, 83rd Congress, with reference to House Document 478, 83rd Congress, by the Chief of Engineers (US Congress 1954). The ORCS began as a combination of several features, including the Low Sill Structure, the Overbank Structure, the Old River Lock and Dam within the Lower Old River channel, earthen dams, earthen levees, bank stabilization, and a new outflow channel. The new outflow channel was constructed north of Upper Old River by dredging an abandoned river channel near Knox Landing. Altogether, these features were established to control the amount of flow from the Mississippi River to the Atchafalaya River. The flow was regulated to match the 1950 distribution of flow between the Mississippi River (70% of the latitude flow) and Atchafalaya River (30% of the latitude flow). *Latitude flow* is defined as the total flow in the Mississippi and Atchafalaya rivers at the latitude of Red River Landing.

The 1973 flood undermined and eroded the foundation material under a portion of the Low Sill Structure (USACE 1982; Reuss 1998). The south guide wall, or wingwall, on the inflow side of the Low Sill Structure collapsed into the river due to massive erosion. Since the repairs to the structure in the 1980s, the maximum head differential across the Low Sill Structure has been set to 22 ft, where prior to the 1973 flood the maximum head differential had been 35 ft (USACE 1954).

Motivated by the damages to the Low Sill Structure and the head differential limitation, the Auxiliary Structure was completed in 1986 to improve water and sediment control and to reduce the reliance on the Low Sill Structure (Reuss 1998, p. 245).

The construction of the J. Bennett Johnston Waterway in the Red River began in 1977[1] (Mossa 2016). The first lock and dam opened in 1984, and the final locks and dams opened in 1994. These structures impact the amount of sediment transported by the Red River.

The Sydney A. Murray, Jr., Hydroelectric Station, along with a newly created channel north of the Overbank Structure, was constructed in 1990 for power generation by a commercial enterprise (Mossa 2013). The hydroelectric station takes advantage of the head differential between the Mississippi and Atchafalaya rivers. The hydroelectric station is operated in coordination with the US Army Corps of Engineers (USACE), but it is owned through the Catalyst Old River Hydroelectric Limited Partnership, a subsidiary of Brookfield Renewable (Brookfield 2019). Since 1991, the

[1] https://www.redriverwaterway.com/sites/default/files/pdf/2016snapsotRRWW.pdf

hydroelectric station has accounted for most of the flow diverted through the ORCC (Heath et al. 2015). The hydroelectric station has a maximum capacity of approximately 170,000 cfs.

1.2 Motivation

A primary driver of this investigation is the observed, consistent trend of rising water surface elevations for given discharges within the Mississippi River (Echevarria-Doyle et al. 2020; Biedenharn et al. 2017), particularly between Natchez, MS, and Bayou Sara, LA, since the 1940s. Furthermore, the Flowline Assessment (Copeland 2018) revealed that the Mississippi River trend of rising water surfaces is projected to continue into the next 50 yr over an extensive length of the Mississippi River from HOP (RM 0) to Helena (RM 663). A technical assessment was needed to better understand how the water and sediment dynamics near the ORCS influenced rising water surfaces and whether potential operational changes would be beneficial.

In the Upper Atchafalaya River system, there has been an observed trend of declining water surface elevations for given discharges. This presents challenges such as channel erosion and bank failures for that part of the system. An assessment was needed to understand the recent and projected future stability and sensitivity of the Atchafalaya River system.

The combination of lower water surface elevations in the Atchafalaya River and rising water surface elevations in the Mississippi River also presents an operational challenge due to the increasing head differential across the ORCS. Specifically, the Low Sill Structure has a 22 ft head differential constraint, which has begun influencing operations more frequently in recent years. To address this constraint, at times more flow is temporarily passed through the Low Sill Structure to decrease the head differential.

Another operational challenge is related to increased water surface elevations at the MCS. The MCS takes flow from the Mississippi River when the river flow is greater than 1,500,000 cfs. The trend mentioned above of higher water surface elevations for given flows has impacted the stage elevation associated with this discharge threshold for MCS operation. With the stage-discharge relationship of recent years, a Mississippi River discharge of 1,500,000 cfs has an associated water surface elevation that is near the top of the MCS gates. Depending on conditions, water could be overtopping the structure at the threshold discharge. However, the gates are not able to be opened once water is over the top. For this reason, the water control manual was modified with interim standing instructions in 2014 (USACE 2014) to allow for the MCS to begin opening based on a reliable forecast of the threshold conditions. Projected continued rising water surface elevations (Copeland 2018) could exacerbate this operational challenge.

1.3 Objectives

The primary goal of the technical assessment is to conduct a comprehensive evaluation that aims to understand the impacts of former and potential changes to the system in the vicinity of the ORCS over time, the water and sediment delivery regime at the ORCS, and the effects to the river system surrounding the ORCS. The assessment will also model large portions of the four rivers both up- and down-stream of the ORCS. The assessment will inform management options for addressing sediment deposition, and it will support water control operations into the future.

To guide the assessment, 10 charge questions focused on particular aspects of performance of the ORCS and individual reaches were posed to the technical team. Those questions are detailed as follows:

1. How much sediment is currently being diverted through the ORCC?
2. How much sediment is being supplied by the Red River to the Atchafalaya?
3. How much water is stored in and released from the Red River backwater area during floods and how does operation of ORCC impact that volume?
4. What are the impacts of sedimentation on operation of ORCC and the MCS?
5. How much sediment could be diverted by USACE operations if the hydroelectric station was not operated?
6. How can water control operations be optimized to improve sediment transfer based on improved understanding of water flow and sediment transport in the system?
7. How much sediment must be diverted to bring the Mississippi at ORCC into dynamic equilibrium?
8. What is the sediment transport capacity of the ORCC combined outflow channel under a variety of potential operational schemes?

9. What are the long-term impacts (i.e., change in flowline) above and below ORCC on the Mississippi and Atchafalaya Rivers for the various operational and dredging management options evaluated?
    a. Operational management options to be evaluated will be based on technical operational constraints of the various structures and include scenarios that maintain the present 70/30 flow split as well as scenarios that modify the flow split.
    b. Dredging management options to be evaluated will include discharge downstream in the Mississippi River as well as discharge to bypass sediment to the Atchafalaya through the ORCC outfall channel and will consider continuous versus episodic dredging.
10. Are there potential structural solutions on either sides of ORCC that could facilitate sediment transport through the system?

The answers to these 10 charge questions will be provided over parts of the following sections. Section 1.4 will provide the framework the team established to address the charge questions. Section 1.5 establishes the spatial and temporal scales of the efforts. Section 2 gives an overview of the water and sediment movement through the system. Section 3.1 outlines the historic changes to the system identified in the geomorphic assessment (Volume 2). Section 4 explores the different numerical modeling, starting with the base condition and then explaining different alternative scenarios. Section 7 is a discussion of the results of the efforts, integrating the individual studies. Last, Section 6 presents the final conclusions, identifies data gaps, and provides recommendations on the path forward.

This effort is a part of the overall Old, Mississippi, Atchafalaya, and Red Rivers (OMAR) Assessment. Table 2 lists the series of reports associated with the overall project, with this report listed in bold font.

Table 2. List of reports included in the overall project.

Vol.	Report Name	Description
1	**Main Report**	Summarizes the entire project assessment
2	Geomorphic Assessment	Analyzes the historic trends in hydrology, sedimentation, and channel geometry of the river reaches of interest
3	Channel Geometry Analysis	Analyzes the hydrographic surveys over the past 6 to 7 decades
4	Mississippi River HEC-6T Model	Evaluate the long-term and system-wide sedimentation effects on the Mississippi River
5	Atchafalaya River HEC-6T Model	Evaluate the long-term and system-wide sedimentation effects on the Old, Atchafalaya, and Red Rivers
6	Mississippi River Multi-Dimensional Model	Evaluate the short-term effects on the Mississippi River
7	Red and Atchafalaya Rivers Adaptive Hydraulics (AdH) Model	Evaluate the short-term effects on the Old, Atchafalaya and Red Rivers
8	HEC-RAS Model	Investigate how water is stored in the Lower Red River floodplain
9	HEC-RAS BSTEM Analysis of the Atchafalaya River	Compare the relative impact of various scenarios on bank retreat in the upper portion of the Atchafalaya River

1.4 Approach

To address the 10 charge questions, six separate tasks were defined, each responsible for supporting synthesis of answers to the charge questions:

Task 1: Review of Past Studies and Data. This task consisted of a literature review on prior work on the system surrounding the ORCS and the ORCS itself. The task also included the collection of existing data to support the later tasks.

Task 2: Geomorphic Assessment. This task consisted of an analysis of geometric trends, specific gage trends, sediment carrying capacity, sediment dynamics (both sediment transport and in situ), historical events, and current field conditions to develop an understanding of the historical changes and existing trends of the system around ORCS.

Task 3: Field Data Collection. This task consisted of the collection of a variety of types of new data to support the ongoing effort. Data collection included the installation of a stage gage in the lower Red River near RM 28 (USGS site #073556009), collection of bed material samples on the

Atchafalaya, collection of bedload measurements around the system, bank sediment sampling, and other related data collection.

Task 4: Multidimensional modeling. This task consisted of the development of three different multidimensional numerical models to run different scenarios. The first model was a Delft 3D water and sediment model of the Mississippi River. The second model was a 2-dimensional (2D)/quasi-3-dimensional (3D) AdH (AdH with sediment library SEDLIB) water and sediment model of the Mississippi River from Natchez to Baton Rouge. The third model was a 2D/quasi-3D AdH/SEDLIB water and sediment model of the Red River, Black River, Old River Outflow Channel, and the Atchafalaya River.

Task 5: HEC-6T Modeling. This task consisted of the development of one-dimensional (1D) HEC-6T water and sediment models, one for the Mississippi River and one for the Red and Atchafalaya Rivers. The HEC-6T models are used to analyze long-term and system-wide sedimentation effects on either side of the ORCC. This included the testing of sediment diversion alternatives through operational and structural changes.

Task 6: HEC-RAS Modeling. This task consisted of the development of two different HEC-RAS models. The first RAS model was a combined 1D and 2D model to investigate the effects in the Red River backwater area. The second RAS model was developed to utilize the Bank Stability and Toe Erosion Model (BSTEM) to investigate lateral bank migration on the Atchafalaya River for various conditions.

1.5 Scales of interest

When discussing changes in riverine systems, it is important to define the scales of interest to establish common communication. This study covers a system-level analysis, and as such, emphasis was placed on the aggregate reach scale trends for reaches. These reaches were defined in part by some feature of hydraulic control (e.g., a confluence or distributary) and in part by stream gaging that made for a convenient evaluation point (e.g., the stream gage at Baton Rouge). Parts of individual tasks focused on individual geometric changes such as deepening downstream of a structure due to scour or lateral channel migration for a single cross section as indicators of change in system-wide performance.

Each task covered its own spatial extent based on the challenge questions that task answered. The cumulative spatial extent for all tasks reaches from Cairo to the Gulf of Mexico on the Mississippi River, from Fulton to Old River on the Red River, from Old River to the Gulf of Mexico on the Atchafalaya River, and all of the Inflow and Outflow Channels of the ORCC. In general, efforts subdivided these extents to reaches defined as the Mississippi River above the ORCS, the Mississippi River below the ORCS, the ORCC inflow and outflow channels, the Red River, and the Atchafalaya River.

Setting temporal scales is also important as the movement of a grain of sediment occurs on a far different timescale than the movement of water through a large river. Given the focus on system-wide trends, the focus of this study is on identifying changes occurring over years to changes over decades. Again, each task and subtask was interested in a specific time period, based on each objective and data available. The cumulative temporal range for the tasks is from the 1880s to 2069.

1.6 Dynamic equilibrium

An important concept within the framework of natural channel reach stability is that of *dynamic equilibrium*. Dynamic equilibrium is the idea that the fluxes of sediment entering and exiting a reach are approximately in balance, and thus, the system is not, as a trend, storing or losing sediment. This results in relatively consistent trends in stage and discharge for the reach and, thus, a conceptualized stability. Within the reach itself, significant sediment transport or sediment location adjustment may be taking place, but the changes in the bed and banks are counteracting each other so that the overall trend reflects little change to the overall reach hydraulic parameters. Natural channels are constantly adjusting towards a dynamic equilibrium condition while at the same time regularly undergoing perturbations that would redefine what that dynamic equilibrium condition would be. As such, dynamic equilibrium is an idealized trend dependent on the period of analysis and reach length, as in reality a perfect balance is never reached or maintained.

2 Conceptual Water and Sediment Movement

Figure 3 shows a conceptual diagram of the average water movement through the system while Figure 4 shows a conceptual diagram of the coarse sediment (i.e., sand and gravel particles > 0.0625 mm in diameter) movement. To maintain the 30/70 split in latitude flow, the fraction of the Mississippi River discharge diverted through the ORCC is varied as needed to balance the relative inflows from the Mississippi and Red Rivers. The sediment estimates are based on available data for the time period 1998–2014 plus bedload estimates derived using the ISSDOTv2 method, as tabulated in Appendix B. Coarse sediment is the dominant component of riverbed sediments, and its transport and storage determines long-term changes in the channel invert. Sediments finer than 0.0625 mm can be important farther downstream near the Gulf of Mexico but are not a primary driver of geomorphic change in the area of interest. A more in-depth evaluation of the suspended sediment movement through the system can be found within Volume 2 of this report (Lauth et al. 2022). All the values shown in Figure 3 and Figure 4 represent the percentage of the total latitude amount of water (Figure 3) or sediment (Figure 4) moving through the system. Specifically, the value at Old River represents the percentage of the total flow (Red River + Mississippi River) and not the fraction of the Mississippi River alone.

Figure 3. Conceptual water movement through area of interest.

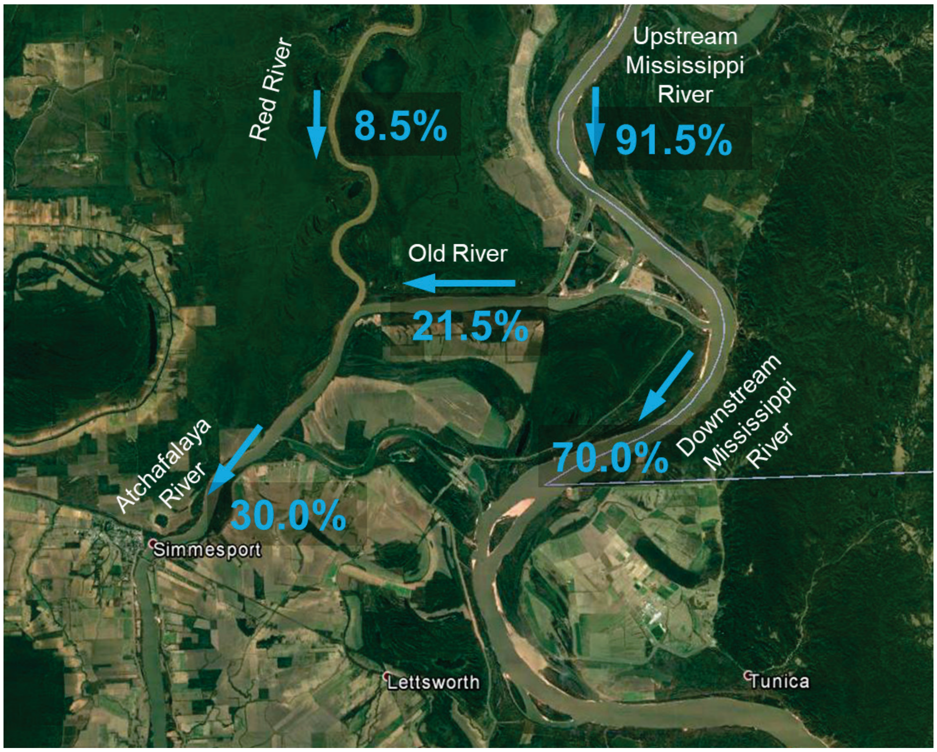
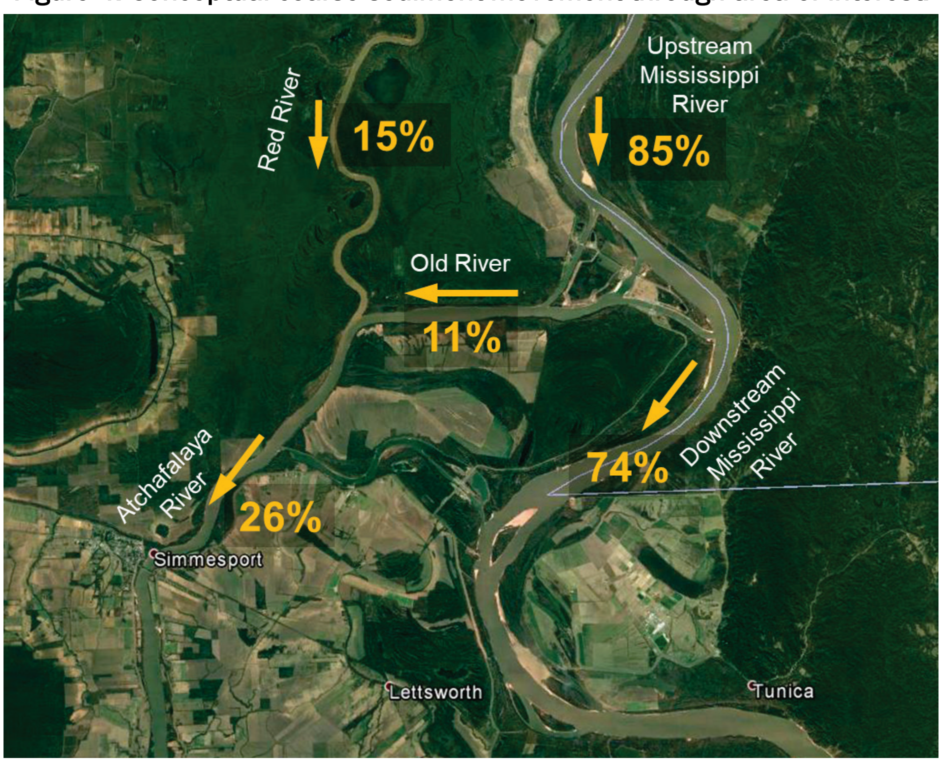


Figure 4. Conceptual coarse sediment movement through area of interest.



3 System Changes – Geomorphic Assessment Findings

A detailed geomorphic assessment was developed for the rivers within the OMAR study reach to document the historical trends of the channels that have led to the present condition. This geomorphic assessment consisted of multiple different analyses, all documented in Volume 2, Geomorphic Assessment report.

The reaches evaluated for the geomorphic assessment were the Mississippi River from Vicksburg to ORCC, the Mississippi River from ORCC to Baton Rouge, Upper Old River from ORCC to the end of the Outflow Channel, the Atchafalaya River from Old River to the Whiskey Bay Pilot Channel, and the Red River from Alexandria to the Atchafalaya River.

The different analyses of the geomorphic assessment were integrated into general findings for each geomorphic reach. These general findings follow.

3.1 Mississippi River reach – Vicksburg to ORCC

The overall trend for this reach has been slightly aggradational. The geometric trends suggest that the reach has been between aggradational to dynamic equilibrium for significant lengths of the analysis period. The specific gage analysis shows increasing stages for the gage record, except for a period immediately following the channel cutoff program and a period of little change during the drought years of the 1950s to 1970s. The stage duration analysis, while subject to many other drivers, does fit with a pattern of increasing stage duration outside of the periods listed above.

3.2 Mississippi River reach – ORCC to Baton Rouge

The reach from ORCC to Baton Rouge has been slightly aggradational. The geometric trends suggest that the reach has been at times aggradational, slightly aggradational, or at dynamic equilibrium during the analysis period. The specific gage analyses show increasing stages for the gage record back to the 1940s. The trends show the system becoming less aggradational starting in the 1970s; this is supported at the lower flows for the different specific gage analyses. There is a jump in the specific gage records in the 1970s, but this corresponds to the historic 1973 flood and not a construction event or operations change at ORCC.

The analysis of stream power shows a significant drop downstream of the ORCC, suggesting a loss of carrying capacity for sediment downstream of the distributary connection. This drop in stream power is not based purely on flow diversion, as changes in slope and flow contribute nearly equally to the drop in stream power. Even without the ORCC diverting flow, the Mississippi River has a loss of stream power from the decreased slope through this reach. This approximate analysis of stream power assumes a uniform channel; in reality, there are geometric changes in the channel shape (such as width and depth) that would also influence the sediment carrying capacity.

3.3 ORCC and the ORCC outflow channel

The ORCC outflow channel had been degradational. This process has been slowing to the point of potentially reaching dynamic equilibrium or becoming aggradational, according to the geometric analysis. The specific gage analysis for the Old River Outflow Channel gage lacks sufficient points in the recent past to make a clear determination but could be understood to support this trend as well.

3.4 Atchafalaya River reach – Old River to Whiskey Bay Pilot Channel

The general trend for the Atchafalaya River for the reach upstream of the Whiskey Bay Pilot Channel is that the Atchafalaya went through a period of significant degradation but has been approximately in dynamic equilibrium since the 1980s. This is demonstrated in the geometric analysis, which finds geometric trends either slightly aggradational, slightly degradational, or at dynamic equilibrium for the current analysis period (1976 on). When compared to the data from the Latimer and Schweitzer study (Latimer and Schweitzer 1951) of Atchafalaya River geometry trends, this shows a significant slowing of channel degradation. The specific gage analysis confirms this trend of declining stages until the early 1980s, when the system approximately reaches dynamic equilibrium. The stage duration plots support this trend as well, with a decreasing stage for earlier periods but with more recent periods plotting nearly on top of each other. Revetment was placed in this reach of the Atchafalaya starting in 1954 and continuing until 2011, reducing the possibility of lateral channel migration and driving the channel towards vertical change if it needed to adjust. An analysis of boring logs in close vicinity to the channel suggest that the bed of the Atchafalaya has not reached a non-erodible layer and should still have the ability to deepen if needed, further supporting the trend of dynamic equilibrium.

3.5 Red River reach – Alexandria to the confluence

Limited digital bathymetric data were available for the Red River reach at the time of this report, precluding an analysis of geometric trends. The specific gage records for the gages with measured flow data on the Red River show declining stages prior to the construction of the locks and dams as part of the J. Bennett Johnston Waterway. A synthetic specific gage analysis developed for the Black River at Acme gage (just upstream from the confluence with the Red River) suggests that the reach below Red River Lock and Dam #1 (L. C. Boggs Lock and Dam) had declining stages past the lock and dam construction until a point early in the 2000s. The specific gage trends are supported by the history of timber raft removal and rock removal resulting in channel enlargement on the Red River. However, more analysis will be needed before a confident assessment of the geomorphic trends on Red River can be presented.

4 Scenarios

This section explains the simulations that were performed in the numerical modeling analyses. As described in the Approach section of this report, there were multiple numerical modeling tasks. The following list in Table 3 summarizes the numerical models.

Table 3. List of numerical models used.

River(s)	Software	Dimensions	Model Extents
Mississippi	AdH/SEDLIB	2D/quasi 3D	Natchez to Baton Rouge
Red and Atchafalaya	AdH/SEDLIB	2D/quasi 3D	Acme and Red River Lock and Dam 1 to Melville
Mississippi	Delft 3D	3D	Natchez to Baton Rouge
Mississippi	HEC-6T	1D	Cairo to the Gulf
Red and Atchafalaya	HEC-6T	1D	Confluence of Red and Black Rivers to the Gulf
Mississippi, Red and Atchafalaya	HEC-RAS	2D	Alexandria and Jonesville to the Gulf

Table 4 shows the entire list of hypothetical scenarios performed within this assessment. Some of the scenarios maintained the 70%/30% flow distribution between the Mississippi/Atchafalaya Rivers, respectively, while other scenarios analyzed how the system would respond to changes in the flow distribution. Some scenarios also considered dredging or structural options (e.g., dikes or weirs). These scenarios will be described in the following paragraphs. Some scenarios mention flushing, which is the process of scouring sediment from an individual structure's inflow channel by increasing the flow for a short period of time. More information about the scenario simulations can be found in volumes 4, 5, 6, 7, 8, and 9 of this report.

Table 4. List of hypothetical scenarios.

Scenario	Explanation
1	Base projection of continuing current operations (no flushing).
2	Base projection of continuing current operations (with flushing similar to how it happens now).
3	“Ratio 1,” as defined in Design Memorandum 17 (USACE 1980), specifies how much flow goes through the Auxiliary, Low Sill, and Overbank Structures for the range of possible flow conditions. There is no hydropower. This maintains 70/30.
4	“Ratio 1 with hydropower,” (as defined in Old River Control O&M Manual, 1988). Low Sill will not be used in this scenario. Anything that would go to Low Sill in the table of the O&M Manual will add to Auxiliary instead. This maintains 70/30.
5	60/40 during high flow, with 70/30 on long-term basis through water volume tracking.
6	80/20 during high flow, with 70/30 on long-term basis through water volume tracking.
7	Push all flow over 1.25 Mcfs at Tarbert Landing through ORCC, with 70/30 on long-term basis through volume tracking.
8A	Daily 80/20 without any constraints.
8B	Daily 80/20 with Low Sill head differential constraint.
9	Daily 60/40.
10	Maintain 70/30. Increase Auxiliary and decrease Hydropower, based on conditions.
Dredging Scenarios	
11 (M)	Mississippi River: Continuous dredging of the main channel in front of/near Low Sill with material removed completely from the Mississippi River.
12 (M)	Mississippi River: Annual dredging of the main channel in front of/near Low Sill with material placed back into the Mississippi River water column.
13 (M)	Mississippi River: Annual dredging of the main channel in front of/near Low Sill with material removed completely from the Mississippi River.
14 (M)	Mississippi River: Continuous dredging of bar across from hydropower entrance channel with material removed completely from Mississippi River.
11 (A)	Atchafalaya River: Permanent sediment increase just downstream of the hydropower outflow/Low Sill confluence (to represent continuous dredging).

Scenario	Explanation
12 (A)	Atchafalaya River: Permanent sediment increase into the deep spot of the Low Sill outflow channel (to represent continuous dredging).
13 (A)	Atchafalaya River: Sporadic placement of sediment just downstream of the hydropower outflow/Low Sill confluence (to represent annual dredging).
14 (A)	Atchafalaya River: Permanent sediment increase into the hydropower channel (to represent continuous dredging).
River Training Structure Scenarios	
15	Bendway weirs on right descending bank of the Mississippi River near the hydropower entrance channel.
16	Dike in the right descending floodplain area of the Mississippi River upstream of the hydropower entrance channel.
17	Four dikes in the right descending floodplain area of the Mississippi River near the individual Old River structures' channels.
18	Five spur dikes on left descending bank of the Mississippi River opposite from the Low Sill Structure.
19	Dikes near the confluence of Low Sill and Auxiliary outflow channels.
20	Dikes in the Old River outflow channel, just upstream of the confluence with the hydropower channel.

4.1 Base scenario

The purpose of the Base scenario is to simulate the system behavior for operations as they have occurred in the recent past and if they continued similarly into the future. The specified discharges for this scenario and each of the scenarios described in the following sections were calculated for the period 1990 through 2019 and provided to the modeling teams.

Since the computational demands of the multidimensional models (AdH/SEDLIB and Delft3D) were so high, the multidimensional models only simulated a selection of representative years for analysis. In particular, the AdH/SEDLIB and Delft3D models used 2008 to represent a high water year, 2012 to represent a low water year, and 2013 to represent a typical water year. More information about why these three water years were selected can be found in Volume 6, the OMAR Mississippi River AdH/SEDLIB Model Report.

Scenario 2 is a slight variation of the base scenario focused on simulating the effects of flushing. Flushing is an important process aimed at mobilizing sediment that has accumulated in the Auxiliary Entrance Channel through the Auxiliary Structure. Only the Mississippi River AdH/SEDLIB model performed Scenario 2.

4.2 Hypothetical flow adjustments

Scenarios 3 through 10 are described in this section and are focused on analyzing the system conditions for changes in the flow regulation through the ORCC. The ORCC is currently regulated to maintain the 70/30 distribution unless there are any operational or emergency constraints. Scenarios 3, 4, and 10 will maintain the daily 70/30 regulation, only changing which structures to pass the flow. Scenarios 5, 6, and 7 will adjust the flow distribution for temporary periods of time but still maintain the 70/30 distribution on a long-term basis. Last, Scenarios 8 and 9 will adjust the daily regulation to be different from 70/30.

Scenario 3 has flow only passing through the USACE structures (i.e., no flow through the hydroelectric plant). Additionally, it is a specific scenario known as “Ratio 1” that was evaluated during previous physical modeling experiments (USACE 1980). It defines how much flow goes through the Auxiliary, Low Sill, and Overbank Structures for the range of possible flow conditions. Scenario 3, labeled “R1,” will be used to analyze how much sediment would pass through ORCS and how the system would respond if only the USACE structures were used.

Scenario 4, is known as “Ratio 1 with hydropower” and comes from the Water Control Manual (USACE 1988). Scenario 4 is labeled “R1WH.” The difference from Ratio 1 (Scenario 3) is basically that the flow prescribed for the Low Sill Structure in Ratio 1 goes through the hydroelectric plant in Scenario 4. For implementation in this investigation, Scenario 4 includes no flow through the Low Sill Structure.

Scenario 5 is intended to adjust the latitude flow distribution to 60/40 during high flow scenarios and maintain the long-term 70/30 balance by tracking the water volumes in both the Atchafalaya and Mississippi Rivers. Scenario 5 is labeled “HF6040.” When developing this scenario, a threshold discharge of 1 Mcfs at Tarbert Landing was used as the definition of high flow. During the rise of an event, when the flow at Tarbert Landing reaches 1 Mcfs, it will maintain 1 Mcfs for the transition going from 70% to 60%, and then it will continue rising such that Tarbert

Landing carries 60% of the latitude flow for any higher flows. When the 60% flow drops back to 1 Mcfs, it will maintain 1 Mcfs for the transition back to 70%. Daily water volume differences from the 70/30 balance were tracked as a deficit. Any days where there exists a deficit and the flow is below 1 Mcfs, the flow distribution will shift by 3% (i.e., a balance of 73/27) until the deficit is back to zero. In some years, the deficit could grow quite large and would require multiple years to get back to zero. The largest deficit would have developed from the year 2019. If the 2019 conditions would have occurred in place of 1989, it would have required 10 yr to get the deficit back to zero.

Scenario 6 is intended to adjust the latitude flow distribution to 80/20 during high flow scenarios and maintain the long-term 70/30 balance by tracking the water volumes. Scenario 6 is labeled “HF8020.” For this scenario, a threshold of 300 kcfs at Simmesport is used to define high flow. During the rise of an event, when the flow at Simmesport reaches 300 kcfs, it will maintain 300 kcfs for the transition going from 30% to 20%, and then it will continue rising such that Simmesport represents 20% of the latitude flow. When the flow drops back to 300 kcfs, it will maintain 300 kcfs for the transition back to 30%. This scenario had an important constraint, the Low Sill head differential constraint, that actually limited the flow from ever getting down to 20% in the Atchafalaya River. For each time-step, the head differential constraint was calculated as described in Appendix C. The flow distribution was limited such that the head differential stayed below 22 ft. Similar to Scenario 5, daily water volume differences from the 70/30 balance were tracked as a deficit and resolved with a 3% shift (i.e., a balance of 67/33) until the deficit was back to zero.

Scenario 7 is intended to manage high flood events by putting extra flow into the Atchafalaya River instead of using the BCS or the MCS. In this scenario, any flow that would cause the Tarbert Landing discharge to exceed 1.25 Mcfs (threshold for BCS) is put through the ORCS instead of through BCS or MCS. Scenario 7 is labeled “CTAR125.” The head differential was computed similar to Scenario 6. However, in addition to limiting the differential head to not exceed 22 ft, Scenario 7 also considered a head differential that approached zero. A differential of zero would indicate that no more flow can be put through the ORCS. For 1990–2019, a differential near zero was calculated for the hypothetical scenario only in the years 2011 and 2019; for these 2 yr, the flow past Tarbert

Landing was increased beyond 1.25 Mcfs. Similar to Scenarios 5 and 6, daily water volume differences from the 70/30 balance were tracked as a deficit and resolved with a 3% shift (i.e., a balance of 73/27) until the deficit was back to zero.

Scenario 8 adjusts the daily regulation such that the Atchafalaya River receives 20% of the total flow at the latitude of Red River Landing and the Mississippi River receives 80% of the flow. This scenario had two subcategories according to whether the Low Sill head differential constraint was considered or not. Scenario 8A does not abide by the head differential constraint, causing head differentials to exceed 22 ft. Scenario 8B limited the head differential constraint to 22 ft.

Scenario 9 adjusts the daily regulation of flow to be 60% down the Mississippi River and 40% down the Atchafalaya River.

Scenario 10 puts more flow through the Auxiliary Structure similar to flushing operations. There are a couple of constraints that limit the flushing operations. First, no flushing is allowed in April, May, or June for Pallid Sturgeon spawning. Second, flushing cannot cause channel bank instability, so flushing can only happen when Knox Landing is below 40 ft (elevation of revetment). Therefore, Scenario 10 checked the month and estimated Knox Landing stage. Whenever these two constraints allowed for flushing, Scenario 10 limited the amount of flow through the hydropower plant to be one-third of the total ORCC flow and passed the rest through the Auxiliary Structure.

Figure 5 shows a time series of the ORCC discharge for the Base and the hypothetical scenarios for 2011. Figure 6 shows a bar chart of the average flow through each structure of the ORCC for the full time period 1990 to 2019. Figure 7 shows the percentage of time flow is exceeded at Tarbert Landing.

Figure 5. Time series of 2011 flows through ORCC for hypothetical scenarios.

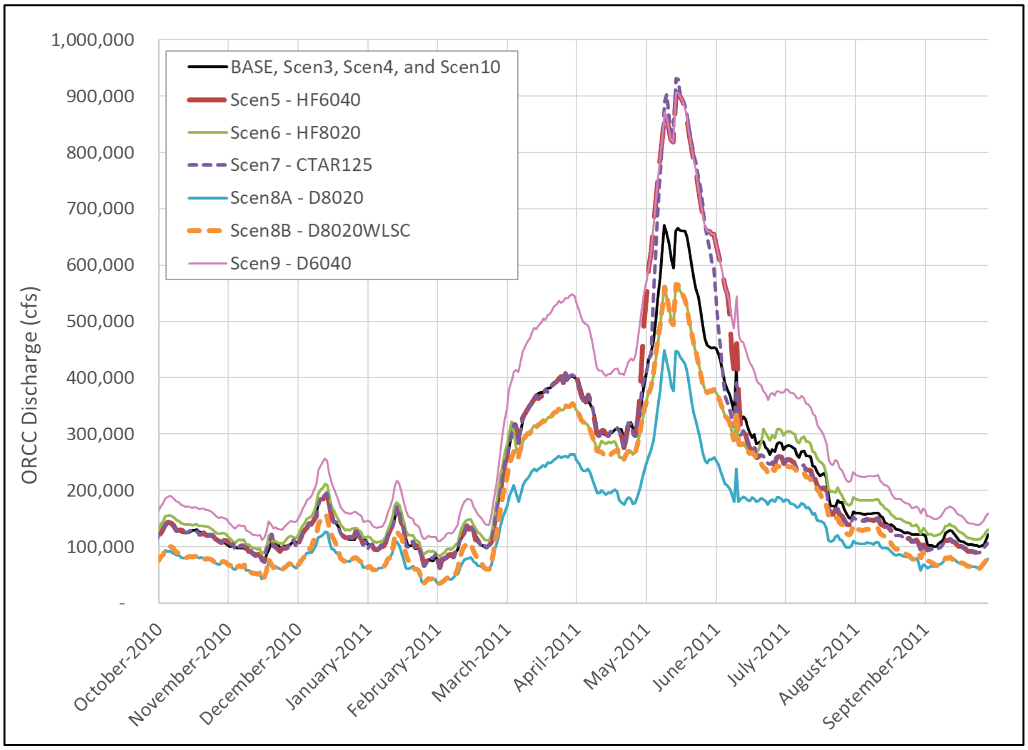


Figure 6. Average flows through each structure for hypothetical scenarios.

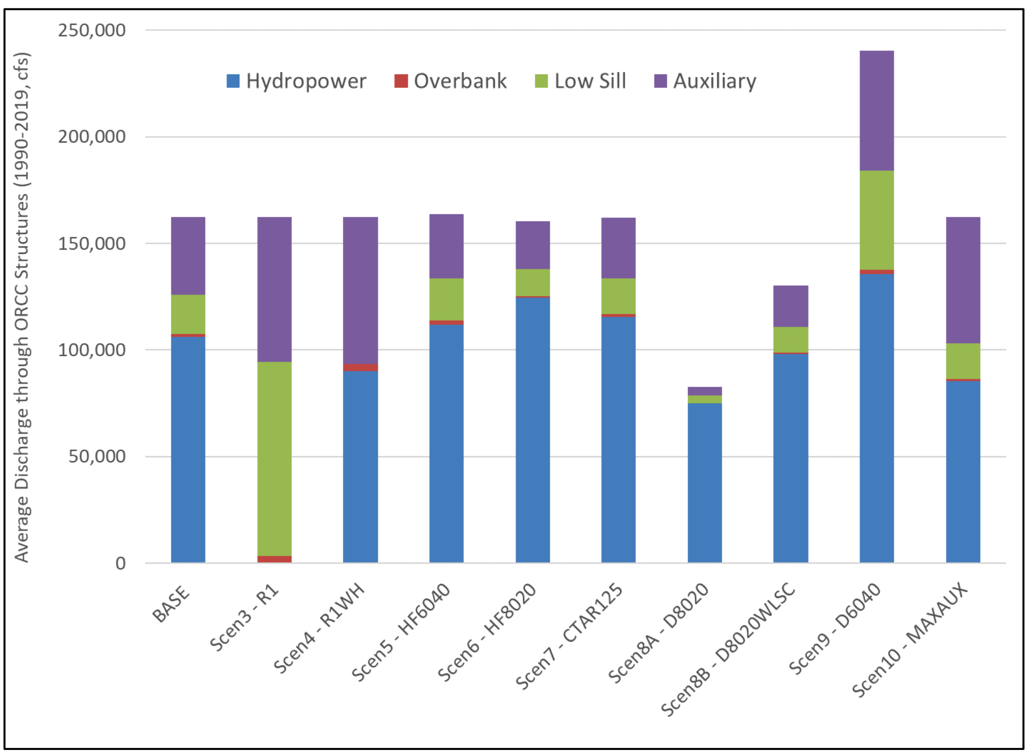
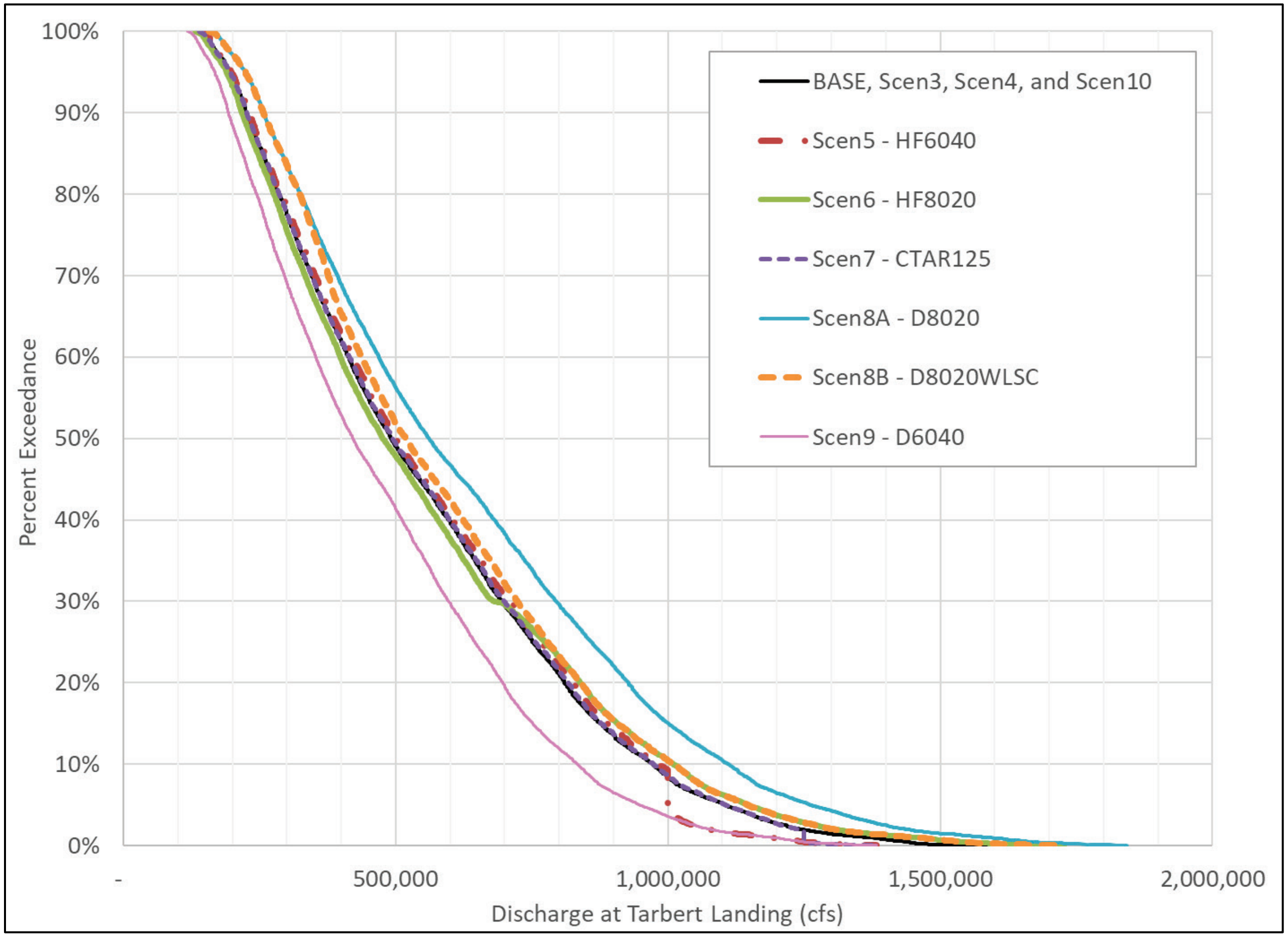


Figure 7. Percentage exceedance discharge at Tarbert Landing for hypothetical scenarios.



4.3 Hypothetical dredging

The assessment also considered several scenarios that introduced hypothetical dredging near ORCC. The purpose of the dredging scenarios was to evaluate how the river system would respond to the mechanical movement of sediment. An additional purpose was to compare whether the movement of sediment by operational flow adjustments had a similar result as mechanical movement. For this reason, the volume of sediment to be dredged in these hypothetical scenarios was based on the difference in sediment transported between the Base and Scenario 3 – “Ratio 1.”

The multi-dimensional models considered four different dredging scenarios on each side of the complex. As listed in Table 4, the Mississippi River AdH/SEDLIB model examined Scenarios 11–14 by performing continuous or annual dredging (i.e., performing dredging every day or once a year) at locations near Low Sill or across the main channel from the hydropower plant’s entrance channel. The Red/Atchafalaya AdH/SEDLIB model examined Scenarios 11–14 by placing the material continuously or annually in various locations (i.e., introducing dredged material every day or once a year).

The Mississippi River HEC-6T model evaluated dredging with three scenarios: annual dredging placing the sediment back into the water column to move downstream, annual dredging removing the sediment from the Mississippi River, and continuous dredging removing the sediment from the Mississippi River. The Red/Atchafalaya HEC-6T model evaluated one dredging scenario, bringing in a continuous/daily amount of dredged material matching the amount removed from the Mississippi River model.

4.4 Hypothetical dike and weir scenarios

Hypothetical structural scenarios were also considered on both the Mississippi and Red/Atchafalaya sides of the complex. The Mississippi River AdH/SEDLIB model evaluated four structural scenarios, Scenarios 15–18, which included bendway weirs, batture dikes, and channel dikes. Information related to these scenarios can be found in Volume 6. The Red/Atchafalaya AdH/SEDLIB model evaluated two structural scenarios (Scenarios 19 and 20), as can be seen in detail in Volume 7.

5 Discussion

The results of the technical assessment have provided the following answers to the initial charge questions stated in Section 1.3, Objectives. The charge questions are restated below, followed by the responses. Results from all of the analyses and scenario simulations can be found in more detail in Volumes 2 through 9 of this report.

5.1 Sediment delivered through Old River

1. How much sediment is currently being diverted through the ORCC? Results from multiple tasks are relevant in answering this question. The geomorphic assessment (Volume 2) states the fine sediment load (i.e., silt and clay particles less than 0.0625 mm) is approximately 17 to 34 million tons per year (Mtons/yr). The estimated coarse sediment load is 2.5 to 7 Mtons/yr, with an average of approximately 5 Mtons/yr.

Utilizing sediment rating curves from the available suspended and bed-load data provides an estimate of approximately 5.5 Mtons/yr of coarse sediment moved through ORCC. Numerical models highlight an important distinction: the amount of sediment drawn from the Mississippi River is significantly higher than the amount of sediment that actually makes it all the way through the structures, particularly the Auxiliary Structure. The design of the Auxiliary Structure described in Design Memorandum 17 (USACE 1980) also shows an awareness of this process. For example, the AdH/SEDLIB model simulations estimate an average coarse sediment load pulled off the Mississippi River of 9.6 Mtons/yr whereas the model simulations estimate an average coarse load diverted through the structures of only 4.5 Mtons/yr. The difference between those values (5.1 Mtons/yr) is stored in the Auxiliary Entrance Channel. If this stored sediment is mobilized via flushing or future events, it eventually passes through the structures. However, if it is dredged and placed in the Mississippi River, it does not. HEC-6T estimates for the future 50 yr show that the coarse sediment load through ORCC is projected to be 6.2 Mtons/yr on average.

Answer: The amount of coarse sediment moving through ORCC is approximately 5.5 Mtons/yr on average. This represents approximately 13% of the coarse sediment coming from upstream in the Mississippi River, or this is also approximately 11% of the combined amount of coarse sediment coming from both the Red and Mississippi Rivers together (Figure 4).

5.2 Sediment delivered by the Red River

2. How much sediment is being supplied by the Red River to the Atchafalaya? The geomorphic assessment in Volume 2 states that there is a large amount of uncertainty in the sediment data in the Red River. Analysis of the measured data suggests that the coarse sediment supplied by the Red River is slightly greater than that from the ORCC. Even after the J. Bennett Johnston Waterway was constructed, the proportion of coarse sediment supplied by the Red River is still greater than the proportion of water supplied.

Answer: Sediment rating curves provide an estimate of approximately 7 Mtons/yr on average coming from the Red River, or approximately 15% of the combined upstream Mississippi River plus Red River coarse sediment load.

5.3 Water storage in Red River backwater area

3. How much water is stored in and released from the Red River backwater area during floods and how does operation of ORCC impact that volume? Results of the HEC-RAS model discussed in Volume 8 show that a significant volume of water flows into the floodplain storage areas along the Lower Red River.

Answer: Water starts flowing into these storage areas when the Simmesport discharge reaches approximately 400,000 cfs. As the Simmesport discharge increases to 600,000 cfs during the rise of an event, the flow into storage reaches approximately 60,000 cfs into the West Storage Area plus approximately 15,000 cfs into the East Storage Area. Near the peak of the event, the storage areas become balanced with the channel. After the peak of the event, water will reverse directions and flow out of storage areas back into the main channel of the Red River.

5.4 Impacts of sedimentation

4. What are the impacts of sedimentation on operation of ORCC and the MCS? The geomorphic analysis (Volume 2) specific gage data suggest long-term trends of stage increases in the Mississippi River between ORCC and Baton Rouge at the higher flows in the vicinity of the MCS. Note that these long-term stage increases are the result of a number of factors, such as sedimentation and changes in overbank roughness (May et al. 2021).

The HEC-6T projections show that the water surfaces are expected to continue gradually increasing on the Mississippi River. The model shows that ORCC operational adjustments do not impact this trend, indicating that ORCC is a small influence compared to other system dynamics.

Answer: The past and projected increases in Mississippi River water surfaces from a variety of factors cause an increase in the differential head at the Low Sill Structure. This gradually requires a more frequent adjustment of additional flow through the structure to satisfy the differential head limitation. The threshold discharge for operating the MCS is now associated with higher stages than when the structure was originally built. If the Mississippi River stages continue to increase, the risk increases of water reaching the top of the gates before the threshold discharge is realized.

5.5 Sediment diversion without hydropower

5. How much sediment could be diverted by USACE operations if the hydroelectric station was not operated? According to numerical model results, the amount of sediment passing through ORCS under the operation of Ratio 1 using only USACE structures would be more than passes through ORCC under current operations. The AdH/SEDLIB model showed that a wet year (such as 2008) can produce an increase of approximately 6.2 Mtons/yr of the coarse sediment through the structures, and a dry year can produce approximately a 1.6 Mtons/yr increase in coarse sediment passing through. The HEC-6T model showed an increase of approximately 2.6 Mtons/yr of the coarse sediment diverted on average over 50 yr (from 6.2 Mtons/yr in the base to 8.8 Mtons/yr for Ratio 1).

Geomorphic analysis suggests that diverting all flows through the Low Sill and Auxiliary Structures could increase the diversion of sands, possibly on the order of approximately 4.5 Mtons/yr. While this represents a large percentage increase in the amount of sand being diverted, this increased load is still small compared to the sand loads at

Union Point. Note that there is significant uncertainty in these results and that this hypothetical calculation is intended only to provide broad scale insight into the charge question.

Answer: The hypothetical calculation provides only broad insights, and there is significant uncertainty in these results. Subject to further analysis, it is possible that a change from current operations to Ratio 1 could increase the amount of coarse sediment passing through ORCC by approximately 1.6 to 6.2 Mtons/yr.

5.6 Water control operations for sediment transfer

6. How can water control operations be optimized to improve sediment transfer based on improved understanding of water flow and sediment transport in the system? A general way to increase the amount of sediment transported through ORCC is to increase the amount of water transported through ORCC. Changing the water distribution has an immediate effect on the hydraulics of the system and a slower response in sedimentation dynamics. For example, a change in operations to 60/40 would increase the amount of sediment diverted, reduce the amount of water flowing downstream in the Mississippi River and therefore reduce the stages in that area of the Mississippi River. However, that scenario would have a reduced stream power in the downstream Mississippi River that would cause a counteracting trend of gradually more water surface increase over a long period of time. An opposite effect would be experienced by the Atchafalaya River. Note that the Upper Atchafalaya River has been relatively stable in recent decades, and a change in sediment diversion could disrupt this regime.

According to the numerical modeling, hypothetical scenarios that make adjustments to the flow for part of the year and maintain the same 70/30 balance long term had limited impacts on diverted sediment loads and geomorphic response.

Answer: To increase the amount of sediment diverted, the two general options are to increase the amount of volumetric water flow diverted or shift a higher proportion of the flow to the Auxiliary and Low Sill Structures.

5.7 Dynamic equilibrium

7. How much sediment must be diverted to bring the Mississippi at ORCC into dynamic equilibrium?

Answer: The Mississippi River specific gage analysis exhibits a trend of increasing stages in this area for a long time due to broader system-wide processes. Numerical model projections indicate that this trend is likely to continue. Furthermore, even a large change such as moving to Ratio 1 operations would cause a small difference in water surfaces over the next 50 yr, and it would influence less than half of the projected water surface increase in the Mississippi River (see Volume 4). A hypothetical dredging scenario in the HEC-6T model shows that an annual removal of 8 Mtons/yr could be enough to counteract the sedimentation trend in this area.

5.8 Sediment transport capacity of Outflow Channel

8. What is the sediment transport capacity of the ORCC combined outflow channel under a variety of potential operational schemes? The HEC-6T model results (Volume 5) indicate a slightly aggradational trend in the Old River Outflow Channel for the base projection. For scenarios that increase the flow distribution through ORCC, the Old River Outflow Channel generally exhibits scour, increasing the carrying capacity. An increase of sediment without an increase in flow, such as during the dredge disposal scenario, would result in additional deposition within the Outflow Channel (on the order of approximately 5–7 ft additional bed change over 50 yr at the RM 3.76 cross section).

The Red/Atchafalaya AdH/SEDLIB model (Volume 7) results show large, localized sediment deposition under certain scenarios. In particular, scenarios that increase sediment loads could cause problematic deposition during relatively dry years, such as 2012. Years with higher flow do not exhibit as much deposition in the Outflow Channel.

5.9 Long-term impacts

9. What are the long-term impacts (i.e. change in flowline) above and below ORCC on the Mississippi and Atchafalaya

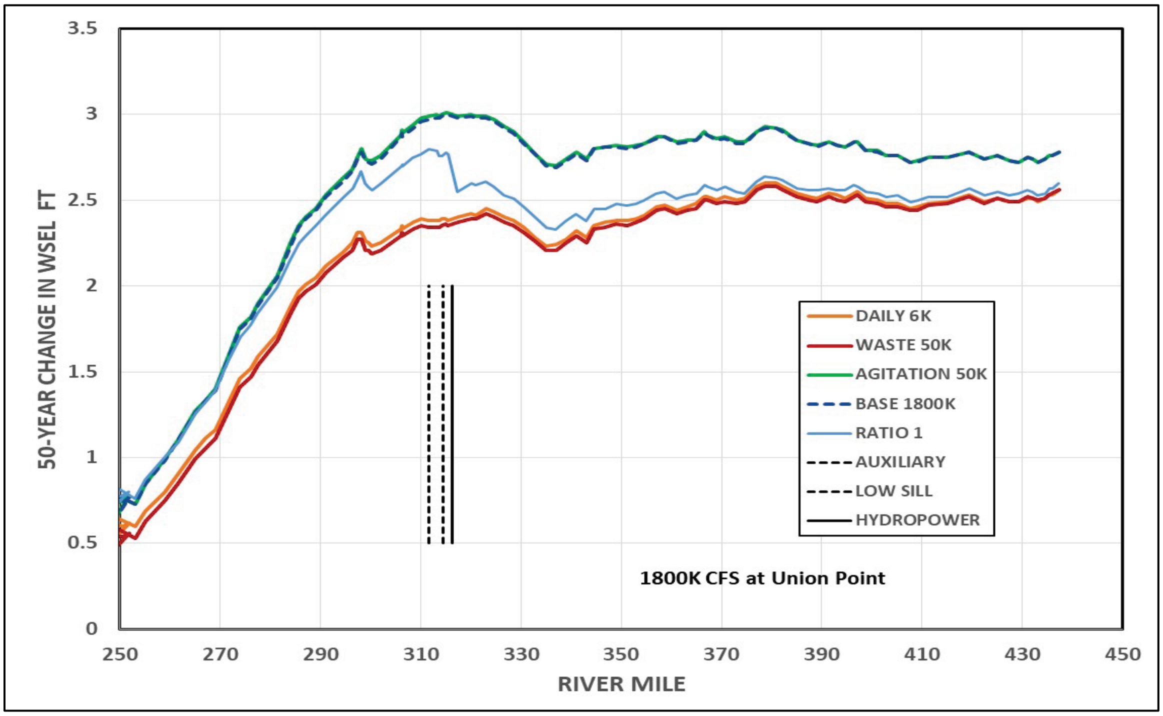
Rivers for the various operational and dredging management options evaluated?

Answer: The long-term impacts of the hypothetical scenarios are best estimated through the HEC-6T sediment models for the Mississippi and Red/Atchafalaya Rivers simulating 50 yr into the future, as described in the following subsections.

5.9.1 Water surface elevation changes

Figure 8 shows the long term 50 yr change in water surface elevations between RM 250 and RM 450 for a flow of 1,800,000 cfs coming from the upstream Mississippi River at Union Point. From this, it is evident that the Base projection is approximately 3 ft higher than present conditions between RM 310 and RM 320. Performing the hypothetical Scenario 3 – Ratio 1 operations over the next 50 yr would have a slightly lower water surface than the base projection, approximately 0.5 ft lower in some locations. The figure also shows interesting information about the dredging scenarios. If the dredged material is put back into the water column to be carried downstream, which is commonly done with in-channel dredging due to a much lower cost, this will have no change on the long-term water surfaces. However, if the dredged material is removed from the Mississippi River, there would be a decrease in the long-term water surfaces at a similar magnitude as Scenario 3 – Ratio 1. This assessment considered dredging near the ORCC, but future analysis could consider whether the dredging could be performed upstream with a similar result. There is a negligible difference between whether the dredging occurs once each year or if it is spread out to daily dredging.

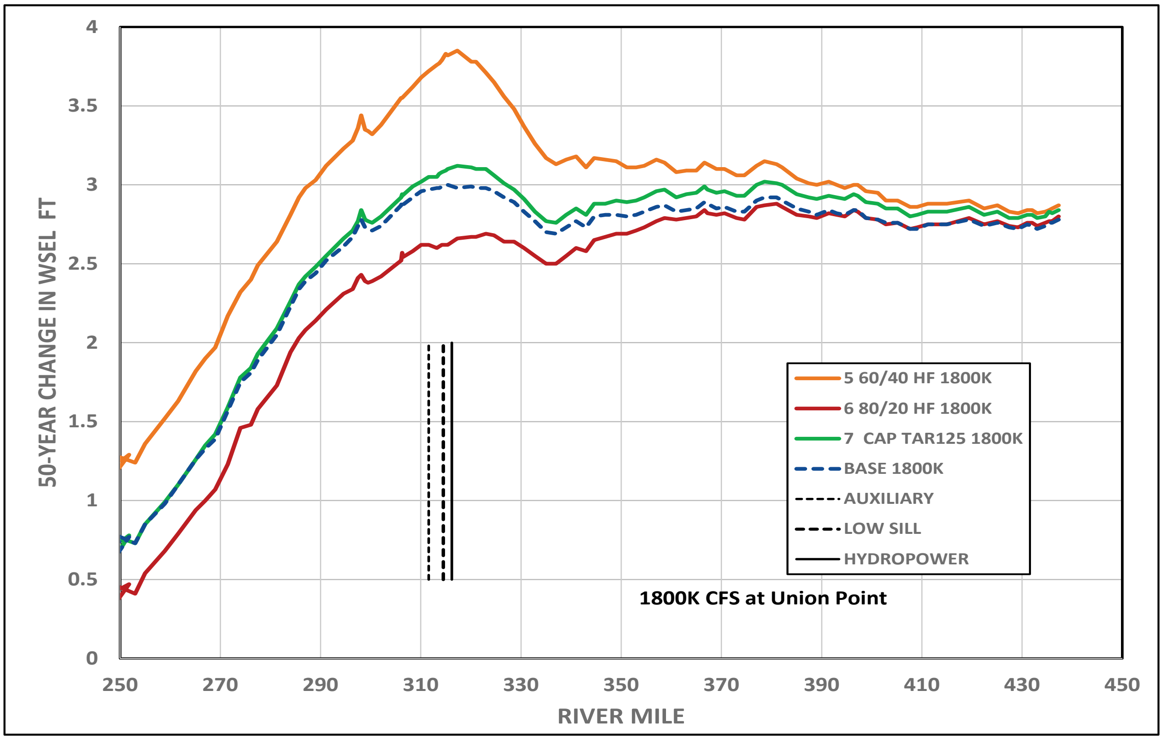
Figure 8. Calculated 50 yr water-surface change with Ratio 1 and dredging scenarios.



For the Atchafalaya River, the base projection shows a slightly increasing water surface trend over the next 50 yr at Simmesport. The Scenario 3 (Ratio 1) operations for the next 50 yr would result in water surfaces approximately 1–1.5 ft higher than the base at Simmesport and negligible change downstream at Morgan City.

Scenarios that make adjustments to the flow distributions for part of the year but still maintain 70/30 long term also have small influences on the future Mississippi River water surfaces. Figure 9 shows the long-term change in water surfaces by river mile for scenarios 5, 6, and 7 for an upstream Mississippi River flow of 1,800,000 cfs at Union Point.

Figure 9. Calculated 50 yr water surface change with scenarios 5, 6, and 7.



For scenarios 8A (D8020) and 9 (D6040), there are counteracting dynamics. The immediate hydraulic adjustment due to the changed flow distribution is large. The 80/20 results increase water levels in the Mississippi River while the 60/40 results decrease water levels in the Mississippi River. The sediment response counteracts this trend such that the 60/40 scenario has a higher increasing trend in water surface than the base over time while the 80/20 scenario has a lower increasing trend in water surface than the base. After 50 yr, the initial hydraulic adjustment is still slightly more influential, but the sedimentation response has nearly caught up. For example, Scenario 8A (D8020) would have an instant increase in water surface elevations, but after 50 yr, the water surfaces would be approximately the same as the base projection; then the water surfaces after 50 yr of operating with 80/20 would be expected to slowly drop lower than the base. The opposite is true for Scenario 9 (D6040); water surfaces would be lower than the base for the first 50 yr and then be expected to slowly rise higher than the base projection after 50 yr.

5.9.2 Long-term dredging changes

This section summarizes the estimates of long-term changes in dredging based on the various scenarios that were simulated with the numerical modeling. Dredging requirements are much larger in the Mississippi River (Figure 10) than the Atchafalaya River (Figure 11). Results are intended to show the relative changes that could be expected for the hypothetical scenarios. For the extreme Scenario 8A, 80% of the flow passing down the Mississippi River would reduce the amount of dredging required in the Crossings but increase the amount of dredging required in the HOP and Southwest Pass (SWP); 60% of the flow passing down the Mississippi River (Scenario 9) would increase the amount of dredging required in the Crossings due to the drop in stream power but would decrease the amount of dredging required in HOP and SWP. For the Atchafalaya River, only Scenario 6 (8020HF) resulted in a significant increase in dredging compared to the Base Scenario. The other scenarios showed either a decrease or a less than 5% increase in Atchafalaya River dredging (see Volume 5).

Figure 10. Change in 50 yr average dredging requirements with each scenario.

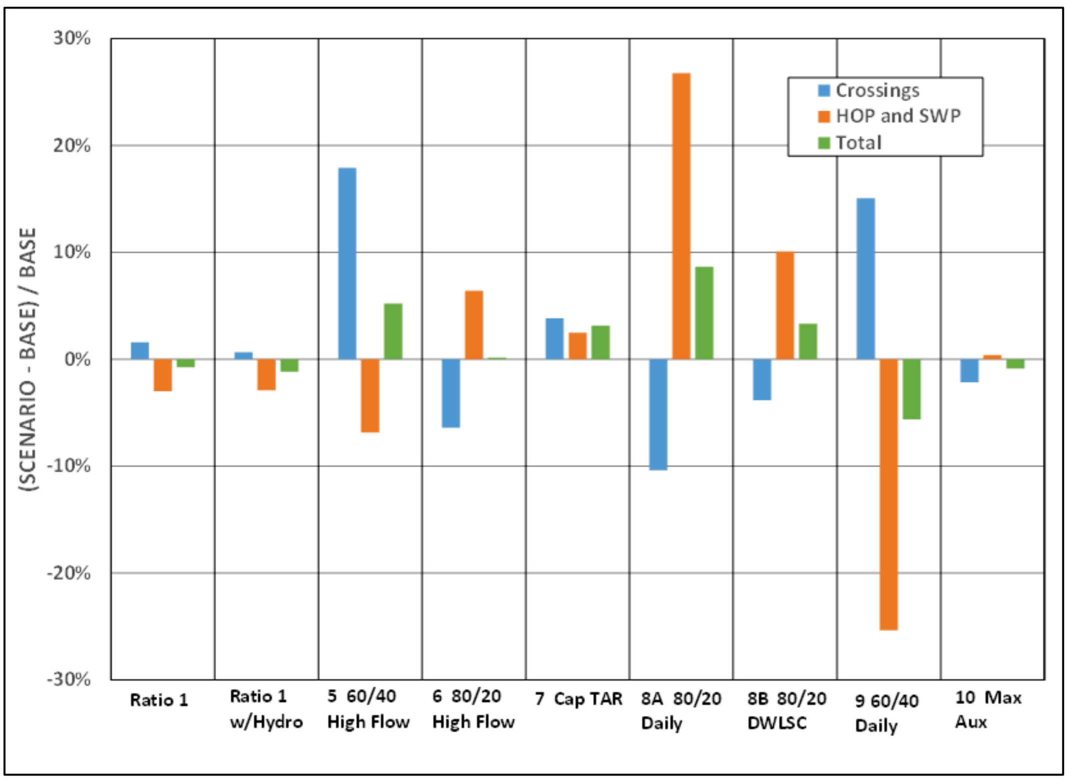
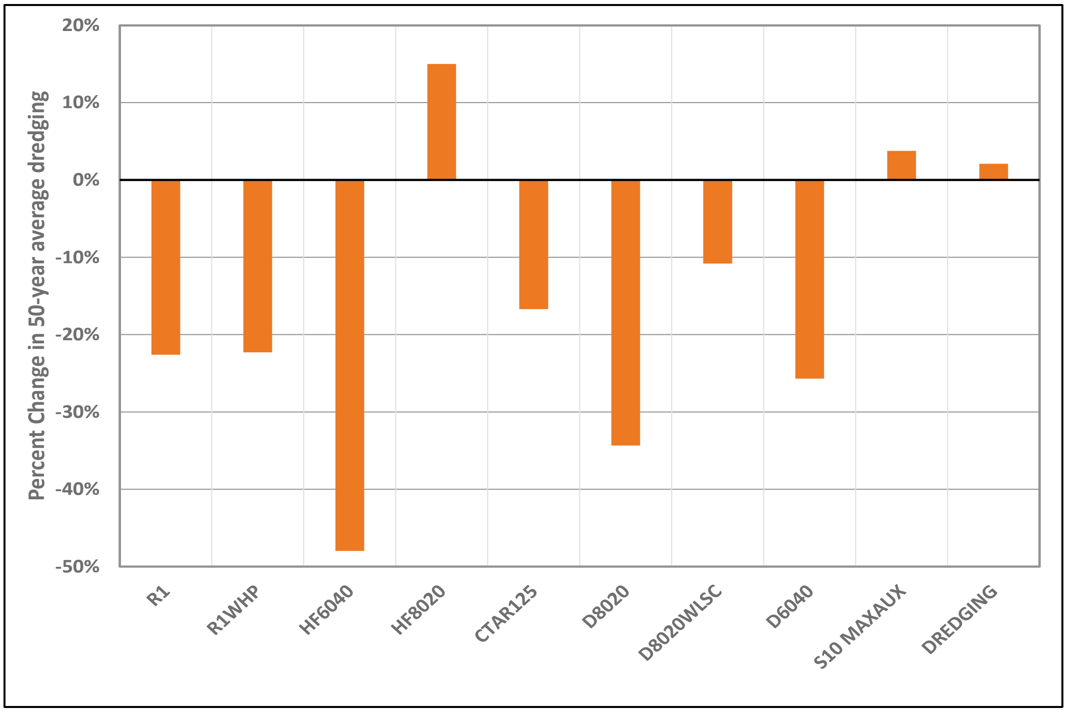


Figure 11. Dredging requirements in Atchafalaya River at Berwick Bay for hypothetical scenarios.



5.9.3 Atchafalaya River bank erosion analysis

An analysis of the Atchafalaya River's sensitivity to bank erosion was performed using the HEC-RAS software's BSTEM module, as described in more detail in Volume 9. Two sites were selected and the BSTEM parameters were calibrated to match measured bank retreat from available imagery. For the time period 1990–2019, Site 1 retreated 230–240 ft while Site 3 retreated approximately 60 ft. The results are listed in Table 5. Notice that representative Site 3 is sensitive to scenarios which temporarily increase the flow through the Atchafalaya River, even if a long-term 70/30 balance is maintained. For Scenario 5, the bank retreat is approximately 500% of the conditions using the actual flows.

Table 5. Bank erosion for two representative sites in the Atchafalaya River under the various hypothetical scenarios (1990–2019).

	Modeled Top of Bank Erosion (ft)	Percentage Difference of Bank Erosion from Actual Flows (%)		Modeled Top of Bank Erosion (ft)	Percentage Difference of Bank Erosion from Actual Flows (%)
Actual Flows			Scenario 7		
Site 1	230 - 240		Site 1	232 – 244	0.9 – 1.7
Site 3	53 - 62		Site 3	191 – 200	260 – 223
Scenario 3			Scenario 8a		
Site 1	232 – 243	0.9 – 1.3	Site 1	0 – 80	-100 – -66.7
Site 3	62 - 79	17.0 – 27.4	Site 3	0 – 0	-100 – -100
Scenario 4			Scenario 8b		
Site 1	232 – 243	0.9 – 1.3	Site 1	169 – 184	-26.5 – -23.3
Site 3	63 - 79	18.9 – 27.4	Site 3	0 - 0	-100 – -100
Scenario 5			Scenario 9		
Site 1	238 – 273	3.5 – 13.8	Site 1	401 – 398	74.3 – 65.8
Site 3	328 - 356	519 – 474	Site 3	346 - 374	553 – 503
Scenario 6			Scenario 10		
Site 1	223 – 230	-3.0 – -4.2	Site 1	0 – 0	-100 – -100
Site 3	0 - 0	-100 – -100	Site 3	0 - 0	-100 – -100

5.10 Structural solutions

10. Are there potential structural solutions on either sides of ORCC that could facilitate sediment transport through the system?

Answer: Results from the Mississippi River AdH/SEDLIB model show that various structural solutions cause only minor changes to the amount of sediment transported through the ORCC. The structures could be expected to cause some localized changes to the channel geometry, but there is not an indication of beneficial changes across the reach.

The Red/Atchafalaya AdH/SEDLIB model showed that dikes downstream of the complex could assist in keeping the center of the channel scoured to a greater depth while some deposition would be expected within the dike fields along the sides of the deeper channel. There was no significant change downstream of the Outflow Channel and Red River confluence to Melville.

6 Conclusions and Recommendations

6.1 Conclusions

The ORCC occupies a very important location for the surrounding river system as all four of the system's major rivers (Old, Mississippi, Atchafalaya, and Red) connect near there.

- History demonstrates multiple adjustments in the management perspective. Some activities limited the amount of flow carried by the Atchafalaya River, such as the construction of sill dams near Simmesport in the late 1880s and the current ORCS regulations. However, other events contributed to expanding the amount of flow the Atchafalaya River could carry, such as the removal of the Red and Atchafalaya River rafts in the 1800s, major dredging and the creation of the Whiskey Bay Pilot Channel in the 1930s, and the closure of Atchafalaya distributaries in the 1950s and 1960s. The Flood Control Act of 1928 represented a shift toward increasing the system's efficiency in moving water, including through the Atchafalaya River, while House Document 478 (83rd Congress, 2nd Session, 1954) regulates the amount of water diverted from the Mississippi River into the Atchafalaya River.
- Estimates from available data indicate that approximately 5.5 Mtons of coarse sediment moves through the ORCC each year, on average. This represents approximately 13% of the coarse sediment arriving from the Mississippi River upstream. These estimates have a significant amount of inherent uncertainty and can vary spatially and temporally.
- The lower Red River supplies approximately 9% of the system's total latitude water and approximately 15% of the system's total latitude coarse sediment. The upstream Mississippi River provides the remainder.
- The Red River Landing gage on the Mississippi River downstream of the ORCC (RM 302.4) has seen increasing water levels for a given flow and is projected to continue experiencing water level increases into the future.
- Subject to further analyses, it is possible that a change from current operations to Ratio 1 could increase the amount of coarse sediment passing through ORCC by approximately 1.6 to 6.2 Mtons/yr. After 50 yr of "Ratio 1" operations (Scenario 3), the projected rise in water

surface elevations would be approximately 2.5 ft near RMs 310–320 as compared to approximately 3 ft in the Base Scenario.

- The largest system changes would be experienced in the scenarios where daily operations are adjusted to an 80/20 balance (Scenario 8A) or a 60/40 balance (Scenario 9). These scenarios had both short-term and long-term effects. Daily 80/20 operations would result in higher Mississippi River water surfaces, due to more water staying in the channel, and long-term lowering of the Mississippi River bed elevations, due to increased stream power. Daily 60/40 operations would result in lower Mississippi River water surface and long-term increases of Mississippi River bed elevations.
- Daily 80/20 would decrease dredging in the deep-draft crossings while increasing dredging at HOP and SWP. Daily 60/40 would increase dredging in the crossings and decrease dredging at HOP and SWP. For the Atchafalaya River, only Scenario 6 (8020HF) resulted in a significant increase in dredging compared to the Base Scenario.
- For dredging scenarios, the sediment models showed no long-term difference in water levels from the Base Scenario when placing the dredged sediment back into the river's water column.
- Sediment models showed that regularly dredging and removing sediment from the Mississippi River reduced the projected rise in Mississippi River water surface elevations. The effects were similar to the Ratio 1 operations. Long-term results for continuous daily dredging or annual dredging were nearly the same.

6.2 Data gaps and recommendations

This report reflects the currently available data and analyses of the ORCS and the surrounding system. The following is a list of data that, should they become available sometime in the future, could provide sufficient novel information as to potentially change the conclusions of this report.

- The anthropogenic geomorphic changes on the Red River have been dramatic, starting with the history of raft clearing to the more recent history of channel realignment for the creation of the J. Bennett Johnson Waterway. The scope of these changes is not well understood and is made more complex by the switch from a free-flowing to a pooled environment. Likewise, geomorphic changes on the Ouachita-Black River system are not understood. There should be no assumption that the relatively low flows and low slope of the system means that little change is occurring. It is recommended that geomorphic analyses be carried out on both the Red River and the Ouachita-Black River system to gain a better understanding of potential inputs into the Atchafalaya River.

- Synchronous lidar and multibeam survey collection after significant flood events is recommended to capture the evolution of the channel and the overbank.
- A review of the available suspended sediment data makes it apparent that differences in procedure between gages and even changes in procedure for individual gages made comparison of data problematic. The recommendation is that suspended sediment data collection be standardized between USGS gages and USACE gages throughout the Lower Mississippi River. This will require another round of procedure changes but in doing so, will greatly increase the value of the data collected for basin-wide analysis. As a secondary recommendation, an intensive historical (to find and document procedure changes) and statistical effort should be undertaken to determine what value can be derived from the currently available historical data. This effort could include new sediment sampling measurements that replicate historical sampling protocols for the purpose of developing relationships to adjust the historical data to data collected using current protocols.
- Research is needed to develop economically viable methods to improve estimates of the unmeasured load, including bed-load, translational load, distortion load, etc.
- The scenario analyses presented here are of use in identifying large trends and making broad assessments of the potential impacts of various proposed changes to the ORCC. However, if any of these scenarios were to be analyzed for possible implementation at the ORCC, significant additional modeling could be needed to inform this decision. This modeling should include 1D modeling for long-term and large-scale impacts, and multi-dimensional modeling for local impacts, and to assess project performance.
- Future multidimensional modeling efforts should have these characteristics, among others:

  - They should be validated to sequential comprehensive bathymetric surveys, if possible.
  - They should be simulated for multiple sequential years (on the order of 10 yr).
  - They should be simulated using multiple sets of forcing conditions, each of which is perturbed about the estimated uncertainty of the

model parameters. These simulations can then be used to generate estimated uncertainty bounds for the results.
  - All reporting of results should be expressed in terms of these uncertainties.

- Next, the recommendation is that additional research be conducted with the Atchafalaya HEC-6T and HEC-RAS models to explore how the possible changes in the flow distribution between the Atchafalaya River and Wax Lake Outlet could affect long-term upstream and downstream sediment transport effects.
- The Atchafalaya River HEC-6T model could be used to explore the effects of closing and/or reopening the many distributaries from the Atchafalaya River to compare and analyze the long-term sedimentation effects and water surface elevation trends.

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Appendix A: Additional Information about Relevant System Features

This section provides additional information about relevant features of the system.

A.1 Old River Low Sill Structure

This feature consists of a reinforced concrete control structure with vertical lift steel gates, an inflow channel from the Mississippi River, and an outflow channel to the Red River. The structure is founded on steel piles and consists of 11 gate bays, each having a 44 ft width between piers. The three center bays have weir crests at elevation -5.0 ft NGVD29 and four outer bays on each side of the center bays having crest elevations at elevation 10.0 ft NGVD29. The bays are closed by vertical lift steel gates that are handled by two 200-ton traveling gantry cranes. The original approach channel was 1000 ft wide with an invert elevation of -5.0 ft NGVD29 and 1-on-4 side slopes.

A.2 Overbank Structure

This feature consists of a reinforced concrete control structure with hinged timber gate panels. It has a gross length of 3,356 ft between abutments, and consists of 73 bays, each having a 44 ft width between piers. The weir crest is at elevation 52.0 ft. NGVD29. Each bay is provided with 15 timber panels each of which is 2 ft, 10.5 in. wide. The panels are hinged at the top and are raised and lowered by two traveling gantry cranes. A 26 ft wide highway bridge is located on the downstream side of the structure.

A.3 Auxiliary Structure

This feature consists of a reinforced concrete control structure with Tainter gates, an inflow channel from the Mississippi River, an outlet channel into the Low Sill Outfall Channel, inflow and outflow guide levees, realignment of the mainline levee and construction of administrative and maintenance facilities. The control structure consists of a reinforced concrete structure founded on steel and concrete piles with six steel Tainter gates in 62 ft wide gate bays. All six bays have a sill elevation of -5.0 ft NGVD29. An articulated concrete mattress- and riprap-revetted inflow channel connects the structure to the Mississippi River approximately 2 mi away. A stilling basin leads to an outlet channel approximately 5,000 ft long. Bulkhead walls serve as the main cutoff barrier to flow between the structure and the mainline levees. A 28 ft wide highway bridge is located on the upstream side of the structure to accommodate Louisiana Hwy 15.

A.4 Sidney A. Murray, Jr., Hydroelectric Station

The Hydroelectric Station is located approximately 2,000 ft north of the existing USACE Old River Control Low Sill and Overbank Structure and 4,600 ft from the right bank of the Mississippi River near RM 316 and will provide continuous generation of electric power to the town of Vidalia, LA. The power station was constructed for private interests by EBASCO Constructors, Inc. The power station, a run-of-river hydroelectric plant, consists of a welded steel, preassembled, concrete-filled structure, an inflow channel from the Mississippi River, an outfall channel to the outflow channel, abutment dams forming a connection between the power station and the mainline levees, training walls bordering the transition of the intake channel to the power station and the tailrace, and the administration and maintenance facilities. A 28 ft wide highway bridge (Louisiana Hwy 15) is located on the downstream side of the power station. The power station is operated and maintained by private interest. The length of the Inflow Channel is approximately 4,600 ft, and the Outflow Channel approximately 9,000 ft.

A.5 Morganza Floodway

The Morganza Floodway extends from the Mississippi River at approximately RM 280 AHP southward to the East Atchafalaya River levee and thence southward to join the Atchafalaya Basin Floodway at the latitude of Krotz Springs, Louisiana. The purpose of the Morganza Floodway is, in combination with the Atchafalaya Basin Floodway, to carry floodwater from the Mississippi River to the Gulf of Mexico. The Morganza Control Structure and the Morganza Floodway have been designed to pass 600,000 cfs of Mississippi River floodwater at design stage to the Gulf of Mexico via the Atchafalaya Basin Floodway and the lower Atchafalaya River and Wax Lake Outlet.

A.6 West Atchafalaya Floodway

The West Atchafalaya Floodway (WAF) lies immediately west of the Atchafalaya River, paralleling the river to just below Krotz Springs. Averaging 5 to 7 mi wide, the WAF is bordered by the West Atchafalaya Basin Protection Levee on the west and the West Atchafalaya River Levee on the east. The design capacity of the WAF is 250,000 cfs. The floodway has never been used. Operation is very unlikely due to the increased carrying capacity of the Atchafalaya River Channel to 930,000 cfs adjacent to the floodway at the latitude of Red River Landing. Like the Morganza Floodway, the West Atchafalaya Floodway extends to the approximate latitude of Krotz Springs and US Highway 190 and, when operated, will discharge into the lower portion of the Atchafalaya Basin Floodway.

Appendix B: Bed-Load Sediment Estimates

This section summarizes the computation of bed-load sediment estimates through the system. There have been numerous attempts to measure the sediment transport distributions in the vicinity of this important location. Until recently, bedload on large river systems has been an unmeasurable quantity, but the last decade has seen several data collection efforts in the vicinity of the ORCC measuring bedload (using the ISSDOTv2 Method), along with additional parameters. These efforts have finally provided a means of quantifying the bedload using actual measured data. ISSDOTv2 bed-load estimates were calculated using rating curves between measurements and discharge at the locations shown in Figure B-1. A supplementary data file (http://dx.doi.org/10.21079/11681/45080) contains daily estimates of bedload for the time period 1/1/1990 through 12/31/2019.

Figure B-1. Layout of bed-load measurement locations.

Appendix C: Low-Sill Head Differential Estimation

C.1 Objective

The primary purpose of this effort was to develop a method for approximating the differential head across the Low Sill Structure that can be used for hypothetical scenarios.

C.2 Background

Due to damages experienced during the 1973 flood event, the Low Sill Structure requires that the differential head across the structure (i.e., the head difference from the upstream side to the downstream side of the structure), remains less than 22 ft. If the differential head approaches 22 ft, or is forecasted to exceed 22 ft, the operations of the ORCC are adjusted to avoid a differential head of 22 ft.

The OMAR Assessment is aimed at improving the understanding of the interactions among these four rivers. One of the goals of the assessment is to understand how the rivers would respond to any potential adjustments to the ORCC operations. To make sure the scenarios that adjust ORCC operations are realistic, it is important to incorporate, and abide by, any necessary constraints. The Low Sill head differential constraint needs to be estimated, monitored, and adjusted within the scenarios to simulate realistic conditions.

C.3 Procedure

The procedure for estimating the Low Sill head differential requires the following relationships:

1. Low Sill upstream: Establish a rating curve to calculate the stage at the upstream side of the Low Sill Structure as a function of the discharge in the Mississippi River.
2. Low Sill downstream
   a. Establish a rating curve to calculate the stage at Simmesport as a function of the discharge in the Atchafalaya River.

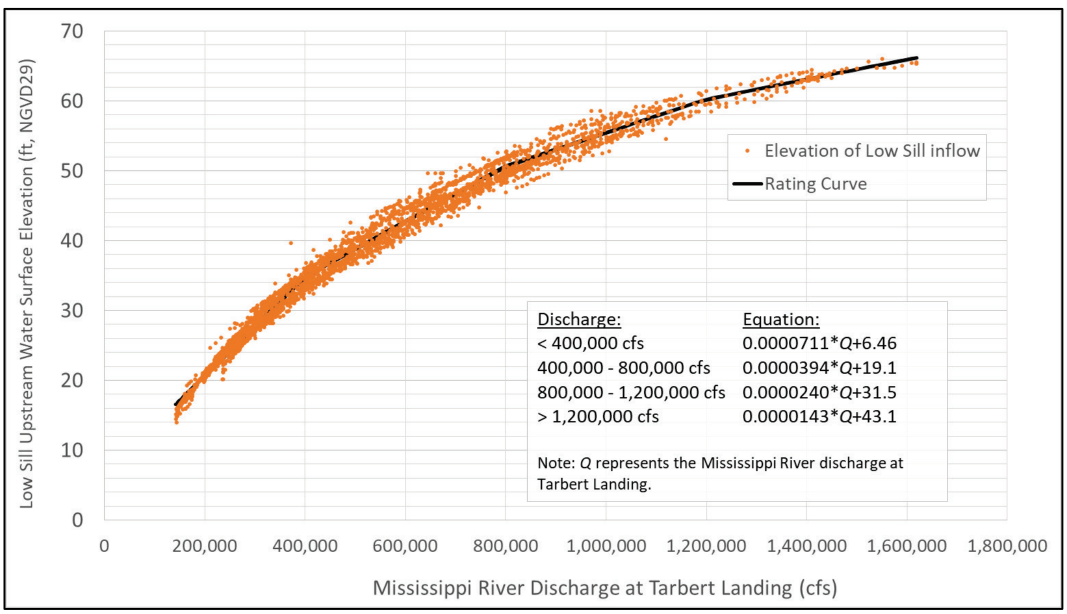
b. Establish an offset from the Simmesport stage to the stage at the downstream side of the Low Sill Structure as a function of the discharge through the ORCC.

The relationships developed for each of these steps were established and tested with observed data.

C.4 Low Sill upstream

Water surface elevation at the upstream side of the Low Sill Structure came from the New Orleans District (daily data for station 02050, received 8/12/19, datum NGVD29_1976, feet). Daily discharge data for the Mississippi River at Tarbert Landing came from RiverGages.com. Using Excel, a piecewise-linear (continuous) relationship was determined to best fit the data since 2010. A slight aggradational trend is noticed in the data at this location, so a stage-discharge relationship was established using only the most recent 10 yr of data. These data, and the piecewise-linear relationship equations, are shown in Figure C-1.

Figure C-1. Rating curve relationship for upstream elevation at Low Sill Structure.



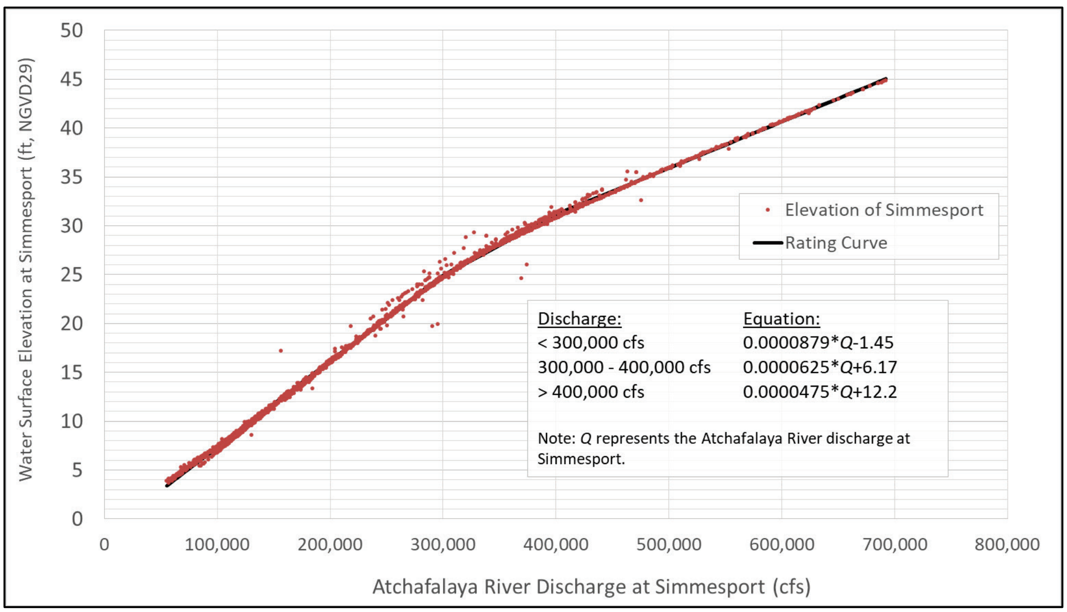
C.5 Low Sill downstream

Observed data showed that the elevation on the downstream side of the Low Sill Structure was a function of multiple variables. Simple relationships between the downstream elevation and the discharge through Low Sill Structure flow, or the discharge through the ORCC, were very scattered with large uncertainty. Therefore, the method had to build upon the rating curve further downstream at Simmesport and calculate adjustments upward toward the ORCC.

C.5.1 Rating curve at Simmesport

Water surface elevation data at Simmesport came from the New Orleans District (daily data for station 03045, received 8/12/19, datum NGVD29_1976, feet). Daily discharge data for the Atchafalaya River at Simmesport came from RiverGages.com. Using data since 2010, Figure C-2 shows the data and equations used to calculate the water surface elevation at Simmesport as a function of discharge.

Figure C-2. Rating curve relationship at Simmesport.



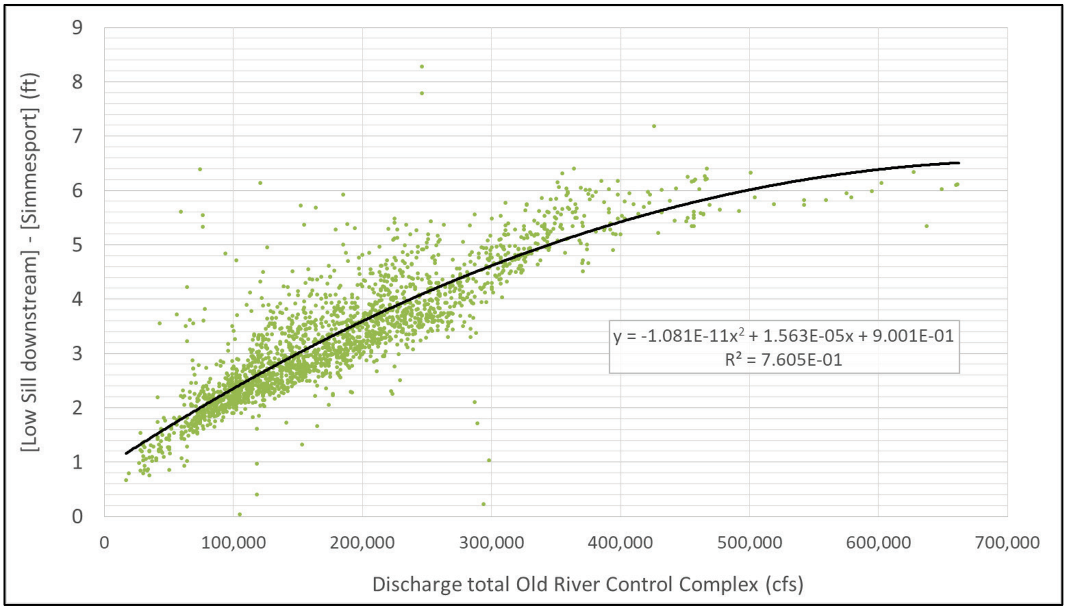
C.5.2 Increment to Low Sill downstream

The difference between the Low Sill downstream elevation and the Simmesport elevation was calculated. Water surface elevation at the downstream side of the Low Sill Structure came from the New Orleans District (daily data for station 02100, received 8/12/19, datum NGVD29_1976, ft). The following relationships were established for this difference, [Low Sill downstream] – [Simmesport], as described below.

C.5.2.1 If Red River ≥ 20,000 cfs

The Red River was determined to be influential. Daily discharge of the Red River was calculated by subtracting the ORCC total complex discharge from the Simmesport discharge. When the calculated Red River discharge was above 20,000 cfs, a relationship was established as shown in Figure C-3. The Red River discharge is used in the logic determining when to use the equation, but the equation to calculate the elevation offset between Simmesport and Low Sill is a function of the ORCC total complex discharge.

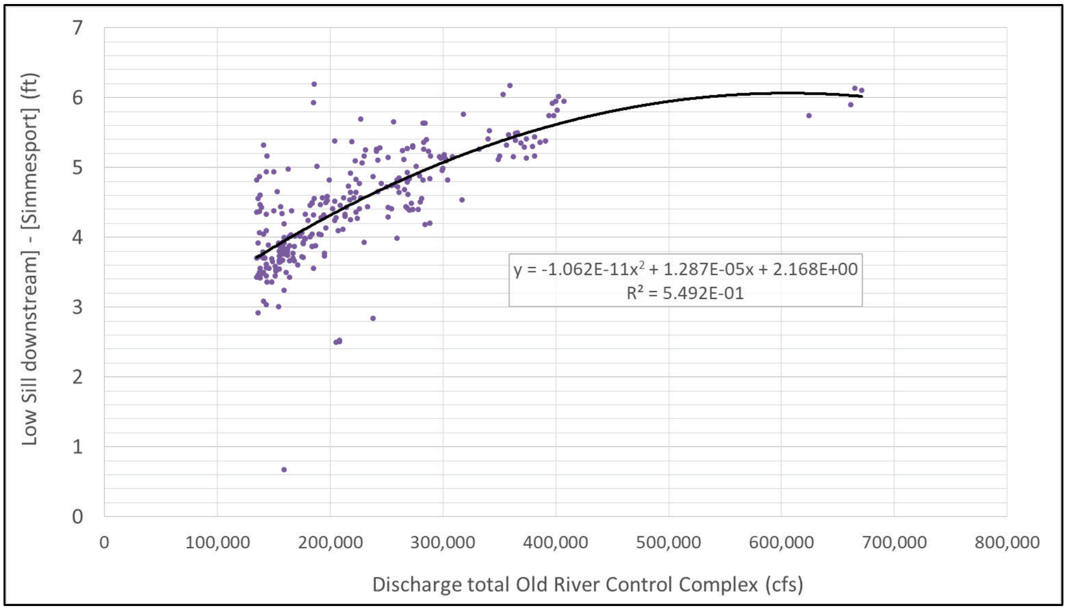
Figure C-3. Relationship for Low Sill downstream offset when Red River ≥ 20,000 cfs.



C.5.2.2 Red River < 20,000 and ORCC ≥ 135,000 cfs

When the Red River is below 20,000 cfs, the value of the ORCC total complex discharge was used to determine which relationship to apply. When the ORCC total complex discharge ≥ 135,000 cfs, Figure C-4 shows the data, relationship, and equation.

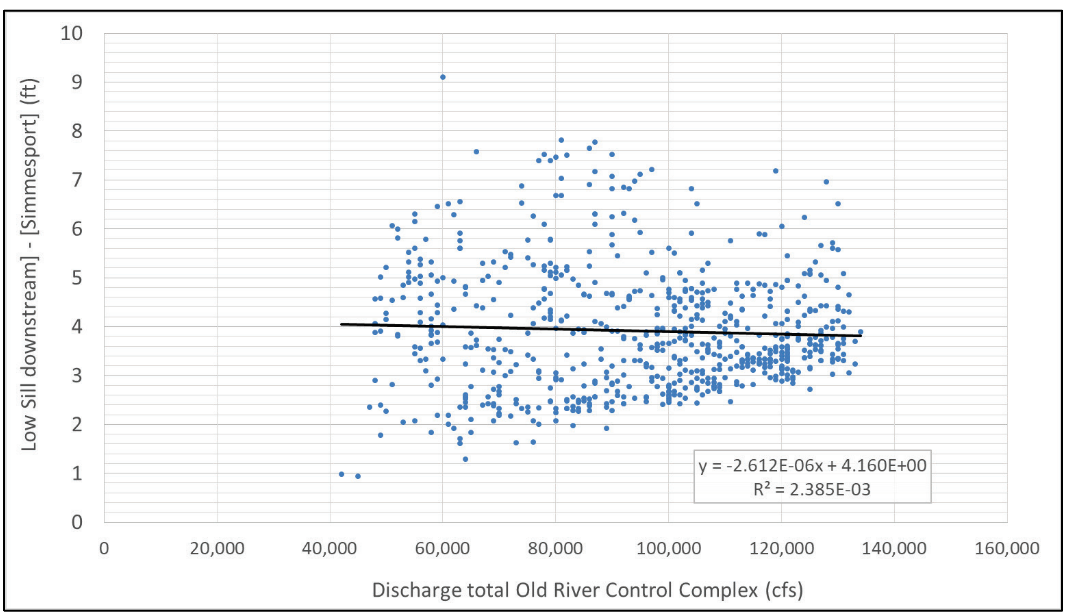
Figure C-4. Relationship for Low Sill downstream offset when Red River < 20,000 cfs and ORCC ≥ 135,000 cfs.



C.5.2.3 Red River < 20,000 and ORCC < 135,000 cfs

When the Red River discharge is lower than 20,000 cfs and the ORCC total complex discharge is lower than 135,000 cfs, there is a large scatter in the offset between Simmesport and Low Sill. Figure C-5 shows the linear approximation that was used in this scenario.

Figure C-5. Relationship for Low Sill downstream offset when Red River < 20,000 cfs and ORCC < 135,000 cfs.



C.6 Checking the procedure

To confirm that the calculated values for the elevations upstream and downstream of the Low Sill Structure are adequate, the following figures were created to compare calculations vs. observations. Figure C-6 shows the comparison for the Low Sill upstream elevation, Figure C-7 shows the comparison for the Low Sill downstream elevation, and Figure C-8 shows the comparison for the Low Sill head differential.

Figure C-6. Calculated vs. observed Low Sill upstream elevation.

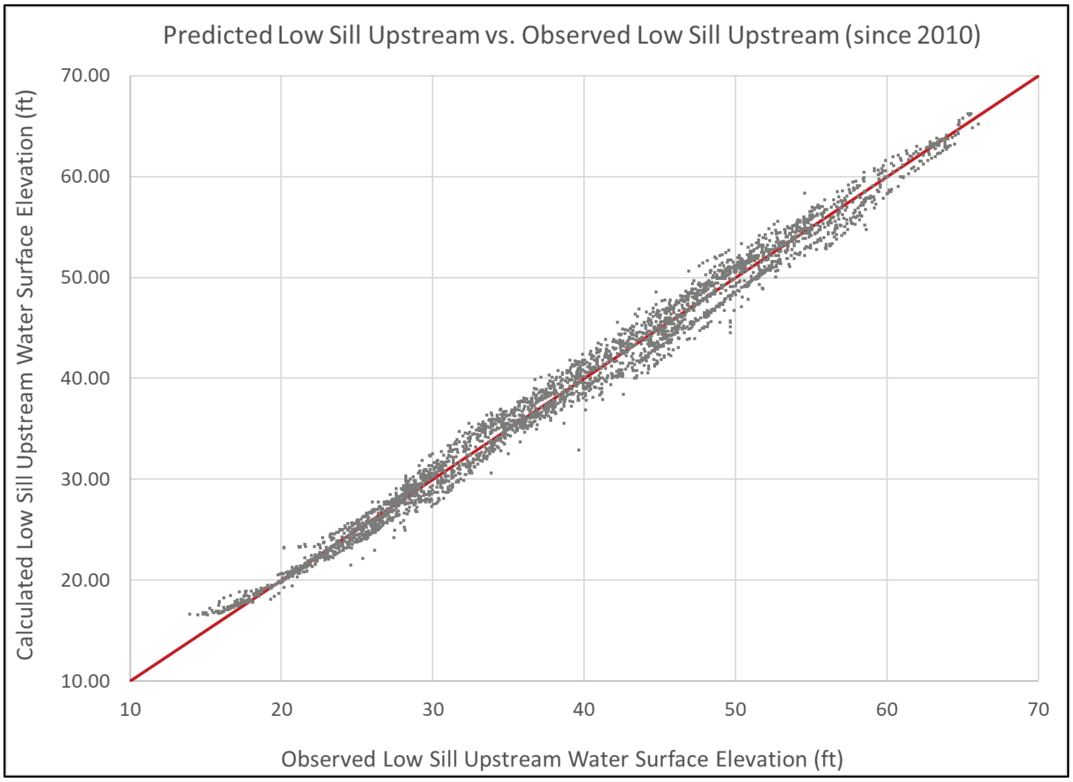


Figure C-7. Calculated vs. observed Low Sill downstream elevation.

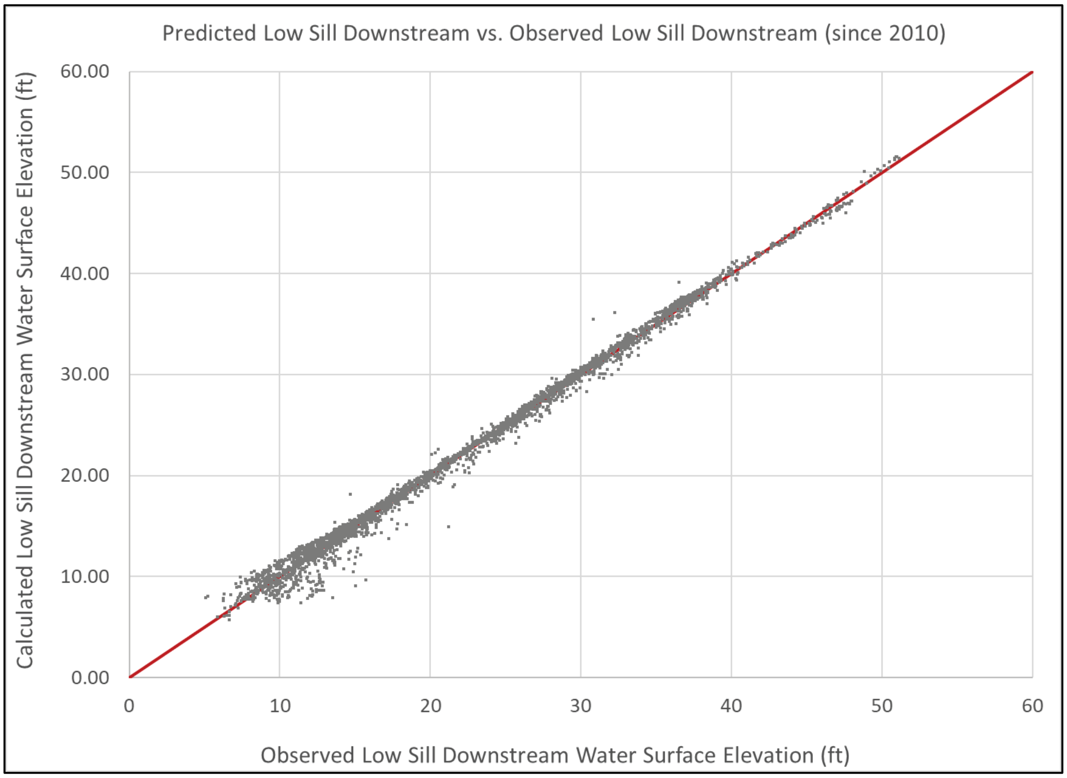
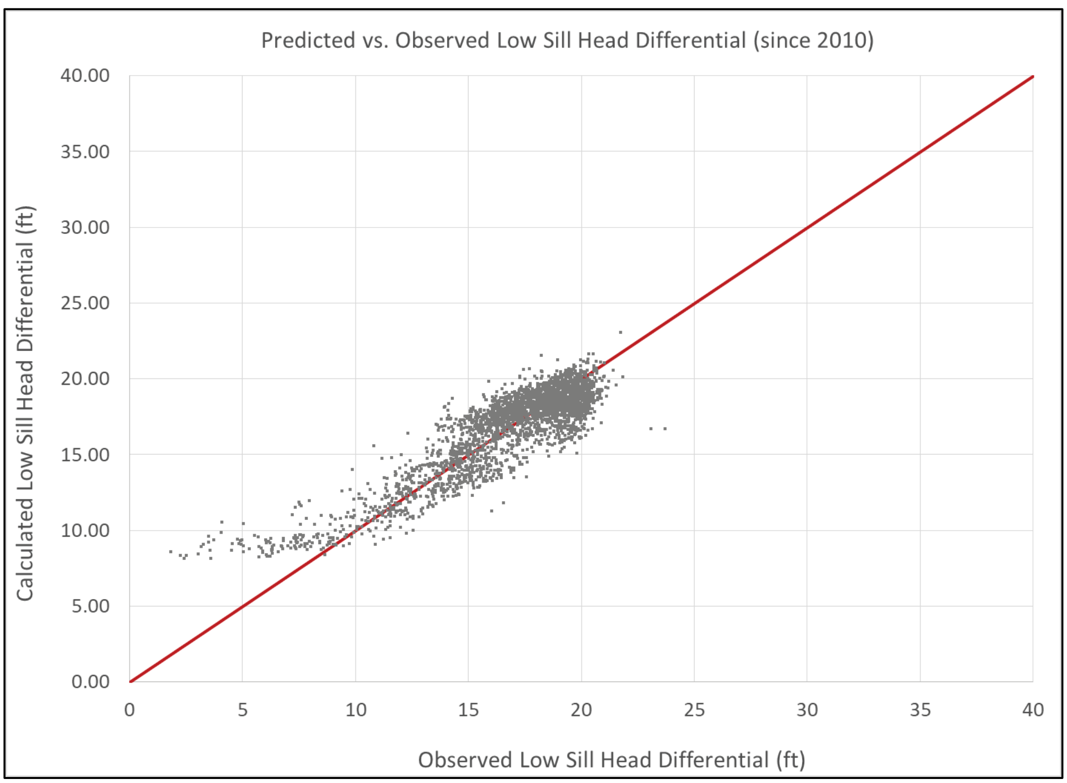


Figure C-8. Calculated vs. observed Low Sill head differential.



C.7 Conclusion

The aforementioned relationships demonstrate a process for calculating the head differential across the Low Sill Structure, which takes into account several different influential variables. The analysis focused on data since 2010 to avoid different stage conditions that may have existed further back in the historical record. For real-time operations and short-term forecasting, it is usually best to work as closely as possible with the observed elevations from the most recent days to capture the river conditions more accurately on either side of the structure. However, for any hypothetical scenarios, the work of this report provides a means for calculating the Low Sill upstream elevation, Low Sill downstream elevation, and Low Sill head differential.

Abbreviations

1D	1-dimensional
2D	2-dimensional
3D	3-dimensional
AdH	Adaptive Hydraulics
BCS	Bonnet Carré Spillway
BSTEM	Bank Stability and Toe Erosion Model
HOP	Head of Passes
MCS	Morganza Control Structure
MR&T	Mississippi River and Tributaries
MRC	Mississippi River Commission
OMAR	Old, Mississippi, Atchafalaya, and Red Rivers
ORCC	Old River Control Complex
ORCS	Old River Control Structure
RM	River Mile
SWP	Southwest Pass
USACE	US Army Corps of Engineers
WAF	West Atchafalaya Floodway

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14. ABSTRACT
This is the main report of Old River, Mississippi River, Atchafalaya River, and Red River (OMAR) Technical Assessment. The primary objective of the OMAR Technical Assessment was to conduct a comprehensive evaluation that aimed to understand the impacts of former and potential changes to the system in the vicinity of the Old River Control Complex (ORCC) over time, the water and sediment delivery regime at the ORCC, and the effects to the river system surrounding the ORCC. Scenarios evaluated in this technical assessment were designed to investigate potential system responses to a wide range of possible operational alternatives and identify knowledge gaps in current understanding of system behavior. This report summarizes and synthesizes the individual reports detailing the investigations into specific aspects of the ORCC and the surrounding region.

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