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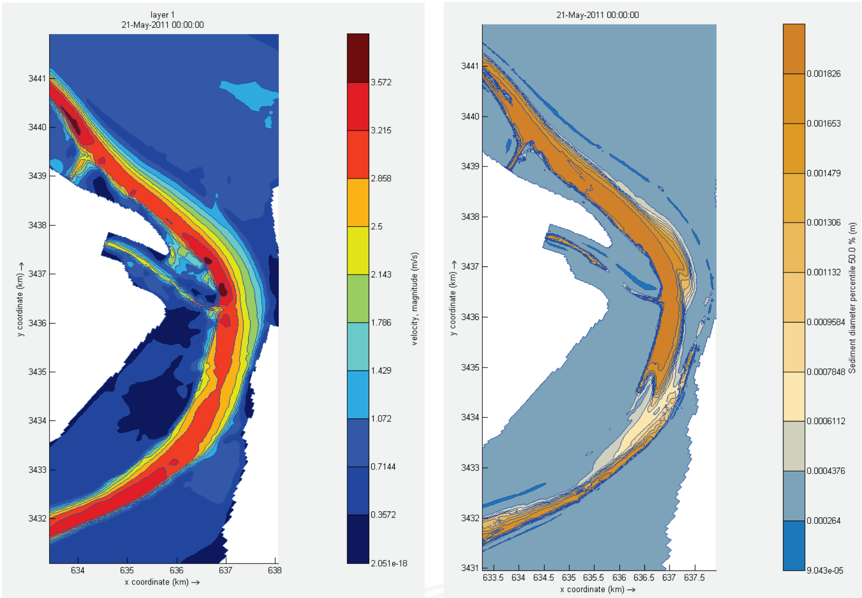
Model Development and Calibration

MRG&P Report No. 21 • October 2018



MRG&P
Mississippi River Geomorphology & Potamology Program

Report prepared for the Mississippi River Commission

Mississippi River Geomorphology &
Potamology Program

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Analysis of the 2011 Mississippi River Flood from Natchez, MS, to Baton Rouge, LA, Using a Three-Dimensional Sediment Model

Model Development and Calibration

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Final report

Prepared for U.S. Army Corps of Engineers, Mississippi Valley Division
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Under Project No. 127672, "Multi-Dimensional Modeling of Mississippi River"

Abstract

This report documents the development and calibration of a three-dimensional (3D) sediment model of the Mississippi River from Natchez, MS, to Baton Rouge, LA. The objective of the study was to provide a modeling tool capable of analyzing sedimentation in this dynamic reach of the river. The modeling domain includes five large river diversion structures: Hydroelectric Station, the Overbank, Low Sill, and Auxiliary Structures that make up the Old River Control Complex (ORCC), and the Morganza Floodway Control Structure. Evidence suggests that the Hydroelectric Station and ORCC Structures do not convey sediment in adequate proportion to maintain downstream channel stability. This modeling tool will provide a means to investigate options to improve this imbalance. In particular, the close proximity of the orifice flow diverted through the Low Sill Structure to the Mississippi River channel bed necessitates a 3D approach to properly assess sediment diversions through this structure. The open source Delft3D finite difference solver utilizing the sigma vertical layer option was the selected model platform running in a massively parallel computing environment. Sand concentration and load data collected at four ranges were compared to model results during the flood of 2011 along with water level and discharge data.

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Preface

The research documented in this report was conducted as part of the Mississippi River Geomorphology and Potamology (MRG&P) Program, “Multi-Dimensional Modeling of Mississippi River,” Project No. 127672 The MRG&P Program is managed by the U.S. Army Corps of Engineers (USACE) Mississippi Valley Division (MVD) in Vicksburg, MS. The MRG&P Technical Director was Dr. Ty V. Wamsley. The MVD Commander was MG Richard G. Kaiser. The MVD Director of Programs was Mr. Jim Bodron.

The Mississippi River Commission provided Mississippi River engineering direction and policy advice. The Commission members were MG Richard G. Kaiser, USACE, President; the Honorable Sam E. Angel; the Honorable James Reeder; the Honorable Norma Jean Mattei, PhD; RDML Shepard Smith, National Oceanic and Atmospheric Administration; MG Mark Toy, USACE Ohio River Division; and BG Paul E. Owen, USACE Southwest Division.

Appreciation is expressed to Ms. Erica Buschel of the USACE New Orleans District and Mr. Todd Baumann of the U.S. Geological Survey Louisiana Water Science Center for their invaluable aid in collecting much of the discharge and sediment data used in this study. Appreciation is also expressed to Mr. Richard McComas of the USACE Vicksburg District and Mr. Gary Brown of the U.S. Army Engineer Research and Development Center for providing the bathymetry sources for this model study.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
tons (long) per cubic yard	1,328.939	kilograms per cubic meter
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Background

Along the west bank of the Mississippi River between Natchez, MS, and Baton Rouge, LA, lie several hydraulic structures constructed for hydropower, navigation, and flood control purposes. These structures include the Sydney A. Murray, Jr. Hydroelectric Station, the original Old River Flood Control Structures comprised of the Low Sill Structure and the Overbank Structure, the Auxiliary Structure at the Old River Control Complex (ORCC), the navigation lock at Torras, and the Morganza Floodway Control Structure. See Figure 1 for the location of these structures along the study reach of the Mississippi River.

Figure 1. Regional map.

The most northerly structure is the Sydney A. Murray, Jr. Hydroelectric Station, which started full operation in 1990 with the purpose of providing power to the city of Vidalia, LA, approximately 40 miles north of the power plant. The structure discharges water through eight power units into the Atchafalaya River through the ORCC outflow channel. The average daily discharge through the structure was approximately 115,000 cubic feet per second (cfs) during 2011.

Immediately downstream of the Hydroelectric Station, the ORCC is comprised of three hydraulic structures designed to allow maintenance of the 1950 latitude flow distribution between the Mississippi River and the Atchafalaya River of 70 percent (%) to 30% latitude flow, respectively. The original Old River Control Structure was comprised of the Overbank Control Structure and the Low Sill Control Structure completed in 1964. The third structure, the Auxiliary Structure, became operational in 1986 and was constructed to reduce pressure on the Low Sill Structure due to the damage sustained by the Low Sill Structure during the 1973 flood. The Auxiliary Structure was purposely constructed in a sediment-rich location to provide a means to divert increased amounts of Mississippi River bed load sediments into the Atchafalaya River over that which the Low Sill Structure is capable of diverting alone. During project floods, the Complex is designed to divert 620,000 cfs from the Mississippi River to the Atchafalaya River. A navigation lock at Torras, LA, was also part of the original facility. The locations of these hydraulic structures along the west bank of the Mississippi River are shown in Figure 2, and a plan view of the Low Sill and Overbank Structures may be found in the Appendix.

Figure 2. ORCC map.

The Morganza Floodway Control Structure, completed in 1953, is approximately 30 miles downstream of the ORCC. This 3,900-foot (ft) long structure was designed to divert 600,000 cfs from the Mississippi River during the project flood into the Atchafalaya Basin through the Morganza Floodway. The structure has been operated only during the 1973 and 2011 floods. These flood control structures at the ORCC and Morganza reduce the project flood flow in the Mississippi River from 2,720,000 cfs at Natchez to 1,500,000 cfs at Baton Rouge. The location of this structure and its proximity to the Mississippi River channel is shown in Figure 3.

Figure 3. Morganza Floodway Structure map.

Deposition in the Auxiliary Outflow channel has resulted in ineffective channel flow and bank instabilities that may affect how the structures are operated during a flood. Although this deposition was factored into the original design with regular channel flushing operations anticipated to maintain channel design performance, these channel flushing operations have not occurred in sufficient frequency and duration to achieve the purpose of long-term channel maintenance. Dredging may be performed to remove the deposition in the Auxiliary inflow channel as a short-term fix; however, a long-term solution to the problem is desired. U.S. Army Engineer Research and Development Center (ERDC) analysis has shown that to maintain equilibrium in the river downstream of the ORCC, it is necessary to divert approximately 5–8 million more cubic yards (cy) of sediment per year than is currently diverted. This is approximately a 50%–100% increase in the volume of sediment diverted. Diverting this additional volume of sediment will require some significant operational changes at ORCC and may require structural solutions (Heath et al. 2015).

Objective

The objective of this study was to develop a comprehensive ORCC/Morganza Delft3D numerical model that enables assessment of hydrodynamic and sedimentation processes. This effort builds on the modeling effort conducted by ERDC, which included Adaptive Hydraulics (ADH) and CH3D model studies (Heath et al. 2015).

Previous studies have shown that the current operational characteristics of the ORCC do not divert sufficient quantities of sediment to maintain equilibrium in the river downstream of the structures and has resulted in long-term channel aggradation with resultant increased flow-line elevation concerns (Heath et al. 2015). This model study will allow future investigations of changes in operational characteristics of the ORCC to achieve equilibrium in the river channel.

Approach

This study develops and calibrates a three-dimensional (3D) sediment model of the Mississippi River from Natchez, MS, to Baton Rouge, LA. The model encompasses a 133-mile stretch of the Mississippi River that includes the influence area of the ORCC, Hydropower, and Morganza diversion structures from Natchez, MS (River Mile [RM] 361), to Baton Rouge, LA (RM 228). This model domain allows investigation of the effects of the operation of the Morganza Structure on the operation of the ORCC. The close proximity of the orifice flow diverted through the ORCC Low Sill Structure to the Mississippi River channel bed necessitates a 3D approach to properly assess sediment diversions through this structure. The Delft3D finite difference solver utilizing the sigma vertical layer option was the selected model. The model was used to simulate the 2011 flood, which served as a model performance verification test. This event was selected due to the large magnitude of the flow and the operation of the Morganza Structure during the event. A summary of sand loads passing through the river and structures during the event is provided.

2 Delft3D Model

Overview

This study utilized the open source version of the Delft3D code. The Delft3D suite is composed of several modules, grouped around a mutual interface, with the capability to interact with one another. The Delft3D-FLOW module was used in this study of the Mississippi River. Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program that calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or curvilinear, boundary fitted grid. In 3D simulations, the vertical grid is defined following the σ-layer approach or Cartesian Z-level approach.

Methodology

Numerical methods

The hydrostatic form of the Reynolds averaged Navier-Stokes (RANS) equations of fluid flow is solved by Delft3D, this version of the RANS equations is also referred to as the shallow water equations. For 3D problems, the vertical velocity is computed from the continuity equation. The k-ε turbulence model was selected to close the shallow water equations of flow for this study. The background horizontal eddy viscosity was set to a minimum of 1 square meter per second (1 m2 · s-1), and the minimum horizontal eddy diffusivity was not adjusted from the default value of 10 m2 · s-1. The water density was set at 1000 kilograms per cubic meter (kg · m-3).

The Cyclic method (Stelling and Leendertse 1992) was selected to resolve horizontal advection. The Cyclic method results in a diagonally dominant matrix with an iterative scheme that converges well. The horizontal velocities of adjacent vertical layers are coupled by the vertical advection and the vertical viscosity term. These terms are resolved using a central difference method. In a shallow water model, the horizontal length scale is much larger than the vertical length scale, and the eddy viscosity term dominates the vertical advection term.

As with other conservative constituents such as temperature and salinity, the transport of suspended sediment is calculated by solving the 3D advection-diffusion equation. However, the exchange of sediment between the bed and the flow, and sediment settling due to gravity, are critical differences in the way suspended sediment is treated in the model. The effect of sediment on the density of the mixture may also be accounted for by subtracting the mass of the displaced water and adding the mass of all sediment fractions.

A first-order upwind numerical scheme is used to compute the process of sediment settling in Delft3D. Hindered settling velocity is accounted for by following the method of Richardson and Zaki (1954) for high concentration mixtures. The fall velocity for each size fraction is a function of the fraction concentration and thus location and time as well. Non-cohesive sediment settling velocity is computed following the method of van Rijn (van Rijn 1993). The settling velocities for the clay and silt size classes were set to 5E-5 and 5E-4 $m \cdot s^{-1}$ respectively.

Cohesive sediment transport is resolved in the Delft3D model using the Partheniades and Krone set of equations. Partheniades developed a non-linear relationship between the erosion rate of mud and the bed shear stress using flume data (Partheniades 1962). Ariathurai later linearized this relationship, resulting in the empirical Ariathurai-Partheniades formula (Ariathurai 1974), which is easily adapted for use in computer models:

$$E = M\left(\frac{\tau_b}{\tau_e} - 1\right)$$

where E is the erosion flux, M is an erosion rate constant that may be used to calibrate the computed rates to observed rates, τ_b is the bed shear stress, and τ_e is the critical shear stress for erosion.

The deposition flux (*D)* of silt and clay classes of sediment is commonly calculated in numerical models with the relationship attributed to Krone (Krone 1962):

$$D = w_s C\left(1 - \frac{\tau_b}{\tau_d}\right)$$

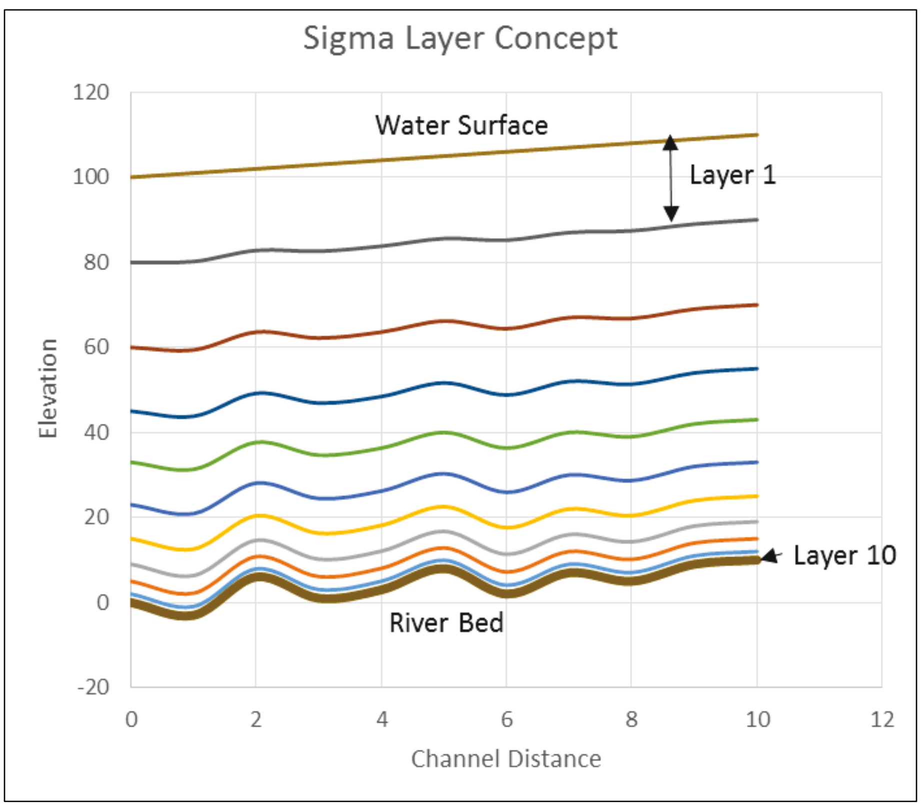
where w_s is the settling velocity of the grain, C is the near bottom concentration of the grain, τ_b is the bed shear stress, and τ_d is the critical shear stress for deposition.

The method of van Rijn (van Rijn 1993) was used to test the non-cohesive sediment transport capabilities of the model, and a layered sediment bed with three lower layers and an active top layer was employed in the model. The maximum thickness of each layer was set to 1 m for a maximum potential bed thickness of 4 m. The transfer of sediment between the bed and the water column is modeled with sink and source terms acting on the near-bottom water layer (reference layer) above van Rijn's reference height.

Vertical layer design

A 10-layer sigma scheme was used to define the vertical resolution. The sigma layer scheme is a contour-following scheme that features accurate shear stress calculation as the bottommost layer follows the terrain. Thinner layers are defined at the bottom to give a better approximation of the Rouse sediment profile and parabolic velocity profile. From top layer to bottom, the thickness of each layer is 20%, 20%, 15%, 12%, 10%, 8%, 6%, 4%, 3%, and 2% of the total depth. The layer design used in this study is displayed conceptually in Figure 4.

Figure 4. Sigma layer concept.



Curvilinear grid design

The finite difference curvilinear grid was designed to give complete coverage of possible project flood inundation areas between Natchez, MS, and Baton Rouge, LA, as displayed in Figure 5. The grid lines follow the meander of the Mississippi River channel as can be seen in Figure 6. At flow splits in the channel, the grid is generally aligned along the main navigation channel. At the flow diversion structures, the grid is aligned along the direction of the inflow channels. Across the main river channel, a resolution of 30 computational cells was used. The grid dimension is 3,526 × 571 with the larger dimension in the longitudinal flow direction. This maximum potential grid size of 2,009,250 was reduced to 623,874 active computational cells by trimming the overbank areas that extended beyond the potential inundation areas. The grid was referenced to the North American Datum 1983, Universal Transverse Mercator Zone 15N horizontal datum for this model study.

Figure 5. Delft3D model domain.

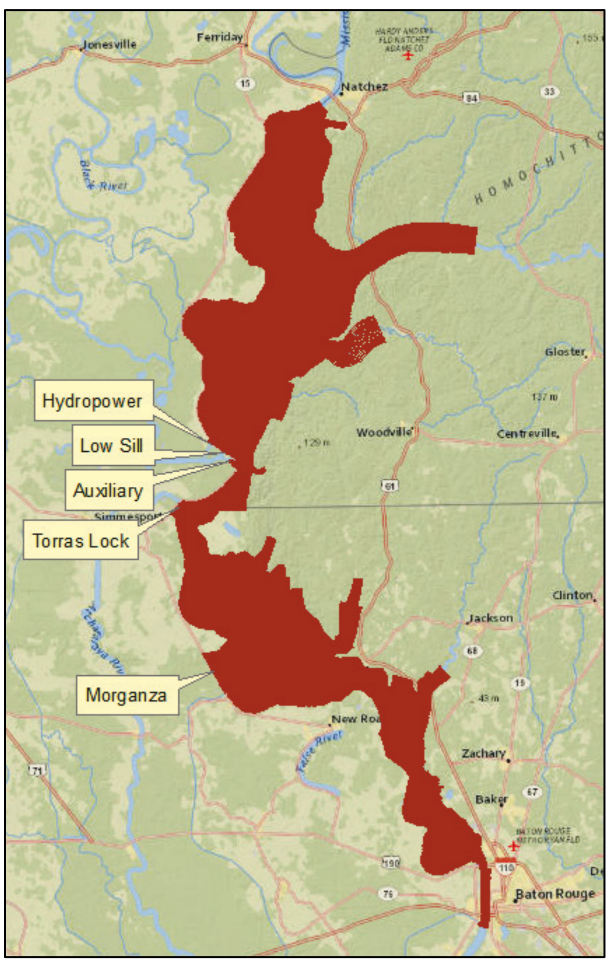


Figure 6. Grid detail in the vicinity of the ORCC.

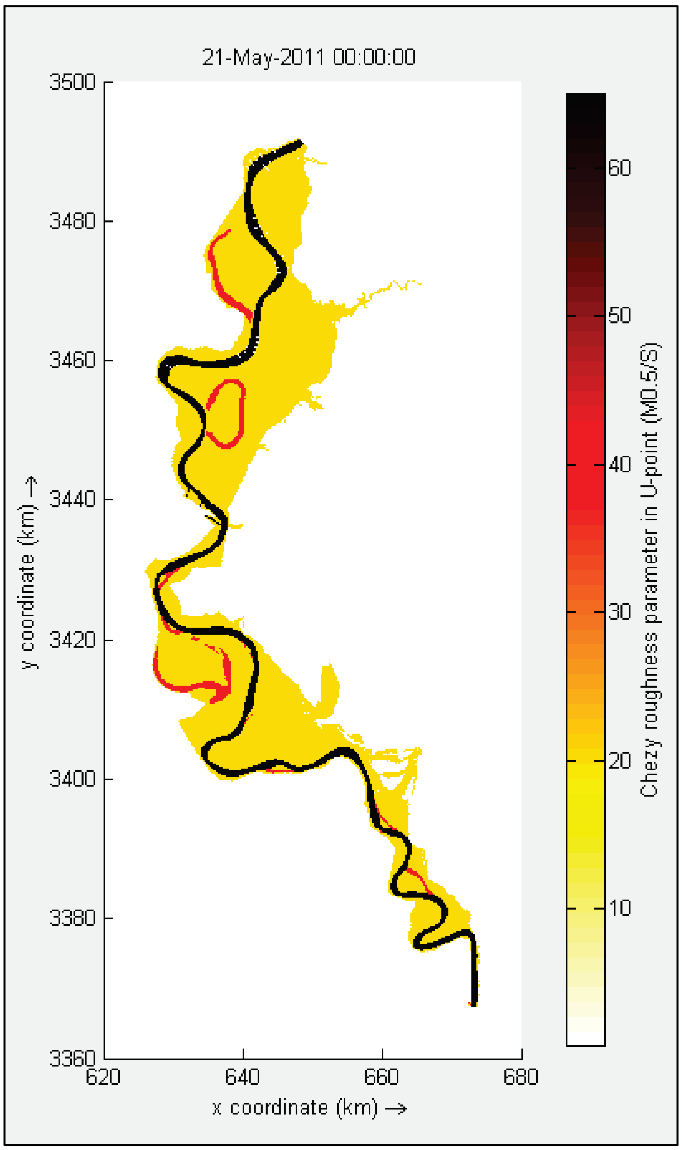
For practicality reasons due to the size of this grid and the number of state variables considered, all computations were performed in parallel using the computing resources at the ERDC Department of Defense Supercomputing Resource Center in Vicksburg, MS.

Bathymetry and bed friction

The bathymetry of the model was defined by the assignment of a depth from a reference level for each grid cell corner. From approximately RM 319 to the upstream boundary at Natchez, MS, the depths were obtained from a surface model obtained from U.S. Army Corps of Engineers (USACE), Vicksburg District (MVK). This MVK surface model was constructed by combining information from lidar and annual hydrographic river channel surveys circa 2012. As the lidar data do not penetrate the water surface, the bathymetry of open water bodies in the river overbanks is not defined. The remainder of the depth information for the model was obtained from an existing ADH model of the area. The ADH model is maintained by personnel at the ERDC Coastal Hydraulics Laboratory. The bathymetry of the Delft3D model is considered to be referenced to 0.0 North American Vertical Datum of 1988 (NAVD88).

The Chezy roughness method was used to define bed friction. A value of 65 $m^{0.5} \cdot s^{-1}$ was selected to represent the Mississippi River channel and intake channels at the structures. A value of 40 $m^{0.5} \cdot s^{-1}$ was used to represent friction in open water bodies such as the various oxbow lakes and secondary river channels. A value of 20 $m^{0.5} \cdot s^{-1}$ was selected to represent overbank areas. These values are spatially depicted in Figure 7.

Figure 7. Chezy roughness coefficient values.



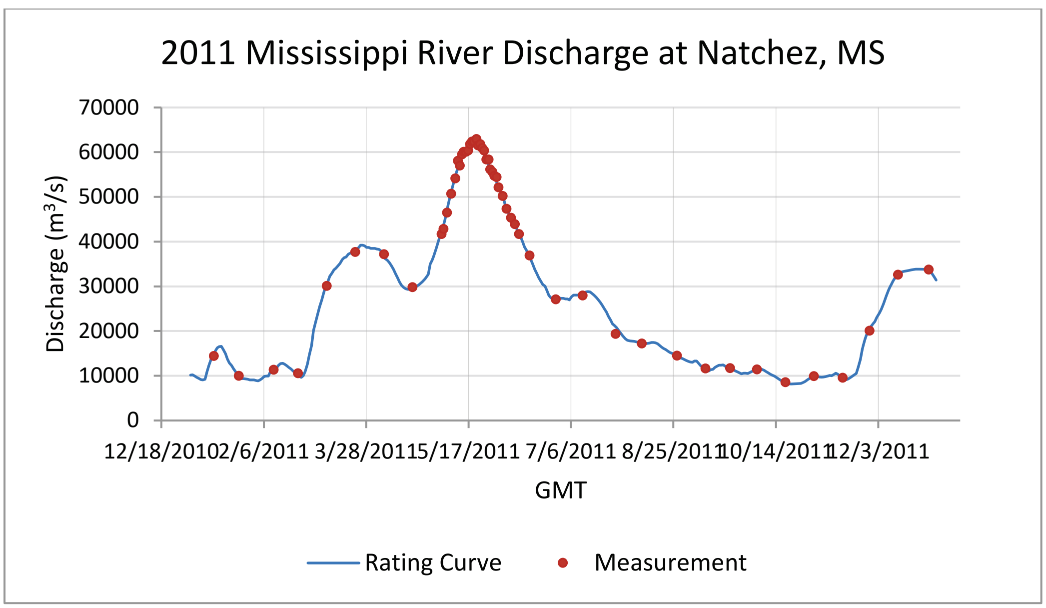
Boundary conditions

River discharge

Computed discharge at Natchez, MS, defined river inflow at the upstream boundary. Flow extractions at the Hydroelectric Plant, Low Sill Structure, Auxiliary Structure, and Morganza Floodway Control Structure were defined from estimated discharge based on gate conditions. The Overbank Structure was not operated during this period of time. Estimates of the Buffalo and Homochitto River contributions were also defined.

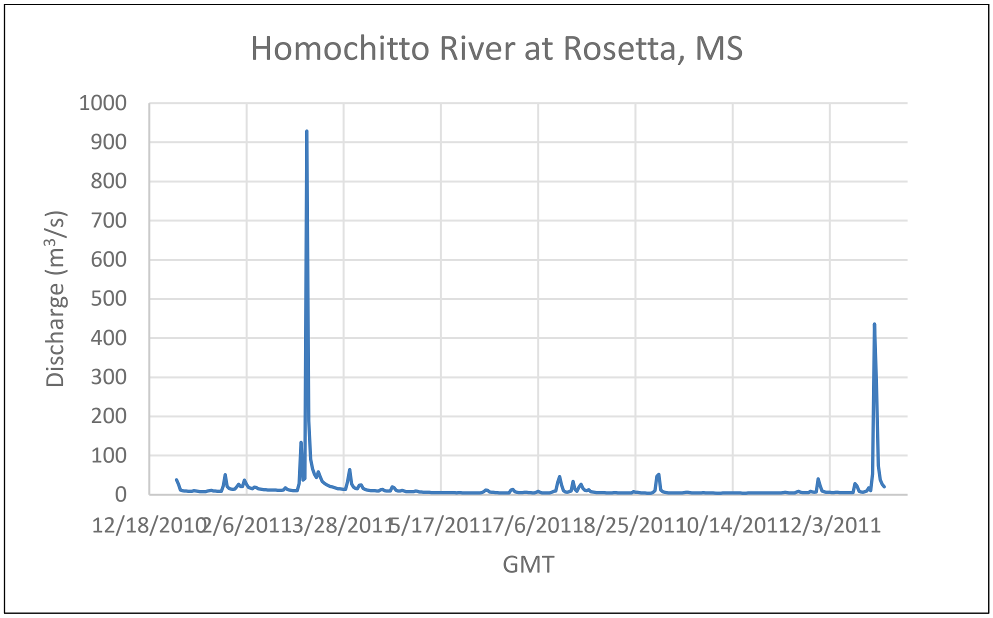
The Mississippi River discharge at Natchez, MS, was based on a rating curve fit to acoustic Doppler current profiler (ADCP) measurements. There were 54 measurements taken during 2011 with a higher concentration of measurements around the peak of the hydrograph in May. The computed and measured data are plotted in Figure 8.

Figure 8. Mississippi River discharge boundary at Natchez.



Daily estimates of flow are provided by the U.S. Geological Survey (USGS) at the Homochitto River at Rosetta, MS (07292500), data collection site. These daily data were used to define the contribution of flow from the Homochitto River. The Homochitto River 2011 flow hydrograph is shown on Figure 9.

Figure 9. Homochitto River hydrograph.



Contribution of flow from the Buffalo River was based on a rating curve developed from discharge data at the USGS Buffalo River near Woodville, MS (07295000), data collection site. The date range of the flow data used to develop the rating was from 1/1/2011 through 3/2/2016. Fifteen-minute water level data were then used to estimate flow from the rating curve. The rating curve data are shown on Figure 10. The resultant Buffalo River 2011 flow hydrograph used to define the Buffalo River flow contribution in the model is shown in Figure 11.

Figure 10. Buffalo River rating curve.

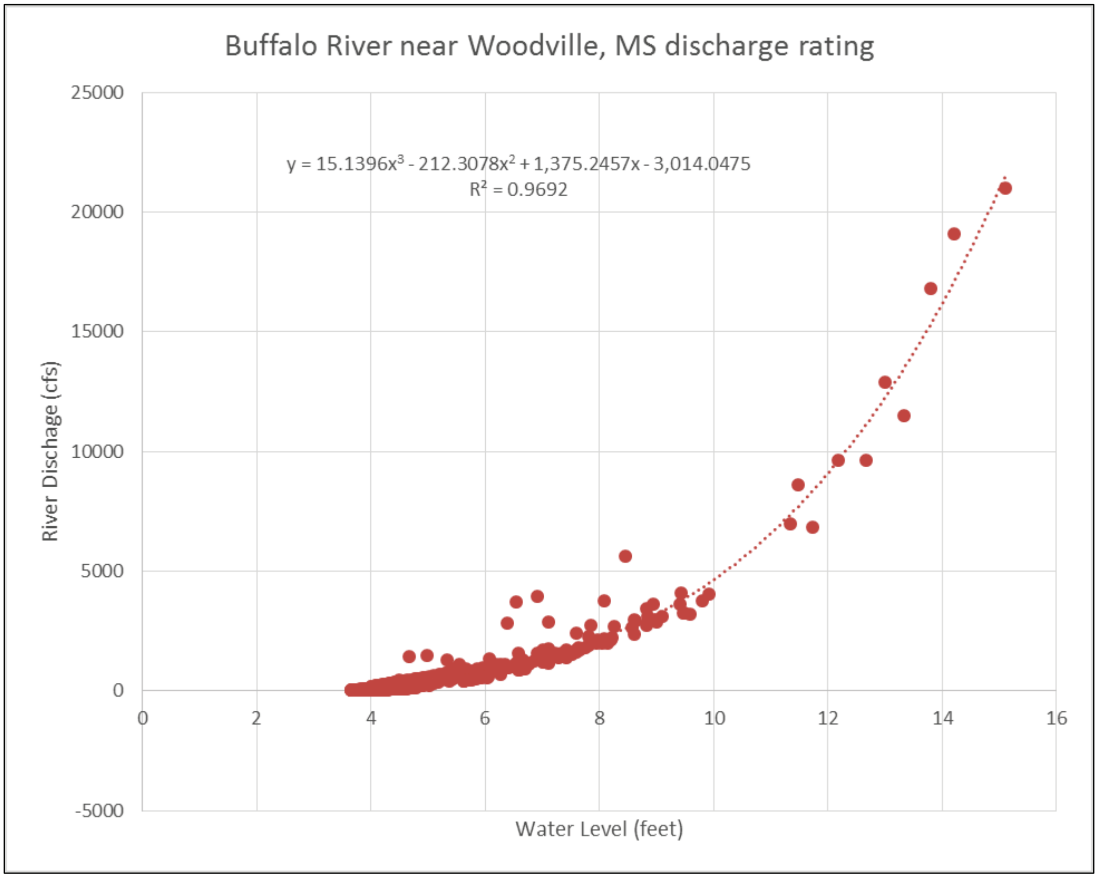
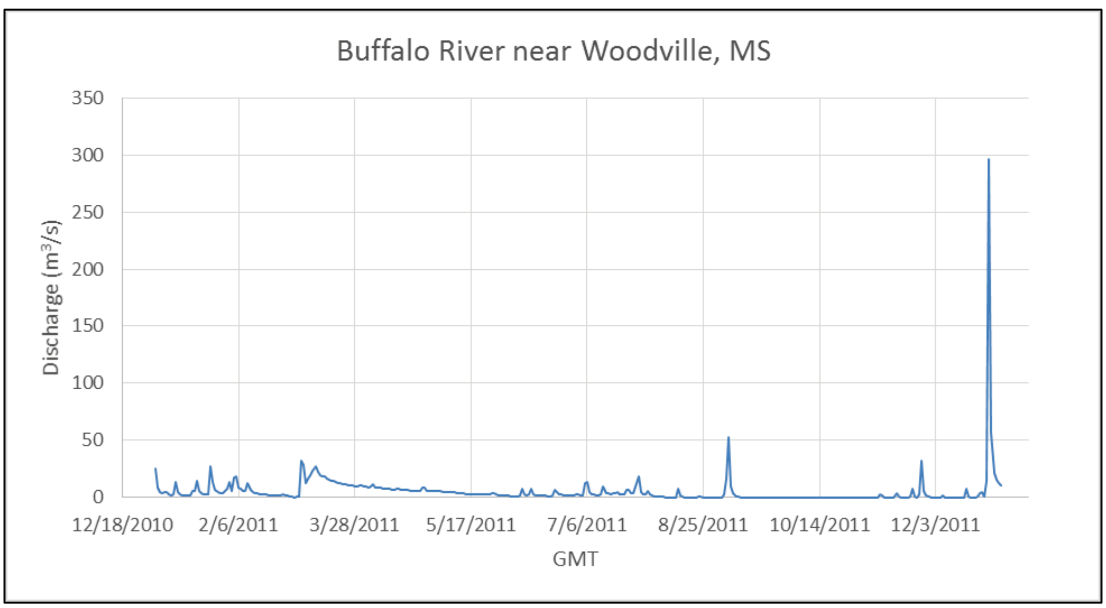


Figure 11. Buffalo River hydrograph.



Gate operations

Lateral flow extraction through the four structures active during this time period were defined as a time series. Details of the flow boundary method used at the Hydroelectric Station, Low Sill, Auxiliary, and Morganza Structures follow.

Sydney A. Murray, Jr. Hydroelectric Station

This structure is comprised of eight power units with submerged intakes as shown in the schematic in Figure 12. The units are either completely open or shut. Currently the total plant flow is distributed evenly across the boundary with flow divided evenly among the computational cells. Due to the proximity of the structure to the river channel and the length of the intake channel, this treatment of the flow distribution is considered to be adequate; however, an improvement to this boundary could be made by withdrawing water from the lower layers of the model to simulate the orifice flow nature of this structure. In addition, each power unit could be given its own time series for a more accurate depiction of this boundary condition. The lateral flow extraction hydrograph for this structure is shown in Figure 13.

Figure 12. Hydroelectric Structure gate schematic.

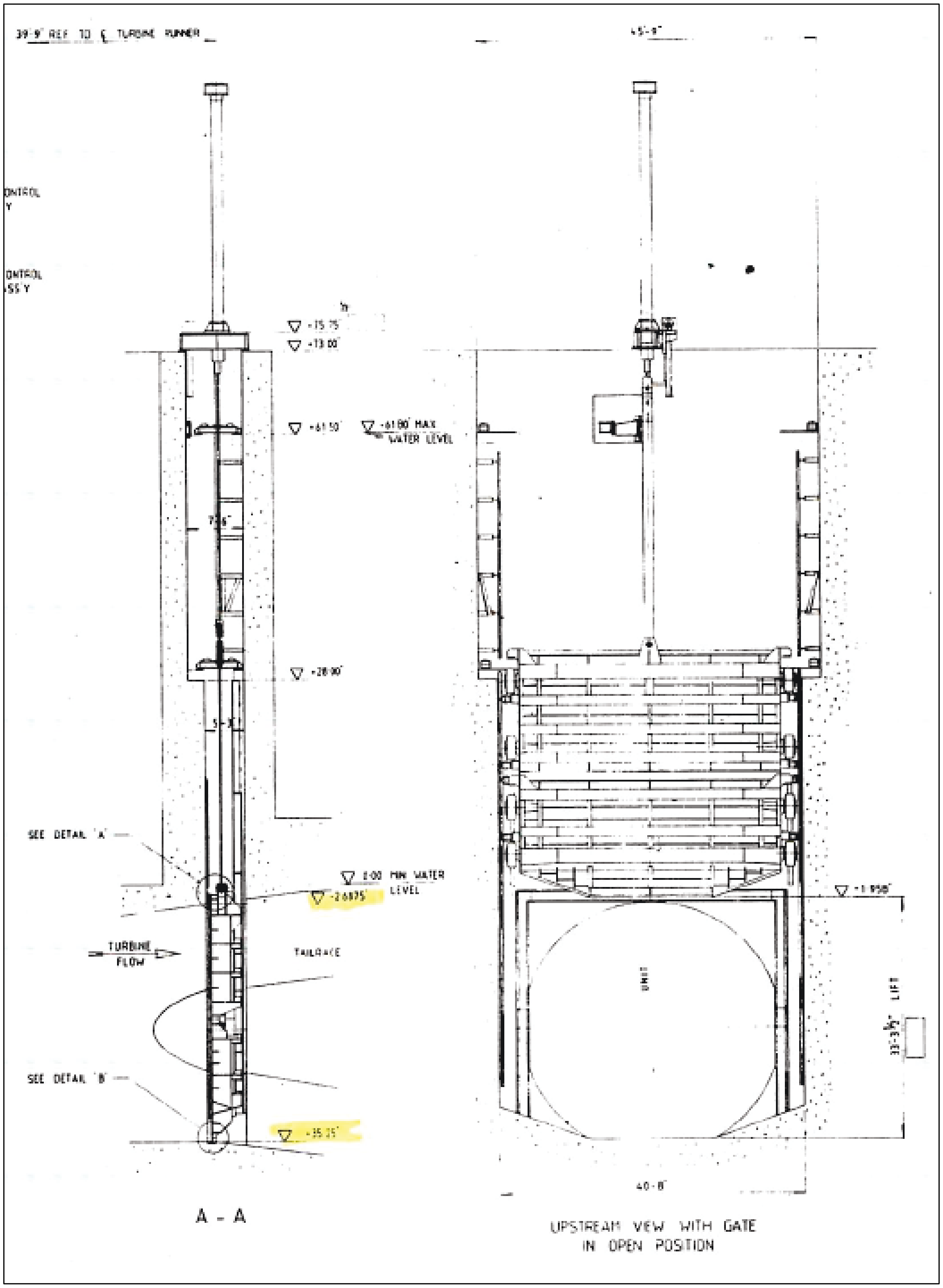
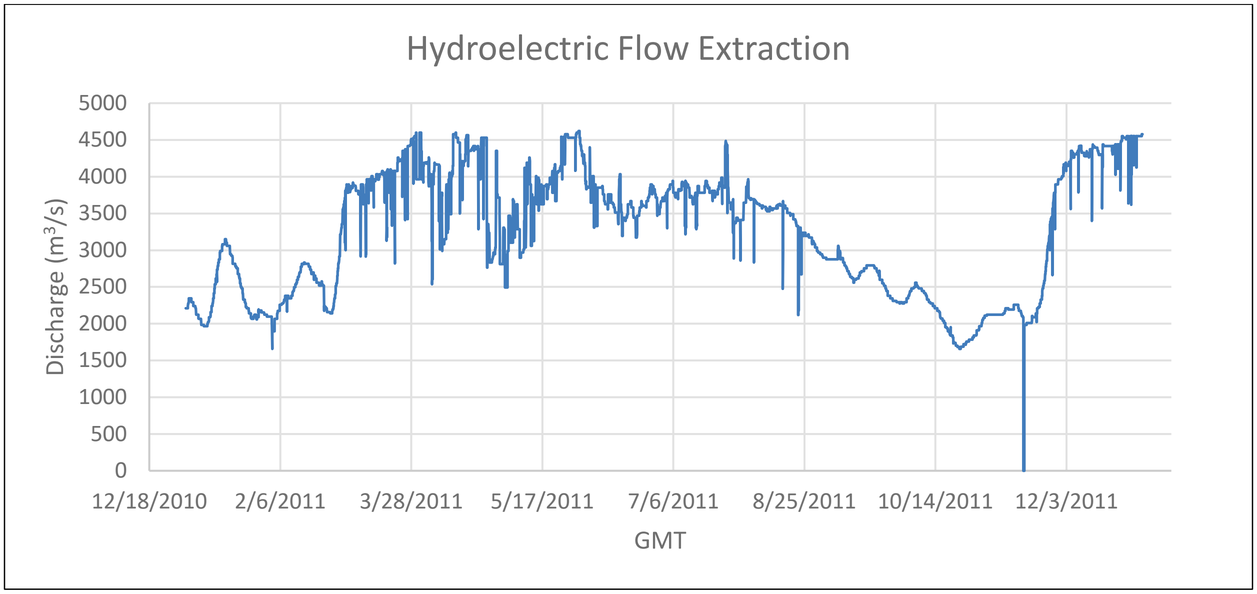


Figure 13. Hydroelectric Structure 2011 hydrograph.



Low Sill Structure

Due to the close proximity of this orifice flow structure to the river channel, each of the 11 gates was treated as a separate boundary condition and given its own flow time series. The sigma vertical distribution of layers moves with the water level; for this reason, the active layers extracting flow changed over time. This was determined using a spread sheet. For 2011, the Low Sill Structure was active from March through December. The total hydrograph for the structure is shown in Figure 14 with the following figures displaying the hydrograph for each gate in the structure (Figures 15–20).

Figure 14. Low Sill Structure lateral flow extraction.

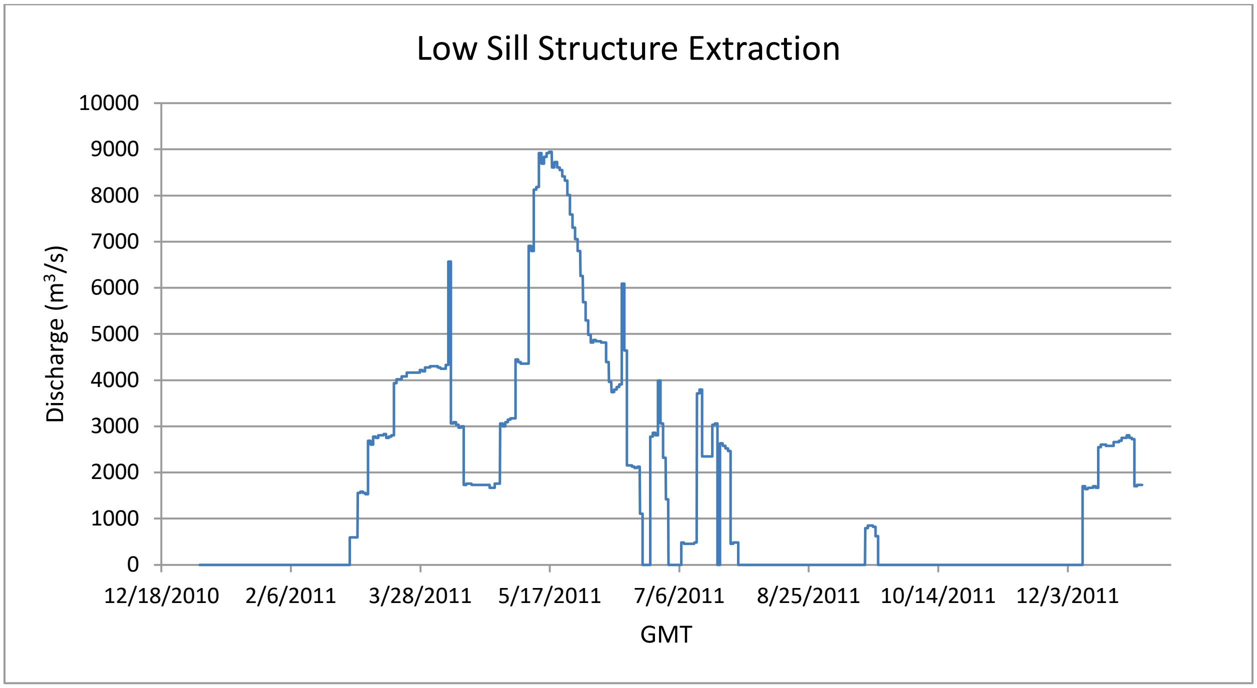


Figure 15. Flow hydrograph for Gates 1 and 11 of the Low Sill Structure.

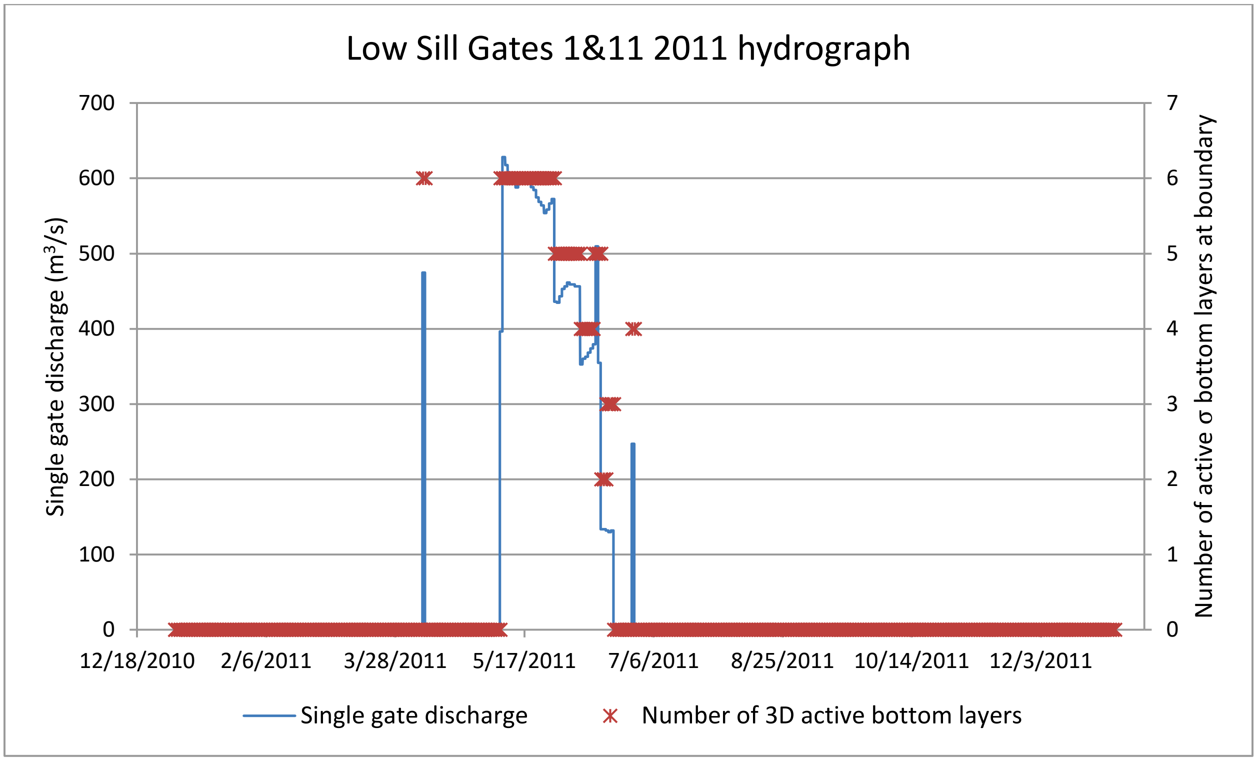


Figure 16. Flow hydrograph for Gates 2 and 10 of the Low Sill Structure.

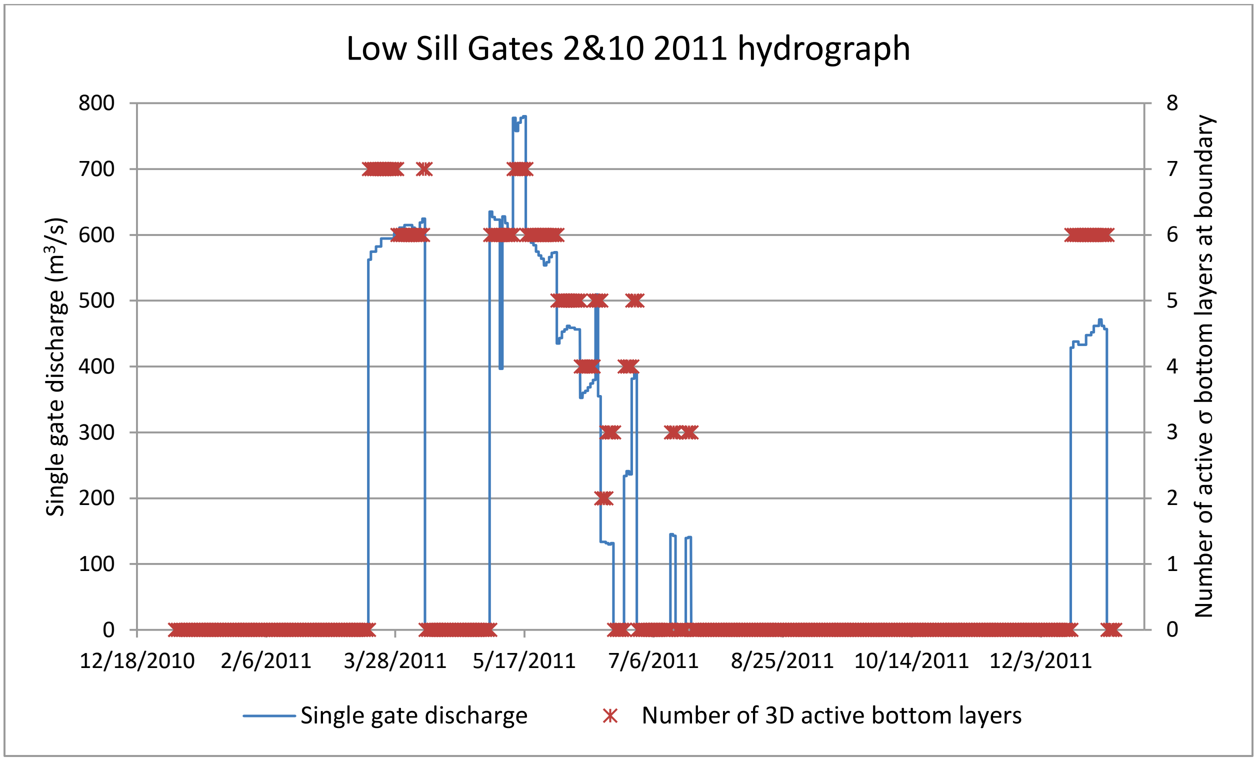


Figure 17. Flow hydrograph for Gates 3 and 9 of the Low Sill Structure.

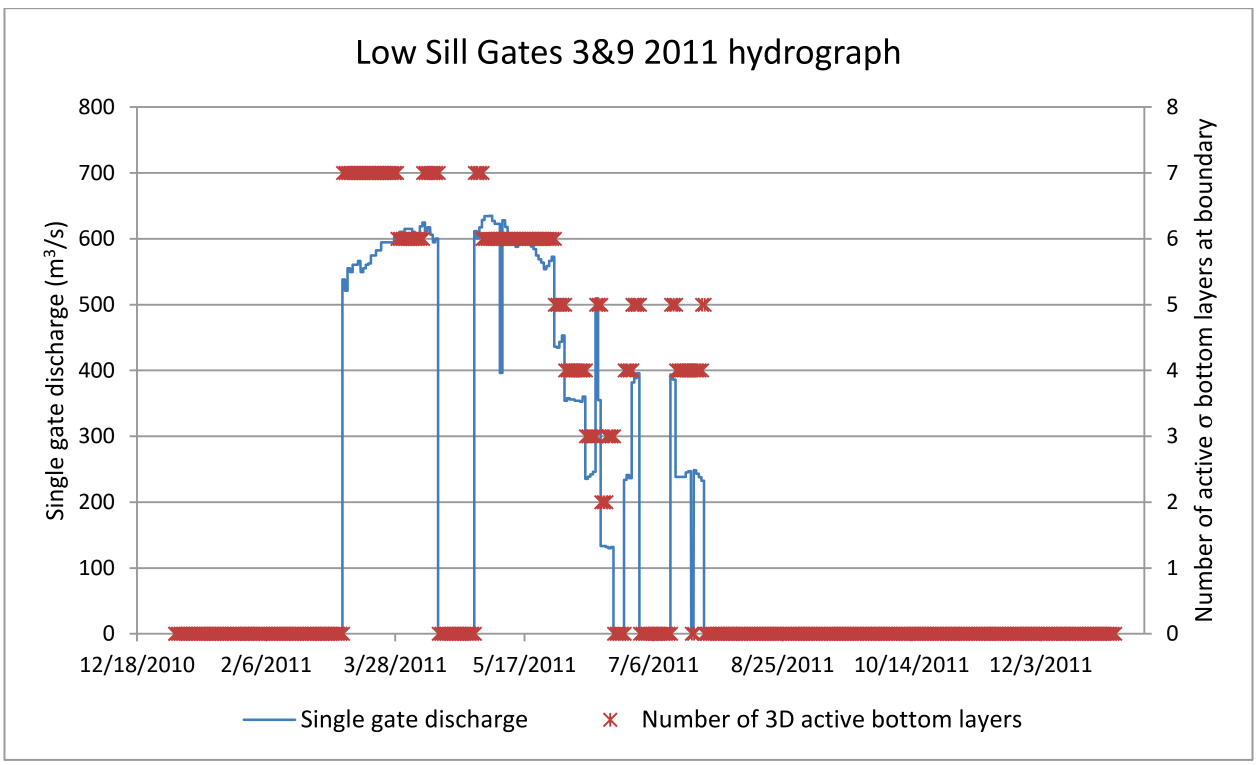


Figure 18. Flow hydrograph for Gates 4 and 8 of the Low Sill Structure.

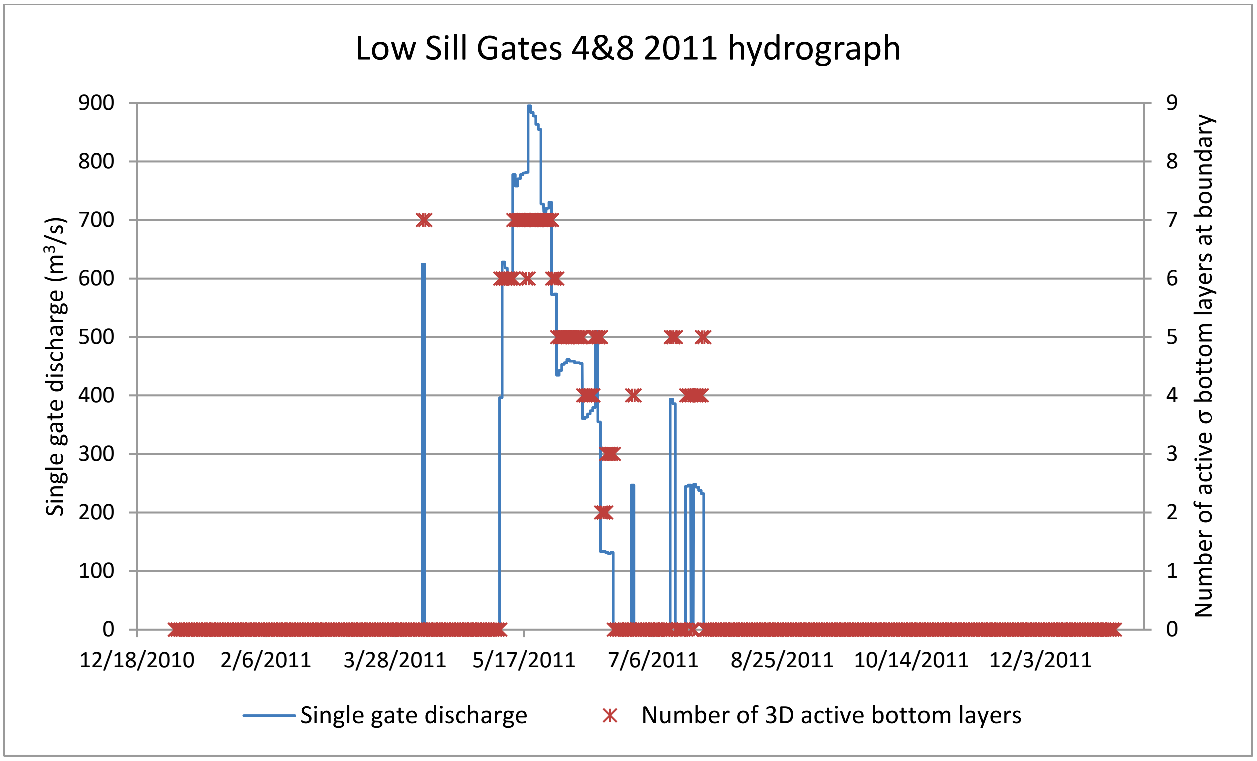


Figure 19. Flow hydrograph for Gates 5 and 7 of the Low Sill Structure.

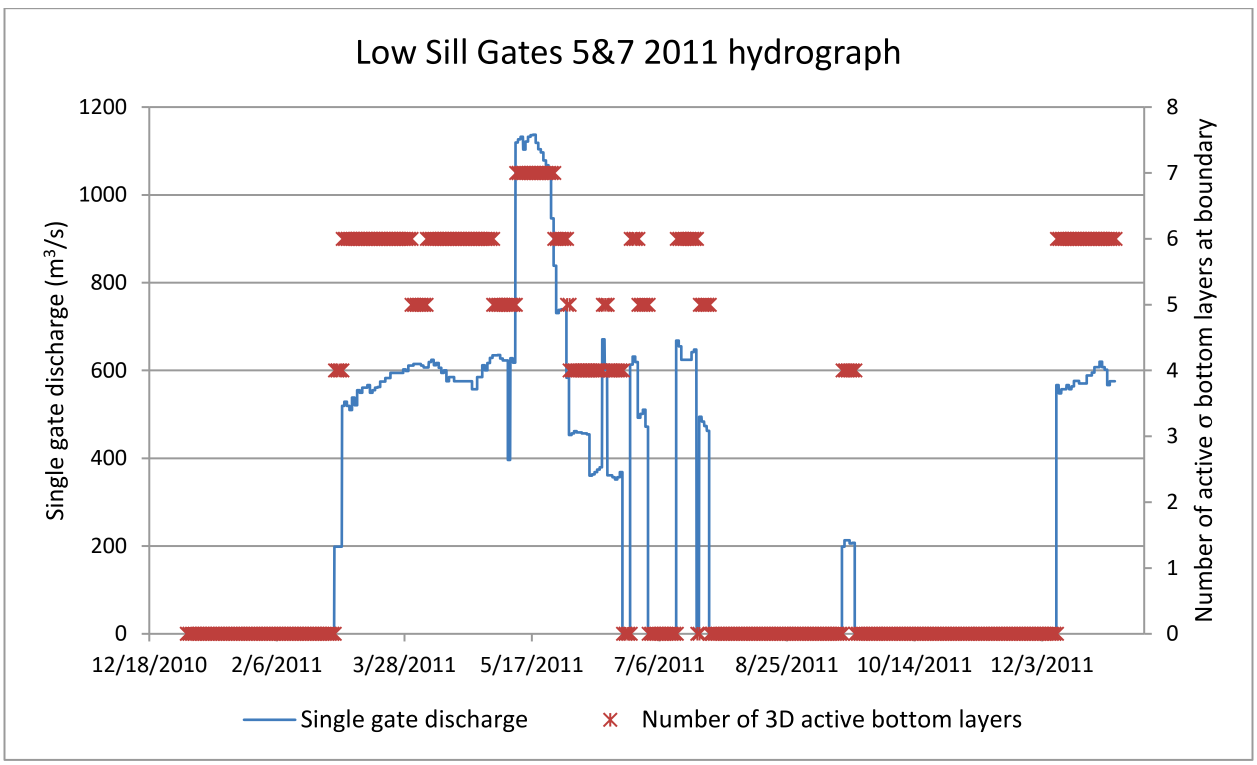
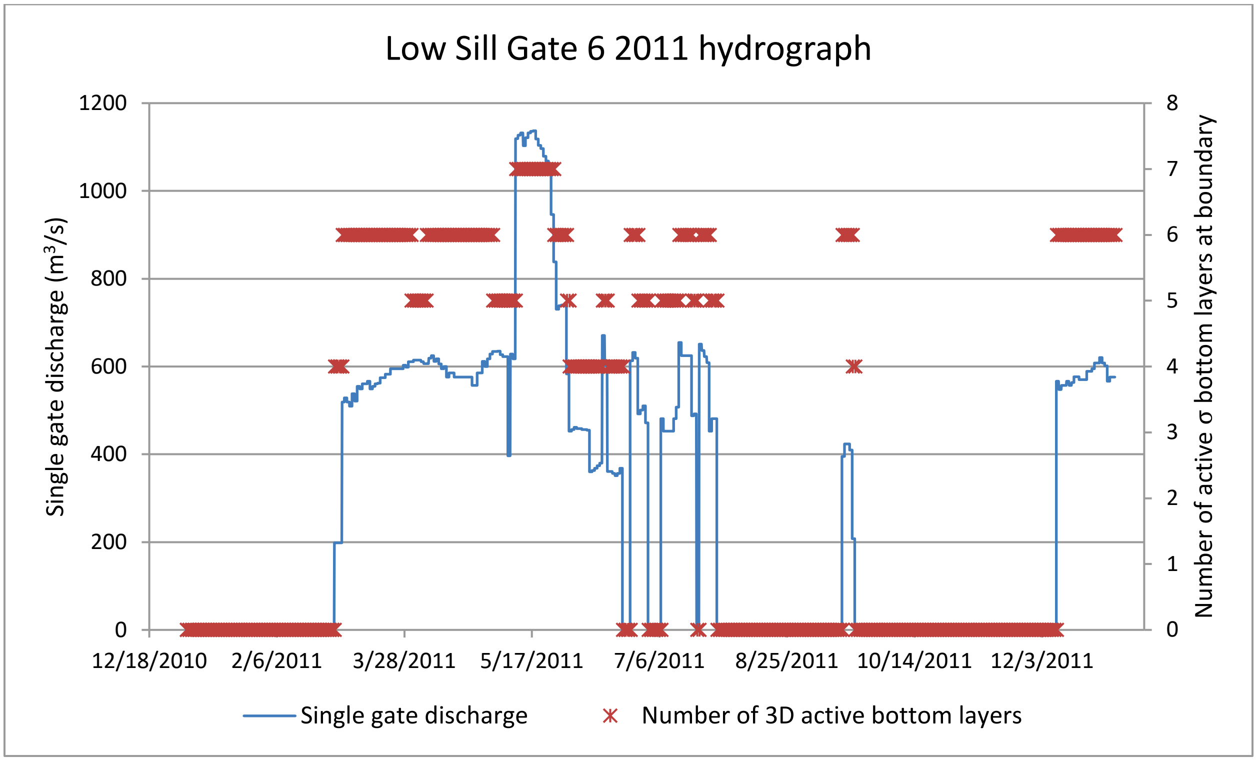


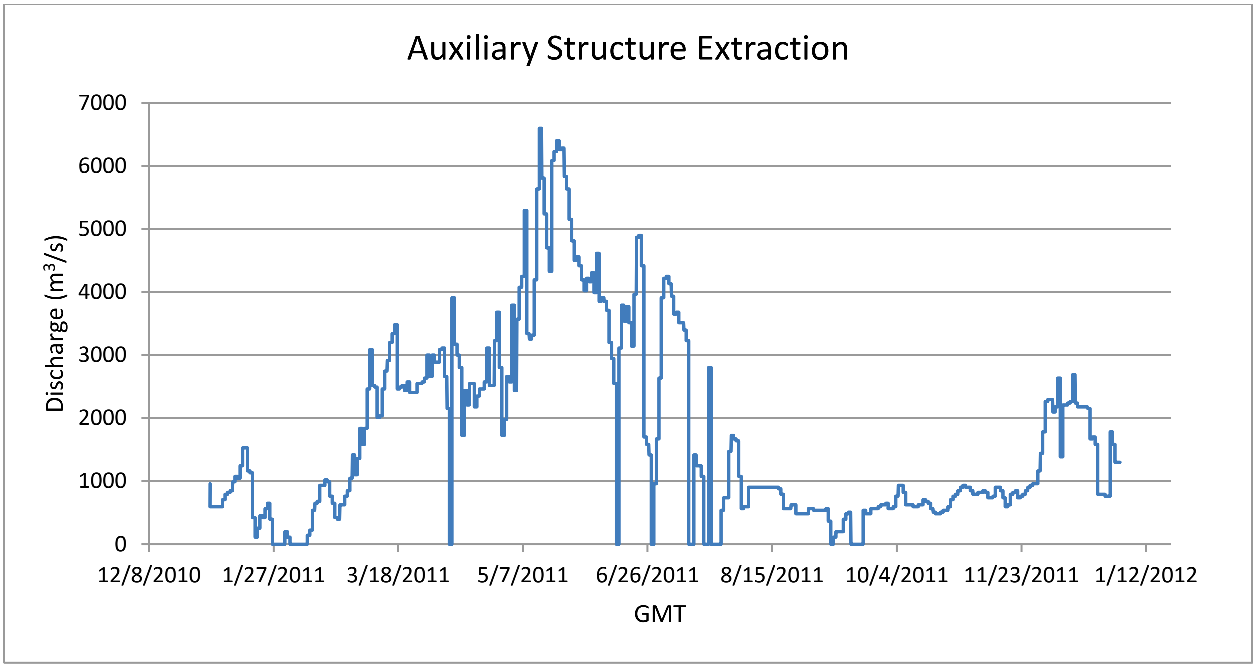
Figure 20. Flow hydrograph for Gate 6 of the Low Sill Structure.



Auxiliary Structure

Flow through this structure is controlled by the operation of six tainter gates. Each gate is operated in the same fashion (i.e., each gate is set to the same opening height during operation). Therefore, the flow through the entire structure was distributed evenly among the computational cells comprising the model boundary. Due to the long approach channel to this structure from the Mississippi River channel, a logarithmic vertical distribution of the flow at the boundary was used to simplify the setup of the boundary condition. The 2011 hydrograph for this structure is shown in Figure 21. A cross section of the gate is shown in the Appendix.

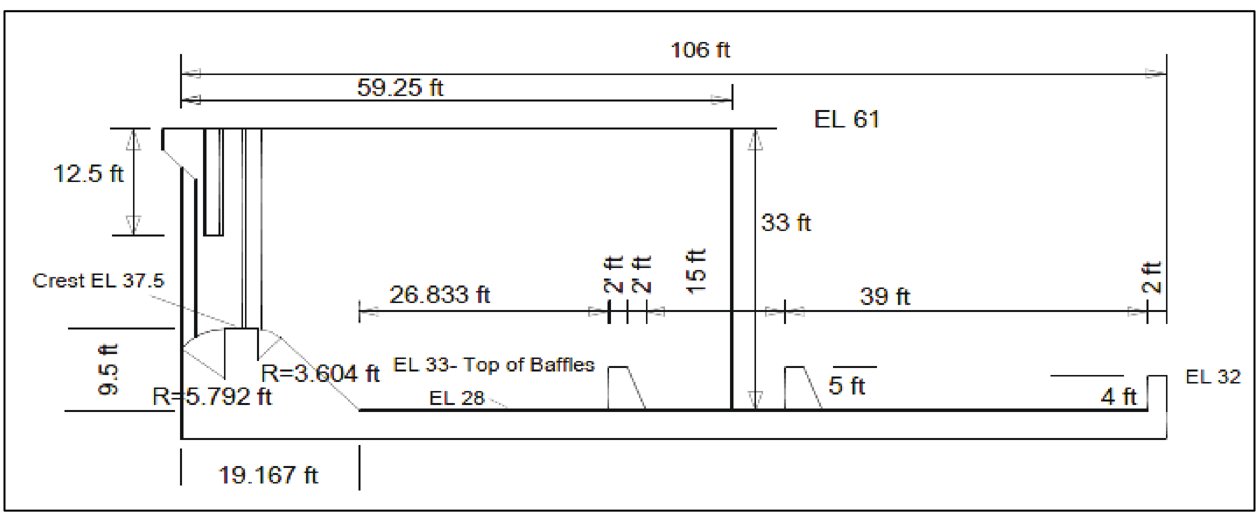
Figure 21. Auxiliary Structure hydrograph.



Morganza Floodway Control Structure

The Morganza Floodway Control Structure is comprised of a 3,906.25 ft long, 125-bay intake structure. Each gate has a clear open width of 28.25 ft separated by a 3 ft wide pier. Each gate has an upstream upper leaf and a downstream lower leaf and is designed to be fully open or closed. Figure 22 displays a typical cross section of the structure with dimensions of gate features.

Figure 22. Morganza Structure cross section.

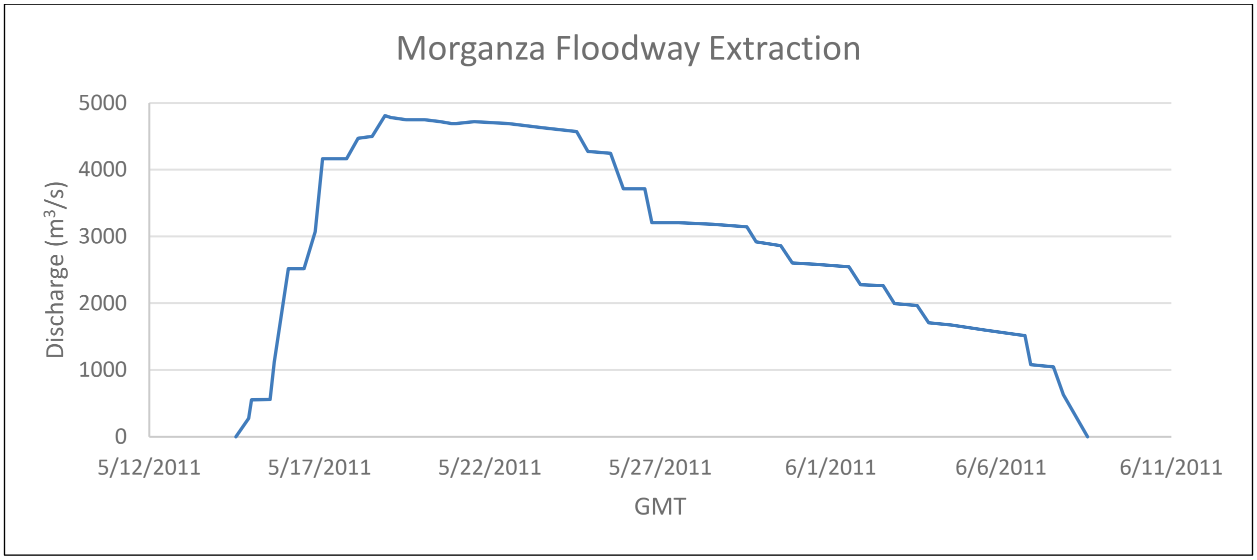


The Morganza Structure flow estimates are based on a tailwater (TW in feet) rating curve (Maynord 2014) valid for discharges below 170,000 cfs (4814 m³/s):

$$Q\ (\text{cfs}) = 377.2TW^2 - 14840TW + 71679$$

The data produced by this rating curve were applied as a total flow boundary shown in Figure 23.

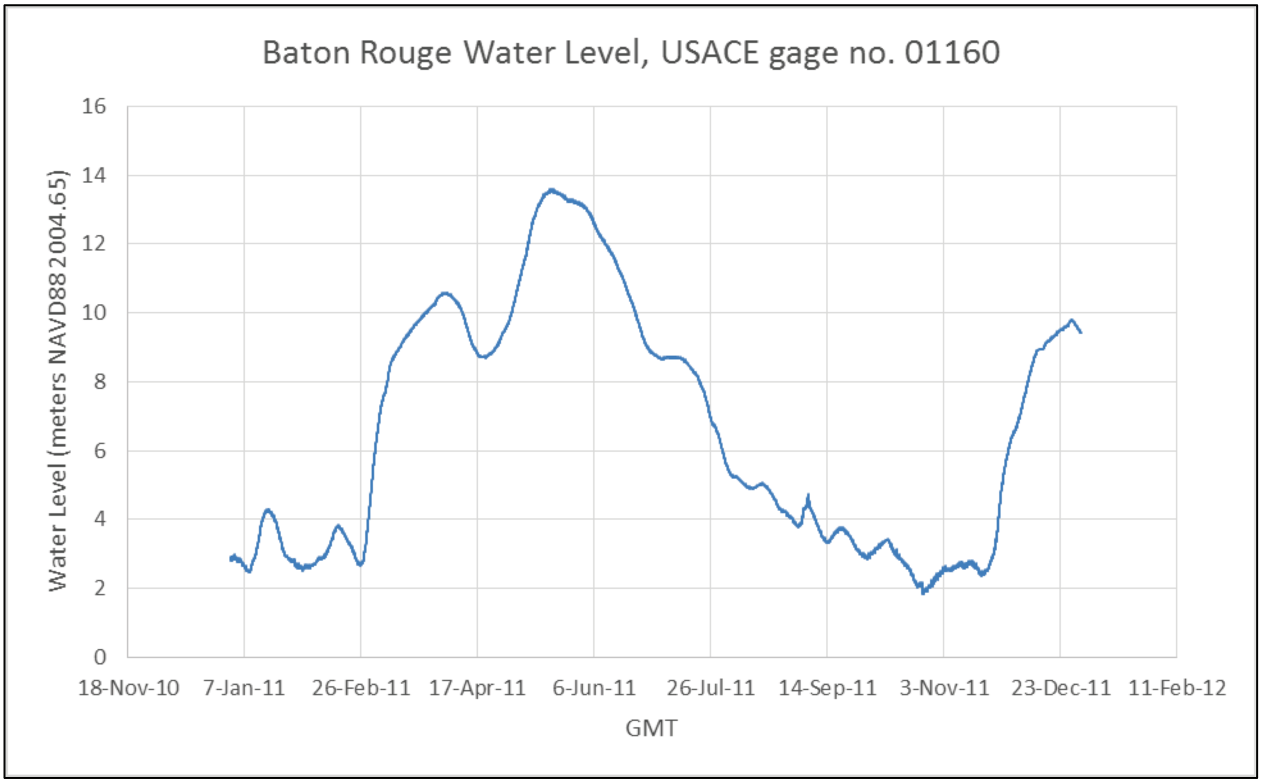
Figure 23. Morganza Floodway Control Structure hydrograph.



Tailwater stage

The river water level at Baton Rouge was used to define the downstream tailwater conditions in the model. Hourly water level data from USACE gage number 01160 with adjustment to NAVD88 (2004.65) defined the boundary condition. Figure 24 shows a plot of the 2011 water level at Baton Rouge.

Figure 24. 2011 Mississippi River water level at Baton Rouge.



Bed sediment gradation

Sediment bed samples collected at Tarbert Landing (RM 306.2) and Union Point (RM 326.1) were analyzed to define the starting bed gradation for the simulation. Four bed samples are collected at each of the four verticals at each site. These four bed samples are combined in the field to get one representative bed gradation for each collection date. These bed gradation data are summarized in Table 1 and Table 2 for data collected in Water Year (WY) 2011, and the average is shown plotted in Figure 25.

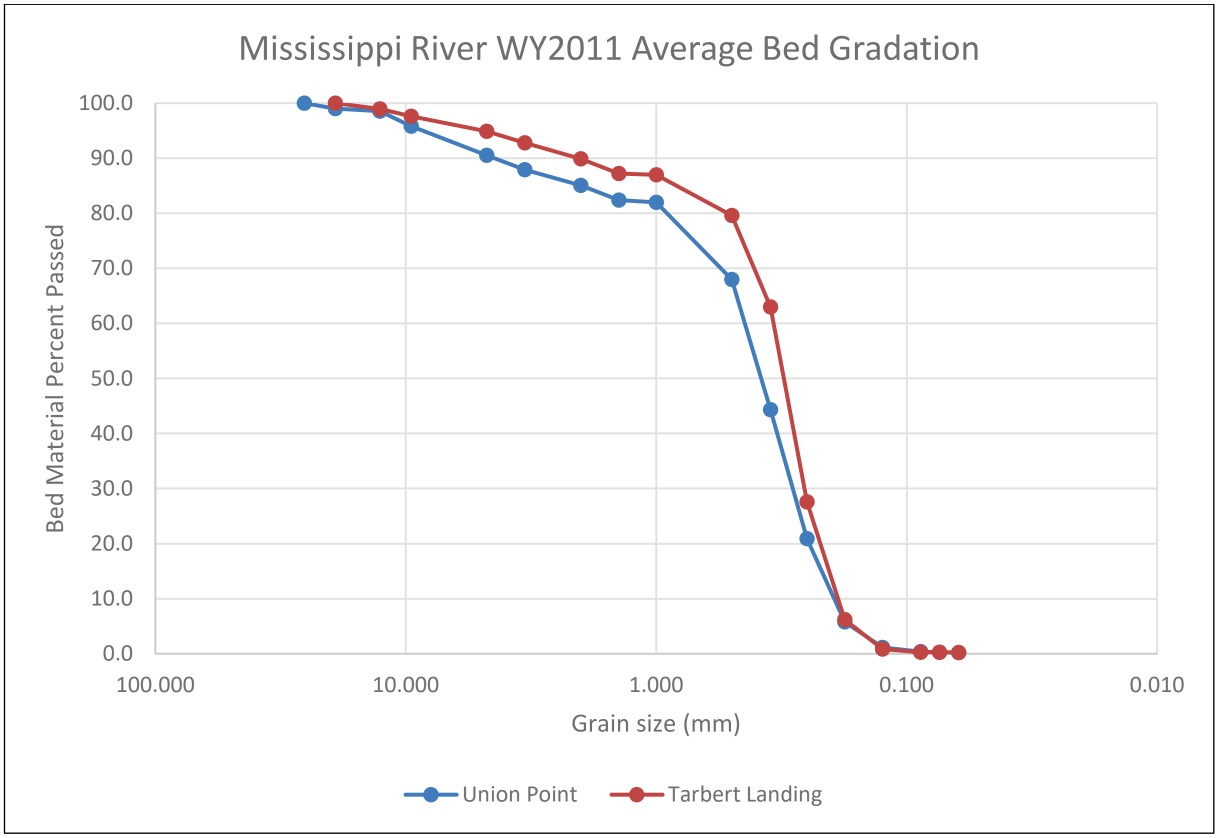
Table 1. Tarbert Landing bed sample gradations.

Collection Date	Sieve Size (mm)																
	25.400	19.100	12.700	9.520	4.750	3.350	2.000	1.410	1.000	0.500	0.350	0.250	0.177	0.125	0.088	0.074	0.062
	Bed Material Passed (percent)																
10/7/2010	100.0	100.0	100.0	97.0	96.9	95.7	94.3	93.3	93.1	87.6	75.0	32.3	3.6	0.4	0.3	0.3	0.3
11/10/2010	100.0	100.0	100.0	96.6	91.1	88.1	85.5	83.9	83.8	74.8	53.7	11.7	0.7	0.0	0.0	0.0	0.0
12/9/2010	100.0	100.0	100.0	97.8	90.7	89.1	87.9	87.5	87.5	83.8	64.5	13.3	2.1	0.7	0.6	0.5	0.5
12/27/2010	100.0	100.0	100.0	100.0	95.6	92.4	87.0	82.2	81.6	60.7	33.8	5.6	1.1	0.6	0.5	0.5	0.5
1/13/2011	100.0	100.0	100.0	100.0	97.4	90.7	79.8	69.7	68.9	54.0	30.8	5.8	0.9	0.2	0.0	0.0	0.0
1/26/2011	100.0	100.0	100.0	98.4	95.9	94.2	91.8	88.8	88.6	71.1	35.7	5.5	0.9	0.2	0.1	0.1	0.1
2/14/2011	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.8	99.3	87.0	14.6	0.7	0.2	0.2	0.2
2/28/2011	100.0	100.0	100.0	100.0	99.1	98.7	98.0	97.8	97.7	96.2	82.3	25.5	3.3	0.2	0.0	0.0	0.0
3/10/2011	100.0	100.0	100.0	100.0	98.7	97.3	94.7	92.7	92.6	90.2	81.0	36.2	5.6	0.4	0.1	0.1	0.1
3/24/2011	100.0	100.0	100.0	98.3	97.2	97.0	96.6	96.2	96.1	88.1	75.8	56.4	24.1	5.4	0.8	0.2	0.0
4/14/2011	100.0	100.0	100.0	100.0	98.0	96.2	91.3	86.1	85.7	74.2	50.9	15.5	2.3	0.6	0.5	0.5	0.5
4/28/2011	100.0	100.0	93.1	85.4	75.6	64.9	53.4	41.2	41.2	35.6	22.0	6.2	0.9	0.2	0.2	0.2	0.2
5/15/2011	100.0	100.0	100.0	100.0	97.7	96.7	95.7	95.0	95.0	90.0	81.3	60.9	23.2	3.0	0.6	0.5	0.5
5/30/2011	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.4	95.1	61.4	10.4	0.6	0.0	0.0	0.0
6/23/2011	100.0	100.0	87.8	83.4	79.5	76.7	72.4	68.6	68.3	61.5	52.2	36.6	14.3	0.8	0.0	0.0	0.0
7/14/2011	100.0	100.0	100.0	100.0	97.4	96.5	95.3	94.2	94.1	89.8	73.5	14.6	1.6	0.5	0.5	0.5	0.5
8/4/2011	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.5	89.5	18.6	1.0	0.0	0.0	0.0	0.0
9/8/2011	100.0	100.0	100.0	100.0	97.6	96.2	94.4	92.7	92.0	76.2	37.5	3.9	0.9	0.9	0.9	0.9	0.9
Averages	100.0	100.0	100.0	97.0	96.9	95.7	94.3	93.3	93.1	87.6	75.0	32.3	3.6	0.4	0.3	0.3	0.3

Table 2. Union Point bed sample gradations.

Collection Date	Sieve Size (mm)																
	25.400	19.100	12.700	9.520	4.750	3.350	2.000	1.410	1.000	0.500	0.350	0.250	0.177	0.125	0.088	0.074	0.062
	Bed Material Passed (percent)																
10/5/2010	100.0	100.0	100.0	98.9	95.5	93.9	91.3	88.8	88.3	67.3	36.4	14.8	3.1	2.0	0.1	0.1	0.1
11/16/2010	100.0	100.0	100.0	95.2	80.4	78.7	76.8	75.5	75.4	64.4	34.3	11.2	2.0	0.3	0.2	0.2	0.2
12/7/2010	100.0	100.0	98.7	95.8	90.9	87.8	86.0	84.4	84.3	66.0	41.0	19.2	3.0	0.5	0.5	0.4	0.4
1/12/2011	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	98.0	80.5	38.3	7.0	1.6	0.5	0.1
2/1/2011	100.0	100.0	100.0	99.0	91.5	85.2	77.1	70.1	69.1	48.9	28.0	8.5	0.7	0.1	0.0	0.0	0.0
3/1/2011	100.0	100.0	100.0	98.5	98.4	98.3	98.1	98.0	98.0	97.3	90.2	29.3	2.7	0.4	0.2	0.2	0.2
4/5/2011	100.0	100.0	100.0	97.8	95.8	95.5	95.1	95.1	95.1	87.8	49.5	23.1	10.3	2.2	0.5	0.3	0.3
4/19/2011	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.0	84.2	52.8	8.6	0.3	0.2	0.2	0.2
5/3/2011	100.0	100.0	100.0	97.6	96.7	96.0	95.7	95.2	95.2	71.6	12.9	1.8	0.8	0.8	0.8	0.8	0.8
6/16/2011	100.0	100.0	100.0	92.3	81.6	75.6	69.9	63.4	62.1	42.3	12.9	0.7	0.2	0.1	0.1	0.1	0.1
7/12/2011	100.0	94.6	91.0	84.1	73.2	68.3	62.9	57.8	57.2	41.4	27.5	11.2	2.3	0.2	0.1	0.1	0.1
8/3/2011	100.0	92.5	91.2	86.3	74.9	67.3	59.0	50.9	49.4	23.3	4.1	0.5	0.4	0.4	0.4	0.4	0.4
9/7/2011	100.0	100.0	100.0	100.0	98.0	96.3	94.2	92.0	91.7	74.8	57.4	18.3	2.6	0.3	0.2	0.2	0.2
Averages	100.0	99.0	98.5	95.8	90.5	87.9	85.1	82.4	82.0	68.0	44.3	20.9	5.8	1.1	0.4	0.3	0.2

Figure 25. WY2011 average bed sample gradation at Union Point and Tarbert Landing.



As can be seen from the data, the Union Point samples were comprised of larger grain sized sediment on average than the samples collected at Tarbert Landing. Analysis of these data indicated that to properly model the bed movement, larger grain sizes would need to be included in the model study. These larger grain size sediments are represented in the model by a grain class with a D_{50} diameter of 2.0 mm. The Wentworth size classification system is used to define the non-cohesive sediment classes selected for model study and is summarized in Table 3. The average gradation at Union Point was used to define the model bed gradation from Natchez to a point between the Hydroelectric Plant and the Low Sill Structure while the Tarbert Landing average gradation defined the model bed gradation in the southern part of the model domain. Seven grain classes are modeled: two cohesive classes (clay and silt) and five non-cohesive sand classes as summarized in Table 3. The bed gradation selected for the CH3D model study of the ORCC detailed in Section 15.11.2 of ASCE Manual 110 is shown for comparison purposes (Spasojevik and Holly 2008).

Table 3. Grain size by Wentworth classification.

Wentworth Grain Size Class	Grain Size Range (mm)	Log Uniform D_{10} (mm)	Log Uniform D_{50} (mm)	Log Uniform D_{90} (mm)	WY2011 Tarbert Landing Average Bed Fraction	WY2011 Union Point Average Bed Fraction	ASCE Manual 110
Clay	< 0.004	N/A	N/A	N/A	Assumed 0.00	Assumed 0.00	0.00
Silt	0.004 – 0.062	N/A	N/A	N/A	0.00	0.00	0.00
Very Fine Sand	0.062 – 0.125	0.06650	0.08803	0.1165	0.01	0.01	0.01
Fine Sand	0.125 – 0.250	0.1340	0.1768	0.2333	0.27	0.20	0.45
Medium Sand	0.250 – 0.500	0.2679	0.3536	0.4665	0.52	0.47	0.45
Coarse Sand	0.500 – 1.000	0.5359	0.7071	0.9330	0.07	0.14	0.08
Very Coarse Sand and Granules	1.000 – 4.000	1.1490	2.0000	3.4820	0.13*	0.18*	0.01

Note * – Gravel larger than 4 mm contributed to this percentage.

Natchez sediment concentration

To estimate the sand sediment load entering the model boundary at Natchez, MS, a small 3D model was constructed that represents the Mississippi River channel in the vicinity of Natchez, MS. This small model allowed for longer-term simulations to estimate the sediment load at Natchez, MS. The equilibrium sediment concentration was computed by the model, which defined the sediment load at the upstream boundary of this small Natchez model. For each of the five sand classes, the sediment load entering the boundary is near perfectly adapted to the local flow conditions, and little accretion and erosion occurs near the boundaries. A 10-layer bed sorted the computed equilibrium load entering the upstream boundary of this Natchez model with an initial bed gradation based on an average of bed samples from the Natchez vicinity reported in *Particle Size Distributions of Bed Sediments along the Mississippi River, Grafton, Illinois, to Head of Passes, Louisiana*, November 2013, MRG&P Report No. 7 (Gaines and Priestas 2016). This average bed gradation is shown in Table 4. The computational grid of the small Natchez model is shown in Figure 26.

Table 4. Natchez bed sediment.

Wentworth Grain Size Class	Grain Size Range (mm)	Log Uniform D_{10} (mm)	Log Uniform D_{50} (mm)	Log Uniform D_{90} (mm)	Natchez Average Bed Fraction from MRG&P Report No. 7 (Gaines and Priestas 2016)
Very Fine Sand	0.062 – 0.125	0.06650	0.08803	0.1165	0.002
Fine Sand	0.125 – 0.250	0.1340	0.1768	0.2333	0.131
Medium Sand	0.250 – 0.500	0.2679	0.3536	0.4665	0.739
Coarse Sand	0.500 – 1.000	0.5359	0.7071	0.9330	0.115
Very Coarse Sand and Granules	1.000 – 4.000	1.1490	2.0000	3.4820	0.013*

Note * – Gravel larger than 4 mm contributed to this percentage.

Figure 26. Natchez vicinity 3d model grid.

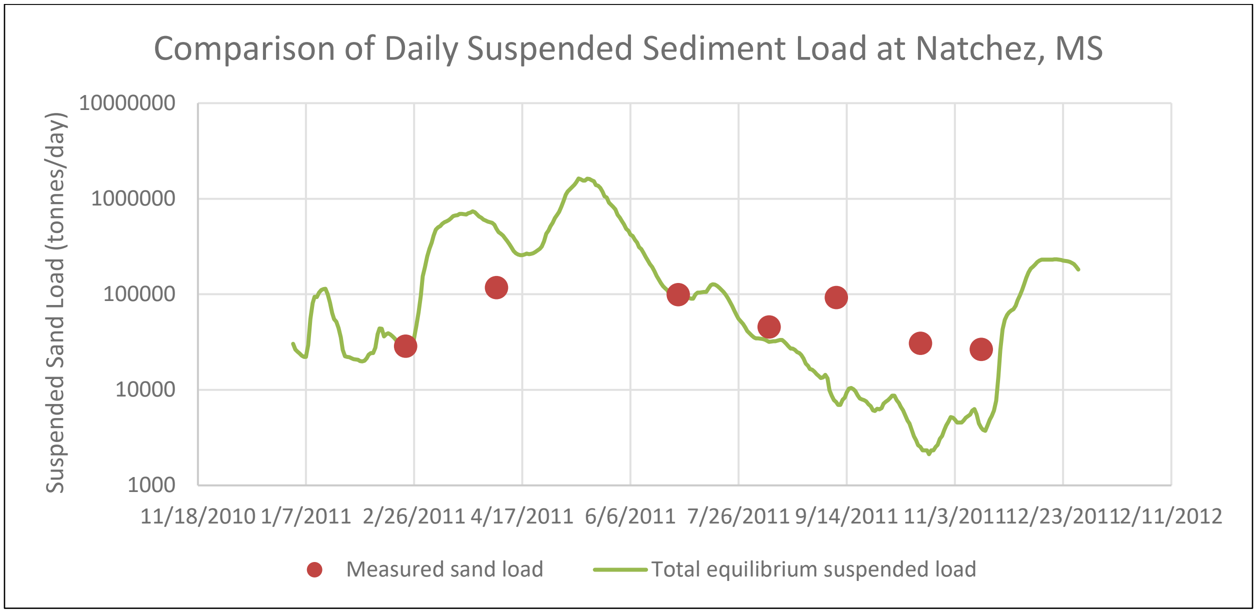
Suspended sediment was collected at Natchez by MVK in 2011 using a P-61 sampler. The samples were collected at six verticals with four samples at each vertical location for a total of 24 possible suspended sample points. Some point samples may have not been collected for every sample event. Fine samples were omitted if lab results were not acceptable. The average Fine concentration for these sample sets was 66 parts per million (PPM) or 0.066 kilograms per cubic meter (kg/m^3). Based on observed historic distribution of clay and silt at Tarbert Landing, this concentration was distributed between the clay and silt fractions at 30% and 70%, respectively, and these uniform concentrations were applied at the inflow river boundary at Natchez for the system-wide model. The 2011 sample sets at Natchez are summarized in Table 5.

Table 5. Mississippi River at Natchez 2011 suspended sediment samples.

Date	Measured River Discharge (cfs)	Water Temp Degrees Fahrenheit	Number Sand Samples Used	Number Fines Samples Used	Sand PPM	Fines PPM	Total PPM	$Q_{sediment}$ tons/day
2/22/2011	372,000	48	6	4	28.2	12.3	40.6	40,744
4/5/2011	1,307,000	51	21	6	32.9	25.8	58.7	207,153
6/28/2011	956,000	81	24	4	37.8	60.0	97.8	252,461
8/9/2011	606,000	90	24	6	27.4	77.2	104.5	171,063
9/9/2011	410,000	78	24	1	82.2	100.1	182.3	201,833
10/18/2011	300,000	71	24	6	37.5	39.8	77.3	62,620
11/15/2011	336,000	60	9	6	28.8	149.5	178.3	161,766

The total equilibrium sand load computed by the small Natchez model is compared to these measured sample sets in Figure 27. As can be seen in the figure, the equilibrium load appears to have more extreme high and low loads than observed in the sample sets.

Figure 27. Equilibrium and measured sand load at Natchez, MS.

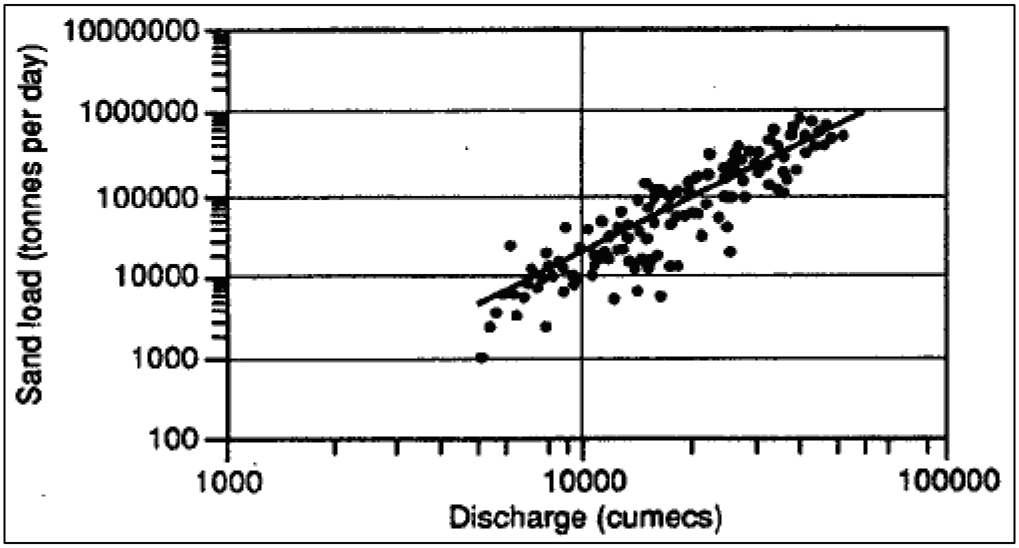


Therefore, a means to normalize the data to the observed data was sought. A sand load rating curve may take the form of a power law relationship:

$$Q_s = aQ^b$$

where Q_s = measured sand load (tonnes/day), Q = discharge (m^3/s), a = a coefficient, and b = an exponent. One such power law relationship is available representing data collected in the time period from 1969 to 1979 (Biedenharn 1999). In this relationship, a = 0.0000408 and b = 2.17, and the coefficient of determination (r^2) is 0.77. The data used to develop this relationship are shown in Figure 28 along with the best fit line.

Figure 28. Sediment rating curve for the period 1969–1979 at Natchez, MS (from Biedenharn 1999).



The total load from the power law relationship appears to provide a better fit to the 2011 measurements than the equilibrium load as shown in Figure 29. Using the computed equilibrium distribution of the various suspended sand classes and the total suspended load from the power law relationship, a time series of suspended load by sand class was generated. The computed equilibrium bed load was then added to the suspended load for each sand class. From this total load, a time series of concen-tration by sand class was developed. The time series concentration values used at the Natchez upstream boundary for the system wide model are shown in Figure 30.

Figure 29. Equilibrium, measured, and rating curve sediment loads at Natchez, MS.

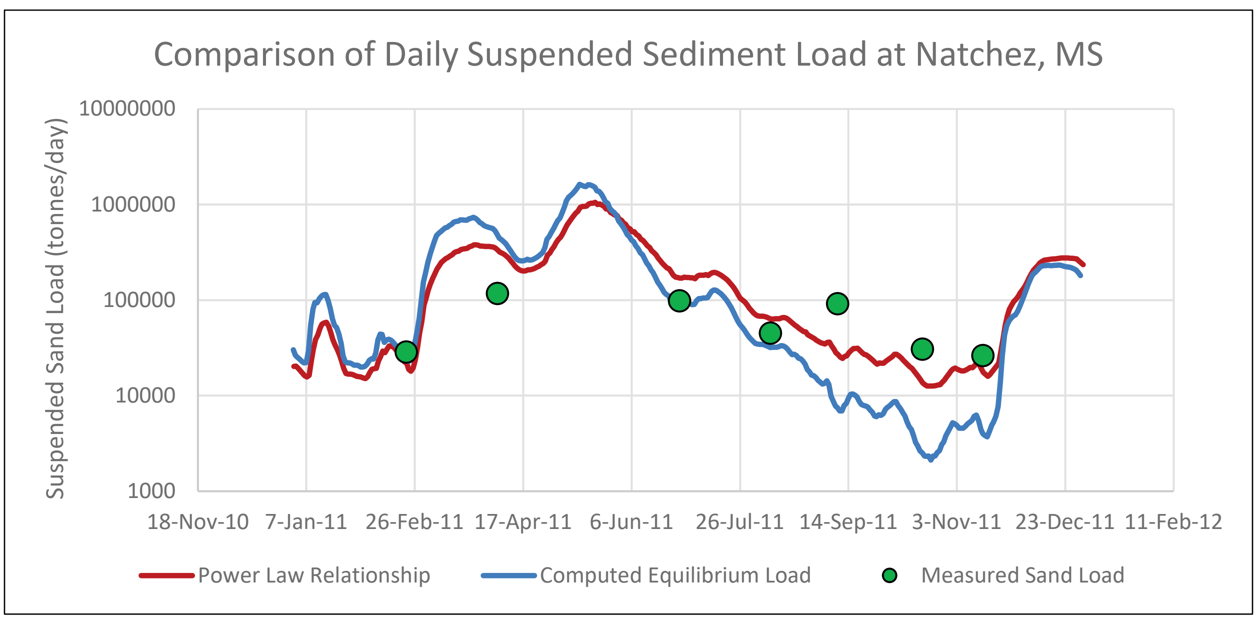
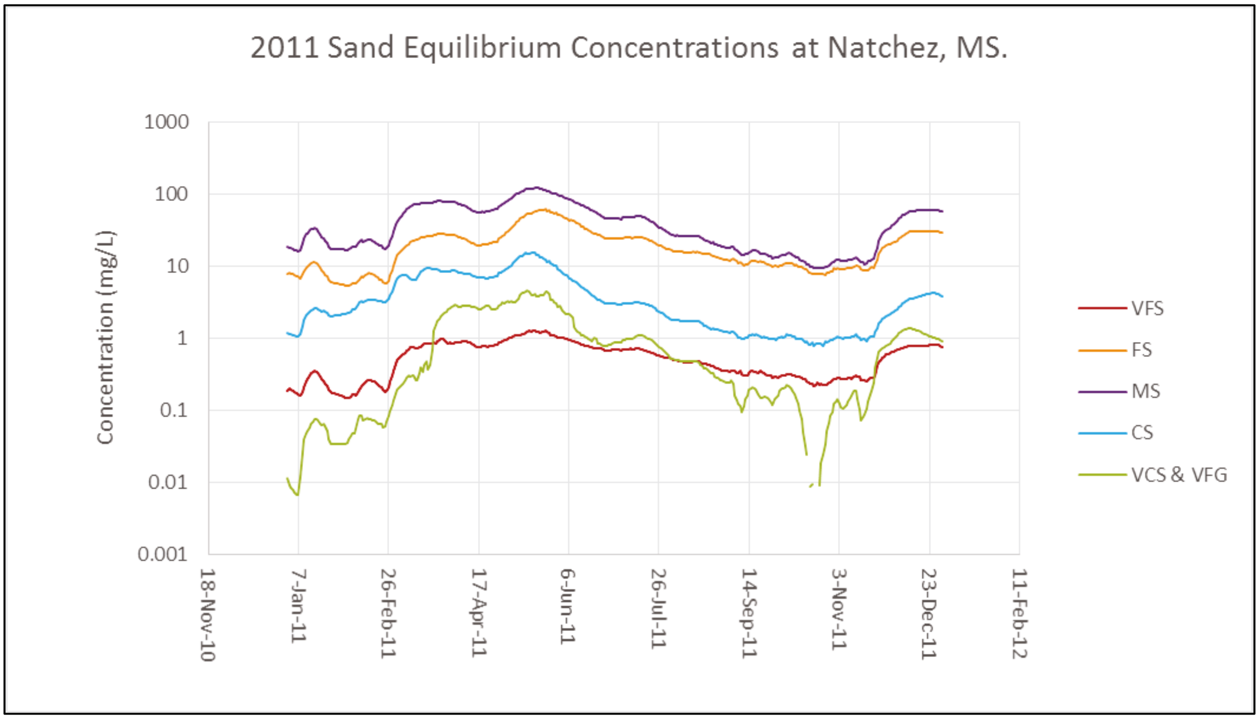


Figure 30. Delft3D sediment boundary concentration at Natchez, MS.



Channel training measures

Bank revetments and training dikes are present in the study reach of the Mississippi River. The concrete mat revetments are simulated by setting the movable bed thickness to zero at the location of the revetment. This will allow deposition on the revetment but prevent erosion below the initial bed level.

Training dikes are simulated by not allowing water and sediment to pass through the edge of the computational cells that follow the alignment of the dike. The dike fields listed in Table 6 are maintained by the MVK.

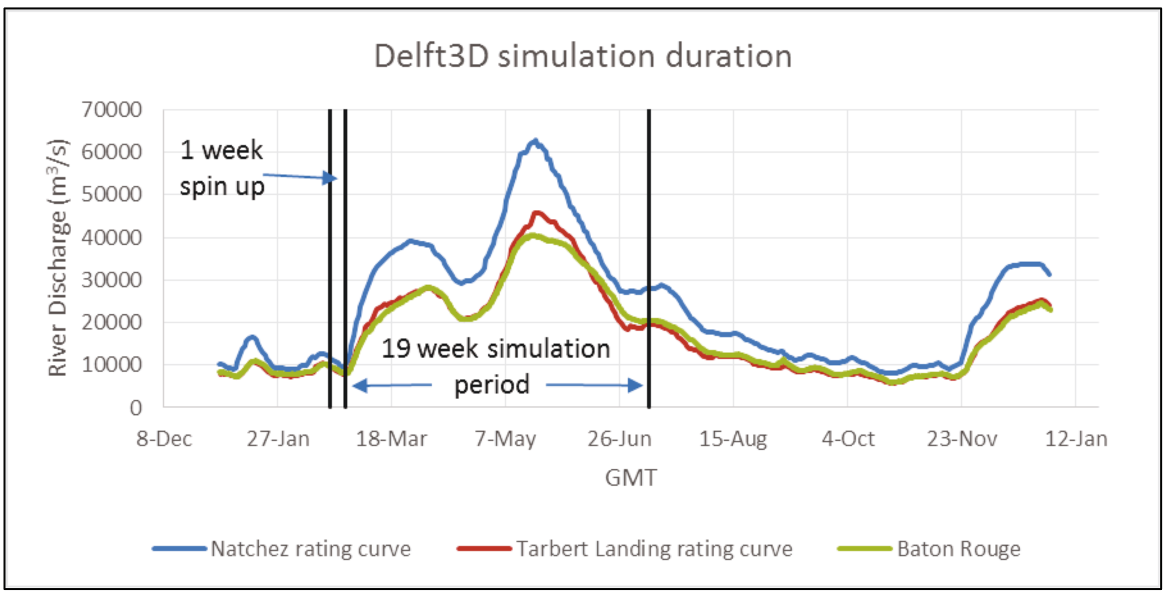
Table 6. Training dike summary.

Dike Field	Dike ID	Dike Crest Depth	Modeled?
Natchez Island	1U	Unknown	No
	1R	-7	Yes
	2R	-5	Yes
	3R	-6	Yes
	4R	-7	Yes
	5R	Unknown	No
	6R	-3	Yes
Carthage Point	1L	-7	Yes
	2L	-9	Yes
Opposite Warnicott Landing	1L	-10	Yes
	2L	-12	Yes
	3L	Unknown	No
	4L	-10	Yes
Esperance Point	1R	Unknown	No
	2R	Unknown	No
	3R	-10	Yes
	4R	-10	Yes
Opposite Esperance Point	1L	-10	Yes
	3L	Unknown	No
Buck Island	1	-6	Yes
	2	-6	Yes
	3	-6	Yes
	4	-6	Yes
Fritz Island	1U	-6	Yes
	1R	-9	Yes
	2R	-9	Yes
Jackson Point	1L	-6	Yes
	2L	-9	Yes

3 Model Validation

To test the model's ability to reproduce conditions in the prototype, a simulation of the 2011 flood event was performed. Given the long model run time due to the high grid resolution and number of sediment classes being evaluated, the simulation was conducted using a series of 1- and 2-week model runs with hot starts. Due to the high velocities and consequent Courant-Friedrichs-Lewy (CFL) limitations near the flood peak, the time-step interval had to be reduced to execute the runs near the peak. The first 1-week run was used to spin up the model and initialize the hydro-dynamics. For the entirety of this first 1-week run, the bed level was held static. The subsequent runs followed this initial cold start run. Results are not reported for the first 1-week run due to the influence of model spin up conditions. The subsequent model results were compared to available measured data including discharge, sediment concentration, and water level. Figure 31 displays the river conditions during the simulation period.

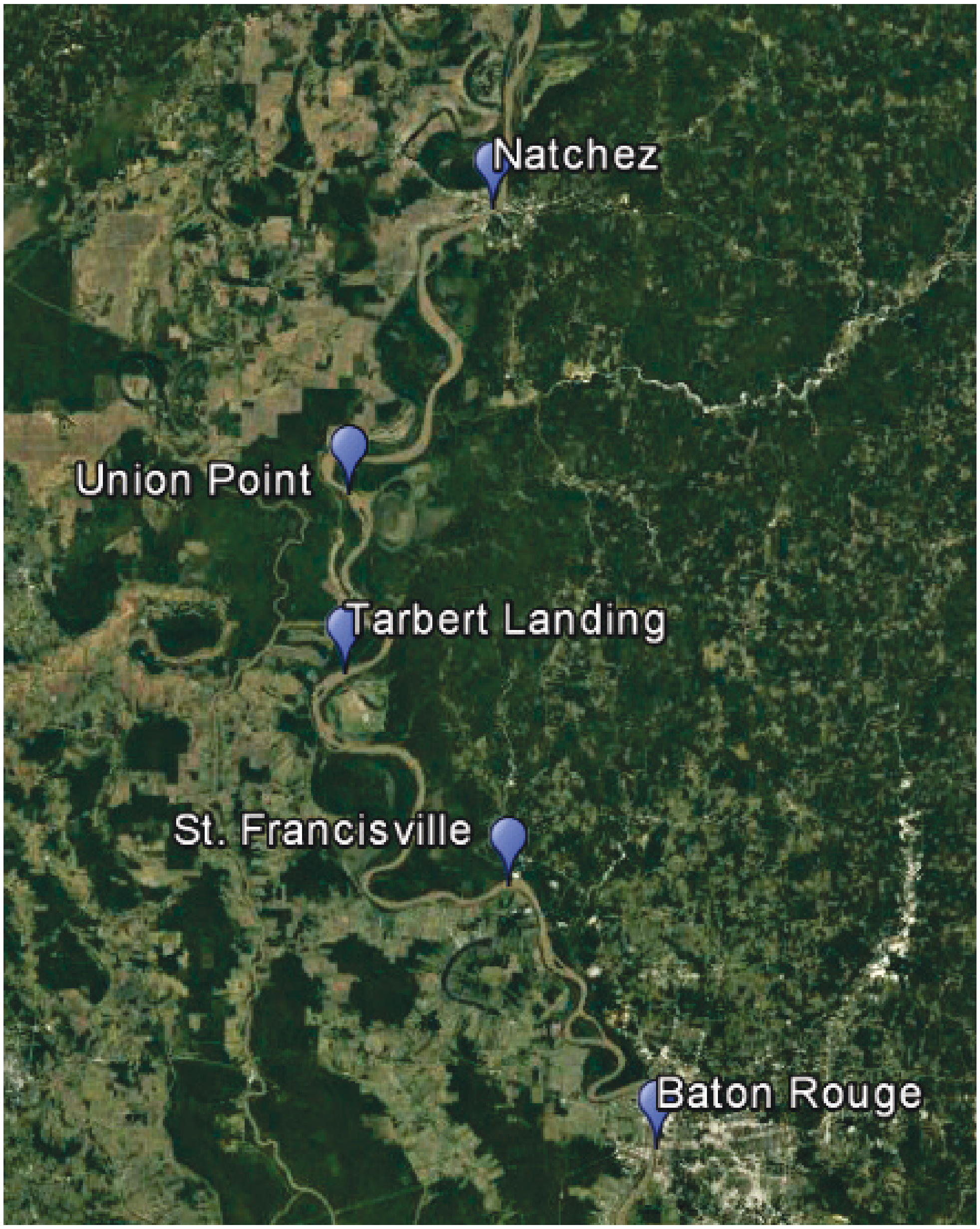
Figure 31. Delft3D simulation duration.



Mississippi River discharge comparison

Mississippi River discharge measurements were collected at five sites in the model domain during the simulation period at the locations shown in Figure 32. The Natchez measurements were used to develop the upstream inflow boundary as discussed earlier. The data collected at Union Point, Tarbert Landing, St. Francisville, and Baton Rouge were used to evaluate the accuracy of model results.

Figure 32. Location of river discharge ranges.



The New Orleans District of the USACE measures discharge at Union Point in conjunction with sediment sampling events. Due to the scarcity of discharge measurements at Union Point, the 2011 Union Point ADCP measurements were related to the daily estimate at Natchez, and a rating was developed to give a complete flow record at Union Point. The rating is shown in Figure 33, and the estimated discharge from the rating along with model results and ADCP measurements is shown in Figure 34. The Union Point range measures discharge in the river channel only and therefore is not considered to represent the entirety of the Mississippi River flow for events that include overbank discharge.

Figure 33. Union Point/Natchez discharge relationship.

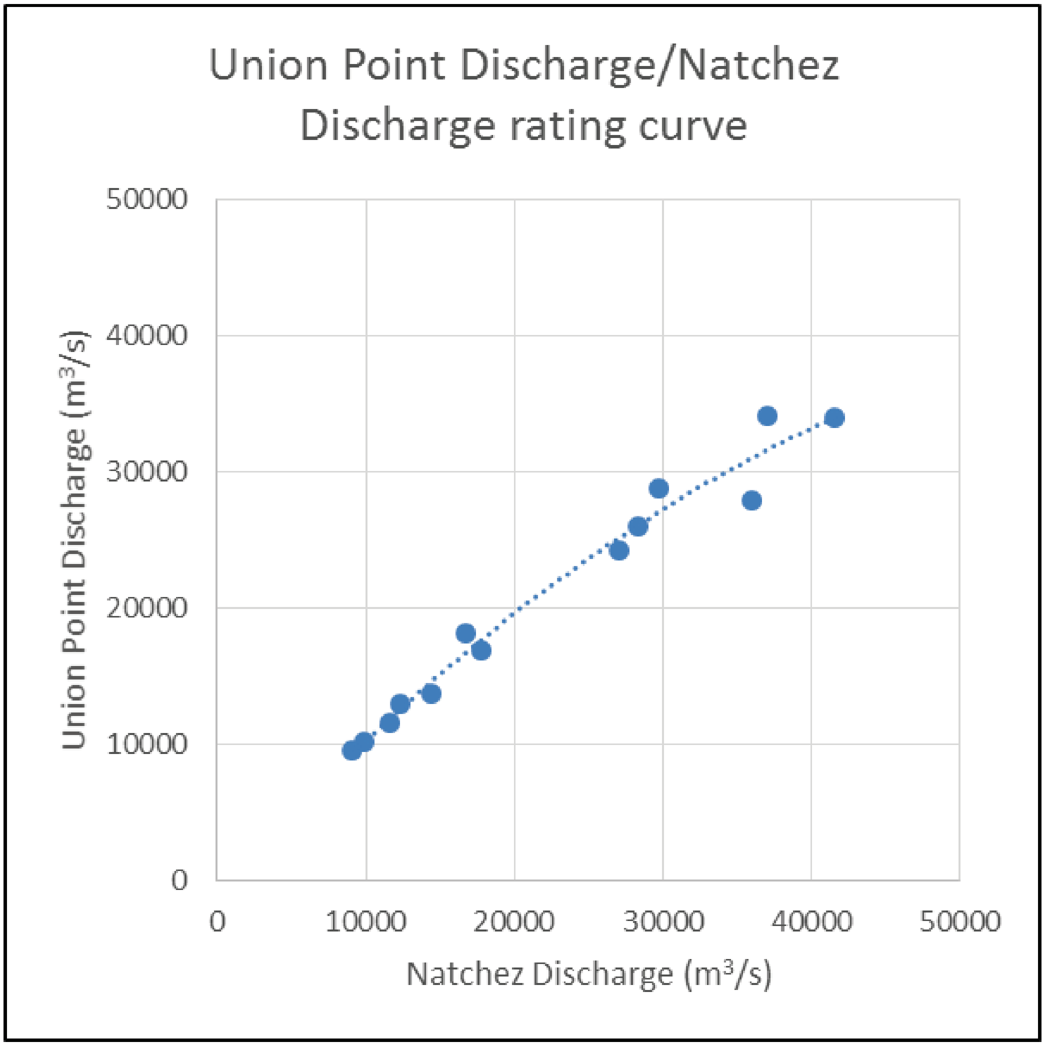
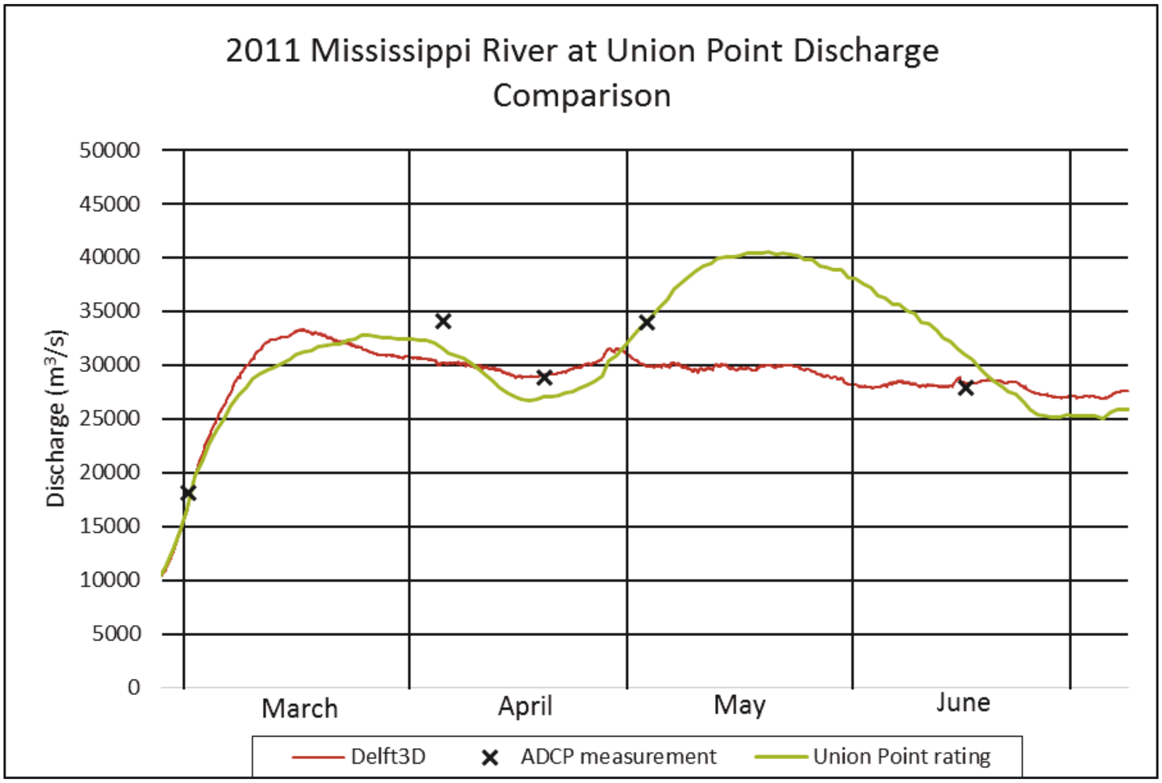


Figure 34. Union Point discharge comparison.



Discharge is measured at Tarbert Landing twice a week, and these measurements are used to update a dynamic rating curve that provides daily published discharge estimates by the USACE New Orleans district. Additional ADCP measurements were collected during the 2011 flood due to the difficulty of ascertaining accurate flow measurements during high velocity flood events. Measurement of flow at this range is made especially difficult due to fluctuations of the velocity in the river channel and the difficulty in estimating the discharge in the overbanks during high river flow events. The flow values are considered to represent the entirety of the Mississippi River discharge at the Tarbert Landing latitude. A comparison of the model values to the flow measurements is shown in Figure 35, and a detail of the comparison during May 2011 is shown in Figure 36.

Figure 35. Tarbert Landing discharge comparison.

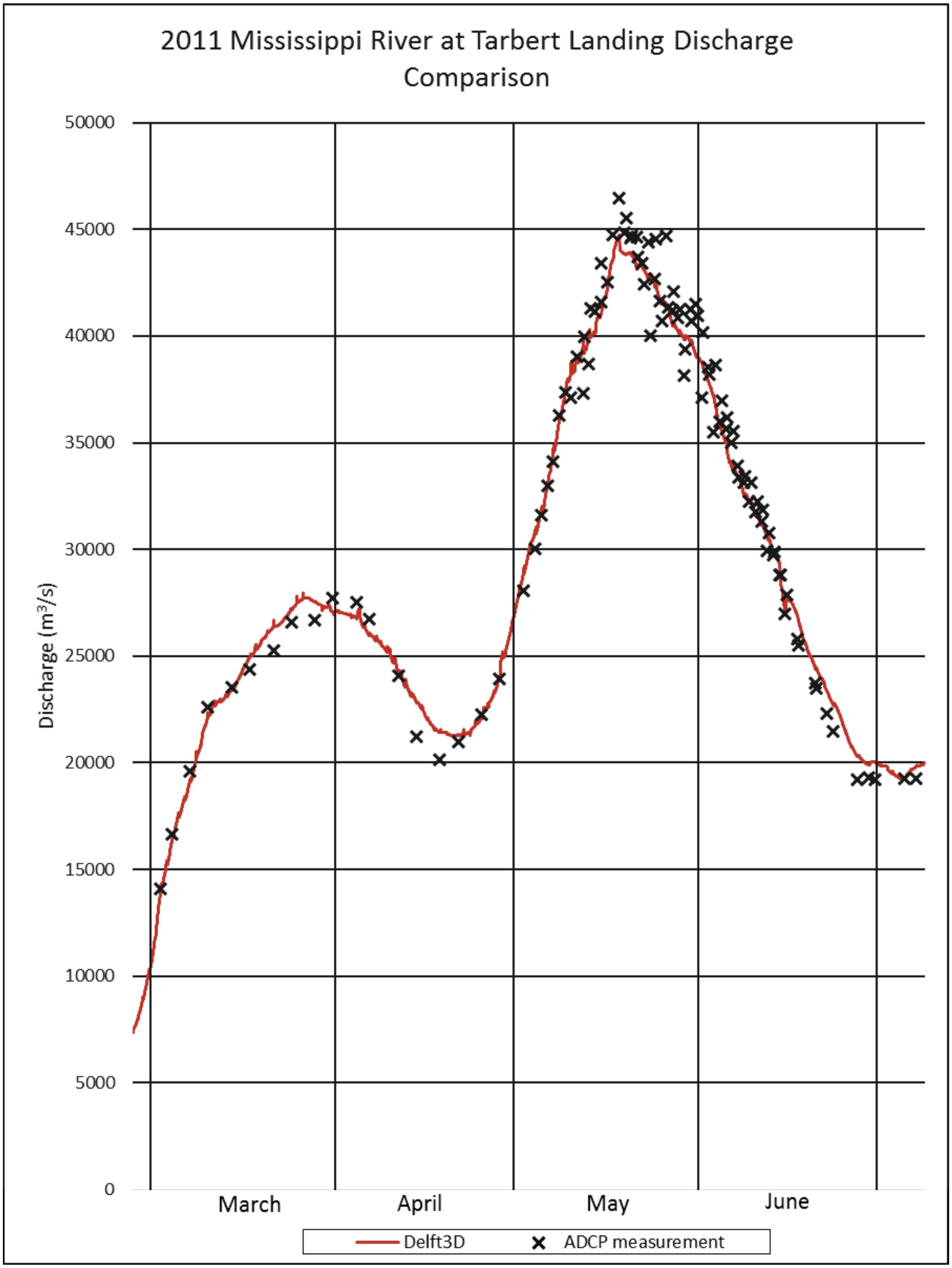
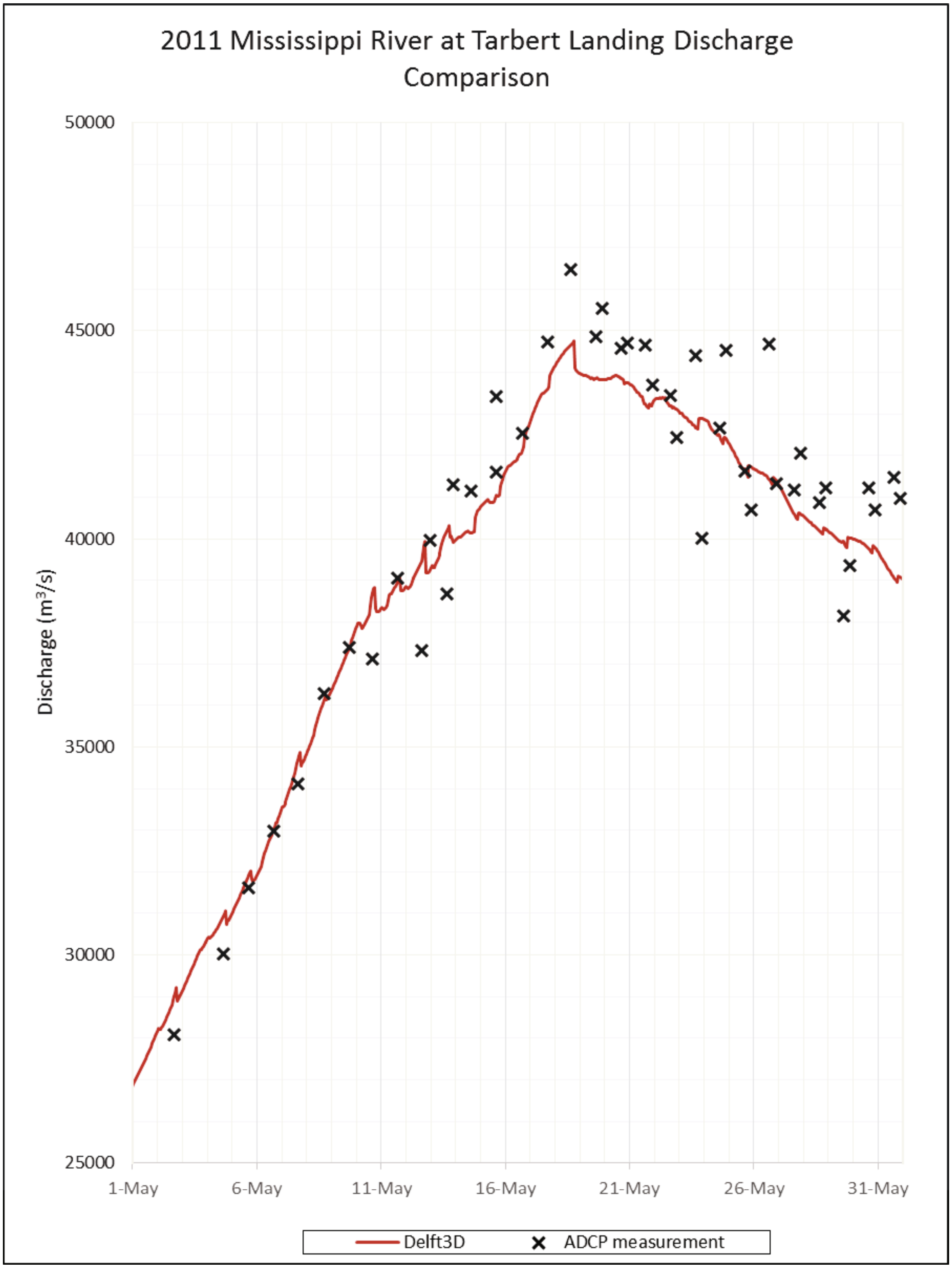
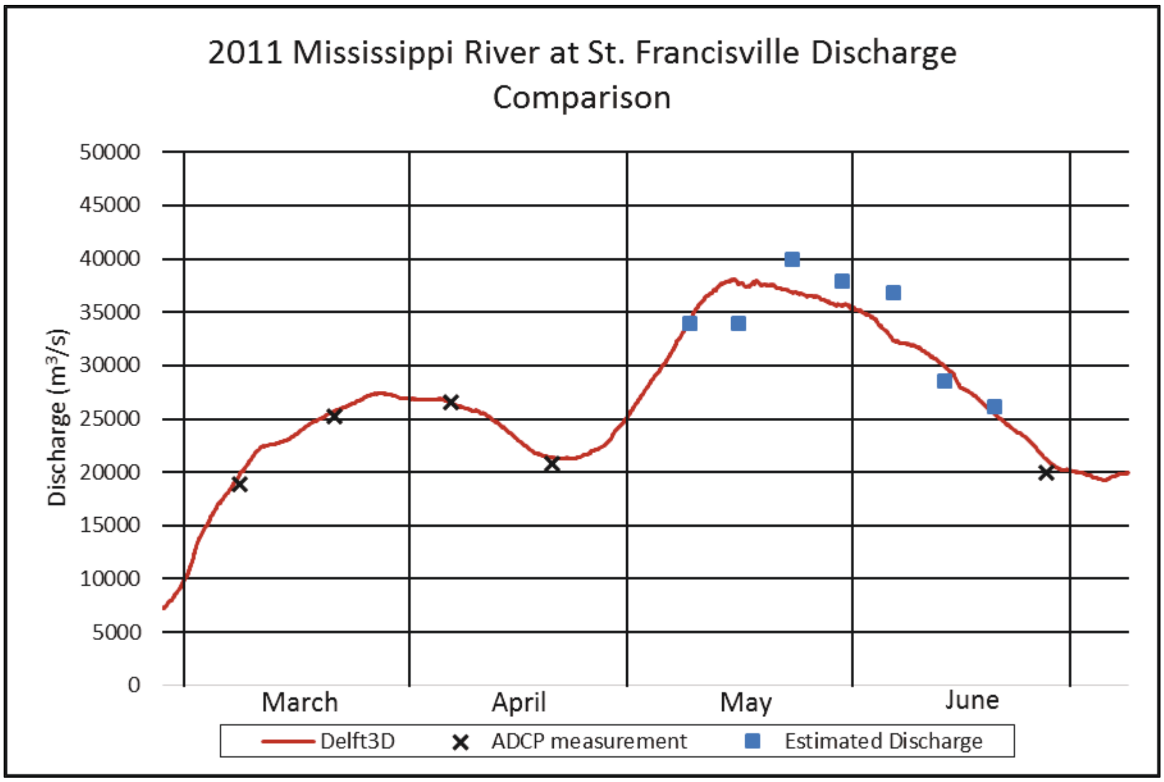


Figure 36. Tarbert Landing discharge comparison during May 2011.



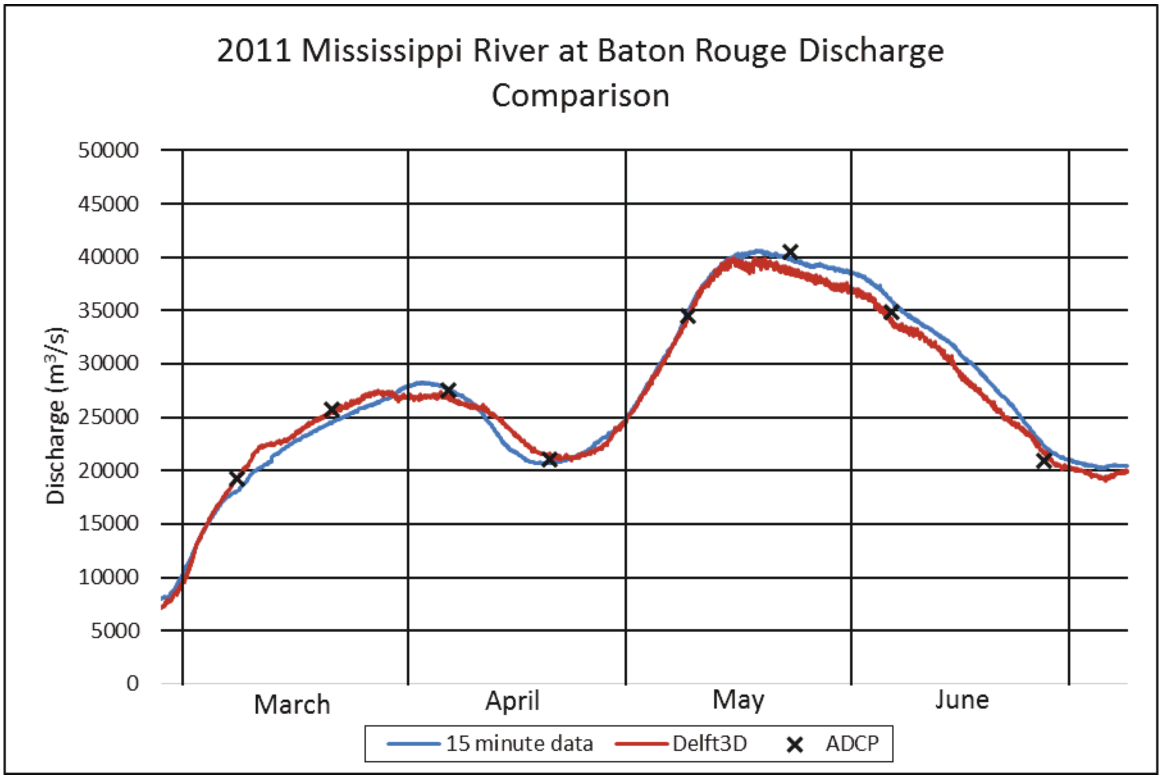
A few ADCP measurements collected by the USGS taken in conjunction with water quality and sediment samples are available at St. Francisville (USGS site no. 07373420) to compare to model results. Estimates are provided when ADCP measurements were not collected. This range does not represent the entirety of the Mississippi River discharge as any flow in the overbank is not included in the measurement. The ADCP and estimated discharge data are compared to model results as shown in Figure 37.

Figure 37. St. Francisville discharge comparison.



The USGS provides 15-minute discharge data at Baton Rouge for the USGS 07374000 Mississippi River at Baton Rouge, LA, data collection site. In addition, ADCP discharge is collected in conjunction with sediment sampling events at this location. These data are compared to model results as shown in Figure 38.

Figure 38. Baton Rouge discharge comparison.



Water level

Seven water level gages are located within the model domain, which were used as downstream boundary condition tailwater data and to calibrate and verify model performance. The gage datums are summarized in Table 7, and the locations within the model domain are shown in Figure 39 and Figure 40. Comparison plots showing measured and modeled data are provided in Figures 41–46.

Table 7. Water level gage summary.

Gage Name	USACE Gage ID No.	River Mile	Longitude	Latitude	Gage Zero	NAVD88 adjustment
Mississippi River at Natchez, MS	15155	361.3	-91.4334	31.5440	17.28 ft NGVD29	+17.28 ft, NAVD88 and NGVD29 assumed equivalent at Natchez
Low Sill Inflow Channel	02050	314.6	-91.5977	31.0779	0 ft NGVD29	None given.
Mississippi River at Knox Landing, LA	01080	313.7	-91.5819	31.0736	0 ft NGVD29	-0.22 feet (valid as of Sept. 20, 2011)

Gage Name	USACE Gage ID No.	River Mile	Longitude	Latitude	Gage Zero	NAVD88 adjustment
Old River Auxiliary Inflow Channel	02200	312.0	-91.5876	31.0646	0 ft. NGVD29	None given.
Mississippi River at Red River Landing, LA	01120	302.4	-91.6644	30.9608	0 ft NGVD29	-0.29 feet (valid as of Sept. 20, 2011)
Mississippi River at St. Francisville, LA	01145	260.3	-91.3442	30.7029	0 ft NAVD88	0 ft, valid as of Sept. 20, 2011
Mississippi River at Baton Rouge, LA *	01160	228.4	-91.2069	30.4292	0 ft NGVD29	-0.37 ft, valid as of Sept. 20, 2011

* The Baton Rouge gage data were used for the tailwater boundary condition; therefore, a comparison to model data is not provided.

Figure 39. Location of water level gages within the model domain.

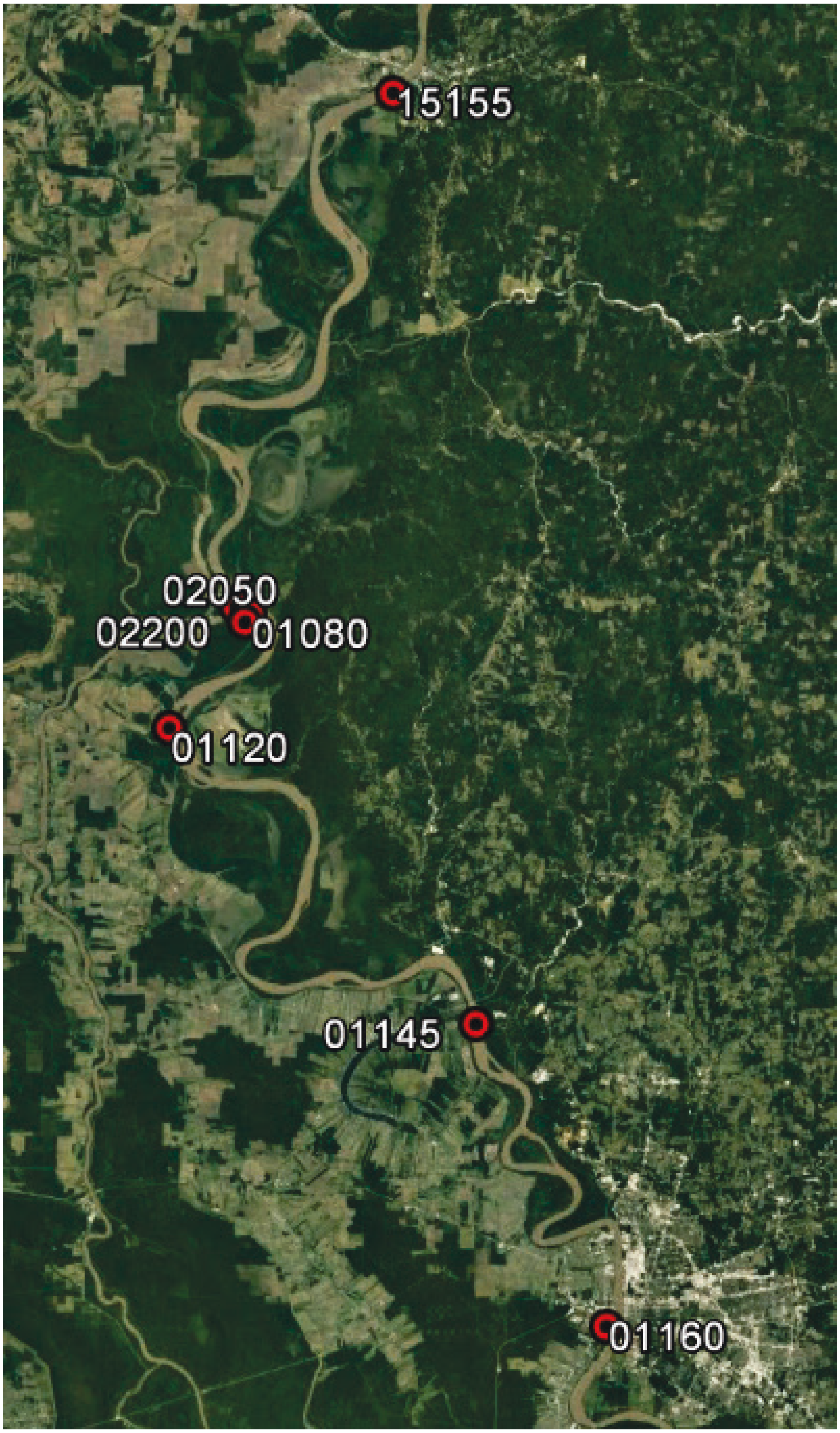


Figure 40. Detail of water level gages near the ORCC.

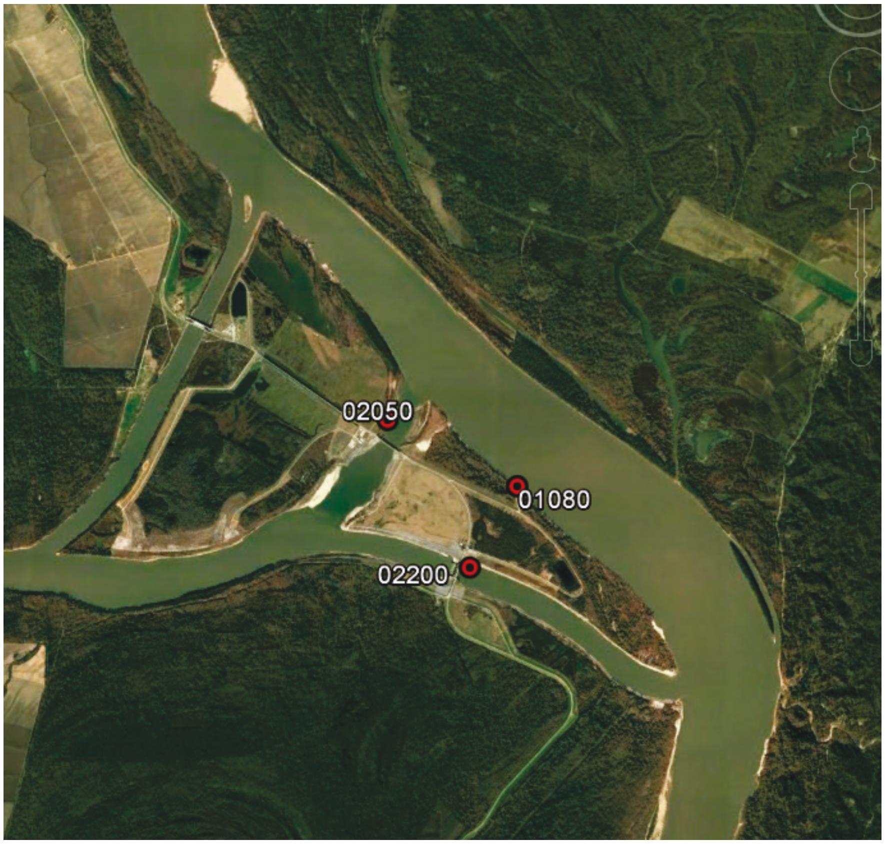


Figure 41. Mississippi River at Natchez water level comparison.

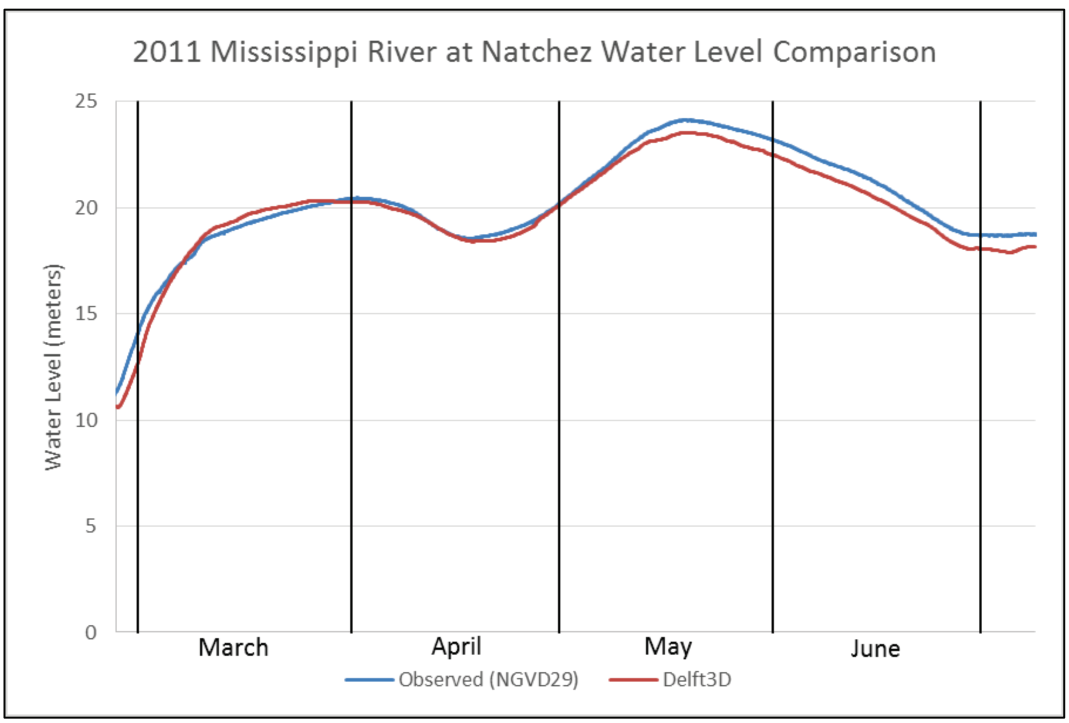


Figure 42. Low Sill inflow channel water level comparison.

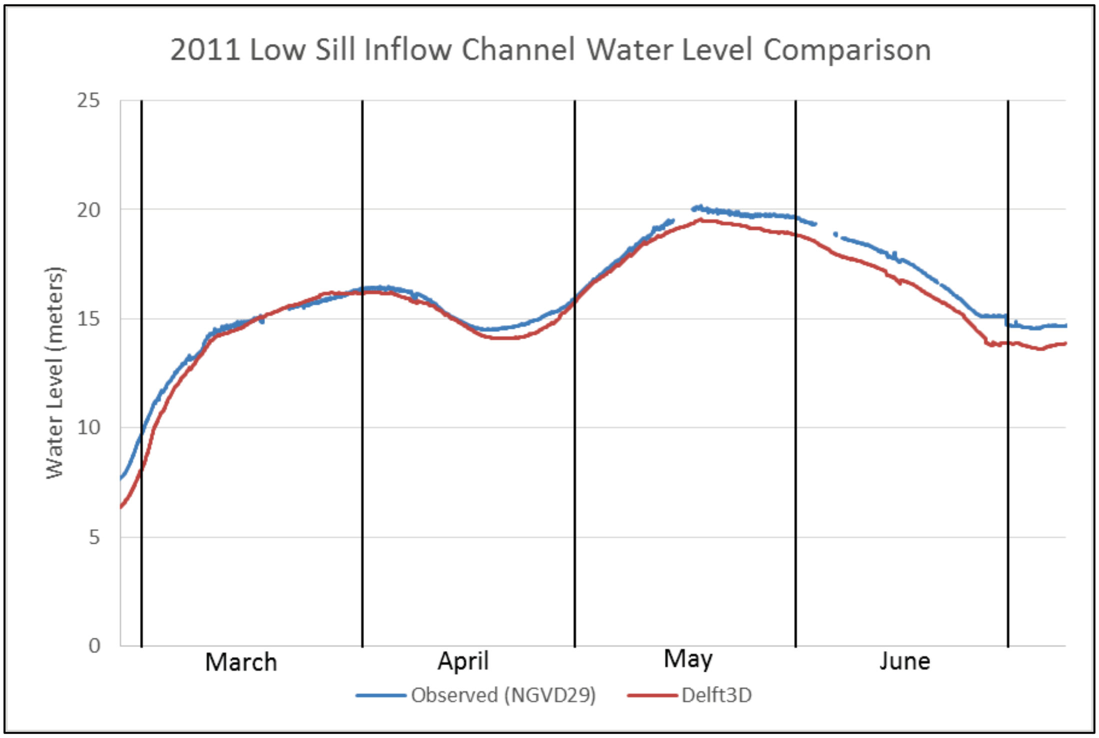


Figure 43. Mississippi River at Knox Landing water level comparison.

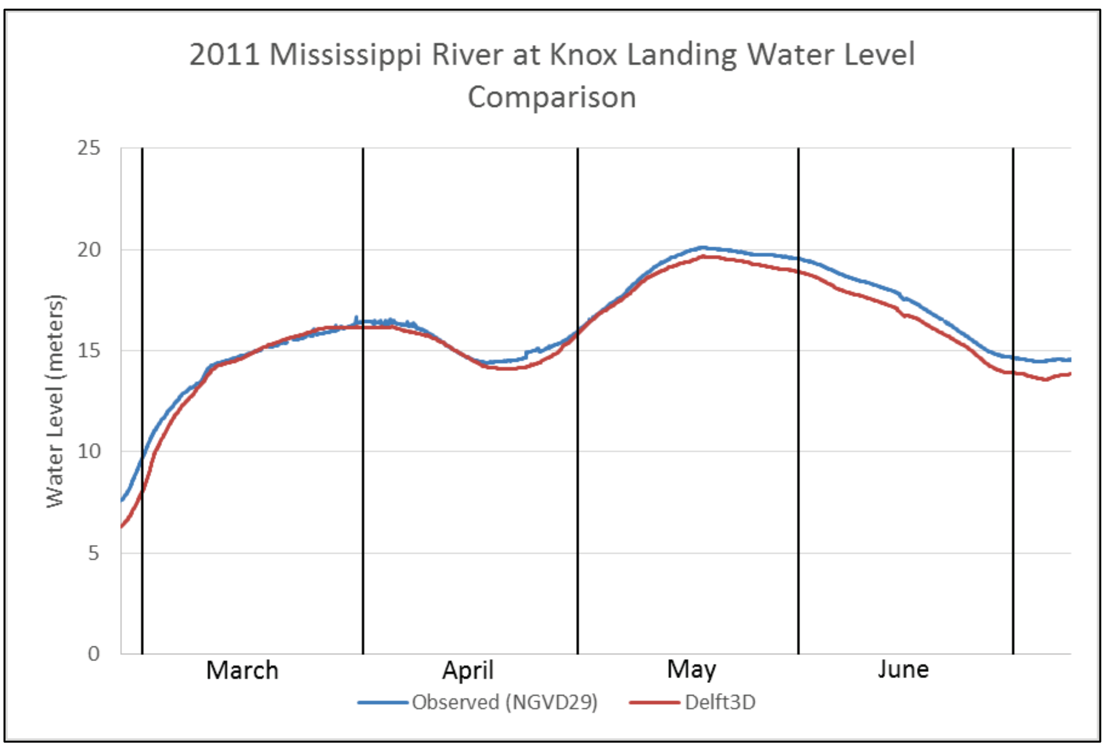


Figure 44. Auxiliary inflow channel water level comparison.

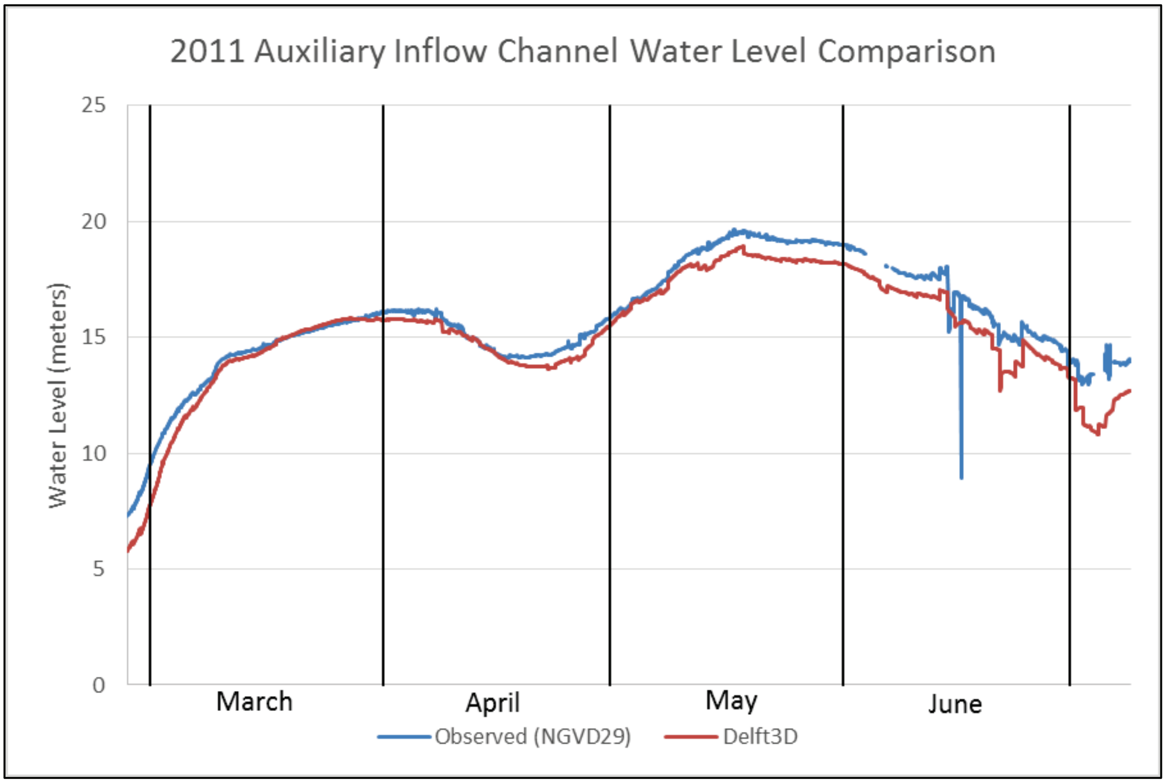


Figure 45. Mississippi River at Red River Landing water level comparison.

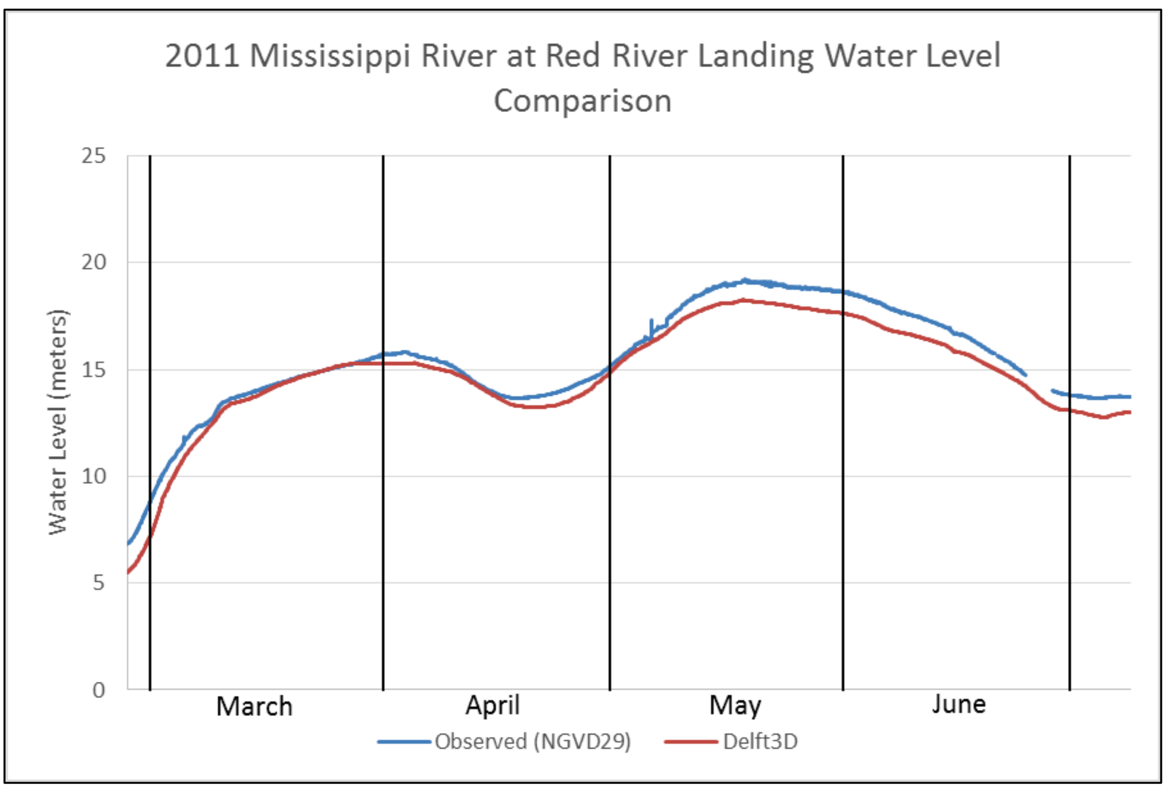
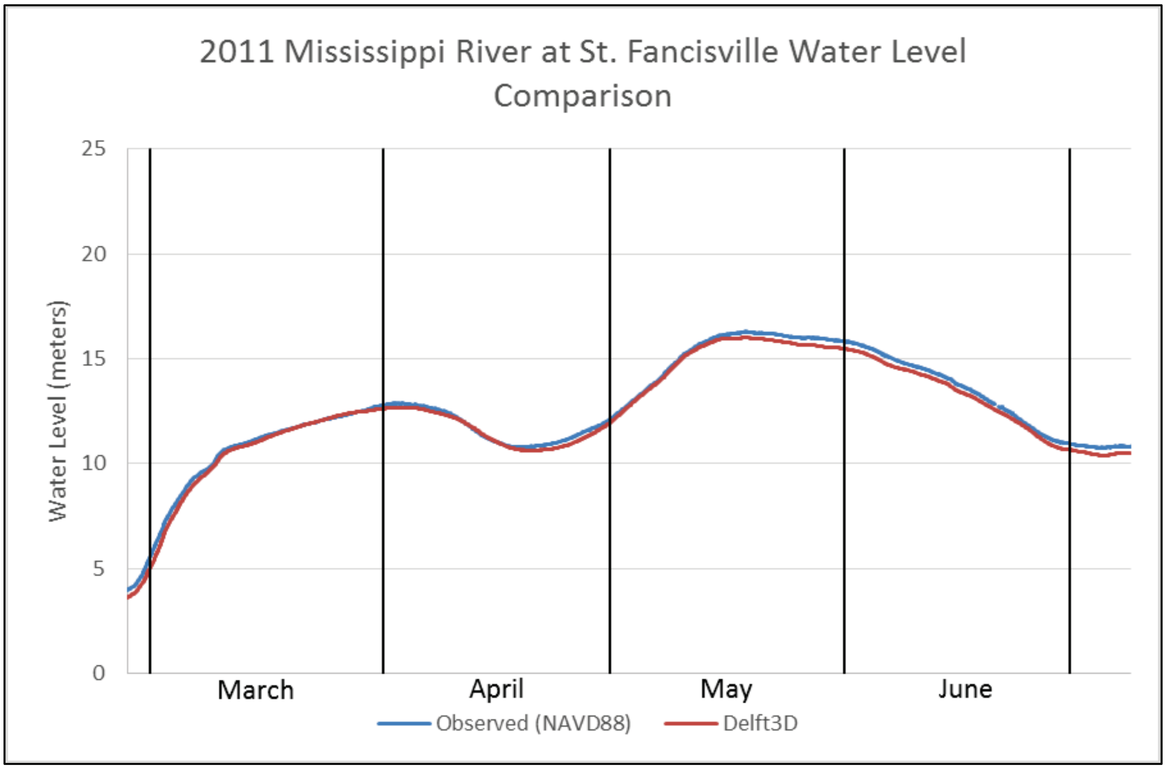


Figure 46. Mississippi River at St. Francisville water level comparison.



Suspended sand concentration

Suspended sediment samples are regularly collected in the river at five locations within the model domain at Natchez, Union Point, Tarbert Landing, St. Francisville, and Baton Rouge. The samples at Natchez are collected by the MVK, and these data were used to inform the upstream boundary at Natchez. The USACE New Orleans District collects the data at Union Point and Tarbert Landing, and the USGS collects data at St. Francisville and Baton Rouge. In addition to the sampling sites in the river, suspended sediment data are collected at the Hydroelectric Station intake, the Low Sill Structure intake, and the Auxiliary Structure intake.

The suspended sediment samples at Tarbert Landing and Union Point are collected with a P-61 or P-63 point-integrating sampler at four vertical locations for each site. Five samples at each vertical are collected at 10%, 30%, 50%, 70%, and 90% of the total depth. For the data utilized in this study, the verticals were located at fixed distances from a point of reference on the bank. At Union Point, the verticals are located 1,050, 1,650, 2,250, and 2,950 ft from a point on the left descending bank (LDB). At Tarbert Landing, the verticals are located 1,400, 2,200, 2,800, and 3,400 ft from the right descending bank. The locations of these verticals are shown in Figure 47 and Figure 48.

Figure 47. Location of sediment sampling verticals at Union Point.

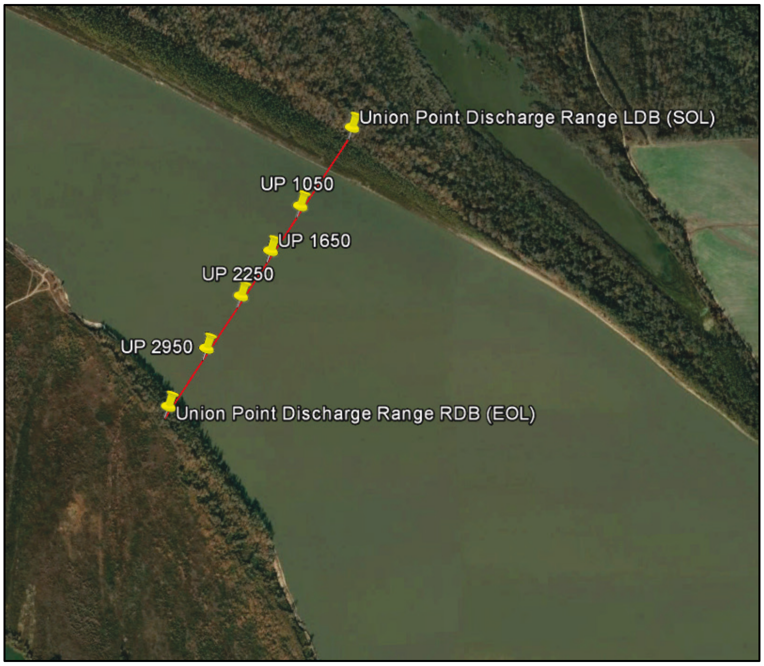
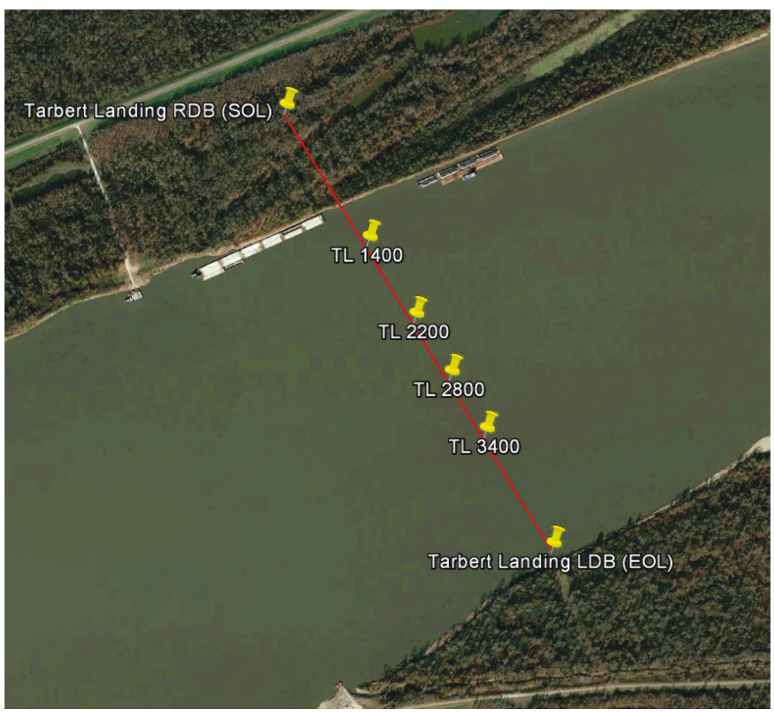


Figure 48. Location of sediment sampling verticals at Tarbert Landing.



Each point sample is analyzed to provide the gradation of the non-cohesive sediment, thus allowing a profile of the concentration at each vertical to be developed. The vertical concentration profiles for the non-cohesive sediment classes in suspension are shown in Figure 49 and Figure 50 corresponding to the samples collected with the highest flow rate during the flood event at each site. The discharge at Union Point on 3 May 2011 was 33,950 cubic meters per second (m^3/s) and 42,359 m^3/s at Tarbert Landing on 15 May 2011.

Figure 49. Union Point concentration comparison for 03 May 2011 sample set.

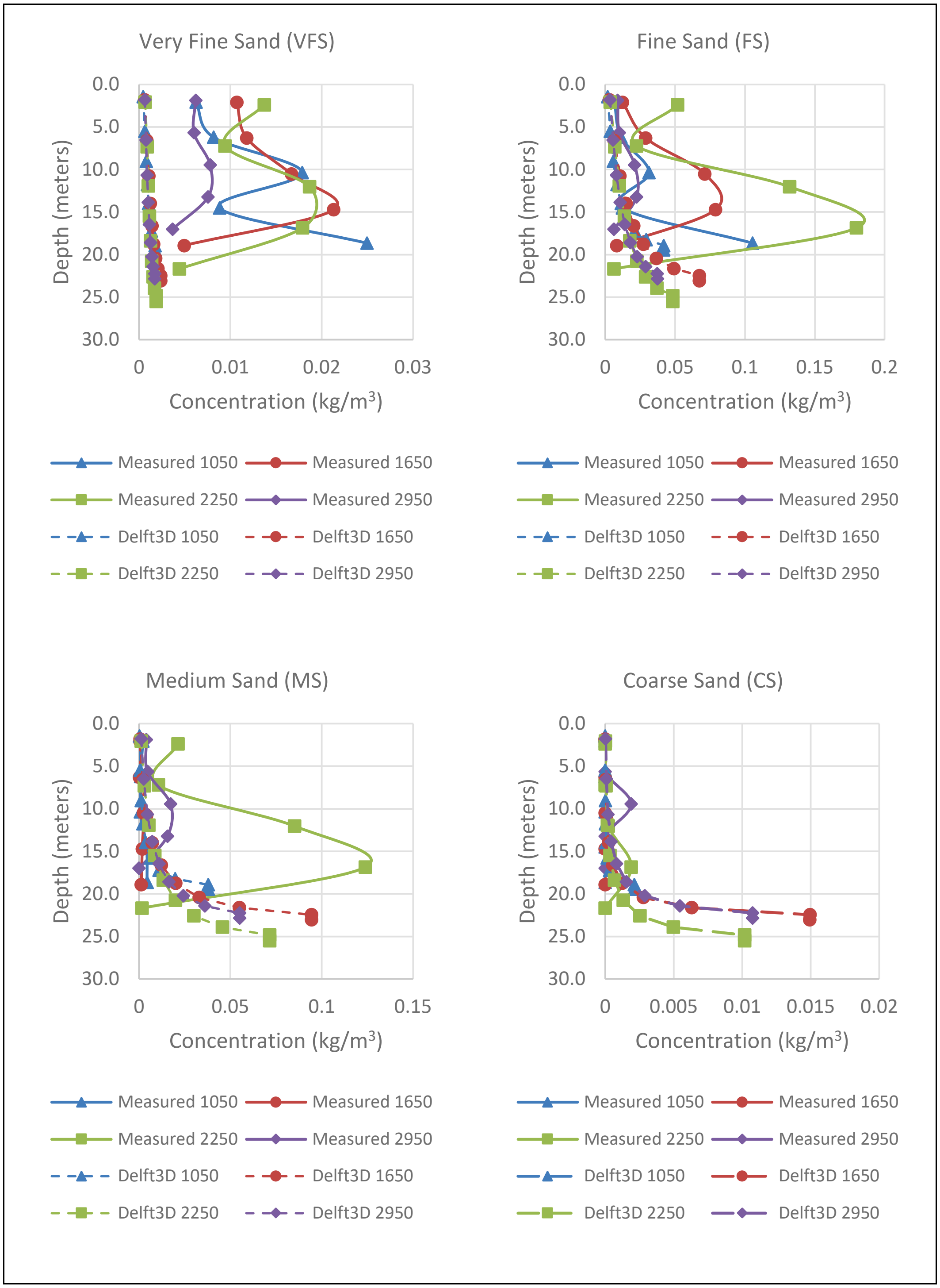
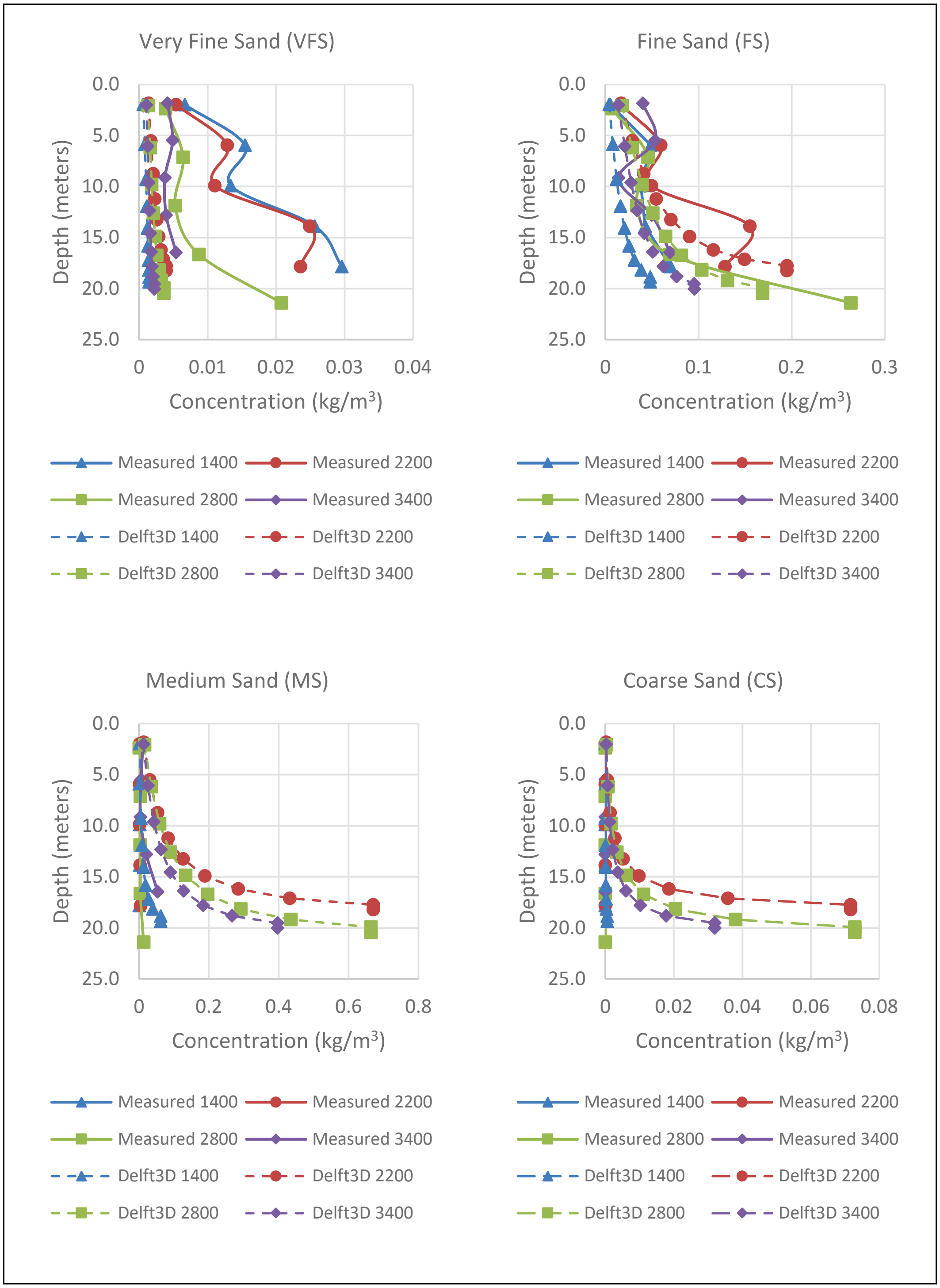


Figure 50. Tarbert Landing concentration comparison for 15 May 2011 sample set.



The total sand concentration was calculated using a straight average of each sample for the Union Point and Tarbert Landing data sets. The 2011 average suspended sand concentration data are plotted in Figure 51 and Figure 52 along with the computed suspended sand concentration for comparison.

Figure 51. Union Point total sand concentration for 2011.

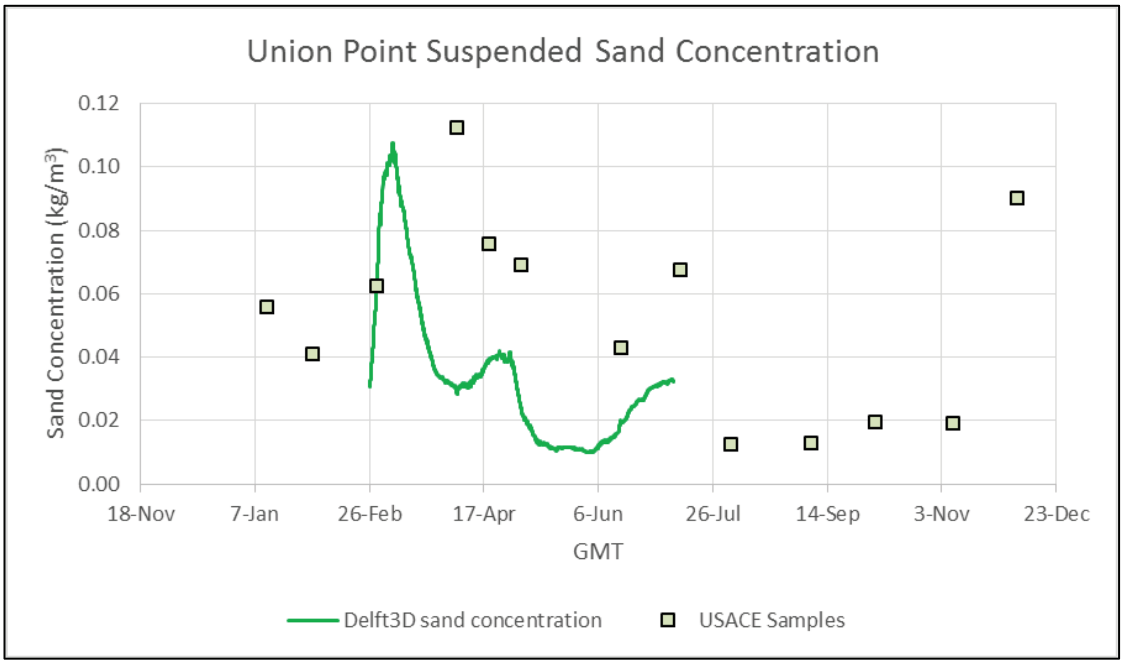
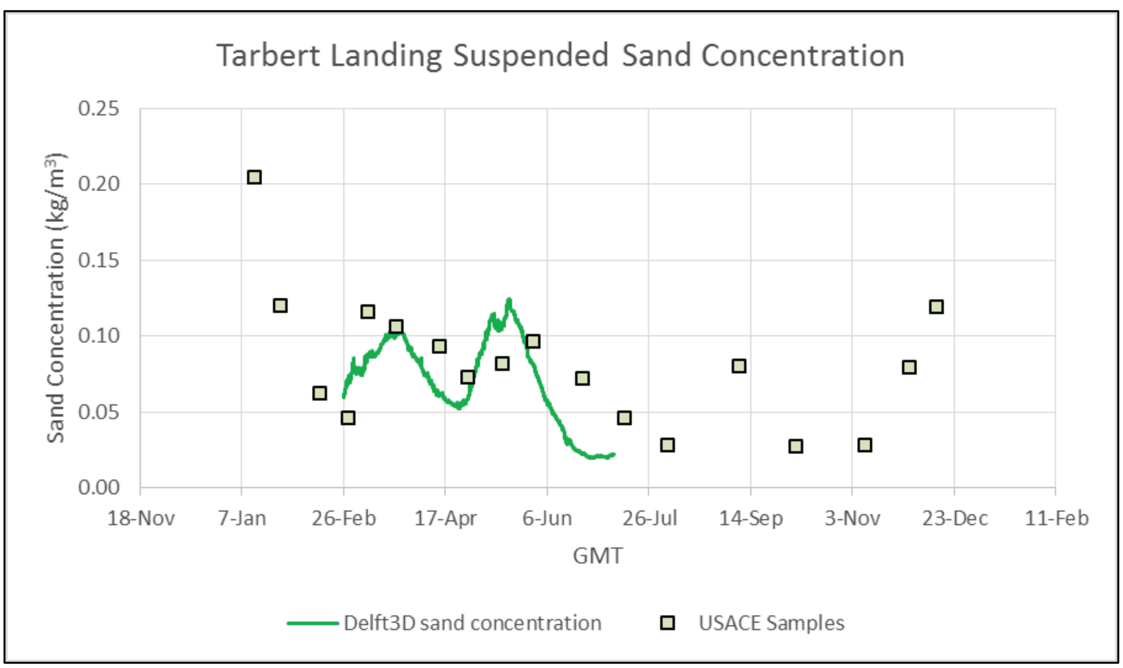


Figure 52. Tarbert Landing total sand concentration for 2011.



The USGS summarized depth-integrated suspended sediment data sets at Baton Rouge and St. Francisville during the simulation period in the Water-Data Report WDR-US-2011 (U.S. Geological Survey 2012). The suspended sediment data at Baton Rouge and St. Francisville are collected with either a D-96 or D-99 depth integrating sampler depending on flow. Typically three verticals are sampled at fixed locations with the sampler being lowered to within 2 ft of the bottom with a variable speed reel so that the samples are collected isokinetically.

The collection site at St. Francisville is located at RM 266.0 at the State Highway 10 Ferry Crossing, 2.0 miles southwest of St. Francisville. The collection site at Baton Rouge is on the LDB at approximately RM 229.7. Comparison plots of computed and measured concentration at St. Francisville and Baton Rouge are provided in Figures 53–54.

Figure 53. St. Francisville total sand concentration for 2011.

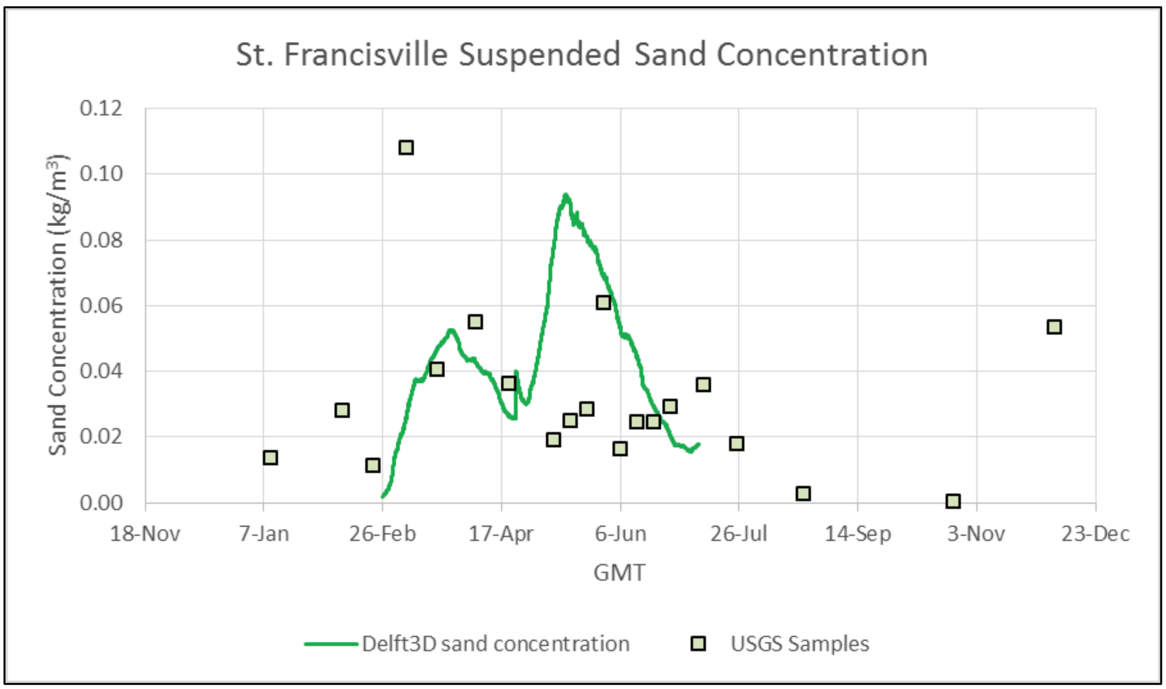
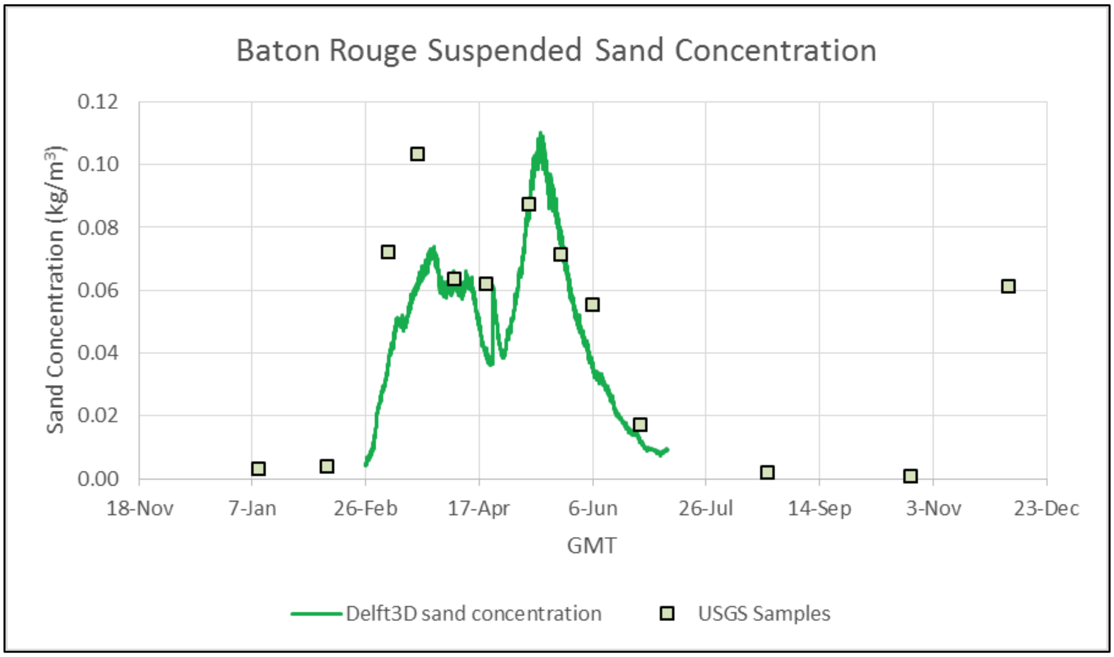


Figure 54. Baton Rouge total sand concentration for 2011.



Sediment samples are collected at the ORCC Structures including the Hydroelectric Structure, the Low Sill Structure, and the Auxiliary Structure. The samples are collected using pump samplers with the assumption that the sediment load is well mixed at the sampler intake. Comparison plots of measured and computed concentration for each sand grain class are provide in Figures 55–63 for the three structures.

Figure 55. Hydroelectric Station very fine sand concentration comparison.

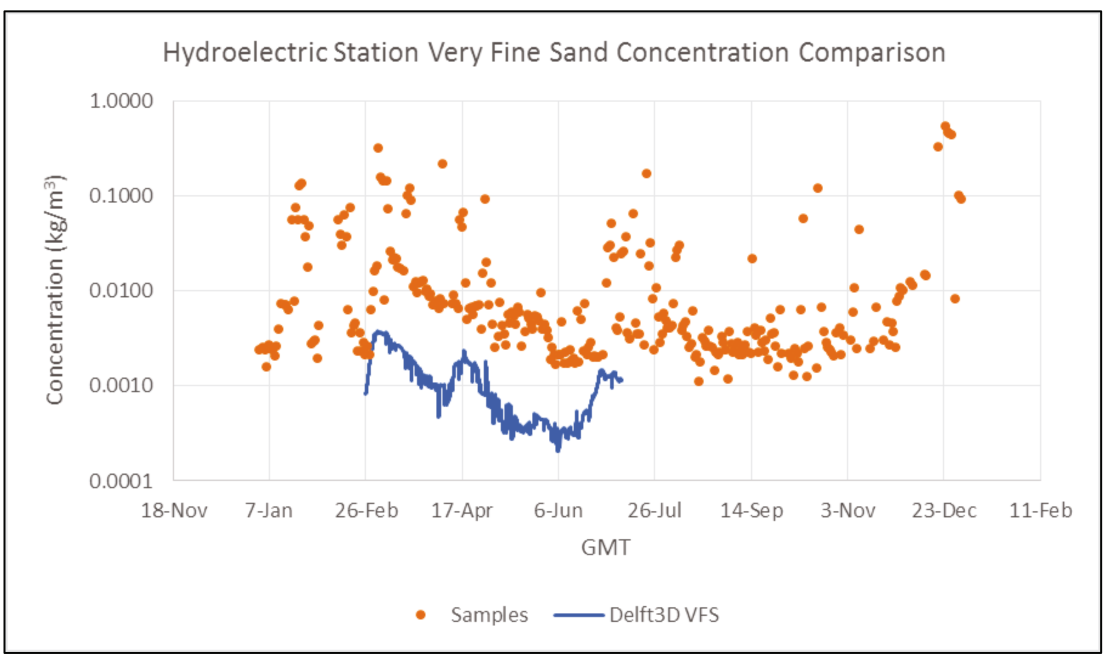


Figure 56. Hydroelectric Station fine sand concentration comparison.

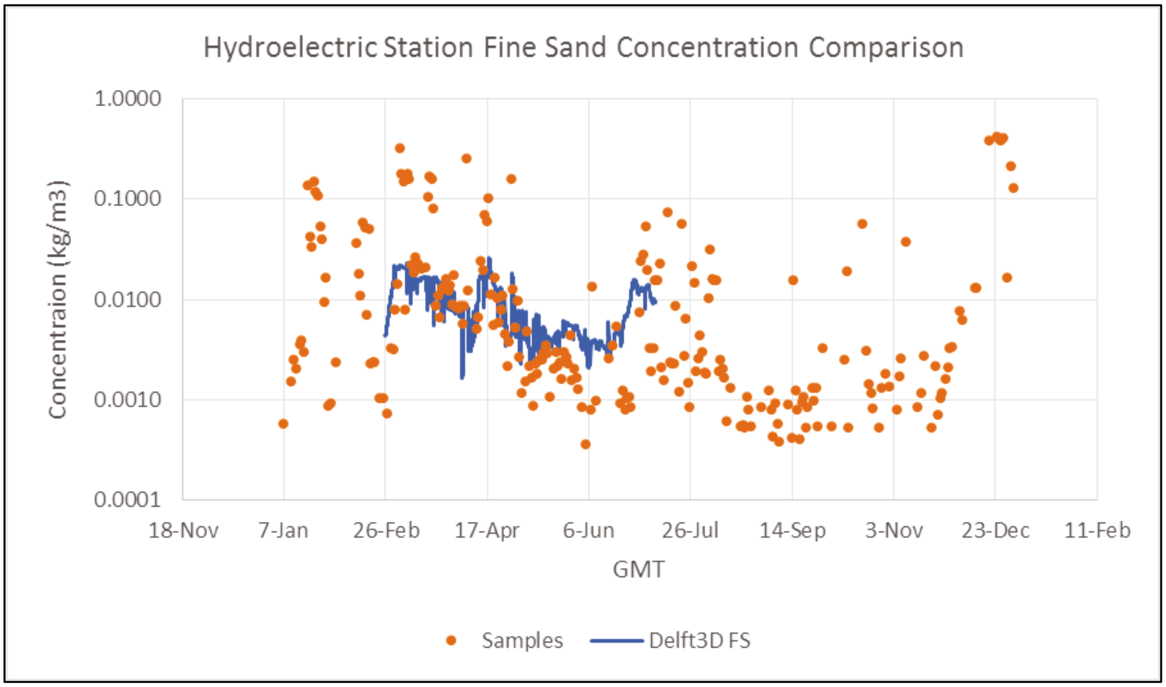


Figure 57. Hydroelectric Station medium sand concentration comparison.

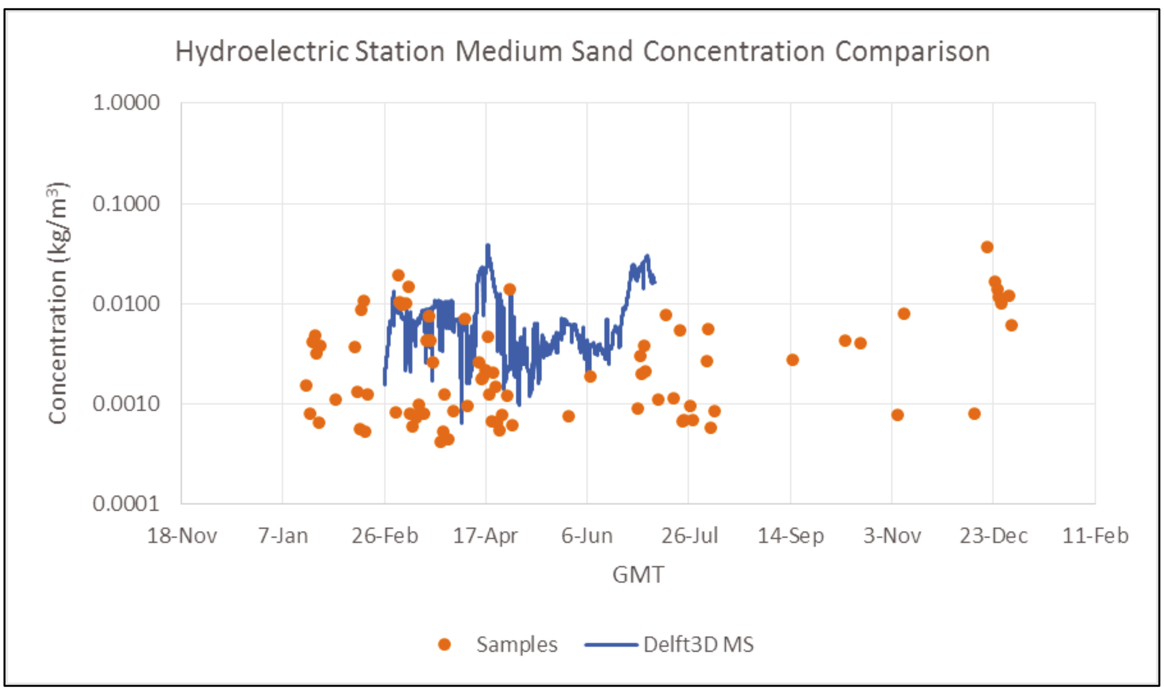


Figure 58. Low Sill Structure very fine sand concentration comparison.

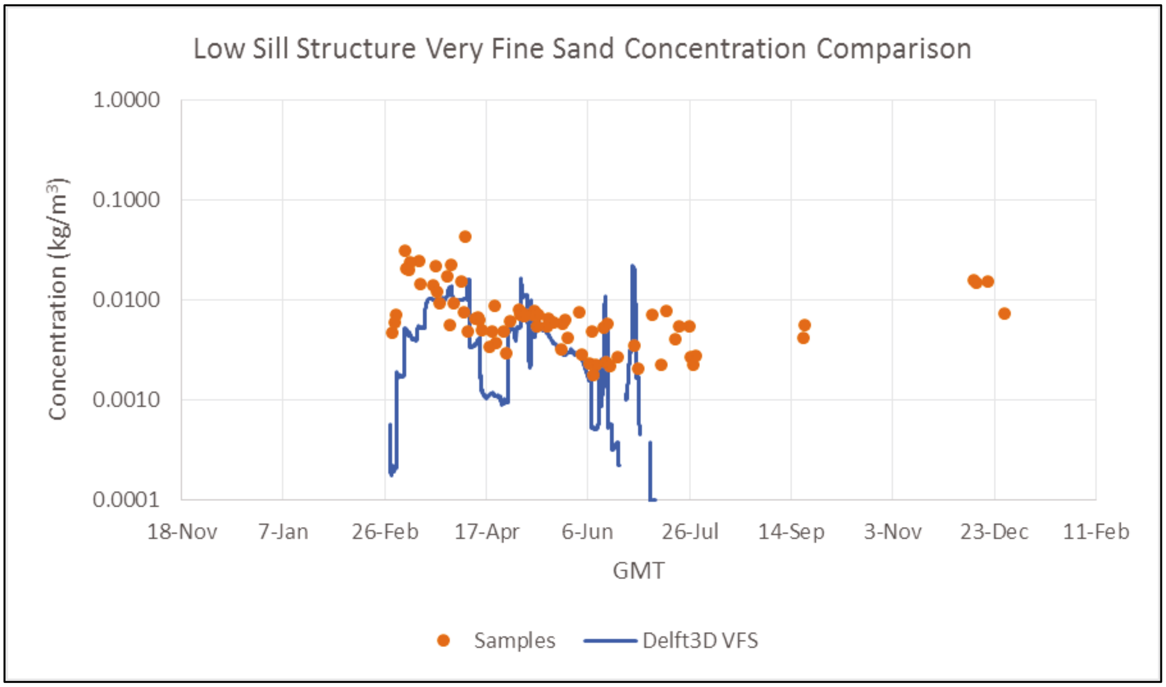


Figure 59. Low Sill Structure fine sand concentration comparison.

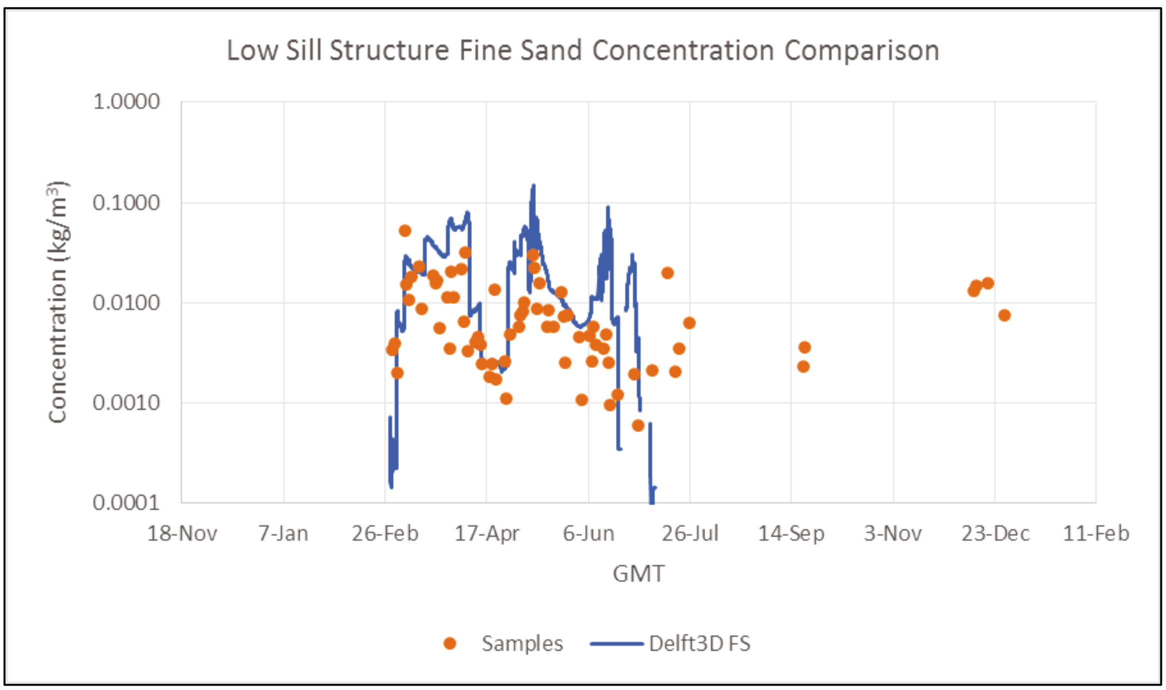


Figure 60. Low Sill Structure medium sand concentration comparison.

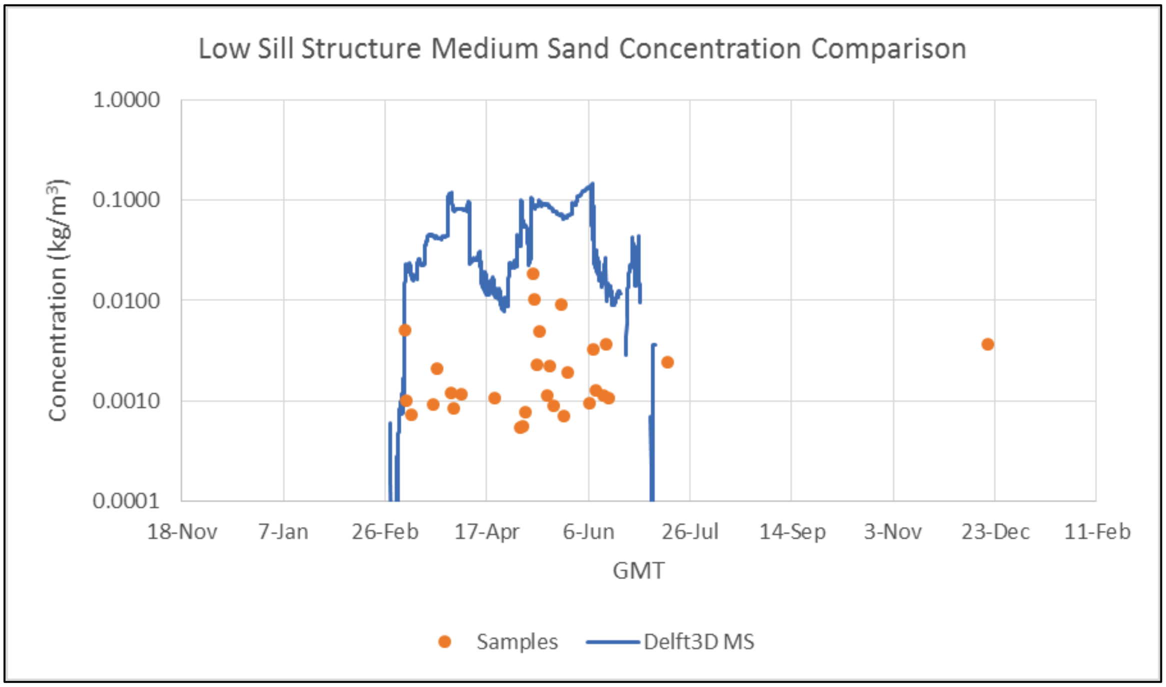


Figure 61. Auxiliary Structure very fine sand concentration comparison.

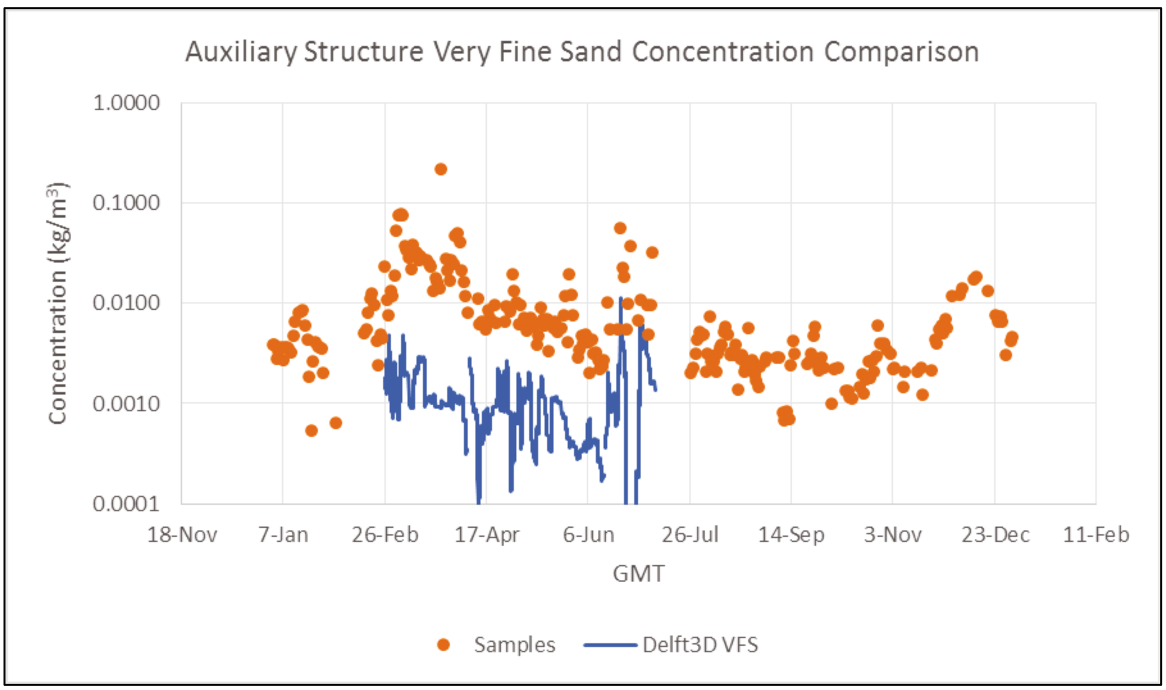


Figure 62. Auxiliary Structure fine sand concentration comparison.

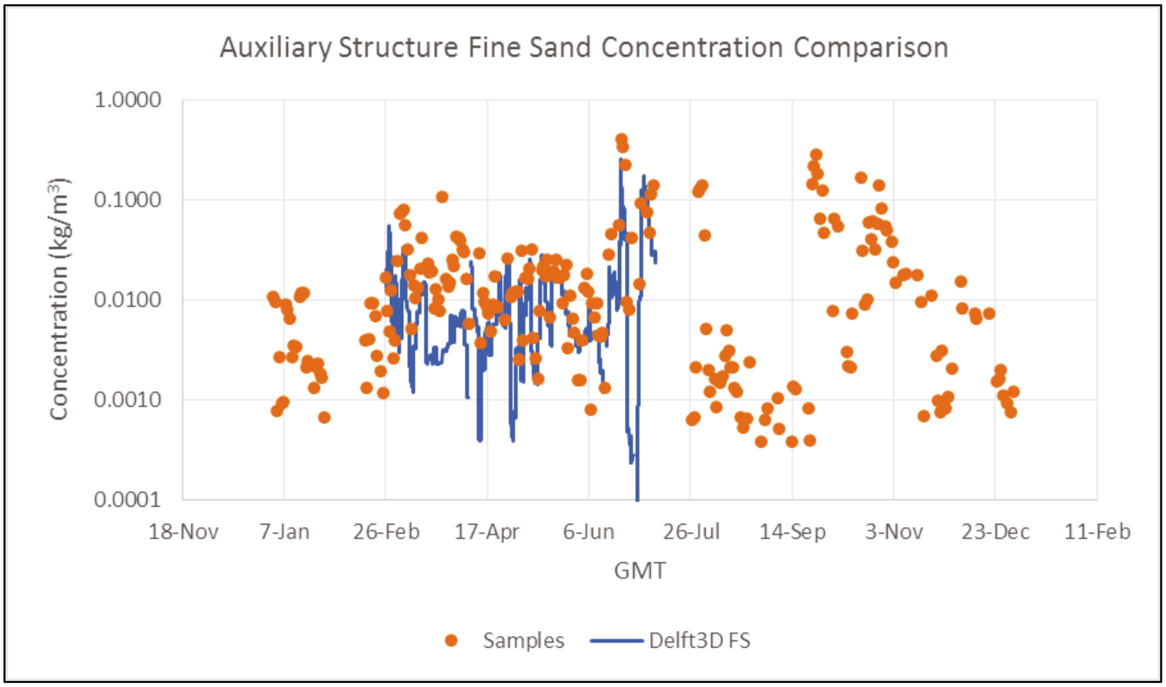
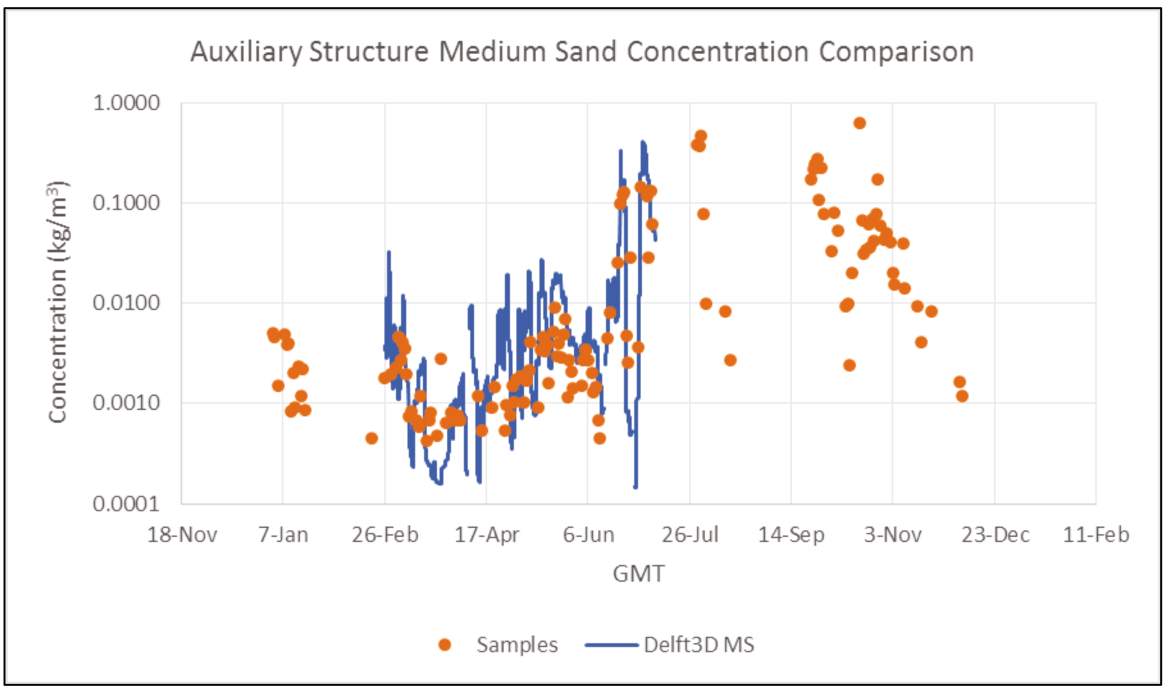


Figure 63. Auxiliary Structure medium sand concentration comparison.



4 Sediment Load

Suspended sediment data were analyzed for longer time periods to determine if the computed loads were reasonable compared to longer-term trends. The total suspended sand load at Tarbert Landing, Union Point, Baton Rouge, and St. Francisville were plotted, and power law relationships were determined. The periods of record at each sediment range and the power law specifics are listed in Table 8.

Table 8. Long-term sand load trends.

Sediment Range	Period of Record	Number of Samples	Coefficient a	Exponent b	Coefficient of Determination r^2
Natchez	1969-1979	Not stated	4.08E-05	2.17	0.77
Union Point	2006-2014	114	1.75E-08	2.94	0.80
Tarbert Landing	2006-2014	155	2.96E-05	2.25	0.81
St. Francisville	2006-2016	159	1.25E-06	2.48	0.74
Baton Rouge	2006-2016	150	3.29E-11	3.56	0.88

The suspended load may be adjusted in Delft3D by changing the current-related reference concentration factor, which is a multiplier to the reference concentration. The reference concentration is taken from the cell above the van Rijn (van Rijn 1993) reference height. This factor was adjusted during the calibration process, and the results were compared to these longer-term trends. Through comparison of model results to the discharge/sand load relationships, a value of 0.4 was considered to give a good comparison to measured loads. Computed sand loads for the simulation period are plotted with the measured loads in the Figures 64–71.

Figure 64. Union Point sand load.

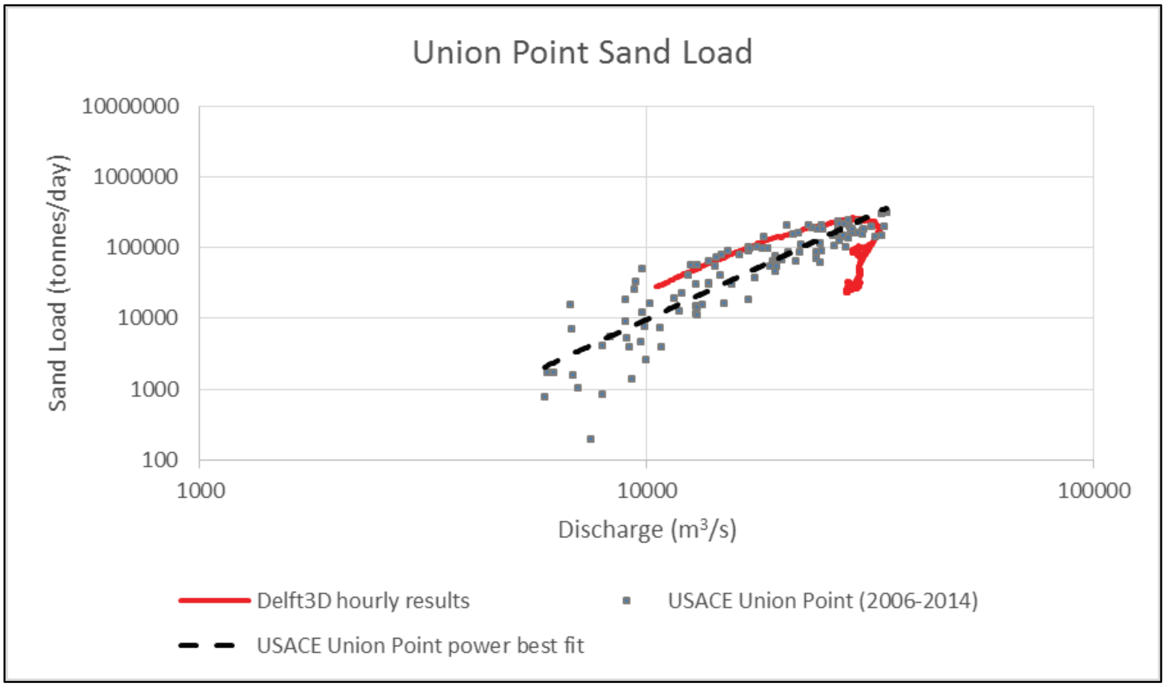


Figure 65. Tarbert Landing sand load.

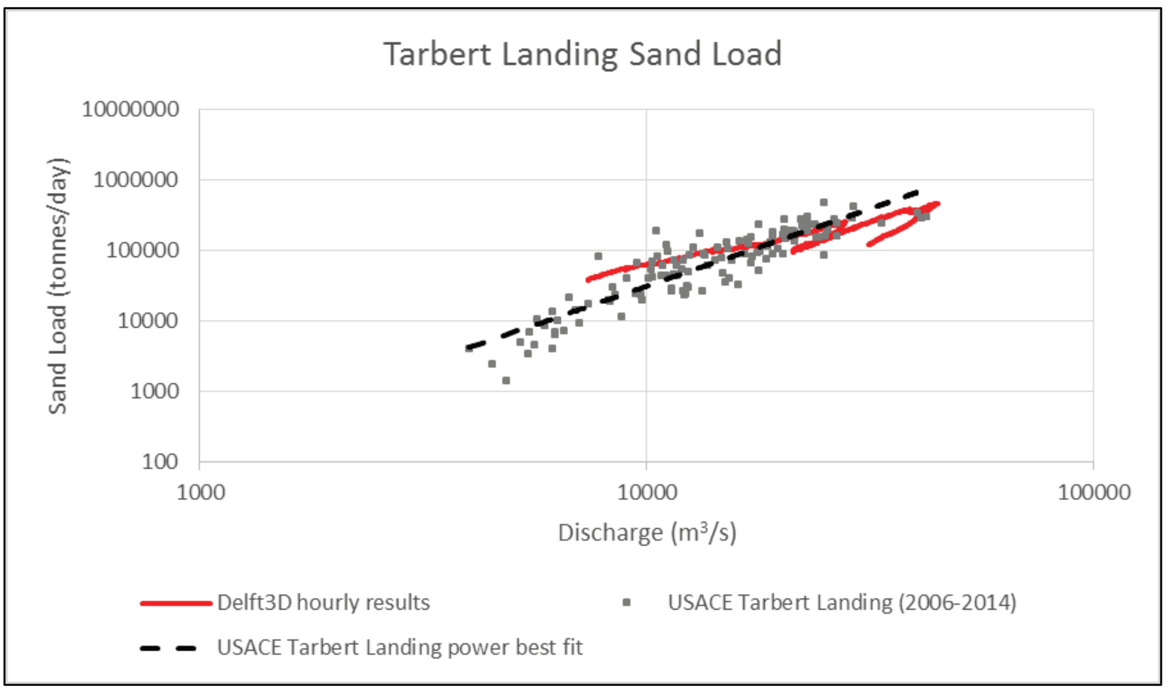


Figure 66. St. Francisville sand load.

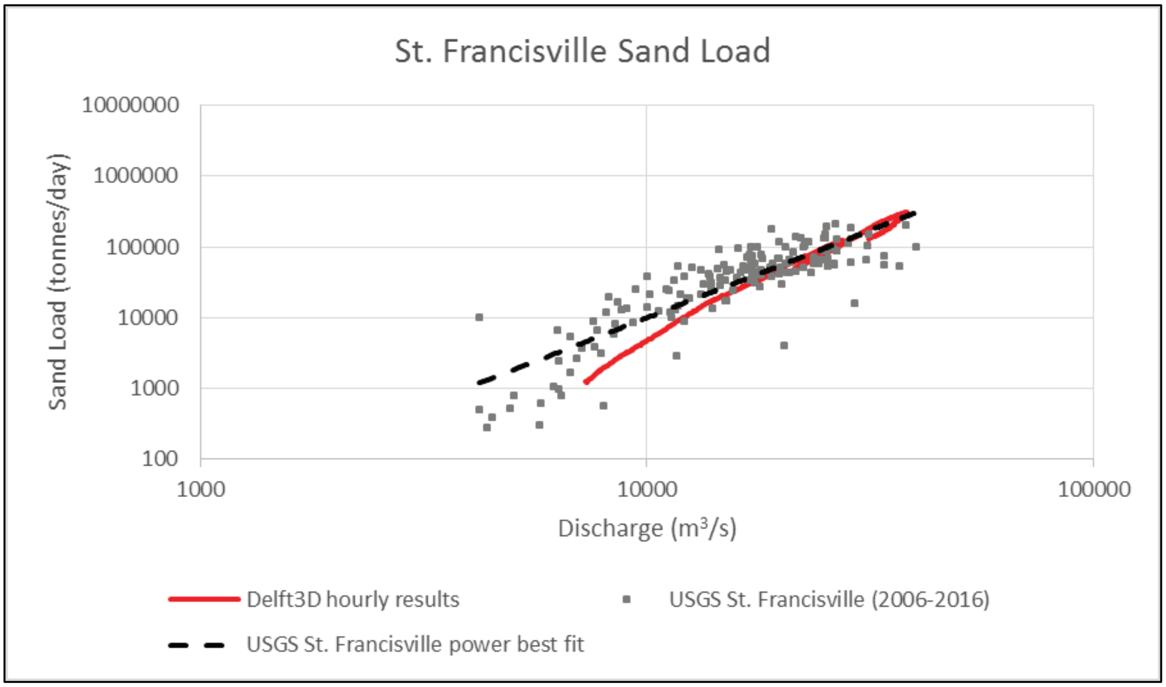
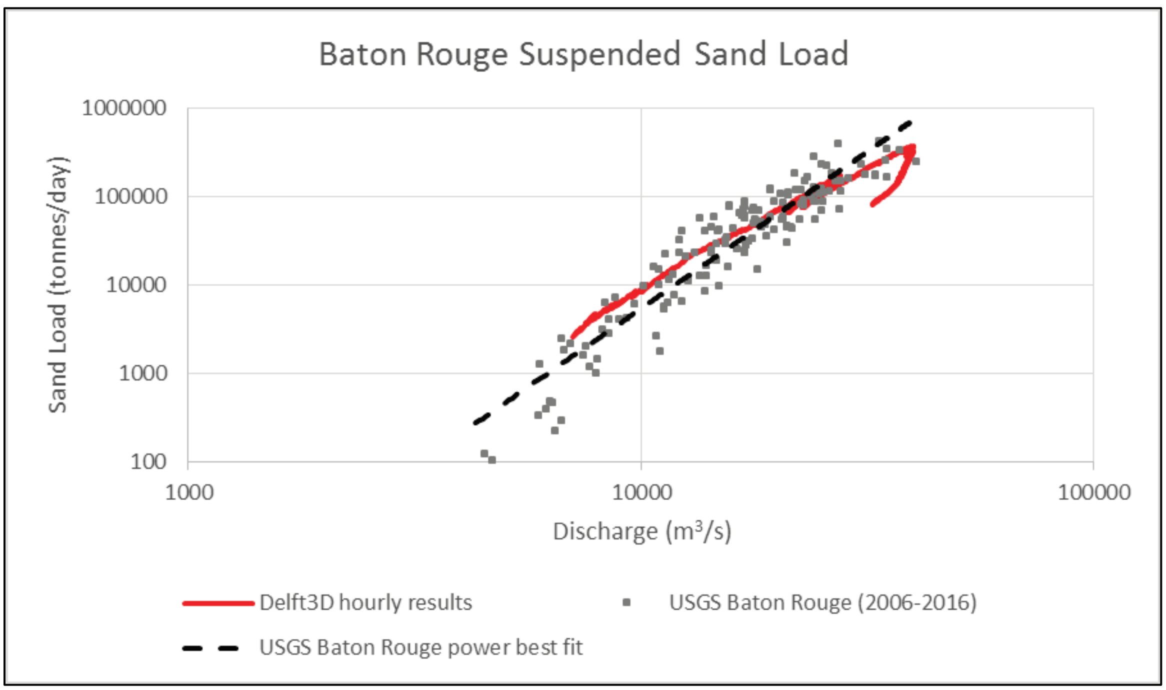


Figure 67. Baton Rouge sand load.



Using the concentration and discharge data, sediment loads may be determined at the structures for each sand size class. Figures 68–71 display the computed instantaneous sand load at each structure.

Figure 68. Delft3D Hydropower sand load.

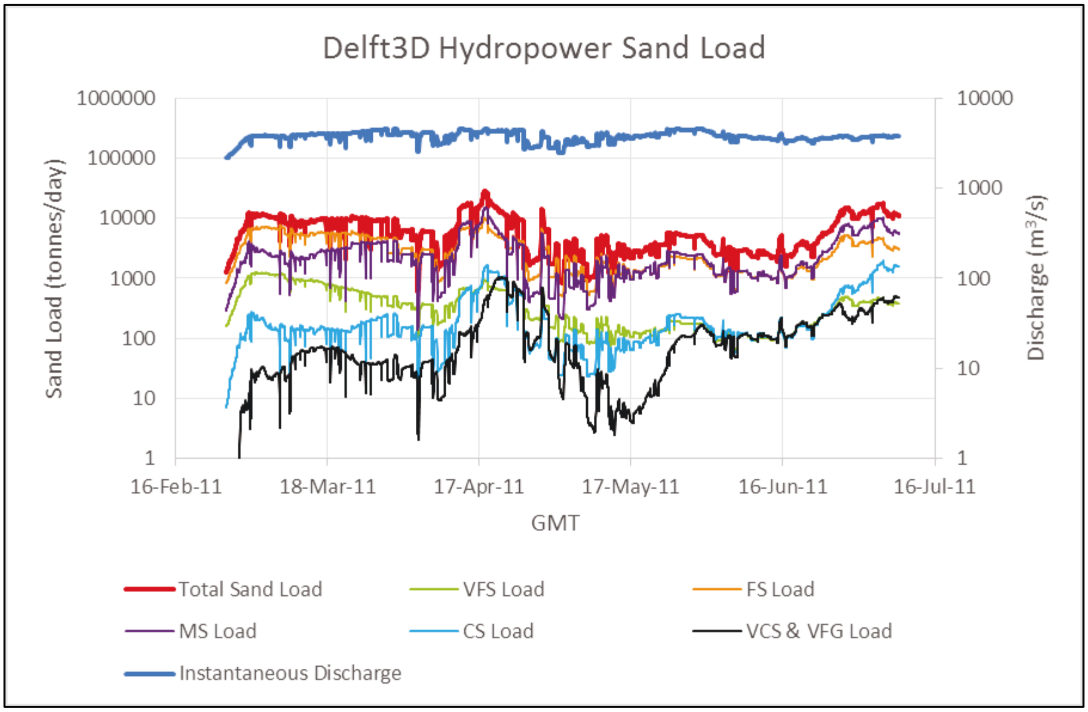


Figure 69. Delft3D Low Sill sand load.

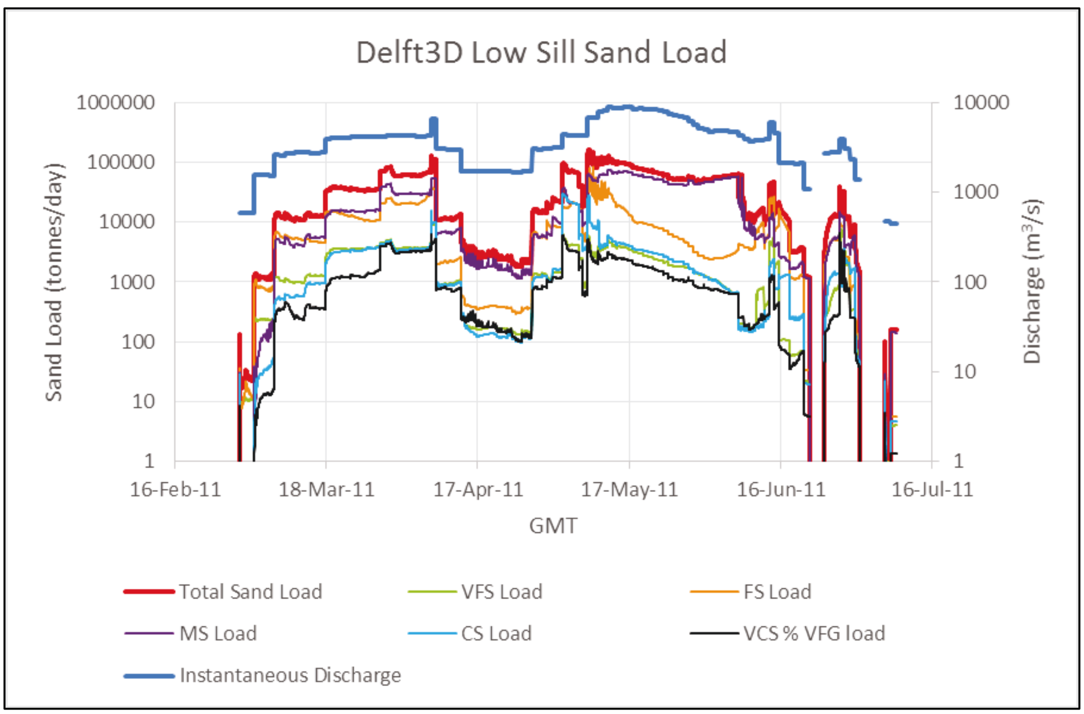


Figure 70. Delft3D Auxiliary sand load.

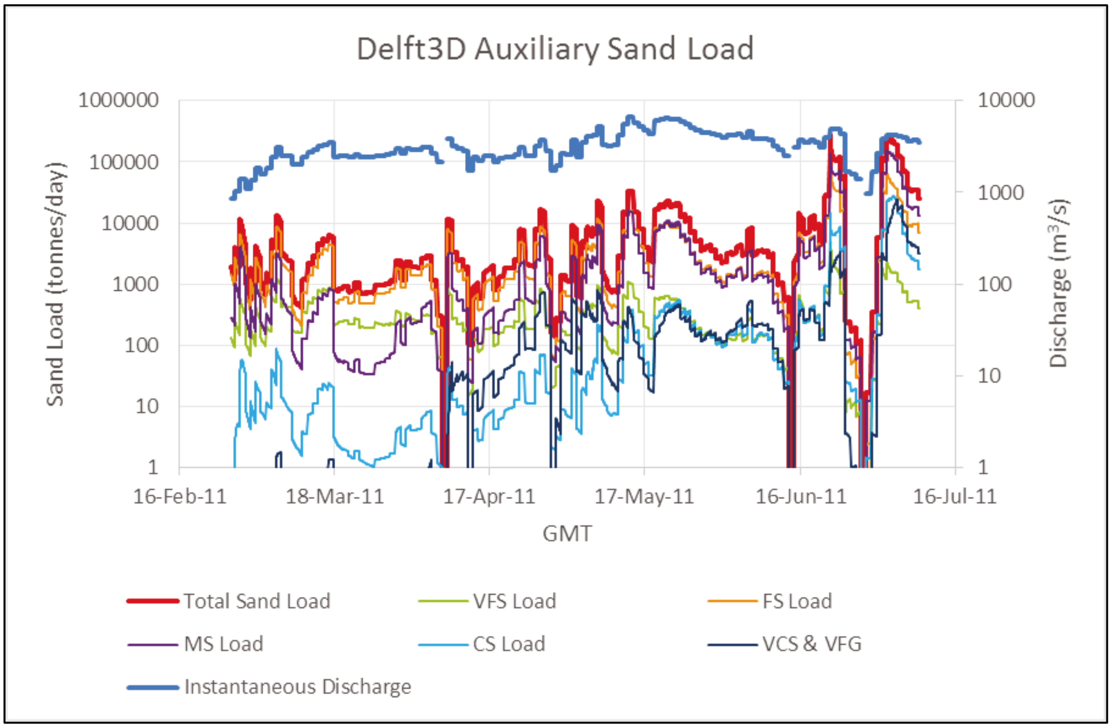
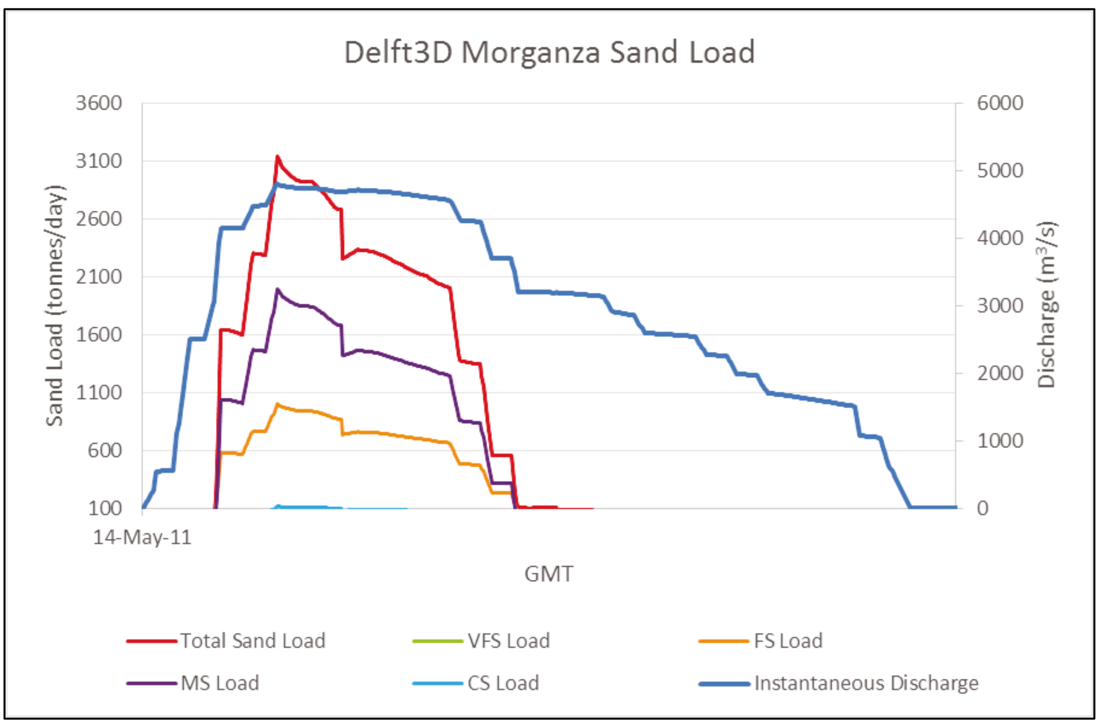


Figure 71. Delft3D Morganza sand load.

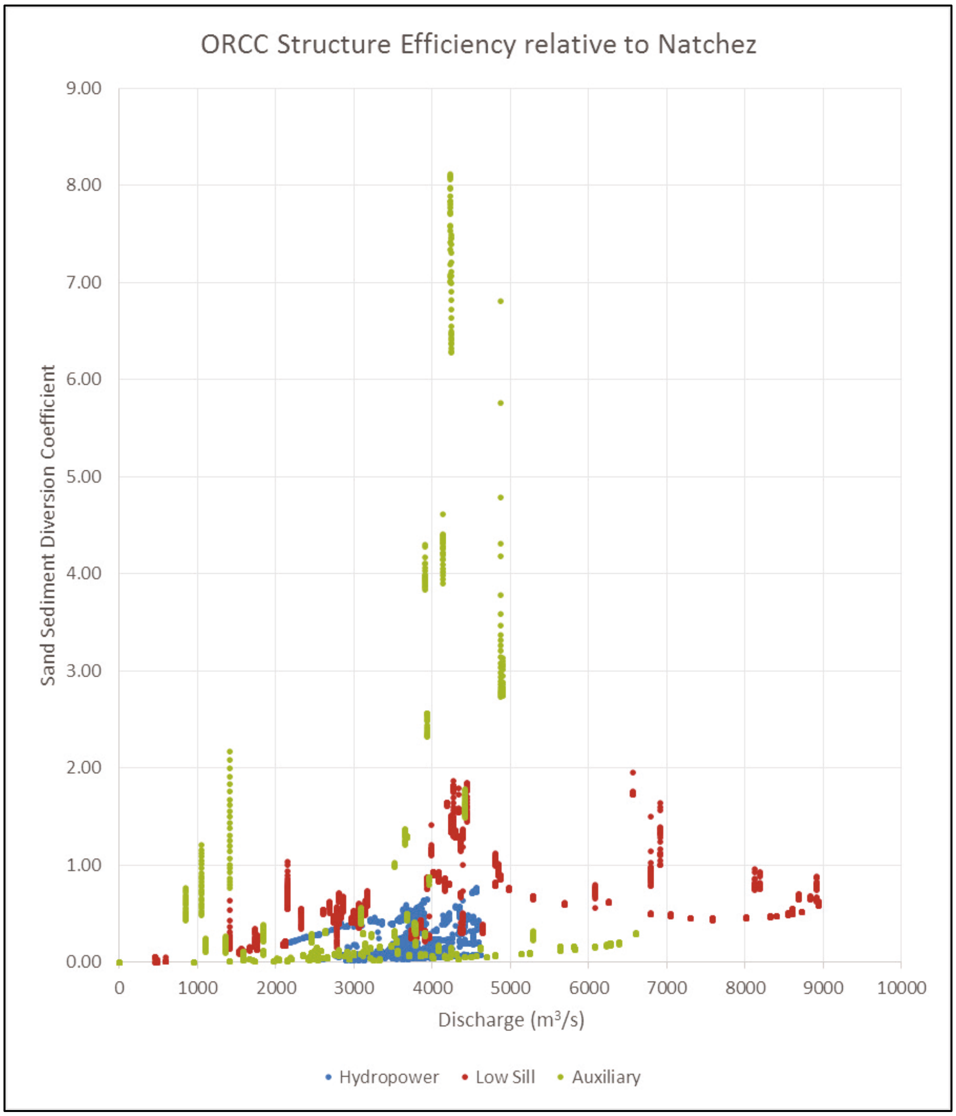


The efficiency of the structures may be evaluated by comparing the computed sand concentration at the structure to the concentration at an upstream location in the river; this term is referred to as the sediment diversion coefficient:

$$\delta_{SD} = \frac{C_{Diversion}}{C_{River}}$$

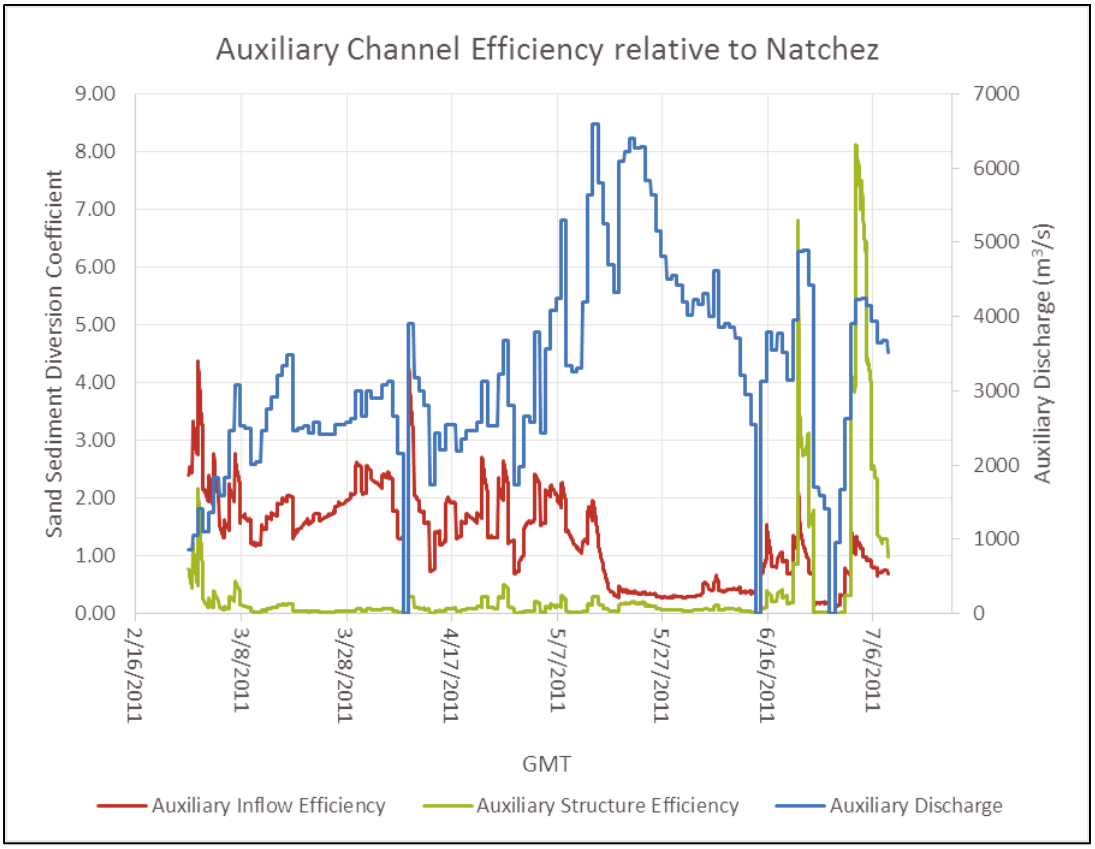
The total sand sediment diversion coefficient was determined for each ORCC Structure using Natchez as a reference location and is plotted in Figure 72.

Figure 72. ORCC Structure sand diversion coefficient.



The ability of the Auxiliary inflow channel to capture sediment may be visualized by evaluating the sand diversion coefficients at the inflow (river end) and outflow (structure end) of the channel. As can be seen in the time-series plot in Figure 73, the inflow channel is efficient at capturing sediment during normal operation as originally designed; however, flushing of the channel may be necessary to keep the channel operating efficiently as the diversion coefficients at the structure are generally lower than the diversion coefficients at the inflow end of the channel.

Figure 73. Efficiency of Auxiliary inflow channel.



5 Conclusions and Recommendations

The model normally requires a very small time-step (Δt) on the order of 3 s to execute without violating the CFL condition to a degree that makes the model go unstable (Courant 1928). The model required an even smaller time-step of 1.5 s to satisfy the CFL condition near the flood peak when the highest velocities of the flood event were experienced. This means that the simulation had to be slowed to the order of real time to analyze the peak of the flood.

A possible way to improve the speed of the model and thus its practicality would be to perform grid sensitivity tests to determine if a coarser grid would provide the same fidelity to the prototype as the current configuration. A coarser grid may allow easing of the small time-step requirement of the current grid configuration to satisfy the CFL condition. The aspect ratio of grid cells may be modified to lengthen the distance of the cell in the longitudinal flow direction to increase the CFL wave travel distance and thus allow a possible increase in the size of the time-step and improvement in model run times. This would be especially beneficial in areas of the grid that experience high-velocity flow. Careful examination of the grid would be necessary to ensure the aspect ratio did not exceed 5:1 (5 in the longitudinal flow direction, 1 in the transverse flow direction) (Deltares 2018).

Another possible improvement in computational speed may be achieved by utilizing the Cartesian vertical layering scheme available in Delft3D. This method overcomes the inefficiencies introduced by the sigma scheme in shallow areas where all vertical layers must be used even if the information is not necessary to the areas of interest. This particular model has large numbers of grid cells that are flooded in the overbank areas during high flows, but the sedimentation information computed by the model in these areas would have little impact on the sedimentation aspects of the model in the river channel. The storage of water in these overbank areas is necessary to accurately determine the flow in the river channel, which is the most important driver for sedimentation. However, a Cartesian model would account for this overbank storage without the large computational burden imposed by the requirement to analyze every vertical level in the sigma scheme. A means to reduce the stair stepping inherent to Cartesian models at the bottom surface would be necessary to allow accurate bed shear stress calculation. Delft3D features a means to accomplish this through bottom layer remapping of the near bed cells (Deltares 2014).

Removal of the clay constituent from the analysis may be considered as a means to improve computation time. The clay constituent would most likely pass through the model domain as wash load, and its removal should not impact model results. Cohesive sediments have been observed in the bed in the study area, notably in the auxiliary intake channel; therefore, removal of cohesive sediment from consideration altogether is not advisable (Spasojevic 2008).

The discharge results compared to measured data at Union Point indicates that additional investigation is needed to improve the calibration in this portion of the model. Areas of investigation and improvement to the model may include refined bathymetry and roughness parameters.

The model may be divided into more manageable pieces if further calibration and testing is desired, especially testing of roughness coefficients and methods. For example, a smaller model may be achieved by placing the downstream boundary at Red River Landing and removing the portion of the grid between Red River Landing and Baton Rouge. This would permit a more focused and efficient analysis of optimum roughness parameters to achieve improved calibration results.

Analysis of results indicates that the very fine sand class is under-represented in the bed composition and in the suspended load at the upstream boundary located at Natchez. This is likely due to the use of bed samples taken from deeper portions of the channel to define the model bed gradations. The very fine sand class would more typically be available for entrainment from shoals located in shallow water. The suspended sediment data at the structures and the Tarbert Landing and Union Point ranges could be used to calibrate the proportion of this sediment class in the bed makeup. Suspended data at Union Point may be used to inform the concentration of this sediment class at the Natchez boundary.

6 Summary

A 3D sediment model of the Mississippi River from Natchez, MS, to Baton Rouge, LA, was constructed and initially tested and calibrated using data collected during the historic 2011 flood. A 19-week simulation was conducted, and model results were analyzed and compared to measured data including river discharge, water level, and suspended sediment concentration data.

As a proof of concept, this analysis showed that it is possible to conduct numerical model studies of a very large domain, approximately 133 river miles in this case, with a high-resolution 3D model with multiple sediment classes. However, the cost of such a model is that any analysis would be limited to event time scales or steady state boundary conditions due to the large computational burden.

With some further refinement to friction parameters, bathymetry, and sediment characteristics, the model may be used as a tool to investigate means to improve management of sediment in the system.

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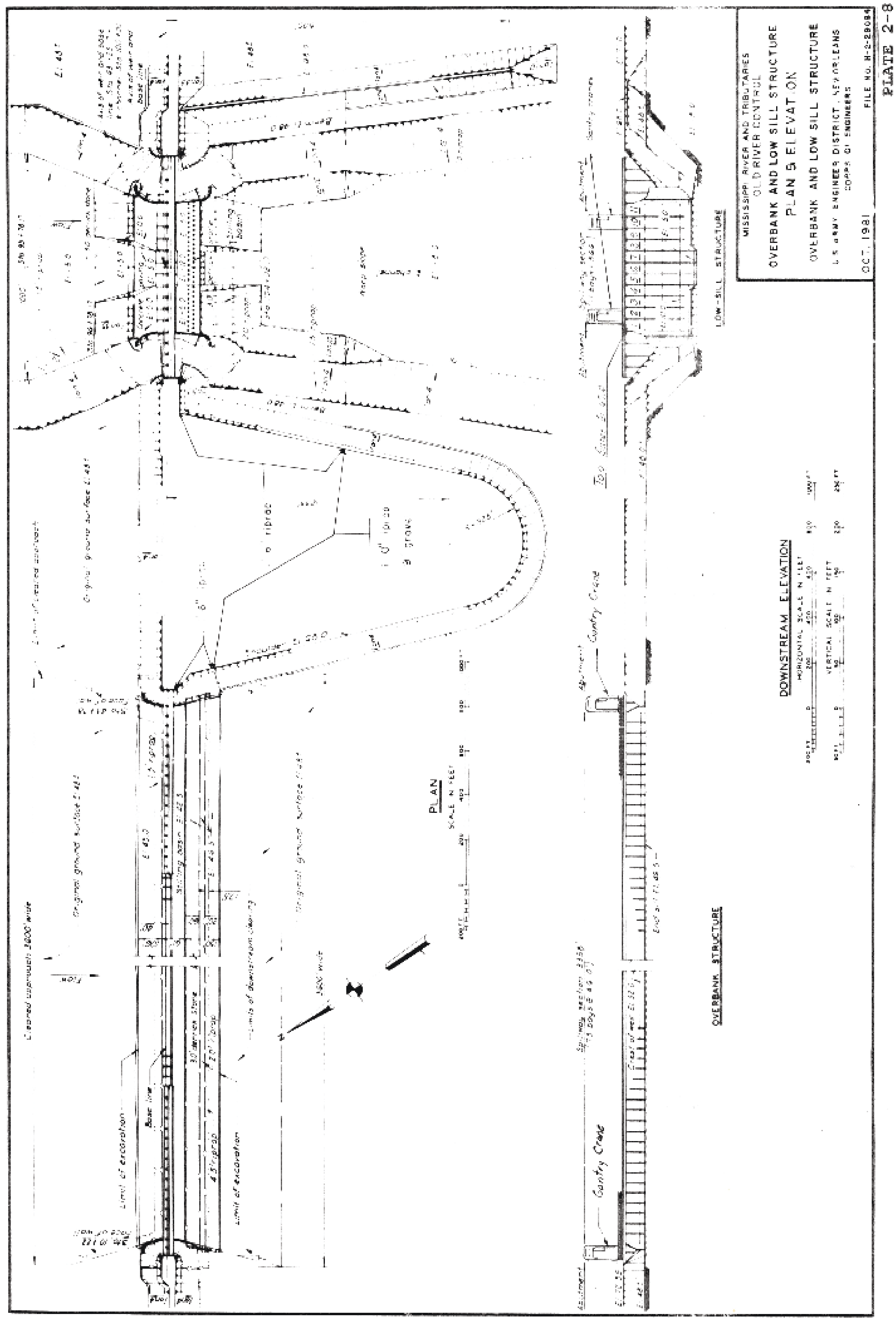
Appendix: Structure Drawings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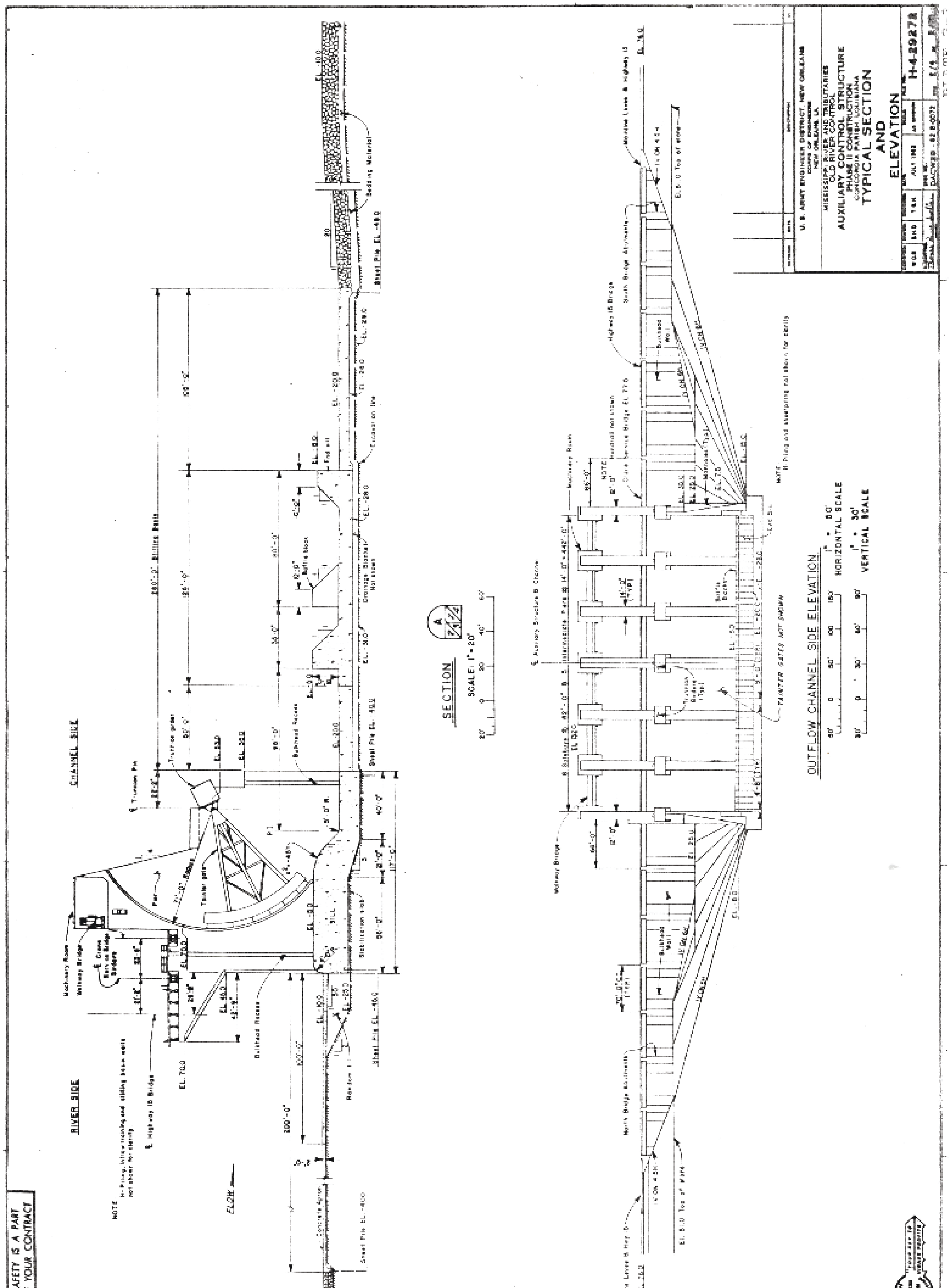
OLD RIVER CONTROL
OVERBANK AND LOW SILL STRUCTURE
PLAN & ELEVATION
OVERBANK AND LOW SILL STRUCTURE
U.S. ARMY ENGINEER DISTRICT, NEW ORLEANS
CORPS OF ENGINEERS
OCT. 1981
PLATE 2-8
PLAN
DOWNSTREAM ELEVATION
OVERBANK STRUCTURE
LOW-SILL STRUCTURE
Gantry Crane


SAFETY IS A PART OF YOUR CONTRACT
RIVER SIDE
CHANNEL SIDE
FLOW
SECTION
OUTFLOW CHANNEL SIDE ELEVATION
HORIZONTAL SCALE
VERTICAL SCALE
TAINTER GATES NOT SHOWN
MISSISSIPPI RIVER AND TRIBUTARIES
OLD RIVER CONTROL
AUXILIARY CONTROL STRUCTURE
TYPICAL SECTION
AND
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13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report documents the development and calibration of a three-dimensional (3D) sediment model of the Mississippi River from Natchez, MS, to Baton Rouge, LA. The objective of the study was to provide a modeling tool capable of analyzing sedimentation in this dynamic reach of the river. The modeling domain includes five large river diversion structures: Hydroelectric Station, the Overbank, Low Sill, and Auxiliary Structures that make up the Old River Control Complex (ORCC), and the Morganza Floodway Control Structure. Evidence suggests that the Hydroelectric Station and ORCC Structures do not convey sediment in adequate proportion to maintain downstream channel stability. This modeling tool will provide a means to investigate options to improve this imbalance. In particular, the close proximity of the orifice flow diverted through the Low Sill Structure to the Mississippi River channel bed necessitates a 3D approach to properly assess sediment diversions through this structure. The open source Delft3D finite difference solver utilizing the sigma vertical layer option was the selected model platform running in a massively parallel computing environment. Sand concentration and load data collected at four ranges were compared to model results during the flood of 2011 along with water level and discharge data.

15. SUBJECT TERMS
Floods—Mississippi River, Hydrodynamics—Computer simulation, River channels—Computer simulation, Sedimentation and deposition—Computer simulation

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