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WATER QUALITY MODELING OF PROPOSED RIVER REINTRODUCTION INTO MAUREPAS SWAMP (PO-0029)

OCTOBER 3, 2019

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FTN No. R05540-1567-001

October 3, 2019

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1.0 INTRODUCTION

The proposed River Reintroduction into Maurepas Swamp (PO-0029) project (the Project) located near Garyville, Louisiana, will divert flow from the Mississippi River to the Maurepas Swamp wetlands (Figure A.1). In 2014, URS provided 95% level design of the proposed PO-0029 project to the Coastal Protection and Restoration Authority (CPRA) of Louisiana (URS 2014). The project consists of a gated intake structure at the river capable of diverting 2000 cfs river water, a large sand settling basin, and a long, banked conveyance channel. Approximately halfway along the route, just north of US Highway 61, the channel follows the existing Hope Canal alignment to distribute the diverted water into the wetlands on the north side of Interstate 10. The proposed diversion channel from the Mississippi River to its end approximately 1000 ft north of its crossing with I-10 highway. The channel has a variable cross-section along its way. The longest segment between the Highway 61 and I-10 has a 60 ft wide bottom and 1V:5H side slope. The invert is -7 ft- and -8 ft, NAVD88 at Highway 61 and I-10, respectively. Additionally, the culvert crossings under I-10 between LA 641 and Mississippi Bayou are proposed to be closed to prohibit backflow from the diversion into the swamp between I-10 and Highway 61. The design also proposes gaps in the railroad embankment along the west bank of Hope Canal. For details, the reader is referred to the 95% Level Design Report (URS 2014).

To support the hydraulic design of the proposed diversion and to evaluate its effect on swamp hydrology, URS developed a two-dimensional (2D) ADvanced CIRCulation (ADCIRC) Model. URS also developed a one-dimensional (1D) Storm Water Management Model (SWMM) of the Garyville-Reserve drainage system to evaluate effects of the water levels in the swamp on the drainage.

The hydrodynamic modeling performed for the 95% level design did not include modeling the transport of nutrients introduced from the Mississippi River diversion water throughout the swamp. The purpose of the modeling efforts outlined in this document is to develop a water quality model (two-dimensional Delft3D) for the study to simulate transport of nutrients carried by the diverted water.

The approach for simulating nutrients in the Maurepas Swamp was initially presented in a memorandum from FTN Associates, Ltd. (FTN) to the CPRA dated August 7, 2018. The information from that memorandum is included in Section 2 of this report with only minor revisions from the memorandum. The nutrient simulations are driven by calibrated hydrodynamic model described in Appendix A.

The model results are presented in Section 3 of this report. The simulation is of a steady flow of 2,000 cfs of Mississippi River water introduced into the swamp via Hope Canal for a duration of 31 days followed by 10 days of simulations without the diversion flow. The results include predictions for water surface elevation, velocity, and nutrients during summer and winter. The results from a "salinity flushing" scenario is also included to demonstrate effects of diversion flow on an initial saline conditions in the swamp.

2.0 APPROACH FOR SIMULATING NUTRIENTS

2.1 Overview of Approach

The objectives for simulating nutrients for this project are to: a) evaluate the fate and transport of nutrients throughout the swamp, and b) evaluate effects of the diversion on nutrient concentrations in Lake Maurepas.

To begin with, a hydrodynamic model of the study area was developed and calibrated. The details regarding the basis for model selection, development of the model geometry, calibration and validation are described in Appendix A. The simulated hydrodynamics (water surface elevations and velocities throughout the study area) are then used to drive the nutrient transport described in the following sections.

As discussed in Appendix A, the Delft3D model was selected to simulate hydraulics. Nutrients and salinity are being simulated with DELWAQ, which is the water quality model in the Delft3D suite of models. Nutrients are being simulated as total nitrogen (TN) and total phosphorus (TP) rather than individual species of nutrients (e.g., ammonia nitrogen, nitrate nitrogen, etc.). Although nutrients in organic and particulate forms are not immediately available for uptake by algae or vegetation, they can be transformed later into inorganic, dissolved forms that have the potential to cause eutrophication. Therefore, predictions for TN and TP are considered appropriate for addressing the modeling objectives.

TN and TP are simulated using a “black box” approach that characterizes the overall loss of nutrients from the water column as the water moves through the swamp. With this approach, the model does not simulate individual processes (mineralization, nitrification, denitrification, sorption of phosphorus, uptake by algae and plants, etc.), but the rates of nutrient loss from the water column are based on published measurements that account for the combined overall effect of all processes. This “black box” approach is being used instead of a more detailed approach of simulating individual processes due to a lack of site-specific data for calibrating numerous coefficients for the processes. The importance of calibration data in applications of complex models is noted in the following statement: “Highly detailed representations of system structures may not be useful to simulate TP dynamics in treatment wetlands if comprehensive data sets are not available to constrain each pathway" (Paudel and Jawitz 2012). Other studies have successfully modeled losses of nutrients from water moving through wetlands without detailed simulations of individual processes (Day et al. 2004; Kadlec et al. 2011; CH2M Hill 2012; CH2M Hill 2013; Kadlec 2016; Merriman et al. 2017).

TN and TP are being simulated with generic user-defined constituents in the model. The nutrient state variables are designated to represent actual concentrations minus background concentrations (i.e., a concentration of zero in the model represents an actual concentration equal to background). With this configuration, the model simulates conditions that represent actual concentrations asymptotically approaching background concentrations without dropping below background concentrations. The assumption that actual concentrations cannot drop below background concentrations has been successfully used in various other studies that estimate losses of nutrients from water moving through wetlands (Kadlec et al. 2011; CH2M Hill 2012; CH2M Hill 2013; Kadlec 2016; Merriman et al. 2017).

The DELWAQ model has been set up to simulate losses of TN and TP from the water column with first order decay rates. For the generic user-defined constituents, the DELWAQ model does not provide any kinetics that are more complex than first order decay. First order decay is not a perfect representation of nutrient loss kinetics in wetlands (Kadlec 2000), but it forms the basis of equations that have been used in recent studies to calculate nutrient loss in wetlands receiving diverted river water and in wetlands receiving municipal wastewater. One of these equations is the "relaxed tanks-in-series" model, also known as the PkC* model (Kadlec and Wallace 2009):

$$\frac{(C_{OUT} - C^*)}{(C_{IN} - C^*)} = \left[1 + \frac{k}{P\,q} \right]^{-P}$$

where: C_{OUT} = Concentration at outlet of wetland (mg/L)
C_{IN} = Concentration at inlet of wetland (mg/L)
C^* = Background concentration (mg/L)
k = First order areal rate constant (m/yr)
q = Hydraulic loading rate per unit area (m/yr)
P = Apparent number of tanks in series (dimensionless)

The parameter "P" in the equation above accounts for: 1) hydraulic inefficiencies of flow through the wetland (i.e., it represents flow through multiple well-mixed tanks in series as opposed to uniform plug flow), and 2) "weathering", which is a term that describes the effect of different loss rates for different fractions of the component (e.g., loss rates for nitrate and ammonia are individually different than an overall loss rate for TN).

For small areas with short residence times, the value of "P" in the equation above approaches 1.0 and the results become similar to a first order decay equation (with a background concentration incorporated):

$$\frac{(C_{OUT} - C^*)}{(C_{IN} - C^*)} = \exp(-k/h \times t)$$

where: h = depth of water (m)
t = residence time (yr)

For example, for k = 0.05 m/day (18.25 m/yr) and h = 0.5 m, the results from the two equations above differ by only 0.5% for a residence time of 1 day.

The DELWAQ model allows the user to vary the first order decay rates spatially or temporally, but not both. For this project, the decay rates are being varied spatially based on predicted depths. The model cells that represent shallow water moving through the swamp have been assigned higher decay rates and model cells that represent deeper, channelized flow have been assigned lower decay rates. Nutrient loss (from the water column) is expected to be greater in shallow vegetated areas due to vegetative uptake, settling and burial of particulates, and transformations by biological organisms that are either on the bottom or attached to vegetation and/or debris.

2.2 Nutrient Loss Rates

Tables B.1 and B.2 (located in Appendix B) summarize information from published literature that was considered for selection of nutrient loss rates for the Delft3D model. These tables include values for first order decay rates that were calculated based on hydraulic residence time and percent reduction of TN or TP (except where noted). These tables also include "k" values for the PkC* model that were either reported by the author or calculated as the first order decay rate multiplied times the depth of water.

These studies represent a range of situations with different source water (river water or treated municipal wastewater), different types of wetlands (forested swamp, estuarine marsh, and constructed wetlands), and different climates (southern Louisiana as well as several other states). The studies based on municipal wastewater are presented for comparison but were not directly used for estimating nutrient loss rates for this project.

The lowest values of first order decay rate and “k” value occurred for the systems with the longest residence times (77 – 512 days for Mandeville, Thibodaux, Luling, and Breaux Bridge). These first order decay rates and “k” values for these systems were not considered useful for developing inputs to the Delft3D model because the residence times for those systems are much longer than the residence time for individual cells in the Delft3D model. Also, the TN and TP concentrations entering those four wetlands are much higher than the concentrations in the Mississippi River water that will be diverted into the Maurepas swamp.

In addition to the studies with field data summarized in Tables B.1 and B.2, a modeling study was conducted by CH2M Hill (2013) in which nutrient retention was simulated in various wetlands (including Maurepas swamp) with existing or proposed diversions of water from the Mississippi River. The CH2M Hill study used the PkC* model with the following “k” values:

- 27.8 m/yr for nitrate in vegetated habitat,
- 8.2 m/yr for nitrate in shallow lake habitat,
- 14.2 m/yr for ammonium,
- 17.3 m/yr for organic nitrogen, and
- 10.0 m/yr for TP.

The published literature that was reviewed for this project demonstrates variability in first order decay rates and “k” values not only among different sites, but also among different seasons. Much of the loss of nutrients from the water column is due to biological processes whose rates vary based on temperature. Therefore, nutrient loss rates are expected to be generally higher during summer and lower during winter.

To address both the uncertainty of nutrient loss rates for the Maurepas swamp as well as seasonal variability of nutrient loss rates, simulations have been run for summer (with higher loss rates) and for winter (with lower loss rates). Based on the CH2M Hill (2013) study, as well as the information in Tables B.1 and B.2, the following "k" values were selected for use in the Delft3D model:

Winter (low) rates for TN:	15 m/yr in swamp, 5 m/yr in Lake Maurepas;
Summer (high) rates for TN:	30 m/yr in swamp, 10 m/yr in Lake Maurepas;
Winter (low) rate for TP:	5 m/yr; and
Summer (high) rate for TP	15 m/yr.

A script file was used to divide these "k" values by the predicted water depth in each cell in the model (after previously running the model for hydraulics) to obtain the first order decay rate that the Delft3D model needs for each cell in the model.

2.3 Background Concentrations

For this project, the background concentrations are based on existing concentrations in the Maurepas swamp and in Lake Maurepas. Table 2.1 provides summaries of TN and TP data measured in the Maurepas swamp (Hope Canal, Mississippi Bayou, and Dutch Bayou) and in Lake Maurepas. Table 2.1 includes data collected by Rob Lane during 2002-2003 and routine monitoring data collected by the Louisiana Department of Environmental Quality (LDEQ). Locations of the sampling sites are shown on Figure 2.1.

Table 2.1. Summary statistics for TN and TP data in Maurepas swamp and in Lake Maurepas.

Sampling location [A]	Period of record for nutrient data	TN data			TP data		
		No. of values	Median (mg/L)	Range (mg/L)	No. of values	Median (mg/L)	Range (mg/L)
Sites within the Maurepas swamp simulation area:							
Site 1 (Hope Canal)	4/04/02 – 5/13/03	11	0.79	0.51 – 1.32	11	0.75	0.04 – 1.21
Site 2 (Hope Canal)	4/04/02 – 5/13/03	11	0.78	0.61 – 1.52	11	0.15	0.07 – 0.66
Site 3 (Hope Canal)	4/04/02 – 5/13/03	11	0.82	0.57 – 1.75	11	0.13	0.05 – 1.00
Site 4 (Dutch Bayou)	4/04/02 – 5/13/03	11	0.65	0.49 – 1.58	11	0.11	0.05 – 0.20
Site 5 (Mississippi Bayou)	4/04/02 – 5/13/03	11	0.76	0.45 – 3.89	11	0.11	0.04 – 0.85
Site 0155 (Mississippi Bayou)	5/20/86 – 4/14/98	45	1.00	0.56 – 3.01	45	0.20	0.06 – 0.51
Site 4870 (Dutch Bayou)	10/03/17 – 4/03/18	7	0.94	0.37 – 4.15	7	0.15	0.09 – 0.19
Sites in Lake Maurepas:							
Site 16 (Lake Maurepas – SW)	4/04/02 – 5/13/03	12	0.64	0.44 – 2.42	12	0.11	0.01 – 0.20
Site 17 (Lake Maurepas – S)	4/04/02 – 5/13/03	12	0.59	0.39 – 0.99	12	0.12	0.08 – 0.17
Site 18 (Lake Maurepas – E)	4/04/02 – 5/13/03	11	0.58	0.43 – 0.91	11	0.10	0.03 – 0.16
Site 19 (Lake Maurepas – NE)	4/04/02 – 5/13/03	12	0.53	0.40 – 0.90	12	0.11	0.06 – 0.35
Site 1105 (Lake Maurepas – N)	1/09/01 – 9/25/07	24	0.67	0.30 – 1.82	24	0.09	0.05 – 0.19
Site 4471 (Lake Maurepas – SW)	10/01/13 – 4/03/18	19	0.85	0.35 – 1.39	19	0.15	0.05 – 0.29
Sites representing inflow entering the simulation area:							
Site 11 (Blind River)	4/04/02 – 5/13/03	12	0.60	0.46 – 0.82	12	0.10	0.05 – 0.69
Site 0036 (Pass Manchac)	3/06/78 – 9/08/16	290	0.90	0.09 – 5.54	291	0.10	< 0.05 – 0.51
Site 0228 (Amite River)	1/16/01 – 4/10/18	54	0.86	0.34 – 2.83	56	0.12	0.05 – 0.38
Site 0243 (Blind River)	1/16/01 – 4/03/18	62	0.82	0.24 – 1.42	64	0.15	0.05 – 0.44
Site 0268 (Amite R. Diversion Canal)	1/16/01 – 4/03/18	55	0.86	0.39 – 1.74	58	0.13	0.05 – 0.30
Site 1102 (Blind River near mouth)	1/16/01 – 4/03/18	62	0.80	0.20 – 4.40	64	0.15	0.05 – 0.29
Site 1106 (Tickfaw River)	1/09/01 – 9/03/15	48	0.98	0.21 – 2.57	56	0.13	0.05 – 0.39

Notes:

A. Site numbers between 1 and 19 are Rob Lane's monitoring sites. Site numbers between 0036 and 4870 are LDEQ monitoring sites.

Figure 2.1. Locations of LDEQ and Rob Lane water quality monitoring stations.

In general, the nutrient concentrations in the swamp were slightly higher than in Lake Maurepas. Median TN values in the swamp were mostly between 0.65 and 0.94 mg/L, while median TN values in Lake Maurepas were between 0.53 and 0.85 mg/L. For TP, median values were mostly between 0.11 and 0.15 mg/L in the swamp, while median values in Lake Maurepas were mostly between 0.09 and 0.11 mg/L. Although measured background concentrations of nutrients vary by location, the background concentrations used in the model need to be spatially constant in order to preserve the calculated mass of nutrients being transported in the model. The following values were selected for use as background concentrations for the DELWAQ model:

- Background TN = 0.60 mg/L, and
- Background TP = 0.10 mg/L.

These two proposed background concentrations are more representative of Lake Maurepas than the Maurepas swamp, but it is better to select values towards the low end of the range because the model is able to simulate concentrations above these values, but it cannot simulate concentrations below these values (i.e., the model is not allowed to simulate negative concentrations).

2.4 Boundary Concentrations and Flows

Concentrations of TN, TP, and salinity must be specified in the model for each boundary where water can flow into the simulated area. The locations of these boundaries are shown on Figure 2.2. Pass Manchac is simulated as a tidal water level boundary (water can flow in or out of the simulated area based on head differences); all of the other boundaries are simulated as flow boundaries (the flow into the simulated area is specified by the user).

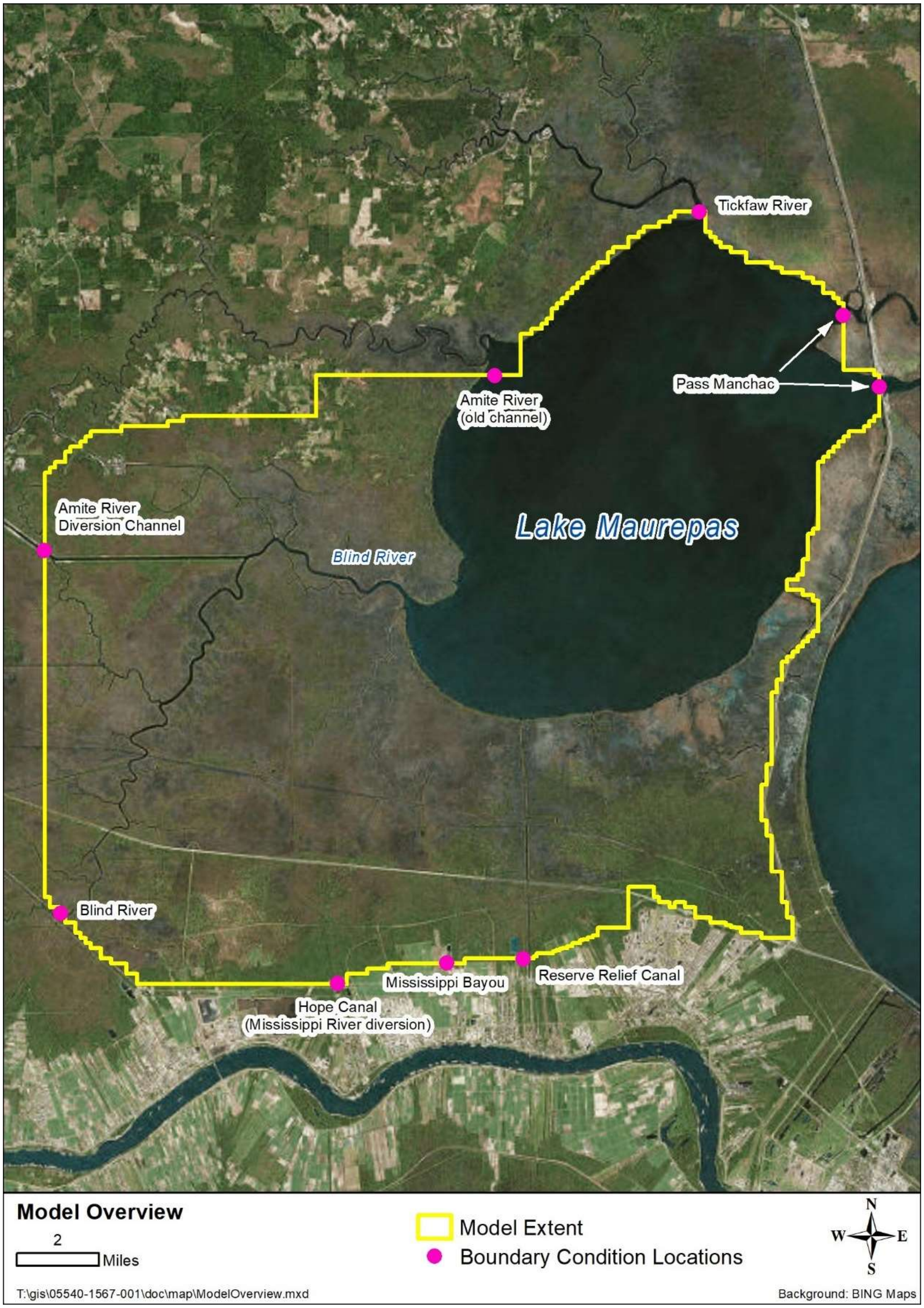

Figure 2.2. Locations where boundary conditions were specified in the model.

For each flow boundary (except the diversion of Mississippi River water), the flow was set to a constant value to represent median (i.e., typical) flow conditions (see Table 2.2). The diversion of Mississippi River water into Hope Canal was set to a constant value of 2,000 cfs. A flow of 280 cfs was taken out of the Hope Canal and introduced (140 cfs on either side) into the wetlands (known as Central Swamp) between the Interstate-10 and the Airline Highway. This flow was released only for the first 7 days during the diversion operation. The release reflects the proposed lateral release valves feature of the project. Thus, for the first 7 days, only 1,720 cfs diversion flow reached the swamps north of Interstate-10.

The stage boundary at Pass Manchac was specified with hourly values to represent typical tidal fluctuations about the historical median water level (See Appendix A).

TN and TP data for the Mississippi River are summarized in Table 2.3 for US Geological Survey (USGS) monitoring stations at Baton Rouge and Belle Chasse. Although these two stations are located 86 miles upstream and 68 miles downstream, respectively, of the proposed diversion location near Garyville, the TN and TP concentrations are similar between the two stations, which suggests that these data are representative of concentrations at Garyville.

Concentrations of TN, TP, and salinity that are being used in the model at each boundary location are summarized in Tables 2.4 and 2.5. Initial conditions for TN, TP and salinity are specified in Table 2.6.

Table 2.2. Input values for flows and stages at model boundaries.

Location of boundary	**Model input value**	**Comment**
Hope Canal (diversion from Mississippi River)	2,000 cfs	Assumed operational flow rate
Hope Canal outflow to Central Swamp (between I-10 and Airline Highway)	2 x 140 cfs	Assumed flow released from Hope Canal each to the east and to the west adjoining marsh between the I-10 and Airline Highway for first 7 days. This is a proposed project feature using lateral release valves.
Tickfaw River	412 cfs	Sum of median flows for Oct. 1989 – Sep. 2017 for Tickfaw River at Holden (158 cfs) and Natalbany River at Baptist (27 cfs) multiplied times ratio of published drainage area at the mouth (727 mi^2; USGS 1971) to combined drainage area at the two gages (247 mi^2 + 79.5 mi^2).
Amite River (old channel)	173 cfs	Median flow for Amite River at Port Vincent (USGS 07380120) for entire period of record (Oct 1987 – Sep 2015) is 1,090 cfs. Assumed flow split is 16% into old channel and 84% into Diversion Canal based on 5/09/2007 flow measurements published by Amite River Basin Drainage and Water Conservation District (2007).
Amite River Diversion Canal	917 cfs	
Blind River	40 cfs	Approximate median flow per unit area of 0.6 cfs/mi^2 (based on USGS gages on Amite, Tickfaw, and Natalbany rivers) multiplied times estimated drainage areas (outside the model grid) of about 60-70 mi^2 for Blind River and < 10 mi^2 for Mississippi Bayou and Reserve Relief Canal
Mississippi Bayou	5 cfs	
Reserve Relief Canal	5 cfs	
Pass Manchac	0.71 – 1.21 ft NAVD88	Synthetic stage hydrograph based on tidal cycle of 24.7 hours, typical tidal fluctuation of 0.5 ft, and median water level of 0.96 ft over entire period of record (Feb. 2002 – Aug. 2018) at Corps station 85420 (Pass Manchac near Ponchatoula)

Table 2.3. Monthly statistics for TN and TP in the Mississippi River.

Month	TN Data			TP Data		
	Number of values	Median (mg/L)	Range (mg/L)	Number of values	Median (mg/L)	Range (mg/L)
USGS 07374000 Mississippi River at Baton Rouge (5/18/04 – 2/13/17):						
January	14	1.88	1.49 – 2.77	13	0.23	0.13 – 0.34
February	13	2.11	1.63 – 3.00	12	0.27	0.15 – 0.33
March	21	2.07	1.56 – 3.48	20	0.24	0.15 – 0.51
April	26	2.15	1.41 – 3.23	26	0.22	0.14 – 0.33
May	23	2.15	1.43 – 3.75	23	0.21	0.14 – 0.37
June	25	2.54	1.62 – 3.38	26	0.25	0.14 – 0.68
July	10	2.63	1.86 – 3.68	10	0.24	0.10 – 0.32
August	14	1.67	1.10 – 2.38	14	0.23	0.13 – 0.35
September	3	1.30	1.21 – 1.57	3	0.22	0.18 – 0.25
October	11	1.39	0.94 – 2.52	10	0.19	0.16 – 0.33
November	6	1.69	1.15 – 2.69	6	0.24	0.14 – 0.29
December	11	1.79	1.30 – 2.41	10	0.22	0.12 – 0.36
All Months	177	2.06	0.94 – 3.75	173	0.22	0.10 – 0.68
USGS 07374525 Mississippi River at Belle Chase (5/11/06 – 5/08/18):						
January	12	1.95	1.50 – 2.79	11	0.28	0.17 – 0.39
February	11	1.97	1.69 – 2.80	10	0.25	0.17 – 0.51
March	23	2.02	1.51 – 3.34	21	0.29	0.17 – 0.62
April	24	2.15	1.50 – 3.80	22	0.25	0.18 – 0.39
May	26	1.99	1.33 – 3.78	25	0.24	0.16 – 0.39
June	24	2.48	1.61 – 3.51	24	0.24	0.14 – 0.35
July	9	2.59	1.99 – 3.86	9	0.27	0.14 – 0.43
August	12	1.83	1.00 – 2.37	12	0.26	0.11 – 0.40
September	2	1.18	1.15 – 1.21	2	0.17	0.17 – 0.17
October	10	1.37	0.81 – 2.54	9	0.22	0.09 – 0.38
November	4	1.48	1.03 – 2.57	4	0.20	0.16 – 0.29
December	10	1.74	1.19 – 2.65	9	0.23	0.14 – 0.37
All Months	167	2.00	0.81 – 3.86	158	0.25	0.09 – 0.62

Table 2.4. Input values for nutrient concentrations at model boundaries.

Location of boundary	Actual concentrations	Model input concentrations*	Comment
Hope Canal (diversion from Mississippi River)	Summer: 2.6 mg/L TN 0.26 mg/L TP Winter: 2.0 mg/L TN 0.25 mg/L TP	Summer: 2.0 mg/L TN 0.16 mg/L TP Winter: 1.4 mg/L TN 0.15 mg/L TP	Developed using USGS data for Mississippi River at Baton Rouge (07374000) and Mississippi River at Belle Chasse (07374525) for 2004 – 2018. Summer values are based on medians for July and winter values are based on medians for Jan.-Feb.
Tickfaw River	0.98 mg/L TN 0.13 mg/L TP	0.38 mg/L TN 0.03 mg/L TP	Median values for LDEQ station 1106 (Tickfaw River near Lake Maurepas) for |2001 – 2015
Amite River (old channel)	0.86 mg/L TN 0.12 mg/L TP	0.26 mg/L TN 0.02 mg/L TP	Median values for LDEQ station 0228 (Amite River at mile 6.5, at Clio) for 2001 – 2018
Amite River Diversion Canal	0.86 mg/L TN 0.13 mg/L TP	0.26 mg/L TN 0.03 mg/L TP	Median values for LDEQ station 0268 (Amite River Diversion Canal north of Gramercy) for 2001 – 2018
Blind River	1.33 mg/L TN 0.24 mg/L TP	0.73 mg/L TN 0.14 mg/L TP	Median values for LDEQ station 0117 (Blind River near Gramercy) for 1978 – 1998
Mississippi Bayou	0.76 mg/L TN 0.11 mg/L TP	0.16 mg/L TN 0.01 mg/L TP	Median values for Station 5 (Mississippi Bayou) from Rob Lane’s 2002 – 2003 data
Reserve Relief Canal	0.79 mg/L TN 0.13 mg/L TP	0.19 mg/L TN 0.03 mg/L TP	Median values for Stations 1 and 2 (Hope Canal) and station 5 (Miss. Bayou) from Rob Lane’s 2002 – 2003 data
Pass Manchac	0.90 mg/L TN 0.10 mg/L TP	0.30 mg/L TN 0 mg/L TP	Median values for LDEQ station 0036 (Pass Manchac at Manchac) for 1978 – 2016

* Model input concentrations are actual concentrations minus background concentrations.

Table 2.5. Input values for salinity at model boundaries.

Location of boundary	Model input values	Comment
Hope Canal (diversion from Mississippi River)	0.20 ppt	Median value for LDEQ stations 0047 (Mississippi River at Luling) and 0048 (Mississippi River near Luling) for 1978 – 1989
Tickfaw River	0.11 ppt	Median values for LDEQ station 1106 (Tickfaw River near Lake Maurepas) for 2001 – 2015
Amite River (old channel)	0.05 ppt	Median value for LDEQ station 0228 (Amite River at mile 6.5, at Clio) for 2001 – 2018
Amite River Diversion Canal	0.05 ppt	Median value for LDEQ station 0268 (Amite River Diversion Canal north of Gramercy) for 2001 – 2018
Blind River	0.30 ppt	Median value for LDEQ station 0117 (Blind River near Gramercy) for 1978 – 1998
Mississippi Bayou	0.25 ppt	Median value for station 5 (Mississippi Bayou) from Rob Lane's 2002 – 2003 data
Reserve Relief Canal	0.30 ppt	Median values for stations 1 and 2 (Hope Canal) and station 5 (Miss. Bayou) from Rob Lane's 2002 – 2003 data
Pass Manchac	5.0 ppt	Assumed to be the same as the initial concentration (see Table 2.6 below). Because the source of the initial salinity in Lake Maurepas and the Maurepas swamp is exchange with Lake Pontchartrain (via Pass Manchac), then the salinity in Pass Manchac should be similar to the initial value for Lake Maurepas and the Maurepas swamp.

Table 2.6. Input values for initial conditions for water quality.

Constituent	Model input value	Comment
Total nitrogen (TN)	0 mg/L	Zero in the model represents background concentrations for TN and TP. Nutrient concentrations throughout the modeled area are assumed to be at background levels at the beginning of each simulation.
Total phosphorus (TP)	0 mg/L	
Salinity	5.0 ppt	Assumed value for conditions following a tropical storm surge or possibly an extreme drought

3.0 MODEL APPLICATION AND RESULTS

3.1 Model Scenarios

A modeling scenario of 41-day duration was simulated. The diversion was operated at a constant, continuous flow of 2,000 cfs for 31 days followed by 10 days of closure. Additionally, during the first 7 days, a flow of 280 cfs was released to the Central Swamp (wetlands between the Interstate-10 and the Airline Highway) from Hope Canal. Therefore, for the first 7 days, only 1,720 cfs reached to the swamp north of Interstate-10. A synthetic diurnal tidal water level boundary was specified at Lake Maurepas with a mean water level of 1.0 ft, NAVD88 and tidal range of 0.5 ft. See Table 2.2 for flows specified at other existing locations. The nutrients (TN and TP) were simulated under summer and winter conditions as reflected in the specified boundary input concentrations.

A separate “salinity flushing” scenario was simulated to evaluate benefits of diversion for salinity reduction after a high salinity event in the swamp. For this scenario, all boundary conditions (flows and tidal water levels) were specified as in the above scenario. The initial water level was set to 1.0 ft, NAVD88 and the initial salinity was set to 5.0 ppt throughout the study area. The salinities at all flow input boundaries, including the diversion, were set to 0 ppt and a constant salinity of 1.5 ppt was specified at the tidal boundary at Pass Manchac.

The model topography represents features proposed in the 95% E&D report. The details are outlined in Appendix A, Section 7.

3.2 Predicted Water Surface Elevation and Velocity

Figures 3.1 and 3.2 show snapshots of contours of water surface elevation and velocity, respectively, at the end of 7, 20, 31 and 41 days. The variation of water surface elevation and velocity (time-series charts) at selected locations over the simulation period is shown in Figure 3.3. These locations are selected to coincide with some of the gages shown in Figure A.6. The maximum water surface elevation in the swamp is predicted to be about 3 ft, NAVD88 and it occurs where the diversion enters the swamp (i.e. in the Hope Canal immediately north of Interstate-10). The velocities peak up to 2.4 ft/s at this location. However, in the adjoining swamp, the high velocities are around 0.1 to 0.2 ft/s just outside the Hope Canal and lesser in the swamp away from the canal. Under the continuous diversion inflow of 2,000 cfs, the water surface elevation in the swamp reaches a steady state in about 10 days, setting a constant water surface gradient across the swamp from high at Hope Canal to low near Lake Maurepas. Note that the oscillation seen at locations S-9 and S-16 are due to the influence of tides specified at Pass Manchac.

It is seen that the diversion water spreads throughout the most of the system within a week. A steady water surface elevation and gradient is established in the system within about 2 weeks. During the last 10 days of the simulation when the diversion is closed, the water surface elevation recedes rapidly in the swamp closer to the diversion canal (location S-9) and slowly in the areas farther from the diversion canal (e.g. location S-23). The rate of water level drop is about 0.75 ft/10-day, becoming slower as time goes by.

Model results show that the diversion water spreading east is intercepted by the Reserve Relief Canal hindering distribution to the wetlands east of this canal in spite of the artificial gapping implemented in the model. This suggests that limited gapping on the east bank of the Reserve Relief Canal may not distribute commensurate quantities of diversion water to the east side. No gapping on the west bank of this canal was tested.

As a result of the 7-day controlled release of the diversion water, the water levels in the wetlands between the I-10 and the Airline Highway reach a water level of about 1.4 ft, NAVD88. Subsequent to closing of this release the water levels drop to about 1.2 ft. In reality, the water level will continue to lower in the absence of any other inflows due to evapotranspiration which is not included in this scenario.

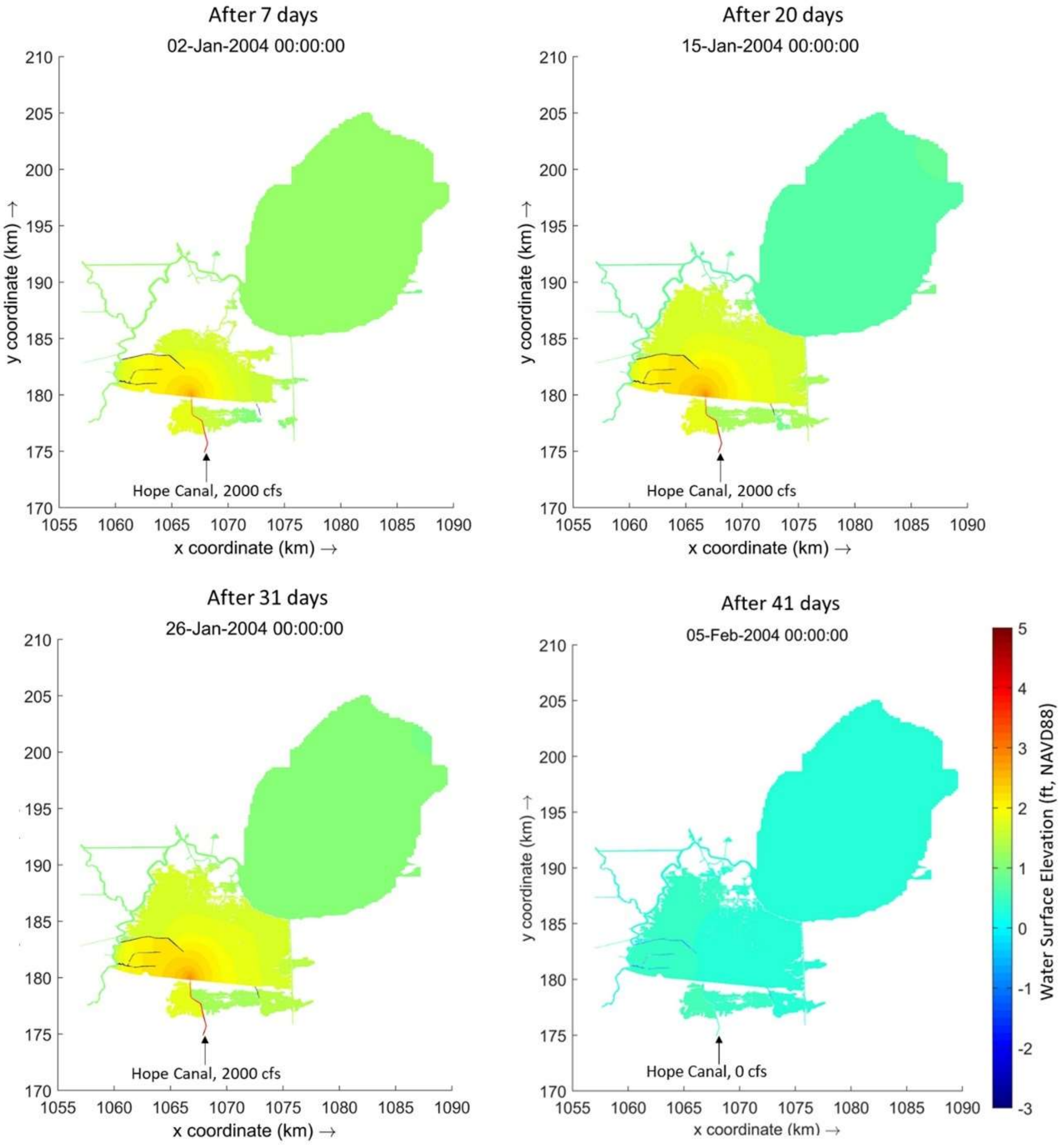

Figure 3.1. Predicted water surface elevation contours at the end of 7, 20, 31 and 41 days.

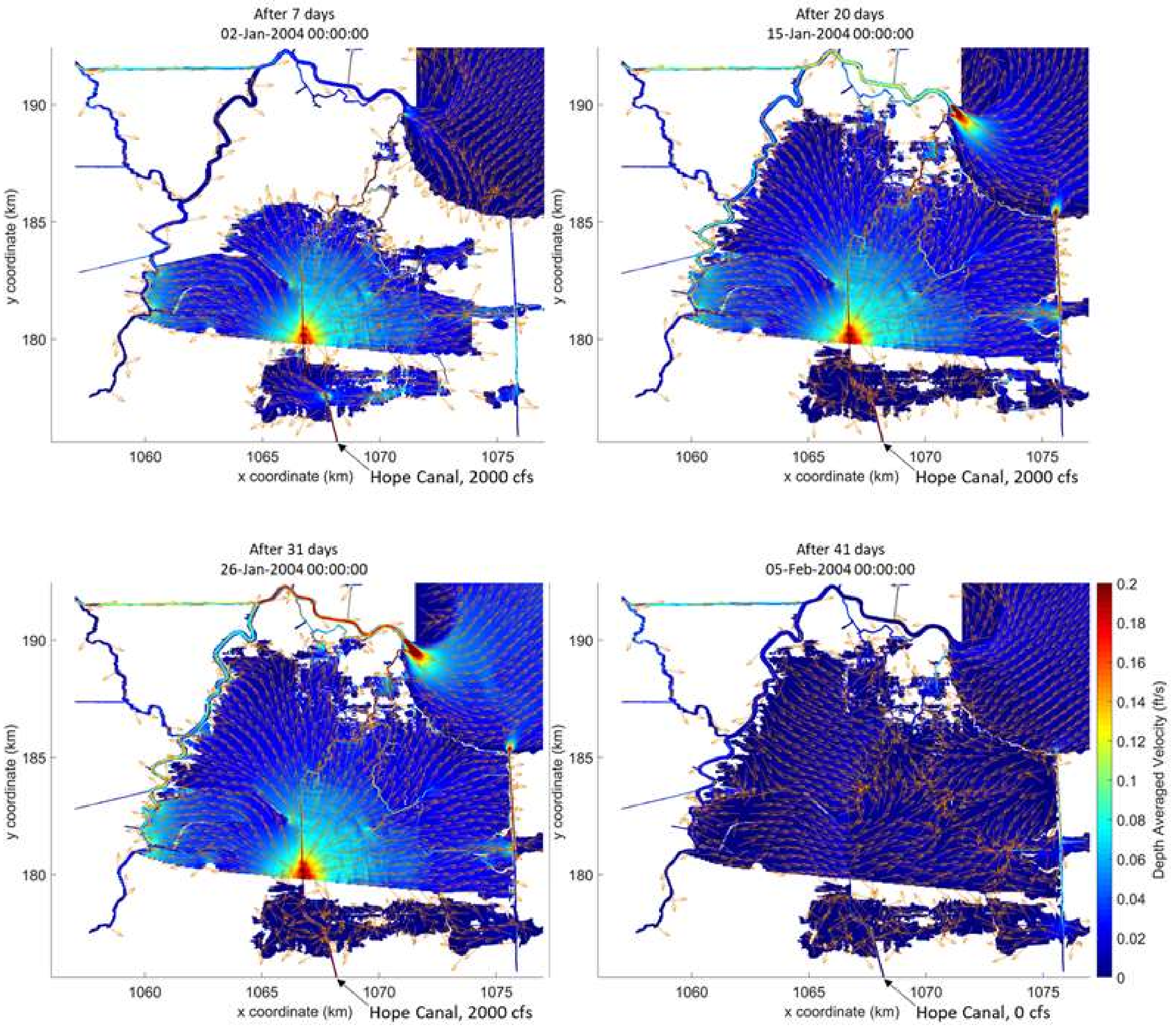

Figure 3.2. Predicted velocity contours at the end of 7, 20, 31 and 41 days.

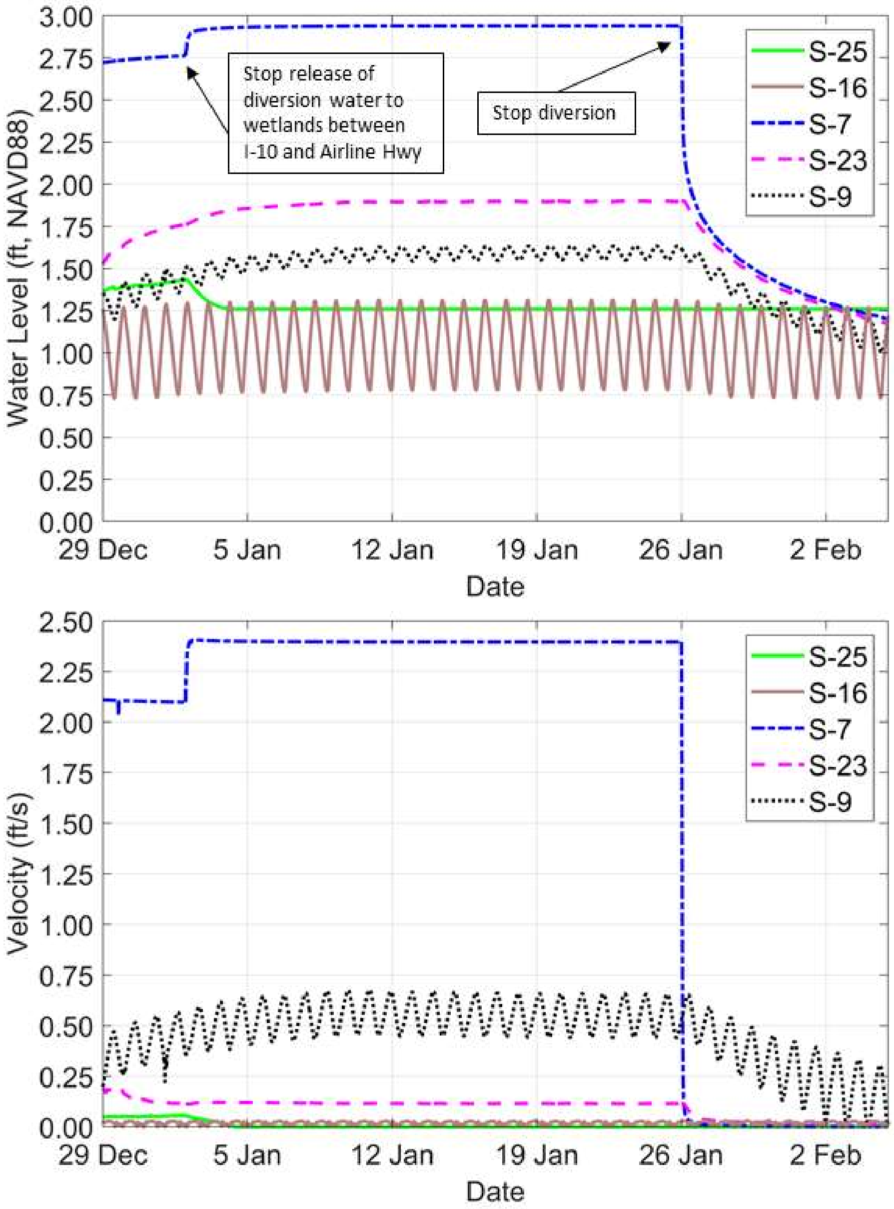

Figure 3.3. Predicted water surface elevation (upper panel) and velocity (lower panel) profiles over the model simulation period at selected locations S-7 (Hope Canal north of I-10), S-9 (Dutch Bayou), S-16 (Blind River), S-23 (North Swamp) and S-25 (Central Swamp).

3.3 Predicted Percent Mississippi River Water

One of the Delft3D model parameters allows accounting of the percentage of water in each model grid cell that originated from the Mississippi River diversion. The purpose of simulating this variable (percent Mississippi River water) was to show where the Mississippi River water travels once introduced into the swamp. The boundary "concentrations" for this variable were set to 100 for the inflow from the Mississippi River (via Hope Canal) and zero for all other boundaries. The initial concentration was set to zero for the entire model grid.

Figures 3.4 shows the predicted values of percent Mississippi River water at the end of 7, 20, 31, and 41 days. The model predicts that the Mississippi River water replaces the majority of the water that existed in the swamp before start of the diversion; no significant amount of water enters Blind River; and that the southern areas of Lake Maurepas are about 40% Mississippi River water after 31 days.

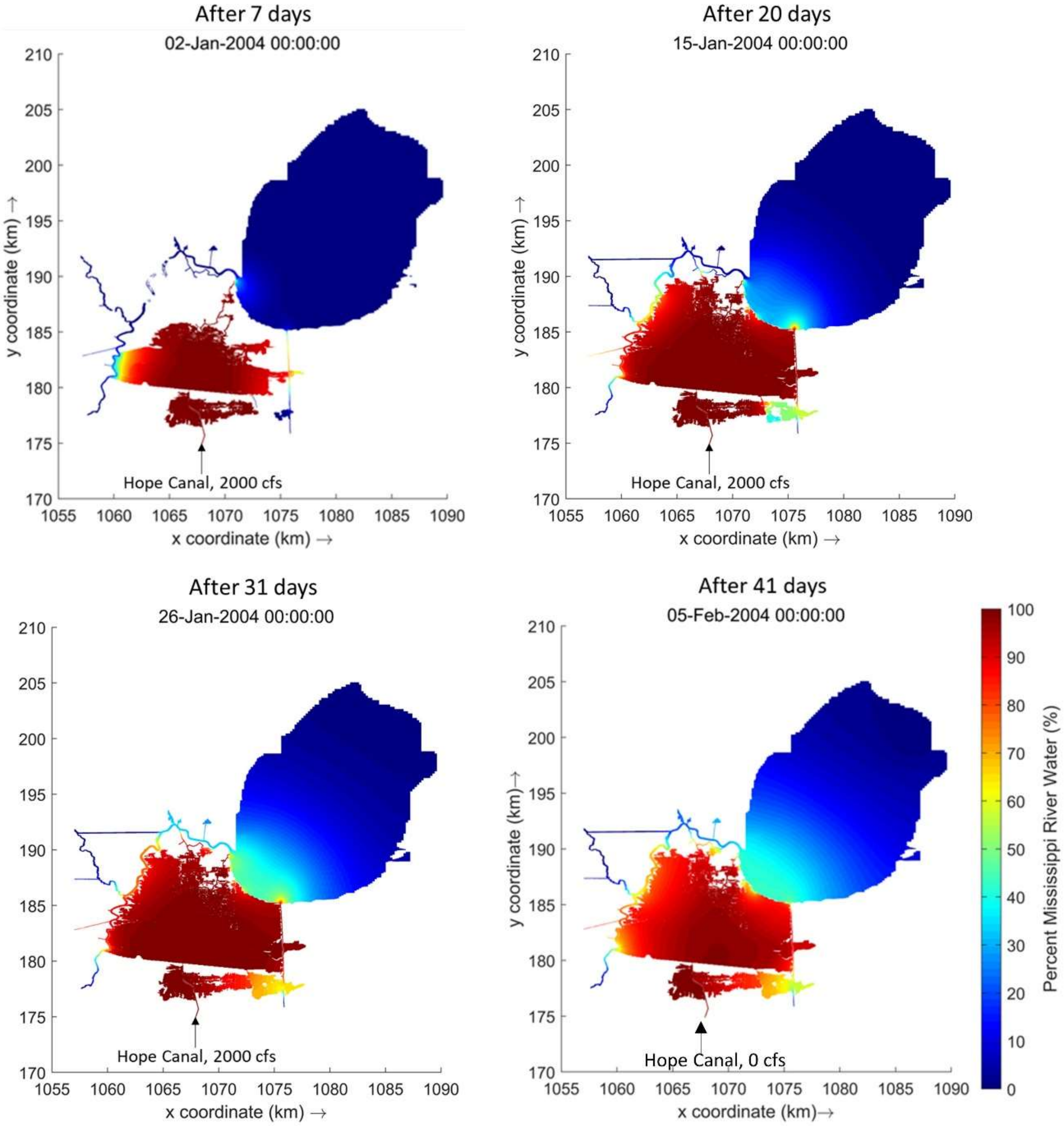

Figure 3.4. Predicted percent Mississippi River water contours at the end of 7, 20, 31 and 41 days.

3.4 Predicted Total Nitrogen Transport

The TN results are shown in Figures 3.5 and 3.6 for summer and winter, respectively. Note that the TN concentration for the Mississippi River inflow was higher for summer (2.6 mg/L) than for winter (2.0 mg/L).

As expected, the highest predicted concentrations of TN are in Hope Canal and its immediately surrounding areas north of Interstate-10. As the Mississippi River water spreads into the swamp and even along channels (e.g., Hope Canal to Tent Bayou to Dutch Bayou), the TN concentrations decrease due to losses from the water column that are simulated with the first order decay rates.

Based on the spatial patterns of predicted TN concentrations in Lake Maurepas, it appears that Dutch Bayou and Reserve Relief Canal are contributing similar loadings of TN to Lake Maurepas. In both the summer and winter simulations, the predicted TN concentrations in the southwest corner of Lake Maurepas (excluding the small areas right at the mouth of Dutch Bayou and the mouth of Reserve Relief Canal) were between 0.8 and 1.0 mg/L at the end of day 20. This represents a small increase over the assumed background concentration of 0.6 mg/L.

The TN in the Mississippi River water consists of approximately 71% nitrate, 2% ammonium, and 27% organic nitrogen (based on long term averages of USGS data at Baton Rouge and Belle Chasse). Among these three forms of nitrogen, nitrate is the form that is expected to undergo the greatest losses from the water column because it can be removed from the water column through denitrification (which is one of the most significant removal mechanisms in wetlands) or uptake by algae or plants. By the time the Mississippi River water reaches Lake Maurepas, the remaining TN is expected to consist mostly of organic nitrogen, which is not available for algal uptake unless it is first converted back to inorganic nitrogen through the process of mineralization, which is a relatively slow process.

After the diversion inflow stops on day 31, the predicted TN values throughout the swamp and in Lake Maurepas return to near background levels by day 41.

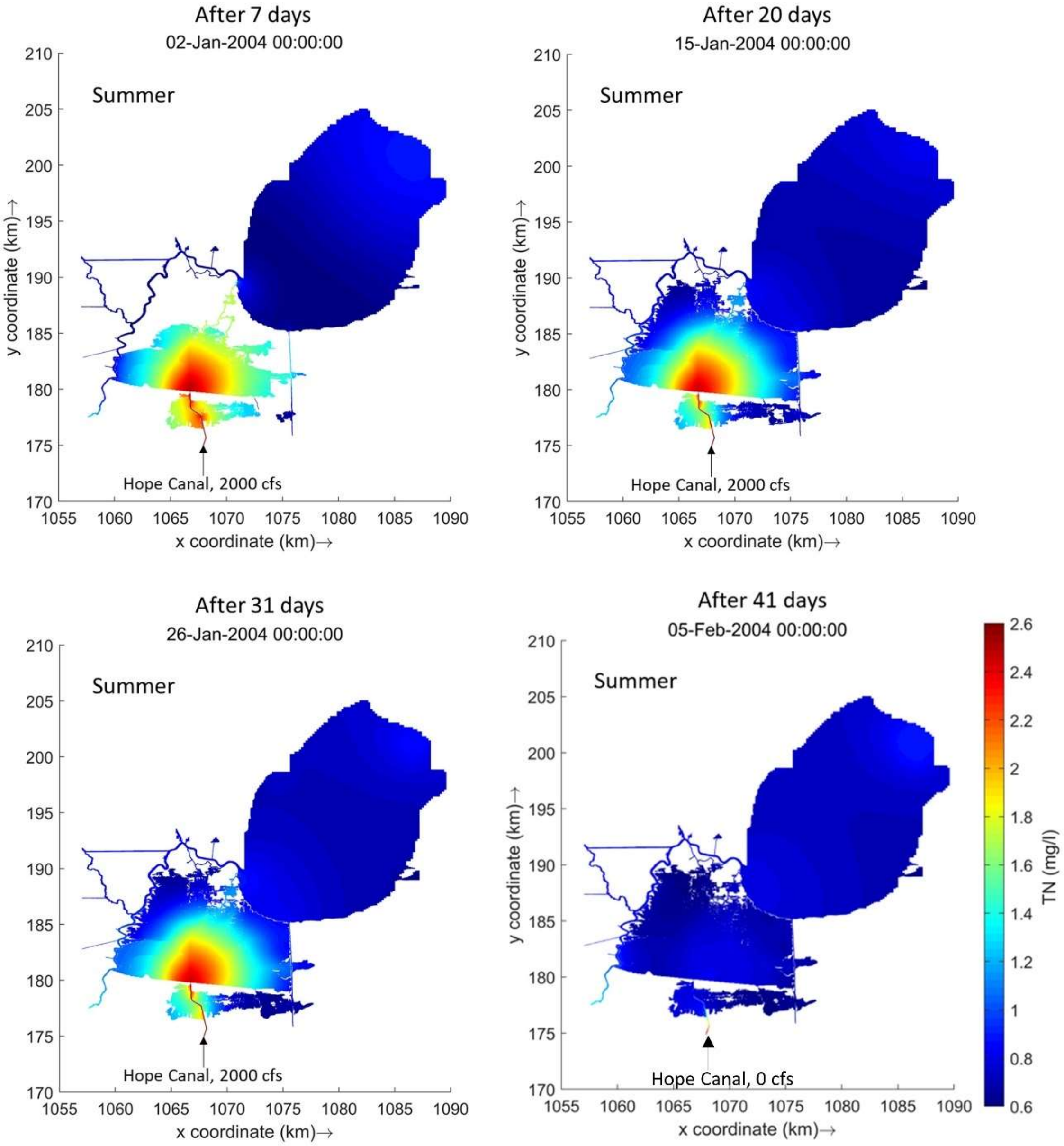

Figure 3.5 Predicted TN concentrations for summer at the end of days 7, 20, 31 and 41 days.

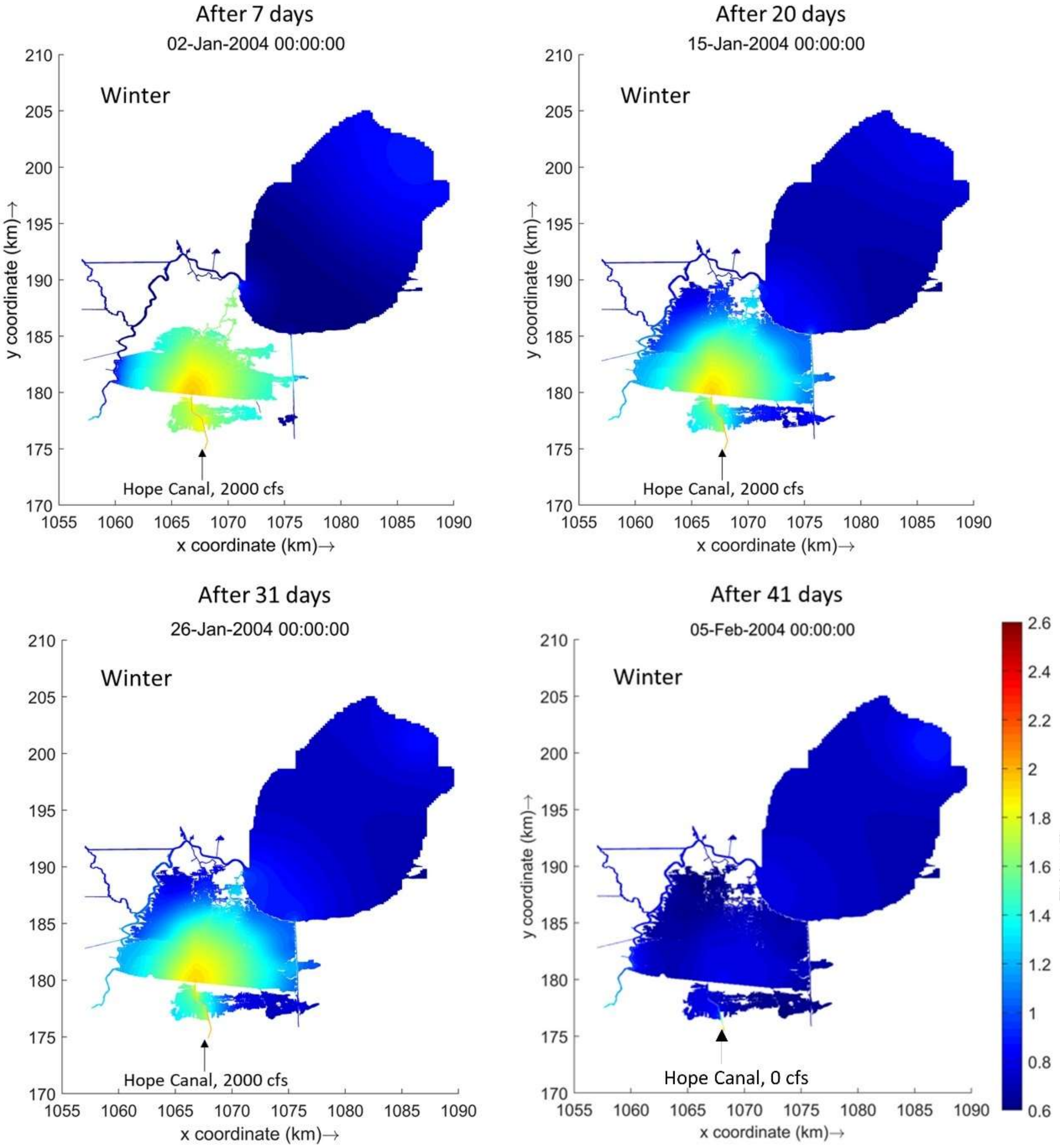

Figure 3.6. Predicted TN concentrations for winter at the end of 7, 20, 31 and 41 days.

3.5 Predicted Total Phosphorus Transport

The TP results are shown in Figure 3.7 and 3.8 for summer and winter, respectively. The TP concentration for the Mississippi River inflow was similar between summer (0.26 mg/L) and winter (0.25 mg/L).

As with TN, the highest predicted concentrations of TP are in Hope Canal and the immediately surrounding areas north of Interstate 10.

For TP, the results are different between summer and winter due to the seasonal difference in decay rates. As the water moves into the swamp and along channels, the decrease in TP concentrations is greater for summer than for winter. This trend continues into Lake Maurepas; the predicted TP concentrations in the southwest corner of Lake Maurepas are slightly higher for winter than for summer.

Dutch Bayou and Reserve Relief Canal appear to be contributing similar loadings of TP to Lake Maurepas.

After the diversion inflow stops on day 31, the predicted TP values decrease in the swamp and in Lake Maurepas. By day 41, predicted TP values return to near background levels in Lake Maurepas but are still higher than background in the swamp.

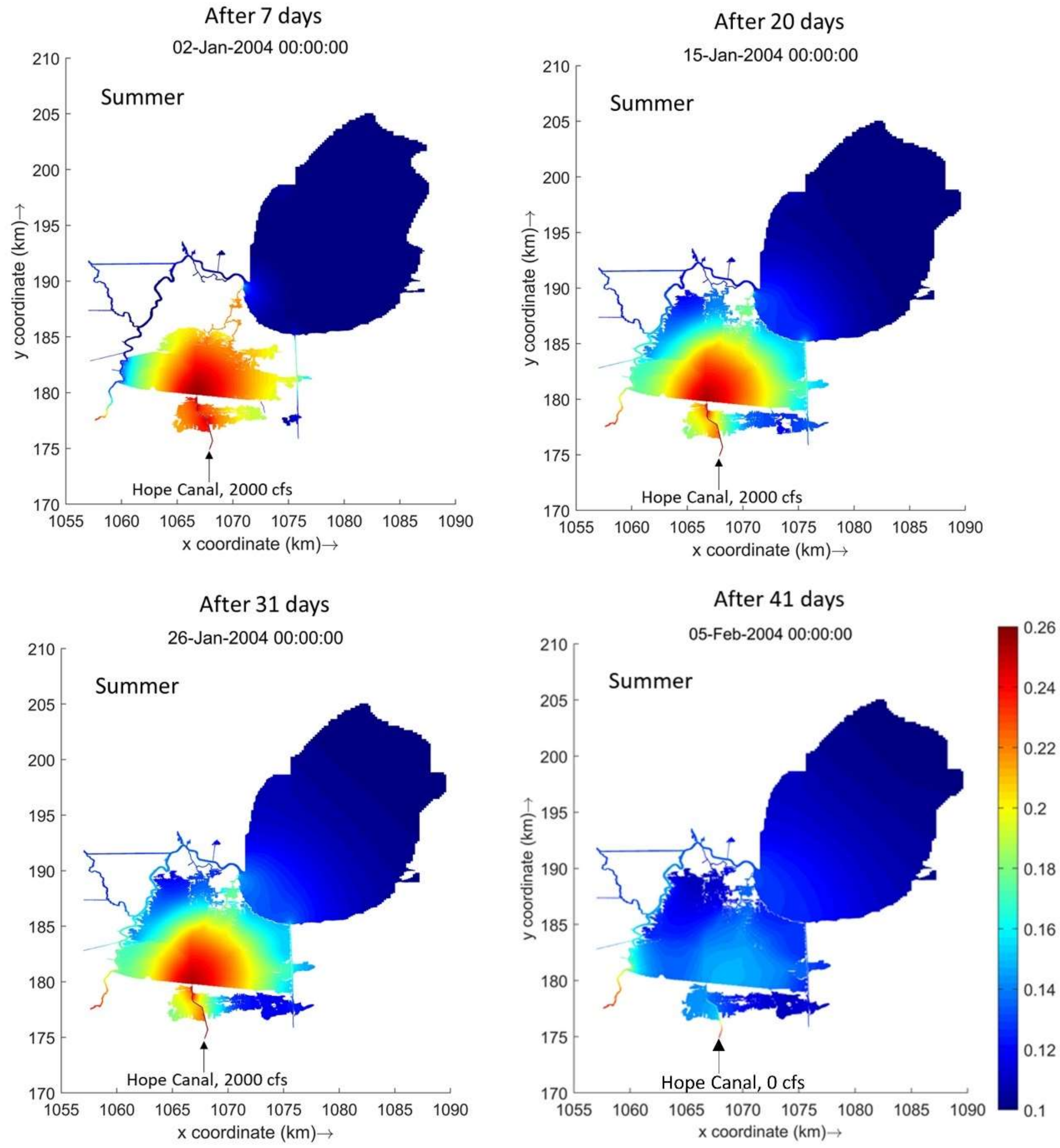

Figure 3.7. Predicted TP concentrations for summer at the end of 7, 20, 31 and 41 days.

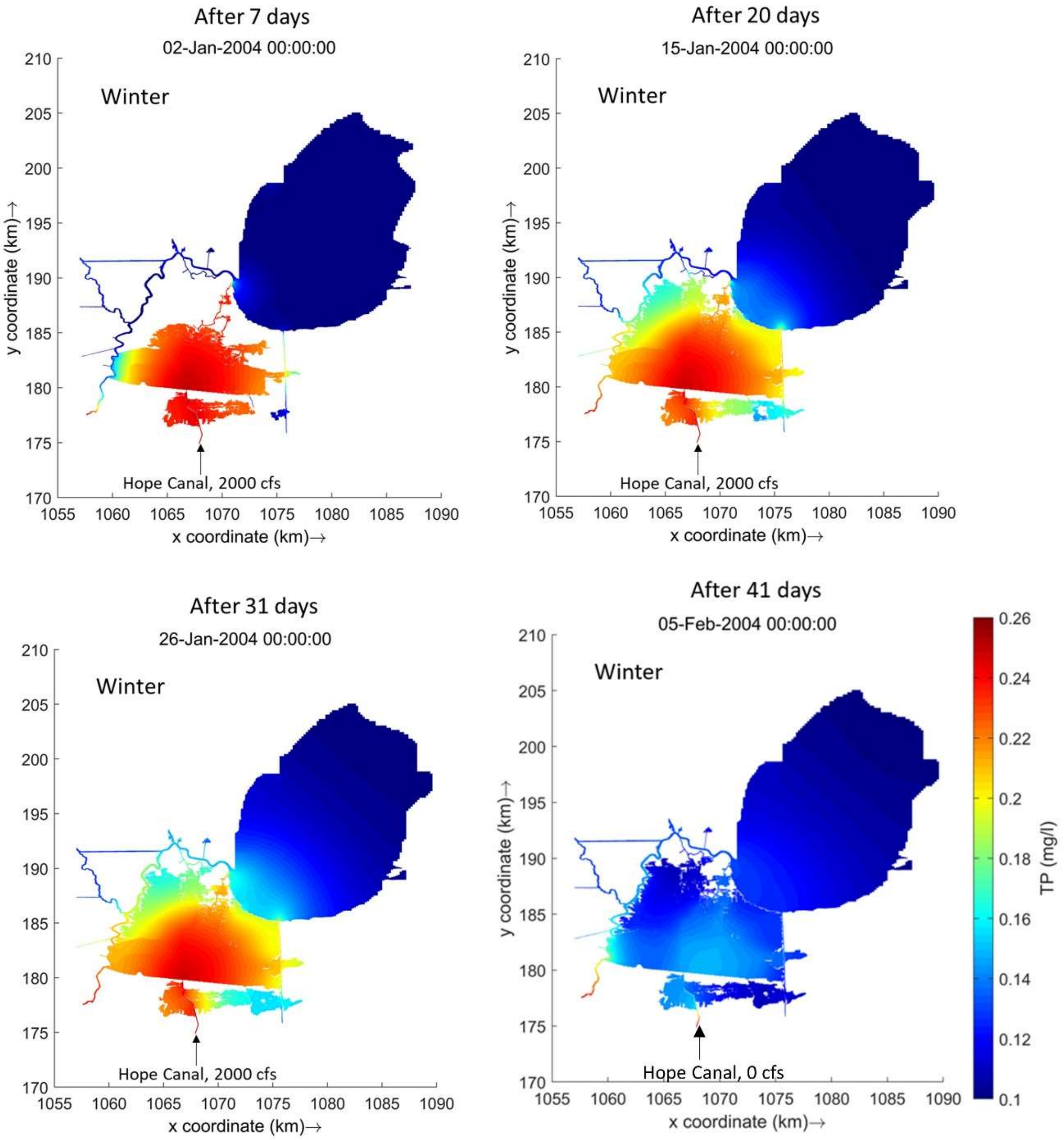

Figure 3.8. Predicted TP concentrations for winter at the end of 7, 20, 31 and 41 days.

3.6 Salinity Flushing Results

The purpose of this simulation is to demonstrate the freshening effect of the diversion on a swamp that has experienced high salinity event due to a tropical storm. Figure 3.9 shows contours of salinity after 7 days of diversion inflow. The initial water surface elevation and the salinity is set to 1.0 ft, NAVD88 and 5 ppt, respectively, throughout the entire study area (model domain). In reality, the Central Swamp (south of Interstate-10) is very unlikely to have a storm surge overtopping Interstate-10 resulting in a high salinity. However, due to the model limitations, it is not possible to specify spatially varying values of initial salinity so the entire domain is set to 5 ppt. Additionally, the constant salinity value of 1.5 ppt specified at Pass Manchac (Lake Maurepas) boundary may not be realistic. However, this does not affect results in our primary area of interest which is the swamp north of Interstate-10. Therefore, the focus of presented results is this region. Also, note that the initial water specified for this simulation is 1.0 ft, NAVD88, higher than -3.0 ft, NAVD88, that was specified for the 41-day diversion simulation. Therefore, the marginal inundation areas may not match for these two simulations.

Figure 3.9 shows that salinity is rapidly flushed out of the swamp by diversion flow. As expected, the flushing process is slower in the areas where little diversion flow reaches. The 7-day duration results demonstrate the freshening effects of the diversion flow. The results are generally expected to be similar to those shown by the Percent Mississippi River Water parameter in Figure 3.4; therefore, a longer simulation was not performed.

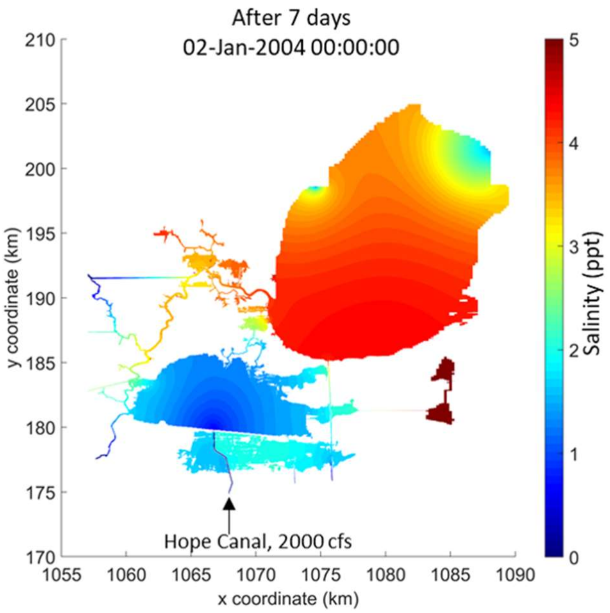

Figure 3.9. Predicted salinity concentrations at the end of 7 days.

3.7 Comparison with Previous Modeling Studies

The TN predictions discussed in Section 3.2 can be compared with two previous modeling studies for the Maurepas swamp. Comparisons must be done with caution because each study used different modeling approaches based on project objectives and available data.

Day et al. (2004) used output from a two-dimensional hydraulic model to calculate nitrate transport and loss in the Maurepas swamp. The model simulated water being diverted from the Mississippi River into Hope Canal and then moving through the swamp towards the Blind River, Reserve Relief Canal, or Lake Maurepas. The swamp was divided into cells and the equation used to estimate nitrate loss in each cell was:

$$\text{Percent removal} = -14.13 * \text{LN}(X) + 25$$

where X = nitrate loading entering that cell ($g/m^2/day$)

The predicted losses of nitrate for water reaching Lake Maurepas were 87% and 81% for diversion flow rates of 1,500 cfs and 2,500 cfs, respectively (Table 4.4 in Day et al. [2004]). It should be noted that this modeling study did not utilize a background concentration for nitrate because existing concentrations of nitrate in the Maurepas swamp are low.

CH2M Hill (2013) conducted modeling to estimate total nutrient removal for multiple planned and existing diversions along the Mississippi River. Based on objectives of this project and the large area that it encompassed, this modeling was developed at spatial and temporal resolutions that were much coarser than the DELWAQ modeling presented in this report. The CH2M Hill modeling used the pKC* model (described in Section 2.1) with background concentrations of zero for nitrate and ammonium, 0.6 mg/L for organic nitrogen, and 0.042 mg/L for total phosphorus. The model predicted a 57% loss of TN and 46% loss of TP in the Maurepas swamp for "average operations" (Table 14 of CH2M Hill [2013]).

In order to compare the DELWAQ results with these two studies, percentage losses of TN and TP were calculated. For the summer simulations, Mississippi River water was introduced into the swamp with concentrations of 2.6 mg/L TN and 0.26 mg/L TP. Water entering Lake Maurepas at the mouth of Dutch Bayou at the end of day 20 had concentrations of approximately 1.2 mg/L of TN and 0.17 mg/L TP, resulting in percentage losses of 54% for TN and 35% for TP. These percentage losses are similar to the results from CH2M Hill (2013). The percentage loss for TN is lower than the nitrate losses calculated by Day et al. (2004), but nitrate losses are expected to be greater than TN losses because nitrate can be removed from the water column through denitrification and uptake by algae or plants, whereas organic nitrogen (the other primary component of TN in Mississippi River water) can be removed from the water column only by settling of the particulate fraction.

3.8 Comparison with Nutrient Concentrations in Lake Pontchartrain

The predictions of TN in the southern end of Lake Maurepas can be compared with TN concentrations that were observed in Lake Pontchartrain after the Bonnet Carré Spillway was opened in 2008 and in 2011. When the Bonnet Carré Spillway is opened, large volumes of Mississippi River water are diverted into Lake Pontchartrain during a short time. This water reaches Lake Pontchartrain quickly with minimal nutrient loss. In both 2008 and 2011, increased algae concentrations were observed in the lake (including cyanobacteria that and were presumably caused by the nutrient loading from the diverted Mississippi River water.

In 2008, the spillway was open for about a month, with a total volume of diverted water that exceeded the volume of Lake Pontchartrain (Bargu et al. 2011). The average concentration of nitrate nitrogen that was measured within the plume during the spillway opening was 1.3 mg/L (Bargu et al. 2011). The modeling for Lake Maurepas does not specify what portions of the TN are nitrate, ammonium, and organic nitrogen, but the TN in the water that reaches Lake Maurepas is expected to be mostly organic nitrogen (see Section 3.2). If the predicted TN in the southern end of Lake Maurepas is assumed to include about 0.5 mg/L of organic nitrogen (most of the background concentration of TN is expected to consist of organic nitrogen), then the predicted TN values of 0.8 to 1.0 mg/L in the southern end of Lake Maurepas would correspond to nitrate concentrations of about 0.3 to 0.5 mg/L. These are much lower than the average nitrate concentration measured within the plume in Lake Pontchartrain during the spillway opening (1.3 mg/L).

In 2011, the spillway was open from May 9 to June 20, with a total volume of diverted water that was approximately 330% of the combined volume of Lake Pontchartrain and the downstream estuary (Smith 2014). The average concentration of nitrate nitrogen that was measured along a transect extending from the Bonnet Carré Spillway to the approximate center of the lake was 0.6 mg/L (individual values ranged from below the reporting limit up to 1.4 mg/L; Smith 2014). It is apparent that some dilution or other nutrient loss mechanisms affected some of these values because the nitrate concentrations measured by the USGS in the Mississippi River during the spillway opening ranged from 1.1 to 1.4 mg/L (3 samples at Baton and 6 samples at Belle Chasse). Nitrate concentrations in Lake Pontchartrain near the spillway were probably more similar to the Mississippi River values than the average concentrations reported by Smith (2014) for an entire transect. As discussed above, the TN values predicted for the southern end of Lake Maurepas correspond to estimated nitrate concentrations of about 0.3 to 0.5 mg/L, which are significantly lower than estimated nitrate concentrations in Lake Pontchartrain near the spillway.

4.0 SUMMARY AND CONCLUSIONS

A two-dimensional Delft3D hydrodynamic and water quality model was developed and calibrated for the study area. The model was applied to simulate water surface elevations, velocity, TN, and TP under a diversion operation scenario. Under this 41-day scenario, the diversion introduced a constant 2000 cfs of Mississippi River water into the swamp continuously for 31 days followed by 10 days of closure. These simulations showed that after the Mississippi River water reaches the north side of Interstate 10, its flow rate greatly exceeds the capacity of Hope Canal, causing the water to flow into the swamp and spread west as far as Blind River, east as far as Reserve Relief Canal (and slightly beyond), and northward into swamps along Dutch Bayou.

The shallow and relatively slow flow through the swamp allows for nutrients to be removed from the water column before the water reaches Lake Maurepas via Dutch Bayou and Reserve Relief Canal. By the time the Mississippi River water reaches Lake Maurepas, it has lost about 54% of its TN and 35% of its TP. Predicted concentrations of TN in the southern end of Lake Maurepas correspond to nitrate concentrations that are much lower than observed concentrations in Lake Pontchartrain that led to increased algae concentrations in 2008 and 2011 after opening the Bonnet Carré Spillway.

Based on these projection simulations, the proposed diversion of Mississippi River water into the Maurepas swamp is expected to provide beneficial freshening and nutrients to a large area of swamp without causing large increases in nutrient concentrations in Lake Maurepas.

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APPENDIX A

Hydrodynamic Modeling

1.0 INTRODUCTION

The proposed River Reintroduction into Maurepas Swamp (PO-0029) project (the Project) located near Garyville, Louisiana, will divert flow from the Mississippi River to the Maurepas Swamp wetlands (Figure A.1; figures are located at the end of this appendix). In 2014, URS provided 95% level design of the proposed PO-29 project to CPRA (URS 2014). The project consists of a gated intake structure at the river capable of diverting 2,000 cfs river water, a large sand settling basin, and a long, banked conveyance channel. Approximately halfway along the route, just north of US 61, the channel follows the existing Hope Canal alignment to distribute the diverted water into the wetlands on the north side of Interstate 10.

To support the hydraulic design of the proposed diversion and to evaluate its effect on swamp hydrology, URS developed a two-dimensional (2D) ADvanced CIRCulation (ADCIRC) Model. URS also developed a one-dimensional (1D) Storm Water Management Model (SWMM) of the Garyville-Reserve drainage system to evaluate effects of the water levels in the swamp on the drainage.

The hydrodynamic modeling performed for the 95% level design, did not include modeling the transport of nutrients introduced from the Mississippi River diversion water throughout the swamp. The purpose of the modeling efforts outlined in this document is to develop a hydraulic model of the study area which will be used to simulate transport of nutrients carried by the diverted water. For the purpose of this analysis, it is not necessary to represent the Mississippi River and the gated structure in the model.

2.0 STUDY OBJECTIVES

The objective of the modeling study is to develop and apply a hydraulic model to simulate water surface elevations and velocities throughout the receiving swamp when the diversion flow is introduced in the system. This hydraulics will then be used as an input to a water quality simulation to evaluate fate and transport of nutrients. The hydraulics will also be used to evaluate freshening of the swamp after a high salinity event.

3.0 MODELING PROGRAM SELECTION AND DESCRIPTION

The study area is an extensive swamp forest surrounding Lake Maurepas in the upper reaches of Pontchartrain estuary. The area is tidally influenced by diurnal micro-tidal regime introduced from Pass Manchac connecting Lake Maurepas with Lake Pontchartrain. The study area includes several natural and man-made channels that carry flow in and out of the swamp while distributing it in the swamp wherever low banks are present. For the purpose of the study, it is appropriate to assume the dominant velocities being in the longitudinal and transverse direction (two dimensions). Due to the relatively shallow water depths, the velocities and accelerations in the vertical direction (the third dimension) are negligible and the flow can be assumed vertically well-mixed. This assumption allows us to apply a two-dimensional (2D) model instead of a three-dimensional (3D) model. A 3D model for the study area will be extremely computationally intensive resulting in prohibitive simulation times without adding to the accuracy of the results. On the other hand, an over-simplified one-dimensional (1D) model will be less applicable for the study purpose. Therefore, two-dimensional depth-averaged (2D) model is an appropriate type of model for this study.

Various public domain and commercial/proprietary computer software is available for 2D, vertically averaged hydrodynamic transport modeling. These models solve the hydrodynamic and constituent transport equations using either a structured or an unstructured computational mesh.

The structured-grid models consist of rectangular or square elements and are simpler in parallel programming implementation as they employ finite-difference schemes to solve governing equations and different portions of the grid can be distributed to multiple processors for optimal load balancing. Additionally, finite difference schemes do not suffer from mass conservation problems often inherent in the finite element schemes of unstructured grids. However, the accuracy in the complex edge-of-the-water geometry in structured grids may not be as good as the unstructured-grid models. The unstructured models (finite element or finite volume-based), on the other hand, allow elements of various shapes (line, triangle, or quadrilateral), which enables fitting elements more closely to the topographic features. Further, the unstructured mesh allows variation of element size in a single mesh enabling creation of a denser mesh where more details are necessary. However, implementation of finite-element models is not as straightforward as finite-difference models. This is mainly due to approximation of the fields within each element with a simple linear, quadratic or polynomial function with finite number of degrees of freedom.

The following are some of the modeling programs commonly used to model 2D, vertically averaged hydrodynamics:

1. RMA-2 model (unstructured mesh) by Resource Modelling Associates, Inc;
2. ADCIRC from the University of North Carolina at Chapel Hill (unstructured mesh);
3. MIKE-21 from the Danish Hydraulic Institute (unstructured mesh); and
4. Delft3D from Deltares (structured mesh).

Although the first two options can better represent present area with broken swamp, lake, channels and bayous, the Delft3D option was considered for this study because it has been widely applied in south Louisiana and for the Louisiana Coastal Master Plan. Delft3D is highly scalable on High Performance Computing (HPC) infrastructures. Equally important is the fact that Delft3D with its DELWAQ module can model a wide range of water quality parameters including secondary processes. DELWAQ can model 18 independent principal substances with over 20 different sub-substances. It has been applied in studies involving eutrophication, Dissolved Oxygen depletion, contaminated sediment, and outfall temperatures. A particularly useful feature of DELWAQ is its ability to specify user-defined spatially variable, depth dependent decay rate constants for the constituents of interest.

3.1 Overview of Approach

FTN developed and applied Delft3D model version 4.02.03 (Deltares 2018) to predict the tidal circulation and the transport of suspended nutrients. Delft3D FLOW module simulates water levels and velocity driven by boundary conditions of tides and currents. The output from DELFT3D FLOW is used in DELWAQ to simulate the advection and dispersion of nutrients.

The Delft3D FLOW module utilizes a robust numerical finite-difference scheme where model results are computed on a horizontal staggered grid. The water level points are designated in the center of a continuity cell and the velocity components are perpendicular to the grid cell faces. Delft3D can be operated in a 2D (vertically averaged) or a 3D mode. In the present application, Delft3D is used in 2D mode only.

4.0 DATA COLLECTION TO SUPPORT MODELING

The following topographic survey data and hydraulic monitoring data were used in this modeling study.

4.1 Topographic Data

The topographic field data are used to develop the model geometry which is a digital representation of the terrain. Specifically, the topographic data were required for Lake Maurepas, the streams and the swamp.

The Lake Maurepas bathymetry was obtained from USGS and is also from the 2002 surveys. Existing channel cross-section data were available at 29 locations on streams in the main swamp north of I-10 (URS 2005). To evaluate whether the cross-sections have changed significantly over the years, new topographic surveys were collected in April 2018 at 6 selected cross-sections (MPH 2018). The original 29 and new 6 survey locations are shown in Figure A.2. Figures A.3 through A.5 compare the old and the new cross-sections. The comparison shows that the previously collected cross-sections have not changed significantly in the cross-sectional area and can be used for the purpose of this study.

To represent the swamp, it would have been prohibitively expensive to collect topographic field survey data in the forested swamp. Therefore, the LIDAR data from 2012 were used. The data contained excessively higher elevations in the main swamp north of Interstate-10 not generally found in this region, therefore upon the recommendation of the Technical Advisory

Group[1] the marsh floor elevation was capped at 1.0 ft, NAVD88. The revised topographic contours are show in Figure A.6.

4.2 Hydraulic Monitoring Data

Hydraulic monitoring data needed for modeling typically consists of time series of water surface elevations, velocity or discharge. These data are used to specify boundary conditions and for calibration/validation of the model. Since the major channels were found to have no major changes, the previously collected monitoring data (URS 2006) were judged to be appropriate for use in this study. The monitoring gage locations are shown in Figure A.7. Water surface elevations were collected at all locations and velocity was collected at location S-9.

5.0 MODEL GEOMETRY DEVELOPMENT

The model geometry is a mathematical representation of the study area topography. The model domain size was selected such that the boundary conditions are specified far away from the area of interest. The domain is represented by a two-dimensional computational grid composed of 1.3 million points. The grid is most refined (cell size 12 m) at Hope Canal, Mississippi Bayou, Relief Canal, Dutch Bayou, and the interior channels connecting them, where detailed hydrodynamic and nutrient dynamics are expected, and becomes coarser (cell size 200 m) towards the boundary at Lake Maurepas. The interior swamps enjoy 12 to 50 m of resolution depending upon location and priority in nutrient dispersal. Figure A.8 shows the model grid for existing conditions.

The bathymetry of the primary channels was assigned using previously collected channel cross-sections. The bathymetry of the swamp areas was assigned using the LIDAR data. Figure A.9 shows the model bathymetry. It should be noted that bathymetry does not capture numerous rivulets and small open water areas that are widespread in the swamp, rather, it represents the overall relief in the terrain. This is the limitation of LIDAR data that were used for the bathymetry.

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[1] Prof. Gary Shaffer, Southeastern Louisiana University; Prof. Richard Keim and Prof. Jim Chambers, Louisiana State University; and Dr. Ken Krauss, USGS.

6.0 MODEL CALIBRATION AND VALIDATION

Model calibration is an iterative process where model coefficients are systematically varied or “tuned” through a series of simulations to improve model’s reproduction of observed data. The range of values used when varying model coefficients should be limited to that which reasonably reflects the physical conditions and processes during the simulation periods. If unreasonable values are required to calibrate a model, it should serve as a warning that there is a process or feature not being represented in the model.

Model validation involves simulating one or more independent sets of conditions, using model coefficients determined in the calibration process, to assess how well the calibrated model can reproduce observed data for those independent conditions. The hydrologic conditions represented by the calibration and validation periods should be similar. For example, a model calibrated for average conditions should not be validated with hurricane conditions. The primary purpose of model calibration and validation is to provide greater confidence in the model when it is used to predict the system response to differing scenarios.

For the present study, two independent observed data periods were available for calibration and validation at monitoring stations shown in A.8. The first period was from December 26, 2003, through January 1, 2004, and represents normal hydrologic conditions. The second period was from October 4, 2004, through October 18, 2004, and represents tropical storm conditions (Tropical Storm Matthew). The two periods represent two distinct hydrologic conditions. Therefore, instead of using them as a calibration and a validation period, they were used as two calibration periods. The water movement in a forested swamp at high water levels can be quite different than the water movement at normal conditions due to the additional frictional drag presented by the tree trunks.

The model parameters involved in calibration are typically coefficients related to the simulation of physical processes in the model (e.g., friction coefficients in fluid flow simulation). However, model calibration may also involve variation of other parameters that have uncertainty associated with them, for example, model geometry or boundary conditions (driving forces).

The model was calibrated and validated for water surface elevation and velocity thorough a series of Delft3D FLOW simulations. The calibration is accomplished mainly through improvement in geometry of the channels and tuning the roughness coefficient to improve the accuracy of the model predictions.

The calibration simulations were performed by applying known tidal water surface elevations at the Pass Manchac boundary. For the normal and tropical storm conditions, Pass Manchac is the most important boundary condition that drives the water movement in the study area. The inflows at the other major boundaries such as Blind River, Amite River, Hope Canal, and Reserve Relief Canal were not measured during the data collection period. However, they have much smaller influence on the swamp water levels under the available conditions. Therefore, these inflows were not specified as the boundary conditions during calibration. These inflows affect local water levels where they enter the study area. Figure A.10 shows the locations of the gages and nodal coordinates where observed and predicted water surface elevations are compared.

The calibration for the normal conditions is shown in Figures A.11 through A.14. The tidal elevations at Pass Manchac are shown in the figures for reference as they are the most important boundary conditions driving water movement in the system. After a series of trial runs, a uniform Manning's roughness of 0.035 s/($m^{1/3}$) is applied for the whole domain. In the case of normal conditions, the statistical measures shown on the figures indicate a good model performance. The model performance is better at the gages in the middle of the swamp. At the gages near I-10 and south, the water surface elevations are more affected by the local runoff from the adjacent areas which are outside the model domain. Rainfall contribution was not modeled in this simulation as it was not the driving force for hydraulics in the mid-swamp region. In the primary area of interest – the mid-swamp region – where the nutrient assimilation is expected, the model performance is excellent.

The calibration for the tropical storm hydrologic conditions is shown in Figures A.15 through A.19. The final selected values of roughness (Manning's n) were 0.02, 0.035 and 0.2 s/($m^{1/3}$) for Lake Maurepas, the channels, and the swamp, respectively. The swamp region is assigned a high roughness due to additional vegetation drag. The open water body lake is assigned a low roughness. The channels are assigned a typical roughness value used for natural streams. The statistical measures of correlation coefficient and root-mean-square error provided for each gage indicate the satisfactory performance of the model predictions. In general, the rising limb and peak of the storm hydrograph is matched well by the model. During the falling limb of the hydrograph, the model underpredicts the water levels indicating faster outgoing flow than observed.

7.0 MODEL APPLICATION – GEOMETRY MODIFICATION

The calibrated model was used to simulate a diversion scenario. First, the model geometry was modified to represent the diversion channel and outfall management features proposed in the 95% design report (URS 2014). The following model geometry modifications were performed:

- Added the proposed diversion channel from the Mississippi River to its end approximately 1000 ft north of its crossing with I-10 highway. The channel has a variable cross-section along its way. The longest segment between the Highway 61 and I-10 has a 60 ft wide bottom and 1V:5H side slope. The invert is -7 ft- and -8 ft, NAVD88 at Highway 61 and I-10, respectively.
- Closed culvert crossings under I-10 between LA 641 and Mississippi Bayou to prohibit backflow from the diversion into the swamp between I-10 and Highway 61.
- Added gaps in the railroad embankment along the west bank of Hope Canal.

The Mississippi River, the details of diversion complex or the sediment settling basin were not represented in the model as they were not necessary to simulate the hydraulics in the swamp which is the purpose of this modeling effort. The model geometry representing proposed diversion is shown in Figure A.19.

The results of the model application are discussed in Section 3.0 of the main report.

8.0 REFERENCES

Deltares. 2018. *Delft3D FLOW, User Manual: Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments*. Delft, The Netherlands.

MPH. 2018. *Topographic Survey in the outfall management area of the Mississippi River Reintroduction into the Maurepas Swamp (PO-29)*, Prepared by Morris P. Hebert, Inc for the Coastal Protection and Restoration Authority, Louisiana. July 18, 2018.

URS. 2005. *Mississippi River Diversion into Maurepas Swamp Project PO-29, Volume III of VII, Topographic and Bathymetric Survey, Prepared for the Coastal Protection and Restoration Authority, Louisiana*. October, 2005.

URS. 2006. *Mississippi River Diversion into Maurepas Swamp Project PO-29, Volume IV of VII, Hydrologic Data, Prepared for the Coastal Protection and Restoration Authority, Louisiana*. June 29, 2006.

URS. 2014. *Mississippi River Diversion into Maurepas Swamp (PO-29, Contract No. 2503-11-63), 95% Design Report, Prepared for the Coastal Protection and Restoration Authority, Louisiana*. May, 2014.

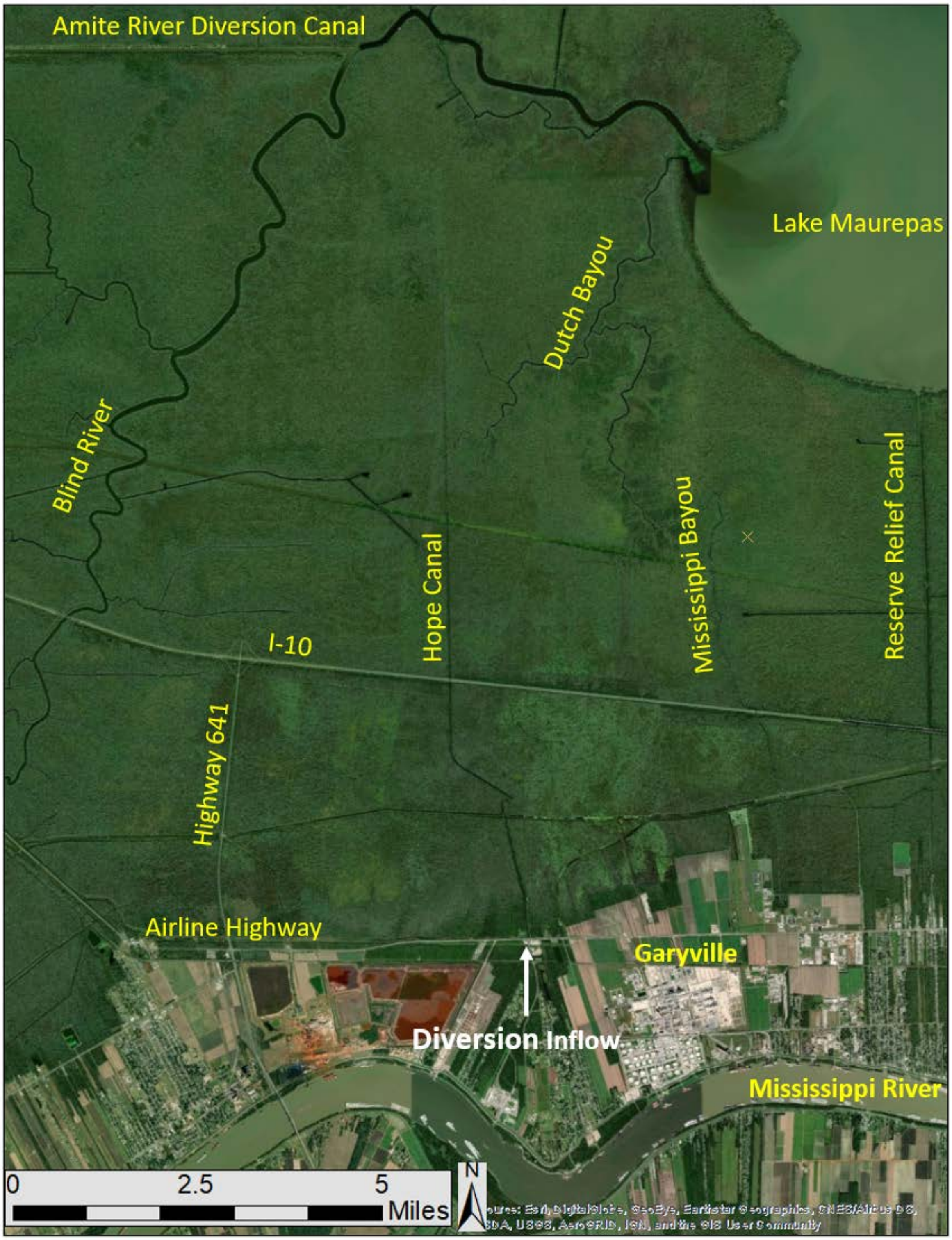


Figure A.1. Maurepas swamp hydraulic modeling study area.

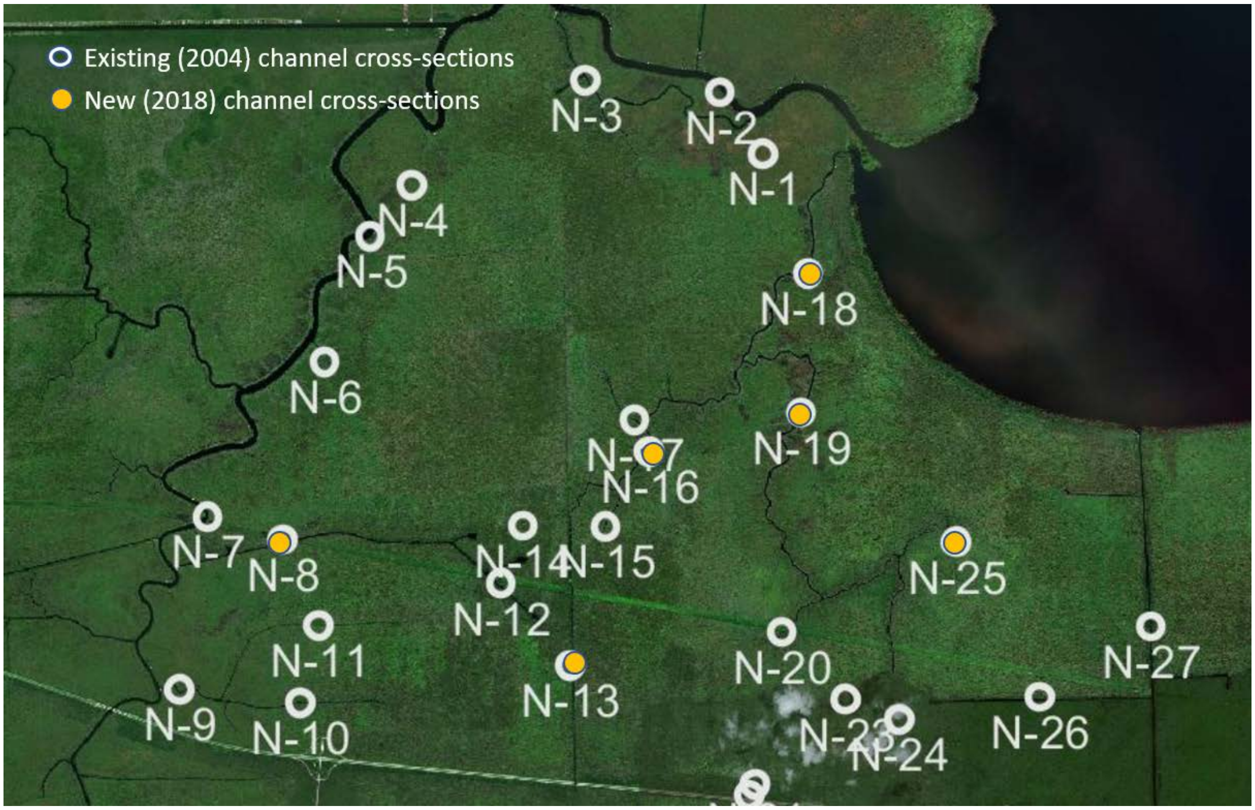
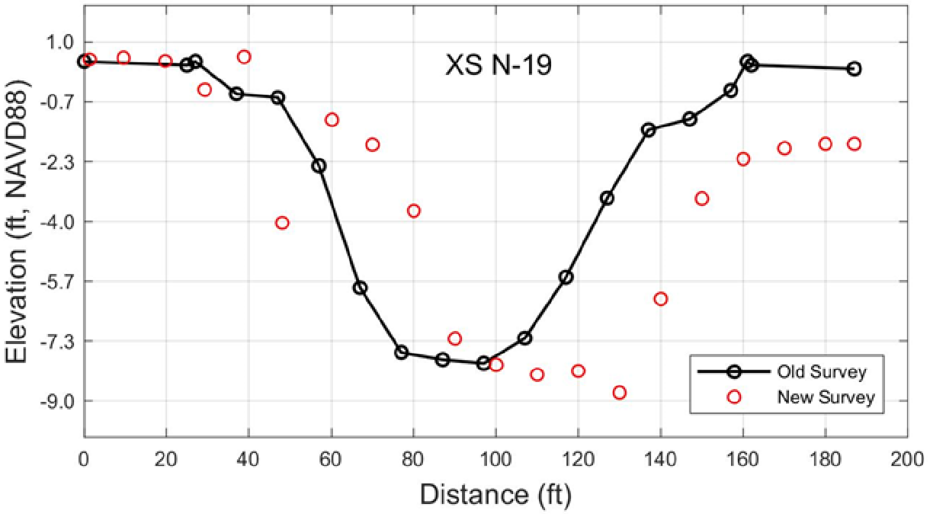
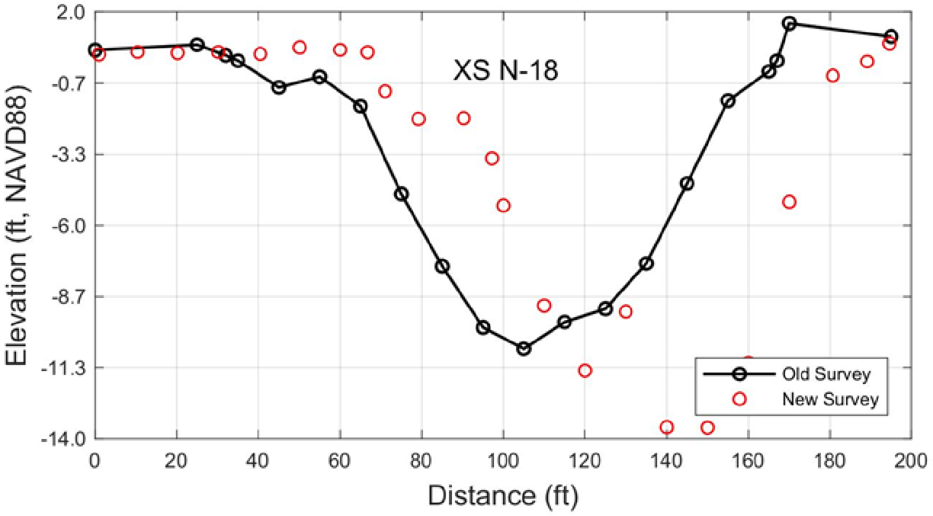
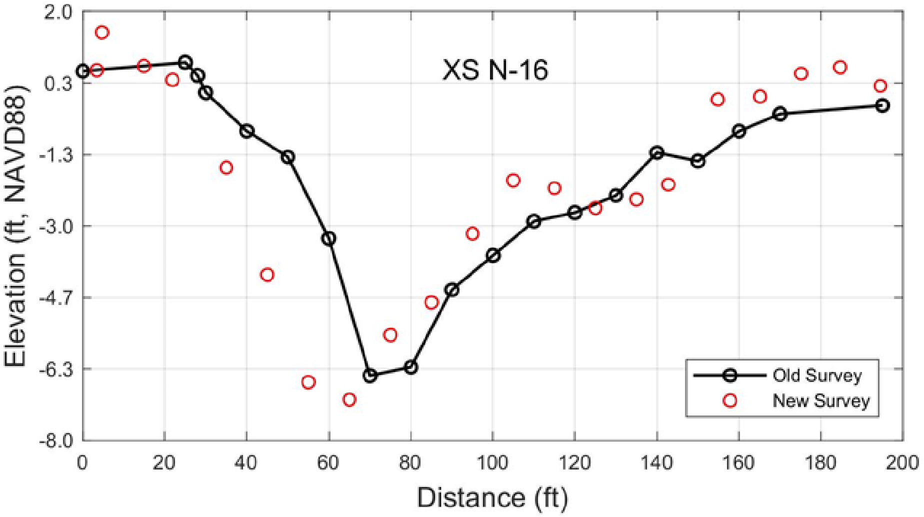


Figure A.2. Locations of existing (2004) and new (2018) channel cross-section field surveys.





FigureA.3. Comparison of old (2004) and new (2018) channel cross-sections at N-19 and N-18.



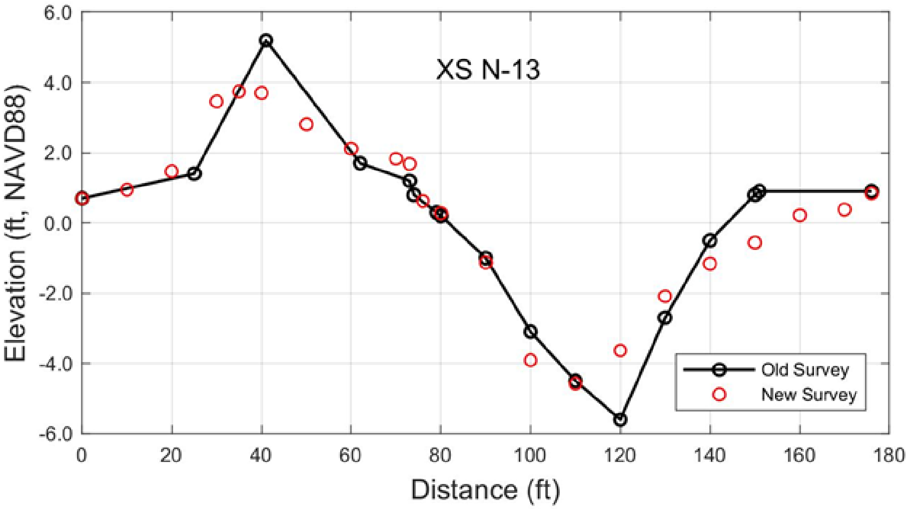
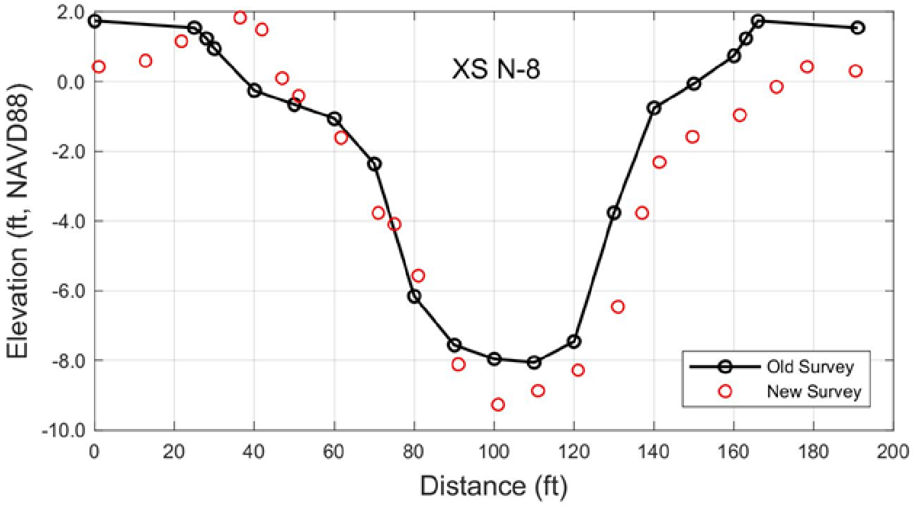


Figure A.4. Comparison of old (2004) and new (2018) channel cross-sections at N-16 and N-13.



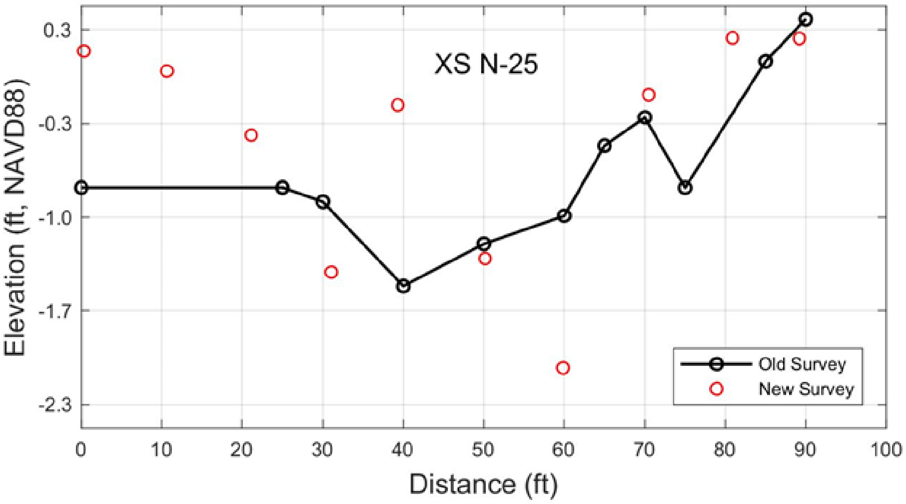


Figure A.5. Comparison of old (2004) and new (2018) channel cross-sections at N-8 and N-25.

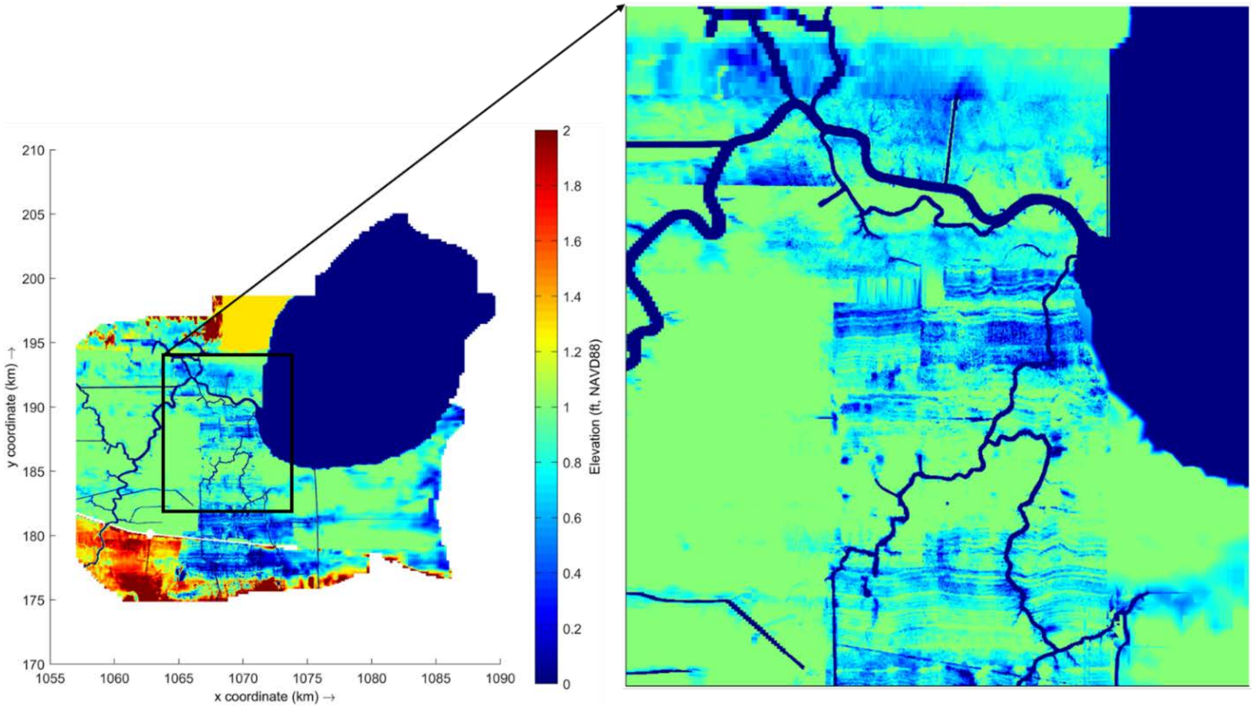


Figure A.6. Delft3D model bathymetry using topographic contours from 2012 LIDAR data. Swamp floor elevation capped at 1.0 ft in the region shown by the inset.

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure A.7. Locations of hydraulic monitoring gages.

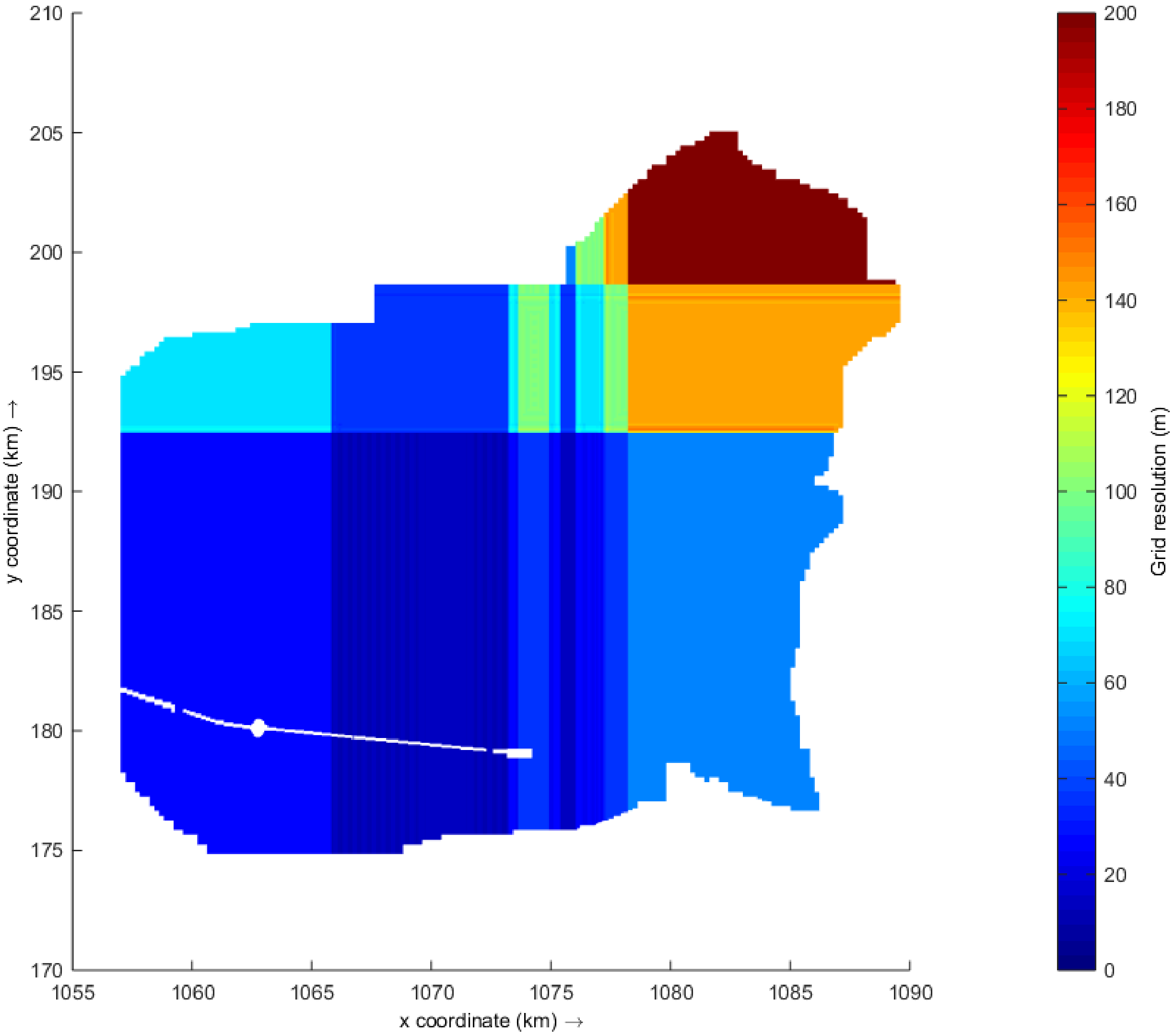


Figure A.8. Maurepas swamp Delft3D model grid resolution.

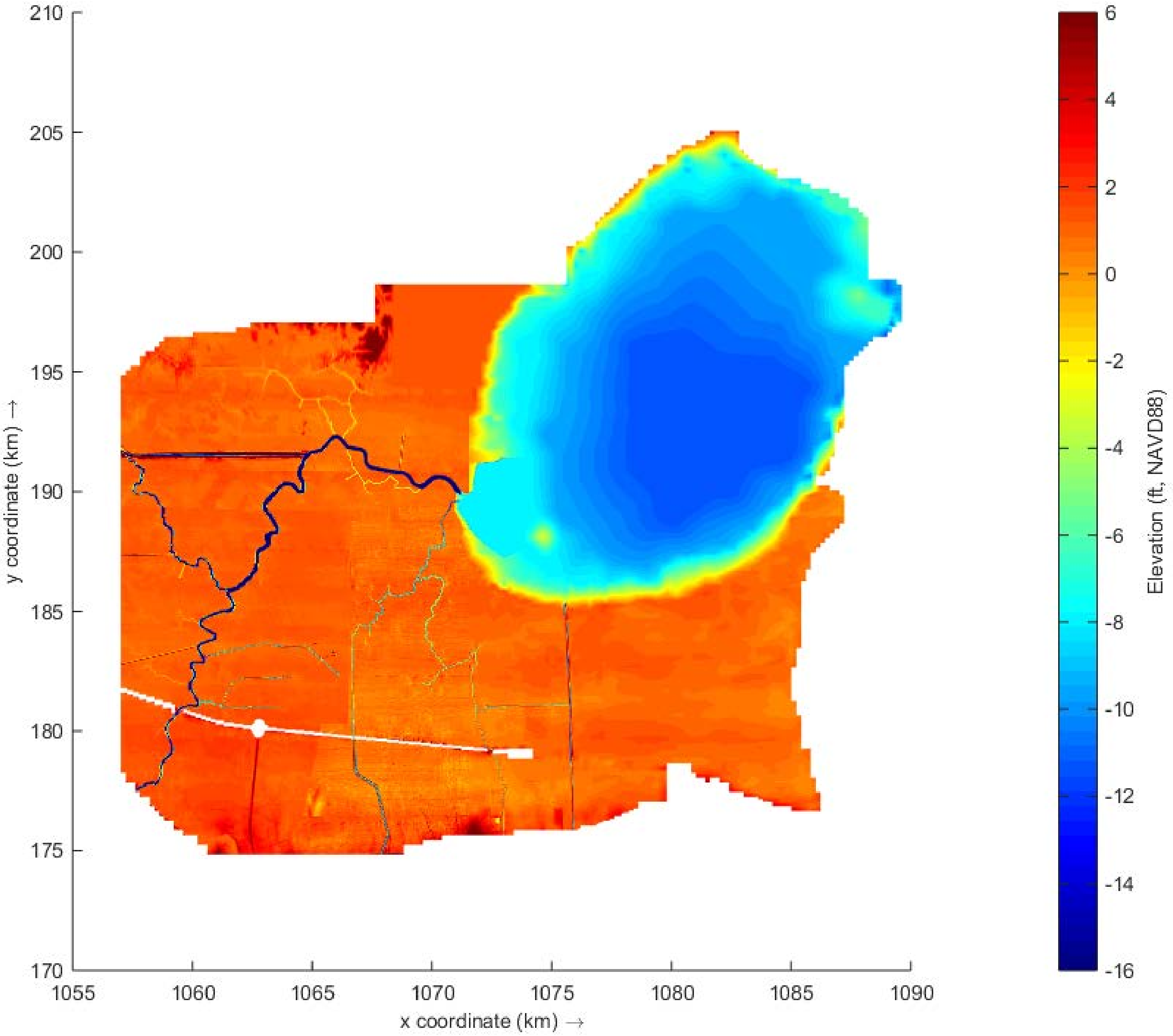


Figure A.9. Maurepas swamp Delft3D model bathymetry.

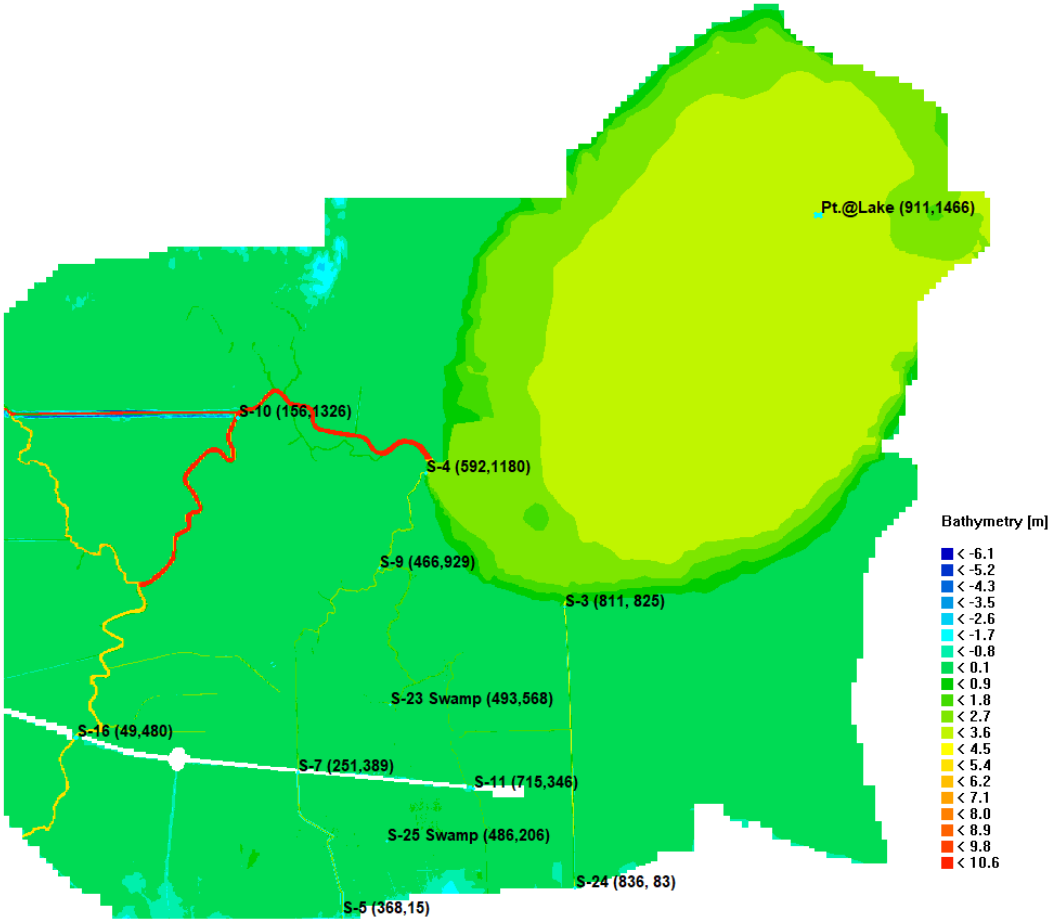


Figure A.10. Delft3D model nodal coordinates closest to the monitoring gages.

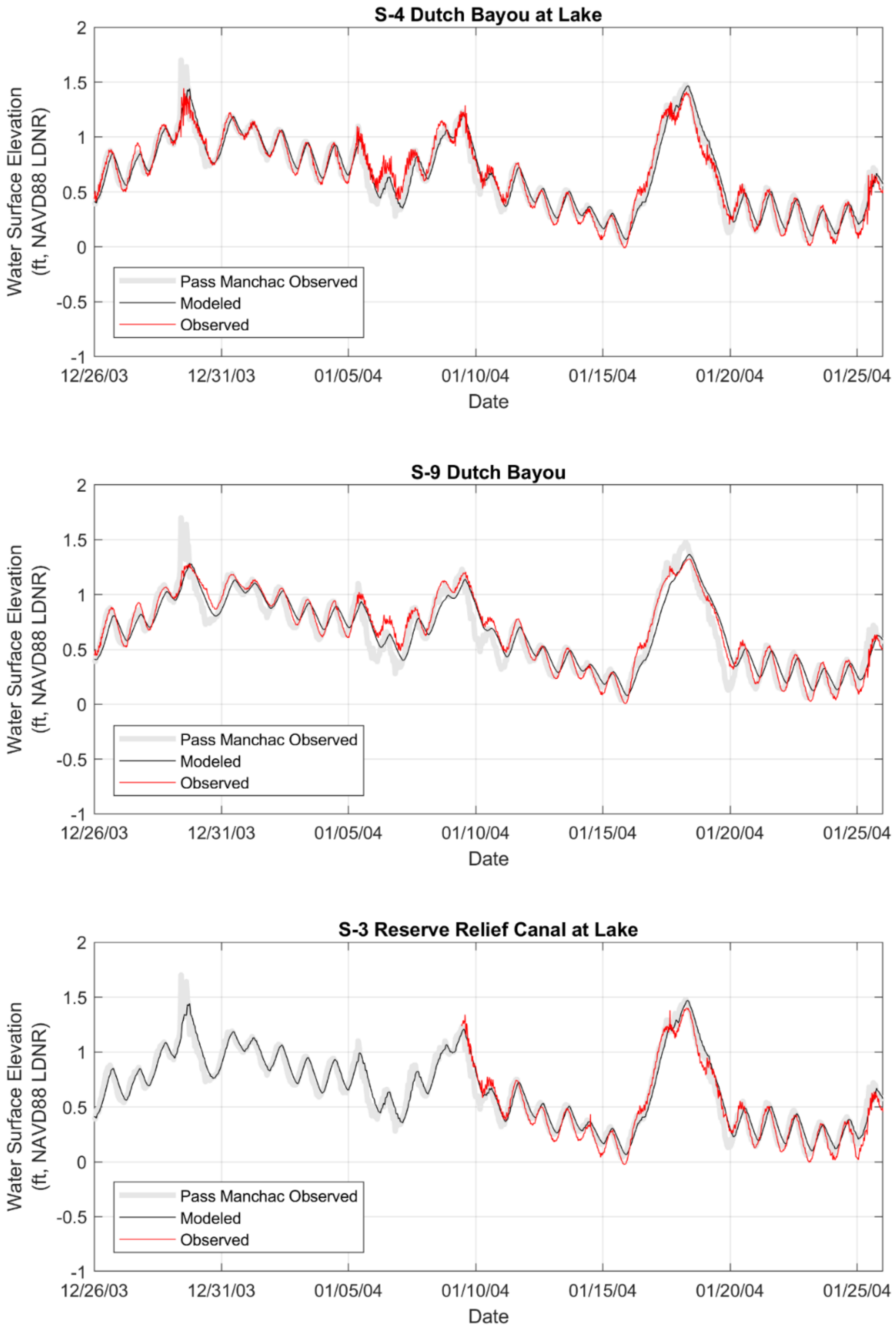


Figure A.11. Observed and predicted water surface elevations at gages S-4, S-9 and S-3 under normal conditions.

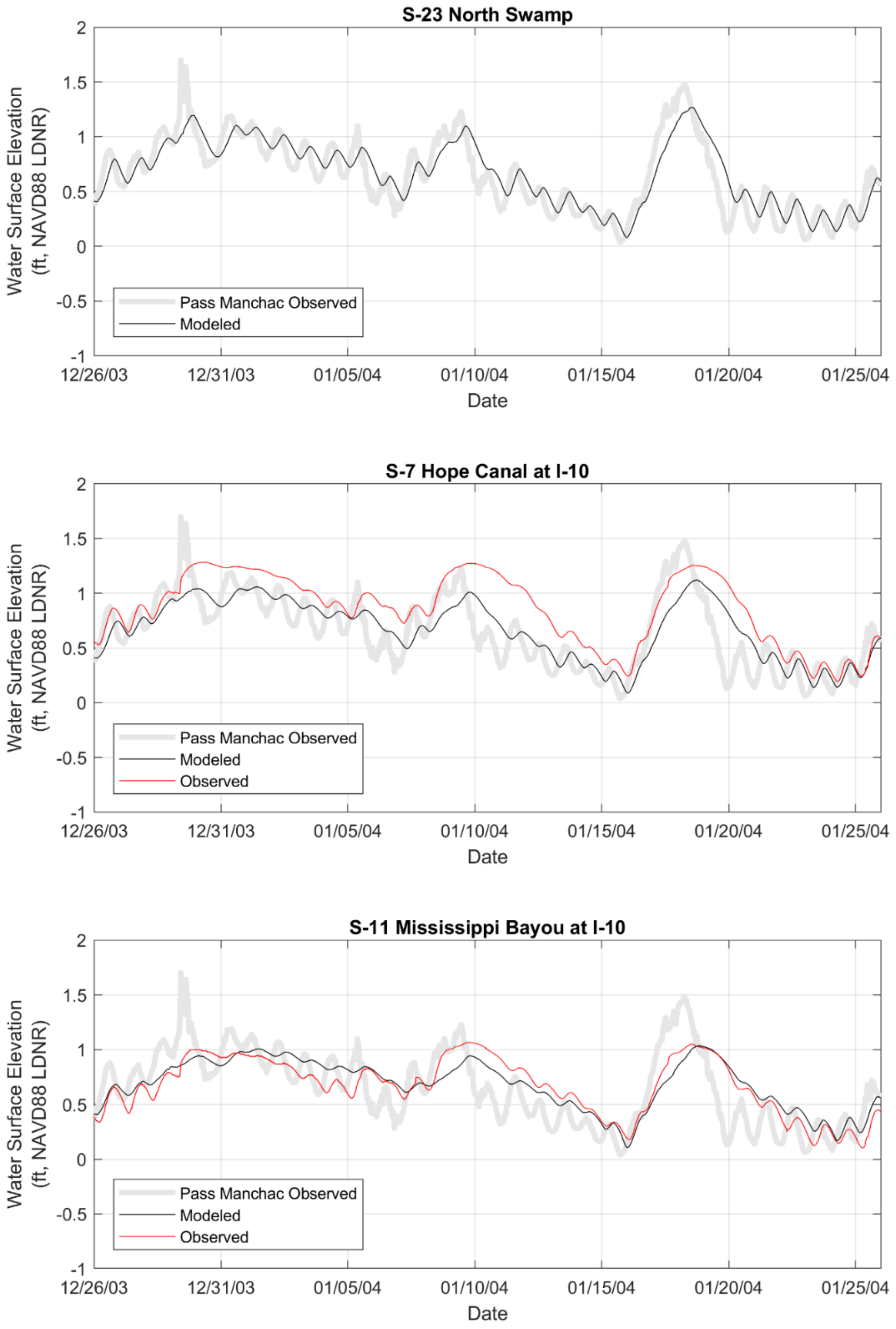


Figure A.12. Observed and predicted water surface elevations at gages S-23, S-7 and S-11 under normal conditions.

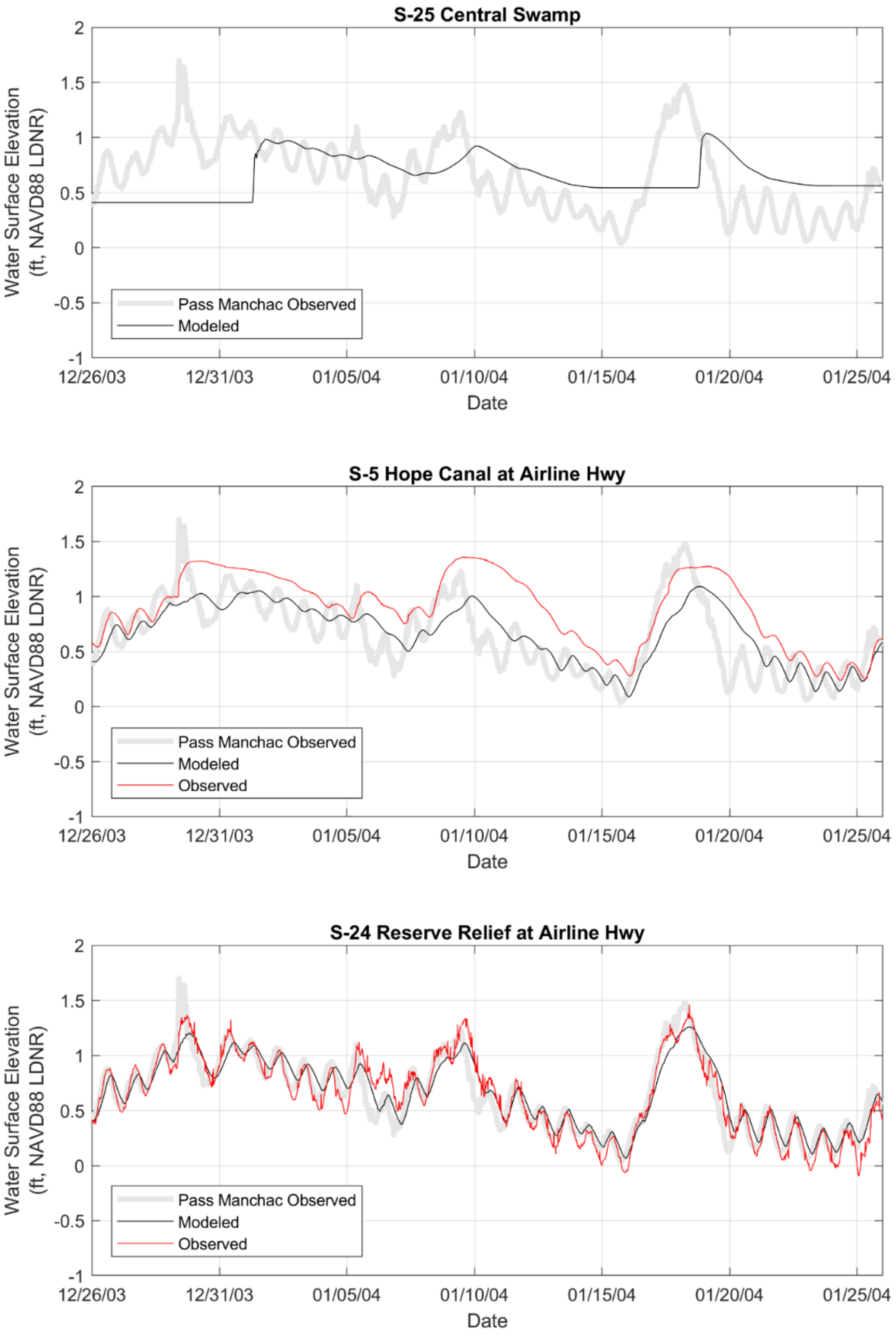


Figure A.13. Observed and predicted water surface elevations at gages S-25, S-5 and S-24 under normal conditions.

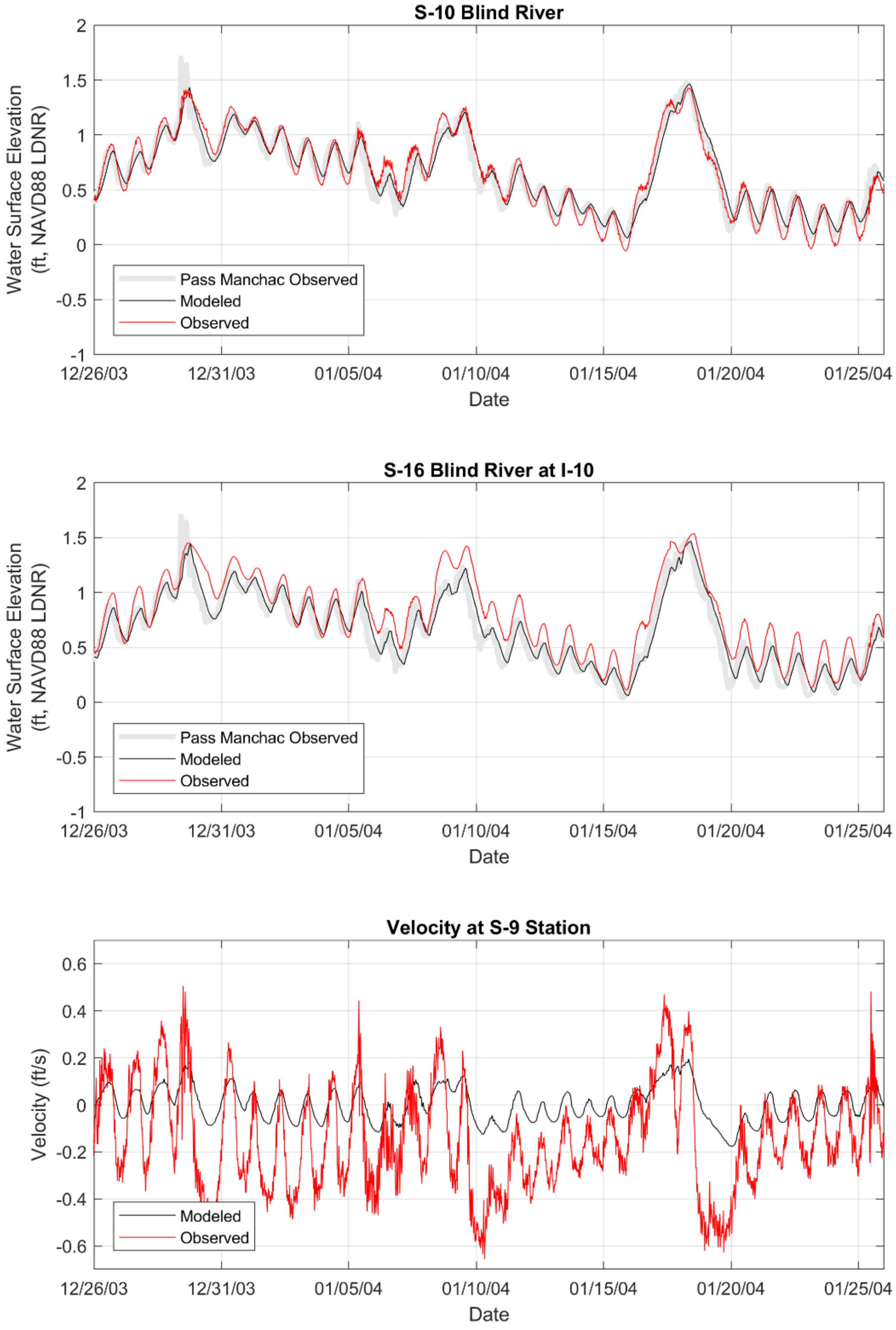
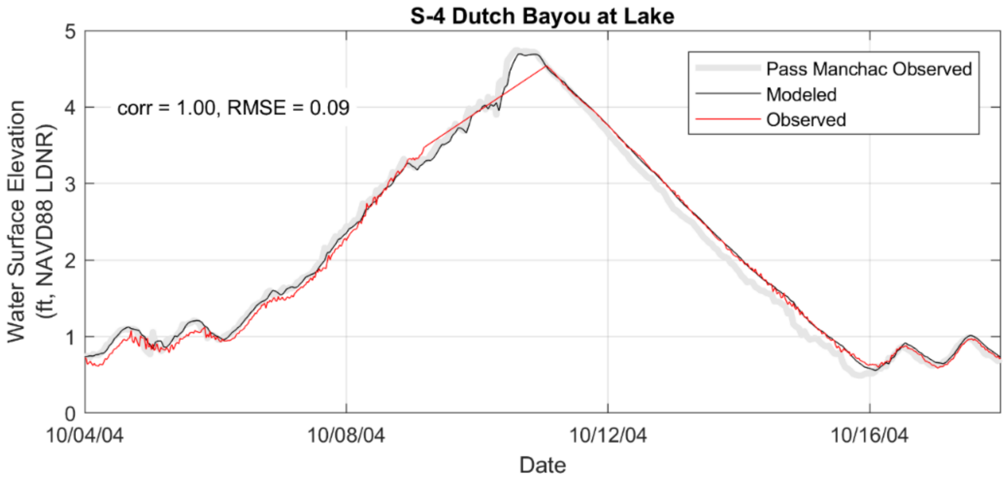
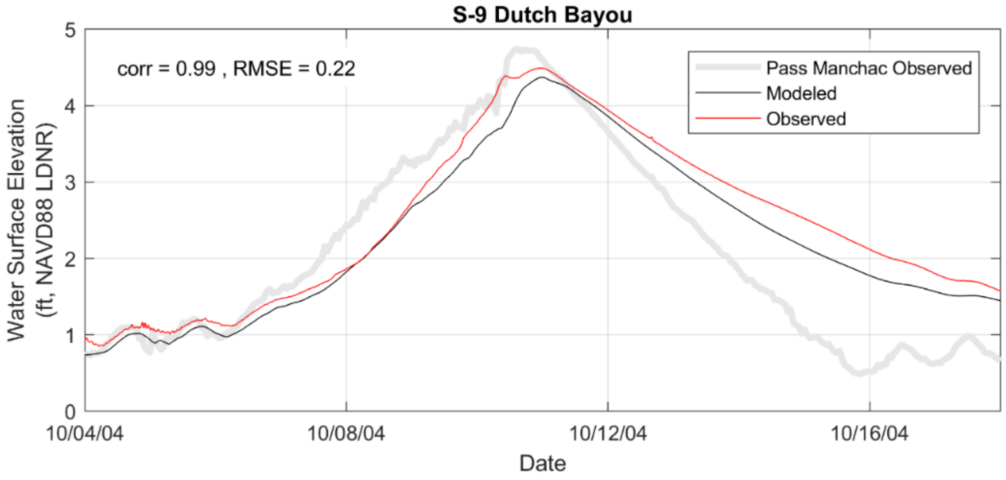


Figure A.14. Observed and predicted water surface elevations at gages S-10, S-16 and velocity at S-9 under normal conditions.





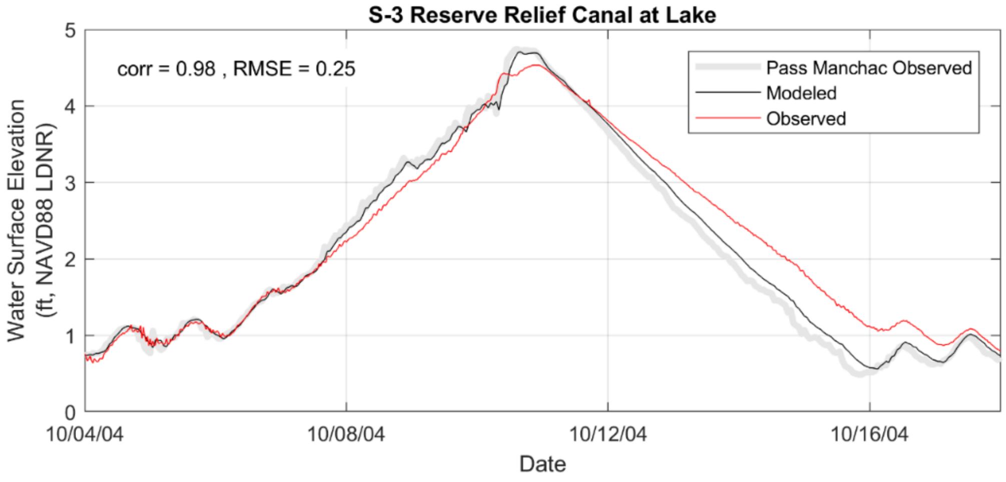


Figure A.15. Observed and predicted water surface elevations at gages S-4, S-9 and S-3 under tropical storm conditions.

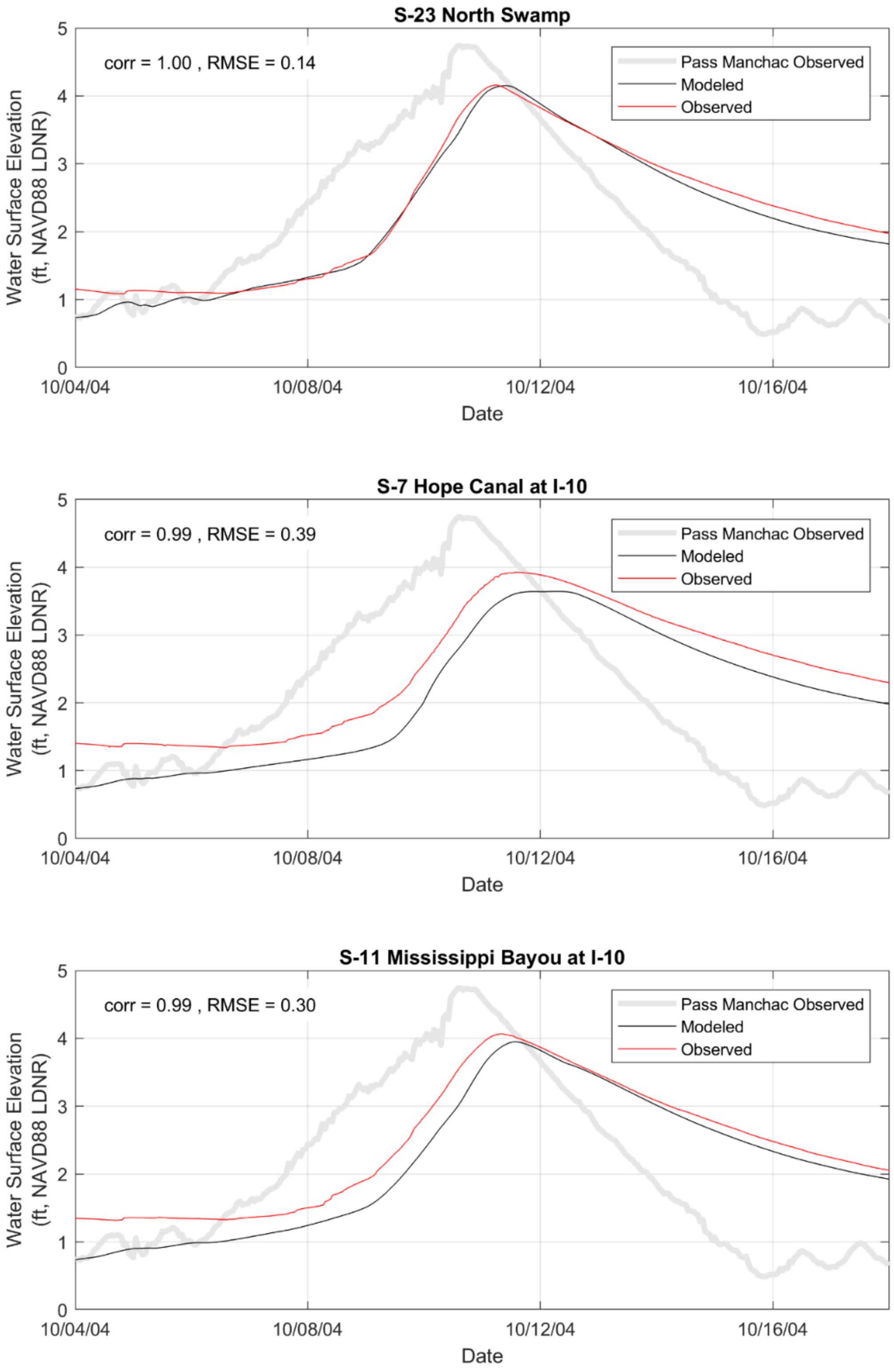


Figure A.16. Observed and predicted water surface elevations at gages S-23, S-7 and S-11 under tropical storm conditions.

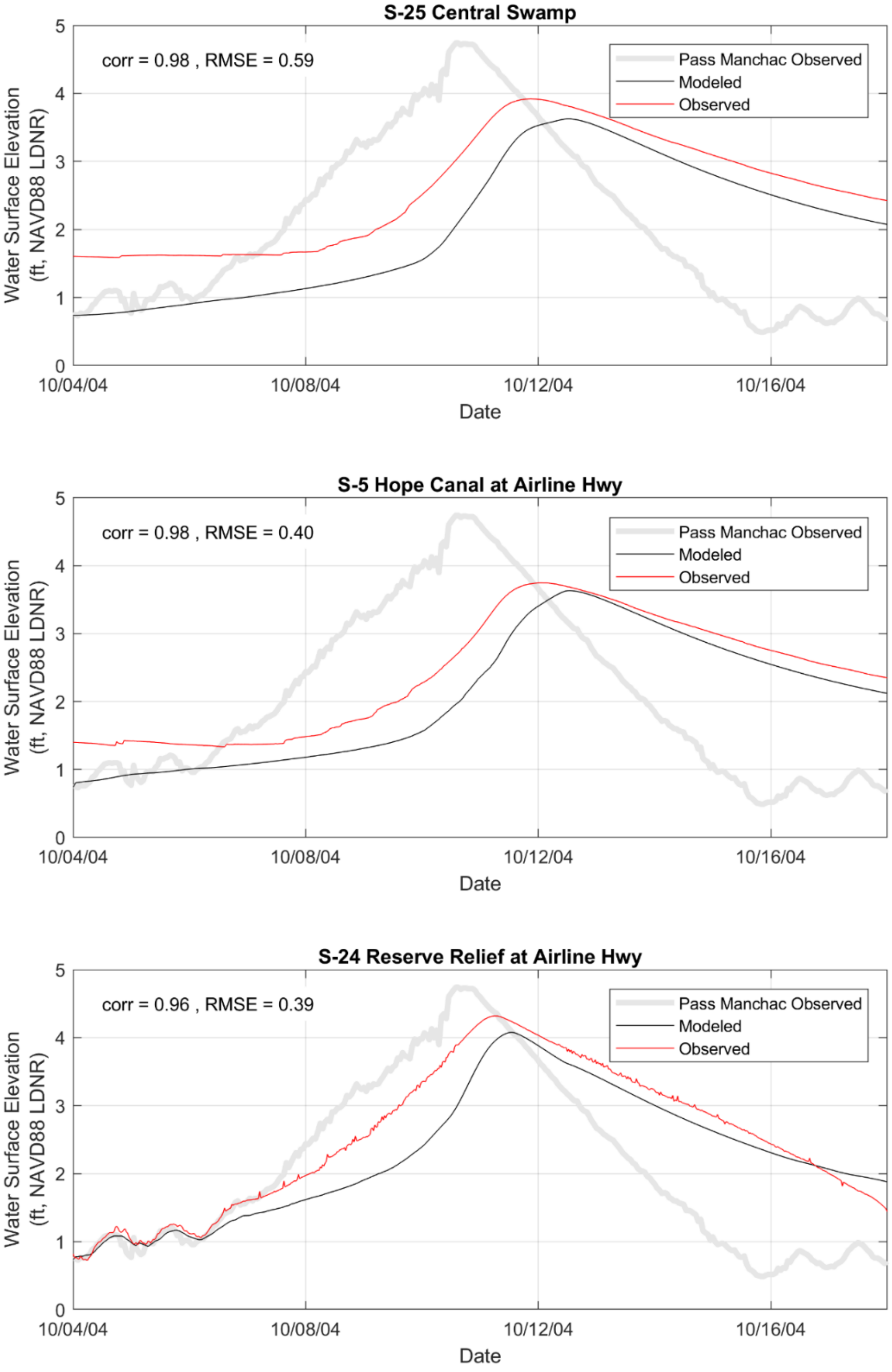


Figure A.17. Observed and predicted water surface elevations at gages S-25, S-5 and S-24 under tropical storm conditions.

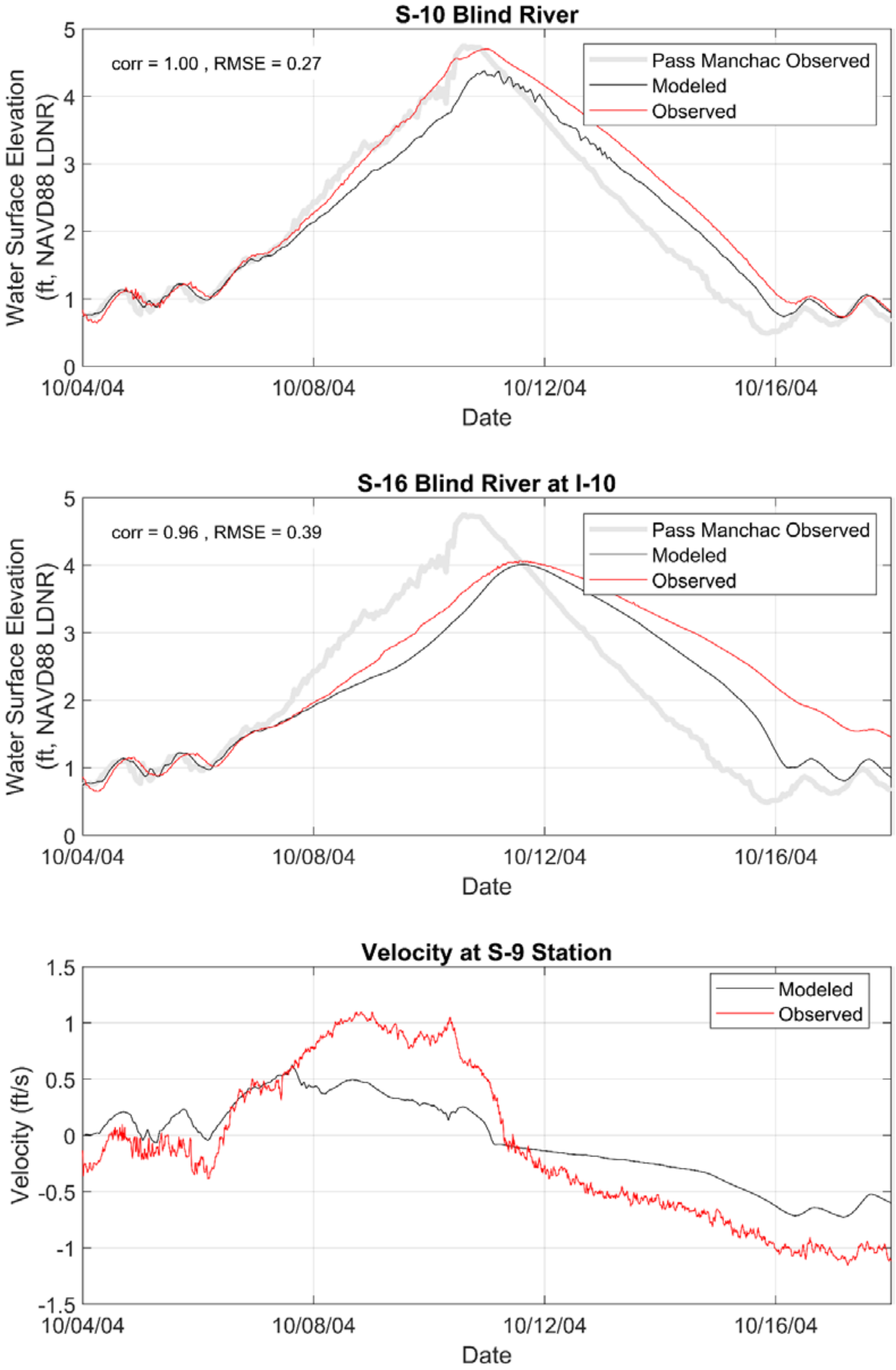


Figure A.18. Observed and predicted water surface elevations at gages S-10, S-16 and velocity at S-9 under tropical storm conditions.

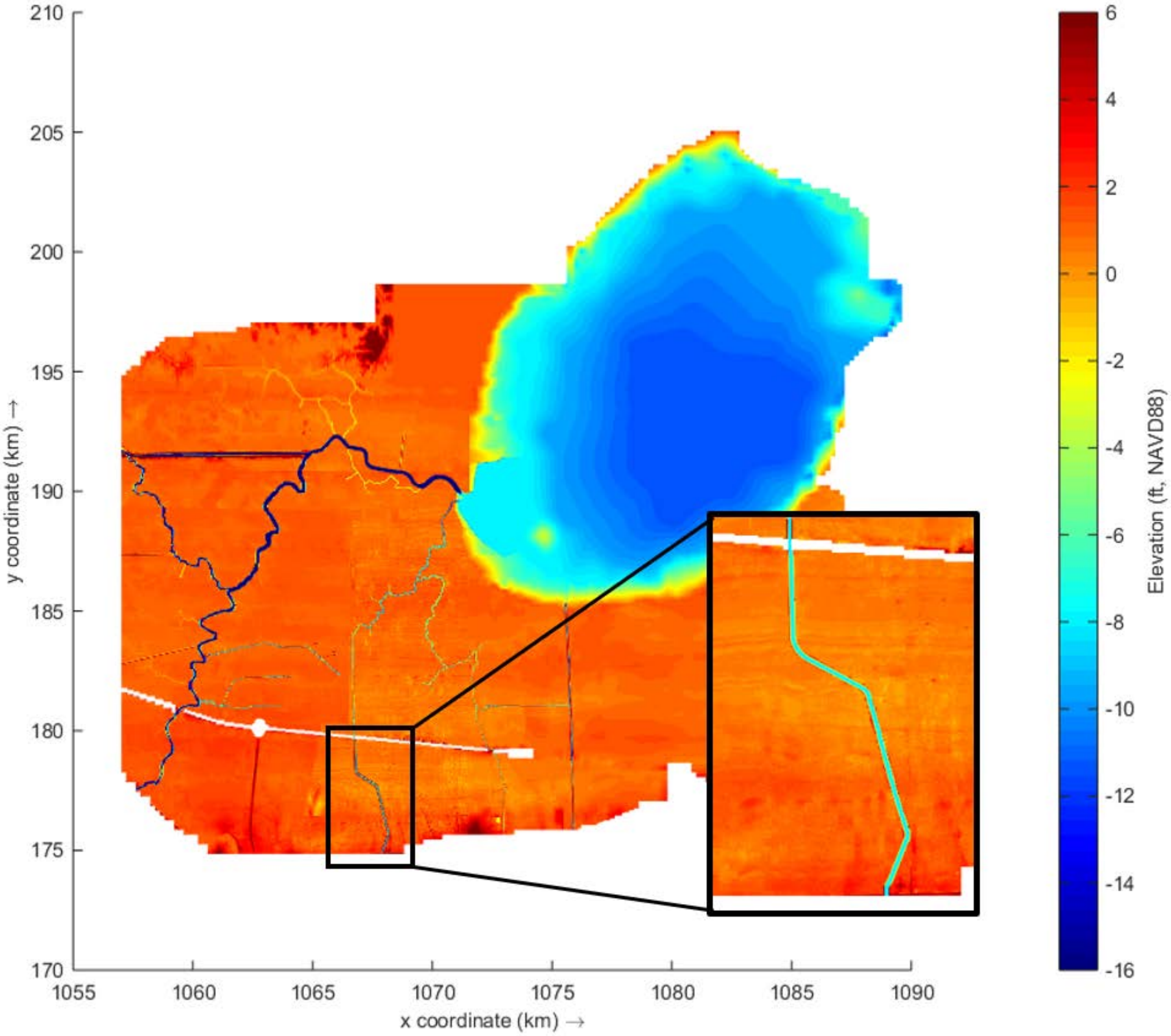


Figure A.19. Maurepas swamp Delft3D model grid with the proposed diversion channel.

APPENDIX B

Information from Published Literature Used to Develop Loss Rates

Table B.1. Information from published literature used to develop loss rates for TN.

Description or name of wetlands	TN conc. entering wetland (mg/L)	TN conc. leaving wetland (mg/L)	TN percent reduction (%)	Hydraulic residence time (days)	First order decay rate for TN (1/day)	Average depth (m)	"k" value for PkC* model (m/yr)	Comments
Wetlands below Caernarvon Diversion [1]	1.94	0.51 – 0.89 [A]	38% [B]	"about two weeks"	0.034	not reported	--	Data were collected during a March 2001 pulse; reductions measured over a distance of about 33 – 39 km. Receives water from Mississippi River.
Fourleague Bay [2]	1.2 – 1.6	0.4 – 0.6	Feb: 42% [C] Mar: 38% [C] Apr: 37% [C]	Feb: 5.3 Mar: 5.0 Apr: 18.7	Feb: 0.103 Mar: 0.096 Apr: 0.025	~ 1	Feb: 37.6 Mar: 34.9 Apr: 9.0	Data collected during Feb. – April 1994. This is an open waterbody. Primary source of nutrients is Atchafalaya River.
City of Mandeville – Bayou Chinchuba wetland [3]	7.5	--	65%	77 [D]	0.014	approx. 0.3	1.5	Data collected during Sep. 1998 – Oct. 2000. This is a forested wetland receiving treated municipal wastewater.
City of Thibodaux treatment wetland [4]	12.6	1.08	91%	120	0.021	0.33	2.4	Data were collected during Mar. 1992 – Mar. 1994. This is forested wetland receiving treated municipal wastewater.
City of Luling treatment wetland [5]	7.06	1.18	83%	512 [D]	0.003	not reported	--	Data were collected during 2006 – 2013. This is forested wetland receiving treated municipal wastewater.
City of Breaux Bridge treatment wetland [5]	8.44	1.38	84%	410 [D]	0.004	not reported	--	Data were collected during 2001 – 2013. This is forested wetland receiving treated municipal wastewater.
Richland-Chambers treatment wetlands in Texas [6] [E]	PS1: 4.95 PS2: 4.43 PS3: 4.43 FSS: 3.53	PS1: 1.32 PS2: 1.14 PS3: 1.36 FSS: 1.44	PS1: 73% PS2: 74% PS3: 69% FSS: 59%	PS1: 9.2 PS2: 7.8 PS3: 11.2 FSS: 8.2	PS1: 0.144 PS2: 0.174 PS3: 0.105 FSS: 0.110	PS1: 0.29 PS2: 0.25 PS3: 0.28 FSS: 0.40	PS1: 33.0 PS2: 55.4 PS3: 29.0 FSS: 32.8	Data were collected during Nov. 1993 – Jul. 2000 for pilot systems and Jun. 2003 – May 2008 for field scale system. Inflow is from Trinity River.

Table B.1 (continued)

Description or name of wetlands	TN conc. entering wetland (mg/L)	TN conc. leaving wetland (mg/L)	TN percent reduction (%)	Hydraulic residence time (days)	First order decay rate for TN (1/day)	Average depth (m)	"k" value for PkC* model (m/yr)	Comments
Stormwater treatment wetlands in North Carolina [7]	0.74 – 2.69	0.56 – 2.06	not calculated	0.1 – 3.0	0.056 – 1.26[F]	0.1 – 0.3	5.1 – 63.1 (median = 46.1)	Ranges are for 10 constructed wetlands receiving stormwater in different regions of North Carolina.
Olentangy River Wetland Research Park [8]	2.90[G]	1.97[G]	31.9%	3.7[G]	0.104	approx. 0.4[G]	16.1	Data were collected during 2004 – 2010. Inflow is from Olentangy River. Located in Ohio.
Des Plaines River Experimental Wetlands [9][H]	< 0.5 to ~ 7.5[I]	0.5 to 1.5[I]	EW3: 54% EW4: 75% EW5: 59%	EW3: 12 EW4: 95 EW5: 13	EW3: 0.065 EW4: 0.015 EW5: 0.069	0.6 – 0.7[G]	EW3: 14.6 EW4: 3.6 EW5: 16.7	Data were collected during Apr. – Nov. 1991. Inflow is from Des Plaines River. Located in Illinois.

Notes:

A. Concentrations leaving the wetland are affected by dilution as well as other (e.g., biological and chemical) processes.
B. The effects of dilution were excluded in the calculations for this reduction percentage.
C. Percent reduction was calculated as 100% minus the percent exported from the bay into the Gulf of Mexico.
D. Estimated value obtained from Table 1 in Hunter et. al. (2009).
E. PS1 = Pilot system #1, PS2 = Pilot system #2, PS3 = Pilot system #3, FSS = Fields scale system.
F. Calculated as "k" value for PkC* model divided by average depth. "k" values were calculated by the author.
G. Calculated using other information in the article.
H. EW3 = Experimental wetland #3, EW4 = Experimental wetland #4, EW5 = Experimental wetland #5.
I. Estimated from Figure 4 (time series plot) in article.

References:

[1] Lane et. al. (2004)
[2] Perez et. al. (2011)
[3] Brantley et. al. (2008)
[4] Zhang et. al. (2000)
[5] Hunter et. al. (2018)
[6] Kadlec et. al. (2011)
[7] Merriman et. al. (2017)
[8] Mitsch et. al. (2014)
[9] Phipps and Crumpton (1994)

Table B.2. Information from published literature used to develop loss rates for TP.

Description or name of wetlands	**TP conc. entering wetland (mg/L)**	**TP conc. leaving wetland (mg/L)**	**TP percent reduction (%)**	**Hydraulic residence time (days)**	**First order decay rate for TP (1/day)**	**Average depth (m)**	**"k" value for PkC* model (m/yr)**	**Comments**
Wetlands below Caernarvon Diversion [1]	0.16	0.059 – 0.065 [A]	35% [B]	"about two weeks"	0.031	not reported	--	Data were collected during a March 2001 pulse; reductions measured over a distance of about 33 – 39 km. Receives water from Mississippi River.
Fourleague Bay [2]	0.11 – 0.15	0.06 – 0. 10	Feb: 0% [C] Mar: 12% [C] Apr: 58% [C]	Feb: 5.3 Mar: 5.0 Apr: 18.7	Feb: 0 Mar: 0.025 Apr: 0.046	~ 1	Feb: 0 Mar: 9.1 Apr: 16.9	Data collected during Feb. – April 1994. This is an open waterbody. Primary source of nutrients is Atchafalaya River.
City of Mandeville – Bayou Chinchuba wetland [3]	2.0	--	50%	77 [D]	0.009	approx. 0.3	1.0	Data collected during Sep. 1998 – Oct. 2000. This is a forested wetland receiving treated municipal wastewater.
City of Thibodaux treatment wetland [4]	2.46	0.85	65%	120	0.009	0.33	1.1	Data were collected during Mar. 1992 – Mar. 1994. This is forested wetland receiving treated municipal wastewater.
City of Luling treatment wetland [5]	2.34	0.51	78%	512 [D]	0.003	not reported	--	Data were collected during 2006 – 2013. This is forested wetland receiving treated municipal wastewater.
City of Breaux Bridge treatment wetland [5]	2.42	0.47	81%	410 [D]	0.004	not reported	--	Data were collected during 2001 – 2013. This is forested wetland receiving treated municipal wastewater.
Richland-Chambers treatment wetlands in Texas [6] [E]	PS1: 0.727 PS2: 0.719 PS3: 0.724 FSS: 0.888	PS1: 0.457 PS2: 0.342 PS3: 0.347 FSS: 0.539	PS1: 37% PS2: 52% PS3: 52% FSS: 39%	PS1: 9.2 PS2: 7.8 PS3: 11.2 FSS: 8.2	PS1: 0.050 PS2: 0.095 PS3: 0.066 FSS: 0.061	PS1: 0.29 PS2: 0.25 PS3: 0.28 FSS: 0.40	PS1: 6.2 PS2: 10.9 PS3: 5.7 FSS: 10.7	Data were collected during Nov. 1993 – Jul. 2000 for pilot systems and Jun. 2003 – May 2008 for field scale system. Inflow is from Trinity River.

Table B.2 (continued)

Description or name of wetlands	TP conc. entering wetland (mg/L)	TP conc. leaving wetland (mg/L)	TP percent reduction (%)	Hydraulic residence time (days)	First order decay rate for TP (1/day)	Average depth (m)	"k" value for PkC* model (m/yr)	Comments
Stormwater treatment wetlands in North Carolina [7]	0.17 – 0.38	0.05 – 0.48	not calculated	0.1 – 3.0	0.048 – 1.01 [F]	0.1 – 0.3	4.4 – 84.2 (median = 37.0)	Ranges are for 10 constructed wetlands receiving stormwater in different regions of North Carolina.
Olentangy River Wetland Research Park [8]	0.148 [G]	0.085 [G]	42.7%	4.1 [G]	0.136	approx. 0.4 [G]	21.2	Data were collected during 1994 – 2001 and 2003 – 2010. Inflow is from Olentangy River. Located in Ohio.
37 large constructed wetlands [9]	median = 0.114	median = 0.038	variable	variable	--	variable	median = 12.5	This is literature review of wetlands with measured data; the PkC* model was calibrated for each system.

Notes:

A. Concentrations leaving the wetland are affected by dilution as well as other (e.g., biological and chemical) processes.
B. The effects of dilution were excluded in the calculations for this reduction percentage.
C. Percent reduction was calculated as 100% minus the percent exported from the bay into the Gulf of Mexico.
D. Estimated value obtained from Table 1 in Hunter et. al. (2009).
E. PS1 = Pilot system #1, PS2 = Pilot system #2, PS3 = Pilot system #3, FSS = Fields scale system.
F. Calculated as "k" value for PkC* model divided by average depth. "k" values were calculated by the author.
G. Calculated using other information in the article.

References:

[1] Lane et. al. (2004)
[2] Perez et. al. (2011)
[3] Brantley et. al. (2008)
[4] Zhang et. al. (2000)
[5] Hunter et. al. (2018)
[6] Kadlec et. al. (2011)
[7] Merriman et. al. (2017)
[8] Mitsch et. al. (2014)
[9] Kadlec (2016)