Utilizing Upper Diversions in River Water Management
Case Study: 2019 Mississippi Floods, Phase 2

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1. Introduction

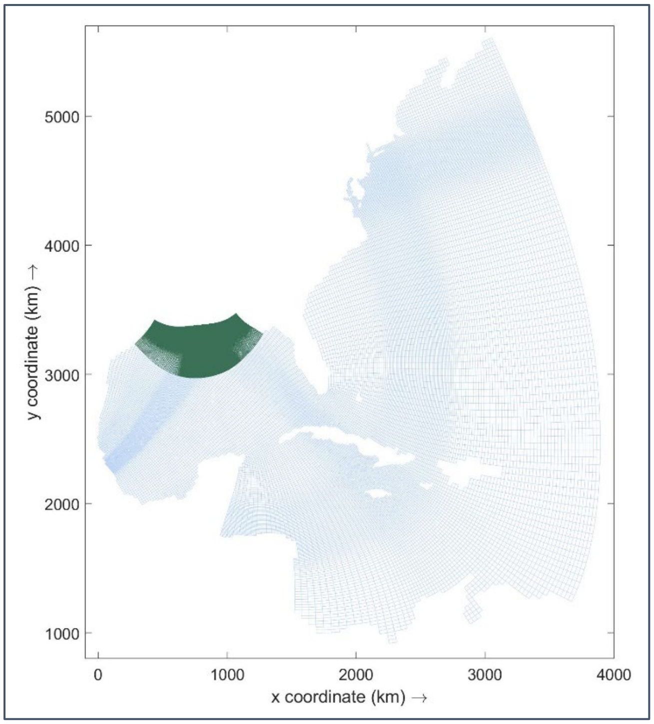
The Bonnet Carré Spillway (BCS) is used to manage and reduce flood risk in Southeast Louisiana. As a result of its operation, sediment and nutrient-rich fresh water are directed into Lake Pontchartrain and, ultimately, the Gulf of Mexico. The operation of this structure as does not optimize the use of these vital resources and can, conversely, induce water quality issues in the receiving basin. The 2018-19 flood event was used to examine the optimization of the operation plans of the BCS.

The Phase 2 focus is a basin-side analysis to explore different aspects of the spillway's influence. One of these aspects is the unique circulation patterns that result from the activation of upper river diversions in addition to BCS. The potential impact on water quality within the receiving basins is also investigated. Additionally, there are potential ecological benefits (freshwater and sediment) that can result from the diversion operation, including changes in salinity and temperature.

The main objective for this study was to develop a three-dimensional (3D) basin side model, using Delft 3D, to represent the effects of flooding, sediment transport, water quality effects, and salinity dynamics resulting from the operation of the BCS.

2. Model development

Based on the Delft3D modeling suite, a 3D hydrodynamic, salinity, temperature, sediment transport and water quality model has been developed to study the effect of BCS operations. As shown in Figure 1, two computational domains were set up for nesting computation.



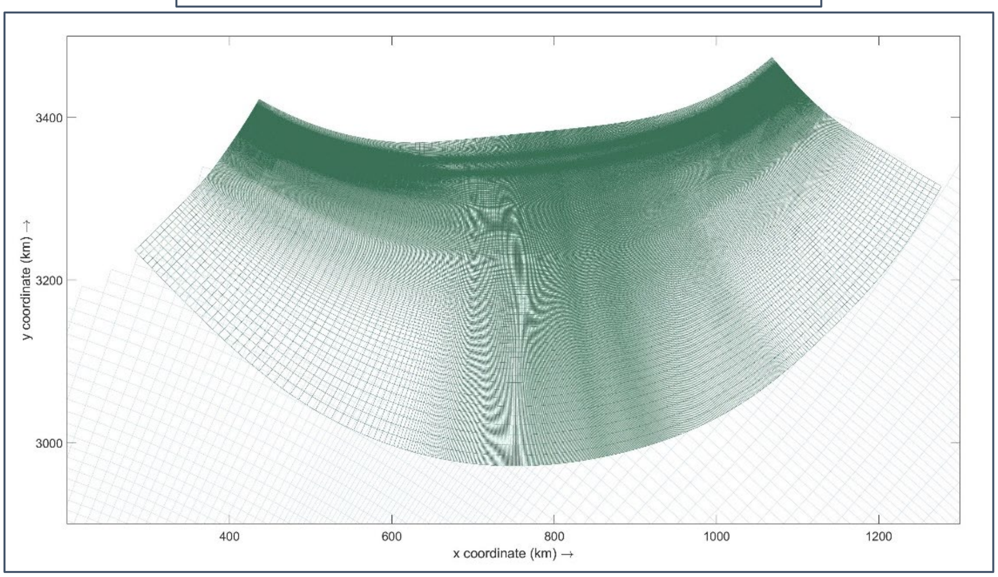


Figure 1. Nested model domains. Top: Gulf-Atlantic domain. Bottom: regional domain.

2.1 Gulf-Atlantic domain

This domain covers the entire Gulf of Mexico and part of the Atlantic Ocean with a spatial resolution ranging from 6 km near Louisiana coast to 40 km in the Atlantic Ocean. The grid size is 253 x 238. Vertically seven sigma-layers are adopted. The thicknesses of these layers are 5, 10, 20, 30, 20, 10 and 5% of total water depth, respectively. This distribution intentionally reduces the layer thickness near the surface and bottom. The time step is 3 min. Bathymetry and roughness (Manning's n) values are adopted from the ADCIRC model used in the Louisiana Coastal Master Plan. From a tidal constituent database (Mukai et al., 2002), seven dominant constituents (O_1, K_1, Q_1, M_2, N_2, S_2 and K_2) are considered to determine tidal levels at the open-sea boundary across the Atlantic

Ocean. The purpose of this large-domain model is to provide water level and 3D temperature boundaries for the regional model. Note that the regional model would experience numerical instabilities if driven by 2D uniform temperature boundaries. As such, temperature calculation is activated in this domain to provide reasonable vertical profiles of temperature at the boundary of the regional model.

2.2 Regional domain

The regional domain focuses on Lake Pontchartrain and Louisiana coast in the north-central region of the Gulf of Mexico. The grid size is 553 x 403. The domain has a spatial resolution ranging from 7 km offshore to 280 m in the area of interest in Lake Pontchartrain. Figure 2 shows the regional domain with computational grids. The USGS 5m-resolution National Elevation Dataset (http://ned.usgs.gov/) is used for interpolation of topography. Figure 3 shows the bathymetry used in the model.

Figure 2. The regional domain with computational grids (yellow line).

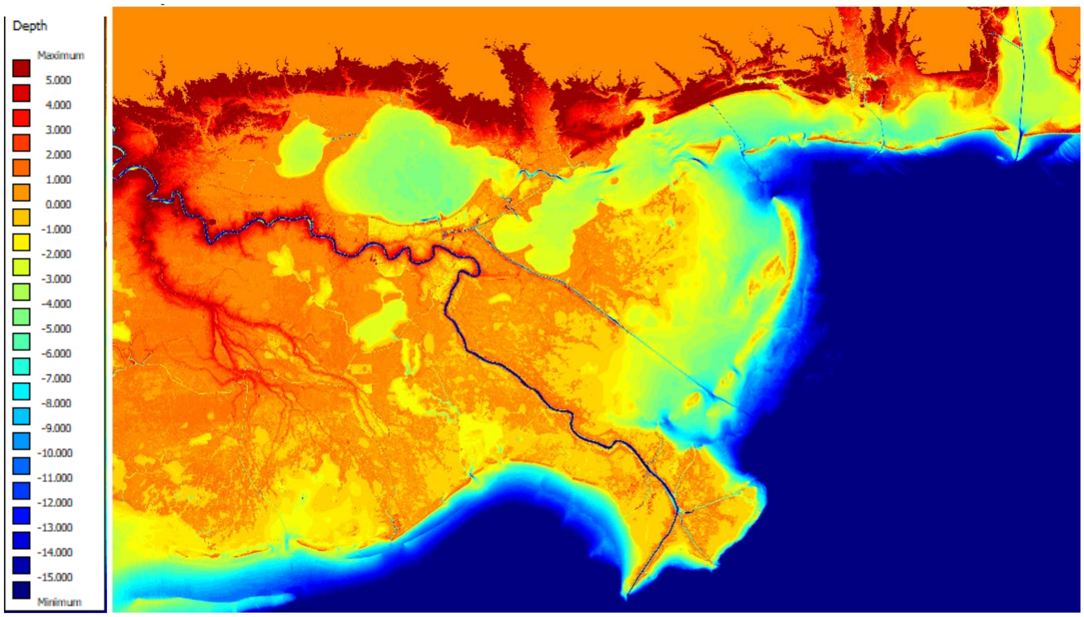


Figure 3. The interpolated bathymetry used in the model.

2.3 DFLOW settings

The hydrodynamic and transport part, DFLOW module, calculates water level, salinity, temperature, and sediment transport. The time step is 0.6 min. At the southern offshore open boundary (see Figure 1), water level is interpolated from the Gulf-Atlantic Model and adjusted according to observations at Shell Beach tidal station. The 3D temperature boundary data are also from the Gulf-Atlantic Model. In terms of salinity, a constant 2D uniform value of 36 ppt is used at the offshore boundary (since the Gulf-Atlantic model does not calculate salinity). Similarly, a constant small value of sediment concentration, 0.01 g/l, is applied at the offshore boundary. As shown in Figure 4, the regional model captures freshwater inputs are from coastal rivers along Louisiana, Mississippi and Alabama coasts. The river discharge data are either from gauge observations (if available) or estimated from anecdotal historical records. It should be noted that the main stem of the Mississippi River was not included in the model domain. Therefore, distributaries such as Bonnet Carré, Davis Pond diversion, Caernarvon diversion, etc., were included as point sources.

In the lower Mississippi River (from Bohemia to Head of Passes) and Birdsfoot Delta, we used historical field observations to estimate the flow distribution among the eight major passes (denoted as orange and red arrows in Figure 4). For Southwest Pass, South Pass and Pass a Loutre (denoted as red arrows in Figure 4), we further distributed the flow within each through smaller distributaries and crevasses (denoted as red arrows in three sub-figures of Figure 4). In addition, the high-resolution (1km) MRMS gauge-corrected product (http://mtarchive.geol.iastate.edu) was used for hourly precipitation input. We adopt multi-year monthly averaged values in 2017 Master Plan (Habib et al., 2017) for evapotranspiration.

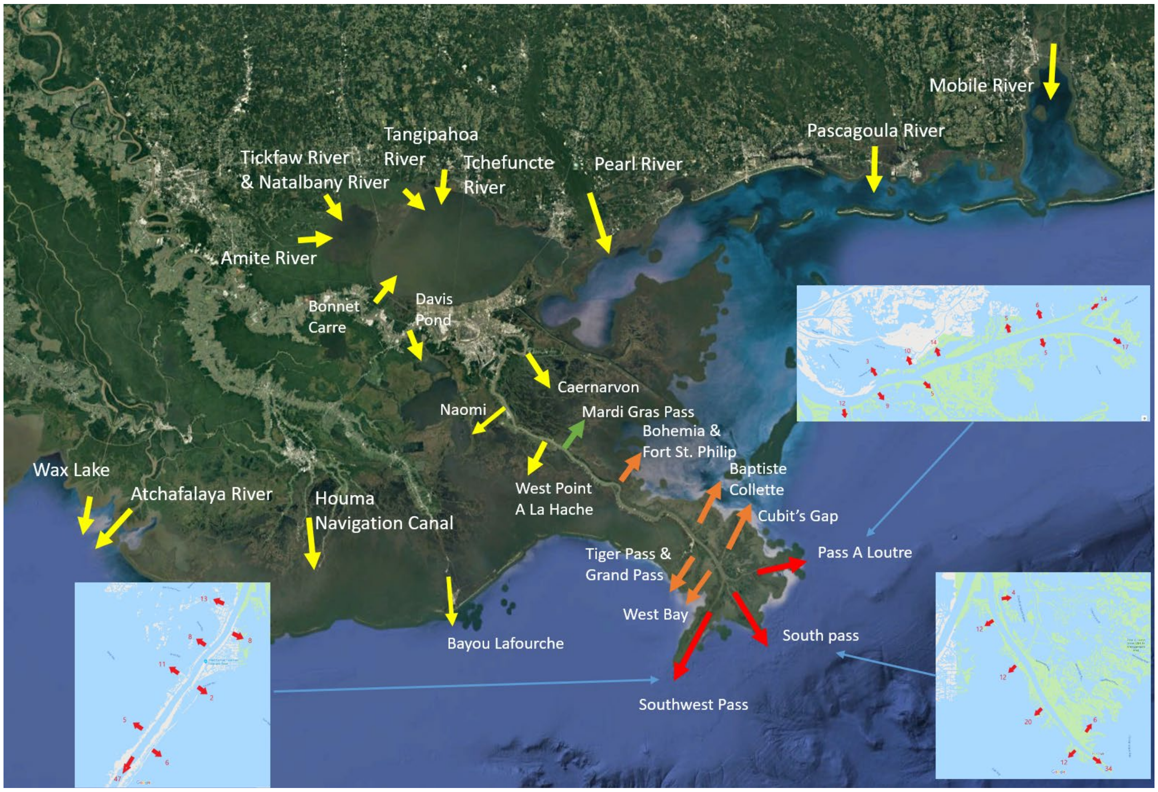


Figure 4. Locations of model freshwater sources.

Table 1. Detailed information about freshwater sources.

Freshwater input	**Data source**
Wax Lake	USGS 07381590
Atchafalaya River	USGS 07381600
Amite River	USGS 07380120
Tickfaw Rive	USGS 07376000
Natalbany River	USGS 07376500
Tangipahoa River	USGS 07375500
Tchefuncte River	USGS 07375000
Pearl River	USGS 02489500
Pascagoula River	USGS 02479310
Mobile River	USGS 02470629
Bonnet Carré	USACE (https://www.mvn.usace.army.mil/Missions/Mississippi-River-Flood-Control/Bonnet-Carre-Spillway-Overview/Spillway-Operation-Information/)
Caernarvon	USGS 295124089542100
Davis Pond	USGS 295501090190400
Naomi	USGS07380238
West Point a La Hache	Estimated by CPRA 2017 Master Plan
Mardi Gras Pass	Estimated by a rating curve based on USACE and UNO measurements.
Eight major passes	Estimated by rating curves (relationships with discharge at upper Bohemia)

The horizontal eddy viscosity and eddy diffusivity are chosen the calibrated values, that is, 2.5 m^2/s and 25 m^2/s, respectively. Vertically, the k-ε turbulence model is selected. The atmospheric forcings including wind velocity at 10 m and surface air pressure are adopted the 6-hourly NCEP/NCAR Reanalysis. The *Ocean* heat flux model is selected for temperature calculation, which needs the input of relative humidity, air temperature and cloud coverage. All these background fields are used the NCEP/NCAR Reanalysis as well. Four fractions of cohesive and non-cohesive sediments are included. Table 2 lists the calibrated sediment parameters in the model. Zero values are set for the initial conditions of water level, current and sediment. We use the HYCOM data (https://www.hycom.org/) to first guess the initial conditions of salinity and temperature, run the model for one month to 'warm-up', then replace these initials with the calculated results from the end of warm-up period.

Table 2. Calibrated sediment parameters in the model.

Sediment fraction	Cohesive or non-cohesive	D50 (μm)	Settling velocity (mm/s)	Critical shear stress (N/m^2)	Erosion parameter ($kg/m^2/s$)
Sand (riverine)	Non-cohesive	175			
Silt (riverine)	Cohesive		0.1	0.05	1e-3
Clay (riverine)	Cohesive		0.001	0.05	1e-3
Local soil (coastal)	Cohesive		0.005	0.1 ~ 0.15 (spatially varying)	2e-6 ~ 1e-5 (spatially varying)

2.4 DWAQ settings

D-Water Quality (DWAQ) is an open-sourced multi-dimensional water quality model framework in the Delft3D suite developed by Deltares. In order to keep the high spatial resolution in water quality calculations, we used the same DFLOW mesh in DWAQ with no aggregation. It also has 7 sigma layers vertically. The DWAQ run imports the DFLOW results (3-hourly) as input, including water level, current velocity, salinity, temperature, and sediment fields. The DWAQ time step is 1 hour. The water quality parameters of interest for this step are dissolved organic carbon (DOC), phosphate (PO4), sulfate (SO4), ammonium (NH4), nitrate (NO3), dissolved oxygen (DO), chlorophyll A, total phosphorous, total nitrogen, absorbed orthophosphate (AOP) and phytoplankton (FDIATOMS, FFLGELA, GREENS, MICROSYSTIS, and ANABAENA). In addition, some essential inorganic and organic matters were included as well. They are dissolved silica (Si), Opal-Si, dissolved organic nitrogen (DON), dissolved organic phosphorus (DOP), particulate organic carbon (POC), nitrogen (PON) and phosphorus (POP), and fast decomposing detrital carbon (DetC), nitrogen (DetN) and phosphorus (DetP) in the bed layer (S1). In terms of SO4, it was not calculated in the DWAQ model directly. Instead, we used salinity to derive SO4 by the relationship SO4 (mg/l) = 7.7% x Salinity (ppt) based on a sea water composition chart (https://www.fws.gov/uploadedFiles/Sea%20water%20composition%20chart.pdf).

Model parameters are either chosen default values or taken values from a previous calibrated DWAQ model (Meselhe et. al., 2015). Initial conditions, open-sea boundary conditions, rating curves for discharge sources, and phytoplankton mortality rates due to salinity are all adopted from Meselhe et. al. (2015) as well. Table 3 lists the rating curves in five rivers for discharge sources. Figure 5 shows the phytoplankton mortality rate curves due to salinity used in DWAQ.

Table 3. Rating curves in five rivers for discharge sources (WQ in mg/l, Q in m^3/s, reproduced from Table 4.26 in Meselhe et. al., 2015).

WQ	Mississippi River	Lake Maurepas	Tangipahoa River	Tchefuncte River	Pearl River
DO	$6.266Q^{0.0303}$	$9.719Q^{-0.087}$	$8.658Q^{-0.003}$	0.0445Q+8.436	$6.8277Q^{0.0384}$
POC	$0.002Q^{0.7405}$	$5E\text{-}4Q^2\text{-}0.029Q + 1.1578$	$0.4329e^{\ 0.0175Q}$	$0.3149Q^{0.5002}$	$0.861Q^{0.1097}$
DOC	$2.4426Q^{0.043}$	$4.8326Q^{0.2228}$	$4.8326Q^{0.2228}$	$2.2894Q^{0.5574}$	$1.7563Q^{0.2383}$
NH4	$0.0108Q^{0.0849}$	$0.0461Q^{0.2294}$	0.0013Q+0.0506	$0.0291Q^{0.4525}$	$0.012Q^{0.2955}$
NO2	$0.0004Q^{0.3526}$	$0.015Q^{0.0214}$	$0.008Q^{0.163}$	$1E\text{-}5Q^2 + 0.0002Q +0.010$	$0.0057Q^{0.1838}$
NO3	5.7606Q-0.158	$0.292Q^{-0.073}$	$0.142e^{0.013Q}$	0.005Q+0.2303	$0.240Q^{-0.031}$
TKN	$0.0473Q^{0.2601}$	$0.2809Q^{0.1973}$	$2E\text{-}5Q^2 + 0.0036Q +0.4847$	0.0204Q+0.4758	$0.3139Q^{0.1417}$
TKND	$0.4477Q^{-0.025}$	$0.3339Q^{-0.096}$	$0.2607Q^{0.2175}$	0.0156Q+0.3821	$06314Q^{0.0252}$
PO4	$4E\text{-}13Q^2 – 2E\text{-}6Q + 0.1332$	$0.0557Q^{0.091}$	$4E\text{-}6Q^2 + 0.0003Q +0.0302$	0.0015Q+0.0356	$0.0861Q^{-0.24}$
TP	$0.021Q^{0.2534}$	$0.1666Q^{-0.017}$	$1E\text{-}5Q^2 + 0.0006Q +0.0701$	0.002Q+0.084	$0.0403Q^{0.1604}$
TPD	$3E\text{-}11Q^2 – 3E\text{-}6Q + 0.1482$	$1E\text{-}5Q^2\text{-} 0.0004Q + 0.0477$	$1E\text{-}5Q^2 + 0.0004Q +0.0477$	0.0014Q+0.049	$0.0362Q^{-0.015}$
SIO2	$2.6032Q^{0.0955}$	$4E\text{-}4Q^2\text{-} 0.0614Q + 12.21$	$2E\text{-}4Q^2 + 0.0745Q +13.12$	$13.386Q^{-0.219}$	$18.227Q^{-0.159}$
SO4	$5E\text{-}8Q^2 – 0.0029Q + 74.935$	$0.3064Q^{0.6783}$	$0.0222Q^{2.095}$	$1.1124Q^{0.4858}$	$0.9045Q^{0.4129}$

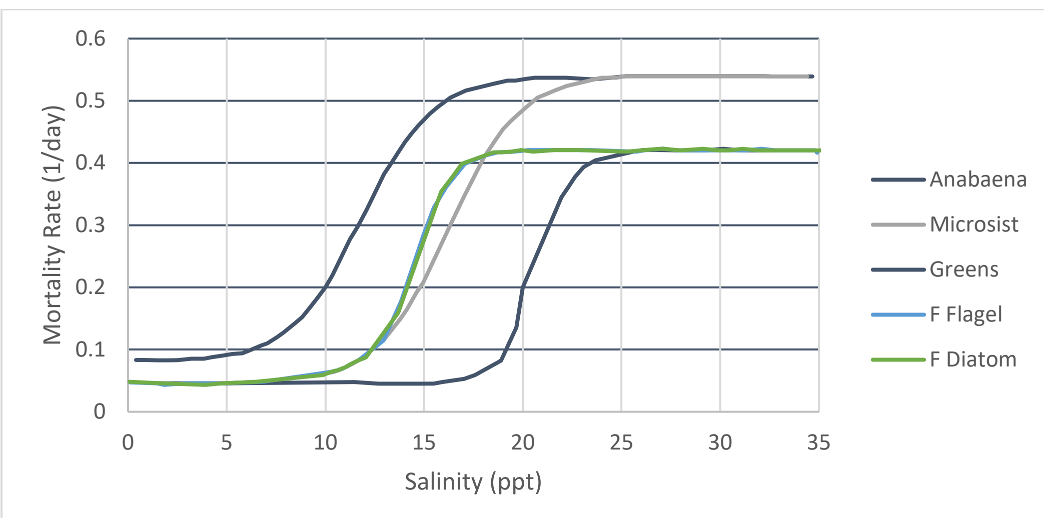


Figure 5. Phytoplankton mortality rate curves due to salinity (reproduced from Figure 4.118 in Meselhe et. al., 2015)

3. Model calibration

The whole year of 2018 is selected for model calibration. Figure 6 shows the 2018 Mississippi River hydrograph at Belle Chasse and BCS operations in 2018.

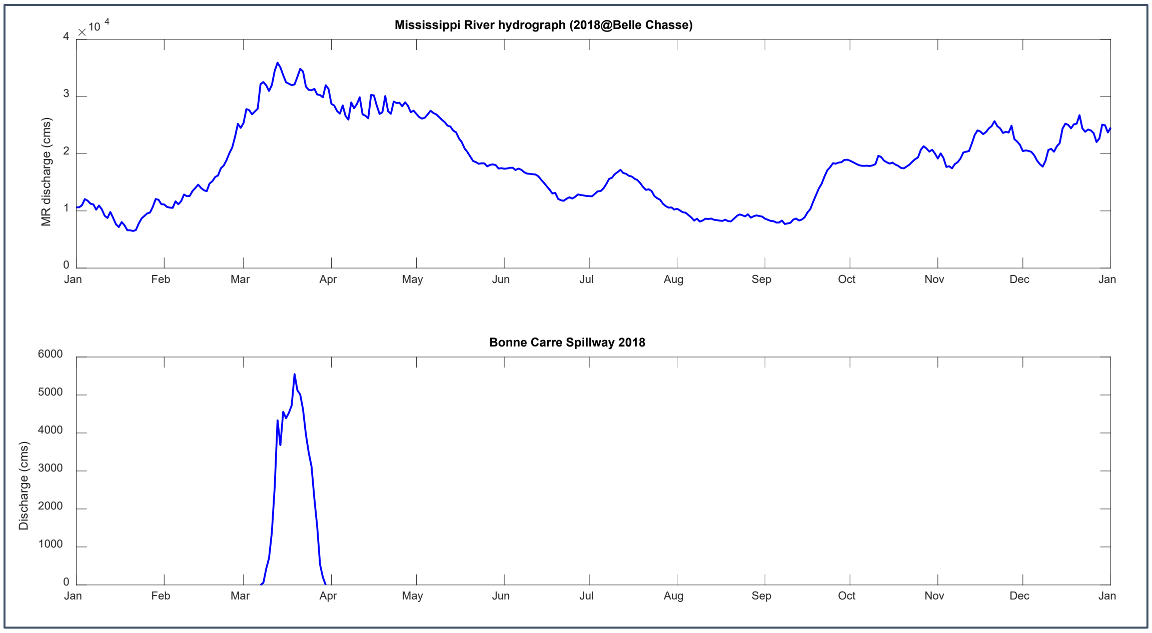


Figure 6. 2018 Mississippi River hydrograph at Belle Chasse (Top) and discharge at BCS (bottom).

Measurements from NOAA, USGS and CRMS stations are used for water level, salinity, and temperature model-data comparisons. Figure 7 shows locations of NOAA, USGS and CRMS stations used in this project. In terms of sediment and water quality variables, we use multi-year measurements at LDEQ sites for model-data comparisons. Figure 8 shows LDEQ sites. Data at yellow-highlighted sites are used in this project.

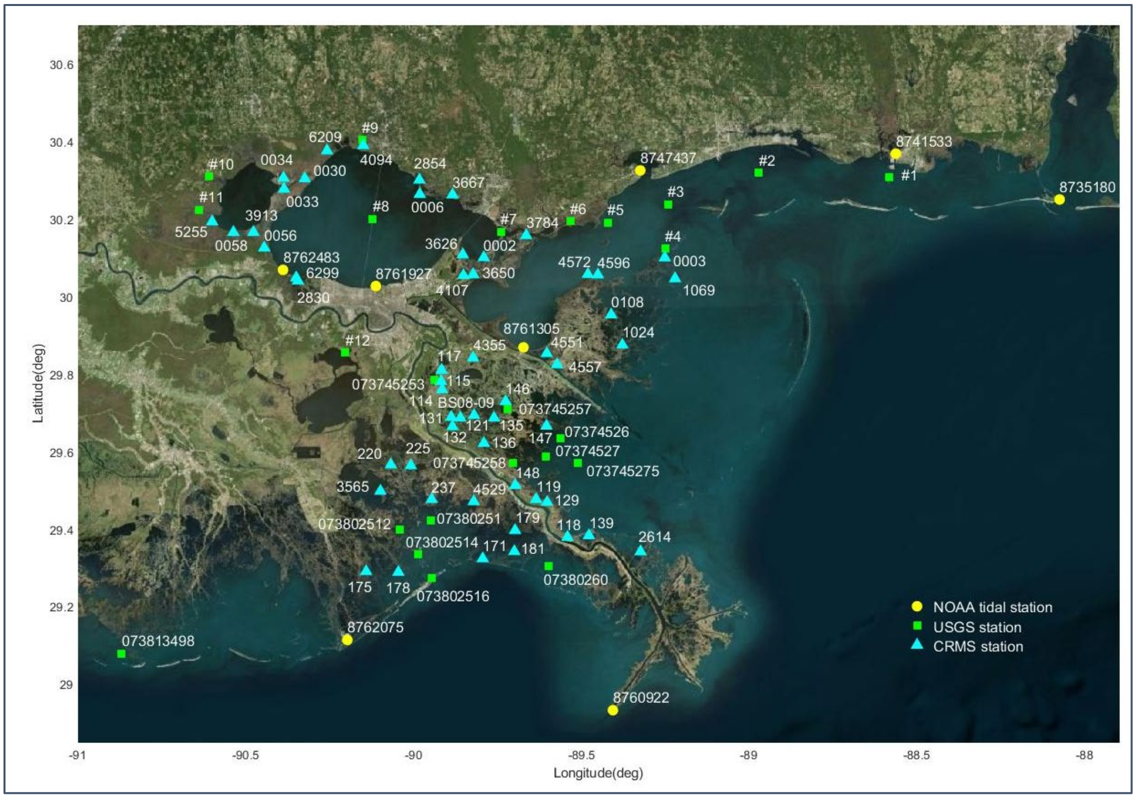


Figure 7. NOAA tidal, USGS and CRMS stations.

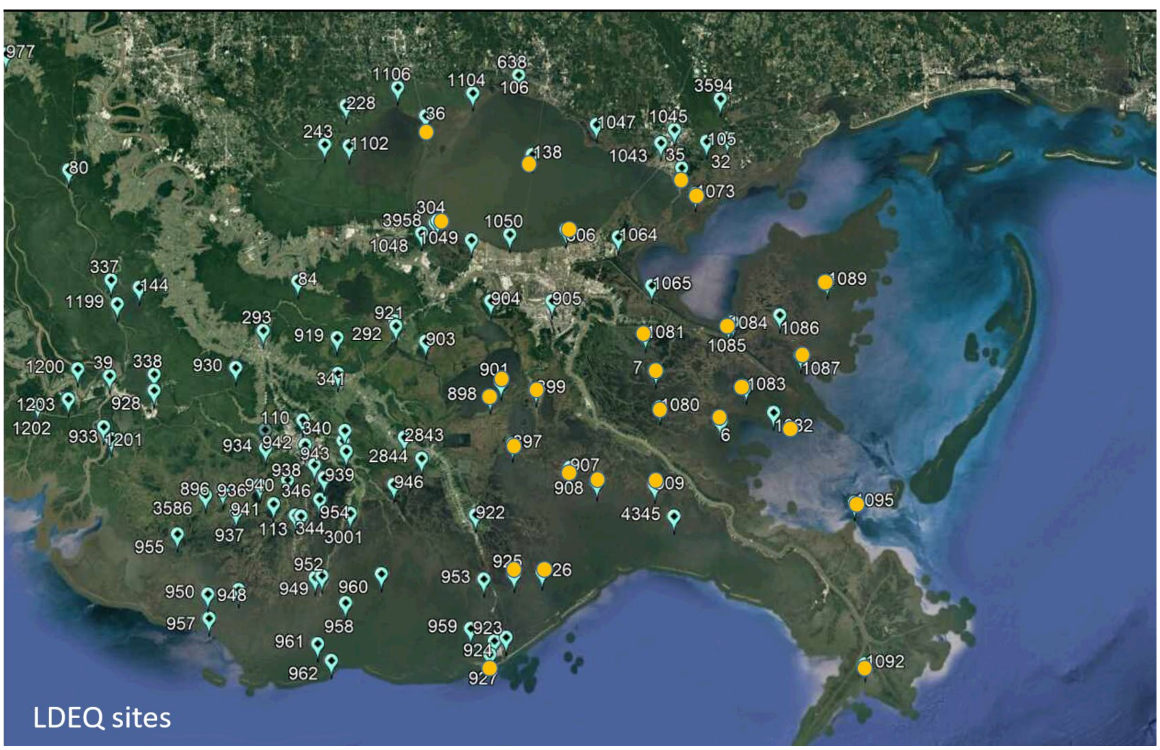


Figure 8. LDEQ sites. The sites used in this project are highlighted in yellow.

3.1 DFLOW calibration

Water level

Figure 9 shows the hourly water level (m, NAVD88) comparison at NOAA stations (see Figure 7) in Lake Pontchartrain, along the North shore and MS/AL coasts. The modeled results agreed very well the measurements.

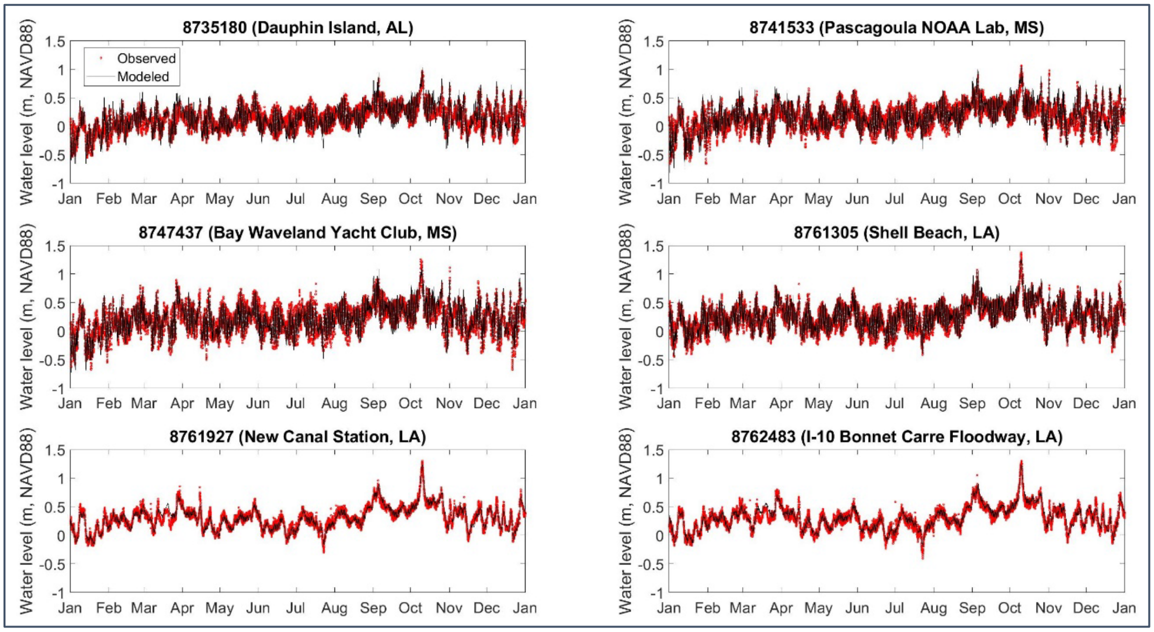


Figure 9. Hourly water level (m, NAVD88) comparison at NOAA stations.

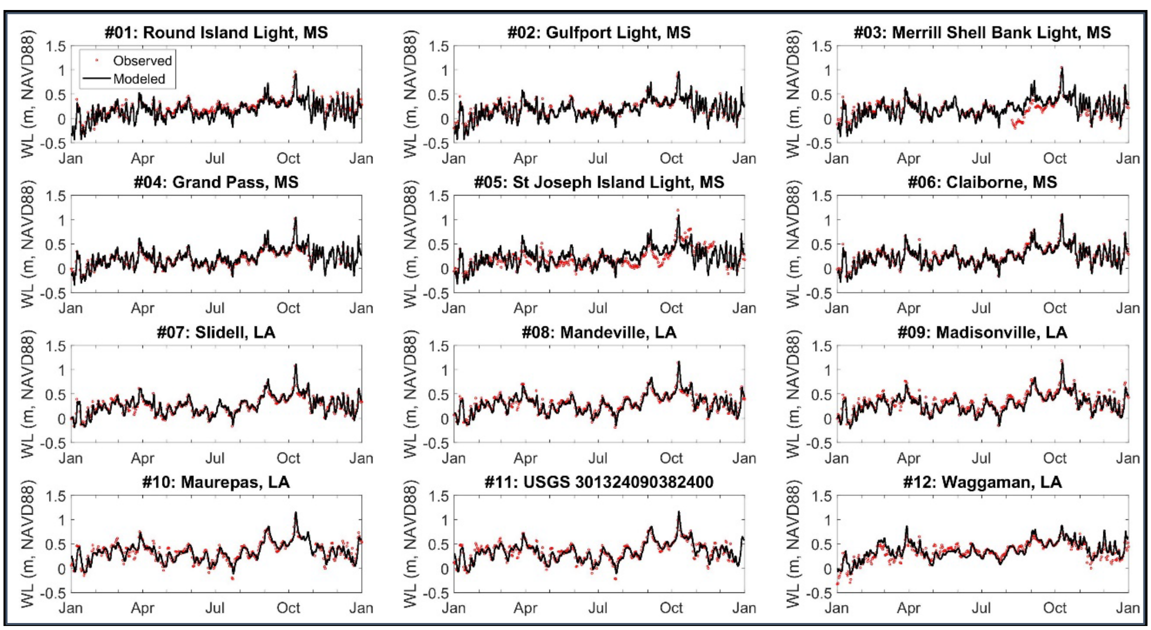


Figure 10. Daily water level (m, NAVD88) comparison at USGS stations.

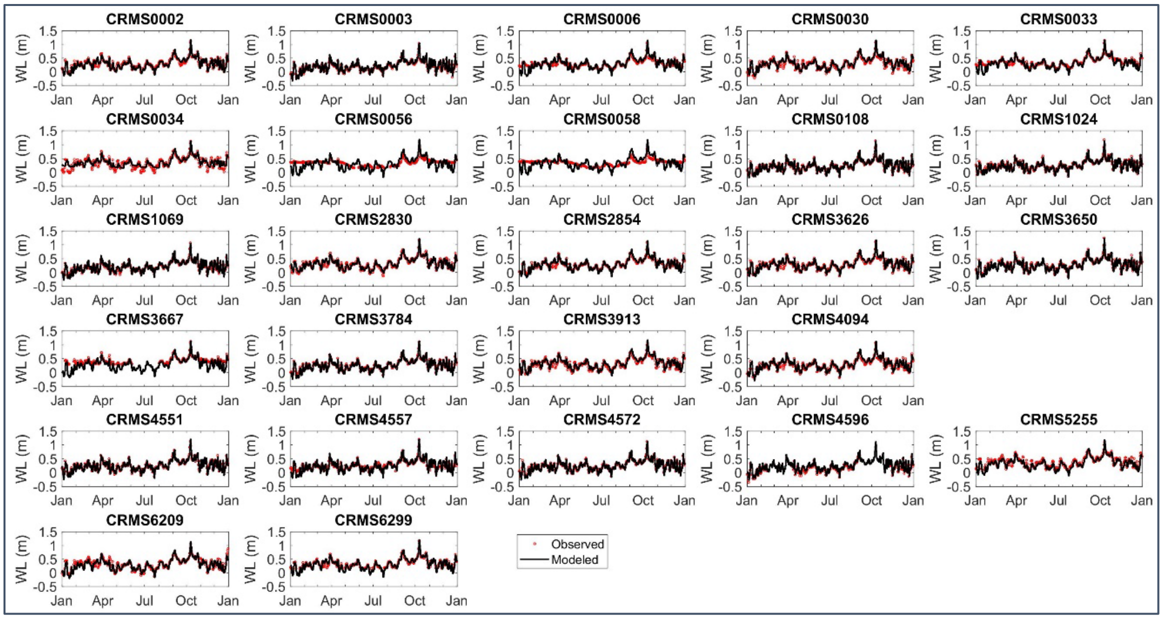


Figure 11. Daily water level (m, NAVD88) comparison at CRMS stations.

In addition, Figure 10 and Figure 11 show the daily water level (m, NAVD88) comparisons at USGS and CRMS stations, respectively. The model performances well at almost all stations except CRMS 4107 where the local bathymetry was not resolved in the model. The good agreement of water level indicates that the model reproduces well with the hydrodynamic fields under the forcings of tides, winds and multiple discharge sources including BCS operations.

Salinity

Figure 12 and Figure 13 show the salinity (ppt) comparisons at USGS and CRMS stations, respectively, throughout the computational domain except Breton Sound. Figure 14 and Figure 15 specifically show the salinity (ppt) comparisons at comparisons at USGS and CRMS stations, respectively, in Breton Sound. The agreements at most stations are fairly well, which means the model performed well with the transport phenomena for the whole year of 2018. For two CRMS stations in the Biloxi Marsh (0108 and 1024), the model overpredicted salinity in the first season of the year. This may be due to the overestimation of initial salinity field in this region since the agreements for the rest of the year are pretty good. We will solve this discrepancy in our future work. Figure 16 shows surface salinity distributions at two instants, one (3/19/2018) with the maximum flow rate during BCS operation and one (9/5/2018) with the low river discharge in dry season. 5-ppt contour lines are highlighted in yellow. The operation of BCS in 2018 caused salinity in Lake Pontchartrain and Lake Borgne less than 5 ppt, and the 5-ppt contour line extended to the coast of MS. During the dry season, salinity in Lake Borgne and along the coast of MS was larger than 5ppt, and the 5-ppt contour line retreated to the entrance of Lake Pontchartrain.

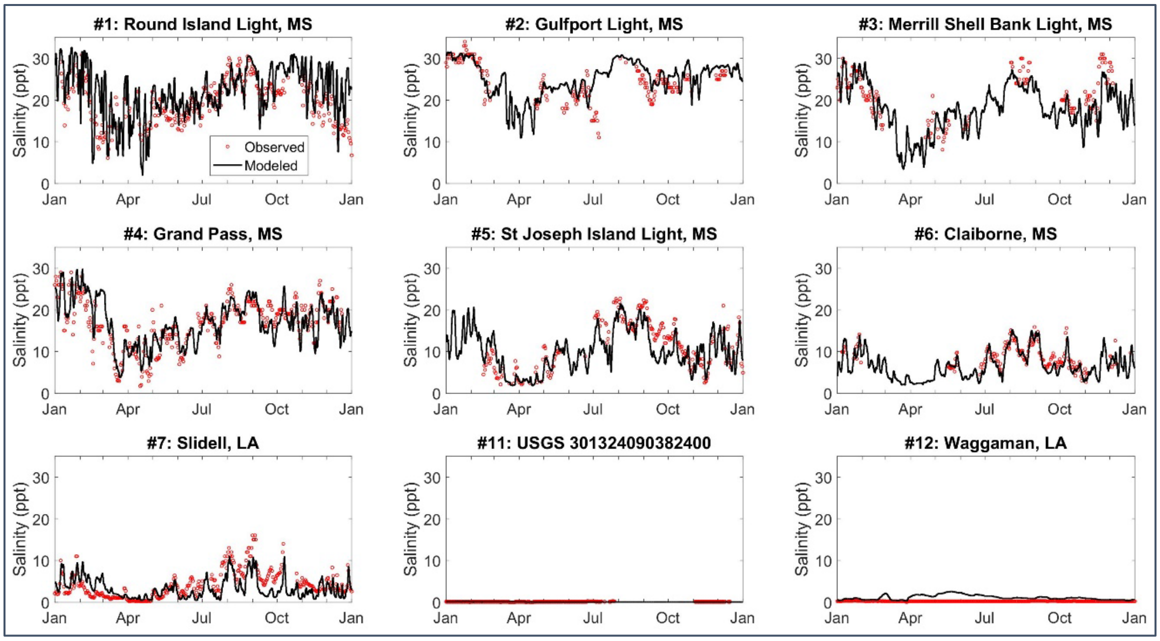


Figure 12. Salinity (ppt) comparison at USGS stations.

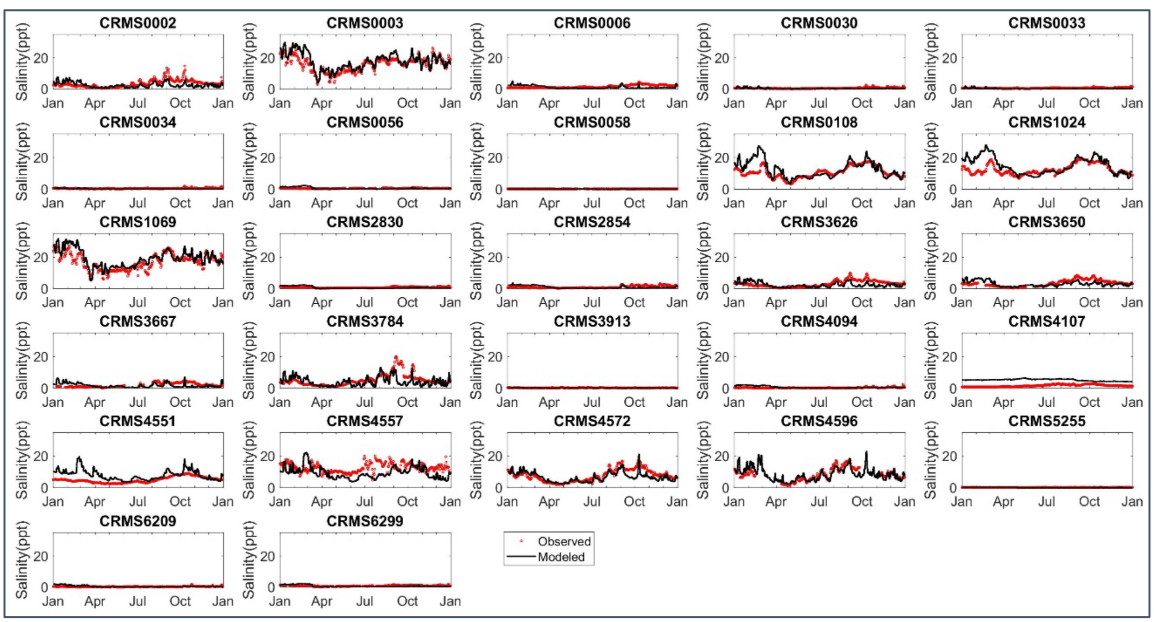


Figure 13. Salinity (ppt) comparison at CRMS stations.

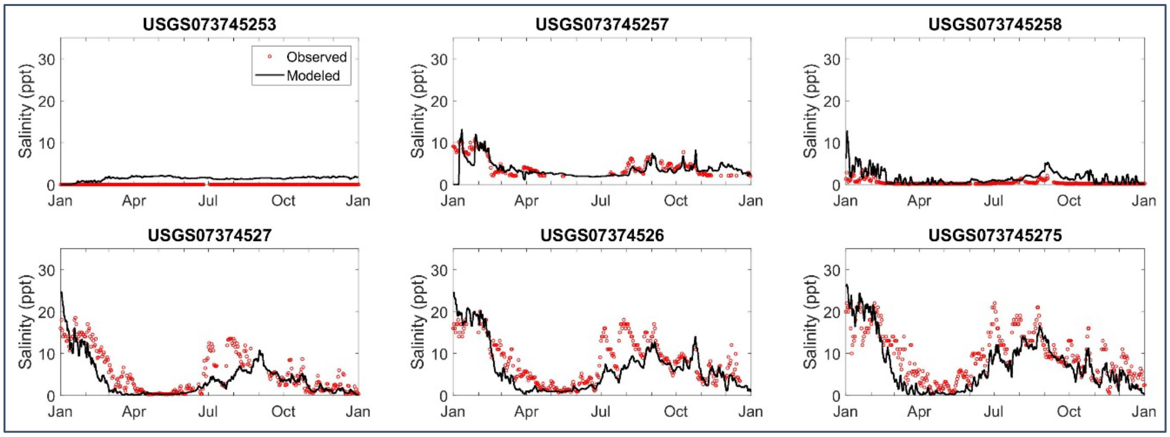


Figure 14. Salinity (ppt) comparison at USGS stations in Breton Sound.

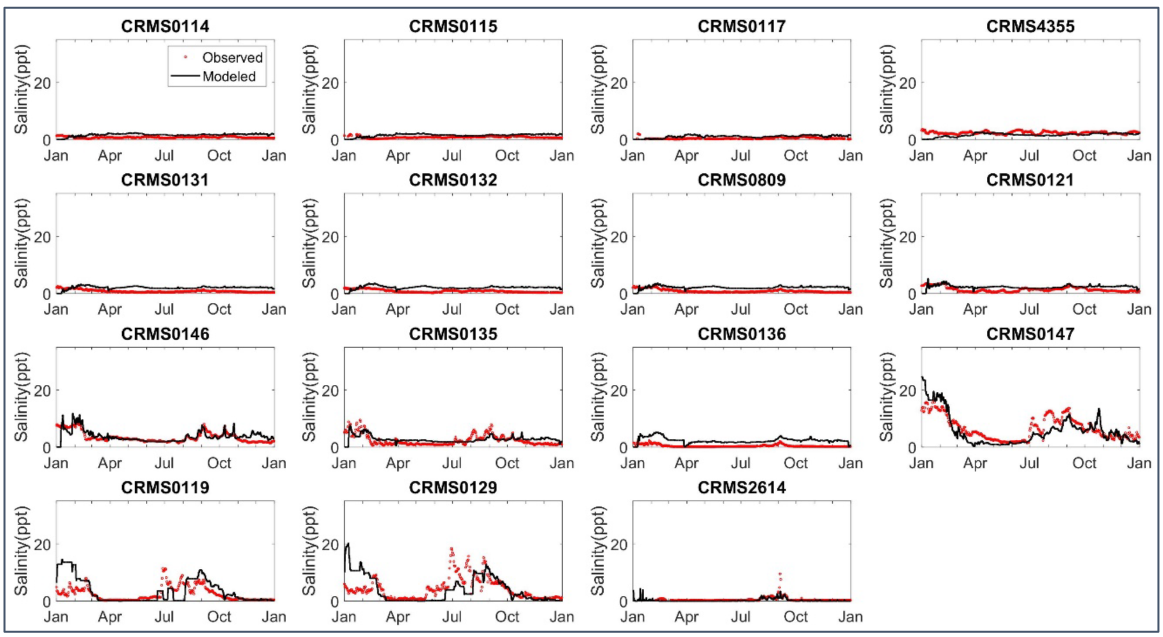


Figure 15. Salinity (ppt) comparison at CRMS stations in Breton Sound.

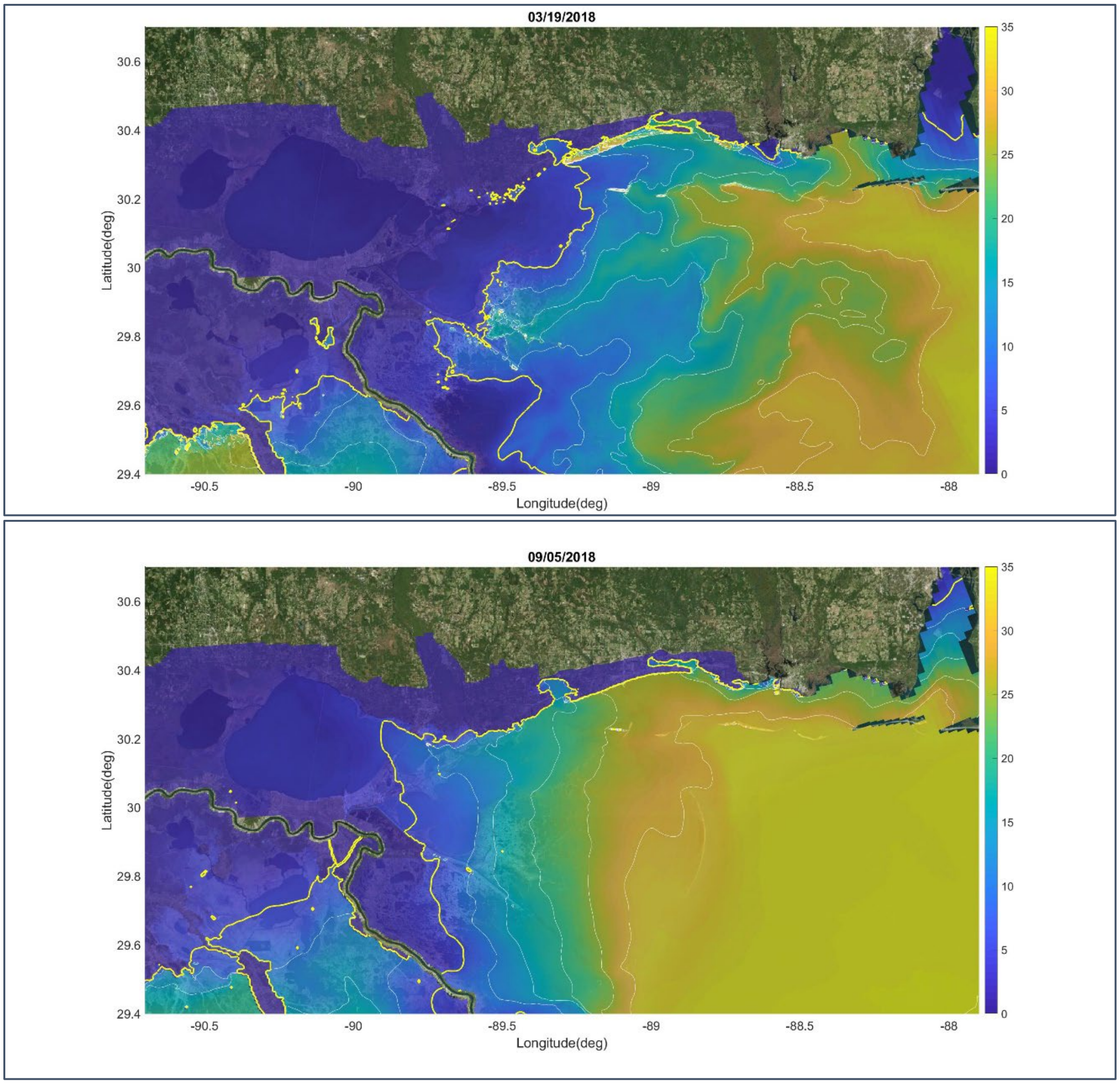


Figure 16. Two Snapshots (one with the maximum flow rate during BCS operation and one with the low river discharge in dry season) of salinity distribution in 2018. Contour lines with a value of 5 ppt are highlighted in yellow.

Temperature

Figure 17 and Figure 18 show temperature comparisons at USGS and CRMS stations, respectively. The modeled results agreed very well with the measurements except some overestimation at wetland CRMS stations (CRMS0033, CRMS0056 and CRMS0058) near Lake Maurepas during summer and fall. Overall, the model reproduced seasonal variations of temperature at almost all stations.

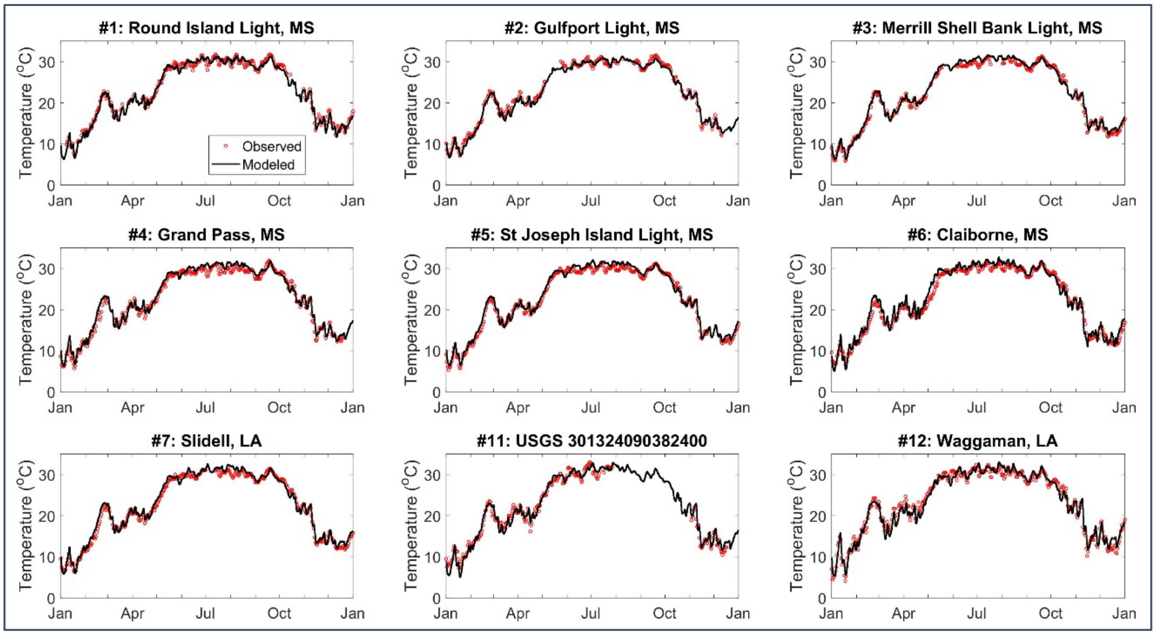


Figure 17. Temperature (ºC) comparison at USGS stations.

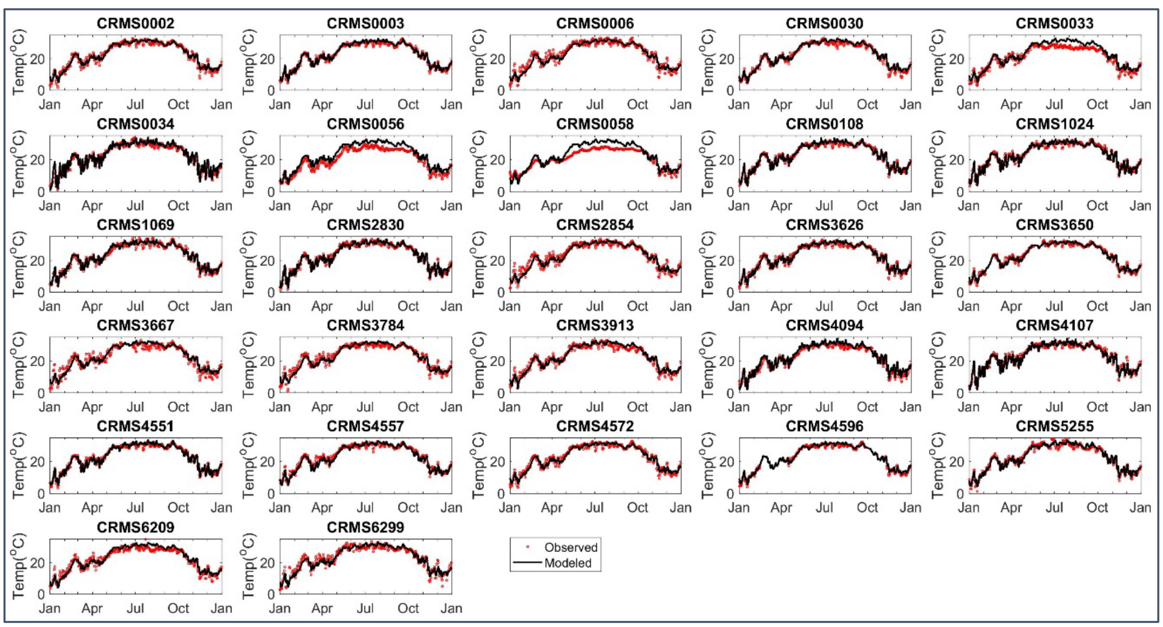


Figure 18. Temperature (ºC) comparison at CRMS stations.

Total suspended solids (TSS)

Figure 19 shows the comparison of TSS at LDEQ stations. Due to data availability, the 2018 modeled results were compared with multi-year TSS data (data in 2018 were highlighted with green triangles). The agreement is fairly good. The modeled concentration peaks at some stations (e.g., LDEQ 138, 304 and 306) at Lake Pontchartrain indicated the operation of BCS in March 2018.

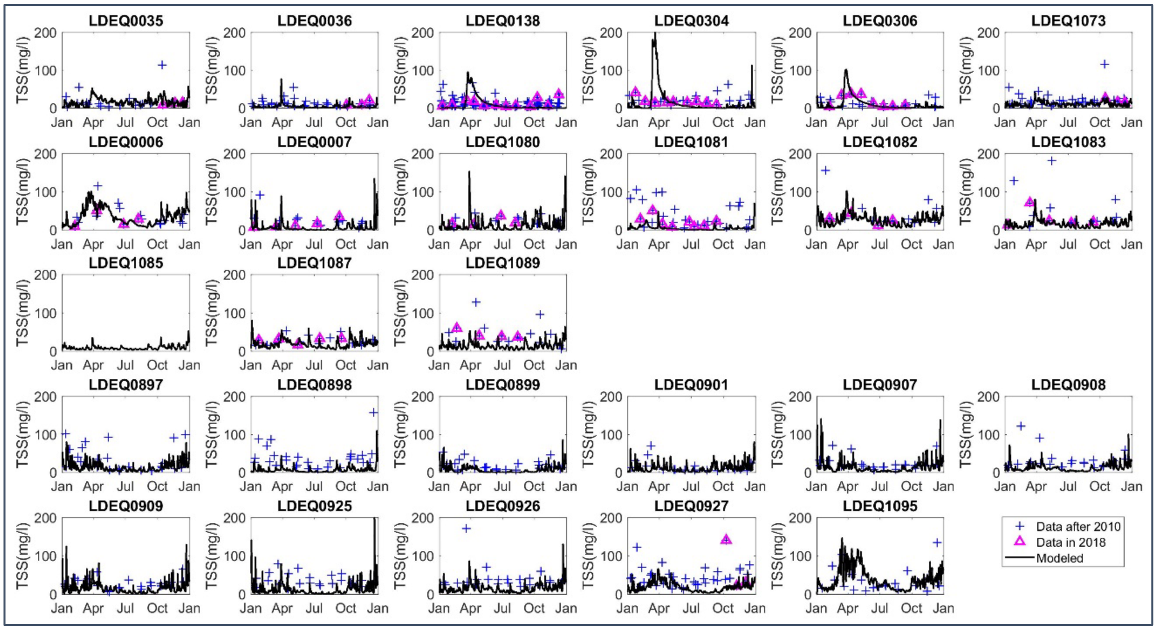


Figure 19. Total suspended solid (mg/l) comparison at LDEQ stations.

3.2 DWAQ calibration

Figure 20 shows the comparison of DO at LDEQ stations. The agreement is good except some abnormal variations at some stations, such as LDEQ 0927 and LDEQ 2092. This should be caused by some relevant water quality processes that we will be further looking into. The comparisons of NO3 and NH4 are showed in Figures 21 and 22, respectively. The modeled NO3/NH4 level was very low, which matched well at some locations, e.g., LEDQ 1080 for NO3, while overall, the model underestimated NO3 and NH4. This indicated either the lack of source input or the overconsumption by algae. The system turned into a nitrogen-limiting situation, which may not be right in reality. Further calibration is needed. At LDEQ 0035, we did find a nitrogen peek due to the operation of BCS. Figure 23 shows the comparison of TKN. The modeled results agreed well with the measurements. TKN has organic contributions. The good agreement of TKN indirectly verified the model performance in terms of organic nitrogen. The comparison of total phosphate is showed in Figure 24. The agreement is fairly good except overestimation for some period at LDEQ 0036 and LDEQ 0138. The comparison of SO4 is showed in Figure 25. The modeled salinity-derived SO4 was able to catch the huge range of measurement from 0 mg/l to over 2000 mg/l across multiple LDEQ stations. This also indicates the good performance of salinity calculation in the hydrodynamic model.

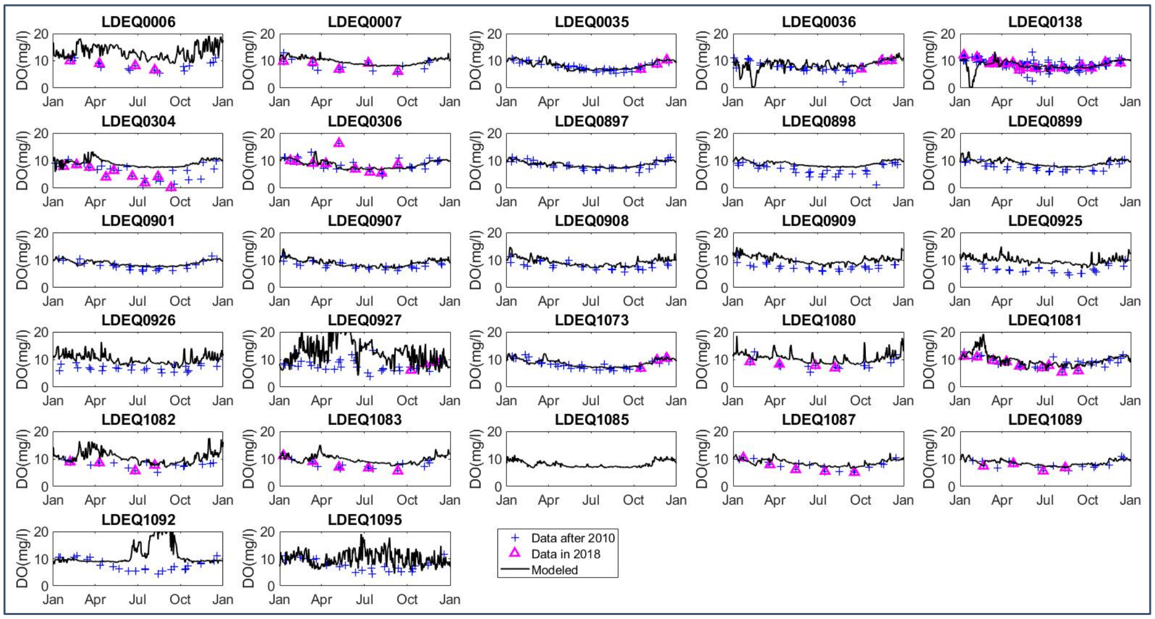


Figure 20. Dissolved oxygen (DO) comparison at LDEQ stations.

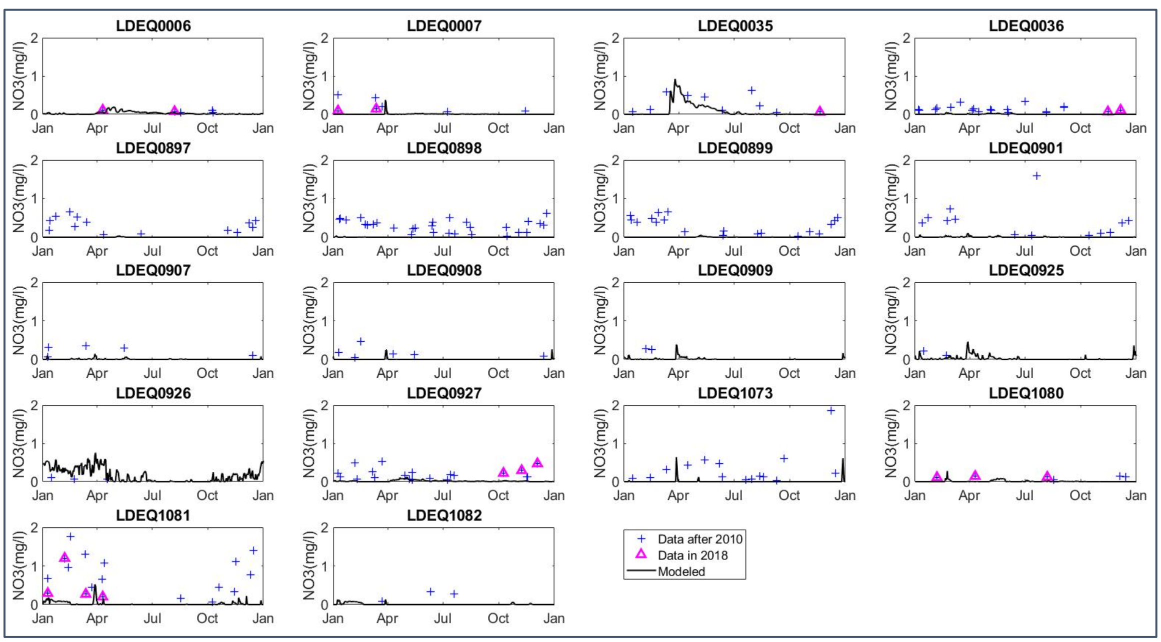


Figure 21. Nitrate (NO3) comparison at LDEQ stations.

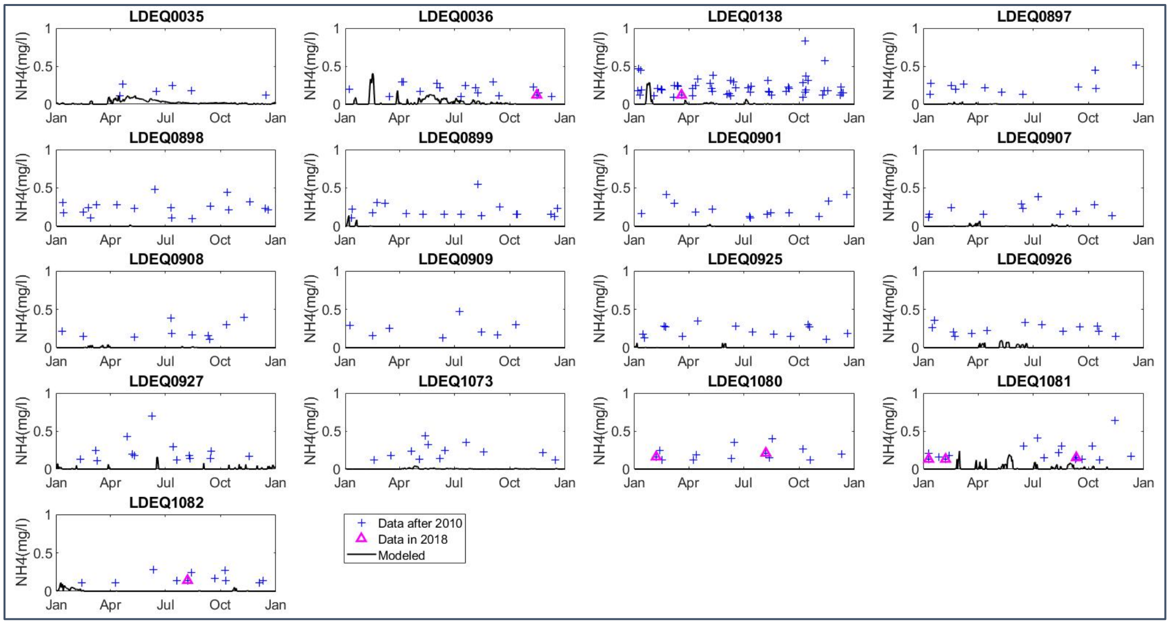


Figure 22. Ammonium (NH4) comparison at LDEQ stations.

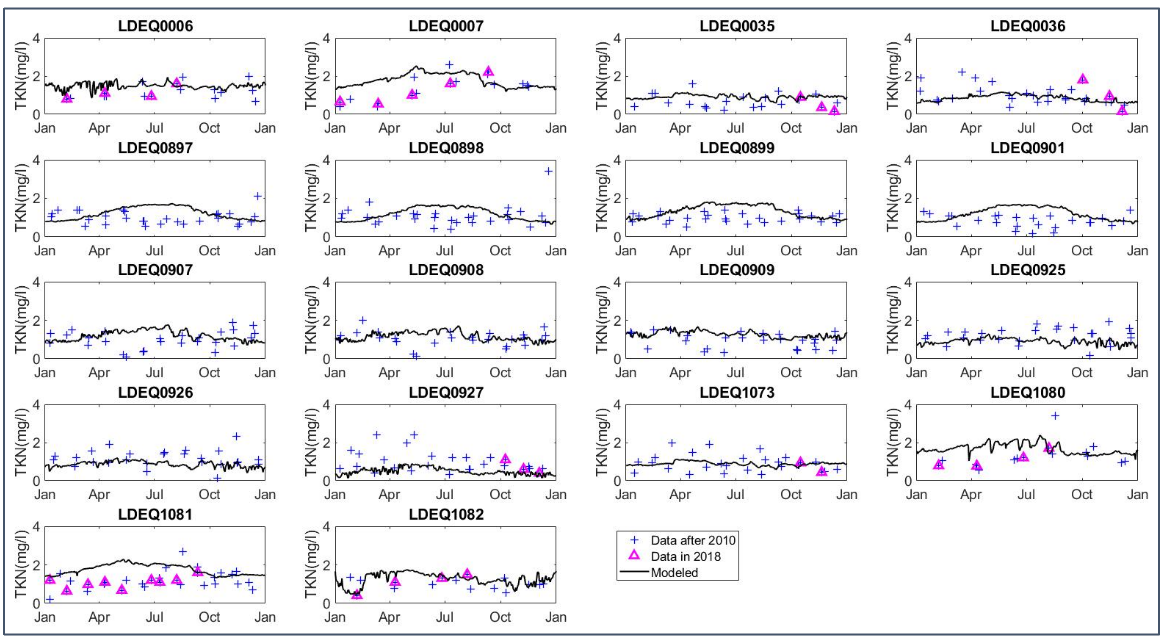


Figure 23. TKN comparison at LDEQ stations.

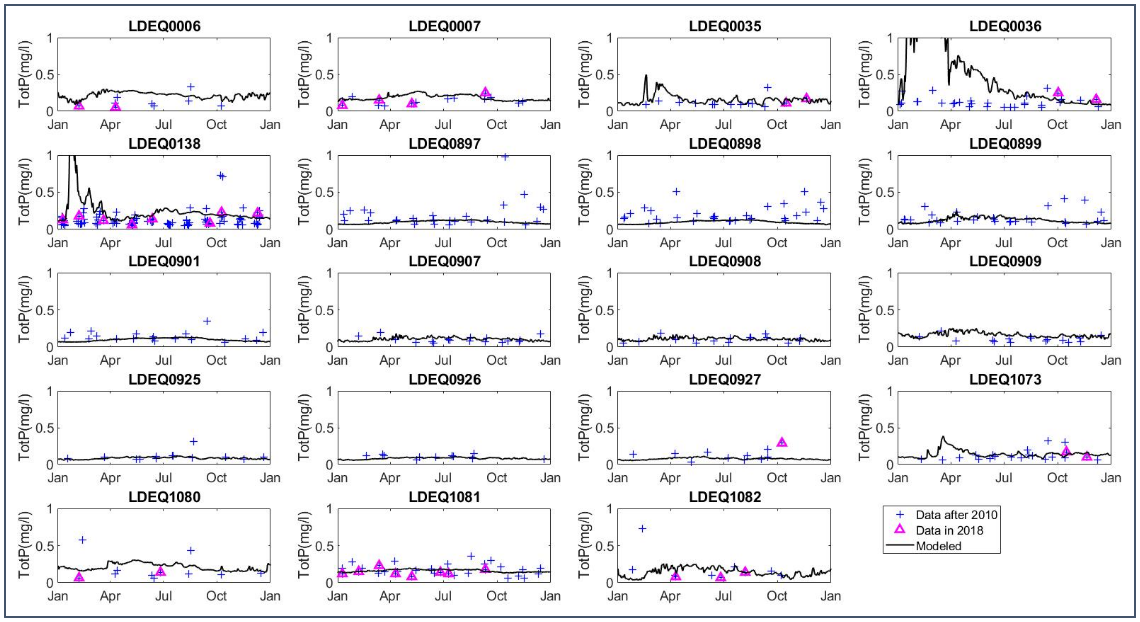


Figure 24. Total Phosphate (P) comparison at LDEQ stations.

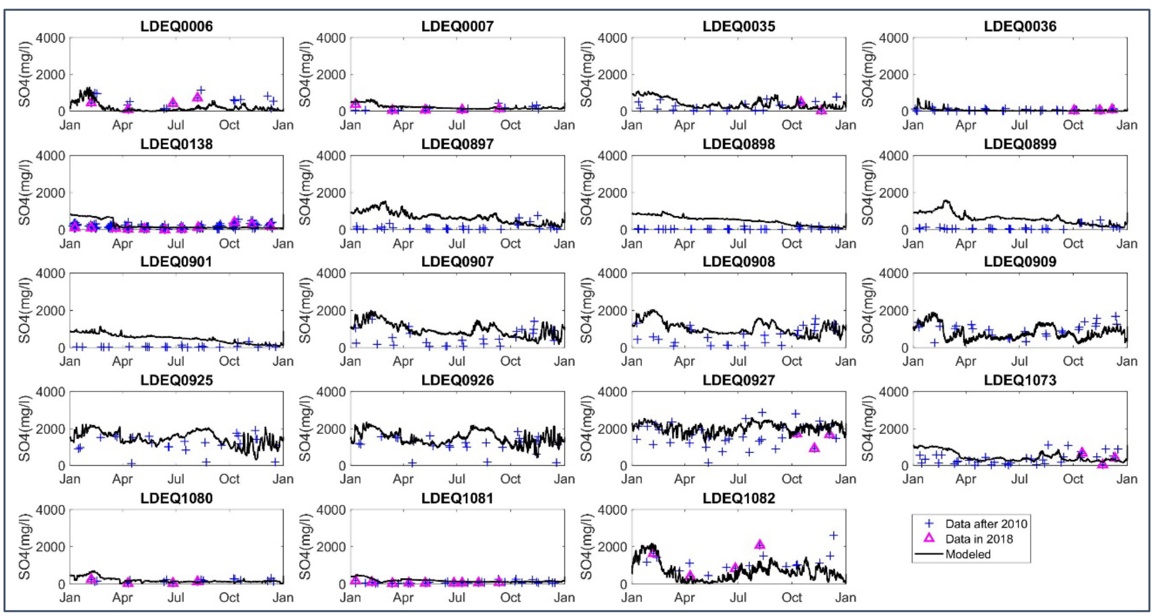


Figure 25. Sulphate (SO4) comparison at LDEQ stations.

Figure 26. Water quality comparison stations in Breton Sound and Barataria Basins.

In addition, we compared model results with measurements at four fixed locations (see Figure 26, two in Barataria and two in Breton Sound). These measurements were carried out in 2015 and reported in Meselhe et. al., 2015. Although model results and measurements were not in the same year, we can still check the model performance, especially for those substances that were not covered at LDEQ stations, such as chlorophyll A (Chla), TOC, TON and TOP. Figure 27 shows the comparison at BB05 which is located in Lake Salvador. Among 12 substances, the model results agreed well with measurements for 8 substances including Chla and organic matters, while the model underestimated NH4, NO3, PO4 and Si. BB18 is located at one of outlets from Barataria to the Gulf. As shown in Figure 28, the periodic variations due to tides were obvious at this station. Surprisingly, the agreements were perfect for most substances except some overestimation for DO and some underestimation for PO4 and Si. Figure 29 and Figure 30 show the comparisons of 10 substance at the upper (BB05) and at the middle (BB10) of Breton Sound, respectively. The agreements of Chla and Si are good at both stations. In terms of organic matters and TSS, the modeled results showed a little overestimation at both stations. Since the modeled and the observed are in different years, these discrepancies are acceptable. The model underestimated NO3 at BS05. The calculated level of PO4 was low at all four stations. The calculated Chla matched well with measurements at all four stations, which indicates the calculation of phytoplankton in the model is reasonable.

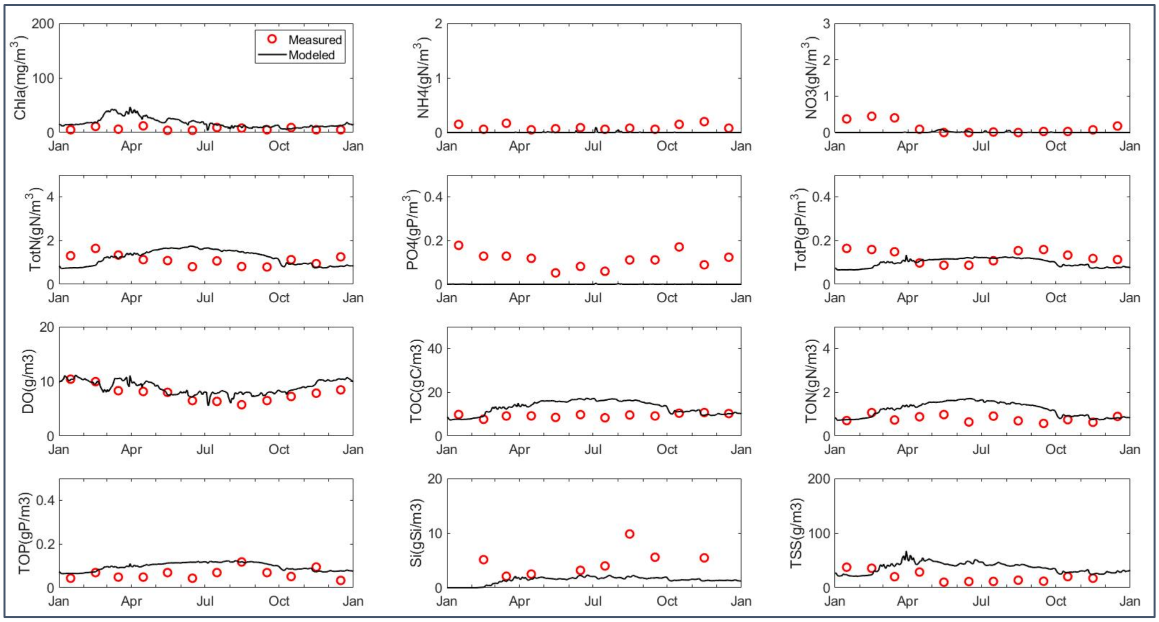


Figure 27. Water quality comparison at Station BB05 in Barataria.

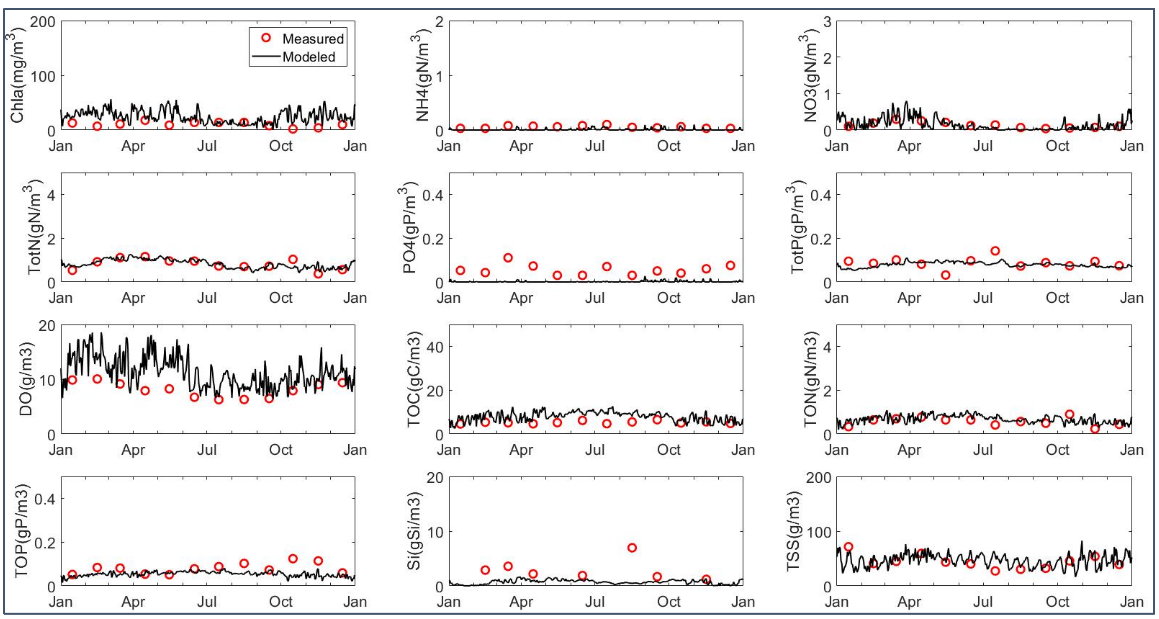


Figure 28. Water quality comparison at Station BB18 in Barataria.

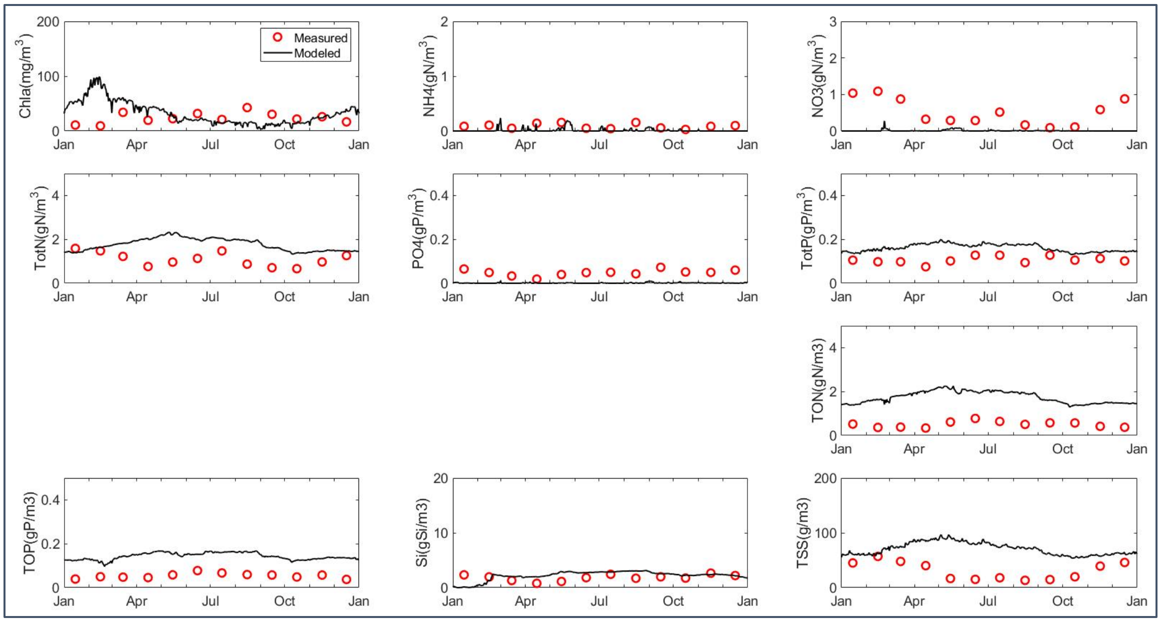


Figure 29. Water quality comparison at Station BS05 in Breton.

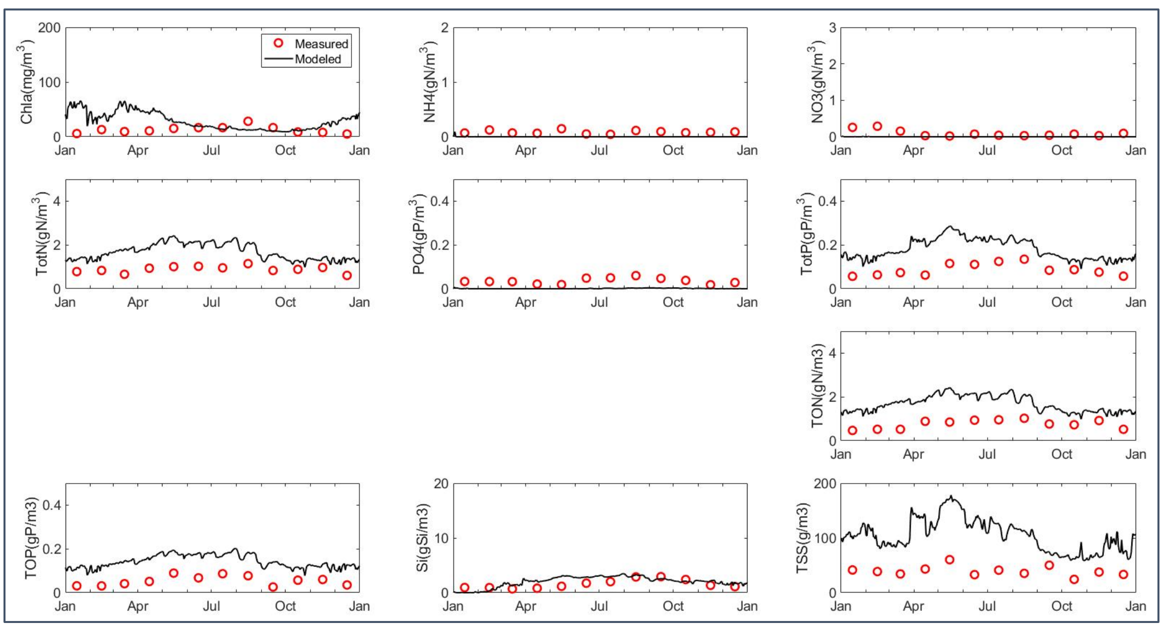


Figure 30. Water quality comparison at Station BS10 in Breton.

4. Sample Scenarios to Illustrate Potential Basin-side Benefits and Impacts

To illustrate the utility of the Delft3D tool developed as part of this effort, we performed a simulation for the year 2019. For demonstration purposes, we performed the historical 2019 conditions. We also simulated the activation of Ama (75,000 cfs) and Union (25,000 cfs) along with the modified/assisted Bonnet Carré. Figure 31 below shows the discharge hydrographs for this scenario.

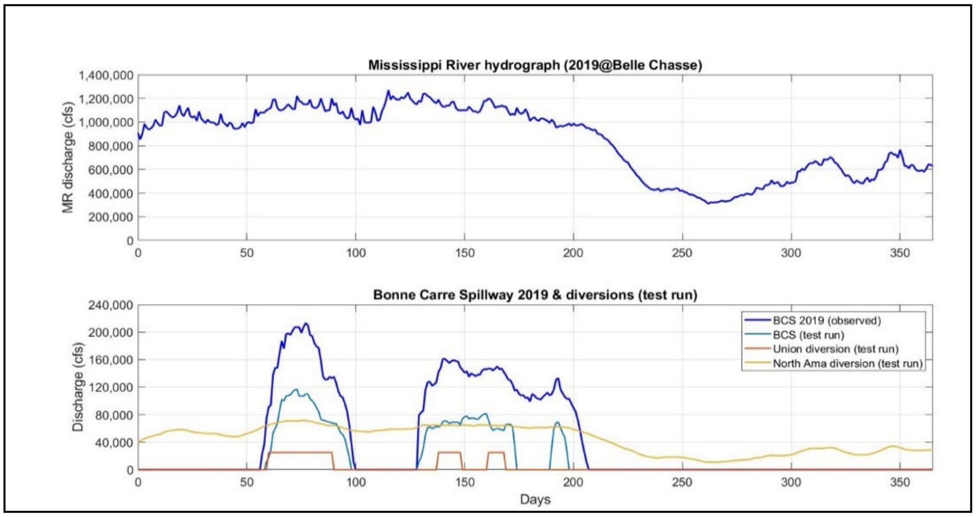
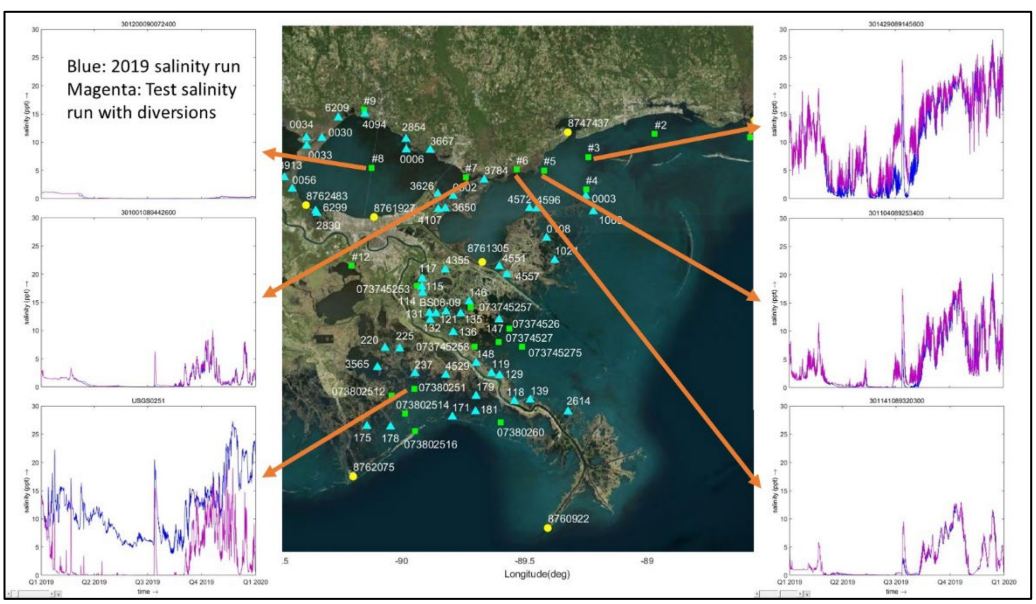


Figure 31. 2019-year simulation with and without the upper river diversions

The implementation of the upper river diversions results in a substantial reduction of the Bonnet Carré pulse in both magnitude and duration. Diverting some of the freshwater through the Barataria Basin and away from the Pontchartrain and Breton Sound, reduces the salinity impacts on the eastern side of the Mississippi River basin especially near the State of Mississippi coastal zone. Figure 32 below, shows salinity time series at select points near the State of Mississippi Coastal zone showing the salinity impacts resulting from the implementation of the upper river diversions.



5. Summary, closing remarks, and recommendations

In order to study the effect of BCS operations, a 3D process-based Delft3D model was developed and calibrated for simulations of hydrodynamics, salinity, temperature, sediment transport and water quality processes. Overall, the modeled results agreed well with the measurements, which indicated a good model performance. Due to the complicated water quality processes, some water quality substances and processes still need to be further adjustments. For instance, the model produced low level of NH4, NO3 and PO4. In this study, most water quality settings are consistent with those in Meselhe et. al., 2015. Some parameters may need to be further checked and adjusted.

It should be emphasized that setting up and calibrating this large-scale basin-side water, sediment, and water quality modeling system reflect a substantial effort and results in a vital predictive tool that can be used to answer restoration and river management questions.

This Delft3D model will continue to be used to provide information on the movement of water, sediment, salinity, temperature, and water quality parameters for various restoration scenarios. Releasing water through the upper river diversions (Union and Ama) allows for Mississippi River freshwater, nutrients and sediment to be routed through wetland areas in need of these resources. These wetland areas (Maurepas fresh swamps and upper Barataria) will filter out sediment and nutrients from the water column before reaching the Gulf of Mexico. Further, routing the freshwater through these upper basins and the associated reduction in the magnitude and duration of the Bonnet Carré pulse, will have positive impact on the salinity and nutrient regime for Lake Pontchartrain and the State of Mississippi's coastal zone.

Overall, the Delft3D model is a valuable tool that can be used by the Mississippi River Delta coalition to explore various scenarios of the upper River Diversions. A clear indicator of the value of the products delivered through this effort, is the fact that the State of Louisiana's Coastal Protection and Restoration Authority included the Upper River Diversions in their annual funding plan and currently tasked the Tulane modeling team to further evaluate the utility of the Union Diversion to assist Bonnet Carré as a supplement flood risk reduction structure while benefiting the fresh swamp of the Maurepas Basin.

Recommendations:

- Continue to improve the predictive quality of this vital water, sediment, and water quality modeling system as more data and funds become available.
- Perform modeling scenarios to evaluate various capacities of the Ama and Union diversions. Note: CPRA is currently evaluating Union diversion capacities of 25K, 50K, 75K, and 100K CFS.
- Communicate with stakeholders about the efficacy of implementation of upper River Diversion to capture the potential benefits and impacts on the ecosystem as well as the local communities.
- Explore the benefits of the upper river diversions in creating added protection benefits to local communities from natural hazards (hurricanes, and rainstorm flooding).

Acknowledgment

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References

Habib, E., Meselhe, E. and White E. (2017). 2017 Coastal Master Plan: Attachment C2-2: *Precipitation and Evapotranspiration.* Version Final. (p. 50). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Meselhe, E.A., Baustian, M.M., Allison, M.A. (Eds.) 2015. *Basin wide model development for the Louisiana Coastal Area Mississippi River hydrodynamic and delta management study.* The Water Institute of the Gulf. Prepared for and funded by the Coastal Protection and Restoration Authority. Baton Rouge, LA.