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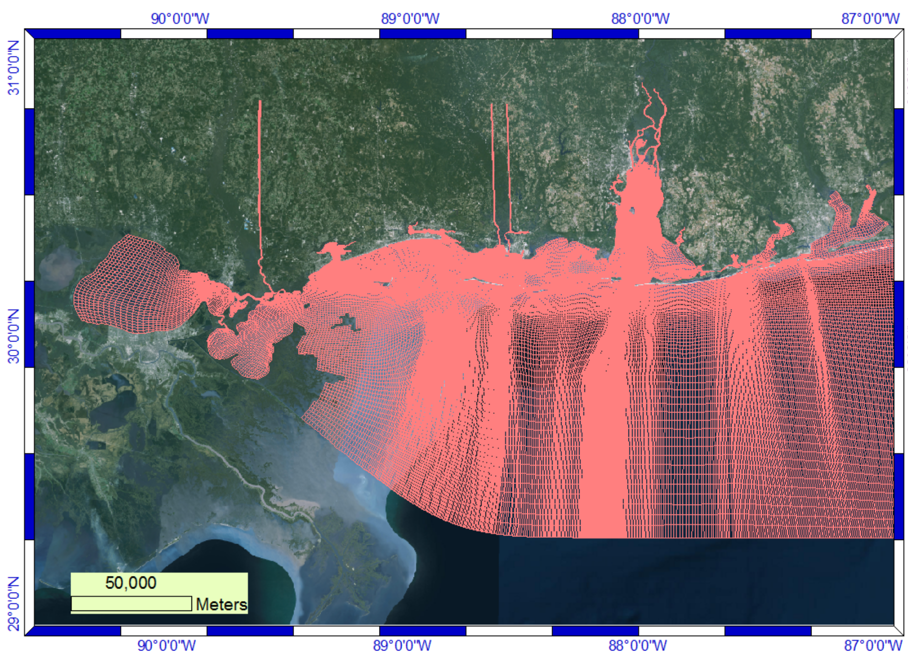
ERDC/Environmental Laboratory

Three-dimensional Hydrodynamic and Water Quality Modeling for Mobile Bay, the Mississippi Sound, and Areas Surrounding Dauphin Island, AL.

Barry W. Bunch, Sung-Chan Kim, and Elizabeth Godsey June 2020



Distribution is limited.

Three-dimensional Hydrodynamic and Water Quality Modeling for Mobile Bay, the Mississippi Sound, and Areas Surrounding Dauphin Island, AL.

by

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Introduction

Dauphin Island, a barrier island off the coast of Alabama, plays an important role in the protection of the state's coastal natural resources. During an 8-year span from 2004 to 2012, the island experienced significant tropical storm events and a man-made disaster that affected the morphology and ecology of the island. These included Hurricanes Ivan, Katrina, and Isaac, as well as the Deep Water Horizon oil spill. One of the most significant impacts was a 2 kilometer (km) breach in the barrier island created by Hurricane Katrina in 2005. As a response to the 2010 Deep Water Horizon oil spill, a temporary rubble mound structure was constructed across the cut to prevent oil moving into the Mississippi Sound. This structure has since been retained by the state due in part to potential longer term water quality benefits. This technical report presents the results of the water quality response modeling that was part of the wider Alabama Barrier Island Restoration Assessment Study sponsored by the National Fish and Wildlife Foundation (NFWF) and the State of Alabama. The hydrodynamic and water quality response modeling was performed by the Environmental Laboratory, US Army Engineer Research and Development Center (ERDC-EL) and the Coastal Hydraulic Laboratory (ERDC-CHL). Changes in water quality were evaluated for different potential large scale morphological change scenarios (i.e. island breaching) that were simulated as part of the United States Geological Survey (USGS) hydrodynamic and morphological changes modeling contained in Mickey et al. (2020) . In addition, results of the water quality modeling were passed off to USGS teams that further evaluated the potential changes in the habitat suitability of oysters and sea grasses. The details of these additional analysis conducted as part of the Alabama Barrier Island Assessment are contained in Enwright et al. (2020).

Geophysical Scale Multi-Block (GSMB) Model

ERDC-EL, ERDC-CHL, and the Army Corps of Engineers, Mobile District (SAM) completed hydrodynamic, water quality and sediment transport modeling of Mobile Bay to determine the potential impact of channel improvements that were conducted as part of the Mobile General Re-evaluation Report (GRR) study (Hayter, et al., 2018). The Geophysical Scale Transport Modeling System (GSMB), comprised of suites of interconnected models, was utilized for this end. A grid system common to the hydrodynamic, water quality, and sediment transport model components was developed to encompass the Mobile Bay and extend beyond the shelf breaks of the adjacent Northern Gulf of Mexico between Lake Pontchartrain and Pensacola, Florida, Figure 1. As detailed in Hayter et al. (2018) the models were calibrated and validated with available data sets for the year 2010. Figure 2 shows the 49 block system. The green lines in these figures shows the overlapping or communication cells for each block.

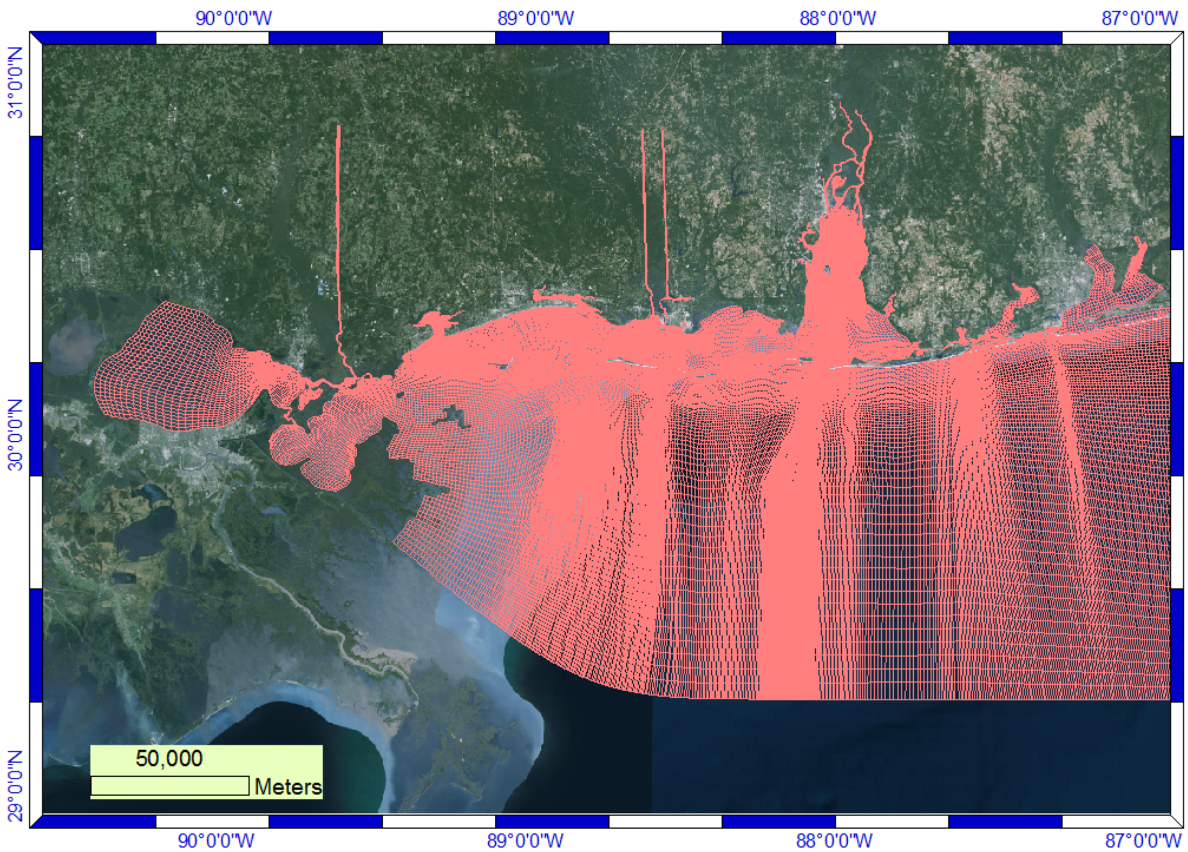


Figure 1. Model grid

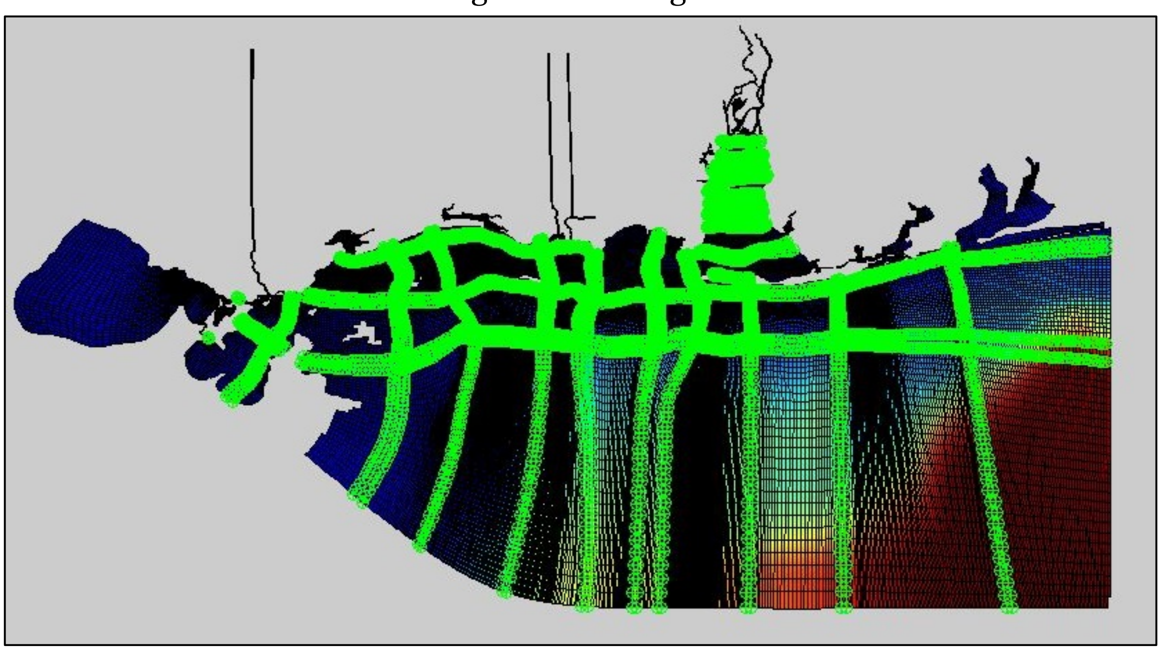


Figure 2. The 49-block setup for GSMB

GSMB Application for the Alabama Barrier Island Restoration Assessment

1. Baseline Condition

The 49-block GSMB grid for the previous Mobile Harbor study was used for water quality modeling of the baseline condition. One-year simulations of water quality and hydrodynamics of Mobile Bay and adjacent Northern Gulf of Mexico for 2015 were performed to line with the time period of hydrodynamic and water quality data collection as part of the Alabama Barrier Island Restoration Assessment. During 2015, wet winter-spring and dry summer-fall was distinct, Figure 3. An apparent meteorological event was set during the latter part of October, Figure 4.

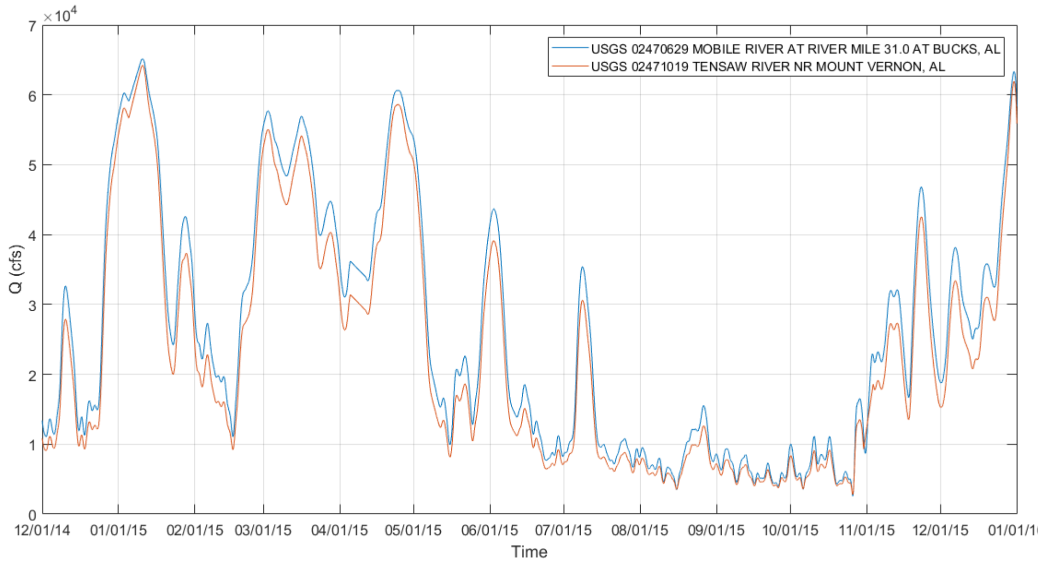


Figure 3. 2015 Hydrology conditions for Mobile Bay

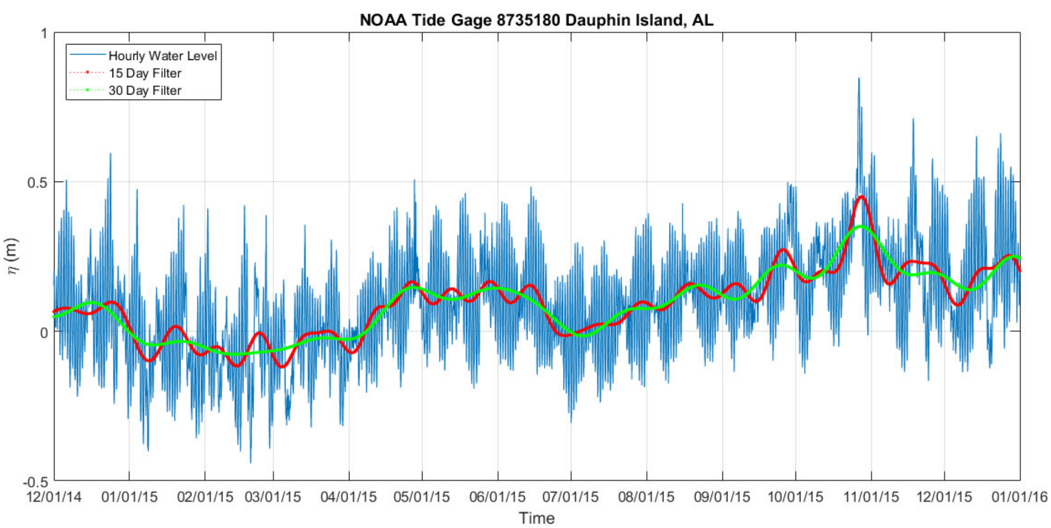


Figure 4. Water levels at Dauphin Island NOAA gage

For validation, predicted salinity time series data at National Oceanic Atmospheric Administration (NOAA) National Estuary Program (NEP) stations, Figure 5, were compared with observation. The salinity distribution over a year in 2015 exhibits the response to both hydrological conditions (low salinity during spring and high salinity during summer) and meteorological conditions (e.g. spiked salinity around 10/25/2015 at Cedar Point) throughout the system, Figures 6 -10.

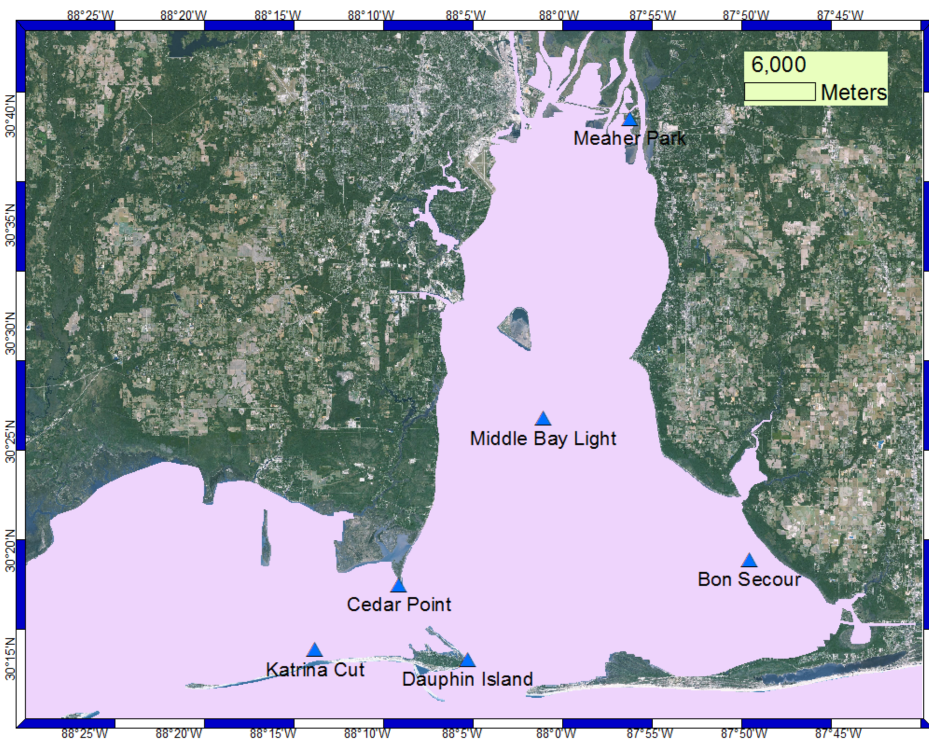


Figure 5. NOAA NEP stations

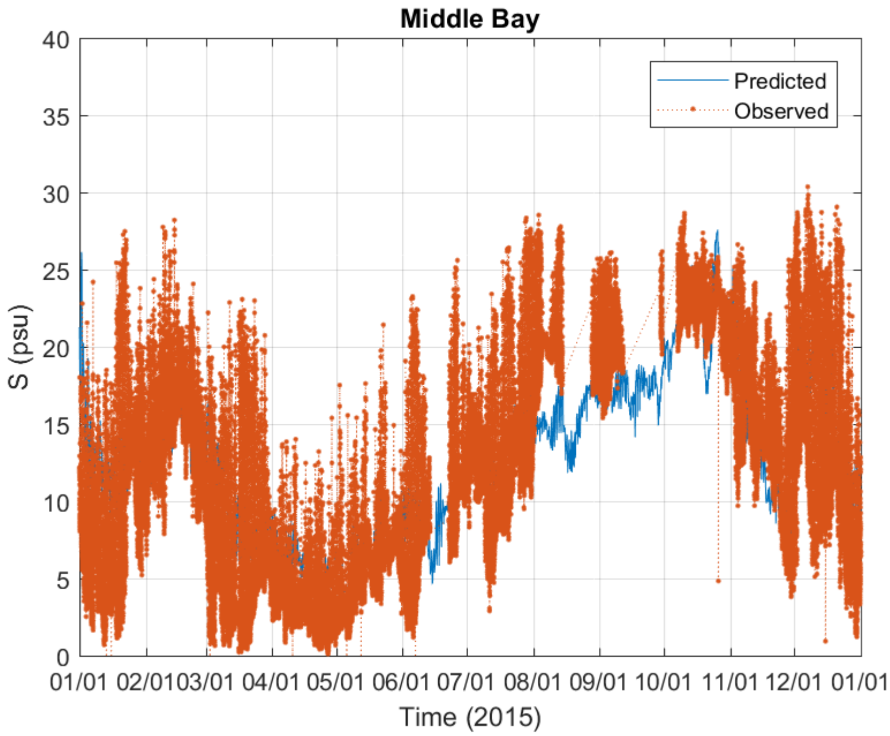


Figure 6. Salinity time series at Middle Bay

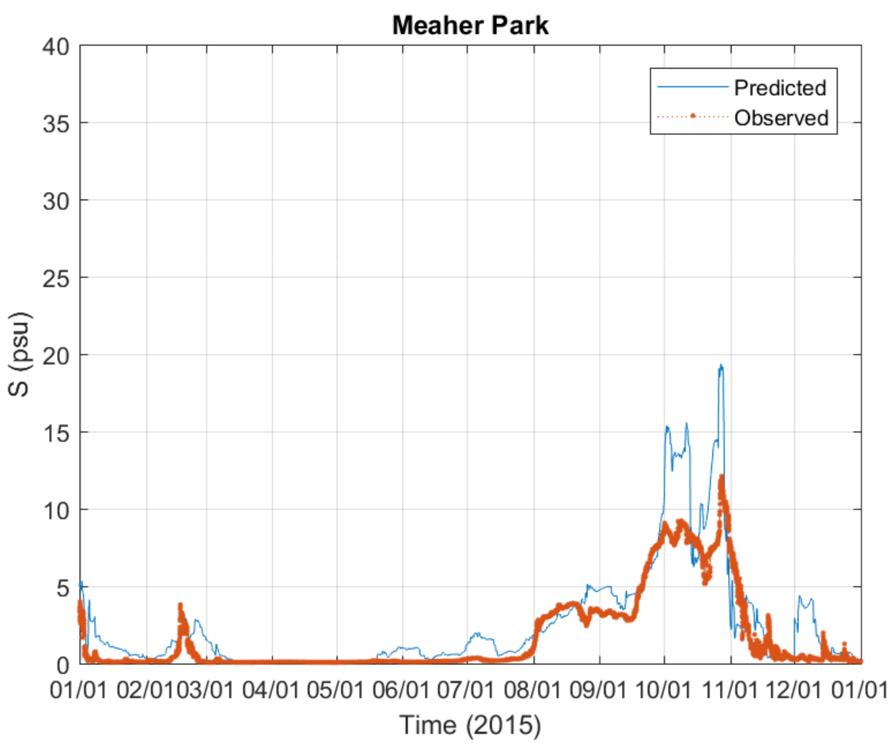


Figure 7. Salinity time series at Meaher Park

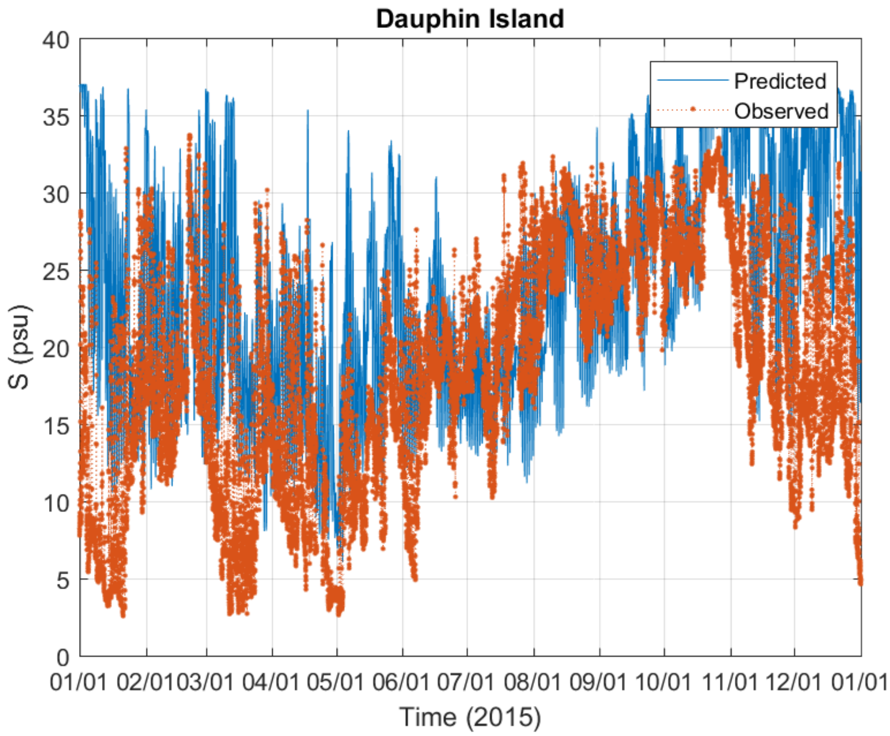


Figure 8. Salinity time series at Dauphin Island

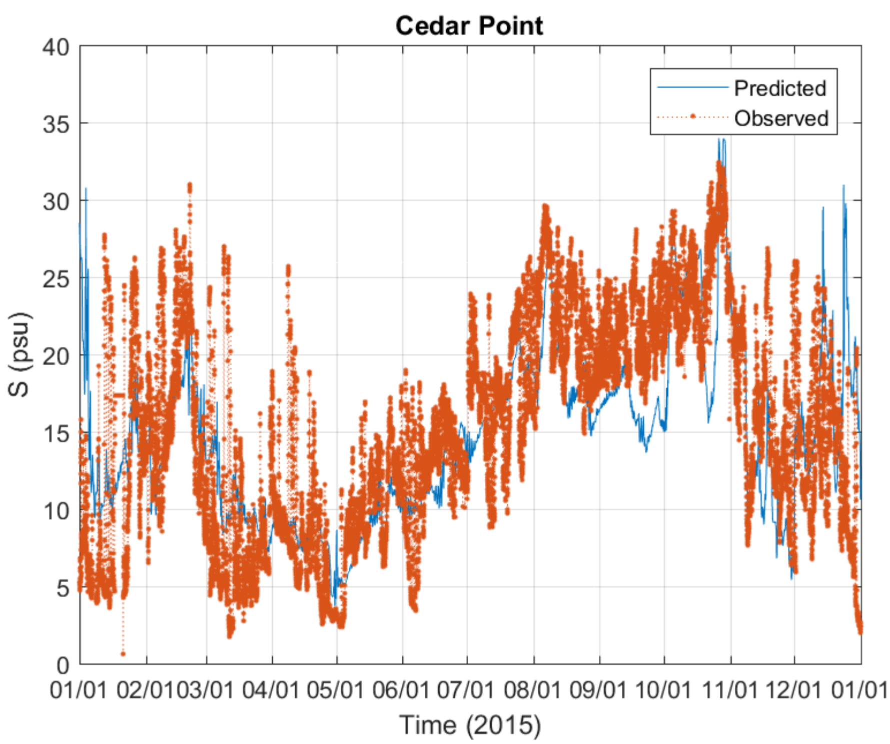


Figure 9. Salinity time series at Cedar Point

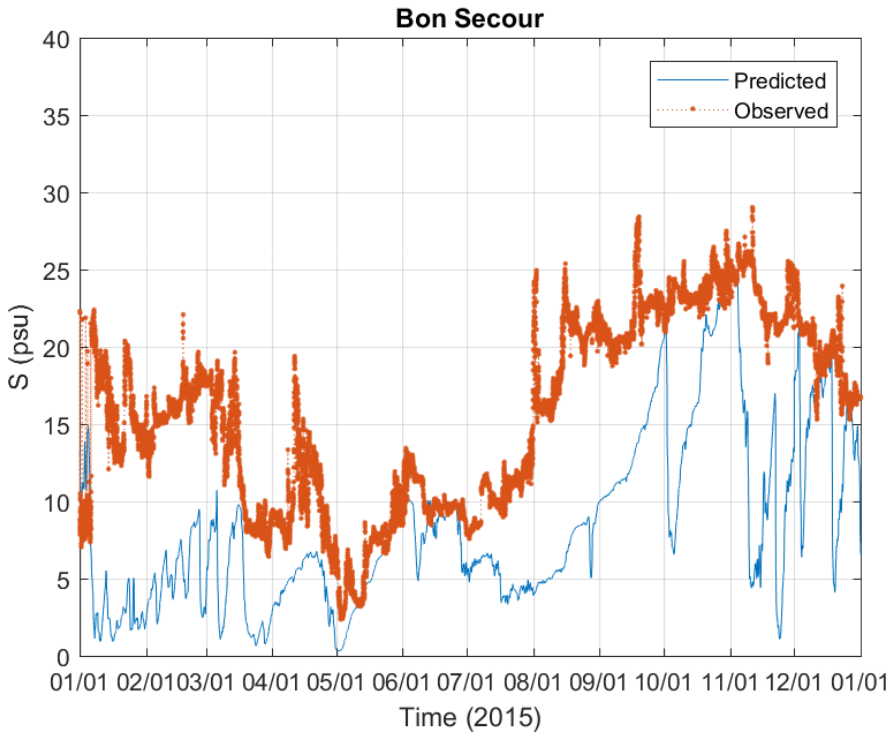


Figure 10. Salinity time series at Bon Secour

In addition, the Alabama Department of Conservation and Natural Resources (ADCNR) Marine Resource Division installed continuous water quality monitoring sondes at five locations within Mobile Bay, Figure 11, funded through the NFWF Gulf Environmental Benefit Funds. Equipment is YSI 600XLM with depth, conductivity, temperature, dissolved oxygen and pH probes. Stations were deployed in mid-year of 2015. Figures 12-16 show the predicted salinity at the 5 reef-locations well represent the observed salinity.

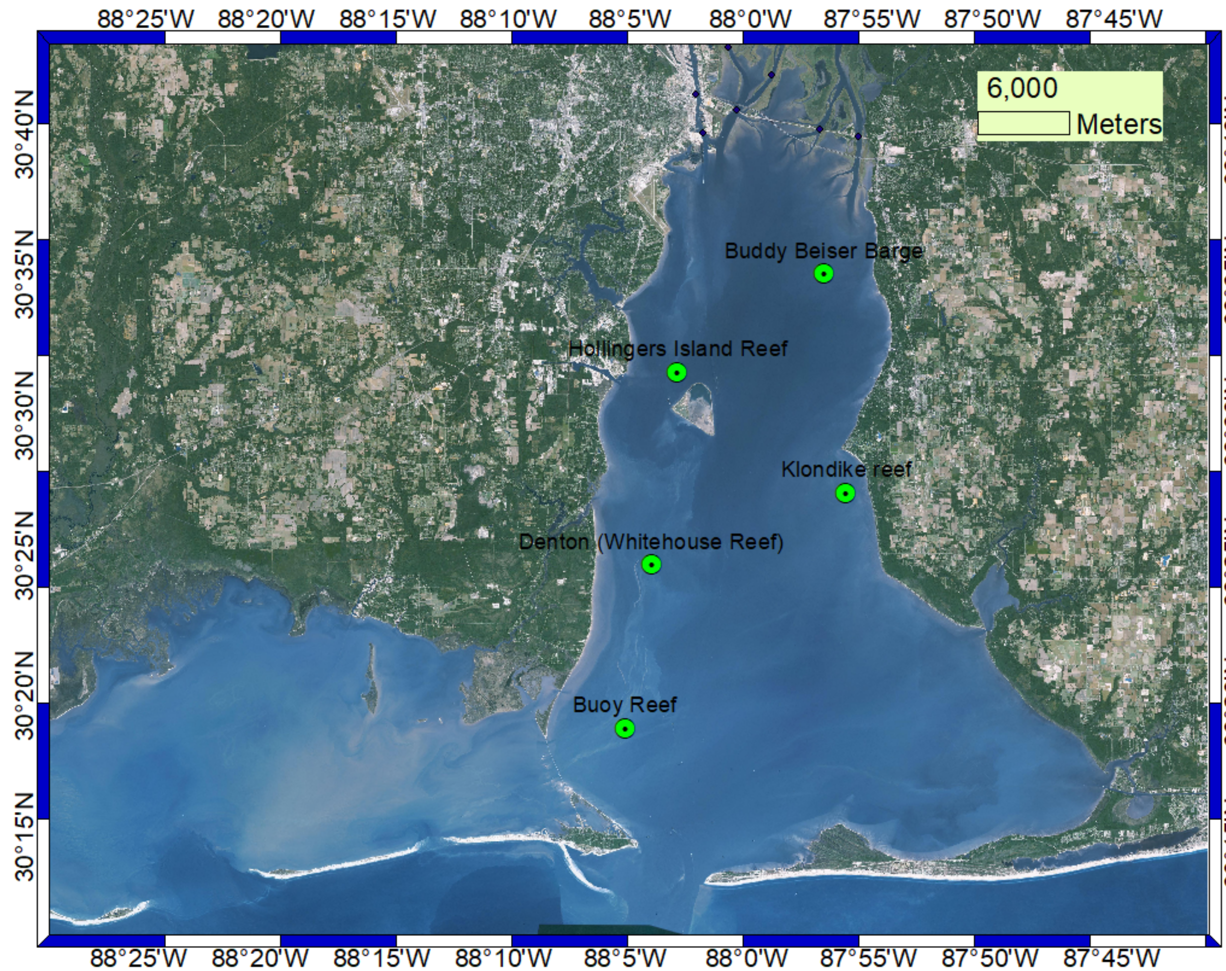


Figure 11. Five ADCNR oyster reef monitoring stations

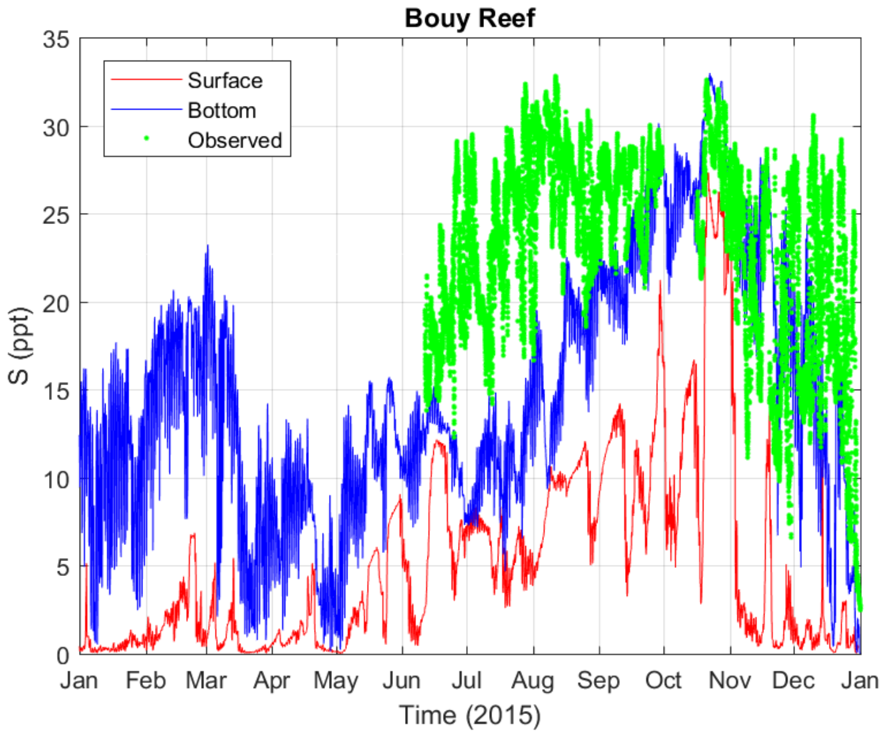


Figure 12. Salinity at the Buoy Reef. Blue and red lines represent simulated bottom and surface salinity, respectively. Green points are observed salinity.

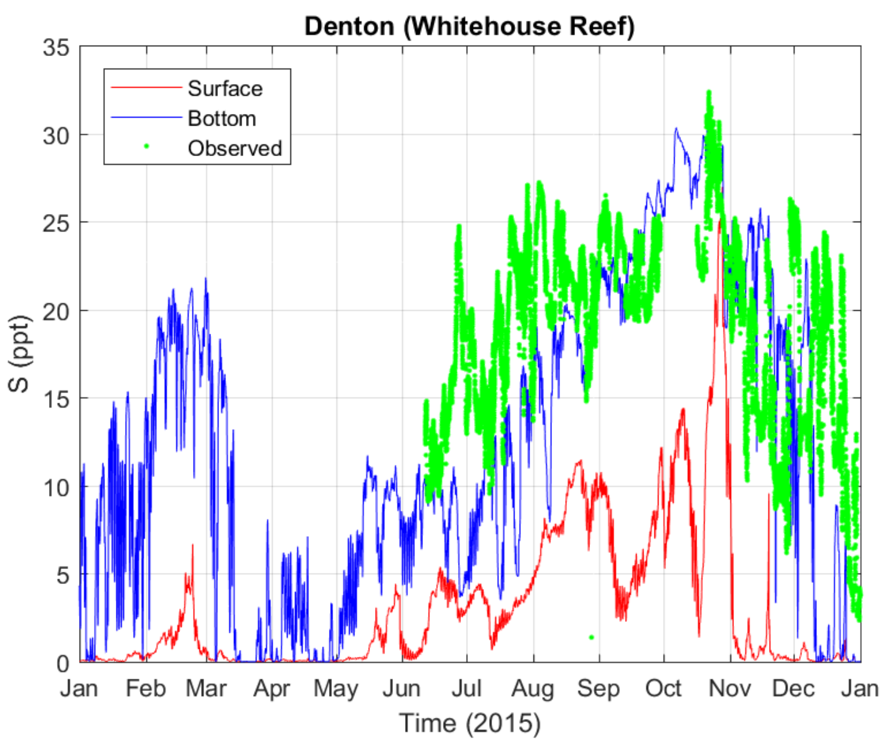


Figure 13. Salinity at Denton. Blue and red lines represent simulated bottom and surface salinity, respectively. Green points are observed salinity.

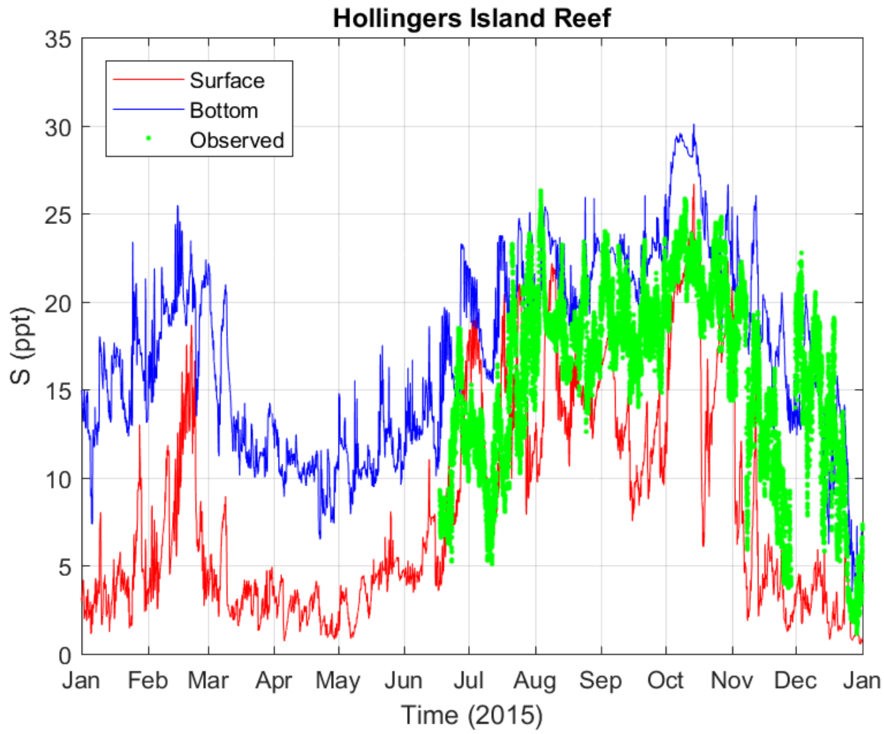


Figure 14. Salinity at Hollingers Island Reef. Blue and red lines represent simulated bottom and surface salinity, respectively. Green points are observed salinity.

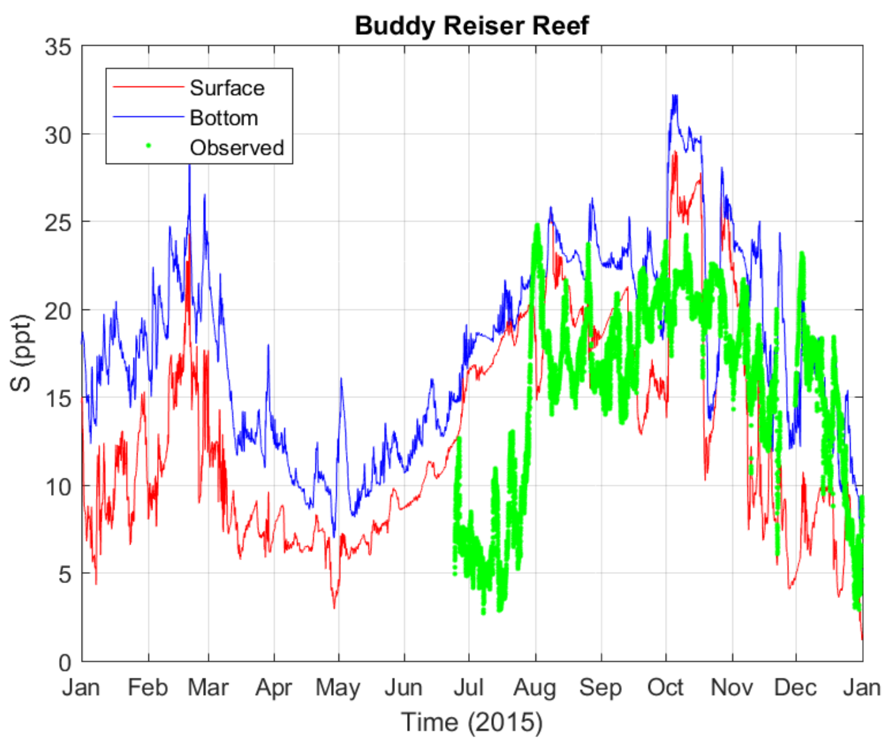


Figure 15. Salinity at Buddy Beiser Barge. Blue and red lines represent simulated bottom and surface salinity, respectively. Green points are observed salinity.

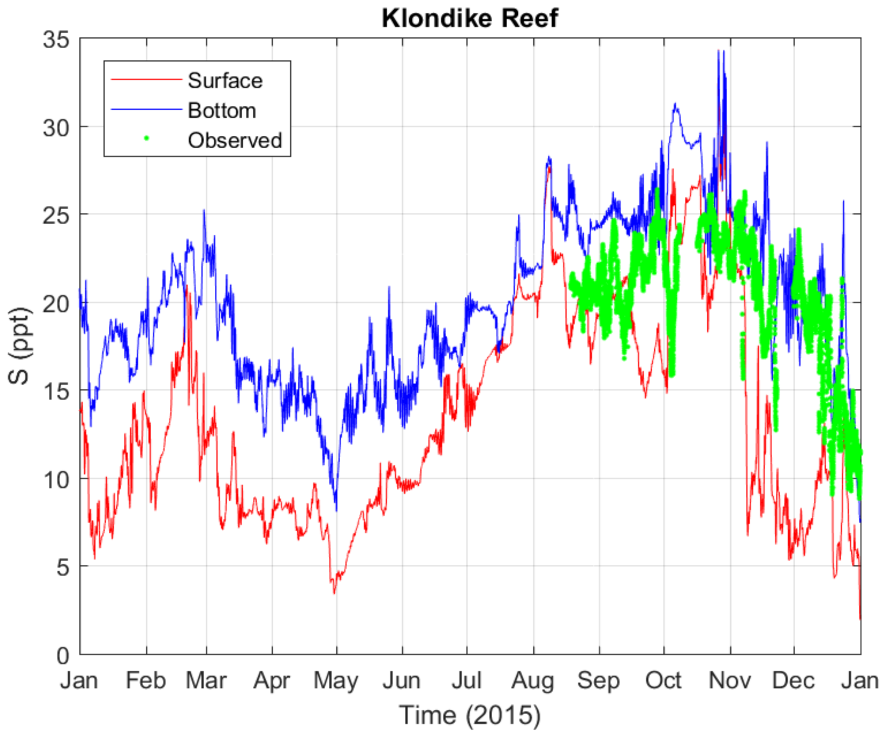


Figure 16. Salinity at Klondike Reef. Blue and red lines represent simulated bottom and surface salinity, respectively. Green points are observed salinity.

Figures 17 and 18 show low salinity regime during wet season and high salinity regime during dry season through monthly mean of depth-averaged salinity. In addition, figure 17 monthly mean surface and bottom simulations indicate strong stratification in the study area during the wet month of March.

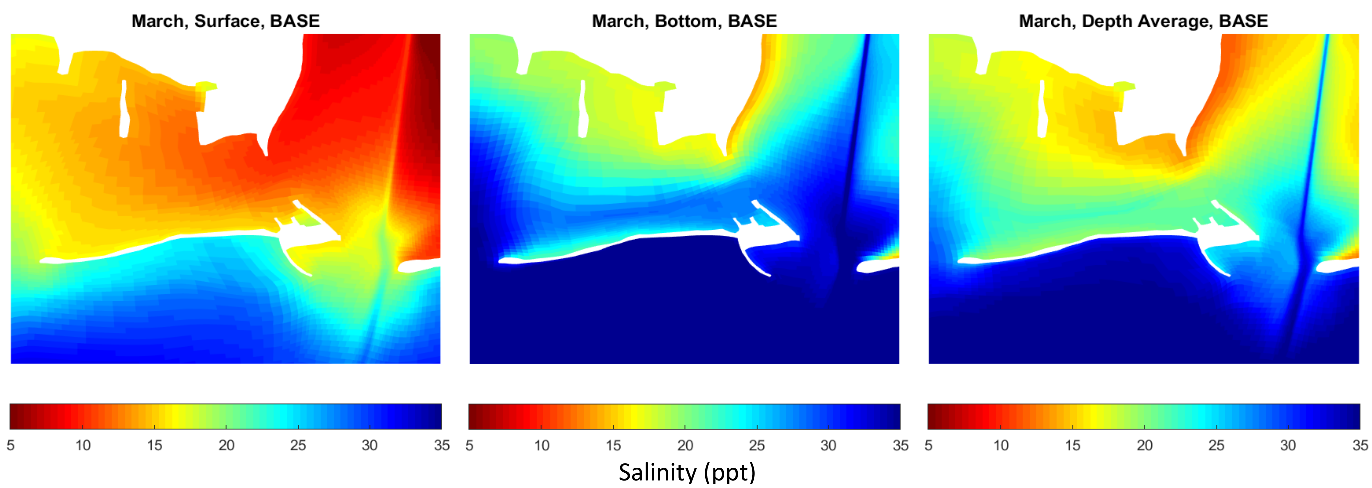


Figure 17. Monthly mean of surface, bottom and depth average salinity for March (wet season), baseline simulation

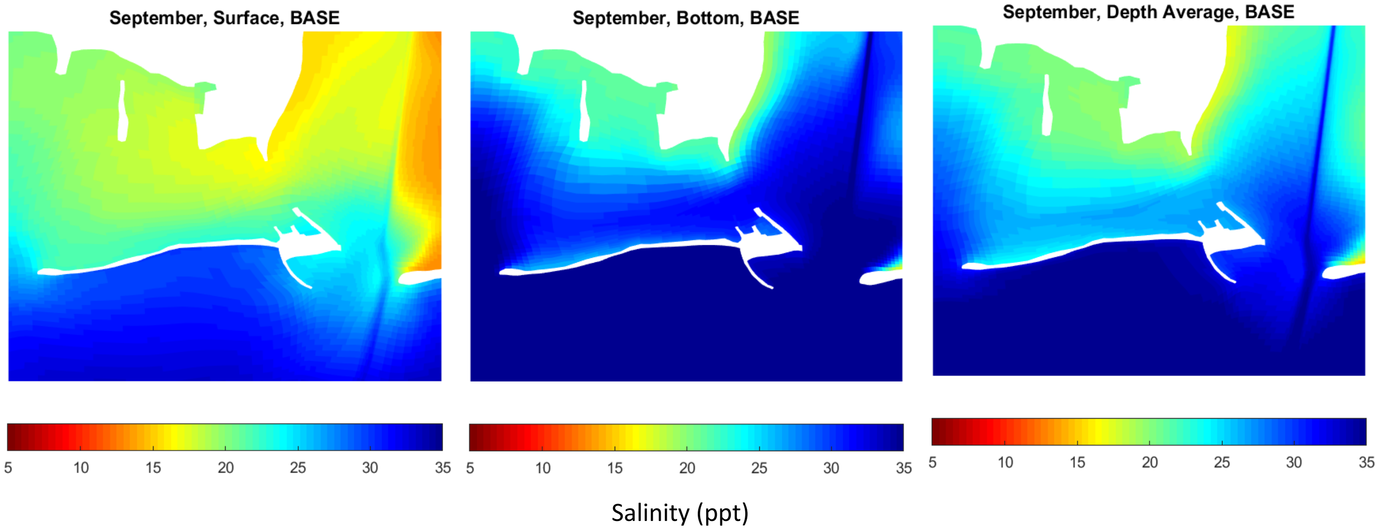


Figure 18. Monthly mean surface, bottom and depth-averaged salinity for September (dry season), baseline simulation

2. Scenarios

One-year simulations of water quality and hydrodynamics of Mobile Bay and adjacent Northern Gulf of Mexico for 2015 were performed on baseline and no-action cases equivalent of USGS hydrodynamic and morphologic modeling of high storminess and sea level condition ST3SL3R0 (Mickey et al. 2020). The USGS hydrodynamic and morphologic simulations result in breaching over two locations on the Dauphin Island as well as breaches in Little Dauphin Island and Pelican Island (Figure 19). The habitat assessment conducted by the USGS as detailed in Enwright et al. (2020) found significant potential habitat changes along the islands associated with these breaches.

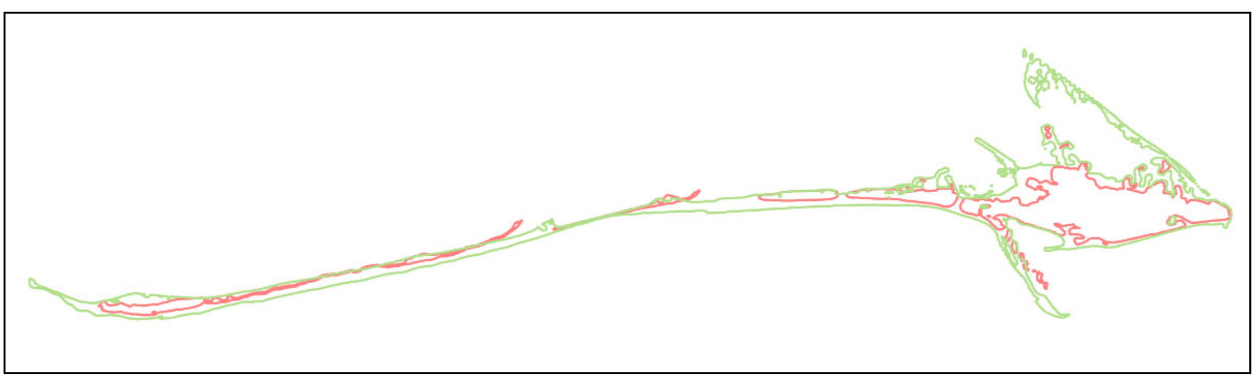


Figure 19. No Action Condition for baseline and Year 10 for ST3SL3

Because the two simulations represent end members for the range of conditions and design measure scenarios, it is prudent to assess the sensitivity of habitat assessment to varying water quality parameters over full range. We selected 3 additional scenarios to the existing ST3SL3R0 simulations, generating a total 4 impact analyses. In the following, the bathymetries around Dauphin Island for the 4 scenarios and base conditions are listed in Table 1. USGS hydrodynamic and morphologic simulation for ST3SL3 are associated with 6 design measure scenarios. Among these, ST3SL3R0 (no action), ST3SL3R2 (Pelican Island Southeast nourishment), ST3SL3R3 (Sand Island platform nourishment and sand bypassing), and ST3SL3R5 (Back Barrier tidal flats and marsh habitat restoration) measures result in 2 breaches in the vicinity of Katrina Cut. The western breach is about 500 m wide, the average depth is about 1.6 m, Eastern breach is about 600 m wide, and the average depth is about 1.7 m for ST3SL3R0 (R0). Measure ST3SL3R1 (Katrina Cut – sand berm) results in a wide breach in the middle—about 3,500 m wide and average depth is about 2.4 m. Measure ST3SL3R4 (West and East End beach and dune nourishment) results in a breach only in the western side. A modification to ST3SL3R0 was set to see the influence of the breaches over Little Dauphin Island and Pelican Island (ST3SL3R0MOD). Table 1 summarizes the physical breach modifications of the scenarios. For each scenario, we estimated monthly mean salinity of surface, bottom, and depth-averaged values to analyze design impacts. Figures 20-24 show the bathymetry around the barrier island for baseline conditions and 4 scenarios.

Table 1. Selected runs for Stormy Bin 3 Sea Level Bin 3 cases to assess design scenarios

Scenario	Description	Dauphin Island Breaches	Little Dauphin and Pelican Island
Baseline			
ST3SL3R0	No Action	2 breaches (East & West)	breach
ST3SL3R0MOD	No Action Modified	2 breaches (East & West)	No-breach
ST3SL3R1	Katrina Cut – Sand Berm	1 breach (Middle)	No-breach
ST3SL3R4	West and East End beach and dune nourishment	1 breach (West)	No-breach

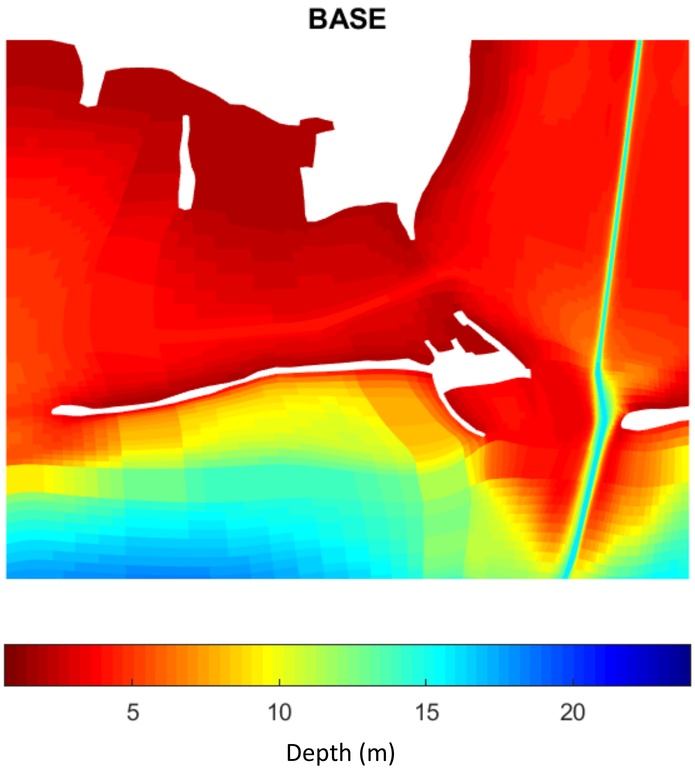


Figure 20. Bathymetry for baseline grid

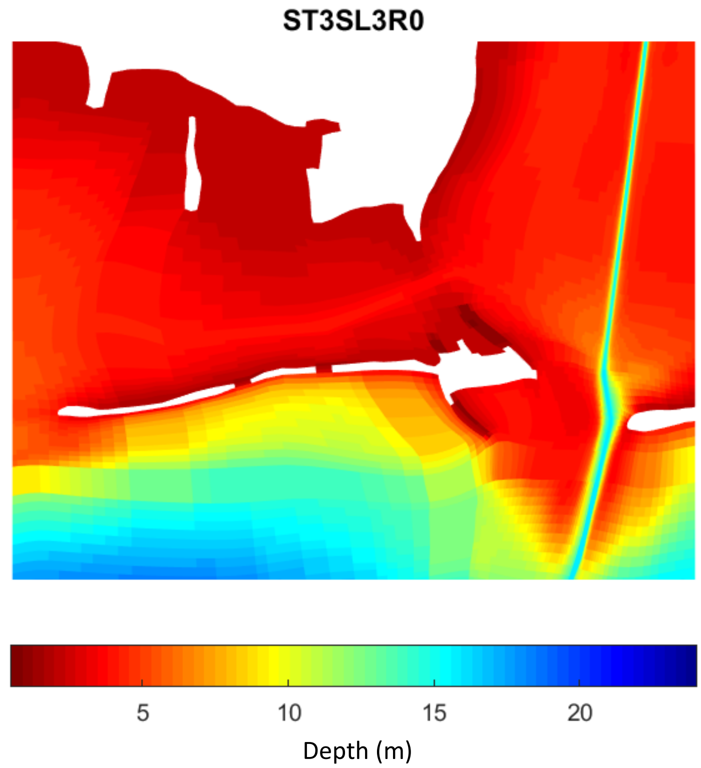


Figure 21. Bathymetry for ST3SL3R0 grid

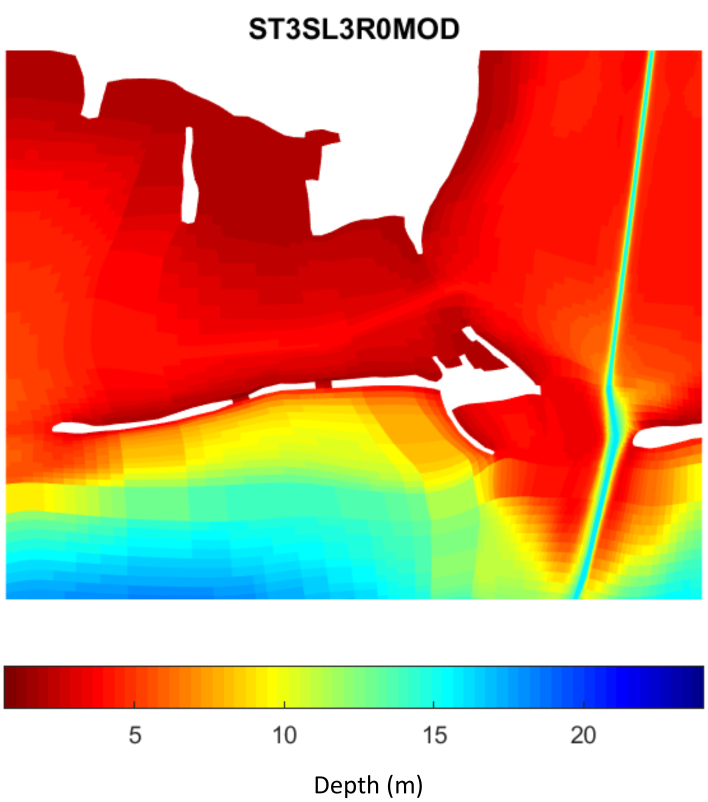


Figure 22. Bathymetry for St3SL3R0 with no-breach over Little Dauphin and Pelican Islands.

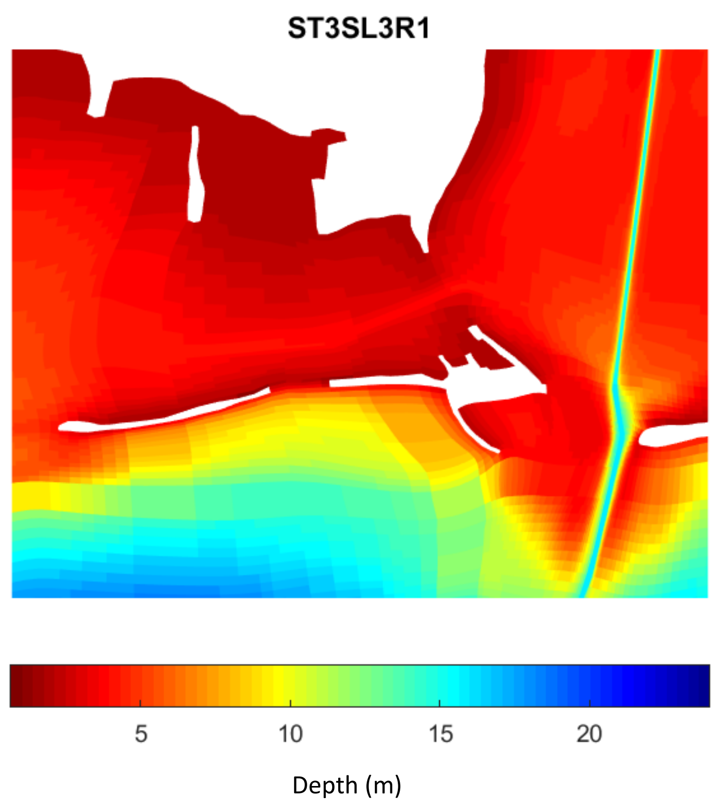


Figure 23. Bathymetry for St3SL3R1 grid

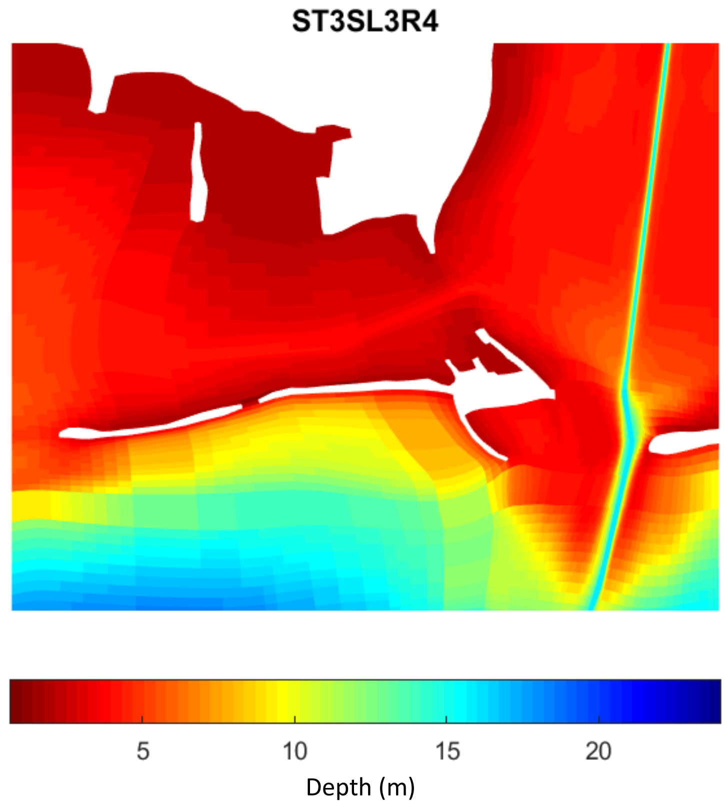


Figure 24. Bathymetry for ST3SL3R4

3. Results from Scenarios

Figures 25 through 32 show monthly mean of depth-averaged salinity over wet (March) and dry (September) months for four design measure scenarios. The impact of breach was seen as a conductor to otherwise separated water masses in the baseline case. Figures 33 through 40 show the changes as scenarios minus baseline conditions. Positive numbers denote increase and negative numbers denote decrease in depth-averaged salinity. The impact of breaches over the barrier island in all four scenarios result in increased salinity along the lee side of the island. The extension was more toward West and North. Impact of breaches over Little Dauphin Island and Pelican Island appears to remain local.

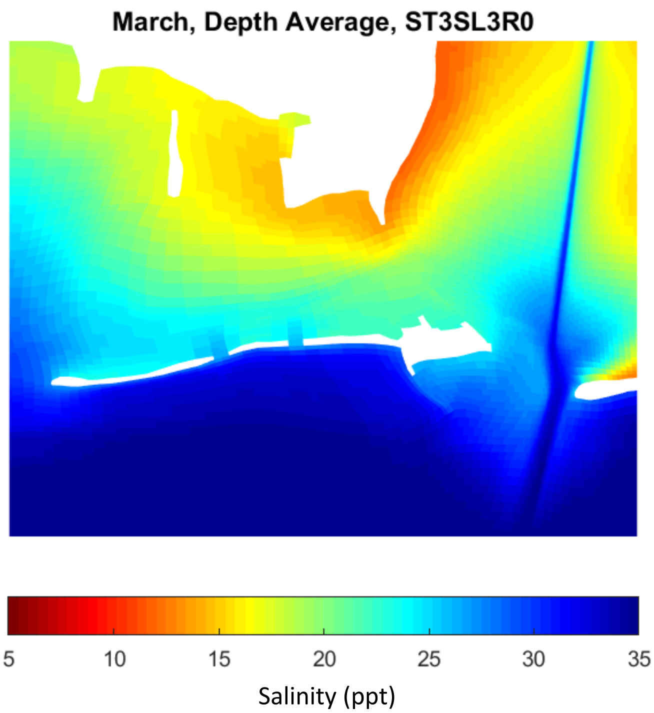


Figure 25. Monthly mean depth-averaged salinity for March (wet season), ST3SL3R0 simulation

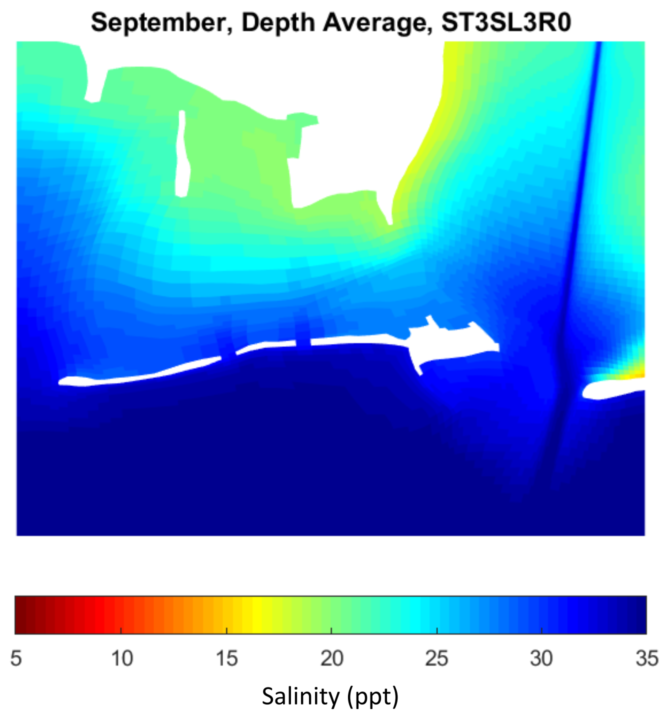


Figure 26. Monthly mean depth-averaged salinity for September (dry season), St3SL3R0 simulation

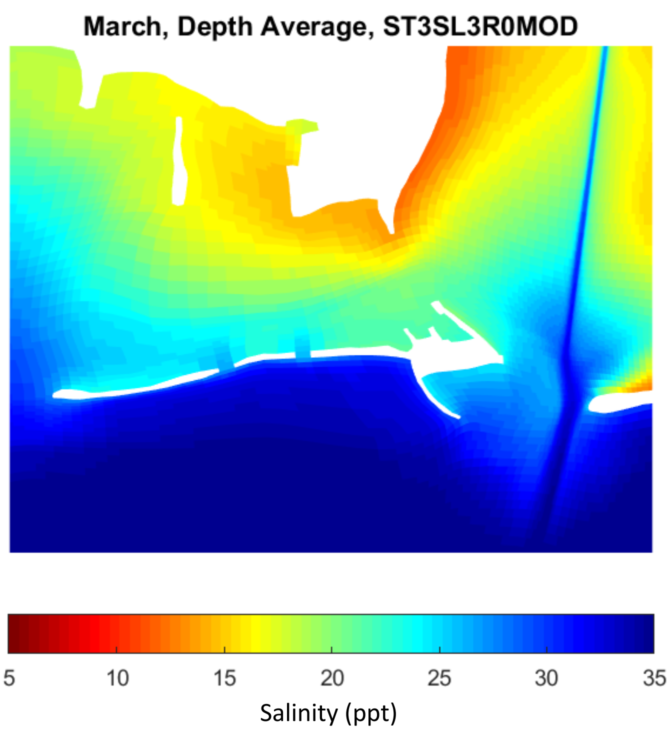


Figure 27. Monthly mean depth-averaged salinity for March (wet season), ST3SL3R0MOD simulation

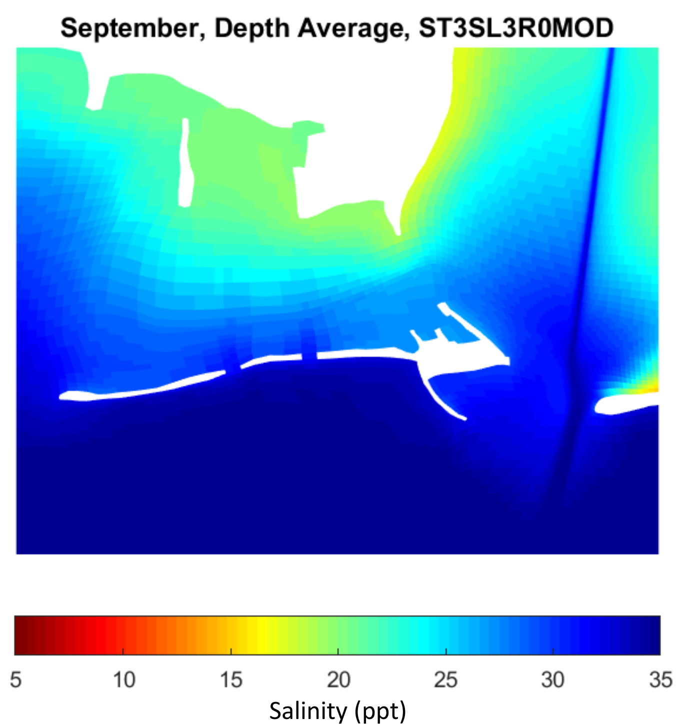


Figure 28. Monthly mean depth-averaged salinity for September (dry season), St3SL3R0MOD simulation

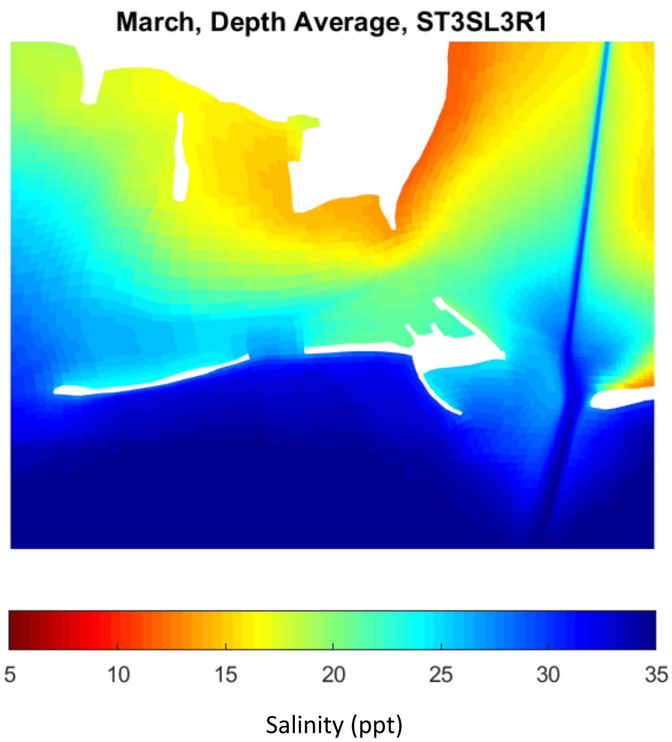


Figure 29. Monthly mean depth-averaged salinity for March (wet season), ST3SL3R1 simulation

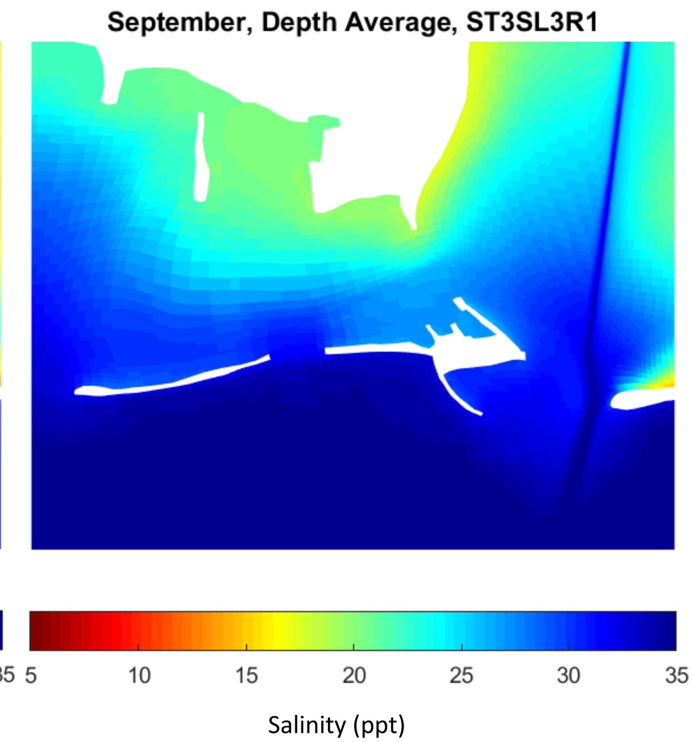


Figure 30. Monthly mean depth-averaged salinity for September (dry season), St3SL3R1 simulation

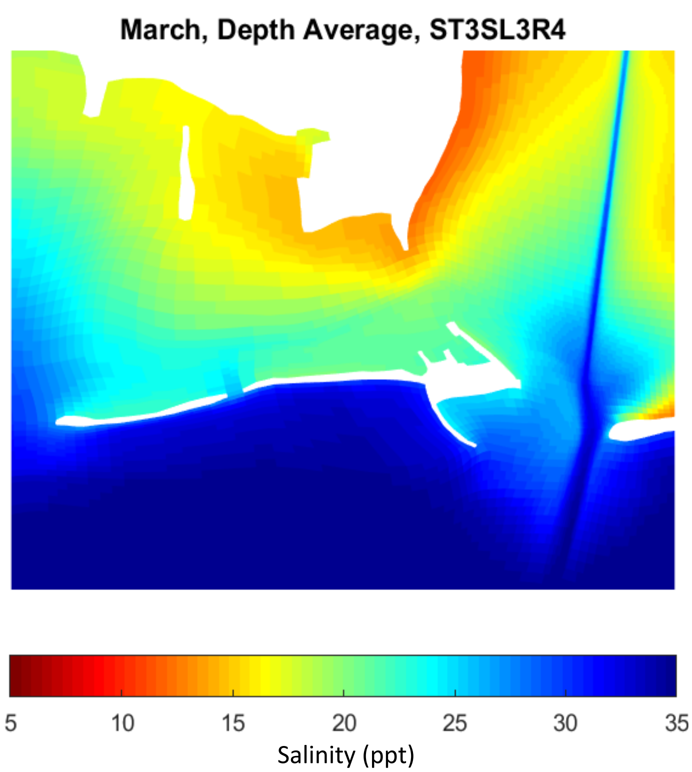


Figure 31. Monthly mean depth-averaged salinity for March (wet season), ST3SL3R4 simulation

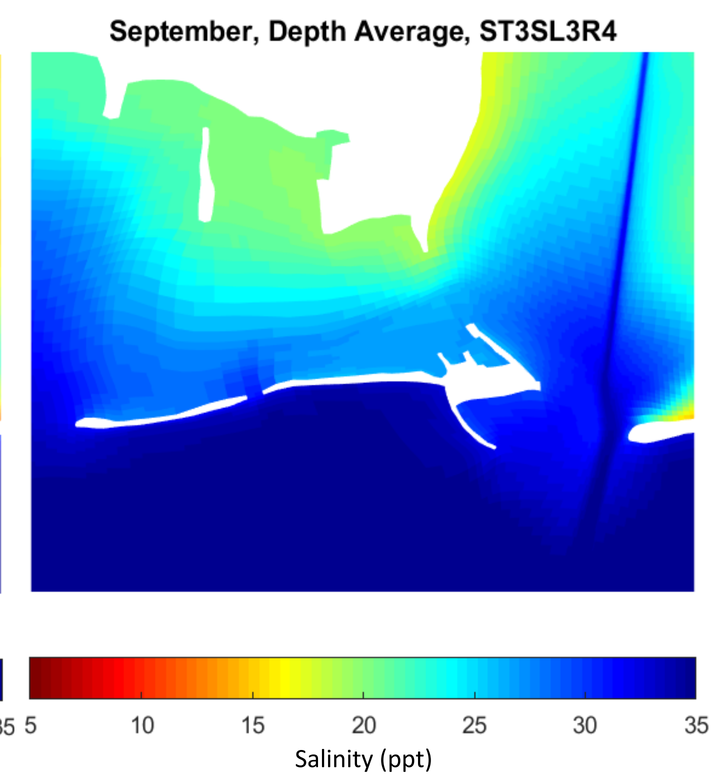


Figure 32. Monthly mean depth-averaged salinity for September (dry season), St3SL3R4 simulation

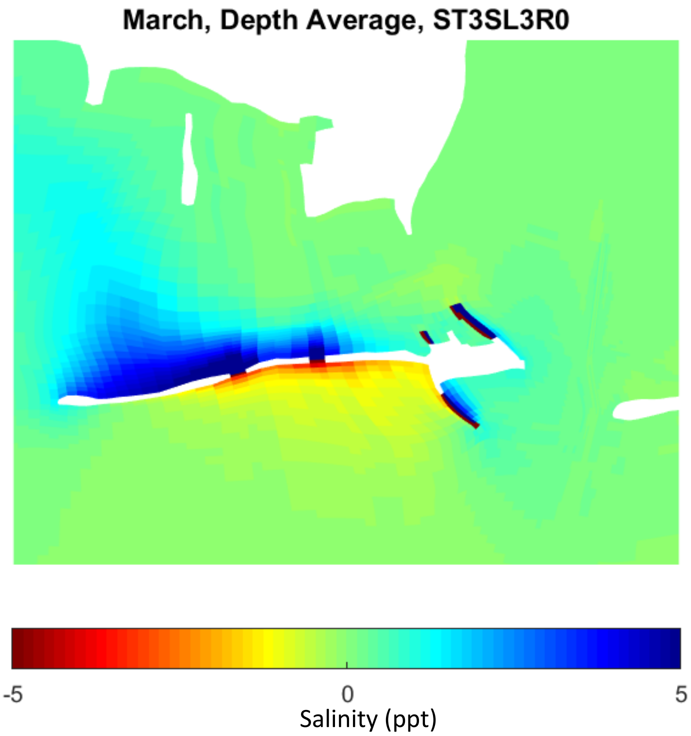


Figure 33. Changes in monthly mean depth-averaged salinity for March (wet season), ST3SL3R0 simulation

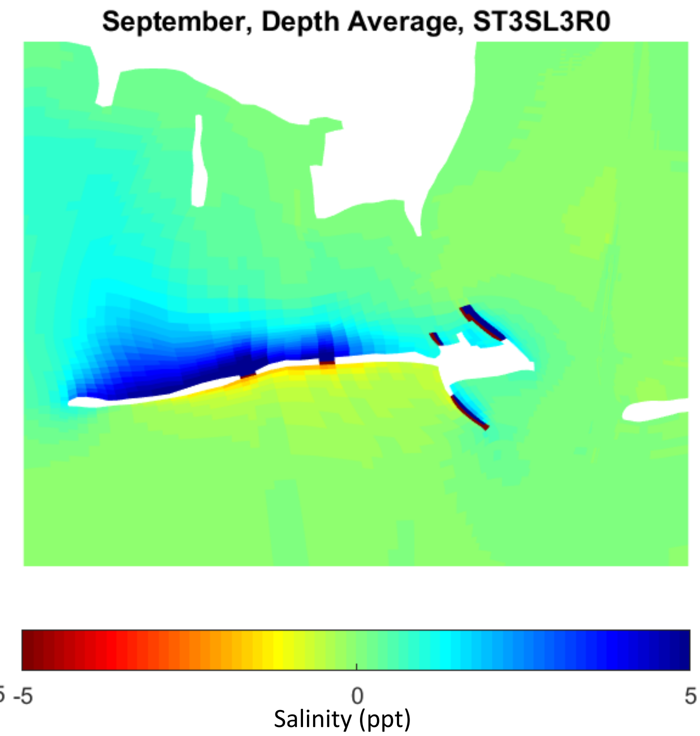


Figure 34. Changes in monthly mean depth-averaged salinity for September (dry season), ST3SL3R0 simulation

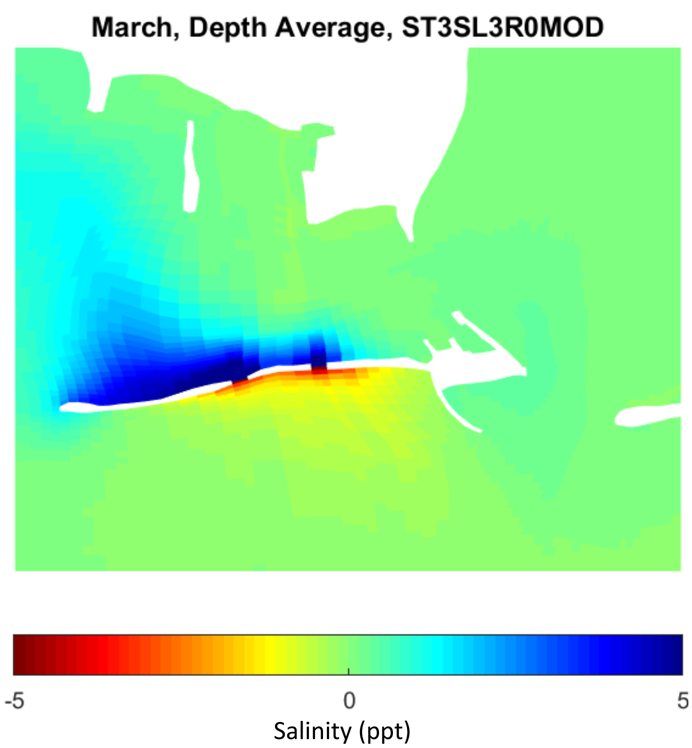


Figure 35. Changes in monthly mean depth-averaged salinity for March (wet season), ST3SL3R0MOD simulation

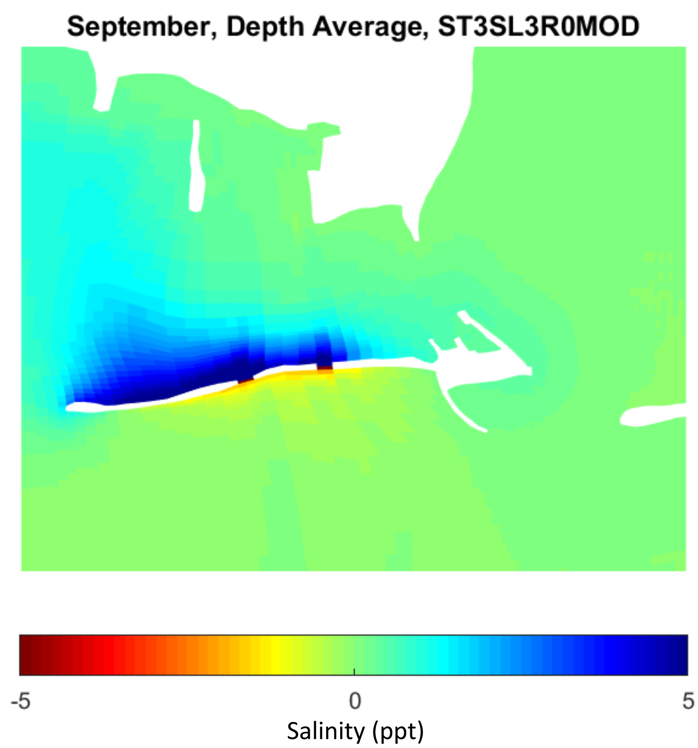


Figure 36. Changes in monthly mean depth-averaged salinity for September (dry season), ST3SL3R0MOD simulation

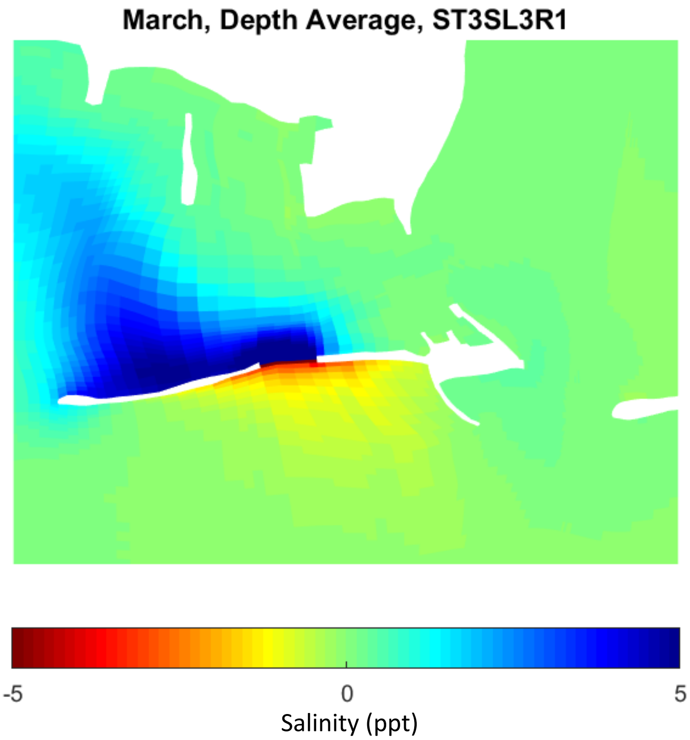


Figure 37. Changes in monthly mean depth-averaged salinity for March (wet season), ST3SL3R1 simulation

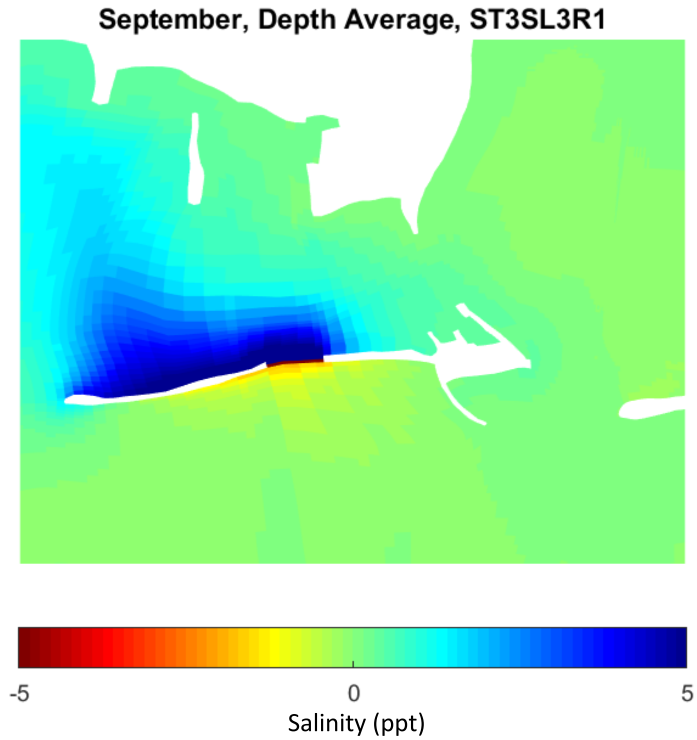


Figure 38. Changes in monthly mean depth-averaged salinity for September (dry season), ST3SL3R1 simulation

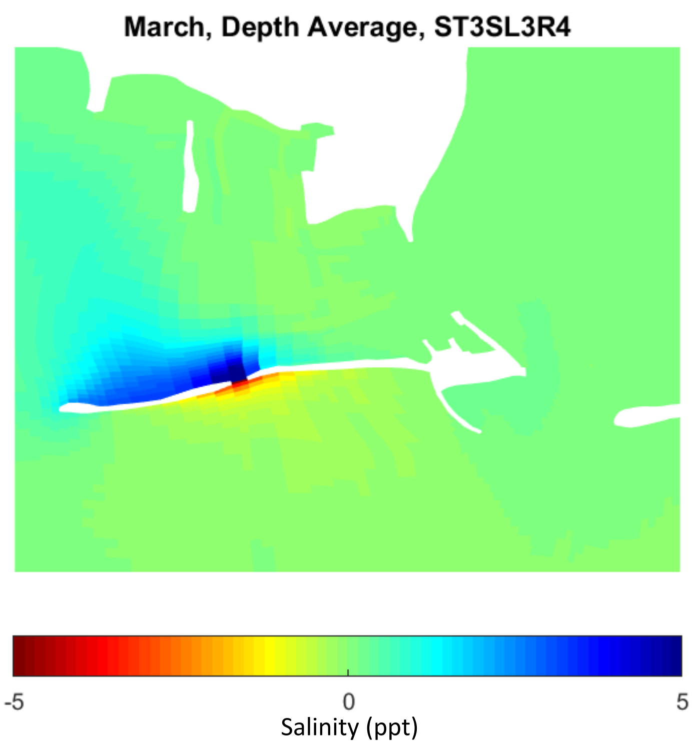


Figure 39. Changes in monthly mean depth-averaged salinity for March (wet season), ST3SL3R4 simulation

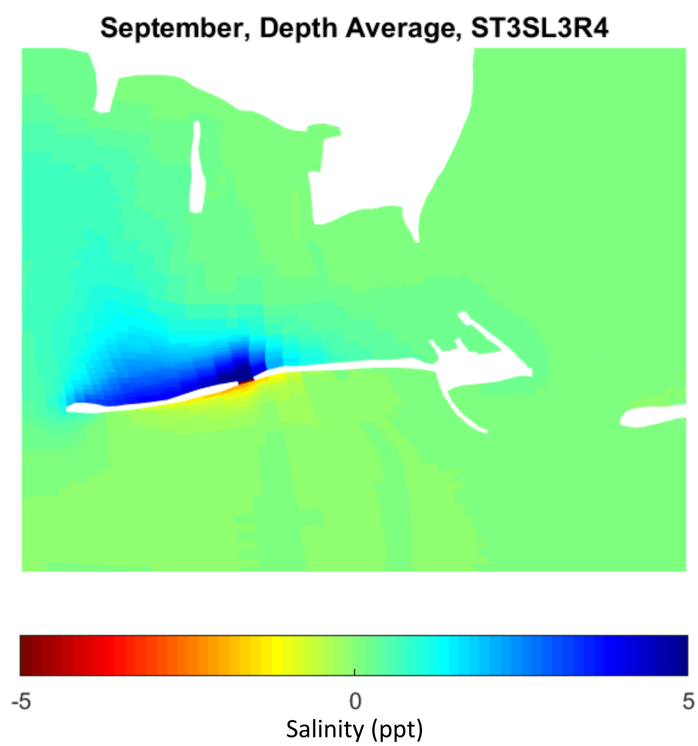


Figure 40. Changes in monthly mean depth-averaged salinity for September (dry season), ST3SL3R4 simulation

CEQUAL-ICM Water Quality Model

CEQUAL-ICM (ICM) is a flexible, widely applicable, state-of-the-art eutrophication model. Initial application was to Chesapeake Bay (Cerco and Cole 1994). Since the initial Chesapeake Bay study, the ICM model code has been generalized with minor corrections and model improvements. Subsequent additional applications of ICM included the Delaware Inland Bays (Cerco et al. 1993), Newark Bay (Cerco and Bunch 1997), the San Juan Estuary (Bunch *et al.* 1999), Florida Bay (Cerco *et al.* 2000), St. Johns River (Tillman *et al.* 2004) and Port of Los Angeles (Bunch *et al.* 2002a and 2002b, and Tillman *et al.* 2008), Mississippi Sound (Wamsley *et al.* 2013), Mobile Bay (Hayter *et al.* 2018). Each model application employed a different combination of model features and required addition of system-specific capabilities.

General features of ICM include:

Operational in one-, two-, or three-dimensional configurations

Thirty-six state variables including physical properties.

Sediment-water oxygen and nutrient fluxes may be computed in a predictive sub-model or specified with observed sediment-oxygen demand rates (SOD)

State variable may be individually activated or deactivated.

Internal averaging of model output over user defined intervals.

Computation and reporting of concentrations, mass transport, kinetics transformations, and mass balances.

Debugging aids include ability to activate and deactivate model features, diagnostic output, volumetric and mass balances.

Operates on a variety of computer platforms. Coded in ANSI Standard FORTRAN F77 and F90.

ICM is limited by not computing the hydrodynamics of the modeled system. Hydrodynamic information (*i.e.*, flows, diffusion coefficients, and volumes) must be specified externally and read into the model. Hydrodynamics may be specified in binary or ASCII format and are usually obtained from a hydrodynamic model such as the GSMB.

1. Conservation of Mass Equation

The foundation of CEQUAL-ICM is the solution to the three-dimensional mass-conservation equation for a control volume. Control volumes correspond to cells on the model grid. CEQUAL-ICM solves, for each volume and for each state variable, the equation:

$$\frac{\delta V_j C_j}{\delta t} = \sum_{k=1}^{n} Q_k C_k + \sum_{k=1}^{n} A_k D_k \frac{\delta C}{\delta x_l} + \Sigma S_j \tag{1}$$

in which:

- V_j = volume of j[th] control volume (m^3)
- C_j = concentration in j[th] control volume ($g\ m^{-3}$)
- t, x = temporal and spatial coordinates
- n = number of flow faces attached to j[th] control volume
- Q_k = volumetric flow across flow face k of j[th] control volume ($m^3\ s^{-1}$)
- C_k = concentration in flow across face k ($g\ m^{-3}$)
- A_k = area of flow face k (m^2)
- D_k = diffusion coefficient at flow face k ($m^2\ s^{-1}$)
- S_j = external loads and kinetic sources and sinks in j[th] control volume ($g\ s^{-1}$)

Solution of Eq. 1 requires discretization of the continuous derivatives and specification of parameter values. The equation is solved explicitly using upwind differencing or the QUICKEST algorithm (Leonard 1979) to represent C_k. The time step, determined by stability requirements, is dependent upon the grid resolution and system energy. For systems with coarser resolution under quiescent conditions time steps can be five to fifteen minutes. In the case of this system, the combination of fine resolution in the channel and rivers results in a shorted time step on the order of 15 to 30 seconds. For notational simplicity, the transport terms are dropped in the reporting of kinetics formulations. The parallel version of ICM was used for improved computational efficiency. The combination of a large number of cells, low average time steps, and long run times necessitates using a version of the model capable of operating on multiple processors in order to reduce the required “clock time” to perform simulations.

2. State Variables

CEQUAL-ICM incorporates 36 state variables in the water column including physical variables, multiple algal groups, and multiple forms of carbon, nitrogen, phosphorus and silica (Table 2). Two zooplankton groups, micro-zooplankton and meso-zooplankton, are available and can be activated when desired.

Of the state variables listed in Table 2, 14 variables were used in this modeling study. These were chosen based on the availability of observed data and the need to represent relevant water quality processes. Variables activated are listed in Table 3. Initial values (initial conditions) and values for inflowing waters (boundary conditions) were required for the period simulated. Where possible boundary conditions are based on observed data from sampling stations close to the physical boundary locations. Conditions for the initial simulation were uniform throughout the water column. Concentrations and other water quality conditions from the end of the first simulation were output and used as initial conditions for subsequent simulations. This output represented a spatially varied data set. Repeating this approach repeatedly resulted in spatially distributed set of initial conditions that are reflective of the boundary conditions and processes occurring in the system.

Table 2. Water Quality Model State Variables

Temperature	Salinity
Fixed Solids	Cyanobacteria
Diatoms	Other Phytoplankton
Zooplankton 1	Zooplankton 2
Labile Dissolved Organic Carbon (DOC)	Refractory Dissolved Organic Carbon
Labile Particulate Organic Carbon	Refractory Particulate Organic Carbon
Ammonium (NH4)	Nitrate + Nitrite Nitrogen (NO3)
Urea	Labile Dissolved Organic Nitrogen (DON)
Refractory Dissolved Organic Nitrogen	Labile Particulate Organic Nitrogen
Refractory Particulate Organic Nitrogen	Total Phosphate (TP)
Labile Dissolved Organic Phosphorus (DOP)	Refractory Dissolved Organic Phosphorus (DOP)
Refractory Particulate Organic Phosphorus	Labile Particulate Organic Phosphorus

Table 2. Water Quality Model State Variables

Particulate Inorganic Phosphorus	Chemical Oxygen Demand (COD)
Dissolved Oxygen (DO)	Particulate Biogenic Silica
Dissolved Silica	Internal Phosphorus Group 1
Internal Phosphorus Group 2	Internal Phosphorus Group 3
Clay	Silt
Sand	Organic Sediments

Table 3. Active Water Quality Model State Variables

Temperature	Salinity
Fixed Solids	Other Phytoplankton
Labile Dissolved Organic Carbon (DOC)	Labile Particulate Organic Carbon (POC)
Nitrate + Nitrite Nitrogen (NO3)	Ammonium (NH4)
Labile Dissolved Organic Nitrogen (DON)	Labile Particulate Organic Nitrogen (PON)
Total Phosphate (TP)	Labile Dissolved Organic Phosphorus (DOP)
Labile Particulate Organic Phosphorus (POP)	Dissolved Oxygen (DO)

CEQUAL-ICM Grid

Mobile Harbor GRR study computational grid is shown in Figure 1. The grid for the existing baseline condition case (Base) and the one for the breach are identical in for this study except for the inclusion of cells representing breach. The base case is consistent with the USGS hydrodynamic and morphological modeling ST3SL3R0 conditions. Figure 24 shows the grid with the breach in place. The Breach case is consistent with ST3SL3 R4, which is the most severe case of breaching considered under the beach and dune restoration measures evaluated as part of the USGS hydrodynamic and morphological modeling. Lesser degrees of breaching (in magnitude and or duration) will have lesser impacts on water quality conditions. The breach results in the hydrodynamic and water quality models for that condition having slightly larger number of cells and flow faces. The characteristics of the Base grid and the Breach grid are listed in Table 4.

Water quality model grids have the same number of cells as the hydrodynamic grid described earlier except along the ocean boundaries. Cells along the ocean boundary were removed due to differences in how ICM handle ocean boundaries. GSMB specifies a water surface elevation or head condition at the ocean boundary while ICM requires a flow for the face along the boundary. Not including edge cells along the ocean boundary in the water quality model has no impact upon water quality computations on the interior of the grid.

Table 4. Water Quality Grid Characteristics

Grid Features	Base	Breach
Total Cells	826830	829540
Surface Cells	82683	82954
Total Flow Faces	2370527	2378546
Horizontal Flow Faces	1626380	1631960
Surface Horizontal Flow Faces	162638	163196

Data Requirements

The following data are required for an application of ICM:

1. Bathymetry
2. Observed data
3. Initial conditions
   a. Temperature
   b. Water quality constituents
4. Boundary conditions
   a. Inflow/outflow
   b. Temperature
   c. Water quality
5. Meteorology

These data initialize conditions at the start of a model run and provide time-varying inputs that drive the model during the course of a simulation. The role of each in the model is described below.

Bathymetry

Bathymetric information described the physical shape (depths, widths) of the waterbody bottom. This information is obtained from the GSMB hydrodynamic and linkage files. Together they define the depth of the water column and the relationship of the individual cells to one another so that the ICM appropriately replicates the actual system structure. ICM uses a single grid configuration of the GSMB multi-block grids described previously including ten vertical layers.

Observed Data

Information for water quality constituents being simulated are necessary to insure the model reasonably represents the biological, chemical, and physical processes occurring in the system. These data do not need to be continuous but should be of such frequency that it realistically is representative of the changes that occur in the system. Observed data are used for three purposes:

1. Define the initial conditions (concentrations, temperature) in the model.
2. Define the conditions at the edges, or boundary, of the model where inflows occur.
3. Serve as a check on model performance with model predictions being compared to observed data.

Boundary Conditions

Water quality conditions for inflowing waters of rivers to the model domain are specified as boundary conditions. These values change with time and are based on observations at or near those locations. Boundary conditions in this study are varied monthly to reflect the change in inflowing water quality conditions. Data from Alabama Department Environmental Management (ADEM) and Mississippi Department of Environmental Quality (MDEQ) monitoring stations were used for this purpose. This information was augmented with data collected for the Alabama Barrier Island Assessment study. Emphasis was placed on the Mobile and Tensaw rivers based on their proximity to study area.

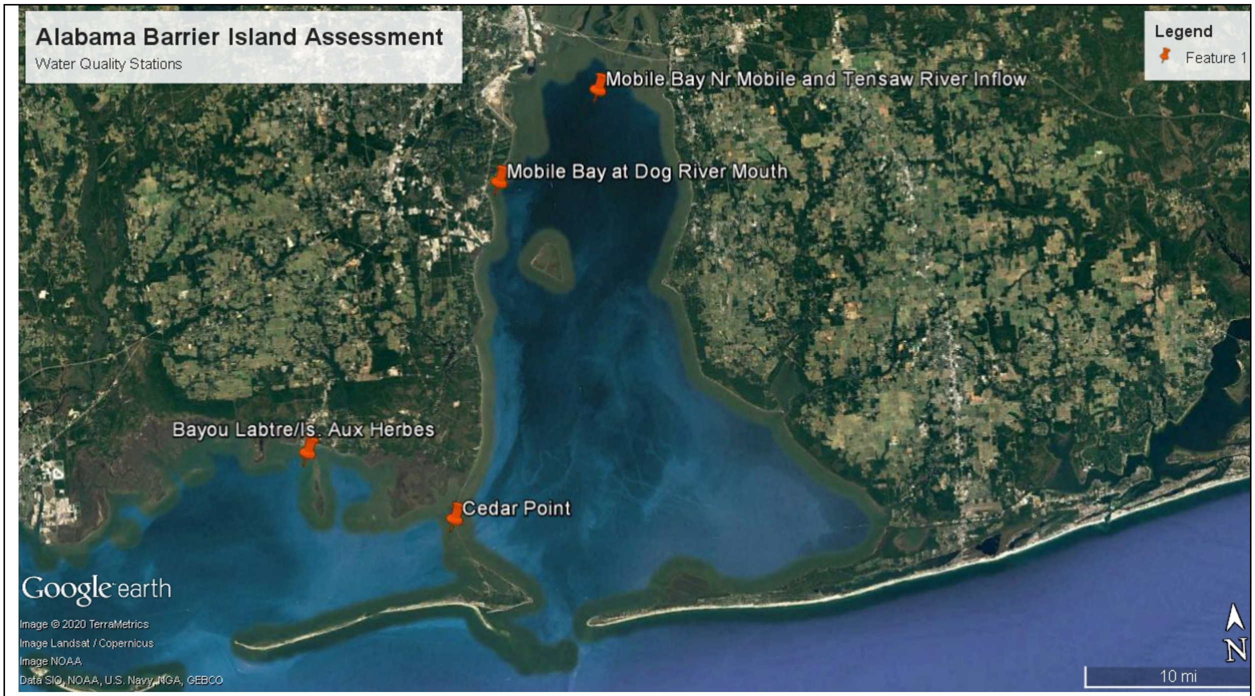


Figure 45. Alabama Barrier Island Assessment Stations

Offshore boundary conditions were set using GOM-9 station. Riverine inflows included the Pearl, Jordan, Wolf, Biloxi, West Pascagoula, Fish, Mobile, West Tensaw, East Tensaw, Perdido, Escambia, and Blackwater rivers. Boundary conditions for the West Tensaw were developed using water quality data from MOMB1 station. East Tensaw boundary conditions were based on data from Mobile River at Mount Vernon. Data from the MDEQ station near Kiln were used for the Jourdan boundary and also the Pearl, Escambia, Perdido, and Blackwater. Wolf River boundary conditions were developed using MDEQ station near Lizana. Wolf boundary values were also used for Biloxi. Escatapwa observations were used to set boundaries for the Fish and West Pascagoula rivers.

Once these boundary inflowing waters are in the model their water quality conditions mix with the waters within the model domain and are affected by the ongoing water quality processes.

Point source loads were incorporated in the model for two large dischargers in the bay, Clifton Municipal Wastewater Treatment Plant and Kimberly Clark. Loads were updated monthly and distributed over the entire water column at the point of discharge. Benthic fluxes consisted of Sediment Oxygen Demand (SOD). SOD was modeled as 0.25 g/m^2 offshore and 1.0 g/m^2 in estuarine waters.

Initial Conditions

Initial conditions are important to ensure that the model represents the conditions that exist prior to the time period being simulated. A set of uniform initial conditions approximating the expected conditions at the beginning of the model simulation are applied to the whole model. The model was run for a period of time during which the physical, chemical, and biological processes in the model alter the conditions in the individual cells of the model. When the simulation is complete, the final concentrations and values for all modeled constituents in all cells are output. These values represent a spatially varying concentration and temperature field that was generated by the modeled processes and conditions. This varied field was then used as initial conditions for a subsequent simulation. An advantage of this approach is that the initial condition at a location is more representative of the process in the model than they would be with uniform initial condition values.

Initial conditions for the water column were specified as uniform throughout the water column and the model simulation begun. The first day of the simulation corresponded to January 1, 2015. The simulation was run for a full year and the conditions at the end of the simulation was used as the initial conditions of the second simulation. This process was repeated one more year to generate a representative set of spatially distributed initial conditions representative of processes and loadings and not dependent on initial condition values.

Meteorological Data

Meteorological data measured at Mobile airport for the simulation period (2015) was obtained from the Air Force Combat Climatological Center. Daily values for cloud cover, dry bulb temperature, dew point temperature, and wind speeds were used in the heat exchange program (Eiker 1977) to compute heat exchange coefficients, solar illumination, fractional day length, and equilibrium temperature. These data are contained in Appendix D. Appendix D contains ICM kinetic (the rate of change in a biochemical or other reaction) rates files used in this study. Complete descriptions of the kinetic processes in ICM can be found in Cerco and Noel (2004). Also contained in Appendix D are the settling file for solids and par.

Comparison Data

Comparison data have no direct effect on model computations but are used to assess model performance. Care must be taken to match the observed data with model output that corresponds to the time and place the data was collected. Model concentration output consists of daily averaged values for all water constituents modeled. Observed data used for comparison are one-time instantaneous observations and measurements. As such they are subject to not reflecting changing conditions that are captured in the daily average water quality model output. Comparison data presented here were collected at sites funded as part of Alabama Barrier Island Assessment in the vicinity of Dauphin Island during 2015 and 2016 (Figure 45). Since the modeling period was 2015 calendar year and the sampling period spanned mid-2015 to mid-2016 several of the samples do not correspond to the period modeled. They were treated though as being representative of the modeling period and included in the comparison data from the period modeled.

Calibration

Base model representativeness of this system was demonstrated in work performed for the Mobile Harbor GRR (Hayter et.al. 2018). Results presented here for the base case are done to demonstrate model performance for this period, 2015. Among the things demonstrated by these comparisons is the dynamic nature of the water quality response short term and long term during the simulation. Processes affecting water quality include short term and seasonal tributary flows which impact tributary loads and flushing and short term met conditions. Long term water quality changes are typically the result of changes in hydrodynamics (affects flushing) and meteorological conditions, namely temperature.

Time series comparisons for Temperature, Salinity, and Dissolved Oxygen are shown in Figures 46-48. In general these results indicate that the model is representative of the conditions occurring at these locations. On that basis the model can be considered to be representative of the water quality conditions occurring in the vicinity of Dauphin Island.

Salinity Time Series

CE-QUAL-ICM salinity time series comparisons are shown in Figure 46. These results are for the surface, mid-depth, and bottom layers of CE-QUAL-ICM. Model output is daily average. Observed data are instantaneous measurements for the sampling conducted in 2015 and 2016. Data collected in 2016 was plotted against model output as if it were from 2015 to show simulations capture the general seasonal trends observed in the system.

Model results and observed data indicate that these areas are dynamic during the year. In the early parts of the year the salinities drop throughout the water column in response to higher tributary inflows. As the year goes on salinities increase as freshwater inflows into the system decrease. Model data agreement at all stations presented are reasonable. A portion of the differences in the early part of the year can be attributed to the model simulation being 2015 and the comparison data is from 2016. Monthly average flows for 2015 and 2016 indicate that Feb 2015 flows (23,510 cfs) were less than half of 2016 (49,930 cfs). Model agreement with observed data is good at the Cedar Point NFWF site.

Temperature Time Series

CE-QUAL-ICM temperature time series comparisons are shown in Figure 47. These results indicate good model agreement with data at all levels. The surface model results have more variability in response to the dynamic nature of the meteorological conditions. Mid depth and bottom model results are less dynamic but still capture seasonal trends. Overall a good agreement between model and data.

Dissolved Oxygen Time Series

Time series results for dissolved oxygen showed seasonal variability and generally followed the pattern of the observed data, Figure 47. DO values were highest during the cooler periods of the simulation and then fell off some during warmer months in response to increased biological activity and lower DO saturation levels. Surface layers tended to be well oxygenated and respond to seasonal temperature changes. Bayou Labatre results compared well to observed data in surface layer. In mid-depth and bottom layer samples the model agrees reasonably well with data. The model output is daily average while the individual observations are instantaneous which can account for some of the differences in model and observations. There is a period in the first portion of the simulation where the model is over predicting the observations. It must be noted that these data are from 2016 and are being presented against 2015 model results. The reason for this increase in subsurface DO is indicative of potential algal DO production in response to tributary nutrient loads. Once the loadings are past, algal DO production decreases as do DO levels in the subsurface.

DO patterns at Cedar Point follow similar patterns to those in Bayou Labatre. There is generally good agreement between model and observations which indicates that the model is representative of the conditions at that location. The model is capturing the bottom low DO values at this site of summer. Later in the year the model is under predicting two observations where the water column appears to be well mixed. This could be that there was a short term event that the model data did not capture.

Model DO predictions for Dog River are more varied. This is expected in a location that can be more quiescent at times. Subsurface waters are predicting high DOs likely due to algal activity and higher tributary loadings. Once this ends and temperatures increase, bottom DO decrease in response to SOD levels. The model does not get as low as some of the observations. This could be due to the SOD being higher in that location in the real world that the in the model. It could also be an artifact of the daily averaging of the water quality model results.

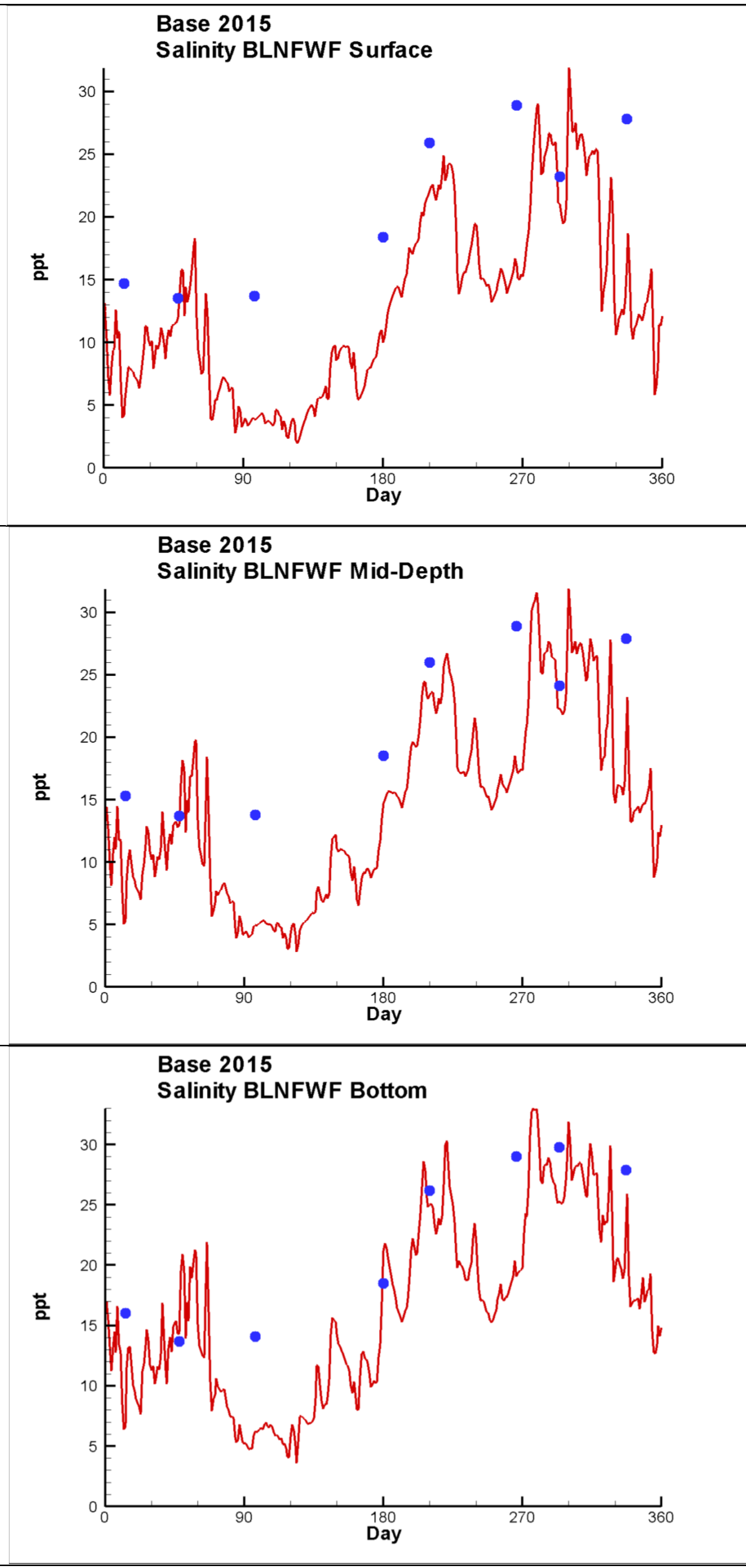
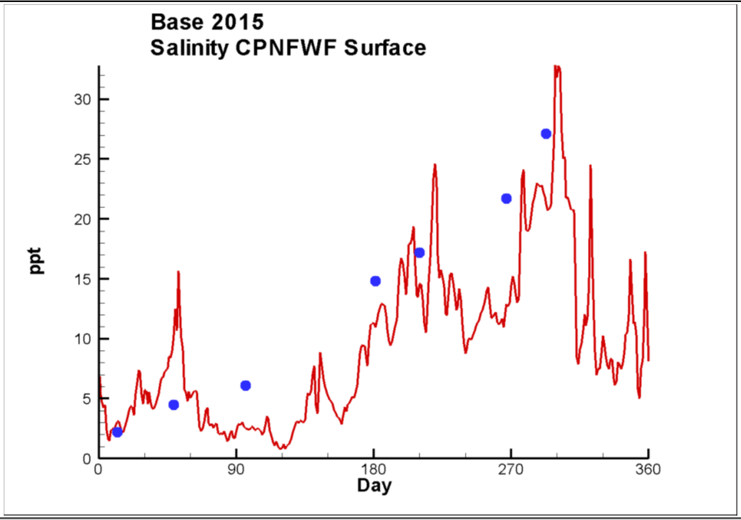
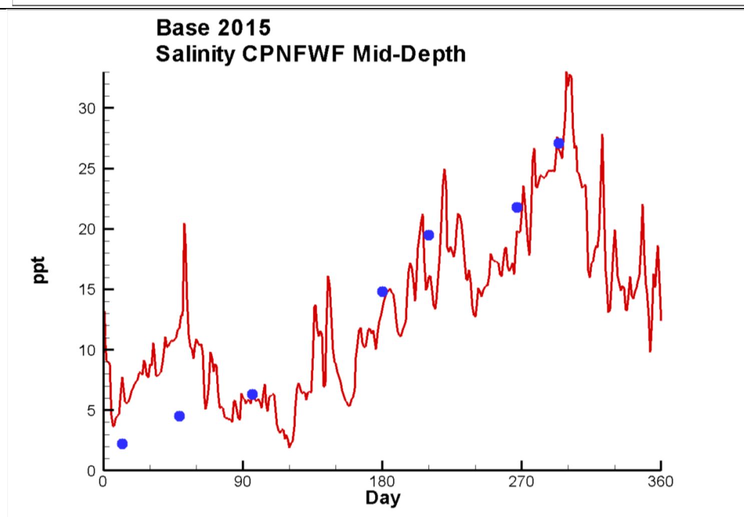


Figure 46. CE-QUAL-ICM Surface, mid-Depth, bottom salinities for NFWF Bayou Labatre sample site





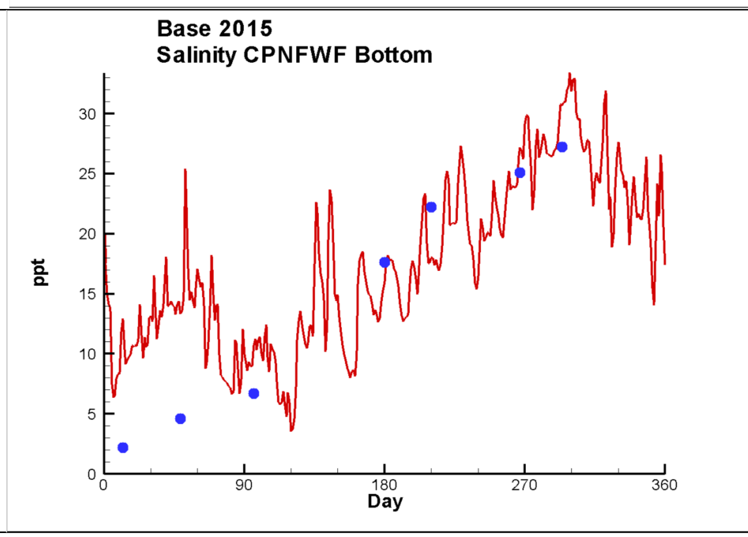


Figure 46 (cont.). CE-QUAL-ICM Surface, mid-Depth, bottom salinities for NFWF Cedar Point sample site

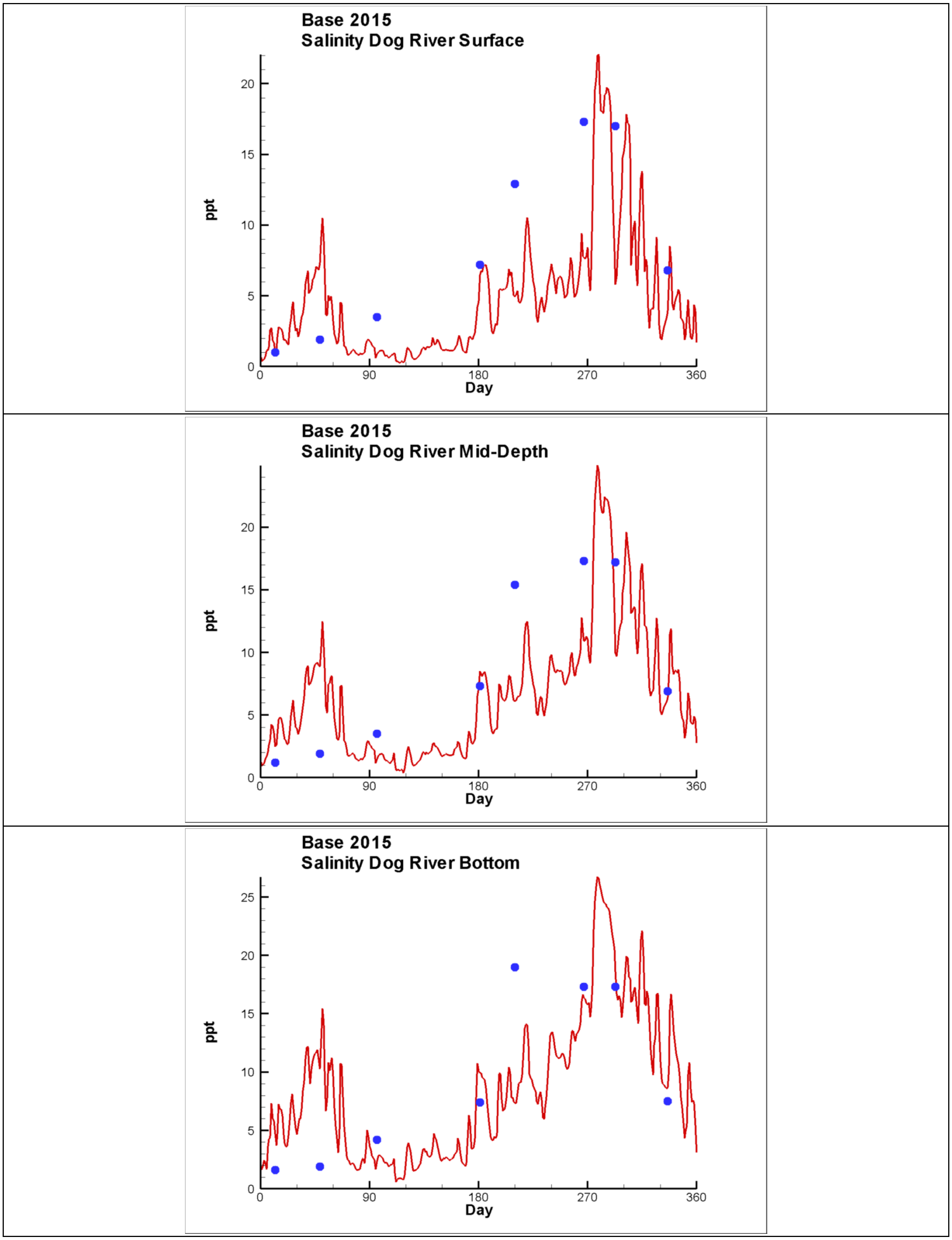


Figure 46 (conc.). CE-QUAL-ICM Surface, mid-Depth, bottom salinities for NFWF Dog River sample site

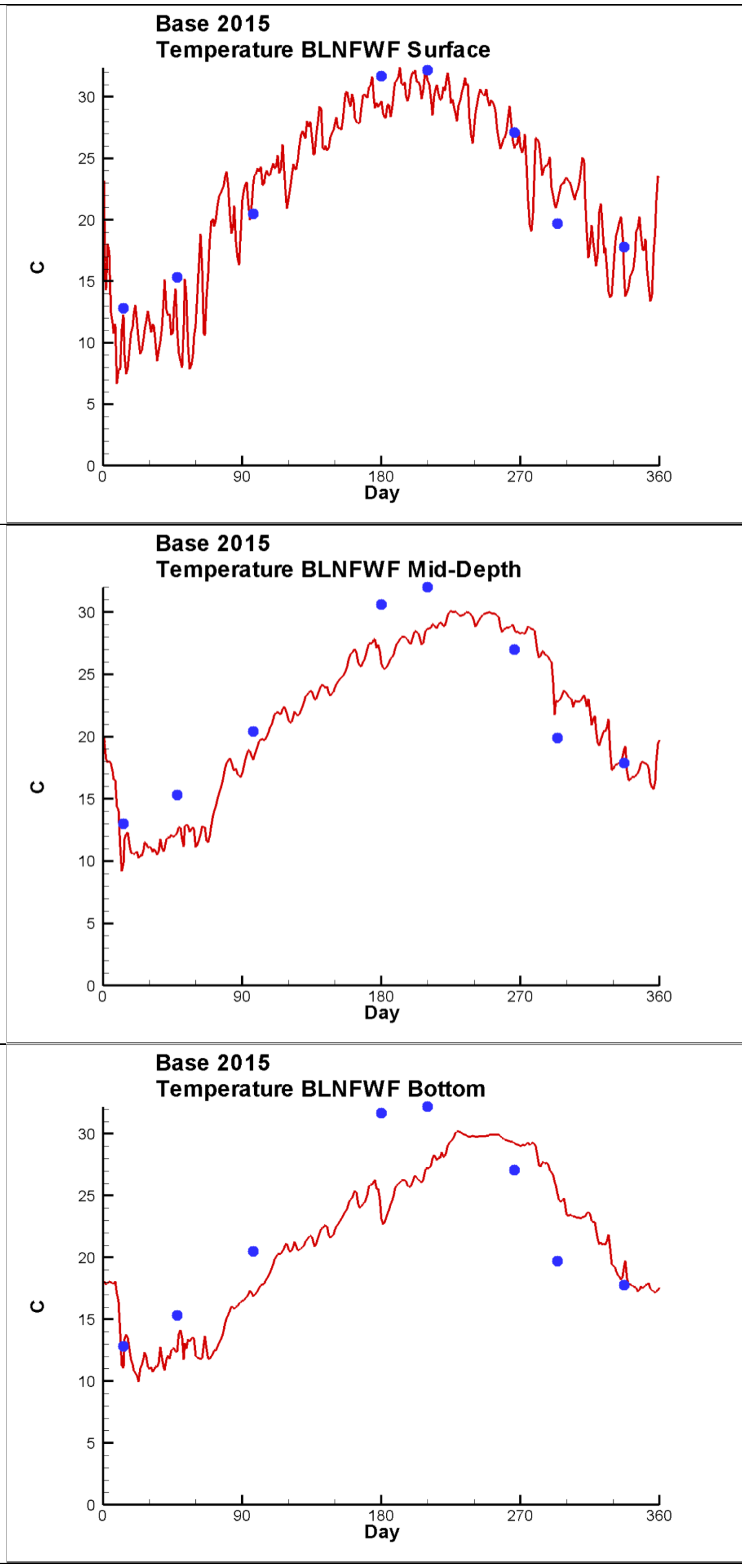


Figure 47. CE-QUAL-ICM Surface, mid-Depth, bottom Temperatures for NFWF Bayou Labatre sample site

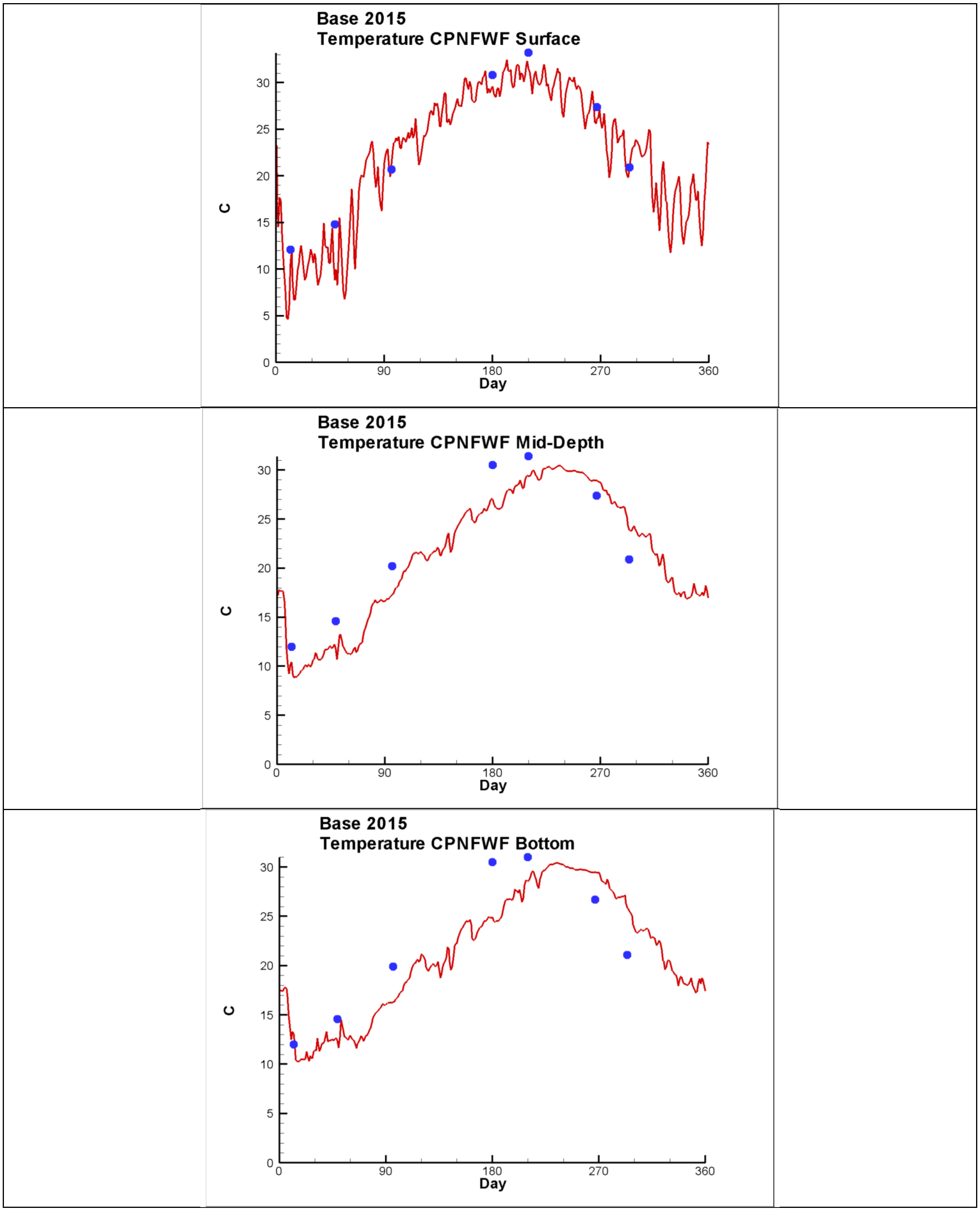


Figure 47 (cont.). CE-QUAL-ICM Surface, mid-Depth, bottom Temperatures for NFWF Cedar Point sample site

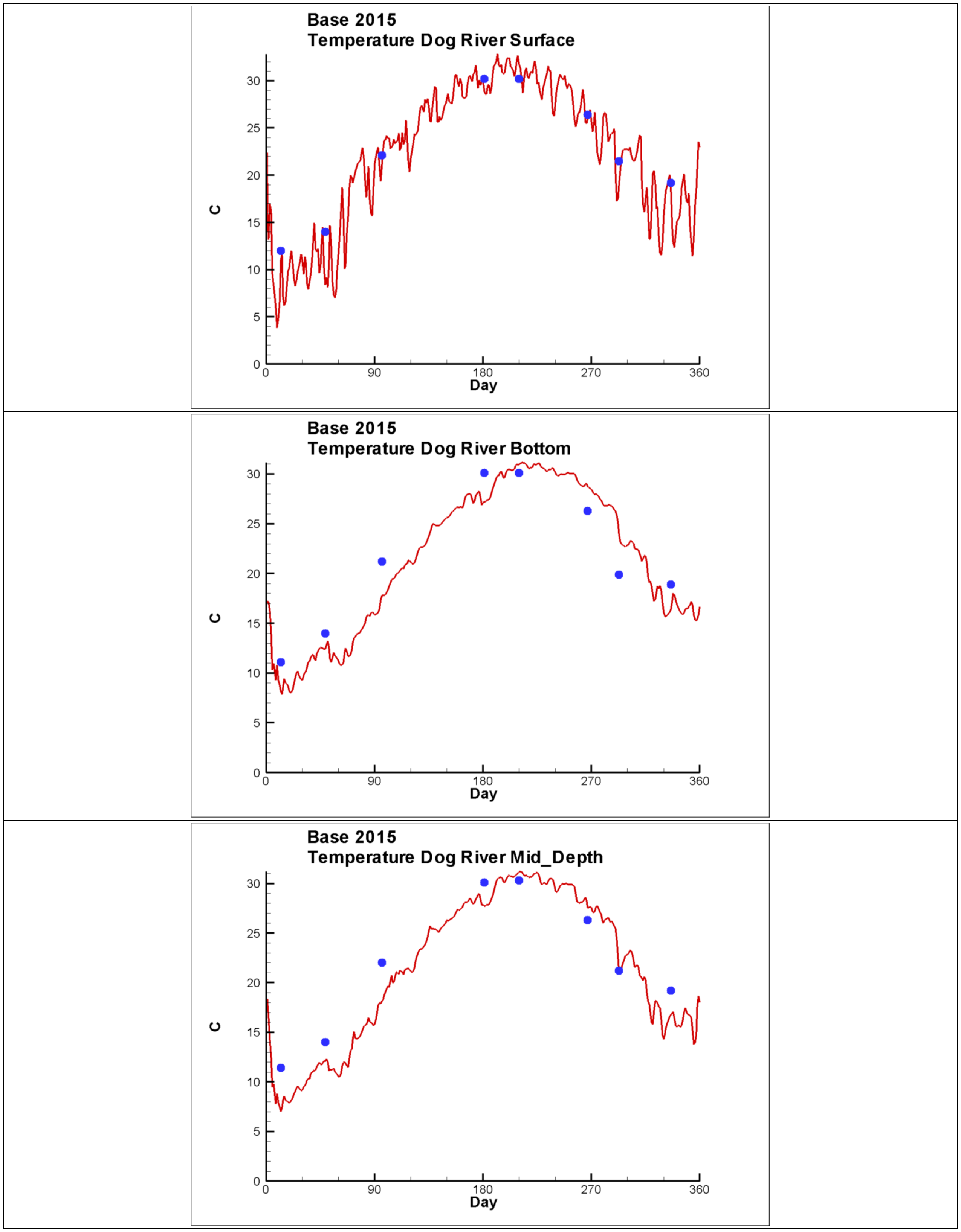


Figure 47 (conc.) CE-QUAL-ICM Surface, mid-Depth, bottom Temperatures for NFWF Dog River sample site

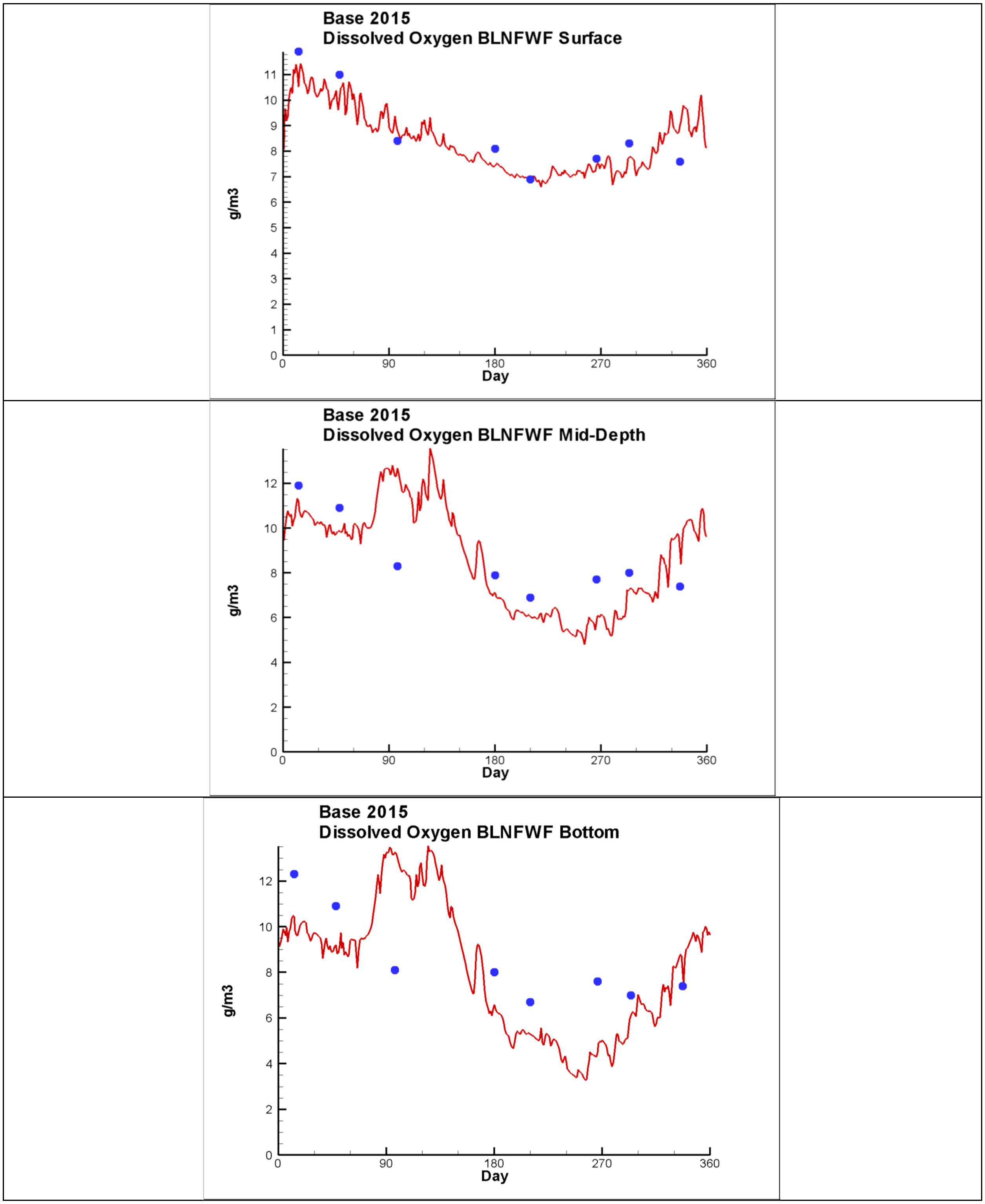


Figure 48. CE-QUAL-ICM Surface, mid-Depth, bottom Dissolved Oxygen for NFWF Bayou Labatre sample site

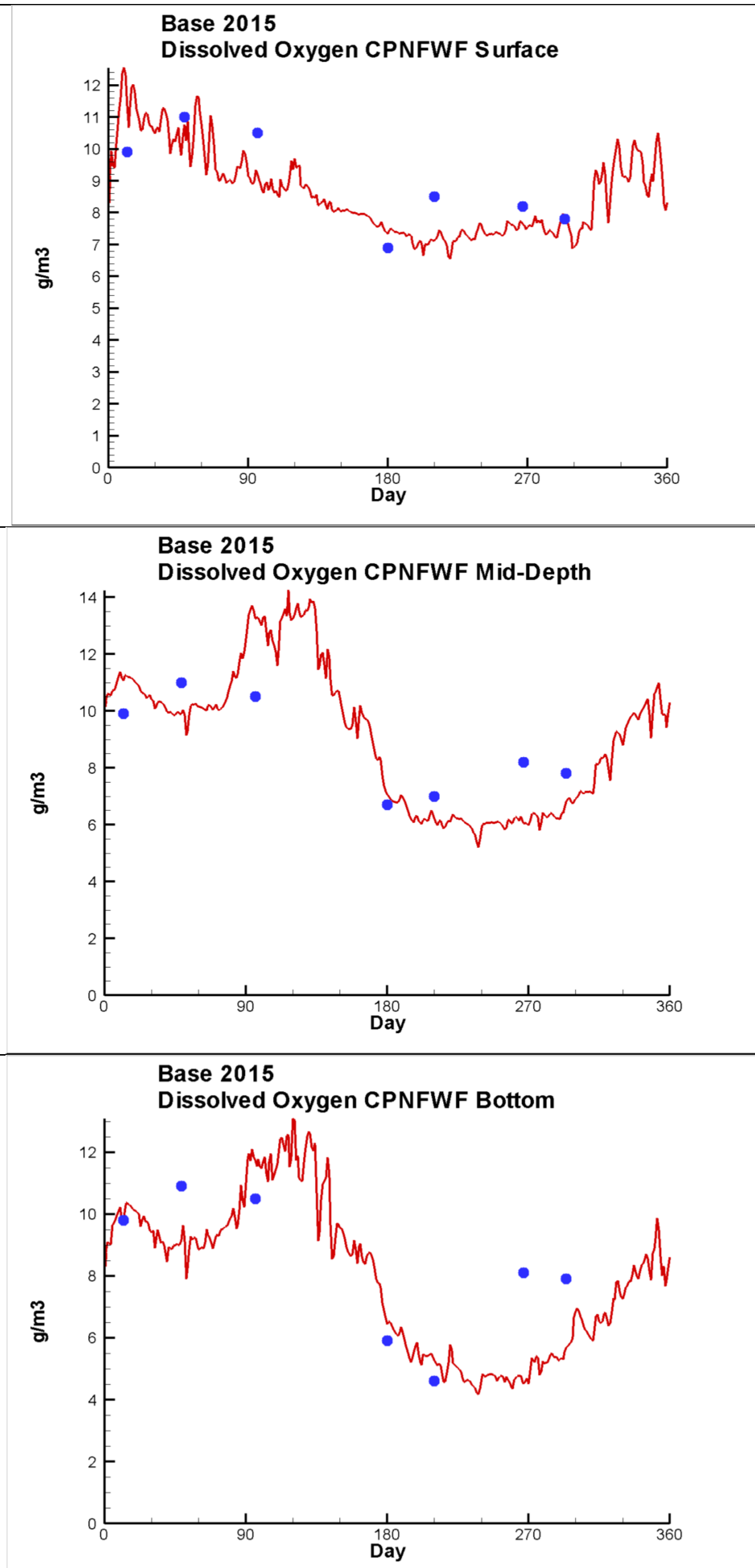


Figure 48 (cont.). CE-QUAL-ICM Surface, mid-Depth, bottom Dissolved Oxygen for NFWF Cedar Point sample site

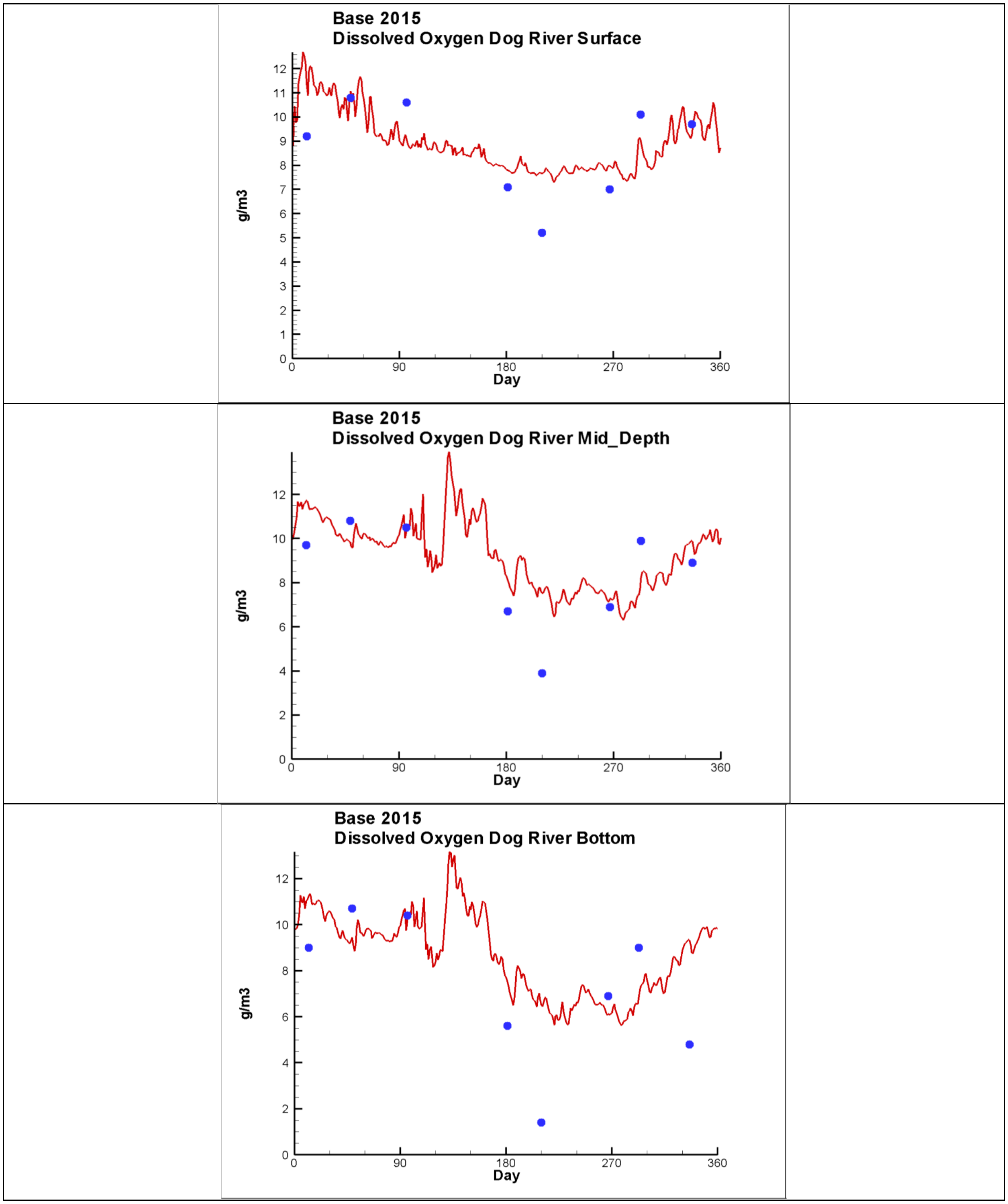


Figure 48 (conc). CE-QUAL-ICM Surface, mid-Depth, bottom Dissolved Oxygen for NFWF Dog River sample site

Time Series Summary

Water quality model output and observations for these parameters at these locations is reasonable. The model is capturing the trends and responding to hydrodynamic and meteorological forcing conditions. The model transport is capturing the basic transport behavior at these locations as evidenced by the salinity results. Model predictions for temperature are also good and the DO results are reasonable. Therefore it is reasonable to use this model to investigate conditions in the waters around Dauphin Island.

Breach Scenario

The breach simulation was conducted in the same manner as the base simulation. A total of three years were simulated. The first year commenced with uniform initial conditions throughout the model for all constituents. The model was run for one year. The final concentrations and levels at the end of the first simulation became the initial conditions for the second year simulation. The second year was simulated and the final concentrations and levels became the initial conditions for the third year simulation. The inputs to the breach case scenario were the same as the base case so that any differences would be attributable to only the hydrodynamic forcing.

Results presented here are for the periods of interest for living resources analysis. These period represent times of higher flows and cooler temperatures (March) and lower flows higher temperatures (August). These two extremes illustrate the range of sustained conditions that can occur.

The March water column average temperature results are shown in Figure 49. They indicate that waters along the immediate backside of Dauphin Island east of the breach are slightly warmer than the waters offshore on the gulf side or in the deeper waters behind the island. This is a result of the shallowness of the water allowing for better heating throughout the water column. The middle of the bay contains the coldest water. The water column over the navigation channel in the middle of Mobile Bay is warmer than that further south and in the mouth.

It is important to remember when viewing these temperature plots that the color scale is relatively fine. Also as water column averages, these temperatures are representative of the whole water column. In areas where the water is deeper or there is a greater vertical variation, then there is a potential for the color to change in response to the lower water column temperatures.

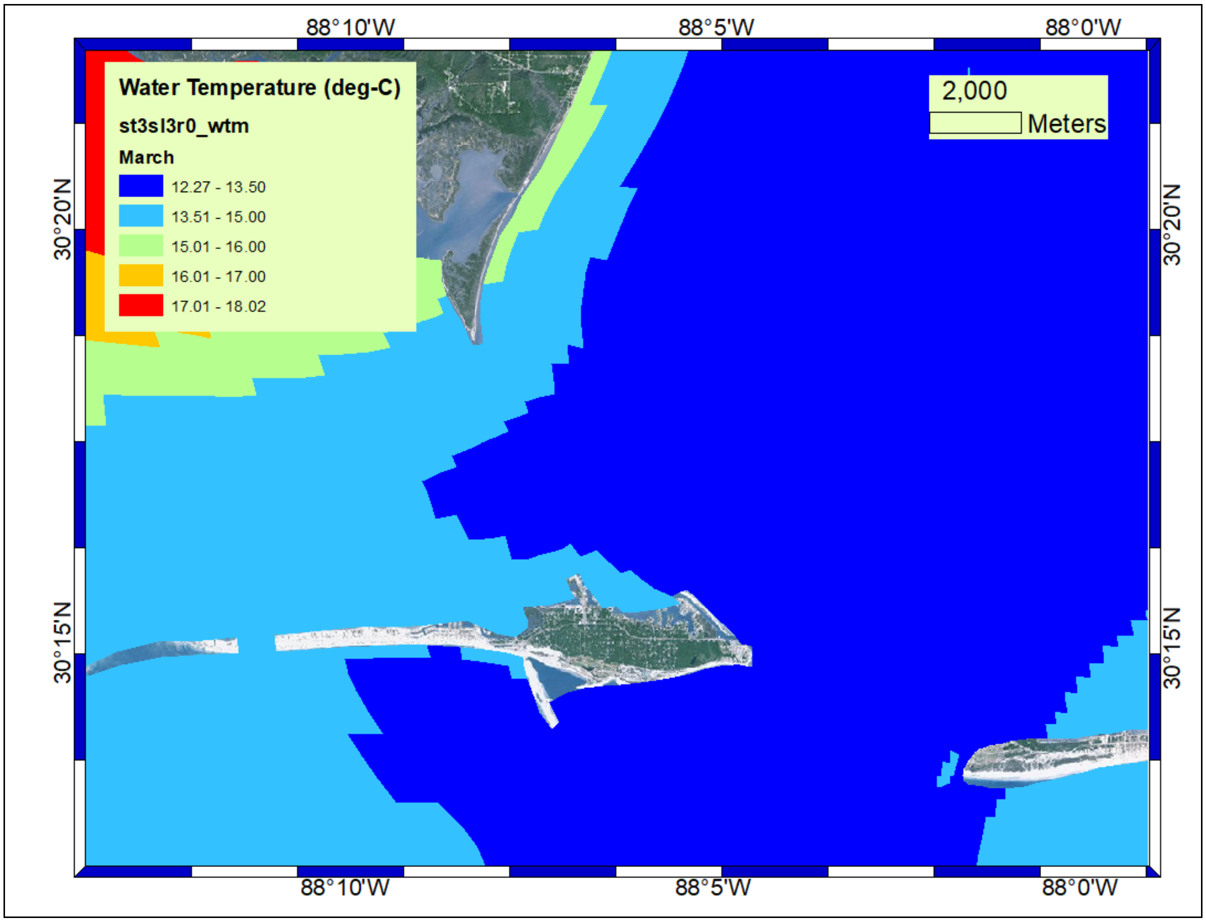


Figure 49. March Breach Water Column Average Temperature

August water column average temperatures are shown in Figure 50. In general terms the water column offshore is cooler than the water column in Mobile Bay. Two reasons for this are that the waters offshore are deeper and the deeper water impacts the overall temperature of the water column. The surface waters are similar temperature but when they are combined with the temperatures throughout the water column, then the difference appears.

When both the March and August results are viewed one large difference appears. In the March image it appears that the variation in water column temperature passes through the Bay mouth towards the Gulf. In August it is the opposite. Given that surface water temperatures are generally the same, their variation is an indication of the effect of temperatures deeper in the water column. It is also an indication of the underlying flow properties of these two seasons. In March, flows from the Bay to the Gulf are greater than in August. To some degree what is happening at the mouth is also happening at the breach site. In general terms, during periods of higher tributary flows the conditions behind and through the breach will be more like those in the Bay. During period of lower flows then the conditions through the breach and on the backside of the island will be more like those of the Gulf.

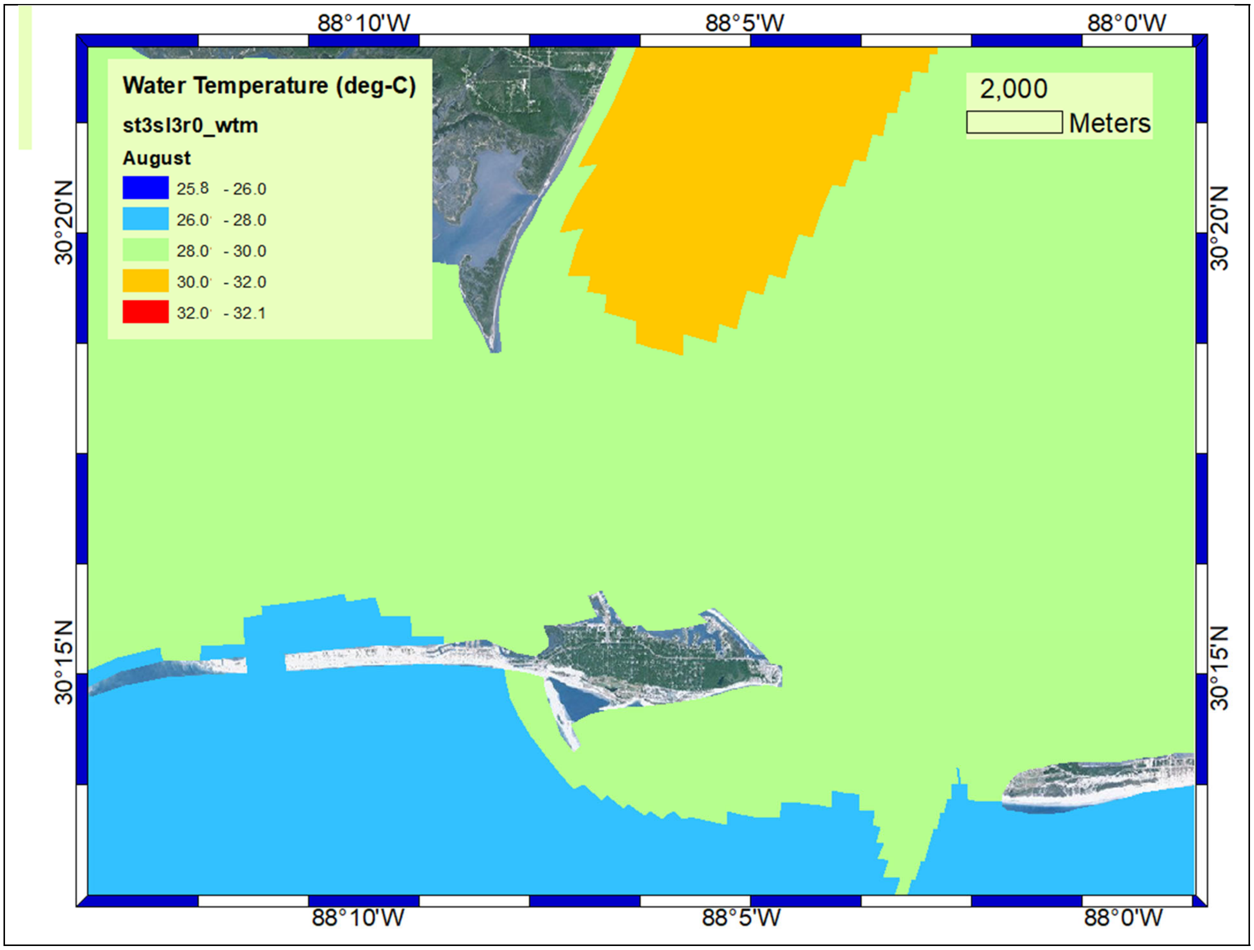


Figure 50. Breach August Water Column Average Temperature

Total Suspended Solids Water Column Averages

March water column average TSS patterns indicated that levels decreased as one travels further down the Bay and out the mouth. Once out the mouth, TSS levels decreased to background levels. In the model the only sources of TSS are boundary condition and point source loadings. Settling works to remove TSS from the water column. Due to the higher flow conditions during this period the TSS is carried further in the system before it is settled out of water column. Higher levels are also associated with the deeper waters of the navigation channel.

Water column average TSS levels near the breach on the backside are similar to those on the Gulf side, Figure 51. Part of the reason for this is that dilution of low TSS offshore waters with higher TSS on the backside reduces TSS levels. This indicates that there is exchange between the Gulf side and the back bay at the breach.

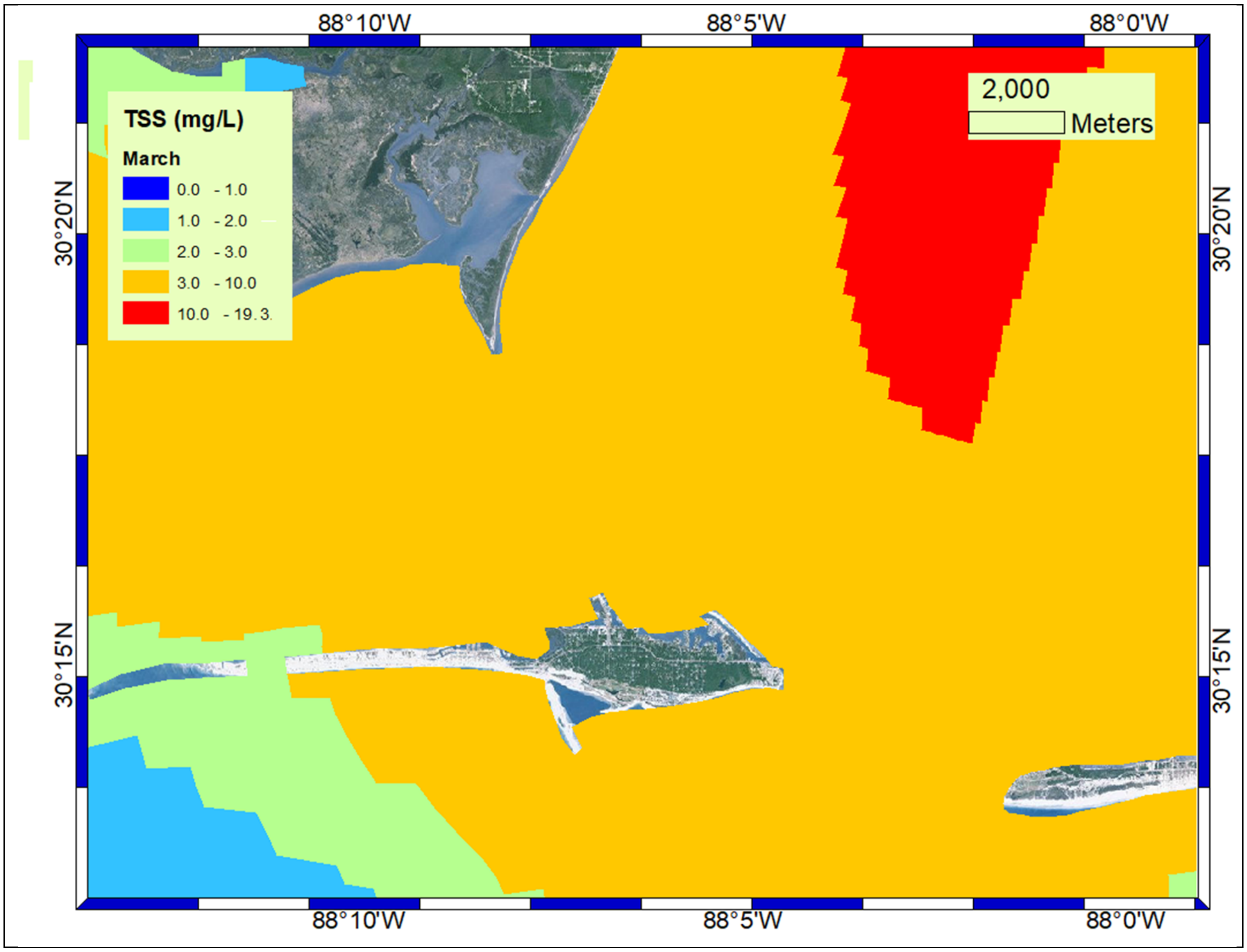


Figure 51. March Water Column Average Total Suspended Solids

August water column average TSS levels indicate that under the lower flow conditions, TSS levels offshore and in the lower bay are low, 1 mg/l or less. Figure 52. Levels further in the bay are higher but still lower than those during March. These low levels around the Breach location prevent and throughout the lower Bay prevent illustration of the impact of breach exchange on water quality in low flow conditions

Dissolved Oxygen Water Column Results

As is evident in the March results, Figure 53, the depth average DO is highest in the bay and the shallow waters north of Dauphin Island. The waters in the middle of the bay in areas corresponding to the navigation channel are relatively lower but still good. The shallower area water columns are more influenced by reaeration and thusly have the higher DO levels. Also, with the higher flow conditions, the bay waters are fresher and therefore have higher DO saturation levels. Increased level in the water column offshore is why the DO levels there are lower but still very good.

What is evident under this condition is the intrusion of some offshore waters through the breach. This is evident due to the decreased DO levels immediately inside the

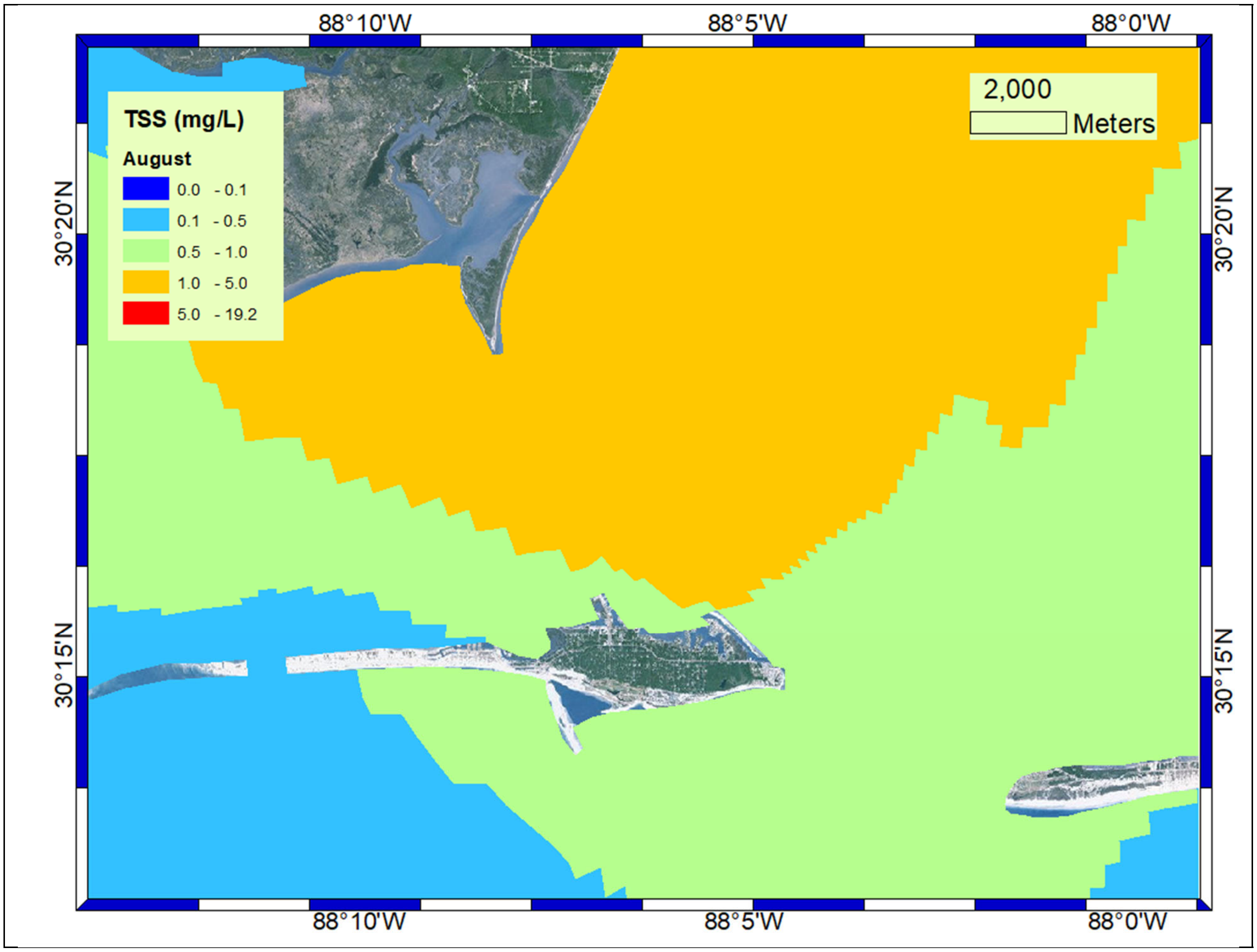


Figure 52. August Water Column Average Total Suspended Solids

breach. A similar effect is not seen at the mouth of Mobile Bay because of the higher rate of outflow in the main channel.

When the August DO average water column conditions are investigated it is evident the degree that both the higher temperature and the lower flows are influencing conditions, Figure 54. Elevated temperatures during the summer decrease the saturation level of DO in the water column. At the same time, typically lower flows during the summer result in less flushing of the bay and increased salinity intrusion from the Gulf. This occurs in the main channel and also through the breach.

Resulting DO levels around Dauphin Island are still satisfactory and higher than those further up the Bay. Only areas north of Dauphin Island close to the mainland have higher DO levels along with waters immediately adjacent to Dauphin Island's eastern end. In the case if the waters near the mainland these waters are both shallower and fresher than those in the main part of the bay. Shallower depths aid in transferring DO throughout the water column while lower salinities enable the water to have higher saturated DO levels. Under these conditions the impact of the breach on DO levels is not definitive. DO levels on both sides of Dauphin Island are similar and appears to be as much driven by water depth and salinity levels.

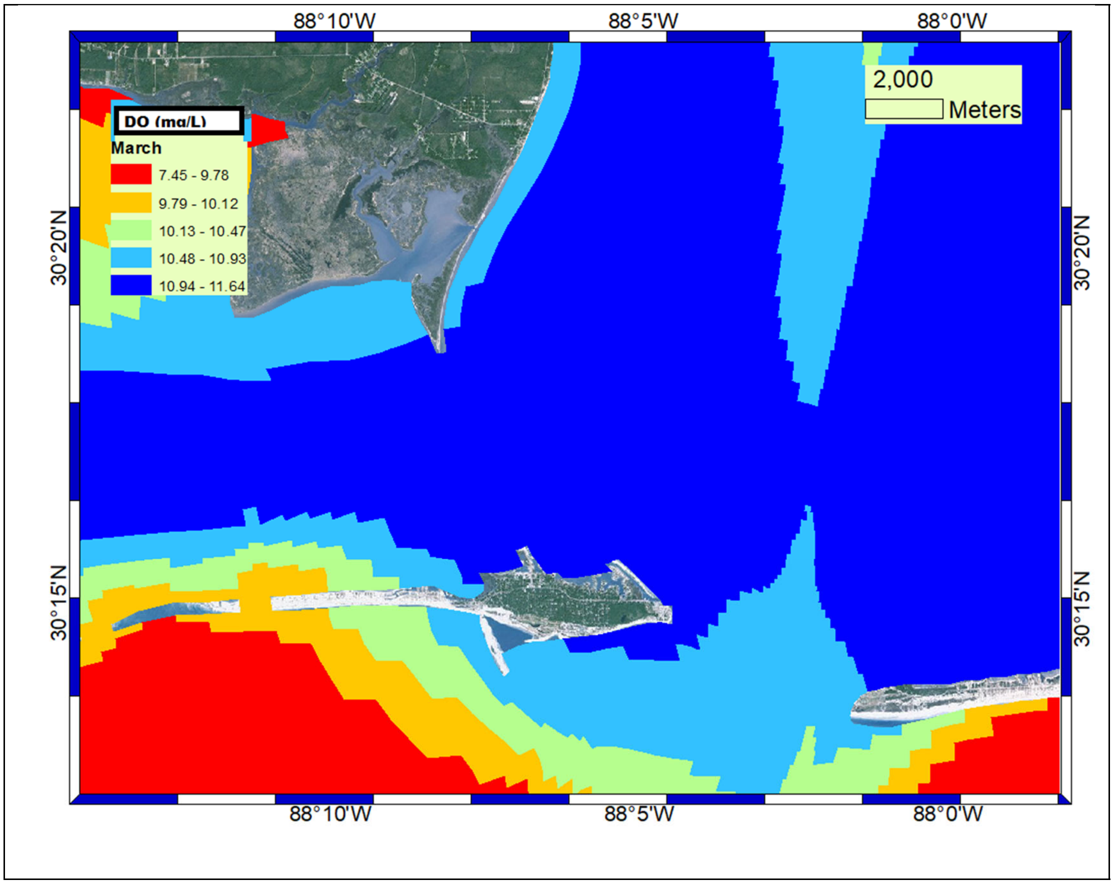


Figure 53. Breach Conditions March Water Column Average Dissolved Oxygen Levels

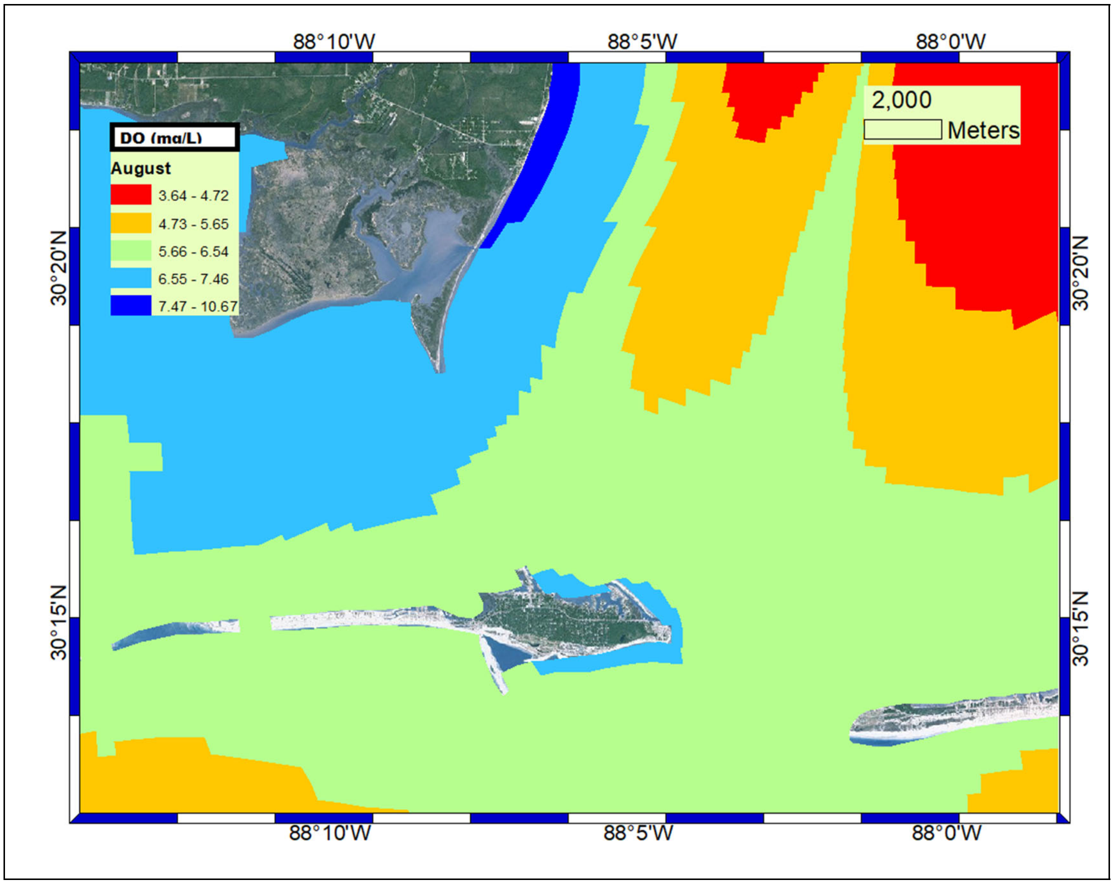


Figure: 54 Breach August Water Column Dissolved Oxygen Levels

Time Series North of Dauphin Island

Station MB-1A is located In Mississippi Sound 1 mile north of Dauphin Island and 2.5 miles west of the Dauphin Island Parkway, Figure 55. Its location is in close proximity to the location of the modeled breach. As such it is a good indicator of the potential impacts of the simulated ocean breach in case ST3SL3. Comparison of water quality conditions for the scenario simulation case and the base case indicate the impact resulting from just this change. All other model inputs are consistent for the two cases.

Overall conditions behind Dauphin Island at MB-1A show limited impact as a result of the breaching, Figures 56-57. Surface layer water temperatures and dissolved oxygen levels are basically unaffected by the breaching. This is in large part due to surface heat exchange and reaeration processes being the dominant process occurring in the surface layer. Bottom layer results are more dynamic but illustrate the same overall trends and behavior in the existing and post-breach conditions. Infusion of offshore waters do not have long-term detrimental impacts at this location.

Figure 55. Breach condition comparison station

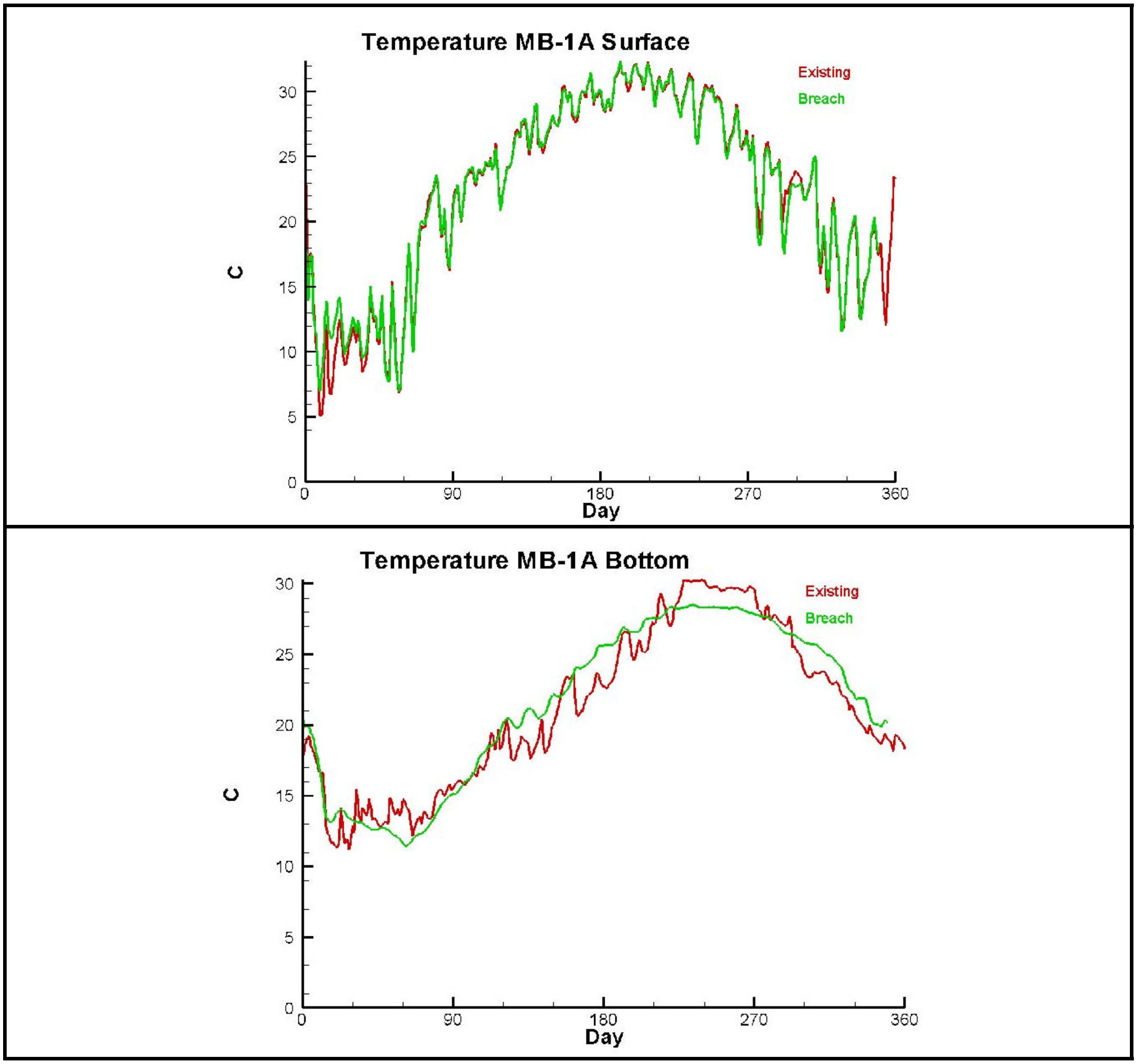


Figure 56. Temperature MB-1A Surface and Bottom.

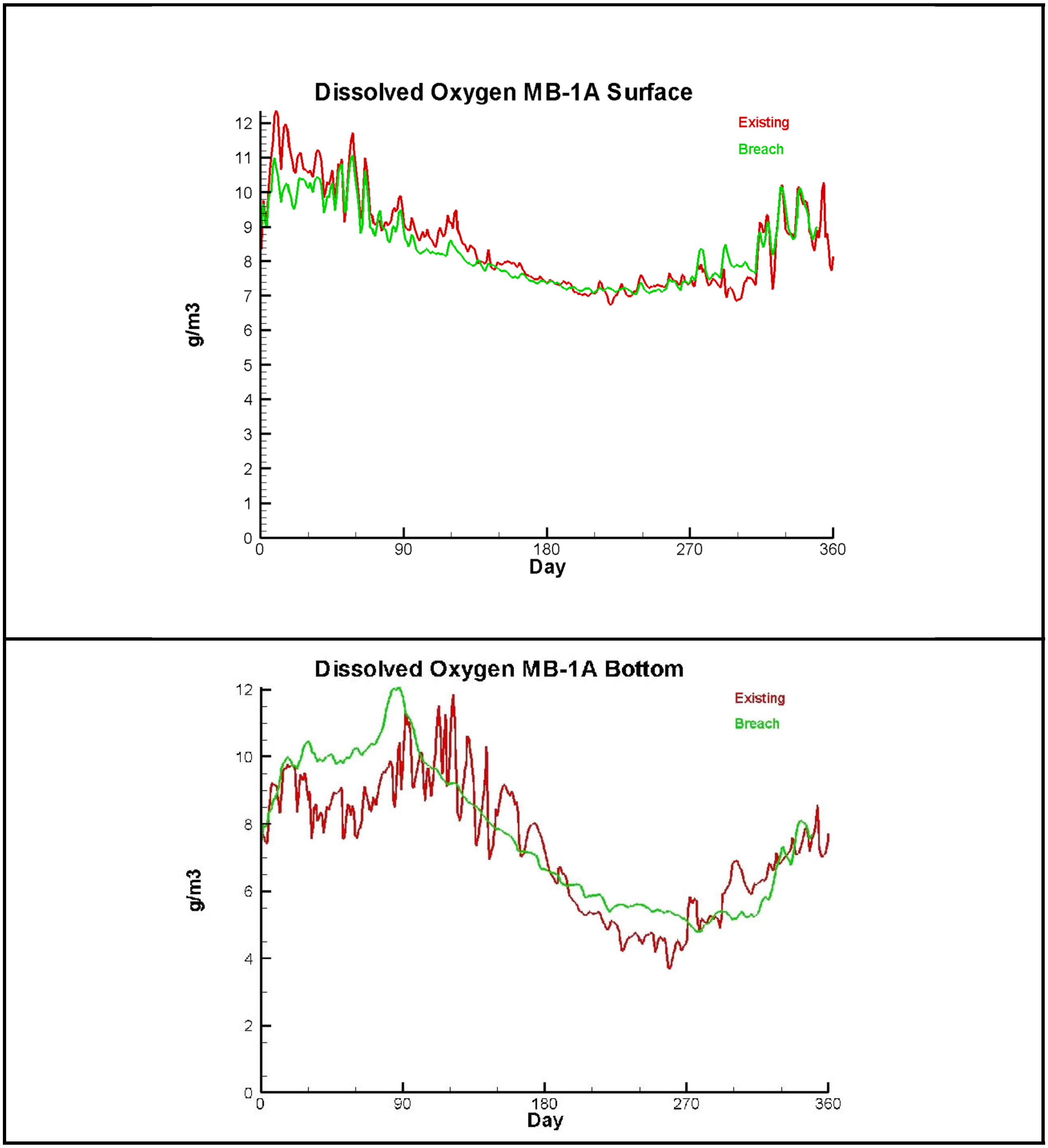


Figure 57. Dissolved Oxygen MB-1A Surface and Bottom.

Conclusions

The Geophysical Scale Multi-Block (GHSMB) hydrodynamic and water quality model set up for Mobile Bay and adjacent Northern Gulf of Mexico and Mississippi Sound provides assessment of potential water quality changes as a result of breaching along Dauphin Island by extreme conditions and sea level changes. The transport was validated with long-term time series of water properties, especially salinity, at several locations throughout the Mobile Bay. The validation indicates the model resolves varying temporal scales over tidal, diurnal, and seasonal scales as well as spatial scales from meters to 100s of kilometers. The model appropriately responds to forcing to the system, specifically for hydrological, meteorological, and oceanic forcing.

The 4 breach scenarios, stemmed from USGS Delft3D simulation for ST3SL3 associated with 6 scenarios, for which all point to increased salinity along the barrier island. The extension of which was more toward the West and North of the island. Impact of breaches over Little Dauphin Island and Pelican Island appear to remain local and do not extend into the broader Mississippi sound and Mobile Bay systems.

To further investigate the impact of breach to water quality, the extreme condition of ST3SL3 was applied to water quality modeling and the results were compared to base case to assess the impact. In order to fully resolve seasonal variation of water quality, the 2015 forcing and loading conditions were repeated for 3 years in both base and ST3SL3 conditions in which the first 2 years give stable initial conditions. The water quality model results from the third year simulation were analyzed for assessment. Output from the hydrodynamic and water quality modeling was then passed off to USGS teams that further evaluated the potential changes in the habitat suitability of oysters and sea grasses behind the Dauphin Island in the event of breaching. Further details of the habitat assessment are contained within Enwright et al. (2020) Predicting barrier island habitats and oyster and seagrass habitat suitability for various restoration measures and future conditions for Dauphin Island, Alabama

The validation of base condition water quality model was done by comparing the simulation results with observation. Overall the model and data agreement at a these stations was reasonable. The ST3SL3 assessment was done comparing water temperature, TSS and DO from base conditions. The comparison shows the similar pattern as in salinity. The breach only affect locally as the water mass from Gulf of Mexico enters the Mississippi Sound through the cut caused by breaching. The assessment of impact of breach on water quality and hydrodynamics indicates no significant impact to the water body of Mobile Bay and Mississippi Sound and limited primarily to the vicinity of the cut from the breach.

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