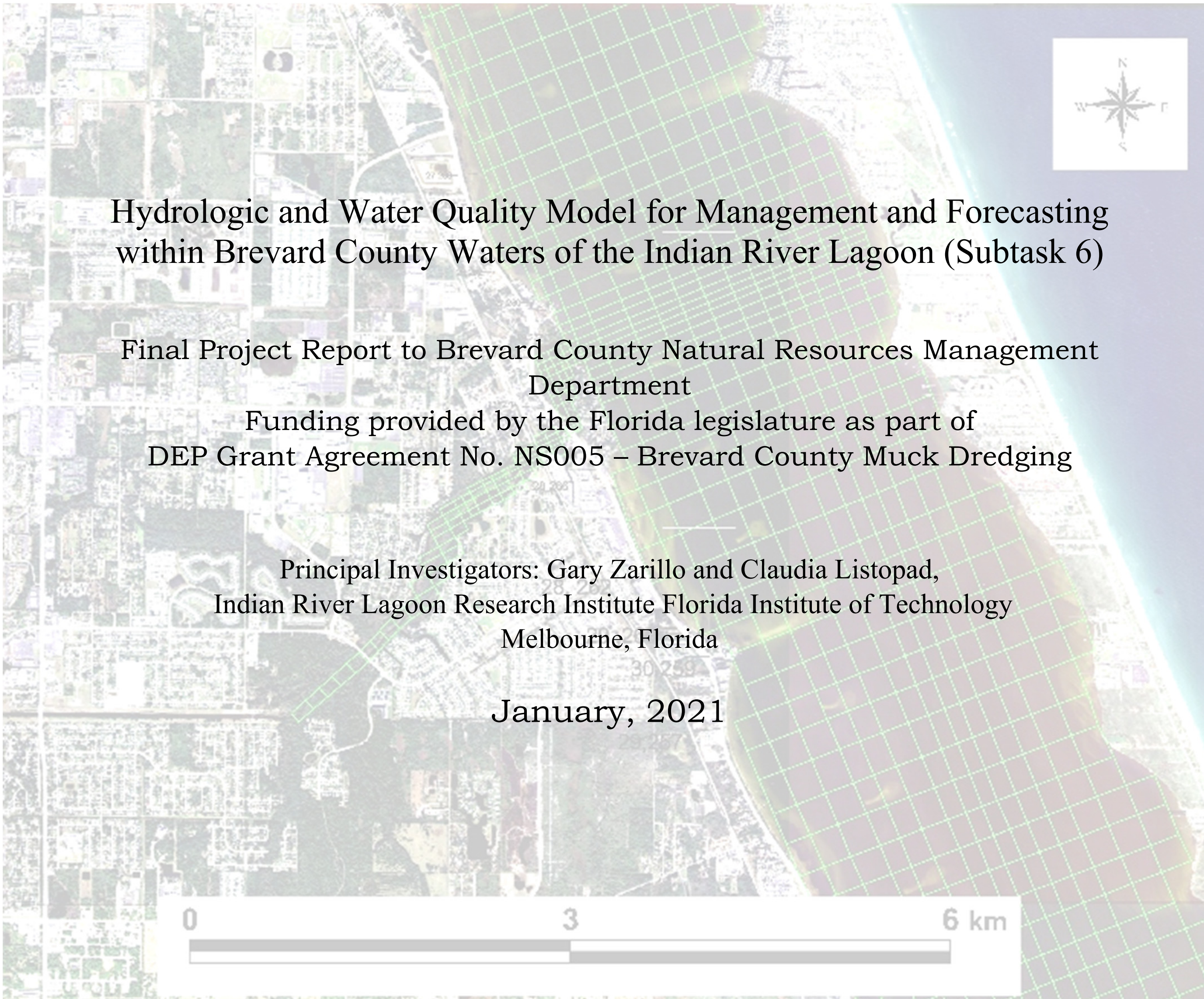
Impacts of Environmental Muck Dredging 2016-2019



Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters of the Indian River Lagoon (Subtask 6)

Final Project Report to Brevard County Natural Resources Management Department
Funding provided by the Florida legislature as part of
DEP Grant Agreement No. NS005 – Brevard County Muck Dredging

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This project integrates water quality and hydrologic, and hydrodynamic process data into the model of the Indian River Lagoon. The overall goal is to combine model simulations with measured data to assess the impact of muck dredging on local and regional water quality. Water quality modeling in the final year of the project benefited from the expansion of muck zone assessment from Turkey Creek to the additional areas. Model experiments in all muck zones show that muck dredging has the potential to reduce nitrogen based nutrient concentration in the water column outside the dredged area, as well as within the dredged areas. Model experiments also demonstrate the potential for reducing phosphorus based nutrient concentrations. The impact of muck dredging in all areas was detectable in the model results, which show a post dredging reduction of total nitrogen concentration. Muck zones tested in this project can be broadly divided into two groups, those directly influenced by seasonally strong freshwater inflows and other zones not directly influenced by inflow due to their location at some distance from tributaries mouths. Muck zones in this study most influenced by inflows are Turkey Creek and the Eau Gallie NE zone. The predicted benefits of muck dredging in both these areas were detectible, particularly during the dryer season. Freshwater inflows from Turkey Creek and the Eau Gallie River partially masked predicted dredging produced reductions in water column total nitrogen (TN) concentrations due nitrogen loading from the inflow. The model-predicted principal form of nitrogen for both the Turkey Creek area and the Eau Gallie area is dissolved organic nitrogen (DON) with lesser contributions from nitrate + nitrite (NOX) and ammonium (NH4). In addition to predicted reductions of total nitrogen (TN), another predicted corresponding benefit of muck dredging is increased dissolved oxygen (DO) levels. In other areas where muck zones are less directly influenced by freshwater inflows, the predicted total nitrogen (TN) concentrations are dominated by nitrate + nitrite (NOX). The predicted benefit from muck dredging in these areas is more persistent over the model runs and the magnitude of total nitrogen (TN) reduction after dredging is larger.

Overall, the ongoing muck dredging program is predicted to have significant benefits in all muck zones investigated in this study. These are gauged by predicted reductions in total nitrogen concentration in the water column above the dredged muck deposits and in areas beyond the immediate foot print of the dredged zone. With respect to the Turkey Creek dredged muck zone, predicted reductions in total nitrogen (TN) and increases in DO were predicted to extend to at least 8 km from the entrance of Turkey Creek. Total phosphorus concentrations were also predicted to decline in the vicinity of some of the muck zones investigated, but not in others. More spatial and temporal samples of nutrient flux from sediments are required to constrain the water quality model calculations, particularly with respect to the forms of phosphorus, which generally occur at lower concentrations in the water column compared to forms of nitrogen. Never-the-less, comparisons between model data and measured data for nitrogen, phosphorus and dissolved oxygen demonstrate that the EFDC/HEM3D model applied to the Indian River Lagoon system to evaluate the impacts of muck dredging is performing with good accuracy despite the lack of spatially and temporally extensive sediment nutrient flux data to constrain the model calculations.

As of this writing the IRL hydrodynamic and water quality model continues to be developed through updates of model boundary conditions and inclusion of additional muck zones in the model grid. As more information is developed on the extent of muck deposits in the IRL system the model can be adjusted to include these zones.

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1.0 Introduction and Goals

The goal of this project is to deploy a full three-dimensional, combined hydrodynamic, hydrologic and water quality model in the Indian River Lagoon (IRL) to address the following: 1) to determine whether the removal (dredging) of muck sediment will improve local water quality in the vicinity of Turkey Creek and other localities that are to be dredged over the next several years, 2) to determine whether improved model guidance by measured *in situ* data and modeled watershed data will allow the relative effects of watershed inputs and nutrient flux from muck sediments to be resolved, and 3) to determine if muck dredging, either locally or regionally, can result in a lasting improvement of IRL water quality. The modeling effort consists of three major software platforms including a three-dimensional hydrodynamic model, a three dimensional water quality or eutrophication model, and a watershed hydrologic model to provide inputs to the coupled hydrodynamic and water quality models.

2.0 Overview of Previous Accomplishments

Final accomplishments of the Hydrologic and Water Quality Model should be viewed from the perspective of all accomplishments in years 1 to 3 of this study, from model development to its application. The details of the development of the Hydrologic and Water Quality Model are given in previous reports (Zarillo and Listopad, , 2015, 2017). Major tasks included assembly of geomorphic data, processes data, and water quality data included in the model setup and calibration procedures. The effort in year 1 was focused on model setup and testing of the hydrodynamic, water quality and watershed models. In year 2, the temporal scope of the model simulation was extended to the close of 2016, and in year 3, the model simulation period was extended to the close of 2017. Results of the initial runs of the water quality model representing about two years of real time suggest that muck removal from Turkey Creek will have a measurable impact on improving water quality, not just in the Turkey Creek basin, but also in the Central IRL. Year 3 efforts, on which most of this report is based, included expansion of the hydrodynamic model grid to include the muck zone areas beyond the Turkey Creek area that were specified by Brevard County. This expansion of model application is reviewed in detail in this report.

In addition to the setup and calibration of the in-estuary hydrodynamic and water quality model (EFDC/HEM3D) in year 2 the Spatial Watershed Iterative Loading (SWIL) model was setup to provide nutrient loadings from the sub-basin watersheds of the IRL. The SWIL model is a custom ESRI ArcGIS toolset, providing a continuous monthly simulation of runoff (surface and baseflows) and yielding robust representation of pollutant loadings and freshwater volumes to the IRL. This watershed runoff model was originally developed as part of a study to incorporate available watershed data into the U.S. EPA and Florida state's nutrient TMDL (total maximum daily load) process for the IRL. For this study, the SWIL model has been expanded and further resolved in space and time to provide calculations of watershed-runoff nutrient loadings to the IRL. Details of model operation can be found in the SWIL Model Methodology Manual (Listopad, 2015) and in Appendix A of this report under separate cover.

3.0 Final Project Tasks

Table 1 summarizes hydrodynamic and water quality modeling tasks. The update of the SWIL watershed model output to the close of 2017 was completed as of April 1, 2018. A further refinement of the SWIL model to include sub-basins surrounding the U.S Air Force Patrick Airforce Base (PAFB) was completed in April of 2019. The updates to the SWIL model are described in Appendix A. These updates allowed the hydrodynamic and water quality model to advance to the close of August 2017 using temporally coincident watershed inputs by re-formatting these data, along with data from the other sub-basins, into files read by the EFDC/HEM3D hydrodynamic-water quality model. Once this was complete, the EFDC/HEM3D sediment diagenesis component was updated to the close of 2017. Final prognostic model runs for water quality in the IRL were then updated to include a 488-day period from the beginning of 2016 though the middle of 2017 and compared with measured data.

Table 1. Final Projects Tasks

Objectives/Tasks
Extend model grid into muck dredging areas.
Update water quality data base through close of 2017
Expand and update SWIL Watershed Model through 2017
Refine sediment diagenesis model zones
Model prognostic simulations
Final Report

4.0 Model Grid

Figure 1 shows the overall extent of the IRL model grid, from Ponce de Leon Inlet in the north to just south of Ft. Pierce Inlet at the south end. The updated model grid includes 10,094 active computational cells in the horizontal dimension and 5 layers in the vertical dimension.

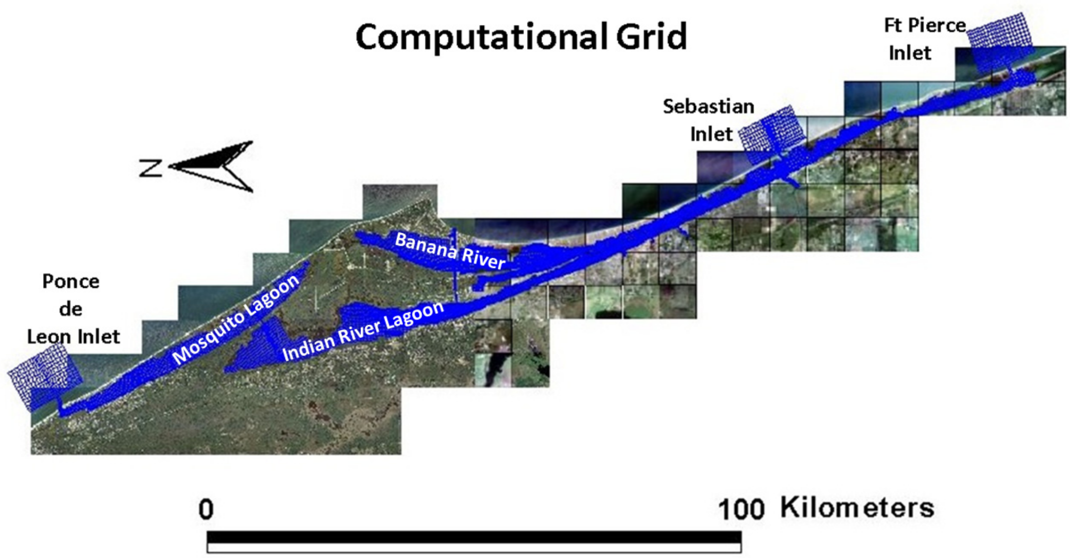

Figure 1. Computational model grid extending from Ponce de Leon Inlet to Ft Pierce Inlet, FL

4.1 Grid Modifications

The model grid as of this writing includes about two-thirds of the IRL system extending from Ponce de Leon Inlet to Ft. Pierce Inlet. The initial model grid as described in previous reports included all of the lagoons of the IRL system: Mosquito Lagoon, Banana River Lagoon, and the main body of the IRL from Titusville to the vicinity of Ft. Pierce Inlet. Recent improvements to the model computational grid include extending it further west up into Turkey Creek, Crane Creek, and the Eau Gallie River, along with refinements to better resolve the numerous causeway bridges that span the lagoons. These are described in Zarillo and Listopad (2018)

More recently, in order to offset the lack of long-term, water-level and salinity records at the model grid boundaries, the model coverage has been extended through the entrance of Ponce Inlet, Sebastian Inlet, and Ft Pierce Inlet. The grid modifications allow model predictions to be extended to any time period that can be covered by water level predictions based on tidal constituents or time periods covered by large, basin-scale models such the ADvanced CIRCulation model (ADCIRC, Westerink et al, 1996). Further, three-dimensional time series of salinity and water temperature for coastal ocean boundary conditions were provided by a basin-scale model, the HYbrid Coordinate Ocean Model (HYCOM) developed under the National Oceanographic Partnership Program (NOPP). Figure 2 is an example of the model grid extended into the coastal ocean through Sebastian Inlet. Similar grid extensions were completed through Ponce Inlet and Ft. Piece Inlet. Model boundary conditions assigned to these areas of the model are outlined in Section 5 of this report. Setup of model boundary conditions in the initial model domain was outlined in an earlier report (Zarillo and Listopad (2015)

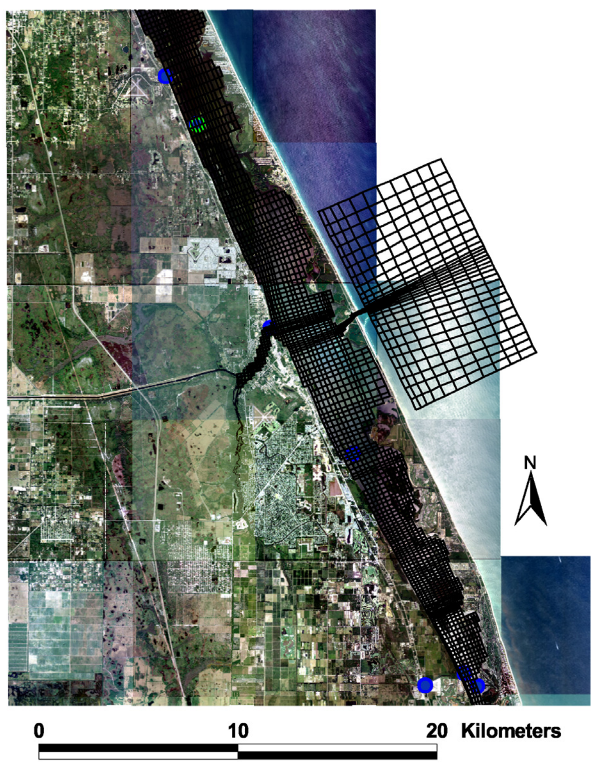

Figure 2. Configuration of the computational model grid in the area of Ft. Pierce Inlet , FL.

5.0 Hydrodynamic Model Update

5.1 Model Boundary Conditions

Water level

The original calibration of hydrodynamics and other components of the overall model were based on data collected in 1999 by the SJRWMD. As part of the quality control procedures for the Hydrologic and Water Quality Model (Zarillo and Listopad, 2017), comparisons were made between measured and modeled water levels. In the time period of the 2015 model runs, the ocean water level boundary conditions of the model were set by a combination of predicted tide levels and non-tidal water levels derived by filtering measured data at NOAA Station 8721604 at the Trident Pier, Cape Canaveral FL. Observations show that non-tidal sea levels are coherent at regional spatial scales as seen in Figure 3 illustrating the comparability between the Trident Pier tidal and filtered non-tidal water-level data and the data at Sebastian Inlet 65 km to the south. The non-tidal records differ by not more than 5 cm. In the tidal spectrum water level records at Trident Pier and Sebastian Inlet are almost identical.

Model water level boundary conditions for the IRL in the post-2015 period are set by combining the non-tidal (low frequency) sea-level record as shown in Figure 3 with a tidal water level time series predicted from the ADCIRC basin scale model. Model runs using ADCIRC were specifically completed to support this project. The ADCIRC model data were produced to fit the EFDC model boundary model grid cells in the coastal ocean as shown in Figure 2.

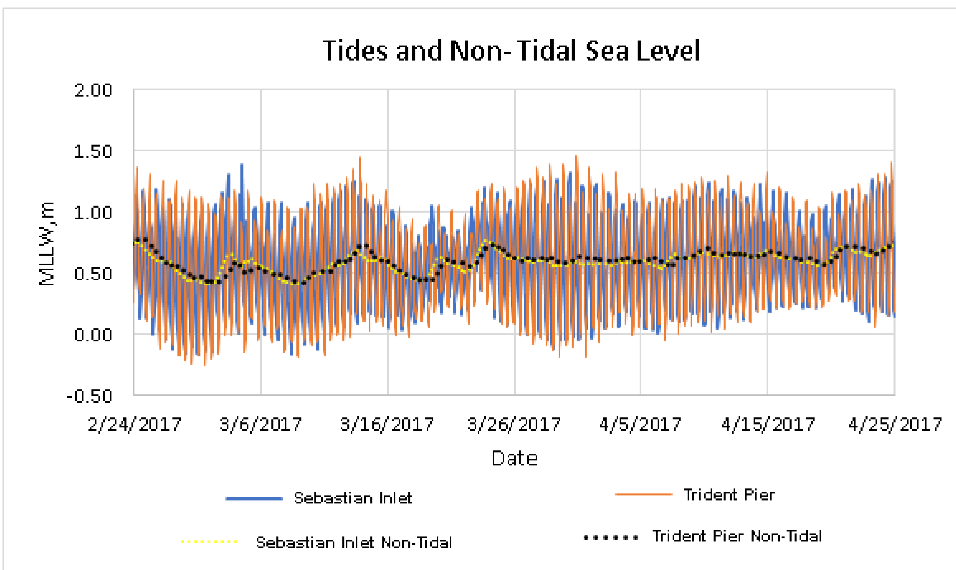

Figure 3. Measured tidal and non-tidal water level records from NOAA Station 8721604 (Trident Pier, Cape Canaveral FL) and Sebastian Inlet.

Figure 4 is an example of model boundary water level time series applied in the coastal ocean offshore of Ponce de Leon Inlet at the north end of the model domain. These data combine the tidal signal from ADCIRC and the non-tidal sea level tie series derived from the Trident Pier NOAA Station.

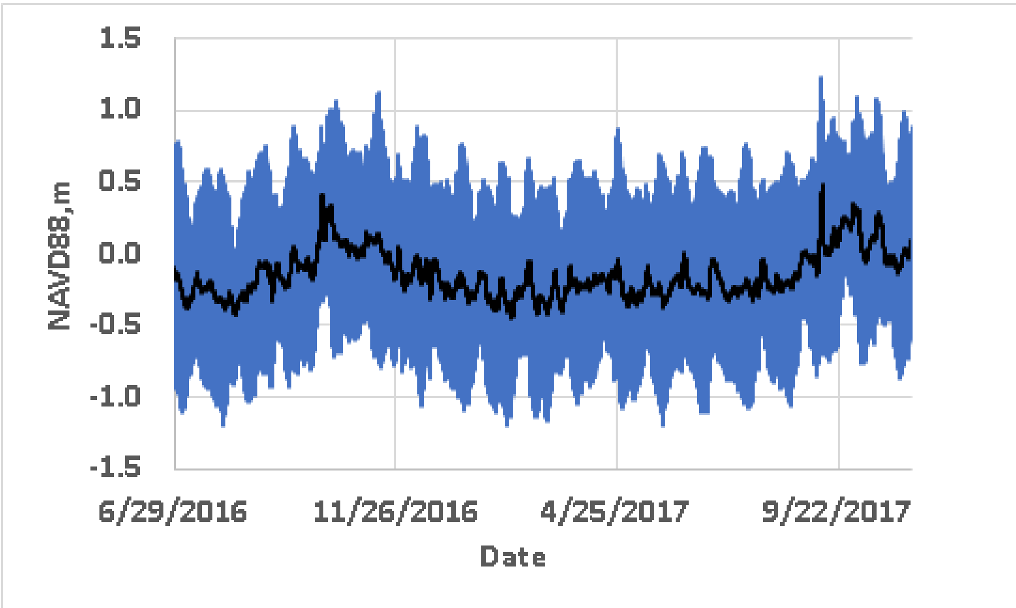

Figure 4. Water level time series applied to model boundary cells offshore of Ponce de Leon Inlet showing the combined tidal and sea level signals. Black line shows the nontidal sea level, whereas the blue line shows the combined series.

Model calibration and validation results were described in an earlier project report (Zarillo and Listopad, 2016). However, since the addition of the grid into and beyond the inlets and an update to model boundary conditions into the newly gridded areas, another check on model water levels was performed.

Figure 5 compares observed and modeled water levels at the Wabasso Bridge, just south of Sebastian Inlet, where a long term water level sensor has been maintained by the USGS on behalf of the SJRWMD. The time period shown in Figure 5 corresponds to the overall time period in which the latest round of model predictions was made. The root mean square error (RMSE) of the comparison is 0.034m (3.4 cm) and the ratio between RMSE and the range (RANGE) of observed values of water level is 0.037 representing an error of 3.7%. This is a substantial improvement over the original calibration and validation exercise, in which the observations to modeled results were 7.7% and 9.4% respectively (Zarillo and Listopad, 2016)

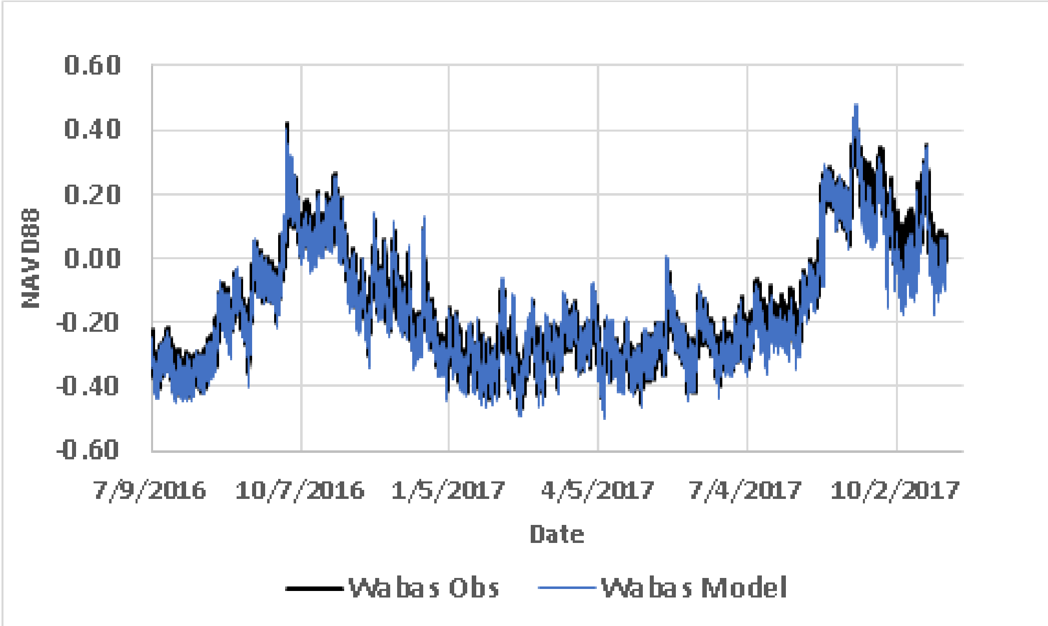

Figure 5. Observed(Obs) and predicted (Model) water levels at Wabasso Bridge (Wabas), north Indian River County, FL

5.2 Salinity and water temperature boundary conditions

Salinity and water temperature boundary conditions in the original model setup are described in Zarillo and Listopad (2016). In the present model configuration, salinity and water temperature time series were assigned to the coastal ocean model boundary cells offshore of Ponce Inlet, Sebastian Inlet, and Ft Pierce Inlet. These data were provided from the archive of model runs maintained by the HYCOM Consortium (https://www.hycom.org/). Figure 6 is an example of salinity and water temperature data provided by HYCOM for offshore model cells at Sebastian Inlet (as shown in Figure 2).

Calibration and validation of model salinity and water temperature data were provided in Zarillo and Listopad (2016). However, since the HYCOM time series are an update of outer model boundary conditions, a comparison of observed and modeled salinity data and water temperature data was made for the 2016 to 2017 period in which the latest model runs were produced.

Figure 7 compares model-predicted salinity values with observed salinity data recorded by the Harbor Branch Land/Ocean Biogeochemical Observatory (LOBO) Station IRL-SB. This station is located in the Intracoastal Waterway to the west of Sebastian Inlet. The observed data to modeled data comparison was made for the surface layer of the model, which represents the upper 20% of the water column. The variability of the measured data to higher and lower extremes compared to the model data, reflects the difference between a point measurement in the water column to model data spatially average over a large grid cell and over 20% of the water column. The RMSE for the comparison is about 2.1 PSU representing an error of about 11.5%, which is comparable to the calibration and validation error values reported earlier by Zarillo and Listopad (2016)

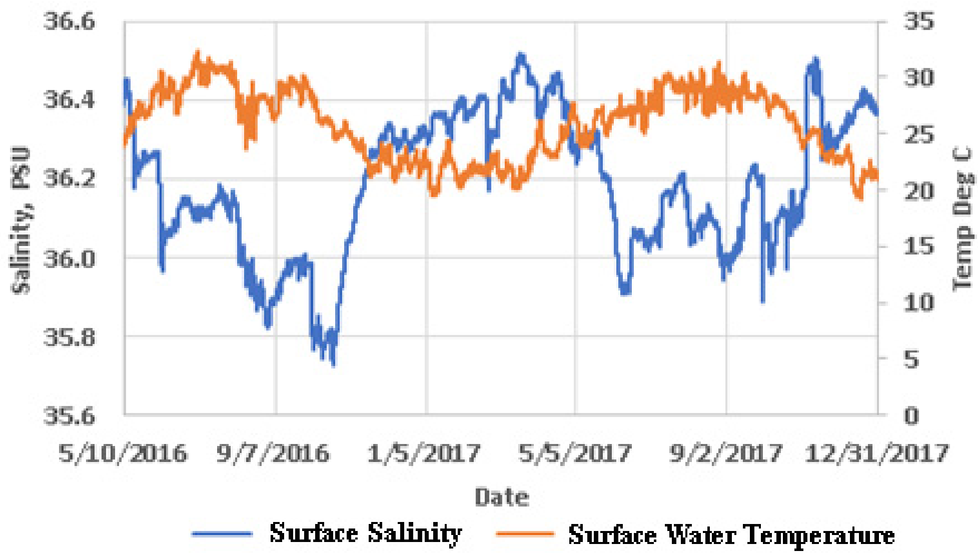

Figure 6. Example of surface salinity and water temperature data provided by the Hybrid Community Ocean Model (HYCOM) for offshore model cells at Sebastian Inlet shown in Figure 2.

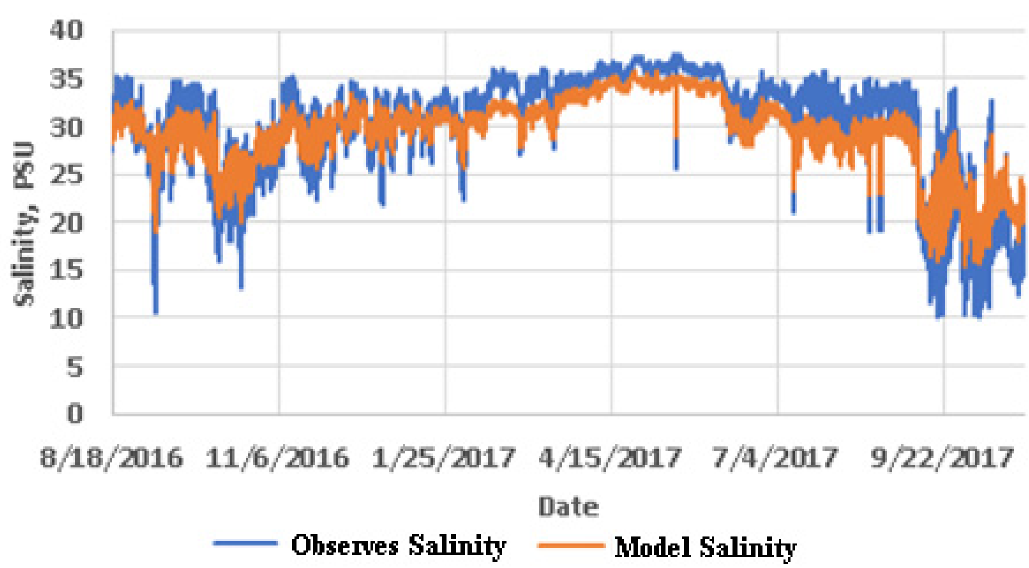

Figure 6. Comparison of observed and model salinity values recorded at Harbor Branch Land/Ocean Biogeochemical Observatory (LOBO) Station IRL-SB. Model data are shown layer 5, which represent conditions in the upper 20% of the water column, where that match with observed data is closest.

Figure 7 compares water temperature observations with model data at LOBO Station IRL-SB. The RMSE for the comparison is 2.14 for a relative percentage error of about 8.2% when comparing the RMSE value to the range of observed values.

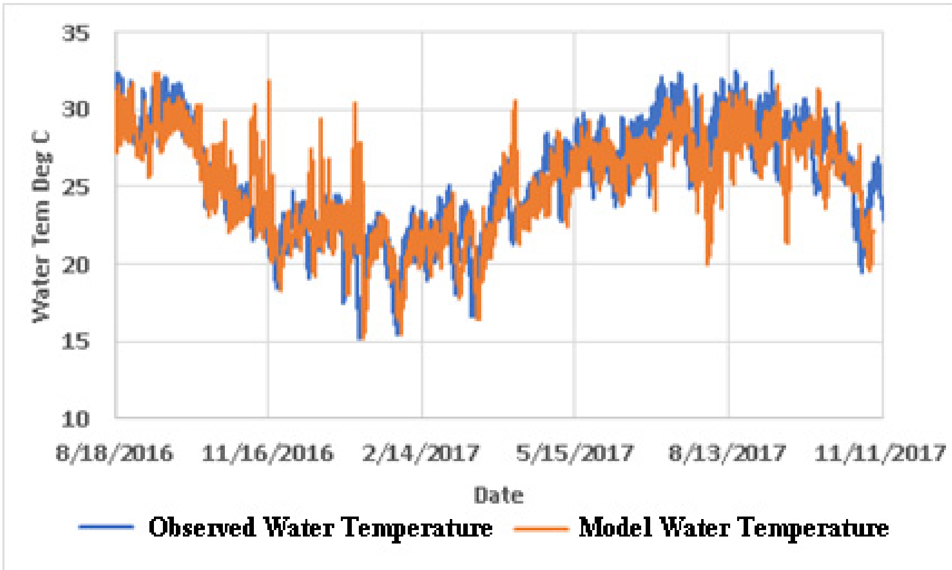

Figure 7. Comparison of observed and model water temperature values recorded at Harbor Branch Land/Ocean Biogeochemical Observatory (LOBO) Station IRL-SB

6.0 Water Quality Model Update

6.1 Water quality model muck zones

In addition to the original goal of the project goal which focused on the impacts of muck dredging in the Turkey Creek area, additional muck dredging sites were specified by Brevard County for further study. Table 2 presents the expanded list of muck dredging sites along with the original Turkey Creek area. Surface area, muck volume, and estimates of flux rates are provided by Fox et al, 2019. These sites were selected from a prioritized list of muck dredging areas developed by Trefry et al. (2019). Table 2 summarizes data collected from these areas in the study. In addition to the muck dredging sites listed in Table 2, muck zones established in the EFDC water quality model are based on the muck surveys carried out by Fox et al (2018). The original muck zones specified in the model were based on the Riegl 2009 study. However, recent surveys of muck completed under this study demonstrated that the older surveys did not accurately identify muck deposits. Fox et al. (2019) found that muck deposits were geographically less extensive than depicted in the Riegl study; nonetheless, high rates of nutrient flux were found in the areas of thicker muck deposits as described in Trefry et al, 2019. Figure 9 shows about 50 of the 80 sample sites sampled by Fox and Trefry (2019) that revealed elevated levels of ammonium flux.

These 50 sites of muck deposits are established in the EFDC/HEM3D sediment diagenesis model component as muck zones having high nutrient flux rates in contrast to remaining sediment (or bottom) areas having minimal or no muck deposits. Of course, sediment zones in the model can be modified at any time to reflect new information on muck deposits and nutrient flux from IRL sediments.

Data summarized in Table 2 are taken from sample analyses performed by Fox and Trefry (2018) and from Trefry et al. (2019) that prioritized muck zones for dredging. Ammonium flux rates provided in Table 2 are in terms of metric tons per square kilometer per year. This unit when specified in the water quality model setup are converted to units of kilograms per meter squared per day. A location plot of each zone is presented within the discussion of model results under Section 8 of this report.

Table 2. Muck dredging zone prioritized for study.

Muck Dredging Zone	**Surface Area M^2**	**Volume M^3**	**Ammonium Flux ($T/km^2/yr.$)**	**Dredging Status**
Turkey Creek	100,000	110,000	28 ± 49	Complete
Grand Canal	250,000	605,000	20 - 100	Underway
Eau Gallie NE	290,000	250,000	23 ± 8	Planned
Cocoa Beach Phase 1	51,600	175,000	50 Est	Complete
Cocoa Beach Phase 2	178,500	150,000	50 Est	Complete
Cocoa Beach Phase 3	155,000	50,000	50 Est	Complete
Sykes Creek	900,000+	660,000	50 Est.	Complete
Mims	26,000	22,000	53 ± 35	Complete

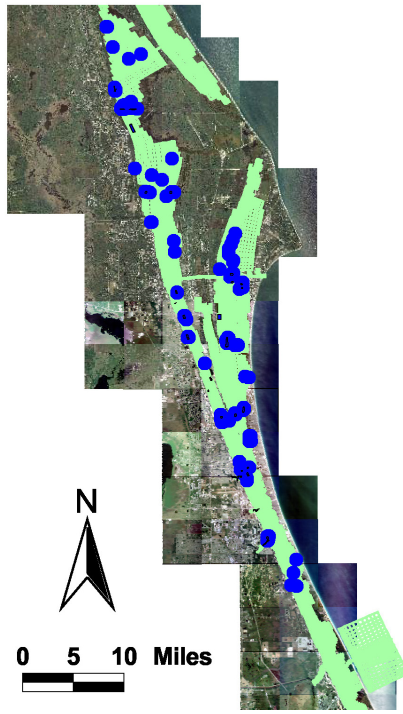

Figure 8. Location of nutrient flux samples and general location of muck deposits investigated by Trefry and Fox, 2019.

Each muck sediment zone is represented in the overall model by an input file that lists the model cells included in each zone according to zone number. Each of the zones is then referenced to another model input file that lists a set of sediment process/diagenesis parameter values that are zone specific. Benthic zones in the water quality model are differentiated based on either measured or estimated fluxes of phosphate (PO_4), ammonia nitrogen (ammonium (NH4)), nitrite + nitrate nitrogen (NO_x), and sediment oxygen demand (SOD). Measured nutrient fluxes, especially the flux of ammonium nitrogen are based on data collected by Trefry and Fox (2019) from approximately 80 station in the north and central IRL. Most of these stations are located in zone of muck deposits and mostly consist of only one point measurement in time. Thus, no time series of nutrient flux data are available from muck zones. Data on phosphate fluxes from muck or and sediment are very limited and phosphate fluxes for muck and non-muck zones are only estimates. Sediment process calculations in each model cell are guided by values of measured or estimated nutrient fluxes in the muck zones (Table 2) along with single regional value for each nutrient constituent from the remainder of non-muck zones over the model grid. Although comparisons between measured and model water column nutrient concentration are generally good as described in a Sub-Section 6.1 of this report, the model performance can be improved by collecting additional sediment nutrient flux data over time throughout the IRL system.

6.2 Comparison of model and measured water quality data

Comparisons between measured and model water quality data were presented in the Year 2 Report (Zarillo and Listopad, 2016) and showed agreement well within an order of magnitude. In order to fully calibrate and verify water quality predictions from EFDC/HEM3D a much more extensive spatial and temporal data set would be required over much of the IRL system. As stated above, mapping of muck zones is still very limited along with sediment nutrient flux from muck zone. However, is it useful to make selected comparisons between measured and model water quality data to assess the overall performance of the model scheme with respect to predictions of nutrient concentrations in the water column and dissolved oxygen concentrations. Comparisons are made at the locations of SJRWMD long-term monitoring stations IRLI 23 and IRLI 27, which are in the central; IRL compartment and located about 9 km north and 15 km south of the entrance of Turkey Creek. Section 8 of this report presents comparison of pre- and post-dredge conditions as these stations.

Figure 10 and Figure 11 compared measured total nitrogen (TN) model data from the pre- and post-dredge model runs to measured data at the IRI23. The data collection period included the Phase II dredging of the Turkey Creek basin as shown in the figures. The agreement between model and measured data is generally good. However, the data do not record the high concentrations of total nitrogen (TN) predicted between about mid-September to mid-October of 2017. It is possible that no data collections were scheduled during this period of high nutrient concentrations. Both comparisons are based on data from the model surface layer.

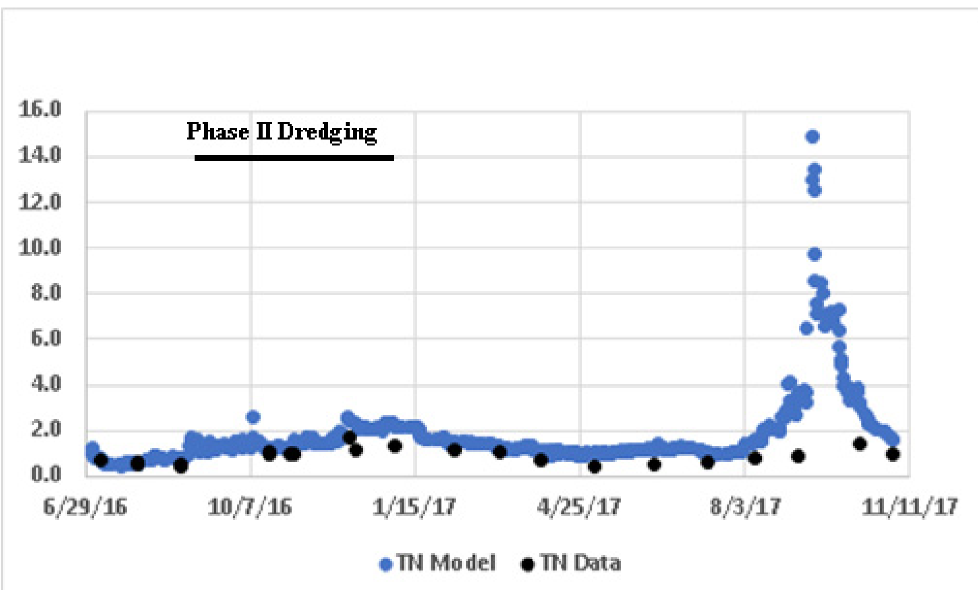

Figure 9. Comparison of pre-dredge model surface layer data with measured total nitrogen (TN) data at IRLI23.

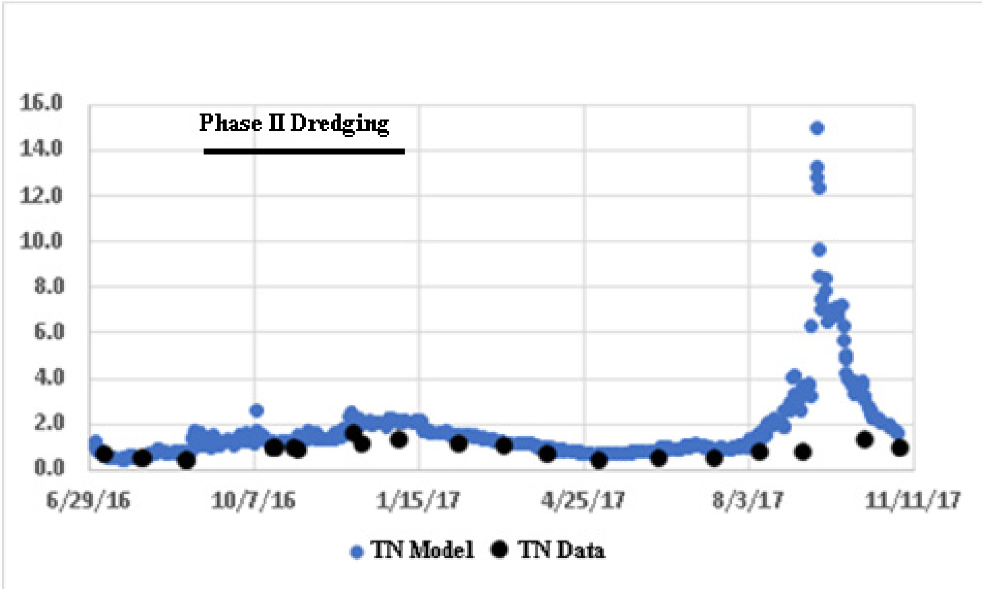

Figure 10. Comparison of post dredge model surface layer data with measured total nitrogen (TN) data at IRLI23.

Figure 12 compares model ammonium in all 5 layers to post -dredge model to measured data at IRLI 23. Similar to the total nitrogen (TN) comparison, the mid-September to mid-October high concentrations were not captured in the measured data. Overall, the low model concentrations were consistent with the measured values.

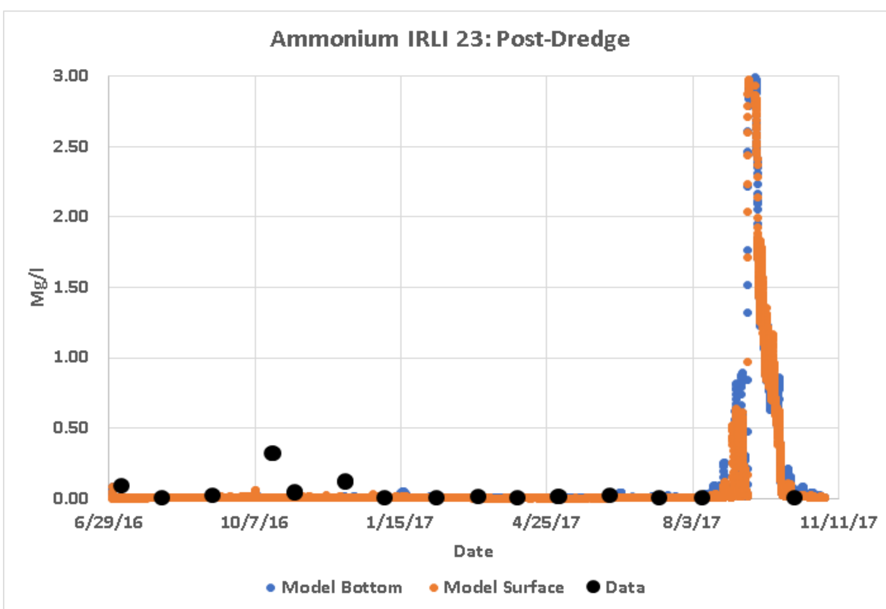

Figure 11. Comparison of post-dredge model ammonium (NH4) data with measured data at IRLI23.

Figure 13 compares model and measured dissolved oxygen (DO) data at IRLI23. Measured data were compared to post dredge model DO data, which plotted out 2 mg/l lower for late 2016 through early 2017. However, from April 2017 to the end of the model run in December 2017, the model data were consistent with the measured data including a trend of lower DO values around the high nutrient concertation event that occurred in the model calculation. During this period measured DO values trended lower with the model values.

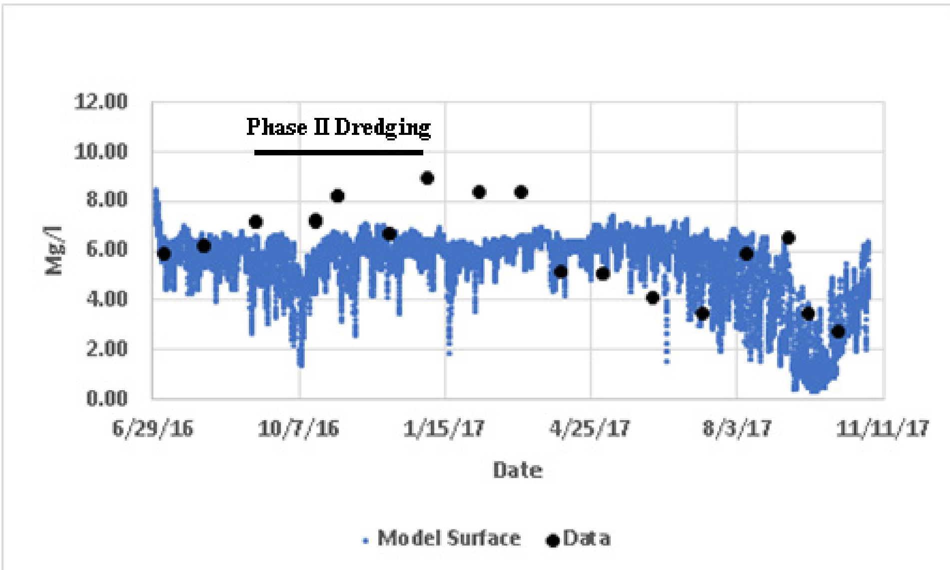

Figure 12. Comparison of post-dredge model surface layer dissolved oxygen (DO) data with measured data at IRLI23.

Figure 14 compares model data with measured data of total phosphorus (TP) concentrations at IRLI27. Data for all model layers are present with the measured values collected from the upper water column. The high model data values in the early part of the model run that decline to much lower values show the model adjusting to an equilibrium. After 2 months of simulation, model data track at or below 1 mg/l and the measured data tracked near the maximum of the model data or slightly above. Given the complexity of the model and difficulty in producing a match between measured and model data at very low concentrations, this result is considered very good.

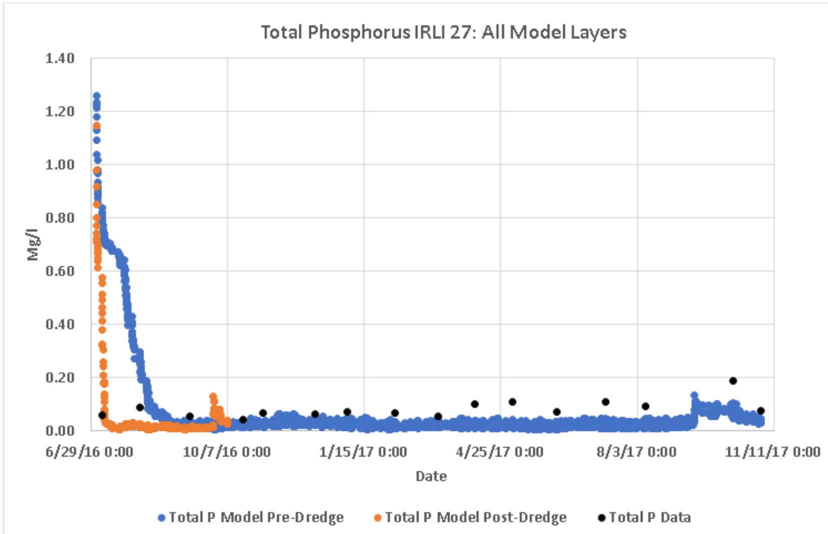

Figure 13. Comparion of pre- and post-dredge model total phophorus (TP) data with measured data at IRLI27.

Figure 15 and Figure 16 compared measured total nitrogen (TN) data with model data from the pre-dredge and post-dredge model cases. This comparison shows that the model closely tracks measured data for the first half of the 488-day run and then predicts total nitrogen (TN) concentration values slightly higher that the measured data. Similar to the IRLI23 comparison the measured data do not capture the high concentrations of total nitrogen (TN) predicted for the mid-September to mid-October period. However, the final 2 measured data points indicate the decline from higher concentrations but plot about 0.5 mg/l below the predicted values. The model performance at both IRLI23 and IRLI27 is considered very good given the limited data available to tune the water quality model. Many more measurements of nutrient fluxes from a wide range of sediment types and many more sample locations would allow more precise tuning of water quality calculations.

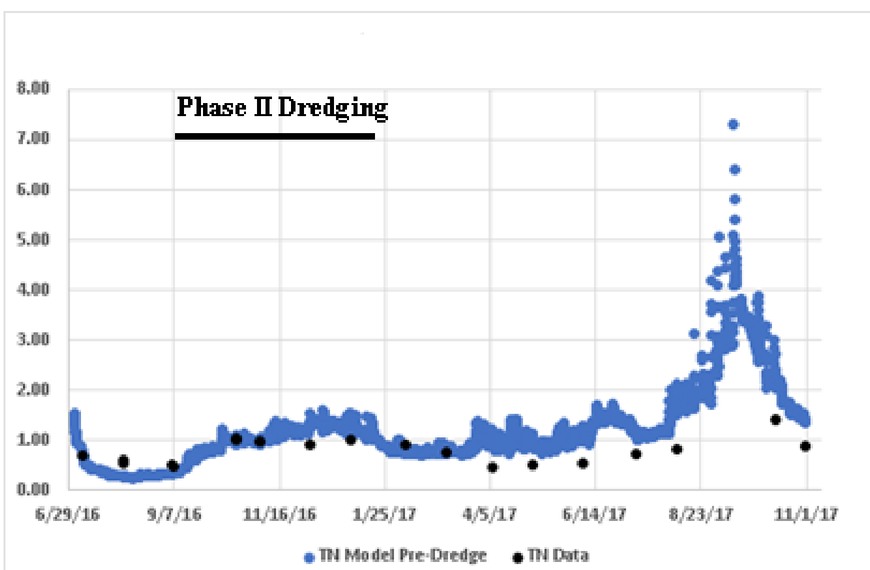

Figure 14. Comparison of pre dredge model surface layer total nitrogen (TN) data with measured data at IRLI27.

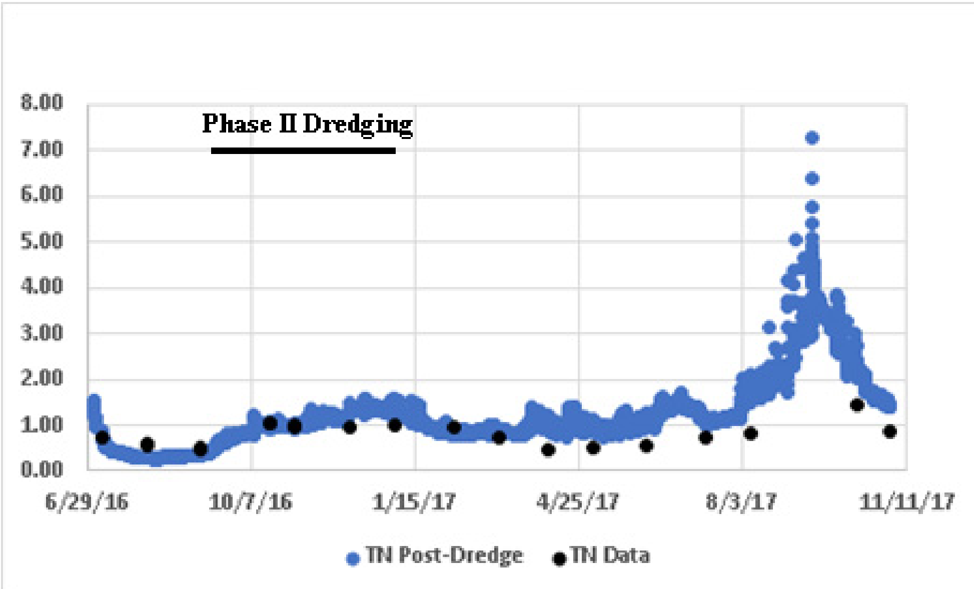

Figure 15. Comparison of post-dredge model surface layer total nitrogen (TN) data with measured data at IRLI27.

7.0 Update of the SWIL Watershed Model

The details of the SWIL watershed setup and updates in year 2 of the project are provided in Zarillo and Listopad (2016, 2018). In a brief summary of these reports, however, the previous version of SWIL (4.0) required three major changes: 1) expansion of the model extent to provide nutrient loadings from Ponce Inlet to Fort Pierce, 2) temporal expansion from August 2015 through the end of 2016, and 3) converting the model from two to three land use/treatment time steps. Appendix A of this report provided under separate cover provides full details of the latest SWIL update to version (5.0). A summary of Appendix A is provided in the following paragraphs.

The SWIL update to version 5.0, included two major changes: 1) the expansion of the model boundary to include the St. Lucie Estuary watershed, and 2) temporal expansion of the model to include predictions volume and loading predictions through December 2017. The main objective of the model development was to produce monthly estimated total nitrogen (TN) and total phosphorus (TP) loads from January 1995 through December 2017 for 87 subsegments of the Lagoon watershed, so these could be integrated into the EFDC/HEM3D water quality model. At this time the in-estuary model was not expanded into the St. Lucie watershed areas due to cost and time limitations of the project.

The project task also included integrating a previously AEI-developed model for the United States Air Force (USAF, 45th Space Wing) into the SWIL 5.0 model. The USAF model was specifically developed for the Cape Canaveral Air Force Station (CCAFS) and Patrick Air Force Base (PAFB) as part of their Environmental Compliance Program. This site-specific model reflects a variety of updated inputs datasets, many of which are based on field validation and years of onsite TMDL monitoring efforts. These higher resolution and field calibrated nutrient loads from both military bases were integrated into the Banana River watershed loading model. Finally, the project task in Year 3 examined the potential impact of future land use of the North Indian River Lagoon (NIRL) watershed on the nutrient loading to the NIRL. Future land use for this watershed was based on Brevard County's and other available municipalities future land use mapping and zoning designations, when available. Increases in watershed urbanization can have the potential to increase runoff volumes and associated nutrient loading to nearby waterbodies. Future scenario modeling efforts are important tools for the development of a watershed-wide resiliency plan.

8.0 Water Quality Simulations in Muck Dredging Zones

This section describes the water quality model results under pre- and post-dredge conditions as represented in the EFDC/HEM3D modeling system. The methods of including nutrient inputs to the model from the various watersheds are described in Zarillo and Listopad (2016). The reader is also reminded that in addition to the watershed inputs from the SWIL model, water quality constituent inputs from several major IRL tributaries are included in the model based of data collected by Trefry et al.(2019), as well as data collected at water quality monitoring stations maintained by the SJRWMD. These include Turkey Creek, the Eau Gallie River, Crane Creek, and the south Prong of the Sebastian River. In addition to the SWIL watershed inputs, the IRL tributaries are a major part of coupling between the water quality model (HEM3D) and the EFDC hydrodynamic model.

Model runs were 488 days long covering the time period of July 3rd 2016 and November 30^{sth} 2017. The first 50 to 100 days of the model runs can be considered a spin-up period during which the hydrodynamic model and the coupled water quality model to adjust to external and internal boundary conditions of water level, salinity, water temperature, freshwater inflows and to ongoing water quality constituent calculations.

8.1 Turkey Creek

The Turkey Creek muck zone in the model that was dredged is represented in Figure 17. Numerical recording stations TCM1 and TCM2 collected water quality data for the model runs under conditions of pre- and post-dredging. TCM1 is located within the dredging zone, whereas TCM2 is located about 0.7 km to the east near the IRL main estuarine body. In addition to those two stations, model results were also examined at SJRWMD Stations IRLI 23 and IRI27, located several kms to the north and south of the Turkey Creek muck zone. This enabled model runs to determine if the impacts of muck dredging at Turkey Creek can be detected at far-field locations.

The main goal for this subsection and the following subsections, representing other muck zones of interest, is to examine the pre- and post-dredge concentrations of nitrogen species (or components) and DO in the water column at each station . For the Turkey Creek area and the other muck zone areas evaluated by the model, ammonium sediment flux rates listed in Table 2 were reduced by 90%. A further consideration for setting the hypothetical reductions in ammonium and phosphorus flux from sediments is the sample analyses performed by Trefry and Fox (2017). Samples were taken prior to, during and after completion of muck dredging in the Turkey Creek basin. These data were limited to 4 stations and just 4 dates as shown in Table 7 of the 2017 report by Trefry and Fox. When comparing the pre- and post- dredge flux rates for ammonium and phosphate the percent reduction in the flux of ammonium varied from about 55% to 95%, on the average based on sample analysis, but include a very high standard deviation as reported in Table 7 (Trefry and Fox). At one of the sample locations in the outer basin (TC3) the rate of ammonium flux was reported to increase by about 90%. Reductions in phosphate flux from sediment followed a similar pattern ranging from a sample averaged decrease of about 15% to 95% to an increase of about 90% at the outer TC3 station near the entrance of Turkey Creek,

Without a muck large temporal and spatial database of sediment flux it is not possible to precisely set nutrient fluxes from sediment from for the Turkey Creek basin or other muck zones based on data. This is consistent with the aforementioned lack of sediment flux data to fully calibrate the water quality model. However, model- data comparisons show that model predictions of nutrient concentrations in the water column are consistent with measured data to well within an order of magnitude and in some instances conforming closely with measure values. Thus, to examine the potential for muck dredging to improve water quality, the model runs were performed assuming that the sediment flux of ammonium and phosphates in muck zone were reduced by 90% relative to higher rates set according to limited sample data as listed in Table 2. No accommodation is made to account for sample standard deviations. Where an estimated range of values are given, the higher range is applied for the pre dredge conditions. As of this writing another round of model runs is planned that will assume a 60% reduction in nutrient flux from sediment. However, the issue still remains of not having adequate measurements to establish actual flux rates.

Figure 17 shows the predicted pre-dredge concentration of total nitrogen (TN) and other forms of nitrogen in the lowest of the five vertical layers in the model before dredging. The gauged freshwater inflow from the Turkey Creek tributary watershed is also shown and corresponds with higher values of nitrogen concentration in the latter part of the model runs.

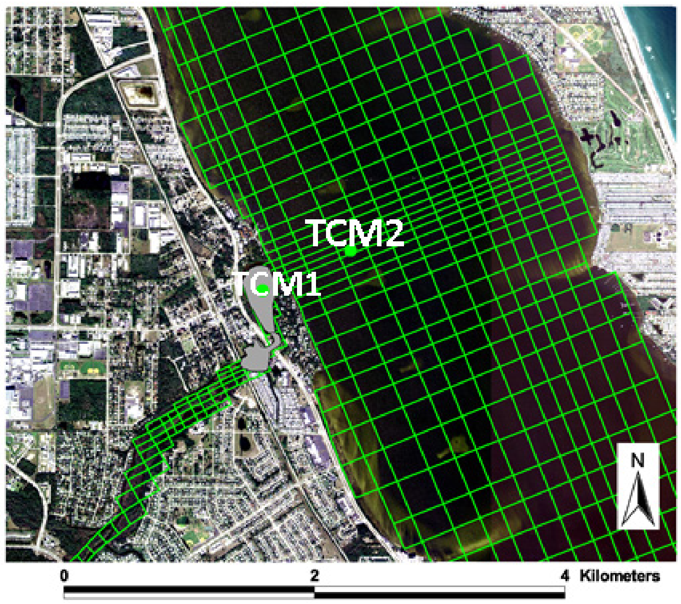

Figure 16. Location of the Turkey Creek muck zone represented in the water quality model. TCM1 and TCM2 are numerical recording stations that collected water quality data from the model run

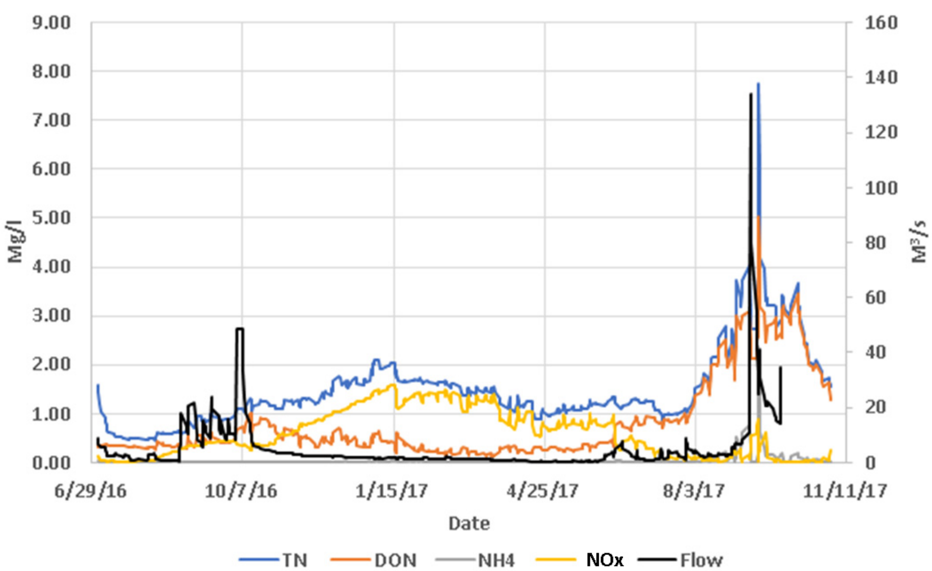

Figure 17. Predicted concentration of nitrogen forms in the bottom model layer at numerical monitoring station TCM1. Location is shown in Figure 17. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate + nitrite.

Figure 18 compares the predicted DO values in the lower model layer with the TN concentration. This shows the relation of lower oxygen levels to increased nitrogen concentration. Low values of DO in the latter part of 2017 correspond to high values of total nitrogen (TN), which apparently were produced by nitrogen loads brought by high inflows during the wet season of 2017 potentially by dissolved organic nitrogen (DON), and consumption of oxygen via decomposition of organic material). Figure 20 presents the comparison between predicted total nitrogen (TN) concentration and DO concentration in the surface layer of the model at station TCM1.

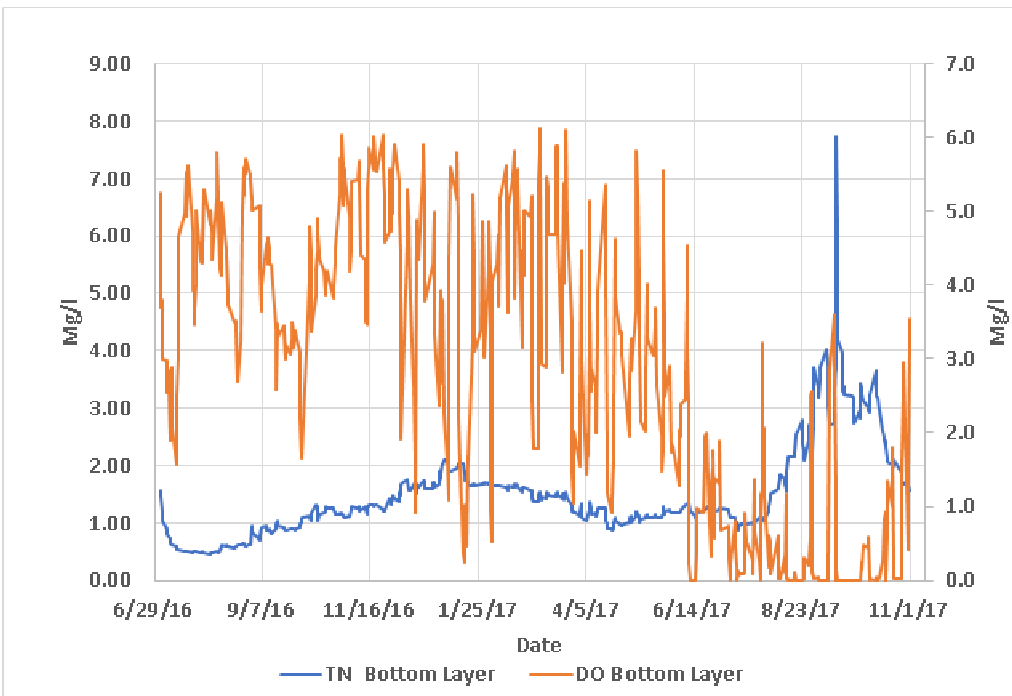

Figure 18 . Predicted total nitrogen (TN) and dissolved oxygen (DO) concentrations in the lower model layer at TCM1.

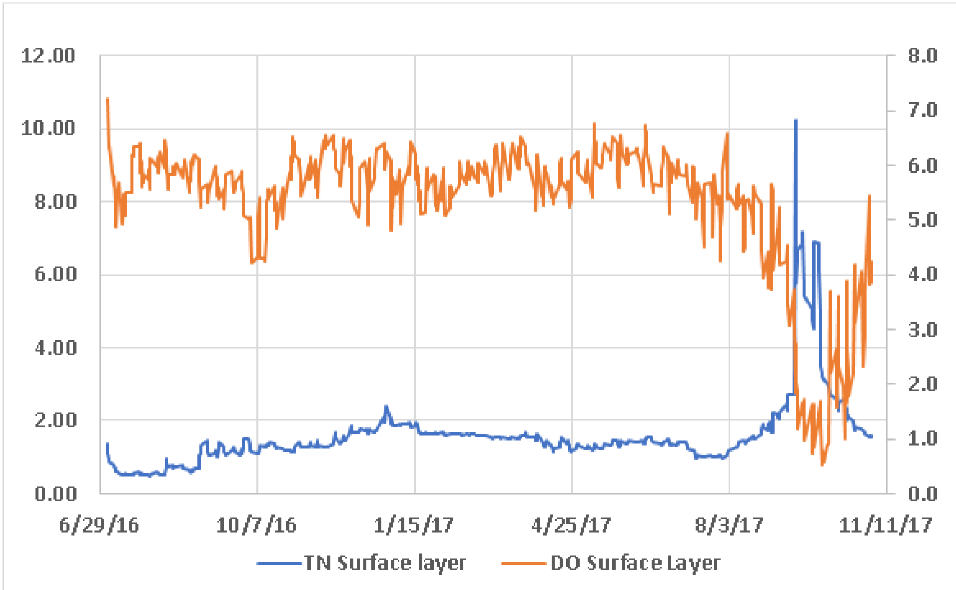

Figure 19. Predicted total nitrogen (TN) and dissolved oxygen (DO) concentrations in the surface layer of the model at station TCM1.

Figure 21 compares predicted pre- and post-dredge total nitrogen (TN) concentration in the lower model layer over the duration of the model run. Freshwater inflow values from the Turkey Creek Basin are also included. Figure 23 presents the same information for a 3-month period in the spring of 2017. The beginning of the transition into the wet season is included marked by higher flows and increasing values of total nitrogen (TN). Figure 21 shows comparatively lower predicted values of total nitrogen (TN) concentration toward end of wet season when inflows subside and during a post-dredge period.

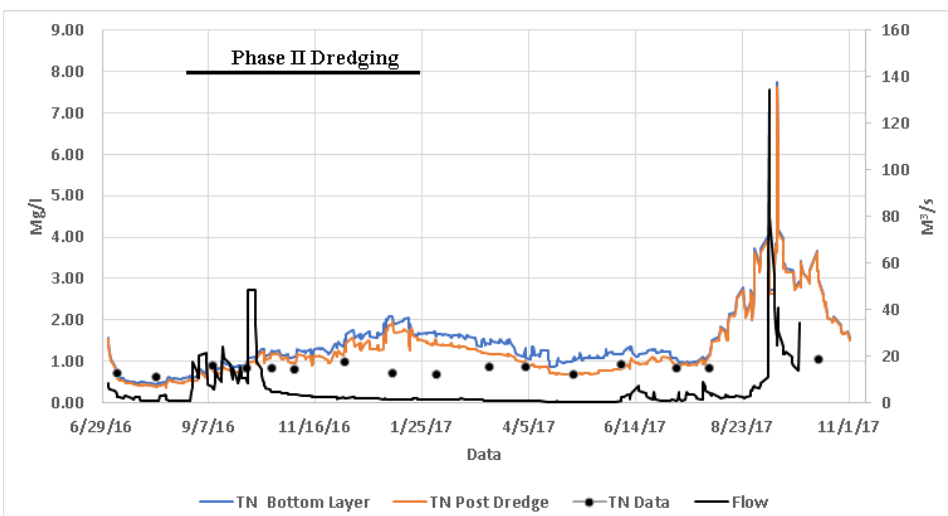

Figure 20. Predicted total nitrogen (TN) concentration in the lower model layer at TCM1 over the duration of the model run for pre- and post-dredge conditions. Freshwater inflow values from the Turkey Creek Basin are shown.

Figure 22 shows the pre- and post-dredge predicted concentration of ammonium (NH4) in the bottom model layer for a portion of the model period. The lower post-dredge ammonium (NH4) concentration is expected since ammonium flux from the sediment bed is reduced by design at this station to correspond to dredging of muck sediment. Figure 23 shows that post-dredge DO concentrations in the lower model layer at this station are higher, but converge with the predicted pre-dredge concentrations apparently produced by higher inflows during the early part of the wet season.

Figure 24 shows the predicted phosphorus forms at station TCM1 indicating that orthophosphate as the dominate species. At the beginning of May 2017, the model stopped producing phosphorus vales. The exact cause is unknown, but is likely to be related to the lack of reasonable boundary conditions to constrain the phosphorus equation of state in the EFDC/HEM3D water quality formulation.   Figure 25 shows the pre- and post- dredge model values for total phosphorus (TP) indicating a reduction in concentration after dredging in the Turkey Creek Basin, along with TP values measured at SJRWMD Station IRLTUS, which is west of the dredged area.

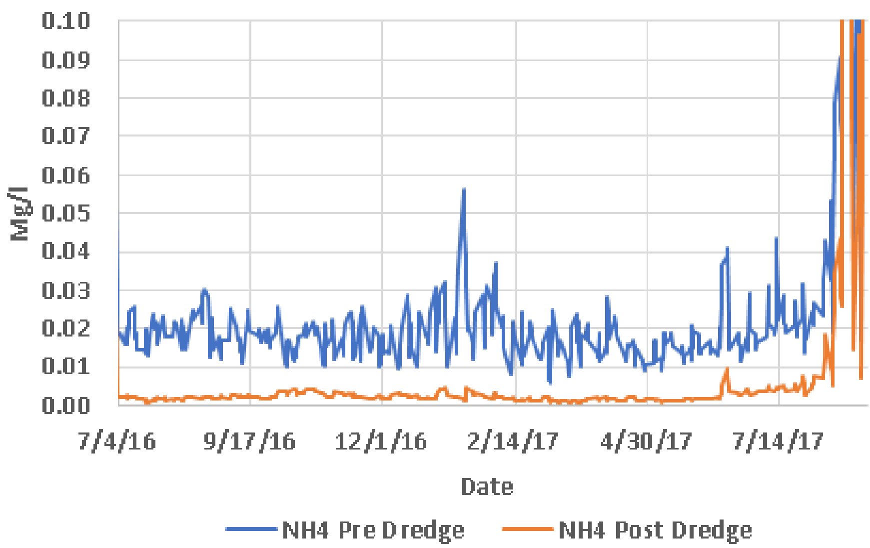

Figure 21. Pre- and post-dredge predicted concentration of ammonium (NH4) in the bottom model layer at TC1 for a portion of the model period

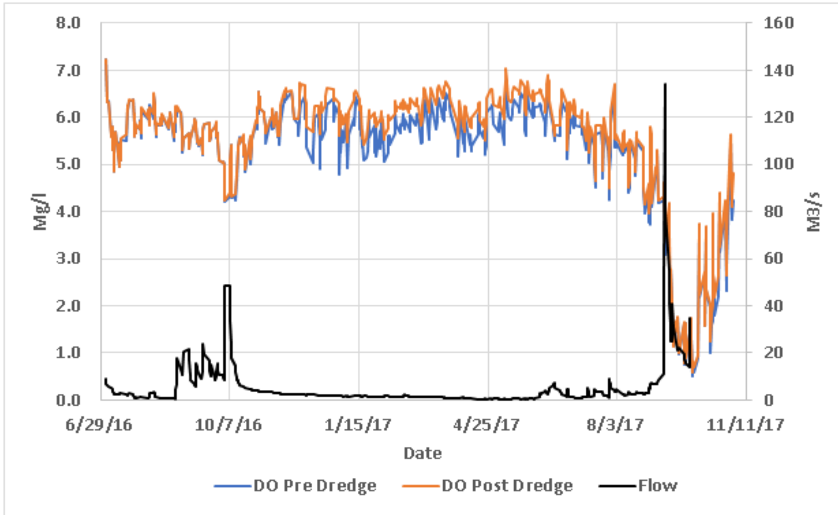

Figure 22. Pre- and post dredge predicted dissolved oxygen (DO) concentration in the surface model layer at TCM1.

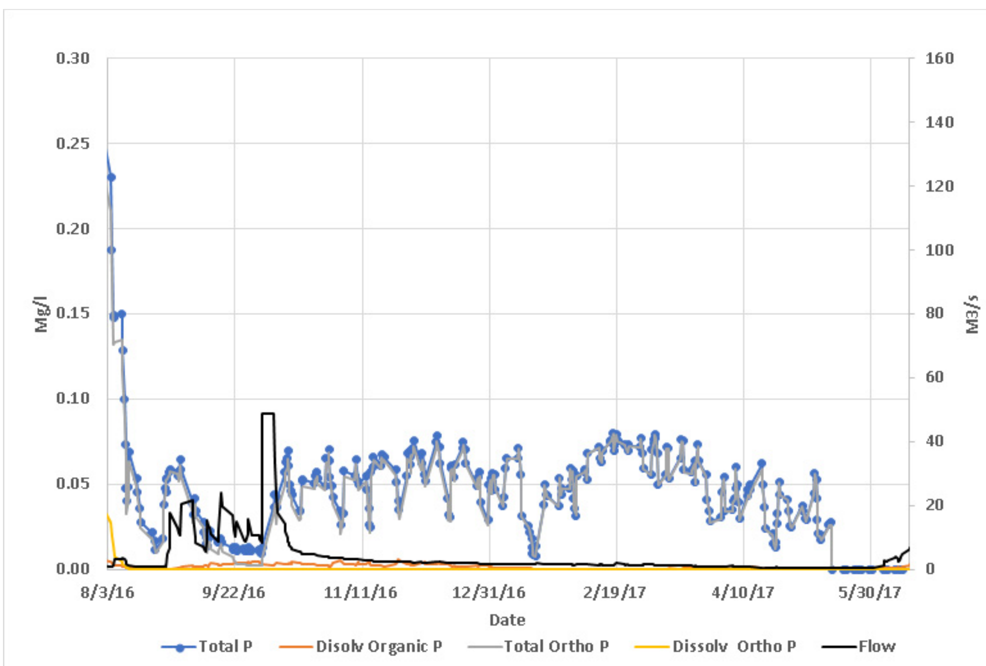

Figure 23. Predicted phosphorus (P) data at Station TCM1

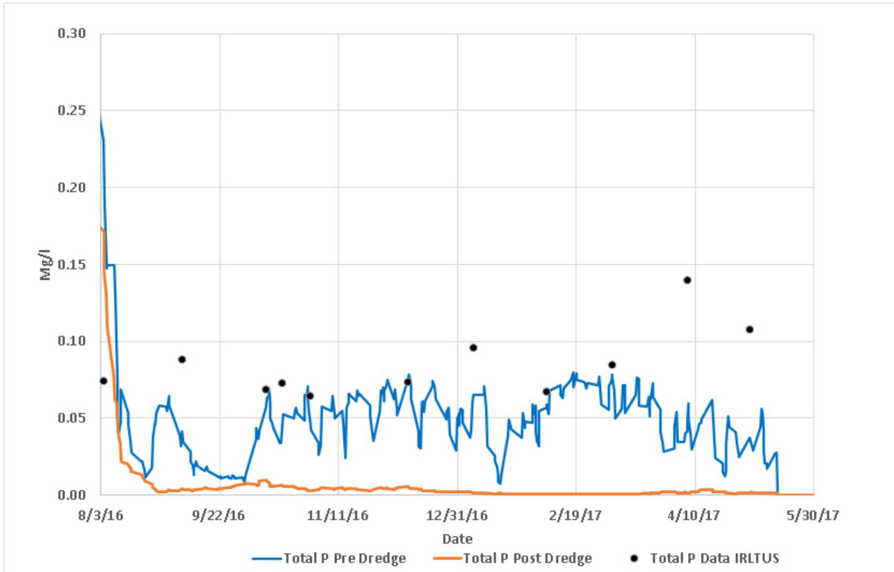

Figure 24. Predicted pre-dredge and post-dredge total phosphorus (TP) data at Station TCM1

Figure 26 shows the concentrations of nitrogen species in the bottom model layer under the pre- dredge conditions at Station TCM2, which is outside the Turkey Creek dredging zone (Figure 10). Here predicted total nitrogen (TN) concentrations are dominated by dissolved organic nitrogen (DON) and to a lesser degree by ammonium (NH4). Predicted nitrate + nitrite (NOx) concentrations are lowest throughout the model run. High concentrations of nitrogen in the water column in the latter part of the model run again correspond to the high inflows of the 2017 wet season.

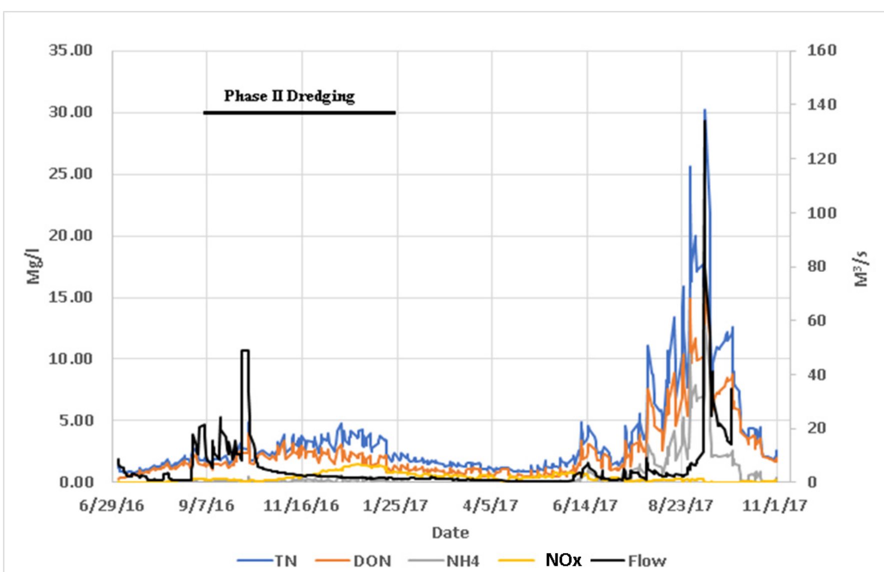

Figure 25. Predicted concentrations of nitrogen forms in the bottom model layer under the pre-dredge conditions at TCM2. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate + nitrite.

Figure 27 is a comparison of pre-dredge and post-dredge total nitrogen (TN) concentrations in the bottom model layer at Station TCM2. The inflows from the Turkey Creek watershed are included and show increasing discharge at the onset of the wet season. The post-dredge total nitrogen (TN) concentrations are predicted to remain slightly below the pre-dredge concentrations but converge during the wet season. Increasing total nitrogen (TN) concentrations (pre- and post-dredge) correspond to increasing freshwater inflows which mask the effect of muck removal.

Figure 28 shows the predicted values of phosphorus at Station TCM2 over the 488-day model run, which includes two wet seasons. Phosphorous values increase during and just after high inflows from the Turkey Creek basin and decline to very low values between the wet seasons. Similar to the predicted values of total nitrogen (TN), predicted total phosphorus concentrations are slightly lower under the post dredge case and converge during the time of high inflows masking the effects of muck dredging in the model calculations (Figure 29).

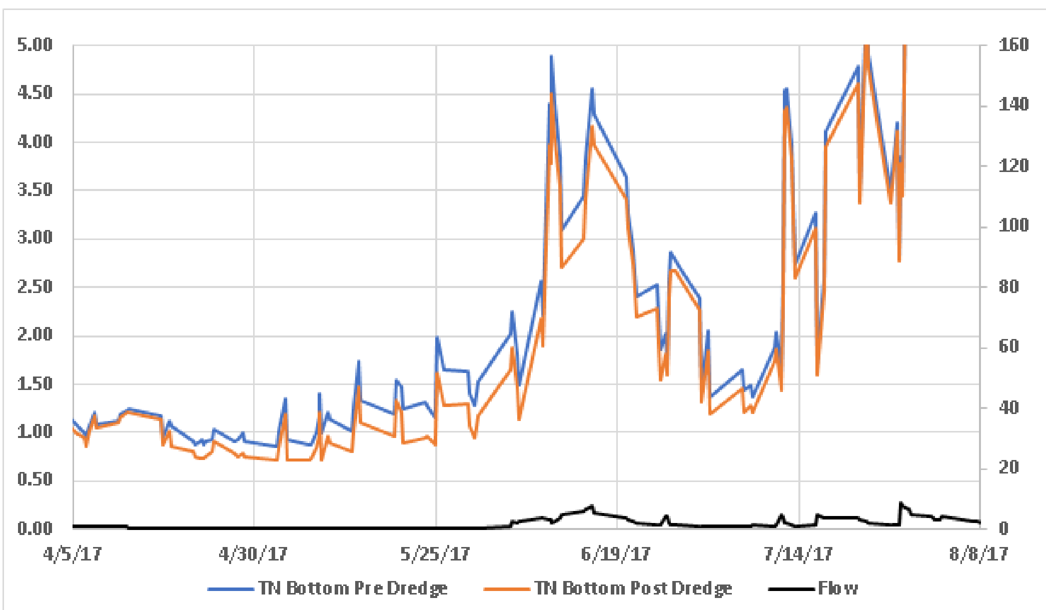

Figure 26. Predicted pre-dredge and post-dredge total nitrogen (TN) concentrations in the bottom model layer at Station TCM2.

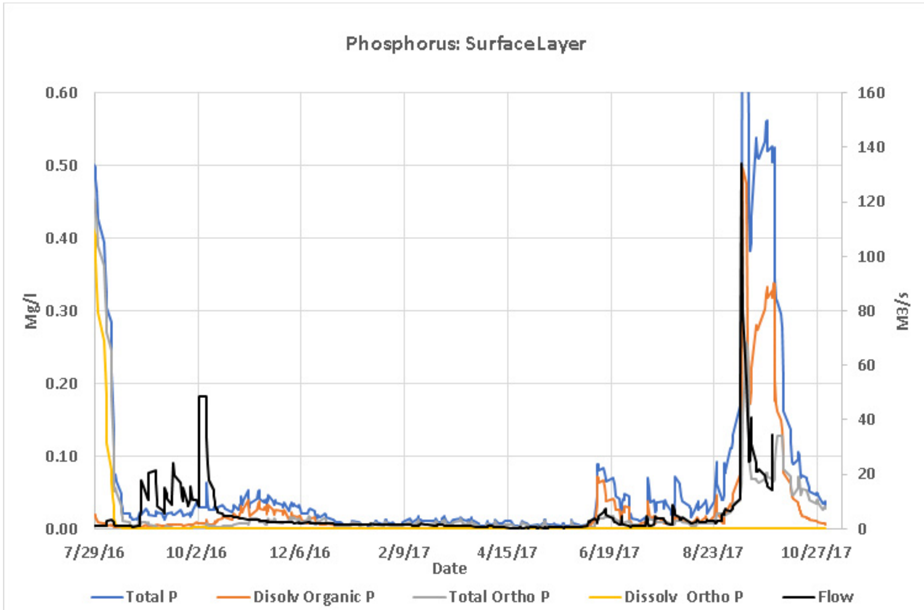

Figure 27. Predicted pre-dredge phosphorus (P) concentrations at Station TCM2.

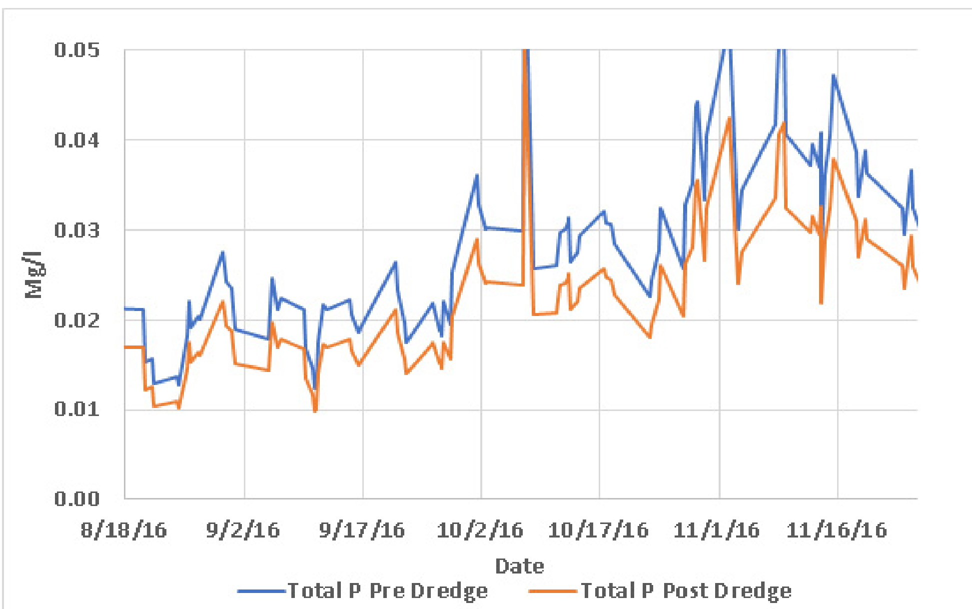

Figure 28. A portion of predicted pre-dredge and post-dredge total phosphorus (P) concentrations at Station TCM2.

The predicted nitrogen and phosphorus concentrations at Station TCM2 indicate that muck dredging in Turkey Creek can impact water quality in the IRL basin beyond the Turkey Creek entrance. Model predictions indicate that the influence of muck dredging is detectable in the water column at distance of up 8 km from the entrance. Figure 30 shows the location of SJRWMD water quality monitoring station IRLI23 about 4 km to the north of Turkey Creek and IRLI27 about 8 km to the south. Figure 31 shows the predicted nitrogen concentration under pre-dredge conditions at Station IRLI 23. Increasing nitrogen concentrations through the spring and summer of 2017 show that this station is likely to be under the influence of nitrogen loads coming into the IRL during the wet season. Figure 32 compares predicted pre- and post-dredge total nitrogen (TN) concentrations from the bottom model layer at IRLI23 through the transition from the dry to the wet season of 2017. Predicted post-dredge total nitrogen (TN) concentrations remained persistently below pre-dredge concentrations. The spatial extent of the impact seems to include DO concentrations, which are predicted to be higher in the post-dredge than pre-dredge period in the bottom model layer at Station IRLI23 (Figure 33).

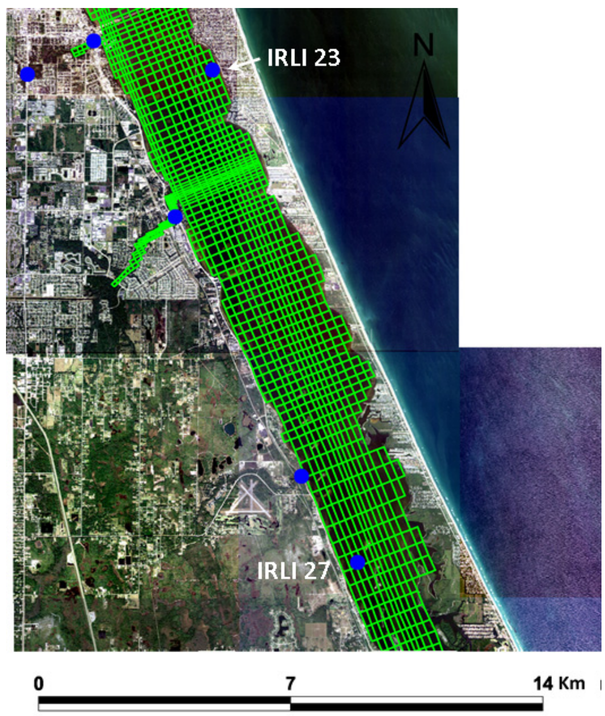

Figure 29. Location of SJRWMD water quality monitoring stations in the vicinity of Turkey Creek.

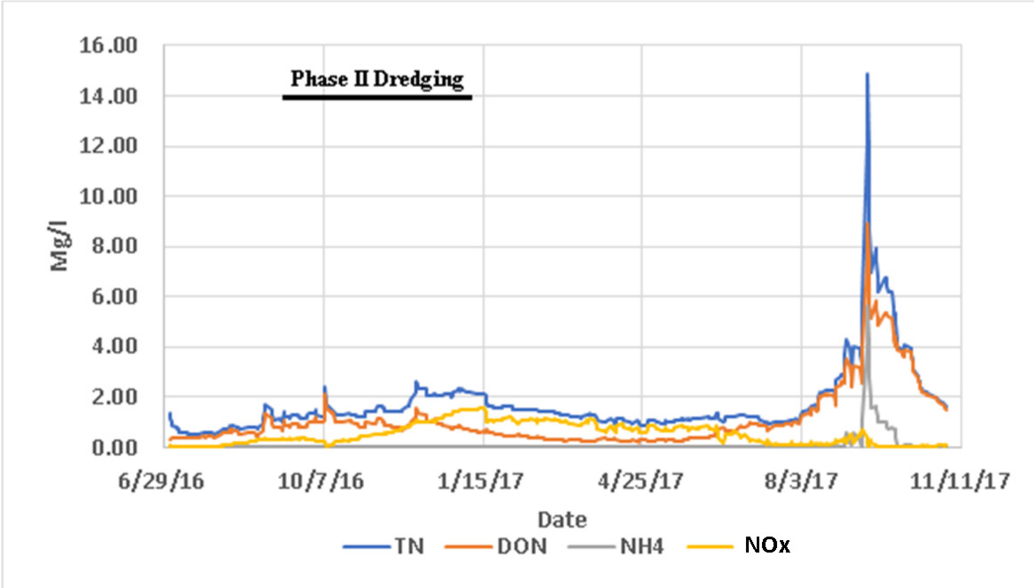

Figure 30. Predicted nitrogen concentrations from the bottom model layer at IRLI 23.
TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

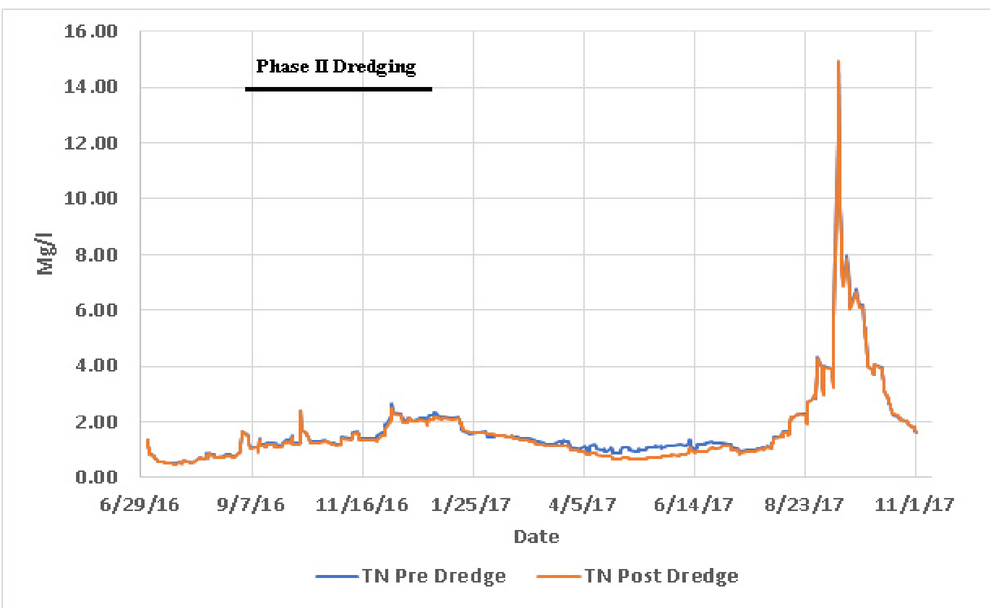

Figure 31. Predicted pre- and post-dredge total nitrogen (TN) concentrations at IRLI 23.

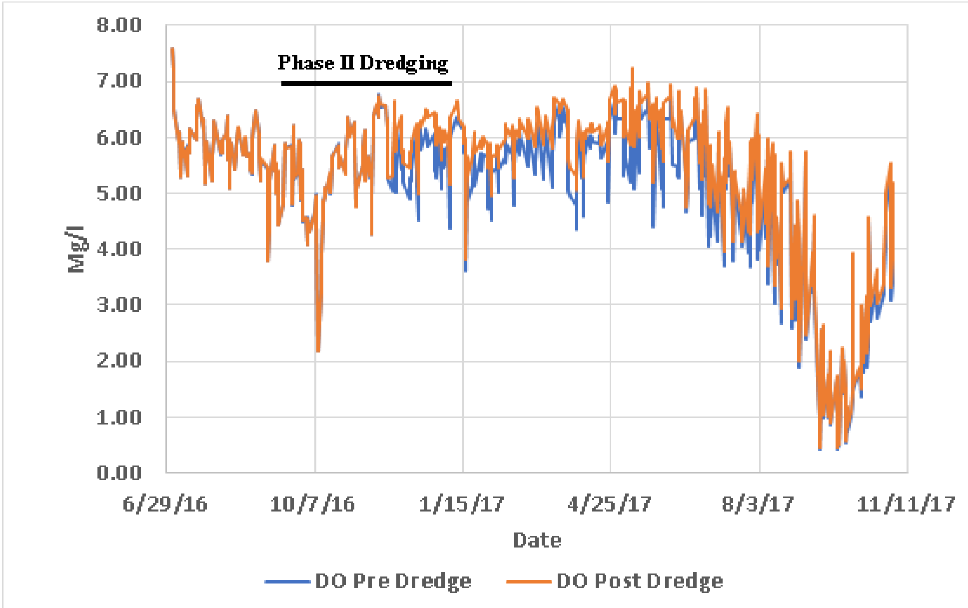

Figure 32. Predicted pre- and post-dredge dissolved oxygen (DO) concentrations at IRLI 23

The influence of muck dredging in Turkey Creek is detectible in model prediction at IRLI 27, which is located approximately 8 km to the south. Here, Figure 34 shows that predicted total nitrogen (TN) concentration in the surface model layer are slightly lower under the post dredge condition. Likewise, predicted DO concentrations are slightly higher under post-dredge conditions (Figure 35). In both of these cases the differences are apparent in the dry season.

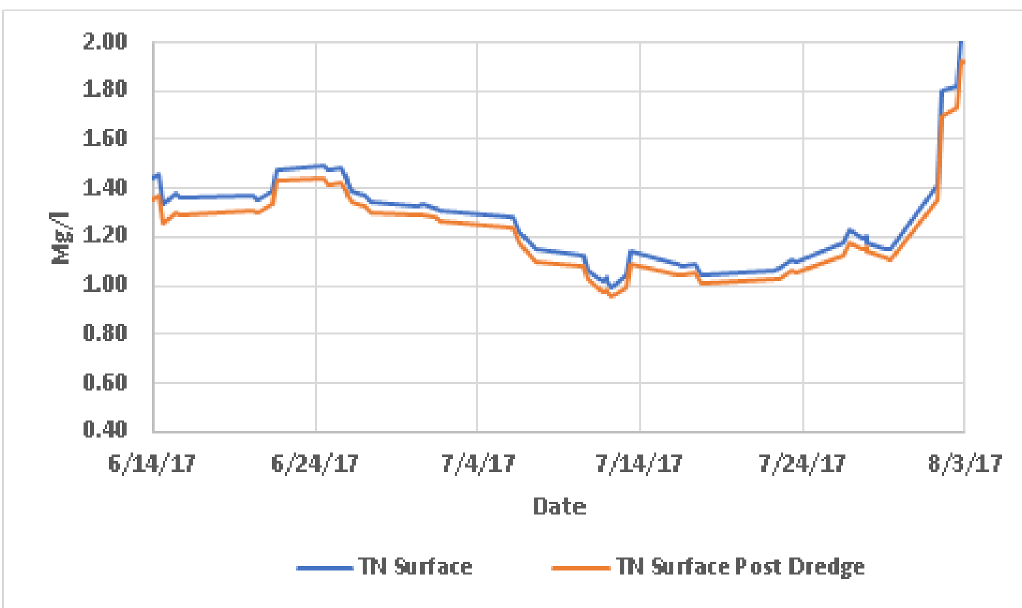

Figure 33. Predicted pre- and post-dredge total nitrogen (TN) concentrations at IRLI 27

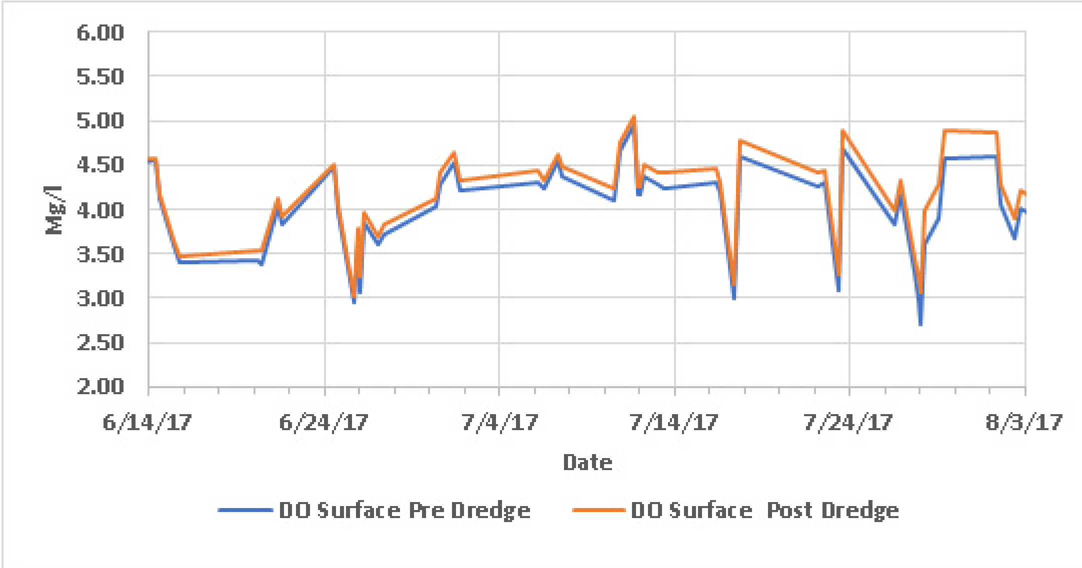

Figure 34. Predicted pre- and post-dredge surface layer dissolved oxygen (DO) concentrations at IRLI 27.

8.2 Eau Gallie Northeast area

Figure 36 shows the location of proposed muck dredging in the Eau Gallie area of the IRL. The Eau Gallie NE (EGNE) area corresponds to one of the top 20 priority sites listed by Trefry et al. 2019. The footprint of the EGNE zone corresponds to the surface area listed in Table 2 of this area. Model data collection stations EGM1 and EGM2 were set up to compare pre- and post-dredge concentrations of water quality constituents . For this study, only the EGNE zone was subjected to hypothetical muck dredging by reducing the rate of ammonium (NH4) flux by 90 percent of the value listed in Table 2. Since the area of the model EGNE zone is approximately the same as the area of the proposed dredging footprint, no prorated value of the flux had to be applied.

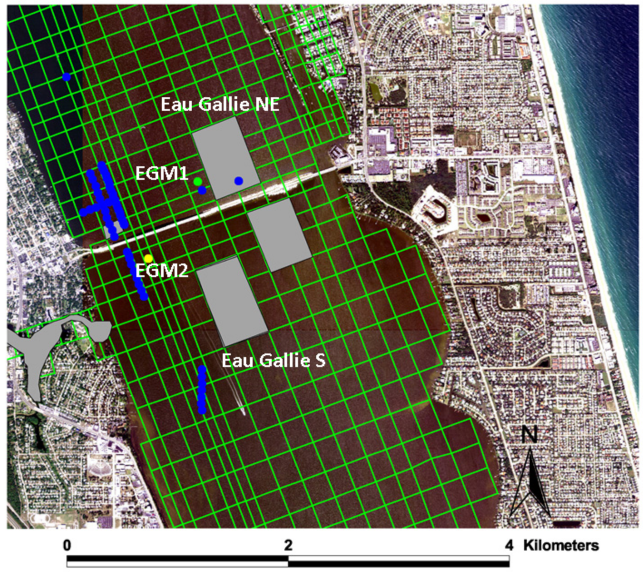

Figure 35. Location of proposed muck dredging zones in the Eau Gallie area.

Figure 37 shows the predicted balance among the nitrogen forms in the bottom layer under pre-dredge conditions. The rate of outflow from the Eau Gallie River is also given for comparison. The distribution of the nitrogen forms shifts from being dominated by dissolved organic nitrogen (DON) during the dry season to a combination of dissolved organic nitrogen (DON) and nitrate + nitrite (NOx) in the wet season. This is likely to reflect the partitioning of nitrogen species that changes with increasing freshwater inflows to the muck zone area from the Eau Gallie River during the wet season. Relative to the other forms of nitrogen, the predicted concentration of ammonium (NH4) remains relatively low through the model runs. However, the reduction in ammonium (NH4) flux assigned in the muck dredging zone in the post-dredge situation results in a detectable reduction in total nitrogen (TN) concentration as seen in Figure 38. As the overall total nitrogen (TN) concentration increased with increasing inflows to the area from the Eau Gallie River, the difference between pre- and post-dredge total nitrogen (TN) concentrations narrows slightly. This also corresponds to the increased concentration of dissolved organic nitrogen (DON), which is likely being brought in by the inflows from the Eau Gallie River. The predicted model trends in total nitrogen (TN) concentration also extend to the surface layer of the model (Figure 39), where the difference between pre- and post-dredge total nitrogen (TN) concentration again narrows with increasing inflows. Figure 40 shows the predicted pre- and post-dredging DO concentration at EGM1 in the surface model layer. There is a detectible increase in DO concentration after removal of muck from the EGNE zone,

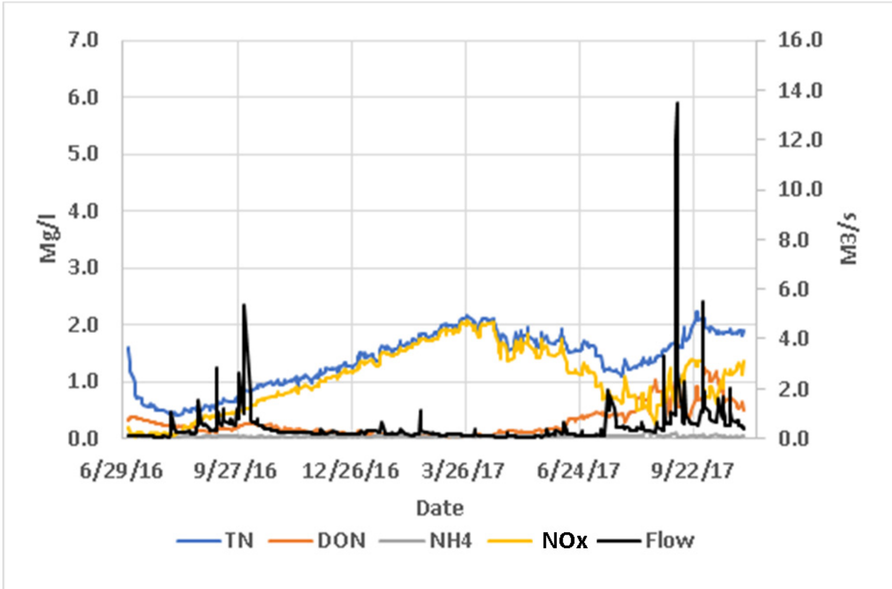

Figure 36. Predicted nitrogen concentrations from the bottom model layer EGM1

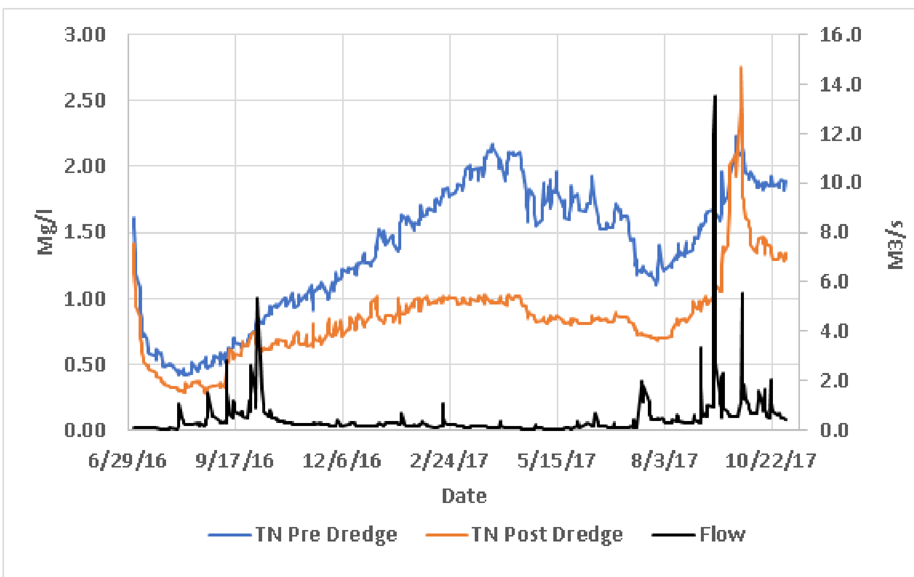

Figure 37. Predicted pre- and post-dredge total nitrogen TN concentrations in the bottom model layer at EGM1. Eau Gallie River flows are shown for comparison.

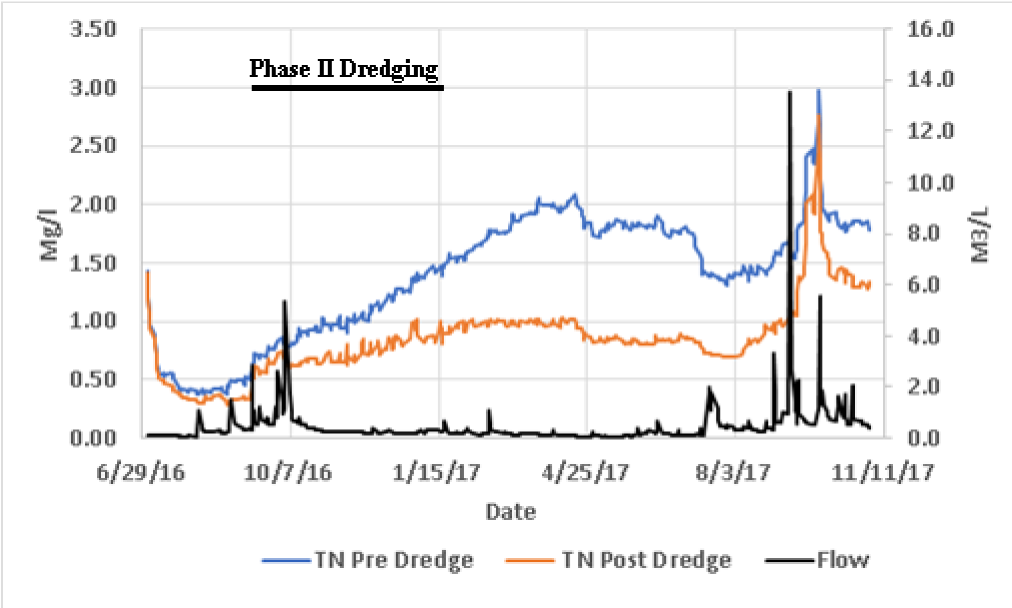

Figure 38. Predicted pre- and post-dredge total nitrogen (TN) concentrations in the surface model layer at EGM1. Eau Gallie River flows are shown for comparison.

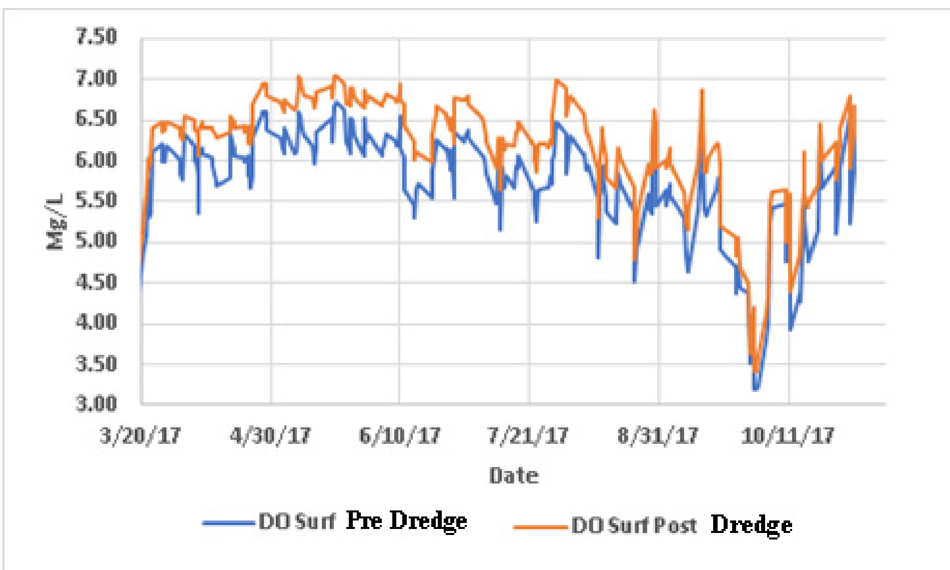

Figure 39. Predicted pre- and post-dredging surface layer dissolved (DO) concentration at EGM1

Figure 41 shows predicted pre-dredge concentration of phosphorous at EG1. Concentrations are low compared to nitrogen as expected and ortho phosphate is the largest contributor to total phosphorous (TP) in the model calculation. Pre- and post-dredge model total phosphorus (TP) values are plotted in Figure 42 showing noticeable decrease in concentration under the post - dredge case. However, in the 2016 and 2017 wet season the differences decrease.

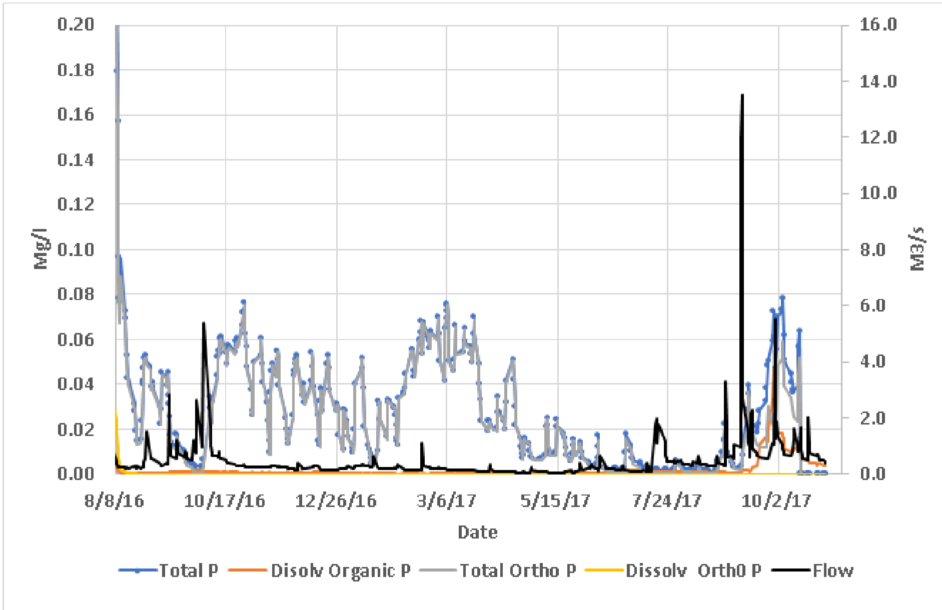

Figure 40. Calculated phosphorus (P) concentrations in the model surface layer at Station EG1

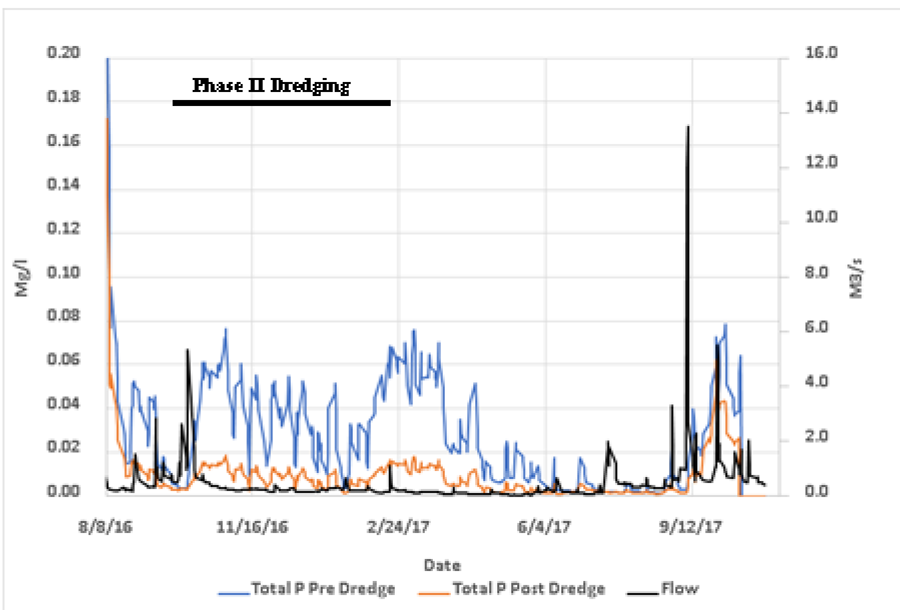

Figure 41. Comparison of pre- and post-dredge phosphorus (P) concentrations in the model surface layer at Station EG1.

Model results were similar at station EG2, its location about 1 km to the southeast of the EGNE muck zone and about 0.7 km east of the mouth of the Eau Gallie River. Figure 43shows the predicted concentration of nitrogen forms under the pre-dredge condition. Similar to predictions at Station EG1 nitrate + nitrite (NOx) dominates the total nitrogen concentrations except during higher inflows period of wet season when dissolved organic nitrogen (DON) concentration increases. This is especially apparent in the 2017 wet season when inflow rates were higher than the previous 2016 wet season.

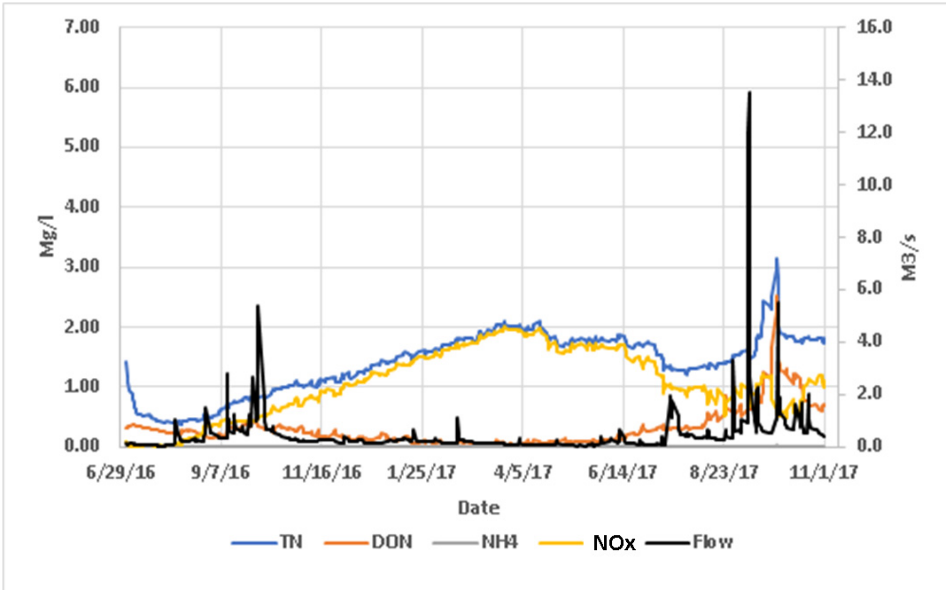

Figure 42. Predicted nitrogen concentrations from the surface model layer at Station EGM2 under pre dredge conditions. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

Figure 44 compares the predicted total nitrogen (TN) concentrations in the surface model layer for the pre- and post-dredge conditions at EG2. The post-dredge reduction in total nitrogen (TN) concertation in the surface layer is apparent. After a period of model equilibration in the early portions of the model run, the pre-dredge concentration during the peak of inflows during the 2017 wet season converge with the post-dredge total nitrogen (TN) concentrations. This indicates that modeled total nitrogen (TN) concentrations are substantially influenced by wet-season inflows.

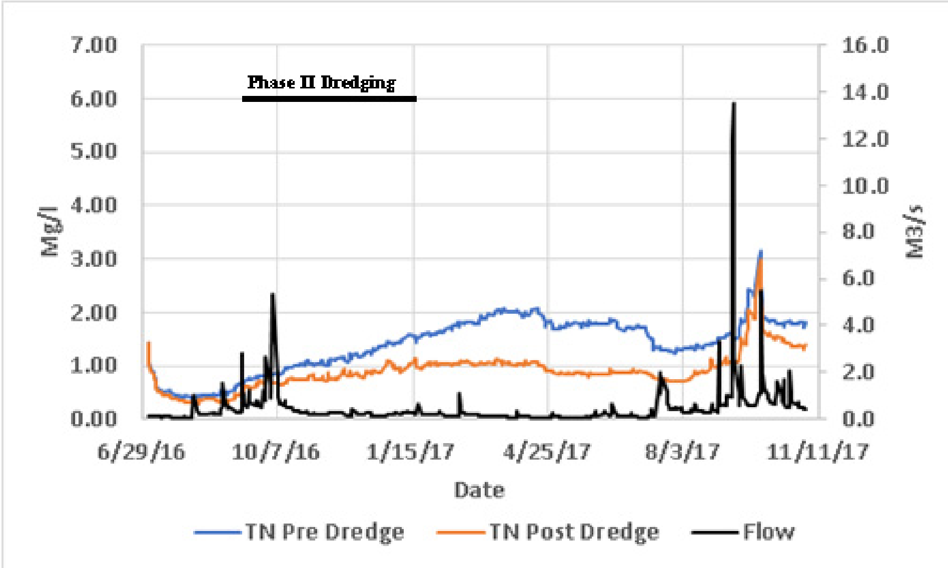

Figure 43.Comparison of pre- and post-dredge total nitrogen (TN) concentrations at Station EG2

Figure 45 shows the pre- and post-dredge predicted DO concentrations in the model surface layer. Post-dredge DO concentrations are detectably lower, but converge with pre-dredge values during the 2017 wet season.

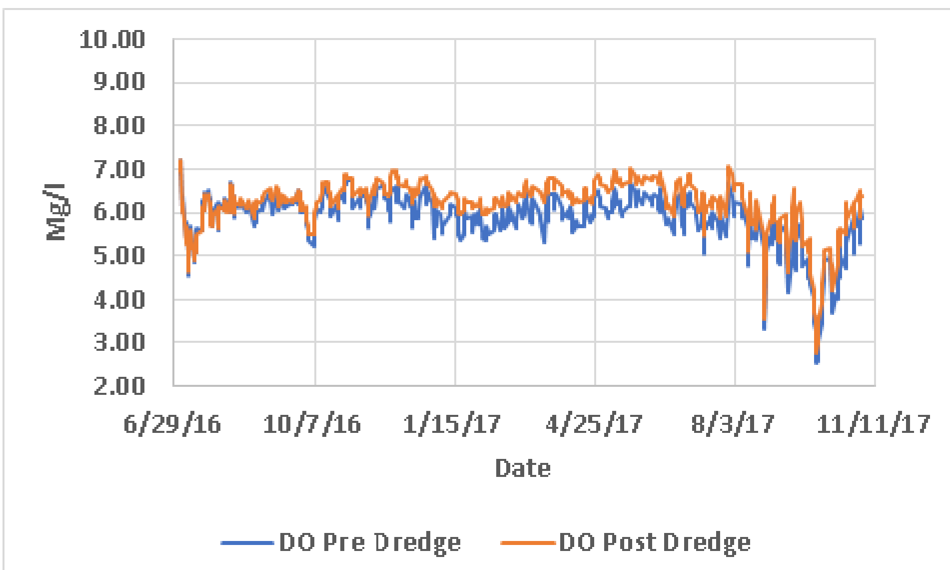

Figure 44. Predicted pre- and post-dredging dissolved oxygen (DO) concentration in the surface model layer at EGM2

8.3 Grand Canal

The Grand Canal muck zone as represented in the EFDC/HEM3D model grid is shown in Figure 46. This zone includes a narrow main channel and a number of finger canals that cannot be directly represented within the resolution of the computational grid. The cells sizes and gradual downsizing of cells sizes into the canals would require an extraordinarily short numerical model time step that could only stay ahead of real time using supercomputing power. Thus, in this case the model grid was extended over the Grand Canal area using larger cells allowing a computational time step large enough to keep the model running ahead of real time. In order to adequately represent the total nutrient flux from Grand Canal the total area of the muck zone to be dredged was measured using GIS spatial analysis. This total area in terms of square kilometers was then used to compute the overall total nutrient flux rate, according to the unit area values listed in Table 2, which was then distributed over the model grid cells representing the Grand Canal project area. This produced a prorated flux rate in terms of kilogram per day per square meter for ammonium and other nutrient species. The reader is reminded that flux rates were determined according the data and calculated estimates provided by the Trefry and Fox (2019).

Figure 47 shows the predicted concentration of nitrogen forms in the bottom layer of the model at station GCM1 located in the Banana River Lagoon adjacent to the Grand Canal (Figure 46). Nitrate+ nitrite (NOx) dominate the concentration levels over the course of the model run, but the contribution of dissolved organic nitrogen (DON) increases over time as the over total nitrogen (TN) concentration increases

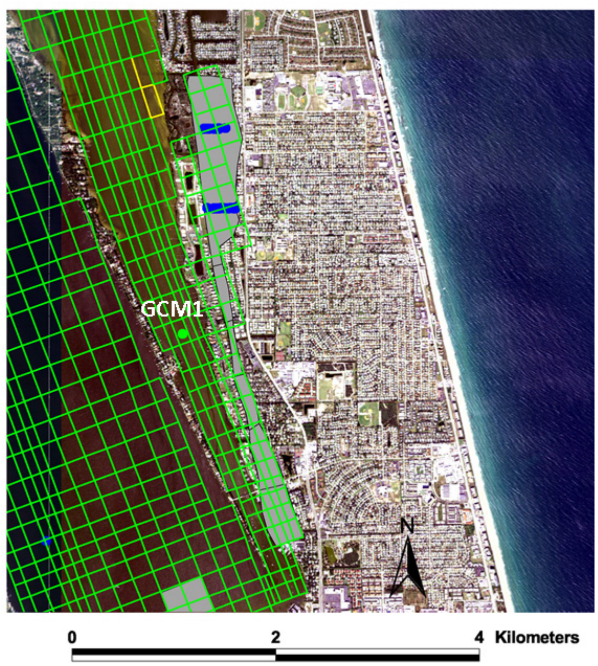

Figure 45. Location of the Grand Canal muck dredging zone represented in the EFDC/HEM3D model. The numerical observation station GCM1 centered in the Banana River, was used to extract water quality data from the model.

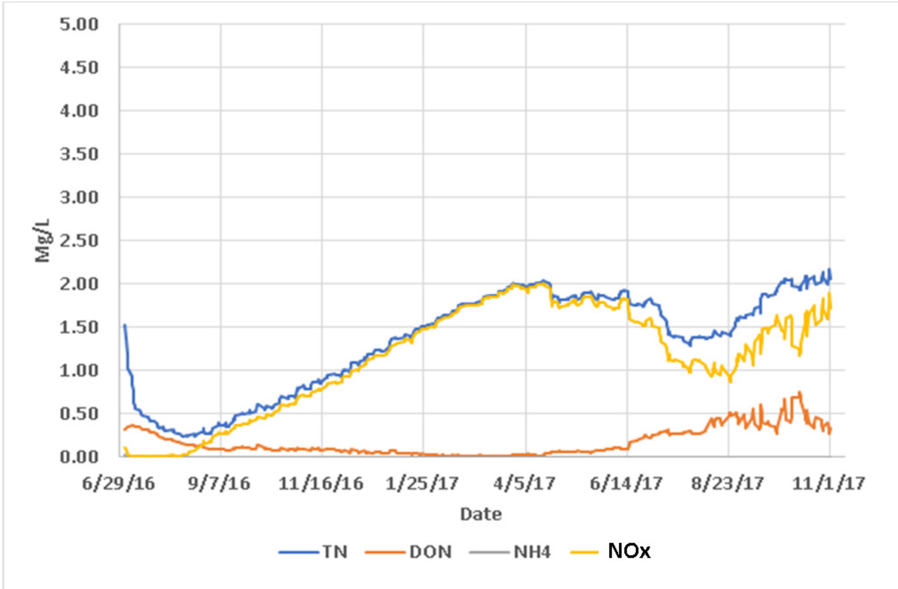

Figure 46. Predicted nitrogen concentrations from the bottom model layer at GCM1 under pre-dredge conditions. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

Figure 48 shows predicted total nitrogen (TN) concentrations at GCM1 in the surface mode layer. The predicted total nitrogen (TN) concentration trend within the surface layer is similar to that of the bottom, but the overall surface water total nitrogen (TN) is slightly lower.

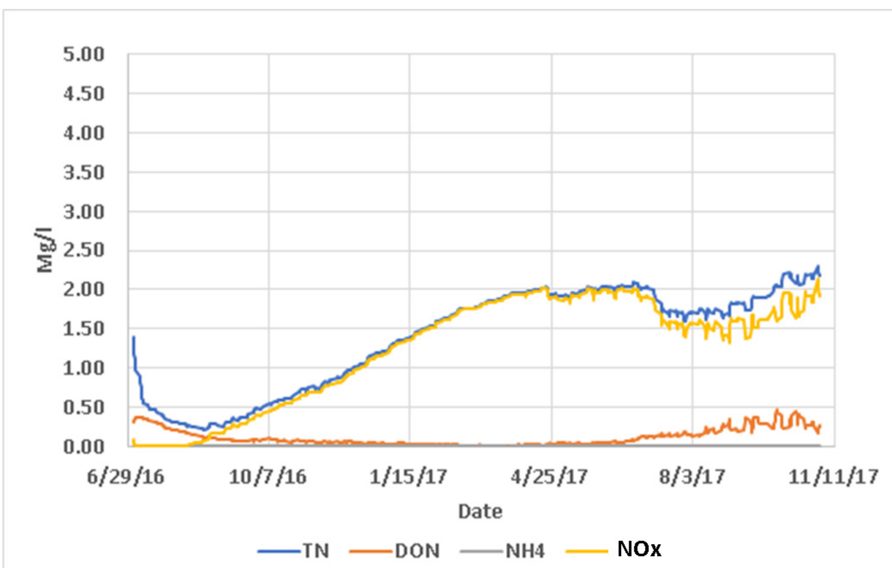

Figure 47. Predicted nitrogen concentrations from the surface model layer at GCM1 under post-dredge conditions. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

Figure 49 compares pre- and post- dredge total nitrogen (TN) concentration in the bottom model layer at Station GCM1 and Figure 50 shows the predicted pre- and post-dredging DO concentration at GCM1. After a model spin up period the predicted total nitrogen (TN) and DO values under the post dredging case remain below the pre-dredge values. The predicted post-dredge DO concentration remains in the range about 6 to 7 mg/l for the duration of the model run. Predicted DO values under the pre-dredge conditions dip as low as about 5.5 mg/l.

Although the model completed the calculation of phosphorus forms though the pre- and post-dredge cases, no discernable difference was found between the two cases. Figure 51 shows the pre-dredge model results for phosphorus. The post-dredge results were essentially identical. More sampling of sediment nutrient fluxes could better constrain the water quality calculations and potentially lead to calculated differences in pre- and post-dredge concentrations.

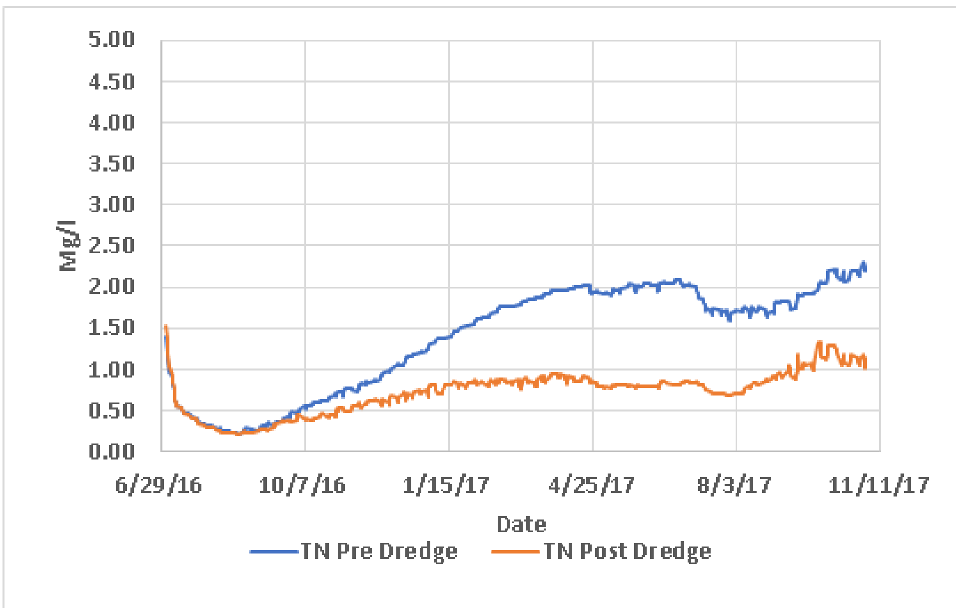

Figure 48. Comparison of pre- and post-dredge total nitrogen (TN) concentrations in the model bottom layer at Station GCM1

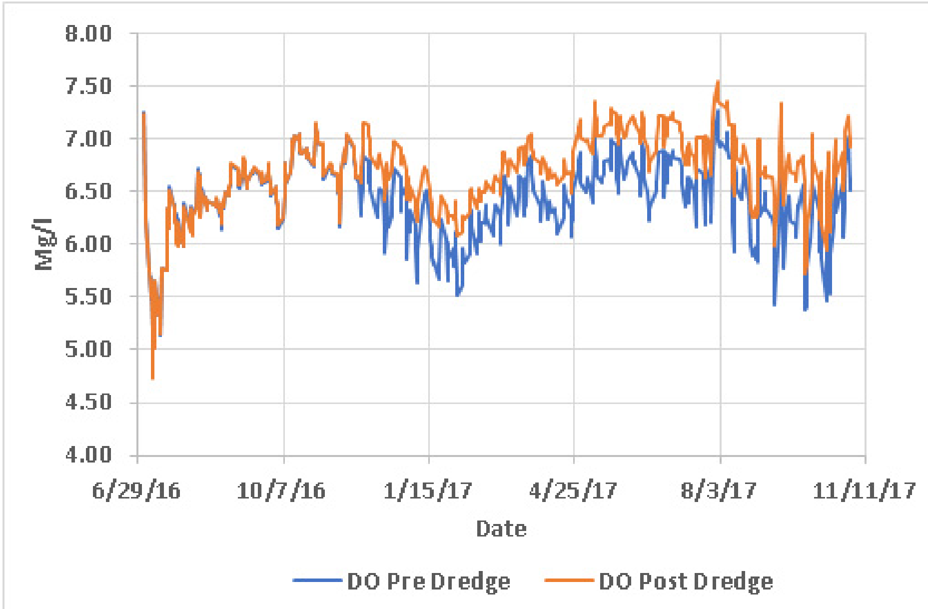

Figure 49. Predicted pre- and post-dredging dissolved oxygen (DO) concentration in the model surface layer at GCM1.

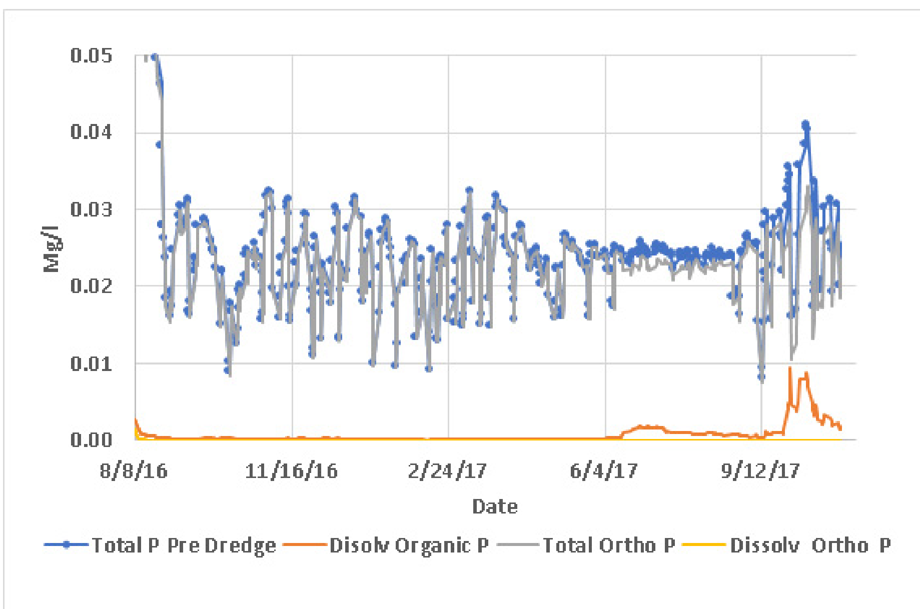

Figure 50. Predicted pre-dredge phosphorus (P) concentrations at Station GCM1.

8.4 Cocoa Beach

The Cocoa Beach phased muck dredging project is represented in Figure 40. Similar, to the case for Grand Canal, the dredging zones are represented by model grid cells that cover a larger area than the individual finger canals. Again, the nutrient fluxes in the sediment digenesis model that includes these zones are prorated according to the ratio between total area covered by the canals and the area covered by the model cells. A limitation of this particular model calculation is that there are no direct measurements of nutrient fluxes within the Cocoa Beach dredging areas. Thus, the pre-dredge nutrient flux was estimated in part from data collected by Trefry and Fox (2019) around the Cocoa Beach Golf Course. These sample locations are shown in blue in Figure 51. Model data were obtained from stations CCM1, CCM2 and CCM3 as shown in Figure 52. The numerical monitoring stations were situated to capture the effects of sediment nutrient flux reduction from phases 1 to 3 of the project. Model calculations of nitrogen and dissolved oxygen are discussed in this section. Phosphorus calculations were also completed, but did not show any detectable differences between the pre- and post-dredge cases. This may be due to the lack of measured data in this area to accurately guide model calculations of phosphorus species.

Figure 53 shows model-predicted bottom water concentrations of nitrogen forms at CCM1 under pre-dredge conditions. Here the total nitrogen (TN) consists principally of nitrate + nitrite (NOx) and the predicted concentrations of dissolved organic nitrogen (DON) and ammonium (NH4) are low. Concentrations of nitrogen forms are very similar in trend in the surface layer of the model (Figure 54).

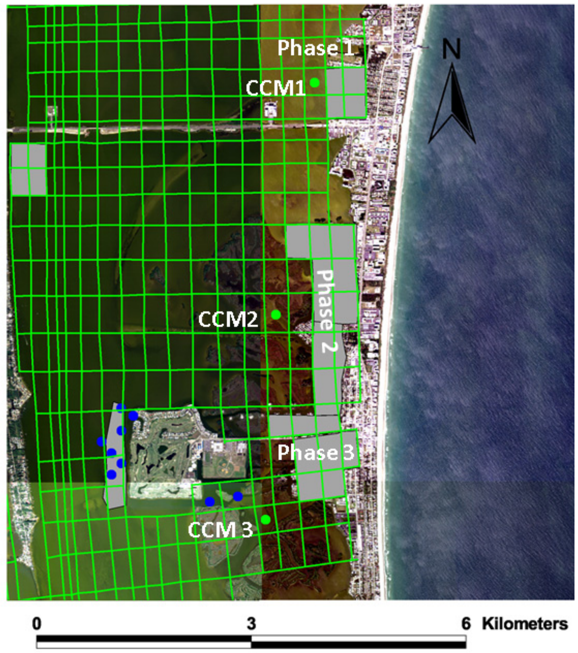

Figure 51. Location of Cocoa Beach Phase 1, Phase 2 and Phase 3 muck dredging zones as represented in the model grid.

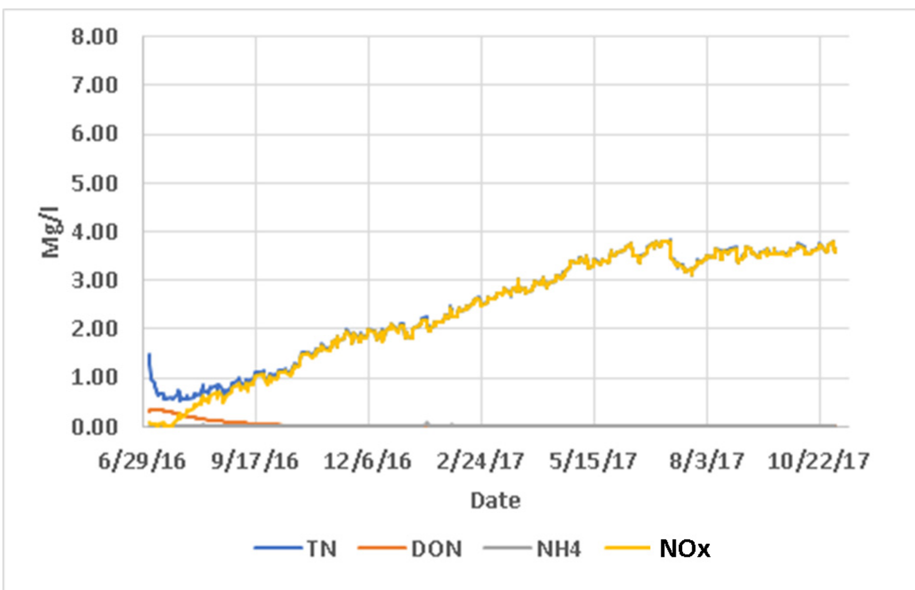

Figure 52. Predicted nitrogen (N) concentrations from the bottom model layer at CCM1
TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

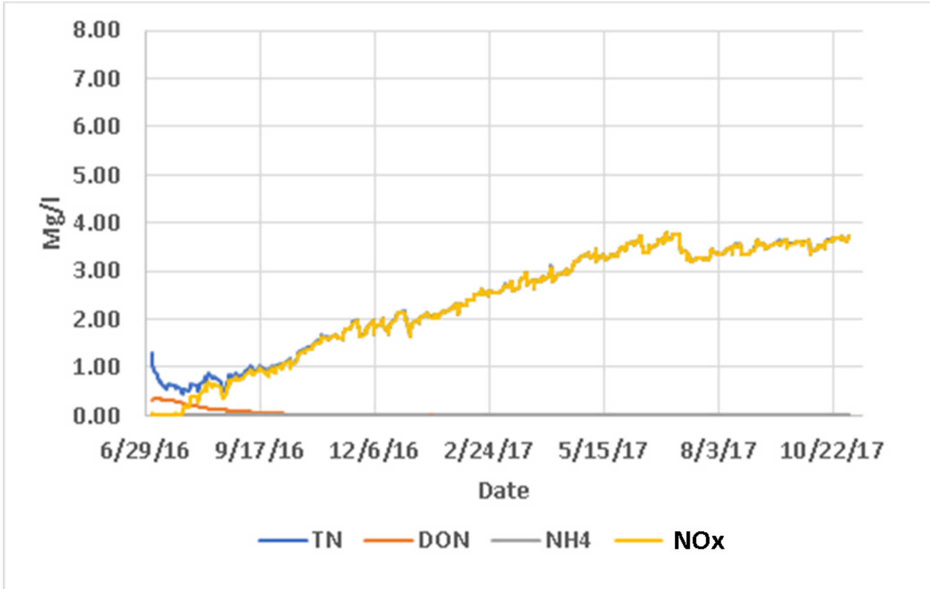

Figure 53. Predicted nitrogen concentrations in the surface model layer at CCM1
TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

Figure 55 compares the predicted pre- and post-dredge total nitrogen (TN) concentration in the bottom model layer at CCM1. After hypothetical dredging, predicted total nitrogen (TN) concentration values in the bottom model layer are reduced from an average of about 4 mg/l to about 1 mg/l.

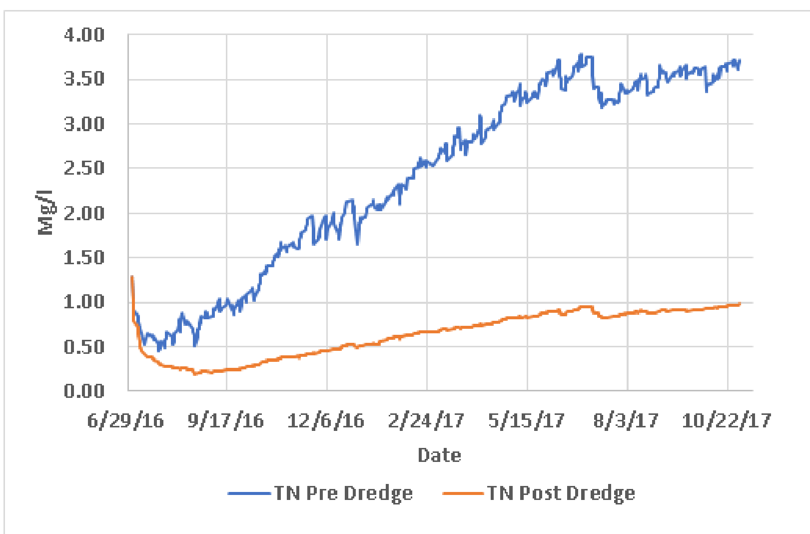

Figure 54. Predicted pre- and post-dredge total nitrogen (TN) concentrations in the surface model layer at CCM1.

Figure 56 shows the predicted pre- and post-dredging DO values in the bottom model layer for the final six months of the model run. After dredging DO values fluctuate around an average of about 6 mg/l and are continuously greater than pre-dredge DO levels, which episodically fluctuated down to near zero over the model run.

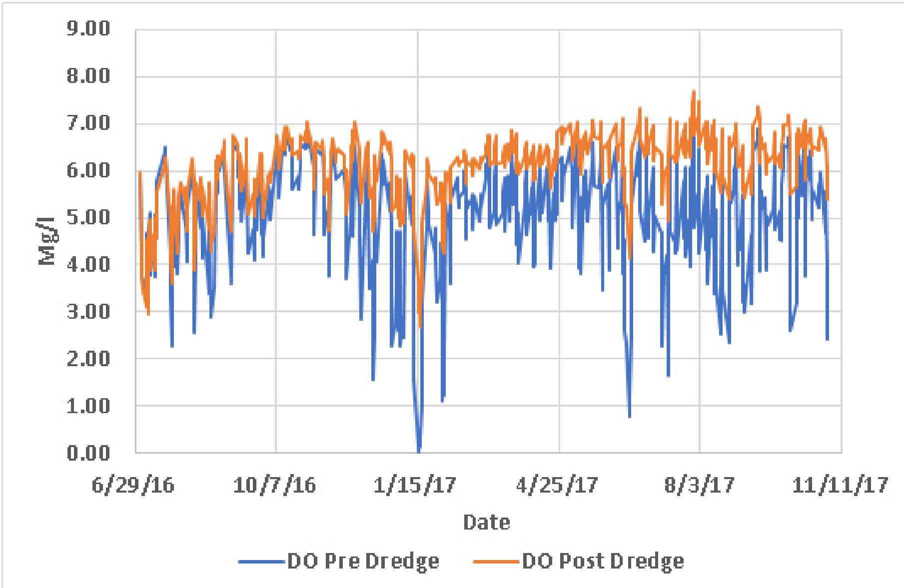

Figure 55. Predicted pre- and post-dredging dissolved oxygen (DO) concentration at CCM1

Figure 57 shows the predicted distribution of nitrogen forms at Station CCM2 adjacent to Cocoa Beach Phase 2. Again, Nitrate+Nitrite dominate the predicted concentrations.

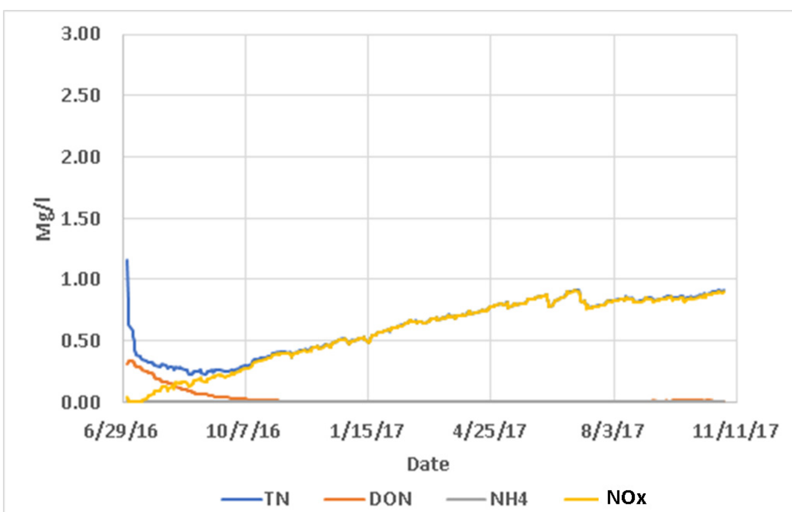

Figure 56. Predicted nitrogen concentrations in the surface model layer at CCM2.
TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

Figure 58 shows predicted pre- and post-dredging total nitrogen (TN) concentrations at CCM2 in the bottom model layer. Post-dredge total nitrogen (TN) concentrations are very similar to those reported at CCM1, being reduced from about 4 mg/l to about 1 mg/l. Likewise, DO values in the bottom model layer increased during post-dredge to an average of about 6 mg/l (Figure 59).

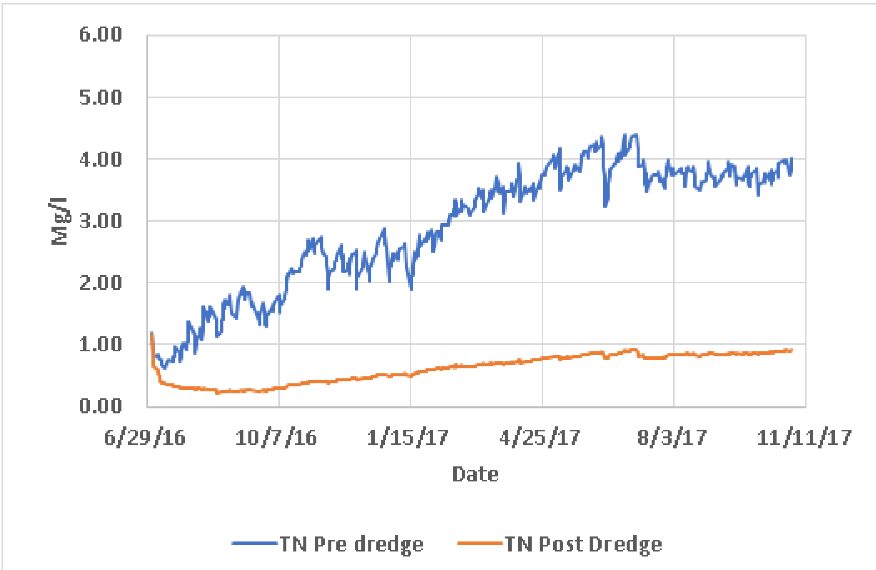

Figure 57. Predicted pre- and post-dredge total nitrogen (TN) concentrations in the surface model layer at CCM2.

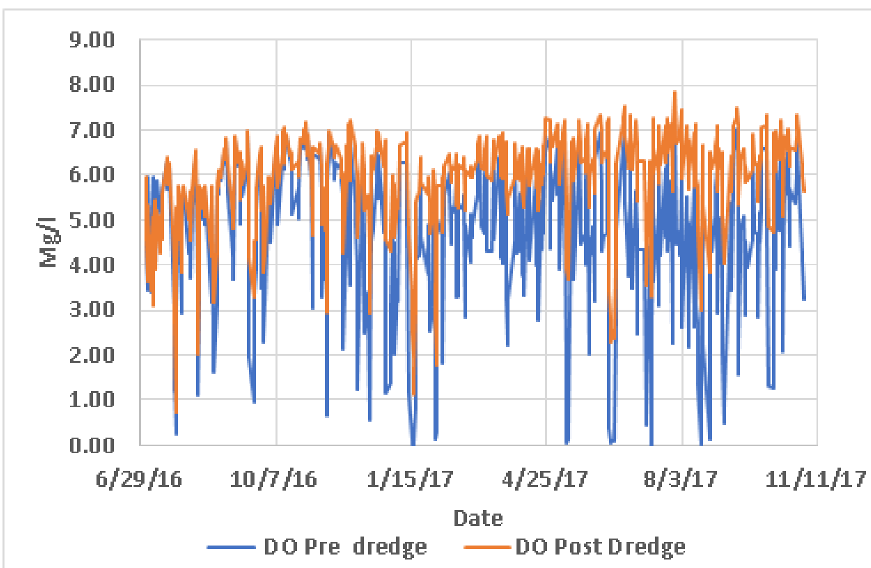

Figure 58. Predicted pre- and post-dredging dissolved oxygen DO concentration at CCM2

Model results at CCM3 adjacent to Cocoa Beach Phase 3 muck dredging zone are similar to those reported for stations CCM1 and CCM2. The main predicted nitrogen constituent is nitrate + nitrite (NOx) as seen in Figure 60. In a comparison of predicted pre- and post-dredging total nitrogen (TN) concentrations in the model surface layer, TN concentrations are reduced to about 1 mg/l from the predicted pre-dredging concentrations of 3 to 4 mg/l (Figure 61).

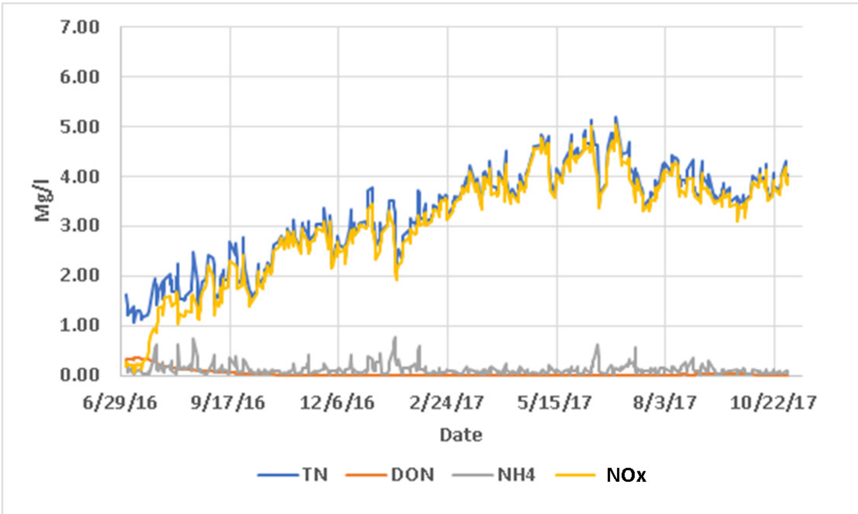

Figure 59. Predicted nitrogen concentrations in the bottom model layer at CCM3. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

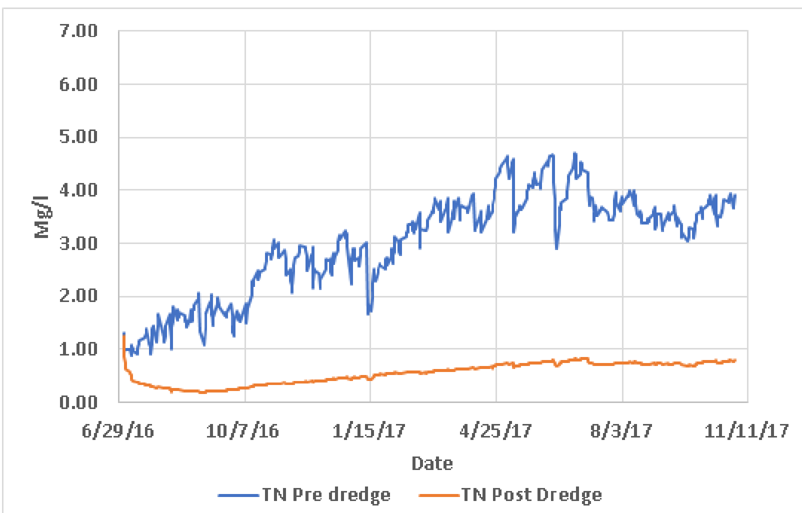

Figure 60. Predicted pre- and post-dredge total nitrogen TN concentrations in the surface model layer at CCM3.

The potential impact of muck dredging is also apparent in predicted DO concentration in the model surface layer at CCM3. A small increase in DO under the post-dredge condition is predicted to persist though the model run (Figure 62). A similar impact is shown in the predicted DO concentrations within the bottom model layer at station CCM3 (Figure 63).

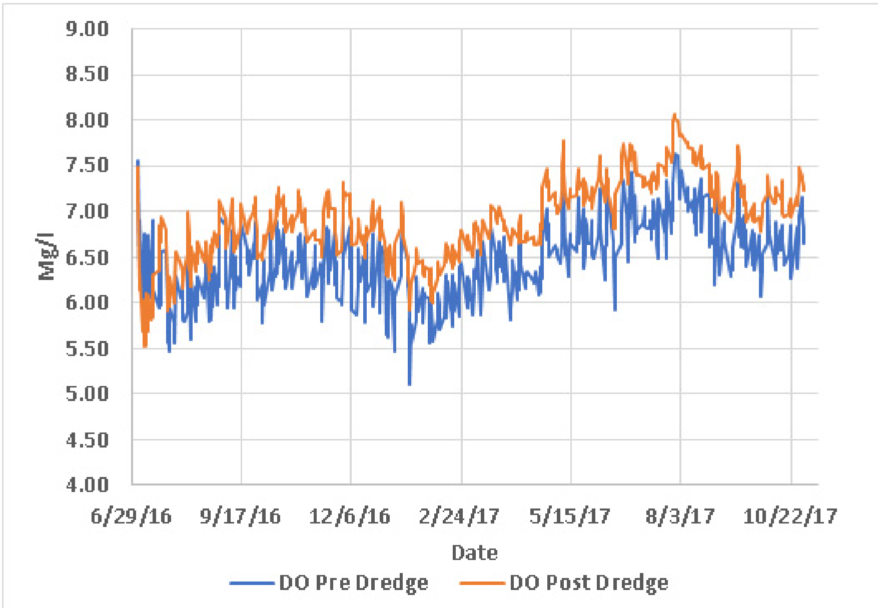

Figure 61. Predicted pre- and post-dredging dissolved oxygen (DO) in the model surface concentration at CCM3.

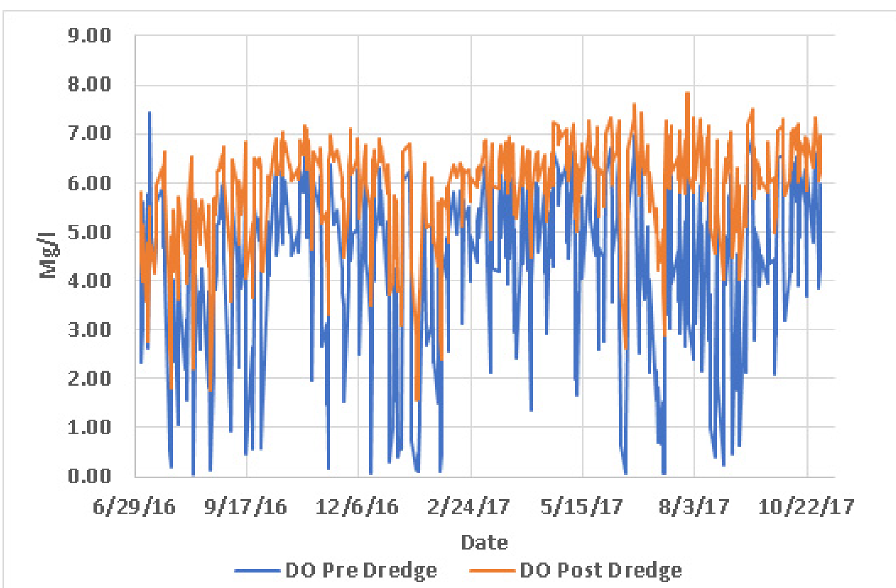

Figure 62. Predicted pre- and post-dredging dissolved oxygen (DO) concentration in the bottom model layer at CCM3.

8.4 Sykes Creek

Figure 64 shows the model presentation of the Sykes Creek dredging project area. Similar to the Grand Canal and the Cocoa Beach project areas the model does not resolve the details of the many finger canals. The rate of ammonium flux per unit area stated in Table 2 was prorated across the model muck zone so that the total rate per unit time in the model and in the actual footprint of the muck dredging zone are equal.

Figure 65 shows the predicted concentrations of nitrogen forms in the bottom layer of the model at Station SCM1 under pre-dredge conditions Similar to predictions in the Cocoa Beach area, the total nitrogen (TN) record is dominated by nitrate + nitrite (NOx). Figure 66 shows the distribution of nitrogen forms in the surface model layer after dredging. Total nitrogen (TN) concentration is again dominated by nitrate + nitrite (NOx), but NOx concentrations are substantially lower under the post-dredge condition (a reduction of generally 7.5 mg/l during the model-simulation period).

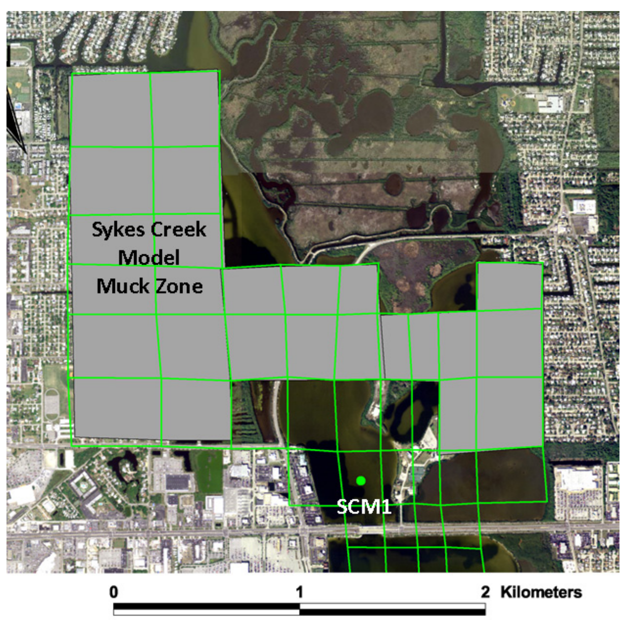

Figure 63. Location of the Sykes Creek muck zone represented in the model grid.

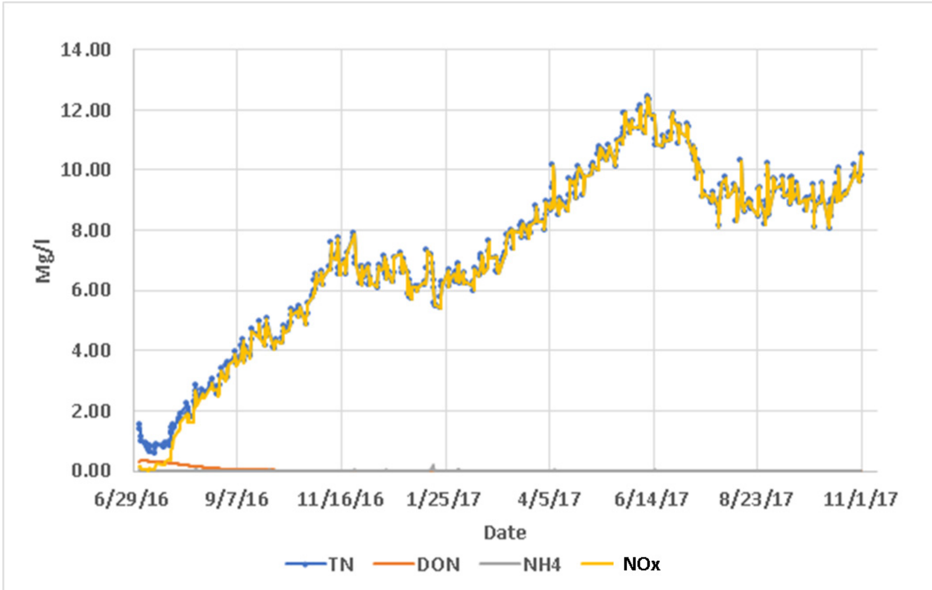

Figure 64. Predicted nitrogen concentrations in the bottom model layer at SCM1.
TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite.

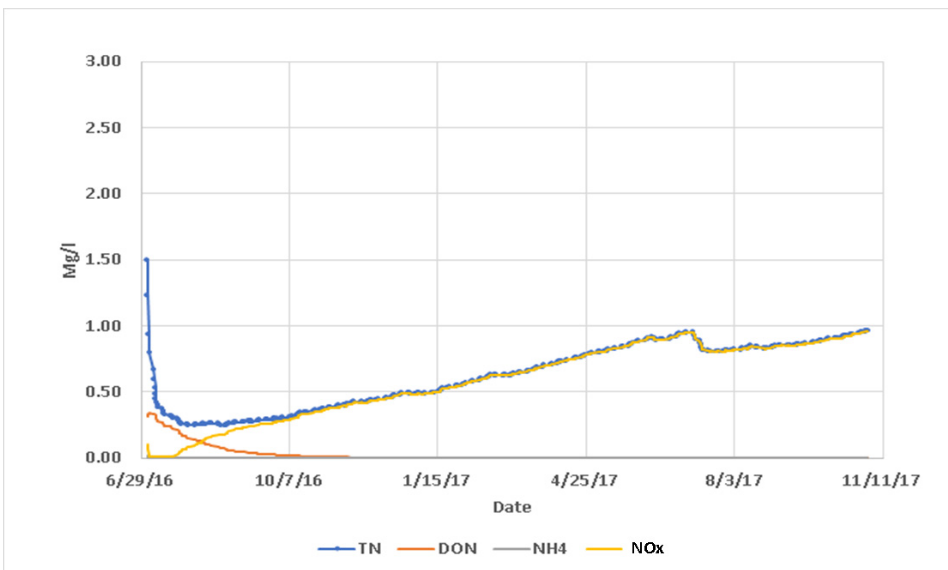

Figure 65. Predicted post-dredge nitrogen concentrations in the bottom model layer at SCM1. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite

Figure 67 shows the predicted concentrations of ammonium (NH4) for a portion of the modeling period under pre- and post-dredge conditions. Ammonium concentration remains low except under the pre-dredge condition except for a predicted spike in mid-June, which corresponds to the higher predicted TN concentrations at this time (See Figure 65and Figure 66). Under the post dredge situation, ammonium (NH4) concentration in the bottom model layer is near zero.

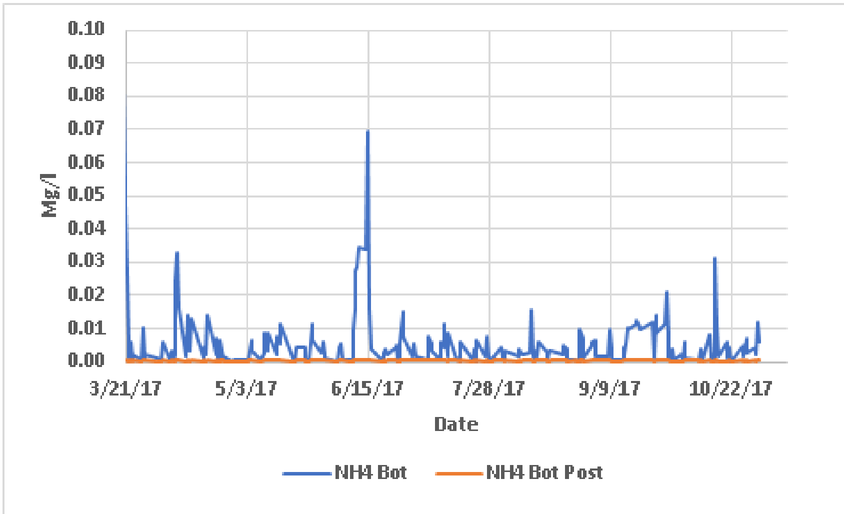

Figure 66. Predicted pre- and post-dredge ammonium (NH4) concentrations in the bottom model layer at SCM1

Figure 68 compares predicted pre- and post-dredge concentrations of TN. After dredging of the nearby Sykes Creek project area, the post-dredge concentration of TN in the surface model layer at SCM1 is reduced from a range at or above 8 mg/l to a consistent concentration of less than 2 mg/l at SCM1. Figure 69 compares pre- and post-dredge DO concentrations in the model surface layer. Dissolved oxygen levels are predicted to be slightly higher for the duration of the model period.

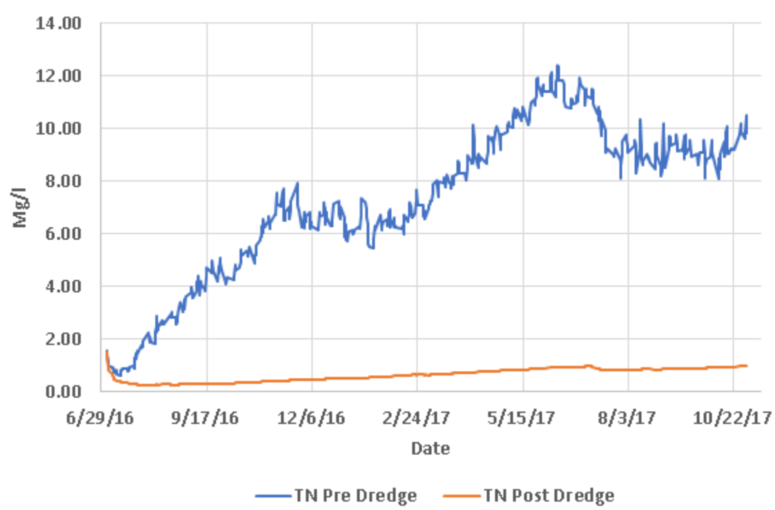

Figure 67. Predicted pre- and post-dredge total nitrogen (TN) concentrations in the surface model layer at SCM1.

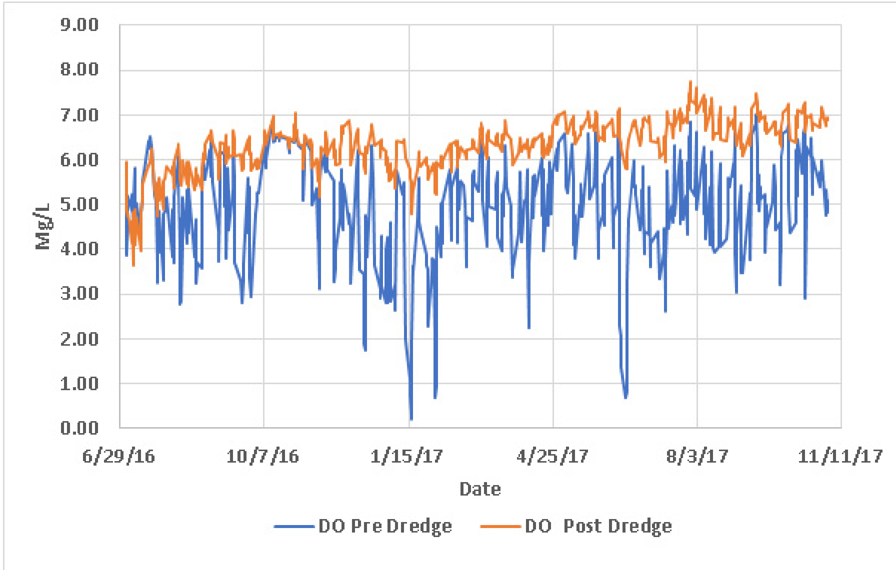

Figure 68. Predicted pre- and post-dredging dissolved oxygen (DO) concentration in the bottom model layer at SCM1.

Model calculations of phosphorus did not indicate any measurable difference between the pre- and post-dredge conditions for any of the species predicted by the model. It is likely that more data on phosphorus flux from sediments in the Sykes Creek area will be required to tune this model calculation. Figure 70 shows a portion of the predicted phosphorus concentrations for the pre-dredge case.

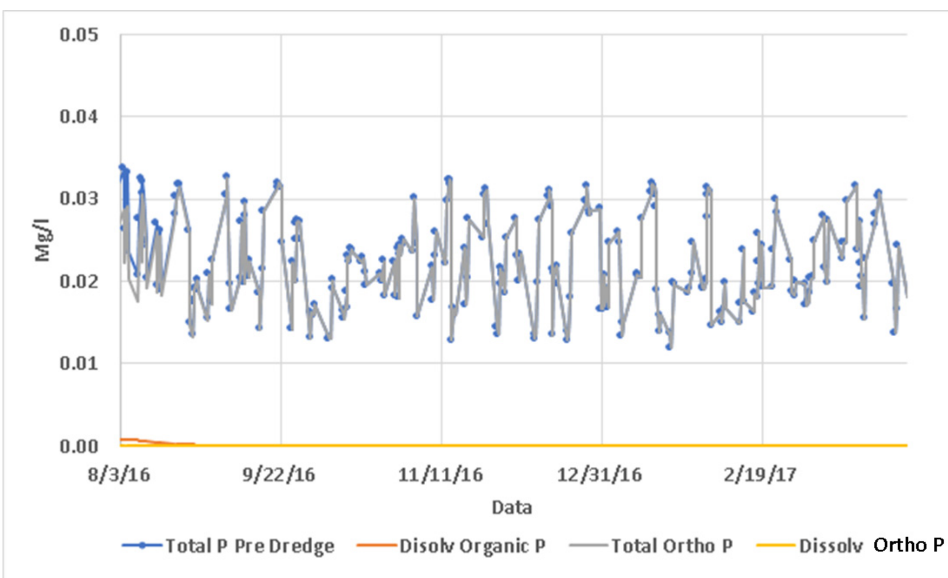

Figure 69. Predicted phosphorus concentrations in the bottom model layer at Station SCM1 under pre-dredge conditions. P = phosphorus

8.5 Mims Boat Ramp

Figure 71 shows the extent of the Mims Boat Ramp dredging area designated by Brevard County. Within the model grid, the muck zone is represented in the three model cells surrounding the M1 monitoring station, including the triangular grid cell to the north east of M1. In these cells the sediment nutrient flux rate is prorated across the area to represent the total flux rate within the actual muck zone to be dredged.

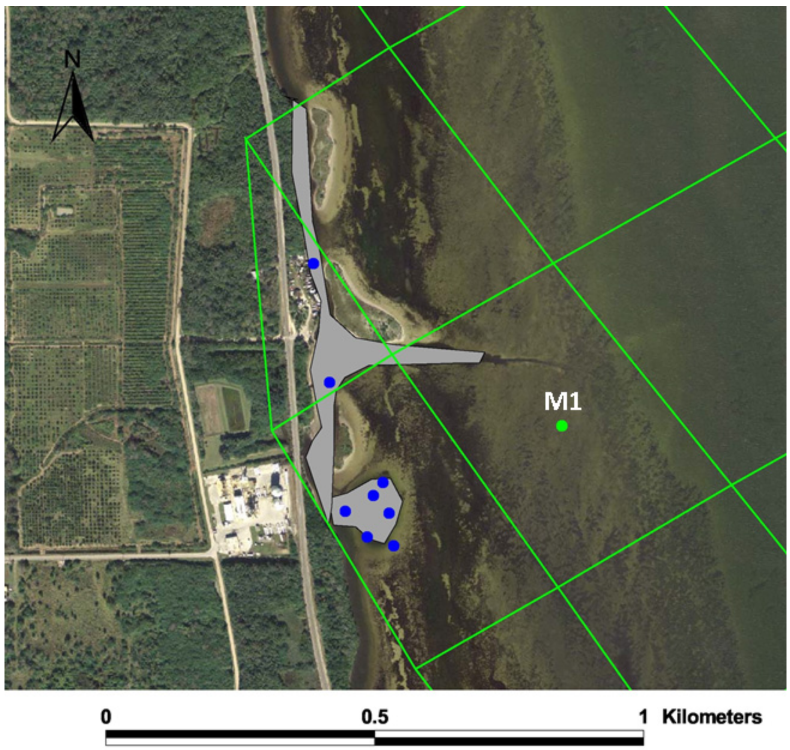

Figure 70 . Location of the muck zone designated for dredging by Brevard County. M1 is the location of the numerical monitoring station outside the muck zone.

Figure 72 and Figure 73 show the concentrations of nitrogen forms in the bottom and surface layers of the model under pre-dredge conditions. In both layers the principal form of nitrogen is nitrate + nitrite (NOx), but with noticeable concentrations of dissolved organic nitrogen (DON) and Ammonium (NH4) throughout the model run.

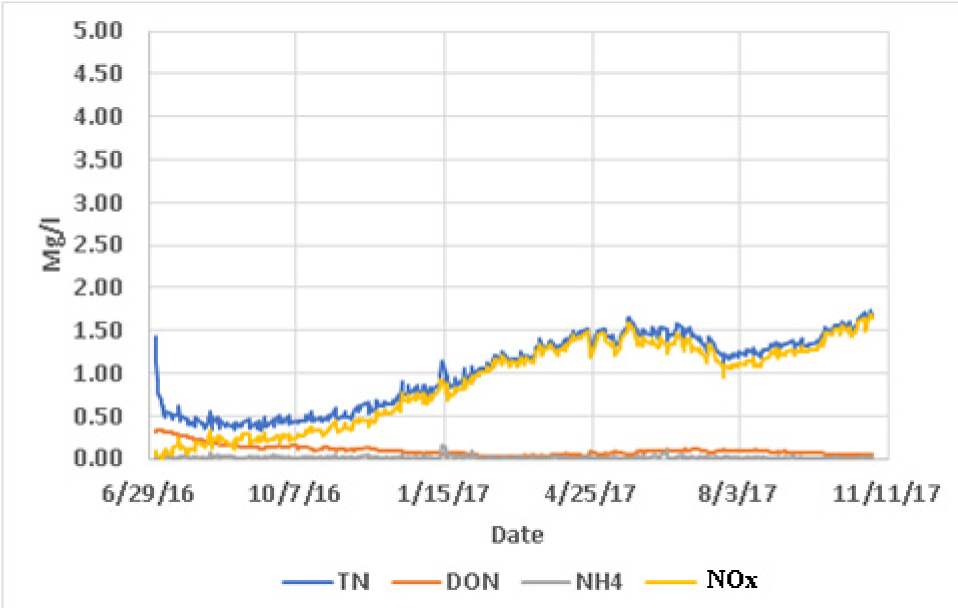

Figure 71. Predicted concentration of nitrogen at M1 in the bottom model layer under pre-dredge conditions. TN=total nitrogen, DON=dissolved organic nitrogen, NH4=ammonium, NOx = nitrate+ nitrite

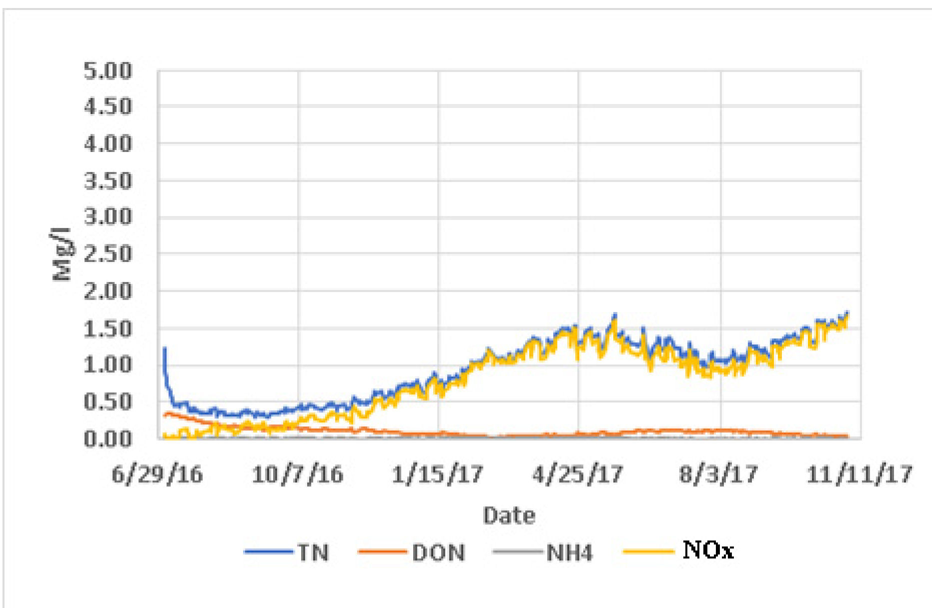

Figure 72. Predicted concentration of nitrogen at M1 in the surface model layer under pre-dredge conditions. TN=total nitrogen, DON=dissolved organic nitrogen, Nh4=ammonium, NOx = nitrate+ nitrite

Figure 74 shows the predicted pre- and post-dredge TN concentrations in the surface model layer at M1. Under the post dredge situation TN values are reduced by 0.4 mg/l or more. Figure 75 shows the predicted pre- and post-dredge ammonium (NH4) concentrations in the surface model layer at M1 for a portion of the model period. Post-dredge predicted ammonium (NH4) concentration is near zero in the surface model layer.

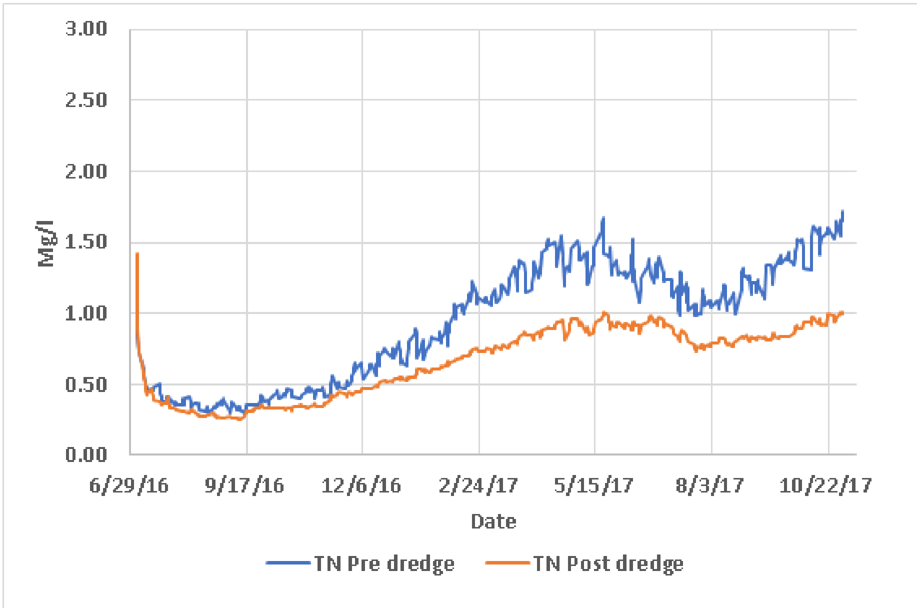

Figure 73. Predicted pre- and post-dredge TN concentrations in the surface model layer at M1.

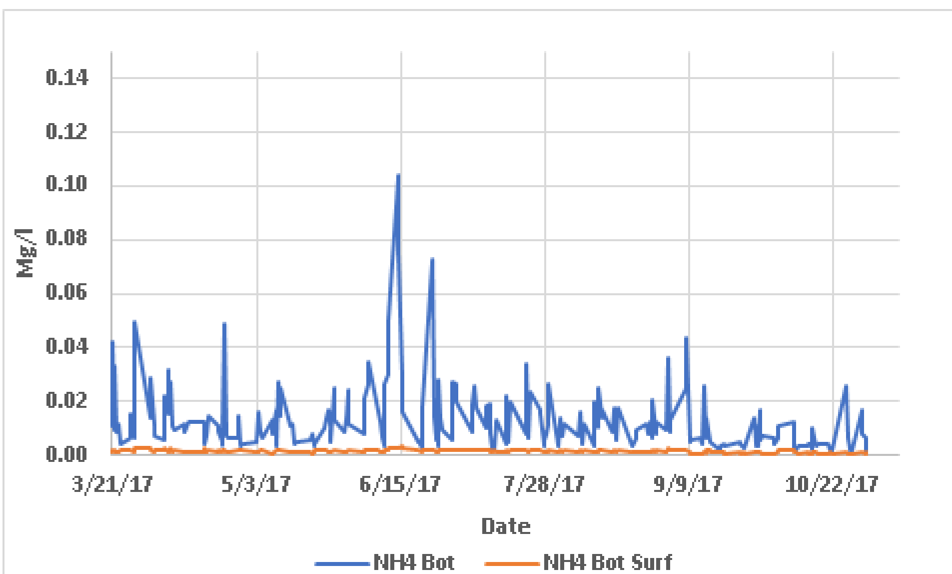

Figure 74. Predicted pre- and post-dredge ammonium (NH4) concentrations in the surface model layer at M1.

Figure 76 compares predicted pre- and post-dredge DO concentration in the surface model layer. During most of the model period predicted post-dredge DO concentration varies around 6 mg/l dropping to about 3 mg/l during a short period in the middle of June 2017. Pre-dredge predicted DO concentration in the surface model layer is lower and varies over a wider range of values, which drop to less than 1 mg/l in mid-June of 2017.

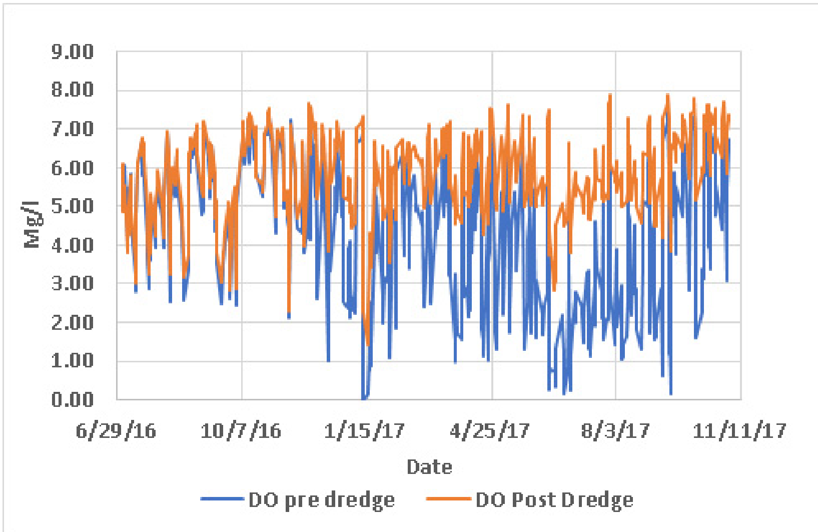

Figure 75. Predicted pre- and post-dredge dissolved oxygen (DO) concentrations in the surface model layer at M1.

Model calculations of water column phosphorus concentration showed a fractional decline in total phosphorus (TP) under the post dredge case (Figure 77). However, it is likely that more data concerning spatial and temporal sediment fluxes of phosphorus will be required to better tune the model for phosphorus constituents.

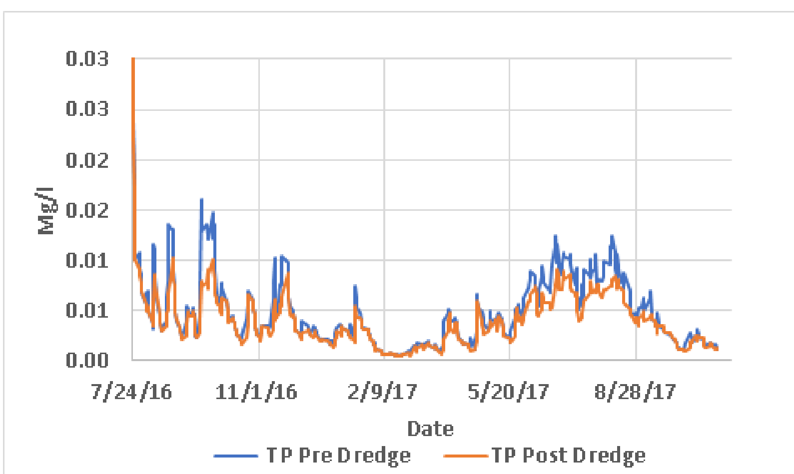

Figure 76. Prediction of pre- and post-dredge total phosphorus (TP) concentrations in the model bottom layer at Station M1

9.0 Summary Conclusions

This project integrates water quality and hydrologic, and hydrodynamic process data into an IRL model. The overall goal of this modeling project is to calibrate model simulations with measured data to predict the impact of muck dredging on nutrient and DO water quality.

Modeling during this project evolved in terms of space and time. The original model grid extended from the north boundary of the Mosquito Lagoon to the Wabasso area of north Indian River County. In the final year of the project model boundaries were extended offshore into the coastal ocean though tidal inlets and the south boundary of the model domain was extended to just south of Ft. Pierce Inlet and extended into the near-coastal area east of Ft. Pierce Inlet. Likewise, the SWIL model was extended south to beyond the Ft. Pierce area and extended in time from the close of 2015 to the end of 2017 to accommodate the in-estuary modeling period. In addition to examining the time and spatial domain of the modeling effort, additional muck dredging assessments were expanded from the Turkey Creek area to five additional areas requested by Brevard County: the Eau Gallie River area of the IRL, the Grand Canal area adjacent to the south Banana River Lagoon, the Cocoa Beach area of the Banana River Lagoon, Sykes Creek, and the Mims area of the north IRL basin.

The modeling platforms introduced in Year 1 of the project include the EFDC/HEM3D coupled hydrodynamic and water quality models, which is supported by the SWIL watershed model. This provides data for sub-basin freshwater inflows and loading of nitrogen and phosphorus into the estuarine body. Physical boundary conditions for model hydrodynamics are in part supported by a combination of data collected by or sponsored by the SJRWMD as part of an ongoing monitoring program to characterize the IRL system from an ecological and water quality perspective. These data were used to set interior boundary conditions for salinity and water temperature associated with freshwater inflow. Separate data were applied to the model calibration and validation process. In the 3rd and final year of the project, ocean boundary conditions were provided by a combination of data from the ADIRC and HYCOM basin-scale ocean models in combination with coastal sea level records derived from NOAA observations. This allowed a complete representation of important non-tidal sea levels, as well as the tidal constituents in the coastal ocean model boundaries.

Calibration checks for a time interval from 2014 to the end of 2015 showed that the modeling scheme is verified for essential hydrodynamic performance including water level, salinity and water temperature and water quality constituents. Likewise, the comparisons made for several water quality constituents show good agreement between measured and model data within the 2014-15-time interval and the ability of the water quality model to resolve small differences in water column nutrient concentrations based on assumed changes to nutrient fluxes from the sediment bed. Since the model grid was extended into the near-coastal ocean, the model performance for water level, salinity and water temperature were re-checked against measured data from 2016 and 2017 and found to continue to perform well without any further adjustments for calibration.

Water quality modeling in the final year of the project benefited from the expansion of muck zone assessment from Turkey Creek to the additional areas, which were prioritized by Trefry et al., 2019. Model experiments in all muck zones show that muck dredging has the potential to reduce nitrogen based nutrient concentration in the water column outside the dredged area (up to 8 km, at the limit of the model's spatial extent) as well as within the dredged areas. The impact of muck dredging in all areas was detectable in the model results, which show a post dredging reduction of total nitrogen concentration (TN). However, the impact of dredging was less dramatic for those zones influenced by strong freshwater inflows, particularly during the wet season. On this basis, the muck zones investigated in this project can be broadly divided into two groups, those directly influenced by seasonally strong inflow and other zones not directly influenced by inflow due to their location at some distance from tributaries mouths.

The two muck zones most influenced by inflows that were included in this study are Turkey Creek and the Eau Gallie NE zone. The predicted benefits of muck dredging in both these areas were detectable, particularly during the dry season. Nitrogen loading from freshwater inflows from the Turkey Creek sub-basin and the Eau Gallie River partially masked the reduction in TN concentrations due to dredging. The model-predicted principal form of nitrogen for both the Turkey Creek area of the IRL and the Eau Gallie area are dissolved organic nitrogen (DON) with lesser contributions from nitrate + nitrite (NOx) and ammonium (NH4). In addition to predicted reductions of total nitrogen (TN), another predicted corresponding benefit of muck dredging is increased DO levels. However, in the Turkey Creek and Eau Gallie areas, post-dredge DO concentrations tended to converge with pre-dredge concentrations during times of high freshwater inflow.

In other areas where muck zones are less directly influenced by freshwater inflows, the predicted TN concentrations are dominated by nitrate + nitrite (NOx) concentrations. The predicted benefit from muck dredging in these areas is more apparent and the magnitude of TN reduction after dredging is larger.

Total phosphorus (TP) and phosphorus constituents that contribute to total phosphorus were calculated along with nitrogen and DO calculations. Similar to the nitrogen calculations, sediment flux of phosphate to the water column was based on a scattering of available data. Specified reductions of phosphate sediment flux to the water column from the muck zones considered in this study resulted in predicted reductions in total phosphorus

(TP) concentrations in some of the zones, but not others based on sediment flux adjustments to simulated muck dredging. However, model data and measured data comparisons indicate that the EFDC/HEM3D model is providing a good match with measured water column data where it is adequately constrained by sediment flux data from measurements. A more extensive set of ongoing sediment nutrient flux data from muck zones and non-muck zones would contribute to the continued development of water quality modeling of the IRL. This, combined with updating of watershed nutrient inputs from the SWIL model would support continued improvement of modeling capabilities.

The ongoing muck dredging program is predicted to have significant benefits in all areas investigated in this study. These are gauged by predicted reductions in total nitrogen concentration in the water column above the dredged muck deposits and in areas beyond the immediate foot print of the dredged zone. With respect to the Turkey Creek dredged muck zone, reductions in TN, total phosphorus (TP) , and increases in DO were predicted to extend to at least 8 km from the entrance of Turkey Creek.

As of this writing, the IRL hydrodynamic and water quality model continues to be developed through updated model boundary conditions and inclusion of additional muck zones in the model grid. As more information is developed on the extent of muck deposits in the IRL system, these areas can be incorporated into the model and tested for the potential benefits of muck dredging.

11.0 References

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