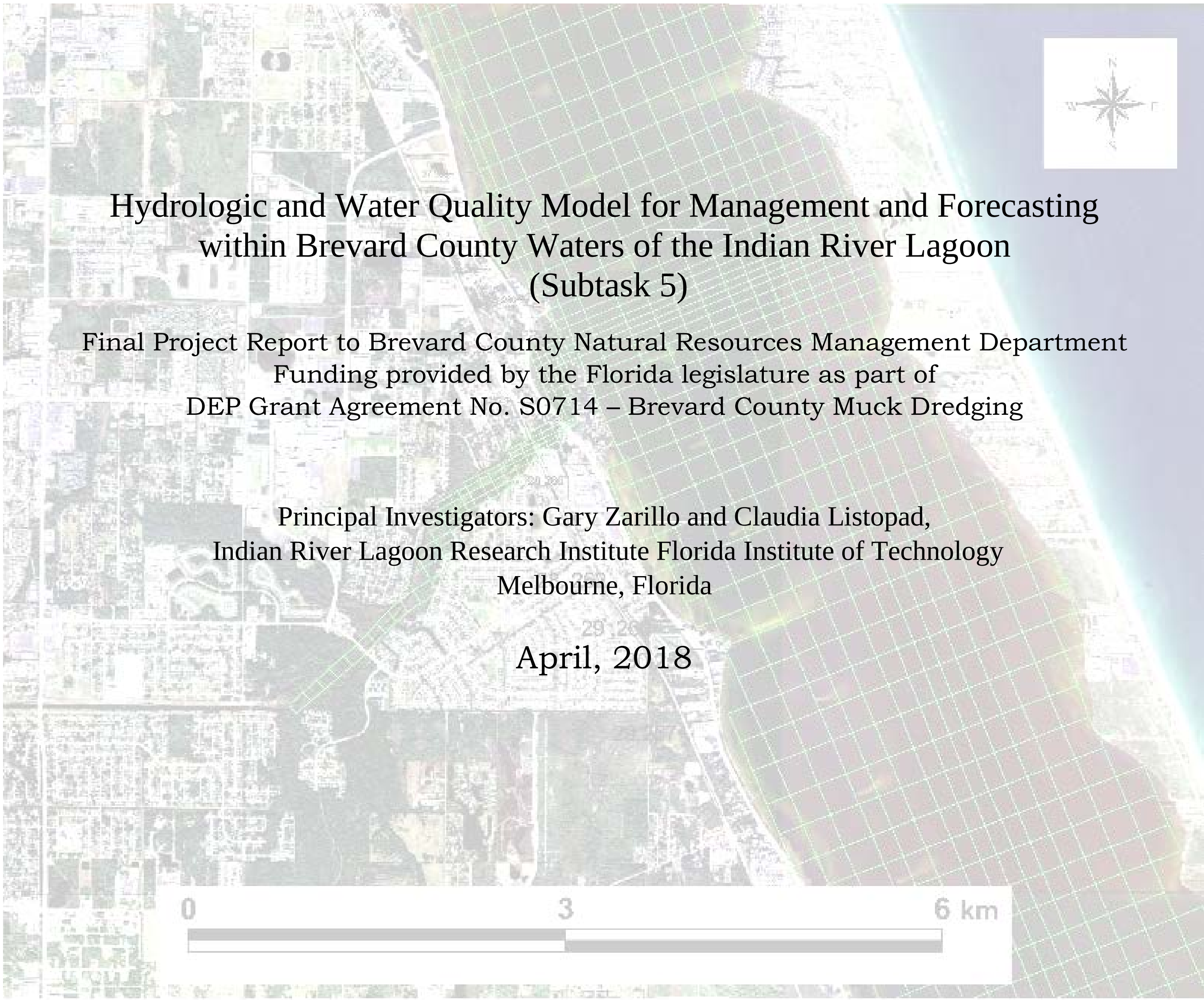
Impacts of Environmental Muck Dredging 2016-2017



Hydrologic and Water Quality Model for Management and Forecasting within Brevard County Waters of the Indian River Lagoon
(Subtask 5)

Final Project Report to Brevard County Natural Resources Management Department
Funding provided by the Florida legislature as part of
DEP Grant Agreement No. S0714 – Brevard County Muck Dredging

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Executive Summary

This project integrates water quality and hydrologic, and hydrodynamic process data into a model of the Indian River Lagoon (IRL) for long-term calibrated and validated predictions of water quality. The overall goal is to combine model simulations with measured data to assess the impact of muck dredging on local and regional water quality. Questions to be addressed include: 1) to determine whether muck dredging 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 calibration 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. Question 3 will be answered more fully in year 3 of the project when all of the data collected by other members of the overall muck project team are fully represented in the model boundary conditions. The modeling platforms include the Environmental Fluid Dynamics Code (Tetra Tech, 2007) coupled hydrodynamic and water quality models (EFDC/HEM3D) and the Spatial Watershed Iterative Loading (SWIL) watershed model (Listopad, 2015). Hydrodynamic, hydrologic and atmospheric model boundary conditions are supported by the ongoing Indian River Lagoon monitoring program establish in the early 1990s by the St. Johns River Water Management District. Nutrient loadings from the Indian River Lagoon watershed sub-basins are from predictions by the SWIL model. In this report, we update model predictions from the coupled EFDC-SWIL modeling scheme into 2015 and provide further validation of water quality predictions by comparison to the SJRWMD data in the Turkey Creek area of the IRL.

Model predictions of ammonium concentrations in the water column within the Turkey Creek Basin compare well with measured data. Predicted and measured ammonium concentrations in the water column in the Turkey Creek basis compare with R-vales of between about 0.72 to 0.85 corresponding to R^2-values of between 0,5 and 0.75, respectively. Reductions in ammonium flux of 90% and 60% were examined in model runs as two post-dredging hypothetical conditions. Reductions of 90% result in very low values of ammonium in all model layers, which divides the water column into 5-vertical segments. A hypothetical reduction in ammonium flux by 60% resulted in low concentrations on ammonium in the upper four model layers and a moderate reduction in the lowest mode layer. The 90% and 60% hypothetical cases produced detectable improvements in water quality in the IRL adjacent to the entrance of Turkey Creek. The continued validation and results of water quality modeling demonstrate that dredging of muck sediments throughout the IRL could be evaluated for local and regional water quality improvements. To date the model scenarios have shown that dredging of muck sediments is likely to locally improve water quality and will have beneficial influence on nearby IRL water quality. This finding is consistent with data collected by Trefry et al. (2016a) that indicate improvement in local water quality within the Turkey Creek basin relative to pre-dredge conditions.

Since the post-dredge period in Turkey Creek continues to be monitored in the upcoming third year of the project, further model verification and model simulations will be based on a suite of measured data collected in the post-dredging period. Based on model performance thus far we expect that model results will continue to compare well to measured data by matching trends of measured data over time and matching measured values well within an order of magnitude. Thus, application of the model can be expanded with confidence to other locations scheduled for dredging of muck deposits.

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1.0 Introduction and Goals

The goal of this project is to deploy a full three-dimensional combined hydrological and water quality model in the Indian River Lagoon to answer the following questions: 1) to determine whether muck dredging 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 water quality or eutrophication model, and a watershed model to provide inputs to the combined hydrodynamic and water quality models.

2.0 Overview of Year 1 Project Accomplishments

Accomplishments in year 2 of the Hydrologic and Water Quality Model should be viewed from the perspective of year 1 accomplishments. The details of the initial development of the Hydrologic and Water Quality Model are given in the year 1 modeling report (Zarillo and Listopad, 2016). Major tasks included assembly of geomorphic data, processes data, and water quality data to be included in the model setup and calibration procedure. Model runs in year 1 were focused on testing the sensitivity of the modeling scheme to the reduction of muck deposits at the mouth of Turkey Creek. Results of the initial model runs representing about two years of real time data 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.

In addition to the setup and calibration of the in-estuary hydrodynamic and water quality model (EFDC/HEM3D) in year 1, the Spatial Watershed Iterative Loading (SWIL) model was set up to provide nutrient loadings from the watershed sub-basins of the Indian River Lagoon. The Spatial Watershed Iterative Loading (SWIL) model is a custom ESRI ArcGIS toolset, providing a continuous monthly simulation of runoff (surface and baseflows) yielding robust representation of pollutant loadings and freshwater volumes to the IRL. SWIL was developed by Dr. Claudia Listopad of Applied Ecology, Inc. Details of model operation can be found in the SWIL Model Methodology Manual (Applied Ecology, Inc, 2015). The SWIL model was developed as part of study to incorporate available watershed data into the TMDL process. In the IRL muck project the SWIL watershed model has been extended in space and time to provide calculations of nutrient loadings to the IRL from the watershed sub-basin. The details of the SWIL model setup and operation are provided in Appendix A of this report.

3.0 Project Tasks Year 2

Table 1 summarizes year 2 hydrologic and water quality modeling tasks. The update of the SWIL watershed model to the close of 2015 was competed as of April 1, 2017. This allowed the hydrodynamic and water quality model to advance to the close of August 2015 using the watershed inputs. These data, along with data from the other sub-basins were re-formatted into files that can be read by the EFDC/HEM3D hydrodynamic-water quality model. Once this was complete the model calibration for sediment diagenesis was updated to the close of 2015. Prognostic model runs for water quality in the IRL were then updated though 2015 and compared with measured data.

Table 1. Year 2 projects Tasks

Objectives/Tasks
Extend & Refine Model Grid into Tributaries
Update Water Quality Data Base through close of 2015
Expand and update SWIL Watershed Model
Implement Sediment transport sub-model
Refine Sediment Diagenesis Model Calculations
Model prognostic simulations
Monthly-Quarterly Reports
Final Report

4.0 Model Grid Improvements

4.1 Grid extension into creeks

The model grid as of this writing includes about two-thirds of the Indian River lagoon system extending from the Mosquito Lagoon to Ft. Pierce Inlet. The initial model grid as described in previous reports included all of the compartments of the IRL including the Mosquito Lagoon, Banana River 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 further to the west in Turkey Creek, Crane Creek, and the Eau Gallie River, along with refinements to better resolve causeways. More recently, to offset the lack of long term water level records and salinity records at the model grid boundaries, the model coverage has been extended through the entrance of Ponce Inlet, and Ft Pierce Inlet. The original grid includes cells through Sebastian Inlet. The recent grid modifications allow mode predictions to be extended to any time period that can be covered by water level predictions based on tidal constituents. Previous model runs were driven by measured data and measured salinity time series. Upon extension of the model grid into the coastal ocean, tide predictions can be used at open ocean boundaries to extend model simulation to any time period. Ocean salinity can be assumed to reach near full oceanic levels of 33 to 34 salinity units.

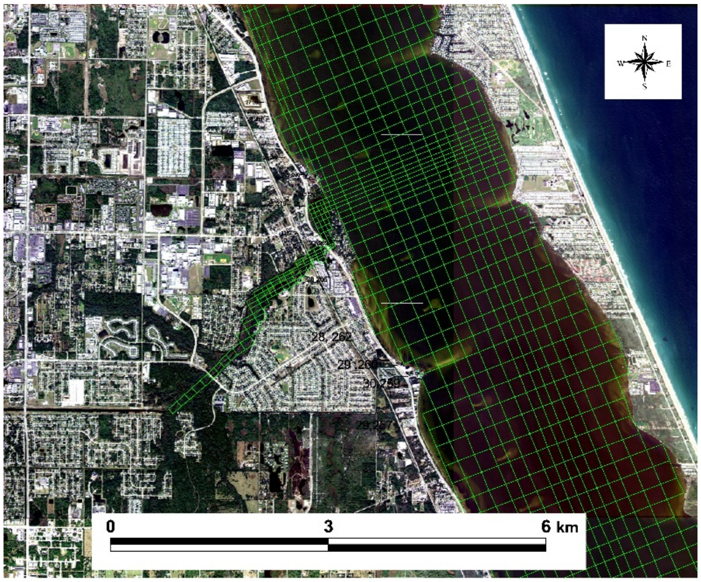

Figure 1. Model grid in the Turkey Creek area

The model grid was also extended into the Eau Gallie River (Figure 2). This extension anticipates later model calculations to test and verify the results of muck dredging now taking place in the lower river. Figure 2 also shows grid details around the Eau Gallie Bridge, including the grid refinement of the ICW and the causeway sections of the bridge structure that block flow.

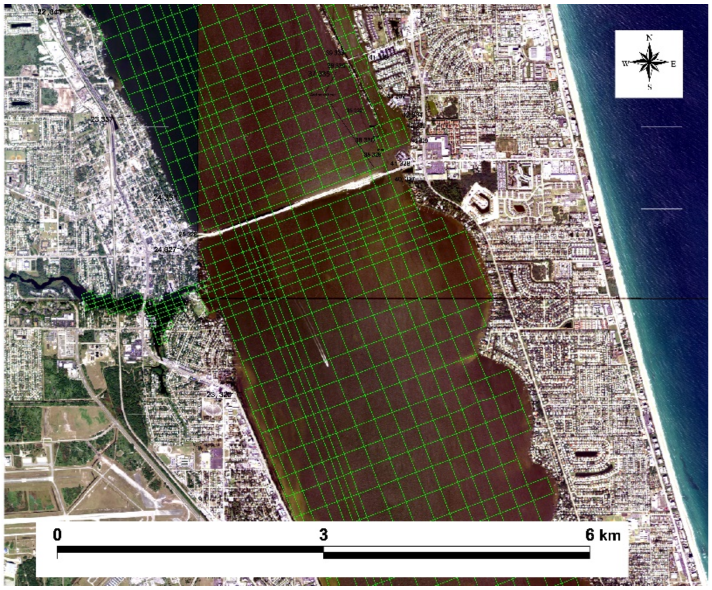

Figure 2. Model grid details in the Eau Gallie area.

4.2 Muck Zones within the water quality model

In year 2 of the water quality modeling project the combined hydrodynamic/eutrophication model (EFDC/HEM3D) code was modified to write selected water quality parameters over the entire model grid rather than only for selected model cells. This allows a regional to global view of water quality predictions across the model cells and through the five layers of the model. Further, the model was continually refined with respect to resolving known muck zones, particularly within the central to south Indian River Lagoon. Figure 3 shows a regional view of muck zones mapped throughout central Indian River Lagoon, whereas Figure 4 shows muck zone details in the vicinity of Turkey Creek. Survey lines of the Riegl muck survey (2009) are shown in Figure 3. The survey lines are too widely spaced to digitally interpolate the extent of continuous muck sediment zones with sufficient accuracy for modeling flux impact on IRL water quality. However, the survey line data set indicates that within the main body of the IRL, muck sediments are concentrated in the Intracoastal Waterway (ICW). Thus, until more comprehensive surveys become available, we assume that muck deposits are present in the ICW. Muck sediment zones shown in the Turkey Creek basin are based on data provided by Brevard County and Trefry, 2016a.

Each muck sediment zone is represented in the overall model by an input file that lists the model cells 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 assumed fluxes of phosphate (PO_{4}), ammonia nitrogen (NH_{4}), nitrite + nitrate nitrogen (NO_{3}), and sediment oxygen demand (SOD). Thus, sediment process calculations in each model cell are guided by values of these parameters in the muck zones or a more global set of parameters that are applied to non-muck zones. The specified flux rates are primarily from work by Trefry et al., 2016b.

In additional to the Riegl data, Brevard County Department of Natural Resources has provided survey maps (Morgan and Eklund, 2014, 2016) of muck zones in the area of Mims, Florida, Sykes Creek, and the Grand Canal area of Indian Harbor Beach and Satellite Beach, FL. The model grid is being refined to include the Mims area and a proposal was made to Brevard County to construct a secondary model of high spatial resolution that covers the Grand Canal area.

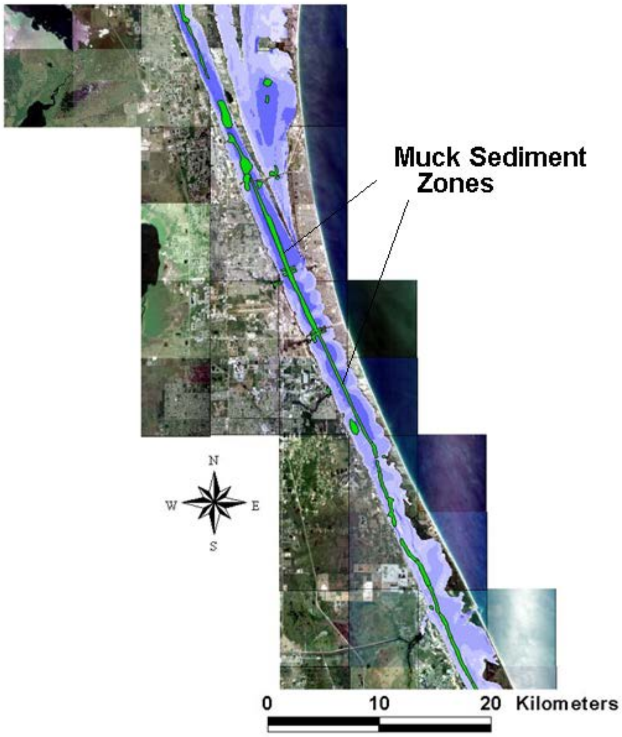

Figure 3. Muck deposits in the central IRL that are represented in the model benthic zones.

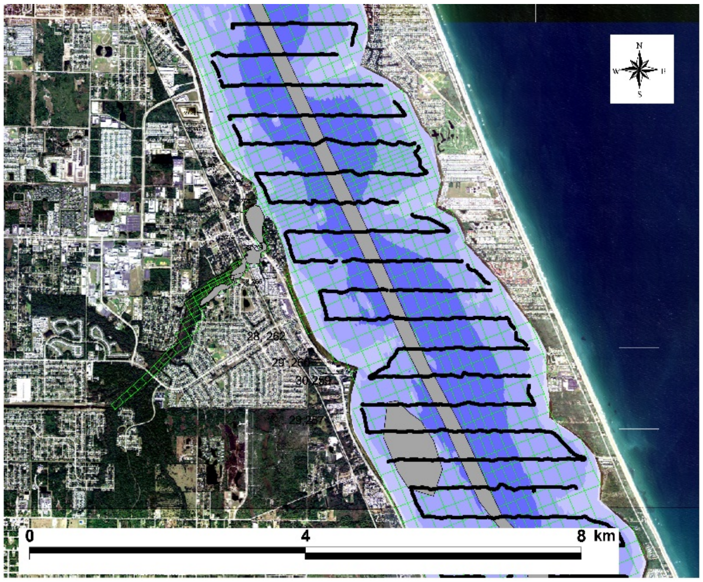

Figure 4. Benthic zones in the Turkey Creek areas representing muck deposits in the model.

5.0 Sedimentation Model Setup

Setup of the sedimentation model within the overall IRL hydrodynamic and water quality model requires assembly of sediment data and corresponding setting of controls in the main input file for the EFDC model. The purpose of sediment transport simulations is to be able in the Year 3 study to be able to estimate the return period of fine grained sediments to basins like Turkey Creek after removal by dredging. Setup of the sedimentation model includes activating the overall sedimentation module within the main EFDC control file and establishment of several input files that define sediment properties related to erosion and deposition potential. Table 2 lists the major parameters and input files that are required by the sediment transport module. The generic details of sediment transport calculations are presented in the EFDC model users guide (Tetra Tech, 2007).

Table 2. Partial list of parameters and files to activate sediment transport calculations in EFDC

File or Parameter	Purpose
SEDMDMX	Maximum fluid mud cohesive sediment concentration
SEDMDMN	Minimum fluid mud cohesive sediment concentration
SEDO	Initial cohesive sediment in bed per unit area
SDEN	Sediment specific volume
WSEDO	Sediment fall velocity
TAUD	Critical shields stress for non-cohesive sediment
TAUR	Boundary stress above which surface erosion occurs
bedlay.inp	Bed layer thickness for each model cell
bedbdn.inp	Sediment bulk density for each model cell
bedddn.inp	Bed layer dry density, porosity or void ratio each cell
sdser.inp	Suspended sediment concentration time series file.

The values for the parameters listed in Table 2 are set according to data provided from Bostater (2016) and Trefry et al., 2016a. Work on the "Movement Measurements of Muck and Fluidized Mud at Dredge Site" by Bostater (2016) provides information on some of the key parameter values for the sediment transport model such as maximum and minimum fluid mud cohesive sediment concentration, sediment specific volume, and initial cohesive sediment in bed per unit area. The primary measurement being made in this work is the flux of fluidized mud at selected location in the Turkey Creek Basin. These data are presented in units of mg cm^{-2} sec^{-1} and mg m^{-2} yr^{-1} dry weight. Such measurements can be directly compared with predicted net sediment transport derived from the correlation between predicted time series of sediment concentration in model layers and layer by layer time series flow velocity. Thus far, predicted and measured suspended sediment concentrations in the Turkey Creek basin are well matched (See Section 9.1). Once the model simulations are extended to the end of 2016 in the Year 3 study, the sediment model performance can be evaluated with a larger group of in-situ sediment flux and sediment concentration measurements that were collected in 2016. When the sediment transport calculations are fully verified (calibrated and validated) a multi-year run will be performed to predict the rate of post- dredge sedimentation in the Turkey Creek Basin.

6.0 Expand and Update of the SWIL Watershed Model

The details of the SWIL watershed setup and update in year 2 of the project are provided in Appendix A of this report. Briefly, however, the latest version of SWIL required three major changes: 1) expansion of the model extent to provide nutrient loadings from Ponce Inlet to Fort Pierce, 2) temporal expansion from 2011 through August 2015, and 3) converting the model from 2 to 3 land use/treatment time steps.

The changes include model process changes and input data changes. In terms of major processing changes, SWIL 4.0 has to be recoded to allow three sets of input data to be used throughout a time period. In the original SWIL 3.0 model, only two modeling periods (1995-2002 and 2003-2010) are captured by using the years 2000 and 2004 land use and treatment input. For SWIL 4.0, three modeling periods are used: the same original 1995-2002 (year 2000 land use/treatments), 2003-2010 (year 2004 land use/treatments), and the newly added 2011-2015 (year 2015 land use/treatments). Most of the other processing changes were minor and were required to allow expansion of the model spatial extent and a longer time series to be modeled. Figure 5 is an example of SWIL model output for total nitrogen, 1995 to 2015.

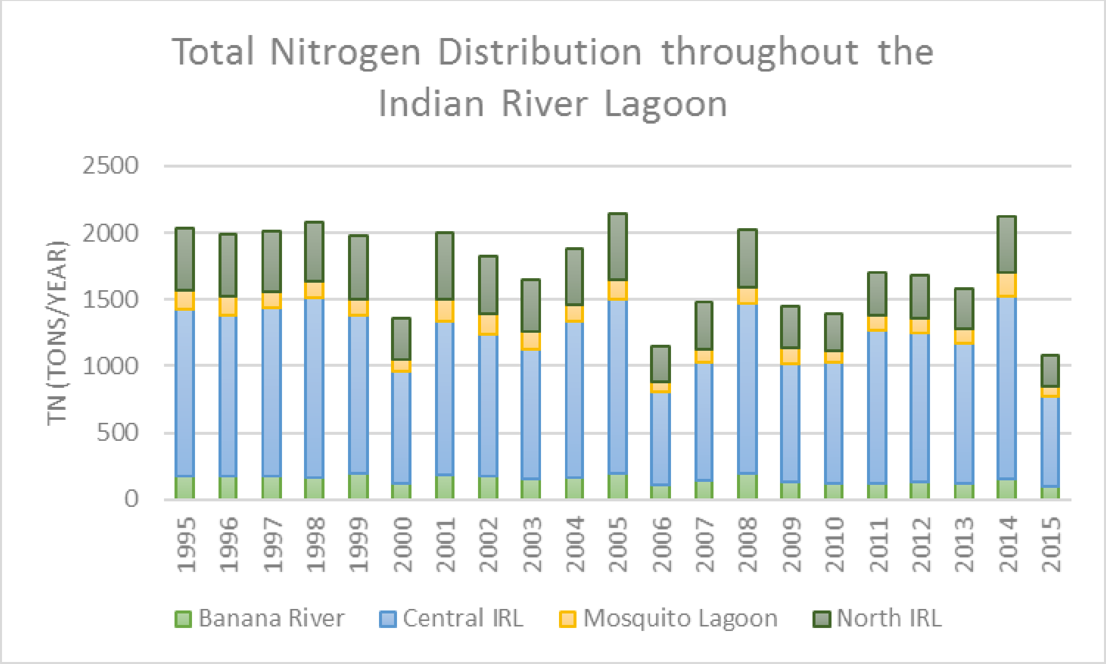

Figure 5. Inter-annual variation of the total predicted TN loadings for each of the IRL compartments

7.0 Update of Model Boundary Conditions

7.1 Water level boundary conditions

The original hydrodynamic calibration and other components of the overall modeling scheme were calibrated based on data collected in 1999 by the SJRWMD. As part of the quality control procedures for the Hydrologic and Water Quality Model (Zarillo, 2017) comparisons were made between measured water level data and model water levels. In the time period after about 2000, the ocean water level boundary conditions of the model are 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. We know from observations that non-tidal sea levels are coherent at regional spatial scales as seen in Figure 6, which shows tidal and filtered non-tidal water level records from Trident Pier and from measured data at Sebastian Inlet 65 km to the south. The non-tidal records differ by not more than 5 cm. Thus, model water level boundary conditions for the IRL in the post 2000 period can be set by combining the non-tidal (low frequency) sea level record with a tidal water level time series predicted from harmonic constituents.

To demonstrate this method Figure 7 compares the 2015 water levels predicted at the entrance of Sebastian Inlet with measured data from the same period. Also shown are the non-tidal and tidal components that were combined to form the synthetic sea level record. The root mean square error (RMSE) between the measured and synthetic records is about 0.02 m, which when compared to the range of measured data is about a 1.2% error. Thus, for periods of time when the water level record at Sebastian Inlet is incomplete, a synthetic record can be applied with confidence.

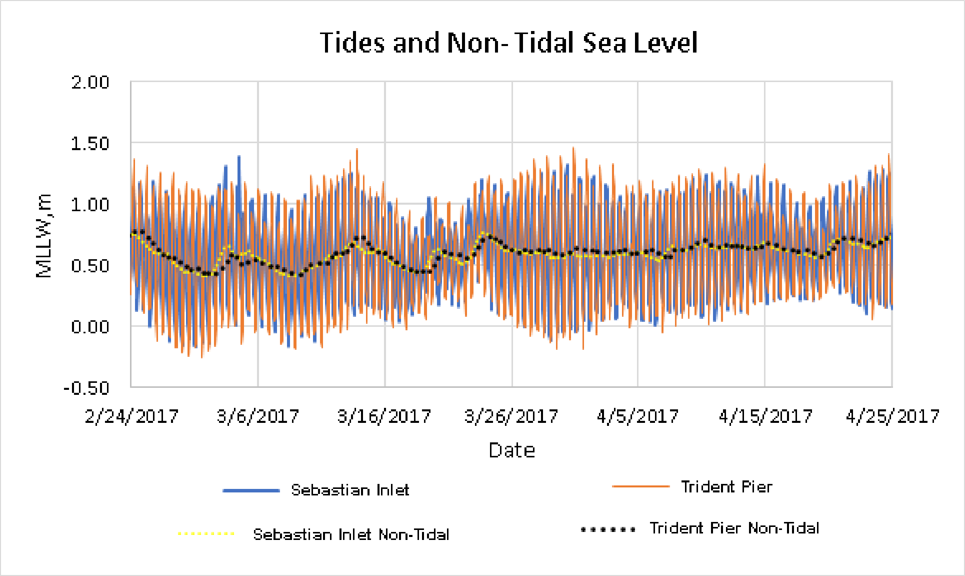

Figure 6. Measured tidal and non-tidal water level records from NOAA Station 8721604 (Trident Pier) and Sebastian Inlet

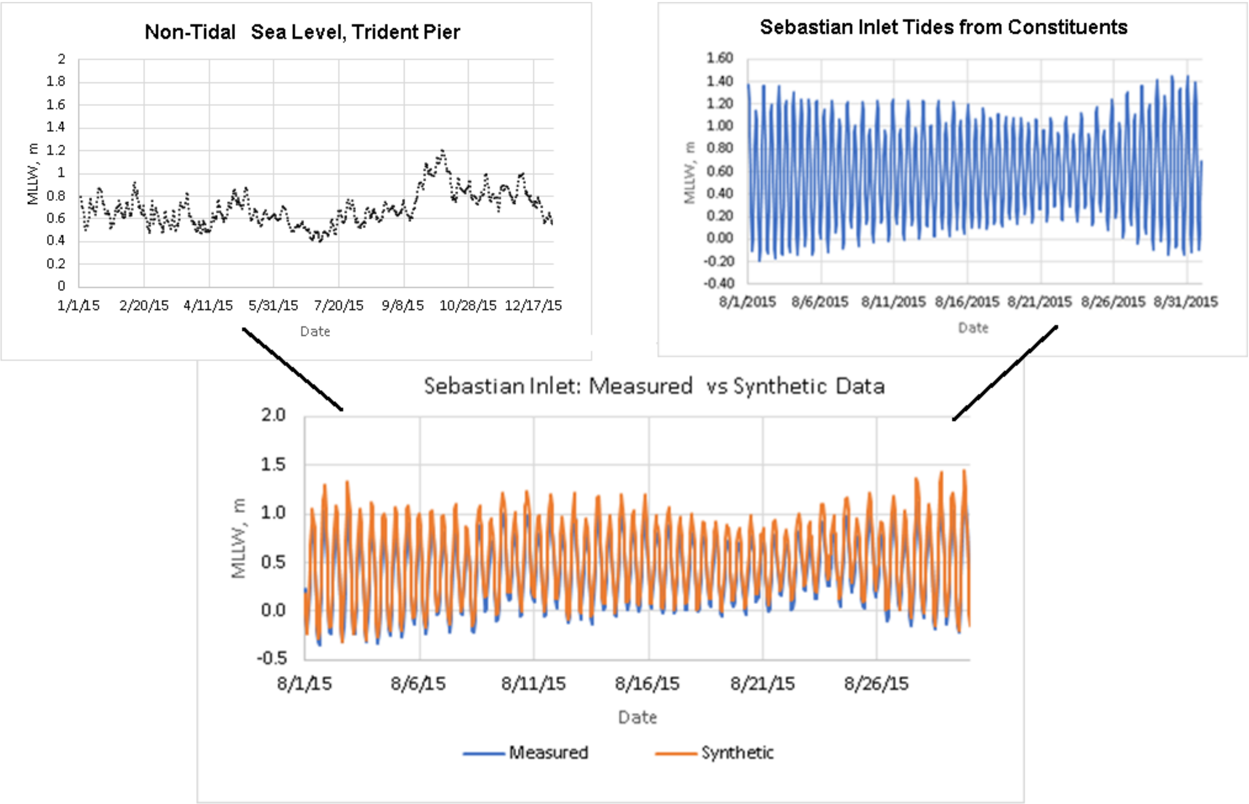

Figure 7. Comparison of mesured and synthetic water level records at Sebastian Inlet. Synthetic records are assembled from tidal harmonic constuents and the non-tidal water level record from Trident Pier.

7.2 Refinement of wind velocity inputs to the hydrodynamic model

Since large portions of the Indian River Lagoon have limited tidal forcing, wind stress can be one of the major factors that force circulation at synoptic time and spatial scales of passing weather systems. Thus, it is important to consider the validly of wind inputs to the model. The recently completed Subtask 7 of the overall muck project entitled “Wind and microclimate analysis for improved site characterization in support of environmental flow modeling” considers the details of wind microclimate along the Indian River Lagoon (Lazarus, 2017). This research applied statistical characterization of measured wind field derived from LIDAR profiling at several key locations including three National Weather Service ASOS stations. Based on the analysis of these data, one of the final products of this research is a set of statistically improved wind time series that can be directly applied to the EFDC hydrodynamic model. These time series will replace the measured time series that are now applied over six subdomains within the hydrodynamic model computational grid. The synthetic wind time series will improve the overall performance of the EFDC/HEM3D model within the IRL. In the upcoming year 3 project, comparison will be made between model results based on the original wind time series and model results based on the adjusted time series.

8.0 Update of Water Quality Model Calibration

Initial calibration results of the EFDC/HEMD model were reported in the Year 1 final modeling report. The timeframe of model calibration was 1999 due to the limitations of measured ocean water level boundary conditions beyond 1999. Given the success of the methodology to extend ocean boundary conditions into 2015 described in Section 5.4, another set of comparisons between measured and modeled water quality constituents was completed. Since the comparisons are made without further adjustments to the model, the model-data comparisons can be classified as model validation with respect to the original calibration. Model performance was compared with measured water quality data at SJRWMD monitoring station IRL123 located about 4 km north of Turkey Creek entrance (Figure 8). Model predicted values of dissolved ammonium in the water column within the Turkey Creek Basin are also compared with measured values reported by Trefry et al, 2016a.

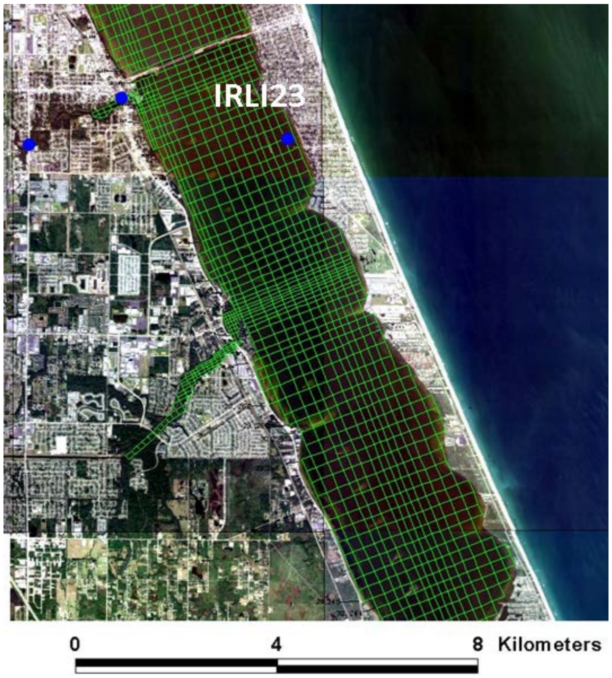

Figure 8. Location of SJRWMD monitoring station IRLI23 4 km north of Turkey Creek entrance

Figure 9 compares measured and predicted dissolved ammonium values at monitoring station IRLI23. The time period is from mid- 2014 to the end of 2015. Water depths at this location are about 1.5 to 2 m depending on seasonal variations in coastal sea levels. The predicted time series of ammonium is shown for all five layers of the model. According to information provided by the SJRWMD ((http://webapub.sjrwmd.com/agws10/edqt/) most of the data were collected from a depth of 0.5 m, along with an occasional second measurement from a depth of between 1.5 and 2 m. The predicted time series shows higher concentrations of ammonium in the lowers layer of the model, which represents the lowest 20% of the water column.

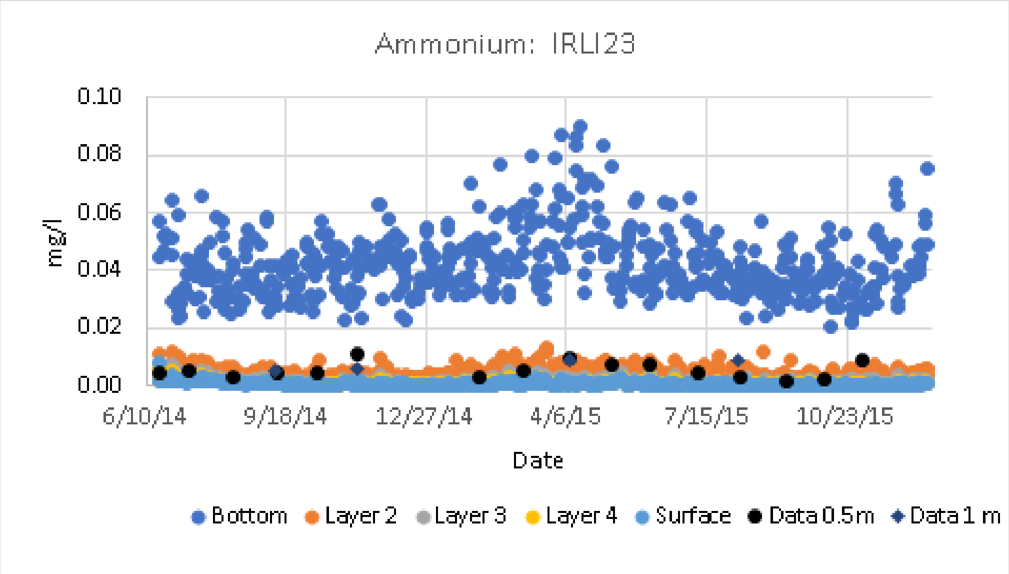

Figure 9. Comparison of measured and model ammonium concentrations of IRLI23

Figure 10 compares measured and predicted dissolved phosphorus values at monitoring station IRLI23. The predicted time series of phosphate is shown for all five layers of the model. The data were collected from a depth of 0.5 m. The model data show a trend of decreasing concentrations over the 2014-2015 interval. The measured data are at an approximate monthly interval that are too temporarily sparse to establish a trend. However, the highest measured values occur at the beginning of the time period. Predicted and measured values are well within the same order of magnitude and most of the measured values are within the range of the five model layers.

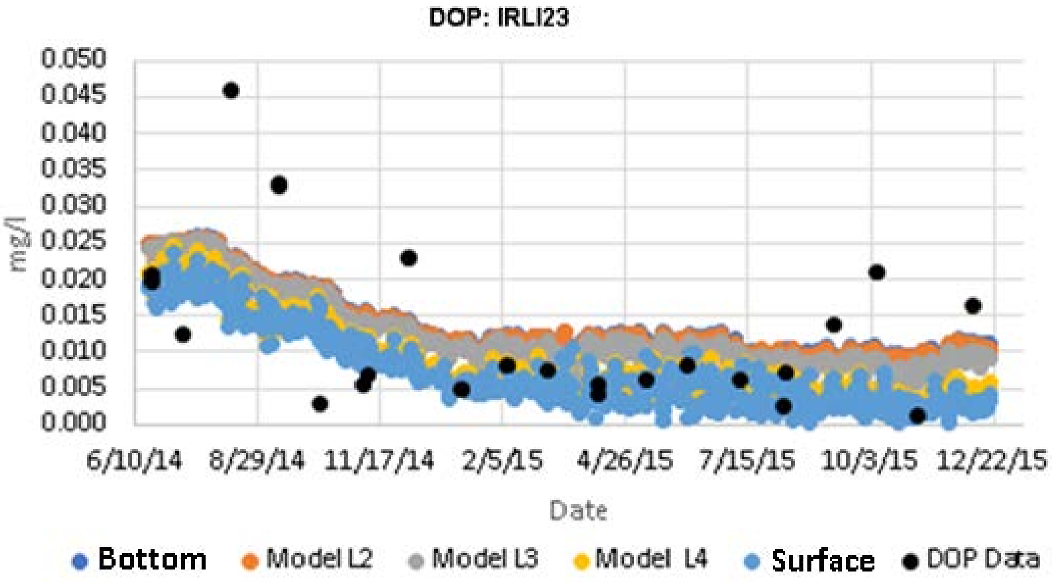

Figure 10. Comparison of measured and model dissolved organic phosphate concentrations at IRLI23.

Measured and predicted total nitrogen values shown in Figure 11 for IRLI23 are within a range of 0.45 and 1.0 mg/l for the 2014 to 2015-time interval. Predicted values are in a range of 0.6 to 0.7 mg/l, whereas measured values span a wider range and trend higher during the first six months of period covered by the model simulation. Later in the simulation the predicted and measured values of total nitrogen are closer. Given the complexity of the processes that contribute to total nitrogen values in the IRL and level of uncertainty of some components, the comparison between measured and model data is considered very good.

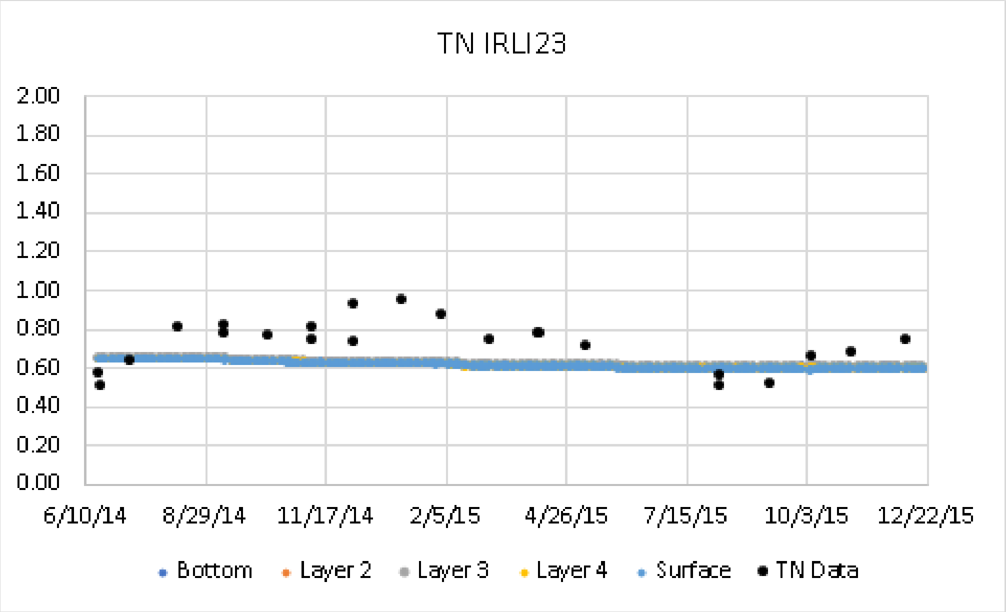

Figure 11. Comparison of measured and model total nitrogenconcentrations at IRLI23.

Measured and model dissolved oxygen values at IRLI23 are in good agreement as shown in Figure 12. As expected the lowest predicted values occur in the bottom layer of the model and the highest predicted values in the surface mode layer. Measured data were taken at a depth of 0.5m at station IRLI23 where the water depth seasonally varies from 1.5 to about 2 m. Thus, more of the measured values are closer to model values reported from the surface layer. An adjustment period during which predicted DO values are scattered over a wider range can be seen in the first month of the model simulation.

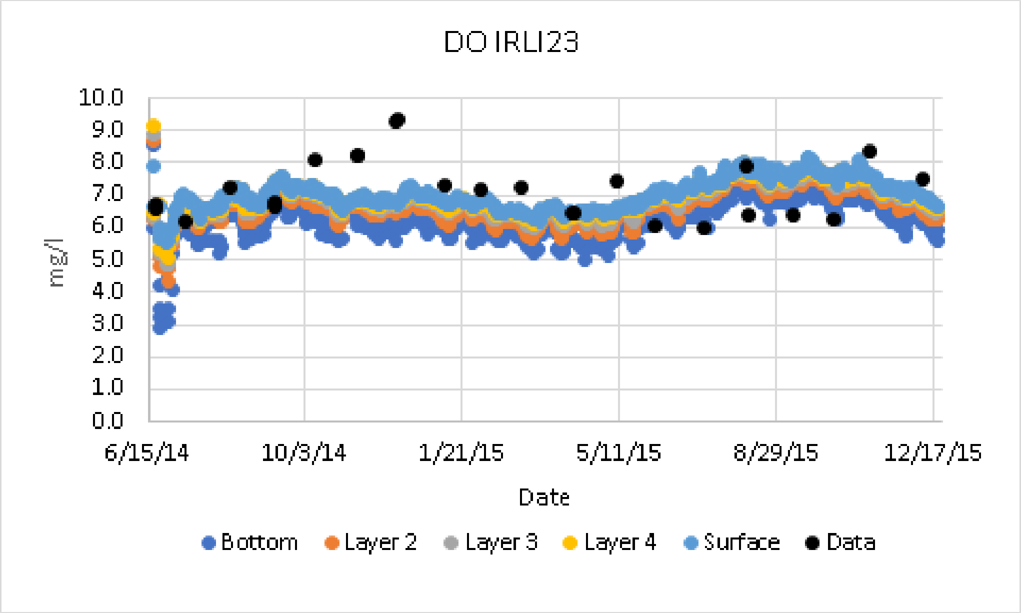

Figure 12. Comparison of measured and model dissolved oxygen concentrations at IRLI23.

9 Model Simulations

9.1 Water quality simulations

In order to verify the EFDC/HEM3D predictions within the Turkey Creek basin, model data from selected grid cells were compared with pre-dredge in-situ measurements. Figure 13 shows a predicted time series of ammonium concentration in the water column at the approximate position of Station TC3 shown in Figure 3.2 in Trefry et al, 2016b. The predicted time series extends from June 2014 through the end of 2015, overlapping time with some of the data shown by Trefry et al (2016b). Model values of ammonium are well within the range of data collected in 2015 by Trefry et al, 2016b (Figure 13). Similar to values predicted at IRLI23, concentrations of ammonium in the lowest model layer are distinctly higher than reported in the model layers above. Measured data are shown for depths of 0.5 and 0.9 m. Only a few measured data are available from 2015, but ammonium concentrations measured at the lower depth were usually greater than those collected at the shallower depth. To illustrate the influence of muck sediments from the Turkey creek basin on the adjacent IRL Figure 14 shows the predicted concentration of ammonium in the bottom, mid, and surface layers of the model averaged over September 16, 2014. The daily average includes model output over each 10-second time step during a 24-hour period (86400 steps). The September 16th example shows the influence of outflows from Turkey Creek on ammonium concentration in the surface model layer

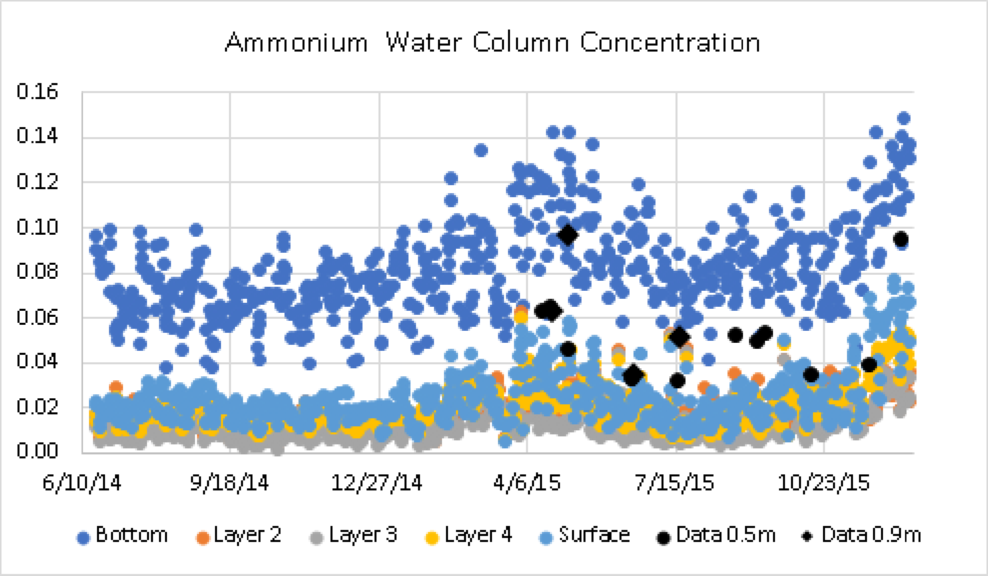

Figure 13. Model simulation of water column ammonium concentration under pre- dredge conditions. Model prediction is compared with measured pre-dredge data collected at Station TC 3 in the Turkey Creek Basin (Trefry et al., 2016) . The depths of 0.5m and 0.9m for measured data correspond to model layers 3 and 5, respectively. Total depth at this location is about 1 m.

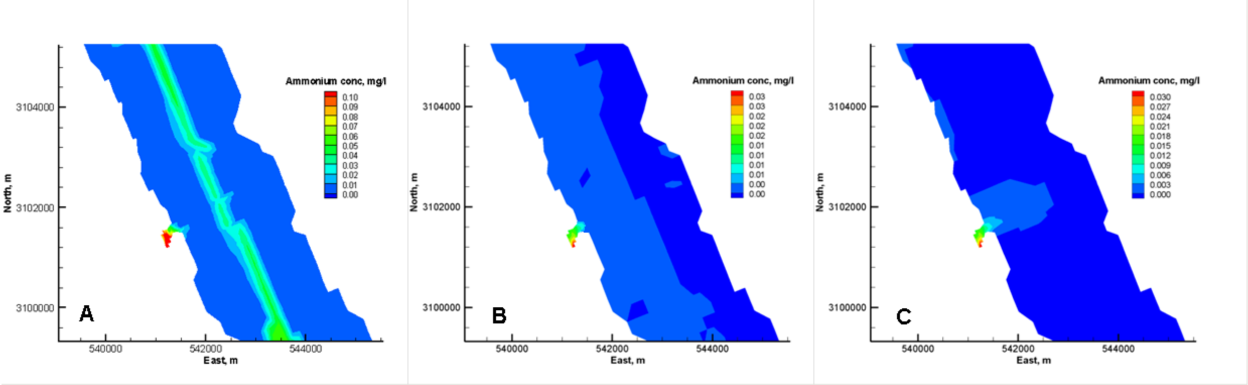

Figure 14. Predicted ammonium concentration in the bottom (A), middle (B) and surface model layers for the pre-dredge case of high ammonium flux from muck sediments.

For comparison Figure 15 shows the predicted daily average concentration for the same day based on a 90% reduction of the ammonium flux from muck sediments specified in the pre-dredge conditions shown in Figure 13. Comparison of Figures 15 and 13 shows that ammonium concentration in the Turkey Creek basin is markedly reduced in the hypothetical post dredge case. The predicted ammonium concentration though the 2014-15 interval did not exceed 0.02 mg/l and concentrations in the bottom model layer were not markedly different than the overlying model layers. In the main body of the IRL adjacent to the entrance of Turkey Creek, reductions in the concentration of ammonium in the mid and surface layers of the model are small but noticeable. Concentrations in the bottom layer of the model are similar due to the continued presence of muck sediment zone along the Intracoastal Waterway as shown in Figures 14 and 16.

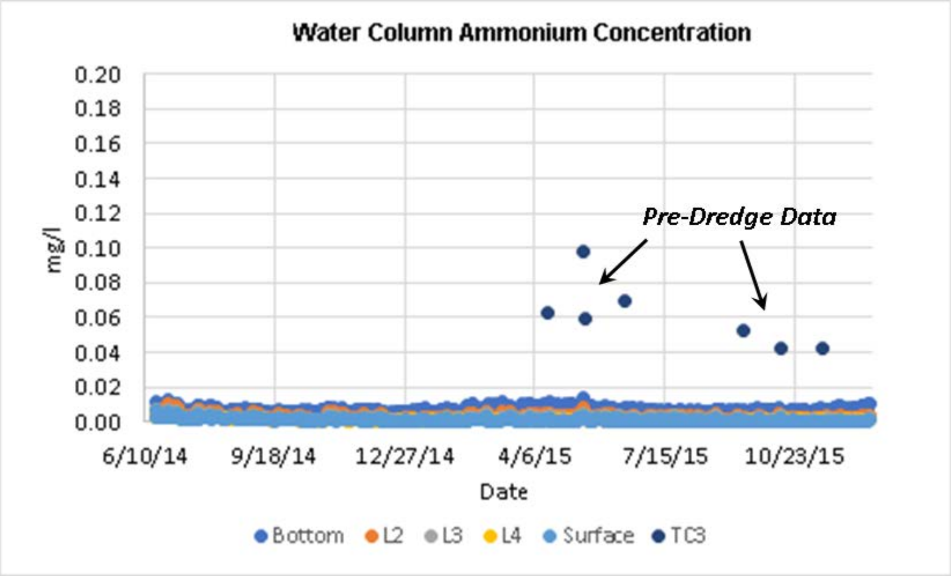

Figure 15. Predicted and adjacent observed (TC3 pre-dredge) concentration of ammonium (mg/l) under the assumption of post-dredge conditions under which 90% of ammonium flux to the water column is eliminated. The model cell location approximates Station TC3 from Trefry et al., 2016b.

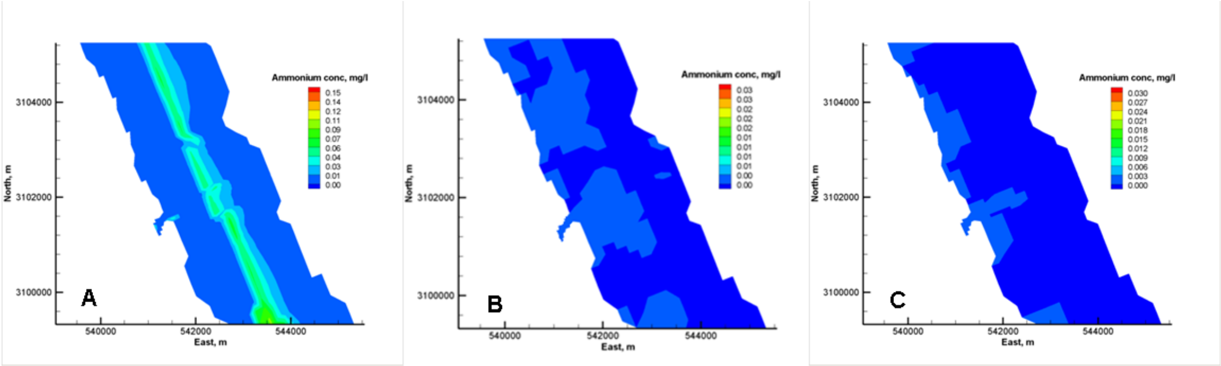

Figure 16. Predicted ammonium concentration in mg/l the bottom (A), middle (B) and surface model layers for the post-dredge case of a 90% reduction of ammonium flux from muck sediments.

Figure 17 shows the predicted daily average concentration on September 16, 2014 based on a 60% reduction of the ammonium flux from muck sediments specified in the pre-dredge conditions shown in Figure 12. Comparison of Figures 15 and 17 shows that ammonium concentration in the Turkey Creek basin is reduced in this hypothetical post-dredge case, but still has a notably higher concentration in the bottom model layer compared to the case of 90% reduction in ammonium flux from muck sediment. The predicted ammonium concentration though the 2014-15 interval did not exceed 0.02 mg/in the upper model layers. Model results in the main body of the IRL adjacent to the entrance of Turkey Creek as shown in Figure 18 were similar to hypothetical the case 90% ammonium. Again, high ammonium concentrations in the bottom layer within the Intracoastal Waterway are due to the continued presence of a muck sediment zone (Figures 14, 15, and 18)

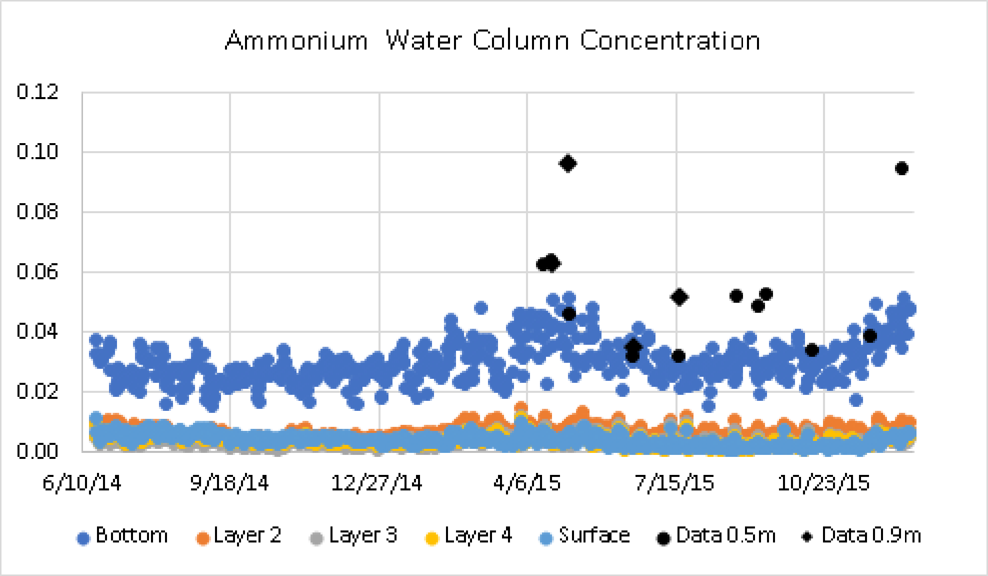

Figure 17. Model simulation of water column ammonium concentration after a hypothetical post-dredge 60% reduction in ammonium flux from muck sediments into the water column. The model prediction compared with measured pre-dredge data (black symbols) collected at Station TC 3 in the Turkey Creek Basin shows a decrease in ammonium concentration compared to pre-dredge data (black symbols).

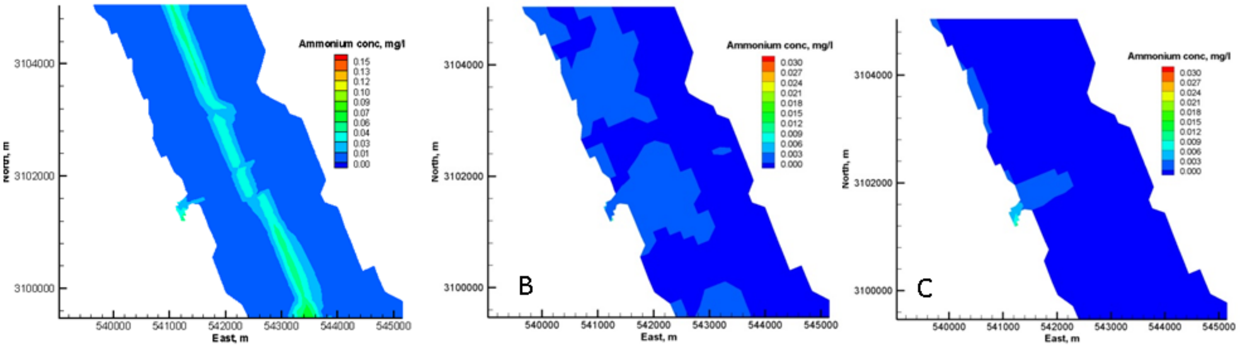

Figure 18. Predicted ammonium concentration in mg/l the bottom (A), middle (B) and surface model layers for the post-dredge case of a 60% reduction of ammonium flux from muck sediments.

9.2 Sediment Transport Simulations

Figure 19 is a comparison between measured and predicted total suspended sediment concentration in the water column in the lower Turkey Creek basin. The predicted time series extends from mid-2014 to late 2015 and shows sediment concentration time series from model layers 2, 3, 4 and the surface model layer. Each model layer is about 20 cm thick or 20% of the total depth at monitoring station TC3. Predicted data from the lower model layer (layer 1) is not shown since values episodically exceed 1000 mg/l. This is interpreted as a fluff layer or a layer of mobile hyper concentrations of flocculated sediment and organic material. The fluff layer has also been termed a fluidized mud layer in related muck work completed by Bostater (2016) who measured the directional flux of high concentrations of muck sediments in the Turkey Creek basin.

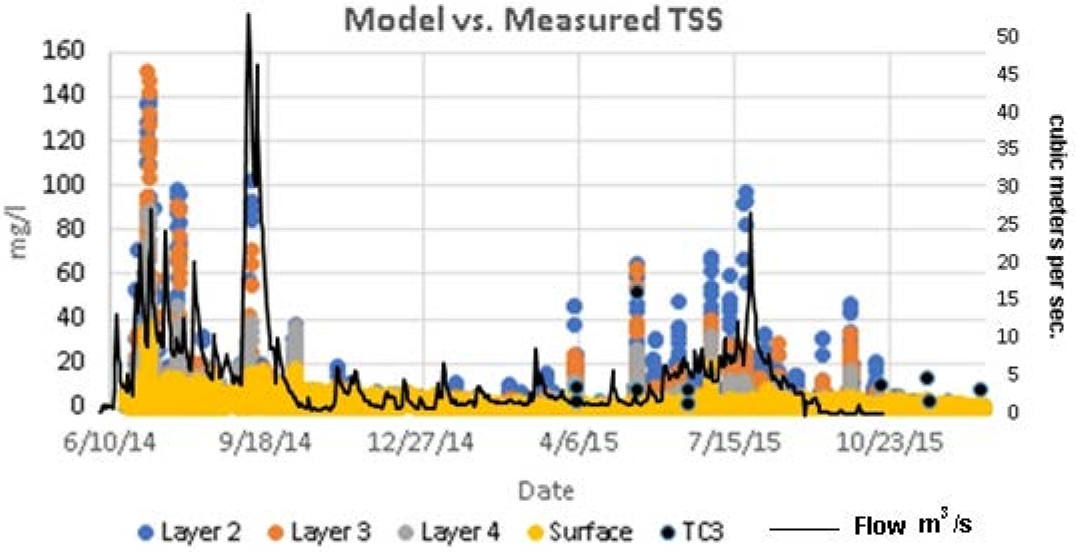

Figure 19. Comparison between measured and predicted TSS data in lower Turkey Creek basin. Measured data are from Trefry et al., 2016a and 2016b. Time series of freshwater flows from Turkey Creek Basin is shown for comparison to water column sediment concentrations.

Figure 20 shows predicted surface and bottom sediment concentrations at the entrance of Turkey Creek on October 12, 2014. Surface suspended sediment concentration in Turkey Creek basin is low but shows some influence in the surface water layer of the main body of the IRL to the east. This is likely due to east-directed suspended sediment transport in outflows from Turkey Creek, which are specified in the model from USGS discharge records. On this particular day combined outflows from Turkey Creek were about 1 m^3/s Overall, predicted sediment concentration in the bottom layer of the model is low, except within the Turkey Creek basin where predicted values are up to 200 mg/l. Zones of higher bottom layer suspended sediment concentration are also predicted along the east side of the IRL. These are likely to be generated by wind and wave stirring of fine grained sediment in very shallow water within the model. Wind conditions on October 12, 2014 were variable from northwest to northeast directions at about 2 to 3 m/s. The higher sediment concentration values in the Turkey Creek basin do not show direct influence beyond the entrance of the basin except in the surface layer of the model. This is due to stratified flow in Turkey Creek and the absence of strong flows in the lower model layers. An ongoing effort in the modeling project is to extend the predicted mass of sediment in the model layers to prediction of net deposition and topographic change over time. This requires iterative model runs to find a realistic balance between settling rates of cohesive sediment and rates of erosion. A long term run of the model will then be used to predict the rate of re-accumulation of fine grained muck sediments in the Turkey Creek basin.

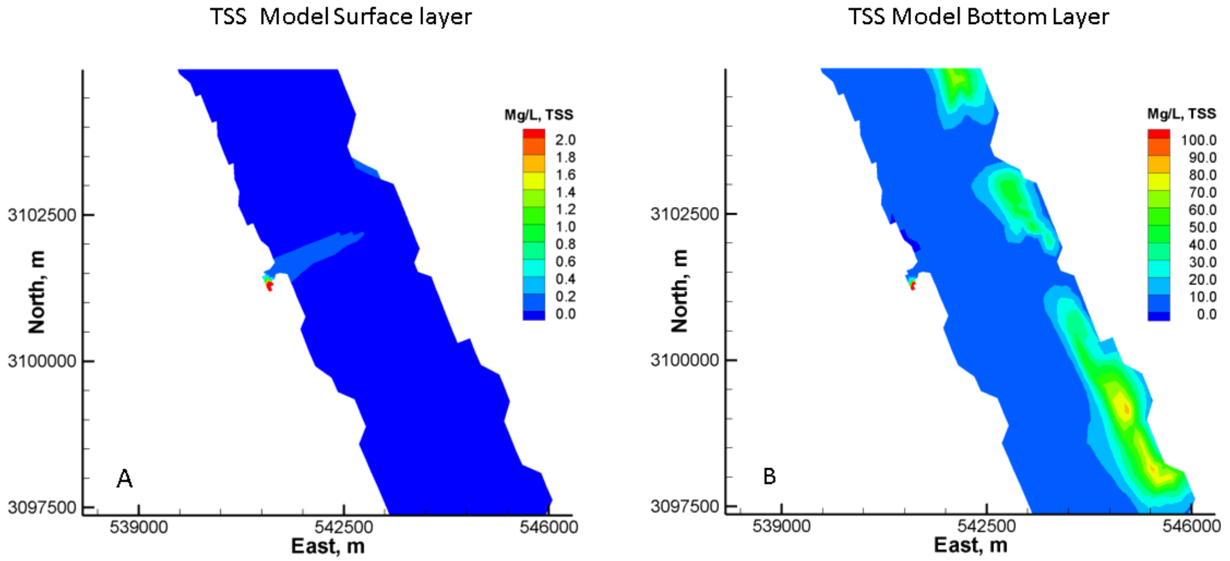

Figure 20. Predicted daily average suspended sediment concentration in the surface (A) and bottom (B) model layers, October 12, 2014.

10.0 Conclusions

This project integrates water quality and hydrologic, and hydrodynamic process data into the model of the Indian River Lagoon for long-term calibrated and validated predictions of water quality. The overall goal is to combine model simulations with measured data to assess the impact of muck dredging on local and regional water quality. The modeling platforms introduced in the Year 1 report include the EFDC/HEM3D coupled hydrodynamic and water quality models, which is supported by the SWIL watershed model. Physical boundary conditions for model hydrodynamics are largely supported by data collected by the SJRWMD as part of an ongoing monitoring program to characterize the Indian River Lagoon from an ecological and water quality perspective. These data are also applied to the model calibration and validation process. In year 2 of the project, the modeling period of the coupled watershed, hydrodynamic, and water quality models was extended to 2015. Since the original model calibration included time periods from the late 1990s and the early 2000s, additional model calibration checks were required to assure model performance in accordance with the quality assurance plan established for the project. This was particularly important since the water level time series applied to model computational cells at the ocean boundaries is derived from a combination of tidal harmonic constituents and non-tidal water level records.

Calibration checks for a time interval from 2014 to the end of 2015 showed that the modeling scheme can be validated for essential hydrodynamic and water quality constituents. A comparison of the synthetic water level time series from non-tidal sea level records and tides from harmonic constituents with measured water level data shows a match having only about a 1% error. This allows the model to be applied to time periods where ocean boundary data are not available and potentially applied into the distant future. Likewise, the comparisons made for several water quality constituents show good agreement between measured and model data within the 2014-15-time interval.

Based on the verification of model performance, predictions from hypothetical reductions of ammonium flux from muck sediments in the Turkey Creek basin indicate that removal of muck from the basin will locally reduce ammonium concentrations in the water column and improve water quality. Further, hypothetical reductions in nutrient flux from muck sediments in Turkey Creek Basin produced detectible reductions in water column ammonium concentrations in the IRL adjacent to the Turkey Creek.

Results of year 2 water quality modeling demonstrate that dredging of muck sediments throughout the IRL could be evaluated for local and regional water quality improvements. To date, the model scenarios and improvements in water quality have been hypothetical since the post dredge period in Turkey Creek continues to be monitored. In the upcoming third year of the project, further model verification will be based on a suite of measured data collected in the post-dredging period. Thus, if model performance continues to compare well to measured data, the model can be used to quantify the importance of muck dredging in the Turkey Creek basin to improvement of local to regional water quality. Further, the model could evaluate the importance or unimportance of dredging muck filled canals for improving open IRL water quality

Acknowledgements

We thank the Brevard County Natural Resources Management Department and its personnel for supporting this project Funding for this research was provided by the Florida legislature as part of DEP Grant Agreement No. S0714 – Brevard County Muck Dredging

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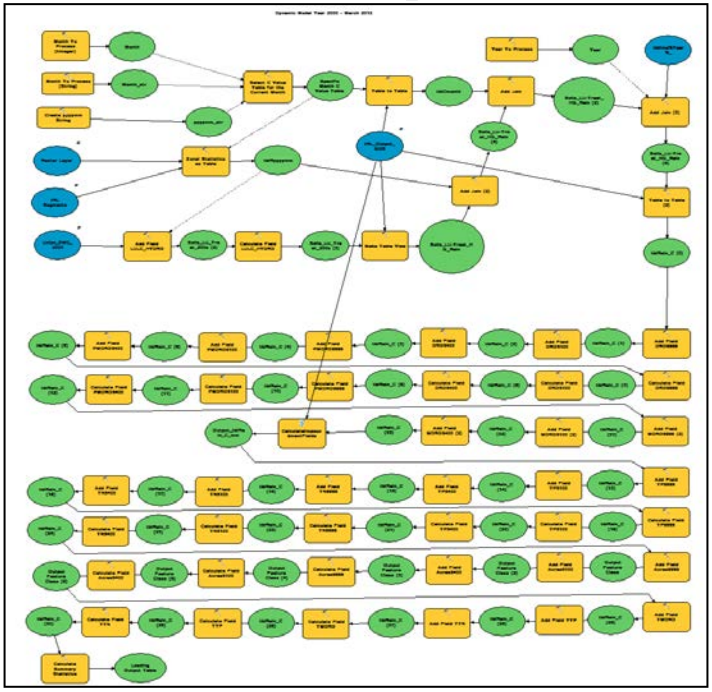
APPENDIX A

Spatial Watershed Iterative Loading (SWIL) 4.0 Model Update

Final Report



Developed by

Applied Ecology Inc.

Florida Institute of Technology

Natural Resources Management Office
Brevard County

April 30, 2018

A1. Background and Purpose of the model

FDEP has identified the Indian River Lagoon and Banana River Lagoon as impaired waterbodies due to nutrient over-enrichment. In March 2009, FDEP issued TMDLs for the IRL and BRL requiring reductions of TN and TP in stormwater runoff by 21% to 69% across the Lagoon (Gao 2009). The TMDL was established on the basis of a relationship between nutrient loading and seagrass depth limits. Nutrient loading estimates were calculated using the Pollution Load Screening Model (PLSM), originally developed for smaller areas within the IRL (Bergman and Donnangelo 1995, 1996a, 1996b, 1998), and later expanded to the entire IRL drainage by SJRWMD to represent loads for the year 2000 (Adkins et al. 2004). Seagrass depth limits were developed by SJRWMD from a 1943 to 2001 series of photo-interpreted seagrass coverages.

Through an Interlocal Agreement and a Joint Participation Agreement, all MS4 permittees within the Brevard County portion of the IRL (17 entities) partnered to fund a Study Team to update and refine the 2000 PLSM model and associated TMDLs for the IRL. After the TMDL was established, additional data were collected enabling the Study Team to re-visit the TMDL and address pertinent questions that have arisen regarding pollutant loading and seagrass relationships. The Spatial Watershed Iterative Loading (SWIL) model was developed as part of this study to incorporate more available data, more recent conditions, and more temporally fine datasets. SWIL is a custom ESRI ArcGIS toolset, originally designed to provide a continuous monthly simulation of runoff (surface and baseflows) over a 16-year period, yielding a more robust representation of pollutant loadings and freshwater volumes in the IRL.

The SWIL model has been updated since the initial version was developed in 2012 (SWIL 1.0). By July 2014, SWIL 2.0 was released focusing on addressing initial FDEP comments, improving the ease of execution and reducing the overall processing time. SWIL 3.0, released in April 2015, focused on improving model calibration to the measured available gage data, which included a change in the methodology to derive baseflow volumes and loads. SWIL 3.0 also incorporated the newly released evapotranspiration (ET) raster datasets, which were updated using the newly improved Mu et al's ET algorithm (2011).

The latest version of SWIL, version 4.0, was developed in support of the 3D Numerical Modeling effort for the Indian River Lagoon and Banana River led by Florida Institute of Technology. This version required three major changes: 1) expansion of the model extent to provide nutrient loadings from Ponce Inlet to Fort Pierce 2) temporal expansion from 2011 through August 2015, and 3) converting the model from 2 to 3 land use/treatment time steps.

The goal of SWIL is to provide a GIS-based model that can be adaptive to changes in input and can batch complex processes through several months or years on demand. SWIL aims to provide both spatially and temporally fine-scale volumes and loads (TP and TN), allowing input data to be related to water quality parameters. Since temporal and spatial differences in water quality appear essential in understanding the Indian River Lagoon and Banana River Lagoon system, an input watershed model that provides data at the same fine scales is critical to the TMDL process.

The portability of the model (a toolset within ArcGIS) and flexibility of its design are key features of the SWIL.

The specific goal of SWIL 4.0 is to provide monthly estimated total nitrogen and phosphorus loads from January 1995- through August 2015 for 70 subsegments of the Lagoon watershed, so these can be integrated in Florida Tech's 3D numeric nutrient model.

A2. Methodology Updates of the SWIL Model Version 4

This section describes the main methodological changes taking place in SWIL 4.0. The changes include model process changes and input data changes. In terms of major processing changes, SWIL 4.0 had to be recoded to allow three sets of input data to be used throughout a time period. In the original SWIL 3.0 model, only two modeling periods (1995-2002 and 2003-2010) are captured by using the years 2000 and 2004 land use and treatment input. For SWIL 4.0, three modeling periods are used: the same original 1995-2002 (year 2000 land use/treatments), 2003-2010 (year 2004 land use/treatments), and the newly added 2011-2015 (year 2015 land use/treatments). Most of the other processing changes were minor and were required to allow expansion of the model spatial extent and a longer time series to be modeled.

Modifications to Model Extend Boundaries

The previous model boundary was extended to include a larger watershed area. Previously only the North Indian River Lagoon, the Banana River, and the Central Indian River Lagoon (up to the end of Indian River County) were included in the modeling extent (Figure 21).

For SWIL 4.0, the model boundary increased by eight basins, including six in the Mosquito Lagoon (ML-1100, ML-1200, ML-1300, ML-1400, ML-1500, and ML-1600) and two in St. Lucie County (IRL-Basin 1 and IRL-NorthCoastal). The model boundary layer expanded from 649,528 acres to 768,112 acres, which is an increase of 118,584 acres, or an 18.3% increase in area.

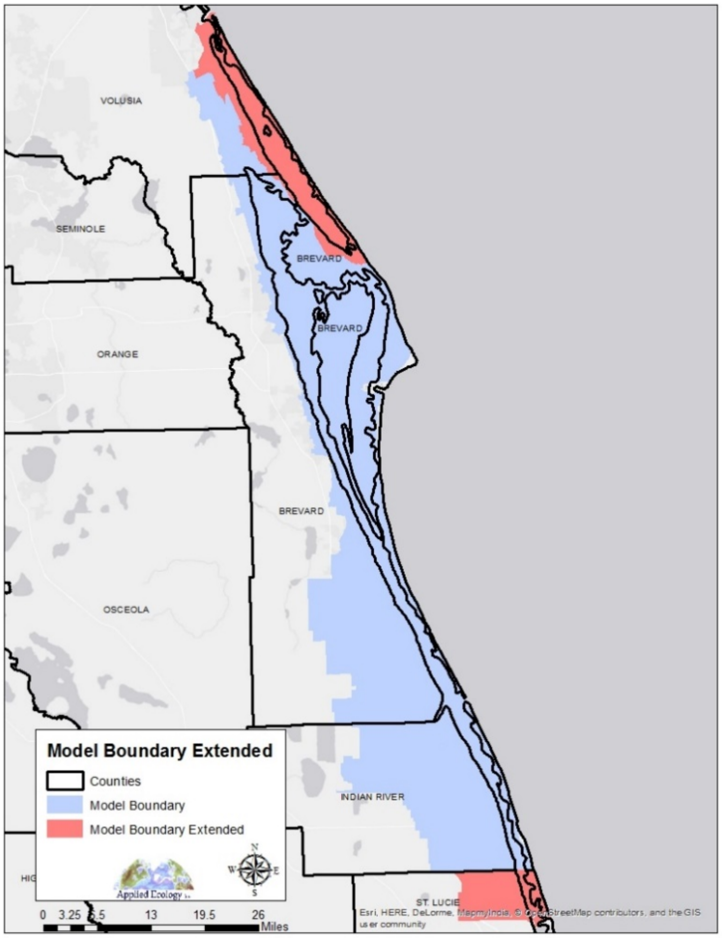


Figure 21. Comparison of the model boundary and the extended model boundary

Land Use Land Cover

The land use land cover layers were temporally extended from January 2011 through August 2015, for a total modeling time frame of January 1995 through August 2015. In addition to the 2000 and 2004 land use land cover, a 2015 land use land cover layer (applicable to modeled months between January 2011 and August 2015) was created. The methodology used to develop the 2015 land use land cover layer was consistent with those previously used to develop the 2000 and 2004 land use layers (Listopad 2015). These included the following steps:

- Property Appraiser (PA) records, spatial files and associated lookup tables or databases were obtained from Brevard, Indian River, Volusia, and St. Lucie Counties. Data from St. Lucie County was required due to the spatial expansion of the model area.
- Land use codes were converted to FLUCCS land use/land cover codes. The same conversion tables for Brevard County, Indian River, and Volusia counties were used, when possible. Conversion tables were modified to incorporate new land use codes were added since 2004. In addition, a new conversion table was developed for the St. Lucie County land use codes.

- Areas in the land use/land cover classified by the PA as urban (residential, commercial, industrial, and institutional) were used as top priority in this dataset.
- In natural areas within Brevard County, the Brevard County Natural Communities Inventory superseded any other information for the land use layer development when available.
- In areas outside of Brevard County without natural area inventories, the SJRWMD and SFWMD land use layers were used in non-urban areas. For the 2015 layer, the SJRWMD 2009 and SFWMD 2008-2009 land use/land cover layers were used.
- In addition, the 2000 and 2004 layers were modified to include the extended areas in St. Lucie County. For the 2000 layer, the SFWMD 1999 land use/land cover layer was used, and for the 2004 layer, the SFWMD 2004-2005 land use/land cover layer was used.
- Finally, a topology check was performed on each of the layers to ensure that there were no gaps or overlaps within the layer.

This methodology allowed the best datasets to be used and still produce a dataset that covers a large areal extent without gaps, a requirement to run the SWIL model. No aerial photointerpretation or ground validation was performed on the land use layers used in the SWIL model due to both budget and time constraints for such a large watershed.

A comparing of land uses between the three model years (2000, 2004, and 2015) for the entire modeling watershed is provided in Figure 22. To simplify this comparison all the land uses were grouped into 5 categories: agriculture, developed (urban), natural (upland and wetland), water (natural and retention ponds), and other (disturbed land, spoil islands, etc.). Over the entire watershed there has been a conversion of about 50,000 acres of agricultural and natural land use types to developed ones. The most significant increase in land use intensification appears to have taken place between 2004 and 2015, but some conversion is also present between 2000 and 2004.

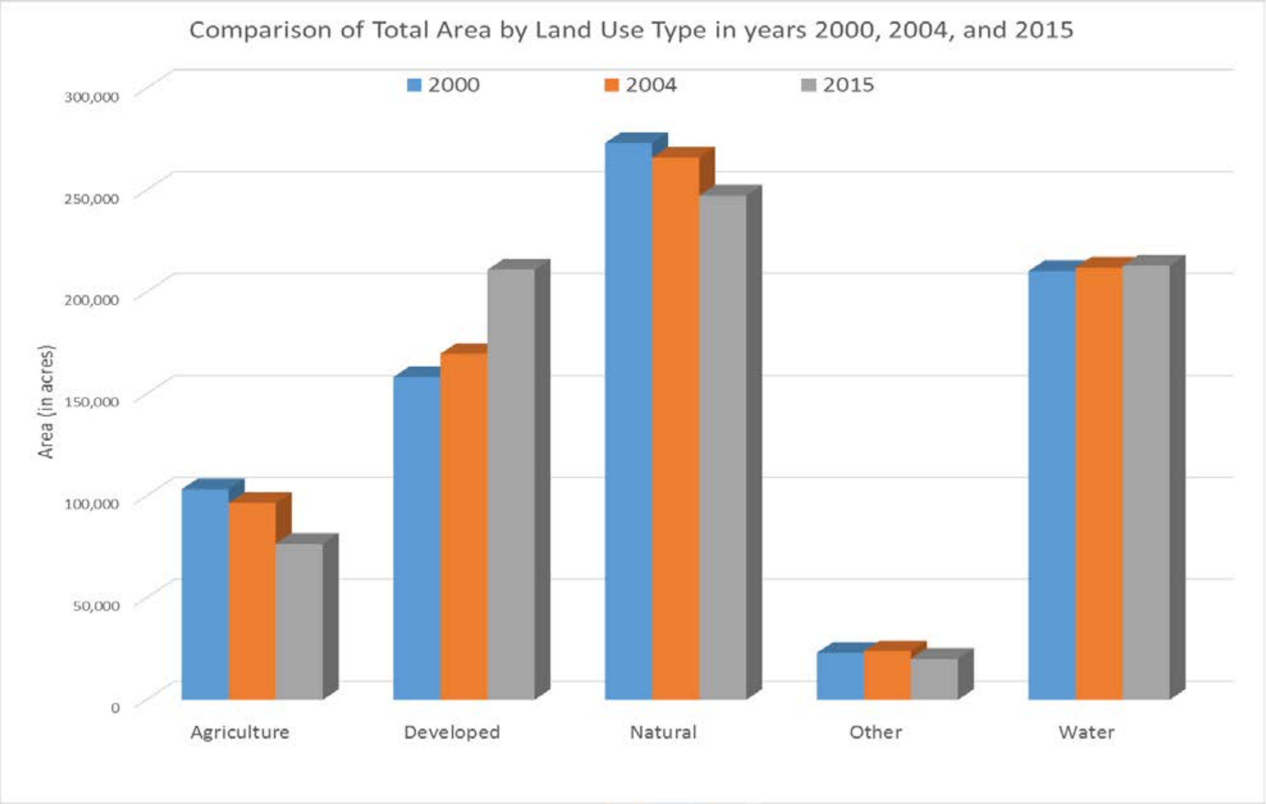


Figure 22. Comparison of Total Area (in acres) by broad land use for the years 2000, 2004, and 2015 for the entire IRL watershed area.

Nine basins appear to have the highest increases in developed land uses within the model extent, and these are centralized in two areas within the model area: south-central Brevard County and southern Indian River and northern St. Lucie counties (Figure 23). Three of the nine basins (IRL12-LW-b, IRL16-20, and IRL-Basin1) have large decreases in agricultural land uses (10-30% loss) that accompany the increases in developed land uses. The other 6 basins, however, appear to show conversions from natural (mostly upland) land uses to urban land uses.

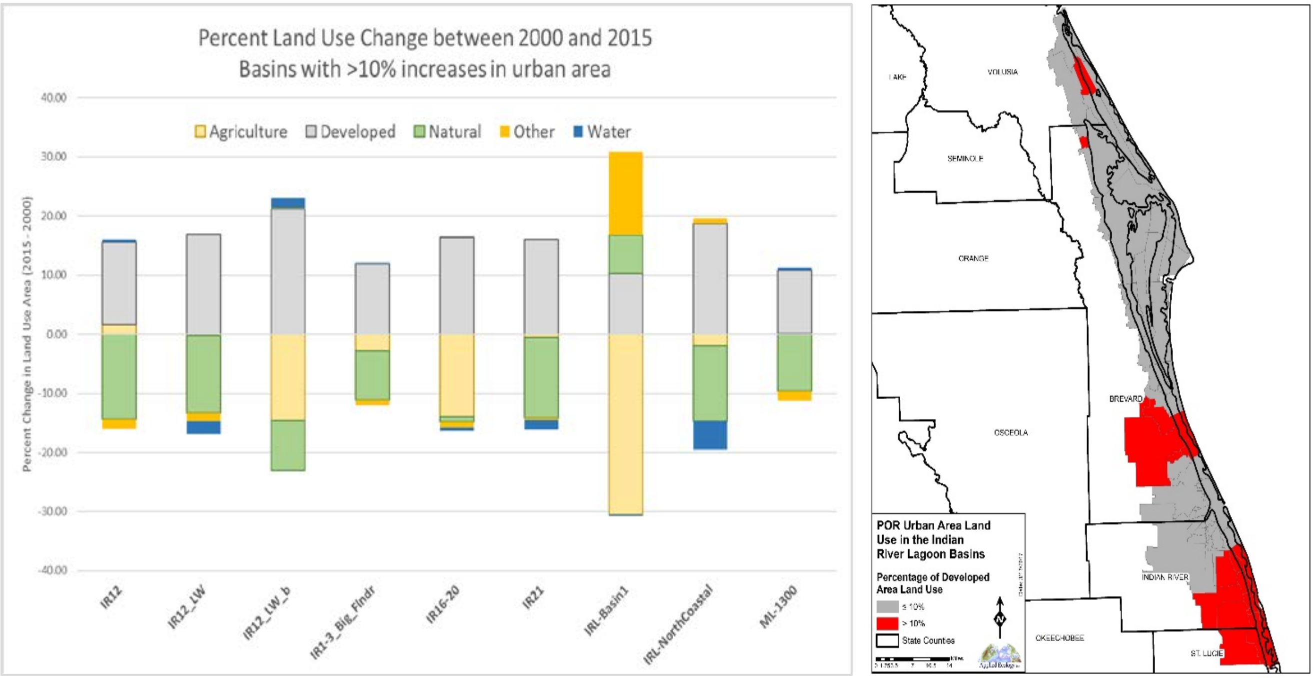


Figure 23. Distribution of the land use changes between 2000 and 2015 for the segments with greatest urbanization on throughout the POR.

Soil Classification

For every soil type classification, there is an associated infiltration characteristic called the hydrologic soil group (HSG) that is a key component in determining appropriate runoff coefficients “C”. Runoff coefficients are critical variables for the development of an accurate watershed loading model. Accordingly, significant effort was taken to obtain and analyze all available soil layers for the original three Counties. The most complete coverage was obtained from the NRCS (formerly the U.S. Soil Conservation Service) which had been extensively updated in 2010. Environmental Research and Design, Inc. (ERD) modified the 2010 NRCS soil layer to provide HSGs for all soils classified by NRCS as "U" or urban. Original HSGs, prior to having been urbanized, is necessary to attribute the correct runoff coefficient. ERD used spatial interpolation, as well as other methods, to fill in missing gaps in the HSG identification of the soil type.

After several comparisons between the 2010, 2012 and 2014 NRCS soil layers, Applied Ecology decided to use the original soils (2010 NRCS) and simply expand the coverage for the new model domain. This decision was based on the two reasons: 1) keep the consistency between the FDEP reviewed SWIL 3.0 model and SWIL 4.0 and 2) avoid calibration of the SWIL 4.0 model based on a potential need to update runoff coefficients with changes in soil types.

The SWIL 4.0 model used the original 2010 NRCS soil layer and expanded it to cover the additional eight basins to cover the new model boundary (Figure 21). Consistent with the previous model, spatial interpolation was used to fill in missing HSG classifications. Soil areas with an ambiguous soil types received a dual HSG classification (“A/D”, “B/D”, or “C/D”) where the first letter is indicative of drained or disturbed soils and the second is indicative of undrained or undisturbed soils. Upon further investigation, the more appropriate HSG was assigned through the combination of aerial imagery photointerpretation and FLUCCS codes provided by the water management districts. When the majority of a specific soil polygon resided within a FLUCCS code boundary indicative of disturbed or “non-natural condition” soil (e.g. residential, agriculture, commercial, etc.) it was classified as the better drained soil classification, often “A” or “B” soil types. In contrast to this, when a soil polygon with dual classification appeared to be natural (e.g. wetlands, forests, etc.), it was classified as the most poorly drained of the two classifications, typically a “D” code. When the FLUCCS code did not correspond with the latest aerial imagery, each soil area was photointerpreted to ensure the application of the correct classification. For example, typically wetland areas received a poorly drained soil classification based upon FLUCCS code as they are natural areas; however, some of these wetlands were altered enough through ditching and urban encroachment that the soil was assigned a more highly drained classification type.

As expected the soils in the Barrier island and near the ridges with higher elevations are the better drained soils ("A" soils), while the soils located on the western basins were dominated by A/D soils (in the north and central IRL basins) and C/D (southern IRL basins) (Figure 24).

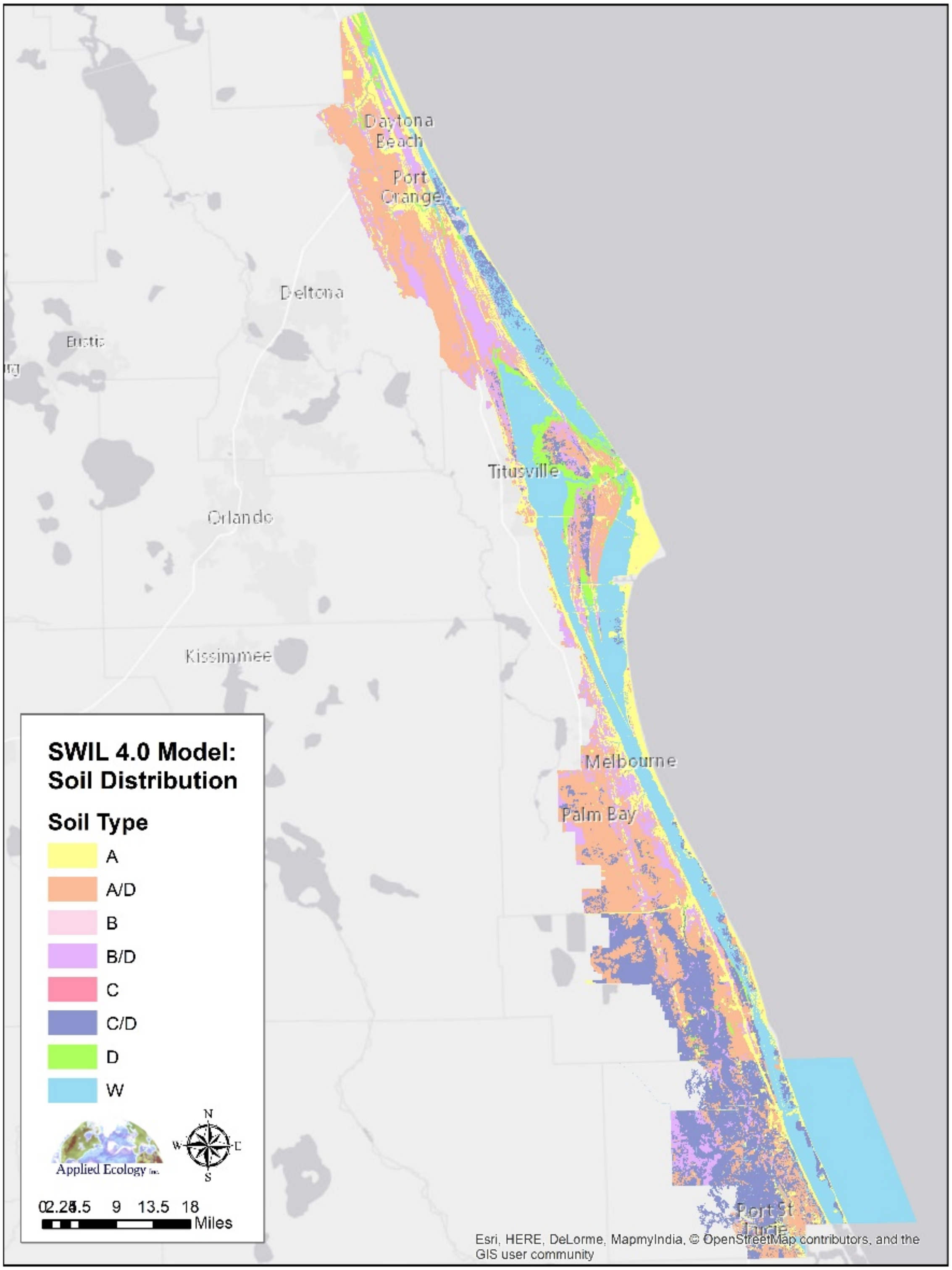


Figure 24. Distribution of soil types throughout the SWIL 4.0 modeled watershed.

The resulting soils were comprised predominantly of the A/D and C/D dual groups (27.25% and 17.07% respectively) (Figure 25). The least common soil types were C and B types of soil, which combined only represented less than 0.5% of all the model domain soils.

Table 3. Representative acres for each hydrologic soil group (HSG) throughout the SWIL 4.0 model

Hydrologic Soil Group	Acres
A	166,578
A/D	343,541
B	4,375
B/D	142,104
C	255
C/D	215,215
D	42,847
W	346,005

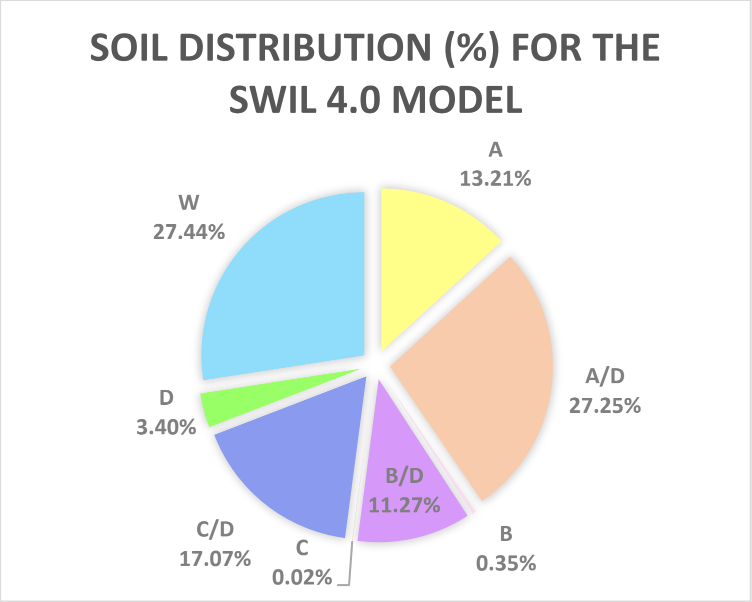


Figure 25. Distribution of the soil type for SWIL 4.0.

Treatment Coverages

Developed land with stormwater treatment systems has cleaner water leaving the site than developed land with no treatment system. Private subdivisions and commercial properties constructed after 1986 were required by the SJRWMD to treat their stormwater runoff as a condition of their ERP permit. In addition, Brevard County adopted stormwater treatment requirements and began permit review in 1978. For the SWIL model, a treatment layer with higher spatial accuracy and additional information (treatment type) was developed based on Property Appraiser datasets. For residential properties, a subdivision layer was built and the year of the first house built within it was assigned to each subdivision. We assumed that an approved site plan with constructed stormwater treatment must be in place by no later than the year that the first house was built within the permitted subdivision, and private residential subdivisions built after 1986 (1986-2000 for the 2000 treatment layer, 1986-2004 for the 2004 treatment layer, and 1986-2015 for the 2015 treatment layer) were considered treated. For non-residential individual parcels (commercial or industrial land uses) constructed after 1986, the year of construction was used to capture additional private development treatment data. All treatments delineated in AEI´s layers were assigned a type, either wet detention or dry retention ponds.

The treatment area was increased by eight basins to include six basins in the Mosquito Lagoon (ML-1100, ML-1200, ML-1300, ML-1400, ML-1500, and ML-1600) and two in St. Lucie county (IRL-Basin 1 and IRL- NorthCoastal). The year 2000 treatment layer increased by 2,507 acres (1,176 acres developed with dry treatments and 1,331 acres developed with wet treatments) and the year 2004 treatment layer increased by 3,107 acres (1,382 acres developed with dry treatments and 1,725 acres developed with wet treatments). The total acreage for the extended treatments is provided in Table 4. The year 2015 area of development with treatment was generated to be used with the 2015 land cover and included over 78,524 acres of treated developments and increase of over 73% of treatment area compared to the 2004 layer.

Table 4. The total, wet treatment, and dry treatment acreage of the 2000, 2004, and 2015 treatments for the extended model boundary.

Year	Total Acreage	Dry Treatment Acreage	Wet Treatment Acreage
2000	35,528	21,296	14,232
2004	45,399	26,365	19,034
2015	78,524	33,443	45,081

Impoundments

After the initial SWIL model had been developed and preliminary runs completed, it became clear that impoundments had to be taken into account in a more spatially and temporally accurate watershed loading model. For more information on how impoundments are incorporated in the SWIL model, please refer to the Methodology Report (Listopad 2015). Impoundment information was difficult to compile, but the Brevard County Natural Resources Management Office was able to delineate the spatial extent of all 206 impoundments within the study area, which cover a total of 40,977 acres. These impoundments are not only managed differently (permanently closed, permanently opened, or rotating between closed and opened for mosquito control or waterfowl management purposes), but some management regimes were updated or changed during the model timeframe. For SWIL 4.0, both Brevard County and the Merritt Island Wildlife Refuge were contacted to obtain an update on any management changes on the delineated impoundments from 2011-2015. No additional impoundment locations were added from SWIL 3.0 to 4.0 and only one impoundment, “Marsh Harbor” located in Merritt Island changed management regimes from closed to rotational. The overall impact of this one change is minimal at the watershed scale but could be important at the local scale.

Rainfall

In order to be able to expand SWIL 4.0 through 2015, additional monthly rainfall rasters had to be developed from 2011-2015. Each monthly rainfall raster was expanded to cover the entire model extent and was constructed by interpolating best available rainfall gage data distributed across the IRL area. For more details on methodology, please review ERD´s report (Harper and Baker 2015).

The number of station locations was increased to accommodate for the expansion of the model boundary. A total of 93 rainfall stations, including SJRWMD, SFWMD, and NOAA sites, were used to develop the monthly raster datasets. Not all the stations had available data for every month, so the number of stations used to interpolate the rainfall for the watershed varied monthly. The mean annual rainfall for each of the modeled watersheds is provided in Figure 26 and the entire model domain annual and dry season averages are included in Figure 27. Since the model was expanded until August 2015 only, the annual totals for the last year could not be accurately represented in these graphs and were not included in any period-of-record means.

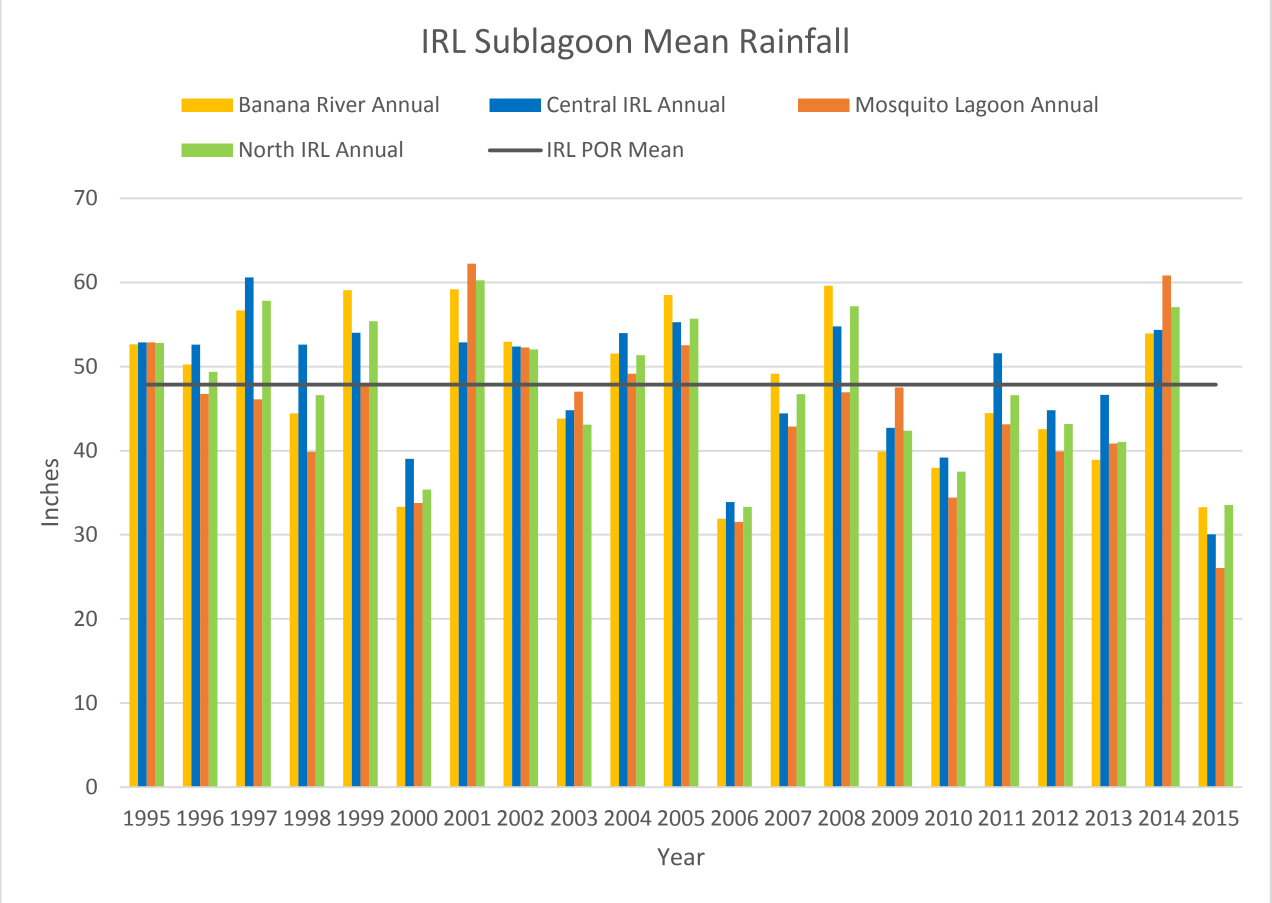


Figure 26. Mean POR annual rainfall in inches per sublagoon area. 2015 is a partial year (January - August 2015) and wasn't used in the IRL POR mean.

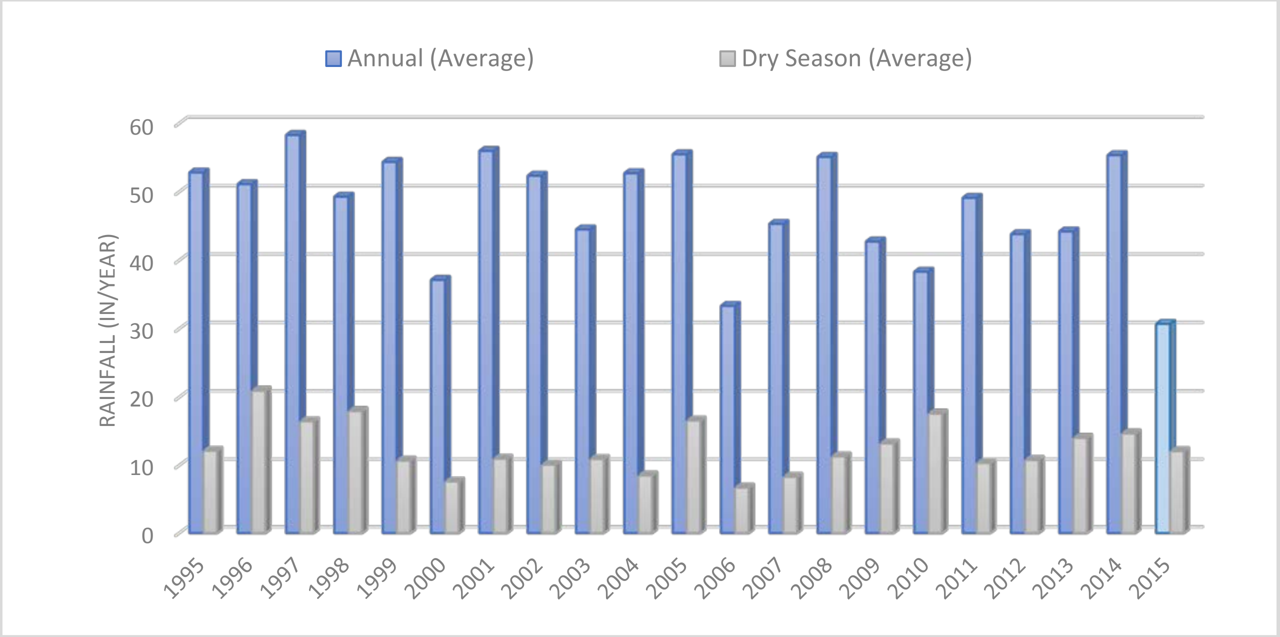


Figure 27.. Mean POR annual and 5-month (Jan-May) rainfall for the modeled IRL watershed. 2015 is a partial year (January - August 2015) and shown in light blue.

Evapotranspiration

Evapotranspiration was included in SWIL 4.0 as monthly raster datasets and was derived from the MODIS (MOD 16) satellite data, more specifically the evapotranspiration product developed by NASA. The resolution of this evapotranspiration product is 1 km and the temporal resolution is one day (daily data). ERD used the NASA source data to create mean daily raster values for every month of the period of interest. In 2014, after SWIL 1.0 and 2.0 had been completed, AEI became aware of changes in the algorithm used by the University of Montana to process MODIS data and produce ET datasets. The newly improved SWIL 3.0 also incorporated the newly released ET raster datasets, which were updated using the newly improved Mu et al’s ET algorithm (2011). For more details, please review ERD´s report (Harper and Baker 2015) and Applied Ecology’s Methodology Report (Listopad 2015).

The SWIL 4.0 model used the same methodology as previous SWIL models to obtain the evapotranspiration layers. Unfortunately, the MOD 16 data product is currently only available between the years of 2000-2014. For the remaining years, monthly POR ET mean monthly? rasters (mean of the 15 years of data for each month?) were used as evapotranspiration input to SWIL 4.0. All ET raster datasets, including those previously generated for SWIL 3.0 had to be expanded for the SWIL 4.0 model domain.

A3. SWIL 4.0 Model Results

A brief summary of the SWIL 4.0 watershed loading estimates are provided in this section.

Figure 28 presents the total annual predicted volume of water reaching the IRL from the entire modeled watershed. The Central Indian River Lagoon (CIRL) watershed, being the largest in total area, provides the largest total volumes, followed by the Banana River (BR), North Indian River Lagoon (NIRL), and finally the Mosquito Lagoon (ML). In general, the volumes are higher in above average rainfall years (1997, 1998, 2001, 2005, 2008, and 2014) and lowest in the driest years (2000 and 2006). However, spatial differences in the rainfall do have an impact in the overall volume predicted to be generated by the model. For example, even though the overall mean watershed rainfall is higher in 1997 than in 1998 (Figure 27), the total volumes are slightly higher in 1998 (Figure 28). Another trend, even more subtle, is that the predicted volumes are higher after 2010 for similar rainfall to pre-2010. For example, even though the rainfall is similar in both 2008 and 2014, the predicted volumes are higher in 2014. This might be directly linked to higher runoff coefficients in urban land uses, which have been increasing rapidly in some basins of the Lagoon watershed after 2010 (2015 land use was implemented in the model run in 2011-2015).

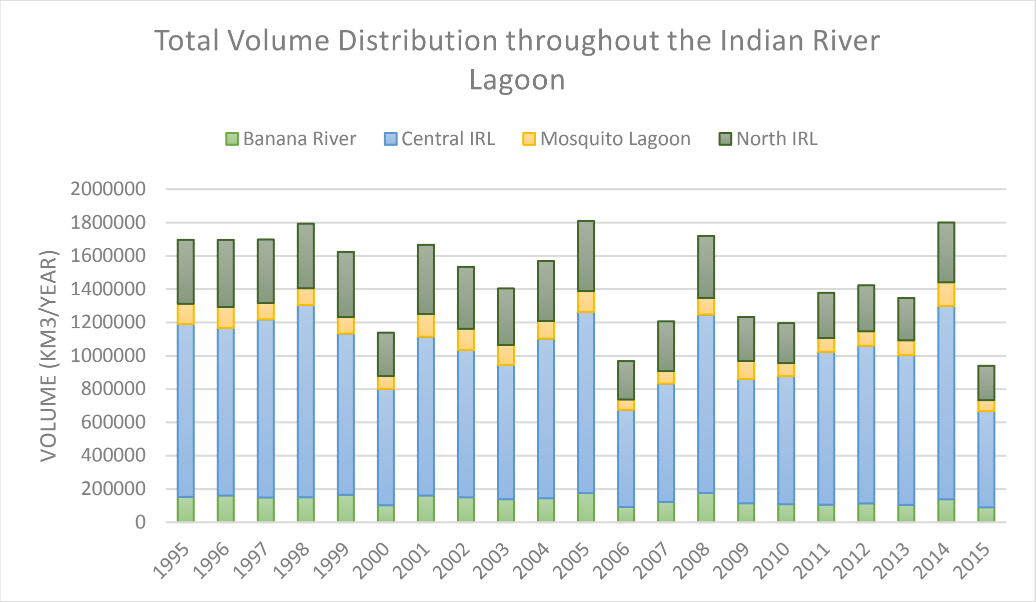


Figure 28. Interannual variation of the total predicted volumes for each of the IRL Sublagoons. Volumes for 2015 are underestimates since they only include 8 months of data.

Across the Lagoon watershed, the distribution of runoff volumes is dominated by baseflow volumes making up ca. 60-70% of the total volumes. The baseflow contribution is higher for the BR and CIRL watersheds and lowest for NIRL and especially the ML (Figure 29). The interannual variation is similar for most of the Sublagoons, with consistently lowest annual volumes estimated for both 2000 and 2006. However, the patterns are slightly different for the highest volume producing years depending on the Lagoon: while 2005 and 2008 produce the highest volumes for the BR, 2014 is the highest volume year for both the CIRL and ML, and both 2001 and 2005 are equally high-volume years for the NIRL. Other average rainfall years do yield different results, with the ML being the most distinctive of all four modeled Sublagoons.

The pattern for the total nitrogen and phosphorus loadings are very similar to the predicted volumes for the entire watershed, both in terms of watershed interannual distribution (Figures 30 and 31) and distribution of baseflow/direct runoff. Years that are predicted to have lowest loading of nutrients into the lagoon are 2000 and 2006, with highest loadings in 1998, 2005, and 2014. Even though the contribution of baseflow loadings to the total Lagoon loadings is still significant, it makes up only 50-60% of the total estimated loadings, depending on the nutrient and specific Sublagoon (Figures 32 and 33).

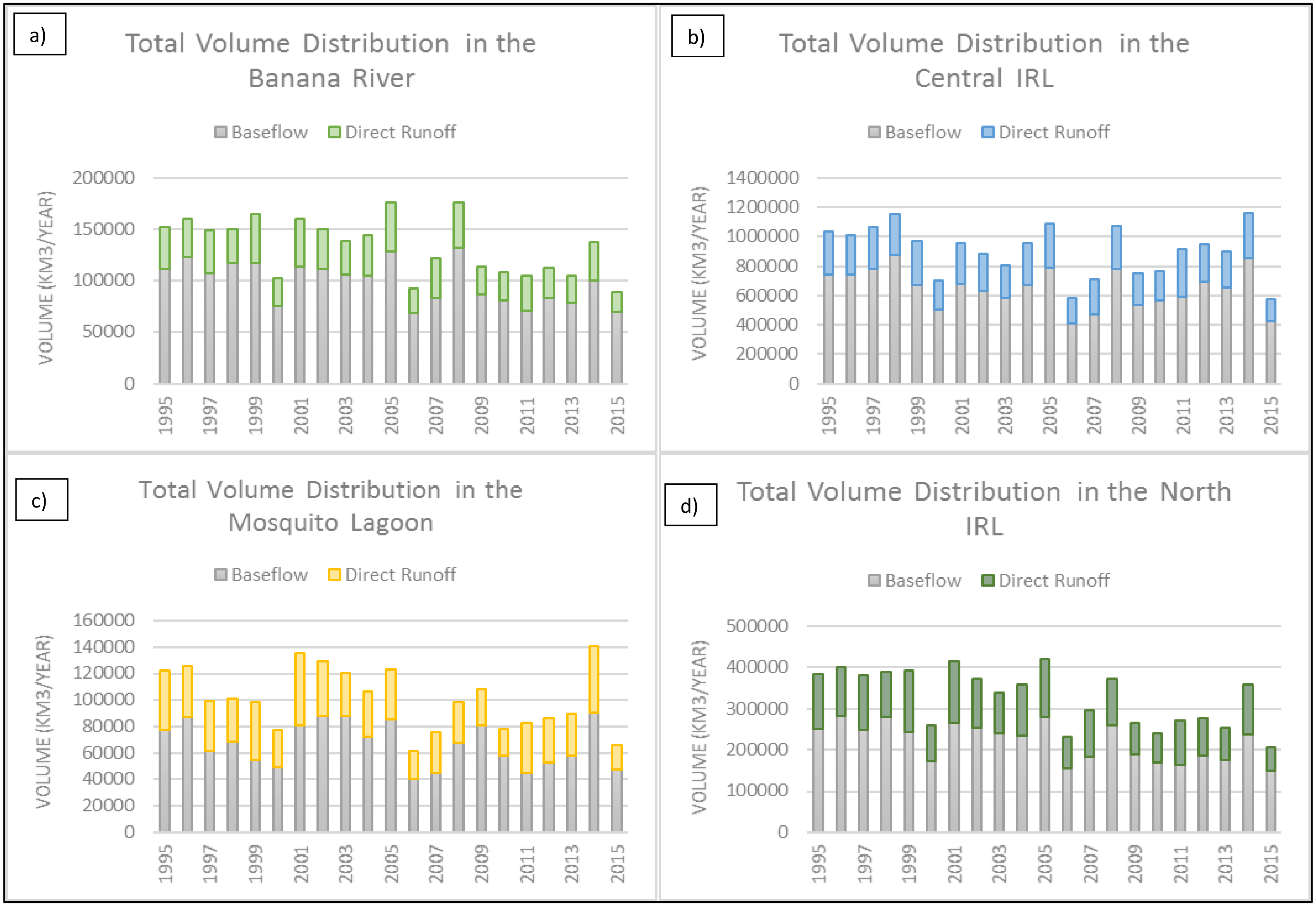


Figure 29. Interannual variation of the baseflow and runoff predicted volumes for each of the IRL Sublagoons: a) Banana River, b) Central IRL, c) Mosquito Lagoon d) North IRL. Volumes for 2015 are underestimated since they only include 8 months of data.

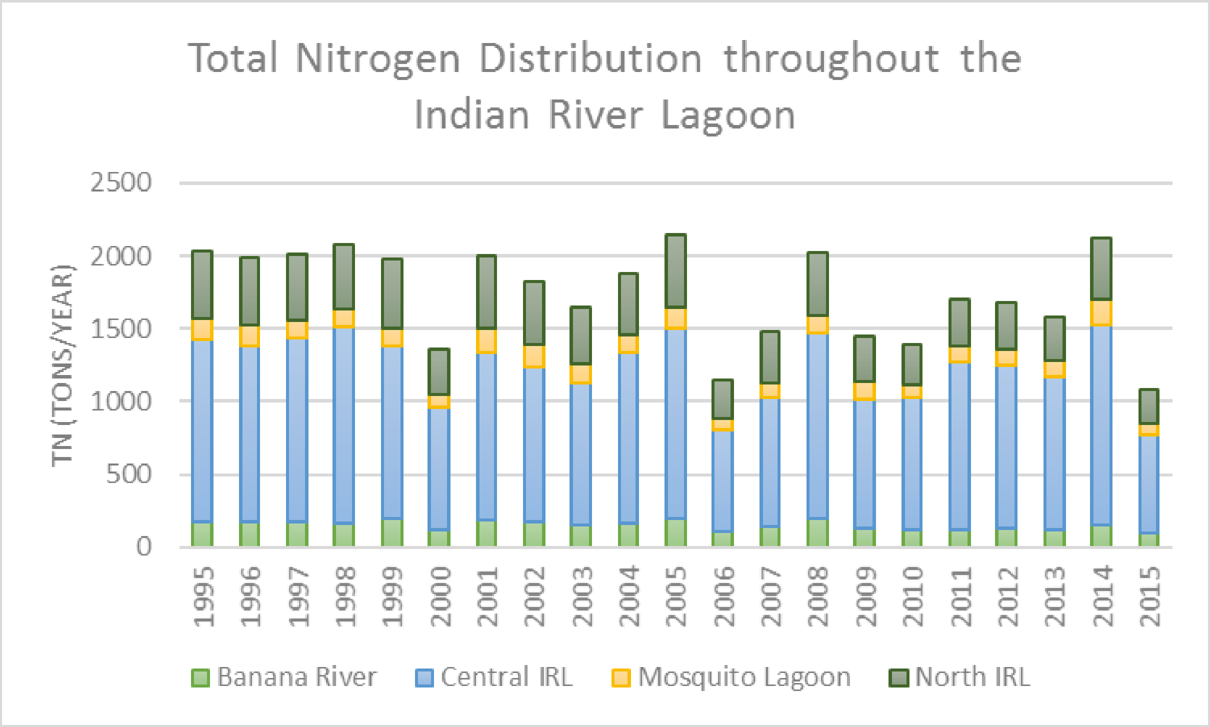


Figure 30. Interannual variation of the total predicted TN loadings for each of the IRL Sublagoons. Volumes for 2015 are underestimates since they only include 8 months of data.

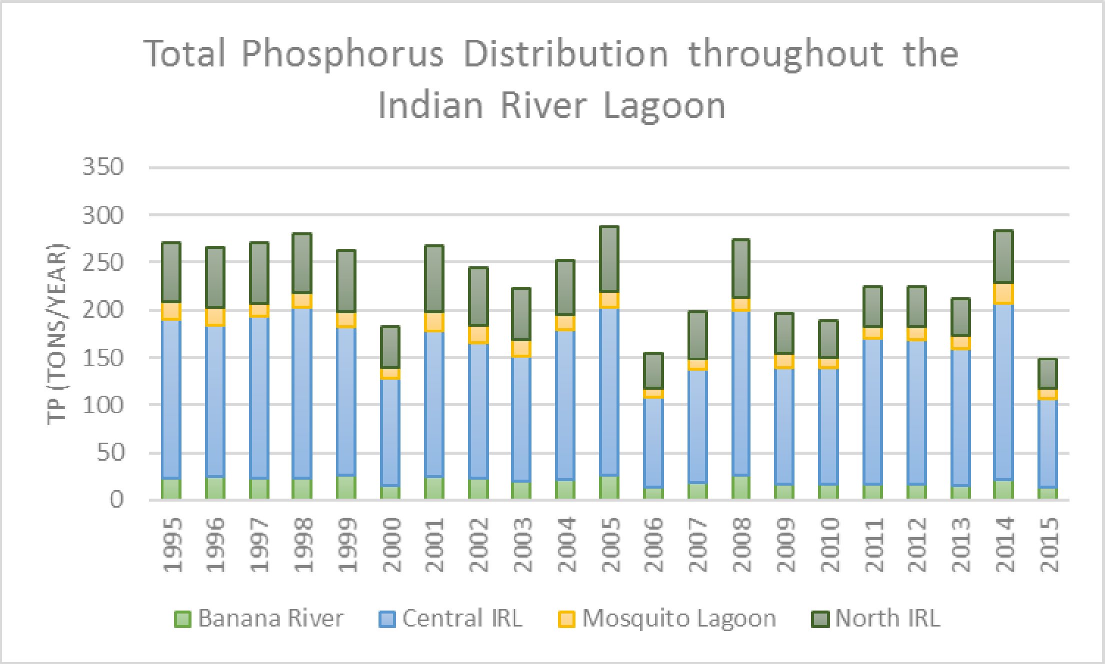


Figure 31. Interannual variation of the total predicted TP loadings for each of the IRL Sublagoons. Volumes for 2015 are underestimates since they only include 8 months of data.

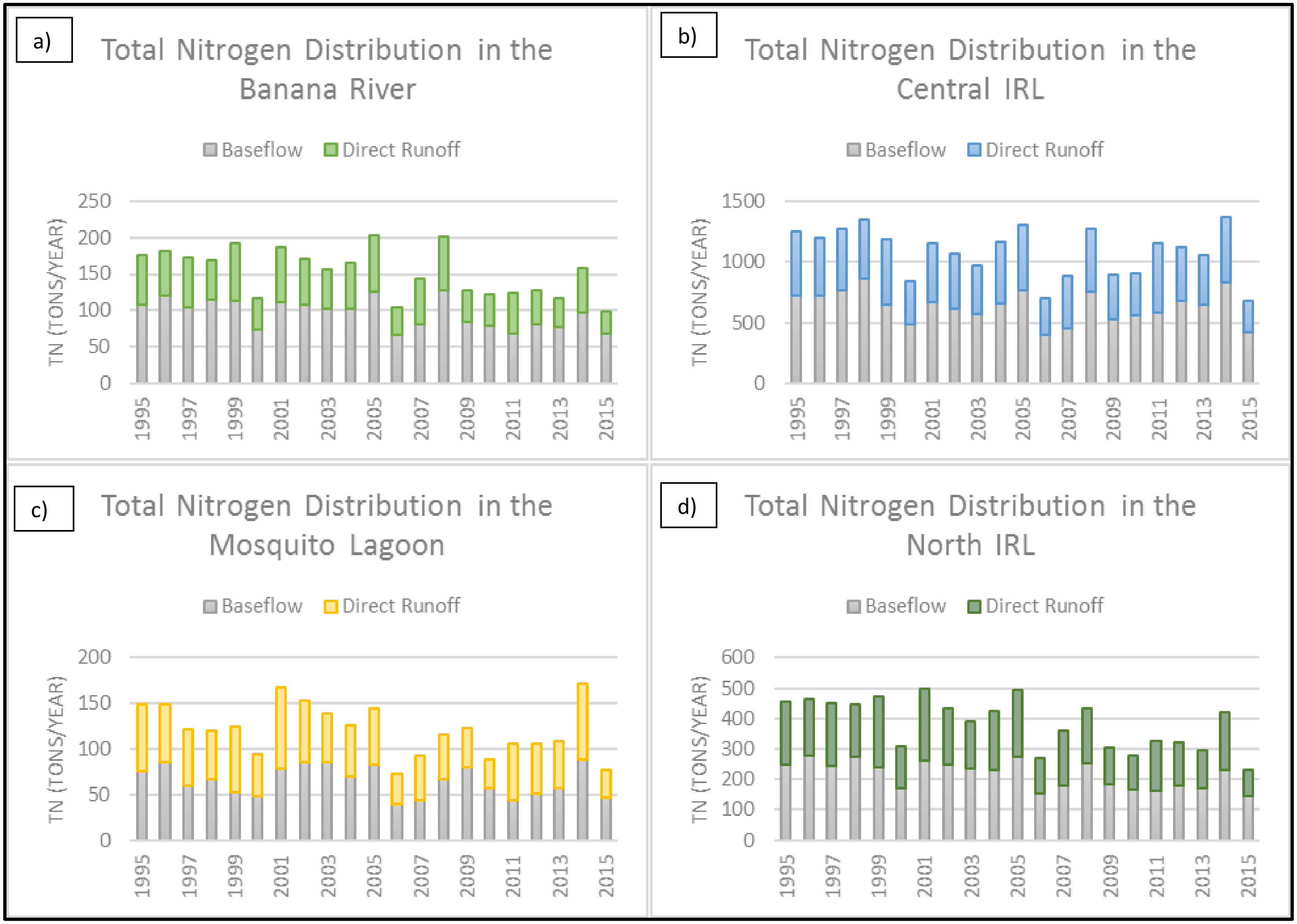


Figure 32. Interannual variation of the baseflow and runoff predicted TN loads for each of the IRL Sublagoons: a) Banana River, b) Central IRL, c) Mosquito Lagoon d) North IRL. Loadings for 2015 are underestimated since they only include 8 months of data.

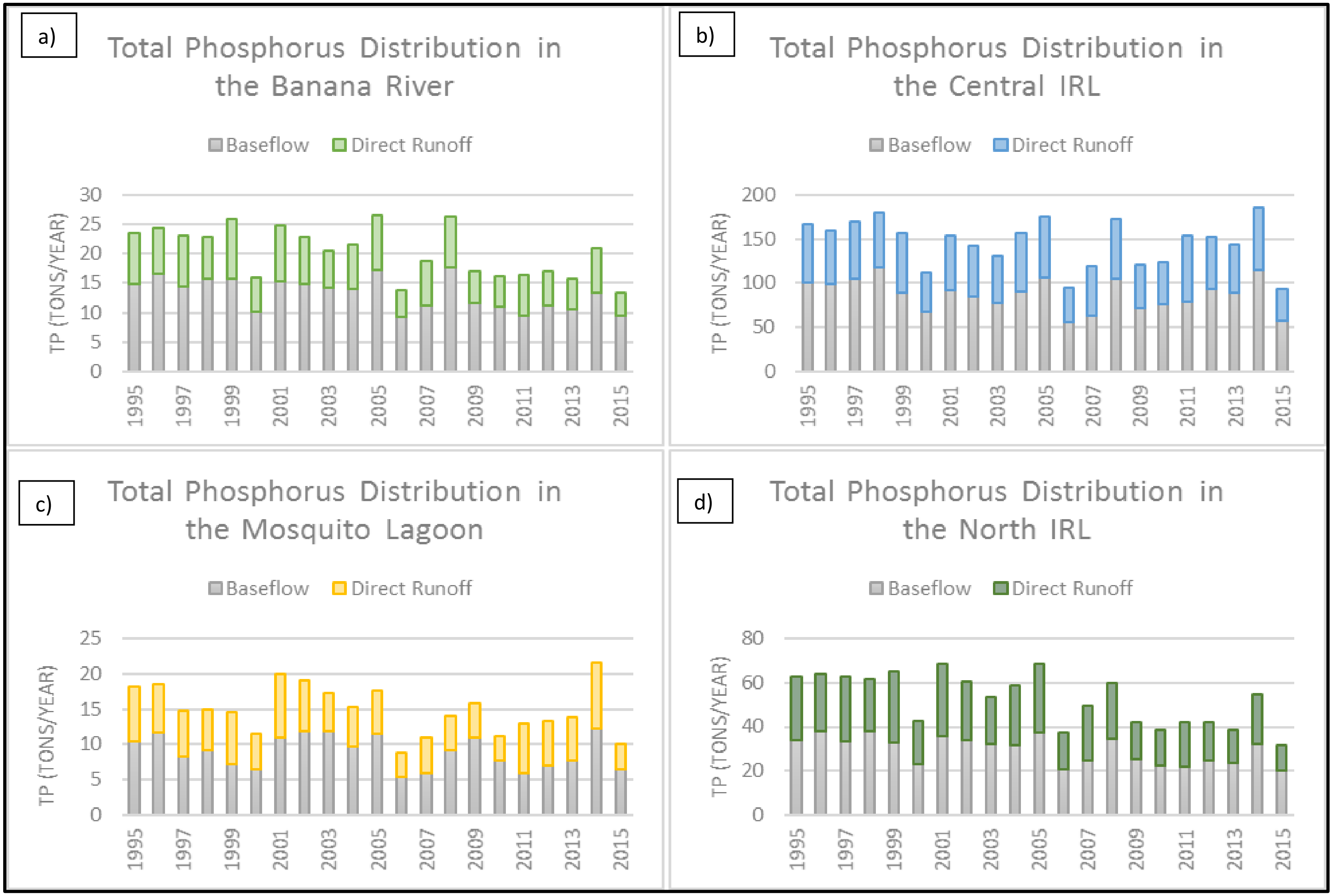
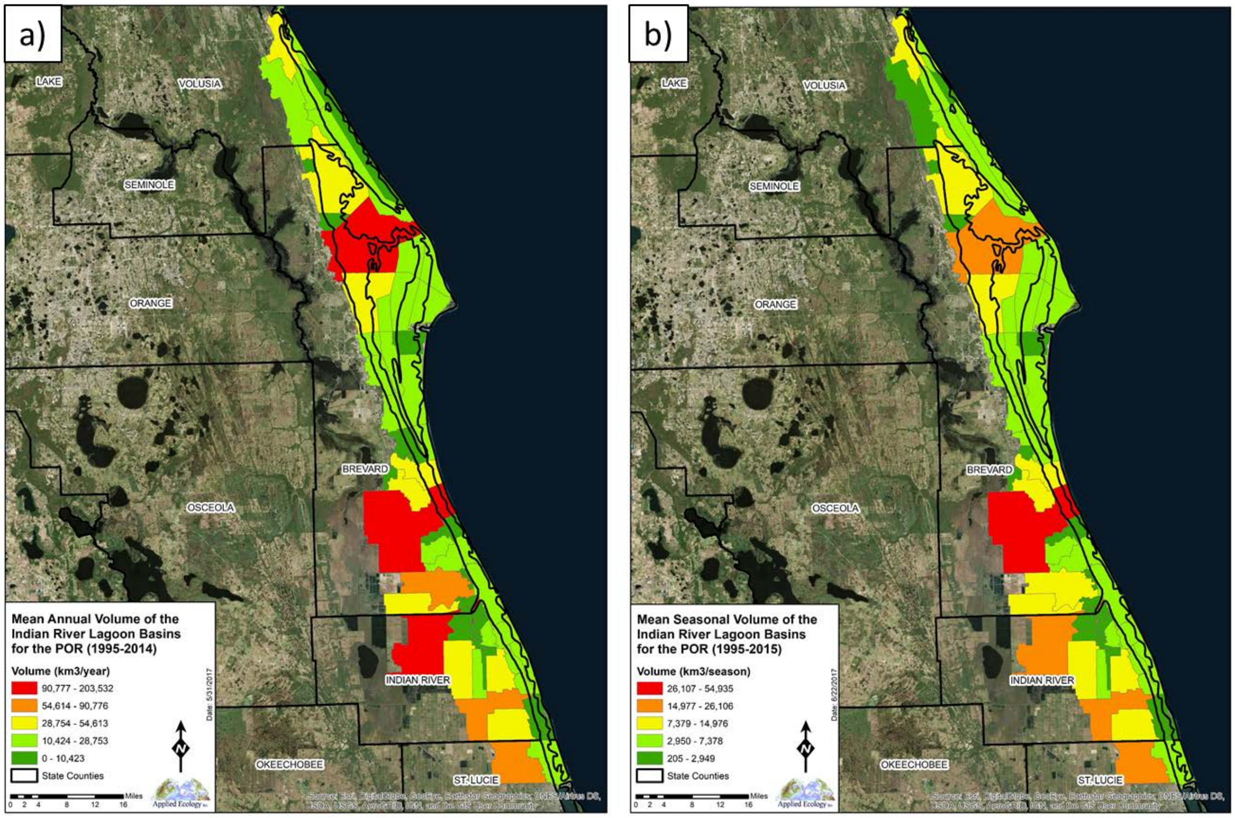


Figure 33. Interannual variation of the baseflow and runoff predicted TP loads for each of the IRL Sublagoons: a) Banana River, b) Central IRL, c) Mosquito Lagoon d) North IRL. Loadings for 2015 are underestimated since they only include 8 months of data.

The spatial distribution of the predicted volumes, TN loadings, and TP loadings can be visualized in Figures 34-36. For each of these predicted variables, the annual period of record mean and seasonal (January-May totals) were provided as "a" and "b" versions of the map. No normalization by area was included in this spatial visualization: basins with larger areas are expected to have higher volume and loading potential than smaller basins, if soil type and urbanization intensity are similar. In addition, since mean period of record averages were used, 2015 data was only used for the seasonal means (data were available for the January-May period), while the annual means excluded the incomplete 2015 results.

As expected the total volume, total nitrogen and phosphorus loading annual means are over three times higher than the seasonal mean corresponding values. The spatial pattern is similar for both predicted volumes and loadings annually and seasonally with one consistent hotspot basin in the Central IRL, Basin IR-12 or Turkey Creek catchment. It is important to note, however, that the C-1 rediversion project has rerouted between 30-50% of the volumes and loads from the Indian River Lagoon to the St. John's River. This large BMP (with Phase II scheduled to begin construction in 2018) has not been included in the current SWIL 4.0 model version.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 34. (a) Distribution of the mean annual total volume throughout the IRL subbasins for the period of record (1995-2014). (b) Distribution of the mean seasonal (January to May) total volume throughout the IRL subbasins for the period of record (1995-2015).

For predicted mean annual volumes, basin IR-5 in the NIRL (Banana Creek Titusville catchment) and the IR-14-15-I (C-54 drainage area) are also important hotspot basins (Figure 34). Additional basins in the CIRL in southern Indian River County and St. Lucie County (IR16-20-D, IR16-20-E and IR-Basin 1 appear to have above average contributions of volumes (Figure 14) and TN/TP loadings (Figures 35 and 36). Each of the above described 7 basins are predicted to have mean POR annual TN loadings of over 65 tons per year and mean POR annual TP loadings of 8.6 tons per year.

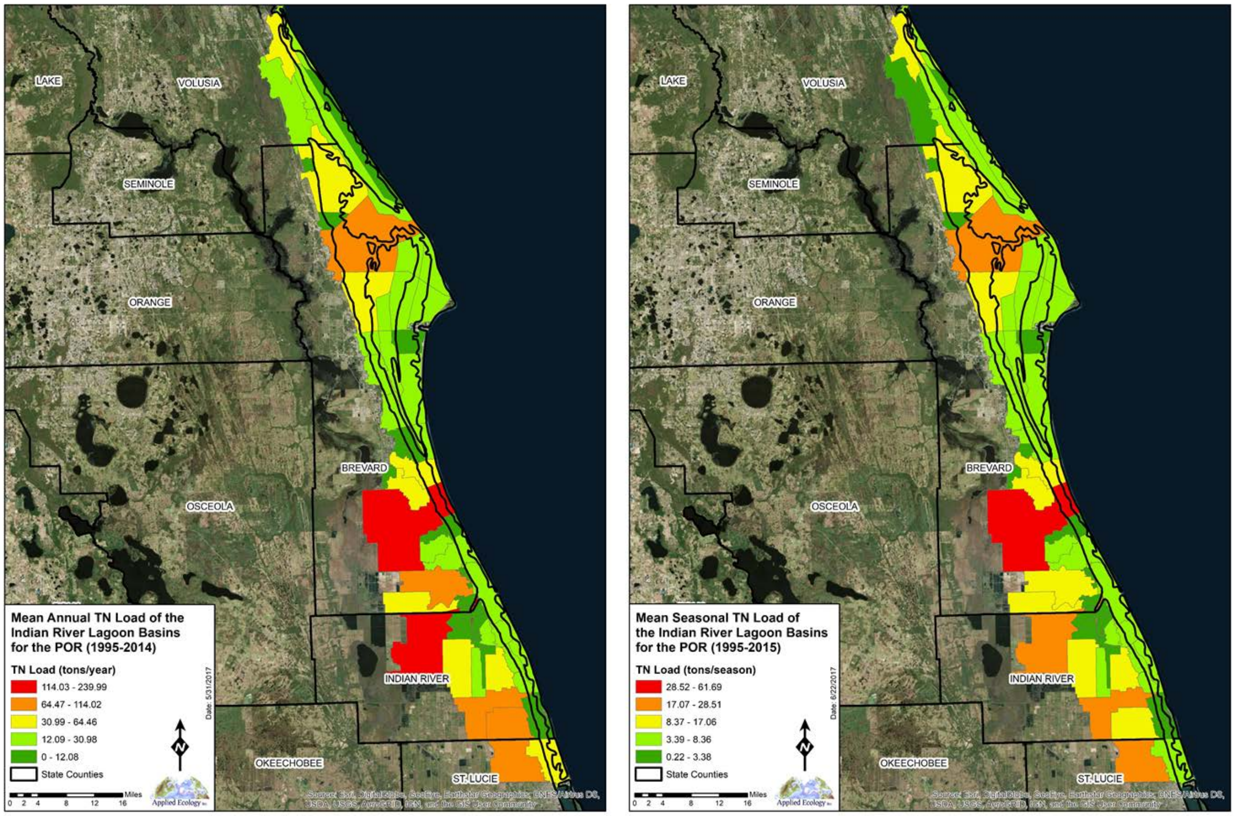


Figure 35. (a) Distribution of the mean annual total nitrogen load throughout the IRL subbasins for the period of record (1995-2014). (b) Distribution of the mean seasonal (January to May) total nitrogen load throughout the IRL subbasins for the period of record (1995-2015).

There are many areas of the Lagoon's watershed that appear to have relatively lower input of volumes and loadings to the IRL: these include portions of the ML, north NIRL, most of the BR, and smaller basins in the CIRL. Most of the basins in the BR and CIRL are smaller watersheds and normalization might allow a better comparison of intensity of loading per basin acre. Nevertheless, the larger hotspot basins should be closely monitored for potential water quality impacts to the Lagoon.

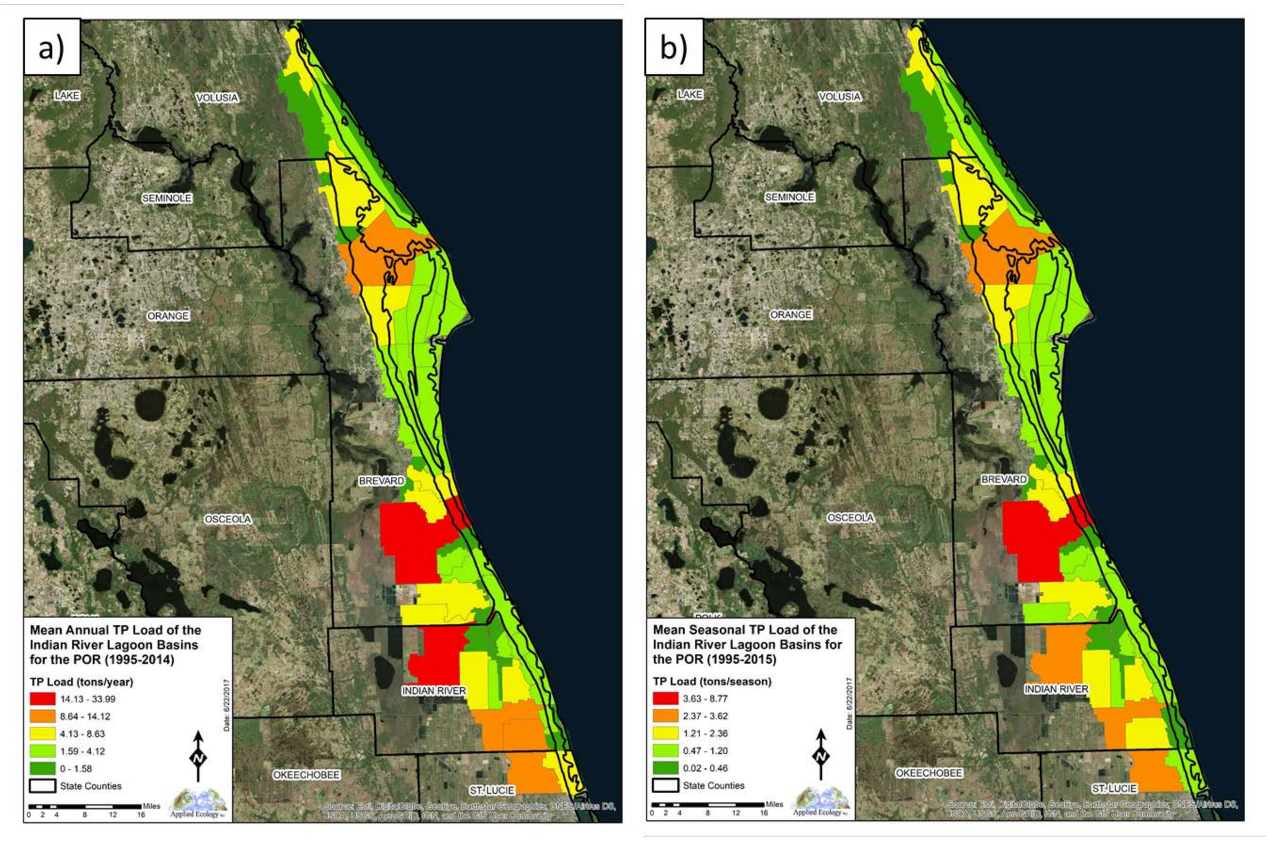


Figure 36. (a) Distribution of the mean annual total phosphorus load throughout the IRL subbasins for the period of record (1995-2014). (b) Distribution of the mean seasonal (January to May) total phosphorus load throughout the IRL subbasins for the period of record (1995-2015).

A4. References

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