MARCH 20, 2019

FINAL MEMORANDUM REPORT FOR THE DEVELOPMENT OF BASELOAD SPATIAL INPUT LAYERS FOR THE INDIAN RIVER LAGOON WATERSHED

BASED ON THE SPATIAL WATERSHED ITERATIVE LOADING (SWIL) MODEL 4.0

PREPARED FOR:

BREVARD COUNTY

NATURAL RESOURCES MANAGEMENT DEPARTMENT

PREPARED BY:

APPLIED ECOLOGY, INC.

Historical Background on the Indian River Lagoon Total Maximum Daily Loads and the Development of the Spatial Watershed Loading Model (SWIL)

FDEP has identified the Indian River Lagoon (IRL) and Banana River Lagoon (BRL) as impaired waterbodies due to nutrient over-enrichment. In March 2009, FDEP issued total maximum daily loads (TMDLs) for the Indian River Lagoon (IRL) and Banana River Lagoon (BRL) requiring reductions of total nitrogen (TN) and total phosphorus (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. The Hydrologic Simulation Program Fortran (HSPF) Model, originally developed by the USEPA, was used to estimate loadings when the loadings derived from the PLSM model did not correlate with seagrass depth limits.

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).

SWIL 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 and 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 most recent updates made to the SWIL model were to improve the efficiency of model run-time without compromising the validity of nutrient load estimates. In early 2018, SWIL 4.0 was further expanded spatially to cover most of the IRL Watershed, and temporally to span until December 2017.

The goal of the SWIL model development was 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.

LOAD ESTIMATION TOOL DEVELOPMENT

In 2013, FDEP adopted Basin Management Action Plans (BMAPs) to meet the TMDLs for the Banana River Lagoon, the North IRL, and Central IRL. To date, no allocations were assigned to the Central Indian River Lagoon and Project Zone A of the Banana River Lagoon. The FDEP requested the use of the latest spatial watershed loading model to update the load allocations for the second 5-year cycle of the IRL BMAPs. The objective of the effort described in this report is to estimate loads for current conditions across the IRL BMAPs (NIRL, CIRL, and BRL) based on a modified SWIL 4.0 version of the model, so these can be used by the FDEP to develop allocations using the adopted TMDLs.

To develop loads that represent updated current conditions the SWIL model was customized for this specific project with the following parameters:

- 50 x 50-meter cell size, much higher spatial resolution than any previously developed watershed loading models for the IRL
- Land use corresponds to 2015 conditions and is derived from water management districts land use, property appraiser data and local government natural communities land cover, where available
- Treatment layer (stormwater BMPs) correspond to 2015 development conditions, excluding any retrofits implemented by the stakeholders within the IRL watershed – retrofit projects will need to be posteriorly calculated and provided as credits to the stakeholders
- Period of record rainfall that includes 2004-2017 data, which allows for a wide range of rainfall conditions to represent the variability in loading to the IRL

The outputs of this modeling effort can be described as static feature classes that include more than 1.2 million 50 x 50-m cells (as features) each. Each individual cell is associated with an estimated volume and both nitrogen and phosphorus estimated loading for the selected mean period of record conditions. For a more detailed description of the provided estimated baseload conditions and formats, please review the Results section.

METHODS IMPLEMENTED TO DEVELOP THE STATIC BASELOAD TOOL

The conversion of a dynamic monthly output model to a static simplified output required SWIL 4.0 to be customized and subsequently executed. Some of the major changes were highlighted above, including spatial resolution, temporal extent, and model conditions (available current land use and treatment data). Changes in the model code were implemented to incorporate aggregated rainfall data and improve performance and did not impact the rationale to estimate direct runoff and baseflow volumes and loads.

SPATIAL RESOLUTION OF BASINS (CELL SIZE)

Previous modeling efforts focused on providing loading estimated for the basins that made up the Banana River Lagoon, North Indian River Lagoon, and Central Indian River Lagoon watershed. These were defined by St. Johns Water Management District (SJWMD) and the South Florida Water Management District (SFWMD) and further refined by stakeholder local knowledge during the SWIL model development. For this project, the input basin layer is composed of a layer of grid cells, 50 x 50-m in cell size, that was constructed to encompass the model boundary extent. The cell size was selected in consultation with the FDEP, with the goal of providing enough spatial resolution for the product to be used to quantify the loading reductions associated with retrofit projects (i.e. Stormwater Best Management Practices or BMPs).

Due to processing limitations of the SWIL model, the grid layer was divided into eight groups and clipped to the model boundary (Figure 1). Table 1 displays the range of basin IDs (i.e. cell size IDs) found in each group area.

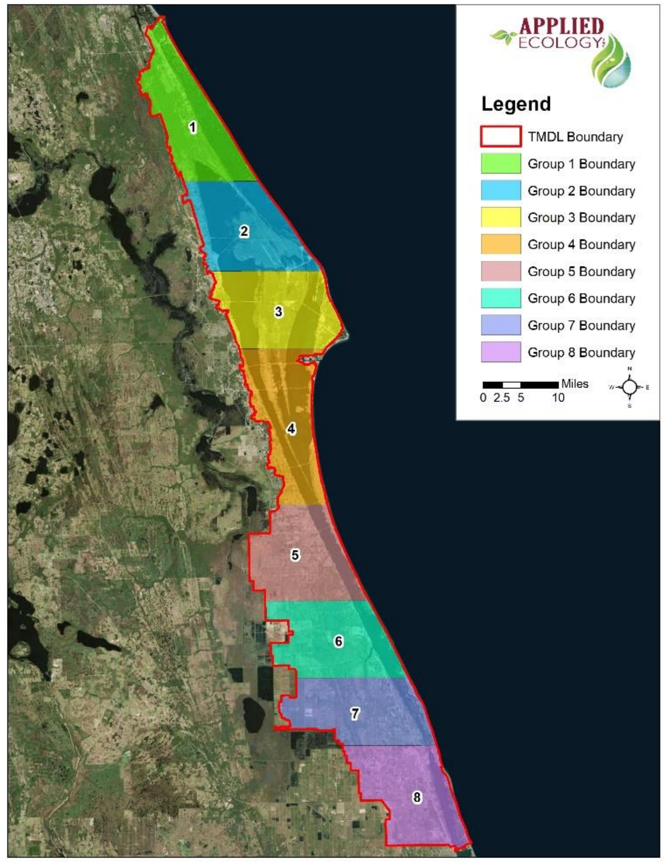

Figure 1. SWIL 4.0 Model extent and location of the eight groups used for developing the baseload estimates at a higher spatial resolution (50 x 50-m cell size).

Table 1. Corresponding Basin IDs (unique grid cells) for each model group area.

Group Number	Basin Number Range
Group 1	1 – 156,200
Group 2	156,201 – 312,400
Group 3	312,401 – 468,600
Group 4	468,601 – 624,800
Group 5	624,801 – 781,000
Group 6	781,001 – 937,200
Group 7	937,201 – 1,093,400
Group 8	1,093,401 – 1,249,605

The watershed model boundary also included partial grid cells (i.e. basins), some small enough to be considered polygon slivers. Grid cells less than 500-m^2 in area were removed from the model run due to the basin size limitations of the SWIL model. However, all cells within the watershed, independently of size, were assigned estimated base volume and loads. Partial cells not modeled directly were assigned volumes and loads based on nearest neighbor volume and loading rate values (m^3 per acre or lb. per acre). Total volumes and load estimates were calculated based on the volume and loading rates and partial cell size.

TREATMENTS AND LAND USE

Since baseload estimates should represent current conditions of the watershed, the latest available land use and associated treatment input layers were used in the model implementation. These correspond to 2015 conditions and were derived from water management district land use and, for urban land uses, from property appraiser datasets. Natural community data from the local government were also incorporated, where available (Brevard County). In addition, field-validated land use datasets for the Patrick Air Force Base, Cape Canaveral Air Force Stations, and the Malabar Annex for the 2015 year were also incorporated in lieu of water management data.

RAINFALL

In order to provide estimated loads that represent variability in rainfall conditions (above and below average rainfall years, different rainfall seasonality patterns, etc.), several years of loading data needed to be simulated for a 10+ year period of record (POR). After a discussion with the FDEP staff and stakeholders, a consensus was reached to use the 2004-2017 POR. This POR represents more recent conditions and is consistent with other approaches for load estimation models in other BMAPs.

In order to reduce the model runtime for 1.2 million cells, POR rainfall conditions were aggregated to create 12 representative months. In the previous SWIL model runs, monthly rainfall rasters were created for the period of record and loading data were estimated for each of the monthly input data. Aggregation, if any, was performed using the monthly loading outputs. For the baseload estimate development, each monthly rainfall raster between January 2004 and December 2017 was first constructed by interpolating best available rainfall gage data distributed across the IRL area (according to methods described Harper and Baker, 2015 an Applied Ecology, 2015). Subsequently, an average was created for each of the 12 months (*e.g*., January, February, etc.) based on all 14 years of rainfall data within the selected POR. Aggregated monthly data (12 months only) were used in the current baseload model development effort.

EVAPOTRANSPIRATION

In addition to aggregating the monthly rainfall rasters, the ET rasters were also aggregated by month for the POR (2004-2017). In previous model runs, ET was included 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 monthly 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 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 ET layers. Unfortunately, the MOD 16 data product is currently only available between the years of 2000-2014. To account for this lapse in data from 2015 to 2017, monthly mean rasters were created to represent the POR in which the measured ET data was available (*i.e.,* the average of identical months for every year from 2000 to 2014). These monthly rasters were then applied to the three subsequent years of the POR with no associated data. Once the data for all years of the POR were created, the aggregated monthly layers were created for the POR of the current SWIL model update (2004–2017). Similar to the rainfall raster datasets, the total number of evapotranspiration input raster layers was reduced from 168 to 12, representing one raster for each month of the year, while also decreasing the run-time and increasing efficiency.

RESULTS: ESTIMATED CURRENT CONDITION BASELOADS FOR THE IRL

Two layers were produced from the updated SWIL 4.0 model run: 1) raw, unmodified total load values by cell and 2) area-normalized load values. The raw values correspond to the estimated totals provided by model for each of the cells, whereas the normalized values are simply the raw outputs divided by the cell area (in acres). Appendix A includes descriptions of the fields that make up the feature class that includes the raw estimates volumes and nutrient loads. Appendix B includes descriptions of the fields that make up the normalized value feature class. The normalized values should never be aggregated as-is by watershed, as they provide a per acre estimate (area ratio loading). Most of the cells within the model domain correspond to about 0.6 acres, so raw values are typically 40% lower than the normalized per acre values.

A brief summary of the custom modification of SWIL 4.0 watershed raw loading estimates, which can be aggregated by watershed region, are provided in this section.

Across the Lagoon watershed, the distribution of runoff volumes is dominated by baseflow volumes making up ca. 61-74% of the total volumes (similar to previous SWIL model runs). The baseflow contribution is higher for the BR and CIRL watersheds and lowest for NIRL and especially the ML (Figure 2).

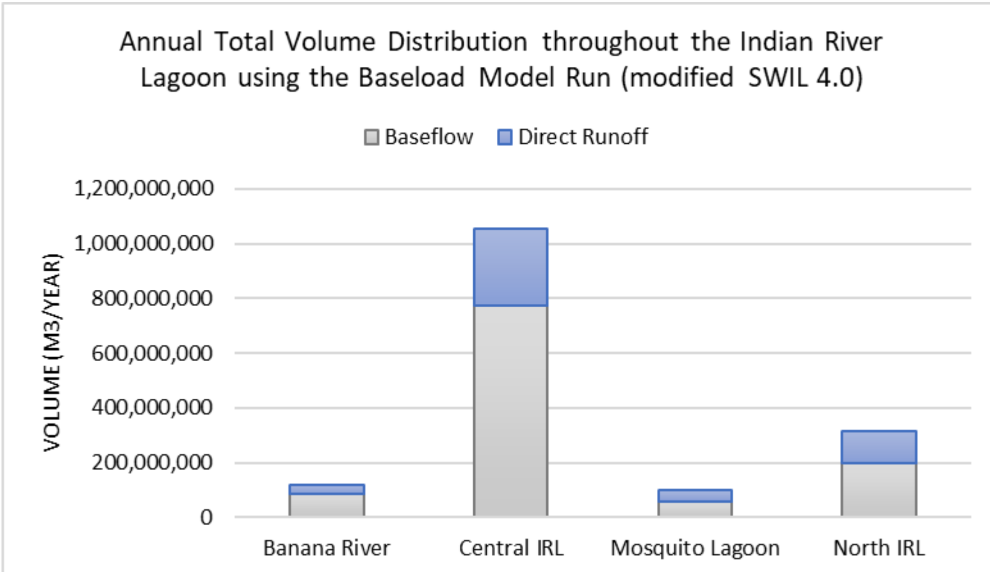

Figure 2. Predicted baseflow and runoff volumes (in m^3) for each of the IRL Sublagoons: Banana River, Central IRL, Mosquito Lagoon, and North IRL.

The pattern for the total nitrogen and phosphorus loadings are very similar to the predicted volumes for the entire watershed (Figure 3 and Figure 4). Even though the contribution of baseflow loadings to the total Lagoon loadings is still significant, it makes up only 48-62% of the total estimated loadings, depending on the nutrient and specific Sublagoon. These results are very similar to those reported for the previous SWIL model run, even those that included a greater POR (1995-2017), multiple land use/treatment conditions through time and monthly, non-aggregated rainfall and ET rasters (Table 2).

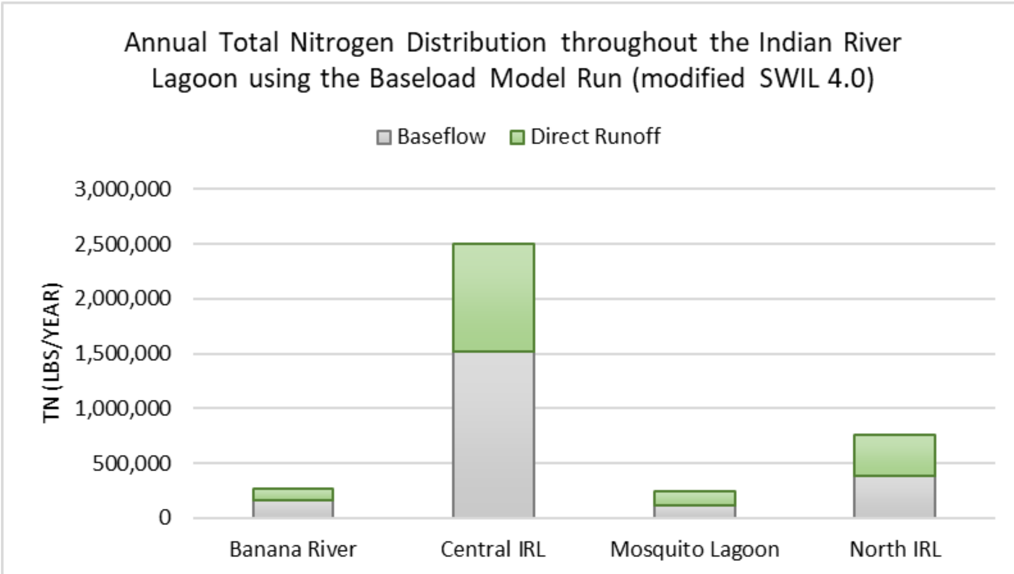

Figure 3. Predicted baseflow and runoff loads of TN for each of the IRL Sublagoons: Banana River, Central IRL, Mosquito Lagoon, and North IRL.

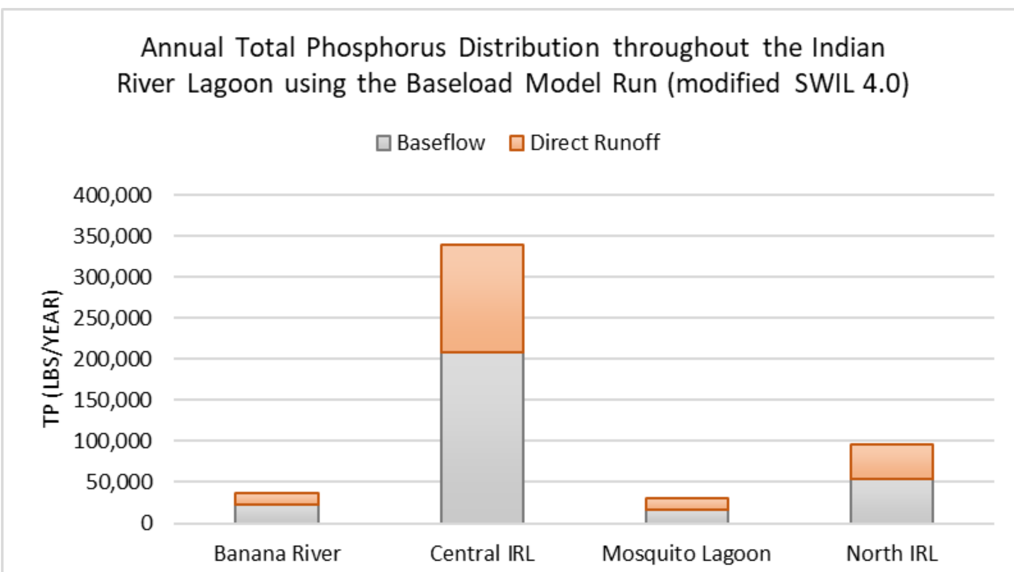

Figure 4. Predicted baseflow and runoff loads of TP for each of the IRL Sublagoons: Banana River, Central IRL, Mosquito Lagoon, and North IRL.

Table 2. Comparison of the direct runoff (DRO) and baseflow (BF) volumes and nutrient loads percent contribution to the totals for the custom Baseload model run (aggregated current condition SWIL) and the previous monthly SWIL model runs by Sublagoon.

Sublagoon	Model Run	Volume		TN		TP	
		% DRO	% BF	% DRO	% BF	% DRO	% BF
Banana River	Monthly SWIL 4.0	26.33	73.67	37.12	62.88	34.93	65.07
	Aggregated Baseload SWIL	28.77	71.23	40.13	59.87	37.82	62.18
Central IRL	Monthly SWIL 4.0	28.21	71.79	41.47	58.53	40.12	59.88
	Aggregated Baseload SWIL	26.37	73.63	39.60	60.40	38.50	61.50
Mosquito Lagoon	Monthly SWIL 4.0	34.29	65.71	46.57	53.43	40.25	59.75
	Aggregated Baseload SWIL	38.83	61.17	52.22	47.78	47.48	52.52
North IRL	Monthly SWIL 4.0	32.94	67.06	44.18	55.82	43.71	56.29
	Aggregated Baseload SWIL	36.86	63.14	49.18	50.82	44.80	55.20

The spatial distribution of the predicted annual and seasonal loadings for TN and TP can be visualized in Figure 5 and Figure 6. For each of these predicted variables, the annual period of record (2004 – 2017) mean and seasonal (January-May totals) were provided as “a” and “b” versions of the map. Since the cell size is consistent throughout the model extent (with rare exceptions in the edges of the model extent), data were normalized by area. Higher loads appeared to be located within the Central IRL, which is likely due to soil type and urbanization intensity. As expected, the total volume, TN, and TP loading annual means are over three times higher than the dry seasonal mean corresponding values (January-May) for each Sublagoon (Figure 7, Figure 8, and Figure 9).

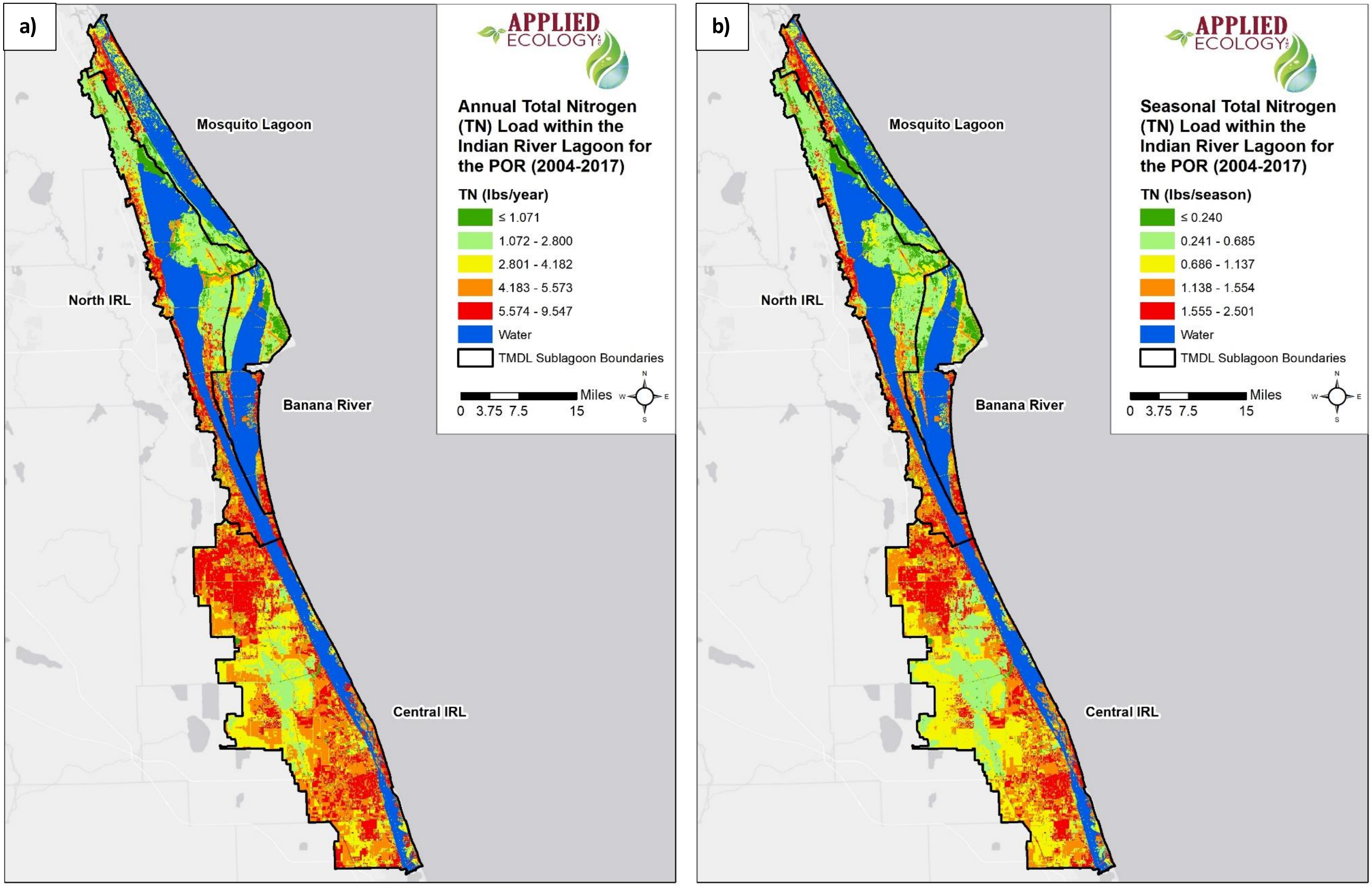

Figure 5. Distribution of the (a) annual and (b) seasonal TN loads for each grid cell (or basin) within the TMDL boundary of the Baseload Model Run (modified SWIL 4.0).

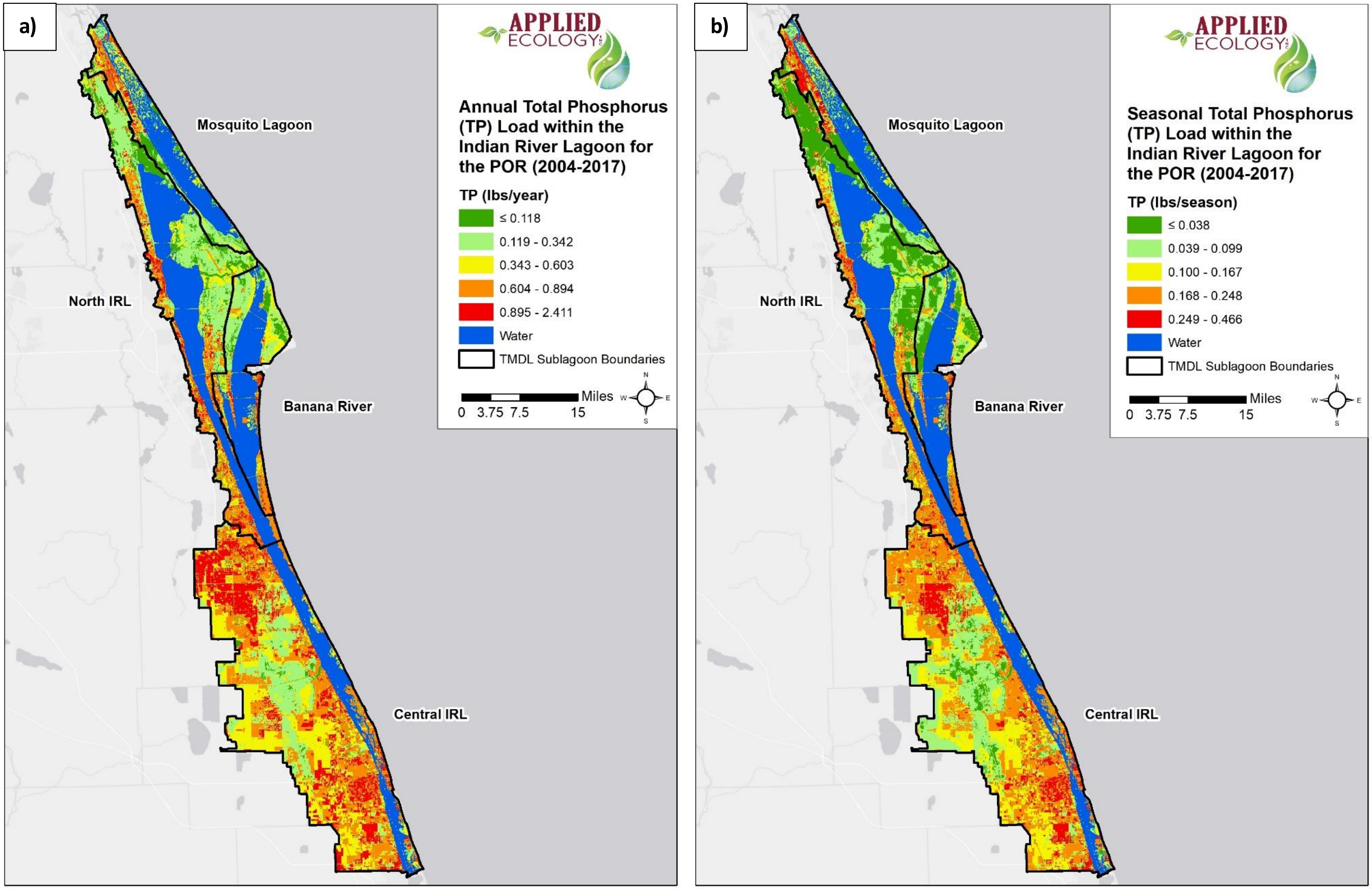

Figure 6. Distribution of the (a) annual and (b) seasonal TP loads for each grid cell (or basin) within the TMDL boundary of the Baseload Model Run (modified SWIL 4.0).

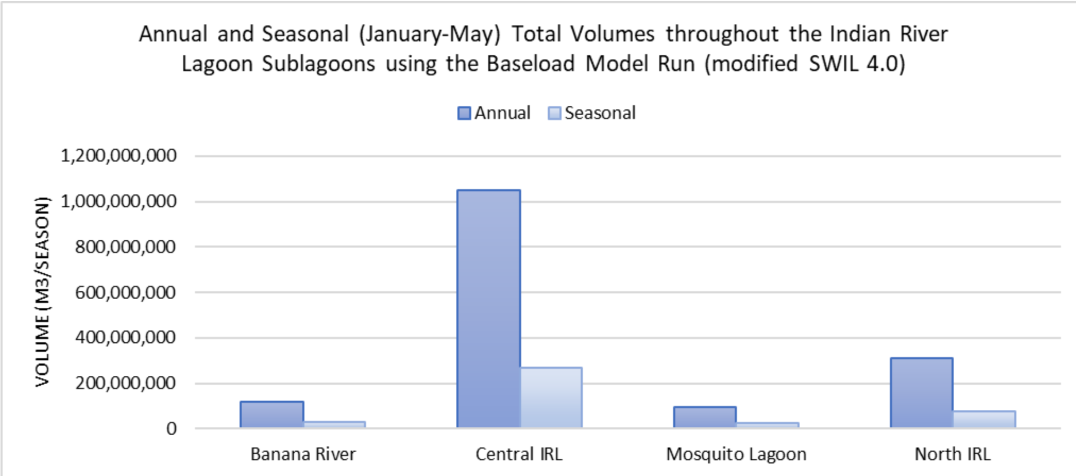

Figure 7. Predicted annual and seasonal total volume distributions for each IRL Sublagoon: Banana River, Central IRL, Mosquito Lagoon, and North IRL.

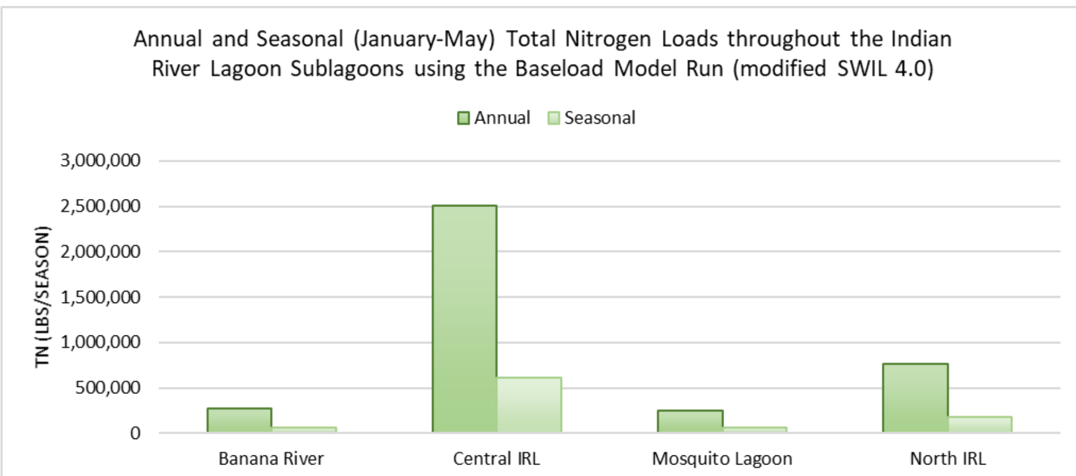

Figure 8. Annual and seasonal TN load distributions for each sublagoon IRL Sublagoon: Banana River, Central IRL, Mosquito Lagoon, and North IRL.

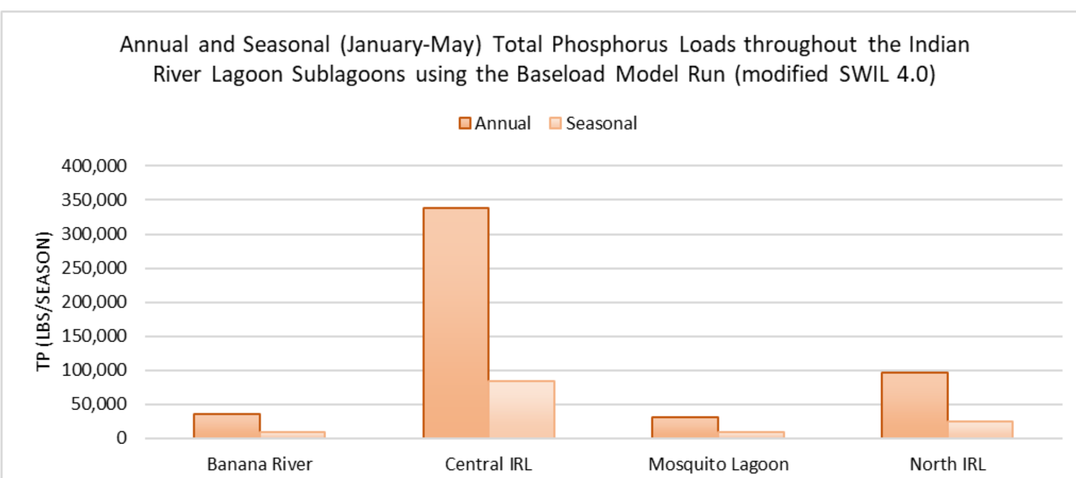

Figure 9. Annual and seasonal TP load distributions for each IRL Sublagoon: Banana River, Central IRL, Mosquito Lagoon, and North IRL.

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APPENDIX A: FIELD DESCRIPTIONS FOR THE BASELOAD RAW ESTIMATES FEATURE CLASS

Field Name	Field Type	Field Description
PageName	String; Length:255	The page name is a unique alphanumeric value that is assigned to each of the grid cells.
PageNumber	Long Integer	The page number is a unique numeric value that is assigned to each of the grid cells.
Annual_DRO_Volume	Double	The raw annual direct runoff (DRO) volume in cubic meters per year.
Annual_BF_Volume	Double	The raw annual baseflow (BF) volume in cubic meters per year.
Annual_Total_Volume	Double	The raw annual total (baseflow + direct runoff) volume in cubic meters per year.
Annual_DRO_TN	Double	The raw annual direct runoff (DRO) total nitrogen (TN) in pounds per year.
Annual_BF_TN	Double	The raw annual baseflow (BF) total nitrogen (TN) in pounds per year.
Annual_Total_TN	Double	The raw (baseflow + direct runoff) annual total nitrogen (TN) in pounds per year.
Annual_DRO_TP	Double	The raw annual direct runoff (DRO) total phosphorous (TP) in pounds per year.
Annual_BF_TP	Double	The raw annual baseflow (BF) total phosphorus (TP) in pounds per year.
Annual_Total_TP	Double	The raw total (baseflow + direct runoff) annual total phosphorus (TP) in pounds per year.
Seasonal_DRO_Volume	Double	The raw dry season (January through May) direct runoff (DRO) volume in cubic meters per season.
Seasonal_BF_Volume	Double	The raw dry season (January through May) baseflow (BF) volume in cubic meters per season.
Seasonal_Total_Volume	Double	The raw total (baseflow + direct runoff) dry season (January through May) volume in cubic meters per season.
Seasonal_DRO_TN	Double	The raw dry season (January through May) direct runoff (DRO) total nitrogen (TN) in pounds per season.
Seasonal_BF_TN	Double	The raw dry season (January through May) baseflow (BF) total nitrogen (TN) in pounds per season.
Seasonal_Total_TN	Double	The raw total (baseflow + direct runoff) dry season (January through May) total nitrogen (TN) in pounds per season.
Seasonal_DRO_TP	Double	The raw dry season (January through May) direct runoff (DRO) total phosphorus (TP) in pounds per season.
Seasonal_BF_TP	Double	The raw dry season (January through May) baseflow (BF) total phosphorus (TP) in pounds per season.
Seasonal_Total_TP	Double	The raw total (baseflow + direct runoff) dry season (January through May) total phosphorus (TP) in pounds per season.
Acres	Double	This field indicates the number of acres in each grid.
Sliver	String; Length:5	This field indicates if the grid was considered a sliver (a grid that is less than 500 square meters).
SUB_BASIN	String; Length:50	The Indian River Sublagoon in which the grid is located.

APPENDIX B: FIELD DESCRIPTIONS FOR THE BASELOAD NORMALIZED ESTIMATES FEATURE CLASS

Field Name	Field Type	Field Description
PageName	String; Length:255	The page name is a unique alphanumeric value that is assigned to each of the grid cells.
PageNumber	Long Integer	The page number is a unique numeric value that is assigned to each of the grid cells.
Annual_DRO_Vol_Norm	Double	The normalized annual direct runoff (DRO) volume in cubic meters per year per acre.
Annual_BF_Vol_Norm	Double	The normalized annual baseflow (BF) volume in cubic meters per year per acre.
Annual_Tot_Vol_Norm	Double	The normalized annual total (baseflow + direct runoff) volume in cubic meters per year per acre.
Annual_DRO_TN_Norm	Double	The normalized annual direct runoff (DRO) total nitrogen (TN) in pounds per year per acre.
Annual_BF_TN_Norm	Double	The normalized annual baseflow (BF) total nitrogen (TN) in pounds per year per acre.
Annual_Tot_TN_Norm	Double	The normalized total (baseflow + direct runoff) annual total nitrogen (TN) in pounds per year per acre.
Annual_DRO_TP_Norm	Double	The normalized annual direct runoff (DRO) total phosphorous (TP) in pounds per year per acre.
Annual_BF_TP_Norm	Double	The normalized annual baseflow (BF) total phosphorus (TP) in pounds per year per acre.
Annual_Tot_TP_Norm	Double	The normalized total (baseflow + direct runoff) annual total phosphorus (TP) in pounds per year per acre.
Season_DRO_Vol_Norm	Double	The normalized dry season (January through May) direct runoff (DRO) volume in cubic meters per season per acre.
Season_BF_Vol_Norm	Double	The normalized dry season (January through May) baseflow (BF) volume in cubic meters per season per acre.
Seasonal_Tot_Vol_Norm	Double	The normalized total (baseflow + direct runoff) dry season (January through May) volume in cubic meters per season per acre.
Season_DRO_TN_Norm	Double	The normalized dry season (January through May) direct runoff (DRO) total nitrogen (TN) in pounds per season per acre.
Season_BF_TN_Norm	Double	The normalized dry season (January through May) baseflow (BF) total nitrogen (TN) in pounds per season per acre.
Season_Tot_TN_Norm	Double	The normalized total (baseflow + direct runoff) dry season (January through May) total nitrogen in pounds per season per acre.
Season_DRO_TP_Norm	Double	The normalized dry season (January through May) direct runoff (DRO) total phosphorus (TP) in pounds per season per acre.
Season_BF_TP_Norm	Double	The normalized dry season (January through May) baseflow (BF) total phosphorus (TP) in pounds per season per acre.
Season_Tot_TP_Norm	Double	The normalized total (baseflow + direct runoff) dry season (January through May) total phosphorus in pounds per season per acre.
Acres	Double	This field indicates the number of acres in each grid.
Sliver	String; Length:5	This field indicates if the grid was considered a sliver (a grid that is less than 500 square meters).
SUB_BASIN	String; Length:50	The Indian River Sublagoon in which the grid is located.