ArcGIS-Based Nitrate Load Estimation Toolkit (ArcNLET) Model Development and Septic System Loading Evaluation in City of Vero Beach, Florida

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PREPARED FOR

City of Vero Beach, Water and Sewer Department
17 17th Street
P.O. Box 1389
Vero Beach, Florida 32961-1389
Tel 772-978-5220

PREPARED BY

Tetra Tech, Inc.
1899 Powers Ferry Rd SE, Suite 400
Atlanta, Georgia 30339
Tel 770-850-0949
tetratech.com

TABLE OF CONTENTS

ACRONYMS/ABBREVIATIONS IV

EXECUTIVE SUMMARY V

1.0 INTRODUCTION 1

2.0 MODEL DESCRIPTION 3

2.1 Groundwater Flow 3

2.2 Particle Tracking 3

2.3 Transport 3

2.4 Load Estimation 3

3.0 DATA AVAILABILITY AND DESCRIPTION 4

3.1 DEM Elevation 4

3.2 Septic System Locations 4

3.3 Waterbodies 4

3.4 Soil Porosity and Saturated Hydraulic Conductivity 4

3.5 Groundwater Measurements 13

3.6 Groundwater Nitrogen Measurements 13

4.0 MODEL CALIBRATION AND RESULTS 17

5.0 STEP SYSTEM CONVERSION NITROGEN LOAD REDUCTIONS 28

5.1 STEP Scenario Model Input 28

5.2 STEP Scenario Model Results 28

5.3 STEP Scenario Model Load Reductions 28

6.0 MODEL UNCERTAINTY IN LOAD ESTIMATES 46

7.0 NEXT STEPS 55

8.0 REFERENCES 56

LIST OF TABLES

Table 4-1. Initial and calibrated ArcNLET parameters 17
Table 4-2. Detailed loads for top ten waterbodies 26
Table 4-3. Estimated nitrogen loads by STEP basin detail 27
Table 5-1. STEP Scenario top ten waterbodies with the highest estimated loads details 36
Table 5-2. STEP Scenario estimated nitrogen loads by STEP basin detail 38
Table 5-3. Top five waterbodies with the highest load reductions detail 43
Table 5-4. Estimated nitrogen load reductions by STEP basin detail 45
Table 6-1. Probability distributions and value ranges for parameters selected for uncertainty analysis 48

LIST OF FIGURES

Figure 1-1. Location of the septic systems and STEP systems in the City of Vero Beach 2
Figure 3-1. City 1.5 feet x 1.5 feet DEM 5
Figure 3-2. Processed and clipped DEM 6
Figure 3-3. Barrier island septic system parcels and STEP system converted parcels 7
Figure 3-4. Mainland septic system parcels and STEP system converted parcels 8
Figure 3-5. Waterbody coverage sources 9
Figure 3-6. 2017 SSURGO soils with missing data 10
Figure 3-7. Modeled soil hydraulic conductivity 11
Figure 3-8. Modeled soil porosity 12
Figure 3-9. Groundwater monitoring well locations 14
Figure 3-10. Observed groundwater level at IR0993 15
Figure 3-11. Observed groundwater level at IR0114 15
Figure 3-12. Observed groundwater level at IR0277 16
Figure 4-1. Smoothed DEM relationship with the measured water level 18
Figure 4-2. Modeled particle paths 19
Figure 4-3. Modeled nitrogen plumes 20
Figure 4-4. Bethel Creek and Live Oak modeled nitrogen concentrations 21
Figure 4-5. South Beach and Riomar modeled nitrogen concentrations 22
Figure 4-6. Country Club and Downtown modeled nitrogen concentrations 23
Figure 4-7. Atlantic Boulevard, 14th Street, and Airport modeled nitrogen concentrations 24
Figure 4-8. Top ten waterbodies with the highest loads 25
Figure 4-9. Top 20 waterbodies with the highest loads 26
Figure 4-10. Estimated nitrogen loads by STEP basin 27
Figure 5-1. STEP Scenario modeled particle paths 29
Figure 5-2. STEP Scenario modeled nitrogen plumes 30
Figure 5-3. STEP Scenario Bethel Creek and Live Oak modeled nitrogen concentrations 31
Figure 5-4. STEP Scenario South Beach and Riomar modeled nitrogen concentrations 32
Figure 5-5. STEP Scenario Country Club and Downtown modeled nitrogen concentrations 33
Figure 5-6. STEP Scenario Atlantic Boulevard, 14th Street, and Airport modeled nitrogen concentrations 34
Figure 5-7. STEP Scenario top ten waterbodies with the highest estimated loads 35
Figure 5-8. STEP Scenario estimated nitrogen loads by STEP basin 37
Figure 5-9. Bethel Creek and Live Oak modeled nitrogen concentration reductions 39
Figure 5-10. South Beach and Riomar modeled nitrogen concentration reductions 40
Figure 5-11. Country Club and Downtown modeled nitrogen concentration reductions 41
Figure 5-12. Atlantic Boulevard 14th Street, and Airport modeled nitrogen concentration reductions 42
Figure 5-13. Top five waterbodies with the highest load reductions 43

Figure 5-14. Estimated nitrogen load reductions by STEP basin 44
Figure 6-1. Monte Carlo simulation model area 47
Figure 6-2. Histogram of 1,000 randomly generated smoothing factors 48
Figure 6-3. Histogram of 1,000 randomly generated values of hydraulic conductivity 49
Figure 6-4. Histogram of 1,000 randomly generated values of first-order decay coefficient 49
Figure 6-5. Histogram of 1,000 randomly generated values of longitudinal dispersivity 50
Figure 6-6. Sample mean (left) and standard deviation (right) of simulated nitrogen concentrations 50
Figure 6-7. Waterbody 154 (IRL) mean (left) and standard deviation (right) of simulated nitrogen loads 51
Figure 6-8. Histogram (left) and cumulative distribution function (right) of 1,000 simulations of nitrogen concentrations at the monitoring point 51
Figure 6-9. Histogram (left) and cumulative distribution function (right) of 1,000 simulations of nitrogen load to waterbody 154 (IRL) 52
Figure 6-10. Relationship between the nitrogen load estimate and concentration at the monitoring point 52
Figure 6-11. Scatterplots for the first-order decay coefficient of denitrification and simulated concentration (left) and load (right) 53
Figure 6-12. Scatterplots for the smoothing factor and simulated concentration (left) and load (right) 53
Figure 6-13. Scatterplots for the longitudinal dispersivity and simulated concentration (left) and load (right) 53
Figure 6-14. Scatterplots for the hydraulic conductivity and simulated concentration (left) and load (right) 54
Figure 6-15. Scatterplots for the 1,000-simulated load estimates and calibrated values 54

ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ArcNLET	ArcGIS-Based Nitrate Load Estimation Toolkit
BMAP	Basin Management Action Plan
CDF	Cumulative Distribution Function
City	City of Vero Beach
DEM	Digital Elevation Model
DEP	Florida Department of Environmental Protection
FDOH	Florida Department of Health
GIS	Geographic Information System
IRL	Indian River Lagoon
lbs/yr	Pounds Per Year
mg/L	Milligrams Per Liter
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
SSURGO	Soil Survey Geographic Database
STEP	Septic Tank Effluent Pumping (system)
UTM17N	Universal Transverse Mercator Zone 17N

EXECUTIVE SUMMARY

The City of Vero Beach (City) has 1,473 homes on septic systems, and as of the time of this report, they have converted 101 of these homes to septic tank effluent pumping (STEP) systems to connect them to the sewer system. The City is evaluating additional areas to convert to STEP systems. The City requested that Tetra Tech develop an ArcGIS-Based Nitrate Load Estimation Toolkit (ArcNLET) model to quantify the water quality benefits of converting the existing septic systems to STEP systems.

Septic systems are one of the significant sources of nitrogen in groundwater and surface water, posing serious threats to human health and the environment. The ArcNLET model has been used to simulate nitrogen transport and estimate nitrogen loading from septic systems to surface waterbodies through the surficial aquifer. It is based on a simplified conceptual model of groundwater flow and nitrogen transport. The purpose of this study is to estimate the nitrogen load from the 1,372 active septic systems and 101 septic systems converted to STEP systems to the Indian River Lagoon (IRL) and other surface waterbodies in and around the City. This study found that all the waterbodies in and around the City (437 total), including the IRL, have been receiving a total nitrogen load of 6,560 pounds per year (lbs/yr). This load was reduced by 511 lbs/yr to 6,049 lbs/yr by converting the 101 septic systems to STEP systems. The IRL directly receives 68.2% (4,126 lbs/yr) of the total load, and the Atlantic Ocean directly receives an additional 14.2% (860.5 lbs/yr) of the total load. The summary of calibrated and current load estimates is shown in the table below:

STEP Basin	Calibrated Model - All Septic Systems		STEP Scenario (Current Conditions) - STEP System Converted to Septic Systems			
	# of Septic Systems	Total Load (lbs/yr)	# of Septic Systems Converted to STEP	Total Load (lbs/yr)	Current Load Reduction (lbs/yr)	Current Load Per Septic System (lbs/yr)
14th St	272	445.0	5	444.1	0.9	1.66
Airport	8	15.6	0	15.6	0.0	1.95
Atlantic Blvd	136	16.2	3	16.2	0.0	0.12
Bethel Creek	141	1,162.2	33	975.8	186.4	9.04
Country Club	81	28.8	1	28.8	0.0	0.36
Downtown	53	243.3	2	225.3	18.0	4.42
Live Oak	343	1,876.4	29	1,737.4	138.9	5.53
Riomar	115	539.1	9	486.0	53.1	4.58
South Beach	244	1,830.0	18	1,722.9	107.1	7.62
Total in STEP Basins	**1,393**	**6,156.5**	**100**	**5,652.1**	**504.4**	**4.37**
Outside of STEP	80	403.8	1	396.8	7.0	5.02
Total in City	**1,473**	**6,560.3**	**101**	**6,048.9**	**511.4**	**4.41**

Tetra Tech is currently working with the City to install groundwater monitoring wells in one of the City's basins. The information gathered through the groundwater monitoring will be used to refine the ArcNLET model. Therefore, the modeling results may change when these new data are available to improve model calibration.

1.0 INTRODUCTION

Nutrients, including nitrogen, are essential for plant and animal growth and nourishment, but excessive amounts of nitrogen in water can cause many adverse health and ecological effects. High nitrogen concentrations in surface waters can lead to overstimulation of growth of aquatic plants and algae, which can block light to deeper waters and lead to fish kills, hypoxia and, eutrophication.

Conventional septic tank and drainfield systems treat wastewater by settling solids and partly digesting the organic matter, allowing liquid effluent to be discharged into the soil beneath the drainfield. Septic systems are significant sources of nitrogen especially in urban areas (U.S. Environmental Protection Agency 2002). In the state of Florida, nearly one-third of households use septic systems (Hazen and Sawyer 2009). The City of Vero Beach (City) has 1,473 homes on septic systems, and they have converted 101 of these systems to septic tank effluent pumping (STEP) systems to connect them to the sewer system. The City is evaluating additional areas to convert to STEP systems (**Figure 1-1**). Understanding the magnitude of nitrogen loading from the septic systems to the surface waterbodies via groundwater discharge is important for restoration and planning purposes. A recent study by the Florida Department of Health (FDOH) showed that septic systems installed before 1983 potentially provide little to no treatment of septic system effluent because of the possible lack of separation from the water table for septic systems installed before modern requirements (FDOH 2015). Some barrier island residents within the City have begun to experience septic system failures over the past 18 months, brought on, in part, by high groundwater levels during extreme high tides. The City's hybrid STEP system project diverts septic system waste that seeps into groundwater via drainfields to a central sewage treatment plant for a higher level of nutrient treatment.

An ArcGIS-Based Nitrate Load Estimation Toolkit (ArcNLET) model was developed for the Florida Department of Environmental Protection (DEP) by Florida State University. The model focuses on nitrate transport and loads at a small scale with septic systems as point sources. ArcNLET includes a simple conceptual groundwater model to estimate the groundwater hydrologic process and uses analytical equations to describe nitrate transport with site-specific septic systems. This model has been used to estimate nitrate load from thousands of septic systems to surface waterbodies in the City of Jacksonville; City of Port St. Lucie, City of Stuart, and Martin County (Ye et al. 2013); and in the Indian River Lagoon (IRL) (Sayemuzzaman et al. 2015). With the above-mentioned advantages, ArcNLET is suited to estimate nitrogen loads from septic systems within the City.

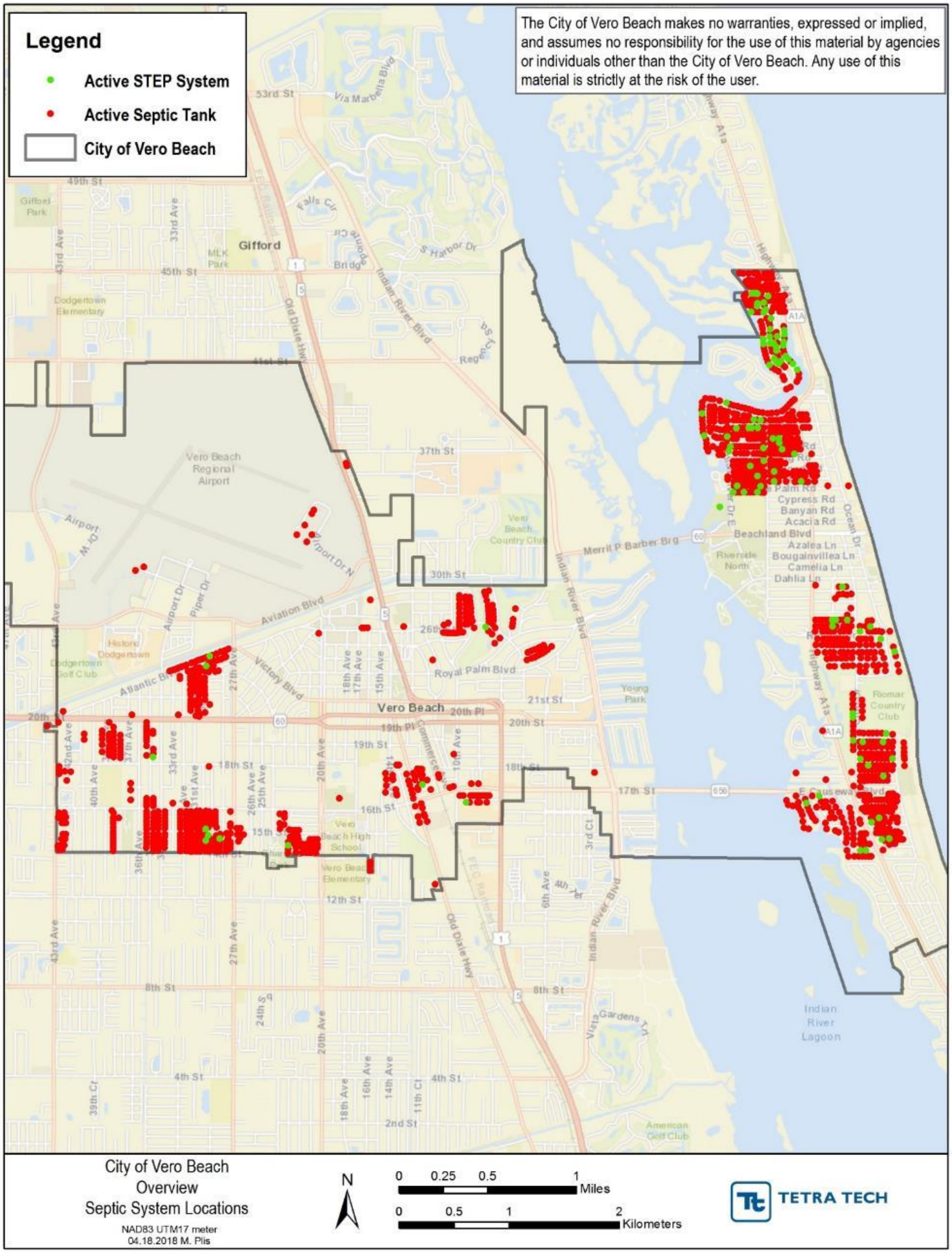

Figure 1-1. Location of the septic systems and STEP systems in the City of Vero Beach

2.0 MODEL DESCRIPTION

The ArcNLET model is intended to model the fate and transport of nitrate in surficial groundwater, originating from septic systems (Rios et al. 2011). The main ArcNLET model consists of four modules: (1) Groundwater Flow, (2) Particle Tracking, (3) Transport, and (4) Load Estimation. The model requires a basic set of geographic information system (GIS) inputs including a digital elevation model (DEM) surface elevation raster, saturated hydraulic soil conductivity raster, soil porosity raster, polygon shapefile representing the waterbodies inside the modeling extent, and point shapefile of the septic system locations. All spatial datasets must be in the same units and projections, and geodatabases are not supported. Individual model modules can be executed independently, making calibration easier and more time efficient.

2.1 GROUNDWATER FLOW

Groundwater Flow is the first module required to build the model. This module uses the DEM, soil conductivity, soil porosity raster, and waterbody shapefile. This module approximates the water table using the topography data, and it is built on the assumption that the hydraulic head of the surficial aquifer is a subsurface replica of the overlying topography. The model accomplishes this task by smoothing the DEM to a calibrated value, and then uses the ArcGIS Spatial Analysis and associated Groundwater Tools to compute the seepage velocity magnitude and direction rasters. Optional outputs include the smoothed DEM, which is very important in the calibration process, and a hydraulic gradient raster. In this module the user can control the parameters related to DEM smoothing including the smoothing factor and the number of cells used for smoothing. The user can also fill sinks or pits in the DEM, if the user find that flow lines calculated in the next module to become trapped. An additional included parameter is the Z-Factor. DEM elevation data often have differing horizontal and vertical units (i.e. the DEM raster is in a meter projection, but the elevation values are in feet) and the Z-Factor allows the conversion of the differing vertical units to the common horizontal unit.

2.2 PARTICLE TRACKING

The Particle Tracking module uses the point source shapefile with septic system locations, waterbody shapefile, soil porosity raster, and seepage velocity magnitude and direction rasters computed in the Groundwater Module to determine the flow path of an imaginary particle placed at the point where effluent enters the surficial aquifer. The output of this module is a polyline shapefile containing a set of flow paths from the septic system location along the gradient of the water table. These paths are then used by the Transport module.

2.3 TRANSPORT

The Transport module inputs are the septic system locations, particle paths polylines, and waterbody shapefile. The outputs are either a single nitrate plume raster containing concentration distributions of the calculated plumes, or separate nitrate and ammonia concentration rasters. The raster output is supplemented by a source point shapefile, whose attributes contain additional plume information, including calculated mass input/outputs, denitrification values, and plume termination waterbody identification. The technical details for this module can be found in the ArcNLET user manual (Rios et al. 2011). The user can control the following nitrate parameters: solution type (with and without denitrification), source plane concentration and dimensions, input mass rate, plume cell size, longitudinal and horizontal transverse dispersivities, and first-order decay constant. The module has additional plume shaping, warping, and post-processing controls.

2.4 LOAD ESTIMATION

This module uses the supplemental source point shapefile from the Transport module output to calculate the loads to individual waterbodies. The output is a list of nitrate load estimates for waterbodies that intersect a flow path.

3.0 DATA AVAILABILITY AND DESCRIPTION

3.1 DEM ELEVATION

The City of Vero Beach provided Tetra Tech with a detailed 1.5-foot x 1.5-foot DEM coverage of the City (**Figure 3-1**). This dataset was projected to the North American Datum 1983 (NAD83) Universal Transverse Mercator Zone 17N (UTM17N) projection with a resolution of 10 meters x 10 meters. The elevation values were converted from feet to meters (**Figure 3-2**).

3.2 SEPTIC SYSTEM LOCATIONS

The City provided a parcel polygon shapefile that contained septic system attributes and a coverage of seven separate STEP basins with STEP eligibility and connection status. Parcels inside the city limits were selected out of this dataset and parcel centroids were calculated and used as the septic drainfield locations. This resulted in 1,372 active septic systems and 101 converted STEP systems. All 1,473 septic systems (881 on the barrier island and 592 on the mainland) were used in the model calibration and uncertainty analysis. The spatial distribution of these parcels and the STEP system basins are presented in **Figure 3-3** and **Figure 3-4**.

3.3 WATERBODIES

The City of Vero Beach provided Tetra Tech with a waterbody polygon shapefile and a polyline shapefile with upland channel drainage lines. The polyline shapefile contained canals, major and minor ditches, and swales. Upon reviewing these data, Tetra Tech converted the polylines to polygons using reasonable buffers of ten meters for the major canals and five meters for the ditches. The swales were not converted and not used in the modeling.

While building the model, Tetra Tech found that due to the drainage line shapefiles being limited by the City boundaries, some of the septic system particle flow paths were flowing outside the City and were not being accounted for in the model. Therefore, the waterbody shapefile was supplemented with National Hydrography Dataset Plus v2 data. The flowline shapefiles were converted to polygons and added around the modeling extent as a “catch-all.” Visualization of these waterbodies and their sources are shown in **Figure 3-5.**

3.4 SOIL POROSITY AND SATURATED HYDRAULIC CONDUCTIVITY

The City provided soil polygons; however, the polygons did not contain porosity or conductivity values. Therefore, Tetra Tech acquired the Soil Survey Geographic Database (SSURGO) for Indian River County, Florida from the U.S. Department of Agriculture Web Soil Survey website. Values of hydraulic conductivity and porosity, bulk density, particle density, horizon depths, and component key were extracted from the horizon attribute table in SSURGO. These data were exported to Excel and the component with the lowest horizon and its attributes were kept. Component key, map unit key, major component flag, and the component percentages were extracted from the SSURGO component table. These data were filtered to only include major components. A series of Excel pivot and lookup tables were used to aggregate the hydraulic conductivity and soil porosity from the horizon level to the component level. Weighted averages were used for values where a map unit contained more than one component. Hydraulic conductivity values were converted to meters per day and missing porosity values were calculated from bulk and particle densities. The resulting values were joined to the soil shapefile in ArcGIS. Some map units still did not have conductivity and/or porosity values, and these were assigned manually based on the surrounding values (**Figure 3-6**).

The resulting soil polygons were converted to conductivity and porosity rasters. Resolution of these rasters matched the DEM raster at 10 meters x 10 meters. The hydraulic conductivity raster is presented in **Figure 3-7.** and the porosity is shown in **Figure 3-8.**

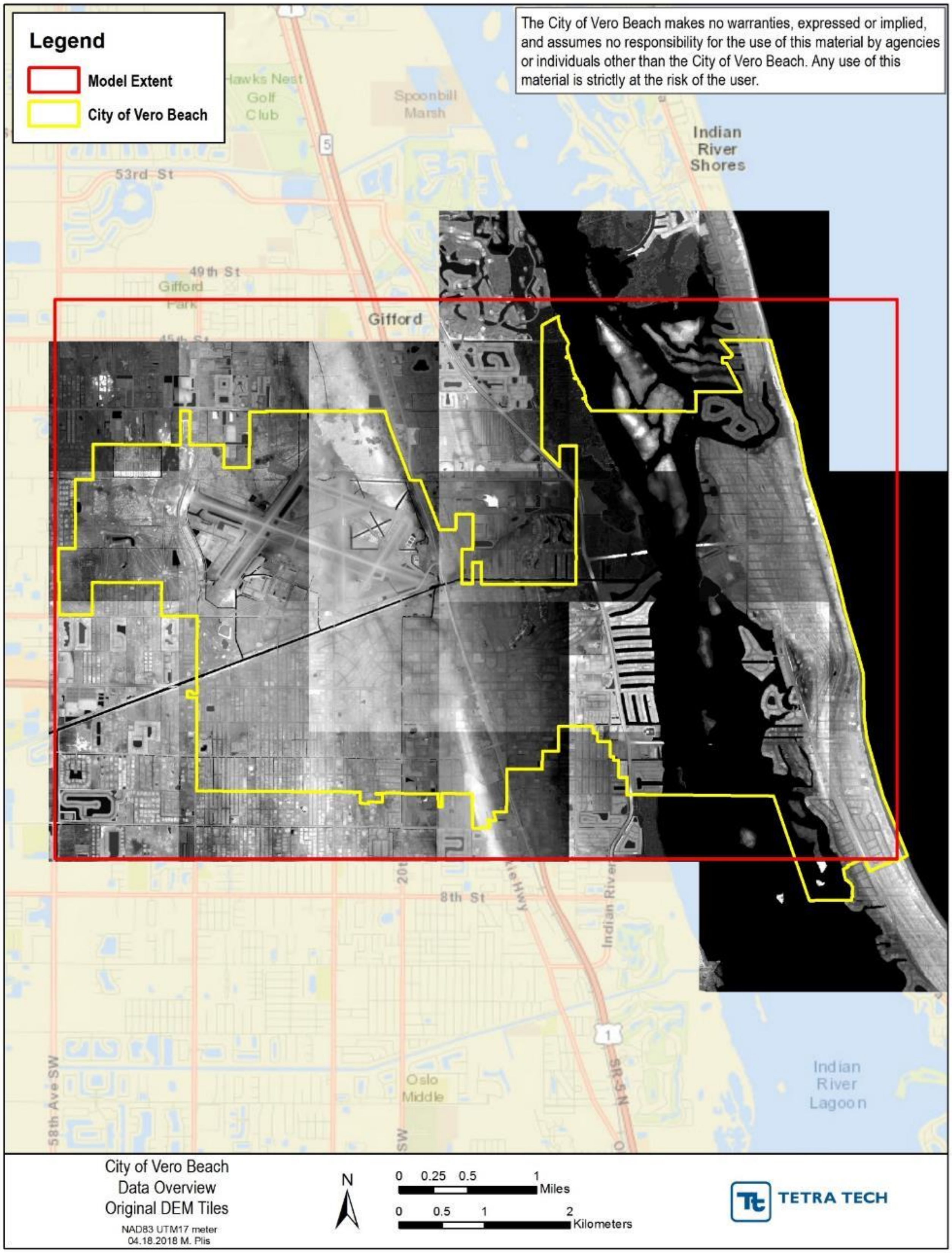

Figure 3-1. City 1.5 feet x 1.5 feet DEM

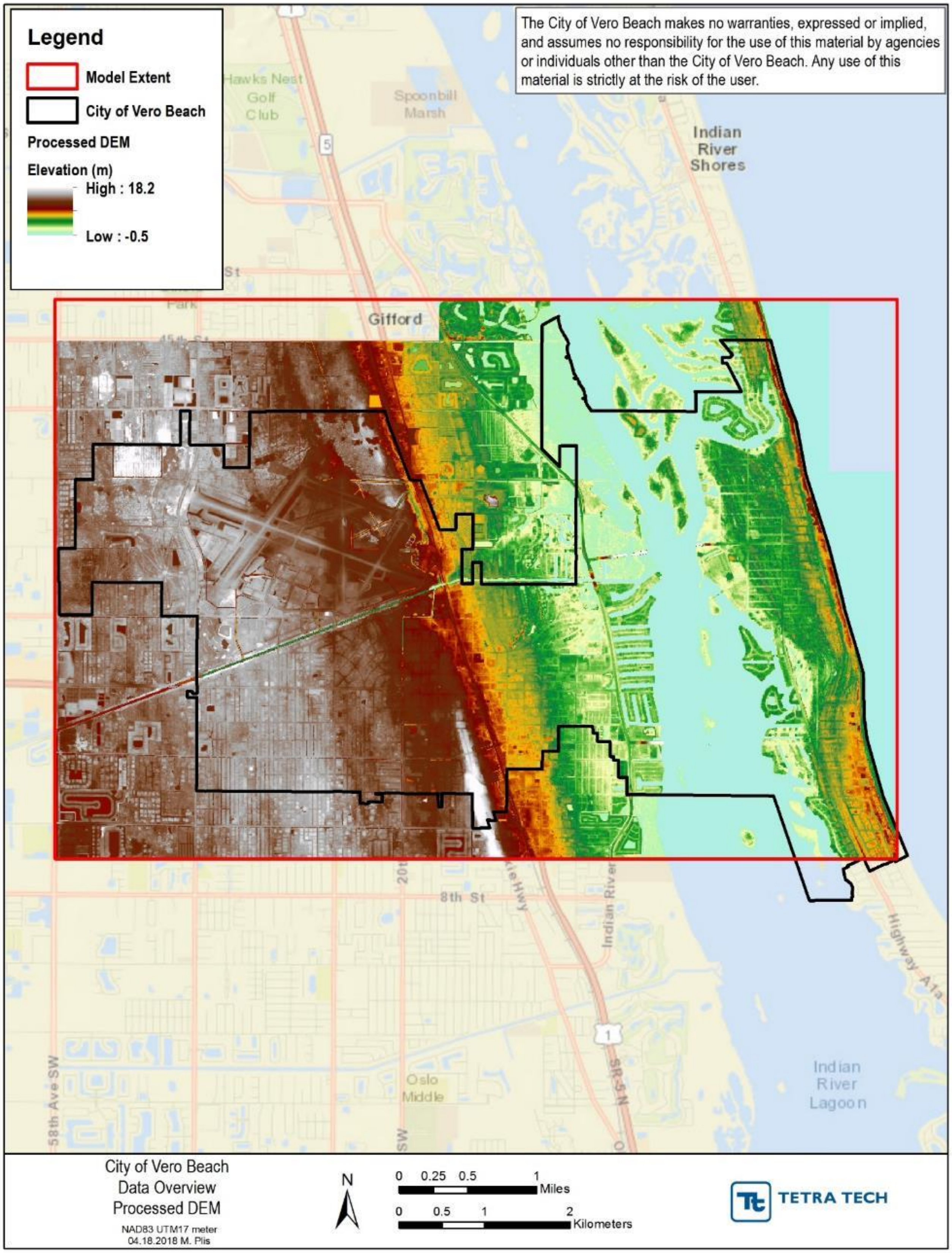

Figure 3-2. Processed and clipped DEM

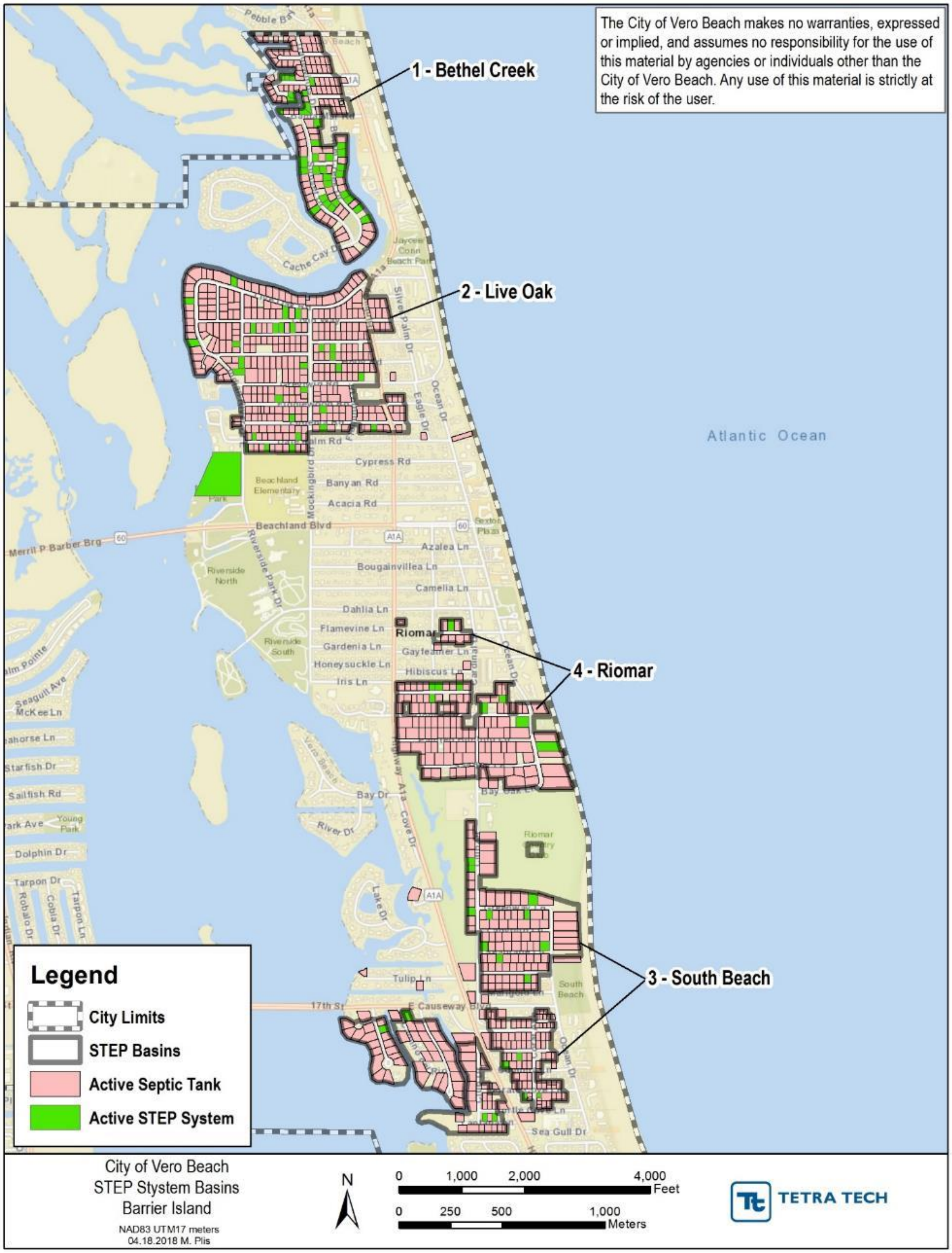

Figure 3-3. Barrier island septic system parcels and STEP system converted parcels

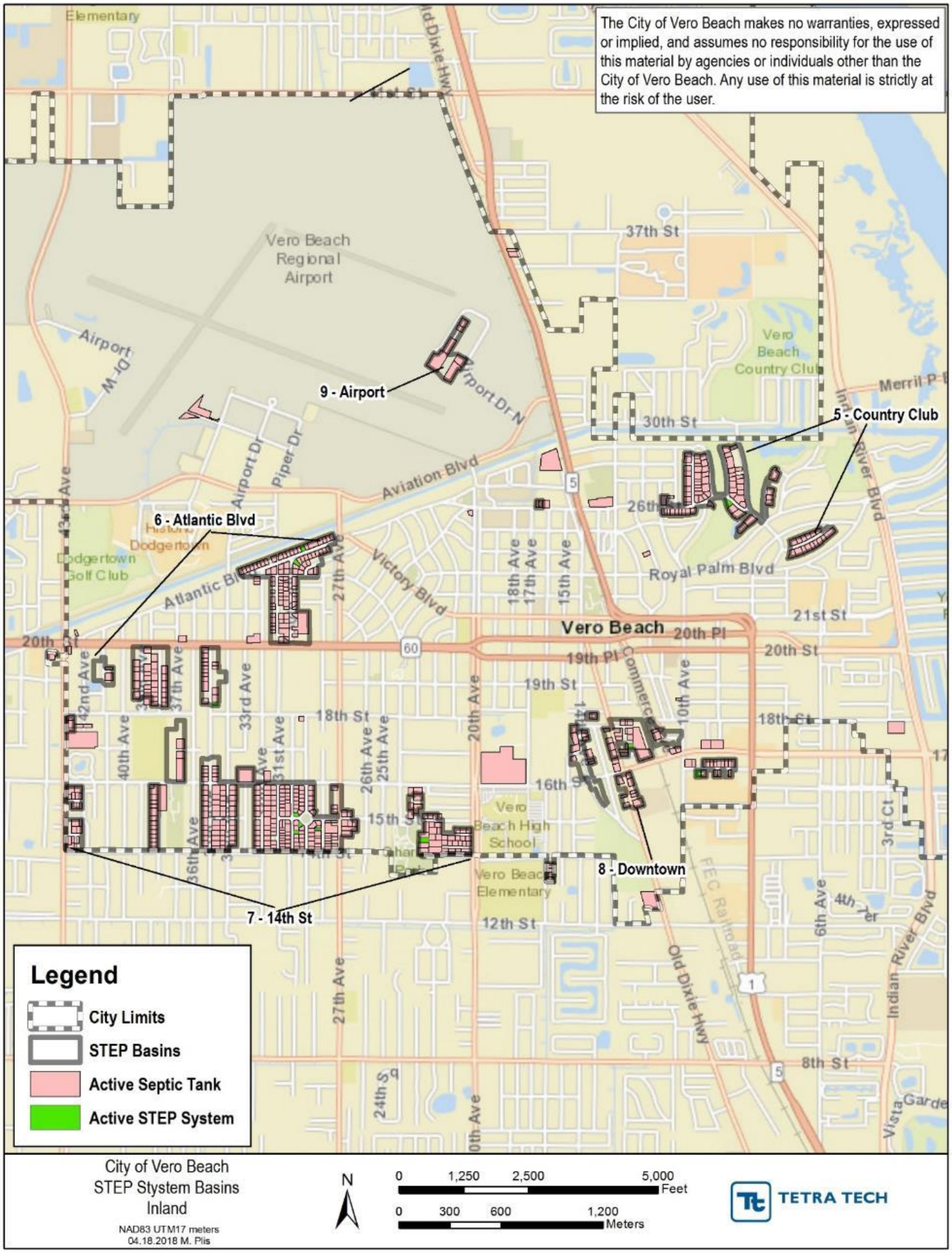

Figure 3-4. Mainland septic system parcels and STEP system converted parcels

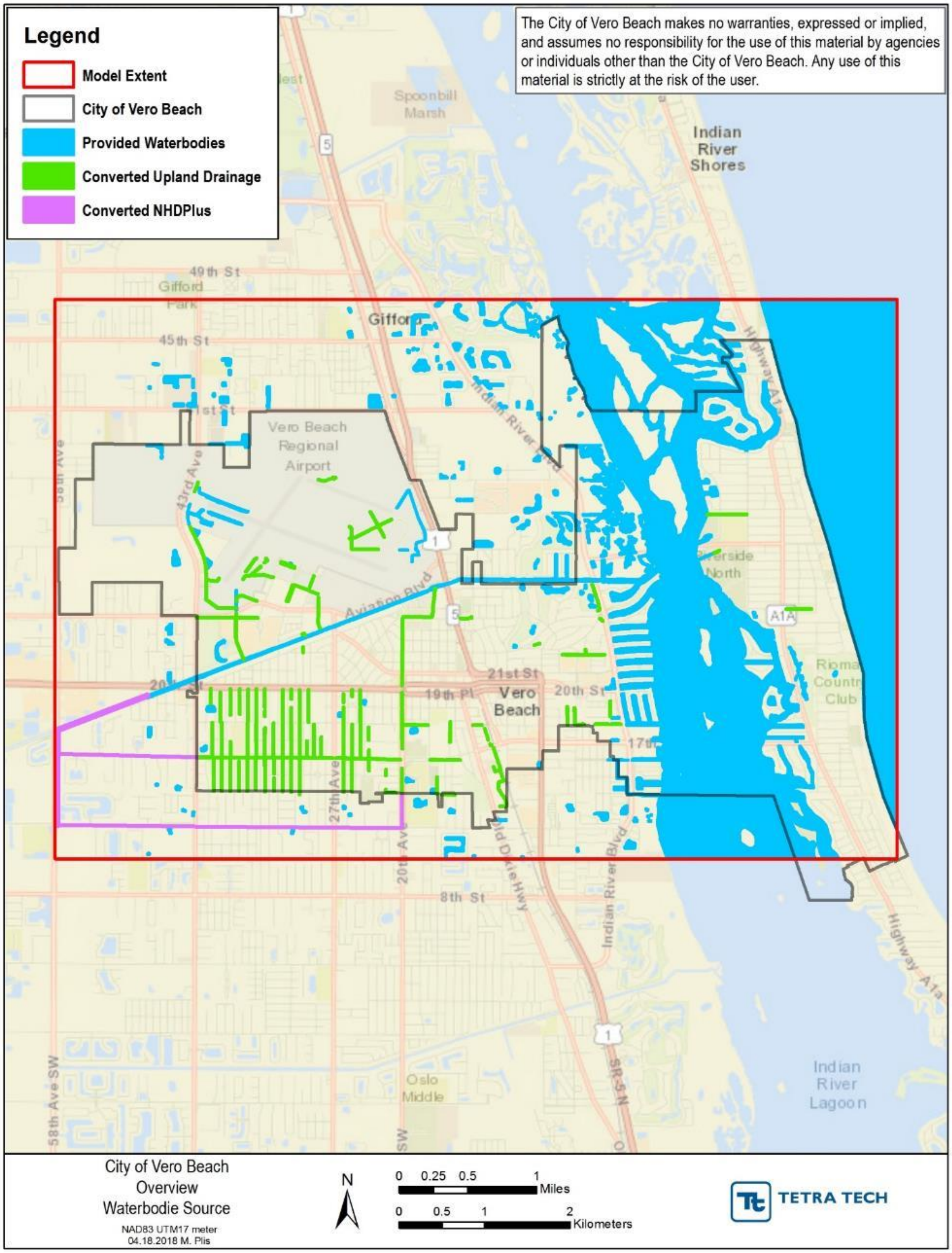

Figure 3-5. Waterbody coverage sources

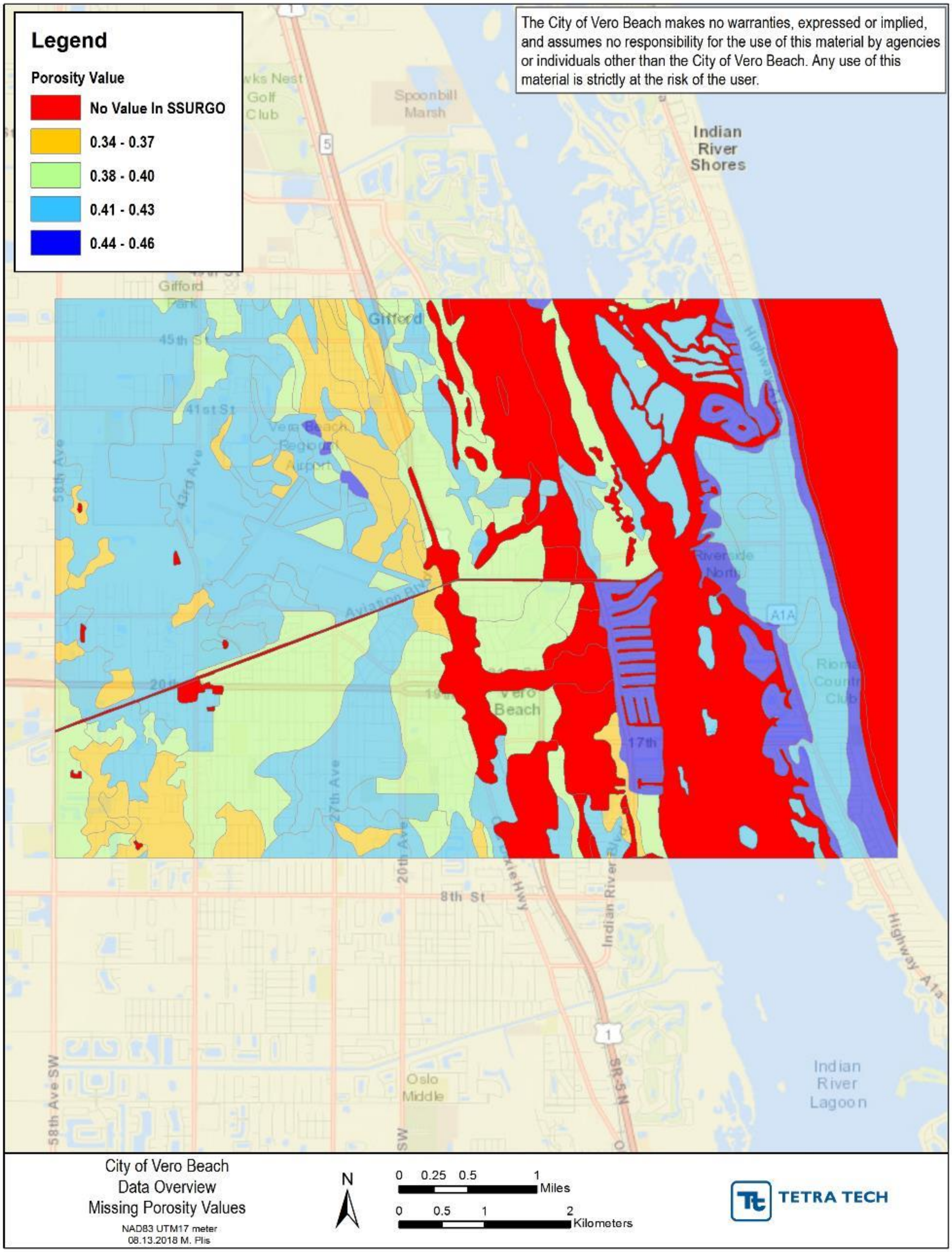

Figure 3-6. 2017 SSURGO soils with missing data

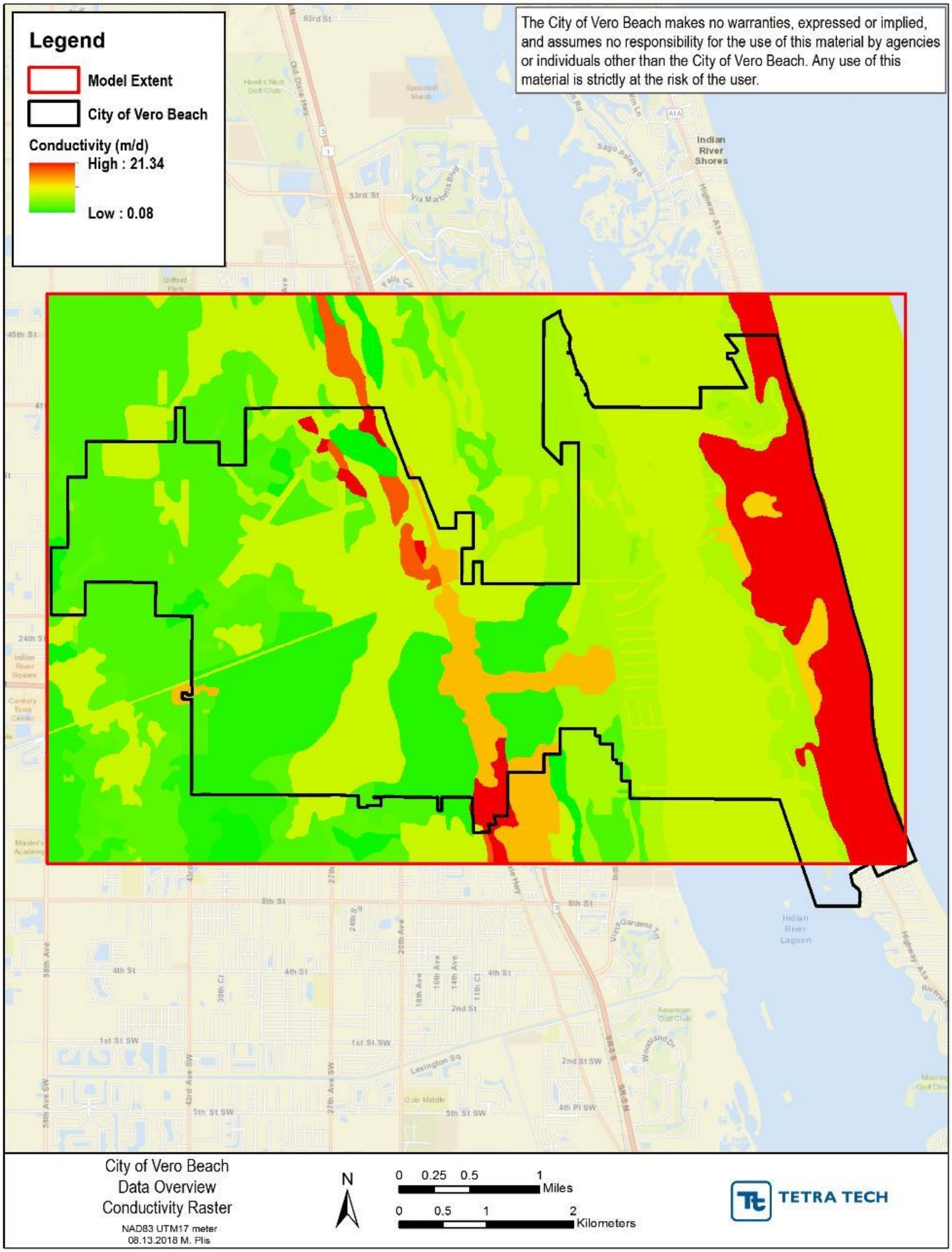

Figure 3-7. Modeled soil hydraulic conductivity

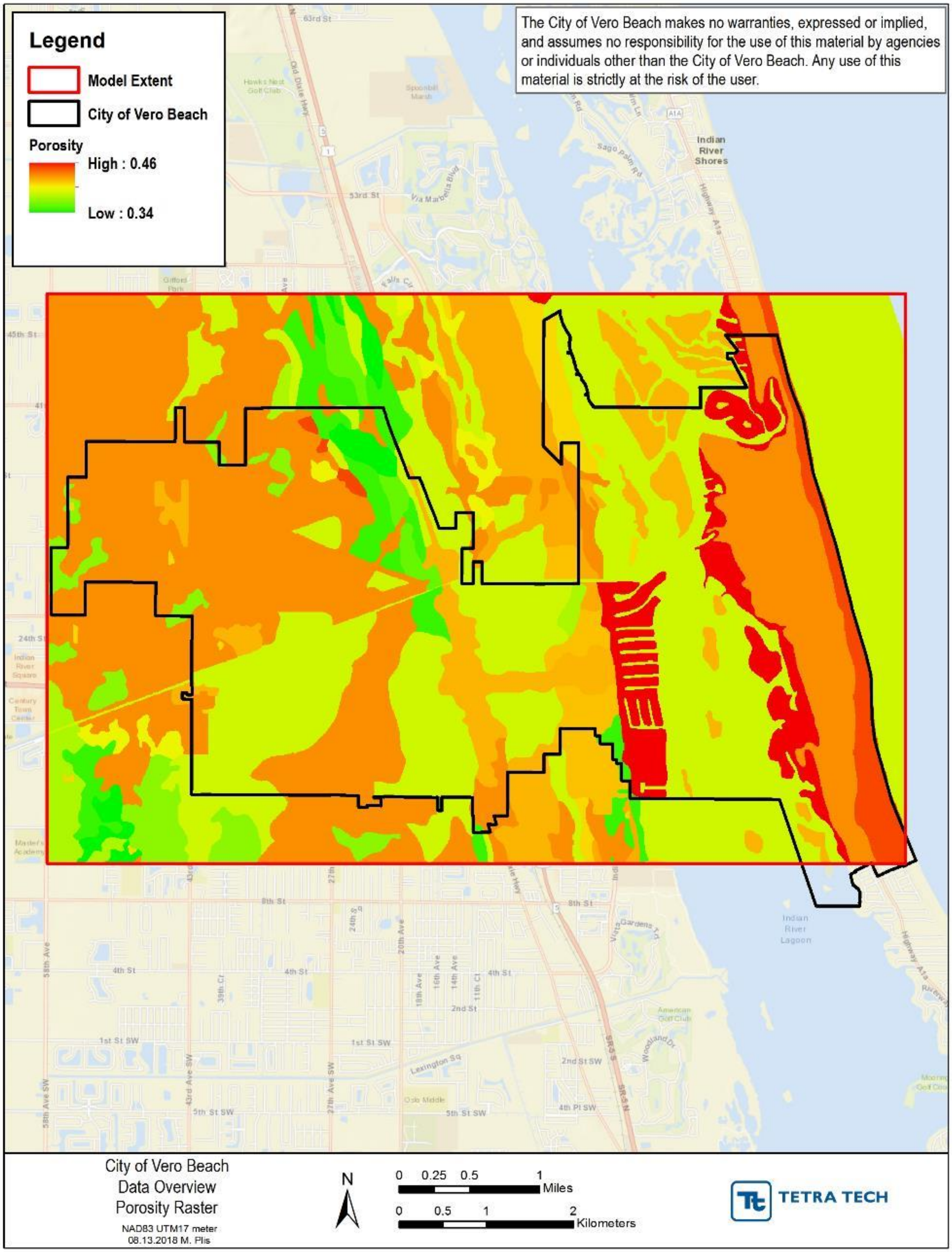

Figure 3-8. Modeled soil porosity

3.5 GROUNDWATER MEASUREMENTS

A search for available groundwater monitoring locations was conducted. Three wells with measured hydraulic head were acquired from the St. Johns River Water Management District website: currently active wells IR0114 and IR0993 and historic well IR0277 (**Figure 3-9**). The data for all wells were converted to meters, and the data from well IR0277 were also converted from National Geodetic Vertical Datum of 1929 (NGVD29) to North American Vertical Datum of 1988 (NAVD88). These three well data sets represent different periods of time; however, the overlapping timeframes show similar trends. The values of observed hydraulic head were averaged and compared to the smoothed DEM. Graphs of the measured values are shown in **Figure 3-10** through **Figure 3-12**.

3.6 GROUNDWATER NITROGEN MEASUREMENTS

No groundwater nitrogen measurements were found within the City.

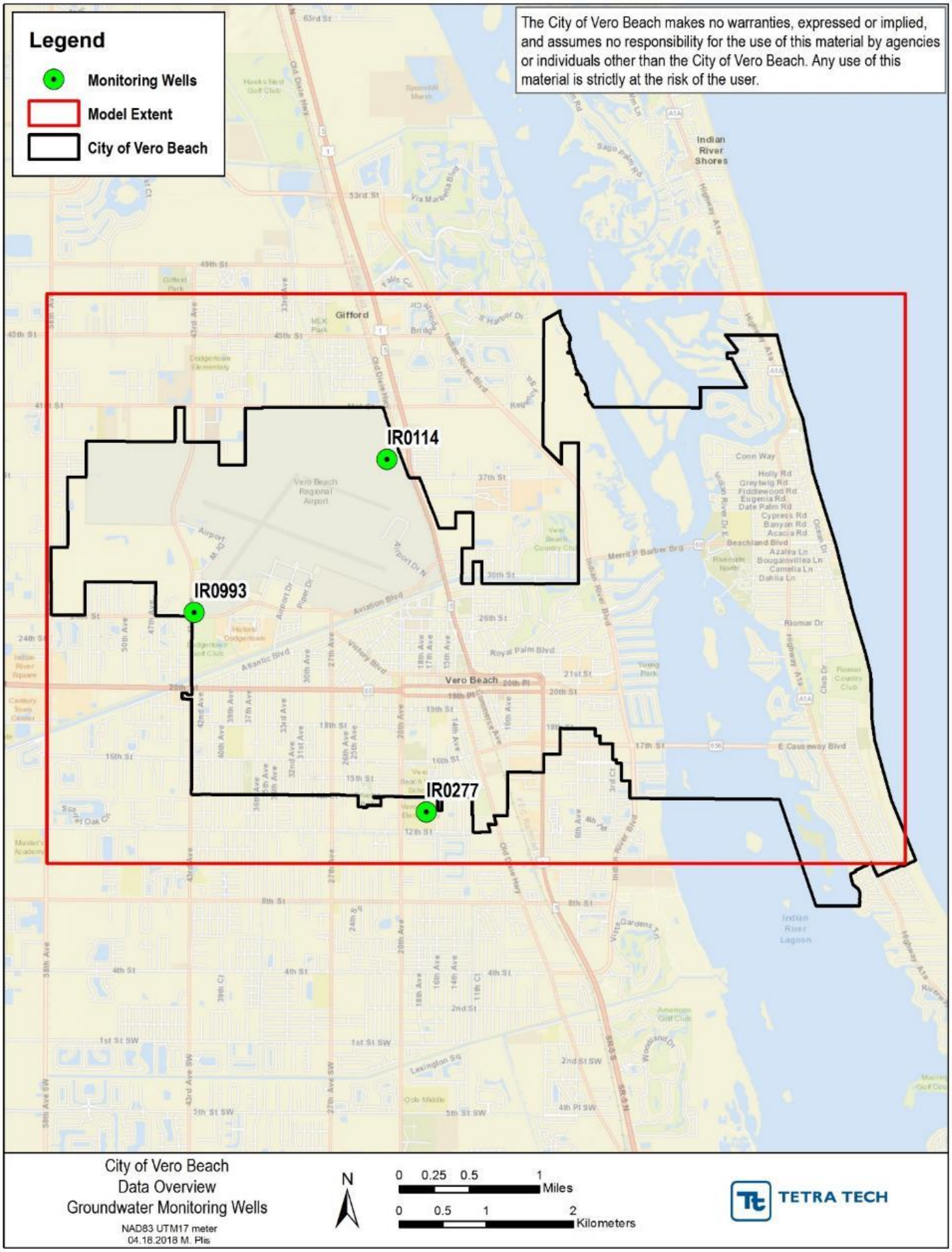

Figure 3-9. Groundwater monitoring well locations

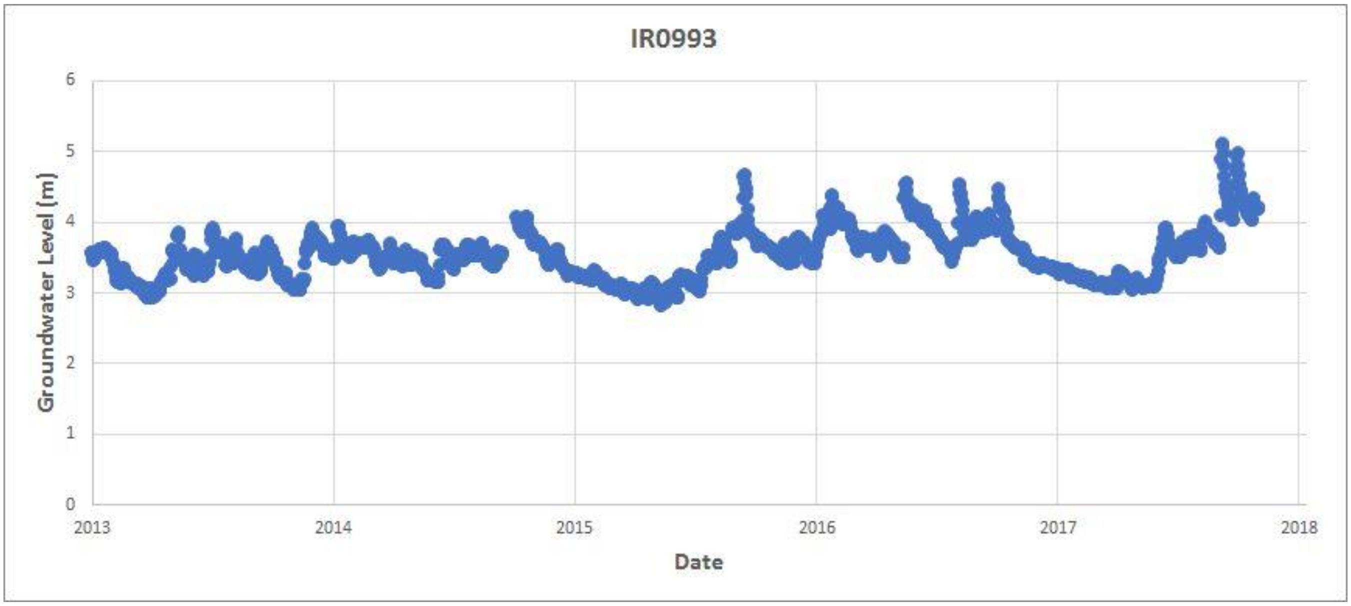

Figure 3-10. Observed groundwater level at IR0993

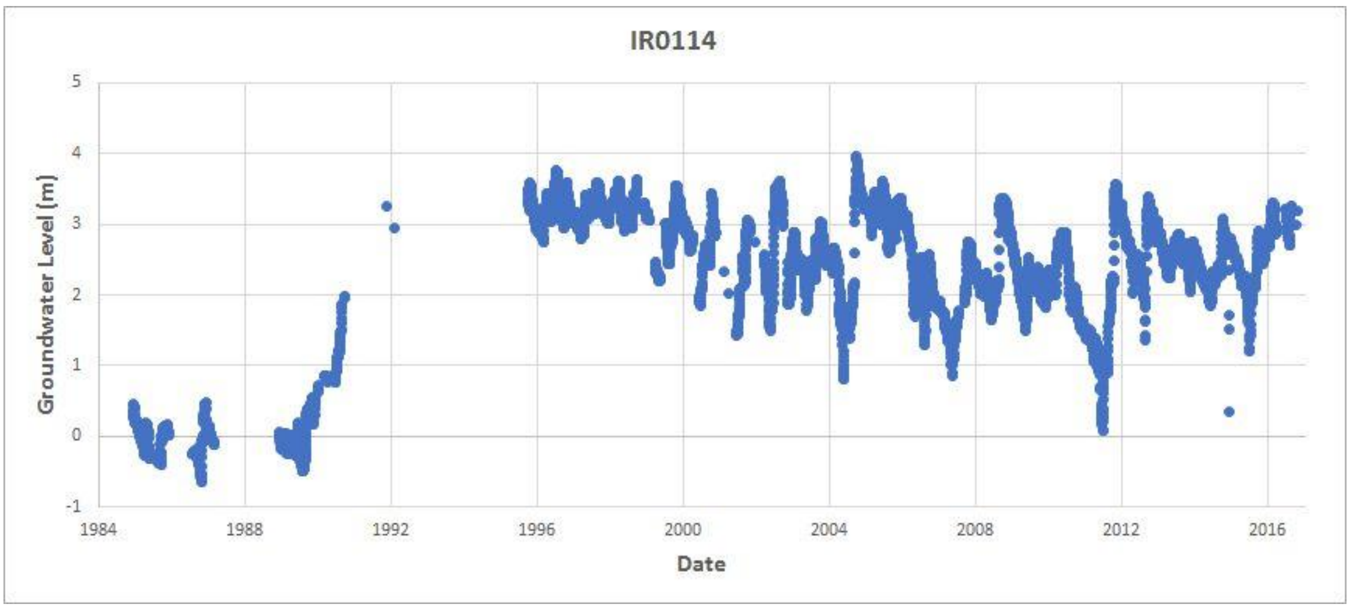

Figure 3-11. Observed groundwater level at IR0114

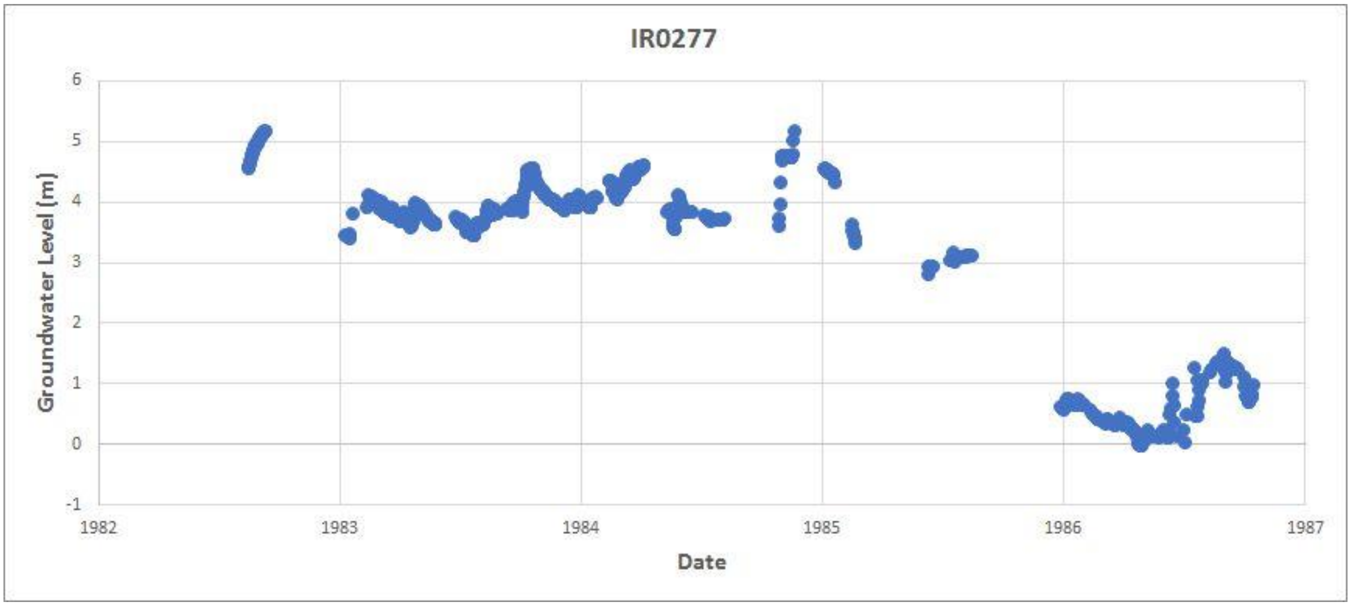

Figure 3-12. Observed groundwater level at IR0277

4.0 MODEL CALIBRATION AND RESULTS

ArcNLET model calibration consists of adjusting modeling parameters to match observed values as closely as possible. In this case there are two major components of the calibration: (1) groundwater flow calibration, and (2) nitrogen concentration calibration. The calibrated model parameters are the smoothing factor, source plane concentration, longitudinal dispersivity, horizontal transverse dispersivity, and first-order decay coefficient of denitrification. **Table 4-1** lists the initial and calibrated values of these parameters. Initial values (taken from Sayemuzzaman et al. 2015) were adjusted to match the available data in the City.

The differences in the parameters used for the City's model, as compared to the above referenced study, can be attributed to a difference in model input data. For instance, the DEM smoothing factor of 65 resulted in the flow paths exhibiting unexpected behavior, such as very closely following ridge lines in the elevation data. This was most likely caused by a much greater resolution of the elevation dataset provided by the City. A smoothing factor of 100 was found to work better in this model and created a smoothed DEM that agreed well with the available measured data (**Figure 4-1**). Source plane concentrations and first-order decay coefficients were not changed because of a lack of measured nitrogen concentrations for comparison. The longitudinal dispersity was increased to its default value to provide a more reasonable distribution of the plumes. The calibrated model particle paths are shown in **Figure 4-2**, and the calibrated nitrogen plume concentrations are show in **Figure 4-3**.

The estimated nitrogen loading results were summarized by each of the STEP basins. The model showed that most of the estimated loads are coming from the barrier island STEP basins – Live Oak, South Beach, and Bethel Creek. While all the nitrogen load ultimately reaches the IRL and Atlantic Ocean, the model showed that more than 83% of the City's modeled septic systems terminate directly into the IRL and Atlantic Ocean. The largest load per septic system is in Bethel Creek (8.24 pounds per year [lbs/yr] per septic system), followed by South Beach (7.50 lbs/yr per septic), and Live Oak (5.47 lbs/yr per septic). These results suggest that focusing on the barrier island STEP basins would yield the greatest load reductions. Interestingly, the Country Club STEP basin, which has a relatively large septic system concentration, does not seem to be contributing much nitrogen load. This is most likely due to a low soil hydraulic conductivity in the area, which allows the nitrogen time to denitrify instead of flowing directly to a waterbody.

Figure 4-4 through **Figure 4-7** show in more detail the modeled nitrogen plume concentrations in the individual STEP basins. **Figure 4-8.** Top ten waterbodies with the highest loads**,** and **Figure 4-9.** Top 20 waterbodies with the highest loads

show the ten waterbodies with the highest estimated loads and the relationship with the entire City's estimated loading. **Figure 4-9** shows the location of the top 20 waterbodies with the highest load. **Figure 4-10** and **Table 4-3** summarize estimated loadings by STEP basing and detail individual septic system load estimates.

Table 4-1. Initial and calibrated ArcNLET parameters

Parameter	Initial Value	Calibrated Value
Smoothing Factor	65	100
Source Plane Concentration (mg/L)	40	40
Longitudinal Dispersivity (m)	1	10
Horizontal Transverse Dispersivity (m)	0.1	1
First-Order Decay Coefficient of Denitrification	0.00055	0.00055

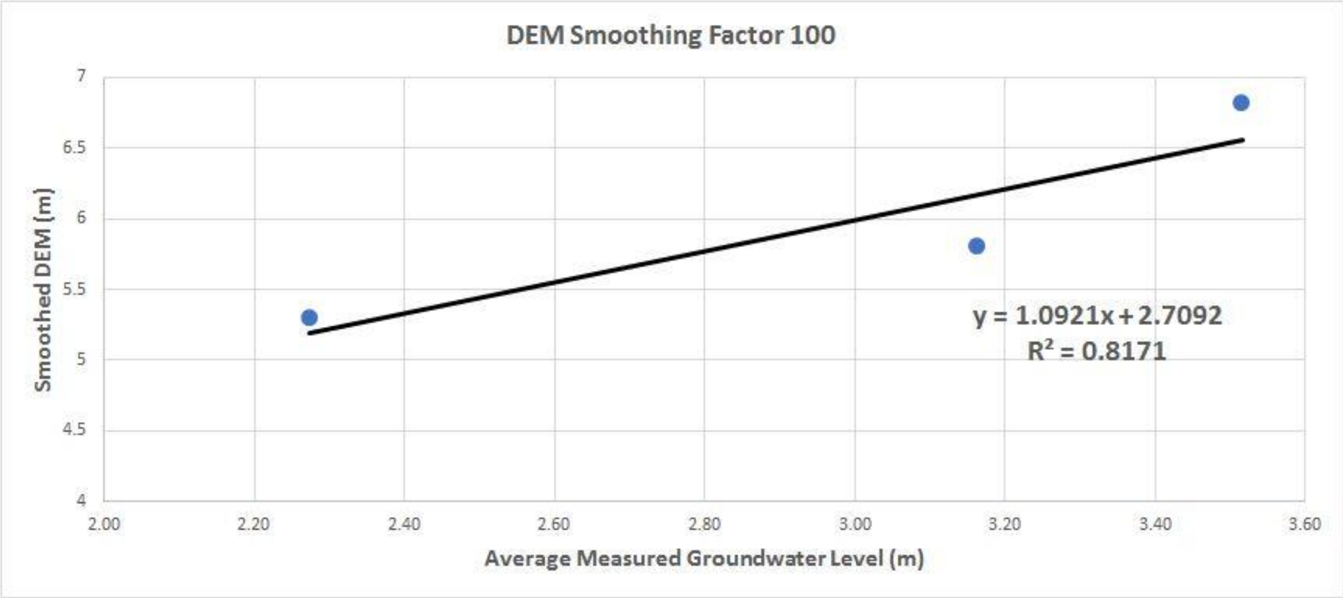

Figure 4-1. Smoothed DEM relationship with the measured water level

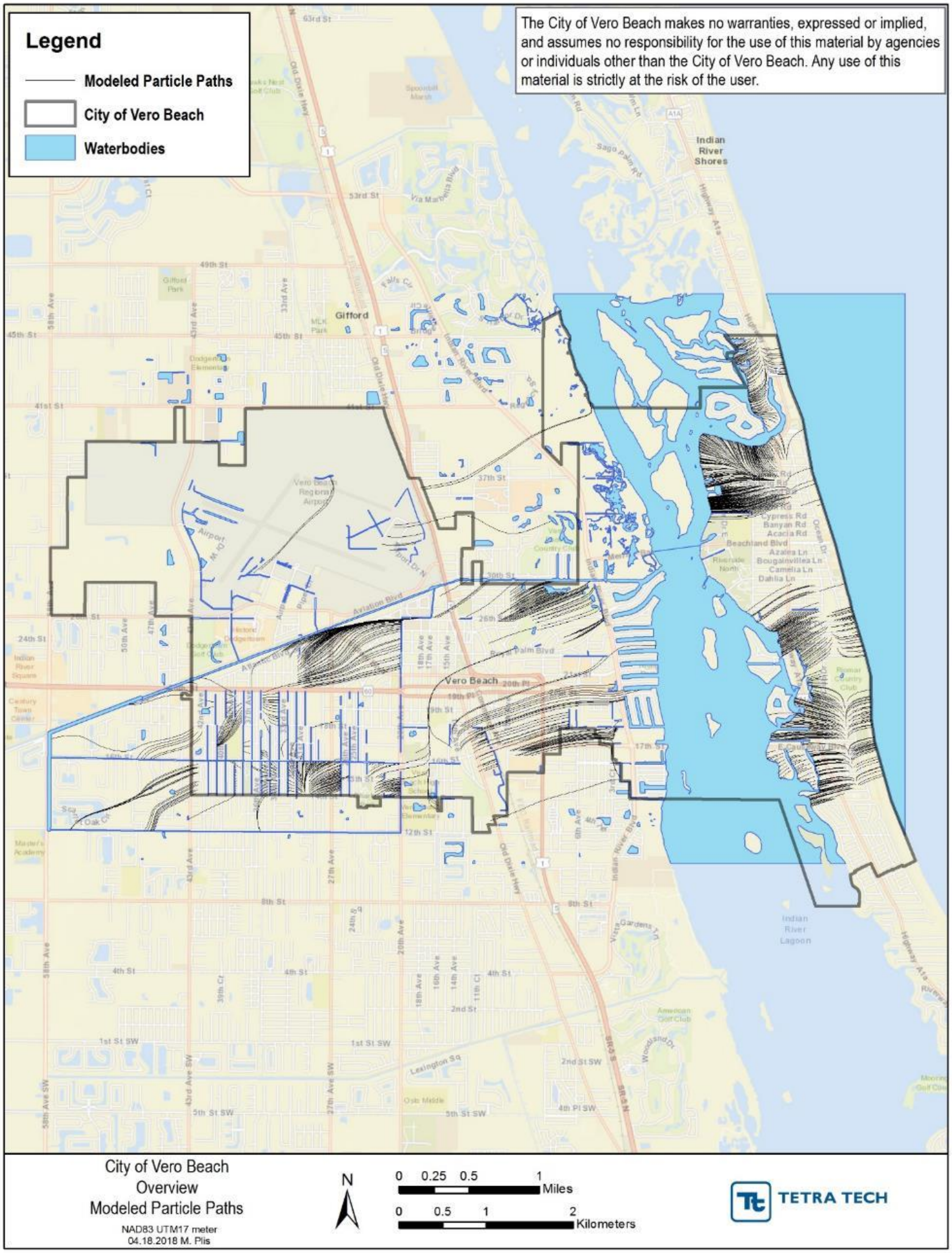

Figure 4-2. Modeled particle paths

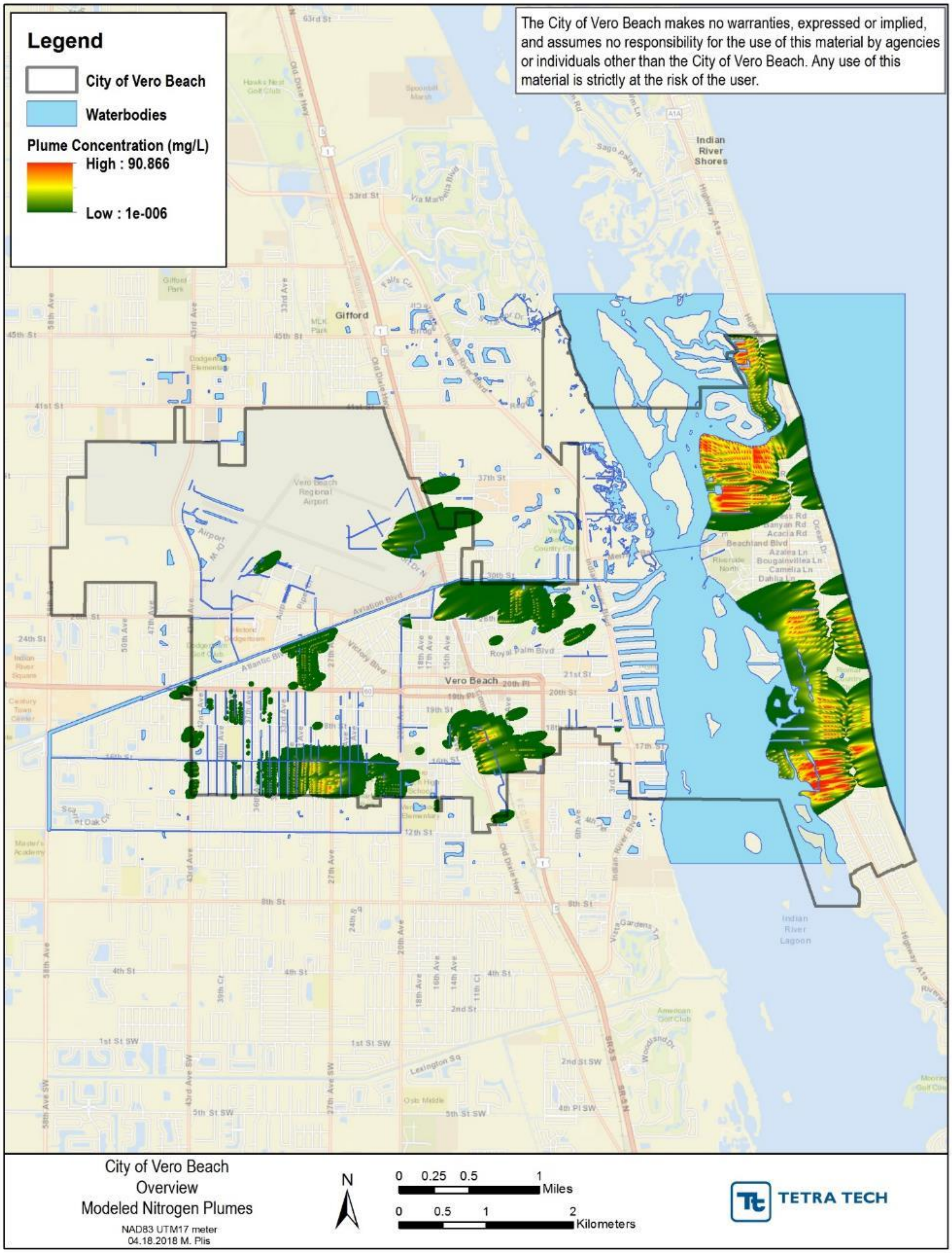

Figure 4-3. Modeled nitrogen plumes

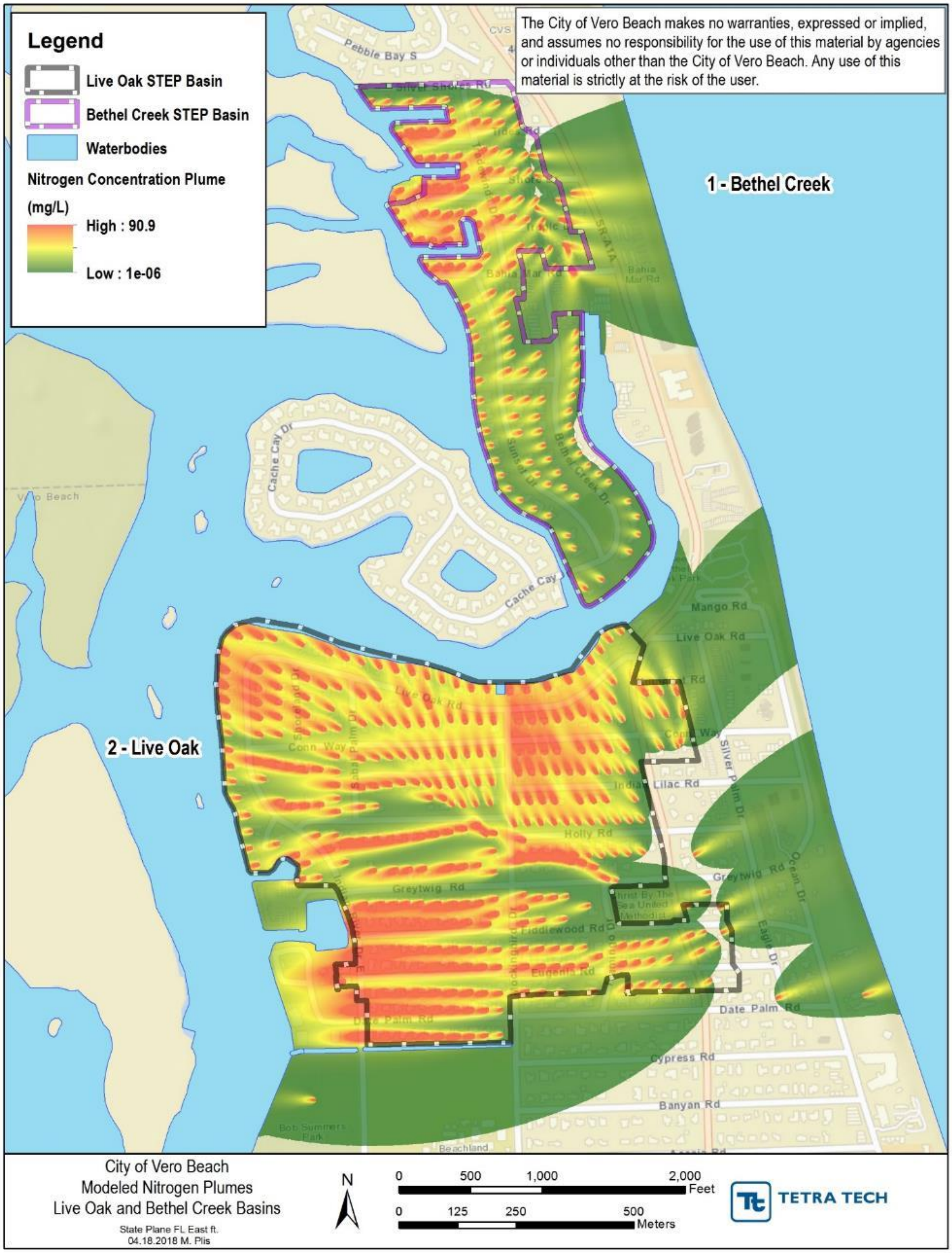

Figure 4-4. Bethel Creek and Live Oak modeled nitrogen concentrations

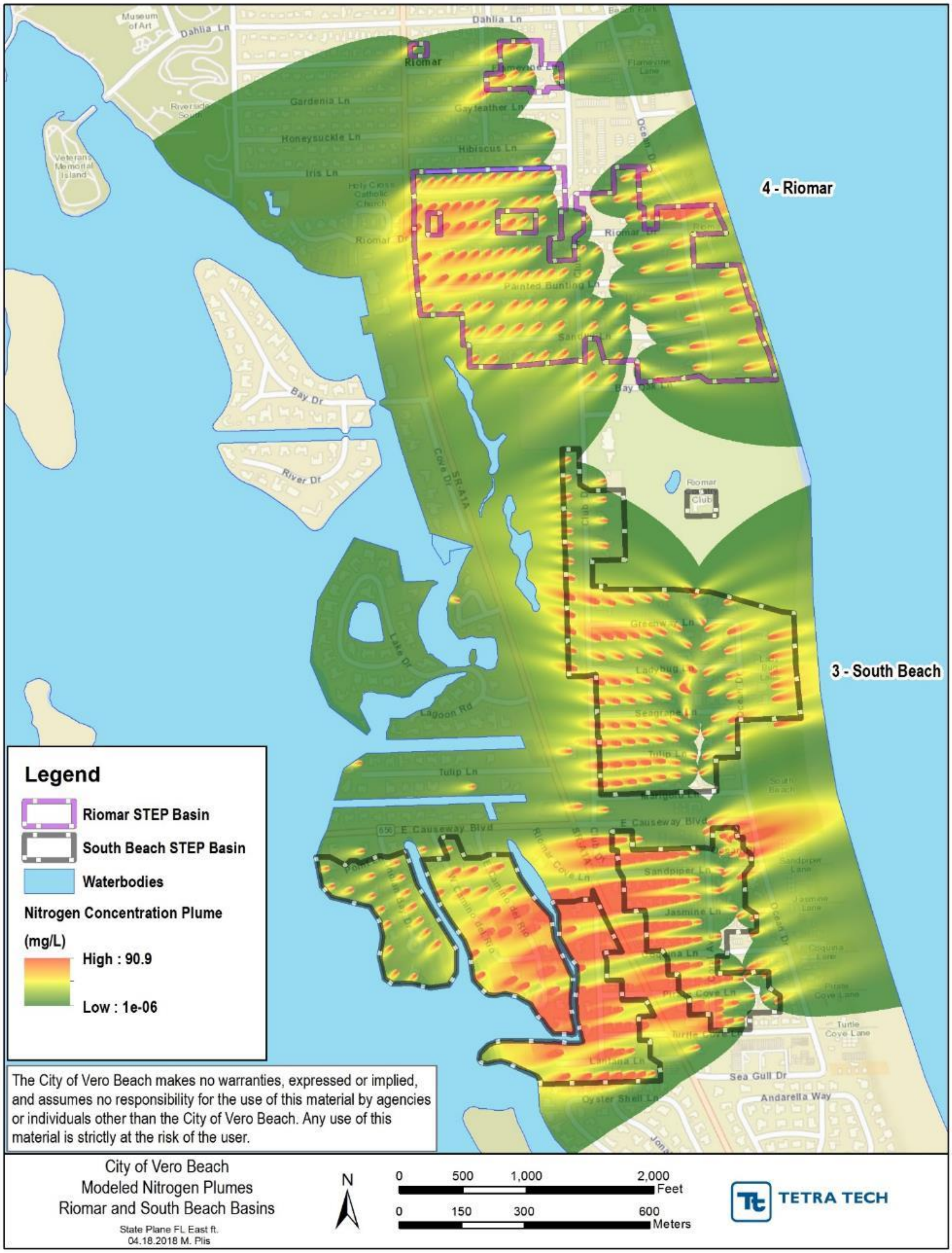

Figure 4-5. South Beach and Riomar modeled nitrogen concentrations

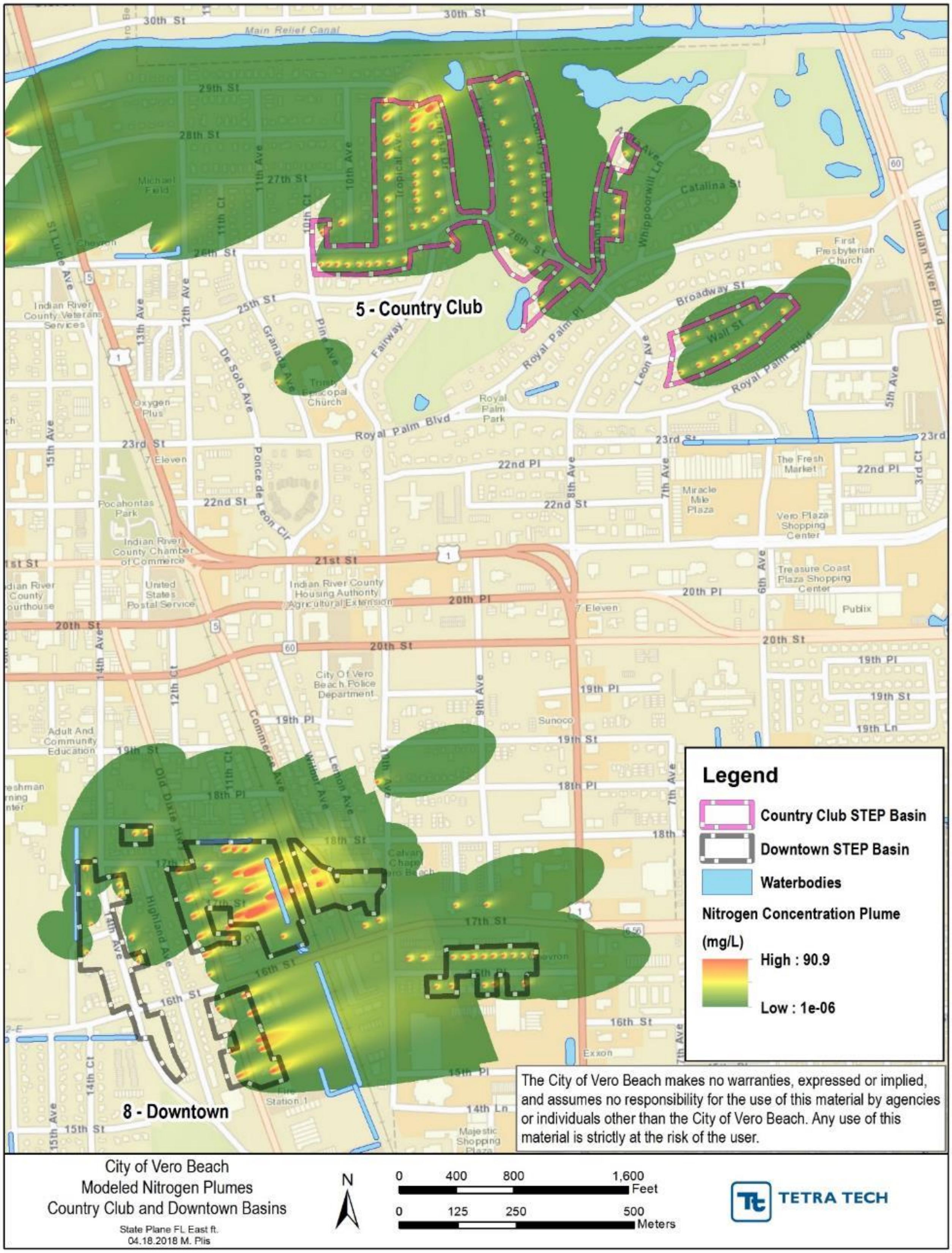

Figure 4-6. Country Club and Downtown modeled nitrogen concentrations

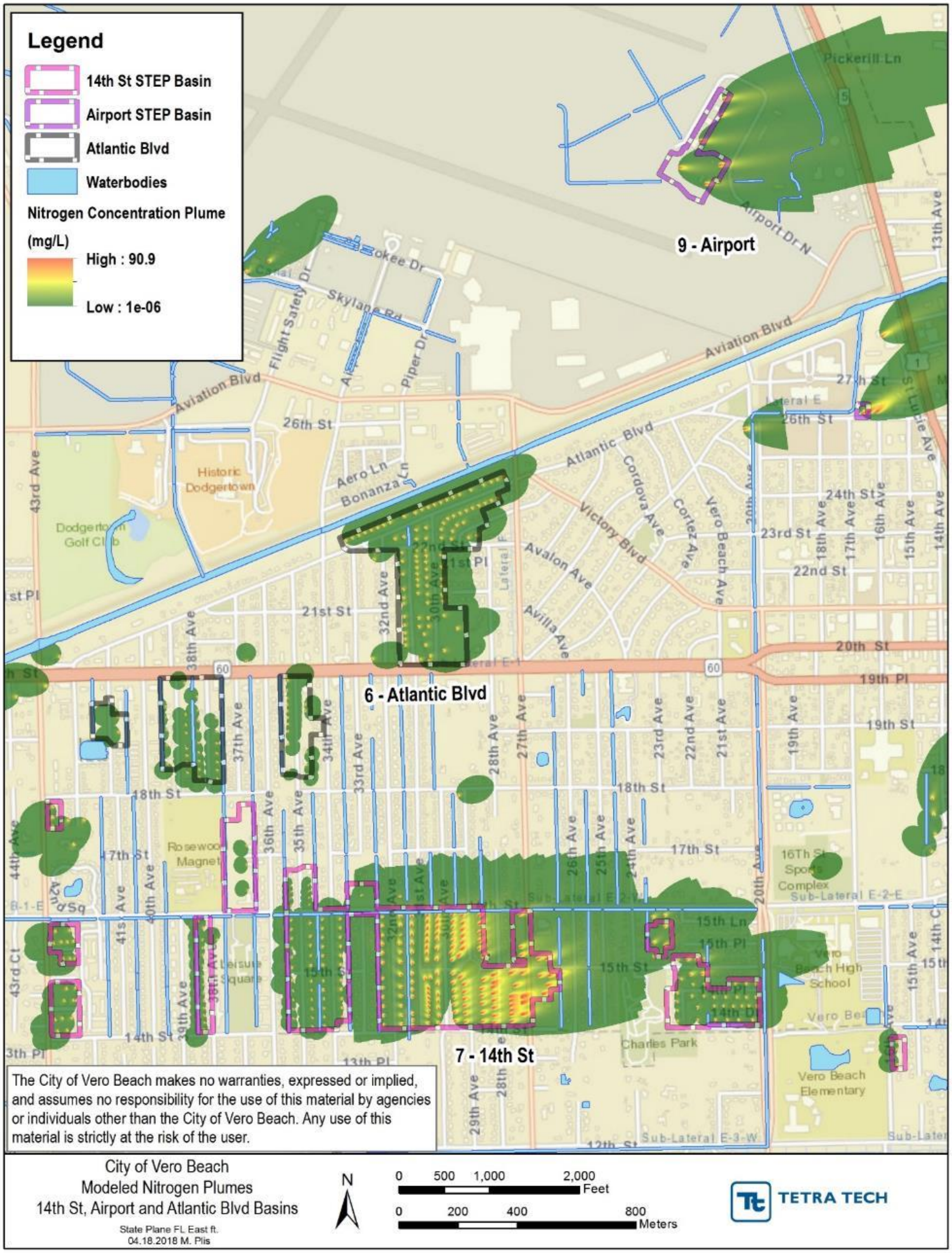

Figure 4-7. Atlantic Boulevard, 14th Street, and Airport modeled nitrogen concentrations

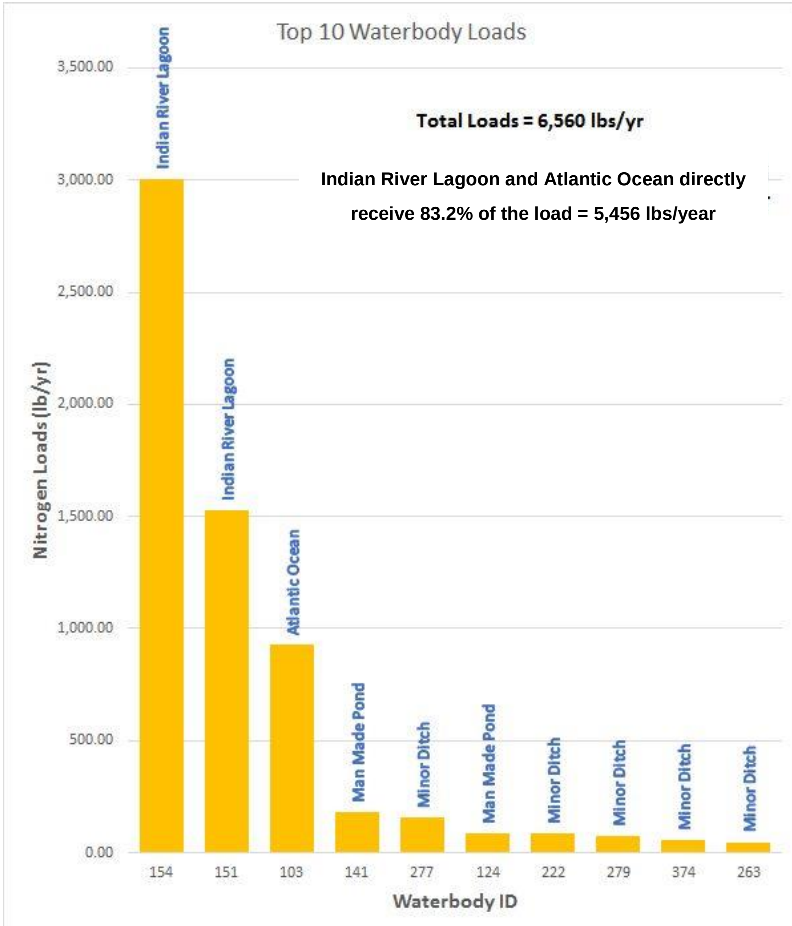

Figure 4-8. Top ten waterbodies with the highest loads

Table 4-2. Detailed loads for top ten waterbodies

Waterbody Name/Type	Waterbody ID	Contributing STEP Basins	Load (lbs/yr)	% of Total Load
IRL	154	Live Oak, Bethel Creek	3,004	45.79%
IRL	151	South Beach, Riomar	1,525	23.25%
Atlantic Ocean	103	Live Oak, Bethel Creek, South Beach, Riomar	928	14.14%
Man Made Pond	141	South Beach	181	2.76%
Minor Ditch	277	Downtown	155	2.36%
Man Made Pond	124	Riomar	86	1.31%
Minor Ditch	222	Downtown	85	1.30%
Minor Ditch	279	14th Street	75	1.14%
Minor Ditch	374	14th Street	57	0.86%
Minor Ditch	263	14th Street	48	0.73%
Total in Top 10			**6,144**	**93.64%**

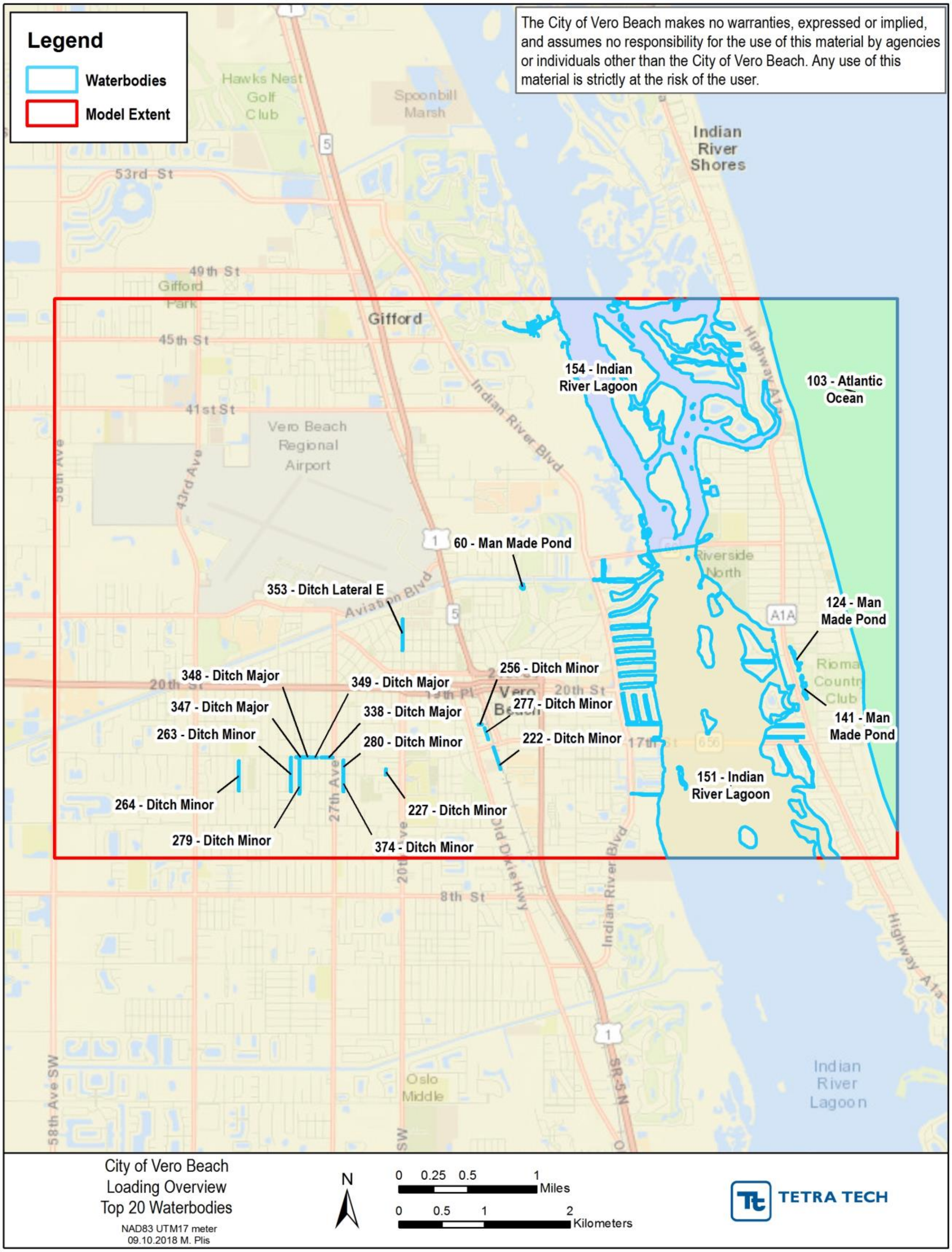

Figure 4-9. Top 20 waterbodies with the highest loads

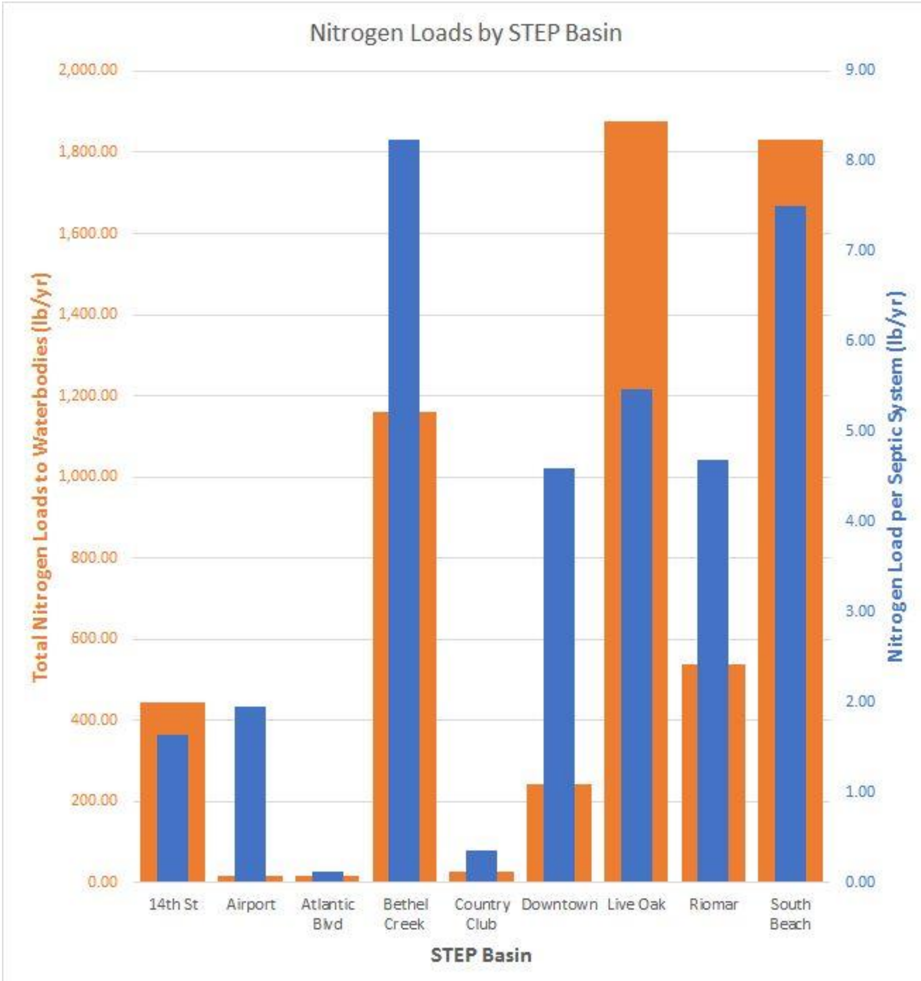

Figure 4-10. Estimated nitrogen loads by STEP basin

Table 4-3. Estimated nitrogen loads by STEP basin detail

STEP Basin	Total Load to Waterbodies	Number of Septic Systems	Load per System	% of Total Load
14th Street	445	272	1.64	6.78%
Airport	16	8	1.95	0.24%
Atlantic Boulevard	16	136	0.12	0.25%
Bethel Creek	1,162	141	8.24	17.72%
Country Club	29	81	0.36	0.44%
Downtown	243	53	4.59	3.71%
Live Oak	1,876	343	5.47	28.60%
Riomar	539	115	4.69	8.22%
South Beach	1,830	244	7.50	27.89%
Total in STEP Basins	**6,156**	**1,393**	**4.42**	**93.84%**

5.0 STEP SYSTEM CONVERSION NITROGEN LOAD REDUCTIONS

As of the time of this report, the City of Vero Beach have converted 101 of its 1,473 homes on septic systems to STEP systems and connected them to the sewer system. To estimate the nitrogen load reductions resulting from these conversions a separate current condition scenario of the model was developed and executed (STEP Scenario). This section discusses the current conditions scenario and findings.

5.1 STEP SCENARIO MODEL INPUT

The DEM, waterbodies, soil porosity, and saturated hydraulic conductivity value inputs to the current condition scenario model remained the same as the calibrated model. Septic system locations were updated to remove the 101 septic systems that were converted to STEP systems. Refer to Beach for the locations of the septic systems converted to STEP.

5.2 STEP SCENARIO MODEL RESULTS

The current condition model particle paths are shown in **Figure 5-1**,and the calibrated nitrogen plume concentrations are show in **Figure 5-2**. **Figure 5-3** through **Figure 5-6** show in more detail the modeled nitrogen plume concentrations in the individual STEP basins**. Figure 5-7** and **Table 5-1**Figure 4-9. Top 20 waterbodies with the highest loads

show the ten waterbodies with the highest estimated loads and the relationship with the entire City's estimated loading. **Figure 5-8** and **Table 5-2** show the estimated loads by STEP basin and detail individual septic system load estimates.

5.3 STEP SCENARIO MODEL LOAD REDUCTIONS

The STEP Scenario results in a 511 lbs/yr reduction in nitrogen loading to the surrounding waterbodies, which is a reduction of 7.9% in the total nitrogen loading. The average reduction per septic system converted to a STEP system is 5.1 lbs/yr of nitrogen. The STEP basins with the largest nitrogen load reductions are Bethel Creek with 186 lbs/yr, Live Oak with 139 lbs/yr, and South Beach with 107 lbs/yr.

Figure 5-9 through **Figure 5-12** show the per-STEP basin reduction in nitrogen concentrations of the modeled nitrogen plumes. **Figure 5-13** and **Table 5-3** show the five waterbodies with the highest estimated load reductions. The largest nitrogen load reductions occur to the IRL and Atlantic Ocean, which account for 471 lbs/yr (approximately 92%) of the total load reductions. **Figure 5-14** and **Table 5-4** show the nitrogen load reductions by STEP basin.

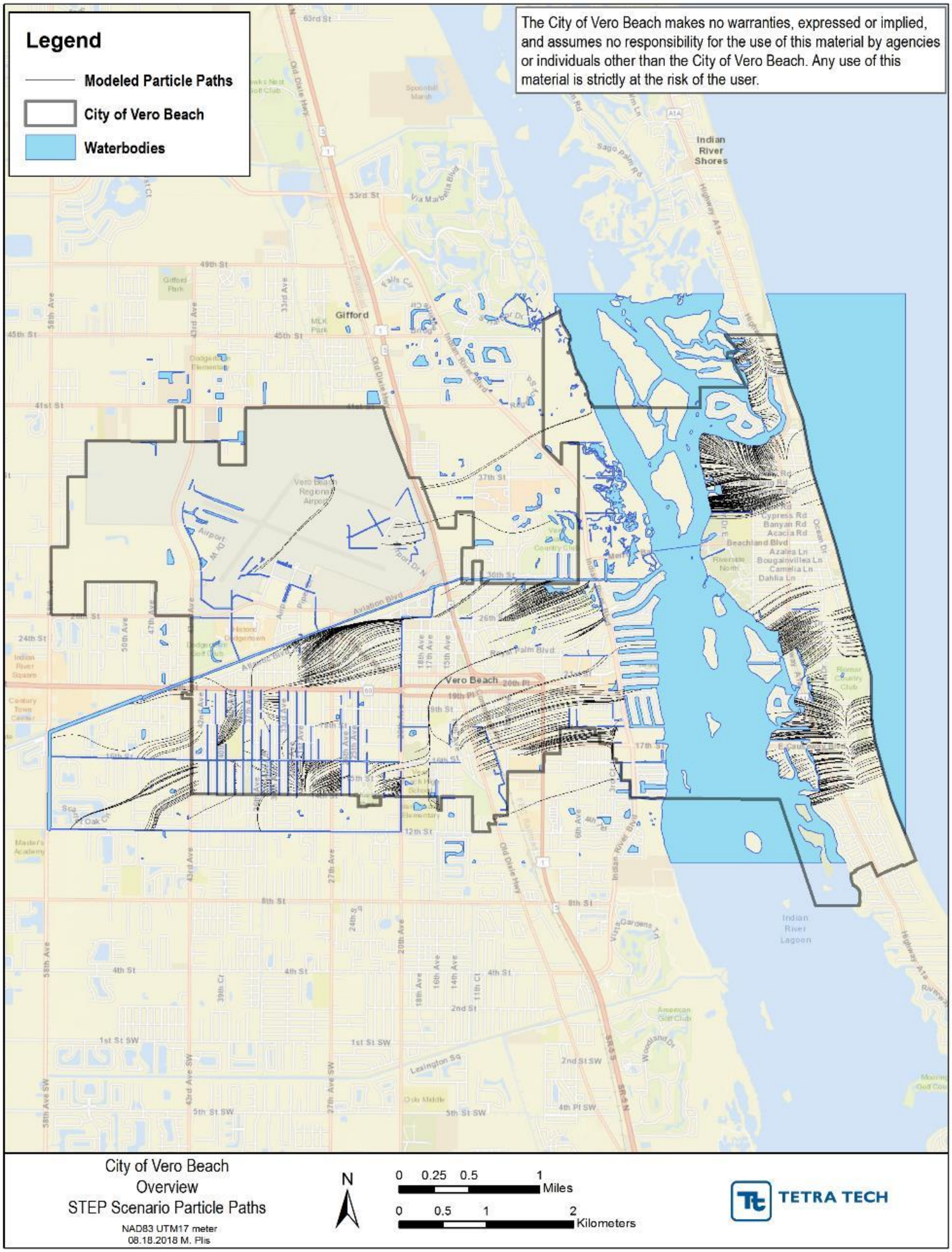

Figure 5-1. STEP Scenario modeled particle paths

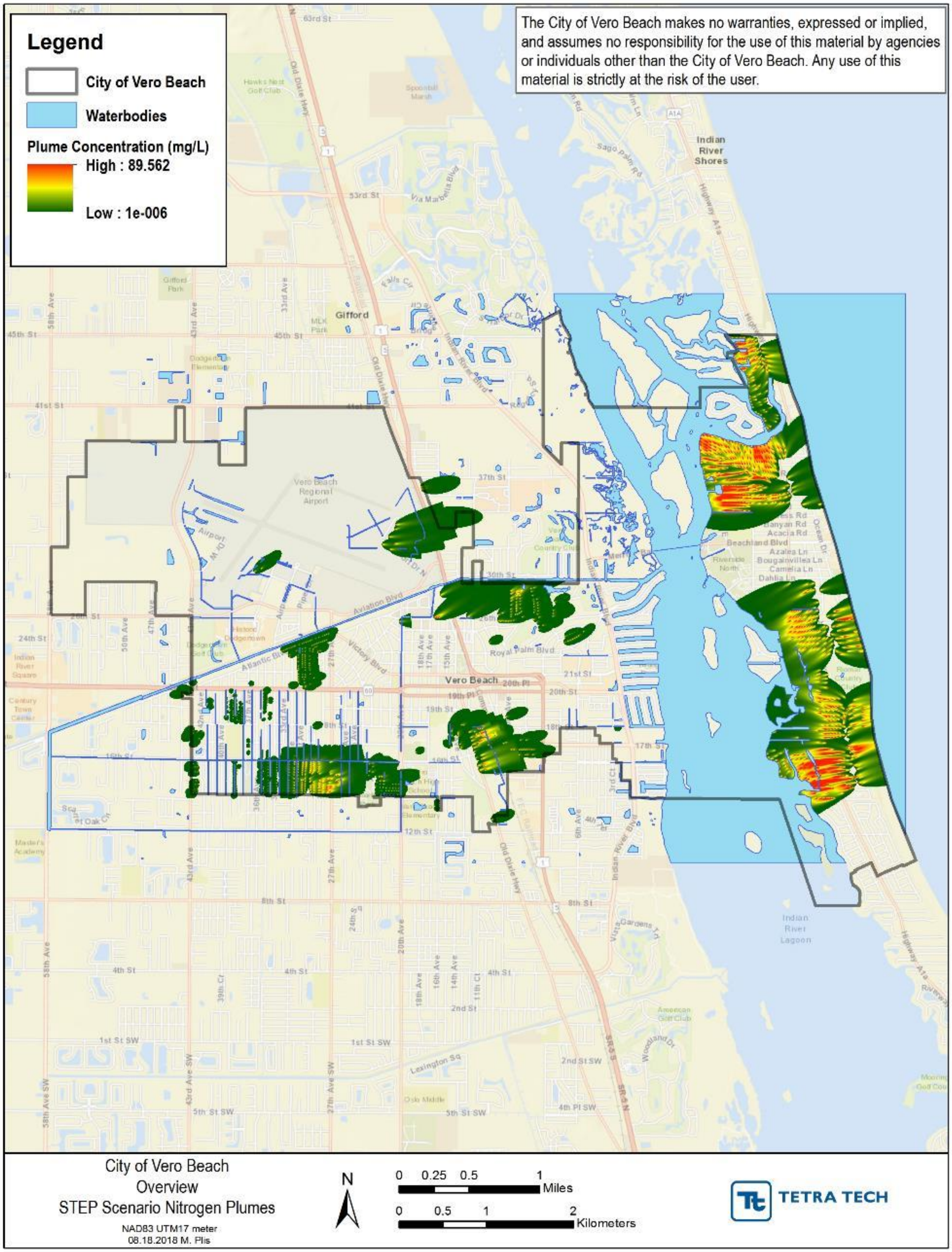

Figure 5-2. STEP Scenario modeled nitrogen plumes

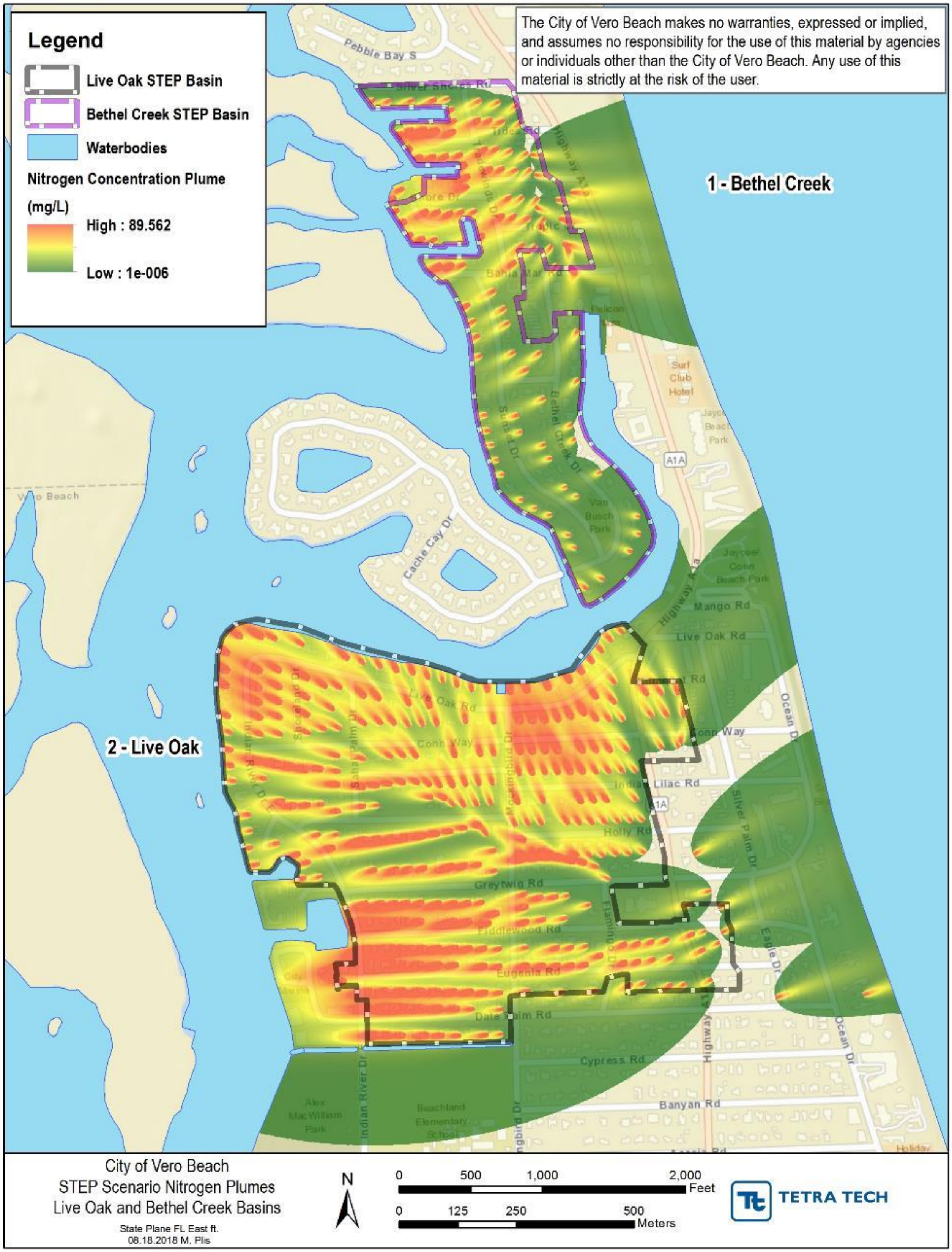

Figure 5-3. STEP Scenario Bethel Creek and Live Oak modeled nitrogen concentrations

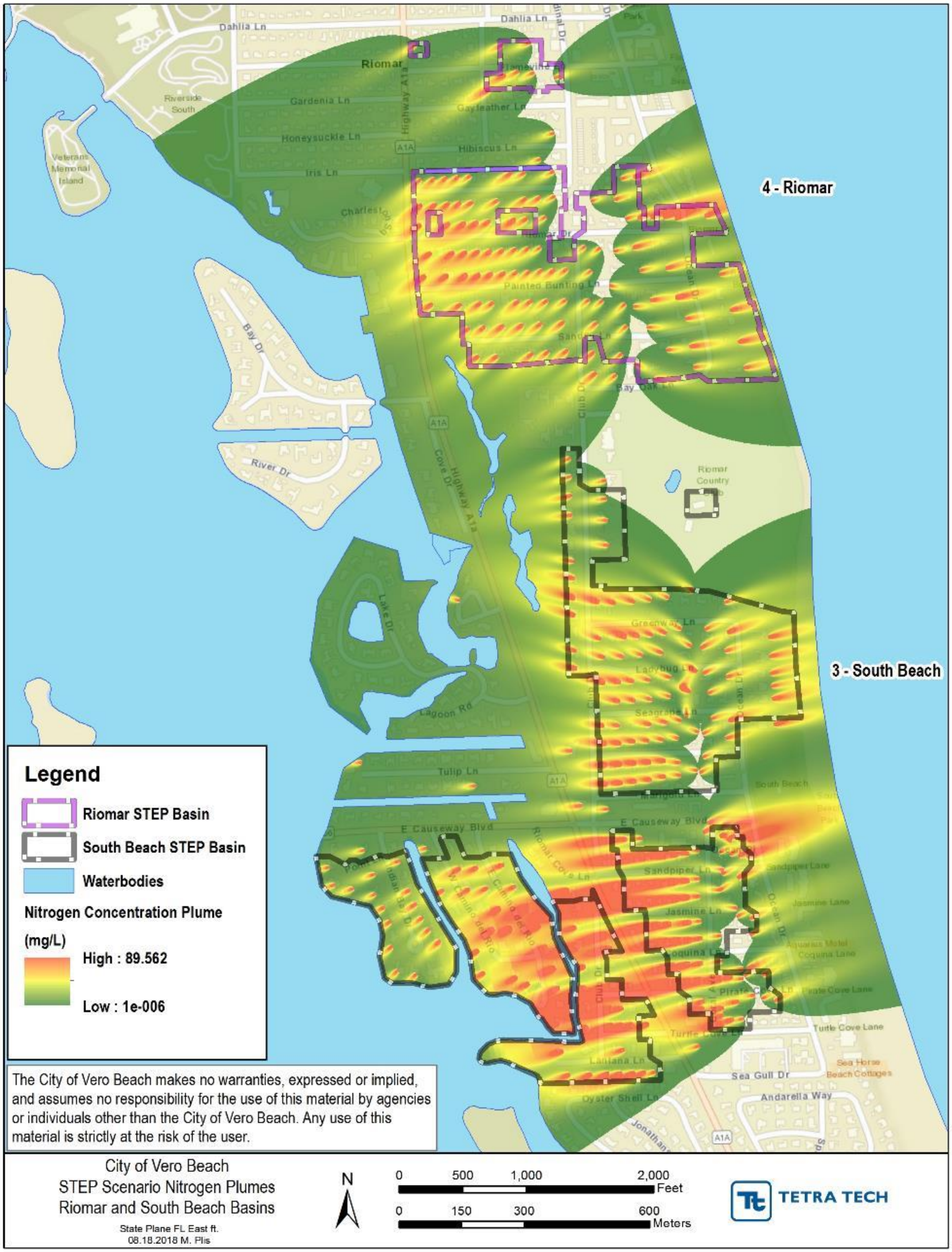

Figure 5-4. STEP Scenario South Beach and Riomar modeled nitrogen concentrations

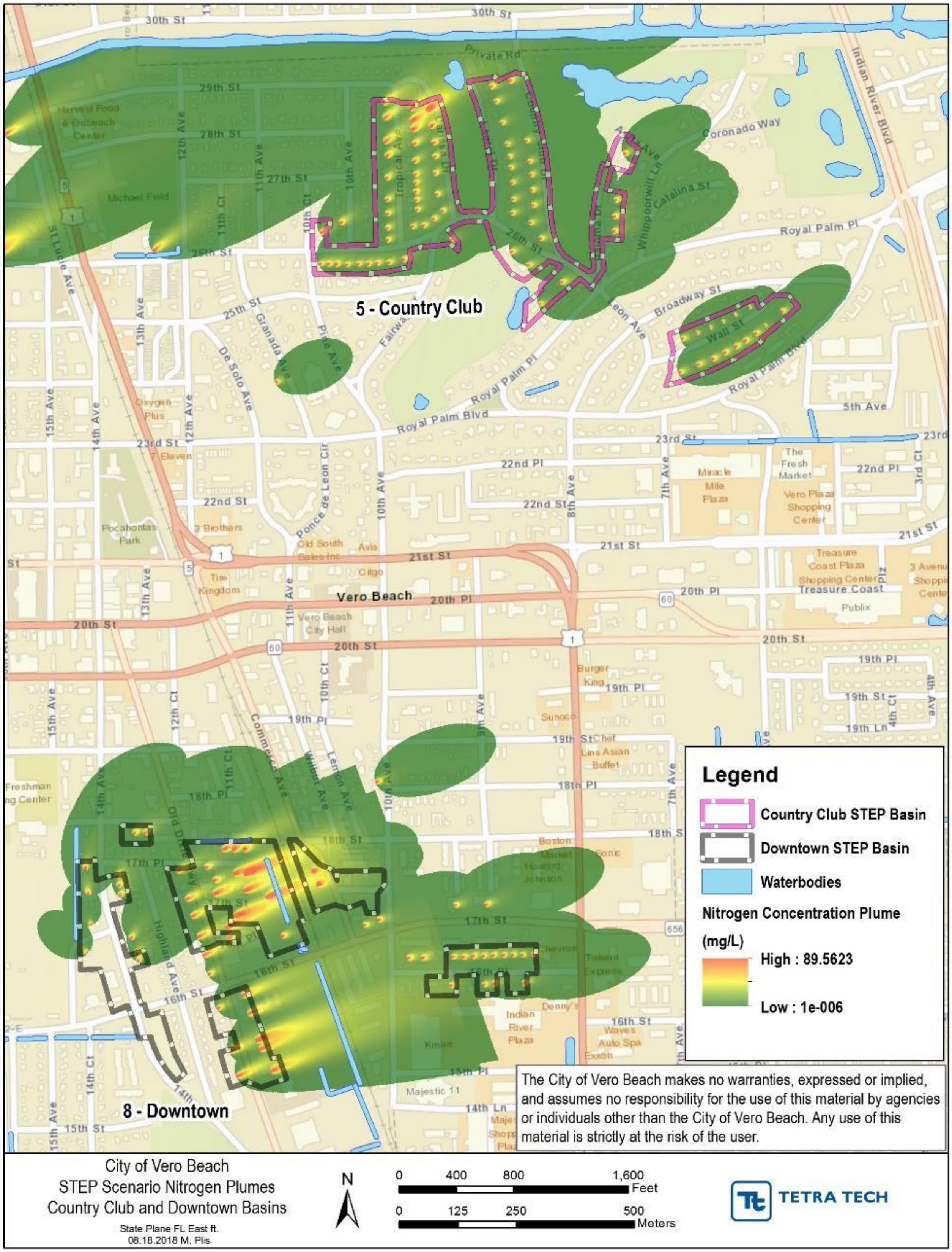

Figure 5-5. STEP Scenario Country Club and Downtown modeled nitrogen concentrations

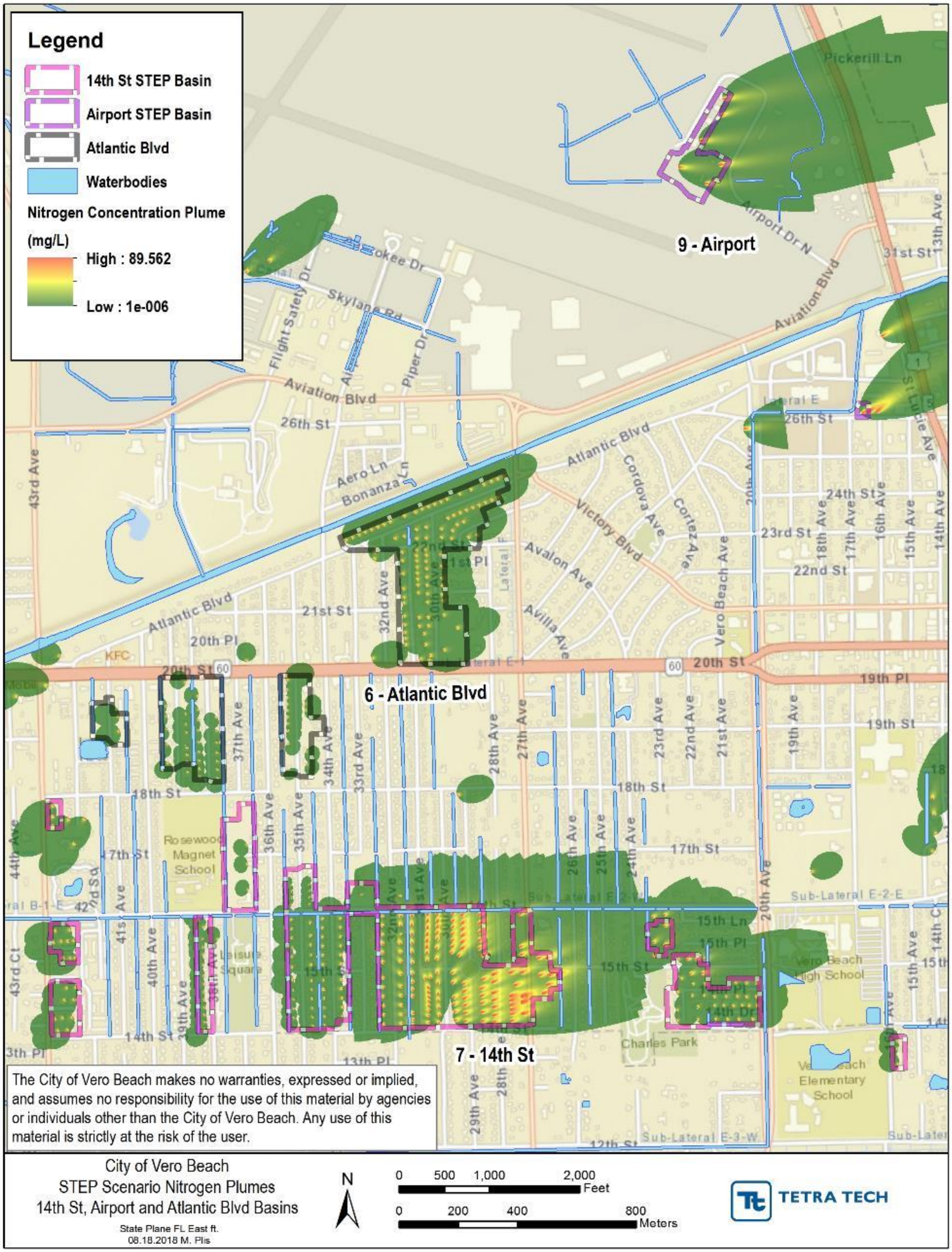

Figure 5-6. STEP Scenario Atlantic Boulevard, 14th Street, and Airport modeled nitrogen concentrations

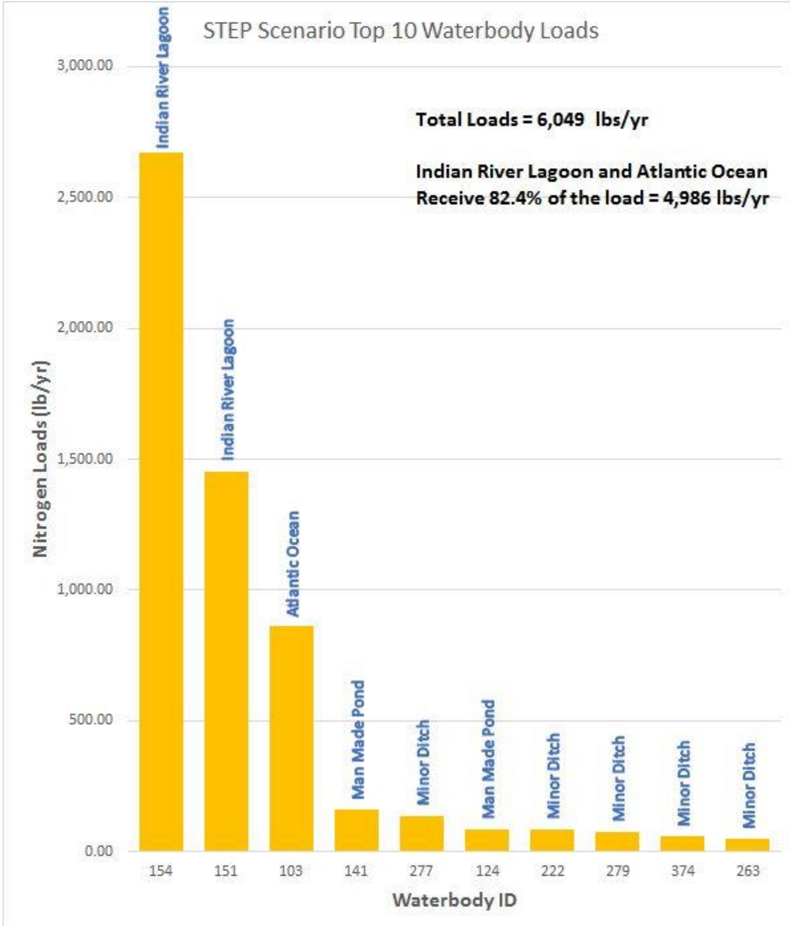

Figure 5-7. STEP Scenario top ten waterbodies with the highest estimated loads

Table 5-1. STEP Scenario top ten waterbodies with the highest estimated loads details

Waterbody Name/Type	Waterbody ID	Contributing STEP Basins	Load (lbs/yr)	% of Total Load
IRL	154	Live Oak, Bethel Creek	2,672	44.17%
IRL	151	South Beach, Riomar	1,454	24.03%
Atlantic Ocean	103	Live Oak, Bethel Creek, South Beach, Riomar	861	14.23%
Man Made Pond	141	South Beach	160	2.64%
Minor Ditch	277	Downtown	137	2.26%
Man Made Pond	124	Riomar	86	1.43%
Minor Ditch	222	Downtown	85	1.41%
Minor Ditch	279	14^{th} Street	75	1.24%
Minor Ditch	374	14^{th} Street	57	0.93%
Minor Ditch	263	14^{th} Street	48	0.79%
Total in Top 10			**5,633**	**93.12%**

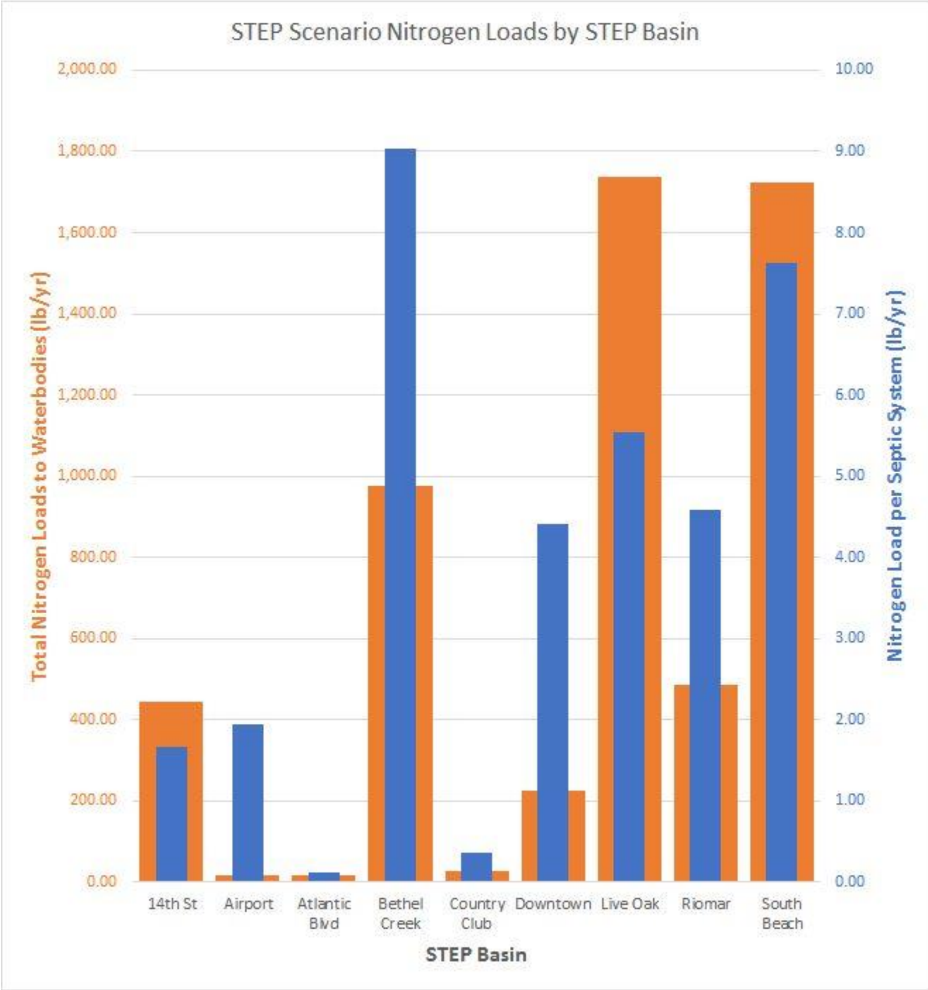

Figure 5-8. STEP Scenario estimated nitrogen loads by STEP basin

Table 5-2. STEP Scenario estimated nitrogen loads by STEP basin detail

STEP Basin	Total Load to Waterbodies	Number of Septic Systems	Load per System	% of Total Load
14th Street	444	267	1.66	7.34%
Airport	16	8	1.95	0.26%
Atlantic Boulevard	16	133	0.12	0.27%
Bethel Creek	976	108	9.04	16.13%
Country Club	29	80	0.36	0.48%
Downtown	225	51	4.42	3.72%
Live Oak	1,737	314	5.53	28.72%
Riomar	486	106	4.58	8.03%
South Beach	1,723	226	7.62	28.48%
Total in STEP Basins	**5,652**	**1,293**	**4.37**	**93.44%**

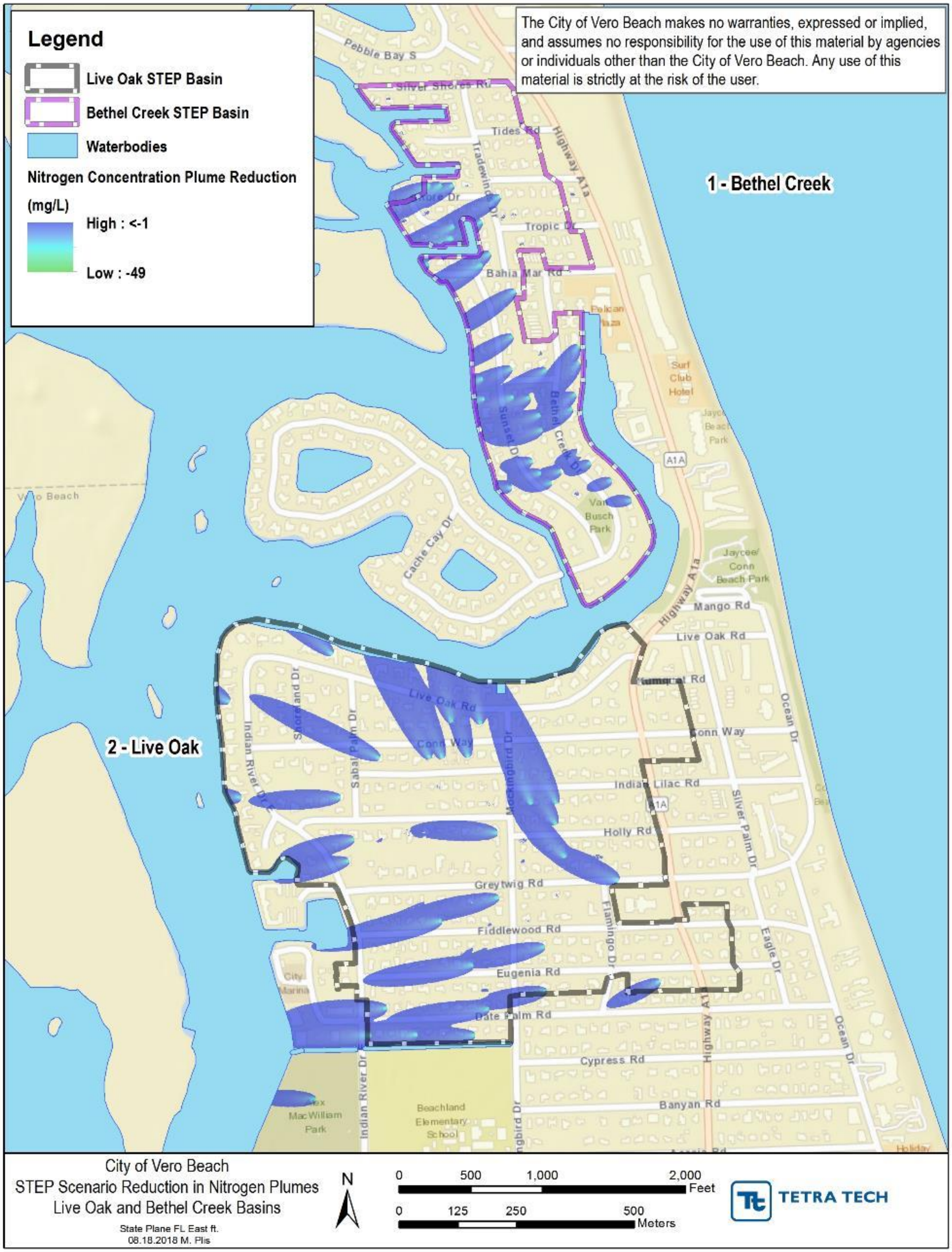

Figure 5-9. Bethel Creek and Live Oak modeled nitrogen concentration reductions

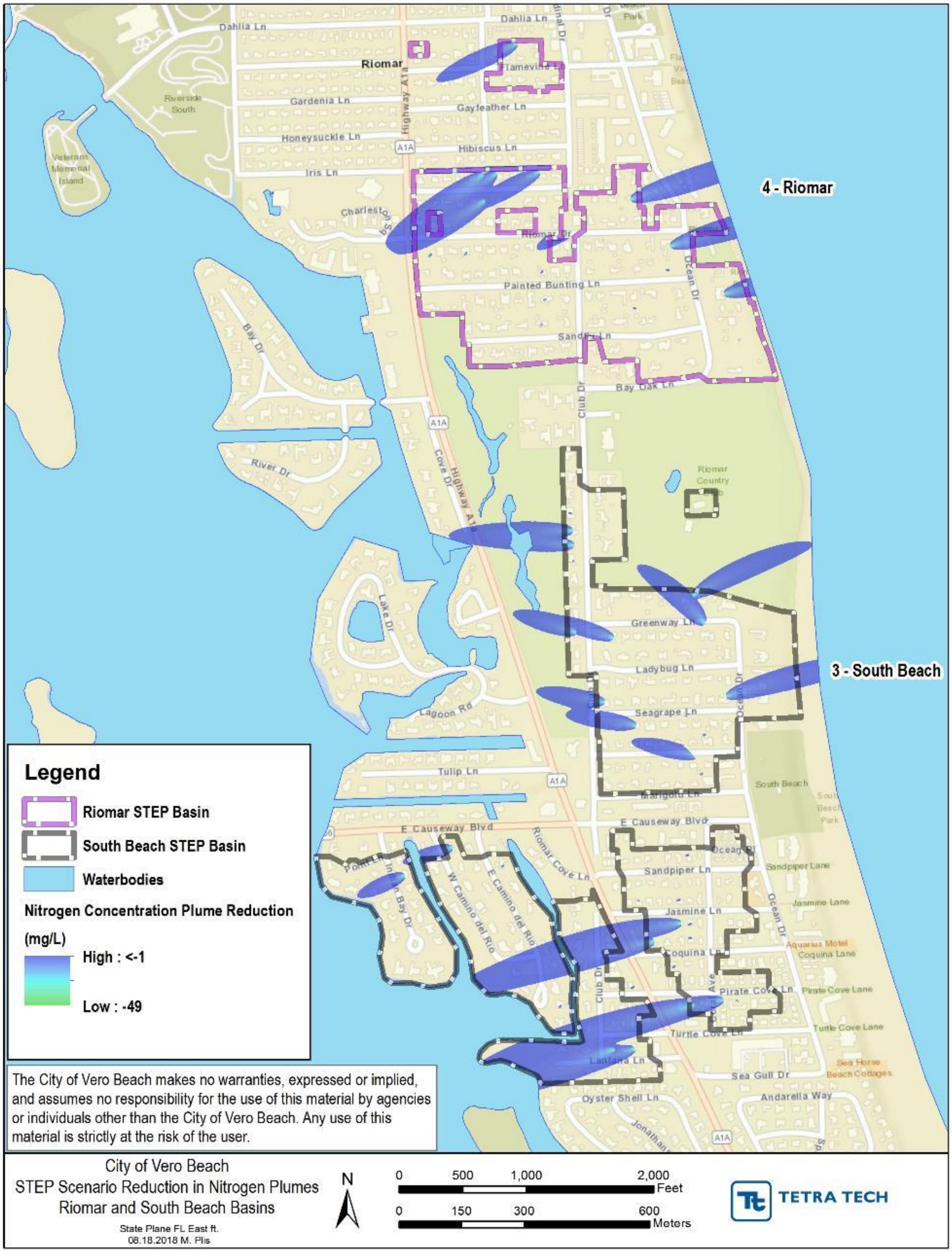

Figure 5-10. South Beach and Riomar modeled nitrogen concentration reductions

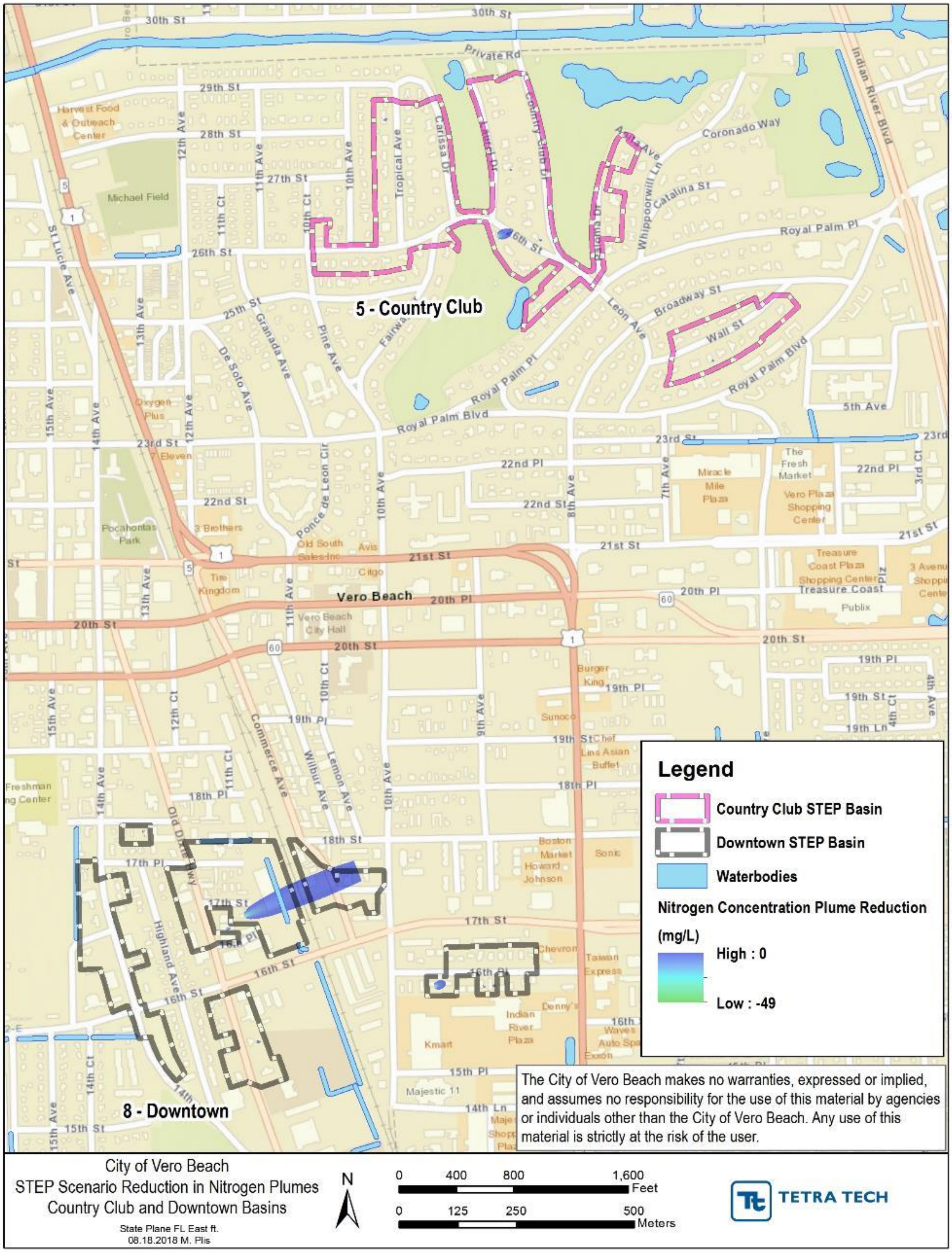

Figure 5-11. Country Club and Downtown modeled nitrogen concentration reductions

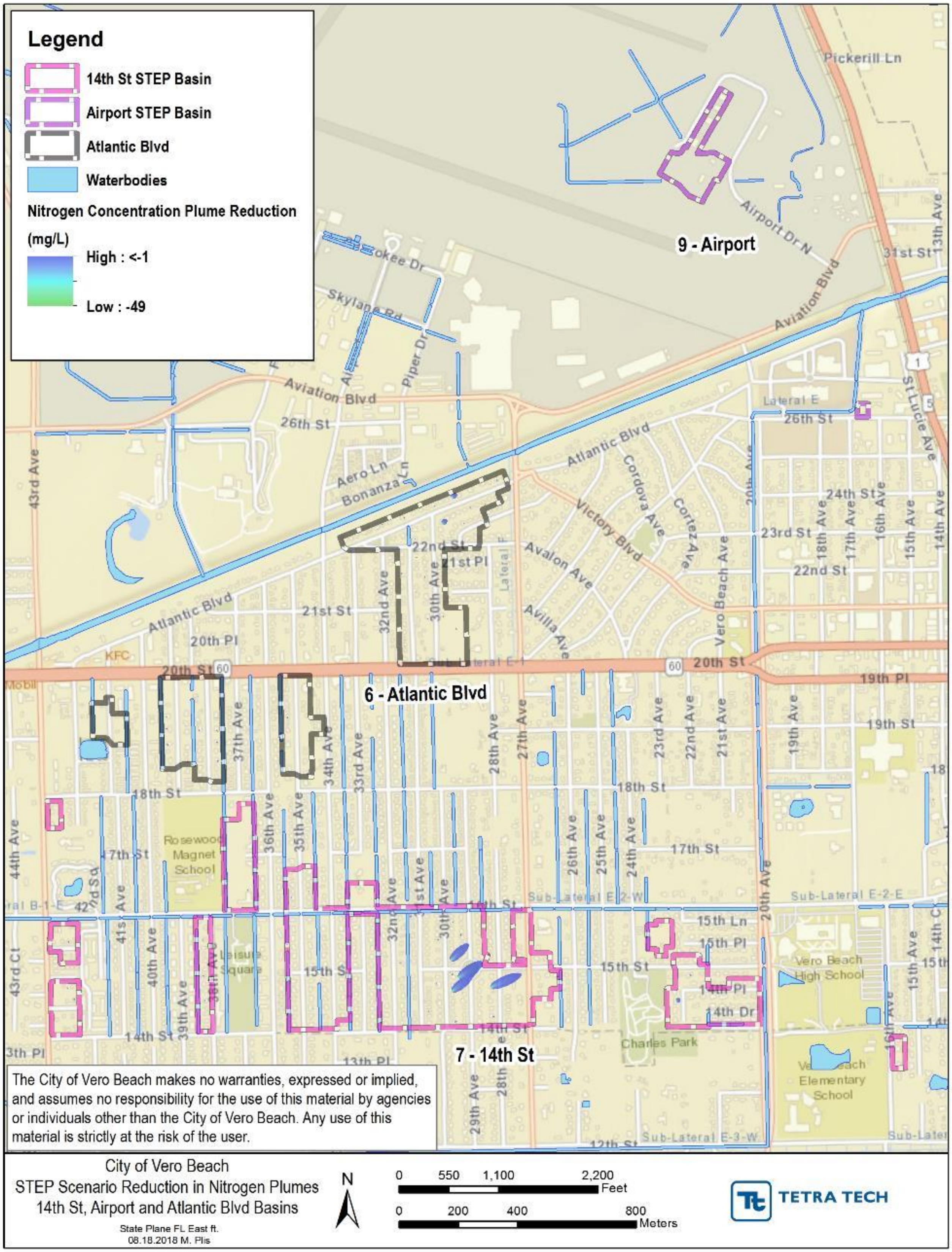

Figure 5-12. Atlantic Boulevard 14th Street, and Airport modeled nitrogen concentration reductions

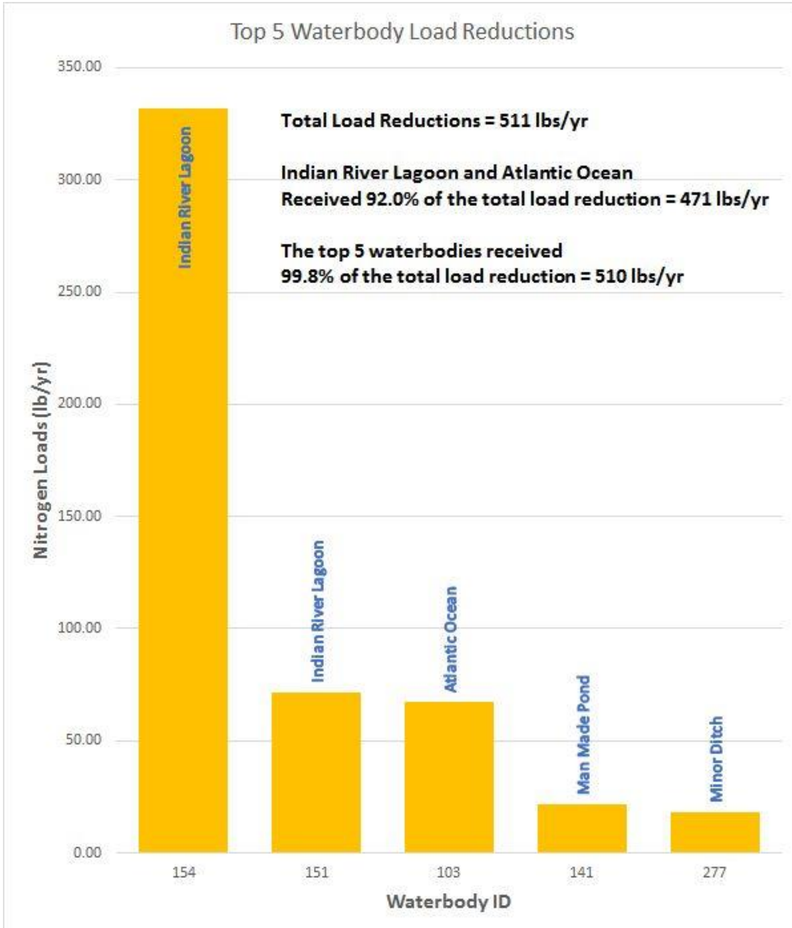

Figure 5-13. Top five waterbodies with the highest load reductions

Table 5-3. Top five waterbodies with the highest load reductions detail

Waterbody Name/Type	Waterbody ID	Contributing STEP Basins	Load Reductions (lbs/yr)	% of Total Load Reduction
IRL	154	Live Oak, Bethel Creek	332	64.94%
IRL	151	South Beach, Riomar	71	13.96%
Atlantic Ocean	103	Live Oak, Bethel Creek, South Beach, Riomar	67	13.17%
Man Made Pond	141	South Beach	21	4.19%
Minor Ditch	277	Downtown	18	3.52%
Total in Top 5			**510**	**99.78%**

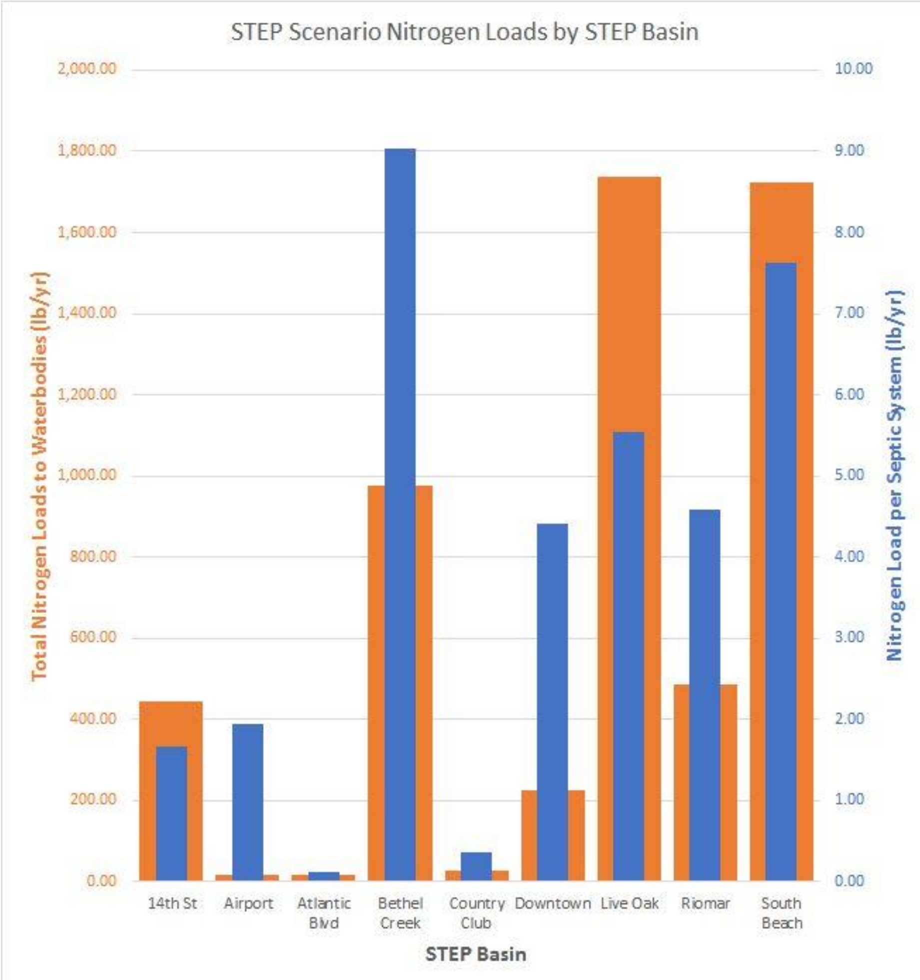

Figure 5-14. Estimated nitrogen load reductions by STEP basin

Table 5-4. Estimated nitrogen load reductions by STEP basin detail

STEP Basin	Reduction in Total Load (lbs/yr)	Number of STEP Conversions	Adjusted Load per System	% of Total Load Reduction
14th Street	1	5	1.66	0.17%
Airport	0	0	1.95	0.00%
Atlantic Boulevard	0	3	0.12	0.00%
Bethel Creek	186	33	9.04	36.47%
Country Club	0	1	0.36	0.00%
Downtown	18	2	4.42	3.52%
Live Oak	139	29	5.53	27.19%
Riomar	53	9	4.58	10.39%
South Beach	107	18	7.62	20.95%
Total in STEP Basins	**504**	**100**	**3.92**	**98.70%**

6.0 MODEL UNCERTAINTY IN LOAD ESTIMATES

A general lack of observations of model parameters including longitudinal dispersivity, source plane concentrations, and first-order decay coefficients, in addition to a very limited number of measured soil parameters (porosity, hydraulic conductivity) and nitrogen concentrations makes the ArcNLET model inherently uncertain. To help with quantifying this uncertainty, ArcNLET includes a Monte Carlo simulation function.

The Monte Carlo simulation function generates samples of random parameter values using the Latin Hypercube Method and based on user specified probability distributions. This function can address uncertainty in seven model parameters including smoothing factor, longitudinal dispersivity, horizontal transverse dispersivity, first-order decay coefficient of denitrification, hydraulic conductivity, porosity, and source plane concentration.

Running these simulations for a large area can be computer intensive; therefore, Tetra Tech conducted the uncertainty analysis for the City's model using a portion of the model area. STEP basins Live Oak and Bethel Creek were chosen to conduct the uncertainty analysis. These two basins are located on the barrier island and they represent a substantial portion of the overall loads, have similar soil compositions, and are the only basins directly discharging to waterbody 154 (the IRL). To conduct the nitrogen concentration uncertainty analysis, a monitoring point was selected within the largest barrier island soil group. The particle paths from this point do not cross any other soils before terminating at the IRL. **Figure 6-1** shows the uncertainly analysis sub-model extent and the monitoring point selected for the analysis.

The Monte Carlo Simulation model was set up to generate 1,000 random parameter samples. The parameters selected for the uncertainty analysis, range of values, and probability distributions of those parameters are presented in **Table 6-1** and the distribution histograms are shown in **Figure 6-2** through **Figure 6-5**.

Figure 6-6 and **Figure 6-7** show that the mean and standard deviations of the simulated nitrogen concentrations at the monitoring point and the estimated nitrogen loads to waterbody 154 converge after approximately 300 runs. This suggests that 1,000 simulations are sufficient to evaluate the uncertainty. Based on the 1,000 simulations, **Figure 6-8** and **Figure 6-9** show the histograms and cumulative distribution function (CDF) of the simulated nitrogen at the monitoring point and the estimated load to waterbody 154. The shape of the loading histogram follows a lognormal distribution, which suggests the most influential parameter for load is the first-order decay coefficient of denitrification. The calibrated estimated load to waterbody 154 is 3,004 lbs/yr, and comparing that to the load CDF plot, there is a 20% chance of a higher load. The calibrated model concentration at the monitoring point is 30.06 milligrams per liter (mg/L) and comparing that value to the concentration CDF plot suggests that this is on the high side of the concentration estimate.

The relationship between the estimated load to waterbody 154 and concentration at the monitoring point is shown on **Figure 6-10**. In general, higher concentrations result in higher loads, but a concentration between 25-40 mg/L can vary dramatically in the amount of loading.

Figure 6-11 through **Figure 6-14** show the relationship between individual model parameters and the resulting simulated concentrations and loads. The only parameter that has a major impact on nitrogen concentrations and loads is the first-order decay coefficient of denitrification.

Figure 6-15 shows the estimated load result of 1,000 Monte Carlo simulations with the calibrated load estimate. The load results varied from 218 lbs/yr to 8,402 lbs/yr. Most of the higher loads resulted from a lower coefficient of denitrification. Additional measured groundwater nitrogen concentrations would help to refine the model and narrow this uncertainty gap.

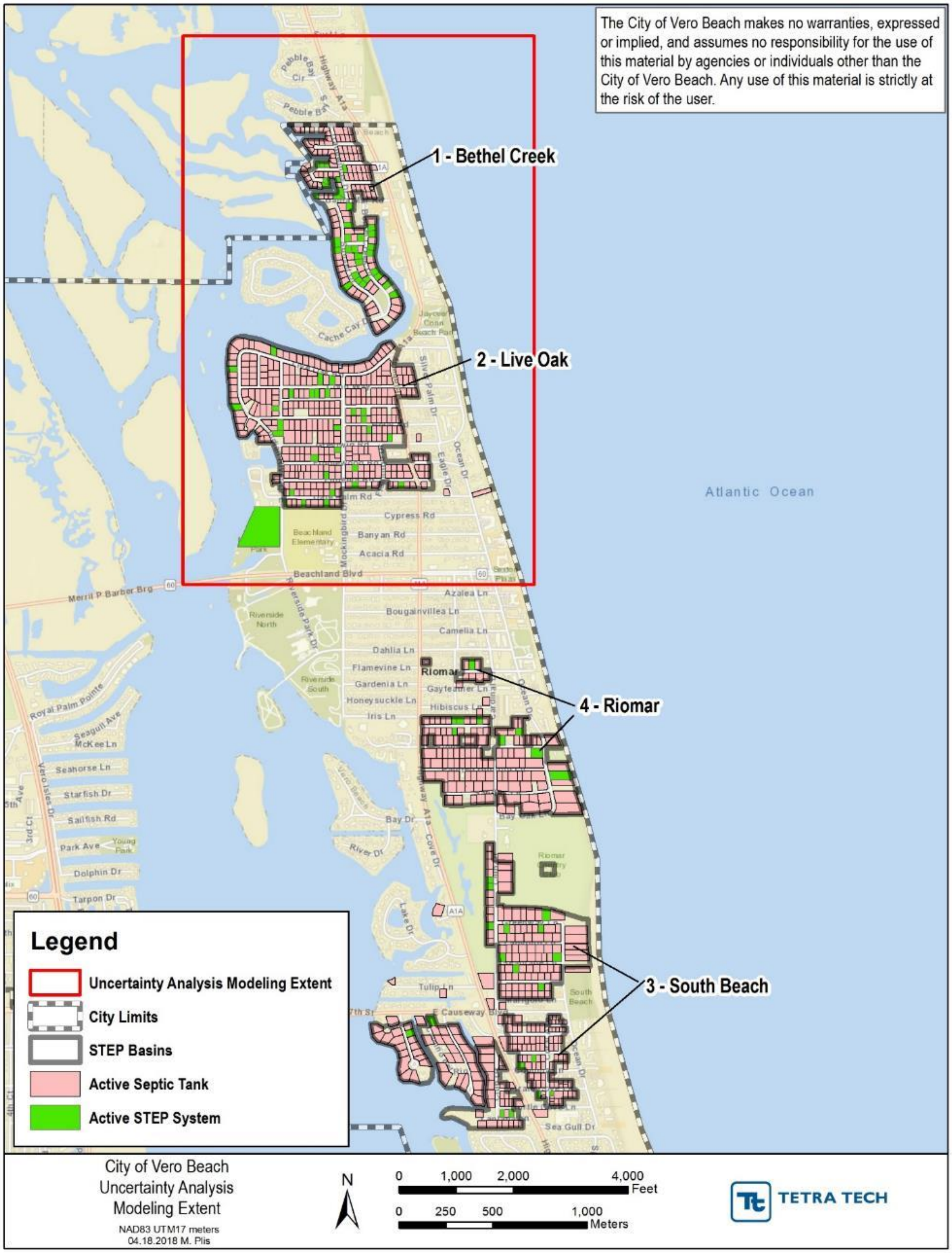

Figure 6-1. Monte Carlo simulation model area

Table 6-1. Probability distributions and value ranges for parameters selected for uncertainty analysis

Model Parameter	Distribution	Minimum	Mode	Max
Smoothing Factor	Uniform	20	N/A	120
Longitudinal Dispersivity	Normal	0.21	N/A	21.34
Decay Coefficient	Lognormal	0.0001	N/A	0.0360
Hydraulic Conductivity	Triangular	12.46	21.34	30.50

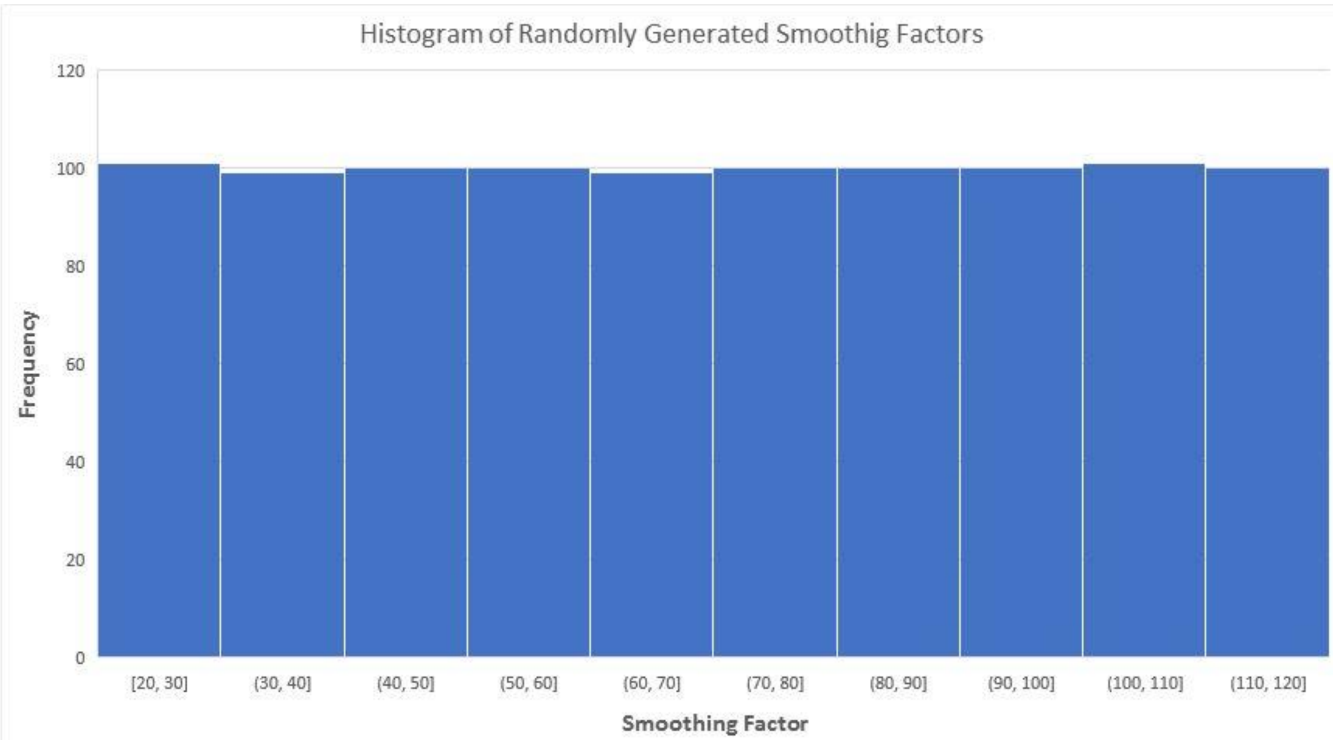

Figure 6-2. Histogram of 1,000 randomly generated smoothing factors

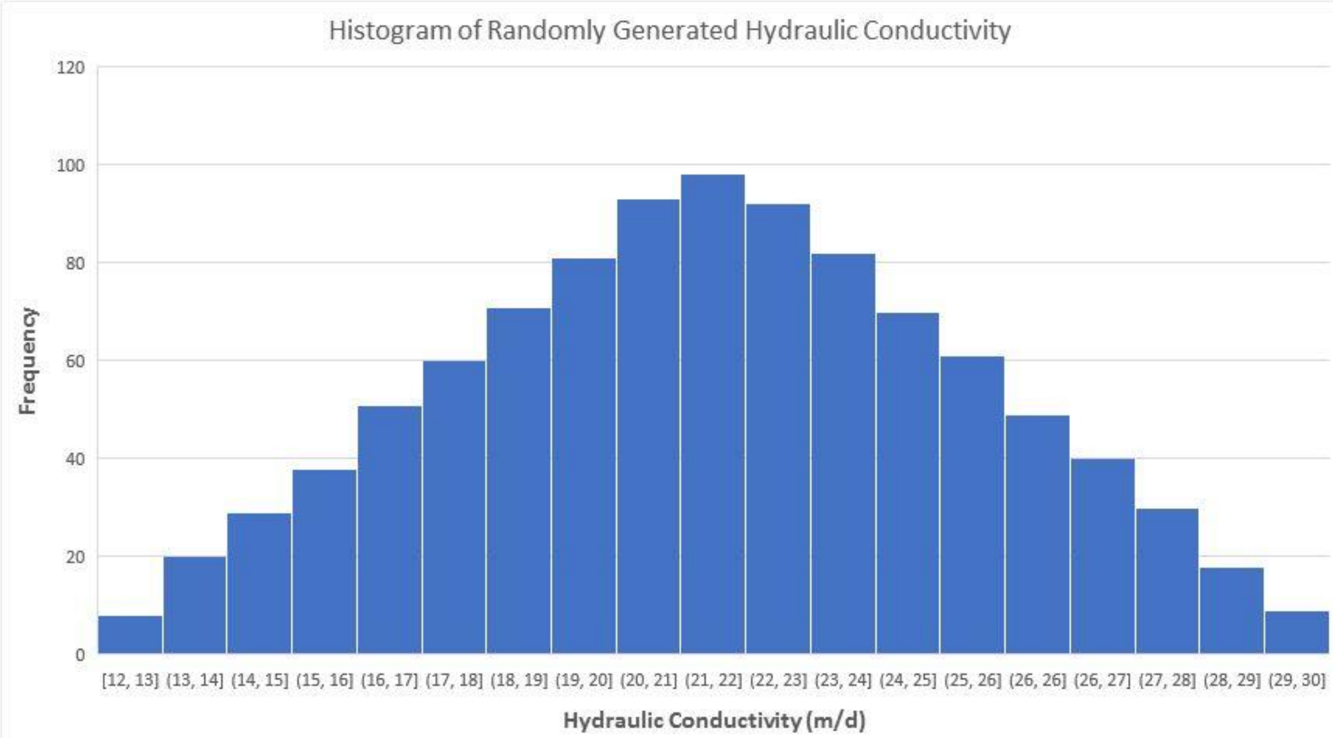

Figure 6-3. Histogram of 1,000 randomly generated values of hydraulic conductivity

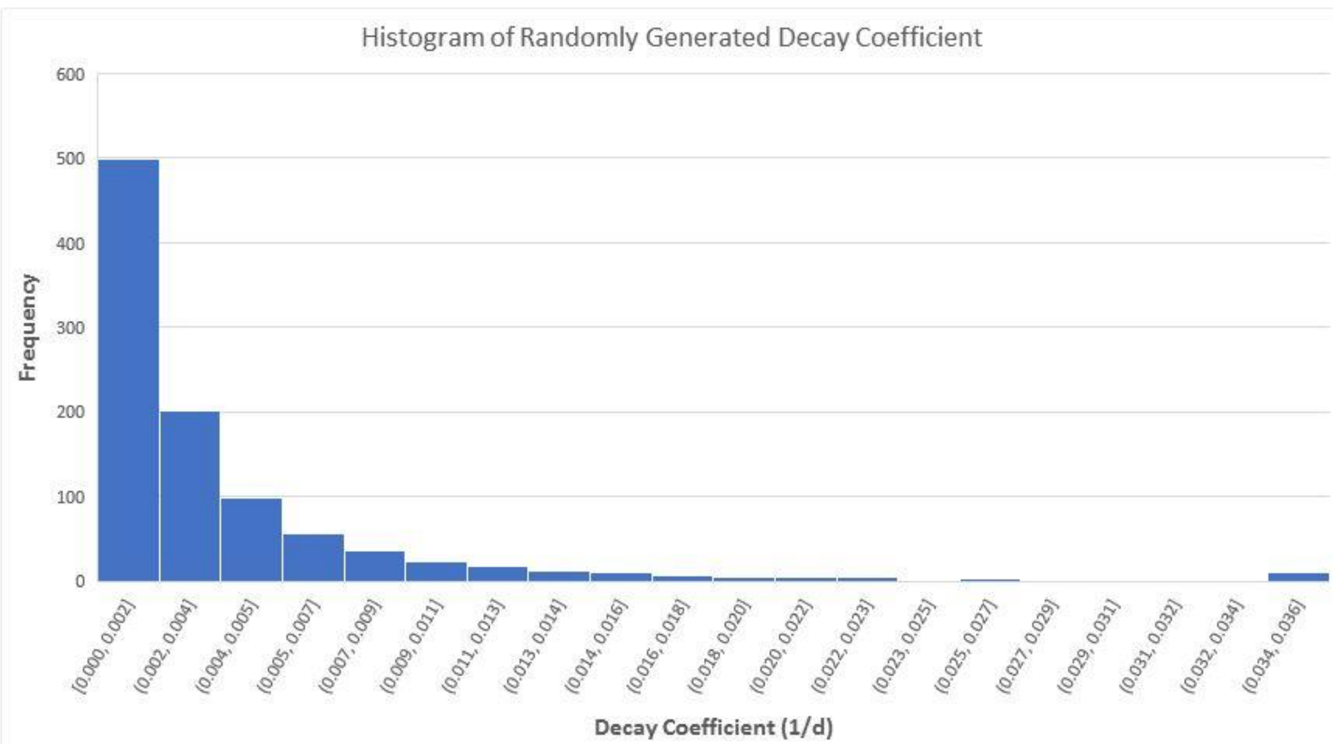

Figure 6-4. Histogram of 1,000 randomly generated values of first-order decay coefficient

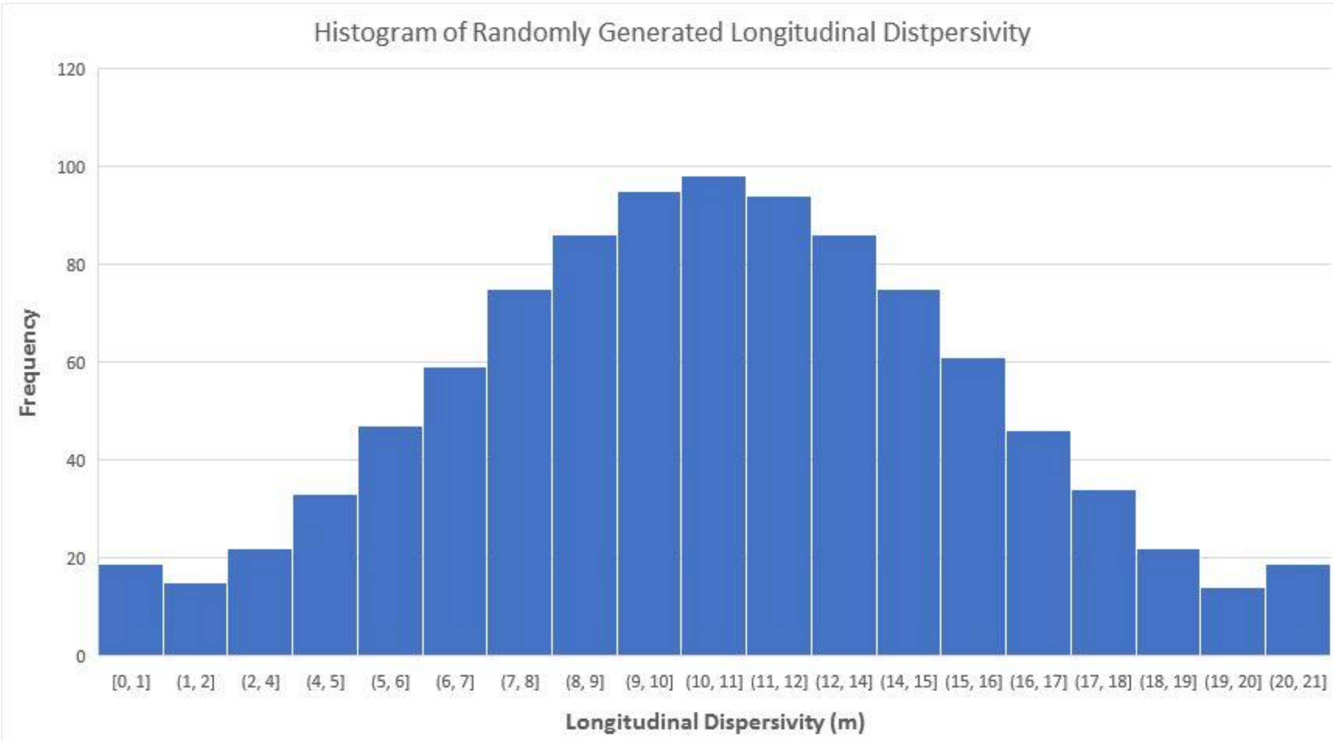

Figure 6-5. Histogram of 1,000 randomly generated values of longitudinal dispersivity

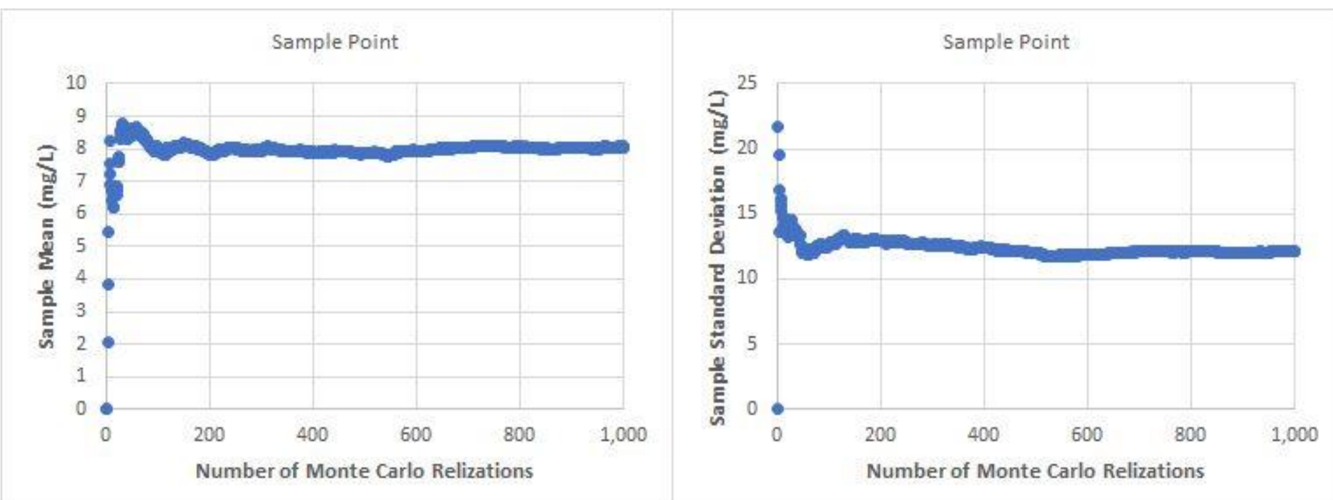

Figure 6-6. Sample mean (left) and standard deviation (right) of simulated nitrogen concentrations

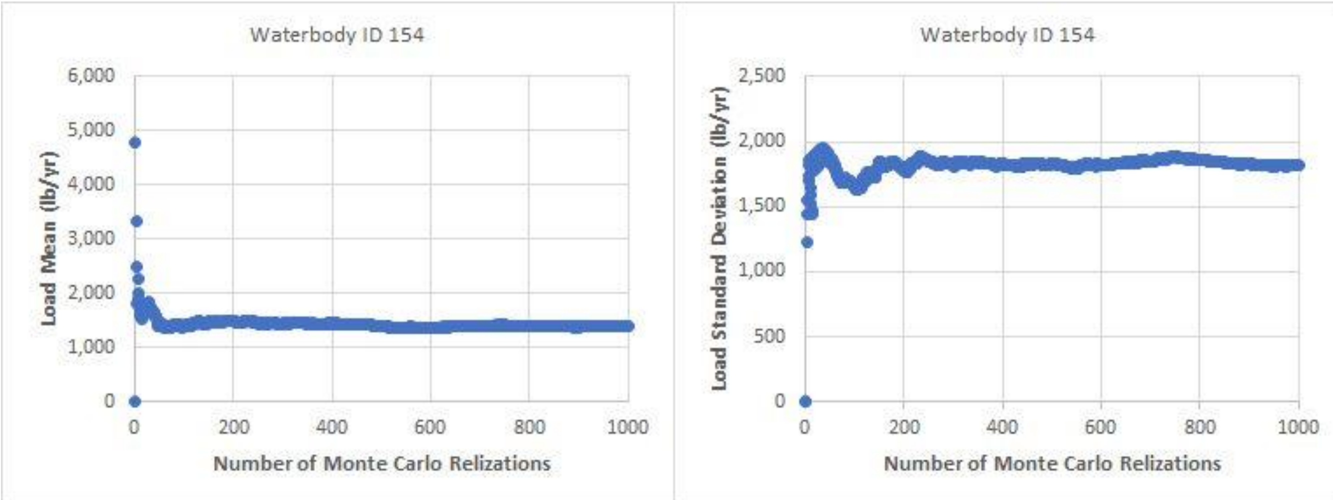

Figure 6-7. Waterbody 154 (IRL) mean (left) and standard deviation (right) of simulated nitrogen loads

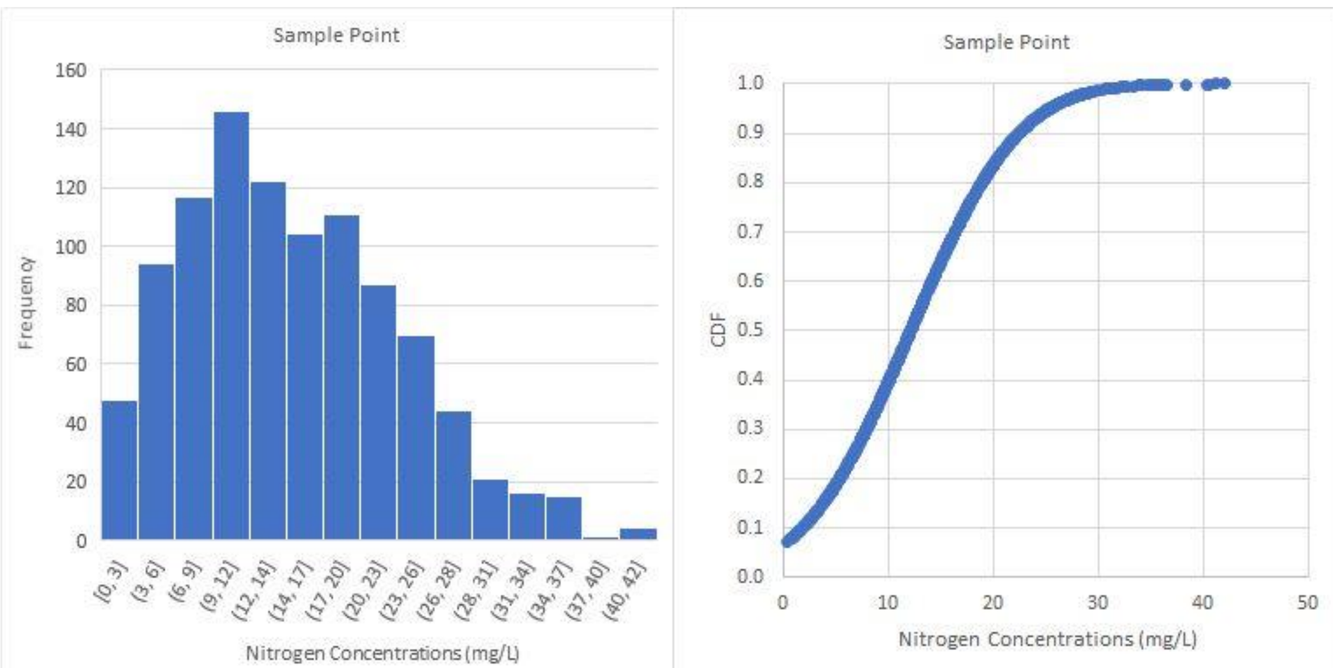

Figure 6-8. Histogram (left) and cumulative distribution function (right) of 1,000 simulations of nitrogen concentrations at the monitoring point

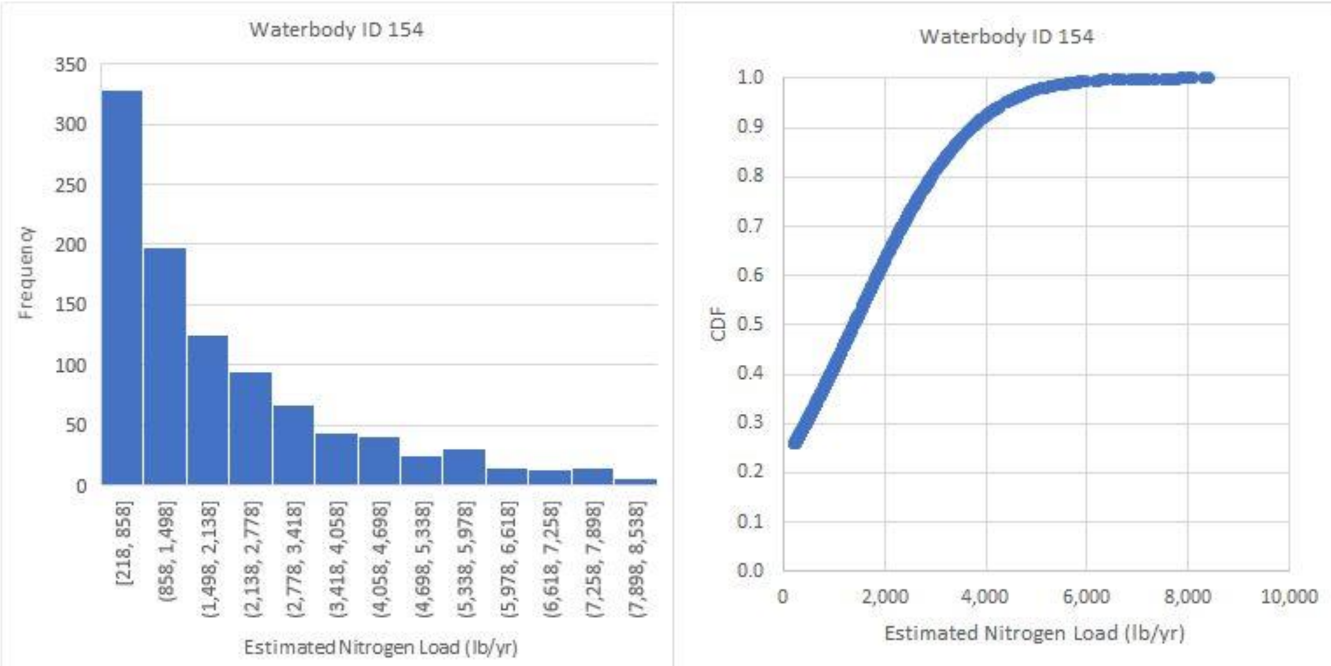

Figure 6-9. Histogram (left) and cumulative distribution function (right) of 1,000 simulations of nitrogen load to waterbody 154 (IRL)

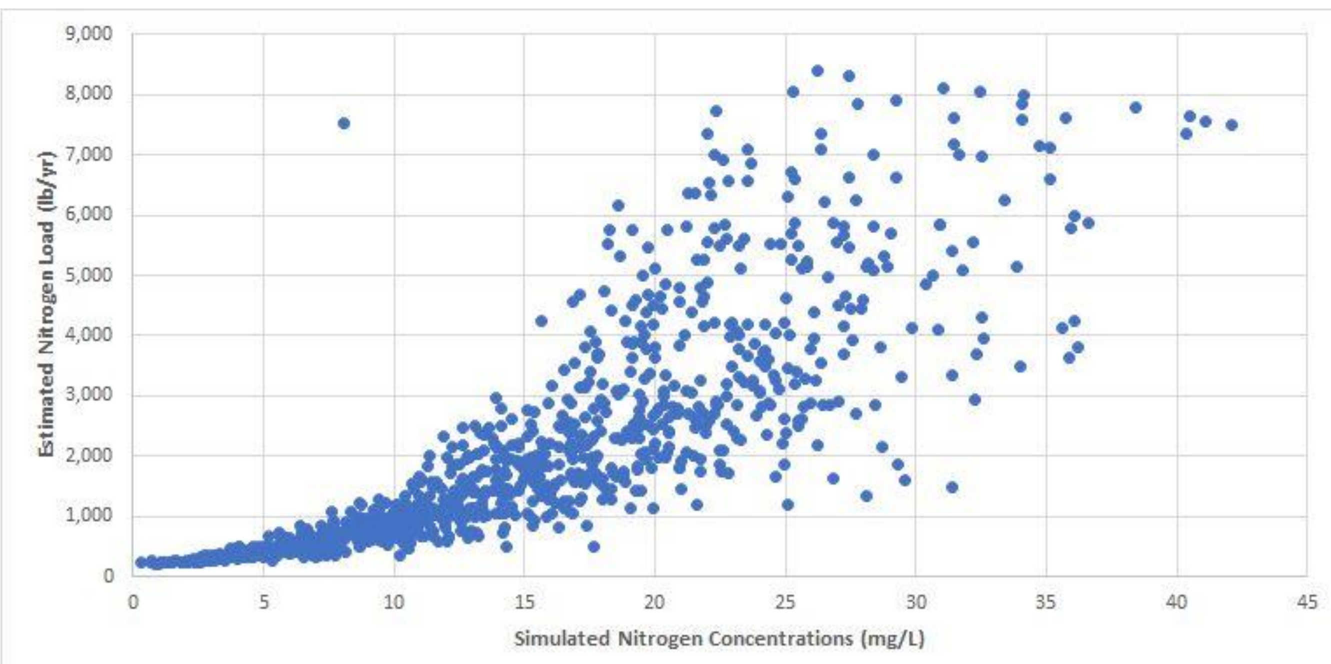

Figure 6-10. Relationship between the nitrogen load estimate and concentration at the monitoring point

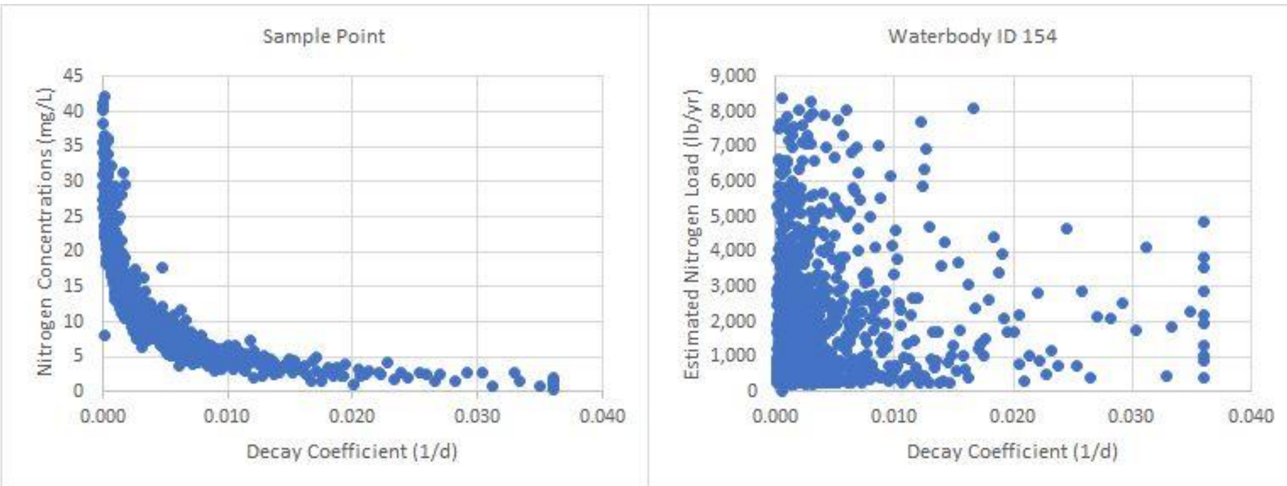

Figure 6-11. Scatterplots for the first-order decay coefficient of denitrification and simulated concentration (left) and load (right)

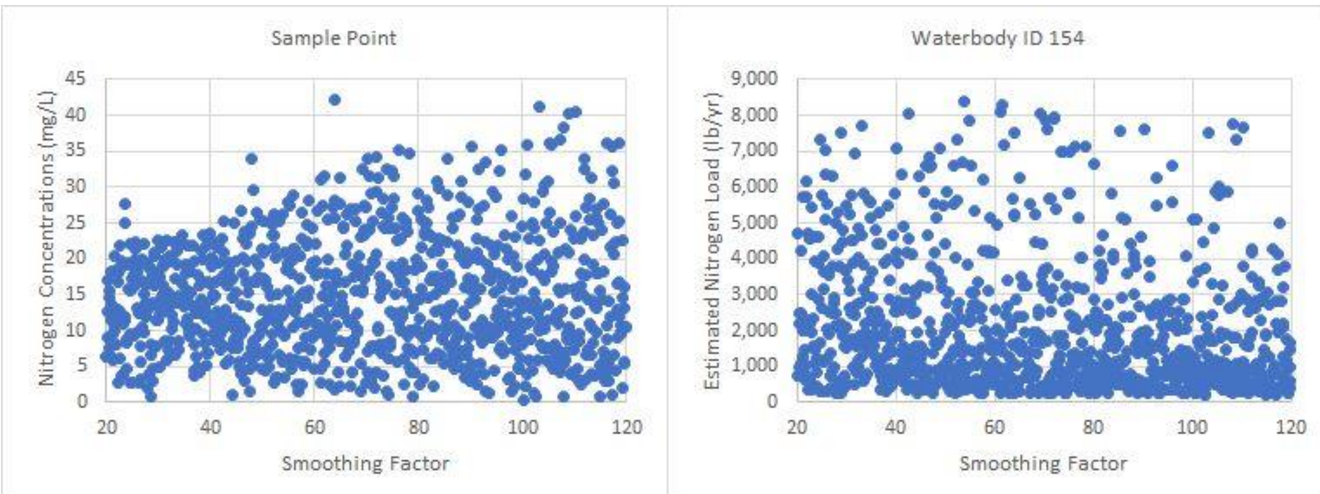

Figure 6-12. Scatterplots for the smoothing factor and simulated concentration (left) and load (right)

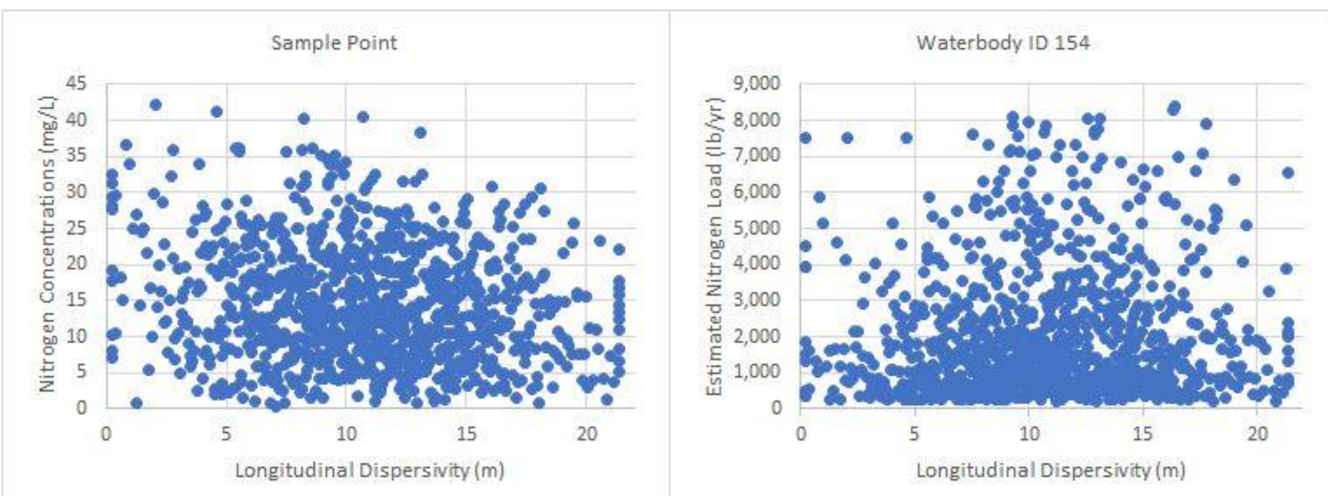

Figure 6-13. Scatterplots for the longitudinal dispersivity and simulated concentration (left) and load (right)

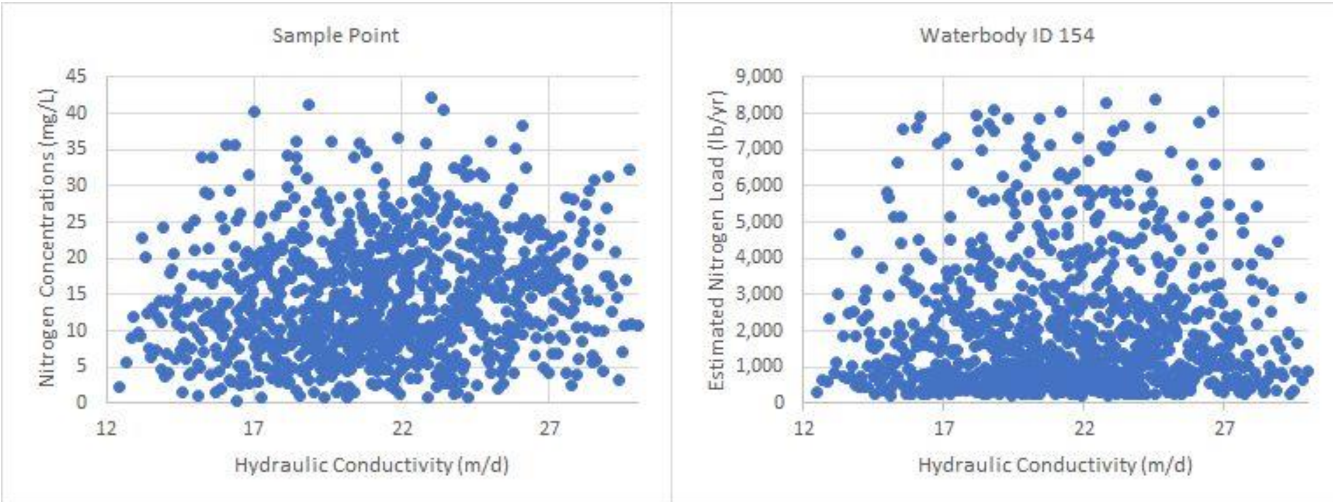

Figure 6-14*.* Scatterplots for the hydraulic conductivity and simulated concentration (left) and load (right)

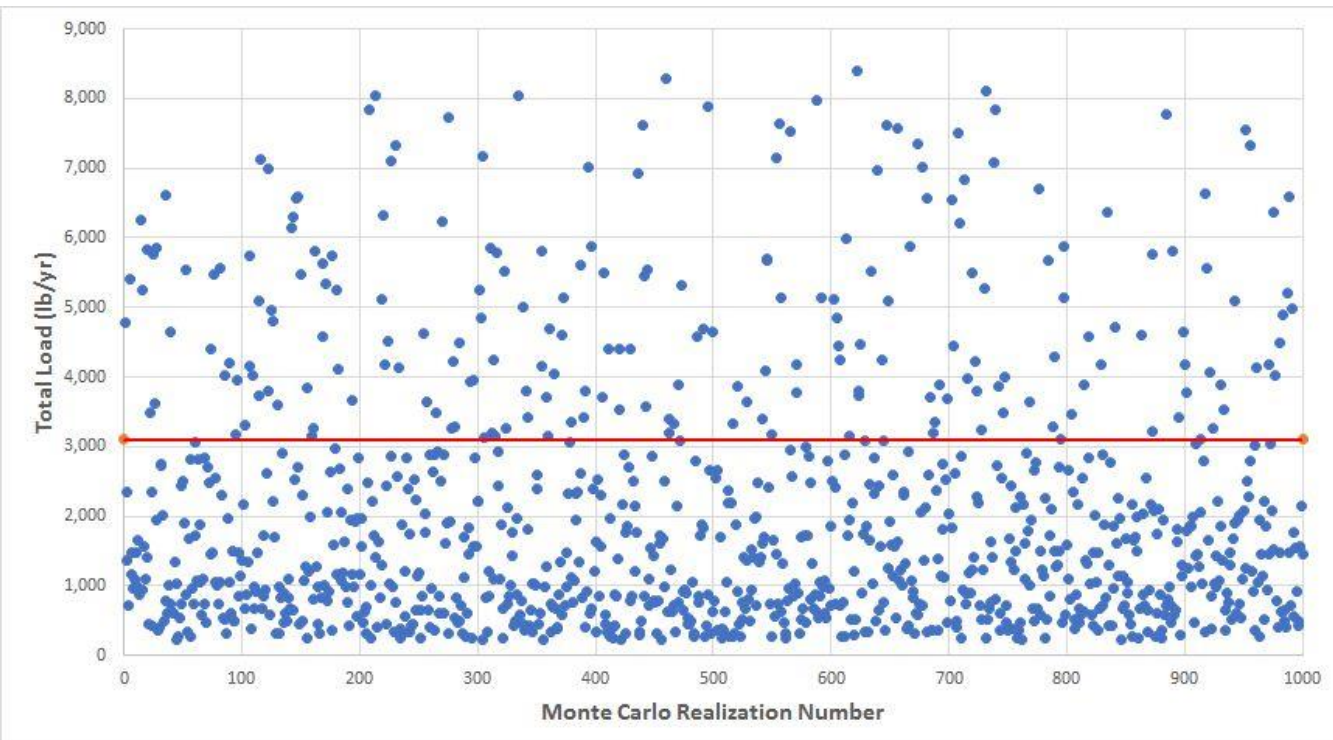

Figure 6-15. Scatterplots for the 1,000-simulated load estimates and calibrated values

7.0 NEXT STEPS

Add information on new monitoring wells and how data will be used to update model

The City of Vero Beach is stakeholder in the Central IRL Basin Management Action Plan (BMAP) that was adopted by DEP in 2013. The stakeholders in the BMAP are required to implement projects to reduce nutrients to improve water quality within the IRL to restore seagrass. As the City connects additional homes to STEP systems, the ArcNLET model can be used to determine the associated nutrient load reduction credit associated with those connections. Additional scenarios, like the STEP Scenario described in **Section 5.0**, can be run to estimate the nitrogen reductions from the STEP system projects each year. By comparing the scenario with the new STEP system connections to the previous scenario, the amount of nitrogen load that was reduced can be calculated and submitted to DEP for BMAP credit. The results from the ArcNLET modeling should also be submitted to DEP to support the City's new BMAP credits. The City can provide updated credit information to DEP on an annual basis as part of the statewide annual report process, which tracks progress towards BMAP targets.

8.0 REFERENCES

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