Appendix A: Model Methodology and Assumptions Used for the Assimilative Capacity Resource Assessment

All Tables and Figures presented in this Appendix are DRAFT and are subject to change.

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This appendix describes the methodology that was used to develop and calibrate the various models. In addition, the assumptions made in the various models for the water quality resource assessment are presented.

A.1 GA Dosag

The primary purpose of the model is to predict DO concentrations in a branching river system, taking into account carbonaceous and nitrogenous biochemical oxygen demand (BOD) contributions from:

- Headwater inflow
- Multiple waste sources
- Tributary inflows
- Lateral inflows
- Benthic demand

GA Dosag can be used as a management tool to predict water quality under various present and future conditions. It was determined to be the appropriate model to determine the available dissolved oxygen for the baseline and future assimilative capacity resource assessments for the State-wide Water Plan. The model was selected for the following reasons:

- It conforms to GA EPD standard practices for developing wasteload allocations;
- It works well for low flow and high temperature conditions;
- It can be developed with a limited dataset; and
- It is able to handle branching tributaries and both point and nonpoint source inputs.

A.1.1 Model Structure

GA Dosag consists of a mainstem segment and may include an unlimited number of branches. GA Dosag can include tributaries, water intakes, and dams, as well as point sources. GA Dosag models were developed to represent the streams and rivers that currently receive permitted wastewater discharges over 0.1 million gallons per day (MGD). Table A-1 provides a list of the mainstems that where modeled in each river basin, while section 6.1 through 6.6 and Appendix B shows the location of these modeled segments throughout the State of Georgia.

USGS quadrangle maps and navigational maps, along with Arcview and MapInfo spatial graphics files, were used to develop drainage areas, stream lengths, bed slopes, segment geometry, and other physical input data for each model.

Table A-1 GA Dosag Models

Number	Mainstem	No. Branches	No. Segments
Chattahoochee River Basin			
1	Anneewakee Creek	3	20
2	Big Creek	2	40
3	Chestatee River	3	32
4	Deep Creek	1	4
5	Dick Creek	1	13
6	Flat Shoal Creek	2	27
7	Hodchodkee Creek	1	20
8	James Creek	1	12
9	Little Bear Creek	1	16
10	Mountain Creek	2	23
11	Mulberry Creek	3	29
12	New River	2	28
13	Nickajack Creek	1	23
14	Richland Creek	1	4
15	Suwanee Creek	2	13
16	Sweetwater Creek	4	64
17	Upper Chattahoochee River	9	69
18	Wahoo Creek	2	24
19	Yellowjacket Creek	1	13
Flint River Basin			
20	Fish Pond Drain	1	6
21	Flint River	24	492
22	Gum Creek	1	16
23	Ichawaynochaway Creek	6	93
24	Muckalee Creek	5	124
25	Spring Creek	5	50
Coosa River Basin			
26	Alpine Creek	2	14
27	Big Cedar Creek	5	61
28	Chattooga River	4	55
29	Coahulla Creek	5	51
30	Coosawattee River	2	18
31	Etowah River	10	146
32	Euharlee Creek	1	40
33	Holly Creek	1	28
34	Little River	2	16
35	Noonday Creek	1	10
36	Oothkalooga Creek	1	27
37	Pumpkinvine Creek	3	39
38	Salacoa Creek	1	19
39	Two Run Creek	1	19
Tallapoosa River Basin			
40	Little Tallapoosa River	2	76
41	Tallapoosa River	4	41
Tennessee River Basin			
42	Brasstown Creek	1	10
43	Butternut Creek	1	3
44	Little Tennessee River	1	9

45	Lookout Creek	1	`0
46	South Chickamauga Creek	1	17
47	Toccoa River	3	31
48	West Chickamauga Creek	1	25
Savannah River Basin			
49	Beaverdam Creek	2	7
50	Brier Creek	5	83
51	Broad River	8	101
52	Buck Creek	1	9
53	Eastanollee Creek	1	16
54	Kiokee Creek	1	8
55	Little River	2	14
56	Spirit Creek	2	30
57	Stekoa Creek	1	13
58	Toccoa Creek	1	6
59	Uchee Creek	2	48
Ogeechee River Basin			
60	Little Ogeechee Creek	3	11
61	Ogeechee River	39	416
Ochlocknee River Basin			
62	Aucilla River	1	12
63	Little Attapulgus Creek	1	5
64	Ochlocknee River	9	93
Suwannee River Basin			
65	Alapaha River	5	57
66	Cane Creek	1	14
67	Tatum Creek	1	31
68	Withlacoochee River	10	96
Satilla River Basin			
69	Satilla River	5	100
St. Mary's River Basin			
70	St Marys River	2	29
Ocmulgee River Basin			
71	Alcovy River	3	50
72	Ocmulgee	27	422
73	South River	20	201
74	Yellow River	2	62
Oconee River Basin			
75	Apalachee River	6	56
76	Little River	7	53
77	Murder Creek	7	79
78	Oconee River (Upper)	13	201
79	Oconee River (Lower)	12	237
80	Sugar Creek	1	8
81	Rooty Creek	1	10
Altamaha River Basin			
82	Altamaha River	16	246

A.1.2 Velocity

Velocity is a critical factor when performing GA Dosag water quality modeling. There are two options for velocity: for each reach the user can either enter a fixed value or choose to compute velocity by formula. If velocity is computed, for each branch, one of two methods for calculating velocity can be specified: the Georgia Soil method or the Velocity Coefficient method. For the Georgia Soil method, equations were developed for each major soil province and for three stream flow ranges within each province: flows less than 100 cubic feet per second (cfs), flows greater than 100 cfs but less than 1000 cfs, and flows greater than 1000 cfs. Where USGS field measurements were recorded when current-meter discharge measurements were made to calibrate the rating curves, these data were analyzed to determine the velocity coefficients and exponents for each of the USGS gauging station included in the models. The USGS current-meter discharge measurements were taken over a range of stages and discharges.

A.1.3 Depth

Sediment Oxygen Demand (SOD) calculations and the Dobbins-O'Connor reaeration equation both require a reach depth. Therefore, GA Dosag allows the user to choose whether to use the depth variable or not for each branch. If, for a particular branch, the depth variable option is chosen, the user can fix the depth, or have GA Dosag compute it using the following equation where the coefficient and exponent are specified for each reach:

$$D = aQ^b$$

where: D = Depth, feet

a = coefficient of depth versus flow relationship

b = exponent of depth versus flow relationship

Q = stream flow, cubic feet/second

Using the USGS current-meter discharge measurements, depth flow power relationships were developed and the depth coefficient and exponent for each USGS gauging station determined.

A.1.4 Decay Rate K1 (1/day) for Carbonaceous BOD

The Carbonaceous Biochemical Oxygen Demand (CBOD) represents the oxygen demanding equivalent of the complex organic carbonaceous material in water. The degradation of this material is assumed to be first order. The ultimate CBOD (CBODu) and the initial CBOD decay rates were determined from the long-term BOD results of a variety of mainstem and tributary tests in the Coosa, Chattahoochee and Savannah River Basins. Based on the long-term BOD data and analyses, the K1 rates initially used were for fast acting material 0.15/day and for slow acting material 0.015/day. In general, the typical ratio of fast acting CBODu1 to the slow acting CBODu2 is 40:60. The rates were varied spatially if needed. A temperature correction factor of 1.047 was used to adjust the CBOD decay rates for the changes in temperature.

A.1.5 Decay Rate Kn (1/day) for Nitrogenous BOD

In the presence of nitrifying bacteria, ammonia is oxidized to nitrite and then to nitrate. The stoichiometric oxygen (O_2) mass required for this reaction is 4.57 mg of O_2 per mg of ammonia oxidized.

This oxidation reaction is assumed to be first order. In GA Dosag, the initial ammonia decay rate (K_n) of 0.04/day was used based on measured rates from the long-term BOD analysis described above. A temperature correction factor of 1.083 was used to adjust the K_n rate for the changes in temperature.

A.1.6 Sediment Oxygen Demand

Oxygen demand by benthic sediments and organisms can represent a significant portion of oxygen consumption in surface water systems. Benthic deposits at a given location are the result of the transportation and deposition of organic material. The material may be from a source outside the system, such as leaf litter, urban runoff, nonpoint sources of organic material, or wastewater particulate CBOD, or it may be generated inside the system as occurs with plant growth and decay. In addition to oxygen demand caused by decay of organic matter, the indigenous invertebrate population can generate significant oxygen demand through respiration. The sum of oxygen demand due to organic matter decay plus the demand from invertebrate respiration is equal to the sediment oxygen demand (SOD). SOD is measured in grams/meter^2/day and is averaged over the water column depth.

Limited SOD studies have been performed in Georgia streams. In general, it was found that SOD measurements in south Georgia were higher than those recorded in north Georgia due to the decrease in stream slope and velocities. The average SOD measurements were 1 grams/meter^2/day and this value was used as the starting SOD value in the GA Dosag models. A temperature correction factor 1.065 was used to adjust the SOD rate for the changes in temperature.

A.1.7 Reaeration

Oxygen transfer in natural waterbodies depends on internal mixing and turbulence due to velocity gradients and fluctuations, temperature, wind mixing, waterfalls, dams and rapids and surface films (Thomann and Mueller, 1987). GA Dosag can compute stream reaeration on a reach-by-reach basin using one of two options: a fixed K_2 value for a reach or a calculated K_2 using an equation. If K_2 is computed, either the Tsivoglou-Wallace or Dobbins-O'Connor equations can be used. The State Water Plan GA Dosag models generally used the Tsivoglou-Wallace equation.

The Tsivoglou-Wallace equation is based on an escape coefficient entered for each reach and uses the stream slope and velocity. The equation is:

$$K_2 = C\left(\frac{\Delta h}{t_f}\right)$$

where: K2 = reaeration rate at 20°C, 1/day
C = Escape Coefficient (1/ft)
C = 0.025-0.054 when 200 cfs < Q < 3000 cfs
C = 0.054 when 50 cfs < Q < 200 cfs
C = 0.054-0.08 when 1 cfs < Q < 50 cfs
C = 0.110 when 1 cfs < Q < 10 cfs
Δh = Change in water surface elevation through the reach, ft
t_f = Travel time through the reach, days

An escape coefficient of 0.054 or 0.110 was used as the starting value depending on the streamflow. A temperature correction factor of 1.024 was used to adjust the reaeration rate for the changes in temperature.

A.1.8 Critical Conditions

The critical conditions were used to assess the dissolved oxygen standard and to determine if there was available assimilative capacity. Model critical conditions were developed in accordance with GA EPD standard practices (GA EPD, 1978).

Low flow analyses of the available flow data were performed. Data from long-term USGS gages were analyzed to determine 7-day, 10-year minimum flows (7Q10s). Productivity factors, in cubic feet per second (cfs) per square mile, were computed by dividing the 7Q10s by the watershed areas at the gages.

Critical water temperatures were determined by examining the water quality data and looking at the long-term trend monitoring data. Harmonic sine functions were developed for the historical data from all of the long-term monitoring stations. The highest summer-time temperature from the water quality data or the harmonic fit was used to represent each of the modeled segments.

Point sources were incorporated into the baseline models at their current 2007 NPDES discharge levels. For NPDES permits that do not have dissolved oxygen and/or NH3 limits, values of 2 mg/L and 17.4 mg/L were used as a starting point and adjusted as needed, respectively.

A.1.9 Natural Conditions Models

For those streams in the Coastal Plain, natural conditions models were run. All point source discharges were completely removed from the critical conditions model. All other model parameters remained the same unless background levels of CBOD and NBOD were abnormally high in the calibration model then these parameters were reduced to typical background levels. These models were used to determine the natural dissolved oxygen concentrations during critical conditions. Then target DO could be determined using the Coastal permitting policy.

A.2 LSPC

A.2.1 Overview

The LSPC watershed model was used to represent the variability of nonpoint source contributions through dynamic representation of hydrology and land practices. The watershed model included all point and nonpoint source contributions. Key components of the watershed modeling included:

- Watershed Segmentation
- Simulation Period
- Soils
- Meteorological Data
- Reach Characteristics
- Land Use Representation
- Point Source Discharges
- Septic Tanks
- Municipal and Industrial Water Withdrawals
- Agricultural Water Withdrawals
- Hydrologic Representation
- Hydrology Calibration and Validation
- Reach Group Representation
- Water Quality Development and Calibration
- Integration of LSPC with Other Models

A.2.2 Watershed Segmentation

In order to evaluate the sources contributing to a waterbody and to represent the spatial variability of these sources within the watershed model, the contributing drainage area was represented by a series of sub-watersheds. The sub-watersheds were developed using the Georgia 12-digit watershed data layer that was provided by the GA EPD as a guideline for further delineations. The sub-watersheds were delineated using the National Elevation Dataset (NED) in 1/3-arc-second resolution (30m), the National Hydrography Dataset (NHD), the University of Georgia (UGA) 2005 Georgia Land Use Trends (GLUT), the USGS flow gauge station locations, and the GAEPD water quality monitoring stations coverage for 1997 through 2008.

A.2.3 Simulation Period

The USGS recommends looking at a minimum of a 10-year time period for hydrology calibrations. This is due to the fact that over a 10-year period, a variety of hydrological conditions will exist, and a model that is calibrated over this time period will have a greater chance of success in predicting future hydrological conditions. The LSPC model was simulated for the 10-year period from January 1, 1998 through December 31, 2007. This time period was selected as it captured two drought periods (1999-2001 and 2006-2007) and several wet years including 2003 and 2005. To allow the model plenty of "spin-up" time, the model was run for a full year (1997) before the simulation period began.

The LSPC watershed hydrology and water quality model was calibrated from 1998 through 2007, and validated to data collected from 1998 to 2007.

A.2.4 Soils

Soil data were obtained from the Soil Survey Geographic Database (SSURGO). The database was produced and distributed by the Natural Resources Conservation Service (NRCS) – National Cartography and Geospatial Center (NCGC). The SSURGO data were used to determine the total area that each hydrologic soil group (A, B, C or D) covered within each sub-watershed. The sub-watersheds were represented by the hydrologic soil group that had the highest percentage of coverage within the boundaries of the sub-watershed.

A.2.5 Meteorological Data

Nonpoint source loadings and hydrological conditions are dependent on weather conditions. Hourly data, from weather stations within the boundaries of, or in close proximity to the sub-watersheds, were applied to the watershed model. The meteorological data available included precipitation, air temperature, dew point temperature, wind speed, cloud cover, evaporation, and solar radiation. These data were used directly, or calculated from observed data. Data for the LSPC model were obtained from either Georgia Automated Environmental Monitoring Network (GAEMN) or National Climate Data Center (NCDC) stations. The GAEMN stations are maintained and operated by the College of Agricultural and Environmental Sciences of the University of Georgia. Each station monitors air temperature, relative humidity, rainfall, solar radiation, wind speed, wind direction, soil temperature at 2, 4, and 8 inch depths, atmospheric pressure, and soil moisture every one second and the data are summarized at 15-minute intervals (GAEMN, 2009). The NCDC stations record daily observations for precipitation, minimum temperature, and maximum temperature.

A.2.6 Reach Characteristics

The LSPC model must have a representative reach defined for each sub-watershed. The characteristics for each reach include the length and slope of the reach, the channel geometry and the connectivity between the sub-watersheds. Length and slope data for each reach was obtained using the Digital Elevation Maps (DEM) and the National Hydrography Dataset (NHD). The channel geometry is described by a bank full width and depth (the main channel), a bottom width factor, a flood plain width factor and slope of the flood plain.

A.2.7 Land Use Representation

The watershed model uses land use data as the basis for representing hydrology and nonpoint source loadings. The land use data used is from the University of Georgia, Georgia Land Use Trends (GLUT) coverage, and included the following 19-Class categories: open water, utility swaths, developed open space, developed low intensity, developed medium intensity, developed high intensity, clear-cut/sparse, quarries/strip mines, rock outcrop, deciduous forest, evergreen forest, mixed forest, golf courses, pasture, row crop, forested wetland, non-forested wetland (salt/brackish), and non-forested wetland (freshwater). The GLUT coverage represented conditions in year 2005. For the LSPC simulation, similar land use classes were grouped together into reduced modeling units (RMU), i.e., deciduous forest, evergreen forest and mixed forest were grouped together into an RMU called forest.

The LSPC model requires division of land uses in each sub-watershed into separate pervious and impervious land units. For this, the GLUT impervious cover was intersected with the GLUT land use cover. Any impervious areas associated with utility swaths, developed open space, and developed low intensity, were grouped together and placed into a new RMU for low intensity development impervious.

Impervious areas associated with medium intensity development and high intensity development, were kept separate and placed into two new RMU's for medium intensity development impervious and high intensity development impervious respectively. Finally, any impervious area not already accounted for in the three developed impervious RMU's, were grouped together into a fourth new RMU.

A.2.8 Point Source Discharges

Facilities permitted under the National Pollutant Discharge Elimination System (NPDES) are, by definition, considered point sources. The NPDES, geographic information system (GIS) coverage, provided by GAEPD, was adopted as the starting point for the evaluation of point sources and reflected discharges as of May 2008. The modeling effort only included those point sources that were permitted at a discharge of greater than 0.1 MGD. Data, for the permits, was collected from GAEPD and the U.S. Environmental Protection Agency's Envirofacts Data Warehouse Permit Compliance System (EPA-PCS).

The GAEPD point source information was provided in three general ways: an electronic file for each discharger with all parameters, an electronic file for each parameter with all dischargers, and in paper format. As a result of the various GAEPD formats, overlap occurred. All files were reviewed to ensure the best possible continuous record was developed from the provided files. However, there were still large gaps and the EPA-PCS data was used as a backstop in those situations. The next step in developing the time series was to address missing periods in the data. If the gaps in the data were three months or less, an average was calculated from before and after gap months. If the gaps in the data were larger than three months, the long term monthly average was supplied. Many of the dischargers did not report loads or concentrations for all constituents in the LSPC model. Default concentrations were therefore adopted for the missing constituents.

A.2.9 Septic Tanks

Data for septics were received from GAEPD. These numbers were compiled by GAEPD for their TMDL work. The reported value representing the year closest to 2007 was used.

There were still some counties that did not have any septic information. A standard approach was used to generate theoretical numbers for these counties. The 1990 US Census for Georgia contained information about the number of septic tanks within each county (US Census, 2009). This data was mined out of the census data and the 2002-2007 yearly installation average was used to create an extrapolated number to reflect 2001 conditions. The 2001 condition was then summed with the total number of septic tanks installed from 2002-2007. This gave a theoretical number reflective of year 2007 conditions.

The number of septic tanks in each sub-watershed was determined through an area weighting method. Sub-watersheds were assigned to counties based on their outfall or pour point. The percentage of county area, represented by the sub-watersheds assigned to that county, was used to determine the total number of septic tanks represented in those sub-watersheds.

Septic tanks contribute nutrients and affect water quality whether they are functioning properly or failing. It was assumed, that at any given time, 15% of the septic tanks are failing, and 85% are working properly. To represent the contribution from non-failing septic tanks, it was assumed that each septic tank serves a household of 2.8 people, each person accounts for 70 gallons/day of water use and 15% of the water used in the house never makes it to the septic tank. It was also assumed that it takes an average of 60 days for the septic flow to reach a body of water. The water quality constituent concentrations were obtained from literature (Gerner, 2004, Lihua, 2002, Jones, 2005). A first order decay rate was applied to each constituent to determine the concentration after 60 days. For phosphorus, it was assumed that 90% was sorbed to sediment; therefore only 10% of the effluent concentration was used to calculated decay after 60-days.

The failing septic tanks were modeled as a land use in the model, since it is assumed that no decay occurs and raw effluent is directly applied to the land. It was determined that the average area of a septic field is 6,750 ft^2 (Inspectapedia, 2009). The land use that was represented for failing septic tanks was subtracted from the low intensity urban pervious land use for each sub-watershed. For a few of the watersheds subtracting septic tanks from low intensity urban pervious resulted in negative areas. For these watersheds, all of the failing septic tank area was subtracted from developed open space. The water quality effluent loadings were obtained from literature (USEPA, 2002).

A.2.10 Municipal and Industrial Water Withdrawals

The location of all surface water withdrawals in the State of Georgia was supplied by GAEPD for both municipal and industrial uses as two separate GIS point coverages. Monthly average water withdrawal data were obtained from GA EPD, and developed into a time-series for inclusion in the model.

A.2.11 Agricultural Water Withdrawals

Agricultural irrigation systems used on Georgia farms, orchards, nurseries, and golf courses are estimated to cover 1.5 million acres. These systems are supplied with water from ground and surface water resources that fall under GA EPD permitting requirements. Most of the wells, surface water pumping stations, and ponds used in these systems, were constructed and paid for by individual land owners. In the 1988 statutes that required permits for agricultural withdrawals, these privately owned pumping systems were specifically exempt from water metering, record-keeping, and reporting to GA EPD. Consequently, Georgia water planners have lacked systematic accounting of water quantities applied in agricultural production. In 1998, GA EPD requested that the Georgia Cooperative Extension Service establish a statewide system for measurement of water application by producers and conduct a multi-year study of those water amounts. The product of the multi-year study was the Ag Water Pumping Report (Hook et al., 2004).

The Ag Water Pumping Report divided the state into four reporting regions. These regions represent Southwest Georgia, Coastal Zone, Central Coastal Plain, and North Georgia. The data collected from the monitored irrigation systems were extensively analyzed by the authors, and they produced monthly minimum, mean, and maximum irrigations depths, for each region, by source water type. The North Georgia reporting region had monthly irrigation depths only for surface water because most of the irrigation systems in that region used surface water for their supply. For the few situations in North Georgia where groundwater was used for supply, the surface water irrigation depth was still used. The maximum irrigation depth was used during drought conditions (1999-2000, 2002, 2006-2007), and the mean irrigation depth was used for the other years of the simulation.

A shape file of all irrigated fields in the State of Georgia was prepared by the University of Georgia (UGA) under contract with GAEPD (Hook, J.E., 2009). The UGA coverage indicated each individual field’s acreage and source water percent along with a few other distinguishing features. This statewide coverage was GIS processed with the sub-watershed delineation coverage, to determine the irrigated acreage supplied by both surface water and ground water in each sub-watershed. The irrigation shape file was also processed with the GLUT coverage of the watershed. The dominant land use “covered” by irrigated land was determined for each sub-watershed, and the total irrigated acreage for each sub-watershed was subtracted from the dominant land use. A new land use was created for the irrigated land.

To determine the volume of water extracted from groundwater and surface water sources for each sub-watershed, the irrigated land acreage was multiplied by the appropriate monthly irrigation depth. The volume of water associated with surface water was withdrawn from the reach within the sub-watershed each day, and transferred to a sub-watershed specific holding pond. The volume of water associated with groundwater was directed, into the sub-watershed specific pond as a point source each day. The groundwater component was handled as a point source because, unlike surface water that can be removed from a certain reach, LSPC is not capable of withdrawing water from the lower layers of the model. It is assumed that the irrigation ponds do not gain or lose water via atmospheric means.

The irrigation module of LSPC is based on irrigation demand. Irrigation demand is calculated by either using a constant, or the model potential evapo-transpiration (PET), and an evapo-transpiration coefficient (ETc). If the model calculates that irrigation demand is high, i.e., a deficit of water in the upper layers of the model, irrigation will occur until the demand is satisfied. If the holding pond is dry then no irrigation occurs.

A.2.12 Hydrologic Representation

Watershed hydrology plays an important role in the determination of nonpoint source flow and ultimately nonpoint source loadings to a waterbody. The watershed model must appropriately represent the spatial and temporal variability of hydrological characteristics within a watershed. Key hydrological characteristics include interception storage capacities, infiltration properties, evaporation and transpiration rates, and watershed slope and roughness. The LSPC model used a water budget simulation for both pervious and impervious land units.

Initial values for the hydrological parameters were taken from a default data set from previous work done in the State of Georgia. During the calibration process, model parameters were adjusted based on local knowledge of soil types and groundwater conditions, within reasonable constraints until an acceptable agreement was achieved between simulated and observed stream flow. The model parameters adjusted included: evapo-transpiration, infiltration, upper and lower zone storage, groundwater storage, and losses to the deep groundwater system.

A.2.13 Hydrology Model Calibration and Validation

The calibration of the LSPC watershed hydrology model involved comparing simulated stream flows to USGS flow stations. The calibration of the hydrologic parameters was performed from January 1, 1998 through December 31, 2007.

The models were also validated and verified. Model validation is the process of taking the hydrological parameters that have been calibrated, applying those parameters to other watersheds, and comparing the simulated flow to measured flow from a USGS stream gauging station for the same period of time.

A.2.14 Water Quality Model Development and Calibration

Once the LSPC watershed hydrology model was calibrated, the LSPC model was used to create a water quality model of the watershed. The watershed water quality model included all point source dischargers that have a permitted flow of 0.1 MGD or greater, and nonpoint source contributions.

The LSPC water quality model was set up to model water temperature, dissolved oxygen, biochemical oxygen demand (BOD), total nitrogen (TN), ammonia (NH3), nitrate+nitrite (NOx), organic nitrogen (Org-N), total phosphorus (TP), orthophosphate (PO4), organic phosphorus (Org-P), total suspended solids (TSS), phytoplankton, chlorophyll *a*, and benthic algae.

For the water quality simulation, the user has the ability to model in-stream processes for the reaches by assigning them to reach groups. This allows the assignment of unique values for certain LSPC parameters by reach group. The parameters that can be assigned differently by reach group include: sediment bed storage parameters, cohesive and non-cohesive suspended sediment variables for in-stream transport, temperature for stream groups, land to stream mapping, variables associated with BOD sinking, decay, and benthic release, variables for oxygen reaeration, benthic oxygen demand, oxygen scour, all nutrient parameters, and all plankton parameters. It was noticed that headwater reaches responded differently than non-headwater reaches. Therefore, headwater reaches were assigned to their own reach group.

Temperature was calibrated after hydrology because the remaining constituents use water temperature in their algorithms. Temperature was calibrated by adjusting surface and interflow slopes and intercepts, and groundwater temperature, by land use and hydrologic soil groups, until the simulated data closely matched observed. After temperature was calibrated, dissolved oxygen was brought into close agreement with the observed data by adjusting reaeration and interflow and groundwater dissolved oxygen concentrations. The sediment module was then turned on and calibrated. After that the nutrients and plankton modules were turned on and calibrated.

The first step in nutrient and plankton calibration involved looking at BOD, TN, and TP only. These three constituents were modeled by build-up/wash-off from various land uses and assigning land use associated concentrations to the groundwater and interflow. Adjustments were made to monthly accumulation rate, monthly storage limit, interflow concentration, and groundwater concentration for BOD, TN, and TP until the simulated data was in range with the observed field data. Build-up/wash-off removes constituents from the land and carries them into the stream.

After the build-up/wash-off simulated values for the total constituents were in range, a fractionation of the constituents was assigned to surface water flow and groundwater flow. This fractionation assigned percentages of each constituent making up the total to the modeled total value. Total nitrogen was broken down into nitrate+nitrite, ammonia, organic nitrogen and sediment adsorbed ammonia, and total phosphorus was fractionated into ortho-phosphorus, organic phosphorus, and sediment adsorbed ortho-phosphorus. The fractionation was adjusted until the modeled data closely resembled the observed field data.

Once the build-up/wash-off and constituent fractionation were close, plankton and decay rates became the last step in calibrating the watershed model for nutrients. The growth and death of plankton and the biochemical cycling of nutrients impacts dissolved oxygen. Decay and transformation rates were calibrated by balancing dissolved oxygen and in-stream nutrient concentrations.

A.2.15 Integration of LSPC with Other Models

LSPC was integrated with the Environmental Fluid Dynamics Code (EFDC). EFDC is a hydrodynamic and water quality modeling package used for simulating one-dimensional, two-dimensional, and three-dimensional flow and transport in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands, and near-shore to shelf scale coastal regions. EFDC was used to simulate the hydrodynamics (velocity, temperature, etc.) and water quality processes in various lakes and estuaries. LSPC provides flows and concentrations to EFDC from adjacent watersheds. Figure A-1 shows how the two models interact with one another and what outputs each model provides.

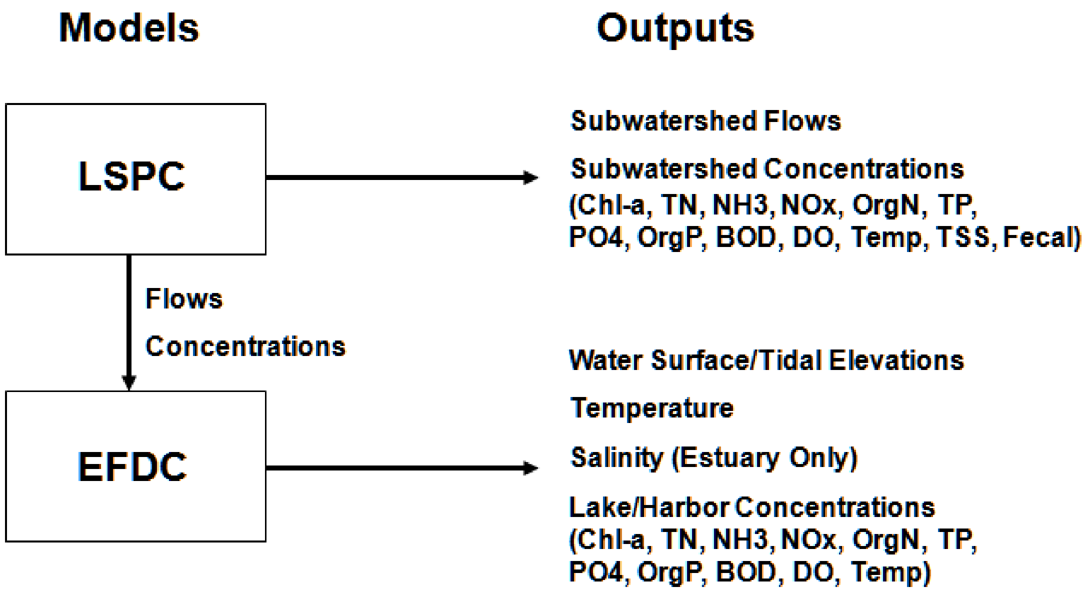

Figure A-1 Linkage between LSPC and EFDC Models

A.3 EFDC

A.3.1 Data Compilation

Data needed for the calibration and validation of the EFDC Hydrodynamic and Water Quality model were obtained from several sources including the GA EPD, Army Corp of Engineers – Mobile District (Corps), USGS, United States Environmental Protection Agency – Region 4 (USEPA4), and Georgia Power. These data were needed for: the computational grid development, point source inputs, water withdrawal inputs, hydrodynamic calibration and validation stations, and water quality calibration and validation stations.

Table A-2 Data Sources for EFDC Model Input

Data Source	Data Type
Georgia Environmental Protection Division (GA EPD)	Point Source Discharges Water Withdrawals Lake Temperature Profiles Lake Dissolved Oxygen Profiles Lake Water Quality
Army Corp of Engineers – Mobile District (Corps)	Water Surface Elevation Dam Outflows
United States Geological Survey (USGS)	Stream Flows
United States Environmental Protection Division – Region 4 (USEPA4)	Nutrient Fluxes Sediment Oxygen Demand
Georgia Power	Water Surface Elevation Dam Outflows Lake Temperature Profiles Lake Dissolved Oxygen Profiles
Kingfisher Maps, Inc.	Lake Bathymetry
National Oceanic and Atmospheric Administration (NOAA)	Harbor Bathymetry
Georgia Automated Environmental Monitoring Network (GAEMN)	Weather Data
National Climate Data Center (NCDC)	Weather Data

A.3.2 Computational Grid

A.3.2.1 Model Segmentation

The lakes and harbor were segmented into curvilinear orthogonal computational grid cells representing horizontal dimensions for the hydrodynamic and water quality model. In some cases, due to the fact that the tributaries are extremely meandering, curvilinear and orthogonal horizontal coordinates were also used to approximate the physical dimension of these waterbodies.

A.3.2.2 Layers

For the lakes, the number of layers was selected to have a good resolution of the temperature stratification of the lake along the deepest part of the main channel and to have at least 2 layers in all of the embayments, which promotes the temperature induced convective circulation.The number of layers, outside the deepest region, was defined based on the bathymetry and the water surface elevation at full pool. The height of each layer, at full pool, was calculated as the water surface elevation minus the deepest bottom elevation divided by the maximum number of layers. At each cell, the number of layers was calculated as the total water depth at full pool, divided by the layer depth at the deepest point. A maximum of 10 uniform distributed (equal height) vertical layers were defined for the lakes, and 4 layers were defined for Brunswick Harbor.

A.3.2.3 Bathymetry

Bathymetry data was obtained from Kingfisher Maps for the lakes and from NOAA for Brunswick Harbor. These data were used to determine the bottom elevation of each horizontal cell in the system. Although it is not possible to achieve an exact representation of the complex details of the rivers, lakes, and harbor's morphometry, the discretization of the grid provided a good representation of the bottom topography. For the lakes, once the bottom elevation was determined for each cell, the stage-area and stage-capacity curves were analyzed to make sure that the computational grid represented reality.

A.3.3 Simulation Period

The simulation period for the EFDC model was a 7-year period – from January 1, 2001 through December 31, 2007. This period was chosen as it overlaps the data collection efforts by GA EPD, which occur monthly during the growing season (April through October).

A.3.4 Meteorological Data

Meteorological inputs consist of precipitation, evaporation, relative humidity, air pressure, air temperature, solar radiation, cloud cover, wind speed, and wind direction. Evaporation was internally calculated by EFDC, and solar radiation was calculated from cloud cover. The other meteorological inputs were obtained from the NCDC station network.

It is important to note that cloud cover is a difficult parameter to characterize in modeling applications. As cloud cover, or sky condition, is typically reported from an observer, not monitoring equipment, there are inherent challenges in its development. For consistency, it is preferred that cloud cover come from the same station for the entire simulation period.

A.3.5 Marsh Representation

The Brunswick Harbor area is characterized to a large extent by its lowlands of marshes that play an important role in the hydrodynamic and water quality of the system, serving as storage of large quantities of water and releasing carbon into the system. The marshes were included as marsh cells in the model. These marsh cells were assigned a low bottom elevation (-0.5 meters below MSL) and using the wetting and drying capabilities of EFDC, they were allowed to go dry during low tide. In order to further reduce the velocity circulation in the marsh cells, typical marsh vegetation drag was included.

A.3.6 Hydrodynamic Boundary Conditions

Deterministic time variable models predict conditions within the computational domain based upon perturbations within the model grid caused by outside forcing functions. These forcing functions need to be described to the model and include:

- Inflows and outflows,
- Meteorological conditions (wind, solar radiation, etc.), and
- Open boundary water surface elevation (tidal) forcing (Brunswick Harbor only).

Time dependent or constant values for each of these parameters must be applied at each of the appropriate boundaries for the entire model simulation period. These values were applied at all of the boundaries within the system including:

- Dam releases,
- Lateral tributaries inflows,
- Water withdrawals,
- Point sources, and
- The open boundary with the ocean (Brunswick Harbor only).

A.3.7 Corrective Flow

In a system such as a lake where there is a hydroelectric dam, it is important to be able to quantify all of the inputs and outputs. If the mass balance, in terms of flow, is not correct, then it will be near impossible to calibrate the hydrodynamics for water surface elevation. If, for example, the net flow (inputs – outputs) to the system is greater than the change in water surface elevation, then there will be a net increase in water surface elevation. Similiarily, if the net flow is less than the change in water surface elevation, there will be a net decrease. Since this is a mass balance system, the associated error in water surface elevation would be carried throughout the simulation.

To help minimize the difference between simulated and measured water surface elevation, the corrective flow feature of EFDC was applied. This feature allows EFDC to calculate, at a given time scale, the amount of flow required to force a match between the calculated and observed water surface elevations. The calculated flow, or "corrective flow," represents the error in volume associated with the model. This flow can be due to a combination of inaccurate readings of flow inputs or outputs, inaccurate estimates of watershed flow, spatial discrepancies in meteorological data, or unaccounted flow terms.

Once calculated, this flow was entered as a time series to adjust the simulated water surface elevation. Positive corrective flows (inflows) were added to the upstream flow and negative corrective flows (outflows) were added to the dam discharge. It is believed that reporting the error in this manner, as a flow time series, could later be insightful as to the nature of the simulation error. Such a time series could show constant volume errors in the simulation, an error dependent on lake storage, or an error that correlates with particular flow inputs.

A.3.8 Open Boundary

Water surface elevation data were only available for Brunswick Harbor at the St. Simons Light station, which was used to generate the open boundary condition. In order to do a comparison of the phase and amplitude of the astronomical component of tides, synthetic astronomical predictions at seven locations were used. These predictions were calculated using the software Tides & Currents for Windows, version 2.5b by Nautical Software, Inc. Tides & Currents predictions are based on measurements done by the NOAA at tidal stations taken as reference by Tides & Currents. The astronomical tidal components were calculated at the reference station based on the measured data and then these astronomical components were extrapolated to other locations by the program based on bathymetry and distance from the reference station. Although these data are not direct measurements, they give a good estimate of the astronomical tide both in phase as well as in magnitude. A comparison was done to model results when the model was forced with real tidal data. These results gave a good estimate of the tidal phase simulation given the fact that the tidal periodicity is due to the astronomical component of the tide. The difference between model results and Tides & Currents predictions are due to the meteorological tides and surges. No comparison can be done to real water surface elevation data to calibrate meteorological tides and surges propagation, but for the comparison done with real forcing, the influence of meteorological tides and surges is less important than astronomical tide, and the comparison with Tides & Currents shows that the tidal amplitude calibration is good.

A.3.9 Hydrodynamic Calibration

The main calibration objective for the hydrodynamic model for the lakes was to adequately represent the physics of the system, by propagating momentum and energy based upon freshwater inflow and wind. Density stratification plays a major role in the water quality of the system. For this reason, another calibration objective was to have the ability to predict temperature that affects the hydrodynamics through density changes. The hydrodynamic model was calibrated to water surface elevations and temperature profiles collected during the growing season.

The main calibration objective for the hydrodynamic model for Brunswick Harbor was to adequately represent the physics of the system by propagating momentum and energy based upon freshwater inflow, tidal propagation from the ocean into the harbor, and wind. Density stratification plays a major role in the water quality of the system. For this reason, another calibration objective was to have the ability to predict salinity and temperature, which affects the hydrodynamics through density changes. The hydrodynamic model was calibrated for water surface elevation, salinity, and temperature. Only temperature data were available for the whole simulation period. Salinity was available for the period January 1, 2005 to March 31, 2007. Water surface elevation data was only available for the boundary station at St. Simon Island, therefore calibration was done using synthetic data from Tides & Currents calculations based on astronomical tide extrapolations.

A.3.10 Water Quality Model Development

The EFDC water quality model was setup using the following variables:

- Ammonia (NH3),
- Nitrate+Nitrite (NO3+NO2),
- Organic Nitrogen,
- Orthophosphate (PO4),
- Organic Phosphorus,
- Algae (2 species – Diatom algae and Green algae),
- Silica,
- Dissolved Oxygen (DO), and
- Carbonaceous Biochemical Oxygen Demand (CBOD).

A.3.11 Water Quality Zones

The computational grid was divided into a number of water quality zones. These zones allowed the kinetics, SOD, and nutrient fluxes to be specified for each zone in the EFDC water quality model.

A.3.12 Sediment Oxygen Demand and Nutrient Fluxes

If SOD or nutrient flux data were available, these data were input into the model as a starting point. These values were then adjusted depending on the calibration.

A.3.13 Marsh Loads

Even though marsh cells are included in the Brunswick Harbor model, not all the processes occurring in the marshes are specifically simulated by the model. Marshes are usually complex ecological systems with high productivity that provide large amounts of carbon to the surrounding waters. The marsh carbon contribution are one of the largest sources of carbon into the system and is the most difficult to quantify. Based upon the field measurements collected in 1982, an initial load of TOC based on marsh area was loaded to the system at the marsh cells. These loads were adjusted in the model calibration to achieve the best fit for TOC and DO.

To address seasonality of the marsh loads, a reference paper was used that measured dissolved inorganic carbon (DIC) in tidal freshwater marshes in Virginia and the adjacent estuary. The paper is titled "Transport of dissolved inorganic carbon from a tidal freshwater marsh to the York River Estuary" by Scott C. Neubauer and Iris C. Anderson from the Virginia Institute of Marine Science, School of Marine Science, College of William and Mary.

A.3.14 Water Quality Calibration

The EFDC water quality model calibration and validation was performed using data collected by GA EPD from 2001 through 2007. This data included monthly Total Phosphorus, Total Nitrogen, Ammonia, Nitrate+Nitrite, Biochemical Oxygen Demand, Chlorophyll *a*, Dissolved Oxygen profiles, and Total Organic Carbon data.

A.4 Wet vs. Dry Years

An analysis was done on the long-term precipitation data collected at Atlanta Hartsfield-Jackson International Airport (Summary of the Day Station 090451). Based on data collected from 1930 through 2007, the long-term annual average total precipitation amount is 48.7 inches (Figure A-2). When the long-term annual average value is compared to the annual precipitation totals from 2001 through 2007 (Figure A-3), it is shown that 2 years have annual totals that less than the average (2001 and 2007), 3 years have totals greater than the average (2003 through 2005), and 2 years have totals very near the average (2002 and 2006). For this analysis, it was assumed that dry and wet precipitation years were those that had a greater than 10% departure from the long-term annual average (+/- 4.9 inches). Therefore, years 2001 and 2007 were considered dry precipitation years, -10.3 and -15.2% respectively, and 2004 and 2005 were considered wet precipitation years, 4.9 and 7.7% respectively (Figure A-4).

This analysis, which was used to determine dry and wet years, is important to understand nutrient loading. During years where there is more rainfall (i.e., wet year), the nutrient loading to a watershed or lake tends to be much higher than those years of less rainfall (i.e., dry year). Therefore, if there are exceedences during wet years, this suggests that non-point sources are a dominant contribution, whereas, exceedences during dry years suggests point source discharges are a dominant contribution.

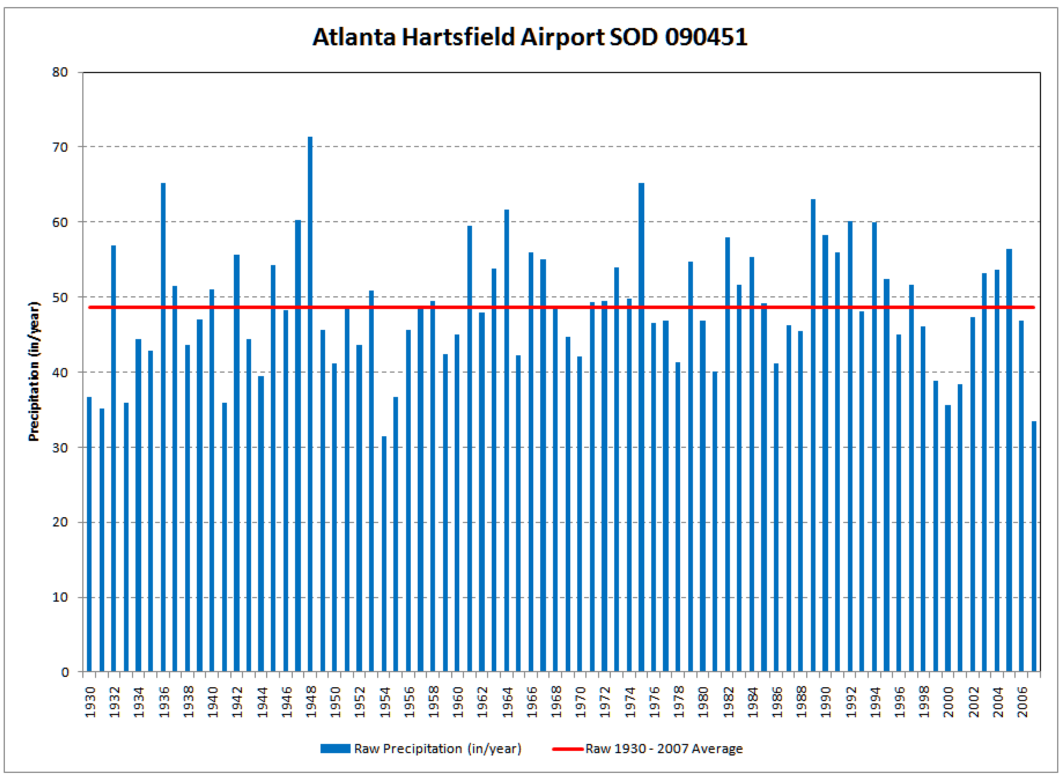

Figure A-2 Long-Term Precipitation for Atlanta Hartsfield Airport (1930-2007)

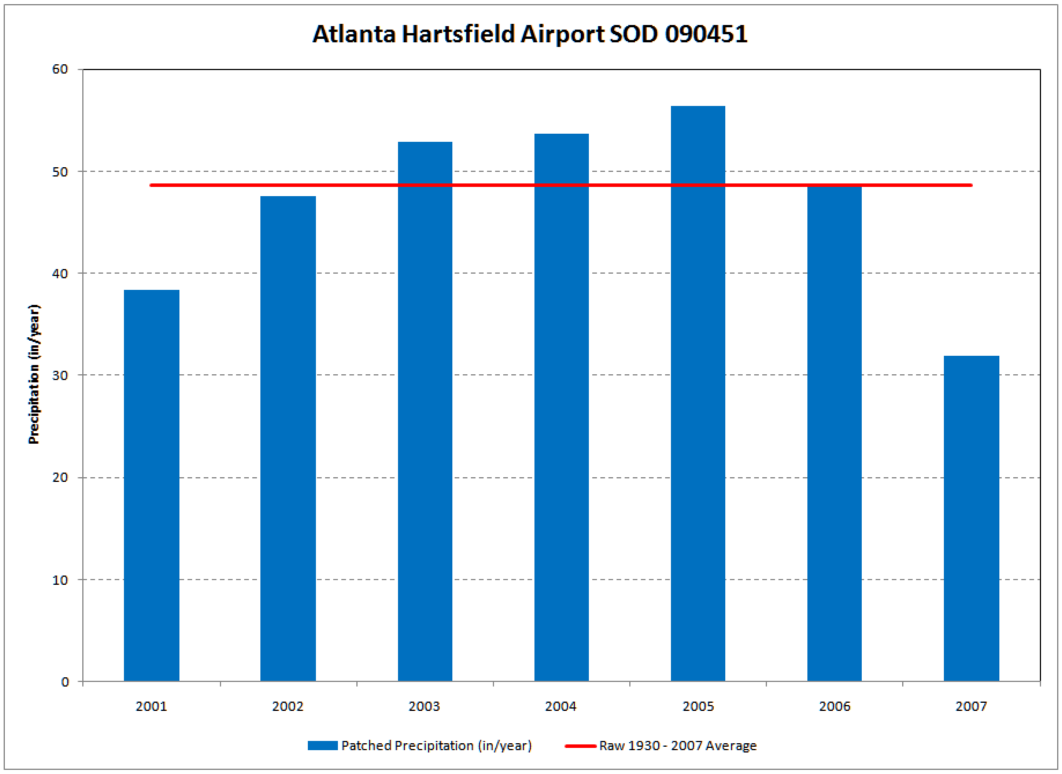

Figure A-3 Long-Term Precipitation for Atlanta Hartsfield Airport (2001-2007)

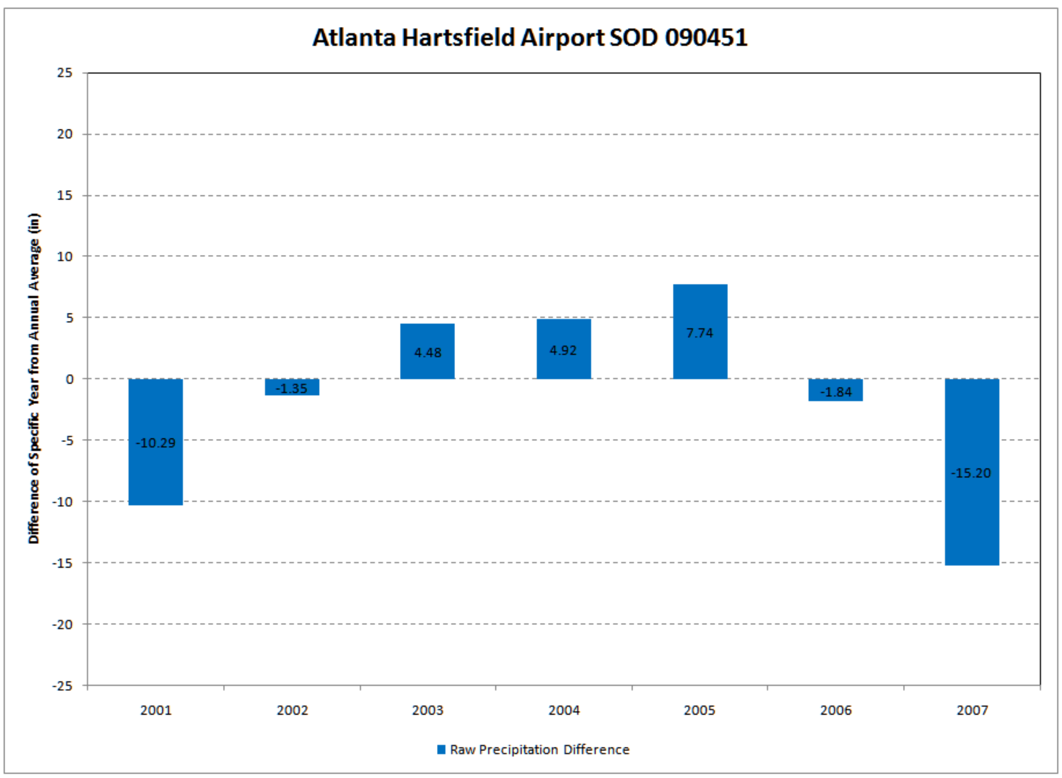

Figure A-4 Percent Departure from Long-Term Annual Precipitation (2001-2007)

Appendix B: Dissolved Oxygen Results

All Figures presented in this Appendix are DRAFT and are subject to change.

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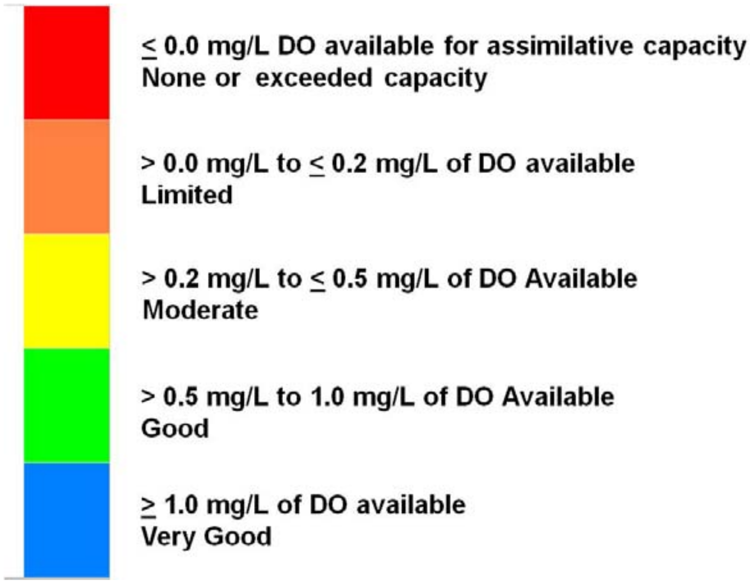


Figure B-1 Description of Dissolved Oxygen Results

B.1 Chattahoochee River Watershed

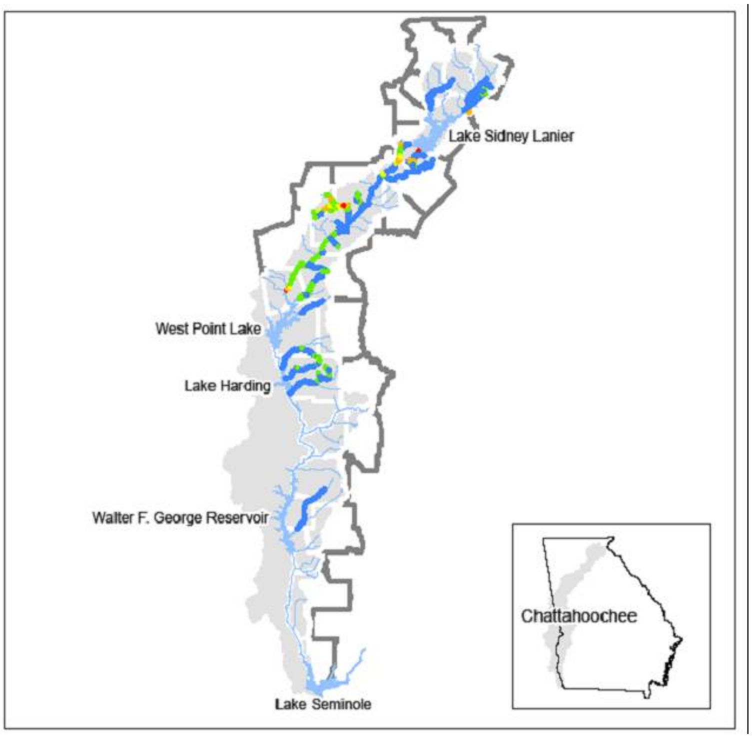


Figure B-2 Results of Dissolved Oxygen Models in the Chattahoochee River Watershed

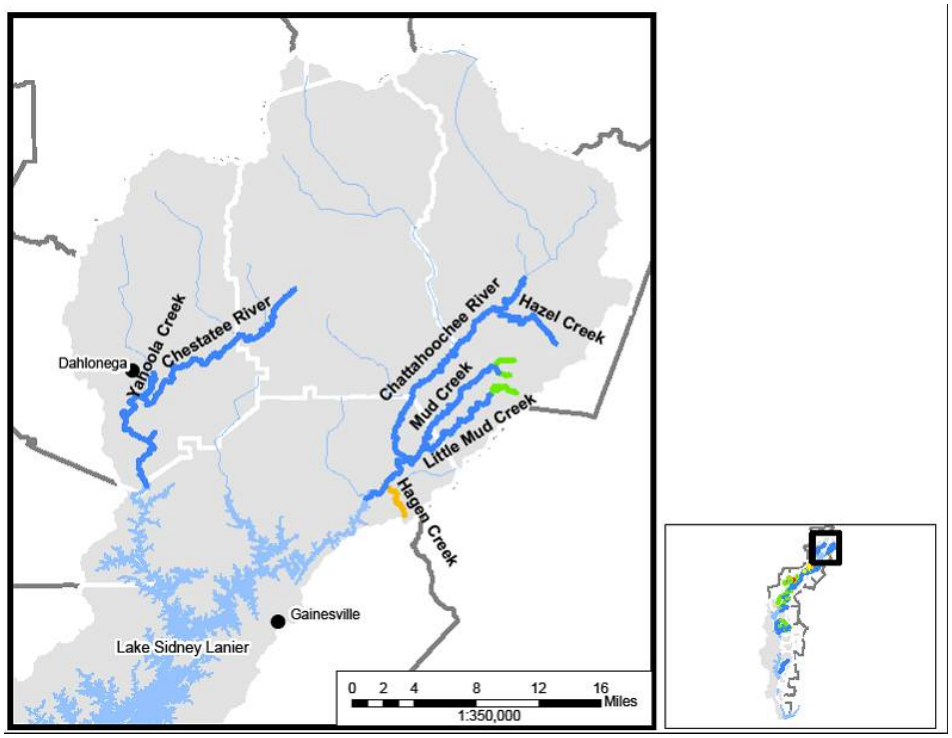
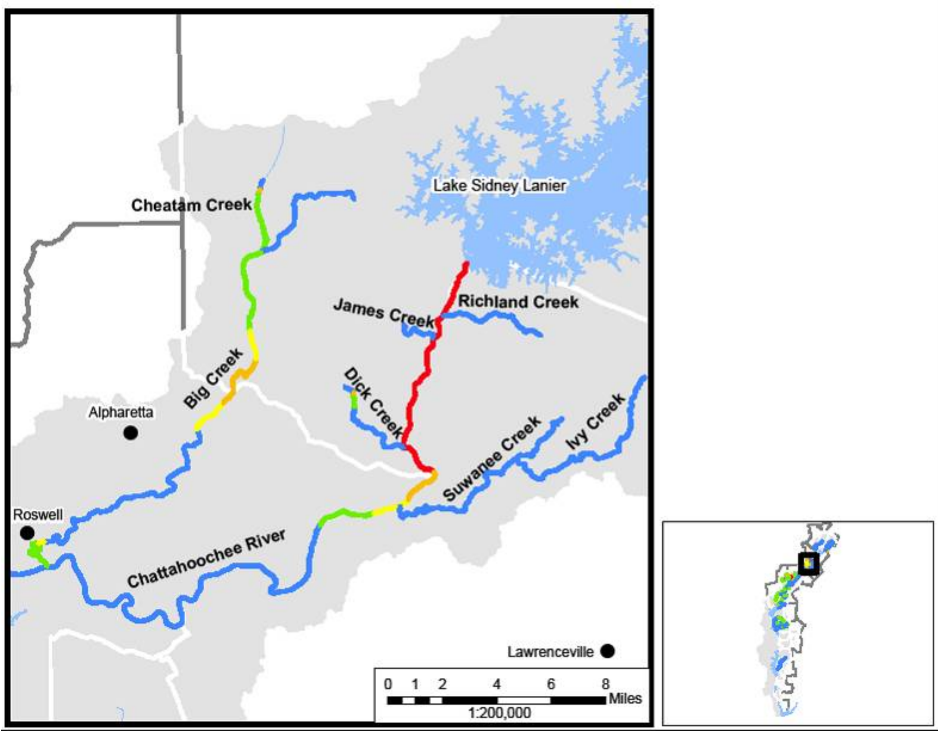


Figure B-3 Detailed Results of Dissolved Oxygen Models in the Chattahoochee River Watershed



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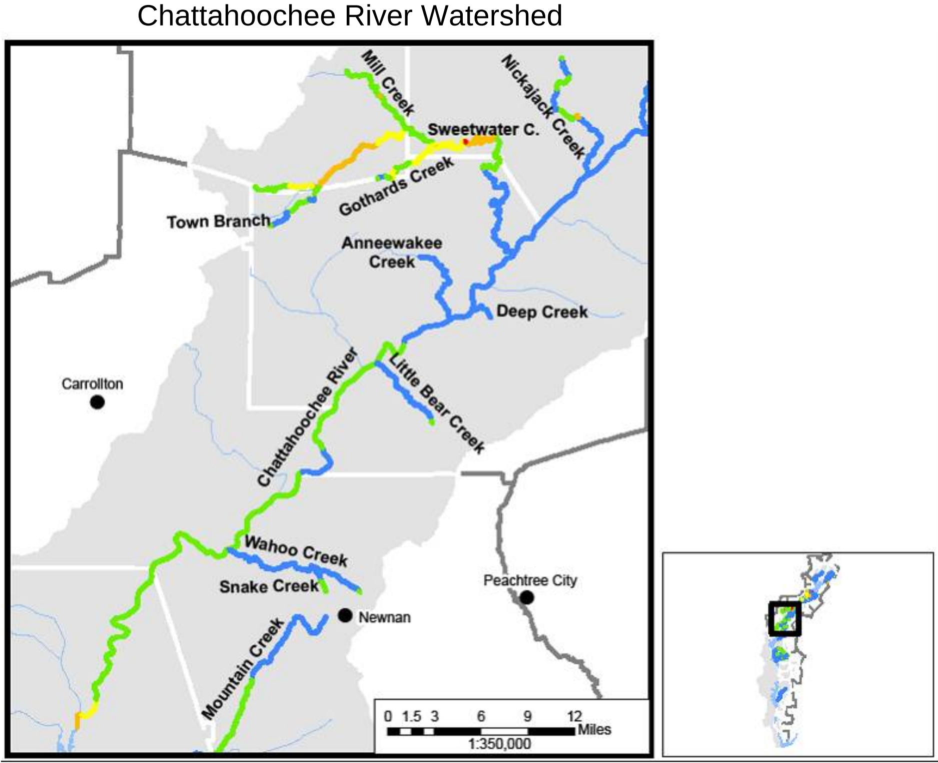
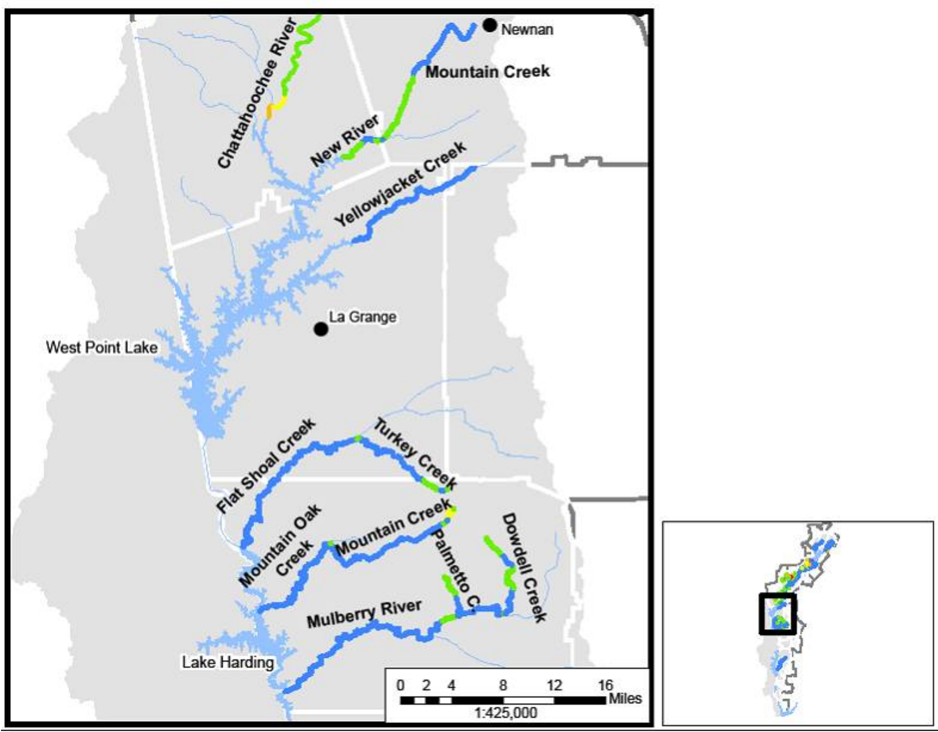


Figure B-3 (cont) Detailed Results of Dissolved Oxygen Models in the Chattahoochee River Watershed



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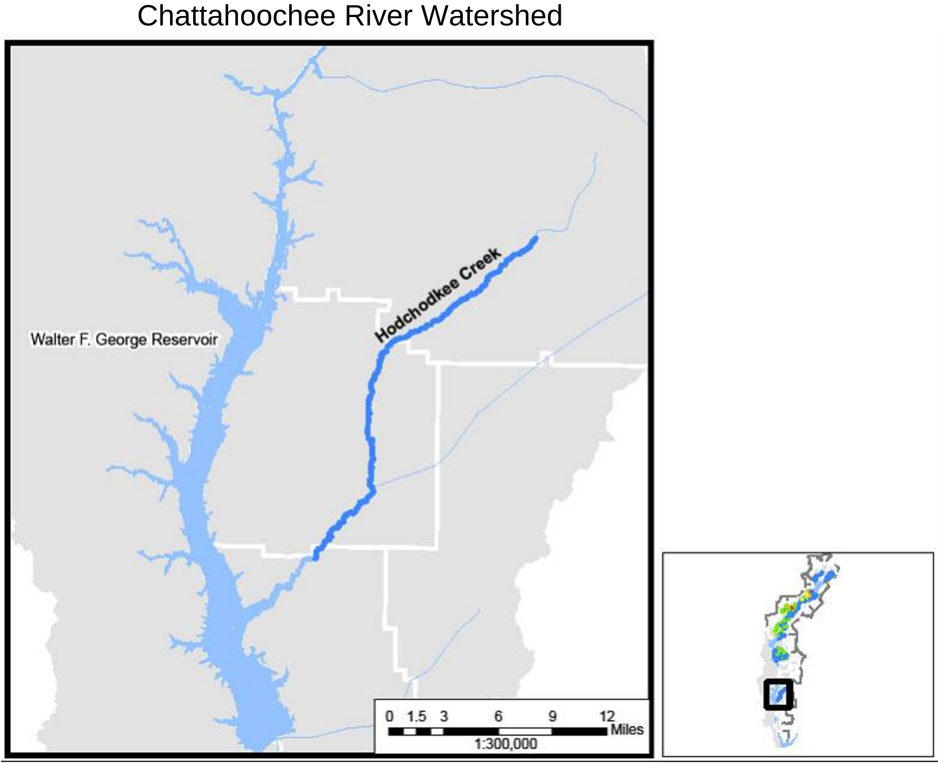


Figure B-3 (cont) Detailed Results of Dissolved Oxygen Models in the Chattahoochee River Watershed

B.2 Flint and Ochlocknee River Watersheds

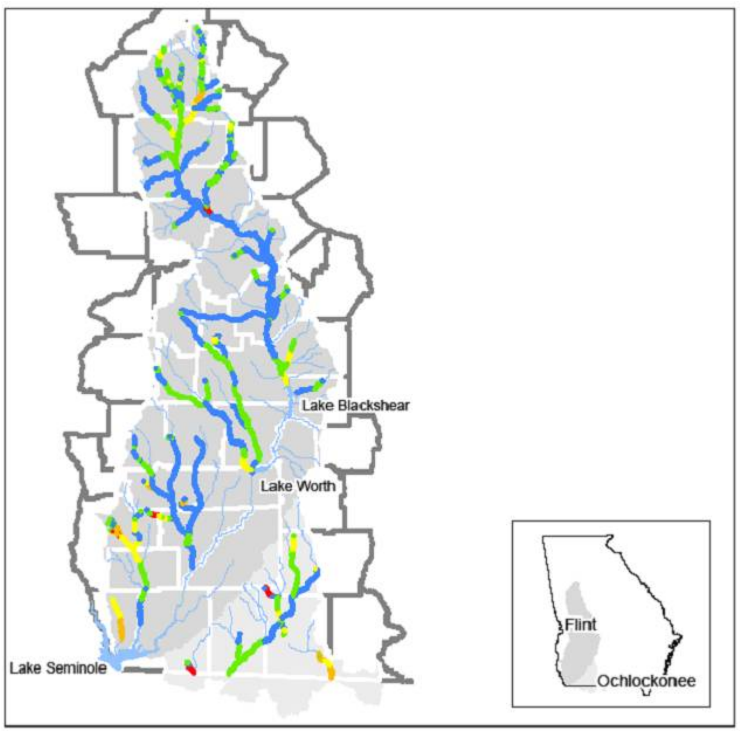
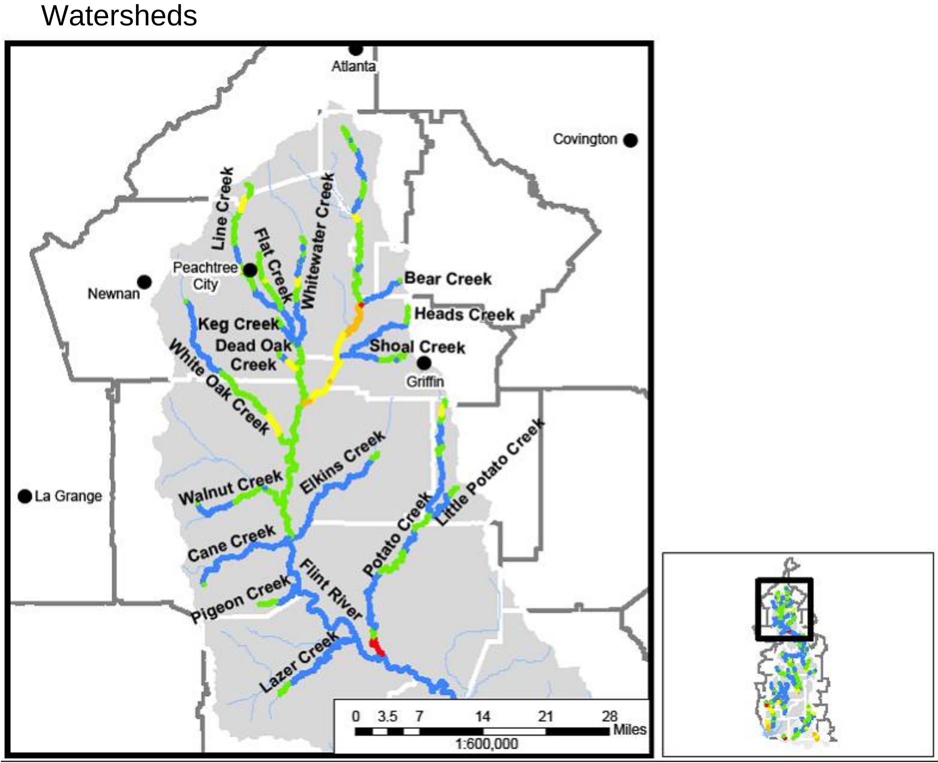


Figure B-4 Results of Dissolved Oxygen Models in the Flint and Ochlocknee River Watersheds



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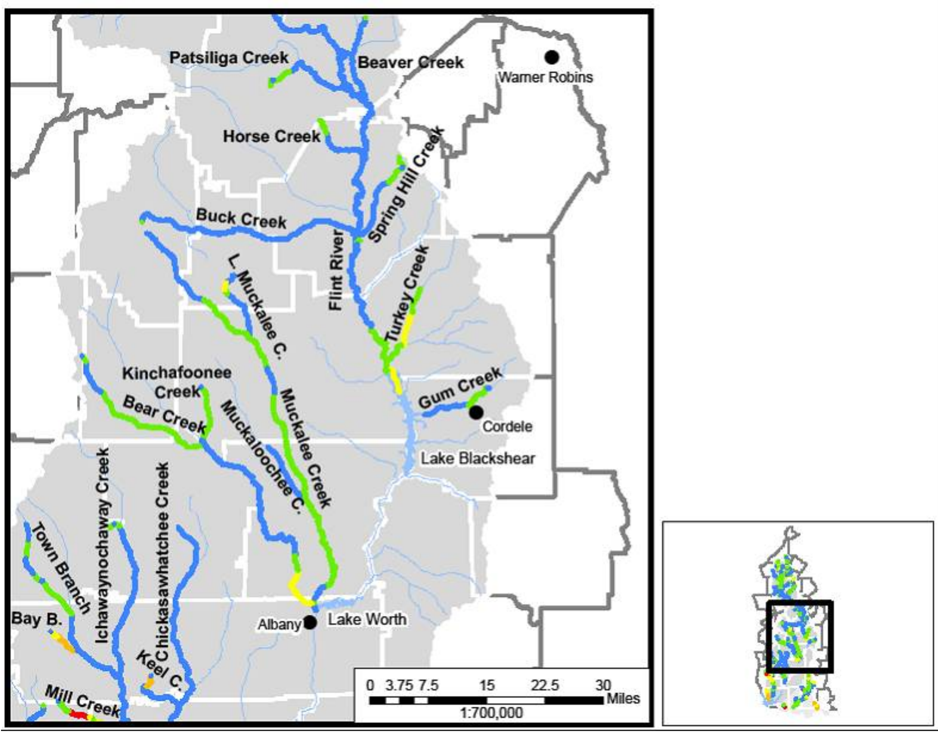

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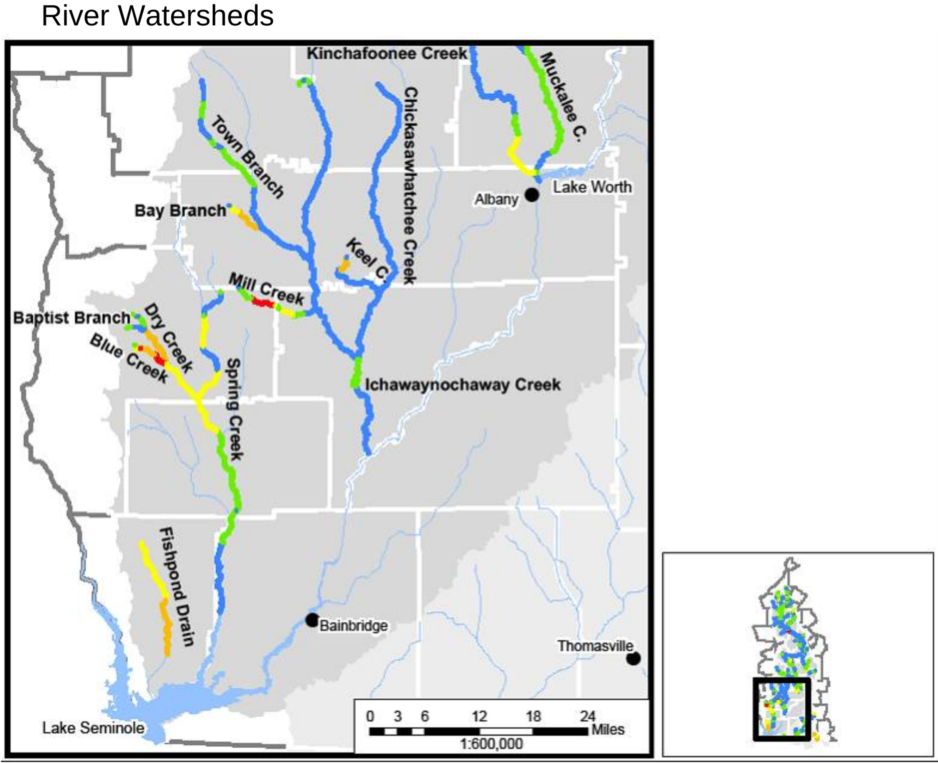

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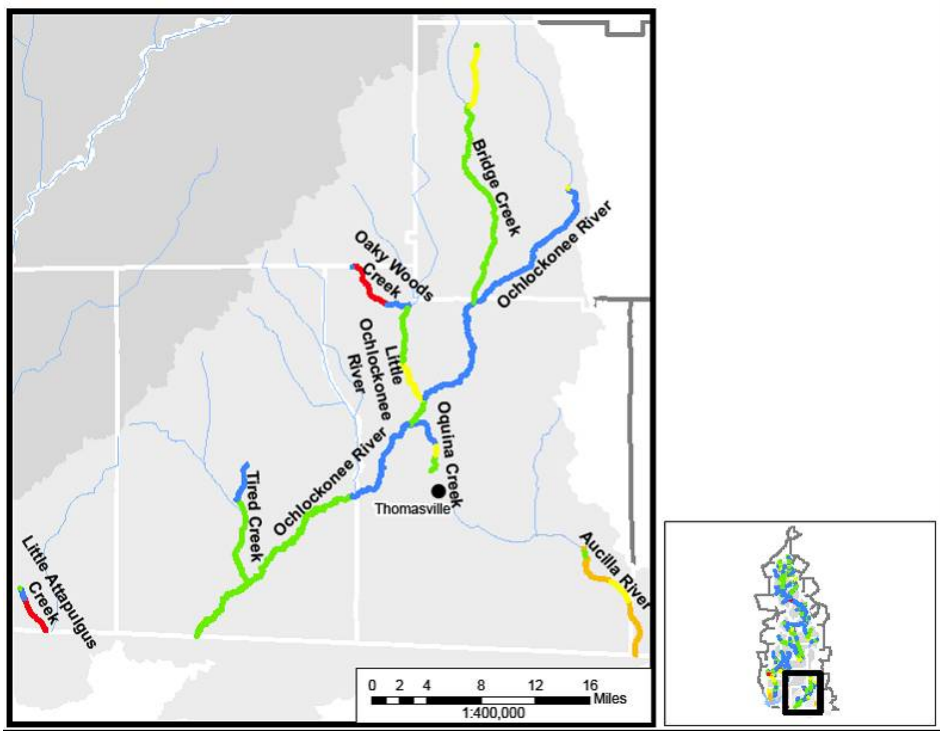


Figure B-5 (cont) Detailed Results of Dissolved Oxygen Models in the Flint and Ochlocknee River Watersheds

B.3 Coosa, Tennessee and Tallapoosa River Watersheds

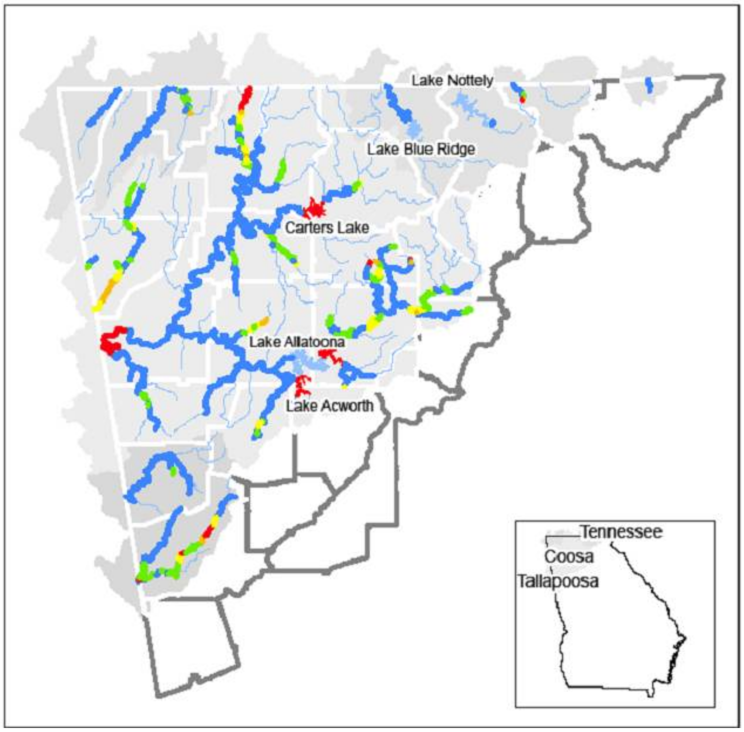
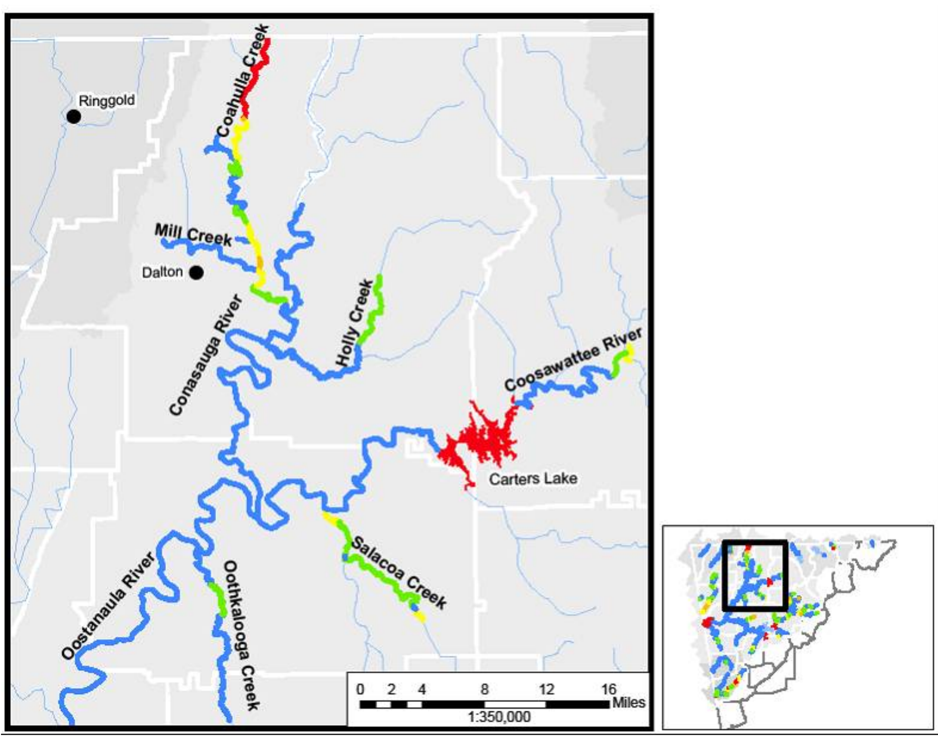


Figure B-6 Results of Dissolved Oxygen Models in the Coosa, Tennessee and Tallapoosa River Watersheds



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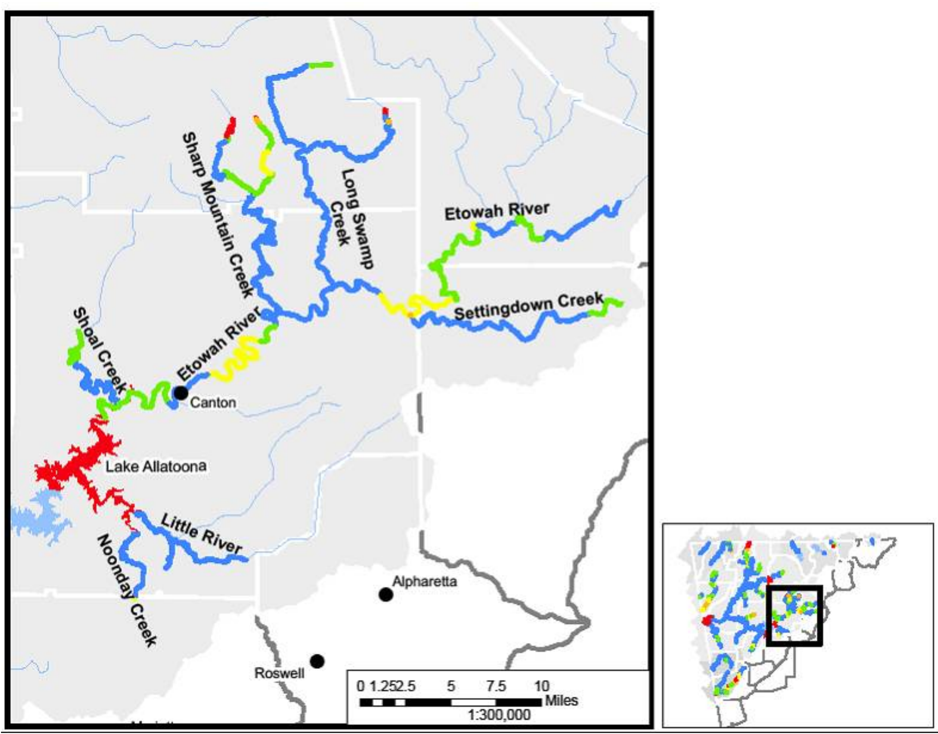

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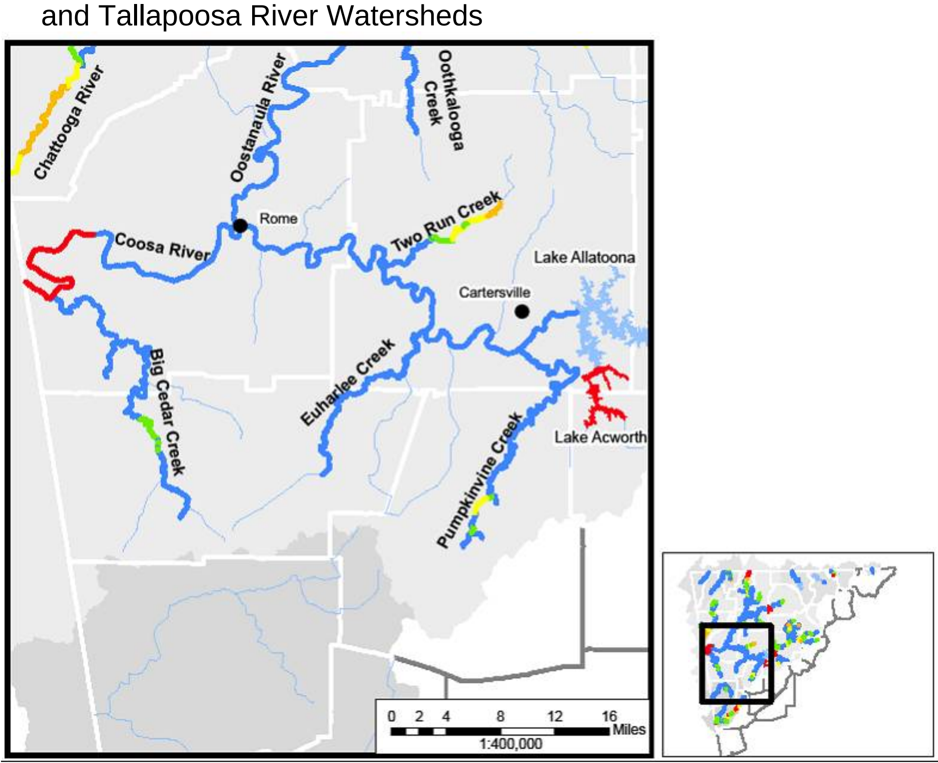

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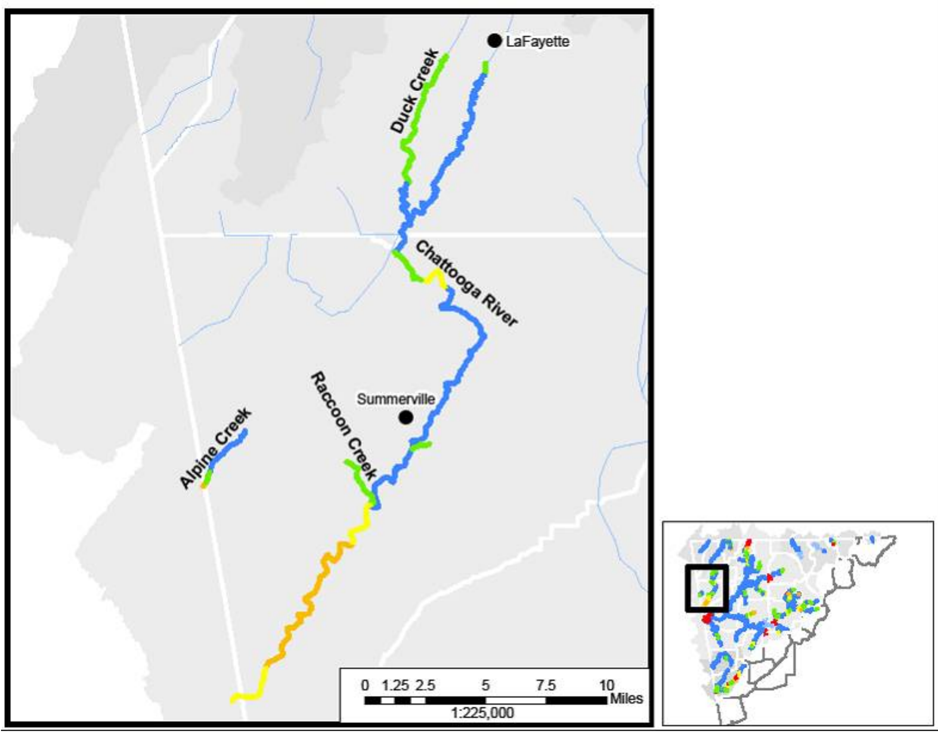

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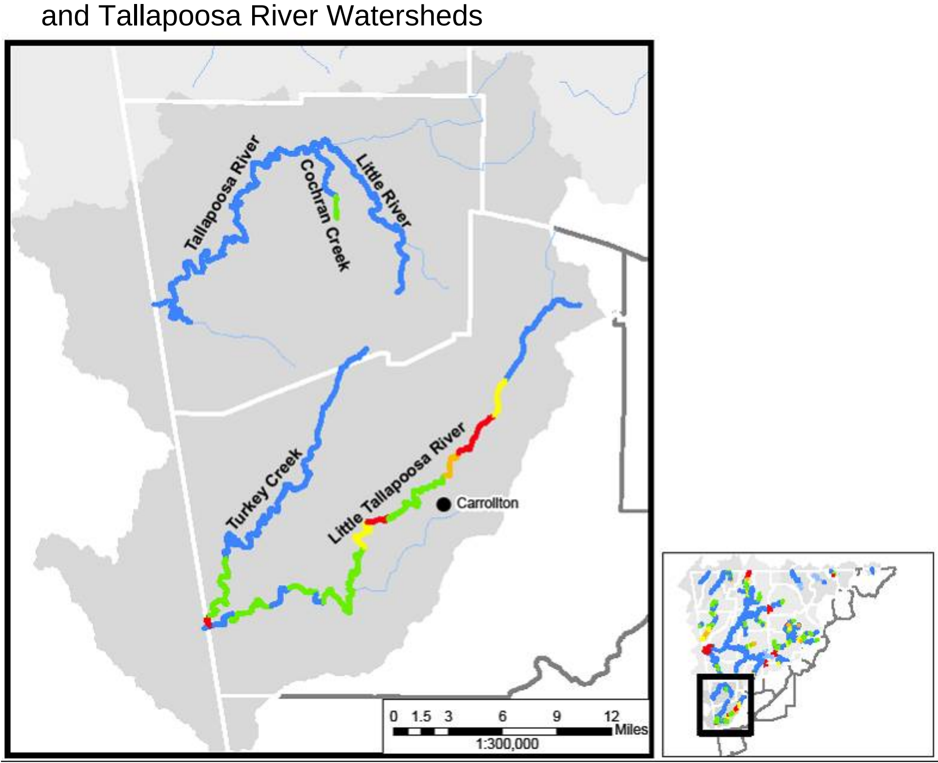

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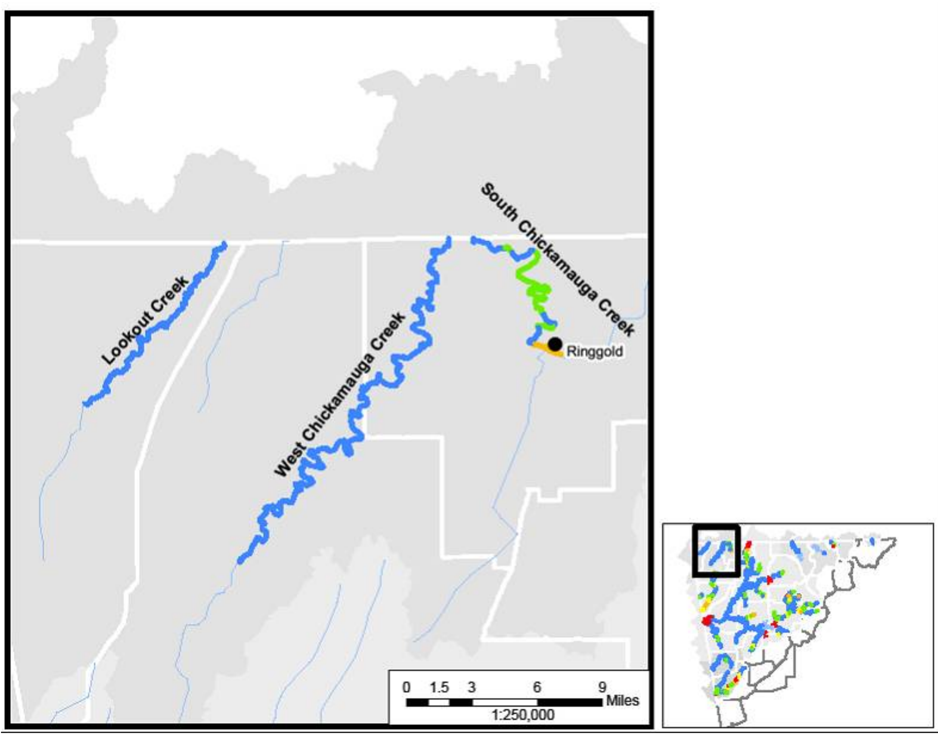

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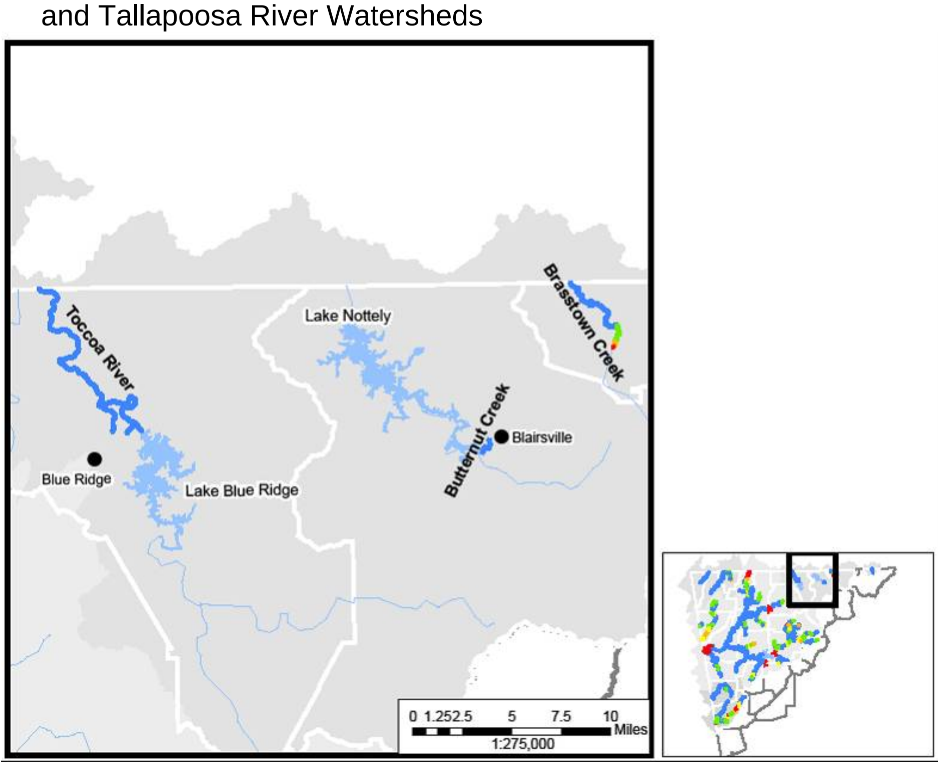

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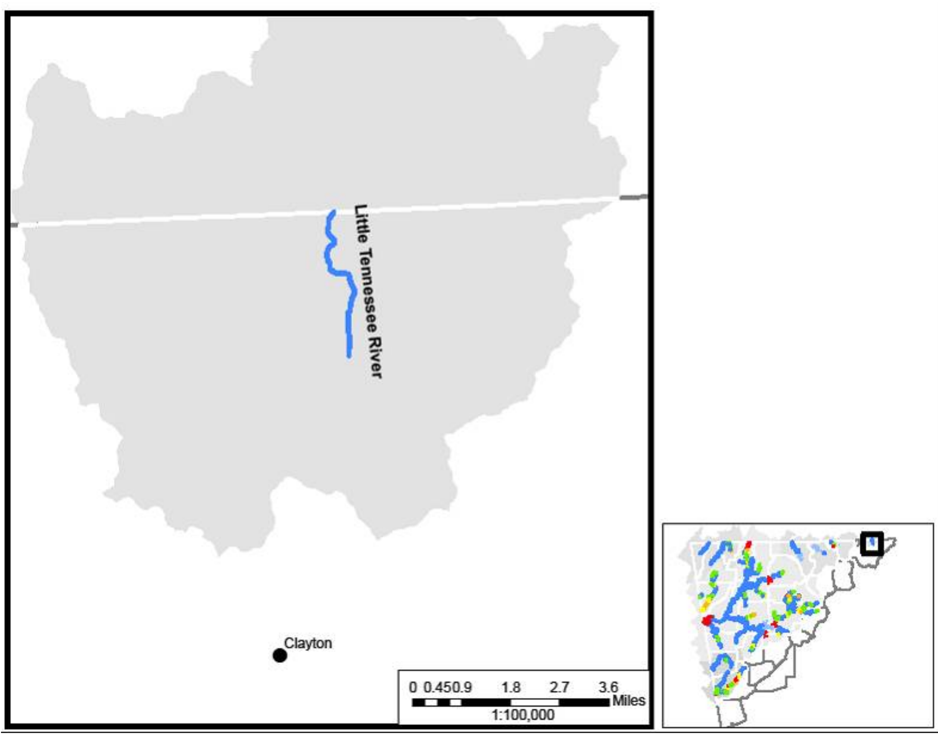


Figure B-7 (cont) Detailed Results of Dissolved Oxygen Models in the Coosa, Tennessee and Tallapoosa River Watersheds

B.4 Savannah and Ogeechee River Watersheds

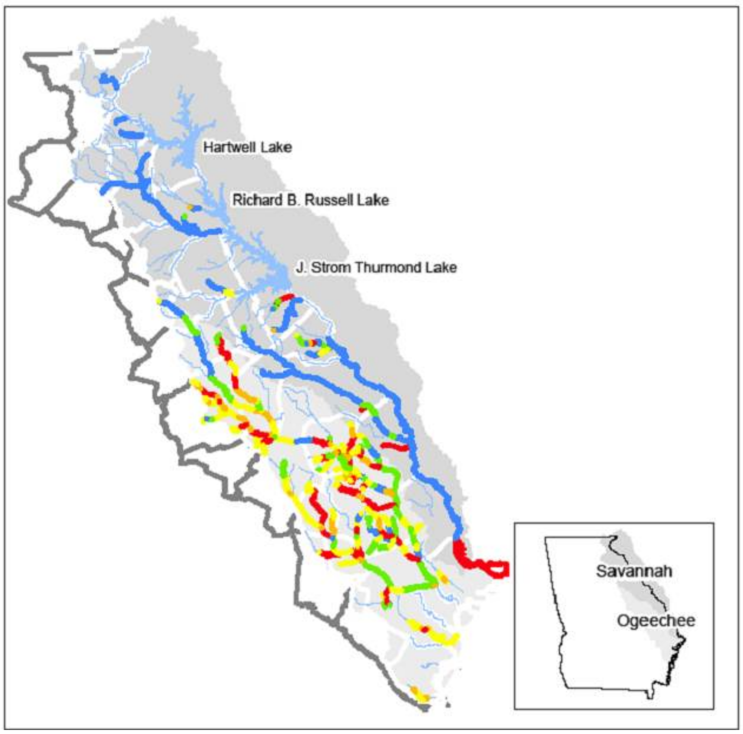
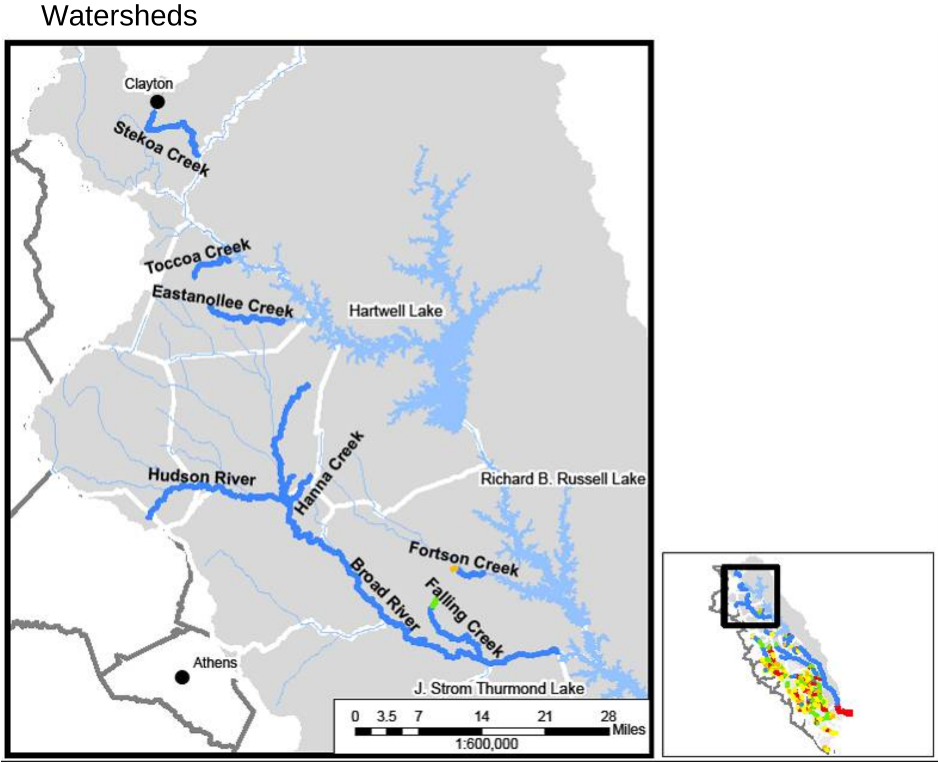


Figure B-8 Results of Dissolved Oxygen Models in the Savannah and Ogeechee River Watersheds



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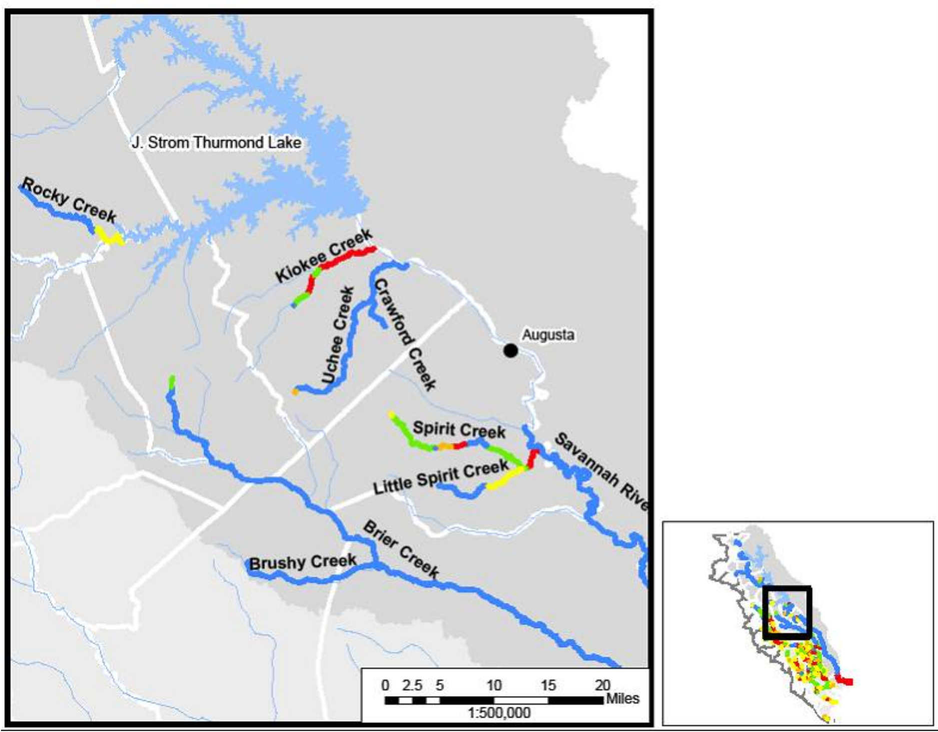

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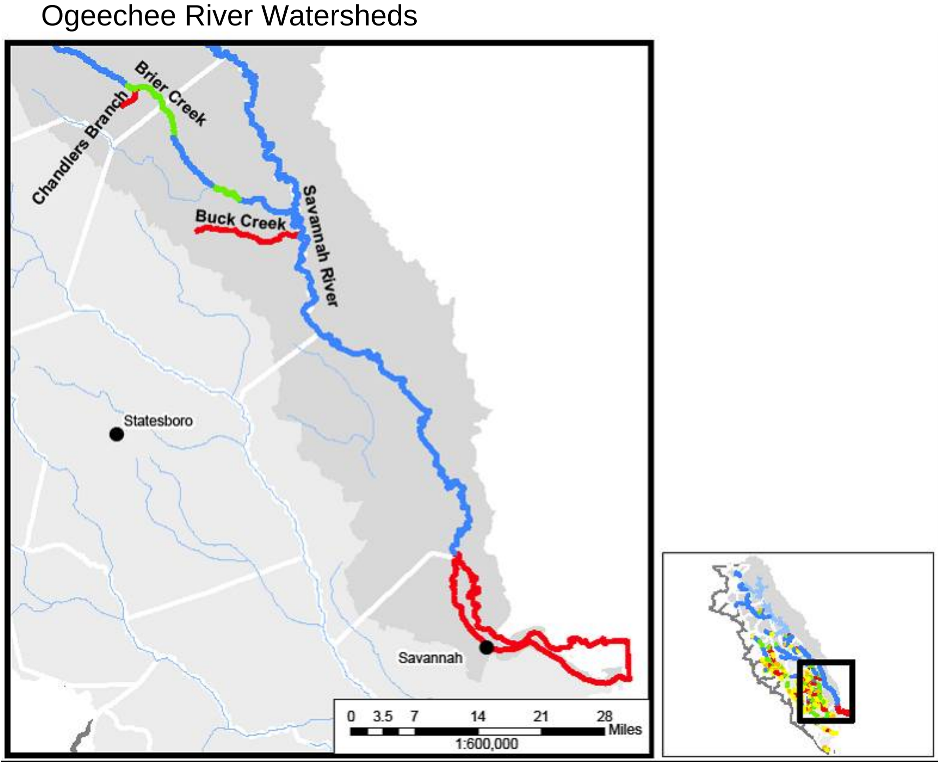

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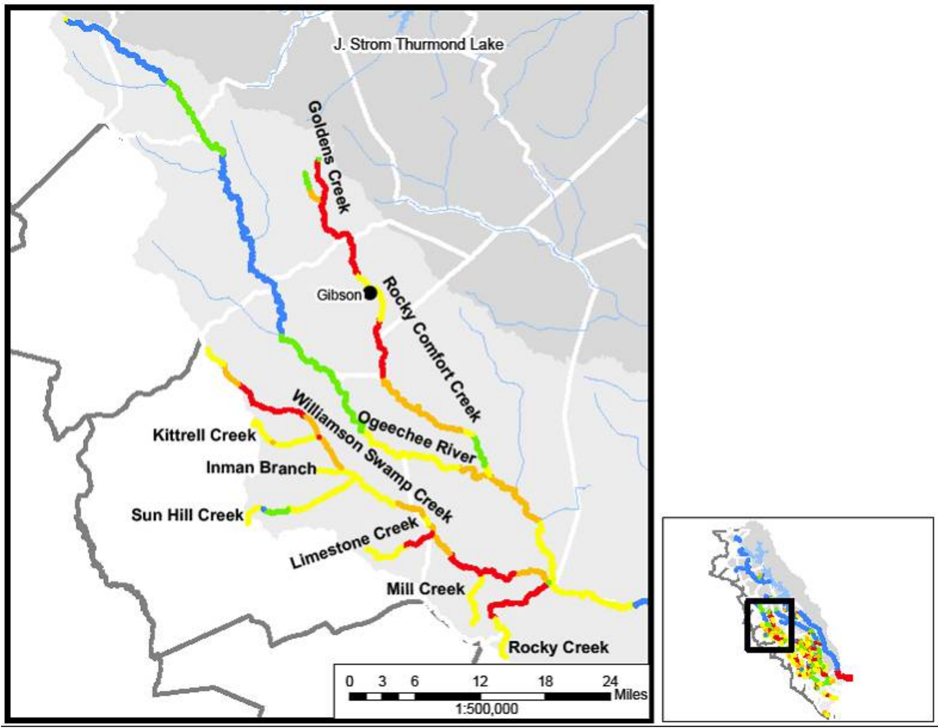

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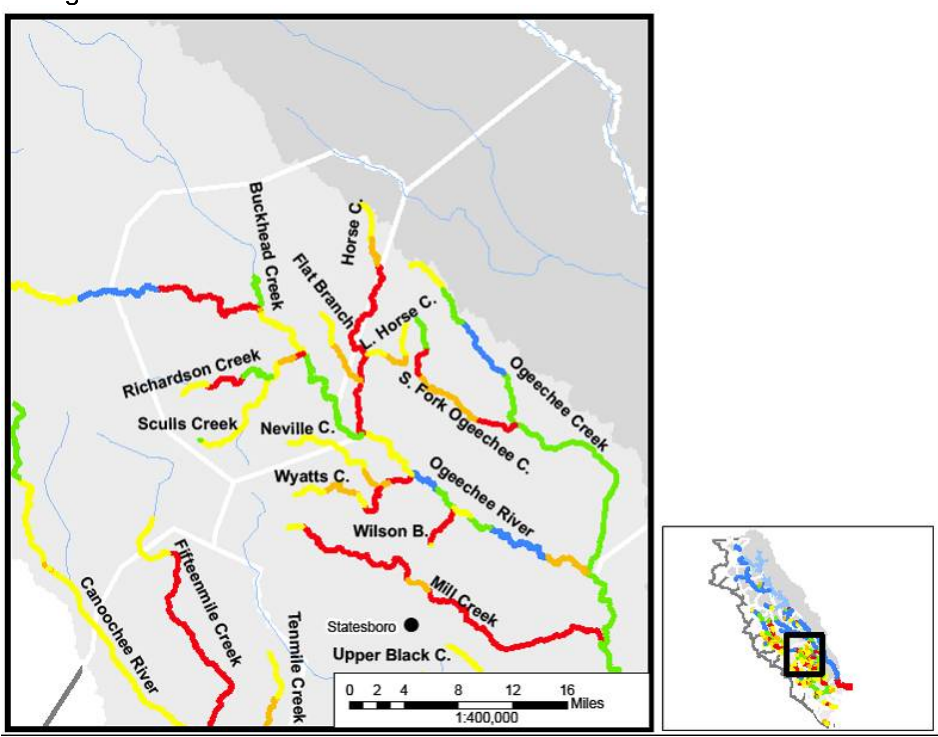

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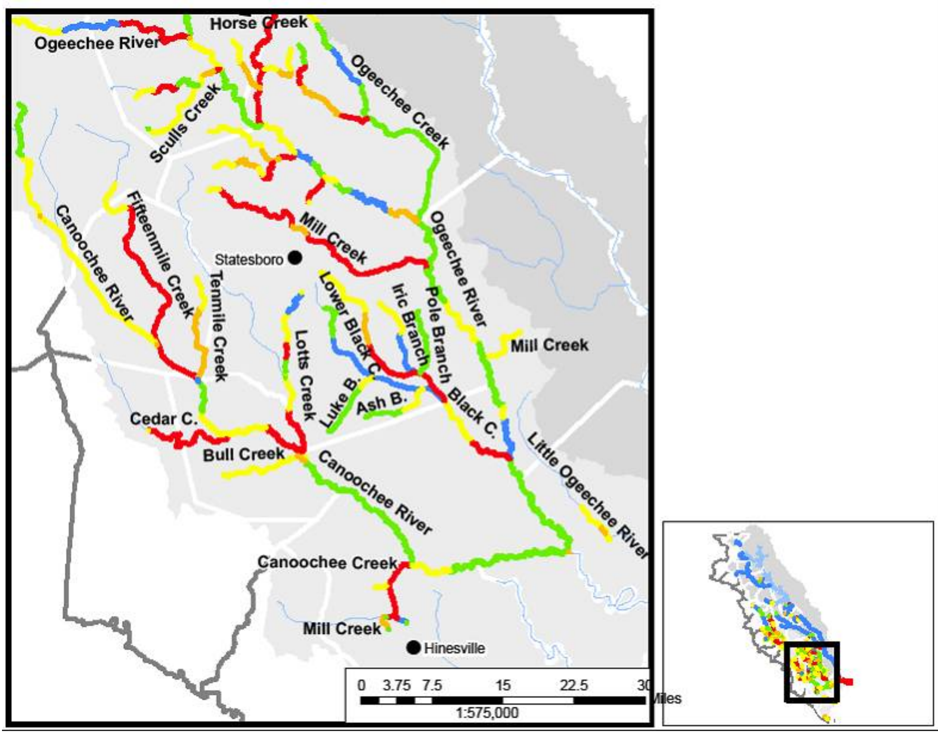

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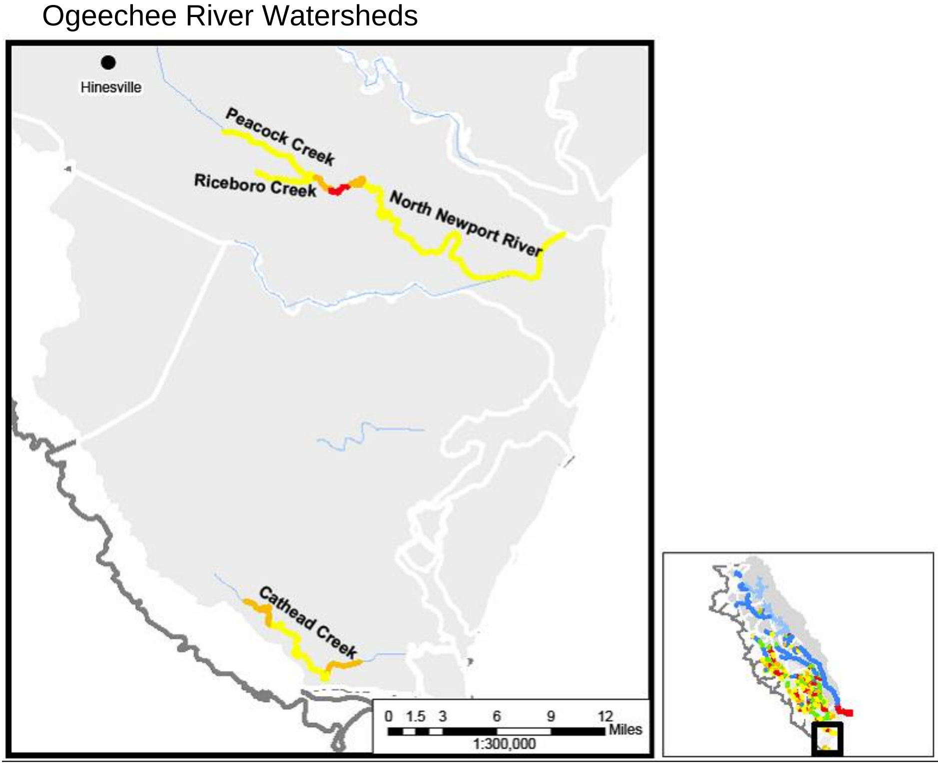


Figure B-9 (cont) Detailed Results of Dissolved Oxygen Models in the Savannah and Ogeechee River Watersheds

B.5 Oconee, Ocmulgee, and Altamaha River Watersheds

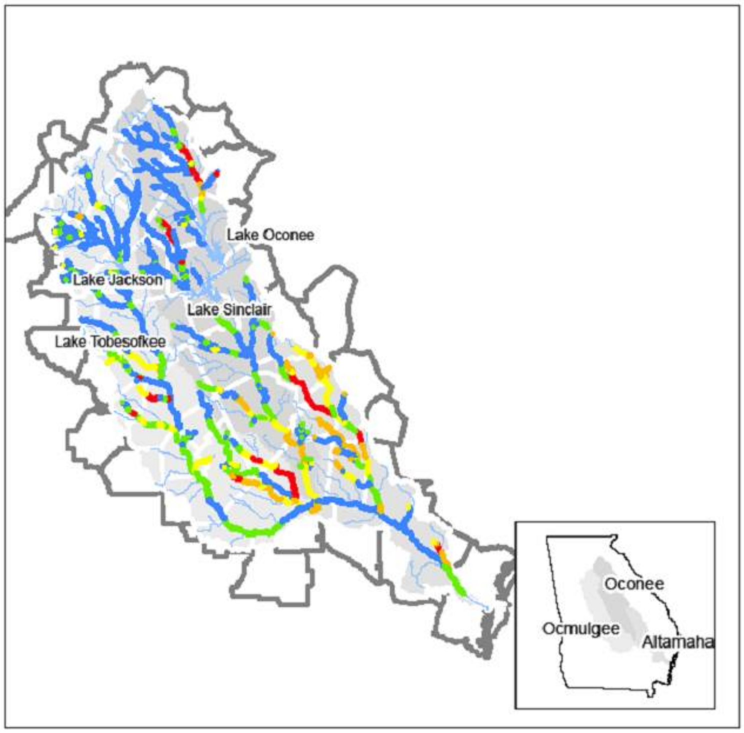
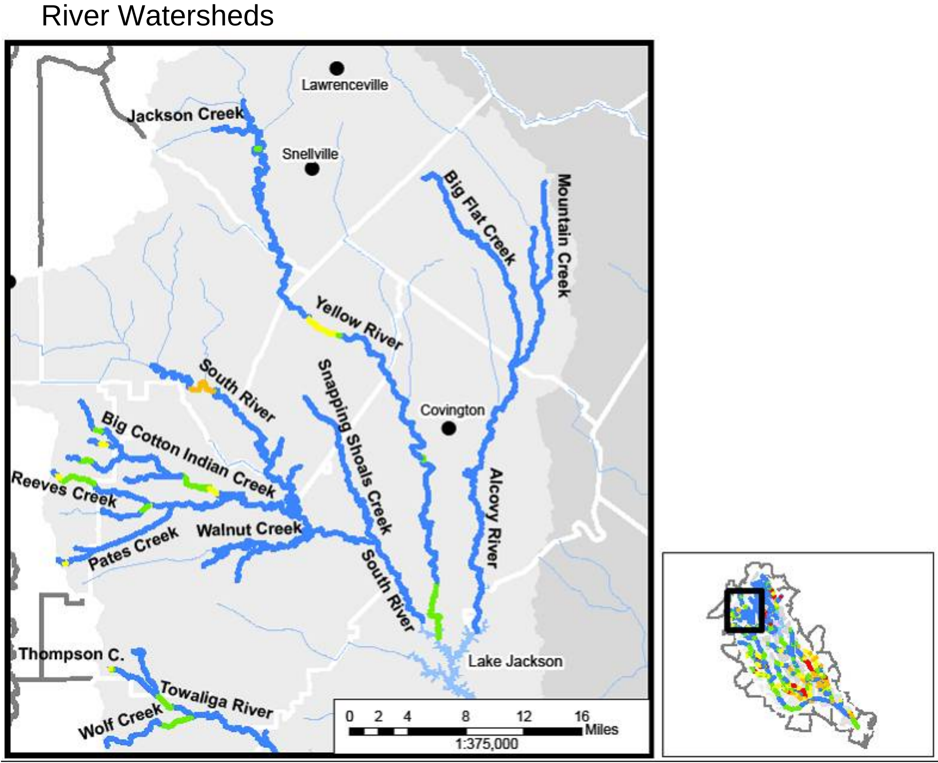


Figure B-10 Results of Dissolved Oxygen Models in the Oconee, Ocmulgee, and Altamaha River Watersheds



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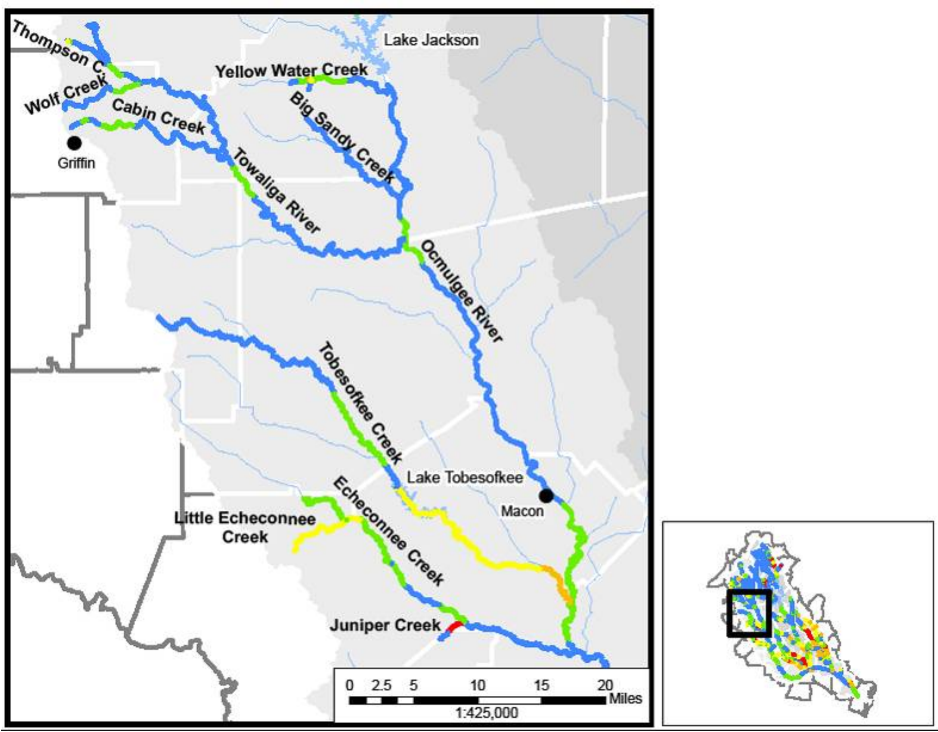

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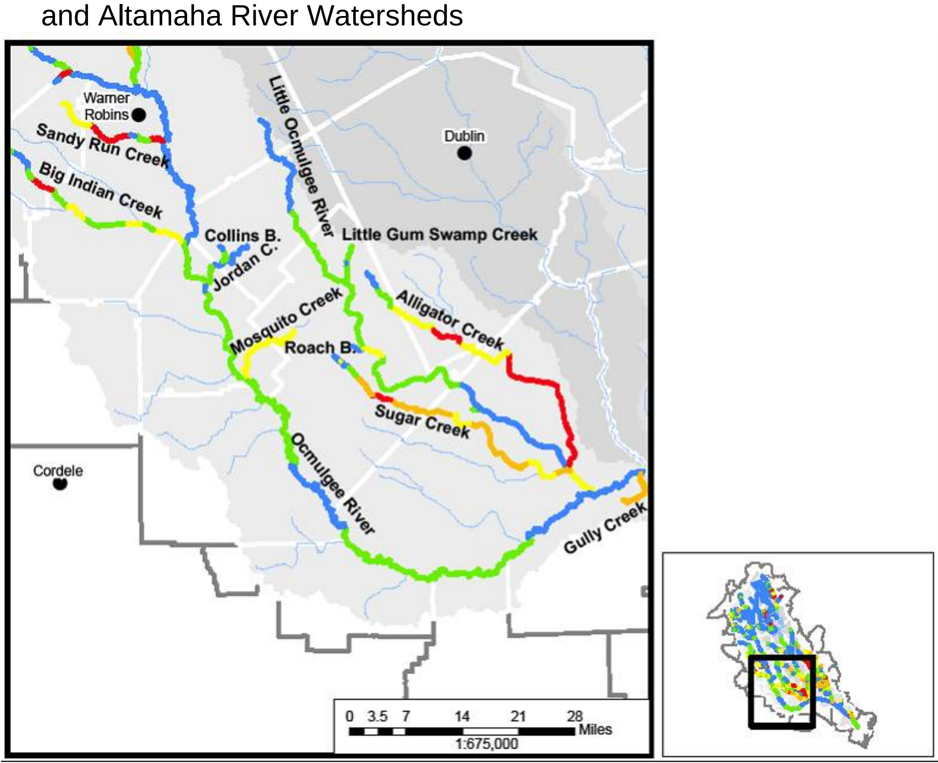

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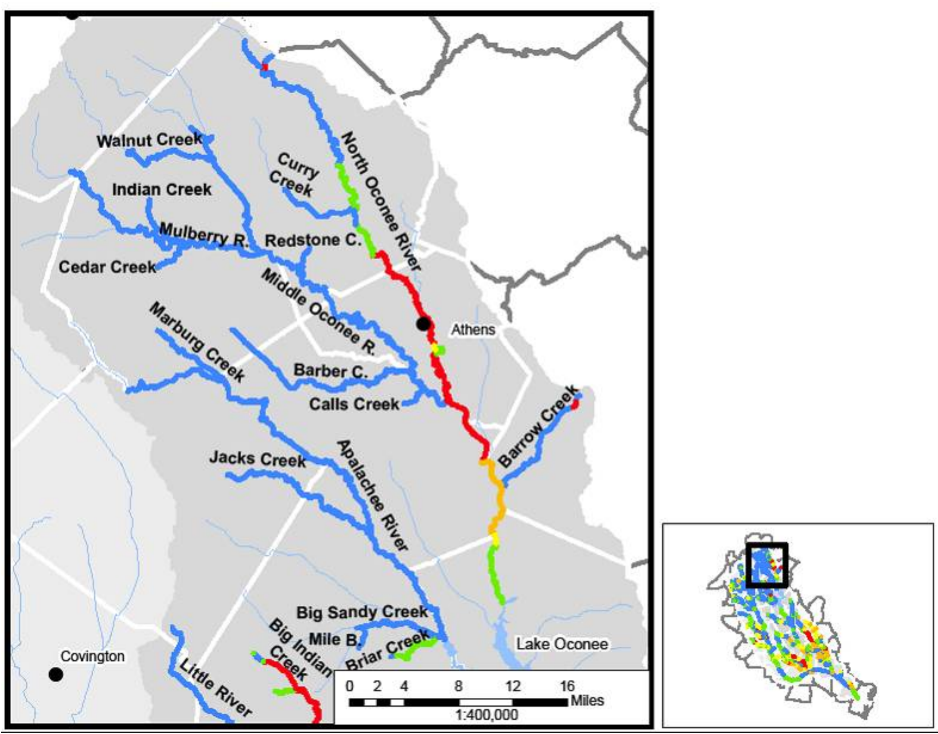

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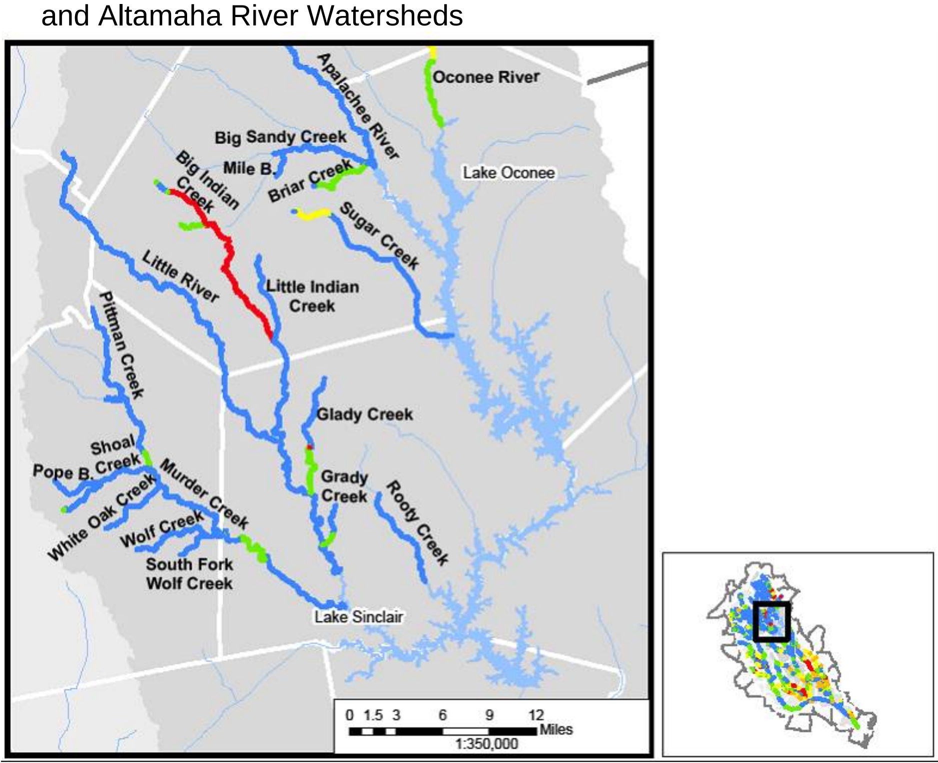


Figure B-11 (cont) Detailed Results of Dissolved Oxygen Models in the Oconee, Ocmulgee, and Altamaha River Watersheds

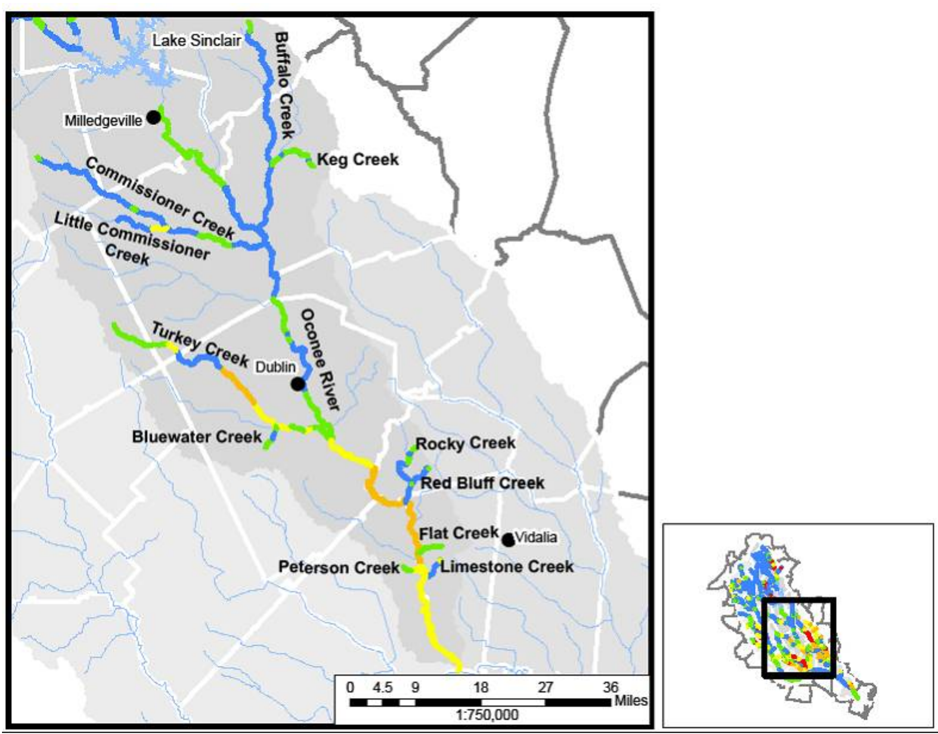


Figure B-11 (cont) Detailed Results of Dissolved Oxygen Models in the Oconee, Ocmulgee, and Altamaha River Watersheds

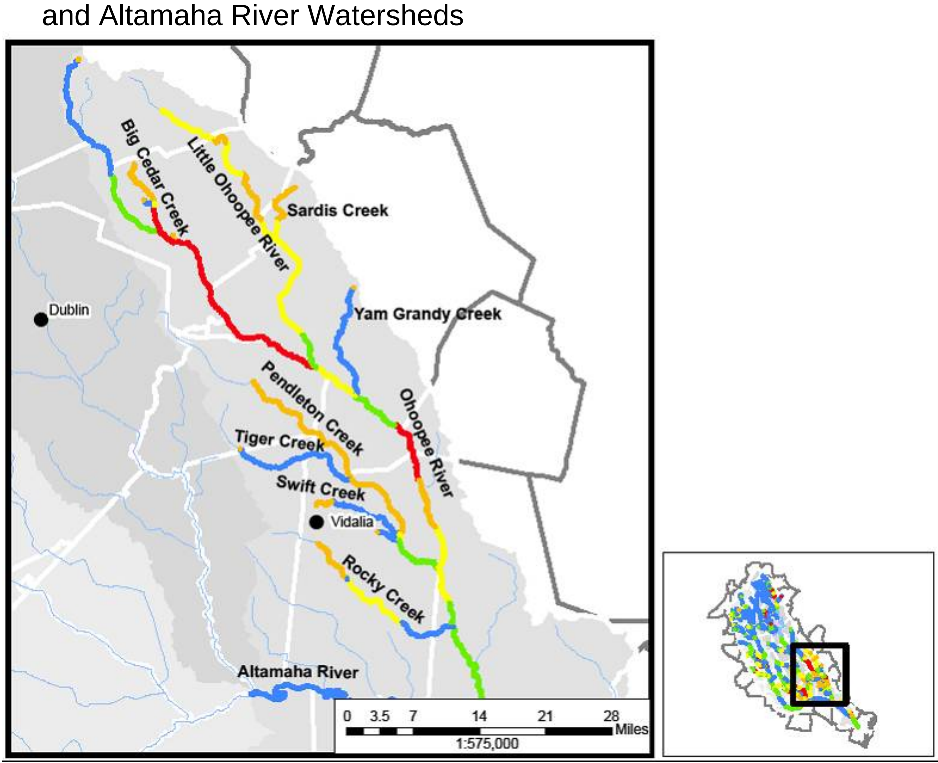


Figure B-11 (cont) Detailed Results of Dissolved Oxygen Models in the Oconee, Ocmulgee, and Altamaha River Watersheds

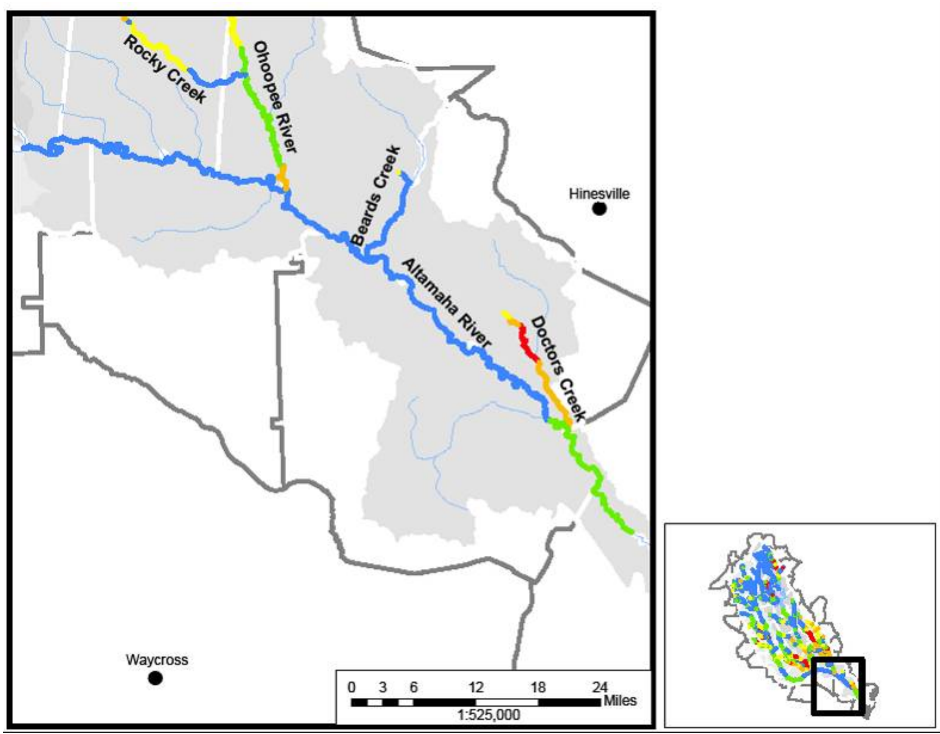


Figure B-11 (cont) Detailed Results of Dissolved Oxygen Models in the Oconee, Ocmulgee, and Altamaha River Watersheds

B.6 Suwannee, Satilla, and St. Mary's River Watersheds

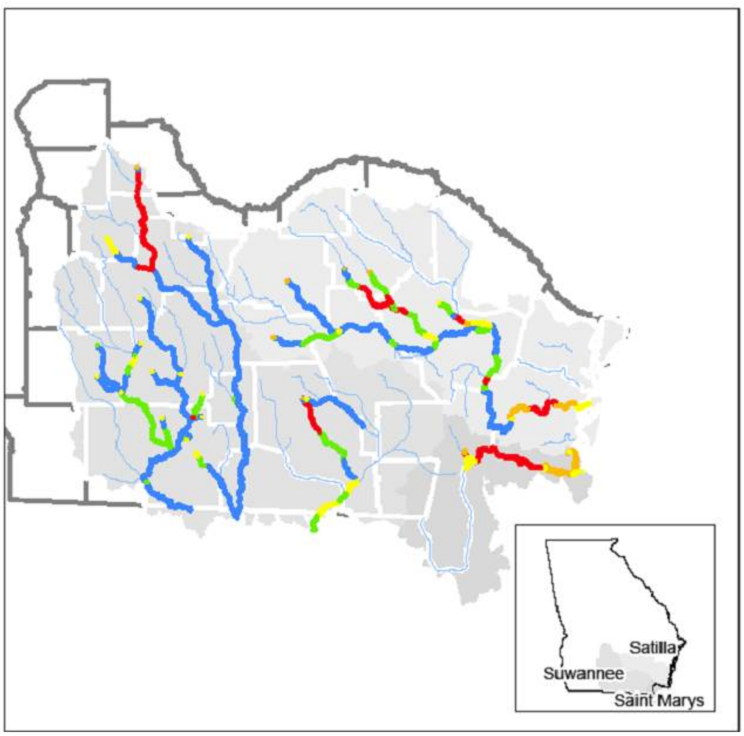


Figure B-12 Results of Dissolved Oxygen Models in the Suwannee, Satilla, and St. Mary's River Watersheds

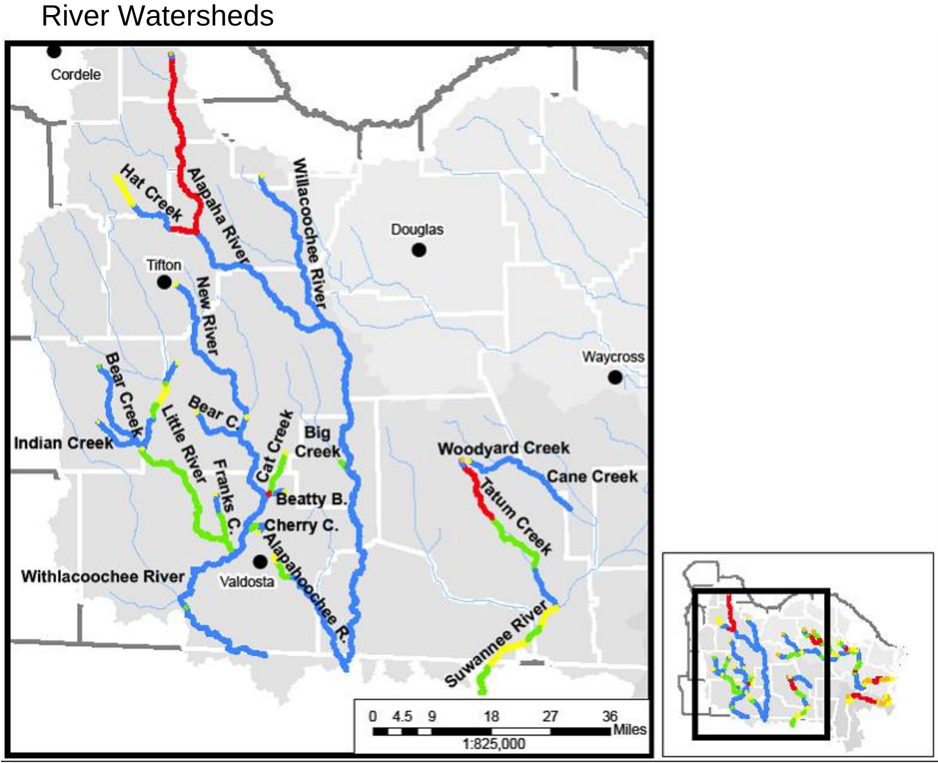
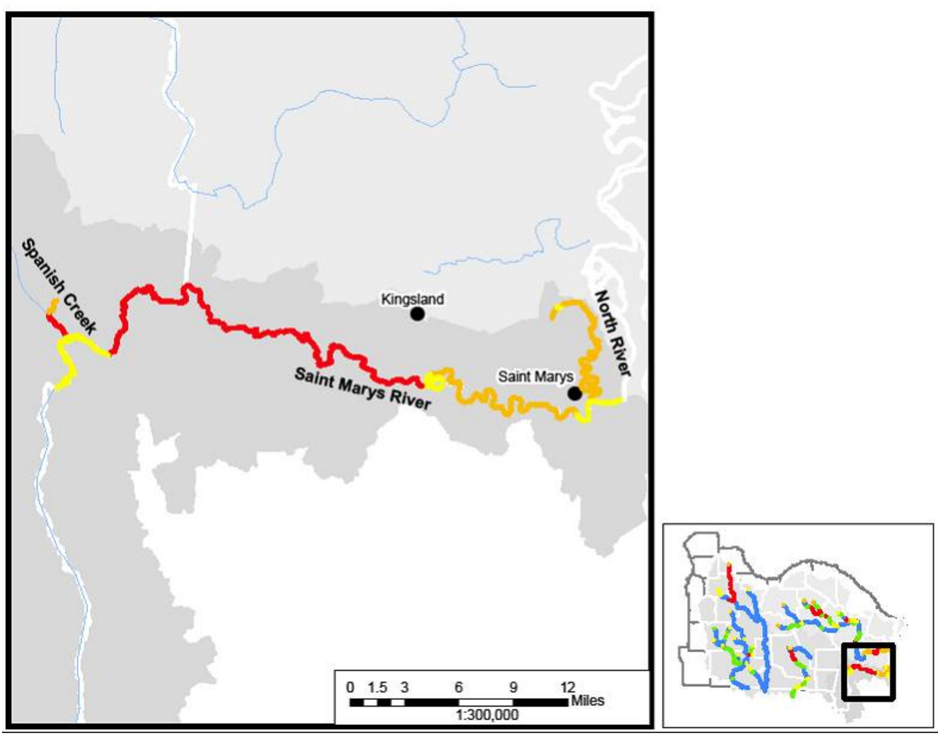


Figure B-13 (cont) Detailed Results of Dissolved Oxygen Models in the Suwannee, Satilla, and St. Mary's River Watersheds



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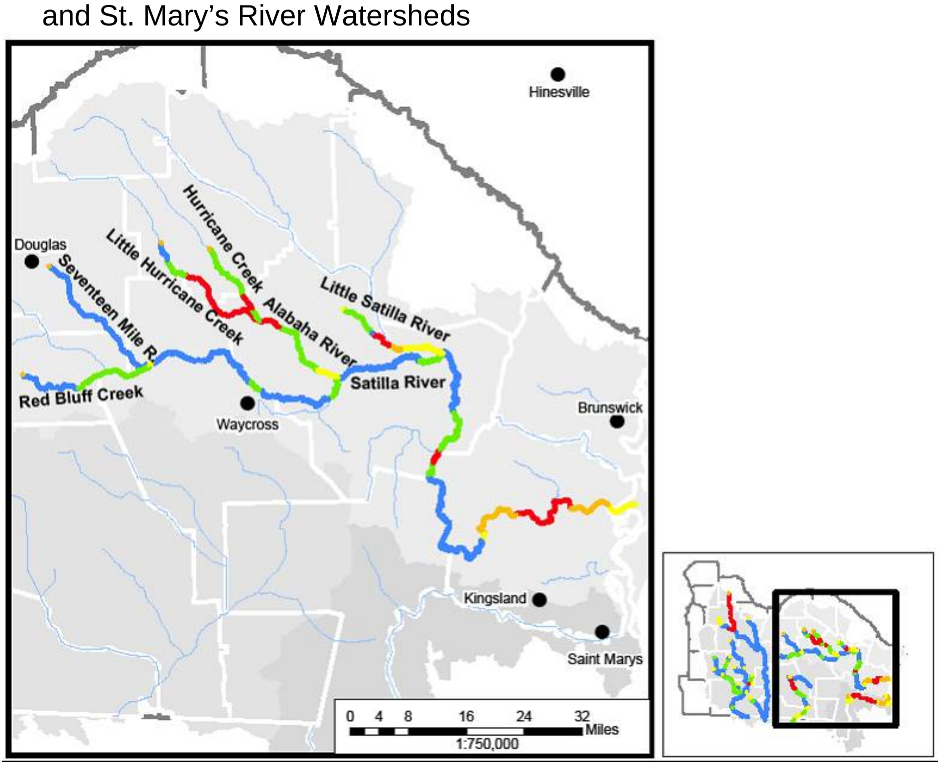

Figure B-13 (cont) Detailed Results of Dissolved Oxygen Models in the Suwannee, Satilla, and St. Mary's River Watersheds

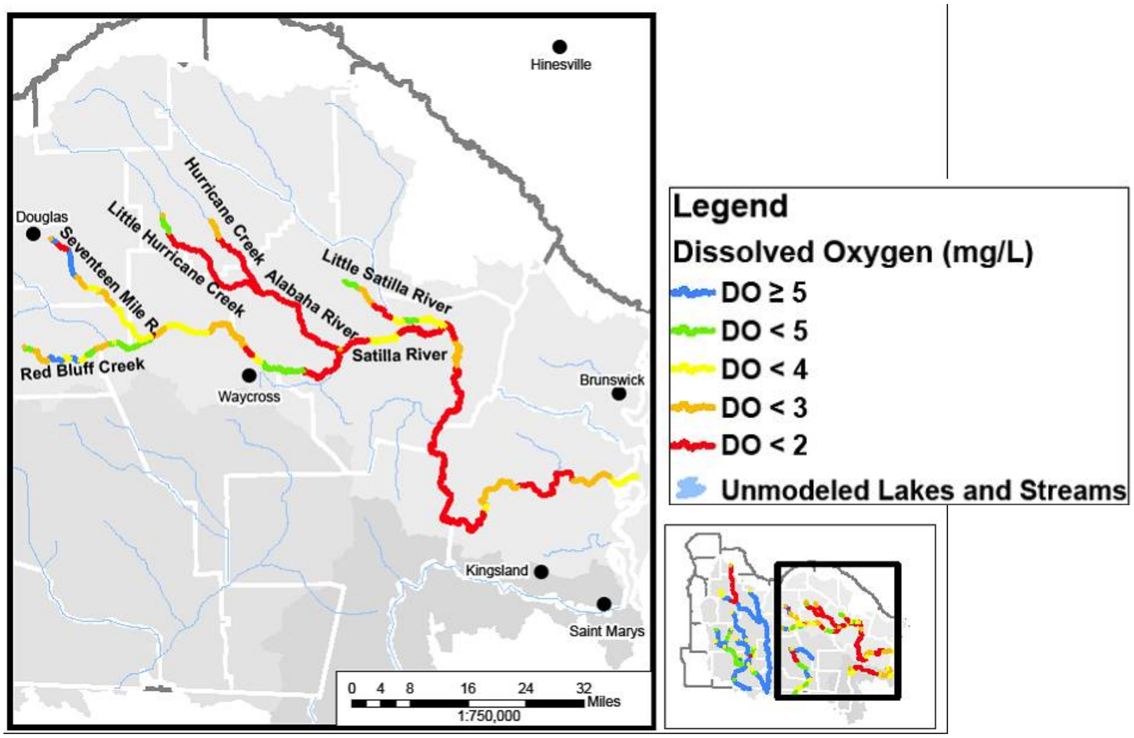

Figure B-13 (cont) Detailed Results of Dissolved Oxygen Models in the Suwannee, Satilla, and St. Mary's River Watersheds

B.7 Brunswick Harbor Watershed

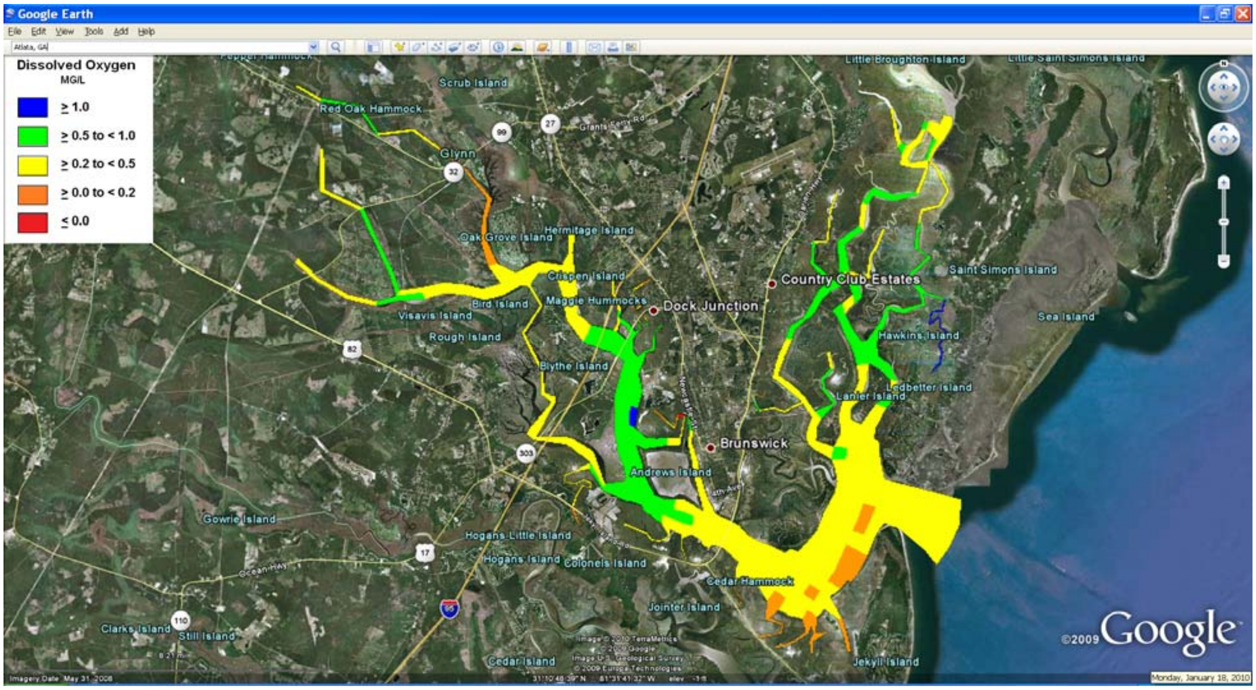

Figure B-14 Available Assimilative Capacity of Dissolved Oxygen in Brunswick Harbor: 2001

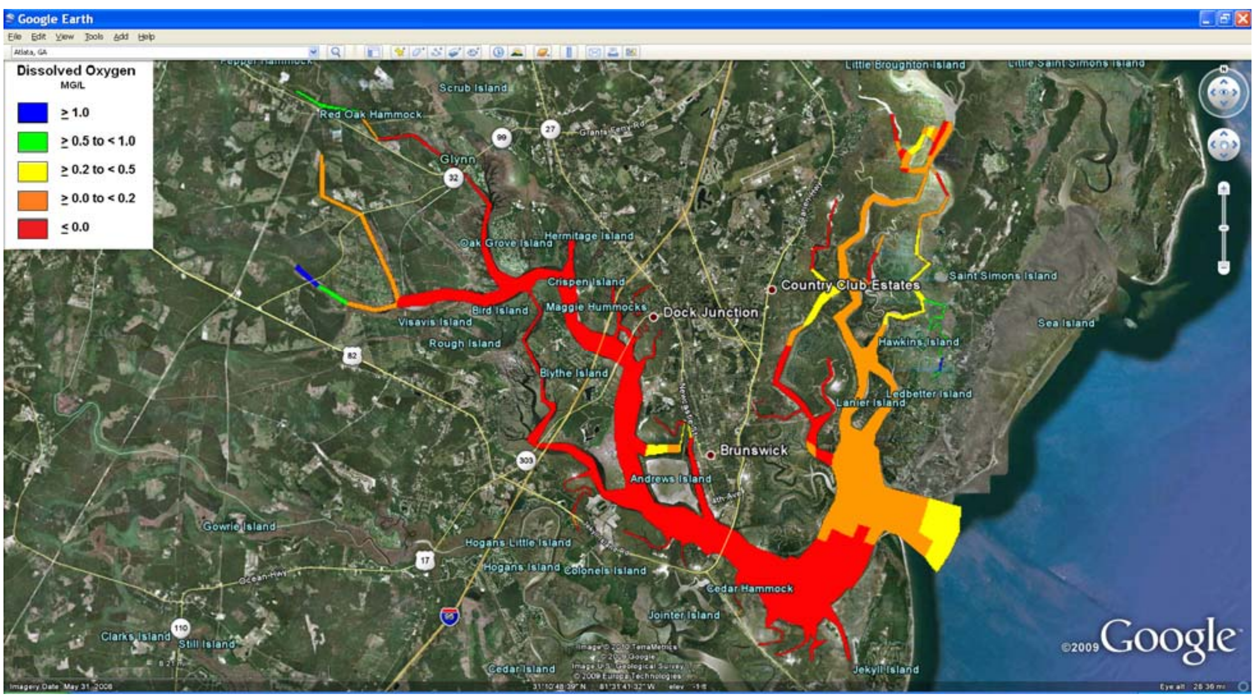

Figure B-15 Available Assimilative Capacity of Dissolved Oxygen in Brunswick Harbor: 2002

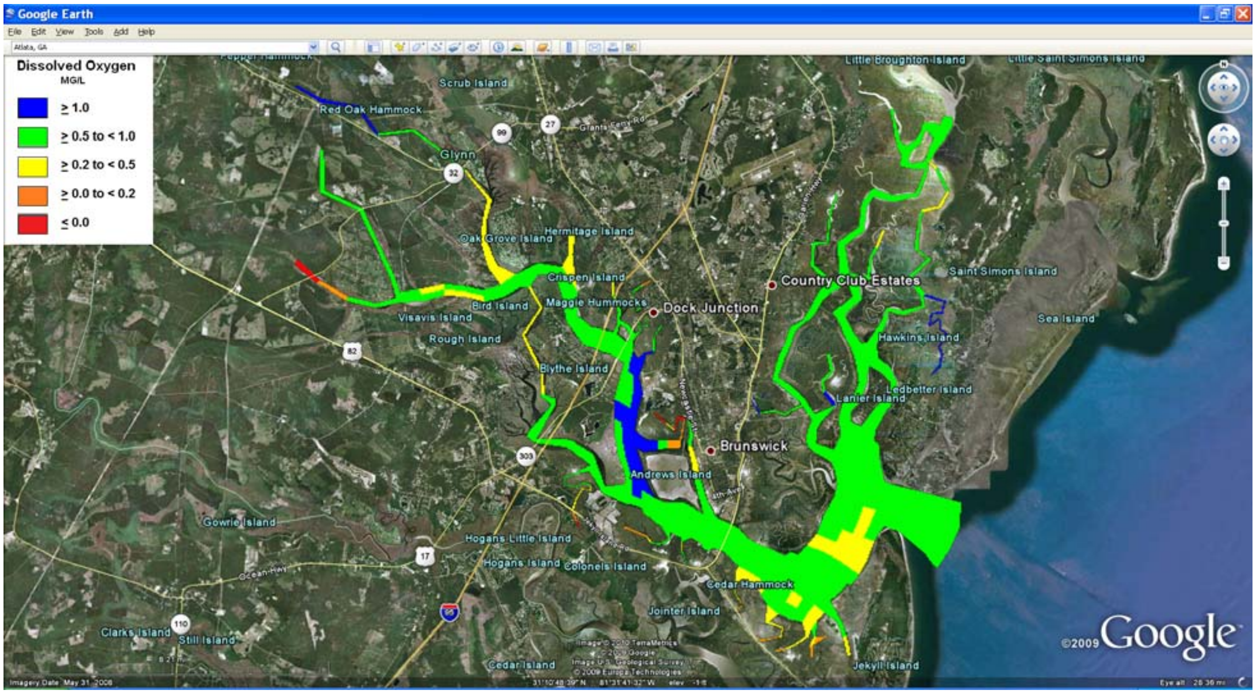

Figure B-16 Available Assimilative Capacity of Dissolved Oxygen in Brunswick Harbor: 2003

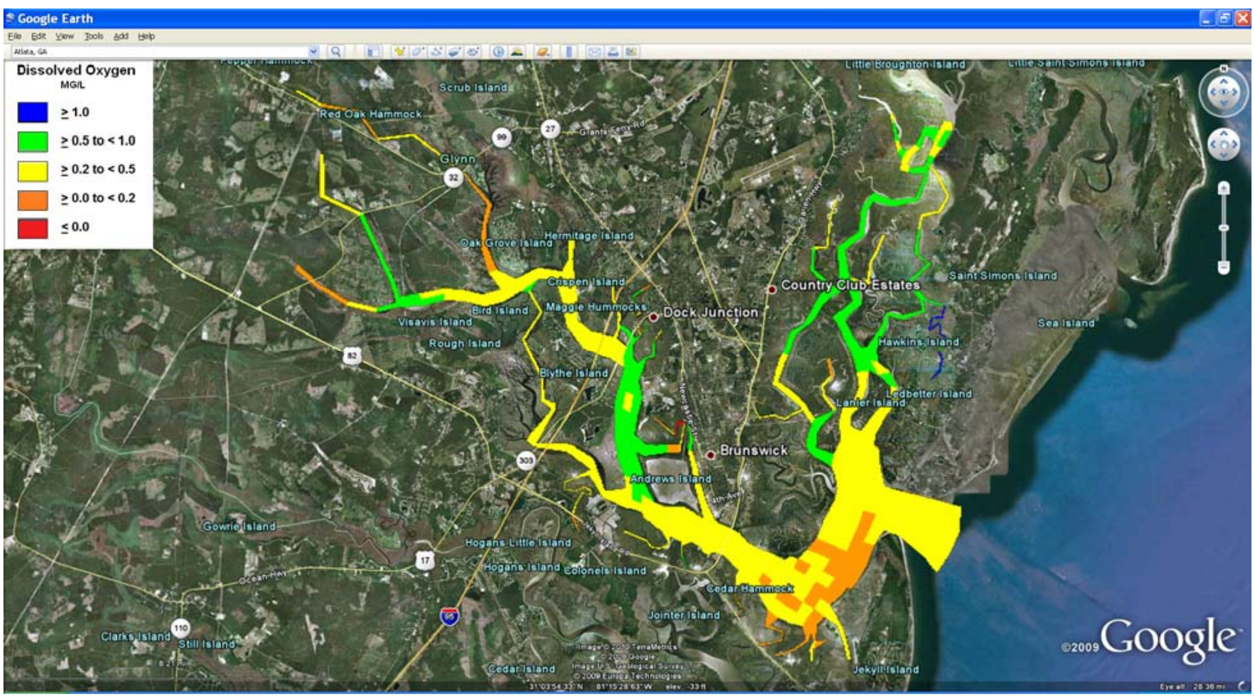

Figure B-17 Available Assimilative Capacity of Dissolved Oxygen in Brunswick Harbor: 2004

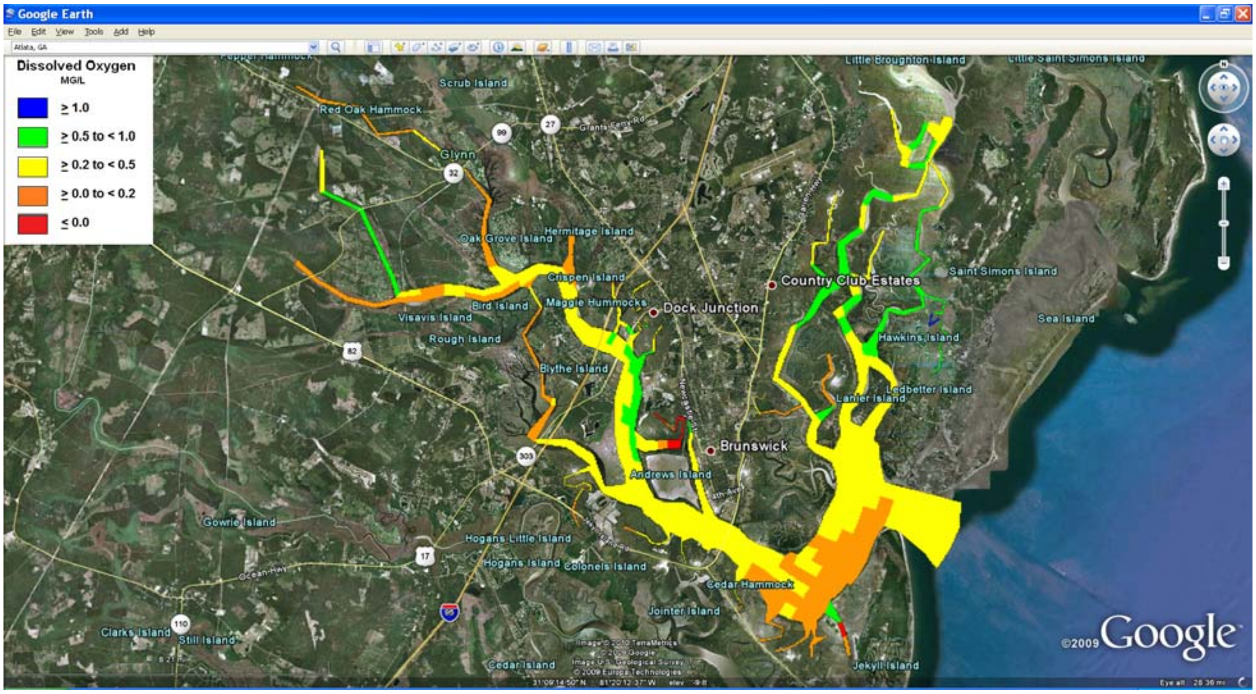

Figure B-18 Available Assimilative Capacity of Dissolved Oxygen in Brunswick Harbor: 2005

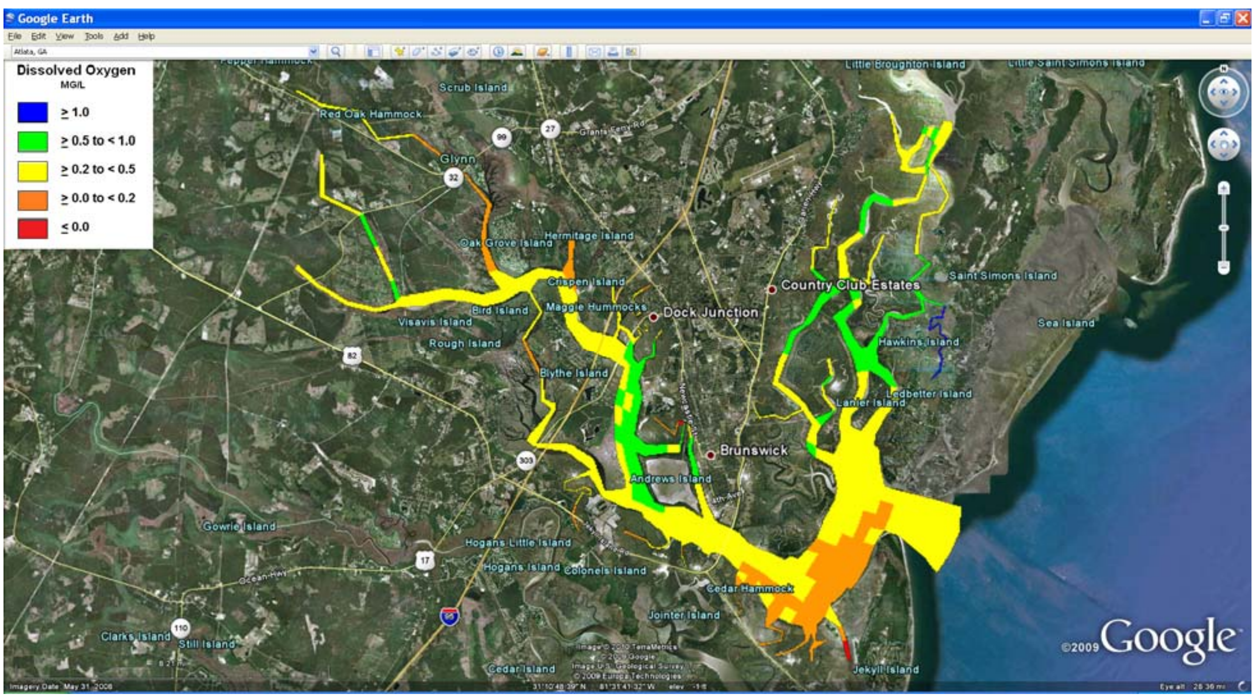

Figure B-19 Available Assimilative Capacity of Dissolved Oxygen in Brunswick Harbor: 2006

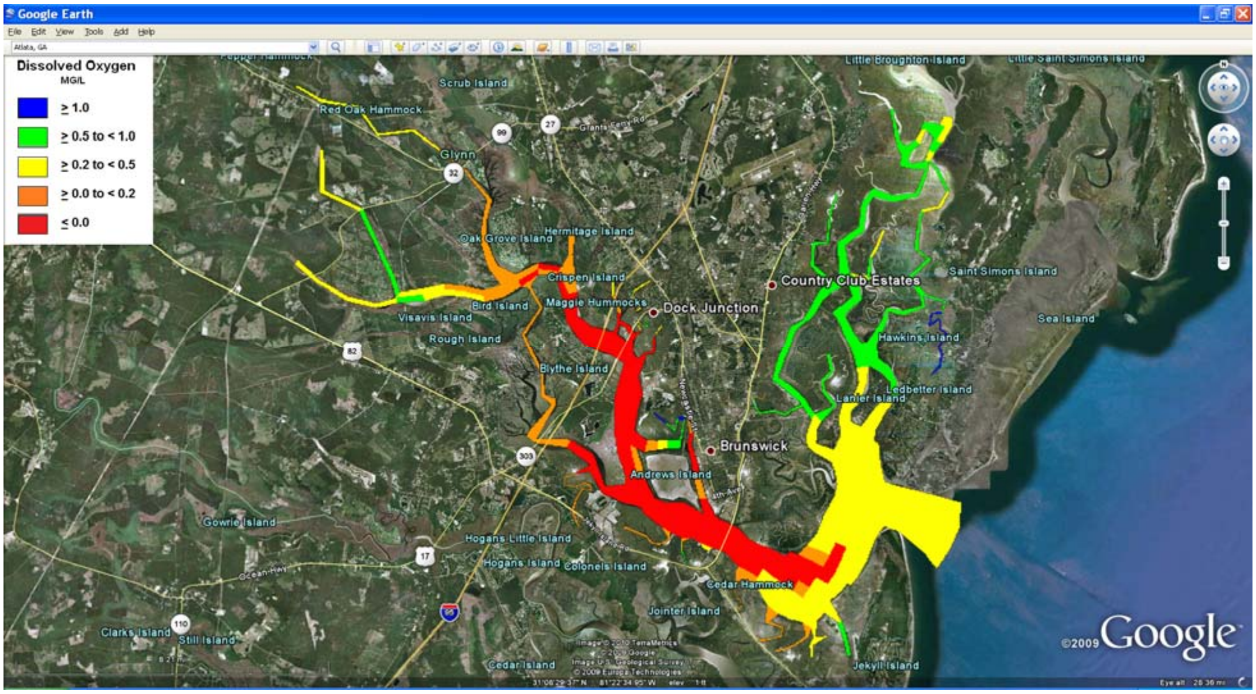

Figure B-20 Available Assimilative Capacity of Dissolved Oxygen in Brunswick Harbor: 2007

Appendix C: Nutrient Results

All Figures presented in this Appendix are DRAFT and are subject to change.

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C.1 WATERSHED RESULTS

Figures C-1 through C-84 present output from the LSPC model in pounds per acre per year (lbs/acre/yr) to show the nutrient results for the watersheds. To determine the unit loading, total annual nutrient loading from each subwatershed in the LSPC model was divided by the total area draining to that subwatershed. Results are presented for both Total Phosphorus and Total Nitrogen. For Lake Allatoona and Lake Jackson, the nutrient compliance watersheds are also shown. The nutrient compliance watersheds are those watersheds that drain to a point where there is an annual Total Phosphorus loading standard. Results are shown for two wet years (2004 and 2005), two dry years (2001 and 2007), and three normal rainfall years (2002, 2003 and 2006).

C.1.1 Coosa River Watershed

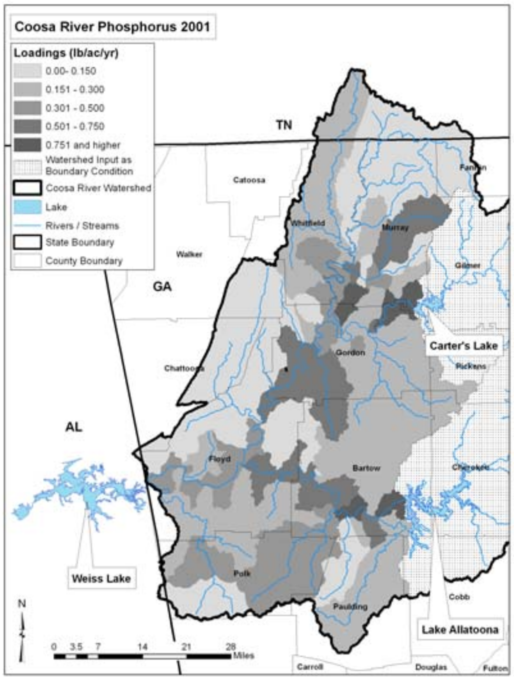

Figure C-1 Total Phosphorus Unit Loading (lbs/acre) for Coosa River Watershed for 2001

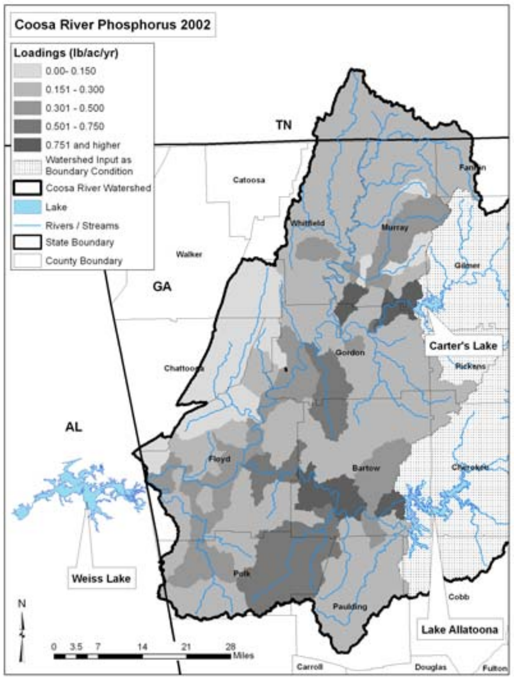

Figure C-2 Total Phosphorus Unit Loading (lbs/acre) for Coosa River Watershed for 2002

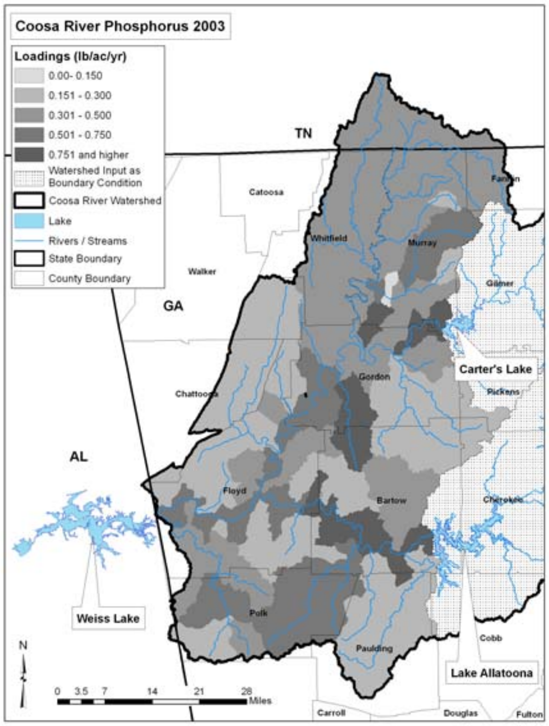

Figure C-3 Total Phosphorus Unit Loading (lbs/acre) for Coosa River Watershed for 2003

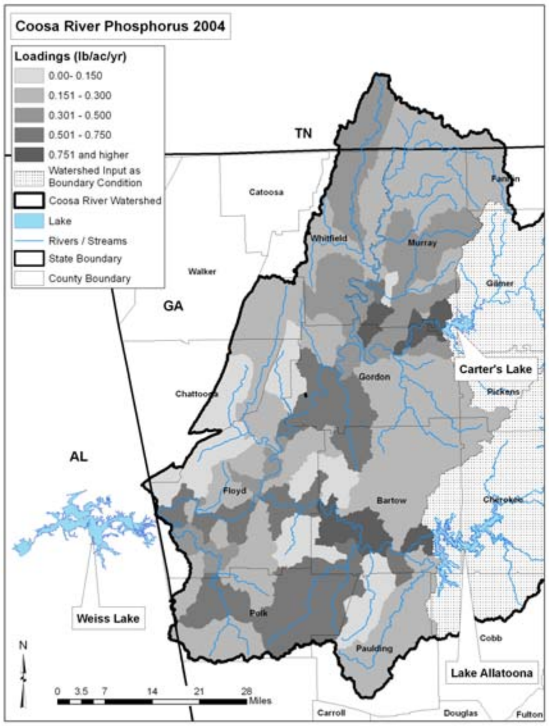

Figure C-4 Total Phosphorus Unit Loading (lbs/acre) for Coosa River Watershed for 2004

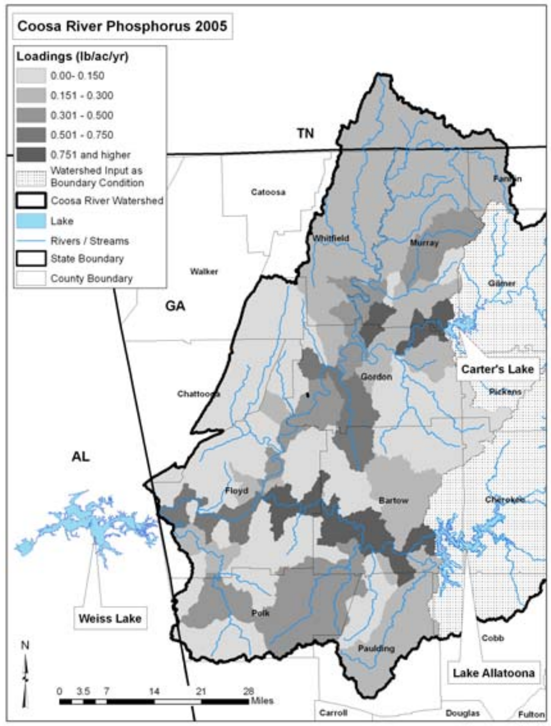

Figure C-5 Total Phosphorus Unit Loading (lbs/acre) for Coosa River Watershed for 2005

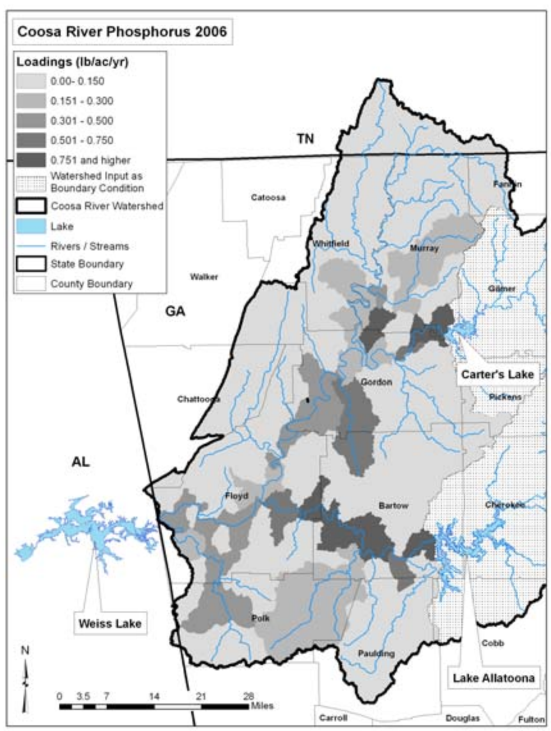

Figure C-6 Total Phosphorus Unit Loading (lbs/acre) for Coosa River Watershed for 2006

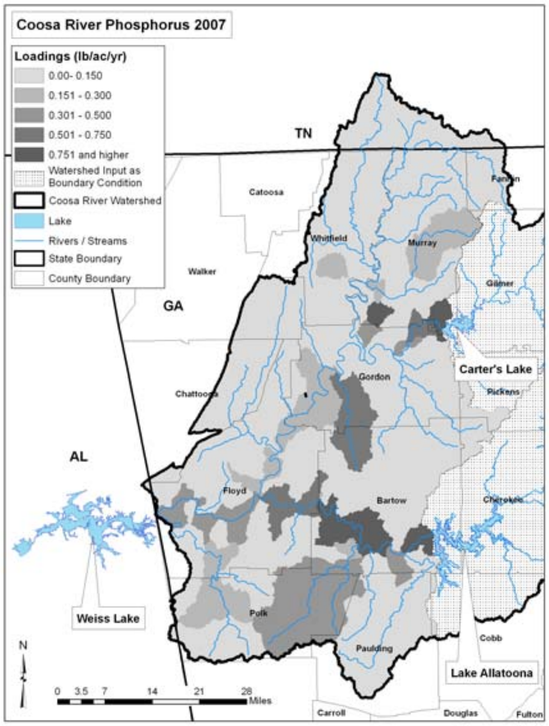

Figure C-7 Total Phosphorus Unit Loading (lbs/acre) for Coosa River Watershed for 2007

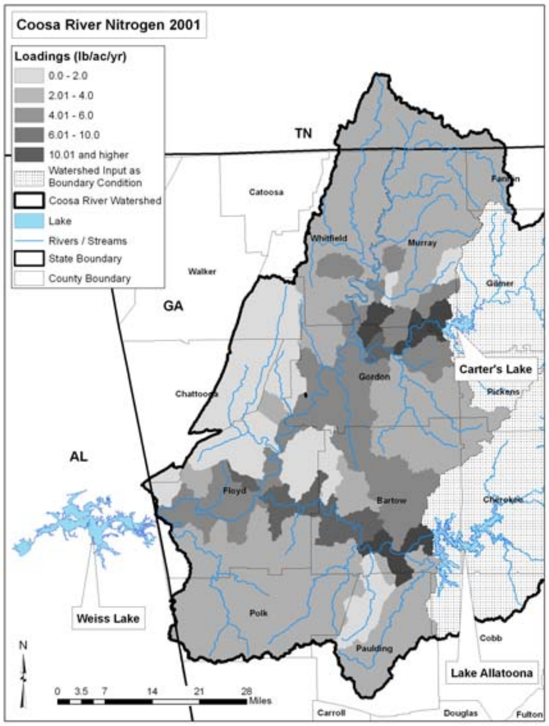

Figure C-8 Total Nitrogen Unit Loading (lbs/acre) for Coosa River Watershed for 2001

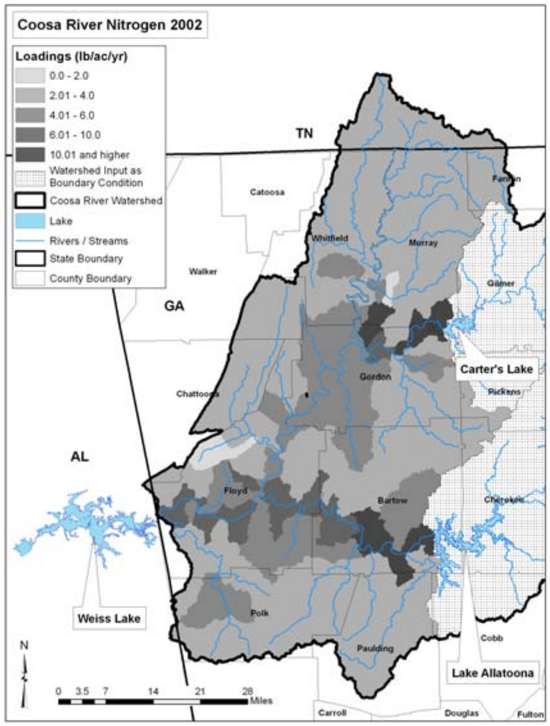

Figure C-9 Total Nitrogen Unit Loading (lbs/acre) for Coosa River Watershed for 2002

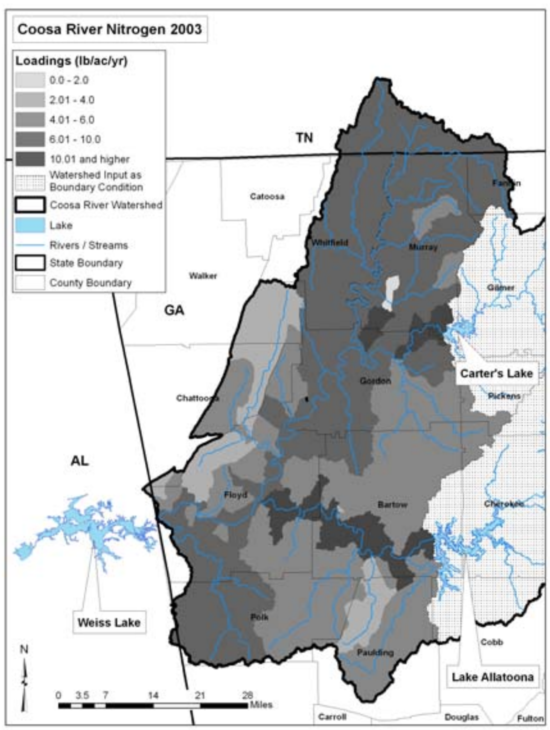

Figure C-10 Total Nitrogen Unit Loading (lbs/acre) for Coosa River Watershed for 2003

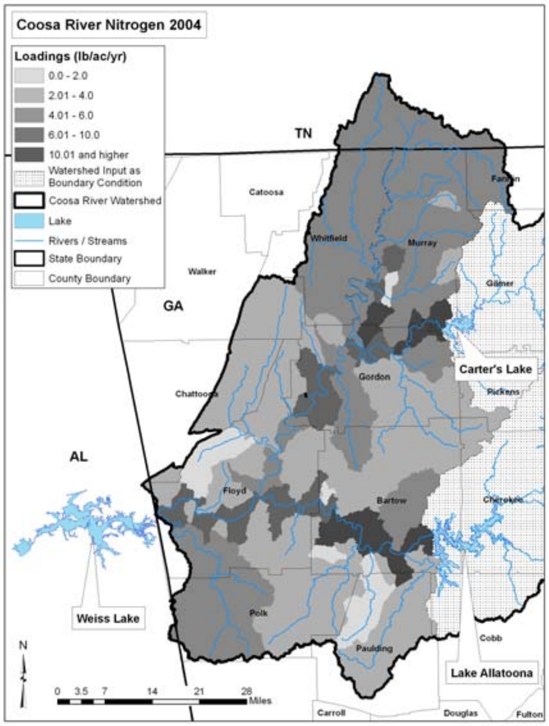

Figure C-11 Total Nitrogen Unit Loading (lbs/acre) for Coosa River Watershed for 2004

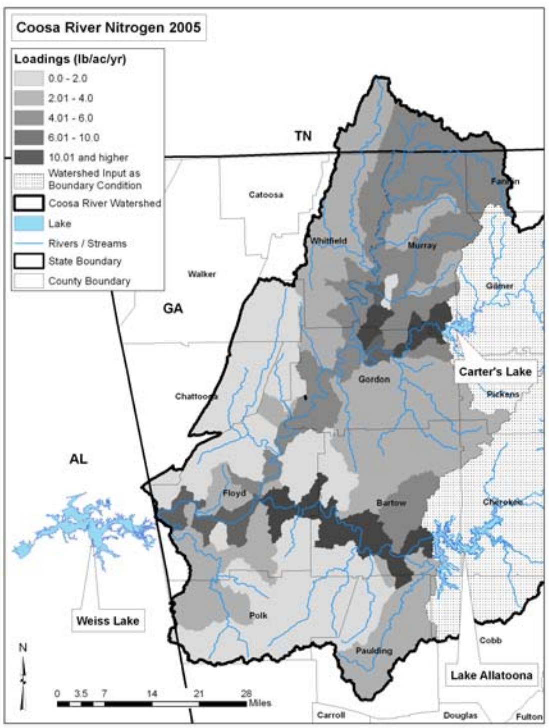

Figure C-12 Total Nitrogen Unit Loading (lbs/acre) for Coosa River Watershed for 2005

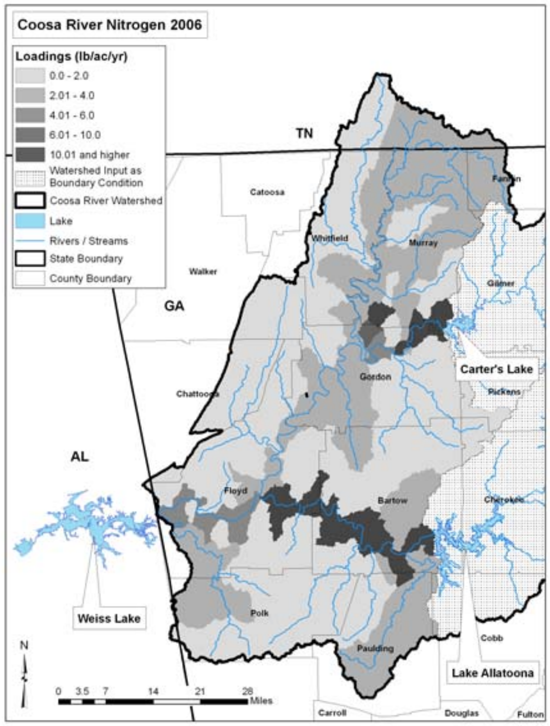

Figure C-13 Total Nitrogen Unit Loading (lbs/acre) for Coosa River Watershed for 2006

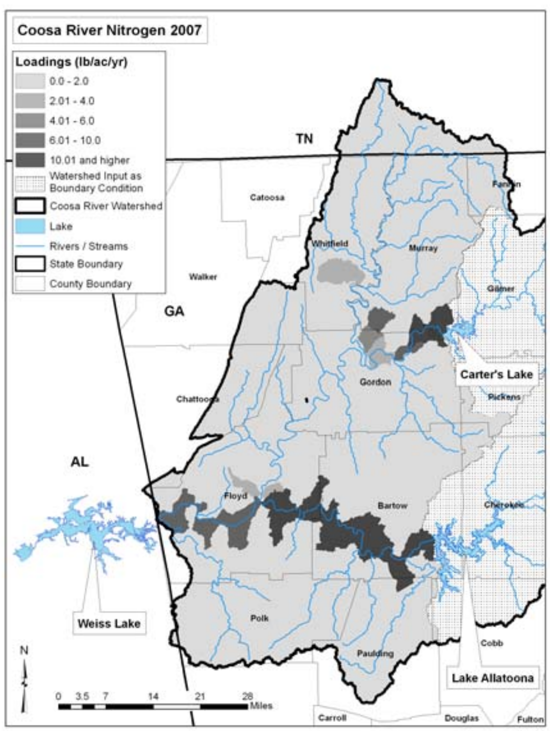

Figure C-14 Total Nitrogen Unit Loading (lbs/acre) for Coosa River Watershed for 2007

C.1.2 Lake Allatoona Watershed

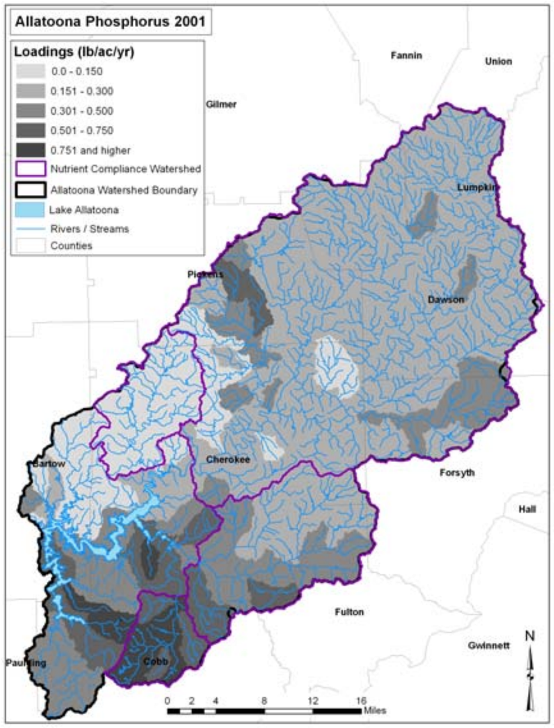

Figure C-15 Total Phosphorus Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2001

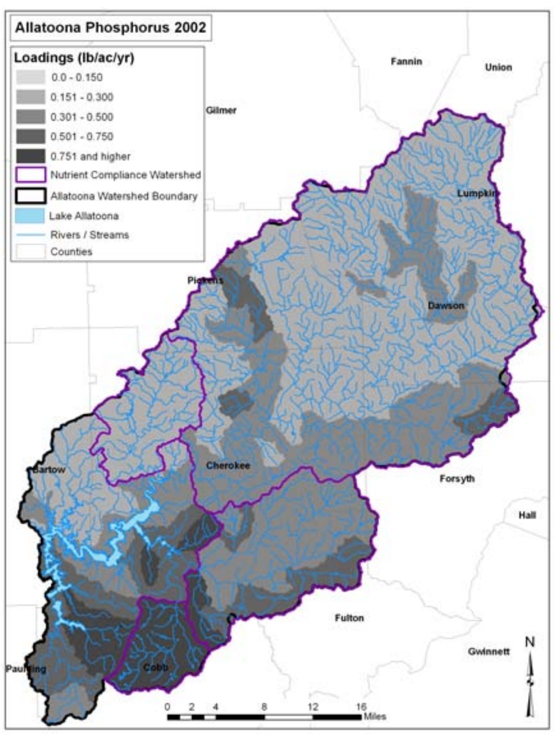

Figure C-16 Total Phosphorus Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2002

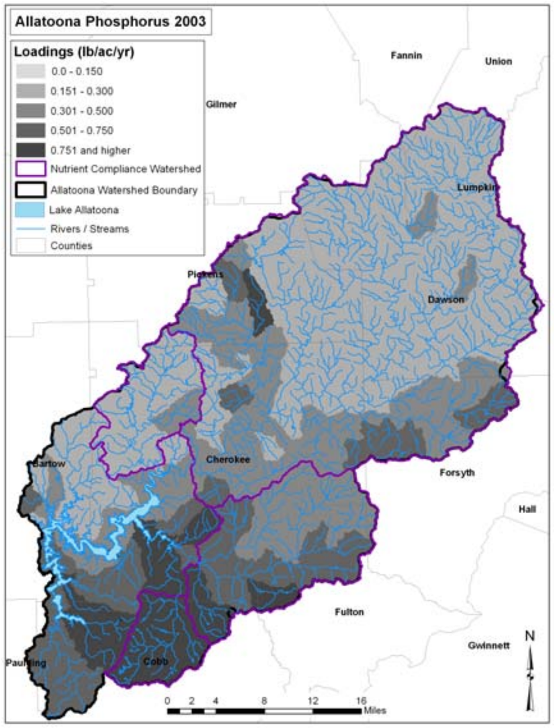

Figure C-17 Total Phosphorus Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2003

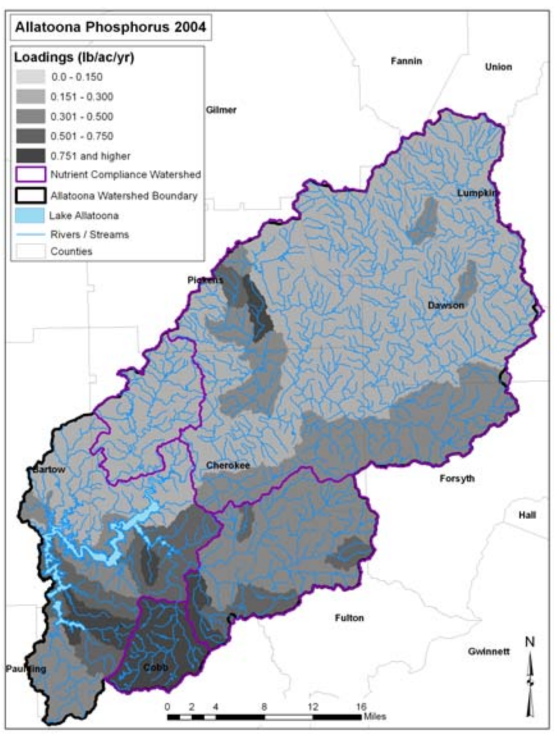

Figure C-18 Total Phosphorus Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2004

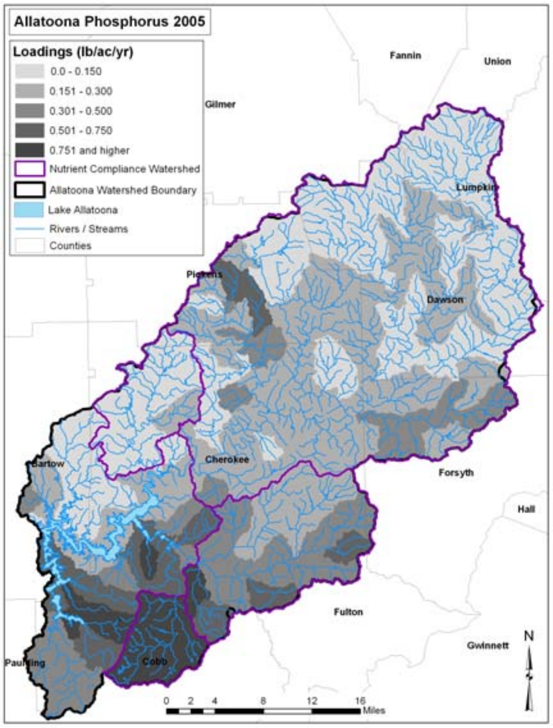

Figure C-19 Total Phosphorus Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2005

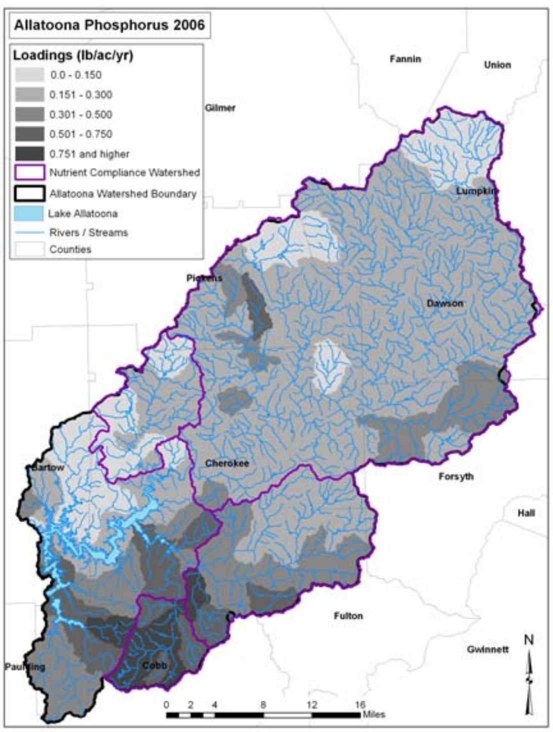

Figure C-20 Total Phosphorus Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2006

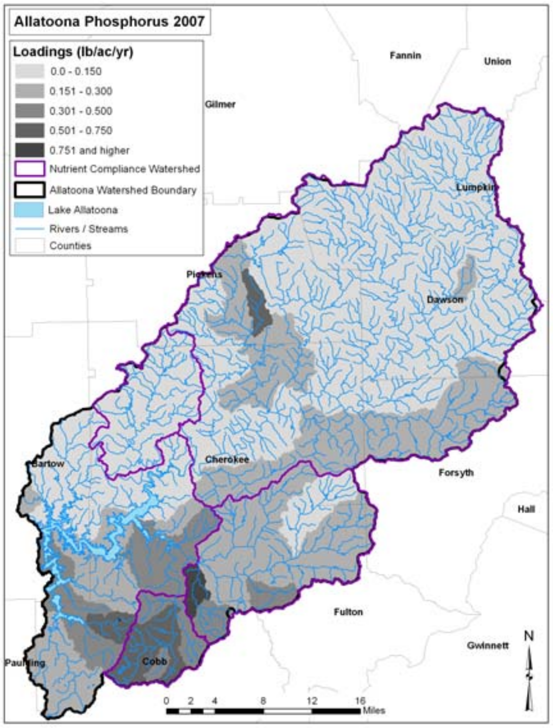

Figure C-21 Total Phosphorus Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2007

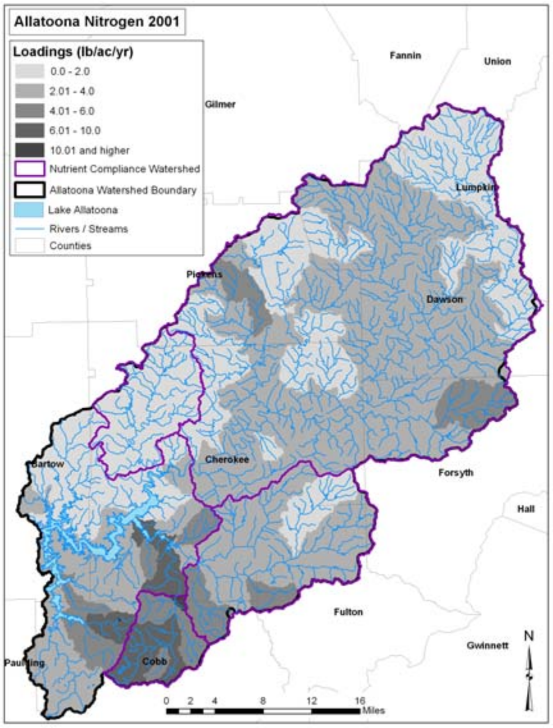

Figure C-22 Total Nitrogen Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2001

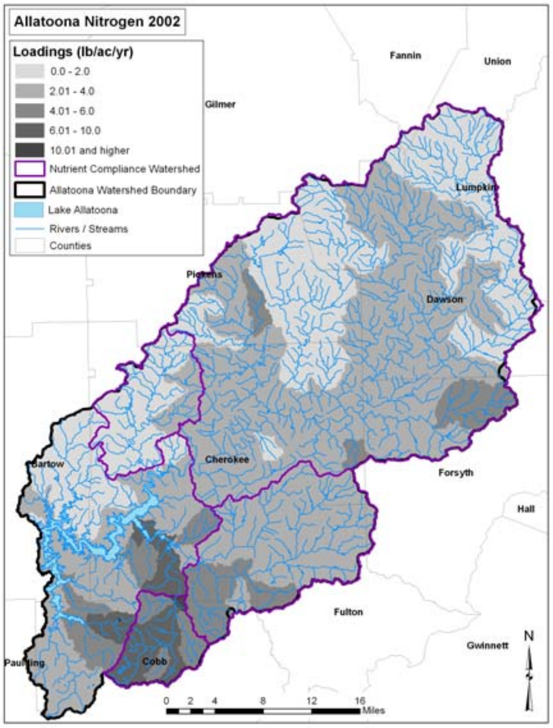

Figure C-23 Total Nitrogen Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2002

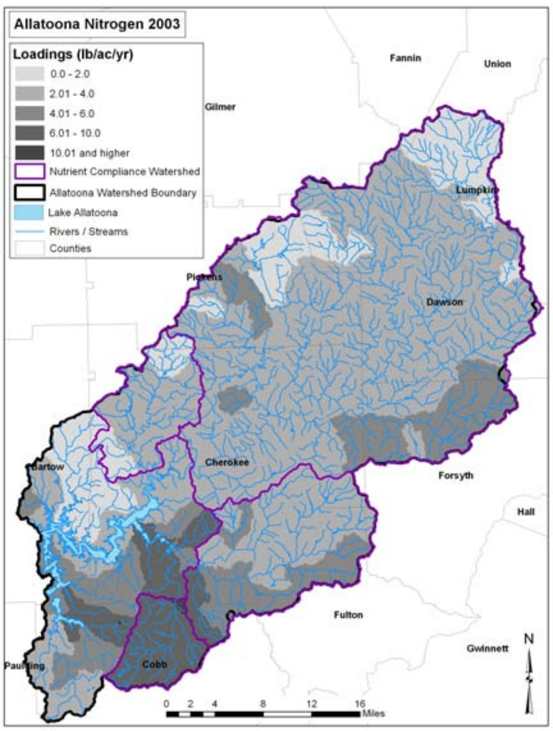

Figure C-24 Total Nitrogen Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2003

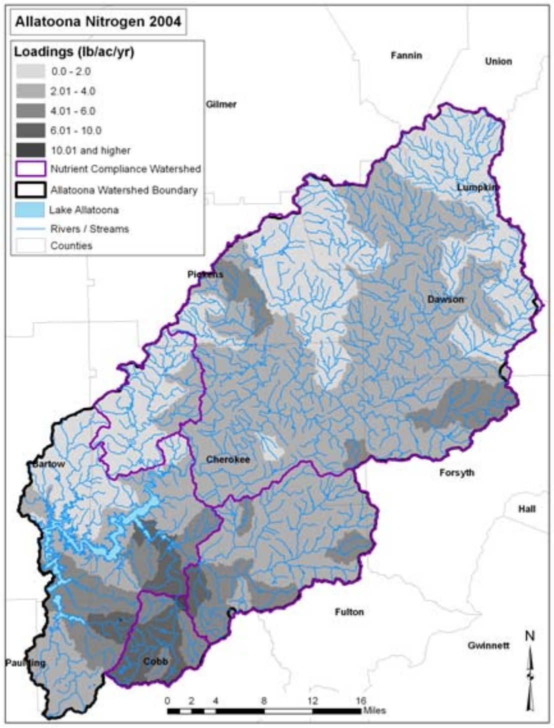

Figure C-25 Total Nitrogen Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2004

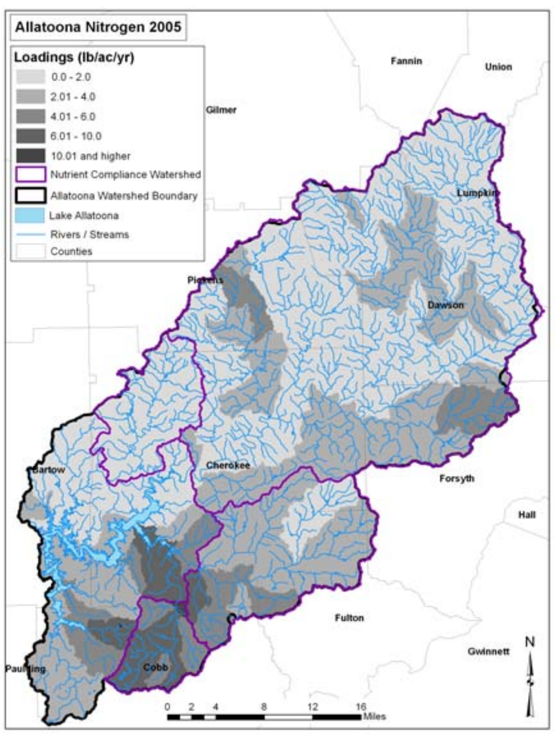

Figure C-26 Total Nitrogen Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2005

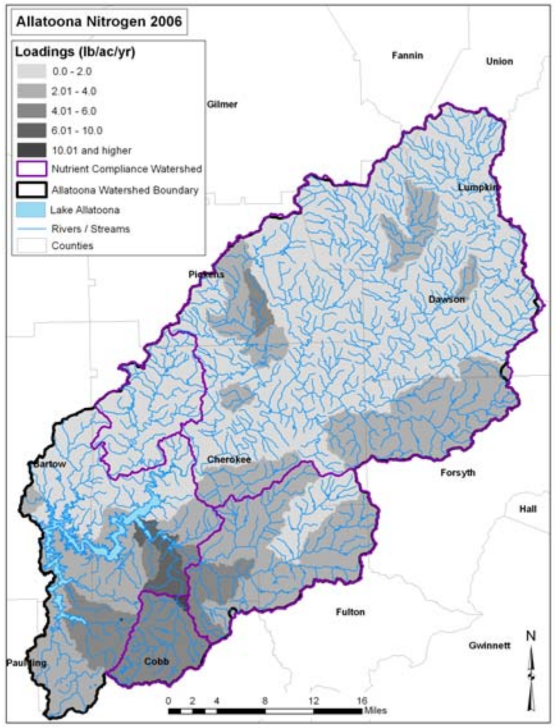

Figure C-27 Total Nitrogen Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2006

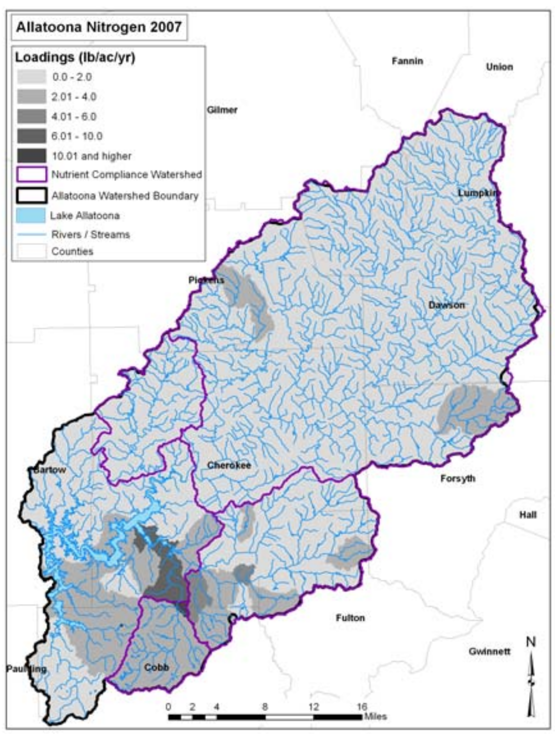

Figure C-28 Total Nitrogen Unit Loading (lbs/acre) for Lake Allatoona Watershed for 2007

C.1.3 Lake Jackson Watershed

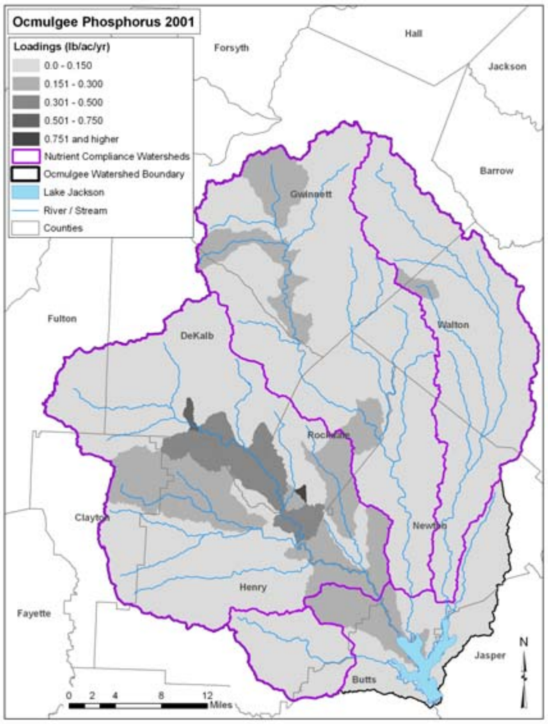

Figure C-29 Total Phosphorus Unit Loading (lbs/acre) for Lake Jackson Watershed for 2001

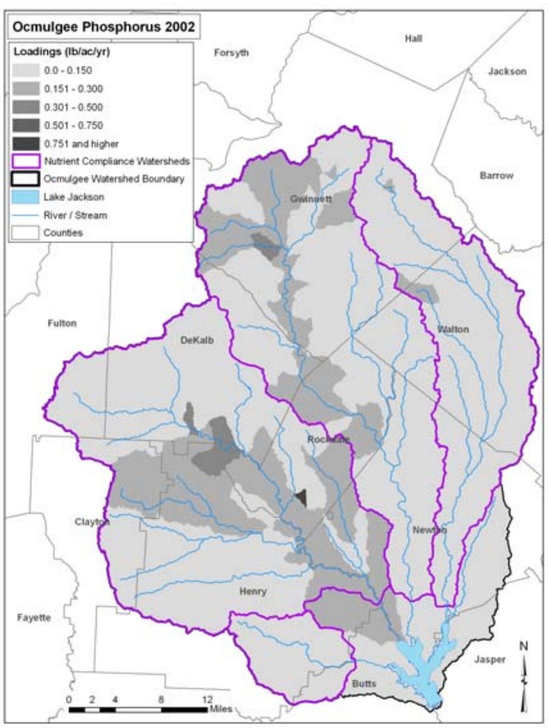

Figure C-30 Total Phosphorus Unit Loading (lbs/acre) for Lake Jackson Watershed for 2002

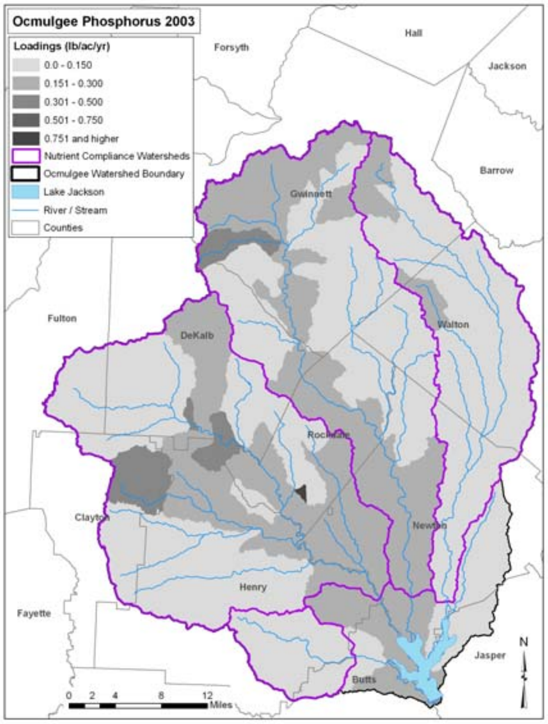

Figure C-31 Total Phosphorus Unit Loading (lbs/acre) for Lake Jackson Watershed for 2003

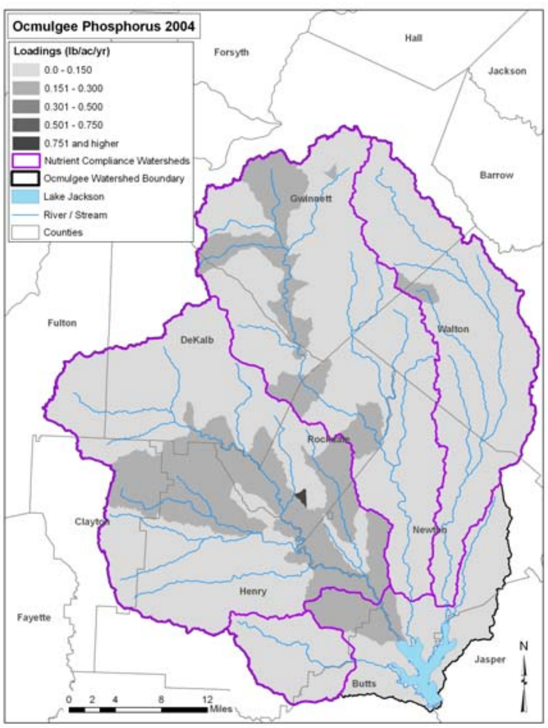

Figure C-32 Total Phosphorus Unit Loading (lbs/acre) for Lake Jackson Watershed for 2004

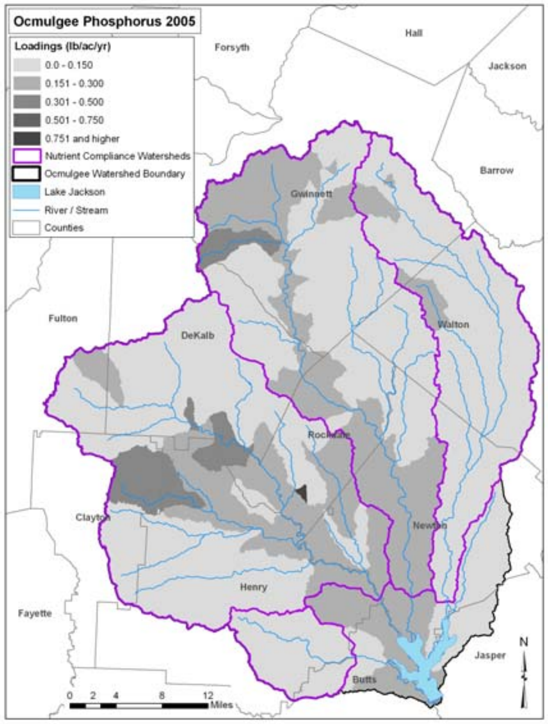

Figure C-33 Total Phosphorus Unit Loading (lbs/acre) for Lake Jackson Watershed for 2005

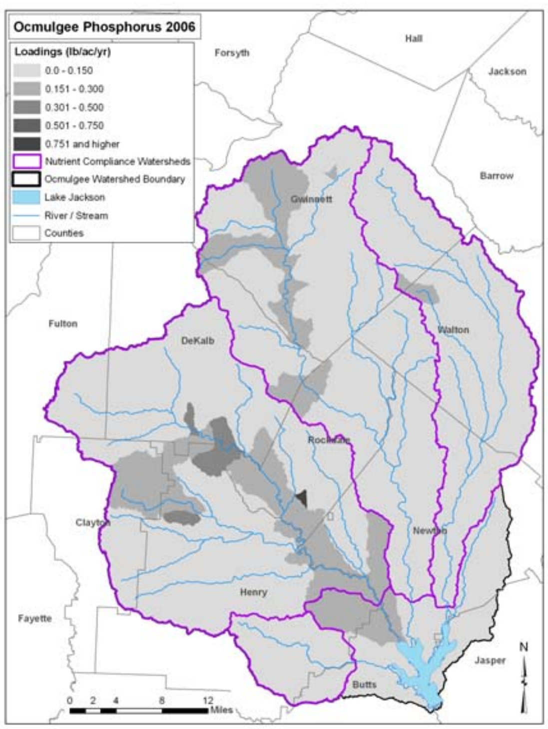

Figure C-34 Total Phosphorus Unit Loading (lbs/acre) for Lake Jackson Watershed for 2006

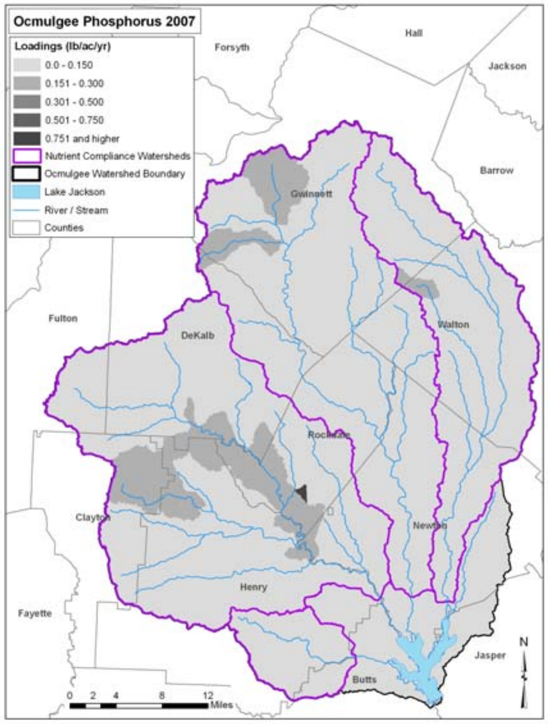

Figure C-35 Total Phosphorus Unit Loading (lbs/acre) for Lake Jackson Watershed for 2007

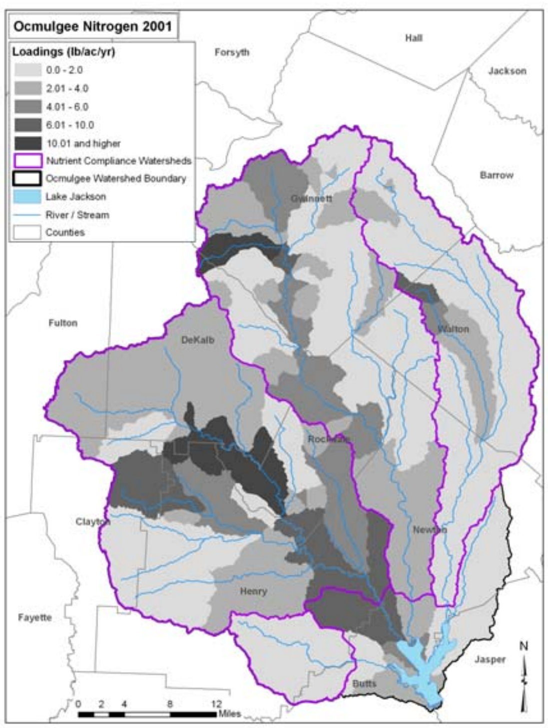

Figure C-36 Total Nitrogen Unit Loading (lbs/acre) for Lake Jackson Watershed for 2001

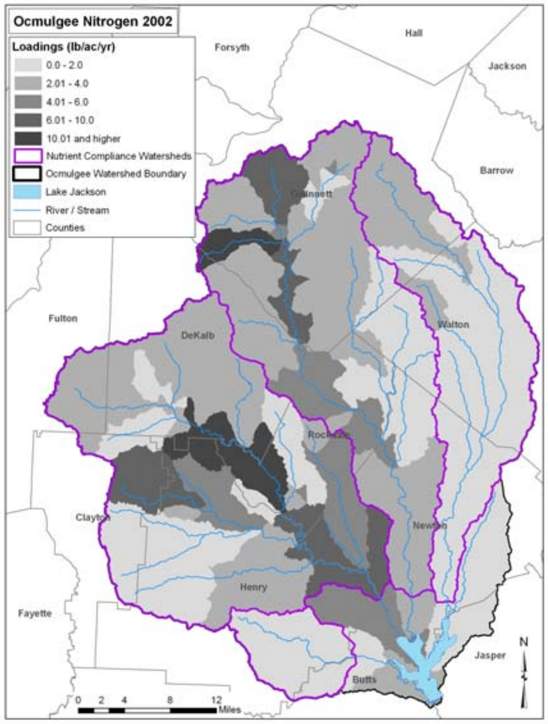

Figure C-37 Total Nitrogen Unit Loading (lbs/acre) for Lake Jackson Watershed for 2002

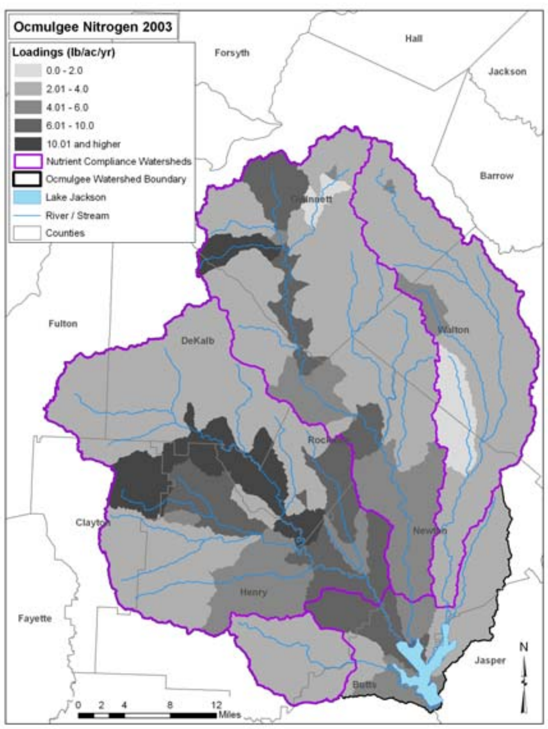

Figure C-38 Total Nitrogen Unit Loading (lbs/acre) for Lake Jackson Watershed for 2003

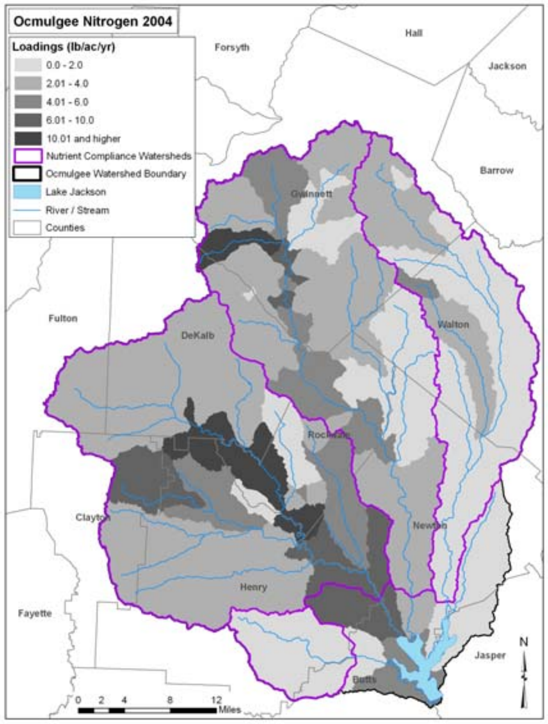

Figure C-39 Total Nitrogen Unit Loading (lbs/acre) for Lake Jackson Watershed for 2004

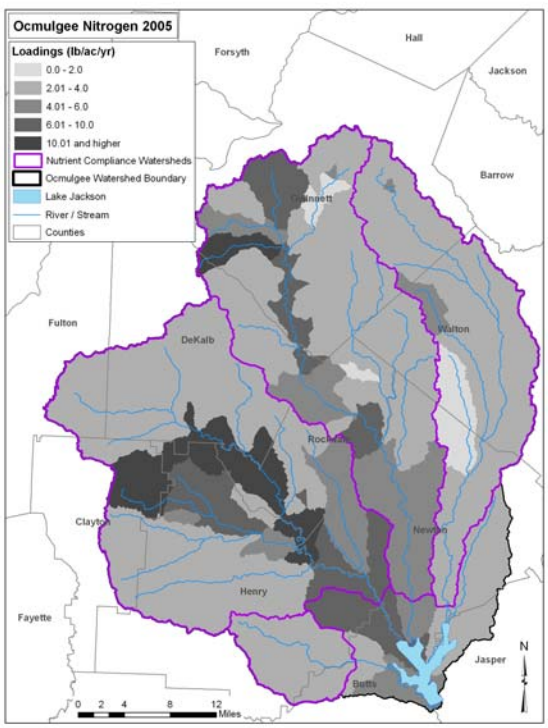

Figure C-40 Total Nitrogen Unit Loading (lbs/acre) for Lake Jackson Watershed for 2005

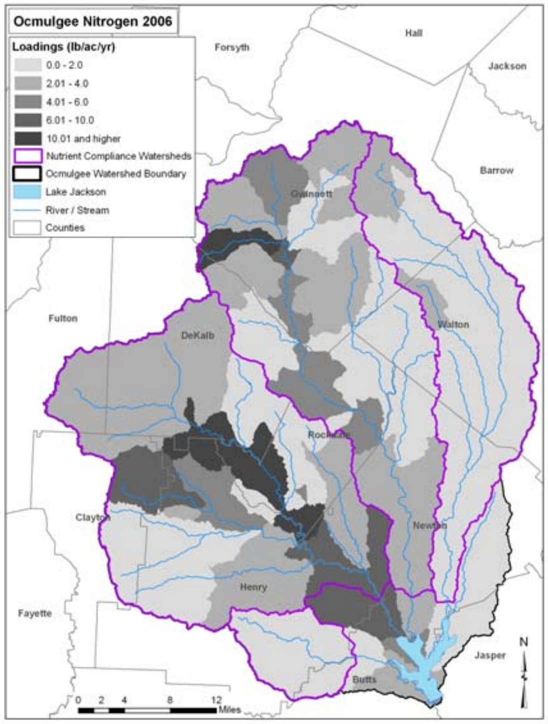

Figure C-41 Total Nitrogen Unit Loading (lbs/acre) for Lake Jackson Watershed for 2006

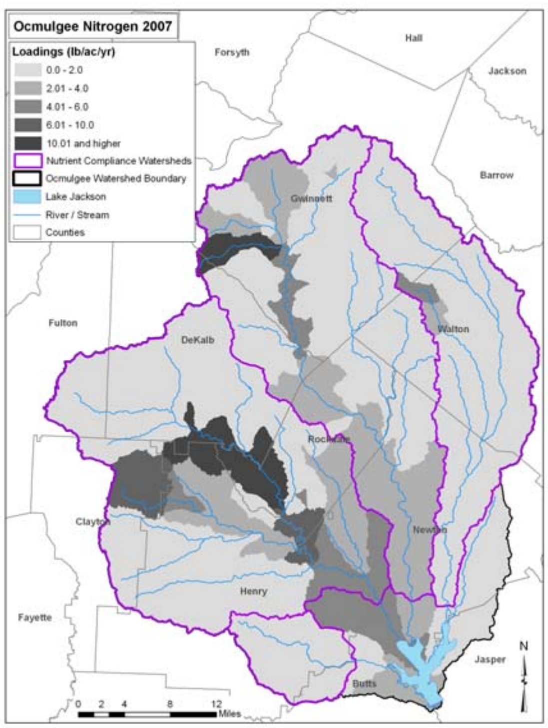

Figure C-42 Total Nitrogen Unit Loading (lbs/acre) for Lake Jackson Watershed for 2007

C.1.4 Lake Oconee and Lake Sinclair Watershed

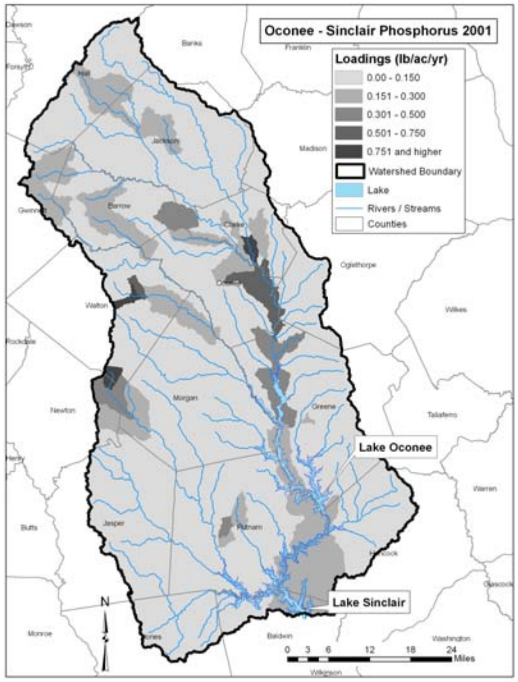

Figure C-43 Total Phosphorus Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2001

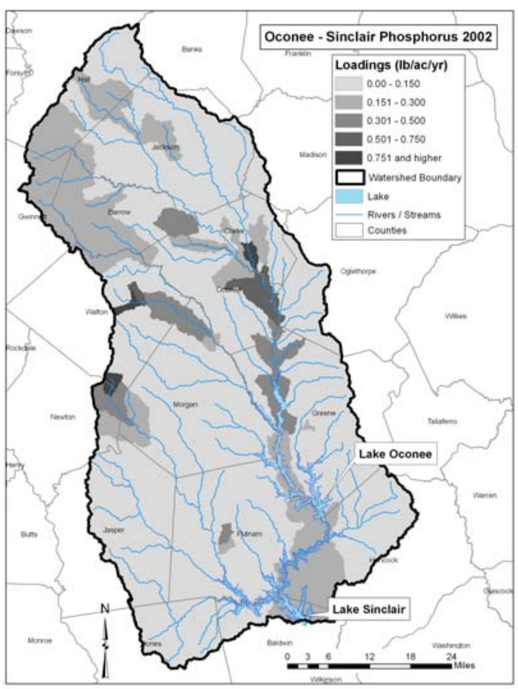

Figure C-44 Total Phosphorus Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2002

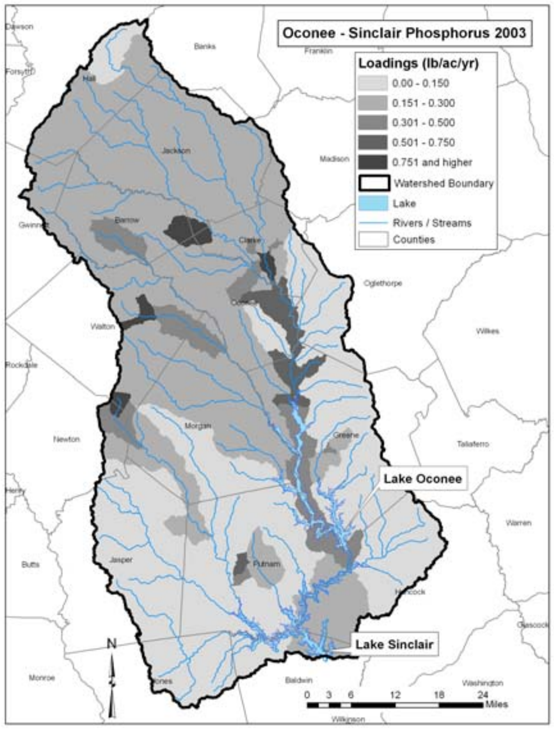

Figure C-45 Total Phosphorus Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2003

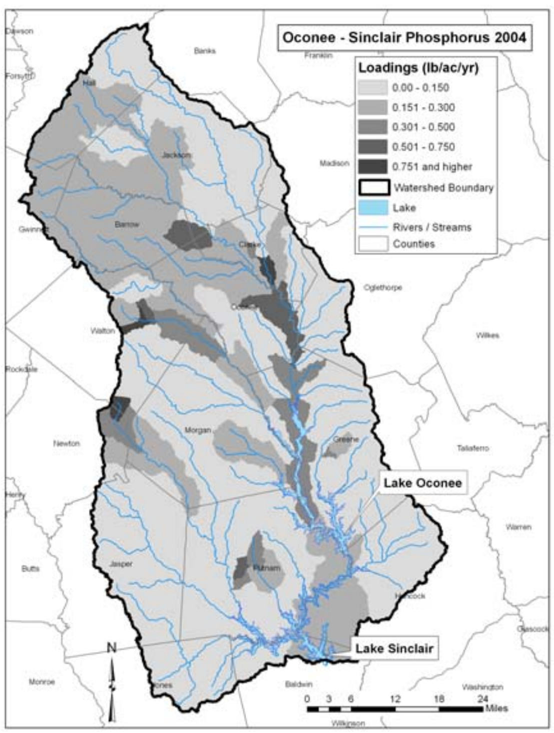

Figure C-46 Total Phosphorus Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2004

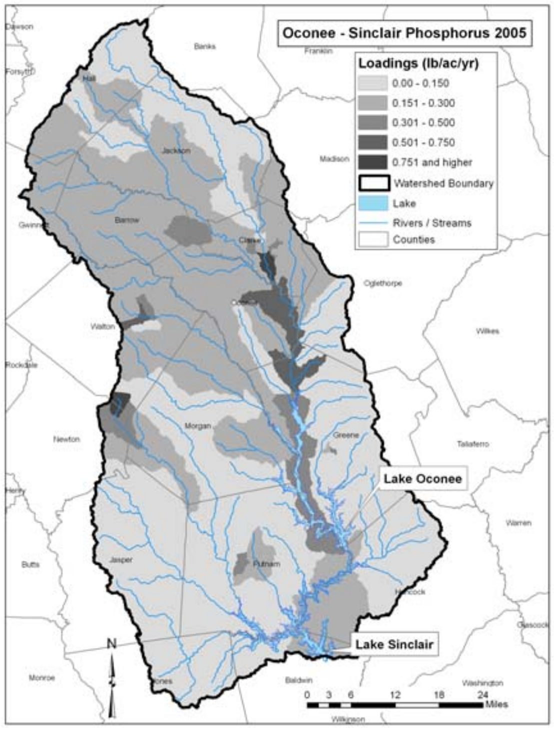

Figure C-47 Total Phosphorus Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2005

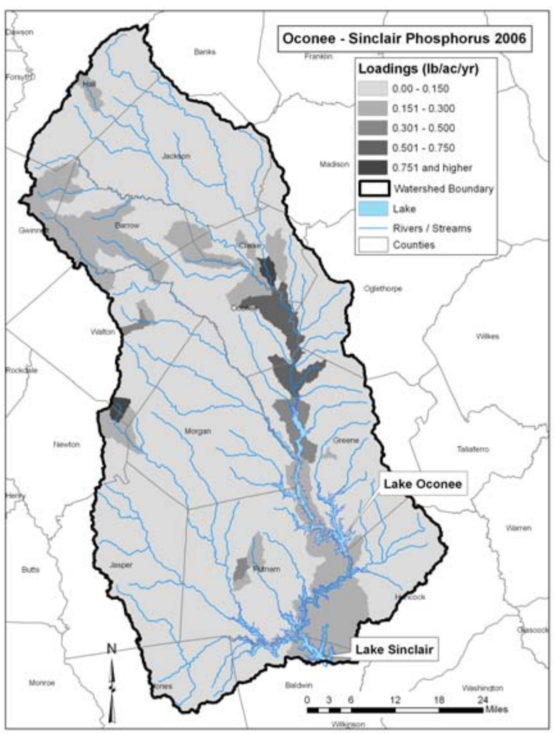

Figure C-48 Total Phosphorus Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2006

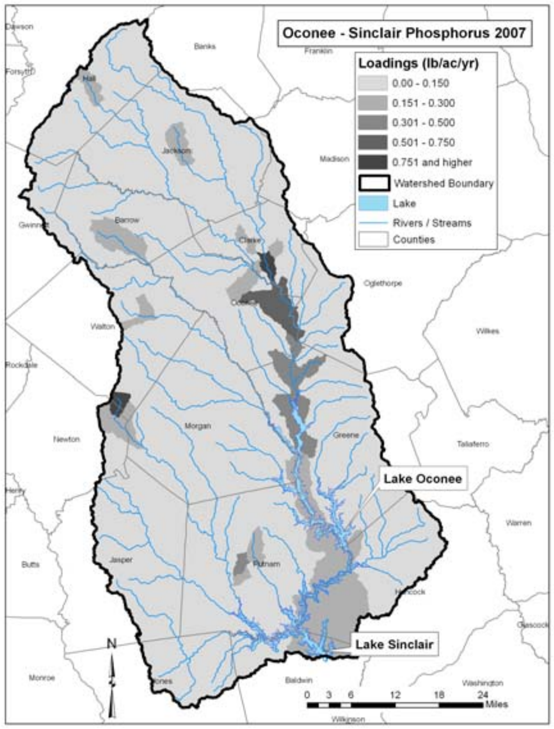

Figure C-49 Total Phosphorus Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2007

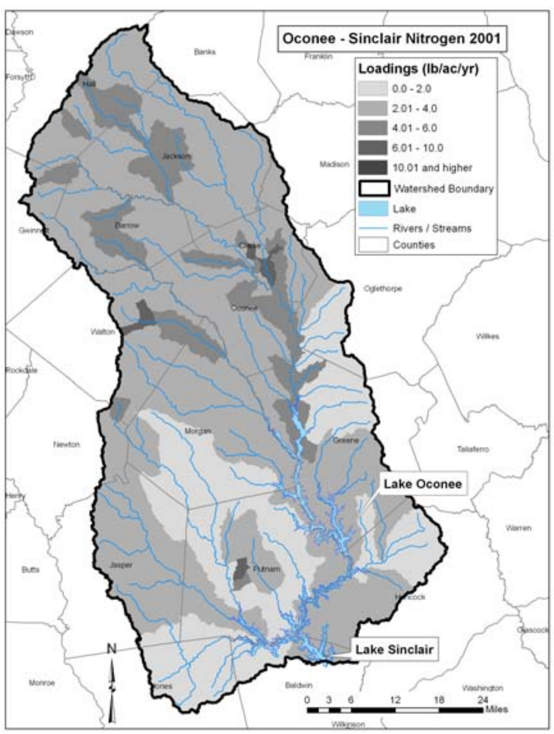

Figure C-50 Total Nitrogen Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2001

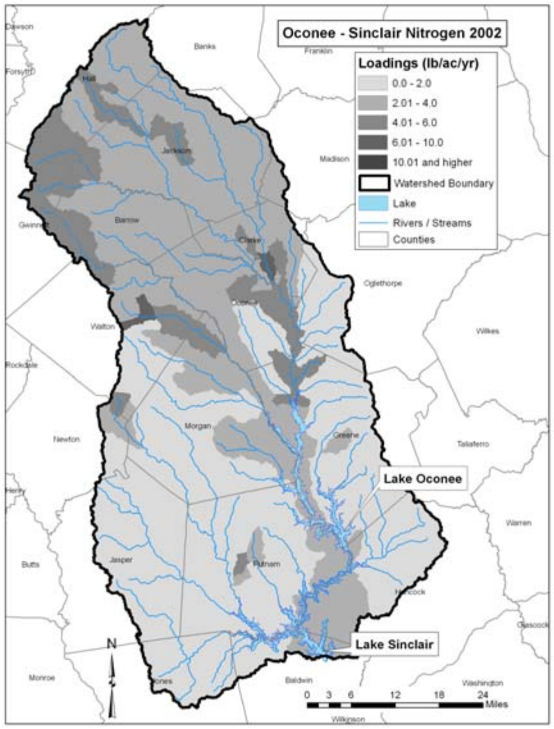

Figure C-51 Total Nitrogen Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2002

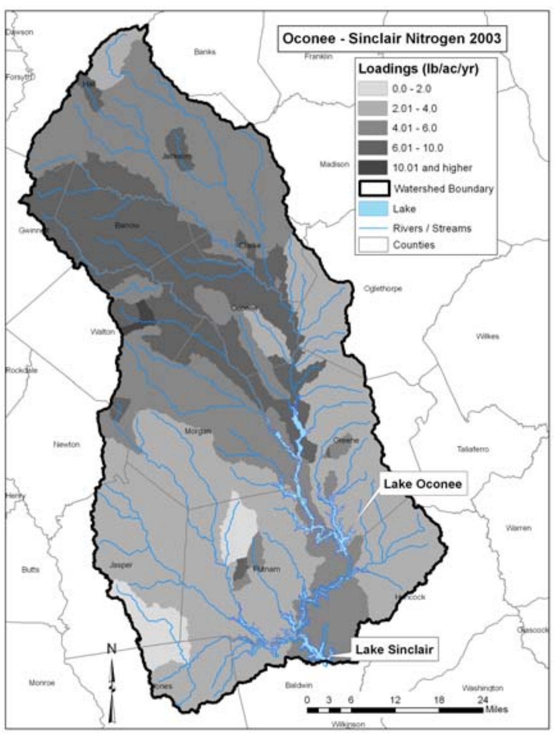

Figure C-52 Total Nitrogen Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2003

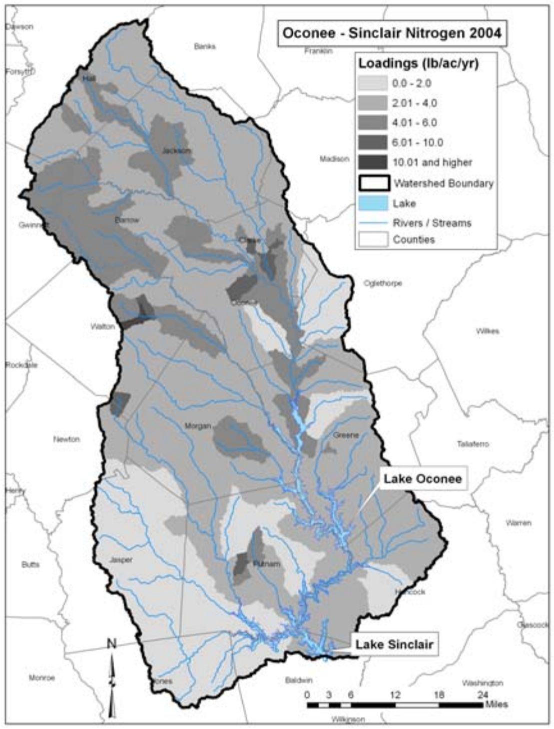

Figure C-53 Total Nitrogen Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2004

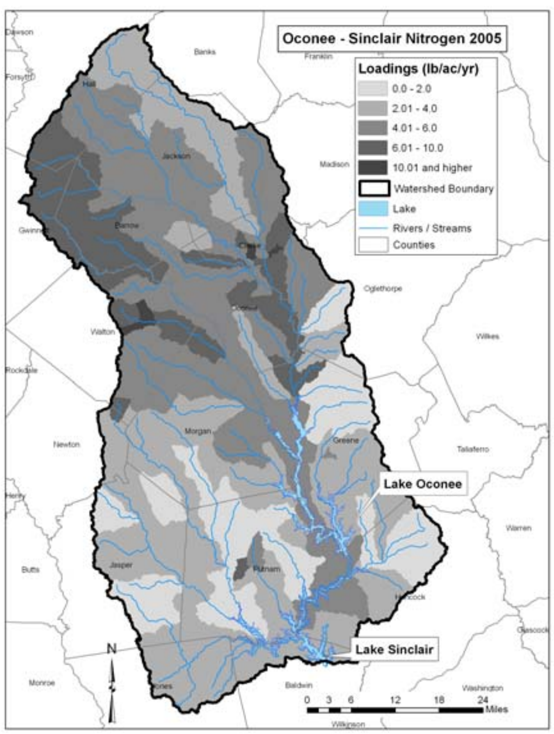

Figure C-54 Total Nitrogen Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2005

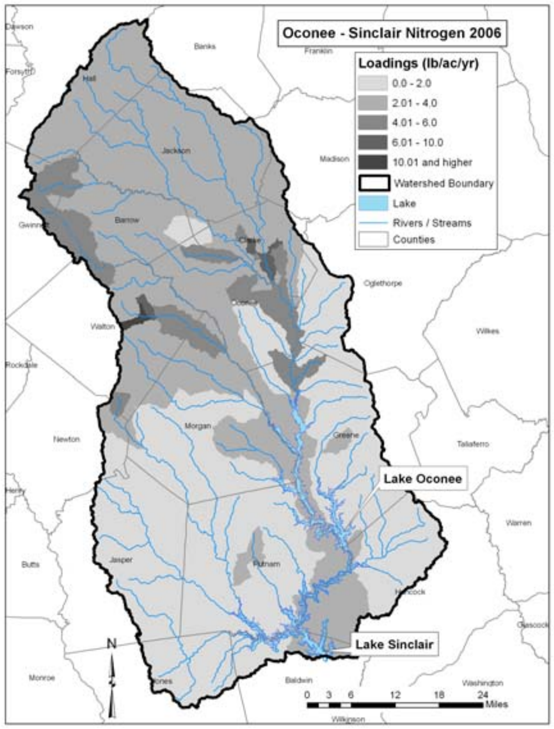

Figure C-55 Total Nitrogen Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2006

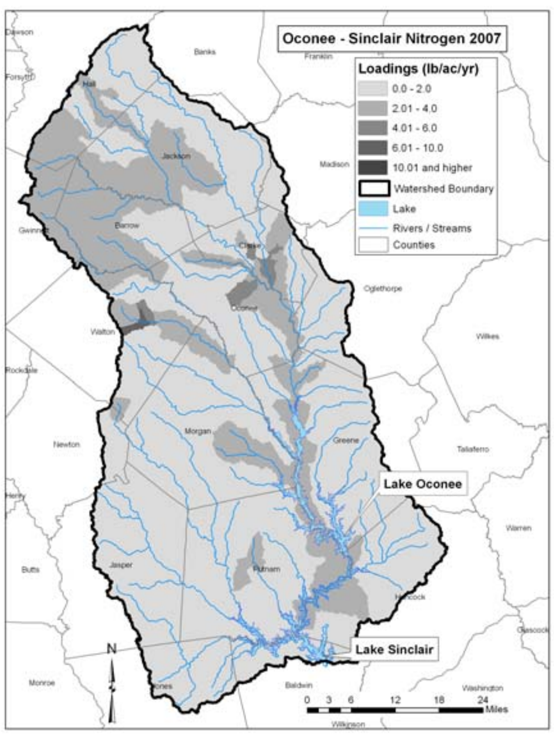

Figure C-56 Total Nitrogen Unit Loading (lbs/acre) for Lake Oconee and Lake Sinclair Watershed for 2007

C.1.5 Lower Savannah River Watershed

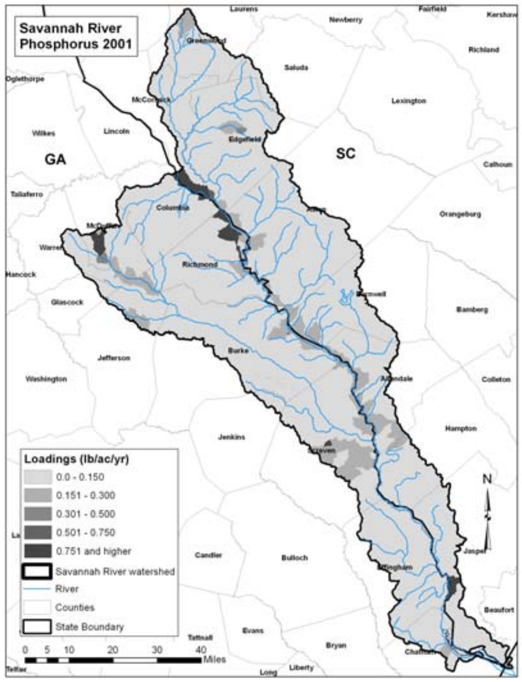

Figure C-57 Total Phosphorus Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2001

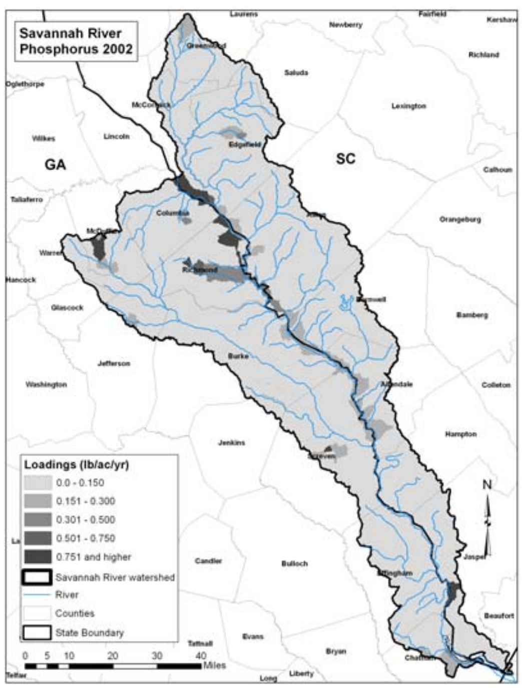

Figure C-58 Total Phosphorus Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2002

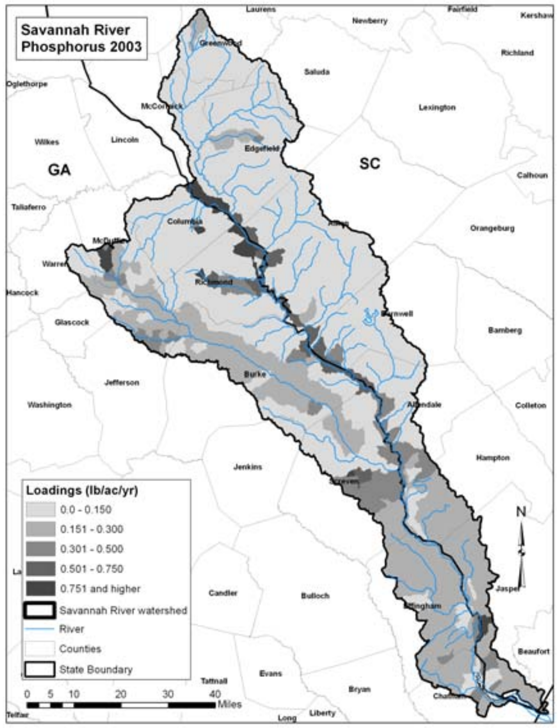

Figure C-59 Total Phosphorus Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2003

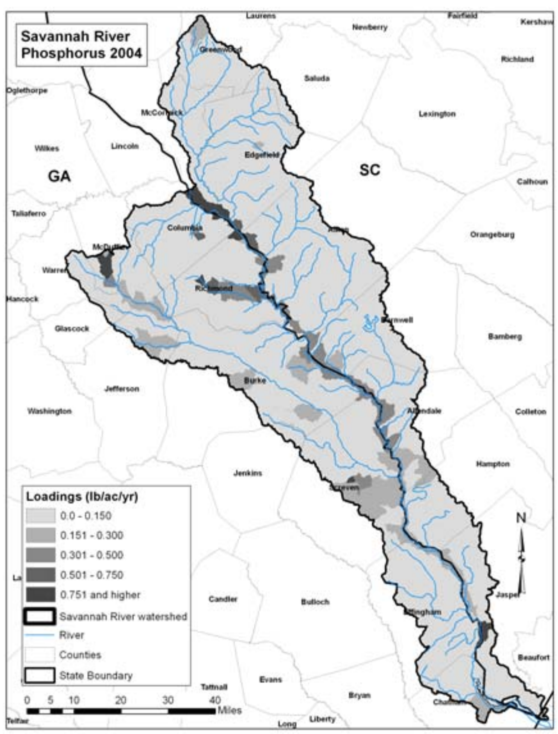

Figure C-60 Total Phosphorus Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2004

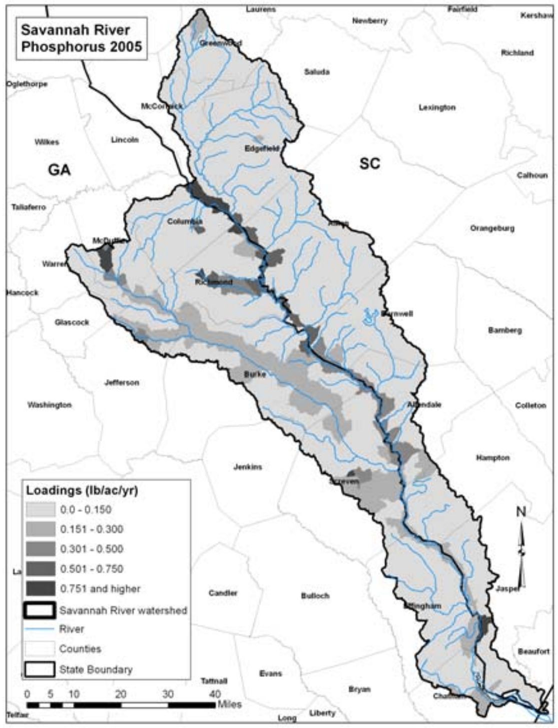

Figure C-61 Total Phosphorus Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2005

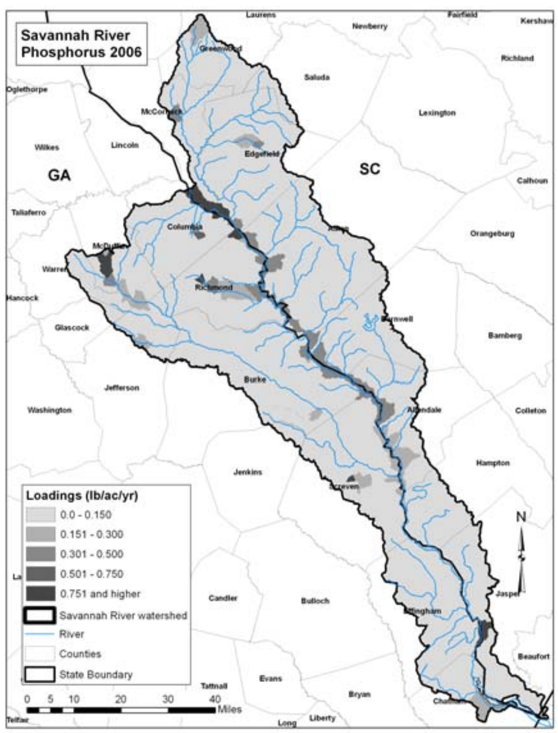

Figure C-62 Total Phosphorus Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2006

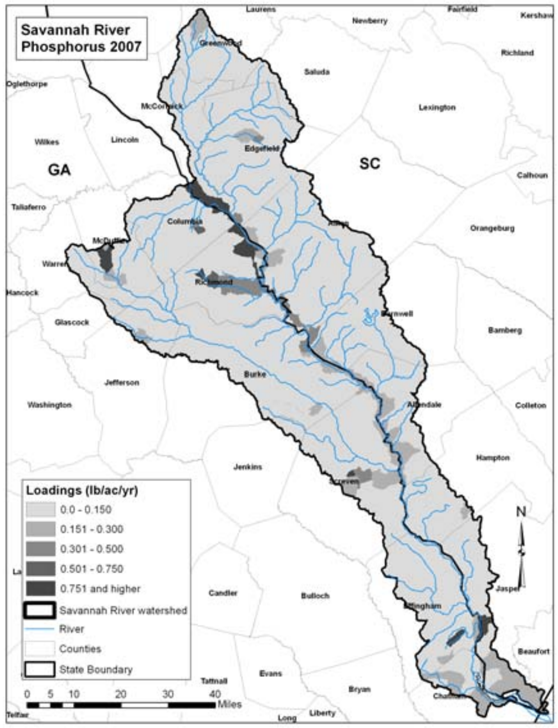

Figure C-63 Total Phosphorus Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2007

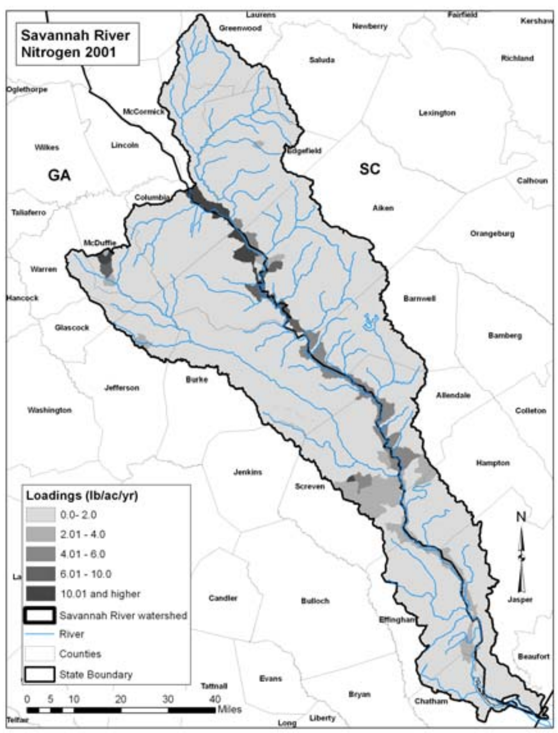

Figure C-64 Total Nitrogen Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2001

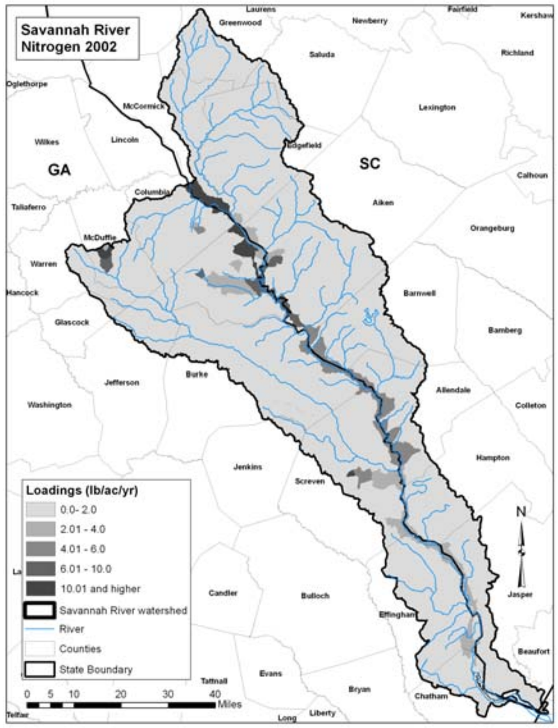

Figure C-65 Total Nitrogen Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2002

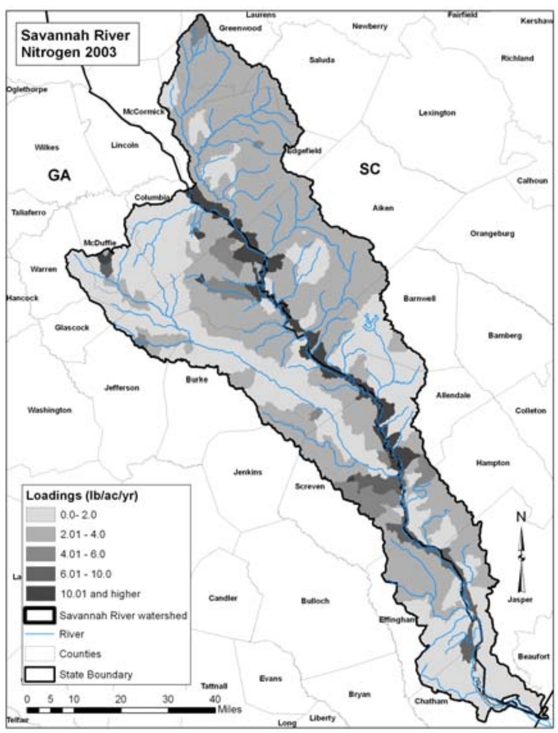

Figure C-66 Total Nitrogen Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2003

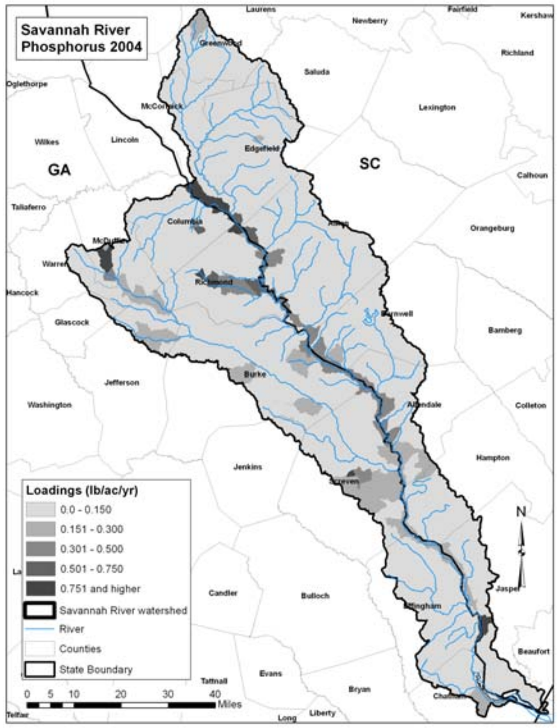

Figure C-67 Total Nitrogen Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2004

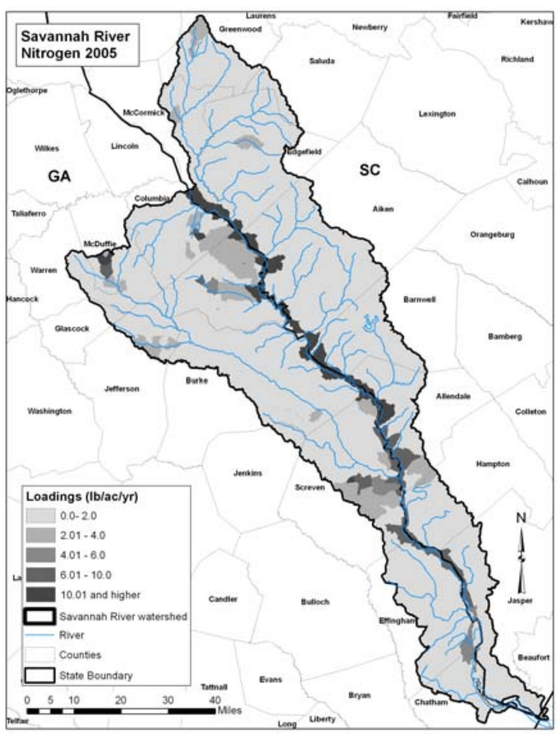

Figure C-68 Total Nitrogen Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2005

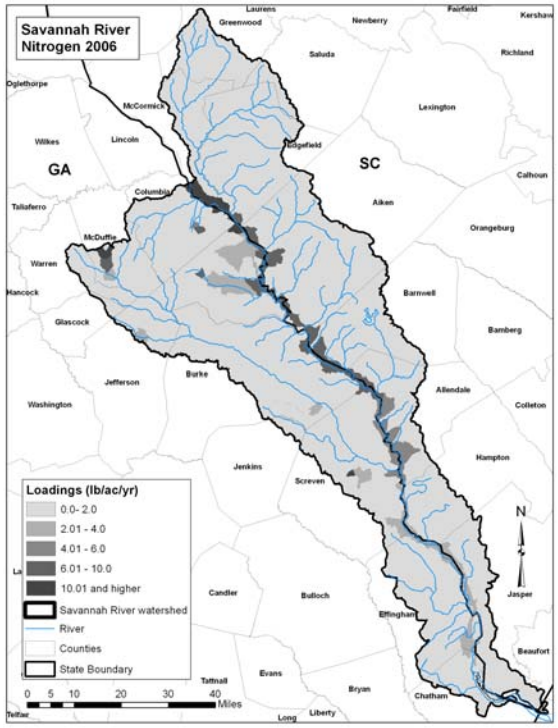

Figure C-69 Total Nitrogen Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2006

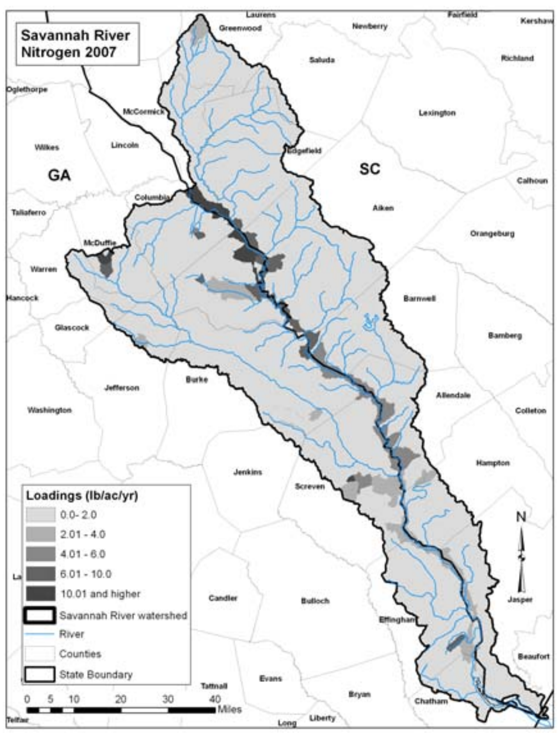

Figure C-70 Total Nitrogen Unit Loading (lbs/acre) for Lower Savannah River Watershed for 2007

C.1.6 Brunswick Harbor Watershed

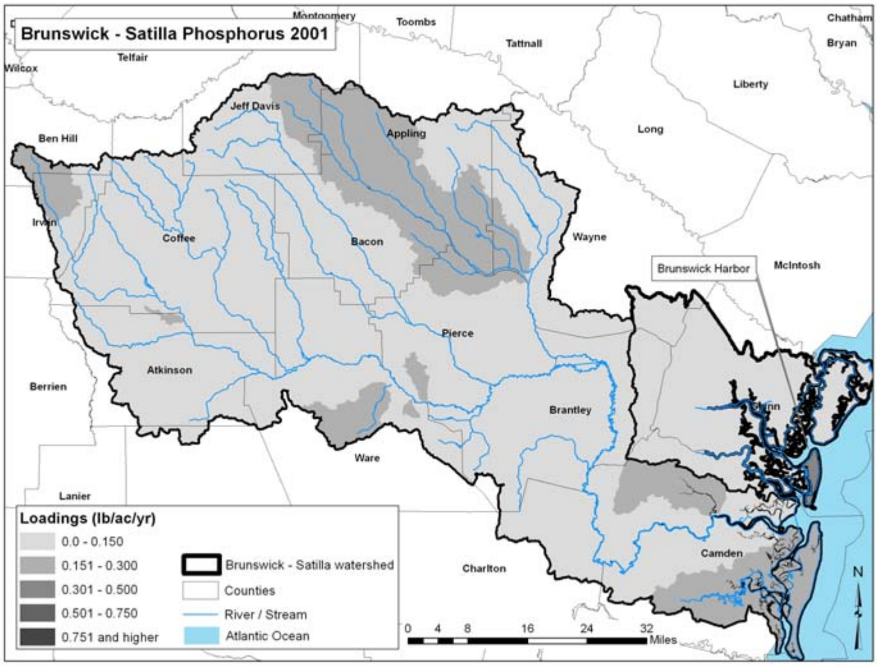

Figure C-71 Total Phosphorus Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2001

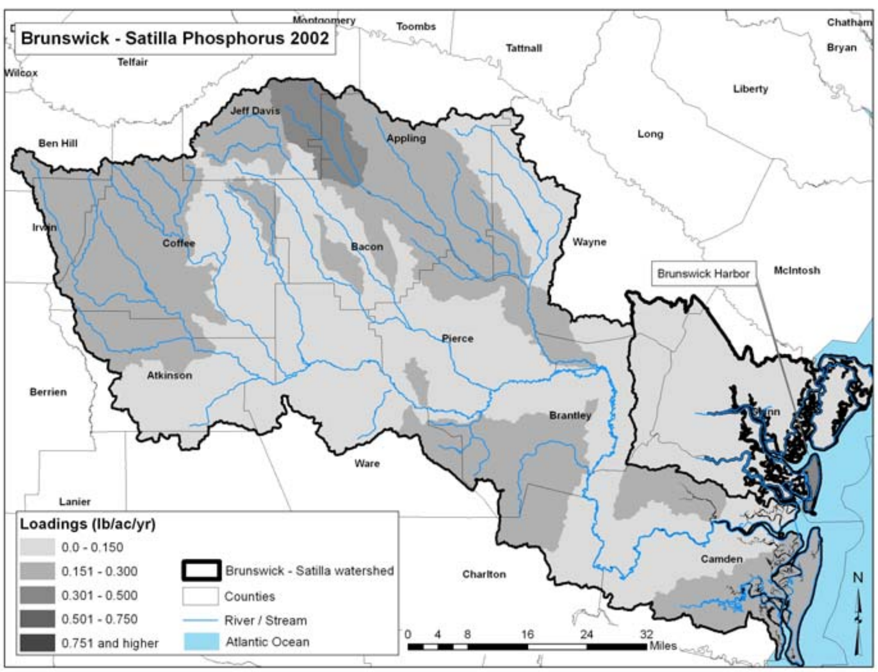

Figure C-72 Total Phosphorus Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2002

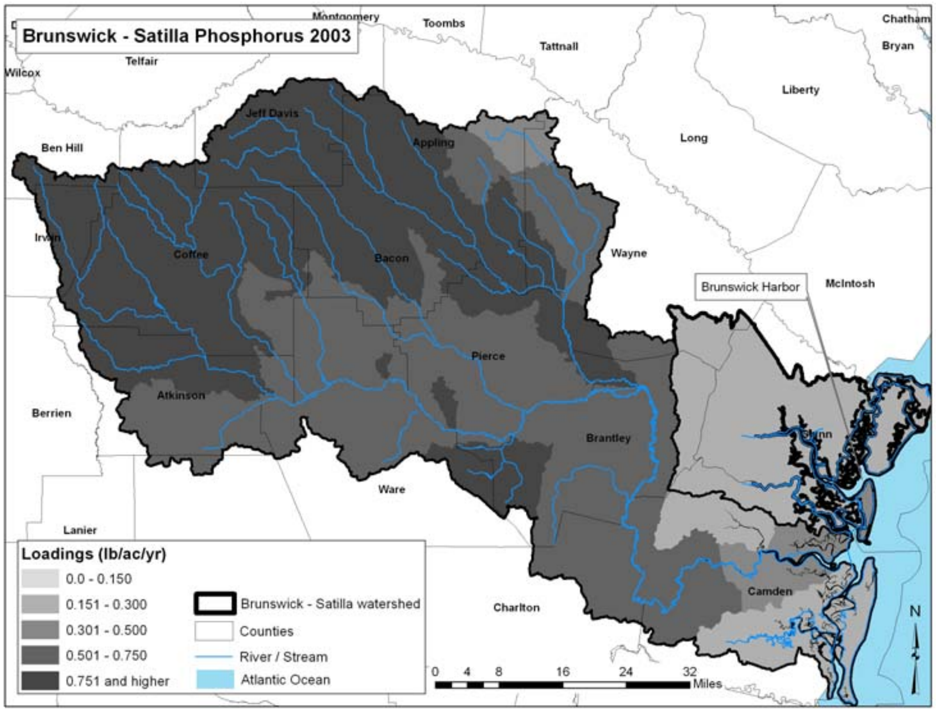

Figure C-73 Total Phosphorus Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2003

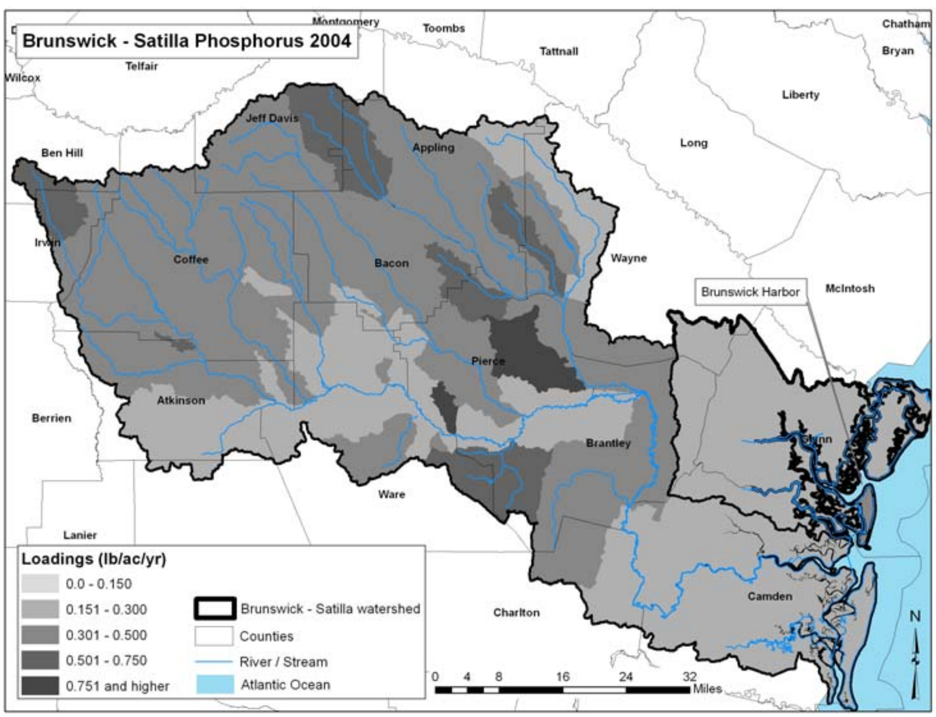

Figure C-74 Total Phosphorus Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2004

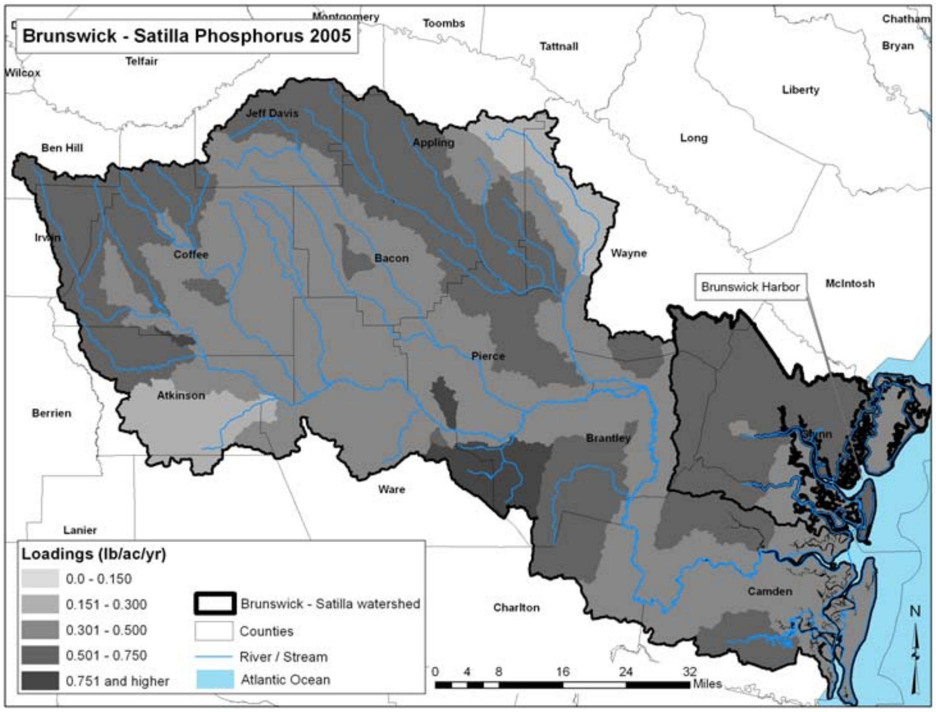

Figure C-75 Total Phosphorus Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2005

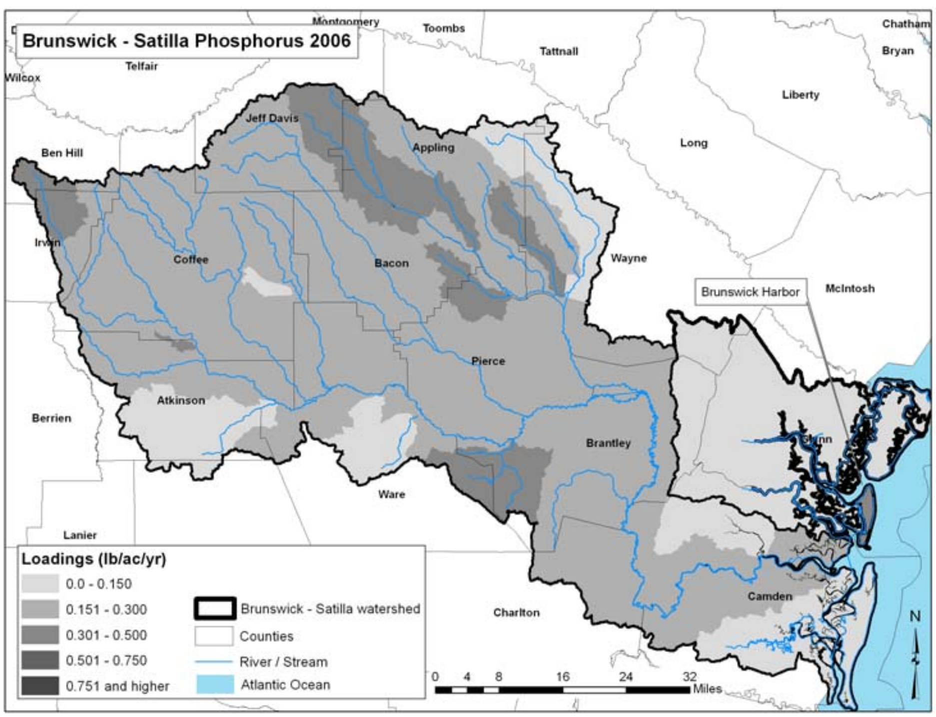

Figure C-76 Total Phosphorus Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2006

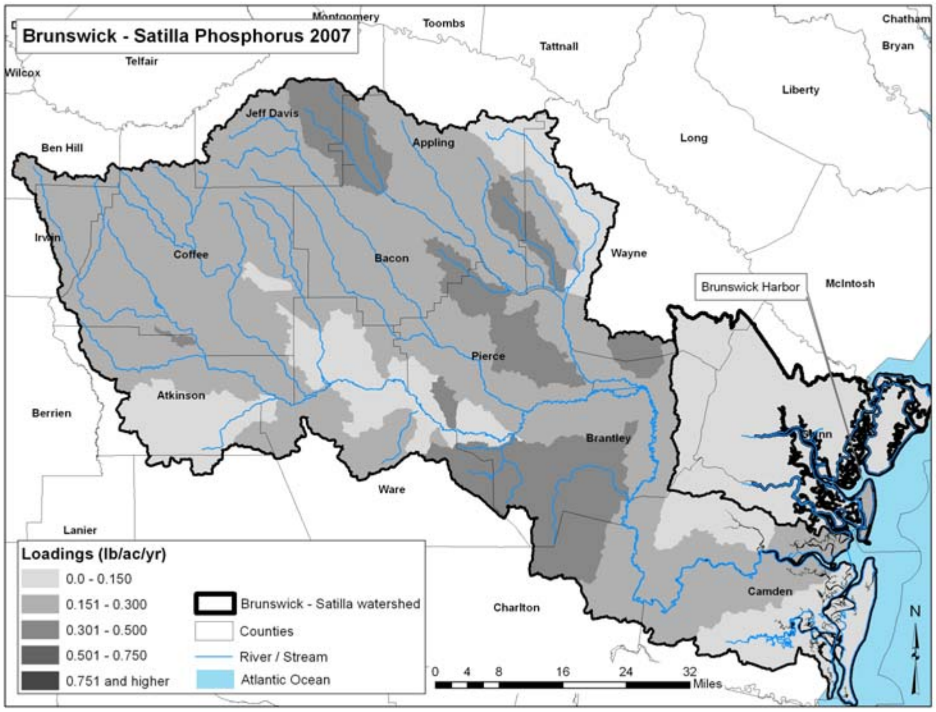

Figure C-77 Total Phosphorus Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2007

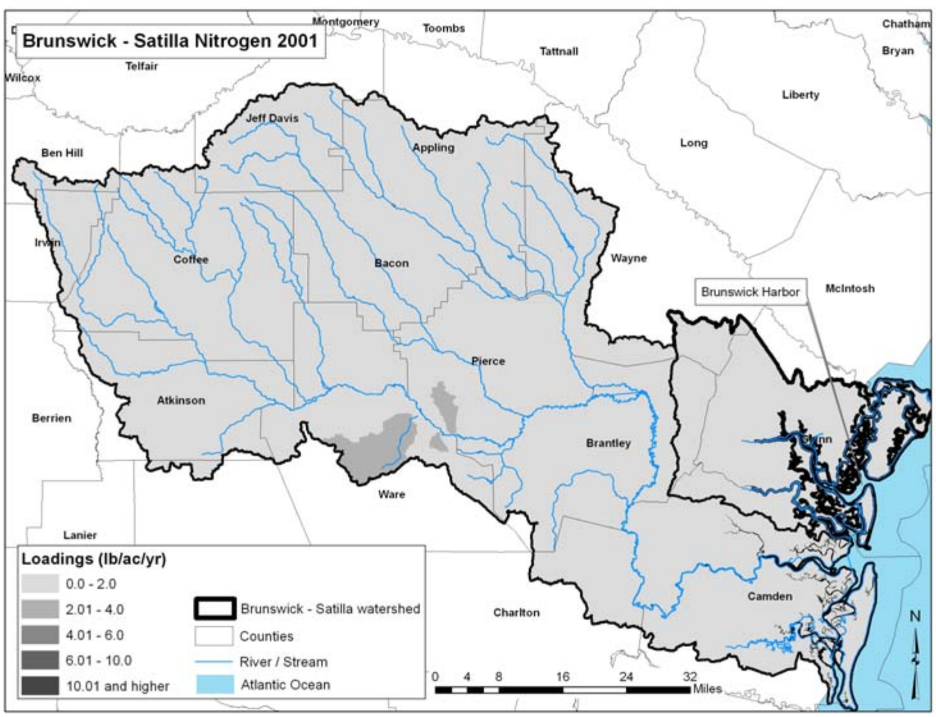

Figure C-78 Total Nitrogen Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2001

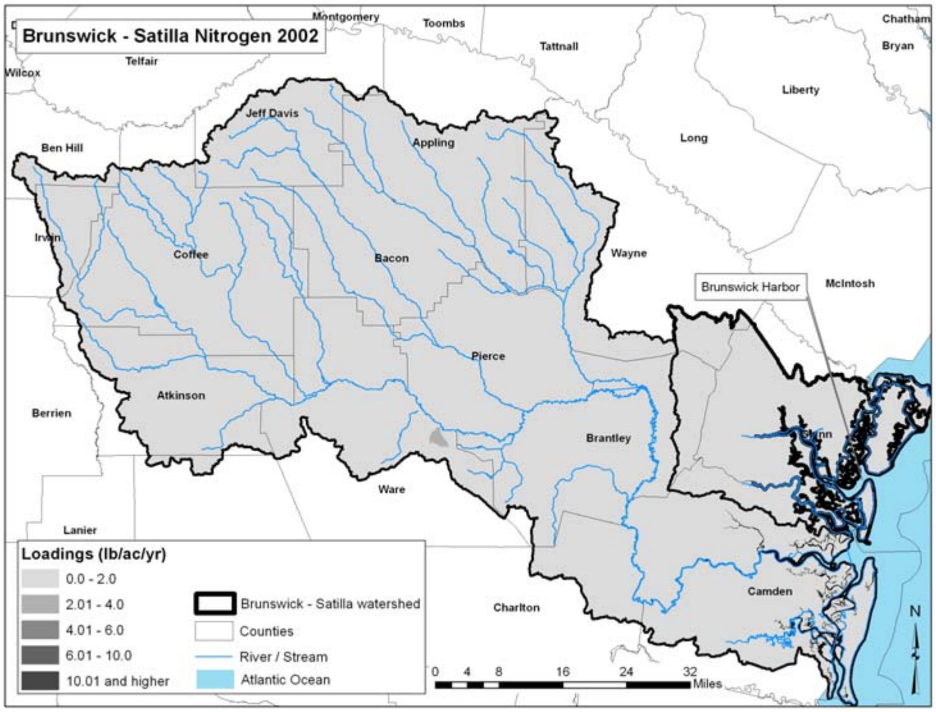

Figure C-79 Total Nitrogen Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2002

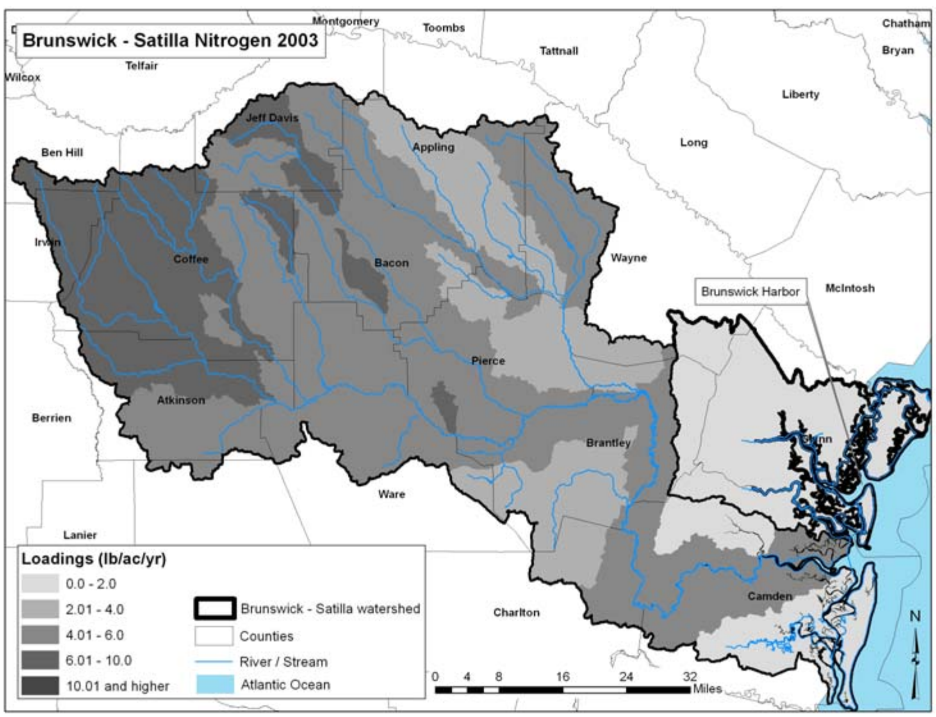

Figure C-80 Total Nitrogen Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2003

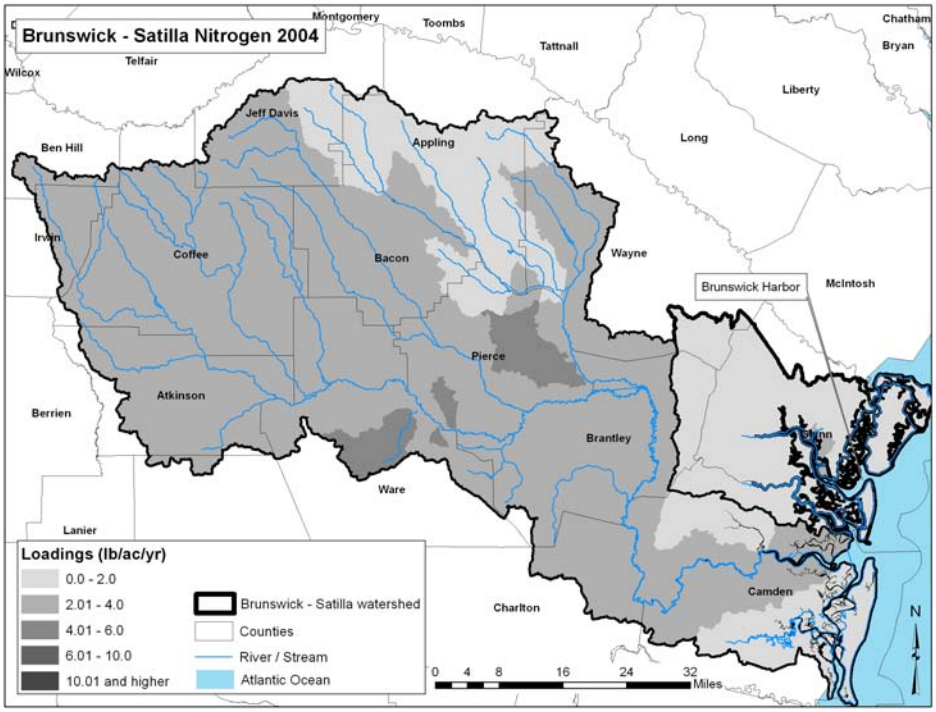

Figure C-81 Total Nitrogen Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2004

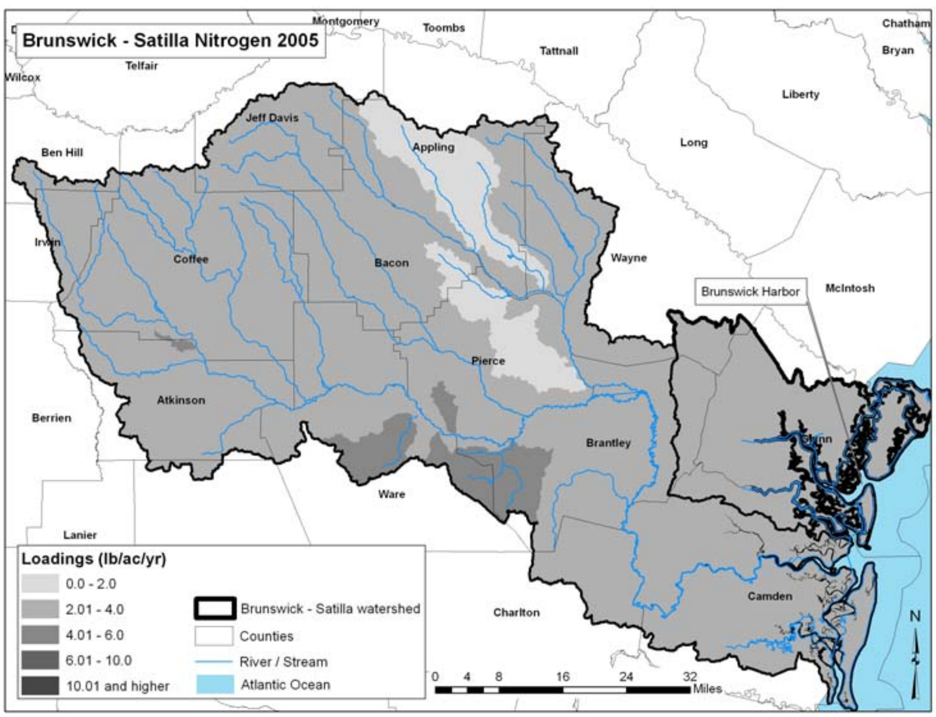

Figure C-82 Total Nitrogen Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2005

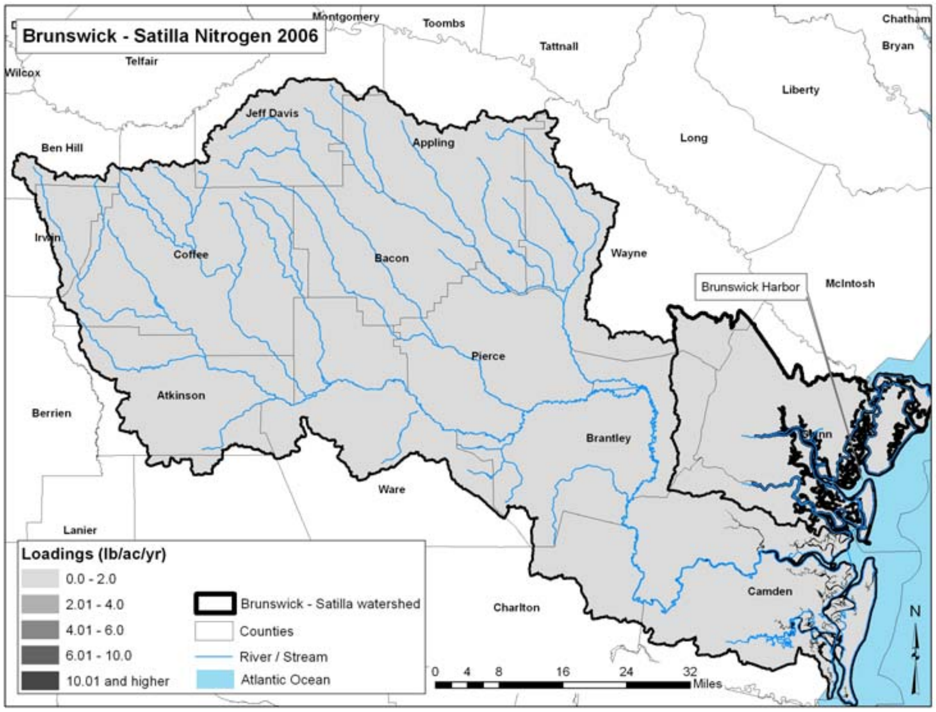

Figure C-83 Total Nitrogen Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2006

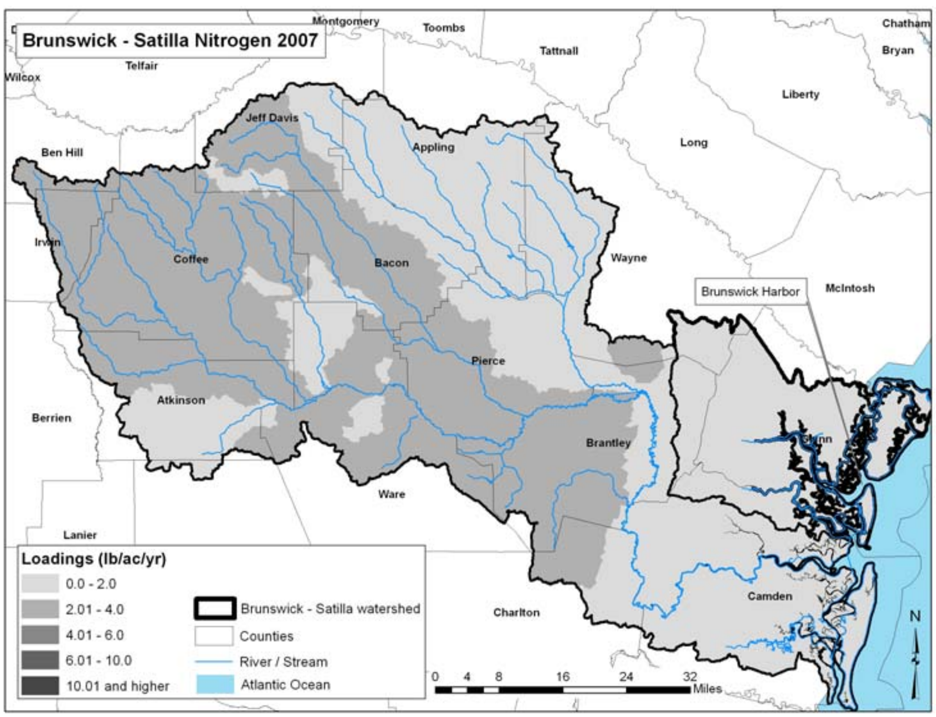

Figure C-84 Total Nitrogen Unit Loading (lbs/acre) for Brunswick Harbor Watershed for 2007

C.2 LAKE RESULTS

Figures C-85 through C-112 present the maximum total nitrogen simulated from the EFDC model for Lakes Allatoona, Jackson, Oconee and Sinclair. Results are shown for two wet years (2004 and 2005), two dry years (2001 and 2007), and three normal rainfall years (2002, 2003 and 2006).

C.2.1 Lake Allatoona Total Nitrogen

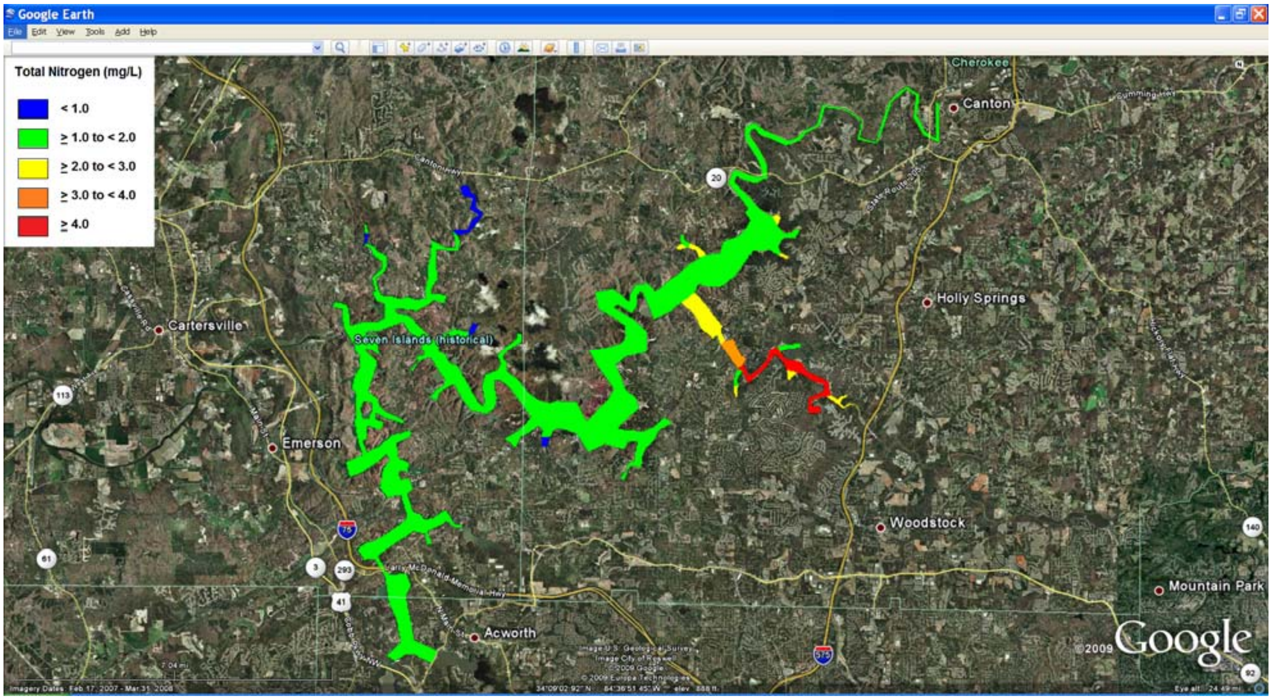

Figure C-85 Maximum Value of Total Nitrogen (mgN/L) in Lake Allatoona in Photic Zone: year 2001

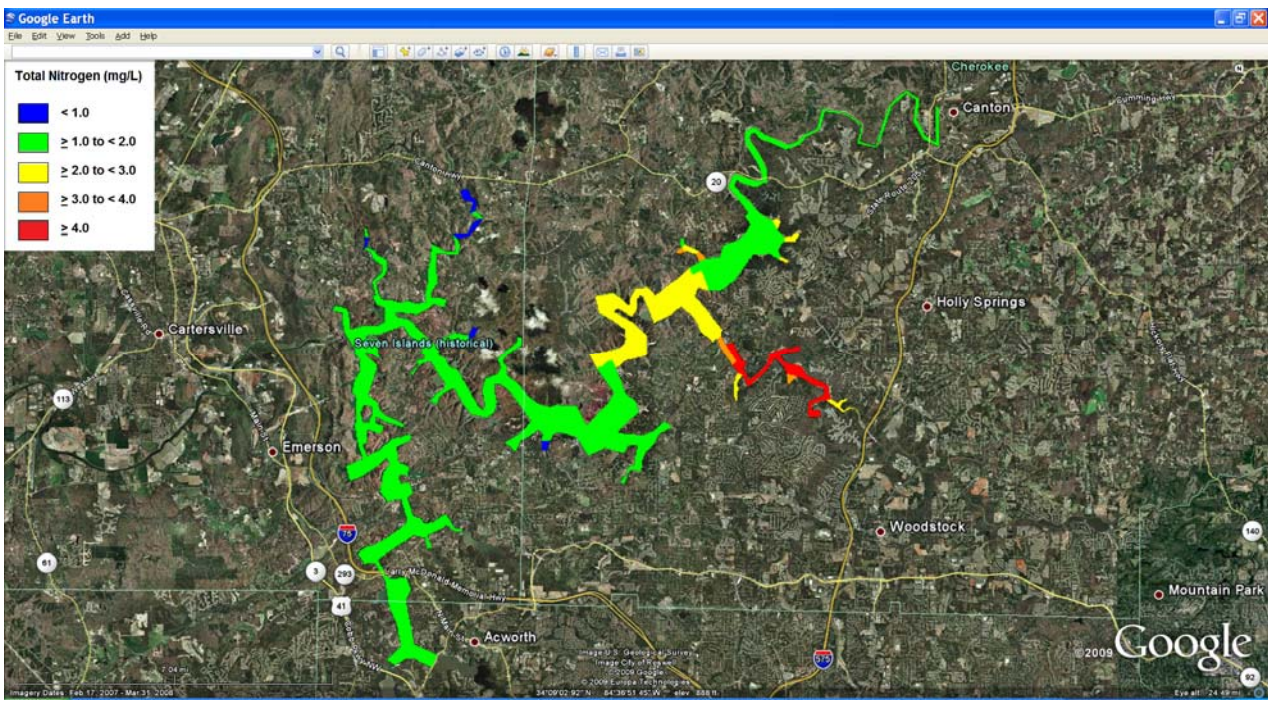

Figure C-86 Maximum Value of Total Nitrogen (mgN/L) in Lake Allatoona in Photic Zone: year 2002

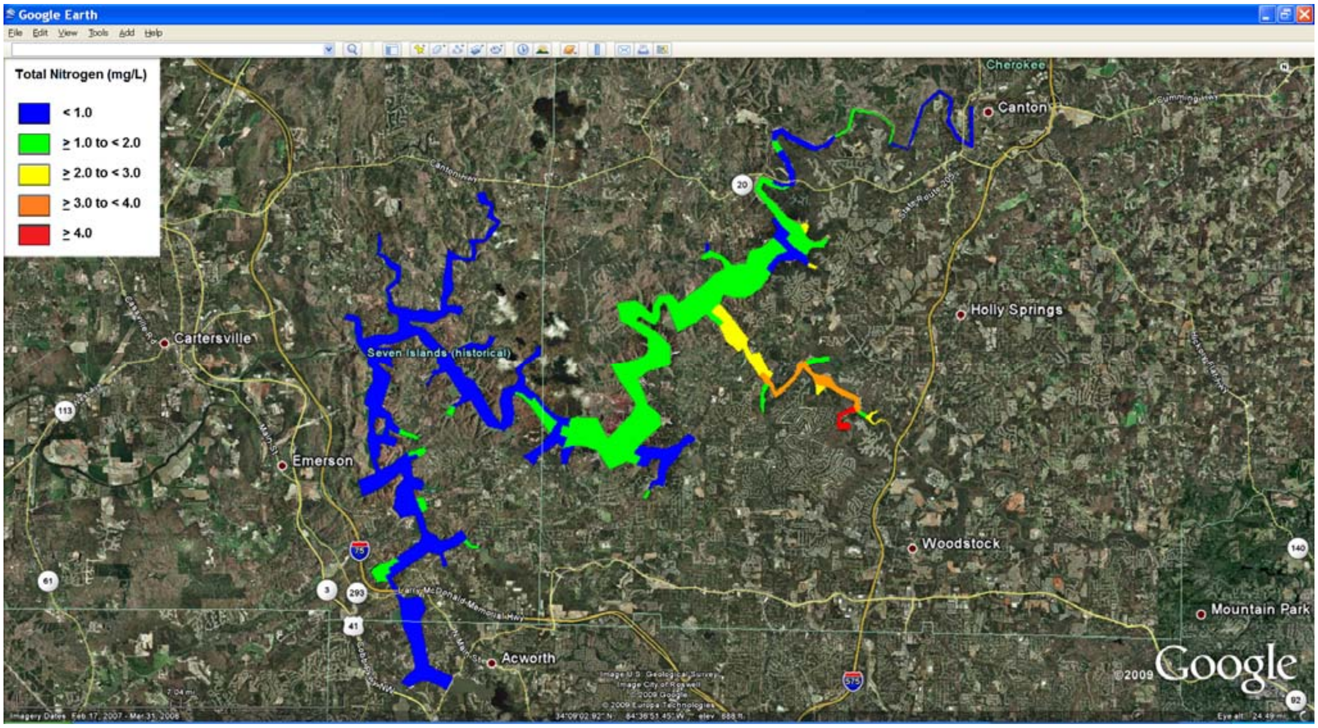

Figure C-87 Maximum Value of Total Nitrogen (mgN/L) in Lake Allatoona in Photic Zone: year 2003

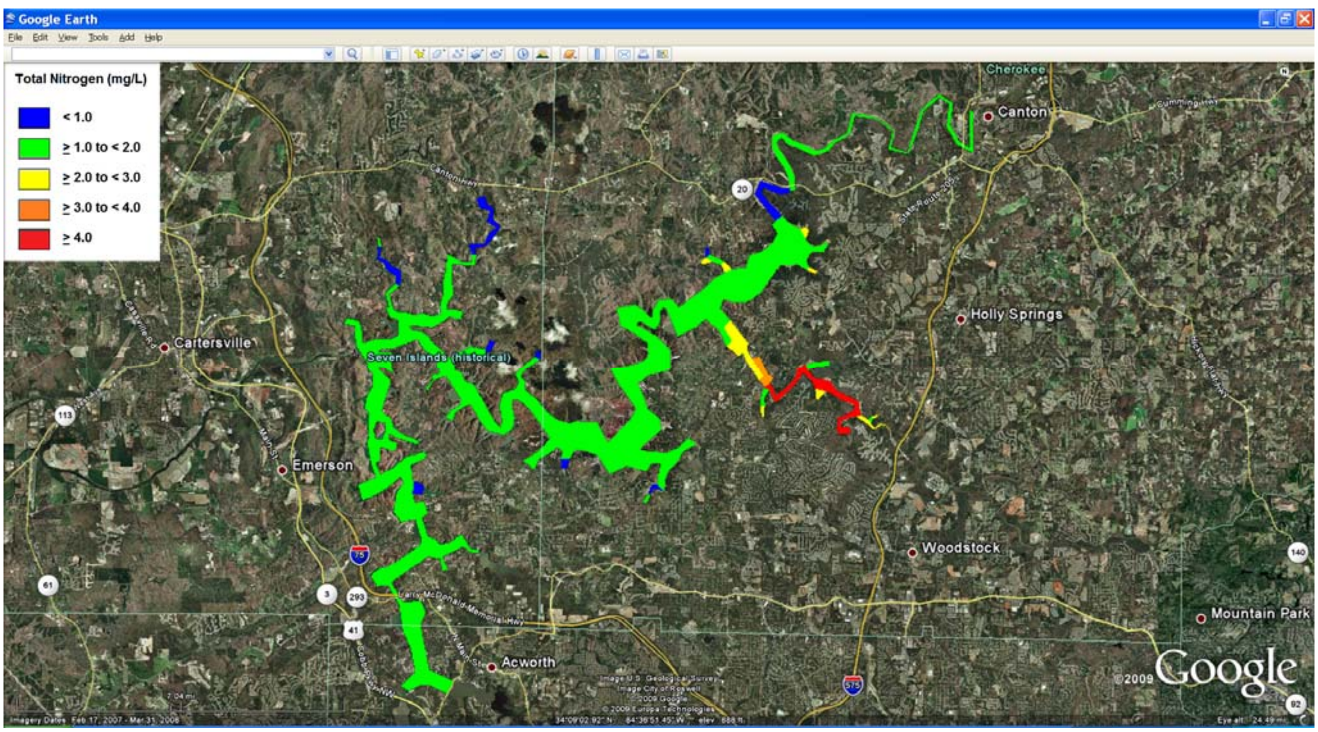

Figure C-88 Maximum Value of Total Nitrogen (mgN/L) in Lake Allatoona in Photic Zone: year 2004

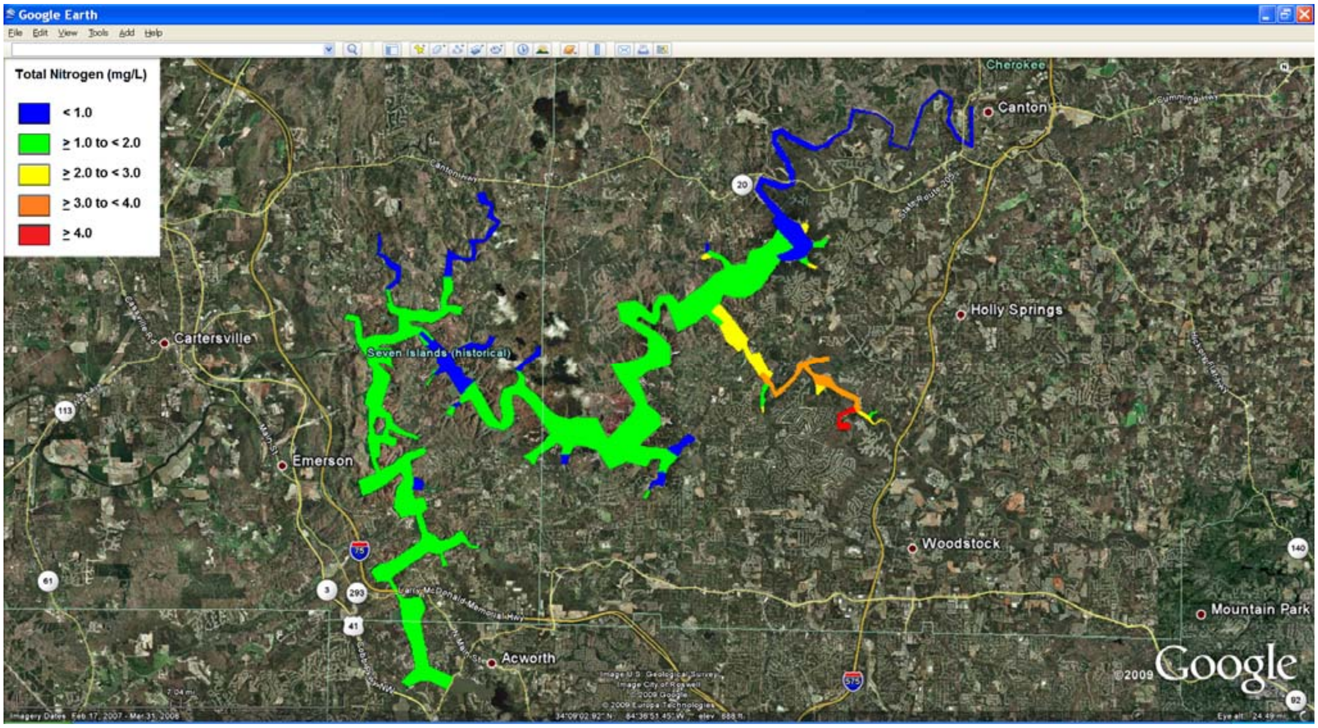

Figure C-89 Maximum Value of Total Nitrogen (mgN/L) in Lake Allatoona in Photic Zone: year 2005

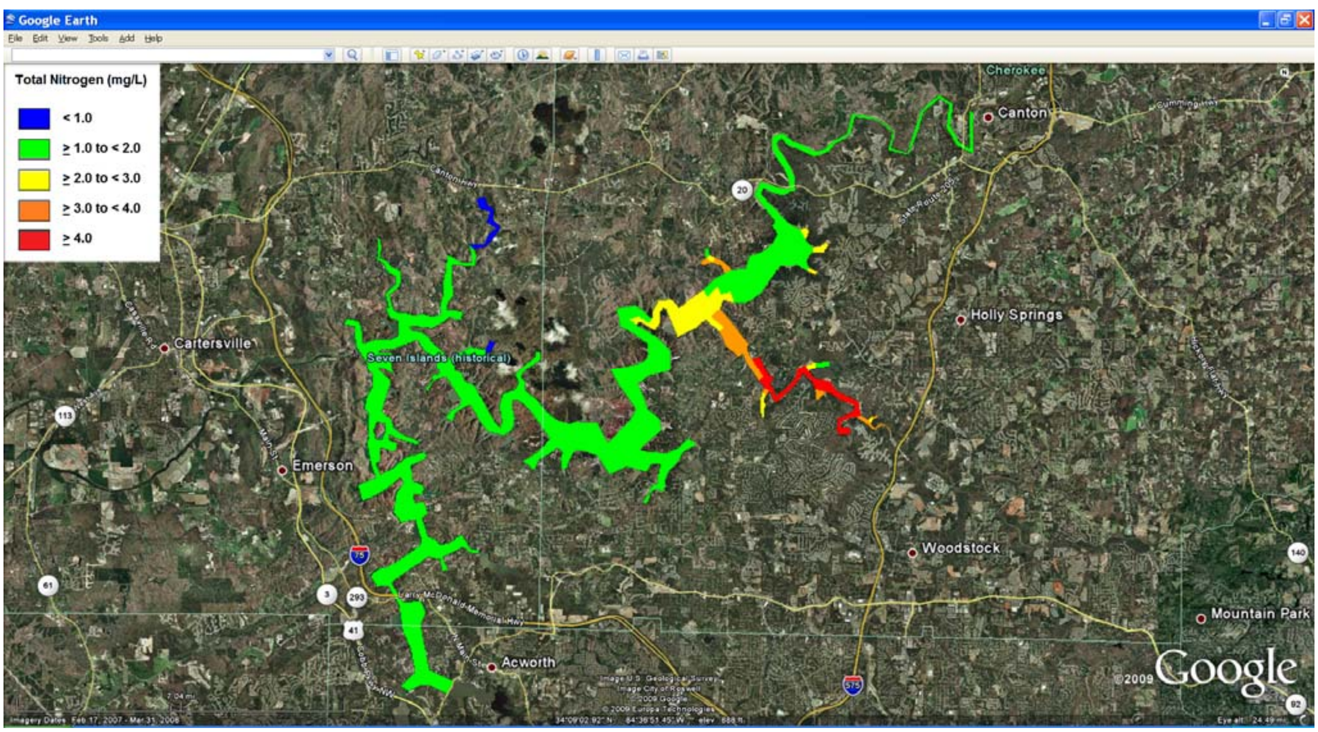

Figure C-90 Maximum Value of Total Nitrogen (mgN/L) in Lake Allatoona in Photic Zone: year 2006

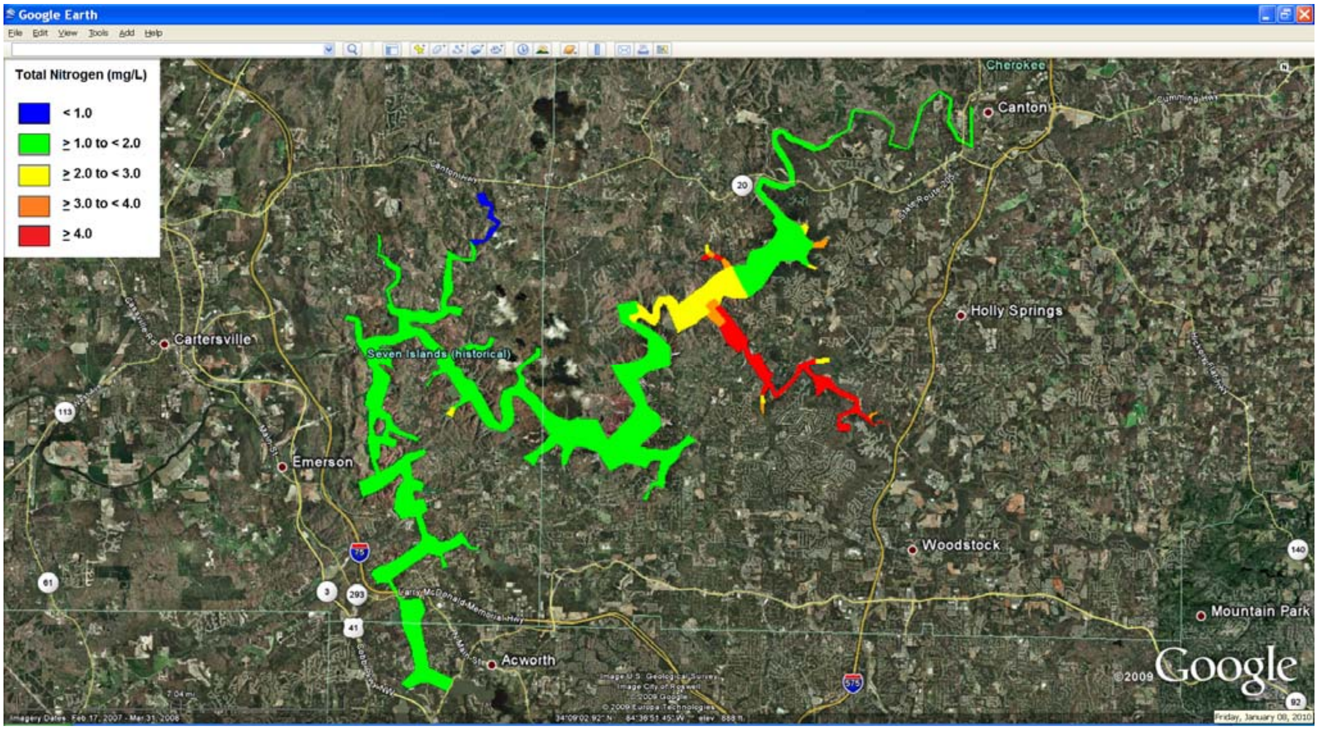

Figure C-91 Maximum Value of Total Nitrogen (mgN/L) in Lake Allatoona in Photic Zone: year 2007

C.2.2 Lake Jackson Total Nitrogen

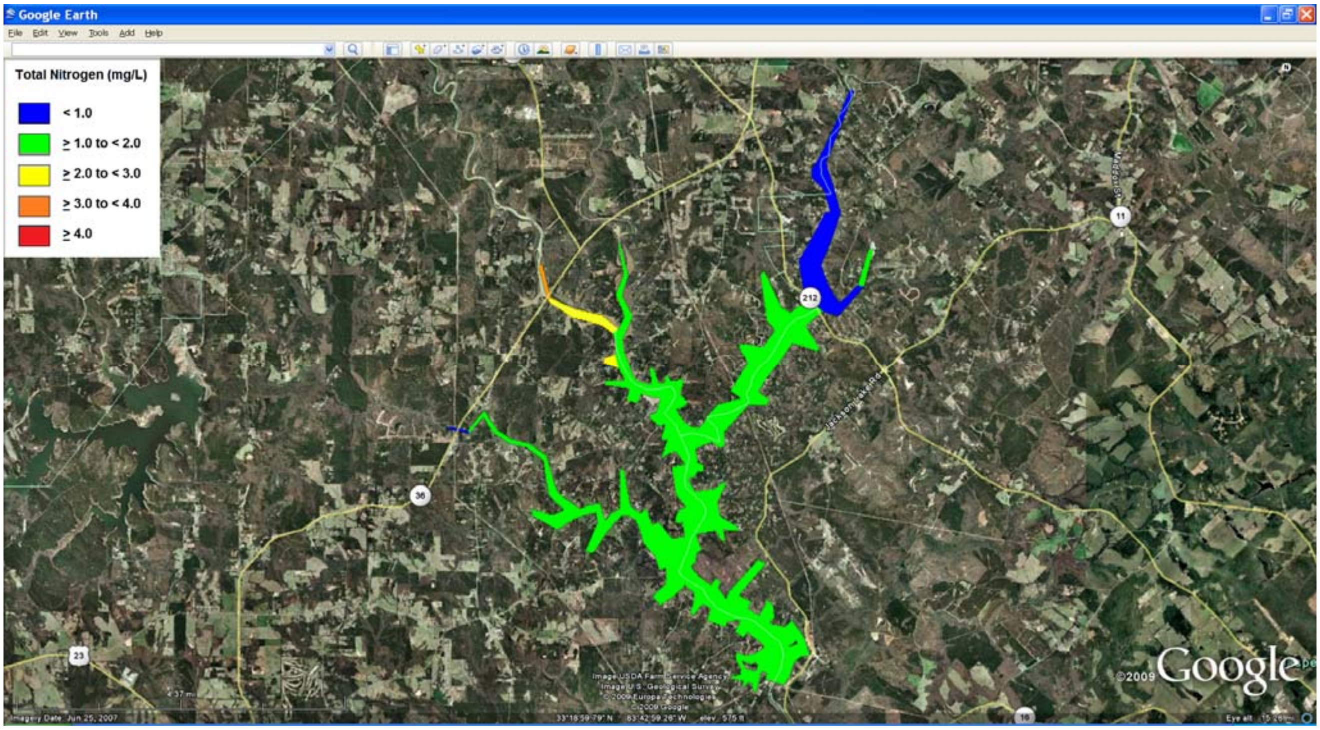

Figure C-92 Maximum Value of Total Nitrogen (mgN/L) in Lake Jackson in Photic Zone: year 2001

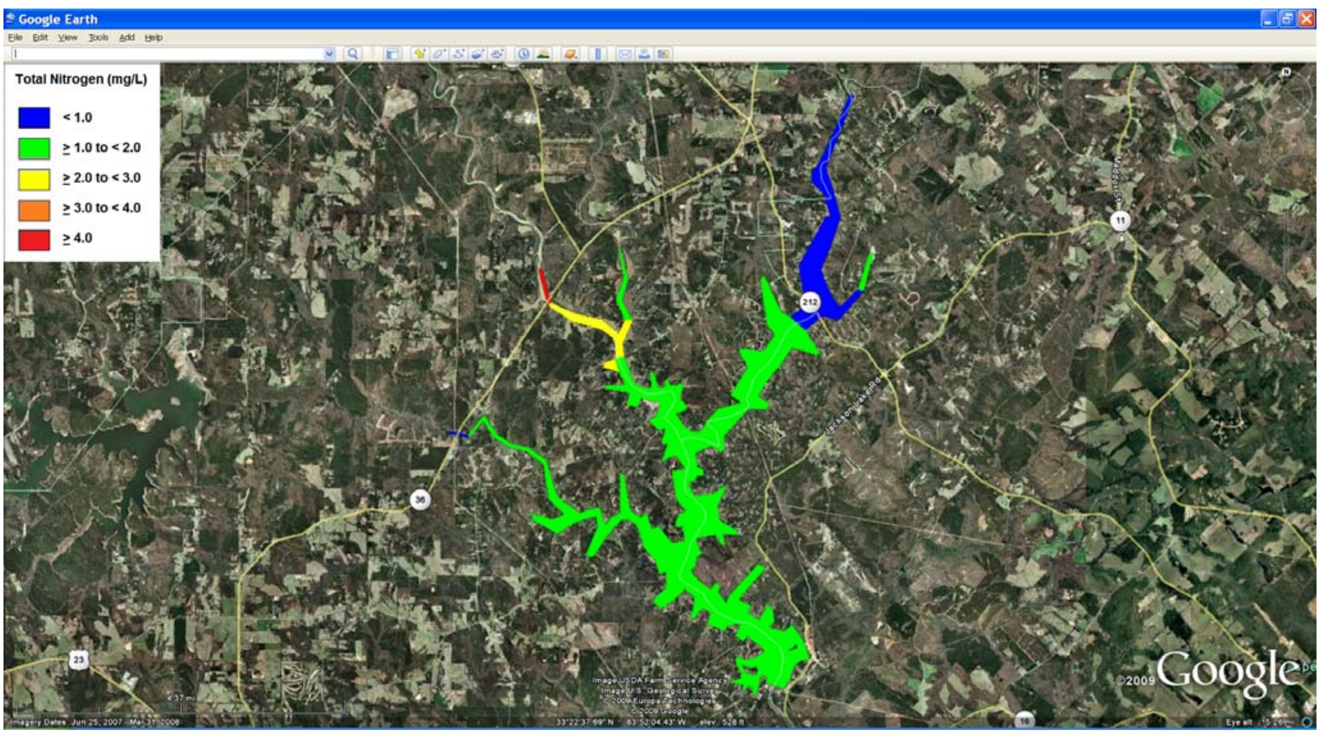

Figure C-93 Maximum Value of Total Nitrogen (mgN/L) in Lake Jackson in Photic Zone: year 2002

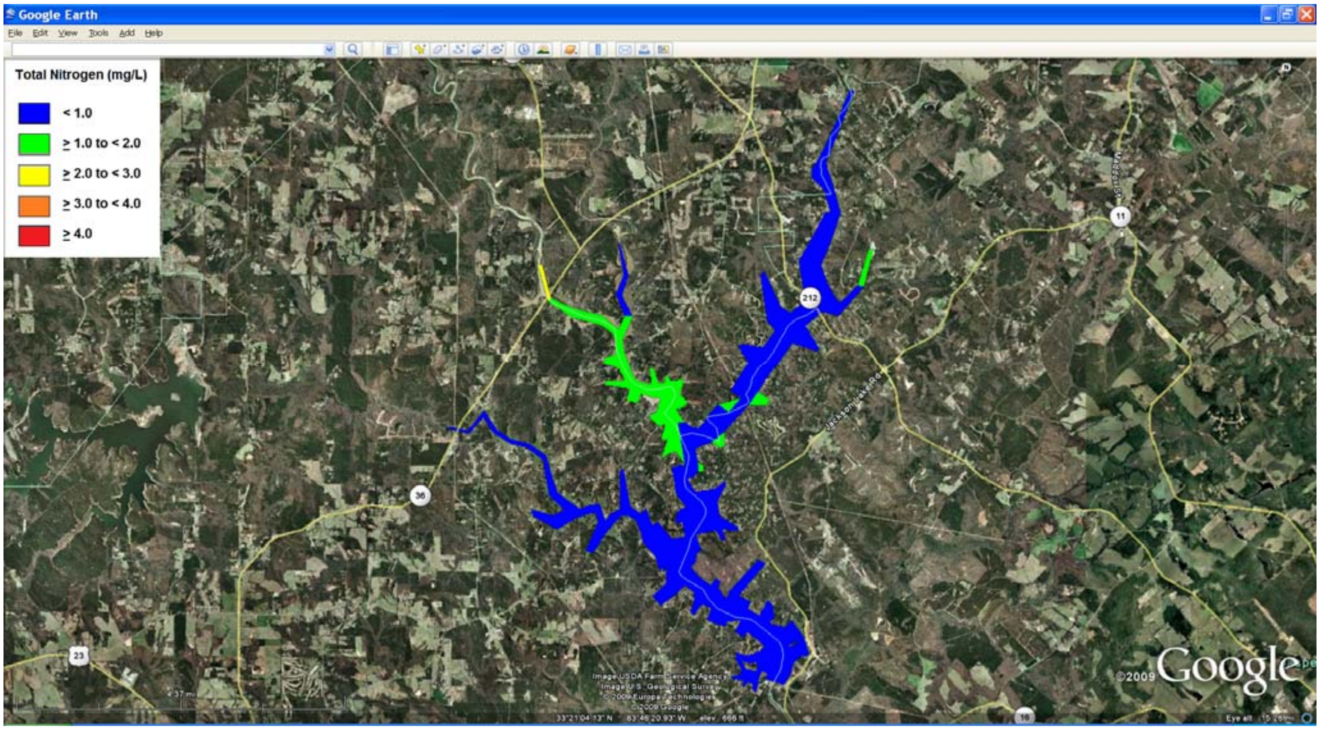

Figure C-94 Maximum Value of Total Nitrogen (mgN/L) in Lake Jackson in Photic Zone: year 2003

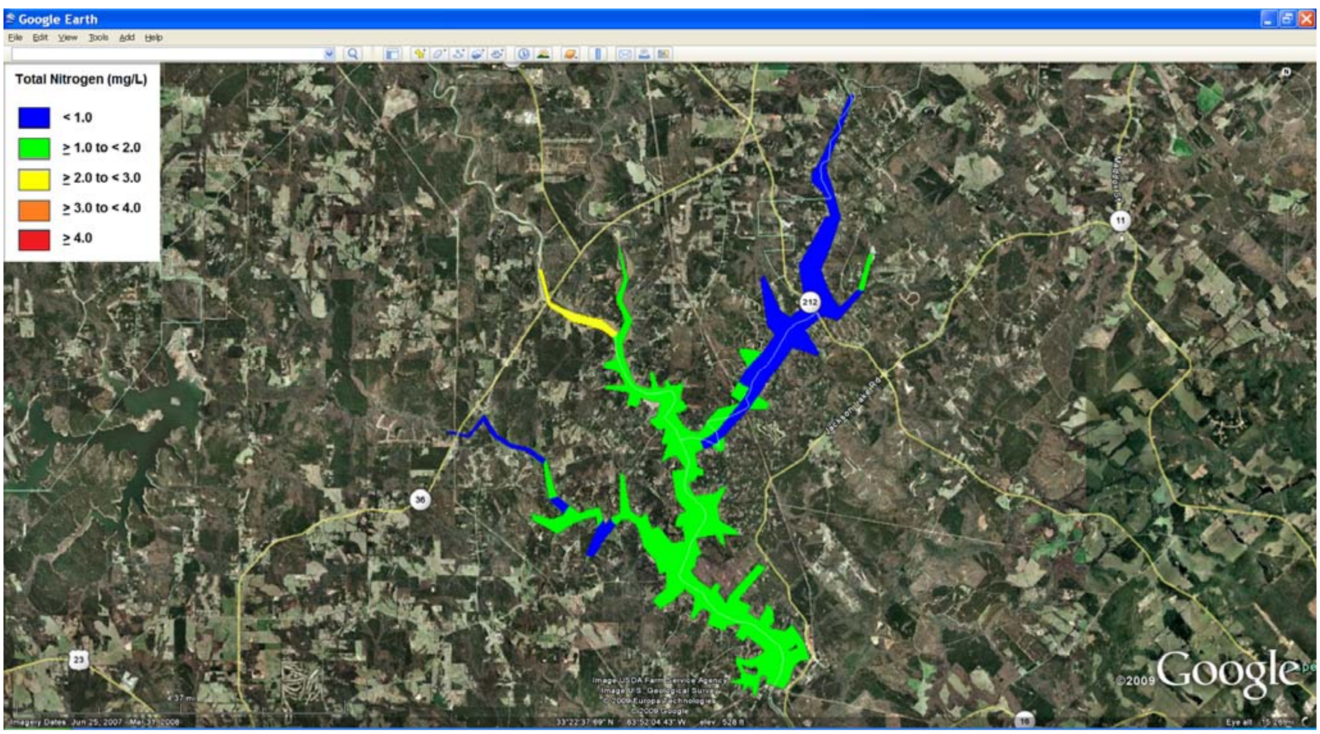

Figure C-95 Maximum Value of Total Nitrogen (mgN/L) in Lake Jackson in Photic Zone: year 2004

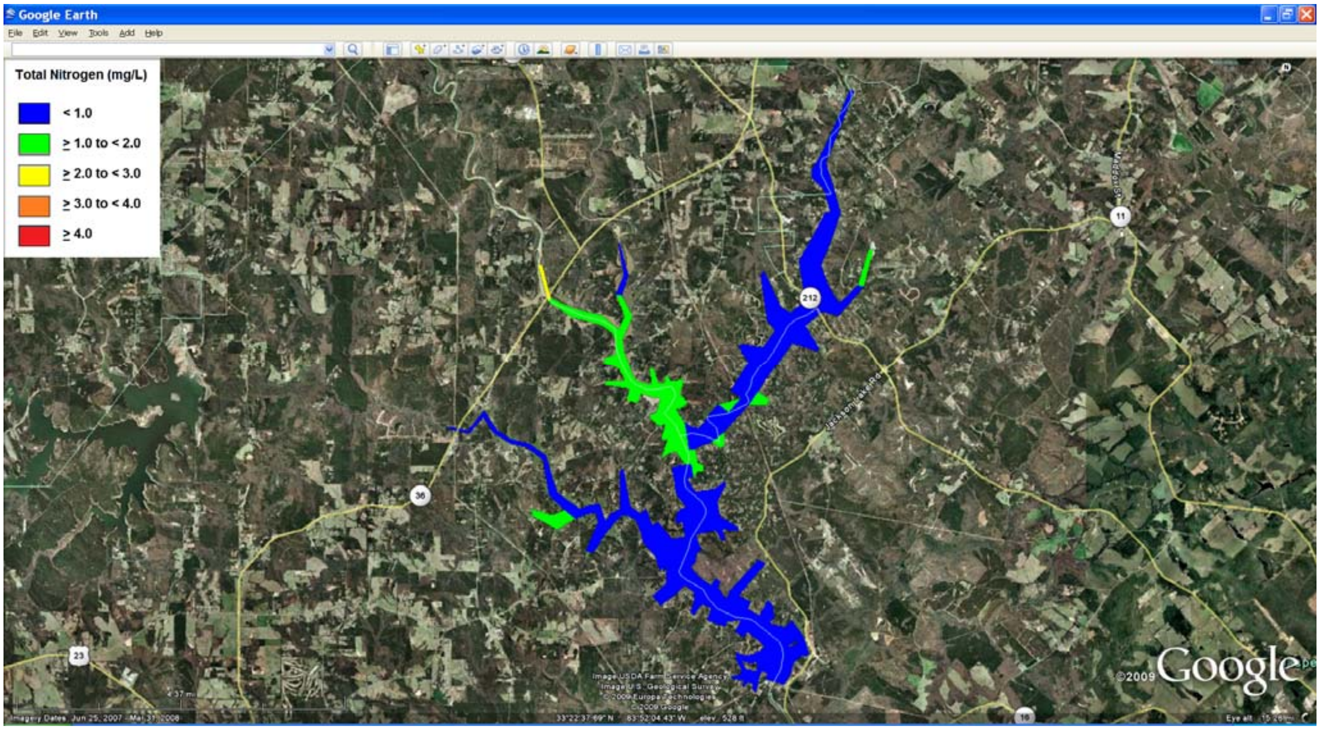

Figure C-96 Maximum Value of Total Nitrogen (mgN/L) in Lake Jackson in Photic Zone: year 2005

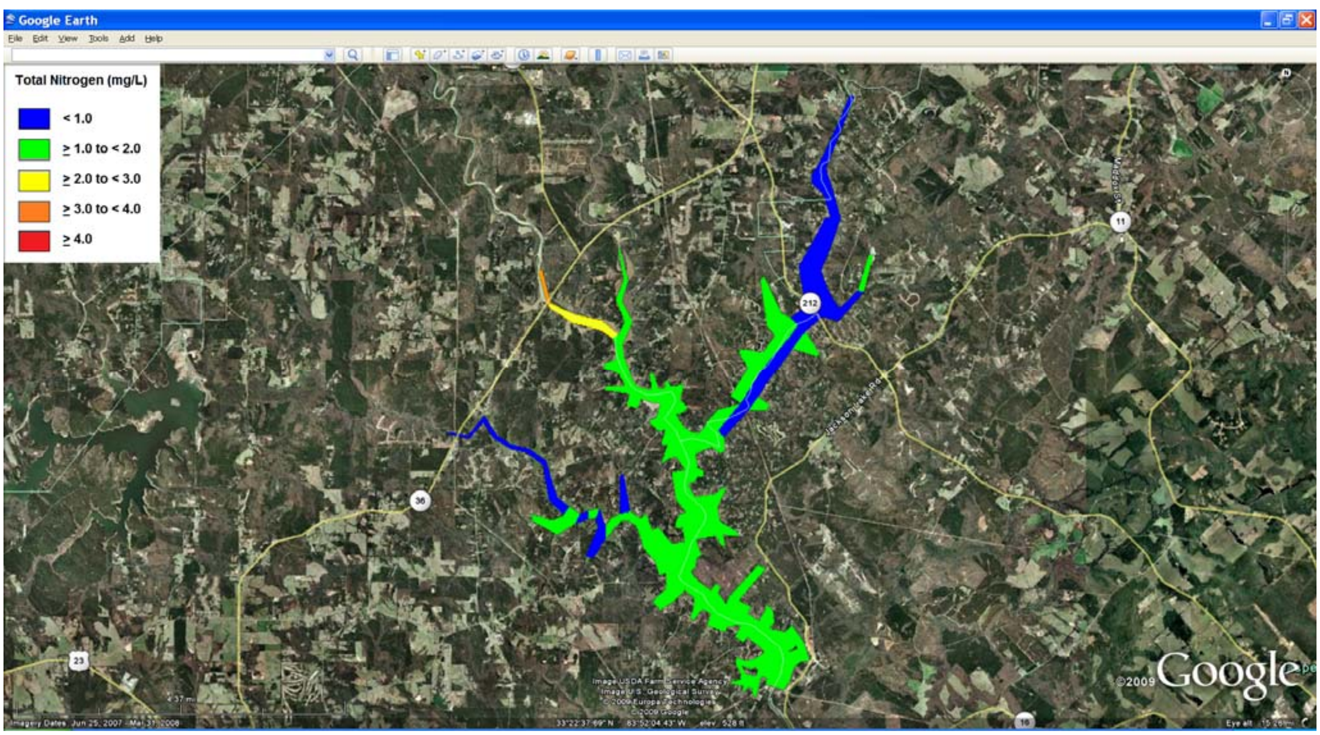

Figure C-97 Maximum Value of Total Nitrogen (mgN/L) in Lake Jackson in Photic Zone: year 2006

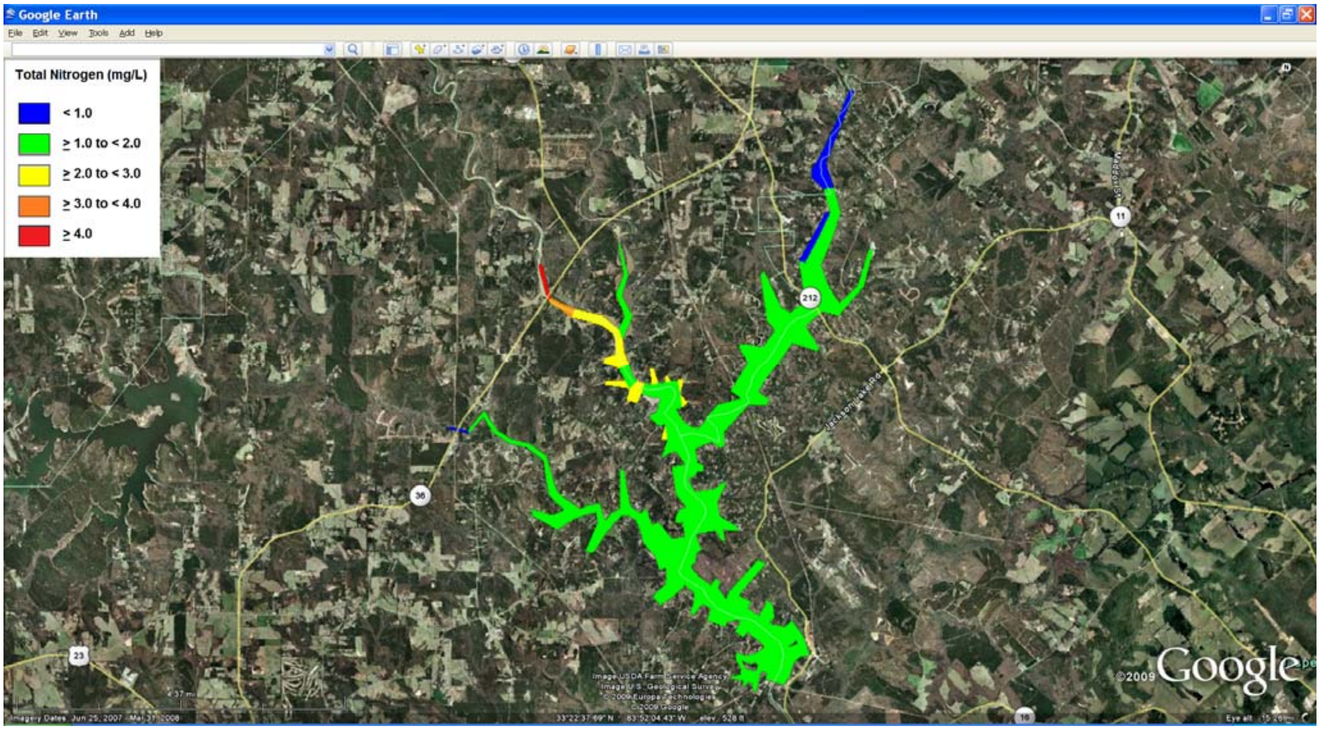

Figure C-98 Maximum Value of Total Nitrogen (mgN/L) in Lake Jackson in Photic Zone: year 2007

C.2.3 Lake Oconee Total Nitrogen

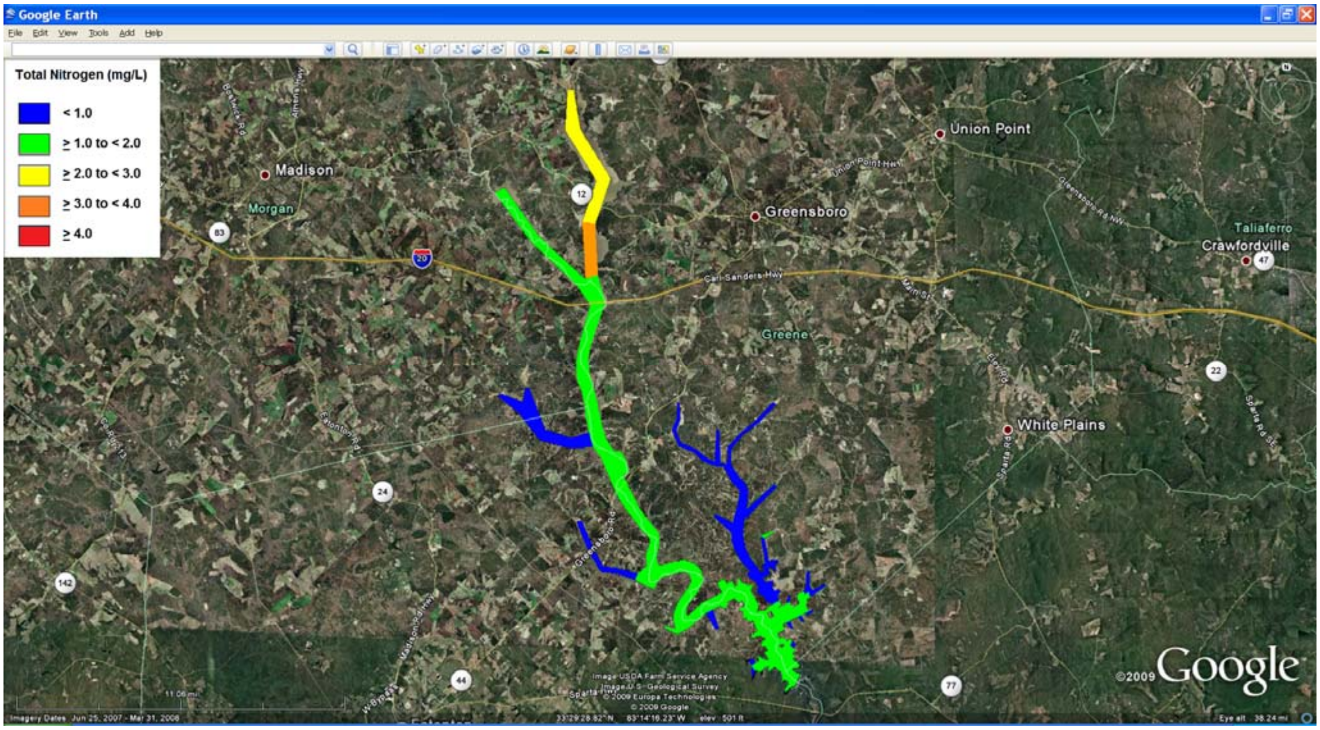

Figure C-99 Maximum Value of Total Nitrogen (mgN/L) in Lake Oconee in Photic Zone: year 2001

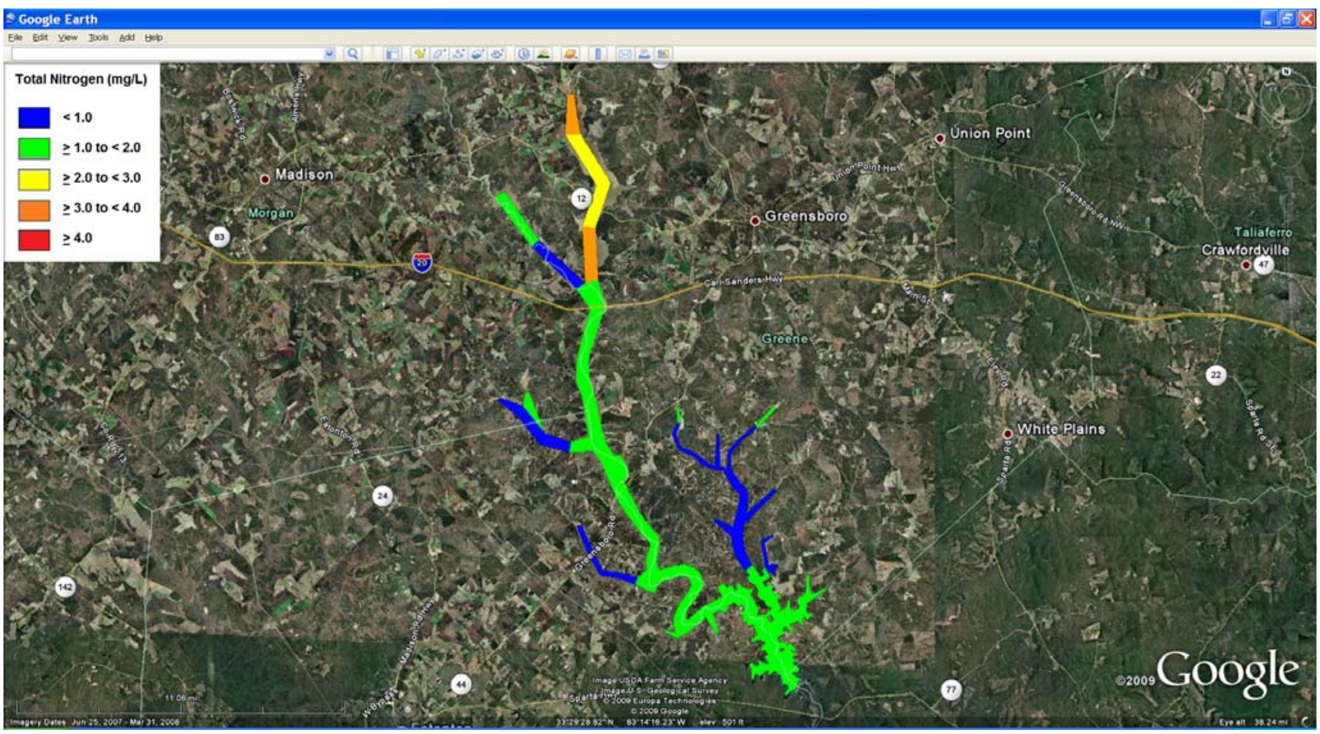

Figure C-100 Maximum Value of Total Nitrogen (mgN/L) in Lake Oconee in Photic Zone: year 2002

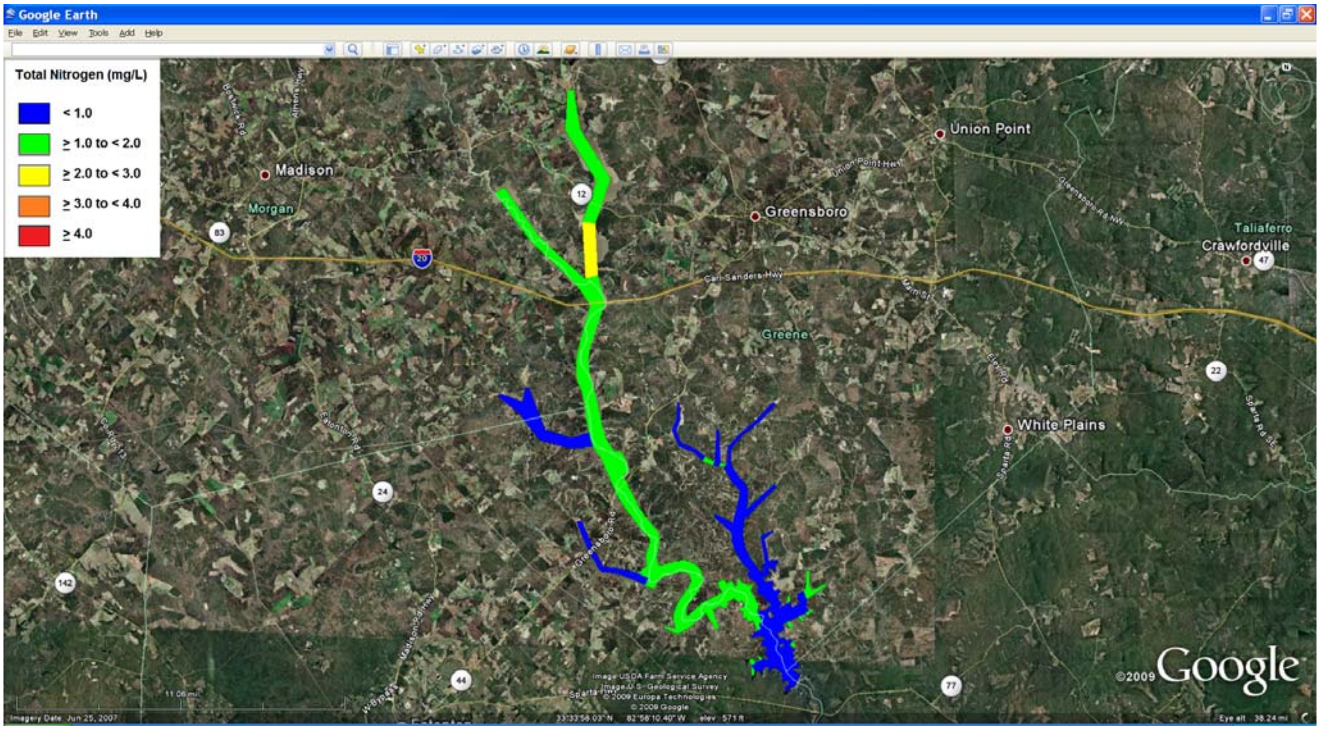

Figure C-101 Maximum Value of Total Nitrogen (mgN/L) in Lake Oconee in Photic Zone: year 2003

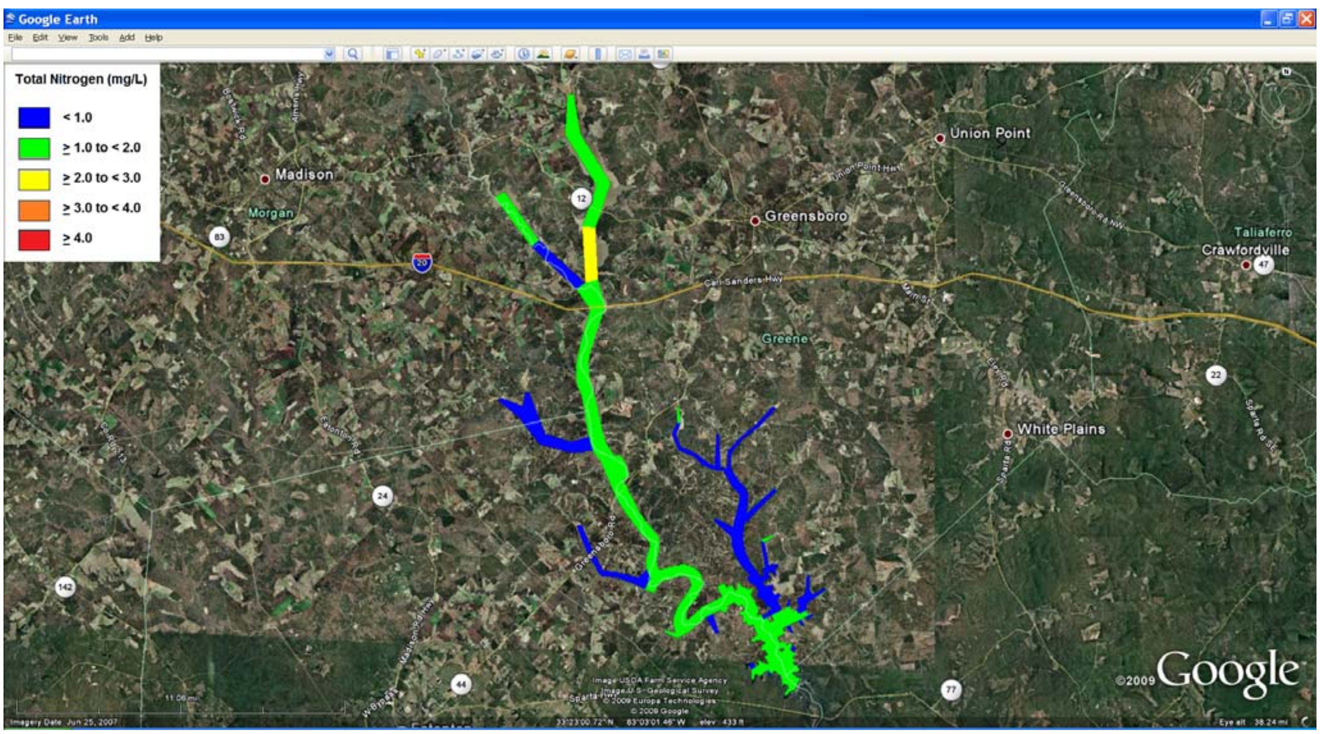

Figure C-102 Maximum Value of Total Nitrogen (mgN/L) in Lake Oconee in Photic Zone: year 2004

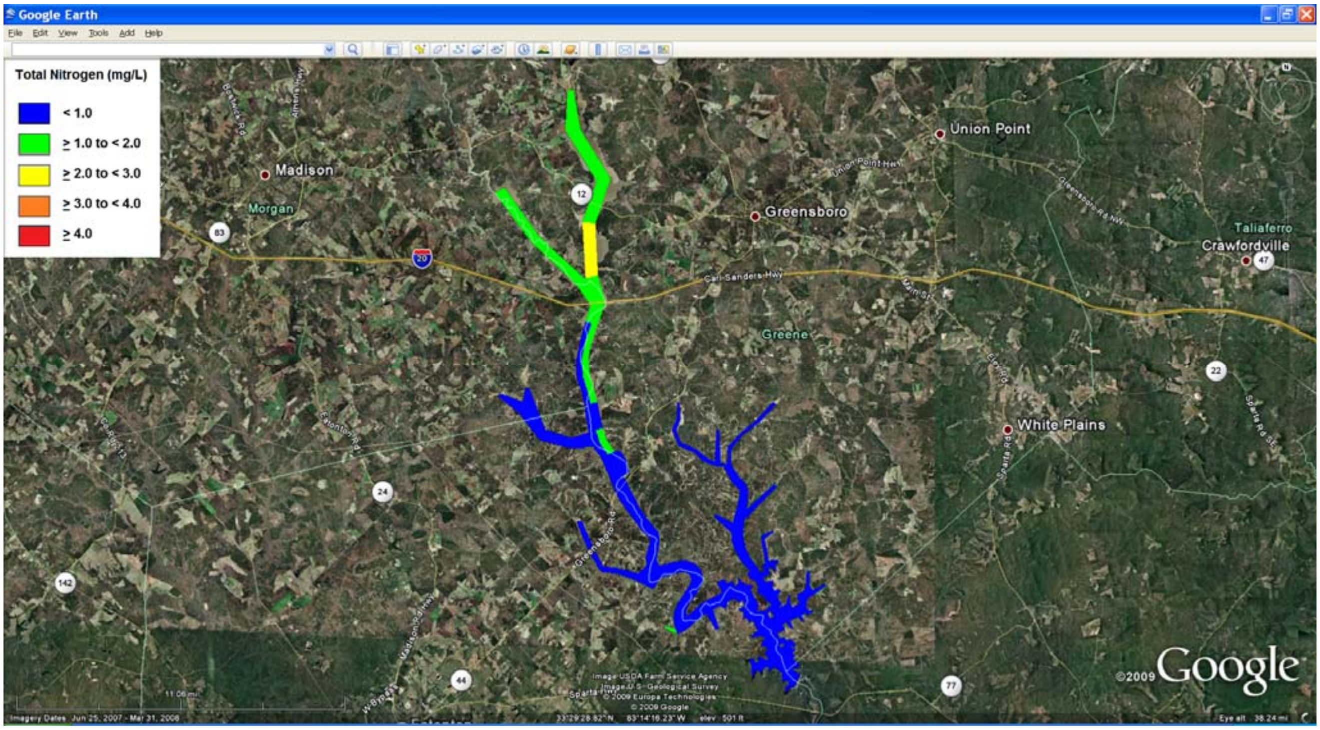

Figure C-103 Maximum Value of Total Nitrogen (mgN/L) in Lake Oconee in Photic Zone: year 2005

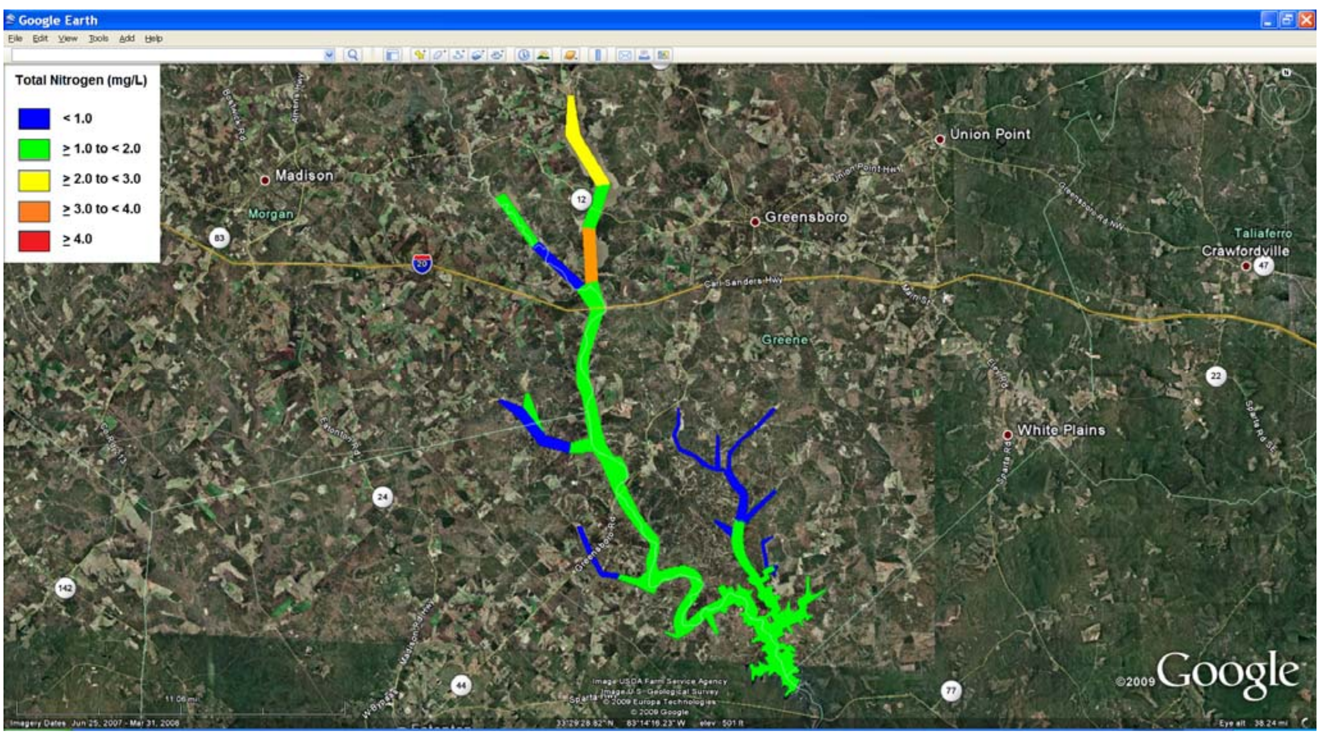

Figure C-104 Maximum Value of Total Nitrogen (mgN/L) in Lake Oconee in Photic Zone: year 2006

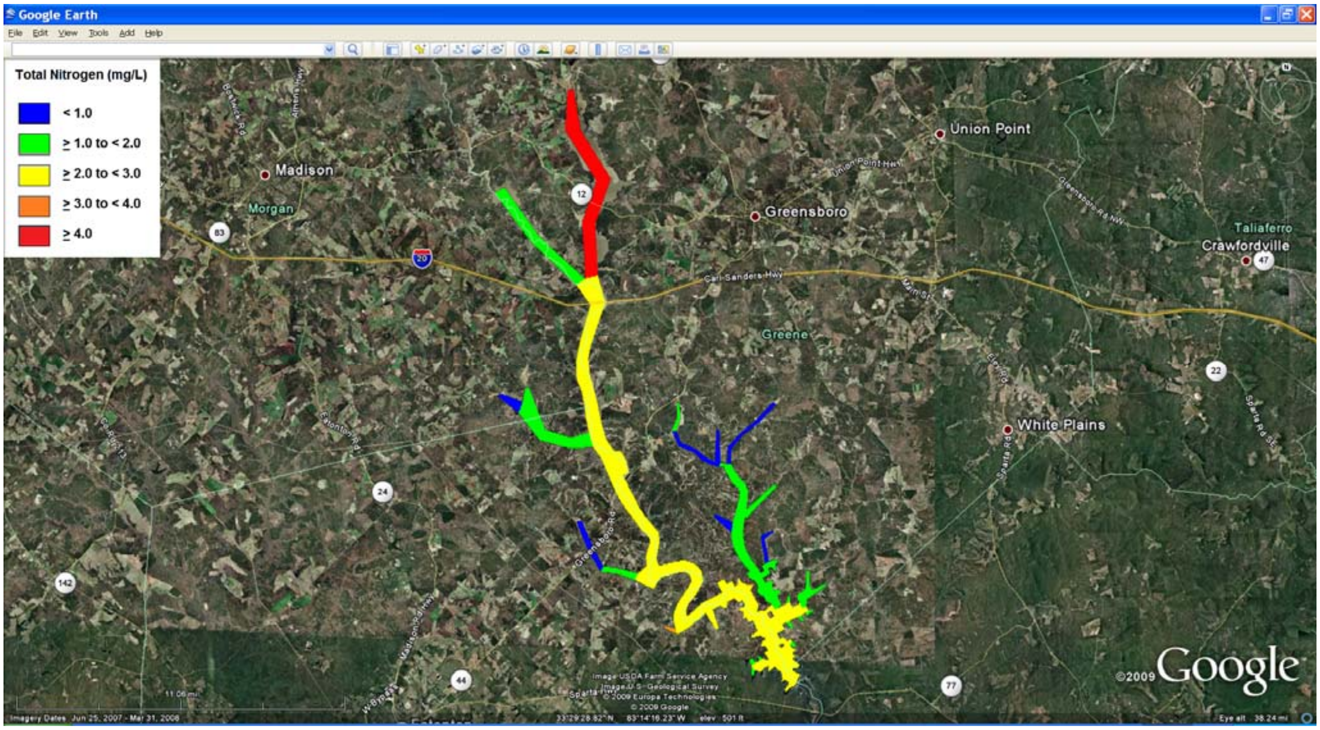

Figure C-105 Maximum Value of Total Nitrogen (mgN/L) in Lake Oconee in Photic Zone: year 2007

C.2.4 Lake Sinclair Total Nitrogen

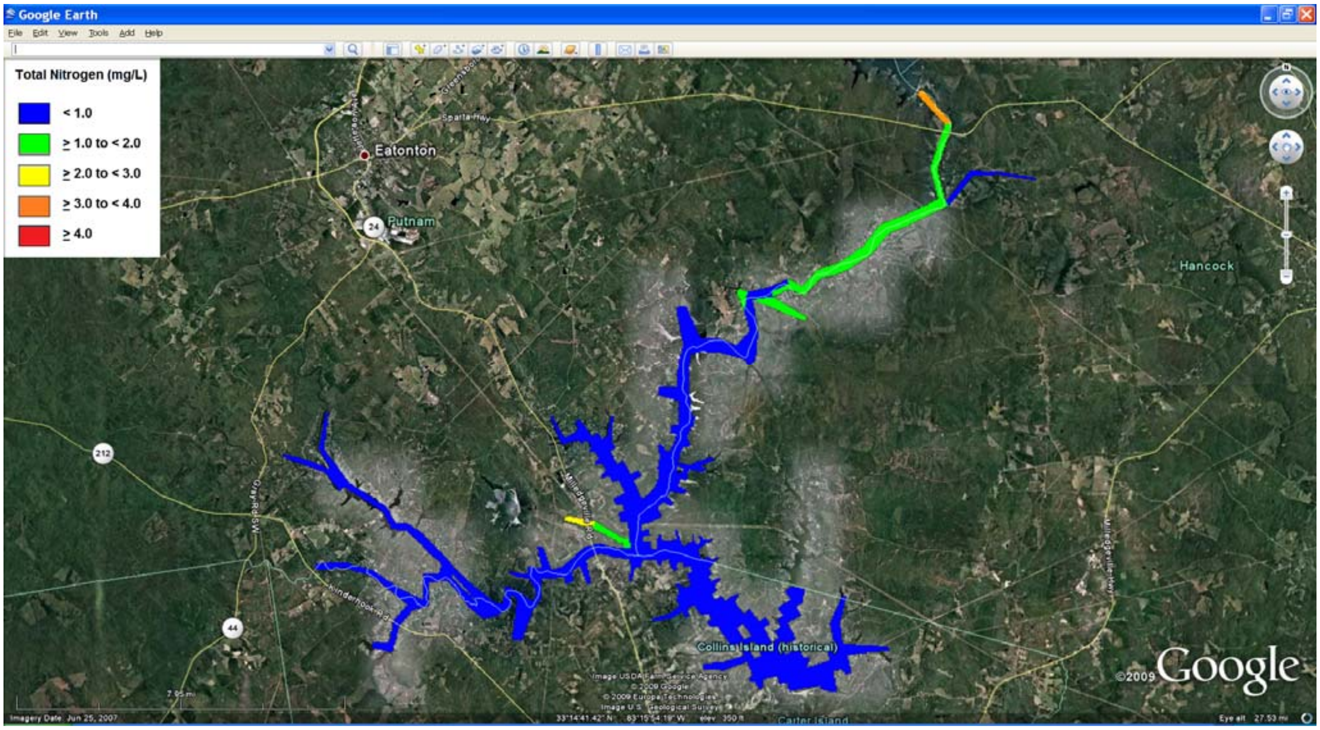

Figure C-106 Maximum Value of Total Nitrogen (mgN/L) in Lake Sinclair in Photic Zone: year 2001

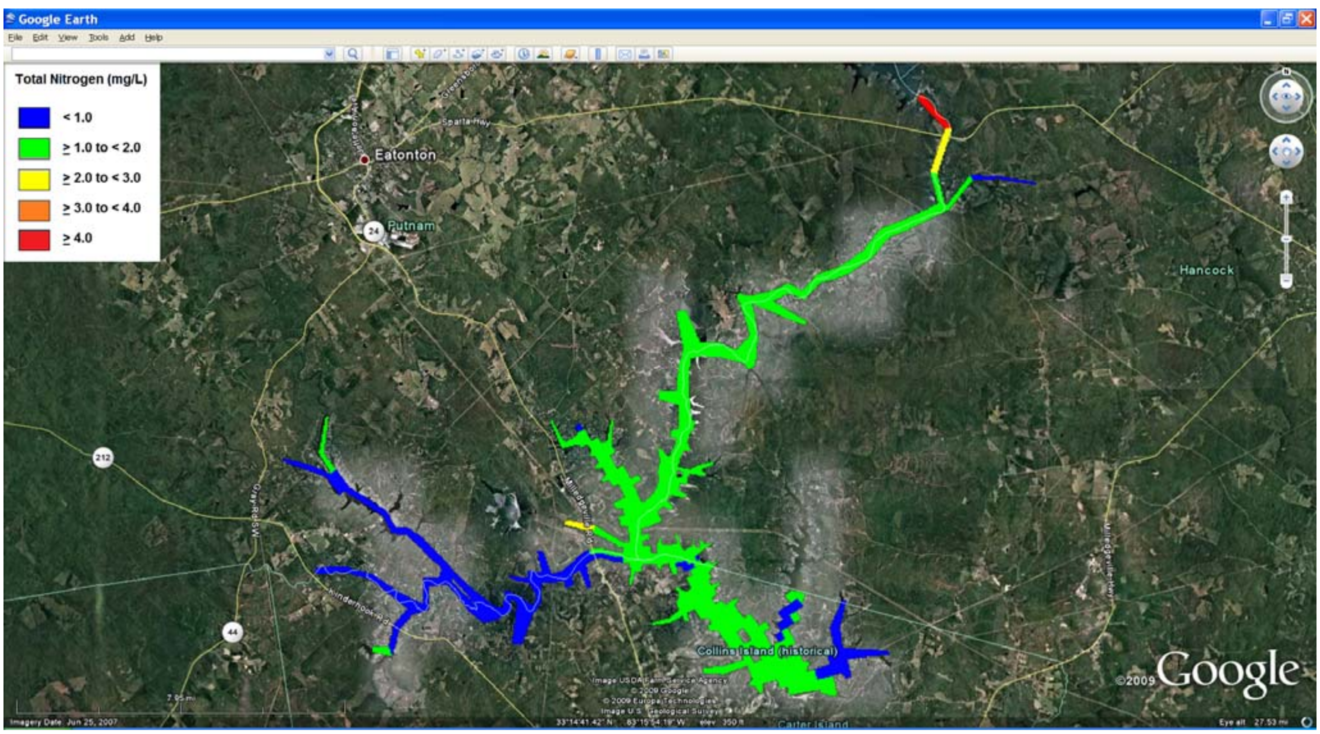

Figure C-107 Maximum Value of Total Nitrogen (mgN/L) in Lake Sinclair in Photic Zone: year 2002

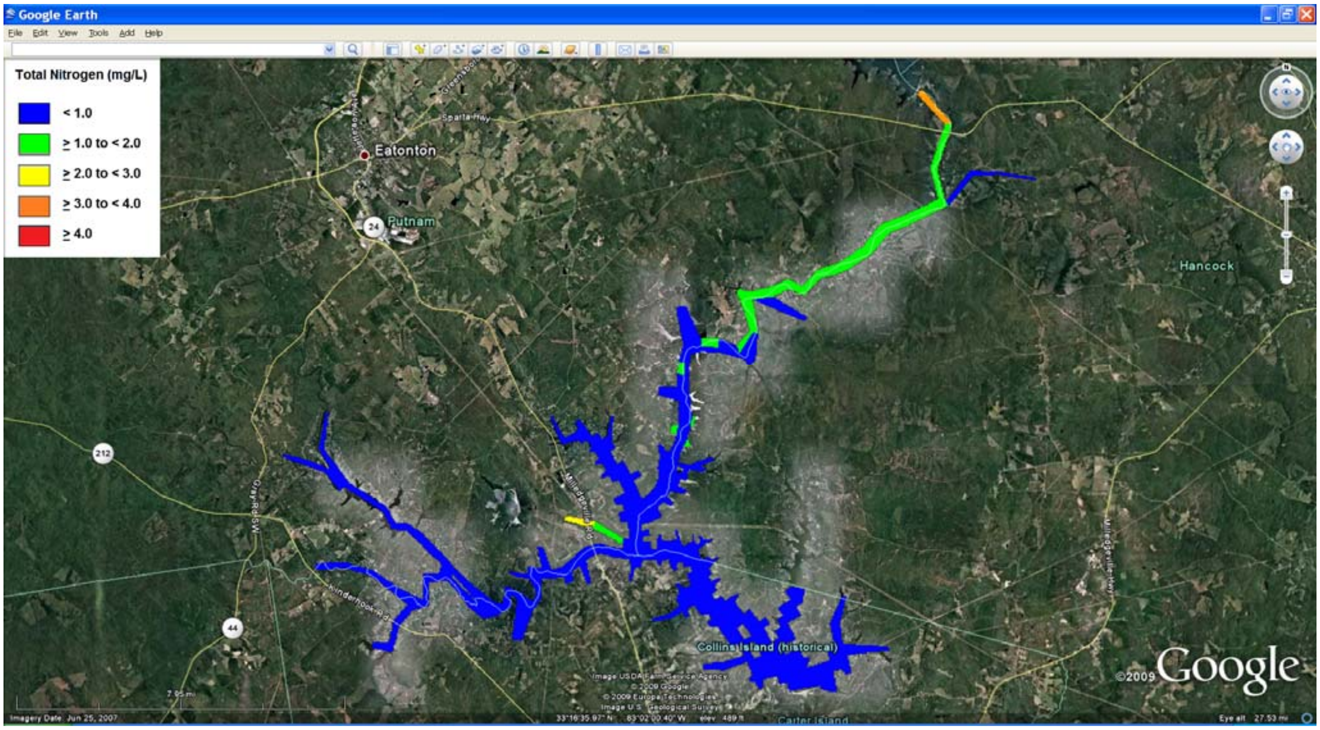

Figure C-108 Maximum Value of Total Nitrogen (mgN/L) in Lake Sinclair in Photic Zone: year 2003

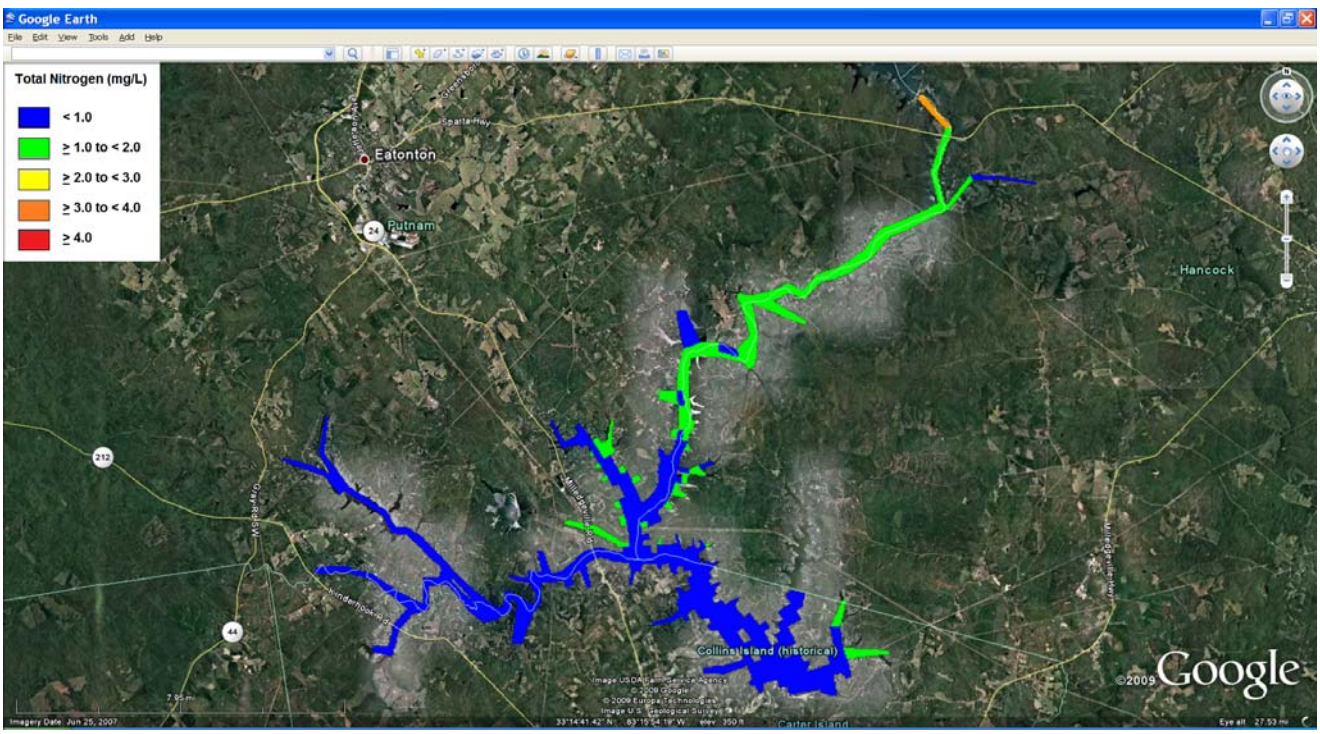

Figure C-109 Maximum Value of Total Nitrogen (mgN/L) in Lake Sinclair in Photic Zone: year 2004

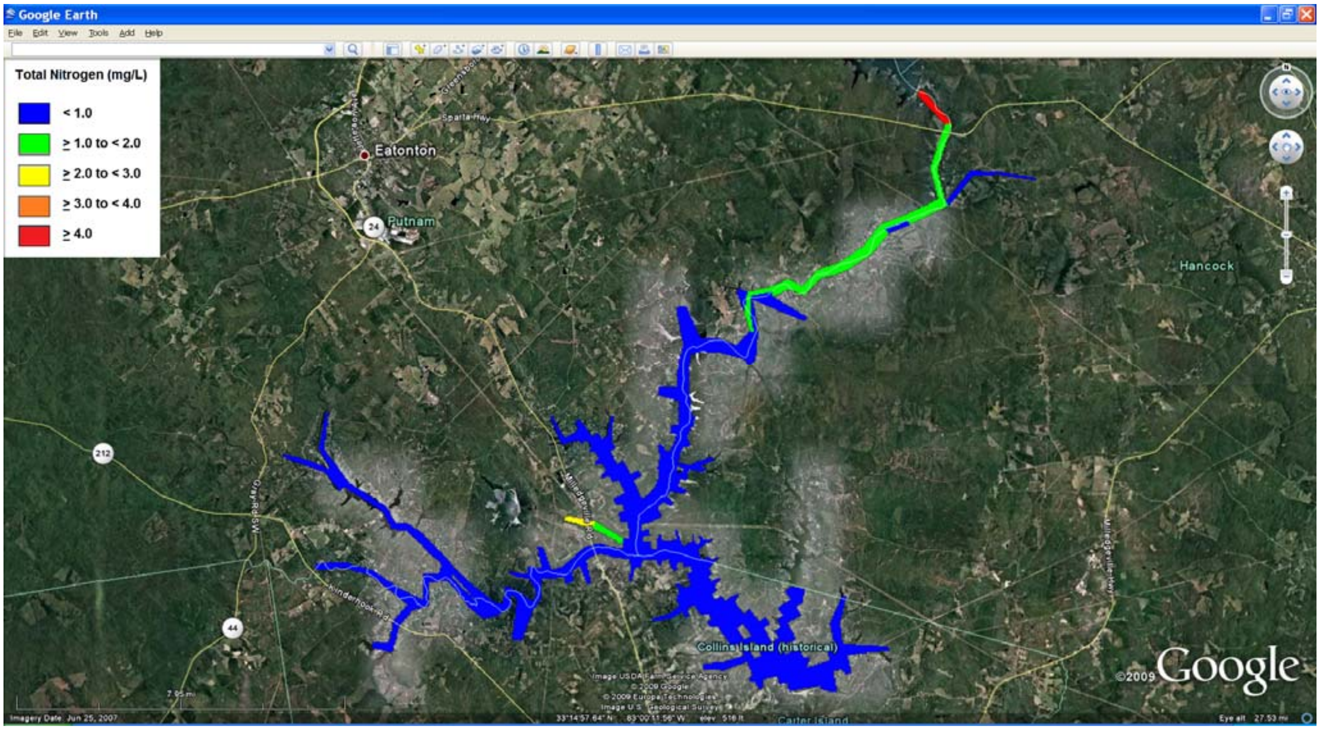

Figure C-110 Maximum Value of Total Nitrogen (mgN/L) in Lake Sinclair in Photic Zone: year 2005

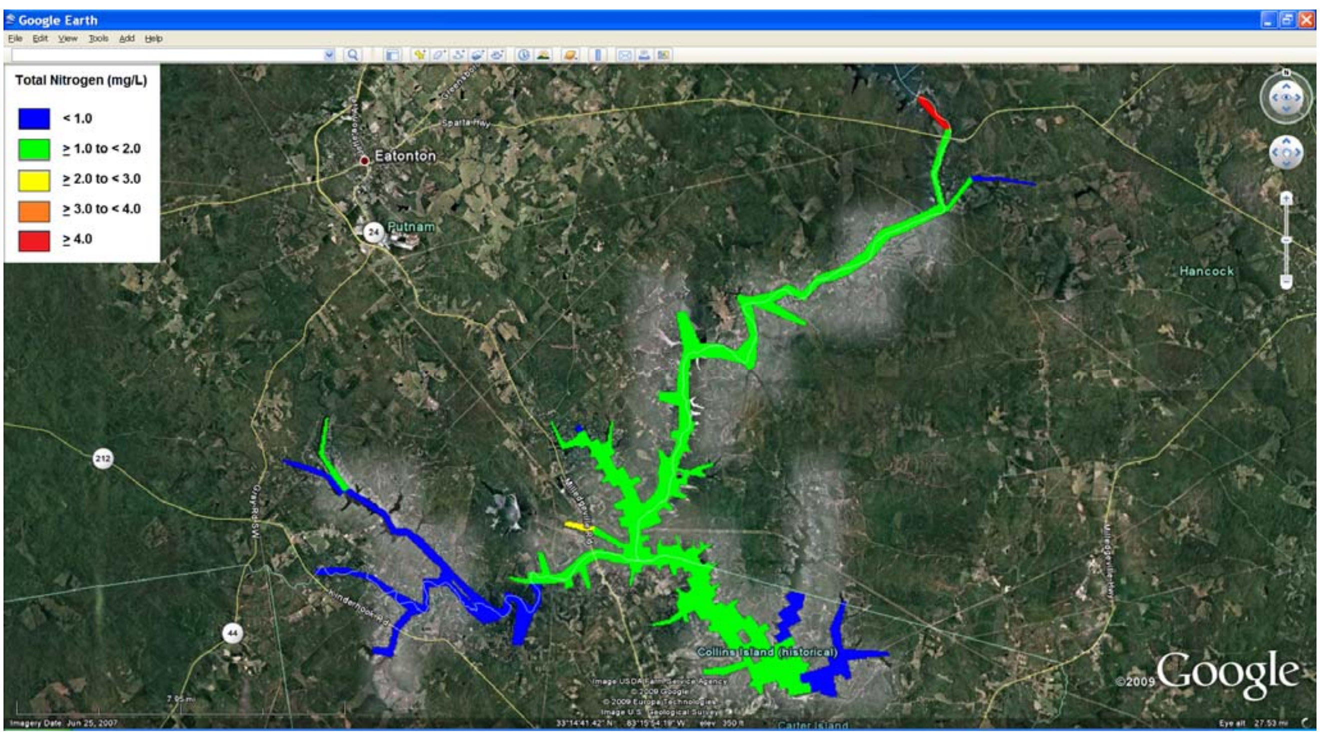

Figure C-111 Maximum Value of Total Nitrogen (mgN/L) in Lake Sinclair in Photic Zone: year 2006

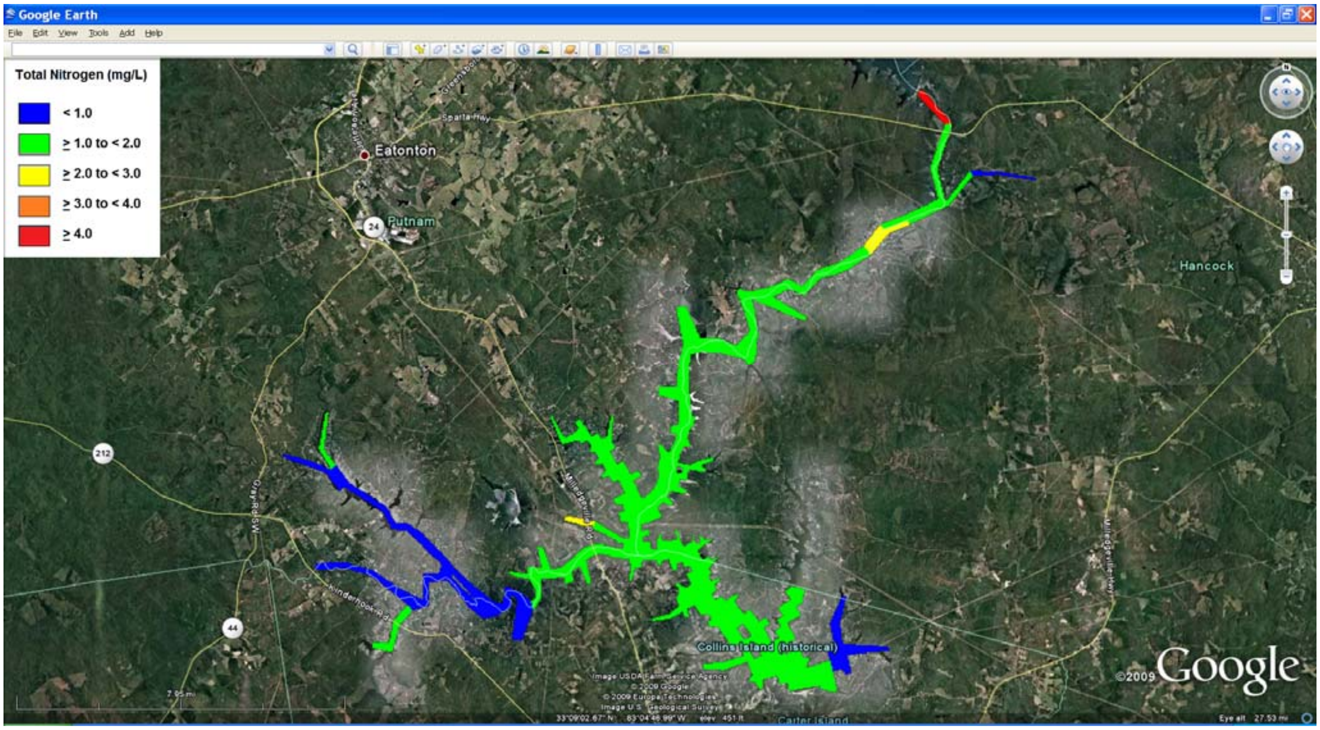

Figure C-112 Maximum Value of Total Nitrogen (mgN/L) in Lake Sinclair in Photic Zone: year 2007