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POLLUTANT LOAD REDUCTION GOALS FOR NEWNANS LAKE

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by

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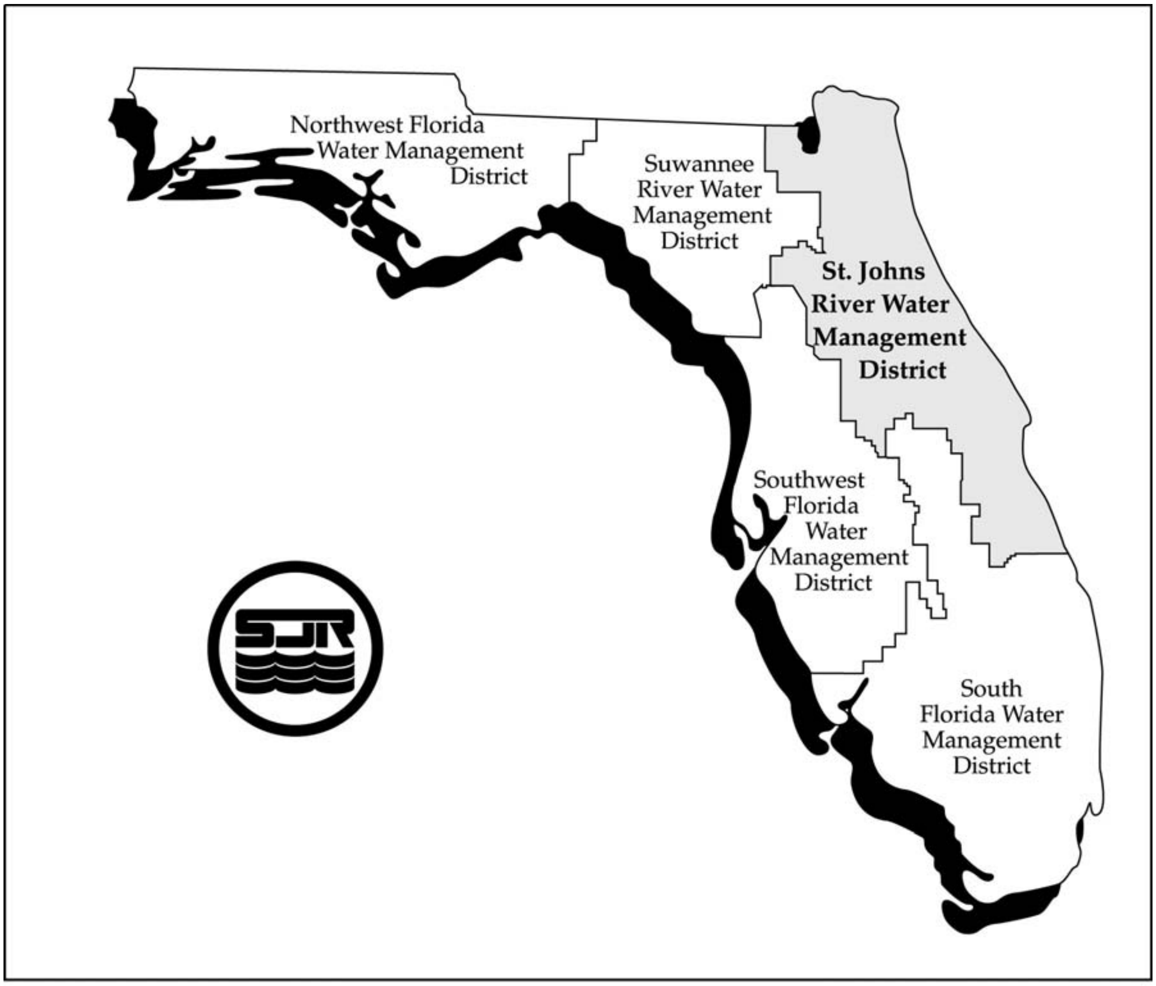

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EXECUTIVE SUMMARY

Newnans Lake covers about 6,600 acres in eastern Alachua County, Florida. Newnans Lake is a hypereutrophic lake because of its high total phosphorus and total nitrogen concentrations. Section 303(d) of the federal Clean Water Act (CWA) requires states to develop a list of surface waters that do not meet applicable water quality standards and to establish total maximum daily loads (TMDLs). Florida's Water Resource Implementation Rule (62-40, *Florida Administrative Code* [*F.A.C.*]), requires water management districts to develop schedules for setting pollutant load reduction goals (PLRGs) for all surface water bodies that receive storm water. The rule also requires that water management districts assist the Florida Department of Environmental Protection (FDEP) in the development of TMDLs.

Four essential steps are required for PLRG development. The first step is to determine the restoration target concentrations for the pollutants of concern—in this case, total nitrogen (TN) and total phosphorus (TP). The second step is to estimate the current loading rates to the lake from all the different sources. The third step is to determine the allowable pollutant load to reach the desired target concentration. The fourth and final step is to determine the necessary load reductions, the PLRGs, necessary to reach the restoration target concentrations.

To determine the appropriate restoration target concentrations of TN and TP for Newnans Lake, we used the following four general approaches:

1. Lake data analysis approach, including water quality, sediment, and plankton data
2. Watershed load modeling approach
3. Reference lake approach
4. Literature values approach

The restoration target concentrations vary among the approaches. The target TN concentrations for Newnans Lake range from 929 to 1,511 micrograms per liter (µg/L); and for TP, the range is 40 to 73 µg/L. Considering the uncertainties within each of the approaches, the 68 µg/L TP restoration target set in the Newnans Lake TMDL by FDEP (Gao and Gilbert 2003) appears to be reasonable and is, therefore, endorsed by the water management district. For TN, the large potential for nitrogen fixation within the water column by cyanobacteria suggests a target based on chlorophyll-a is most appropriate. Therefore, a TN concentration target of 1,294 µg/L, which correlates with a chlorophyll-a concentration of 40 µg/L, is recommended.

The TN and TP loading sources to Newnans Lake include surface runoff from nine land use categories in the watershed as well as from base flow, a permitted point source, atmospheric deposition, and nitrogen fixation (N-fixation). The current mean annual loading rates from all sources were estimated to be 12,859 kilograms/year (kg/yr) for TP and 236,702 kg/yr for TN.

The allowable TN and TP loads were estimated by adjusting the input loads in a calibrated BATHTUB Model (Walker 1999) for Newnans Lake until the target TN and TP concentrations were met. The model estimates that a total annual TN load of 80,706 kg/yr would allow the lake to reach the TN concentration target of 1,294 µg/L. The current annual average TN load from the watershed is 118,144 kg/yr. In addition to the watershed load, an estimated 118,558 kg is contributed each year by N-fixation by cyanobacteria in the lake, resulting in a total load of 236,702 kg/yr. Therefore, it will require 155,996 kg/yr nitrogen load reduction, or 66% of the current mean annual loading, to reach the target TN concentration (Table ES1). The watershed TN reduction needed to reach the TN target concentration if the N-fixation was eliminated as an input source was estimated. This would be accomplished by reducing the TP concentration in the lake to decrease total phytoplankton productivity and biomass and to facilitate a shift in the species composition from N-fixing cyanobacterial taxa to other non-fixing taxa. The watershed TN reduction needed to reach the concentration target without N-fixation as an input source is 37,438 kg/yr, or 32% of the current mean annual loading from the watershed.

Table ES1. Nitrogen and phosphorus loads and PLRGs

	Mean Annual Loading Rate (kg/yr)	Target Loading Rate (kg/yr)	Reduction Needed (kg/yr)	Percent Reduction Needed
TP	12,859	6,703	6,156	48%
TN	236,702	80,706	155,996	66%
TN (without N-fixation)	118,144	80,706	37,438	32%

TP = total phosphorus
TN = total nitrogen
PLRG = pollutant load reduction goal
kg/yr = kilograms per year

The model estimates that an annual TP load of 6,703 kg would allow the lake to reach the TP concentration target of 68 µg/L. The current, annual total TP load is 12,859 kg; therefore, a reduction of 6,156 kg/yr, or 48%, will be required for achieving the restoration target (Table ES1).

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INTRODUCTION

Newnans Lake covers about 6,600 acres in eastern Alachua County, Florida. It is currently a hypereutrophic lake because of high total phosphorus (TP) and total nitrogen (TN) concentrations (average TP and TN concentrations are 186 and 4,236 micrograms per liter (µg/L), respectively, during the period 1995–2005). Newnans Lake is listed as an impaired water body based on the "Identification of Impaired Surface Waters Rule" (IWR, Chapter 62-303, *Florida Administrative Code* [*F.A.C.*]). Section 303(d) of the federal Clean Water Act (CWA) requires states to develop a list of surface waters that do not meet applicable water quality standards and to establish total maximum daily loads (TMDLs) for impaired surface water bodies. The "Water Resource Implementation Rule" (Chapter 62-40, *F.A.C.*) requires water management districts to develop schedules for setting pollutant load reduction goals (PLRGs) for all surface water bodies that receive storm water. The rule also requires that water management districts assist the Florida Department of Environmental Protection (FDEP) in the development of TMDLs. According to the Florida Watershed Restoration Act (Chapter 99-223), TMDLs may be based on PLRGs developed by a water management district.

PLRGs are defined in statute as estimated numeric reductions in pollutant loading needed to preserve or restore designated uses of receiving water bodies and maintain water quality consistent with applicable state water quality standards.

There are five general tasks in the PLRG development process:

- Identify the pollutant(s) responsible for impairment.
- Determine the desired pollutant concentration target for restoration.
- Estimate the current pollutant load.
- Determine the allowable pollutant load to achieve the target concentration.
- Determine the necessary load reductions necessary to reach target concentration.

DESCRIPTION OF THE WATERSHED

The Newnans Lake watershed covers 73,000 acres in eastern Alachua County, Florida (Figure 1.1). Major land uses in the basin are forest, wetland, and urban groups, which represent 57%, 22%, and 10% of the overall landscape, respectively. Miocene-aged sediments belonging to the Hawthorn Formation cover about 30% of this basin (Brook 1982). The Hawthorn Formation consists primarily of sands, silts, clays, or combinations of these and is composed of phosphatic, kaolinitic, and/or siliceous materials. More recent phosphatic sands belonging to the Bone Valley Formation (Pliocene-Pleistocene Age) cover 70% of the Newnans Lake watershed.

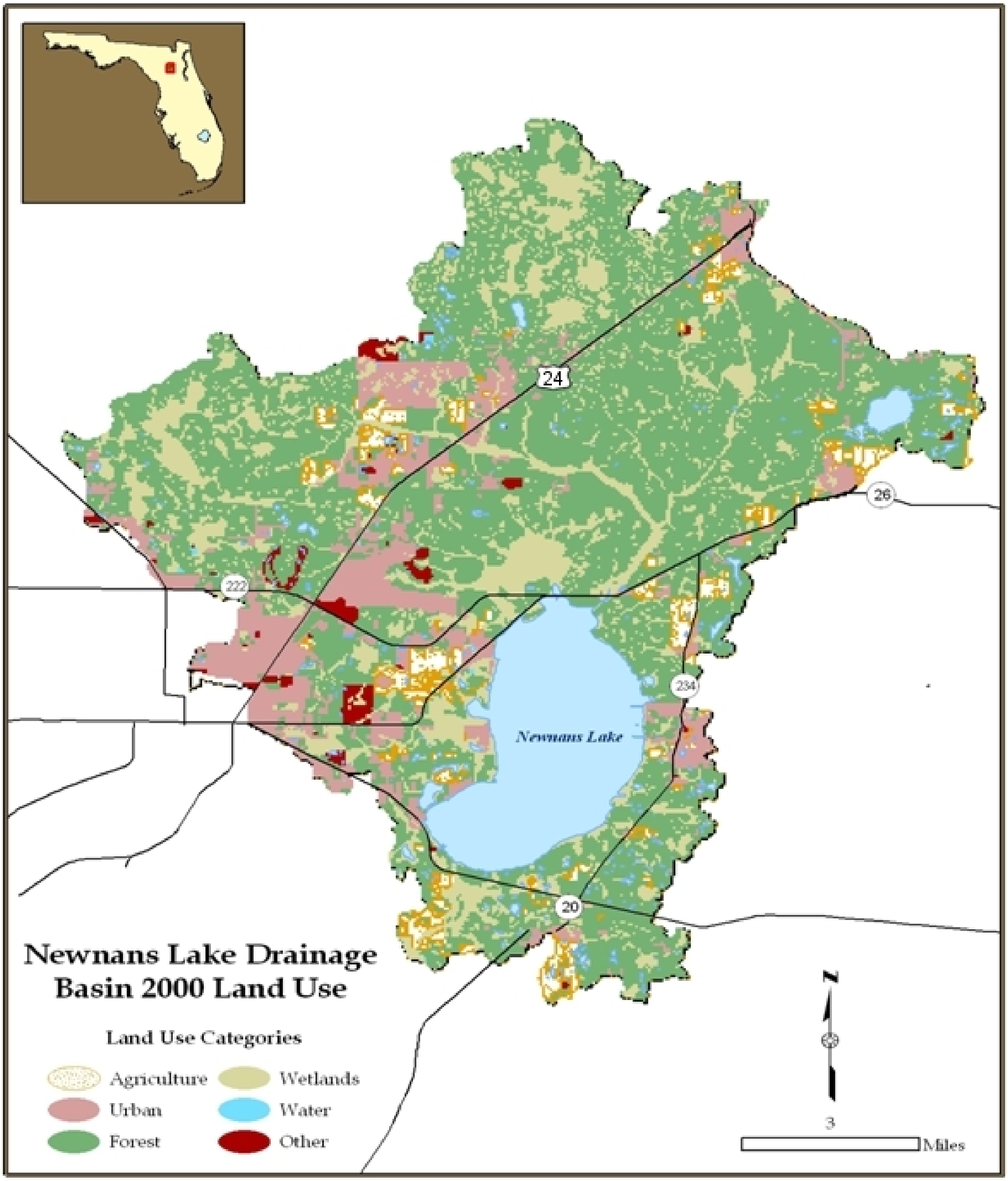

Figure 1.1. Newnans Lake location and watershed land uses

Five subbasins (Hatchet Creek, Little Hatchet Creek, Little Hatchet Creek East, Lake Forest Creek, and the shoreline drainage area) discharge water into Newnans Lake (Figure 1.2). Hatchet Creek is the major inflow to Newnans Lake. Little Hatchet Creek and Lake Forest Creek are two other inflows into Newnans Lake. Prairie Creek at the south end of the lake is the only surface water outlet for the lake, with a 30-year (1978–2008) average discharge rate at 58 cubic feet per second (cfs).

A weir was constructed at the Prairie Creek outlet in 1966 to reduce the natural, seasonal water level fluctuations of the lake. The elevation of the weir crest was at 66.7 ft above mean sea level (NGVD 1929). In 1976, the weir was modified by the addition of removable flashboards to provide the option to manage lake level fluctuations. This modification included a cut in the existing structure approximately 70 ft wide and 6.8 ft deep, with slotted columns and flashboards for control options. However, during most of the structure's history, the flashboards were kept in place to maintain high water levels. In 1991, the flashboards were permanently removed from the weir to allow natural lake level fluctuations. In 1999, the entire weir was removed by the Florida Department of Transportation (FDOT) as part of the replacement of the State Road (SR) 20 bridge over Prairie Creek.

DESCRIPTION OF THE LAKE

Newnans Lake has a surface area of 6,600 acres at an average stage of 66.5 ft (NGVD) and is a shallow basin lake that is typical in Florida. Table 1.1 summarizes some general features of the lake. More detailed information on the bathymetry and sediment characteristics of the lake are available in a report prepared by Environmental Consulting and Technology Inc., for the St. Johns River Water Management District (ECT 2002).

Table 1.1. General hydrological features of Newnans Lake

Surface Area (acres)	Volume (ac-ft)	Average Stage (ft NGVD)	Average Depth (ft)	Residence Time (year)	Drainage to Lake Area Ratio
6,600	29,000	66.5	4.4	0.69	11

ac-ft = acre-feet
ft NGVD = feet National Geodetic Vertical Datum

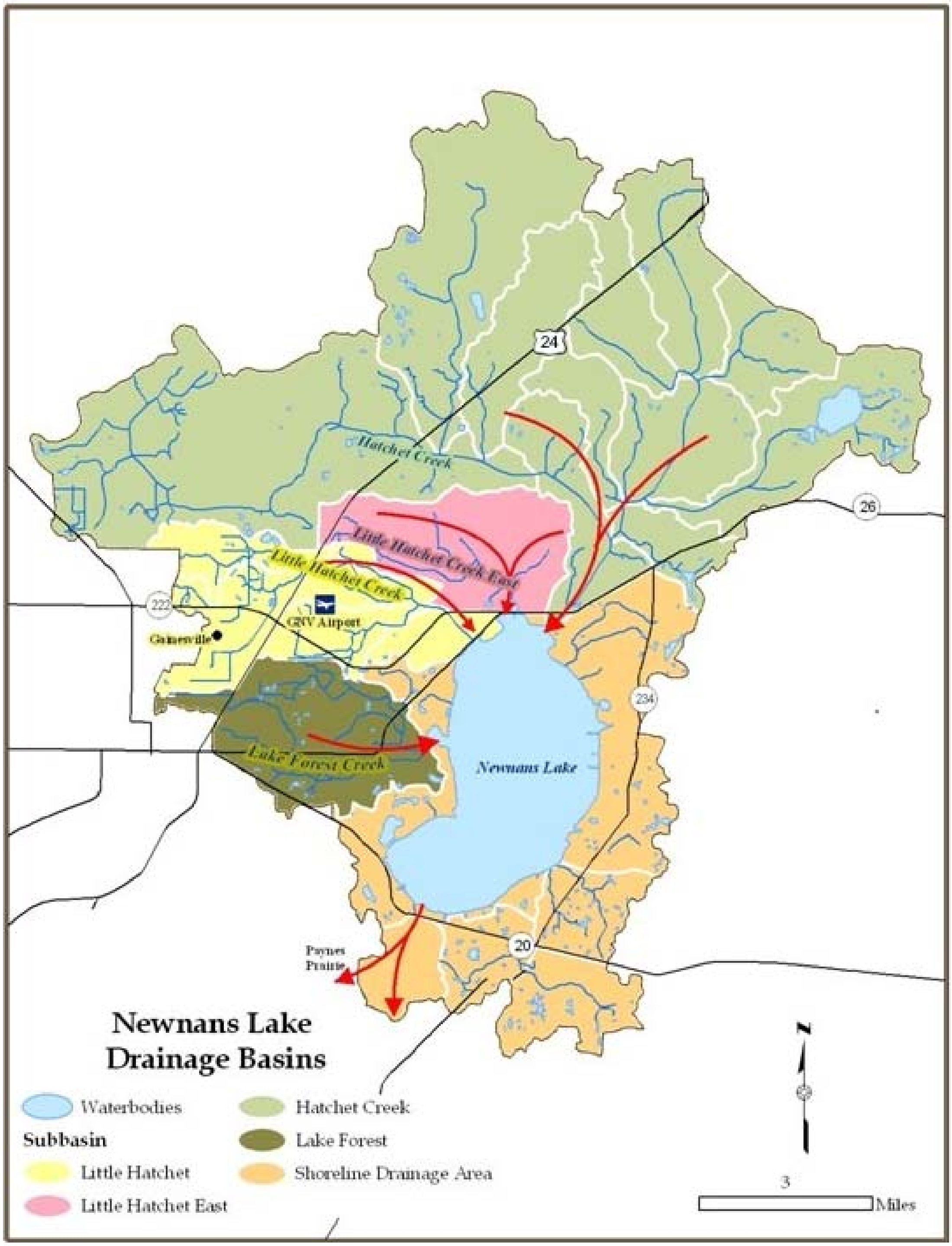

Figure 1.2. Newnans Lake watershed subbasins and its major inflows and outflow

IDENTIFICATION OF POLLUTANTS CAUSING IMPAIRMENT

Water quality in this lake has been deteriorating since at least the 1960s, when the collection of water quality data began. Total nitrogen (TN) and total phosphorus (TP) concentrations have increased by more than two and three times since the late 1960s, respectively (Figures 2.1 and 2.2). During the same period, the chlorophyll-a concentration has increased by about six times (Figure 2.3), and there is now a persistent algal bloom on the lake. Both TN and TP concentrations in the water column are significantly correlated to the chlorophyll-a concentration. To reduce algal abundance and increase water clarity, both TP and TN concentrations in the lake need to be reduced. Therefore, TN and TP concentration targets need to be established.

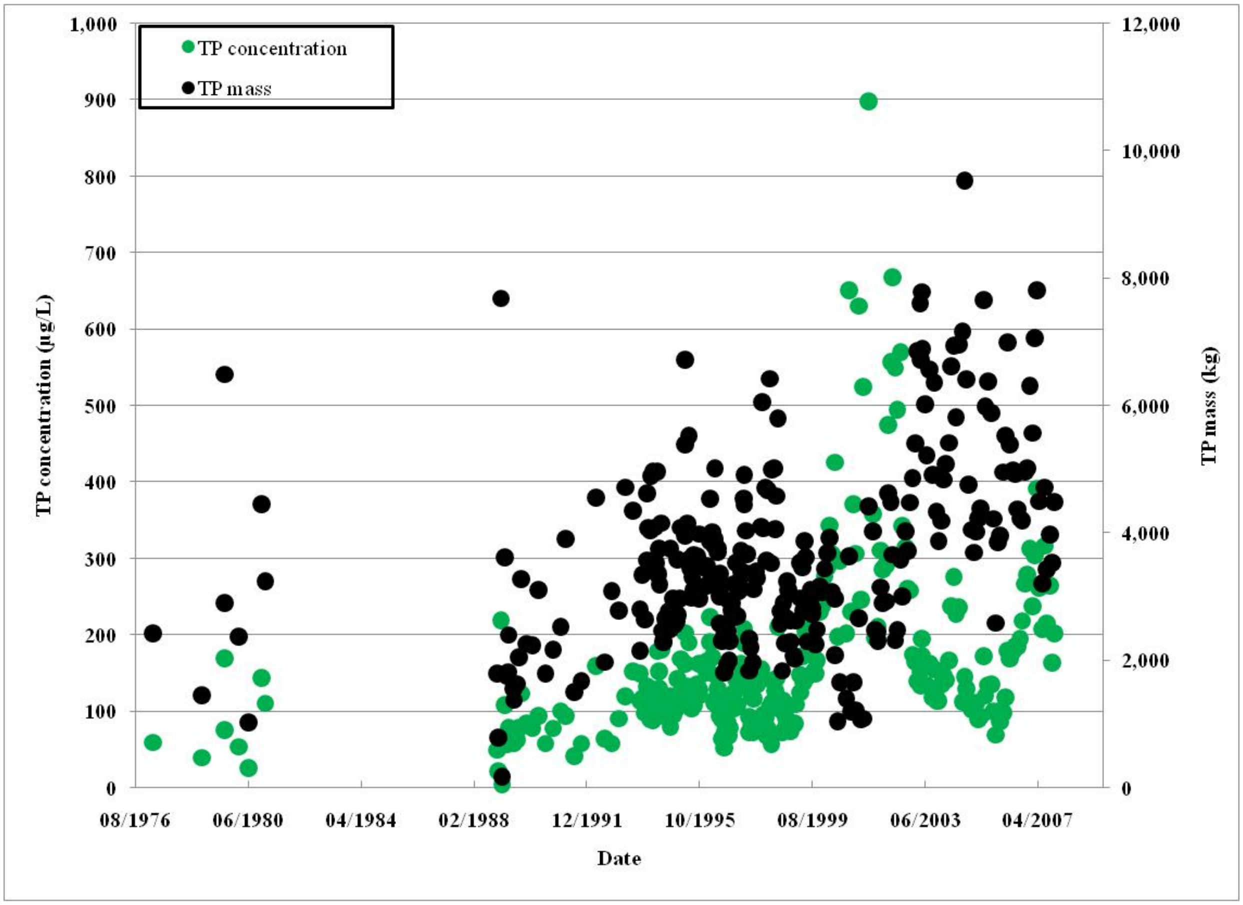

Figure 2.1. Monthly average total phosphorus (TP) concentrations and masses in Newnans Lake, 1967–2007

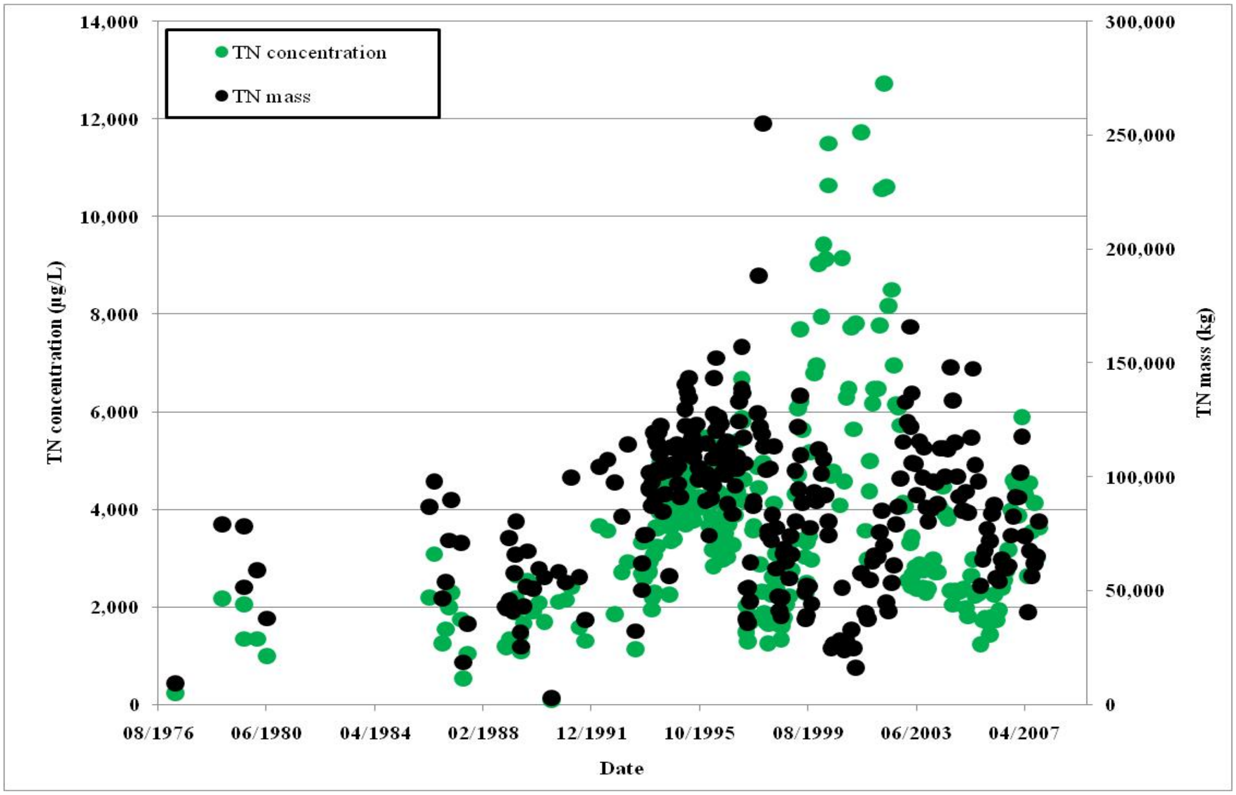

Figure 2.2. Monthly average total nitrogen (TN) concentrations and masses in Newnans Lake, 1967–2007

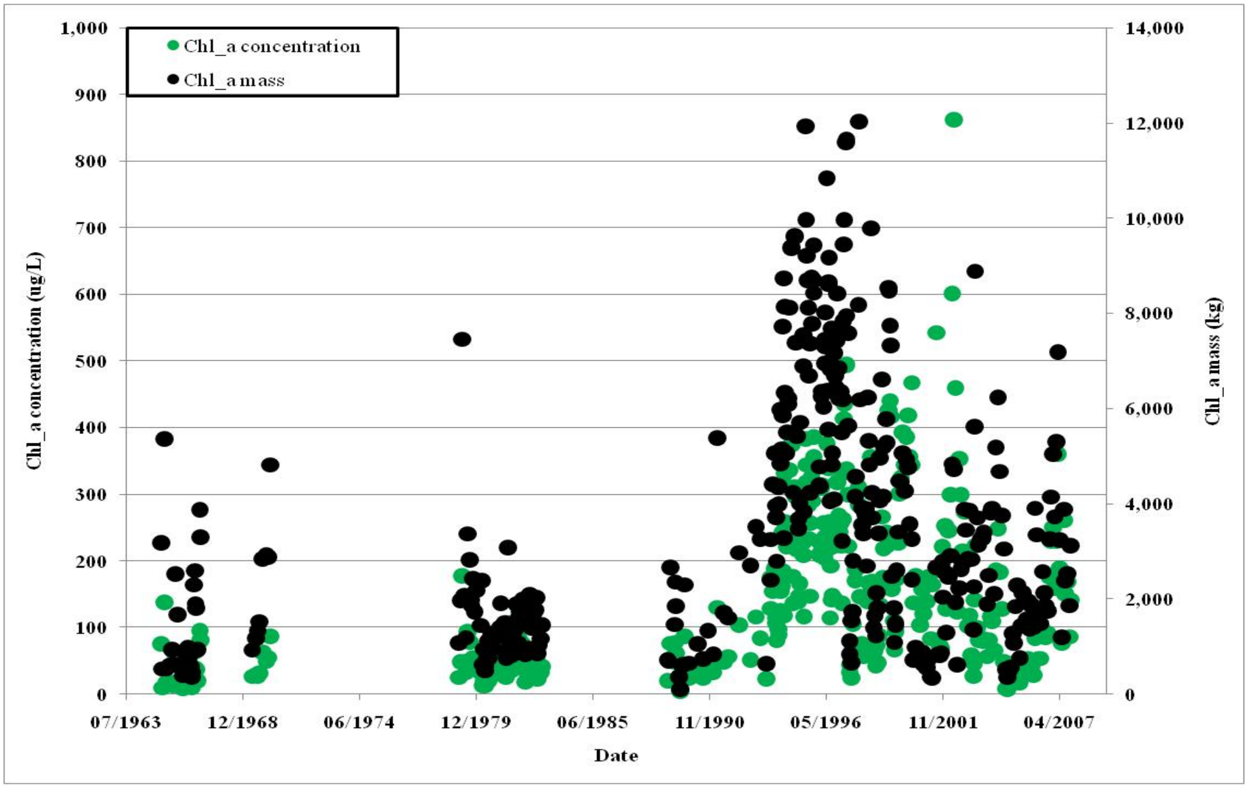

Figure 2.3. Monthly average chlorophyll-a concentrations and masses in Newnans Lake, 1965–2007

RESTORATION CONCENTRATION TARGET DETERMINATION

The overall strategy for setting water-quality restoration targets for total nitrogen (TN) and total phosphorus (TP) was to develop an array of justifiable targets, using multiple and scientifically sound methods based upon available data for Newnans Lake. The following four approaches were used to establish separate TN and TP concentration targets:

- Lake data analysis approach, which includes water quality, sediment, and plankton data
- Reference lake approach
- Literature values approach
- Watershed load modeling approach

LAKE DATA ANALYSIS APPROACH

Three types of data (phytoplankton data, water quality data, and sediment data) were used to develop nutrient concentration targets. The data used were collected from the 1960s through 2007. The analysis methods and results for each data type are described below.

Phytoplankton Data Approach

Cyanobacteria, also called blue-green algae, often dominate the phytoplankton assemblage in eutrophic, shallow, warm, slow-moving, or still waters. The effects on a lake ecosystem due to cyanobacterial blooms include lower-quality food sources for zooplankton, input of nitrogen fixed from the atmosphere, surface scum formation, lower diurnal dissolved oxygen concentrations, and occasionally the production of toxins. Although many other physical or biochemical factors such as temperature, color, and pH can affect cyanobacteria production, nutrient concentrations in the water column are one of the major factors regulating biomass production in many Florida lakes. Walker and Havens (1995) reported that cyanobacteria bloom frequency increases as TP concentrations increased in Lake Okeechobee.
The potential for sudden increases in cyanobacteria biomass production increases as the TP concentration exceeds 90 µg/L in many Upper St. Johns River Basin lakes (Keenan et al. 2002).

Phosphorus is an essential nutrient necessary for the growth of phytoplankton as well as macrophytes in lakes. Chlorophyll-a is the primary photosynthetic pigment present in all algae and cyanobacteria. Despite the fact that the chlorophyll molecule contains no phosphorus, the relationships between chlorophyll-a and TP have dominated the empirical linkages of nutrients and the biological response of the algae in lakes (Nurnberg 1996). Strong relationships between chlorophyll-a and TP have been observed and reported in both freshwater lakes and coastal waters in Florida (Canfield and Bachmann 1981, Havens et al. 1999, and Hoyer et al. 2001).

Nitrogen is another essential nutrient for algal growth. Walker and Havens (1995) reported that nitrogen concentration is also a key factor affecting algal biomass production. They found that at a given phosphorus concentration, algal bloom frequency increases at higher nitrogen concentrations and TN/TP ratio conditions. The water quality data analysis approach is based on the strong correlation between chlorophyll-a and TP and TN in many lake systems.

Newnans Lake's phytoplankton community has been dominated by cyanobacteria since at least the early 1990s (Di et al. 2006). The phytoplankton-data approach is based on the correlation between cyanobacteria biomass and TN and TP concentrations. Monthly water quality and cyanobacteria biovolume data from 1995 to 2001 were analyzed. The relationship between both nutrient (TN, TP) concentrations and cyanobacteria biovolume was examined by scatterplots (Figures 3.1 and 3.2). Total cyanobacteria biovolume is positively correlated to both TN and TP concentrations, but no clear threshold for both TN and TP concentrations is evident above which there is a sudden increase in cyanobacteria biovolume. This may be the result of insufficient data at low nutrient concentrations. Due to the lack of a threshold in nutrient concentrations above which cyanobacteria biovolume increases nonlinearly, no restoration target is determined.

Water-Quality Data Analysis Approach

Two steps were used to determine the TN and TP concentration targets via the water-quality data analysis approach. First, two statistical regression models based on the TN and TP data against chlorophyll-a were created. Mean monthly TN, TP, and chlorophyll-a data were used to build these regression models. The data were collected between 1966 and 2007. Prior to 1994, the data were collected by several agencies on an irregular basis. Since 1994, the St. Johns River Water Management District (SJRWMD) has regularly collected water quality samples. Data were eliminated with monthly average chlorophyll-a concentration greater than 100 µg/L, to focus on the relationships at lower chlorophyll-a concentration, when nutrients are most likely to be limiting algal biomass.

The following regression models were formulated:

$$\text{Chlorophyll-a} = 25.957 + 0.2463\ \text{TP}\ (R^2 = 0.20,\ p < 0.0001)$$
$$\text{Chlorophyll-a} = 16.841 + 0.0179\ \text{TN}\ (R^2 = 0.20,\ p < 0.0001)$$

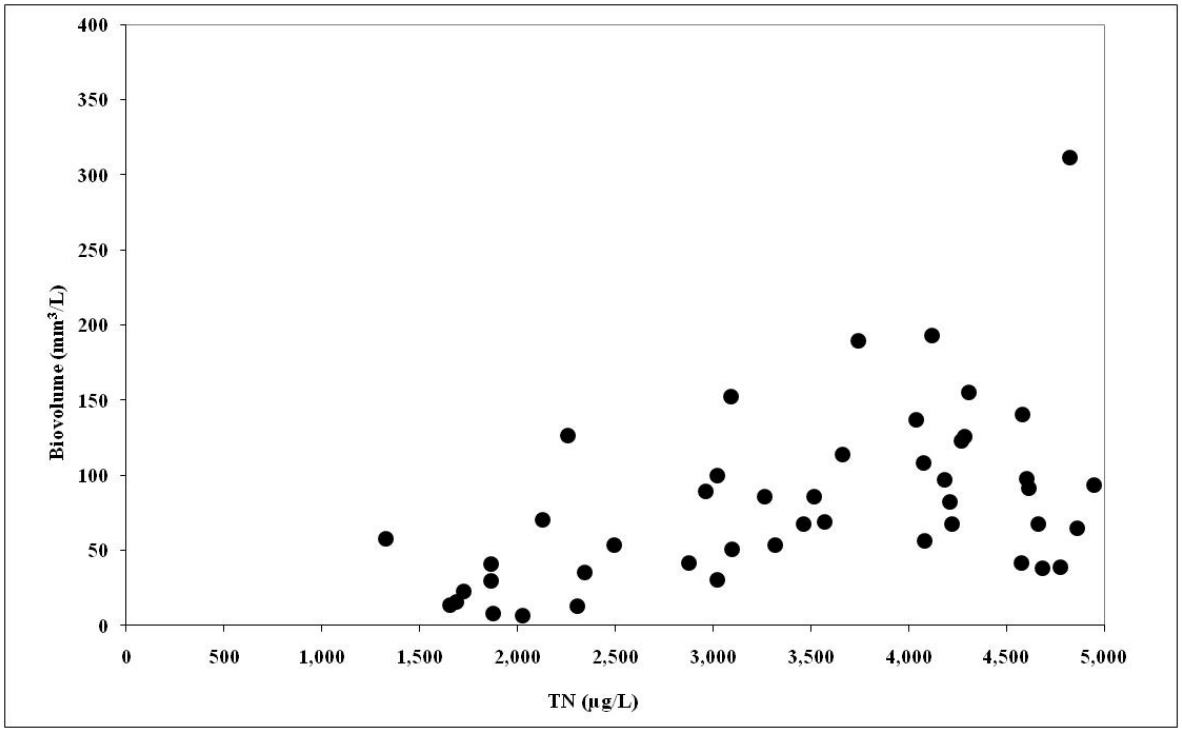

Figure 3.1. Cyanobacteria biovolume versus total nitrogen (TN) concentration in Newnans Lake, 1995–2001

The next step involved the substitution of a chlorophyll-a concentration of 40 µg/L into the regression models and solving for the TN and TP concentration targets. A chlorophyll-a target of 40 µg/L was selected because this concentration has been accepted as a threshold either for health purposes or as a water quality criterion by several states and many scientists. Heiskary and Walker (1988) set a chlorophyll-a threshold of 40 µg/L as the lower limit of categories “no swimming” and “high algae” for several Minnesota lakes. North Carolina uses 40 µg/L of chlorophyll-a as a water quality standard for warm waters (NALMS 1992). A bloom criterion of 40 µg/L chlorophyll-a has been set for Lake Okeechobee (Havens 1994) and has been adopted by FDEP. It is also the basis for the lower St. Johns River nutrient TMDL (U.S. EPA 2008). The resulting TP and TN concentrations for this chlorophyll threshold in Newnans Lake are 57 µg/L and 1,294 µg/L for TP and TN, respectively (Figures 3.3 and 3.4).

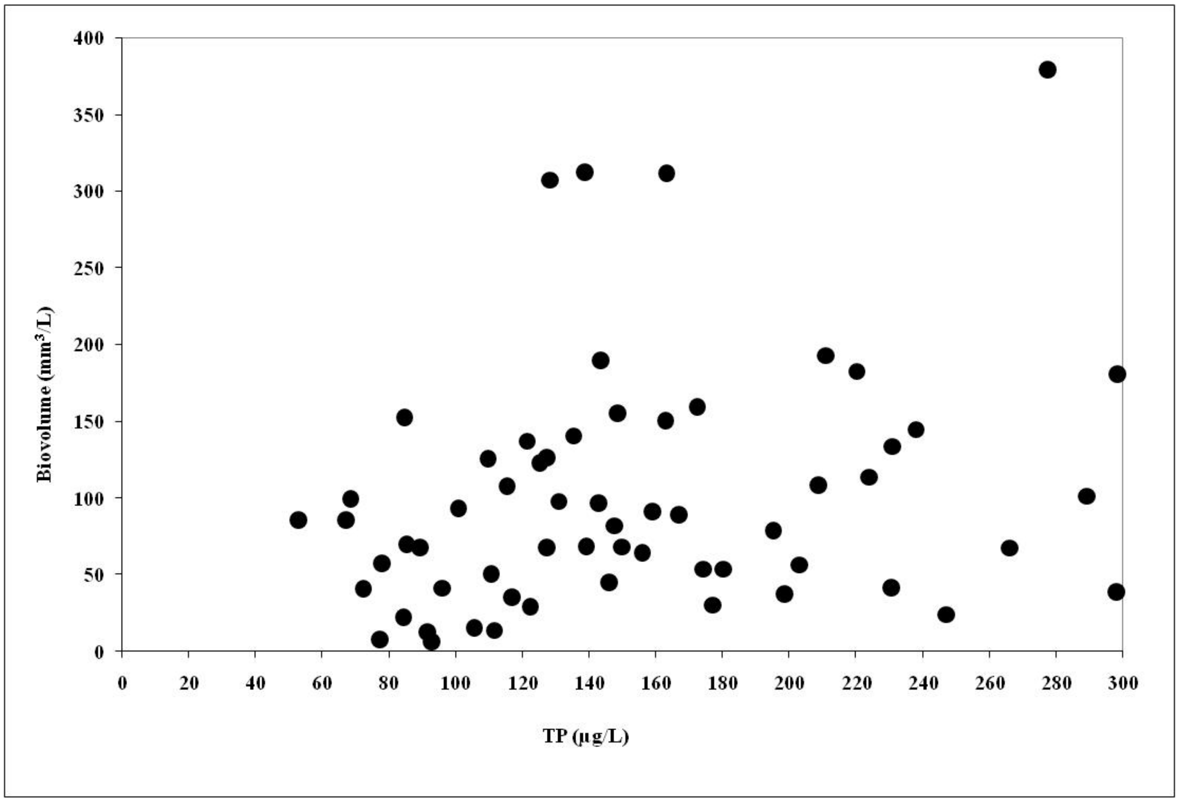

Figure 3.2. Cyanobacteria biovolume versus total phosphorus (TP) concentration in Newnans Lake, 1995–2001

Sedimentation Data Approach

Sedimentation in lakes is a natural process that leads to the slow accumulation of material on the lake's bottom. Sediments are deposited in a sequential manner that records inputs to a lake over time. The sediments are an important source of information about the characteristics of the watershed, such as land use, vegetation type, geology, and changes over time. For example, Holly (1976) used the presence of pollen in Newnans Lake's sediment to conclude that the lake appears to be 5,000–8,000 years old and that it began as a grassy marsh. Other paleolimnological methods are based on the nutrient and biological composition of sediments and can be used to infer historic water quality and trophic conditions, thereby setting water quality target conditions (Brenner et al. 1993). Whitmore and Riedinger-Whitmore (2004) summarized several approaches for how sediment assessment can be used for setting lake concentration targets. Radiometric dating techniques such as ^{210}Pb (Lead 210) can be used on sediments of varying depths to determine ages of the sediment layers.

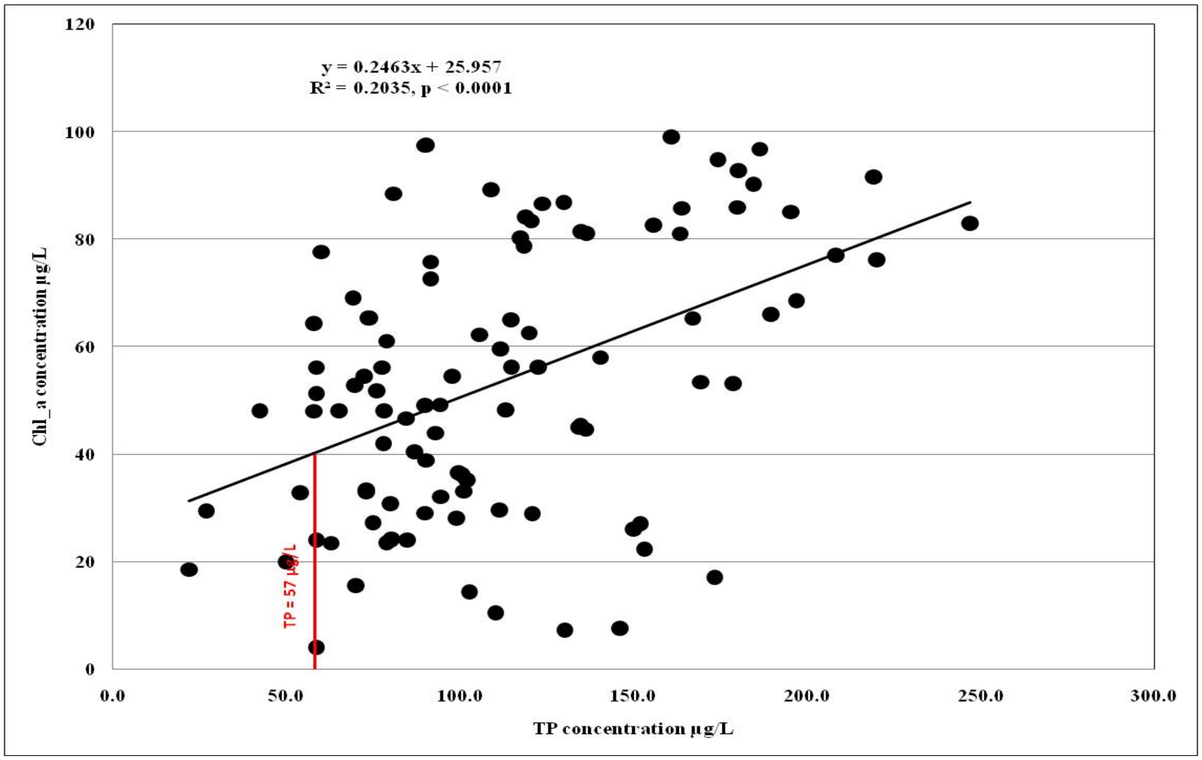

Figure 3.3. Newnans Lake total phosphorus (TP) and chlorophyll-a concentration regression

Once dates are determined for different layers of sediment, varying amounts of fossil remains and various chemical compounds can be used to make predictions about the water quality for different historical periods. For example, diatoms in the sediment have been used to infer past water quality conditions for many lakes (Brenner et al. 1996; Brenner and Whitmore 1998).

The nutrient accumulation rate in sediments is related to many environmental factors, such as hydrologic (depth and residence time), physical (wind-driven resuspension), and biochemical processes (redox potential and diffusion processes) of a lake system. However, the most significant factor that affects nutrient accumulation rates is the overall rate of nutrient loading to the lake. Since in-lake nutrient concentration is highly correlated to the overall external loading to a lake (Vollenweider 1975, Shannon and Brezonik 1972), it is reasonable to assume that the nutrient accumulation rate in sediment is proportional to the contemporaneous nutrient concentration in the overlying water column. This assumption has been used in the development of PLRGs for the Upper St. Johns River Basin lakes (Keenan 2002), Lake Apopka (Lowe et al. 1999), and major lakes in the Upper Ocklawaha River

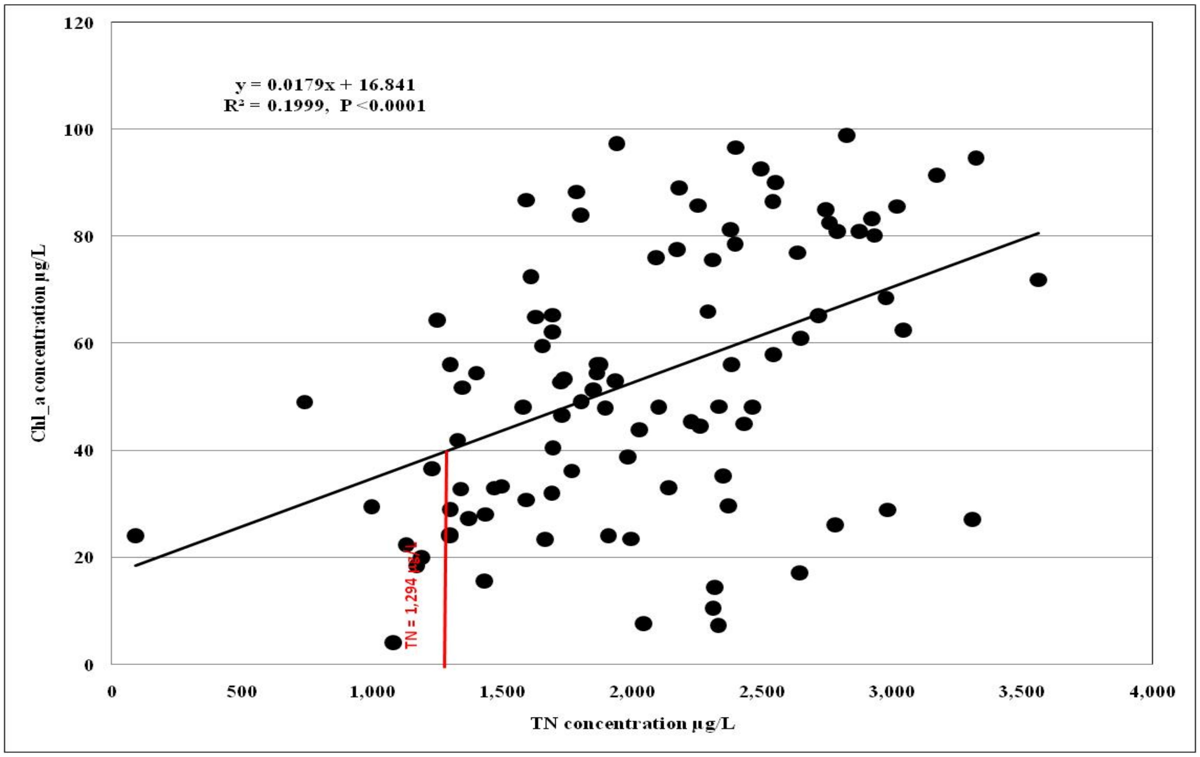

Figure 3.4. Newnans Lake total nitrogen (TN) and chlorophyll-a concentration regression

Basin (Fulton et al. 2003). The assumption is made that the net sedimentation coefficient (σ) with a unit of 1/year is constant for a lake. The sedimentation coefficient was calculated using the following equation:

$$\sigma = \frac{K}{Z * C}, \qquad \text{Eq. (1)}$$

where

K = nutrient accumulation rate (mg m^{-2} year^{-1})
σ = sedimentation coefficient of nutrient (year-1)
Z = mean depth (m)
C = mean nutrient concentration (mg m^{-3}).

If the sedimentation coefficient and the long-term average lake depth are constant, then the nutrient accumulation rate is proportional to the mean nutrient concentration. Brenner et al. (1993) reported that there was a significant correlation between TP content of the overlying waters and the sedimentary P accumulation rate. This conclusion was based on data collected from 33 Florida lakes.

Since the sediment nutrient accumulation rate is proportional to the water column nutrient concentration, the following equation will predict the historical TN and TP concentrations in Newnans Lake:

$$HC = RC * \frac{K_h}{K_r}, \qquad \text{Eq. (2)}$$

where

HC = historic nutrient (TN or TP) concentration (here defined as the concentration prior to 1950)

RC = recent nutrient (TN or TP) concentration (here defined as the concentration from 1991 to 1997). The most recent sediment cores from Newnans Lake were collected in 1997

K_h = historic nutrient (TN or TP) accumulation rate is the calculated average values based on measurements from four sediment core samples that were ^{210}Pb dated from 1900 to 1950

K_r = recent nutrient (TN or TP) accumulation rate is the calculated average values based on measurements of four sediment core samples that were ^{210}Pb dated from 1991 to 1997.

It is assumed that both watershed and in-lake water quality conditions prior to 1950 represent natural background conditions for the Newnans Lake area. Prior to 1950, human activity impact on the lake was considerably less than current conditions. Major land alterations have not been documented in the Newnans Lake watershed until the 1950s. Since 1950 some of the human activities within the Newnans Lake watershed (DRMP 2003) include:

1950s

- Nessler’s Dairy operated west of County Road (CR) 234 near Windsor
- Watermelon farms west of CR 234 near Windsor (irrigation withdrawals directly from the lake)

1960s

- Chicken processing plant on southwest side of the lake
- Large-scale herbicide treatments of water hyacinth

The historic and recent nutrient accumulation rates as well as the recent (1991–1997) average water column nutrient concentrations are summarized in Table 2.1.

Table 2.1 Nutrient deposition rates and water quality in Newnans Lake

	Recent Accumulation Rate ($mg/m^{-2}/year^{-1}$)	Historic Accumulation Rate ($mg/m^{-2}/year^{-1}$)	Recent Nutrient Concentration (µg/L)
TN	1.61	0.46	3,251
TP	0.12	0.06	110

Note: Nutrient accumulation data collected by Brenner and Whitmore (Brenner and Whitmore 1998).
$mg/m^{-2}/year^{-1}$ = milligrams per square meter per year
µg/L = micrograms per liter

By substituting corresponding values from Table 2.1 into equation 2, the estimated historic TN and TP water column concentrations for Newnans Lake are:

$$\text{Historic water column TN concentration} = 3{,}251\ (\mu g/L) * \frac{0.46}{1.61} = 929\ \mu g/L$$

$$\text{Historic water column TP concentration} = 110\ (\mu g/L) * \frac{0.06}{0.12} = 55\ \mu g/L$$

Based upon this methodology, the water column concentration targets for TN and TP are 929 µg/L and 55 µg/L, respectively.

REFERENCE LAKE APPROACH

The use of reference lakes' water quality conditions to set nutrient concentration targets is one method that the U.S. Environmental Protection Agency (EPA) recommends in the *Nutrient Criteria Technical Guidance Manual for Lakes and Reservoirs* (Gibson et al. 2000). This approach is based on the assumption that similar lakes in the same region with minimal impacts will have similar historic TP and TN concentrations. Appropriate candidate reference lakes can be determined from compiled data and with the help of experts familiar with the lake resources of the area. The results from two separate studies in which reference lake data sets for Florida have been developed were used here for determining TN and TP concentration targets.

The first study was conducted by Tetra Tech, Inc. and was based on data collected from 200 Florida lakes between 1993 and 1997, including more than 100 relatively unimpacted reference lakes (Paul and Gerritsen 2002). A variety of analyses suggested the strongest organizing forces on the biota of the relatively undisturbed lakes are water color and pH (Gerritsen et al. 2000). On the basis of these results, the sampled lake regions were aggregated into five lake biological classes such that the lakes within each class have similar biological assemblages. The lake classes were divided based on color (greater than or less than 20 platinum cobalt units [PCUs]), pH (greater than or less than 6.5), and ecoregion for acid clear lakes only (Omernik 1987), Region 65 in northwest Florida and Region 75 in peninsular Florida. Newnans Lake has an average color of 135 PCU and average pH of 7.9 and is, therefore, in the alkaline-colored lake category. The 75th percentile of the referenced water body's concentration is recommended as a target because this concentration is protective of most of the diversity within a region's natural lake types (Gibson et al. 2000). The 75th percentiles of TP and TN concentrations from alkaline-colored reference lakes are 73 µg/L and 1,110 µg/L, respectively.

A second-reference lake data set was compiled by the Florida LAKEWATCH program. Detailed descriptions of the selection and grouping procedures are in Griffith et al. (1997). Newnans Lake was included in Group 75-08, the Central Valley Region, which consisted of 40 referenced and impacted lakes. Since this data set included impacted lakes, the median values of the 40 lakes—1,400 µg/L for TN and 40 µg/L for TP—were determined to be the concentration targets for Newnans Lake.

LITERATURE VALUES APPROACH

The rationale of the literature values approach is to use nutrient target values that others in the scientific community have developed for Newnans Lake. The FDEP developed nutrient concentration criteria for TN and TP as part of the 2003 TMDLs for Newnans Lake (Gao and Gilbert 2003). They used the Watershed Management Model (WMM) to estimate natural background TN and TP loading rates, and put these loading rates into the BATHTUB eutrophication model (Walker 1999) to estimate the water column TP and TN concentrations under natural loading conditions. The BATHTUB model is a suite of empirically derived, steady-state models developed by the U.S. Army Corps of Engineering (USACE), Waterways Experimental Station. The primary function of these models is to estimate nutrient concentrations and algal biomass resulting from different patterns of nutrient loadings. Gao and Gilbert (2003) concluded that the water column TN and TP concentrations under natural conditions were 1,192 µg/L and 68 µg/L, respectively.

MODELING THE BACKGROUND CONDITION APPROACH

A combination of a watershed loading model and an in-lake water quality model was used in the "modeling the background condition" approach. A watershed loading model was developed and calibrated by using observed discharge, lake stage, and water quality data (see chapter 4 for details about the model development and calibration). This calibrated watershed loading model was then used to predict the background loading rates by changing land uses impacted by human activity to their historic predevelopment land use (forest). Tables 3.1 and 3.2 show the model-predicted annual TP and TN loading rates under the background condition. The current watershed TN and TP loading rates were based on the average annual loading rates in the periods 1995–1998 and 2002–2005 (see chapter 5 for details); therefore, the background loading rates were also predicted using the same hydrological and meteorological data for those years.

Table 3.1 Annual total phosphorus (TP) and total nitrogen (TN) loading (kg/yr) to Newnans Lake, under the background conditions in the watershed

	1995	1996	1997	1998	2002	2003	2004	2005	Average
TP	4,174	4,029	4,519	13,048	2,435	6,472	8,209	5,432	6,040
TN	44,562	57,667	64,042	133,898	37,829	71,888	111,850	71,387	74,140

kg/yr = kilograms per year

Table 3.2 Model predictions by year of Newnans Lake water column total phosphorus (TP) and total nitrogen (TN) concentrations (µg/L), under background conditions in the watershed

	1995	1996	1997	1998	2002	2003	2004	2005	Average
TP	69	57	62	85	60	75	63	58	66
TN	1,552	1,550	1,615	1,239	2,144	1,457	1,270	1,263	1,511

µg/L = micrograms per liter

The background condition loading rates were then entered into a calibrated BATHTUB model (see chapter 5 for details about the BATHTUB model development and calibration) to predict the background TN and TP concentrations in the lake. Table 3.2 shows the background water column TN and TP concentrations for Newnans Lake with the same hydrological conditions (discharge, lake volume, surface area), from 1995–2005. The model output illustrates that the background concentrations could vary between years depending on the meteorological and hydrological conditions in a given year. The model predicted background water column TP concentrations between 57 and 85 µg/L with a mean of 66 µg/L. The model predicted background water column TN concentrations of between 1,239 and 2,144 µg/L with a mean of 1,511 µg/L. The average concentrations were selected as water column targets (66 µg/L TP, 1,511 µg/L TN) for Newnans Lake (Table 3.2).

RECOMMENDED WATER COLUMN TN AND TP TARGET CONCENTRATIONS

Seven different methods were used to determine water column TP and TN concentration targets for Newnans Lake. Concentration targets for TN and TP could not be determined based upon thresholds in the relationship between plankton biovolume and nutrients; however, all the remaining methods allowed for targets to be estimated (Table 3.3). Thus, the water column TP concentration target should be

Table 3.3. Summary of water column total phosphorus (TP) and total nitrogen (TN) targets

Approaches	TP (µg/L)	TN (µg/L)
Plankton Data	*No threshold*	*No threshold*
Reference lakes – LAKEWATCH	40	1,400
Sediment data	55	929
Water quality data	57	1,294
Historic watershed loading model	66	1,511
Literature – Gao et al. (2003)	68	1,192
Reference lakes - Paul and Gerritsen (2002)	73	1,110
Minimum	40	929
Maximum	73	1,511
Mean	60	1,239
Median	62	1,243
Recommended water column concentration targets	68	1,294

µg/L = micrograms per liter

set between 40 and 73 µg/L, and the TN concentration target should be set between 929 and 1,511 µg/L. Newnans Lake has been recognized as eutrophic to hypereutrophic throughout its history. Relatively high TP concentrations were observed in the early 1950s through 1970s. A water column TP concentration of 81 µg/L was observed in May 1952 (Odum 1953). In 1970, Shannon reported an average TP concentration of 110 µg/L based upon five samples collected from June 1969 through April 1970 (Shannon 1970). Pollen and diatom analyses on several sediment cores indicated that the lake formed 5,000–8,000 years ago and that it has been eutrophic throughout its predevelopment history (Holly 1976). A natural eutrophic condition could be due to Newnans Lake's location within a geologically phosphorus-rich Miocene, Hawthorn Formation and the Pliocene Bone Valley Formation region (Brooks 1981). The Hawthorn Formation is within 2 ft or less of the land surface within 37% of the watershed. These observations suggest that a TP target toward the low end of the suggested values (e.g., 40 µg/L) is unrealistic. On the other hand, the maximum TP concentration target of 73 µg/L is likely too high. The TP concentration target of 73 µg/L TP was estimated based on the Paul and Gerritsen (2002) reference lake method, and the authors acknowledged that the concentration may be too high as a concentration criterion for colored-alkaline reference lakes in Florida, because the reference lakes' water quality data were likely already affected by human disturbances.

The four remaining targets suggest a TP target between 55 and 68 µg/L. Considering the uncertainties within each of the approaches, the 68 µg/L TP restoration target set in the Newnans Lake TMDL by FDEP appears to be reasonable and is endorsed here.

For nitrogen, the large potential for nitrogen fixation within the water column by cyanobacteria suggests a target based upon chlorophyll-a is appropriate. Therefore, the threshold associated with the 40 µg/L chlorophyll-a threshold (TN = 1,294 µg/L) is recommended.

CURRENT POLLUTANT LOAD ESTIMATION

Watershed loading to Newnans Lake primarily occurs from surface runoff and base flow from the surficial aquifer via creeks. Direct groundwater input to the lake appears to be negligible (Cohen 2008). In this study, nutrient loadings from the watershed were estimated using an Excel spreadsheet model developed by the St. Johns River Water Management District (SJRWMD). This model is based on a U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS), curve number and was used in PLRG development for major lakes in the Upper Ocklawaha River Basin (Fulton et al. 2004).

INPUT DATA

Land Uses

The Newnans Lake watershed has 66,655 acres of drainage area. The land use area delineation was derived from aerial photography taken in 2004. For modeling purposes, the land uses were aggregated into nine general categories, as shown in Table 4.1.

Table 4.1. Land use categories with their acreages and percentages in the Newnans Lake watershed

Land Use	Area (acres)	Percent
Agriculture	1,423	2.13
Forest	28,118	42.18
Forest regeneration	10,176	15.27
Industrial	3,442	5.16
Low density residence	1,444	2.17
Med-high density residence	1,826	2.74
Open land	3,020	4.53
Pasture	2,267	3.40
Water/wetlands	14,939	22.41
Total	66,655	100.00

Hydrologic Soil Groups

The Soil Survey Geographic Data Base (SSURGO) developed by the Natural Resources Conservation Service was used. Soils were classified using the hydrologic soil groups A, B, C, and D (SCS 1972). The dominant hydrologic soil group is D, which by definition has a low infiltration rate. Figure 4.1 shows the spatial distribution of the hydrological soil groups in the watersheds of the three major lakes in the Orange Creek Basin. Table 4.2 presents the acreages and relative percentages for the four soil groups in the Newnans Lake watershed.

Rainfall and Evaporation

NEXRAD rainfall data purchased from OneRain, Inc. (http://www.onerain.com), available from January 1, 1995, through the end of the modeling period was used in the model. The OneRain NEXRAD rainfall data was collected using a 2- by 2-km grid at 15-minute intervals. Daily OneRain NEXRAD rainfall, resampled at the subbasin level was used as model input for this study. The daily rainfall data was extracted from the OneRain data by using a geographic information system (GIS) tool developed by SJRWMD.

Pan evaporation data collected in the Gainesville area were used in the model. These data are a compilation of two different sites, Gainesville 11WNW (administered by the University of Florida) and an SJRWMD site located at the Orange Lake weather station at Lochloosa. The Gainesville 11WNW pan evaporation data (1995–2000) was obtained through the EarthInfo subscription from NCDC. This station was discontinued after December 2000. From February 1997 through December 2005, SJRWMD collected pan evaporation data at the Orange Lake weather station at Lochloosa. The pan evaporation data collected at these two stations were compared to each other for the period between February 1997 and December 2000. This comparison showed that the data collected by the SJRWMD at the Orange Lake Weather station needed to be multiplied by 1.15 to have a similar amount of evaporation as the Gainesville 11WNW station. A unified pan evaporation data set for the Newnans Lake Basin was developed using the Gainesville 11WNW station from 1995 to 2000 and the Orange Lake Weather Station data multiplied by 1.15 from 2001 to 2005.

Curve Numbers and Average Antecedent Moisture Conditions

Curve numbers (CN), based on average antecedent moisture conditions (AMC) II, were developed for the nine land uses in each of the four hydrological soil groups (Table 4.2).

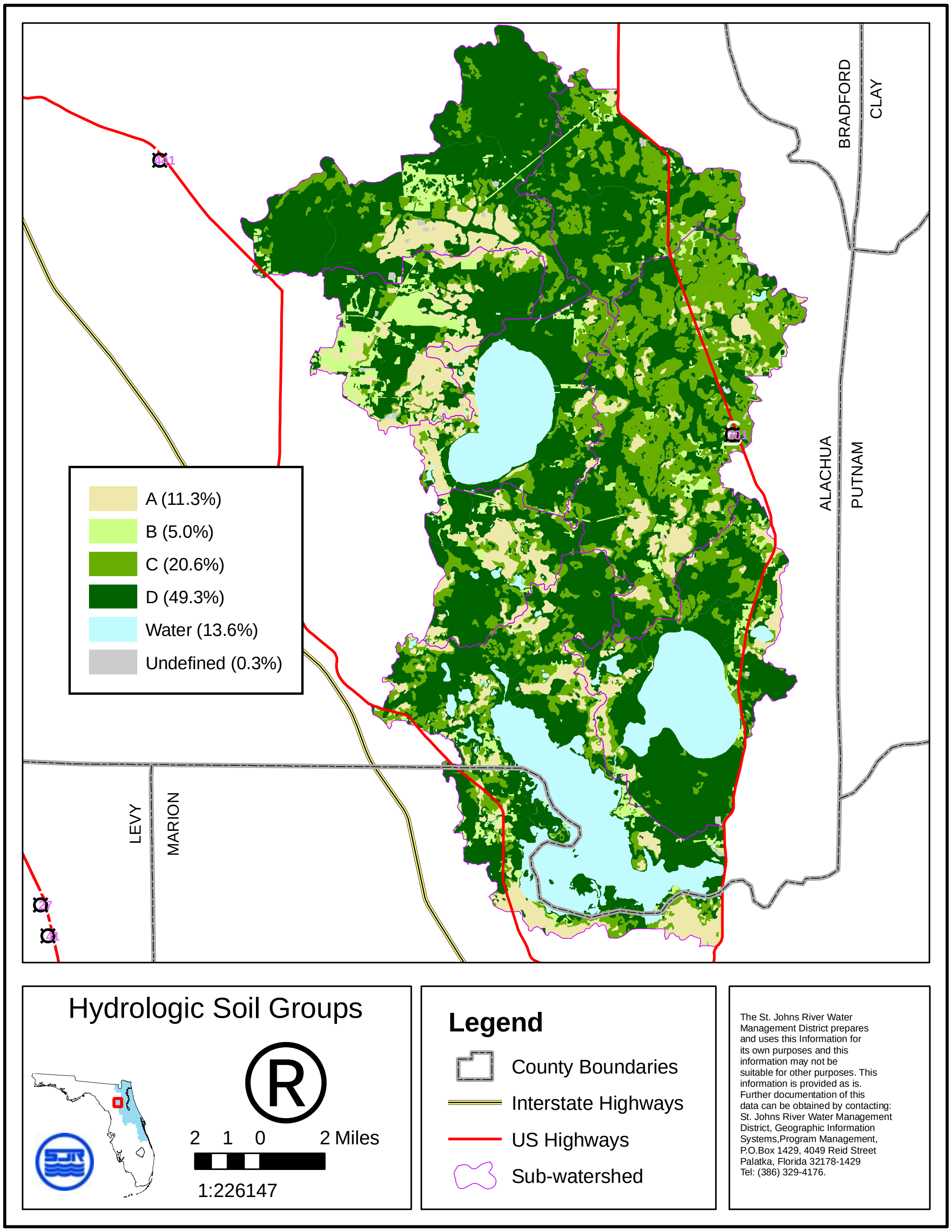

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Figure 4.1. Hydrologic soil groups in the Newnans, Lochloosa, and Orange lakes watersheds

Table 4.2. Acreages and percentages of the hydrological soil groups in the Newnans Lake watershed

Soil Type	Acres	Percentage
A	8,366	13
B	5,093	8
C	12,056	18
D	41,140	62
Totals	66,655	100%

A weighted curve number (CN) was developed for the entire watershed. The weighted CN was based on total impervious area, which under-predicts runoff for smaller storm events (1 inch [in.] to 2 in.), when used with the standard SCS runoff equation (Eq [1]). Therefore, the equation for predicting direct runoff (Q) was expanded to account for directly connected impervious areas (DCIA) and non-directly connected impervious areas (NDCIA) (Eq [2]). The percentages of DCIA and NDCIA were adjusted from literature values based on field observation and review of aerial photography. Table 4.3 shows typical values used in the watershed. The DCIA, NDCIA, and pervious areas were calculated by applying the percentages in Tables 4.3 to the land use areas. The runoff coefficient for the DCIA was assumed to be 0.9. The weighted CN (Eq [3]) (DCIA, NDCIA and pervious area) for the watershed was calculated. With these two numbers, an AMC II CN for the pervious areas (NDCIA and pervious) could be determined (Eq [4]).

Table 4.3. Curve numbers by soil type and land use

Land Use	A	B	C	D
Agriculture	51	60	70	84
Forest	40	50	65	75
Forest regeneration	40	50	65	75
Industrial	45	55	65	80
Low density residence	45	55	65	80
Med-high density residence	45	55	65	80
Open land	40	50	65	75
Pasture	45	55	65	80
Water/wetlands	49	65	72	80

Antecedent moisture conditions (AMC) I and III were accounted for in applying the curve numbers (Table 4.6) to the direct runoff equations by analyzing the previous 5-day rainfall totals using the criteria in Table 4.4 and adjusting the calculated CN up or down based on an AMC of I or III (Table 4.5). This adjustment was made separately for the dormant and growing seasons. If the rainfall event produced less rain than the soil storage volume, only the runoff from the DCIA was calculated.

Table 4.4. Percentages of impervious area by land use for the entire watershed

Percentages of Impervious Area by Land Use				
Land use	NDCIA	DCIA	Pervious	Totals
Agriculture	1	1	98	100
Forest	1	1	98	100
Forest regeneration	1	1	98	100
Industrial	40	40	20	100
Low density residence	10	5	85	100
Med-high density residence	40	25	35	100
Open land	1	2	97	100
Pasture	1	1	98	100
Water/wetlands	1	1	98	100

NDCIA = non-directly connected impervious area
DCIA = directly connected impervious area

Table 4.5. Classifications of antecedent moisture conditions (AMC)

Total 5-Day Antecedent Rainfall (inches)		
AMC	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

AMC = antecedent moisture condition

ESTIMATED RUNOFF FROM THE WATERSHED

Direct runoff (Q) was calculated for every rainfall event for the 10-year period. Q was multiplied by the watershed area to produce a volume of runoff.

$$\mathrm{Q} = \frac{(P - 0.2S)^2}{P + 0.8s} \qquad \text{Eq. (3)}$$

$$\mathrm{Q} = \mathrm{Q}\,pervious + \mathrm{Q}\,dcia \qquad \text{Eq. (4)}$$

$$\mathrm{CN}\,watershed = \frac{((\mathrm{CN}dcia * \mathrm{A}dcia) + (\mathrm{CN}\,pervious * \mathrm{A}\,pervious))}{\mathrm{TOTAL\ AREA}} \qquad \text{Eq. (5)}$$

$$\mathrm{CN}\,pervious = \frac{((\mathrm{CN}\,watershed * \mathrm{TOTAL\ AREA}) - (\mathrm{CN}\,dcia * \mathrm{A}\,dcia))}{\mathrm{A}\,pervious} \qquad \text{Eq. (6)}$$

$$\mathrm{Q}\,pervious = \frac{(\mathrm{P} - 0.2\mathrm{S})^2}{\mathrm{P} + 0.8\mathrm{S}} * (\mathrm{PERVIOUS\ AREA} \div \mathrm{TOTAL\ AREA}) \qquad \text{Eq. (7)}$$

$$\mathrm{Q}\,impervious = \mathrm{P} * (\mathrm{dcia} \div \mathrm{TOTAL\ AREA}) \qquad \text{Eq. (8)}$$

$$S = \frac{1000}{\mathrm{CN}\,(pervious) - 10} \qquad \text{Eq. (9)}$$

Note:

Q = Actual direct runoff, inches
P = Rain, inches
P’ = Rain on pervious areas adjusted for NDCIA volume, inches
S = Watershed storage, inches
CN = Curve number

ESTIMATED WATERSHED TN AND TP LOADING RATES

Event Mean Concentration by Land Uses

For water quality modeling purposes, the land uses in the Newnans Lake watershed were grouped into nine categories. The event mean concentrations (EMCs) of TP and TN for each of the nine categories were estimated from stormwater samples collected in the area and from reported values in the published literature. Nutrient EMCs for each of the categories are presented in Table 4.7

Determine Base-Flow TN and TP Concentration

The nutrient load associated with base flow was calculated separately from storm-related loads. The annual base-flow volume was estimated using a typical base-flow separation method. The base-flow TN and TP concentrations were calculated as follows.

Table 4.6. Curve numbers for antecedent moisture conditions (AMC)

AMC II	AMC I	AMC III
0	0	0
5	2	17
10	4	26
15	7	33
20	9	39
25	12	45
30	15	50
35	19	55
40	23	60
45	27	65
50	31	70
55	35	75
60	40	79
65	45	83
70	51	87
75	57	91
80	63	94
85	70	97
90	78	98
95	87	99
100	100	100

Methods

Rainfall data collected at the Alachua County Fairgrounds were analyzed and used to determine which water quality grab samples collected from the tributaries to Newnans Lake represented base-flow conditions. The monthly water quality data from each of the five subbasin stations collected between 1995 and 2006 were used in the analysis. If the cumulative rainfall in the five consecutive days prior to any sampling date was less than 0.5 in., the sample was considered to represent base flow and the concentration data were used to estimate base-flow conditions. The average concentrations were calculated for each station using data representing base flow. Subsequently, the overall watershed base-flow concentrations were calculated by area weighting each subbasin's data.

Table 4.7. Total nitrogen (TN) and total phosphorus (TP) event mean concentrations for different land use categories

Land use	EMC TP µg/L	EMC TN µg/L
Agriculture	344	2,320
Forest	53	1,250
Forest Regeneration*	90	1,580
Industrial	310	1,790
Low-density residence	177	1,770
Med-high density residence	400	2,630
Open land	53	1,250
Pasture**	1,300	3,000
Water/wetlands	190	1,600

EMC = event mean concentration
*Based on the samples collected from Newnans Lake watershed
**From Lower St. John River Basin data (J. Hendrickson)
All other EMC data from Harper (1994)

Results

The average base-flow TP concentration ranged from 95 to 392 µg/L, and TN concentration varied from 558 to 1,423 µg/L among the five stations (Tables 4.8 and 4.9). An area-weighted concentration was used to represent the basinwide base-flow concentration. The average watershed base-flow TP and TN concentrations were 165 µg/L and 1,171 µg/L, respectively.

The changes in land use due to increased human development over the past several decades have the potential to alter base-flow concentrations. To estimate predevelopment base-flow concentrations, data collected from Hatchet Creek during the early 1950s were used. Since Hatchet Creek is the major inflow tributary to Newnans Lake these data are thought to best represent predevelopment times. Three samples collected during the summer of 1952, from two locations on the Hatchet Creek, had an average TP concentration of 112 µg/L (Odum 1953). Since nitrogen concentration data are unavailable, the background nitrogen concentration condition was assumed to be proportionally reduced from the current TN concentration, this based upon the ratio of current to background base-flow TP concentration data. The resulting background base-flow TN concentration was 820 µg/L.

Table 4.8. Newnans Lake watershed base-flow total phosphorus (TP) concentration

Sample Station	N	Standard Deviation	SE	Base Flow [TP] (µg/L)	Area (ac)	Percent Area (%)	Weighted Concentration (µg/L)
HAT26	108	104	10	143	41,468	73.7	105
LF	65	39	5	95	5,027	8.9	8
LHAT	47	144	20	370	340	0.6	2
LHATE	74	105	13	200	5,000	8.9	18
LHATNB	69	185	22	392	4,421	7.9	31
Basinwide average							165

N = number of observations
SE = standard error
µg/L = micrograms per liter
ac - acre

Table 4.9. Newnans Lake watershed base-flow total nitrogen (TN) concentration

Sample Station	N	Standard Deviation	SE	Base Flow [TN] (µg/L)	Area (ac)	Percent Area (%)	Weighted Concentration (µg/L)
HAT26	108	520	50	1,262	41,468	73.7	930
LF	65	200	24	691	5,027	8.9	62
LHAT	47	450	65	1,423	340	0.6	9
LHATE	74	740	88	1,422	5,000	8.9	126
LHATNB	69	250	30	558	4,421	7.9	44
Basinwide average							1,171

N = number of observations
SE = standard error
µg/L = micrograms per liter
ac - acre

HYDROLOGICAL MODELING VERIFICATION

The predicted stormwater runoff and base-flow inflow to the lake from the watershed were verified by developing a water budget for Newnans Lake.

The lake water budget in acre-feet (ac-ft) is expressed as:

$$\Delta V = P - E + R + B$$

Note:

ΔV = Change in lake storage volume
P = Rainfall on lake
E = Lake evaporation
O = Stream discharge from lake
R = Runoff from land to the lake
B = Base flow to the lake

Lake Volume

Lake volume changes (ΔV) were determined from observed daily water elevations in the lake. Lake areas and volumes were determined from water elevations using bathymetric data for the lakes reported in ECT (2002), supplemented with additional topographic LiDAR data from the Environment Protection Department of Alachua County.

Rainfall

Rainfall (*P*) estimates for the basin were developed from SJRWMD radar rainfall data in the basin.

Evaporation

Estimates of lake evaporation (*E*) were developed using the same stations and monthly varying pan evaporation coefficients as used in the Orange Creek Basin hydrological model, which is under development by SJRWMD. (See Section 4.1.3.)

Base Flow

Base flow (*B*) to Newnans Lake was calculated by performing a sliding-interval method (Pettyjohn and Henning 1979) of base-flow separation on the flow measurements for Hatchet Creek. Daily base flow was divided by the contributing watershed upstream of the gauge, which yields a base flow per acre. The base flow per acre is multiplied by the contributing watershed to Newnans Lake, providing the total base flow to the lake.

Discharge

Lake outflow discharges (Δ*O*) were determined from a lake stage-discharge relationship. Adjustment to the water budget components were made to minimize the differences between observed and model-predicted lake stage, as well as discharge rate at the lake outlet station. The model predicted the lake stage level and discharge rate at Prairie Creek reasonably well for most of the years. The model predicts lake stage better during normal or wetter rainfall years compared to drought years. For the 2000–2002 period-of-record drought, the model prediction of the lake stage was poor (Figures 4.2 and 4.3).

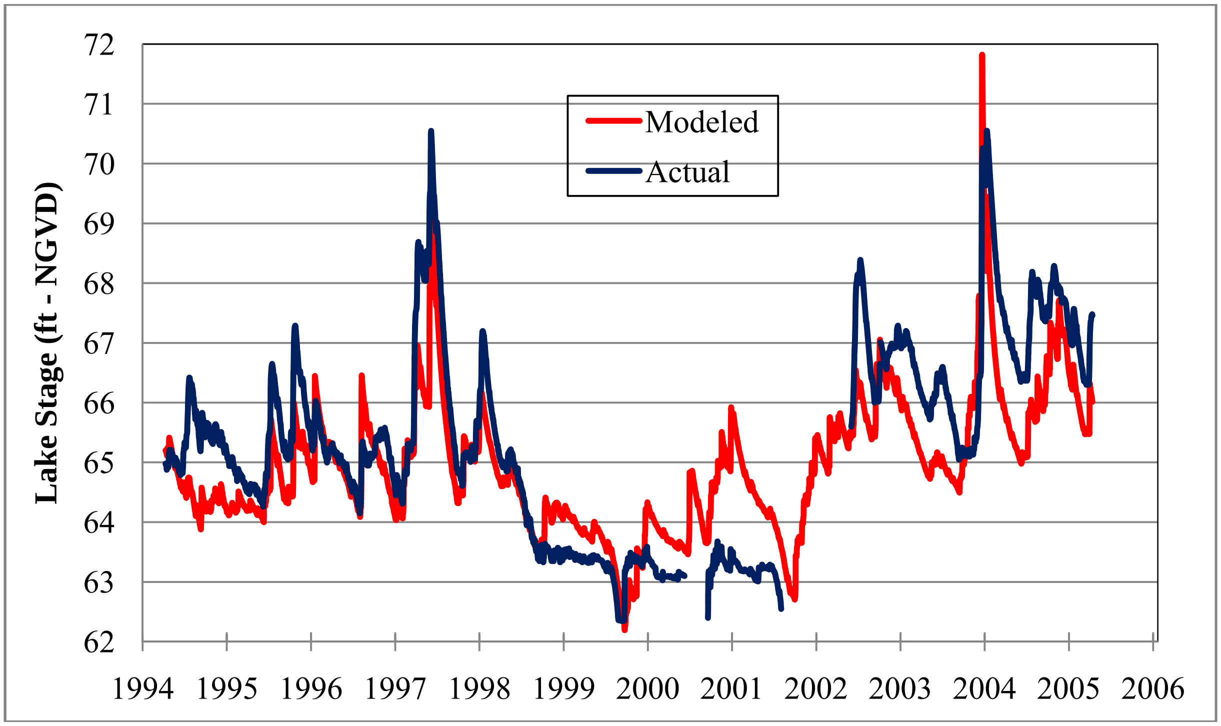

Figure 4.2. Model simulated and observed Newnans Lake stage

Annual Nutrient Loading and Runoff by Land Use Categories

The runoff volume calculated by the SCS method for the entire watershed is the sum of runoff from the pervious and impervious lands. The percentage of pervious and impervious area is calculated for each land use. These percentages for each land use were multiplied by the total pervious and impervious runoff. The nutrient loads were partitioned into dissolved and particulate fractions. Particulate nutrient loads were subject to a delivery ratio (Novotny 2003). This ratio is multiplied by the event mean concentration and runoff volume for each land use. The dissolved nutrient fraction was multiplied by the event mean concentration and the runoff for each land use. The daily loads by each land use were summed to provide a total stormwater load to the lake. The model-predicted annual runoff volumes for each land use category are presented in Table 4.10. Tables 4.11 and 4.12 are the model-predicted annual TN and TP loading rates from the different land use categories.

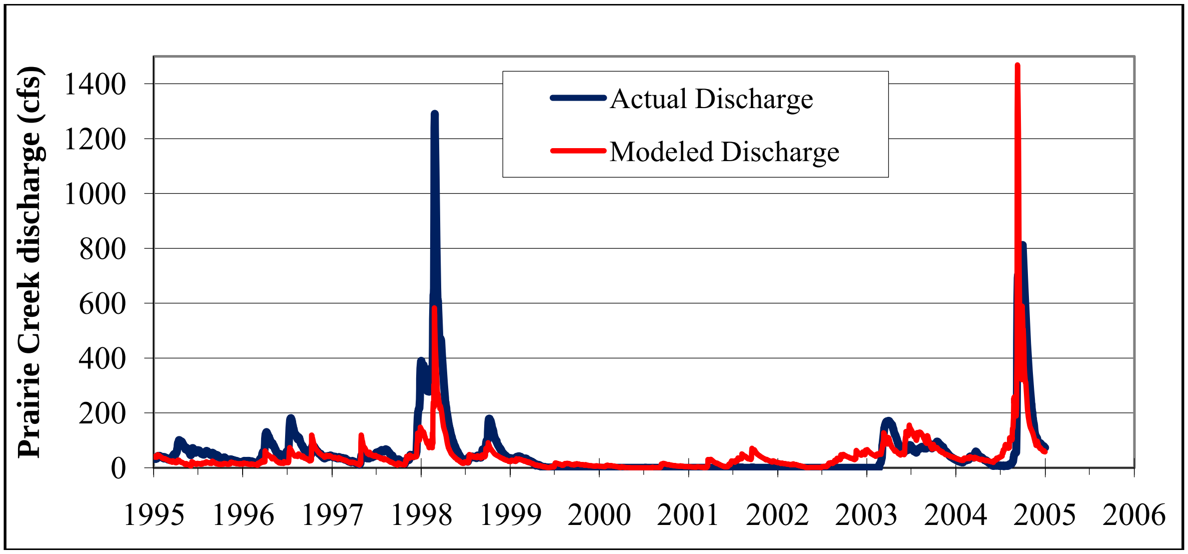

Figure 4.3. Model simulated and observed discharge rate at Prairie Creek

Table 4.10. Annual runoff rates (ac-ft/yr) by land use categories, 1995–2005

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean
Agriculture	126	539	623	801	140	240	457	413	465	1,216	688	519
Forests	2,483	10,644	12,301	15,814	2,774	4,740	9,027	8,160	9,194	24,015	13,585	10,249
Forest regeneration	899	3,852	4,452	5,723	1,004	1,716	3,267	2,953	3,327	8,691	4,917	3,709
Industrial	4,816	5,440	5,799	5,498	3,863	3,244	4,272	4,965	5,065	6,685	6,365	5,092
Low density residence	318	700	787	927	289	347	578	571	620	1,335	868	667
Med-high density residence	1,619	1,947	2,089	2,043	1,310	1,137	1,539	1,753	1,802	2,556	2,294	1,826
Open land	370	1,247	1,430	1,795	379	574	1,050	974	1,085	2,689	1,579	1,198
Pasture	200	858	992	1,275	224	382	728	658	741	1,936	1,095	826
Water/wetlands	1,319	5,655	6,535	8,402	1,474	2,518	4,796	4,335	4,885	12,759	7,218	5,445
Base flow	19,517	7,734	9,731	62,050	2,351	1,210	1,818	4,202	29,624	19,963	16,539	15,885
Total	31,665	38,616	44,740	104,326	13,807	16,107	27,532	28,984	56,809	81,845	55,148	45,416

ac-ft/yr = acre-feet per year

Table 4.11. Annual total nitrogen (TN) loading rates (kg/yr) by land use categories, 1995–2005

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean
Agriculture	389	1,667	1,926	2,476	434	742	1,414	1,278	1,440	3,760	2,127	1,605
Forests	3,699	15,858	18,327	23,560	4,132	7,062	13,449	12,157	13,698	35,779	20,240	15,269
Forest regeneration	1,830	7,845	9,067	11,656	2,044	3,494	6,654	6,014	6,776	17,700	10,013	7,554
Industrial	11,111	12,553	13,379	12,684	8,912	7,485	9,857	11,456	11,687	15,424	14,686	11,748
Low density residence	726	1,599	1,799	2,118	660	794	1,322	1,305	1,418	3,051	1,983	1,525
Med-high density residence	4,904	5,896	6,328	6,188	3,969	3,443	4,660	5,310	5,457	7,742	6,950	5,532
Open land	596	2,009	2,305	2,892	611	924	1,692	1,569	1,749	4,333	2,544	1,929
Pasture	716	3,069	3,547	4,560	800	1,367	2,603	2,353	2,651	6,924	3,917	2,955
Water/ wetlands	2,733	11,719	13,544	17,411	3,054	5,219	9,939	8,984	10,123	26,441	14,958	11,284
Base flow	28,203	11,176	14,062	89,665	3,397	1,748	2,627	6,072	42,809	28,847	23,900	22,955
Total	54,906	73,391	84,283	173,210	28,014	32,277	54,217	56,498	97,806	150,002	101,318	82,357

kg/yr = kilogram per year

Table 4.12. Annual total phosphorus (TP) loading rates (kg/yr) by land use categories, 1995–2005

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean
Agriculture	47	202	234	301	53	90	172	155	175	457	258	195
Forests	149	637	736	946	166	284	540	488	550	1,437	813	613
Forest regeneration	91	391	452	581	102	174	332	300	338	883	500	377
Industrial	2,019	2,281	2,432	2,305	1,620	1,360	1,791	2,082	2,124	2,803	2,669	2,135
Low density residence	63	140	157	185	58	69	116	114	124	267	173	133
Med-high density residence	731	879	943	922	592	513	695	792	813	1,154	1,036	825
Open land	22	75	86	107	23	34	63	58	65	161	94	72
Pasture	248	1,062	1,227	1,578	277	473	901	814	917	2,396	1,355	1,023
Water/wetlands	282	1,209	1,398	1,797	315	539	1,026	927	1,045	2,729	1,544	1,165
Base flow	3,974	1,575	1,981	12,634	479	246	370	856	6,032	4,065	3,368	3,234
Total	7,627	8,452	9,646	21,357	3,683	3,783	6,005	6,586	12,183	16,351	11,810	9,771

kg/yr = kilogram per year

DETERMINATION OF THE ALLOWABLE POLLUTANT LOAD WHILE ACHIEVING THE IN-LAKE CONCENTRATION TARGET

RELATIONSHIP BETWEEN NUTRIENT LOADING AND IN-LAKE NUTRIENT AND CHLOROPHYLL-A CONCENTRATIONS

The BATHTUB model is a suite of models developed by the U.S. Army Corps of Engineers (USACE), Waterways Experimental Station (version 6.1). The program performs water and nutrient mass-balance calculations in a steady-state hydraulic network. It predicts eutrophication-related water quality conditions (expressed in terms of TP, TN, chlorophyll-a, transparency, organic carbon and oxygen depletion rate) by using empirical relationships developed and tested for reservoir applications (Walker 1985). The BATHTUB model has been used for modeling water quality in Newnans Lake because it addresses the parameters of concern (TP and TN) and because it has been used previously for many lake TMDLs in Florida and elsewhere. The U.S. Environmental Protection Agency (EPA) also recommends the use of BATHTUB for nutrient TMDLs (EPA 1999). The BATHTUB model was used to establish the relationships between total TN and TP loading and in-lake concentrations. The established relationships were used to estimate the required nutrient reductions to achieve the concentration targets. This link was established through a variety of techniques ranging from simple mass balance analyses to sophisticated computer modeling.

BATHTUB MODEL SETUP

The BATHTUB model requires the following data for configuration and calibration:

- Lake bathymetry (surface area, mean depth, and volume)
- In-lake nutrient concentrations (TN, TP, and chlorophyll-a)
- Evaporation and precipitation volumes
- Nutrient loading rates from different sources in the watershed expressed as inflow volume and concentration
- Nutrient loading from atmospheric deposition

All of the data required for model configuration and calibration are shown in Tables 5.1 through 5.3.

Table 5.1. Newnans Lake bathymetry, total nitrogen (TN), total phosphorus (TP), and chlorophyll-a data, 1995–1998

Year	Lake Surface Area (km^2)	Mean Depth (m)	Volume (hm^3)	Lake TN Concentration (µg/L)	Lake TP Concentration (µg/L)	Lake Chl *a* Concentration (µg/L)
1995	26.29	0.98	28.28	4,781	148	261
1996	26.20	0.99	28.24	4,078	114	211
1997	26.10	0.98	27.85	3,996	143	229
1998	27.92	1.43	42.00	2,230	105	113
Mean	26.63	1.10	31.60	3,771	128	203
CV	0.04	0.17	0.22	0.29	0.17	0.31

µg/L = micrograms per liter

Table 5.2. Hydrologic data for the BATHTUB model

Year	Precipitation (m/year)	Evaporation (m/year)	Stage Change (m)	Atmospheric Loading TN ($mg/m^2/yr$)*	Atmospheric Loading TP ($mg/m^2/yr$)*
1995	1.18	1.12	–0.13	658	39
1996	1.28	1.04	0.18	697	40
1997	1.29	1.16	1.10	701	40
1998	1.27	1.28	–1.14	697	40
Mean	1.22	1.15	0.00	688	39.8
CV	0.04	0.09	606	0.03	0.01

Note: Estimates based upon data collected during 2002 and 2003.
m/year = meters per year
$mg/m^2/yr$ = milligrams per square meter per year

Table 5.3. Average flow, total nitrogen (TN), and total phosphorus (TP) concentrations from different land uses, base flow, and point sources, 1995–1998

Land Use	Flow (hm^3/yr)		TP (µg/L)		TN (µg/L)	
	Mean	CV	Mean	CV	Mean	CV
Agriculture	0.64	0.54	304	0.00	2,507	0.00
Forests	12.70	0.54	48	0.00	1,208	0.00
Forest regeneration	4.60	0.54	82	0.00	1,651	0.00
Industrial	6.60	0.07	340	0.00	1,870	0.00
Urban low impact	0.84	0.38	162	0.00	1,853	0.00
Med-high impact	2.40	0.10	366	0.00	2,455	0.00
Open land	1.50	0.50	48	0.00	1,306	0.00
Pasture	1.00	0.55	1,003	0.00	2,898	0.00
Water/ wetlands	6.80	0.55	173	0.00	1,680	0.00
Base flow	30.54	1.0	165	0.00	1,171	0.00
Point source	0.03	0.00	2,182	0.019	11,221	0.30

hm^3/yr = cubic hectometers per year
µg/L = micrograms per liter

Lake surface area and lake volume were estimated using the bathymetry data. Polynomial equations between water surface elevation (measured at 1-ft increments) and lake area and volume were developed to continuously interpolate lake surface area and lake volume.

These data were used as part of the overall water and nutrient budget calculation for the lake. Precipitation and evaporation data were collected at the Gainesville airport. Atmospheric TN and TP deposition data were collected near the southeast shoreline of Lochloosa Lake, about 10 miles southeast of Newnans Lake, from June 2000 through January 2003.

Annual average flow volumes and concentrations from different land uses, point sources, and base flow were estimated using the watershed loading model from chapter 4.

BATHTUB MODEL CALIBRATION

The BATHTUB model provides several alternatives for estimating the influence of sedimentation on water column TN and TP concentrations. The settling velocity model for simulating TN and TP concentrations was used for this analysis. This model assumes that the sedimentation of TN and TP is linearly correlated to the in-lake TN and TP concentrations. The model also assumes that the sedimentation is influenced by lake depth. The deeper the lake, the slower the sedimentation. This model fits the Newnans Lake condition because the lake is shallow with a relatively large surface area and was previously used by FDEP in setting nutrient TMDLs for several shallow lakes in north central Florida (Gao 2003).

The BATHTUB model was calibrated using watershed loading estimated in the previous chapter and observed lake water quality data for the period 1995–1998. Then the calibrated model was used to estimate the average TN and TP concentrations for both current and background conditions. In initial runs, calibration factors were unnecessary for TP concentration. The average observed water column TP concentration was 128 µg/L and the model simulated TP value was 133 µg/L for the period 1995–1998 (Figure 5.1-A). However, this was not the case for TN, as the model underestimated the TN concentration by more than 50% (Figure 5.1-B). This indicated that some additional source(s) of nitrogen to the lake was missing as input to the model. Nitrogen fixation by cyanobacteria has not been measured in Newnans Lake and the initial BATHTUB model runs did not include any estimate of this source. The phytoplankton community in Newnans Lake has been dominated by cyanobacteria since at least 1992 (SJRWMD unpublished data). More than 90% of phytoplankton biovolume, consists of cyanobacteria species (Di et al. 2003), and approximately 70% of the total phytoplankton biovolume has been *Cylindrospermopsis raciborskii*, a nitrogen-fixing species of cyanobacteria. Other nitrogen-fixing cyanobacterial genera frequently observed in the lake are *Anabaena* and *Aphanizomenon*. Shannon and Brezonik (1972) observed that the lake produced an extremely dense bloom of *Aphanizomenon* in winter and was predominated by *Anabaena* and *Microcystis* during summer. Because nitrogen-fixing taxa dominate the phytoplankton community, an estimate of the nitrogen load by fixation was developed within the BATHTUB model.

The nitrogen fixation rates typically vary both seasonally and interannually depending upon many factors that affect the N-fixing taxa. Nitrogen fixation rates used for the Lake Jesup TMDL (Gao 2005) were used as a guideline to estimate the appropriate N-fixation rates for the Newnans Lake BATHTUB model. Similar to Newnans Lake, Lake Jesup, located in central Florida, is a hypereutrophic lake dominated by cyanobacteria. Nitrogen fixation rates in Lake Jesup were estimated by Florida Department of Environmental Protection (FDEP) to range from 8.0 to 37.4 milligrams per square meter per day (mg/m^2/day). Various N-fixation rates were

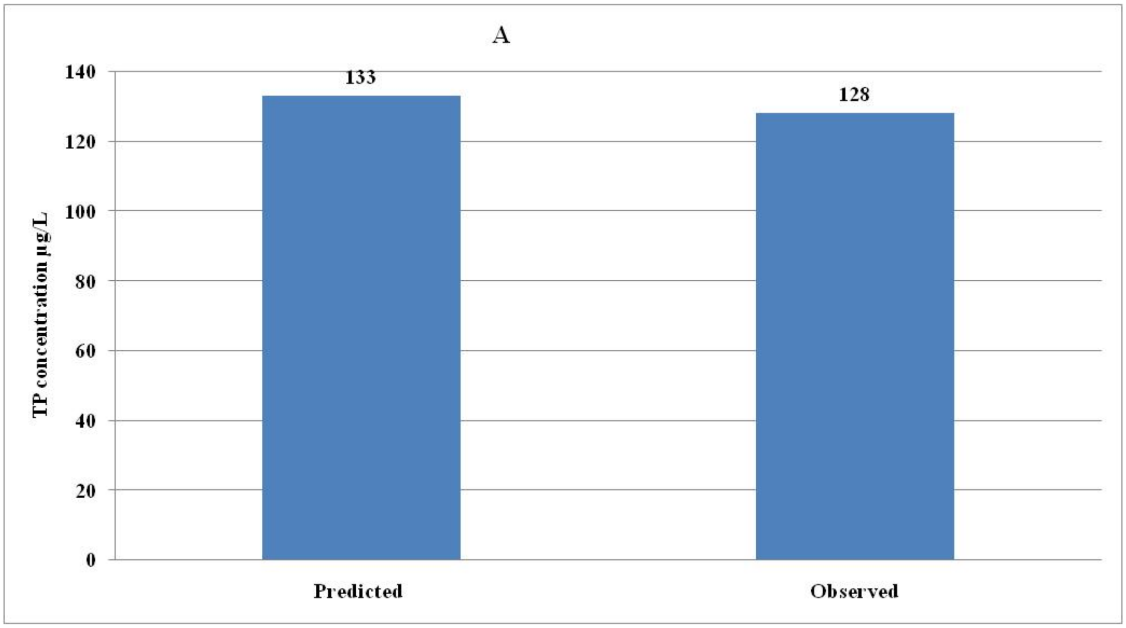

Figure 5.1 A. Predicted and observed water column total phosphorus (TP) concentrations without applying calibration factors in the model

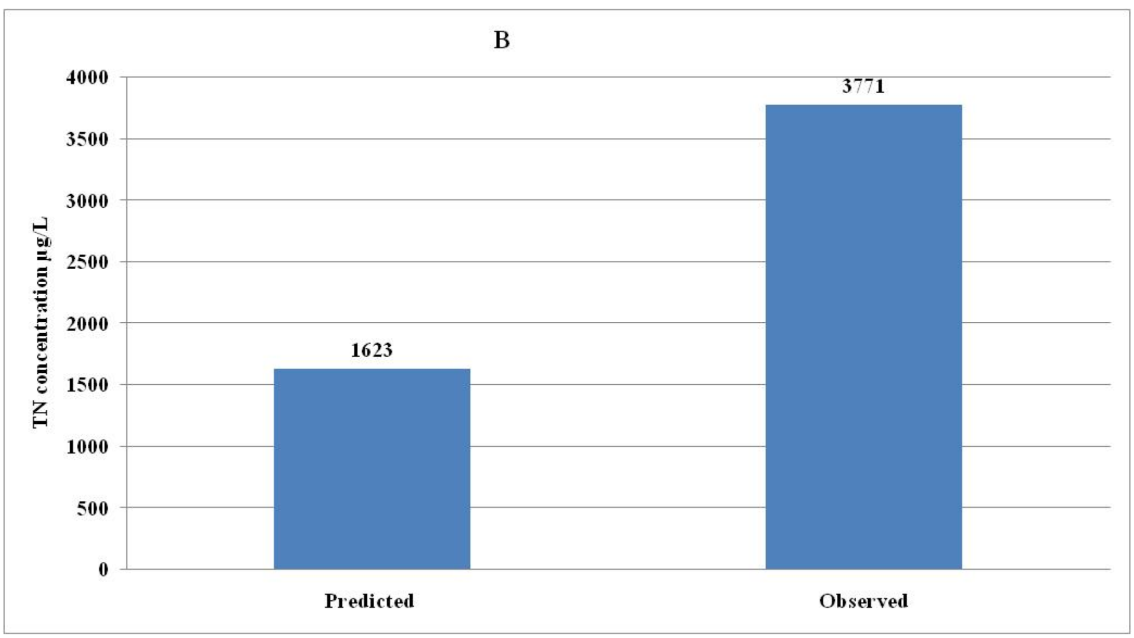

Figure 5.1 B. Predicted and observed water column total nitrogen (TN) concentrations without applying calibration factors in the model

applied in the BATHTUB model, and ultimately a rate of 13 mg/m^2/day was applied for 1995 to 1997, and a rate of 9 mg/m^2/day for 1998 (Table 5.4). With these nitrogen fixation rates, the model predicted the water column TN concentration well (Figure 5.2). The estimated N-fixation rates in the Newnans Lake BATHTUB model were comparable with N-fixation measured in Lake George on the St. Johns River (Paerl et al. 2005). Paerl et al. (2005) reported an average acetylene reduction rate of 5.5 nanomoles per microgram (nmol/µg) chlorophyll-a per hour. Assuming an active photosynthetic period of 8 hours per day and a light compensation depth of 1 meter, the photosynthetic N-fixation rate was about 15 mg/m^2/day.

Table 5.4. Nitrogen fixation rates applied in Newnans Lake BATHTUB model

Year	1995	1996	1997	1998
N-Fixation rate (mg/m^2/day)	13	13	13	9

mg/m^2/day = milligrams per square meter per day
N = nitrogen

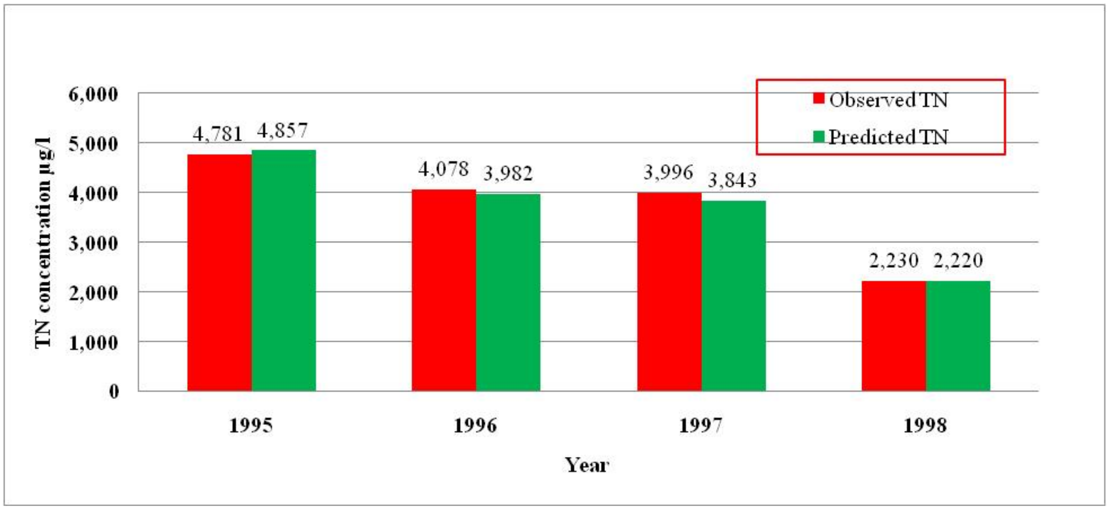

Figure 5.2. Predicted and observed average annual total nitrogen (TN) concentrations, 1995–1998, after nitrogen fixation rates were applied to the model

The lower N-fixation rate required in 1998 could be due to a shift in the lake's nutrient limitation. The ratio of dissolved inorganic nitrogen (DIN) to soluble reactive phosphorus (SRP) indicated that Newnans Lake was a nitrogen-limited system from

1995 through 1997, and it shifted to N and P co-limitation in 1998 (Table 5.5). Scott et al. (2005) found that N-fixation potential for periphyton in a wetland system was significantly decreased when the nutrient condition in the water column shifted from N limited to N and P co-limited. The significant increase in ammonium (NH_4^+) concentration in 1998 and 1999 was potentially another factor that led to lower N-fixation in both of the years (Figure 5.3). Wurtsbaugh et al. (1985) found that nitrogen fixation by cyanobacteria was stimulated 40–130% by PO_4 and Fe^{2+} and inhibited by NH_4^+. It should be noted that the applied N-fixation rates were integers and not applied to precisely match predicted and observed water column concentrations. This methodology blends unaccounted-for model error and N-fixation; however, the applied rates were within the range observed in other cyanobacteria-dominated lakes in Florida. In addition, the close agreement between the observed and modeled TP data suggest the watershed hydrology and nutrient loading are reasonable.

Table 5.5. Dissolved inorganic nitrogen to soluble reactive phosphorus ratio in Newnans Lake

Year	1995	1996	1997	1998
DIN/SRP	5	7	7	22

DIN = dissolved inorganic nitrogen
SRP = soluable reactive phosphorus

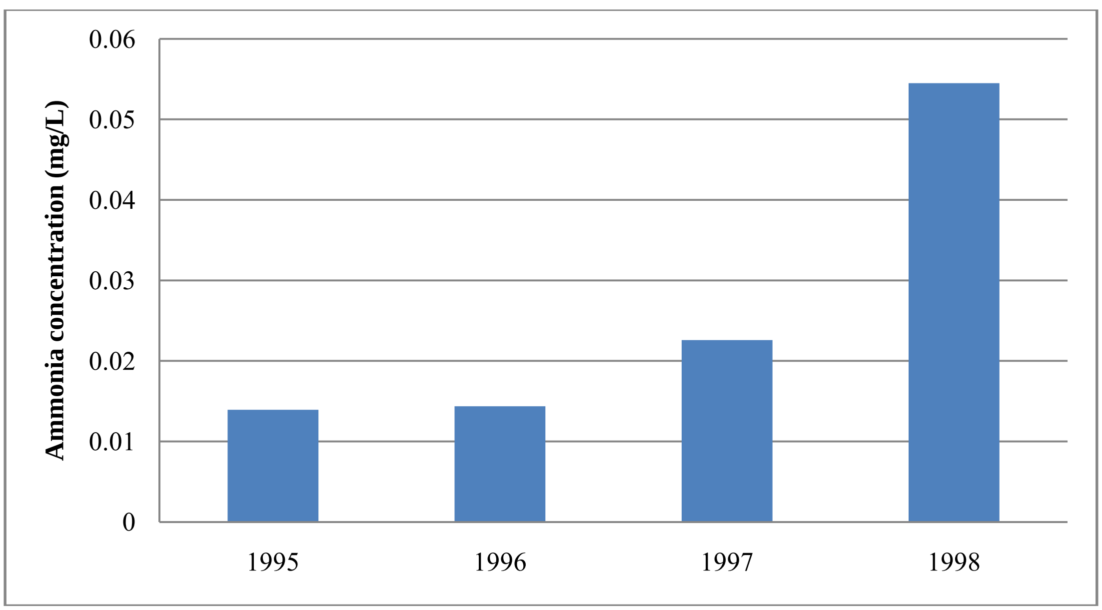

Figure 5.3. Average annual ammonium concentration in Newnans Lake

The BATHTUB model allows users to apply calibration factors to fit the predicted TN and TP concentrations to the observed data. The typical calibration factors for TN and TP recommended by the BATHTUB model user's manual are 0.5–2.0 for TP and 0.33–3.0 for TN. In the final calibrated model, we applied calibration factors of 0.96 for TP and 1.1 for TN.

Model Validation

The BATHTUB model was validated using annual flow and concentration data predicted by the watershed loading model for the years 1995–2005 (see Figures 5.8 and 5.9). The model predicted TP and TN concentrations well for most of the years except during 2000, 2001, and 2002. During those 3 years, the observed TP concentration was more than double the predicted value. The extremely high TP concentration observed in the lake probably related to the low lake stage level during those years as a result of a record drought. The average annual lake depth was less than 50 centimeters (cm) for those 3 years, and nutrient masses were concentrated in a declining lake volume. When the lake is so shallow, the flocculent sediment can be more easily mixed into the water column, causing higher TP concentrations. In addition, during these drought conditions, flow from Prairie Creek ceased. Thus, when the lake stage was equal to or less than 64 ft NGVD, the hydraulic residence time of the lake was undefined. Under this condition, the hydrologic residence time for this lake is much longer than 2 years, which is the upper boundary for the BATHTUB model's ability to reliably simulate water quality (Walker 1999). Water levels were historically low during most of those 3 years (Figure 5.4).

Because the goal of the model was to predict the impacts of nutrient loading during typical conditions, the stage data were screened to exclude unusual events. Based on the frequency analysis of lake stage data from 1936 to the present, the 5th percentile was determined and used as the filter for atypical stages. The stages during these 3 years were below the 5th percentile, and therefore, the model's results were not incorporated further in the PLRGs' development. The ability of the model to accurately predict TN and TP concentrations during years of no drought is indicated in Figures 5.5 and 5.6.

Estimate of the Current Annual N and P Watershed Loading Rate

To calculate the load reduction required to achieve the restoration TN and TP concentration targets the current loading rates must be calculated. The current TN and TP loading rates from all sources in the watershed including surface runoff from all the land uses as well as from point sources, base flow, atmospheric deposition, and N-fixation are presented in Figures 5.7 and 5.8. The current annual loading rates were estimated as 12,859 kg/yr for TP and 236,702 kg/yr for TN.

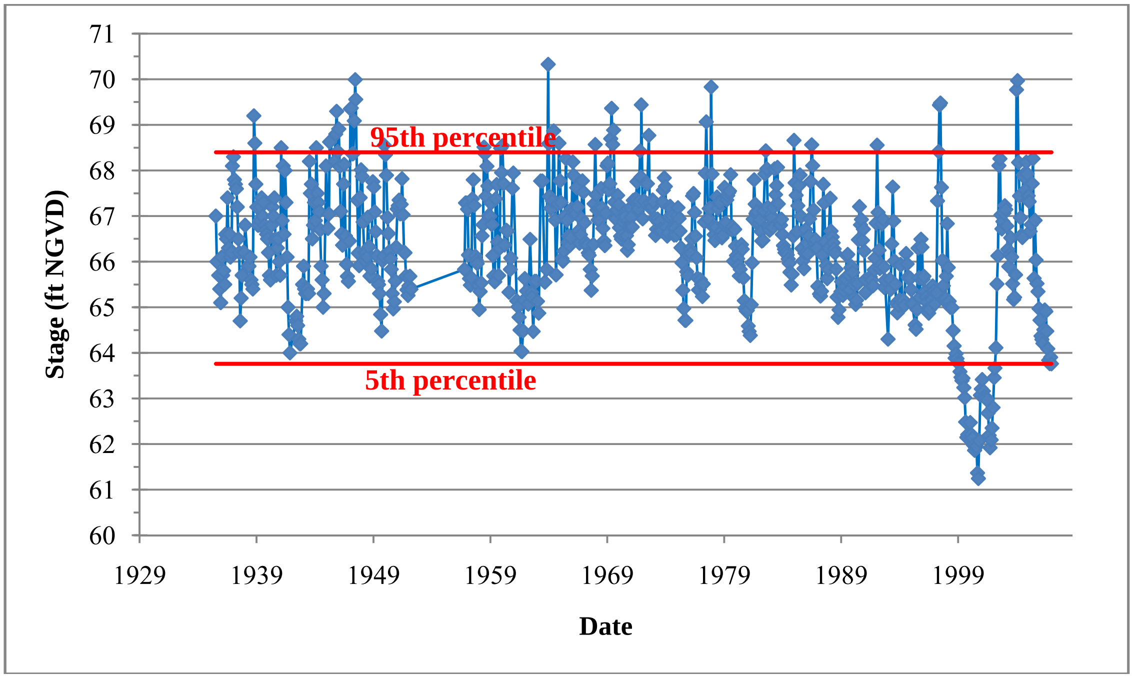

Figure 5.4. Newnans Lake stage, 1936-2007, with 5th and 95th percentiles

Only the annual average loading rates 1995–1998 and 2002–2005 were calculated to represent the current loading rates. This was done to exclude the atypical conditions that existed during the extreme drought period 1999–2001 in this area. Figure 5.9 shows the annual rainfall for 1995–2005 in the area at the Gainesville Regional Airport near Newnans Lake. The annual rainfall in these 3 years was about 23% to 40% less than the long-term average annual rainfall of 50.7 inches for Gainesville (Adkins and Rao 1995). Due to the extreme drought condition in those years, the watershed nutrient loading was significantly lower in 1999, 2000, and 2001 than that in the other 8 years of the model simulation period. For 3 years, the average annual TP loading from the watershed was about 5,300 kg, compared to the annual TP loading average of 12,860 kg over the other 8 years of the model simulation period.

Estimate of the Appropriate N and P Annual Loading For Achieving the Target Concentrations

The allowable TN and TP loads were estimated by adjusting the input load in the calibrated BATHTUB model until the in-lake target concentrations were met. The model estimated the allowable annual TN load as 80,706 kg/yr for the lake to equal

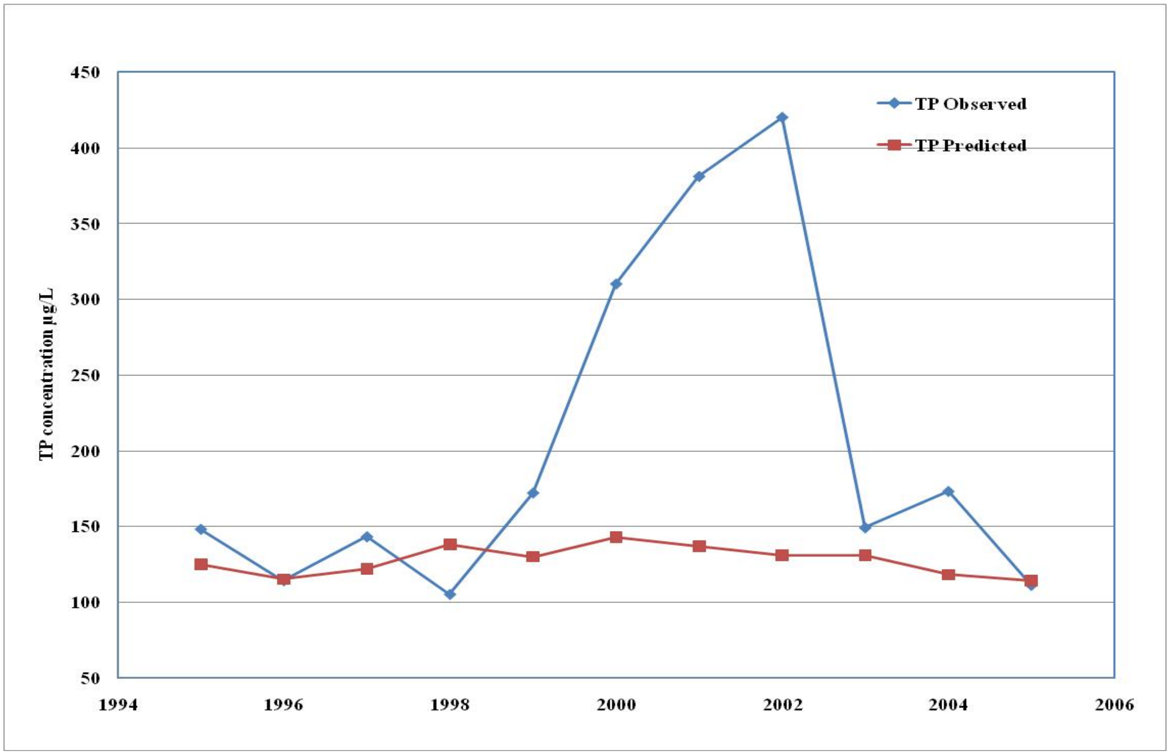

Figure 5.5. Observed and predicted mean annual total phosphorus (TP) concentrations in Newnans Lake

the TN concentration target of 1,294 µg/L. The current annual average TN load from the watershed is 118,144 kg/yr. In addition, an estimated 118,558 kg/yr is contributed by N-fixation processes in the lake, resulting in a total load of 236,702 kg/yr. Therefore, it will require 155,996 kg/yr nitrogen load reduction or 66% of the current mean annual loading to reach the target TN concentration (Table 5.6). We also estimated the watershed TN reduction needed to reach the TN target concentration if the N-fixation was eliminated as an input source. This would be accomplished by reducing the TP concentration in the lake sufficiently to decrease total phytoplankton productivity and biomass and shift the species composition from N-fixing taxa to other taxa. The TN reduction needed to reach the concentration target without N-fixation as an input source is 37,438 kg/yr or 32% of the current mean annual loading from the watershed.

For TP, the water column target concentration is 68 µg/L, which the model estimates will be met by an annual TP load of 6,703 kg/yr. The current total TP load is 12,859 kg/yr; therefore, a reduction of 6,156 kg/yr, or 48%, will be required for achieving the restoration target (Table 5.6).

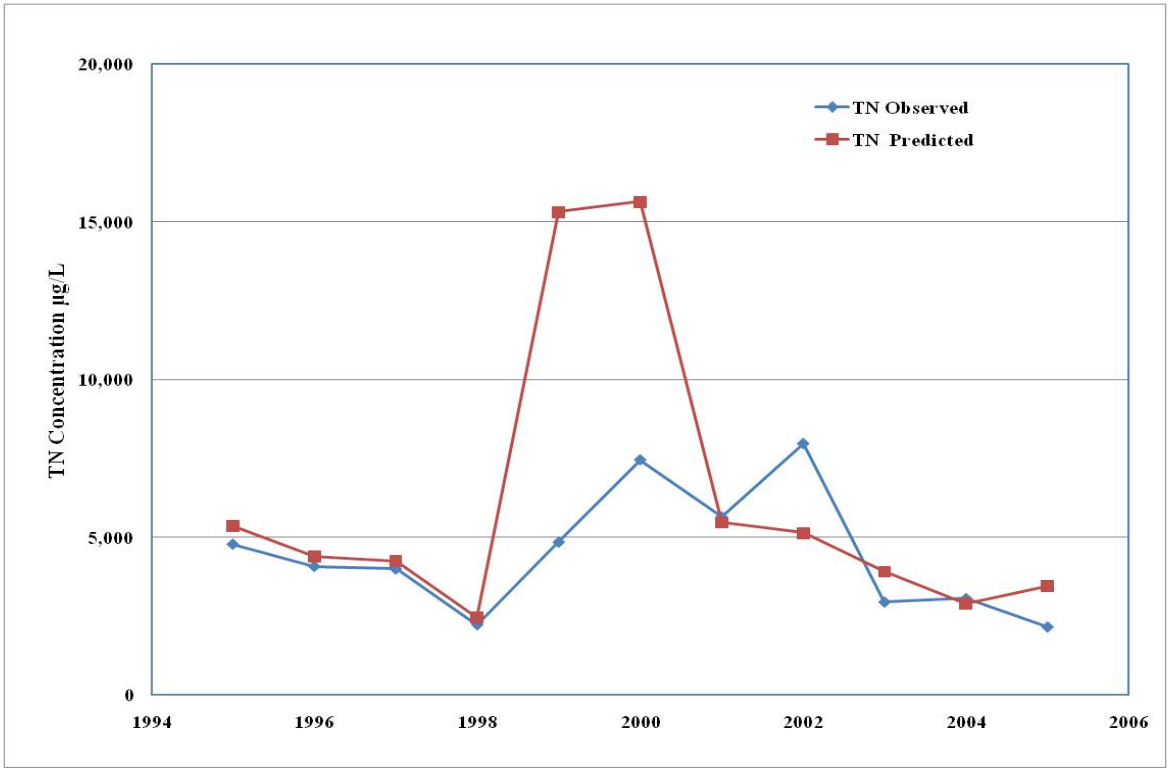

Figure 5.6. Observed and predicted mean annual total nitrogen (TN) concentrations in Newnans Lake

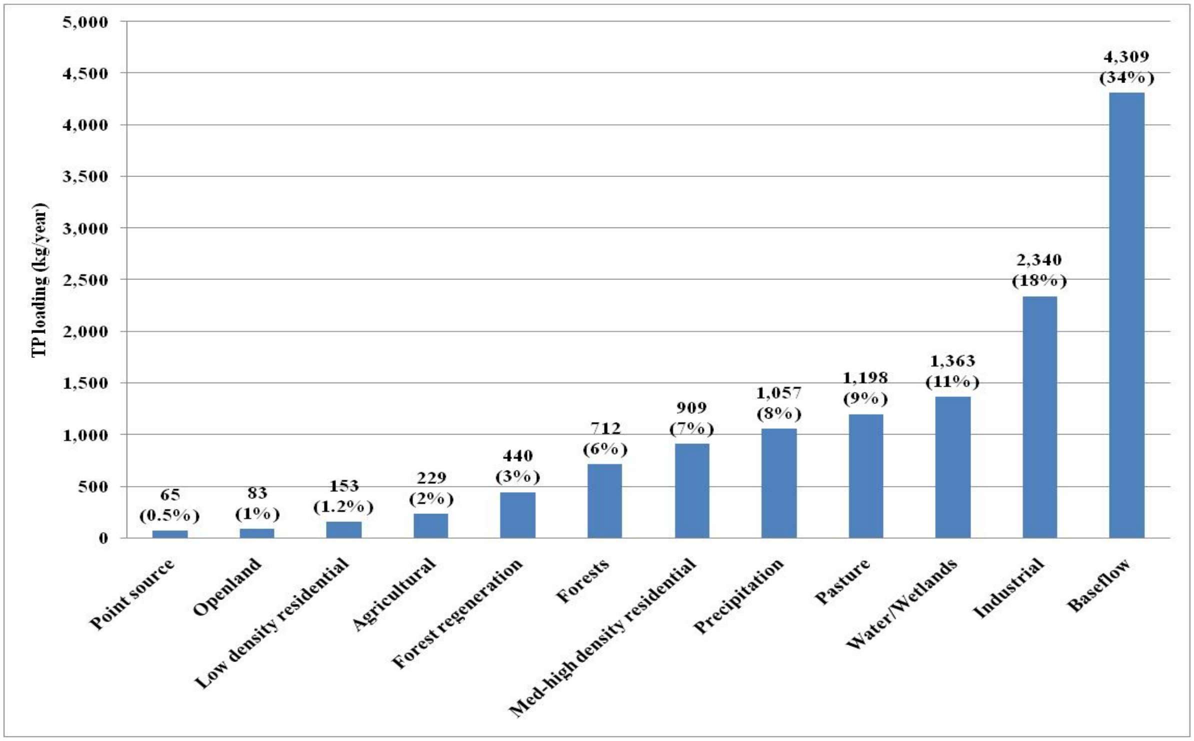

Figure 5.7. Average annual total phosphorus (TP) loading (kg/yr) from all sources in Newnans Lake watershed, under current conditions (total TP loading = 12,859 kg/yr)

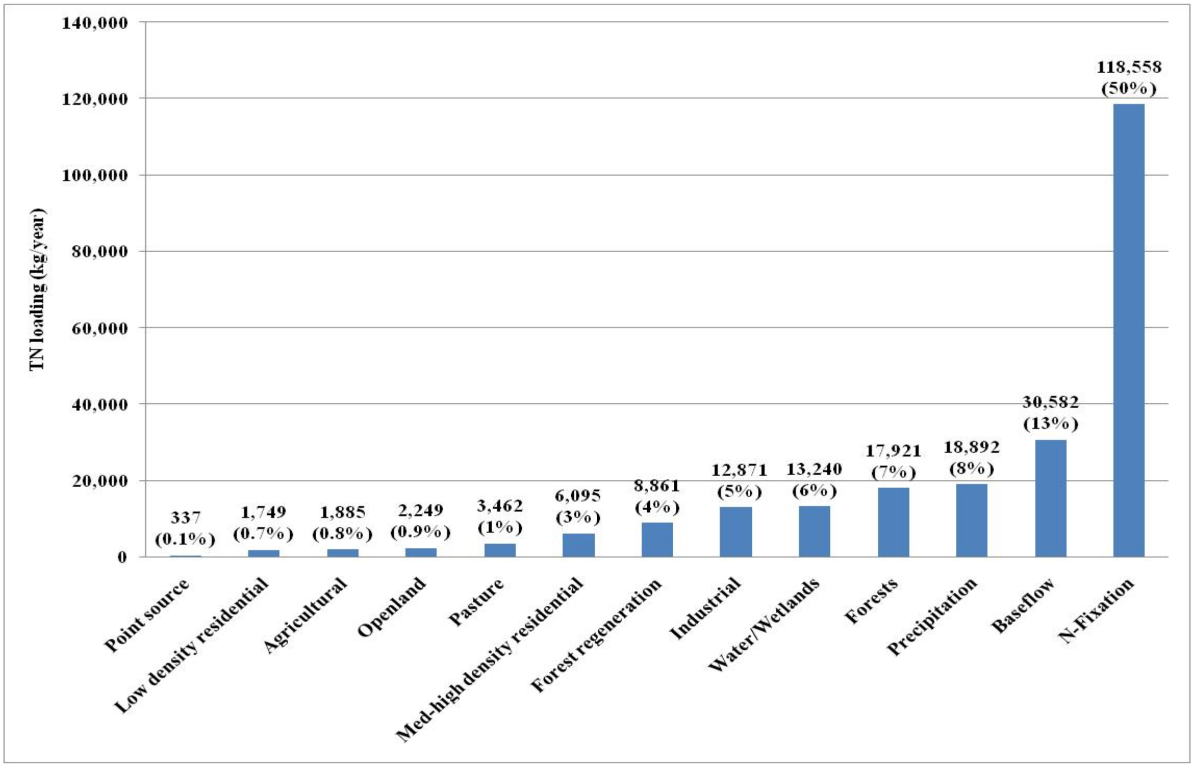

Figure 5.8. Average annual total nitrogen (TN) loading (kg/yr) from all sources in Newnans Lake watershed, under current conditions (total TN loading = 236,702 kg/yr)

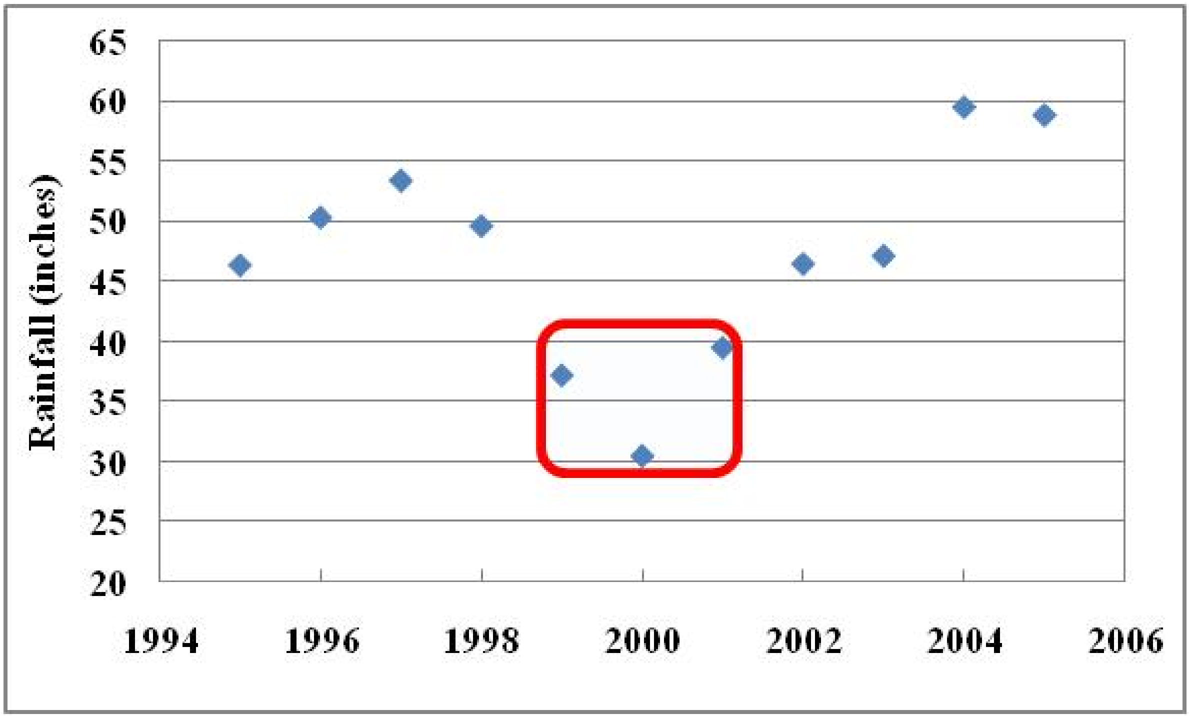

Figure 5.9. Annual rainfall at the Gainesville Regional Airport, 1995–2005

Table 5.6. Nitrogen and phosphorus loads and pollutant load reduction goals (PLRGs)

	Mean Annual Loading Rate (kg/yr)	Target Loading Rate (kg/yr)	Reduction Needed (kg/yr)	Percent Reduction Needed
TP	12,859	6,703	6,156	48%
TN	236,702	80,706	155,996	66%
TN (without N-fixation)	118,144	80,706	37,438	32%

TP = total phosphorus
TN = total nitrogen
PLRG = pollutant load reduction goal

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