Final Nutrient Total Maximum Daily Load

For Newnans Lake,

Alachua County, Florida

Xueqing Gao and Douglas Gilbert

Watershed Assessment Section

Florida Department of Environmental Protection

2600 Blair Stone Road, MS 3555

Tallahassee, FL 32399-2400

September 22, 2003

Table of Contents

List of Figures

List of Tables

Acknowledgments

This study could not have been accomplished without the significant contributions from other staff within the Watershed Assessment Section. Particular appreciation to Barbara Donner for her contributions. All of the basin delineation's, landuse aggregations, and much of the data gathering are a result of her efforts. Additional appreciation to Dr. TS Wu for his assistance and insights on modeling and to Dr. Paul Lee for his assistance in understanding the groundwater system. The Department also recognizes the substantial support and assistance provided by the St. Johns River Water Management District staff, particularly their contributions towards understanding the issues, history, and processes at work in the Newnans Lake watershed.

1. Introduction

1.1 Purpose of Report

This report represents the efforts to develop a nutrient TMDL for Newnans Lake (Lake) and to assess the impact of proposed total nitrogen reductions on the concentration of unionized ammonia in the Lake. The Lake, located in Central Florida near Gainesville (Figure 1), was verified as impaired by nutrients based on elevated levels of the Trophic State Index for lakes, and was included on the verified list of impaired waters for the Ocklawaha Basin that was adopted by Secretarial Order on August 28, 2002.

According to Section 303(d) of the federal Clean Water Act (CWA) and the Florida Watershed Restoration Act, Chapter 403, Florida Statutes, the Florida Department of Environmental Protection (DEP) is required to submit to EPA on a recurring basis lists of surface waters that do not meet applicable water quality standards (impaired waters). The methodologies used by the state for the determination of impairment are established in Rule 62-303, Identification of Impaired Surface Waters (IWR), Florida Administrative Code (FAC).

Once a water body or water body segment has been verified as impaired and referenced in the Secretarial Order Adopting the Verified List of Impaired Waters, work on establishment of the Total Maximum Daily Load (TMDL) begins. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions, so that states can establish water quality based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA, 1991)

1.2 Identification of Water Body

Newnans Lake is located in a topographical region of the state that is known as the Central Lowlands (Clark et al. 1964, Latitude $29^0$38'42", Longitude $82^0$13'8", Figure 1). The geology of the area is dominated by the Hawthorn formation, which is relatively impermeable and acts as a confining layer separating surface water from the influence of the Floridian Aquifer. Poorly drained soil, which is dominated by Pomona-Wachula-Newnans series, and low elevation gradients of the area result in moderately high sheetflow and poorly defined channels. Ponds and wetlands occur throughout the area. The major sources of water to the lake include surface runoff, subsurface flow, and direct rainfall (Canfield 1981).

The lake has an average surface area of about 7,200 acres and is a typical shallow basin lake. The maximum depth is not more than 12 feet, and the mean depth is approximately 5 feet (Nordilie, 1979). A large drainage area north of the lake supplies inflow via two major streams: Hatchet Creek and Little Hatchet Creek. The lake has a single major surface-water outlet, Prairie Creek. Once water leaves the lake, it is split into two parts. Based on long-term USGS flow measurements (1942-1991), about 41% of the flow from Newnans lake goes to the south into Paynes Prairie, and the rest flows towards Orange Lake by way of Camp's Canal (Gottgens and Montague 1987). In 1966, a weir was constructed at the outlet of Newnans Lake by the Alachua County Recreation and Water Conservation and Control Authority (ACRWCCA) to increase the water level. The weir was altered in 1976 by the Florida Game and Fresh Water Fish Commission (FGFWFC) to include removable boards for lake management purposes.

Boards were removed from the weir for five months in 1989 to increase lake level fluctuations and were totally removed in 1991 to increase lake level fluctuation.

For assessment purposes, the State of Florida has been divided into water body assessment polygons termed Water Body Ids or WBIDs. Additional information about the derivation and use of these WBIDs is provided in the "Documentation For The 2002 Update To The State Of Florida's 303(d) List" dated October 1, 2002, and GIS shapefiles of the WBIDs can be obtained from the following website:

http://www.floridadep.org/water/watersheds/basin411/downloads.htm

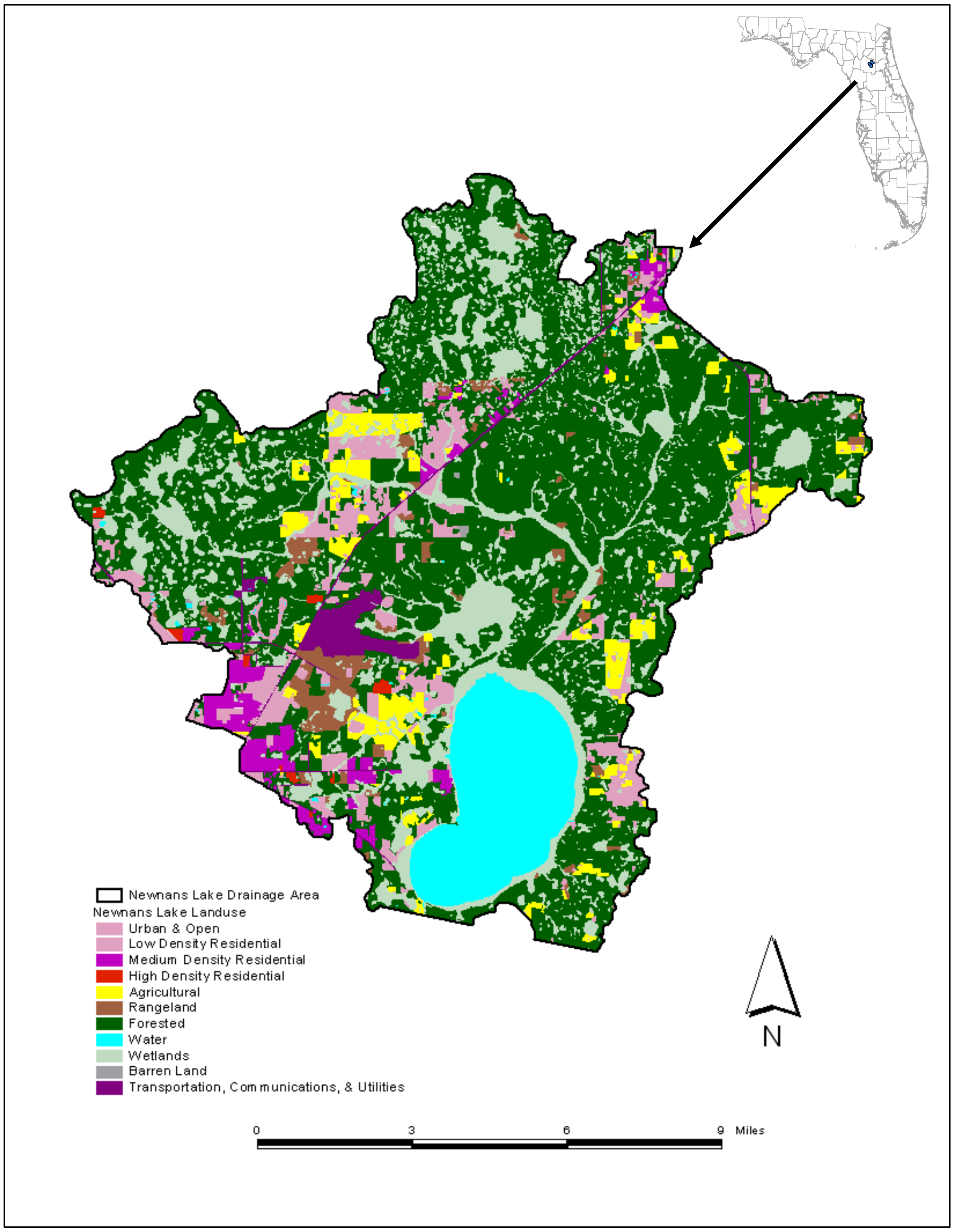


Figure 1. The general location and landuse types of Newnans Lake watershed.

2. Description of Applicable Water Quality Standards and Criteria

Newnans Lake is classified as a Class III Freshwater body, with a designated use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The Class III water quality criteria applicable to the observed impairment is the narrative nutrient criterion (nutrient concentrations of a body of water shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna). Because the nutrient criterion is narrative only, a nutrient related target was needed to represent levels at which imbalance in flora or fauna are expected to occur. For this TMDL, the IWR threshold for impairment for lakes, which is based on a trophic state index (TSI), was used as the water quality target.

The TSI originally developed by R. E. Carlson (1977) was calculated based on Secchi depth, chlorophyll concentration, and total phosphorus concentration and was used to describe a lake's trophic state. Carlson's TSI was developed based on the assumption that the lakes were all phosphorus limited. In Florida, because the local geology produced a phosphorus rich soil, nitrogen can be the sole or co-limiting factor for phytoplankton population in some lakes. In addition, because of the existence of dark-water lakes in the state, using Secchi depth as an index to represent lake trophic state can produce misleading results. Therefore, the TSI was revised to be based on chlorophyll a, total nitrogen, and total phosphorus concentrations.

The Florida-specific TSI was determined based on the analysis of data from 313 Florida lakes. The index was adjusted so that a chlorophyll a concentration of 20 ug/L was equal to a TSI value of 60. A TSI of 60 was then set as the threshold for nutrient impairment for most lakes (for those with a color higher than 40 platinum cobalt units) because, generally, the phytoplankton may switch to communities dominated by blue-green algae at chlorophyll a levels above 20 ug/L. These blue-green algae are often an unfavorable food source to zooplankton and many other aquatic animals. Some blue-green algae may even produce toxins, which could be harmful to fish and other animals. In addition, excessive growth of phytoplankton and the subsequent death of these algae may consume large quantity of dissolve oxygen and result in anaerobic condition in lakes, which makes conditions in the impacted lake unfavorable for fish and other wildlife. All of these processes may negatively impact the health and balance of native fauna and flora.

Because of the amazing diversity and productivity of Florida lakes, some lakes have a natural background TSI that is different from 60. In recognition of this natural variation, the IWR allows for the use of a lower TSI (40) in very clear lakes, a higher TSI if paleolimnological data indicate the lake was naturally above 60, and the development of site-specific thresholds that better represent the levels at which nutrient impairment occurs. For this study, the Florida Department of Environmental Protection (DEP) used modeling to estimate the natural background TSI by setting land uses to natural or forested land, and then compared the TSI to the IWR thresholds. If the natural background TSI is higher than 60, then the natural background TSI will be used as the water quality target for the TMDL because it is unreasonable to abate the natural background condition. If the natural background TSI is lower than 60, then the IWR threshold (a TSI of 60) will be established as the target for TMDL development (since Newnans Lake has a mean color greater than 40 platinum cobalt units, the IWR threshold for impairment is 60).

3. STATEMENT OF PROBLEM

Analyses of pollen and diatoms in several sediment cores from the lake indicate that the lake was formed between 5000 and 8000 years ago and that it has been eutrophic throughout its history (Holly 1976). However, water quality data from the last 15 years indicates that the lake has experienced accelerated eutrophication and elevated TSIs (SJRWMD 2002) (Table 3). Based on data in the DEP database (IWR-data), the long-term (1989 – 2000) average concentrations of total phosphorus (TP), total nitrogen (TN), and chlorophyll a (Chla) were 0.120 mg/L, 3.323 mg/L, and 173.4 µg/L, respectively. The TP, TN, and Chla concentrations were even higher for the verified period for the IWR assessment (1995 –2000), with mean values of 0.151 mg/L, 4.340 mg/L, and 249 ug/L, respectively. The mean color of the lake was calculated as 69 platinum-cobalt units. The average TSI for the verified period is 89.3, well above the IWR annual average TSI threshold for nutrient impairment for lakes.

4.0 Assessment of Sources

4.1 Types of Sources

An important part of the TMDL analysis is the identification of source categories, source subcategories, or individual sources of nutrients in the Newnans Lake watershed and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either “point sources” or “nonpoint sources.” Historically, the term point sources has meant discharges to surface waters that typically have a continuous flow via a discernable, confined, and discrete conveyance, such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of traditional point sources. In contrast, the term “nonpoint sources” was used to describe intermittent, rainfall driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, runoff from agriculture, runoff from silviculture, runoff from mining, discharges from failing septic systems, and atmospheric deposition.

However, the 1987 amendments to the Clean Water Act redefined certain nonpoint sources of pollution as point sources subject to regulation under EPA’s National Pollutant Discharge Elimination Program (NPDES). These nonpoint sources included certain urban stormwater discharges, including those from local government master drainage systems, construction sites over five acres, and from a wide variety of industries (see Appendix A for background information about the State and Federal Stormwater Programs).

For the purposes of allocating pollutant load reductions (see Section 6) required by a TMDL, the term “point source” will be used to describe traditional point sources (such as domestic and industrial wastewater discharges) AND stormwater systems requiring an NPDES stormwater permit. However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this section does not make any distinctions between the two.

4.2 Estimating TN and TP loadings using WMM

<u>Overall Strategy to Determine Loadings and Assimilative Capacity</u>

The goal of the nutrient TMDL development for Newnans Lake is to identify the maximum allowable TP and TN loadings to the lake so that the lake will meet the water quality standard and maintain its function and designated use as a Class III water. Specifically, the goal is interpreted in this study as a TSI of 60 or the natural background TSI if the natural background is higher than 60. While TMDL development is a very complex process, the process used for this TMDL can be divided into three main steps:

1. TN and TP loadings from various point and nonpoint sources in the Newnans Lake watershed were estimated using the Watershed Management Model (WMM).
2. Loading estimates from the WMM were entered into the Bathtub eutrophication model to establish the relationship between TN and TP loadings and in-lake TN, TP, and Chla concentrations. The model results for in-lake TN, TP, and Chla were used to calculate TSI-predicted (TSI-P) for several different loading scenarios discussed later.
3. The loadings to the lake were adjusted until the TSI-P calculated from the model results was less than 60, and the TN and TP loadings that resulted in a TSI below 60 were the nutrient TMDL for Newnans Lake.

<u>Breakdown of Sub-basins and Landuses</u>

The Newnans Lake watershed drains an area of about 74,730 acres. For modeling purposes, the watershed was broken into three sub-basins (Figure 2). These sub-basins are Little Hatchet Creek sub-basin (LHC – the area discharging directly into Little Hatchet Creek), Hatchet Creek sub-basin (HC – the area discharging directly into Hatchet Creek), and Newnans Lake sub-basin (NL – the area discharging directly into Newnans Lake).

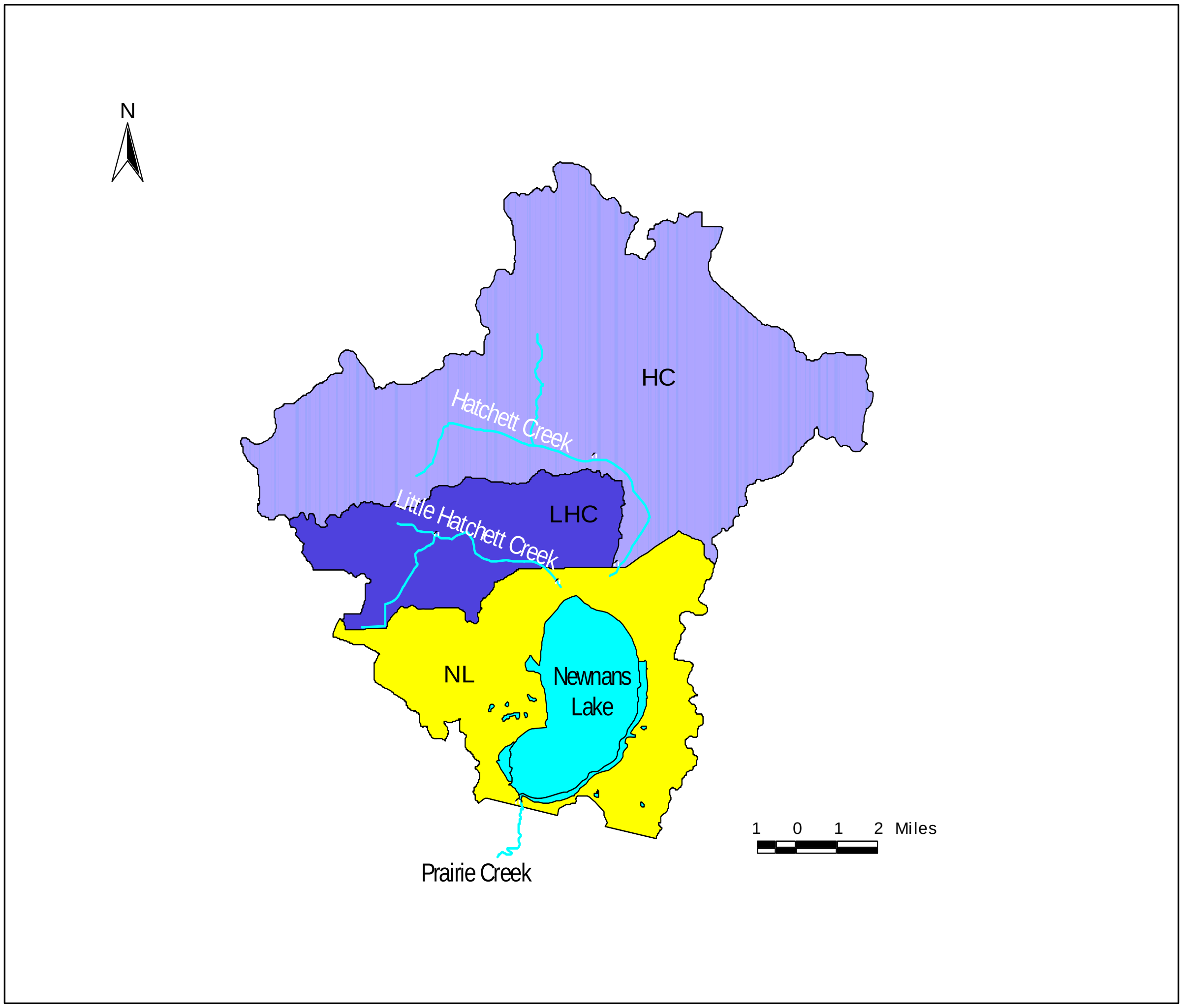


Figure 2. Sub-basins of Newnans Lake watershed. LHC, HC, and NL represent Little Hatchet Creek, Hatchet Creek, and Newnans Lake sub-basins, respectively.

Landuse categories in each sub-basin were aggregated using the simplified level 1 codes tabulated in Table 1. The spatial distribution of different landuse types of the Newnans Lake watershed is demonstrated in Figure 1.

Table 1. Classification of landuse categories of Newnans Lake

Code	Landuse Urban Open	Acreage
1000	Urban Open	2366
	Low density resident	3348
	Medium density resident	1891
	High density resident	205
2000	Agriculture	3444
3000	Rangeland	1935
8000	Transportation, communication, and utilities	1524
4000	Forest/rural open	39134
5000/6000	Water/Wetland	20883

Source assessment: potential sources of TN and TP in Newnans Lake watershed

The TN and TP loadings to Newnans Lake are generated from both nonpoint and point sources.

Nonpoint sources addressed in this study include TN and TP loadings from surface runoff, stream baseflow, precipitation directly on the surface of the lake, and the contribution from leaking septic tanks. TN and TP loadings through surface runoff were estimated using the Watershed Management Model (WMM) based on the imperviousness and event mean concentration (EMC) of TN and TP from the different landuse types of the watershed. The spatial distribution and acreage of different landuse categories were identified using the St. Johns River Water Management District (SJRWMD) 1995 landuse coverage (scale 1:40,000) contained in the DEP GIS library. Methods used to estimate the TN and TP loadings from stream baseflow, precipitation directly on the surface of the lake, and the contribution from leaking septic tanks are described in detail in Section 5.2.

Brittany Estates Mobile Home Park (Permit number: FL0040215) was the only point source discharger identified in the Newnans Lake watershed. The facility was identified using the Permit Compliance System (PCS). The facility discharges into Little Hatchet Creek, which in turn flows into Newnans Lake. Detailed information about the TN and TP loading capacity of this facility is discussed in Section 5.2.

Estimating Watershed TN and TP Loading from Nonpoint Sources

WMM development was originally funded by DEP under contract to Camp Dresser and McKee (CDM). CDM further refined and developed the model to its present state. WMM is a watershed model designed to estimate annual or seasonal pollutant loadings from a given watershed and evaluate the effect of watershed management strategies on water quality (WMM User's Manual: 1998). While the strength of the model is its capability to characterize pollutant loadings from nonpoint sources, such as those through stormwater runoff, stream baseflow, and leakage of septic tanks, the model also handles point sources such as discharge from wastewater treatment facilities. Estimation of pollution load reduction due to partial or full-scale implementation of onsite or regional best management practices (BMP) is also part of the functions of this model. The fundamental assumption of the model is that the stormwater runoff from any given landuse is in direct proportion to annual rainfall and is dictated by the portion of the landuse category that is impervious and the runoff coefficients of both pervious and impervious area. The governing equation is:

(1) $R_L = [C_p + (C_I – C_p)\ IMP_L] * I$

Where:

R_L	=	total average annual surface runoff from land use L (in/yr);
IMP_L	=	fractional imperviousness of land use L;
I	=	long-term average annual precipitation (in/yr);
C_P	=	pervious area runoff coefficient; and
C_I	=	impervious area runoff coefficient.

The model estimates pollutant loadings based on nonpoint pollution loading factors (expressed as lbs/ac/yr) that vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for each land use L by the following equation:

(2) $M_L = EMC_L * R_L * K$

Where:

M_L	=	loading factor for land use L (lbs/ac/yr);
EMC_L	=	event mean concentration of runoff from land use L (mg/L); EMC varies by land use and pollutant;
R_L	=	total average annual surface runoff from land use L computed from Equation (1) (in/yr); and
K	=	0.2266, a unit conversion constant.

Data required for WMM application include:

- Area of all the landuse categories and the area served by septic tanks
- Percent impervious area of each landuse category
- EMC for each pollutant type and landuse category
- Percent EMC of each pollutant type that is in suspended form
- Annual precipitation
- Annual baseflow and baseflow concentrations of pollutants
- Point source flows and pollutant concentrations.

Calibration of WMM was conducted on both runoff quantity and quality. This was a two-step procedure since the water quality calibration is a function of the predicted runoff volumes. Calibration of water quantity is usually achieved through adjusting the pervious and impervious area runoff coefficients. Typical ranges of runoff coefficients are 0.05 – 0.30 for pervious area

(WMM User's Manual: 1998) and 0.85 – 1.0 for impervious area (Linsley and Franziani, 1979). After the water quantity calibration, water quality was calibrated by adjusting the pollutant delivery ratio – the percent quantity of pollutant in the surface runoff that is eventually delivered to the destination waterbody. In this study, the range of the pollutant delivery ratio was estimated using the method developed by Roehl (1962) that correlates the delivery ratio to watershed area. The calibration results will be presented and discussed in Section 5.

4.3 Lake Modeling Using the Bathtub Model

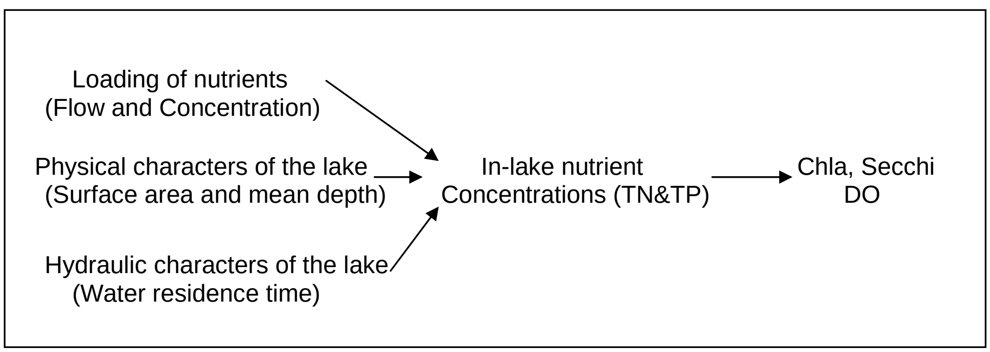
<u>Bathtub eutrophication model</u>

The Bathtub eutrophication model is a suite of empirically derived steady state models developed by the U. S. Army Corps of Engineering (ACOE) Waterways Experimental Station. The primary function of these models is to estimate nutrient concentrations and algal biomass resulting from different patterns of nutrient loadings. The procedures for selection of the appropriate model for a particular lake are described in the Users Manual. The empirical prediction of lake eutrophication using this approach typically can be described as a two stage procedure using the following two categories of models (Walker 1999):

- *Nutrient balance model.* This type of model relates in-lake nutrient concentration to external nutrient loadings, morphometry, and hydrology.
- *Eutrophication response model.* This type of model describes relationships among eutrophication indicators within the lake, including nutrient levels, Chla, transparency, and hypolimnetic oxygen depletion.

Figure 3 describes the concept scheme used by Bathtub to relate external loading of nutrients to the in-lake nutrient concentrations and the physical, chemical, and biological response of the lake to the level of nutrients.

Figure 3. Bathtub concept scheme



The *nutrient balance model* adopted by Bathtub assumes that the net accumulation of nutrients in a lake is the difference between nutrient loadings into the lake from various sources and the nutrients carried out through outflow and losses of nutrient through whatever decay process occur inside lake:

(3) Net accumulation = Inflow – Outflow – decay

Equation (3) is solved by assuming that the pollutant dynamics in the lake is at a steady state, i.e. the net accumulation of the pollutant in the lake equals zero.

In this study, "inflow" included TN and TP loadings though stormwater surface runoff from various landuse categories, baseflow, a point source, leakage of septic tanks, atmosphere precipitation, and potential loadings from internal recycling from the sediment of the lake. Nutrient outflow was considered primarily through the outflow stream. To address nutrient decay within the lake, Bathtub provided several alternatives depending on the inorganic/organic nutrient partitioning coefficient and reaction kinetics. The major pathway of decay for TN and TP in the model is through sedimentation to the bottom of the lake.

Prediction of the *eutrophication response* by Bathtub also involves choosing one of several alternative models depending on whether the algal communities are limited by phosphorus or nitrogen, or co-limited by both nutrients. Scenarios that include algal communities limited by light intensity or controlled by the lake flushing rate are also included in the suit of models. In addition, the response of chlorophyll a concentration to the in-lake nutrient level is characterized by two different kinetic processes: linear or exponential. The variety of models available in Bathtub allows the user to choose specific models based on the particular condition of the project lake.

One feature offered by Bathtub is the "calibration factor." The empirical models implemented in Bathtub are mathematical generalizations about lake behavior. When applied to data from a particular reservoir, measured data may differ from predictions by a factor of two or more. Such differences reflect data limitations (measurement or estimation errors in the average inflow and outflow concentrations), unique features of the particular lake (Walker 1999), and unexpected processes inherent to the lake. The calibration factor offered by Bathtub provides model users with a method to calibrate the magnitude of lake response predicted by the empirical models. The model calibrated to current conditions against measured data from the lake can then be applied to predict changes in lake conditions likely to result from specific management scenarios under the condition that the calibration factor remains constant for all prediction scenarios.

Steady State Assumption for the Lake

Before Bathtub could be used to establish a relationship between TN and TP loadings and the in-lake TN, TP, and Chla concentrations, the input and output of TN and TP were analyzed to examine the presumption of steady state. Usually, if the input of TN and TP to the lake is significantly lower than the output, internal recycling is assumed. Based on reviewing the IWR-data, the Department concluded that internal recycling was occurring during the verified period and that the Lake was not at steady state during most of this period. In this study, the rate of TN and TP internal recycling for Newnans Lake was not available and therefore literature published values were adopted (James and Bierman 1995).

Data requirement for running Bathtub

Data requirement for Bathtub model includes:

- Physical characteristics of the lake (surface area, mean depth, length, and mixed layer depth)
- Meteorological data (precipitation and evaporation retrieved from Climate Interactive Rapid Retrieval Users System of National Climate Data Center)

- Measured water quality data (TN, TP, and Chla concentrations of the lake water, TN and TP concentrations in precipitation, etc.)
- Loading data (flow and TN and TP concentrations of the flow from various point and nonpoint sources, flux of TN and TP from internal recycling, and flow and TN and TP concentrations of outflow water)
- Coefficient of variance (CV) of all the measured data

<u>Calculation of Trophic State Index (TSI)</u>

TSI values were calculated using the procedures outlined in Florida's 1996 305(b) report:

$TSI = (CHLA_{TSI} + NUTR_{TSI})/2$

Where:

$CHLA_{TSI} = 16.8 + 14.4 \times LN\ (CHLA)]$

$TN_{TSI} = 56 + [19.8 \times LN(TN)]$

$TN2_{TSI} = 10 \times [5.96 + 2.15 \times LN(TN + 0.0001)]$

$TP_{TSI} = [18.6 \times LN(TP \times 1000)] -18.4$

$TP2_{TS} = 10 \times [2.36 \times LN(TP \times 1000) - 2.38]$

The procedure addresses limiting nutrient considerations by calculating $NUTR_{TSI}$:

If $TN/TP > 30$ then $NUTR_{TSI} = TP2_{TSI}$

If $TN/TP < 10$ then $NUTR_{TSI} = TN2_{TSI}$

If $10 < TN/TP < 30$ then $NUTR_{TSI} = (TP_{TSI} + TN_{TSI})/2$

<u>Error and variability analysis</u>

The distinction between "error" and "variability" is important. Error refers to a difference between a measured and a predicted mean value and is usually described as: the absolute value of |measurement – prediction/measurement. Variability refers to spatial or temporal fluctuations in measurement around the mean. Spatial variability is not usually included in the variability analysis of empirical modeling efforts. Empirical modeling variability analysis usually concentrates on those changes caused by temporal fluctuation.

Variability is frequently described using the mean coefficient of variance (CV), which is defined as the standard error (SE) of the estimate expressed as a fraction of the predicted value (Walker 1999). In this study, model estimates were presented as mean ± 1SE whenever a CV could be determined.

When WMM was calibrated against measured water quantity and quality data, only error analysis was conducted. This was because the variability analysis of WMM required CVs for the EMC of TN and TP from different landuse categories and the CV for the suspended fraction of TN and TP from different landuse categories. Because we did not have these CVs, the variability analysis was not conducted with WMM. Additionally, WMM does not have a place to input CVs of the measured annual precipitation and baseflow. WMM calibration was conducted using all the years for which we have data and efforts were made to make sure that the error between model estimates and measured data were no greater than 10% for all the years.

Bathtub allows the input of the CV for both measured data and model predictions from WMM. Therefore, both error and variability analyses were conducted with Bathtub. To accomplish this, several years of measured data from the non-model variables (precipitation, lake volume, and evaporation) and the WMM predictions (TN, TP, and flow) were averaged and the mean values and CVs of these data were entered to Bathtub as input.

4.4 TMDL Scenario Development for Newnans Lake

Formatted: Bullets and Numbering

Once WMM and Bathtub model calibrations were achieved (results discussed in the next section), the TMDL of the lake was developed through evaluating TSIs of the following scenarios:

A. TSI of current condition
B. TSI after the internal recycling was addressed
C. TSI after both the internal recycling and all the human landuse categories (urban open, low, medium, and high density residential, agriculture and rangeland, and transportation, communication, and utilities) were removed

Scenario C was considered the natural background condition of the lake. The TN and TP loadings that result in a TSI of 60 would typically be considered as the TMDL of the lake. However, if the TSI of Scenario C were higher than 60, it would become the new target TSI threshold for the lake.

Available Data and Data Use

Model calibration and simulation of this study requires a historical record of several types of data. These data types and their availability are listed in Table 2.

Table 2. Data types that are required to have historical records and the period these data are availability

Data type	Available time period
Precipitation	1990 – 2000
Stream flow	1996 –2000
Lake stage	1996 –2000
Stream water quality data	1995 – 2000
Lake water quality data	1989 –2000

Because calibration of the model requires that data from the different types be in the same time period, 1996 to 2000 were chosen as the years from which data were used for model calibration.

5. RESULTS

5.1 Data Analysis

Historical trend of trophic status of Newnans Lake

Monthly TN, TP, and Chla concentrations for Newnans Lake from 1989 through 2000 were retrieved from the IWR-data. The locations of the individual stations from which water quality data were collected are shown in Figure 4. Analysis of the data indicated that the spatial variation between stations across Newnans Lake is not significant. Therefore, data from all the stations within Newnans Lake were pooled together and treated as data collected from one station. Quarterly mean values for TN, TP, and Chla concentrations were calculated based on the monthly data and quarterly TSIs were calculated based on the quarterly mean values of TN, TP, and Chla concentrations. Quarterly TN, TP, Chla, and TSI values were then used to calculate annual mean values.

The seasonal trend of TN, TP, Chla, and TSI were examined by calculating the long-term quarterly mean values based on the quarterly mean values of each year (1989 – 2000). The quarterly means for the verified period were calculated using the data from 1995 through 2000. The individual annual mean TN, TP, Chla, and TSI values are listed in Table 3 and the long-term quarterly TN, TP, Chla, and TSI results are listed in Table 4.

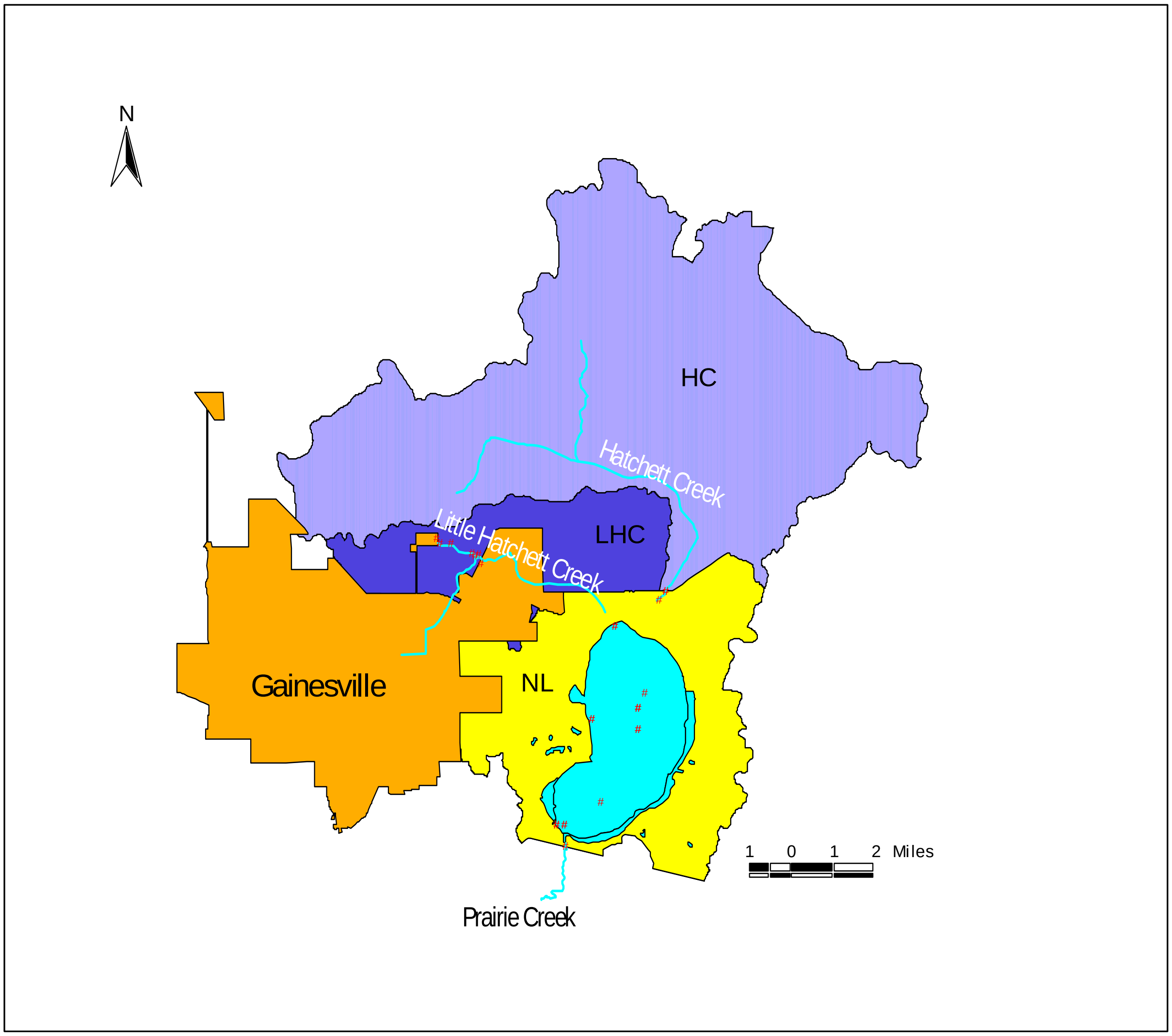


Figure 4. Locations of water quality stations

As shown in Table 3, the long-term annual average of TN, TP, and Chla concentrations are 3.32 mg/L, 0.120 mg/L, and 173.4 µg/L, respectively. The long term TSI is 79 ± 4. Long-term average TN/TP ratio is about 29, indicating that the algal communities in this lake may be either co-limited by both nitrogen and phosphorus, or phosphorus limited. For the verified period, the TN, TP, and Chla concentrations are 4.34 ± 0.73 mg/L, 0.151 ± 0.03 mg/L, and 249.0 ± 26.2 µg/L, respectively. The TSI of the verified period is 89 ± 3. Based on these data, the lake is eutrophic and exceeded the IWR TSI threshold of 60 for lakes.

Table 3. Annual averages of TN, TP, Chla, and TSI values of Newnans Lake from 1989 through 2000. Data represent mean ± 1SE (n=4)

	TN	TP	Chla	TSI
	(mg/L)	(mg/L)	(µg/L)	
1989	1.56± 0.11	0.082± 0.006	45.1± 13.1	63± 6
1990	1.57± 0.47	0.081± 0.008	32.1± 4.3	58± 9
1991	1.87± 0.17	0.070± 0.012	62.1± 19.7	70± 2
1992	3.00± 0.47	0.083± 0.017	68.1± 15.8	57± 19
1993	2.52± 0.46	0.110± 0.005	132.4± 14.2	79± 1
1994	3.31± 0.32	0.099± 0.006	245.9± 45.0	88± 4
1995	**4.10± 0.13**	**0.120± 0.007**	**271.8± 26.6**	**93± 1**
1996	**3.80± 0.15**	**0.111± 0.008**	**272.2± 24.8**	**90± 1**
1997	**3.81± 0.09**	**0.126± 0.008**	**261.8± 18.6**	**89± 1**
1998	**2.36± 0.09**	**0.089± 0.003**	**120.5± 27.4**	**77± 1**
1999	**4.26± 0.10**	**0.172± 0.012**	**269.6± 14.1**	**90± 1**
2000	**7.70± 0.12**	**0.291± 0.013**	**298.8± 11.3**	**97± 1**
Mean-L	3.32± 0.49	0.120± 0.018	173.4± 30.4	79± 4
Mean-V	4.34± 0.73	0.151± 0.030	249.0± 26.2	89± 3
Mean-P	2.31± 0.31	0.088± 0.006	97.6± 32.8	69± 5

Notes:

- Mean-L represents results of record mean
- Bolded data were annual means for the verified period.
- Mean-V: mean values for the modified verified period (January of 1995 through December of 2000)
- Mean-P: mean values for the pre-verified period (1989 through 1994)

Table 4. Seasonal variation of TN, TP, Chla, and TSI in Newnans Lake

	TN	TP	Chla	TSI
	(mg/L)	(mg/L)	(µg/L)	
		General long-term quarterly mean		
1st quarter	3.56± 0.55	0.123± 0.018	167.4± 32.5	82± 3
2nd quarter	3.44± 0.72	0.122± 0.019	207.1± 40.4	74± 9
3rd quarter	2.82± 0.29	0.108± 0.017	138.0± 28.0	78± 4

4th quarter	3.20± 0.38	0.110± 0.013	182.9± 37.5	82± 3
Quarterly mean for the verified period				
1st quarter	4.65± 0.87	0.148± 0.034	243.7± 45.5	89± 4
2nd quarter	4.88± 1.02	0.162± 0.028	294.1± 36.8	94± 4
3rd quarter	3.13± 0.44	0.135± 0.031	163.8± 31.6	83± 3
4th quarter	4.10± 0.57	0.135± 0.025	294.0± 30.5	91± 3

Data represent mean ±1SE. n equals to 12 years for the general long-term quarterly mean values and 6 for quarterly mean values for the verified period.

TN, TP, and Chla concentrations of the lake were relatively constant and low from 1989 through 1991 (Table 3). The TN concentration ranged from 1.58 to 1.87 mg/L, TP concentration from 0.070 to 0.082 mg/L, and Chla concentration from 32.1 to 62.1µg/L during this period of time. The TSI was relatively low during this period, ranging from 58 to 70. At this time, the lake could be considered high mesotrophic to eutrophic.

Starting from 1991, a significant increase in TN was observed. The increase continued until 1995. During this period, the average TN concentration jumped from 1.87 mg/L to 4.10 mg/L, a more than 2-fold increase. Elevated levels of TP were also observed, which increased from 0.070 mg/L in year 1991 to 0.120 mg/L in 1995, about a 70% increase. Chla increased by more than a factor of 4 from 62.1 µg/L in 1991 to 271.8 µg/L during this period. The TSI reached 93 in 1995, and the lake had become hyper-eutrophic .

The in-lake TN, TP, and Chla concentrations held fairly constant from 1995 through 1997. A significant drop of TN, TP, and Chla was observed in 1998, followed by a dramatic increase again for TN and TP concentrations in 1999 and 2000. The Chla concentrations remained relatively constant during these two years, although a large intra-year variation was observed. The TSI remained high, around 90 throughout the period.

Although a dramatic change of annual TN, TP, and Chla concentrations was observed between years, seasonal variation was not very obvious. TN, TP, Chla, and TSI values of the different quarters were not significantly different from each other throughout an average year (Table 4).

To explain the annual variation, stage data of Newnans Lake collected from 1989 through 2000 were converted to lake volumes using the Elevation – Lake Volume curve of Newnans Lake developed by the St. John River Water Management District (Robison 1997). The annual average stage elevation and lake volume are listed in Table 5. The long-term quarterly average stage elevation and lake volume calculated based on data from 1989 through 2000 are listed in Table 6.

Table 5. Annual average stage elevation and volume of Newnans Lake. Data represent mean SE (n=4)

	Stage elevation	Lake volume
	(feet)	(acre-foot)
1989	65.5 ± 0.3	33,000 ± 1,732
1990	65.6 ± 0.2	33,125 ± 1,390
1991	66.0 ± 0.4	35,250 ± 2,658

1992	65.9 ± 0.5	34,000 ± 2,739
1993	65.9 ± 0.3	34,000 ± 1,472
1994	65.9 ± 0.4	34,250 ± 2,454
1995	65.4 ± 0.2	31,500 ± 1,323
1996	65.5 ± 0.3	32,000 ± 1,957
1997	65.3 ± 0.3	31,100 ± 1,797
1998	66.7 ± 0.3	39,750 ± 1,886
1999	64.2 ± 0.1	22,275 ± 427
2000	62.7 ± 0.2	14,250 ± 1,336
mean	65.4 ± 0.5	31,208 ± 2,982

According to Table 5, stage elevation and volume of Newnans Lake were high in 1998 and low in 2000. However, seasonal variation of stage elevation and volume of the lake was not obvious. According to Table 6, long-term quarterly average stage elevation and lake volume are not significantly different between all the four quarters in the average year (1996 – 2000). An inverse relationship between the lake volume and TN, TP, and Chla concentrations was observed during 1997 – 2000. TN, TP, Chla, and TSI levels were significantly lower when the lake volume was significantly higher, and vise versa (Figure 5 – A, B, C, D). Chla concentration did not increase as dramatically as TN and TP concentrations in 2000. This was probably because the algal communities were limited by density dependent factors. For example, when algal biomass was too high, self-shading effects or simply lack of sufficient space could limit any further increase in algal biomass.

Table 6. Quarterly average stage elevation and volume of Newnans Lake. Data represent mean SE (n=6).

	Stage elevation (feet)	Lake volume (acre-foot)
1st quarter	65.7 ± 0.4	33,383 ± 2,773
2nd quarter	65.5 ± 0.3	31,792 ± 1,950
3rd quarter	65.2 ± 0.3	30,083 ± 2,122
4th quarter	65.2 ± 0.4	29,575 ± 2,236

No clear long-term seasonal trend was found with the lake volume (Table 6). This was consistent with the findings that TN, TP, Chla, and TSI did not show significant variation between different quarters of an average year.

From examining Figures 5 – A, B, C, and D, lake volume alone obviously can not explain the variation of TN, TP, and Chla concentrations for the entire period from 1989 through 2000. This is especially true for the dramatic increase of TN, TP, and Chla concentrations observed during 1991 – 1995, because the lake volume stayed relatively constant during this period.

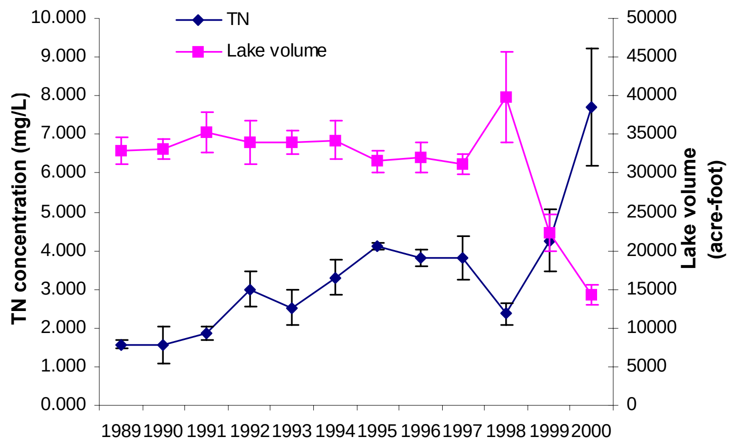


Figure 5-A TN concentration vs. volume of Newnans Lake

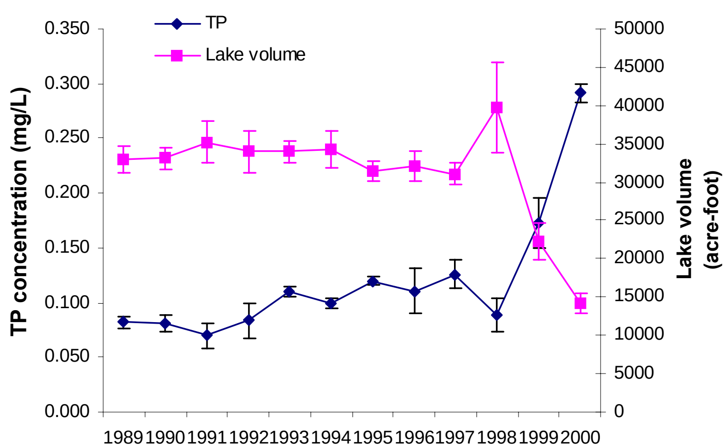


Figure 5-B. TP concentration vs. volume of Newnans Lake

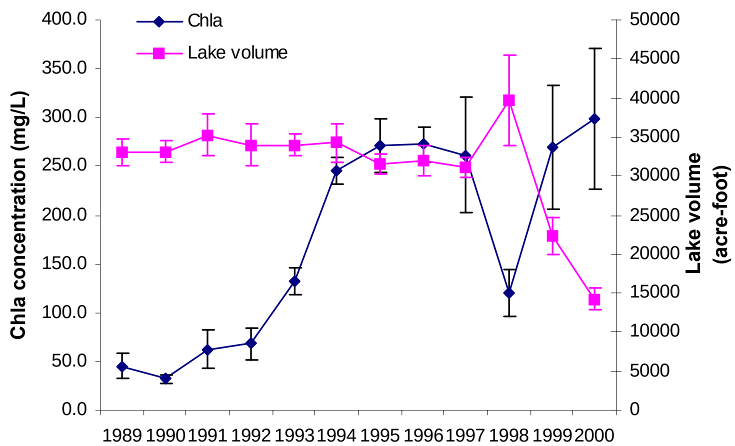


Figure 5-C. Chla concentration vs. volume of Newnans Lake

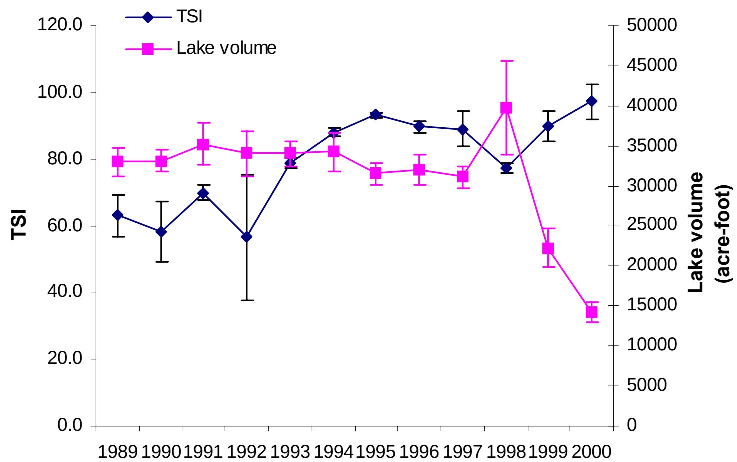


Figure 5-D. TSI vs. lake volume of Newnans Lake

However, the inverse relationship between TN, TP, and Chla concentration and lake volume during 1997 – 2000 indicates the importance of the lake volume on the overall water quality of the lake. Recall that the major sources of water for Newnans Lake includes surface runoff, baseflow, and direct precipitation into the lake. Therefore, the inverse relationship between water quality indices and lake volume during the period studied suggests that the TN and TP concentrations of these sources may be lower than the in-lake concentrations, and that internal recycling from nutrients stored in the bed could play a role in the observed degree of eutrophication.

TN and TP concentrations of inlet and outlet streams of Newnans Lake

TN and TP data for Hatchet Creek (inlet), Little Hatchet Creek (inlet), and Prairie Creek (outlet) were also retrieved from the IWR-Data database. Annual average TN and TP concentrations of these streams are listed in Table 7 and Table 8, respectively.

Except for one TN and TP measurement in each of 1996 and 1997, no data were found for Little Hatchet Creek in the period from 1995 through 1998. Therefore, the long-term annual averages of TN and TP concentrations for this stream were calculated based on only two years of data (1999 and 2000). For Prairie Creek, year 2000 data were missing and the long-term annual averages for the creek were calculated based on data from 1995 through 1999.

Table 7. Annual average TN concentration of Hatchet Creek, Little Hatchet, and Prairie Creek. Data represent mean ± SE.

Unit: mg/L

	Inlet Streams		Outlet Stream
	Hatchet Creek	Little Hatchet Creek	Prairie Creek
1995	1.32 ± 0.13	----	4.686 ± 0.282
1996	0.97 ± 0.97	----	4.185 ± 0.482
1997	0.91 ± 0.09	----	4.440 ± 0.619
1998	0.86 ± 0.07	----	2.097 ± 0.277
1999	0.98 ± 0.09	0.840 ± 0.184	4.744 ± 0.362
2000	1.05 ± 0.18	1.015 ± 0.060	----
Mean	**1.02 ± 0.07**	**0.927 ± 0.088**	**4.030 ± 1.103**

Table 8. Annual average TP concentration of Hatchet Creek, Little Hatchet, and Prairie Creek. Data represent mean ± SE.

Unit: mg/L

	Inlet Streams		Outlet Stream
	Hatchet Creek	Little Hatchet Creek	Prairie Creek
1995	0.09 ± 0.01	----	0.223 ± 0.097
1996	0.09 ± 0.01	----	0.138 ± 0.031

1997	0.10 ± 0.01	----	0.143 ± 0.028
1998	0.11 ± 0.04	----	0.117 ± 0.020
1999	0.18 ± 0.01	0.254 ± 0.035	0.242 ± 0.074
2000	0.16 ± 0.02	0.375 ± 0.060	----
Mean	**0.12 ± 0.02**	**0.314 ± 0.060**	**0.172 ± 0.056**

The long-term annual averages of TN concentration for the two inlet streams – Hatchet Creek and Little Hatchet Creek - were not significantly different from each other and were about 1 mg/L (Table 7). This concentration was significantly lower than the in-lake concentration, which was about 4 mg/L (Table 3). The TN concentration in Prairie Creek, the outlet stream, was also about 4 mg/L. This concentration was significantly higher than the TN concentration in two inlet streams, but was not significantly different from the in-lake concentration.

The long-term annual average TP concentrations in Hatchet Creek and Prairie Creek were similar (Table 8) and were similar to the in-lake TP concentration. TP concentration in Little Hatchet Creek, however, was significantly higher than all the other waterbodies. It was difficult to interpret the high TP concentration in Little Hatchet Creek because we had only two years of data. Although the influence from human activities is high in the Little Hatchet Creek sub-basin, the TN concentration from this stream was not significantly different from Hatchet Creek. This made it equivocal to pinpoint human activity as the cause of high TP in Little Hatchet Creek.

Several trends can be identified from the historical water quality data of Newnans Lake and its inlet and outlet streams.

1) There was a rapid increase in TN and TP concentration in Newnans Lake from 1991 through 1995. The TN more than doubled during this 5-year period, while the increase of TP concentration was milder, about 70%. What caused this increase remains unclear, but the change in the lake volume alone could not explain this dramatic change in nutrient concentrations.
2) The long-term TN/TP ratio of the lake was about 29, suggesting that algal communities were co-limited by nitrogen and phosphorus. This ratio increased from around 20 in the late 1980s and early 1990s to about 30 in 1990s, indicating a gradual shift from nitrogen-phosphorus co-limitation to phosphorus limitation. The trend was caused by the more rapid in-lake increase of TN than TP during the 1991 – 1995 period. The dramatic increase of chlorophyll a concentration in this period (more than 4 times) could be a synergistic effect from the increase of TN and TP concentrations at the same time.
3) Pre-1991 data indicated that the lake might have been mesotrophic to eutrophic, but not hypertrophic. This was indicated by TSIs between 60 – 70 in the late 1980s and early 1990s. Given this, the current high TSI of more than 90 should be reversible.
4) The significantly lower TN concentration in the inlet streams than the in-lake and outlet TN concentration suggests that the rapid increase of TN concentrations in the lake might not be caused solely by the current surface runoff, baseflow, and direct precipitation into the lake. This is consistent with the finding that when the lake volume increased, TN, TP, Chla concentrations and TSI all decreased. Again, we suspect that the increase of TN in the lake could have been caused by an increase in the internal recycling within the lake.

To evaluate the importance of landuse patterns and internal recycling to the trophic status of the lake, WMM and Bathtub were used to estimate the loading of TN and TP from various sources and the influence of these loadings to the TSI of the lake.

5.2 Estimating TN and TP Sub-basin loadings using WMM

Further breakdown of LHC and HC

As it was described in Section 4, the Newnans Lake watershed was subdivided into three sub-basins, including LHC, HC, and NL. WMM was used to estimate the TN and TP loading from various point and nonpoint sources from these sub-basins. To estimate the TN and TP loading into Newnans Lake from LHC and HC, flow data at the mouth of the Hatchet Creek and Little Hatchet Creek and the TN and TP concentrations of each creek were used (Figure 6).

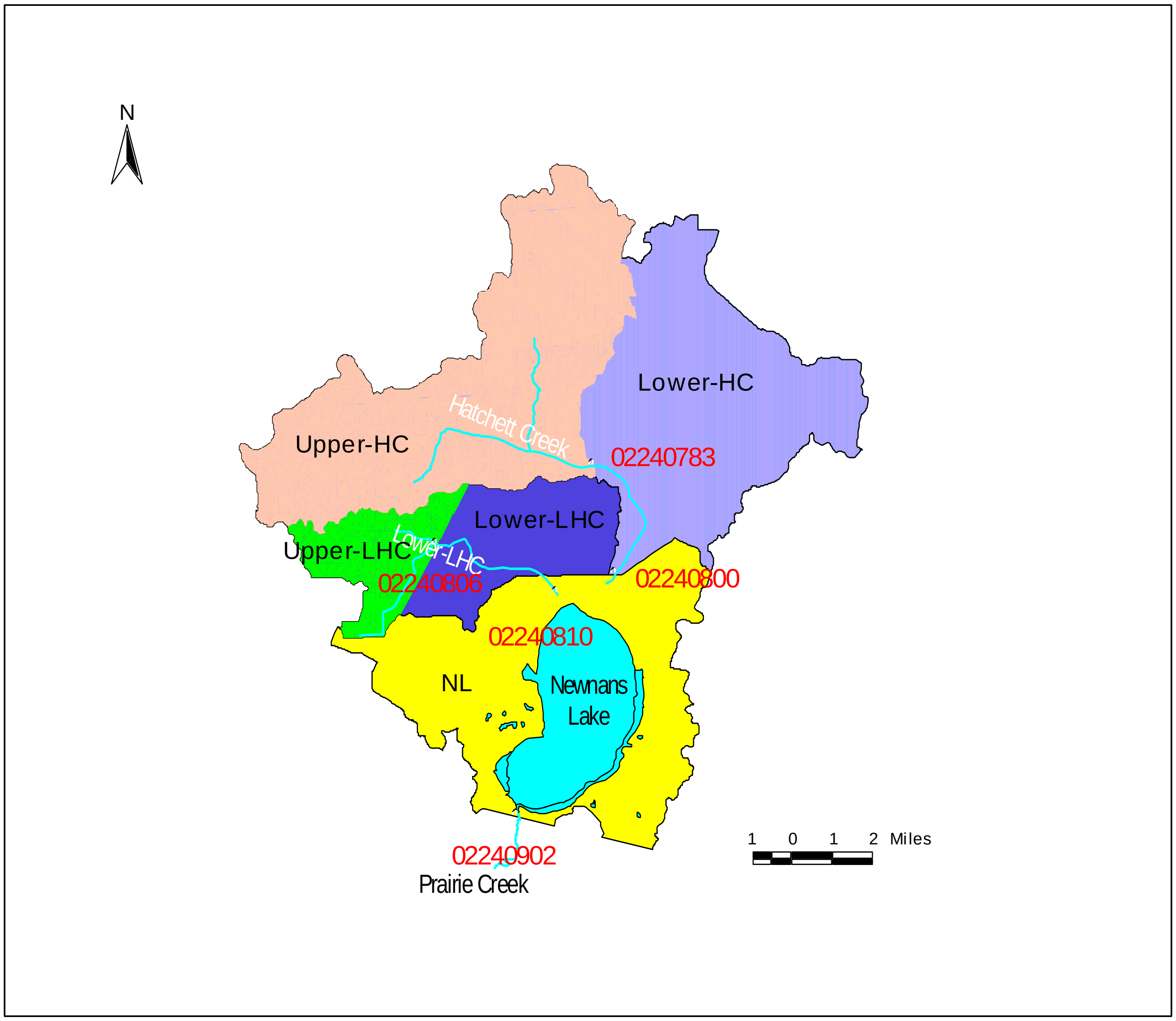


Figure 6. USGS gauging stations and further breakdown of Hatchet Creek into Upper Hatchet Creek (Upper-HC) and Lower Hatchet Creek (Lower-HC) and Little Hatchet Creek into Upper Little Hatchet Creek (Upper-LHC) and Lower Little Hatchet Creek.

Two USGS gauging stations located at the mouth of the two inlet streams (SiteID: 02240800 and 02240810, Figure 6) were identified in this study. However, no flow record could be found for the two stations. Therefore, flow records of two other stations located in the upper reaches of Hatchet Creek and Little Hatchet Creek (SiteID: 02240783 and 02240806, Figure 6) were used for WMM water quantity calibration. To do this, the Hatchet Creek sub-basin was further subdivided into the Upper Hatchet Creek sub-basin (Upper-HC) and the Lower Hatchet Creek sub-basin (Lower-HC), and the Little Hatchet Creek sub-basin was divided into the Upper Little

Hatchet Creek sub-basin (Upper-LHC) and the Lower Little Hatchet Creek sub-basin (Lower-LHC). Both upper sub-basins were delineated so that they terminate at the flow gauging station.

After the water quantity of WMM was calibrated, surface runoff of the Hatchet Creek sub-basin and Little Hatchet Creek sub-basin was estimated by applying the calibrated parameters to the entire area of the two sub-basins. Water quality calibration of WMM was conducted against the data retrieved from the IWR-data (Table 7 and 8**)**.

Data required for estimating TN and TP loadings from point and nonpoint sources using WMM

To calibrate the water quantity of WMM, the following data were collected:

A. *Rain precipitation data* from the weather station located at the Gainesville regional airport (UCAN 3964, COOP 083326, Figure 7) were retrieved from the Climate Interactive Rapid Retrieval User System (CIRRUS) hosted by the Southeast Regional Climate Center. Annual average precipitation and seasonal variation are listed in Table 9 and Table 10, respectively.

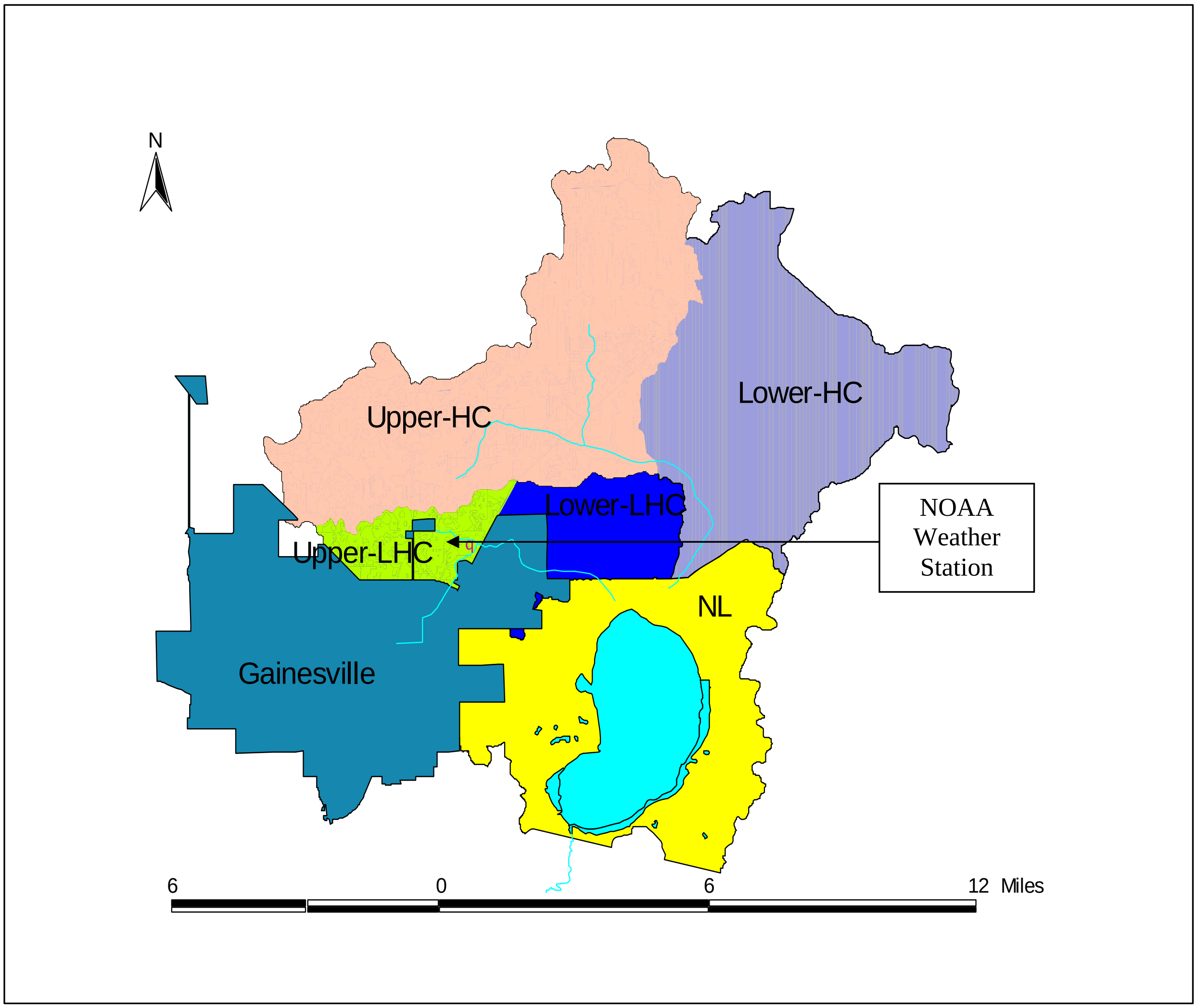


Figure 7. Location of the Gainesville Regional Airport NOAA weather station

Table 9. Annual precipitation at Gainesville Regional Airport

Year	Annual Precipitation (in/year)
1996	54.65
1997	58.22
1998	45.62
1999	38.34
2000	34.39

Table 10. Long-term average quarterly precipitation. Data represent mean ±SE (n=5)

Quarter	Quarterly Precipitation (in/quarter)
1st quarter	10.40 ± 2.53
2nd quarter	10.47 ± 2.60
3rd quarter	17.32 ± 1.49
4th quarter	8.10 ± 3.37

B. *Daily flow data* of two USGS gauging stations (SiteID: 02240783 and 02240806) were provided by USGS Florida Integrated Science Center. Of the data that we received, data sets for 1996, 1997, 1998, and 2000 were complete for Station 02240783 (located on Hatchet Creek). Data for Station 02240806 (located on Little Hatchet Creek) were only available for 1996. Data of all the other years were excluded from this study because of the significant amount of missing records.

The flow records for 1998 for Station 02240783 were not included in this study because the aggregated annual flow of this year was more than three times higher than annual flows for 1996 and 1997 even though the annual precipitation for 1998 was actually lower than 1996 and 1997 (Table 9). This decrease in precipitation in 1998 was confirmed by examining the records from several other weather stations located in proximity to the Gainesville Regional Airport. Further, examining the geology of Newnans Lake watershed indicated that it was not very likely that the flow in the two streams could be significantly influenced by the Floridian Aquifer because the project area is confined by the Hawthorn formation (Copeland et al. 1991). There were also no drastic changes in landuse within the project area within a single year that would explain the sudden increase in surface runoff. Therefore, we considered 1998 flow data at Station 02240783 not reliable and excluded it from this study. The flow data for the two gauging stations were aggregated into annual flow data and are listed in Table 11.

Table 11. Annual stream flow and baseflow of Upper Hatchet Creek and Upper Little Hatchet Creek

Unit: acre-foot/year

	Upper Hatchet Creek		Upper Little Hatchet Creek	
	Stream flow	Baseflow	Stream flow	baseflow
1996	17216	5292	3293	1220
1997	19633	6494	----	----
1998	----	----	----	----
1999	----	----	----	----
2000	1079	397	----	----

C. *The streams baseflow* were obtained through conducting baseflow separation on the daily stream flow data, using the Hydrograph Separation Program (HYSEP) version 2.2 developed by USGS. The Local minimum method was used for the baseflow separation (Sloto and Crouse 1996). The aggregated annual baseflow data of the two streams is listed in Table 11.

D. *Areas of different landuse categories* in each sub-basin were obtained by aggregating GIS landuse coverage based on the simplified level 1 code listed in Table 1. Acreage of each landuse category for Upper-HC and Upper-LHC (the two sub-basins whose surface runoff was used for WMM water quantity calibration) is listed in Table 12. Acreage of each landuse category of HC, LHC, and NL is listed in Table 13. Percent distributions of each landuse category in HC, LHC, and NL are shown in Figure 8.

Table 12. Area of each landuse category of Upper-HC and Upper-LHC

Unit: acre

	Upper-HC	Upper-LHC
Forest/Rural Open	19120.31	1964.86
Urban Open	643.63	589.76
Agriculture	1028.32	116.66
Low Density Residential	1265.53	4.15
Medium Density Residential	166.40	441.15
High Density Residential	26.28	79.84
Communication and Transportation	132.94	190.15
Rangeland	393.38	128.81
Water/Wetlands	5785.94	672.76
Total	22352.74	4188.14

Water/wetland and Forest/rural open dominated the landuse in all the three sub-basins (Figure 8). Hatchet Creek had the highest percentage of Water/wetland and Forest/rural open area, which accounted for 85.5% of the total area of this sub-basin. Water/wetland and Forest/rural open accounted for 69.5% and 76.2% of total area for Little Hatchet Creek and Newnans Lake sub-basins, respectively. Among the human landuse categories, residential appeared to be important in all the three sub-watersheds,

Table 13. Area of each landuse category of HC, LHC, and NL

Unit: acre

	HC	LHC	NL
Forest/Rural Open	26220.09	5415.89	7497.64
Urban Open	734.58	865.48	765.77
Agriculture	1880.69	142.37	1420.55
Low Density Residential	1970.12	94.59	1283.36
Medium Density Residential	386.03	441.15	1063.86
High Density Residential	28.83	83.10	93.28
Communication and Transportation	307.35	1065.97	150.24
Rangeland	654.31	636.54	644.02
Water/Wetlands	8902.87	2161.97	9818.15
Total	41084.86	10907.04	22736.89

and accounted for 5.8%, 5.7%, and 10.7% of the total area for Hatchet Creek, Little Hatchet Creek, and Newnans Lake sub-basins, respectively. The highest percent landuse area occupied by Transportation/communication was found in Little Hatchet Creek sub-basin, which accounted for about 10% of the total area of the basin. This was mainly caused by the land area used by Gainesville Regional Airport. In no sub-basin were human landuse categories significantly higher than 30% of the total area. Little Hatchet Creek had the highest percent area of human landuse, which accounted for 30.5% of sub-basin area. For Hatchet Creek and Newnans Lake sub-basin, percent of human landuse was 14.0% and 23.8%, respectively.

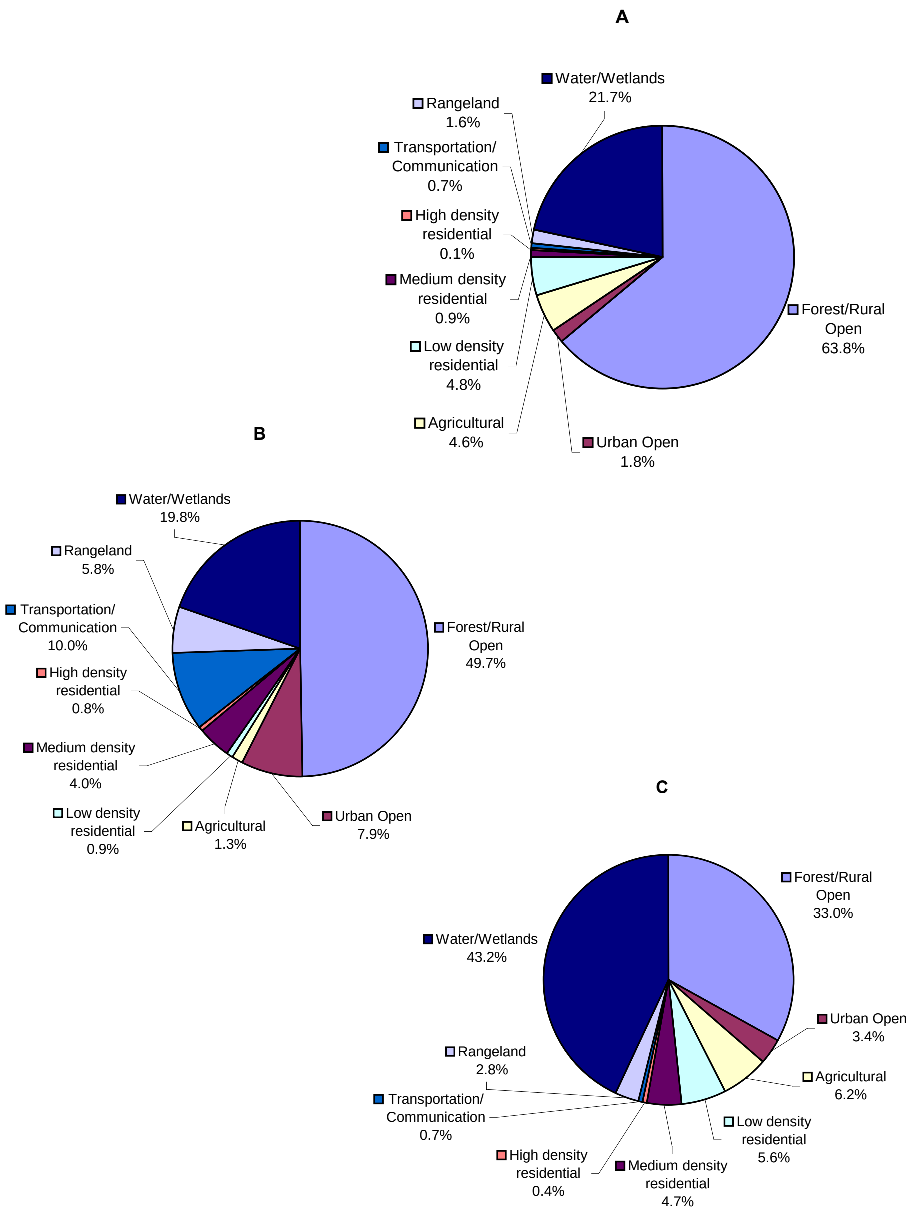


Figure 8. Percent distribution of different landuse categories in HC (A), LHC (B), and NL (C) sub-basins

In summary, the percent distribution of different landuse categories had some overall similarity across all three sub-watersheds. Water/wetland and Forest/rural open area dominated the entire Newnans Lake watershed. This overall similarity of landuse distribution provided us with the basis to extrapolate some model parameters calibrated in one sub-basin to the others, when local data were not available for developing the TMDL.

E. *Percent impervious area* of each landuse category is a very important parameter in estimating surface runoff using WMM. Nonpoint pollution monitoring studies throughout the U.S. over the past 15 years have shown that annual "per acre" discharges of urban stormwater pollution are positively related to the amount of imperviousness in the landuse (WMM User's Manual 1998). Ideally, *impervious area* is considered as the area that does not retain water and therefore, 100% of the precipitation falling on the impervious area should become surface runoff. In practice, the runoff coefficient for impervious area typically ranges between 95 to 100%. Impervious runoff coefficients lower than this range were observed in the literature, but usually this number should not be lower than 80%. For pervious area, the runoff coefficient usually ranges between 10 to 20%. However, values lower than this range were also observed (WMM User's Manual: 1998). In this study, impervious and pervious runoff coefficients were adjusted to fit model estimates to measured data in the process of WMM water quantity calibration.

   It should be noted that the impervious area percentages do not necessarily represent directly connected impervious area (DCIA). Using a single-family residence as an example, rain falls on rooftops, sidewalks, and driveways. The sum of these areas may represent 30% of the total lot. However, much of the rain that falls on the roof drains to the grass and infiltrates to the ground or runs off the property, and thus does not run directly to the street. For WMM modeling purpose, whenever the area of the watershed that contributes to the surface runoff was considered, DCIA was used in place of impervious area. Because local values were not available, DCIAs used in this study were collected from literature published values or results from other studies (Table 14).

Table 14 Percent direct connected impervious area for different landuse categories

Landuse Categories	DCIA	Reference
Forest/Rural Open	0.5%	WMM User's Manual: 1998
Urban Open	0.5%	WMM User's Manual: 1998
Agriculture	3.7%	Brown 1995
Low Density Residential	12.40%	Brown 1995
Medium Density Residential	18.70%	Brown 1995
High Density Residential	29.60%	Brown 1995
Communication and Transportation	36.20%	Brown 1995
Rangeland	3.7%	CDM
Water/Wetlands	30%	Harper and Livingston 1999

F. Local *Event mean concentrations (EMC)* of TN and TP for different landuse categories were not available and therefore were obtained from literature values (Table 15).

EMCs of TN and TP for most landuse categories were cited from a review prepared by Harper (1994). EMCs for Agriculture, Low Density Residential, and Water/Wetlands were directly provided by the review. However, EMCs for Urban Open, Medium Density Residential, High Density Residential, Transportation and

Table 15. Event mean concentration of TN and TP for different landuse categories

Unit: mg/L

Landuse Categories	TN	TP	Reference
Forest/Rural Open	1.85	0.33	CDM 1990
Urban Open	1.18	0.15	Harper 1994
Agriculture	2.32	0.334	Harper 1994
Low Density Residential	1.77	0.177	Harper 1994
Medium Density Residential	2.29	0.30	Harper 1994
High Density Residential	2.42	0.49	Harper 1994
Communication and Transportation	2.08	0.34	Harper 1994
Rangeland	2.32	0.334	Harper 1994
Water/Wetlands	1.6	0.19	Harper 1994

Communication, and Rangeland were not directly defined in Harper's review. Therefore, some extrapolations were made between the landuse categories in this study and the landuse categories defined by Harper's review. Basically, the Urban Open area was treated as the Low-Intensity Commercial area in Harper's review. Medium Density Residential was treated as Single Family area; High Density Residential was treated as Multi-Family area; Transportation and Communication was treated mainly as Highway; and Rangeland was treated the same as general Agriculture.

G. Not all the TN and TP are transported by the stormwater in the dissolved form. The *percentage of the total EMC represented by TN and TP attached to suspended particles* is allowed to be defined in WMM. Percent suspended TP values were calculated from total phosphorus (TP) and dissolved phosphorus (DP) values of various landuse categories determined in a study conducted by CDM (not published). These values were used for all three sub-watersheds. No percent suspended TN values were available for this study. Therefore, the same value was assigned to all the landuse categories and was adjusted to fit the estimated TN concentration to the actual measurement in each sub-basin. Because percent suspended TN was used as an adjustable parameter in the process of model calibration, Hatchet Creek and Little Hatchet Creek sub-basins had different values of percent suspended TN. The percent TN for Hatchet Creek sub-basin was applied in estimating the TN loading from Newnans Lake sub-basin. Values for percent TP and TN in suspended form adopted in this study are listed in Table 16.

Table 16. Percent TP and TN in suspended form for different landuse categories. HC, LHC, and NL represent Hatchet Creek, Little Hatchet Creek, and Newnans Lake sub-watershed, respectively.

Landuse Categories	TP	TN		
		HC	LHC	NL
Forest/Rural Open	92%	33%	45%	33%
Urban Open	55%	33%	45%	33%
Agriculture	32%	33%	45%	33%
Low Density Residential	25%	33%	45%	33%
Medium Density Residential	40%	33%	45%	33%
High Density Residential	55%	33%	45%	33%
Communication and Transportation	63%	33%	45%	33%
Rangeland	32%	33%	45%	33%
Water/Wetlands	47%	33%	45%	33%

H. The *Sediment delivery ratio* determines how much TN and TP attaching to suspended particles will be delivered to the destination waterbody eventually. In this study, the range of sediment delivery ratio was estimated using the correlation between delivery ratio and watershed area developed by Roehl (1962). Because of the difference in total area of the watershed for each sub-basin, Hatchet Creek, Little Hatchet Creek, and Newnans Lake sub-basins were assigned different sediment delivery ratios, which were 0.18, 0.21, and 0.19, respectively.

I. *TN and TP concentrations of baseflow* were treated as the TN and TP concentration of the groundwater in the project area. The only well found for the entire project area is located in the Little Hatchet Creek watershed (Figure 9). The TN and TP concentration of the well were obtained from the Florida Groundwater Quality Monitoring Network (http://tlhdwf2.dep.state.fl.us/ambient/triennial/). At the time this project was carried out, TN and TP concentrations were only available for 1997 for the well, which was 0.22 mg/L for TN and 0.06 mg/L for TP. These values were used as the baseflow TN and TP concentrations throughout the entire period from 1996 through 2000.

J. To estimate the TN and TP loadings from *leakage of septic tanks*, WMM incorporates the concept of "septic tank failure loading rate", which defines the percent increase of TN and TP loadings from Low Density Residential areas under septic tank leakage. The typical range of septic tank failure loading rate for TP is about 160% to 250**%**, for TN is 140% to 200%. To provide a Margin of Safety, this study adopted the high end of the range, which was 200% for TN and 250% for TP, respectively (WMM User Manual: 1998). Another value required by WMM to estimate the influence from leaking septic tanks on TN and TP loading is the "septic tank

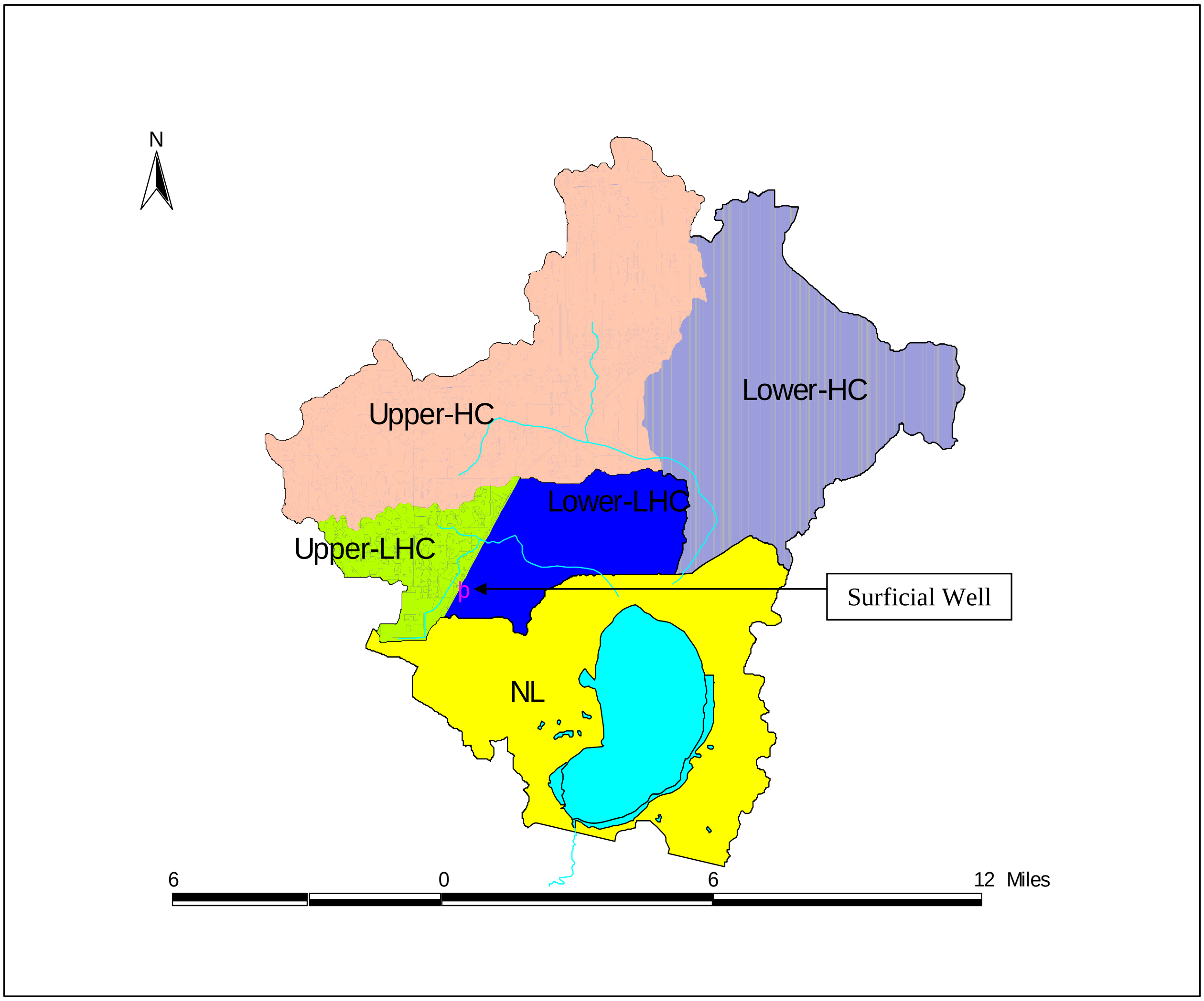


Figure 9. Location of a surficial well from which the baseflow TN and TP concentrations were obtained.

Failure rate", which defines the frequency at which septic tanks may fail. Studies conducted on the water quality of the Ocklawaha River Basin found that annual frequency of septic tank repairs was about 0.97% (Basin Status Report 2001). For average annual conditions, it is conservative to assume that septic tank systems failures would be unnoticed or ignored for five years before repair or replacement occurred (WMM User Manual: 1998). Therefore, the septic tank failure rate used in this study was calculated by multiplying repairing frequency (0.97%) by 5 (years) and was about 5%.

K. There is one permitted point source, Brittany Estates Mobile Home Park, in the Little Hatchet Creek sub-basin (Figure 10). The facility is permitted (Permit number: FL0040215) to discharge up to 0.06 million gallons per day (MGD) annual average daily flow into Little Hatchet Creek. The permit for the facility includes effluent nutrient limitations for organic nitrogen (6.4 mg/L max a 3.2 mg/L annual average), nitrate (12.0 mg/L maximum, with no annual average limit), and total ammonia (4.8 mg/L maximum and 2.4 mg/L annual average). Based on these limitations, the total nitrogen limits are 23.2 mg/L maximum and 5.6 mg/L annual average. No limitations are contained in the permit for phosphorus. Existing daily discharge and the TN concentration of the discharge from 1996 through 2000 were retrieved from the EPA Permit Compliant System (PCS) database. Records of TP concentration in the discharge were only found for 1999 and 2000 (St. John River Water Management District 2003). The average annual TP concentration was calculated based on these records and assigned to all the years from 1996 through 2000. The daily discharge and the TN and TP concentrations of the discharge are listed in Table 17.

Table 17. Daily discharge and TN and TP concentrations in the discharge from Brittany Estates Mobile Home Park

	Daily Discharge	TN	TP
	(MGD)	(mg/L)	(mg/L)
1996	0.028	16.97	2.17
1997	0.024	17.29	2.17
1998	0.025	7.51	2.17
1999	0.022	2.95	2.17
2000	0.024	4.44	2.17

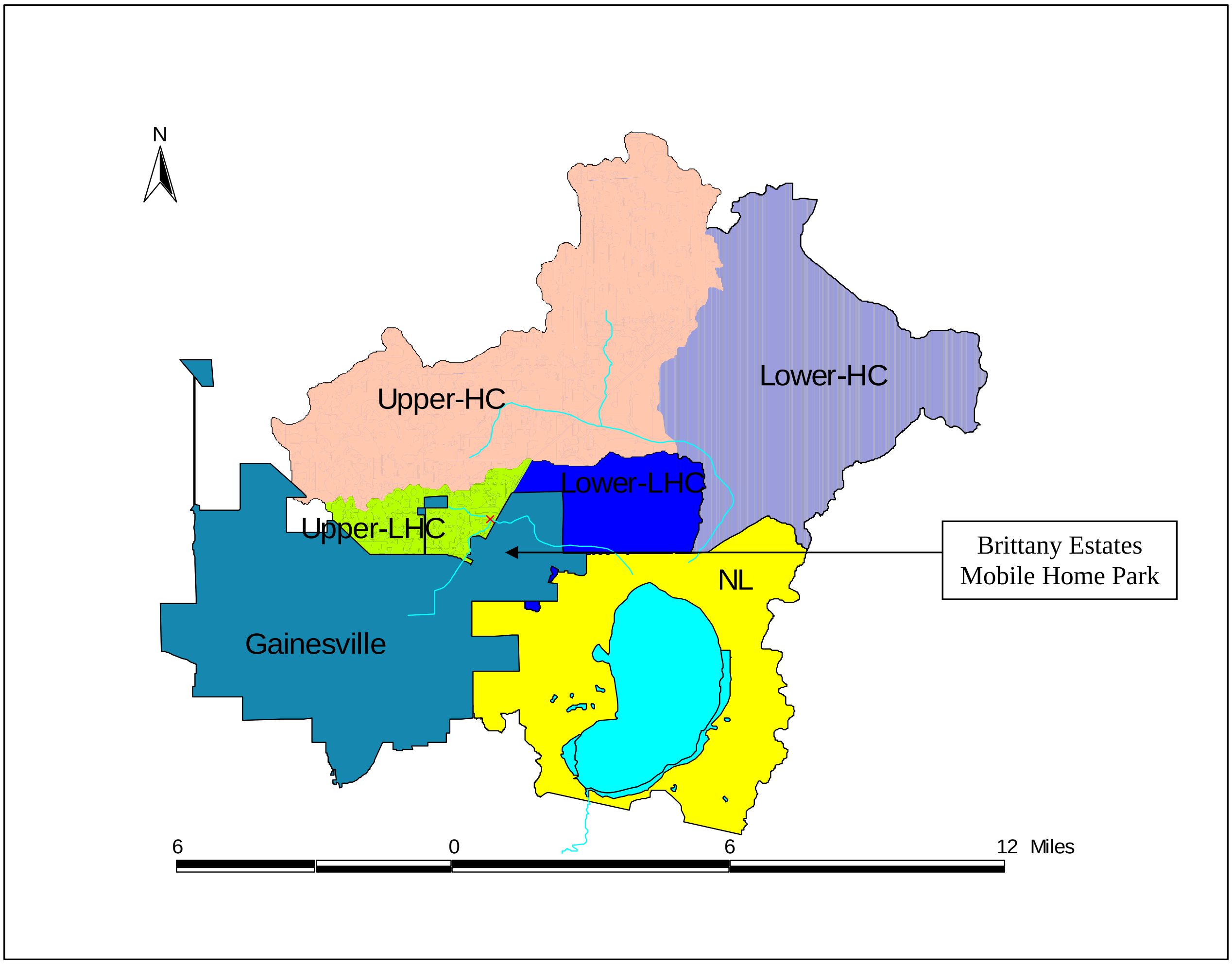


Figure 10. Location of Brittany Estates Mobile Home Park discharging into the Little Hatchet Creek.

Preparing rainfall data for WMM water quantity calibration

As it has been discussed in section 4, WMM uses Equation (1) to estimate the surface runoff from precipitation data. Equation (1) assumes that the amount of surface runoff is in direct proportion to precipitation, which implies that all the rainfall contributes to the surface runoff to some extent. This assumption, however, is an oversimplification of the ambient condition, in which a certain amount of rainfall is retained by soil and never contributes to the surface runoff. In other words, when the precipitation value is lower than a certain threshold, no surface runoff will form (Viessman, et al. 1989). This can be described using the following equation:

(4) $Q = k^*(P – P_0)$

Where,

Q is the surface runoff produced by a given amount of annual precipitation
k is equivalent to $[C_p + (C_I – C_p) IMP_L]$ of Equation (1), which is the runoff coefficient of landuse category L.
P is the annual precipitation
P_0 is the base precipitation value below which Q is zero.

Equation (4) can be rewritten as:

(5) $Q = k^*P – k^*P_0$

Comparing Equation (5) to Equation (1), which is

(1) $R = [C_p + (C_I – C_p) IMP_L] * I$

It is obvious that Equation (1) fails to take into account $–k^*P_0$, which is the portion of rainfall that will never contribute to surface runoff. Therefore, using Equation (1), WMM may overestimate the surface runoff, especially for dry years during which the majority or even all of the rainfall is retained in the watershed and very little or even no surface runoff will be produced.

To address this problem, this study analyzed the correlation between the annual rainfall and areal annual surface runoff (the difference between stream flow and baseflow divided by the area of the watershed) using the three years that we had complete data sets in the Upper-HC sub-basin (1996, 1997, and 2000). A strong linear correlation was found between annual rainfall and areal annual surface runoff (R^2 was almost 1, Figure 11). The form of the correlation was identical to the form of Equation (5). Therefore, the slope of the correlation line was equivalent to k of Equation (5), and the intercept of the correlation is equivalent to k^*P_0 of Equation (5). P_0 was then calculated as the quotient between the intercept (k^*P_0 = - 9.4) and the slope (k = 0.29) of the correlation line and equaled 32.6 inches/year. This value, according to Viessman, et al. (1989), was the base precipitation value below which surface runoff would be zero.

Before the actual measured precipitation was used for WMM calibration and simulation, this value (32.6 inches/year) was subtracted from the original precipitation observations to created a set of “adjusted precipitation values” (Table 18), which were equivalent to I in Equation (1), and were used for WMM model calibration and simulation. Although P_0 was only characterized using the data from the Upper-HC sub-basin due to insufficient data availability, considering the overall similarity of the landuse pattern, P_0 was assumed the same for all the other sub-basins in the project area, and so were all the adjusted annual precipitation values.

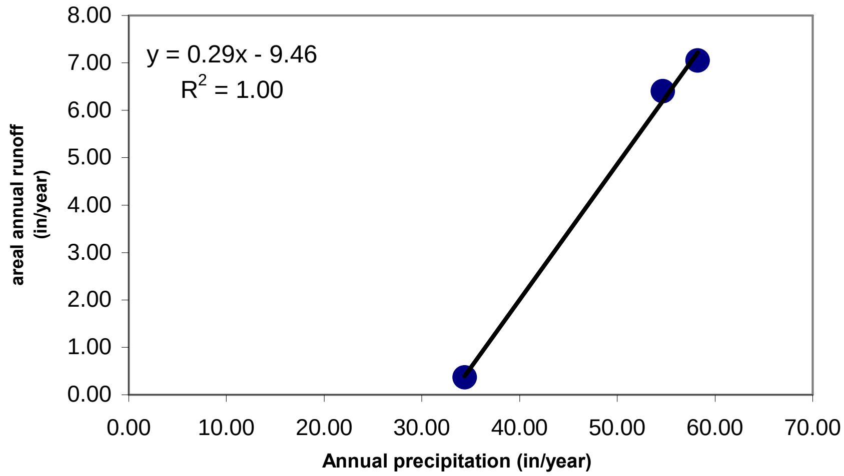


Figure 11. Correlation between areal annual surface runoff and annual precipitation.

Table 18. Adjusted annual precipitation calculated based on P_0. Bold values were baseflow interpolated using the correlation between areal annual baseflow and annual precipitation.

	Annual Flow	Annual Baseflow	Areal annual flow	Areal annual baseflow	Areal annual runoff	Annual precipitation	Adjusted annual precipitation
	Acre-foot		Inches/year				
1996	17216	5292	9.24	2.84	6.40	54.65	22.03
1997	19633	6494	10.54	3.49	7.05	58.22	25.60
1998	----	----	----	**1.72**	----	45.62	13.00
1999	----	----	----	**0.72**	----	38.34	5.72
2000	1079	397	0.58	0.21	0.37	34.39	1.77

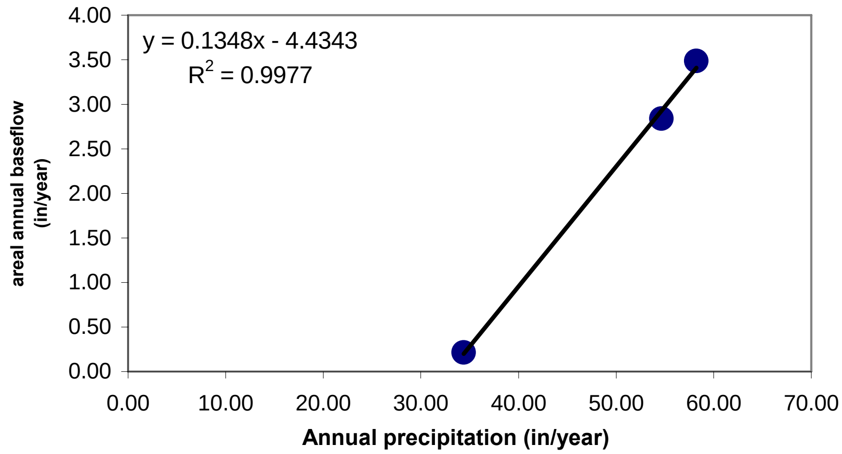


Figure 12. Correlation between areal annual baseflow and annual precipitation.

A tight correlation was also observed between annual baseflow and annual precipitation using the data from 1996, 1997, and 2000 (Figure 12). This allowed predictions of the annual baseflow of 1998 and 1999 (Table 18), which was required for WMM model simulation.

WMM flow calibration

WMM flow calibration was conducted using the data from 1996, 1997, and 2000 for the Upper-HC sub-basin, and 1996 data for the Upper-LHC sub-basin. Calibration was primarily conducted through adjusting the runoff coefficients for pervious and impervious landuse area to fit the estimates to the actual measurements. Because we calibrated the model against ALL the years from which data were available, a criterion had to be set up to define the point of best fit of model estimates to observations. The error between model predictions and measured observations (the quotient between the prediction-measurement difference and the observations) was used to determine the best fit.
For the Upper-LHC, WMM water quantity calibration was only conducted for 1998 because it is the only year with data.. Table 19 lists observations, WMM predictions, errors, and pervious and impervious runoff coefficients from both Upper-HC and Upper-LHC sub-basins. From the table it can be seen that the model predicted the measured flows within 11 percent. The model tended to under predict wetter years.

WMM flow simulation for the entire area of Hatchet Creek, Little Hatchet Creek, and Newnans Lake sub-basin

The pervious and impervious runoff coefficients calibrated above were used to estimate the annual stream flow of Hatchet Creek and Little Hatchet Creek derived from the surface runoff of the entire area of the two sub-watersheds. Annual precipitation, percent impervious area, and areal annual baseflow were kept the same as when WMM was calibrated. For the flow simulation of Little Hatchet Creek, the annual flow contributed by the Brittany Estates Mobile Home Park was included into the model. Also, using the precipitation data for 1998 and 1999 and the model parameters calibrated for the Upper-HC sub-basin, stream flows for 1998 and

1999 were simulated for Hatchet Creek. Using the same procedure, stream flows for 1997, 1998, 1999, and 2000 were also simulated for Little Hatchet Creek. Surface runoff and baseflow from the Newnans Lake sub-basin were simulated using all the model parameters calibrated against the data from Upper-HC sub-basin. Simulated WMM estimates from all the three sub-watersheds are listed in Table 20.

Table 19. Results of WMM water quantity calibration.

	Measured annual flow	Estimated annual flow	Pervious runoff coefficient	Impervious runoff coefficient	Error
	Acre-foot				
For Upper Hatchet Creek					
1996	17216	15273	0.17	0.95	11%
1997	19633	18102	0.17	0.95	8%
1998	----	----	----	----	----
1999	----	----	----	----	----
2000	1079	1193	0.17	0.95	11%
For Upper Little Hatchet Creek					
1996	3293	3236	0.19	0.95	2%
1997	----	----	----	----	----
1998	----	----	----	----	----
1999	----	----	----	----	----
2000	----	----	----	----	----

Table 20. Estimated annual flow of Hatchet Creek and Little Hatchet Creek and the water directly contributing to Newnans Lake from its immediate surrounding sub-watershed.

Unit: Acre-foot/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
1996	27322	8100	12037
1997	32400	9588	13988
1998	16274	4836	7103
1999	7096	2116	3125
2000	2133	659	967

WMM Water Quality Calibration and Simulation of Watershed Loadings

WMM water quality calibration for HC and LHC sub-basins was conducted using data from the entire Hatchet Creek and Little Hatchet Creek sub-basins. The calibrated model was then used to estimate the TN and TP loading from HC, LHC, and NL sub-basins. For Hatchet Creek, measured TN and TP concentrations were available from 1996 through 2000. These data were used for model calibration. After the best fit between predicted and measured concentrations was achieved, model estimates of TN and TP loadings from this sub-basin were also obtained. Therefore, no extra model simulation for TN and TP was needed. For Little Hatchet Creek, TN and TP concentrations were available for 1999 and 2000. Therefore, calibration was conducted using the data from these two years, and the calibrated model was used to estimate TN and TP loadings for all the other years. Due to the overall similarity in landuse between the HC and NL sub-basins, the model as calibrated for HC was applied to estimate the TN and TP loadings directly discharging into Newnans Lake from the NL sub-basin.

The WMM user's manual recommends that WMM calibration on water quality be through adjusting the sediment delivery ratio while keeping all the other model parameters unchanged (WMM User's Manual 1998). This approach was not used in this study because it could produce a sediment delivery ratio that was unacceptably high. Instead, the sediment delivery ratio was calculated using the delivery ratio to watershed area correlation characterized by Roehl (1962). Using this technique, delivery ratios for HC, LHC, and NL sub-basins were calculated as 0.18, 0.21, and 0.19, respectively.

After the sediment delivery ratio was defined, no further parameter adjustment was conducted for TP. TN concentration was calibrated by adjusting the percent TN attached to suspended particles. The results of model calibration are shown in Table 21, and estimated TN and TP loadings from each sub-watershed are listed in Table 22.

Table 21. Results of WMM water quality calibration

Unit: mg/L

	Measured concentrations		WMM predictions		Error	
	TN	TP	TN	TP	TN	TP
Hatchet Creek						
1996	0.970	0.086	0.936	0.095	3.3%	11.1%
1997	0.910	0.099	0.922	0.095	1.0%	4.3%
1998	0.860	0.110	0.929	0.095	7.9%	13.7%
1999	0.980	0.184	0.935	0.095	4.8%	48.5%
2000	1.050	0.161	0.957	0.096	9.3%	40.4%
Little Hatchet Creek						
1996	----	----	----	----	----	----
1997	----	----	----	----	----	----

1998	----	----	----	----	----	----
1999	0.840	0.250	0.903	0.132	7%	48%
2000	1.010	0.370	1.107	0.194	9%	48%

Table 22. TN and TP loadings from HC, LHC, and NL sub-basins

Unit: lbs/year

	Hatchet Creek		Little Hatchet Creek		Newnans Lake	
	TN	TP	TN	TP	TN	TP
1996	69539	7049	20628	2545	46517	5183
1997	81197	8297	23679	2928	54270	6081
1998	41126	4184	11911	1564	27500	3072
1999	18040	1826	5175	757	12071	1343
2000	5550	556	1856	346	3717	410

As shown in Table 21, in all the modeling cases, the error between measured and estimated TN concentrations was less than 10%, indicating an overall good fit. WMM estimated TP concentrations reasonably well in 1996, 1997, and 1998 for the HC sub-basin, with an error between measured and estimates ranging from 4.3 – 13.7% for these three years. However, the error of estimates for TP was relatively high for 1999 and 2000 for both HC and LHC sub-basins. Error in these years ranged from 40 to 48%, and the predictions were always lower than observations. It should be noted that the error was relatively constant for both years and in both sub-basins. Considering that 1996, 1997, and 1998 were three relatively wet years and 1999 and 2000 were dry years, the high error of model predictions in 1999 and 2000 implies that sources of TP were underestimated and the sources may somehow be related to the amount of precipitation that these sub-basins received. Because the error held relatively constant for both years and in both sub-basins, it is possible that the high error was caused by a source of TP that had a more or less similar influence on the entire project area. In our case, one possible source was the TP in baseflow. As discussed in the previous section, the TP concentration in baseflow was only available for 1997 and was assumed to be constant for all the modeling years. Whether TP concentration in baseflow will change significantly with the change of rainfall remains unknown and is one uncertainty associated with this study.

The combined total loading of TN and TP from HC, LHC, and NL sub-basins correlated well with the annual precipitation. The higher the rainfall, the higher the total TN and TP loadings, and vise versa. The highest loading for both TN and TP came from the HC sub-basin, with the second highest from the NL sub-basin, and the least from LHC sub-basin (Table 22, Figure 13-A and Figure 13-B). This is consistent with the area of the three sub-basins and suggests that loadings from surface runoff dominated the loadings from all the sources.

TN and TP loadings from different landuse categories are listed in Tables 23 and 24. Figures 14, 15, 16, and 17 show the percent contribution of TN and TP from different landuse categories in the wettest year (1997) and the driest year (2000), respectively. Baseflow, septic tanks, and point sources are not classical landuse categories. They were included to offer a complete picture of sources of TN and TP loadings. The graphs show how, the amount of annual precipitation influences the relative importance of TN and TP contribution from different point and nonpoint sources.

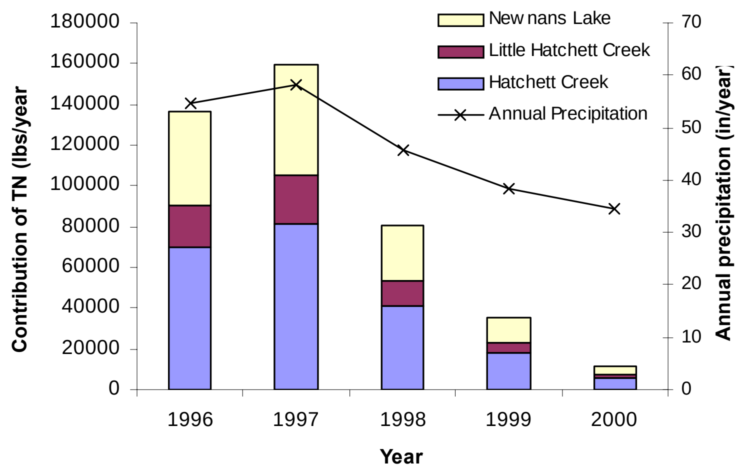


Figure 13-A. Contribution of TN loading from Hatchet Creek, Little Hatchet Creek, and Newnans Lake sub-basins.

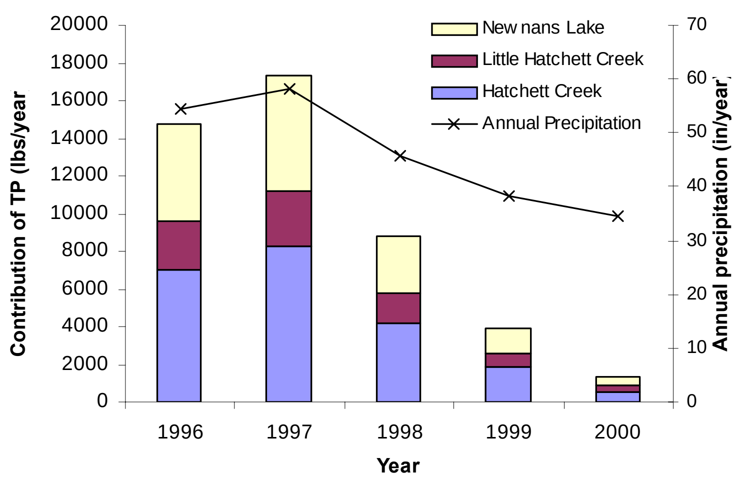


Figure 13-B. Contribution of TP loading from Hatchet Creek, Little Hatchet Creek, and Newnans Lake Sub-watersheds.

Table 23. Contribution of TN from different landuse categories in 1996

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	30716	6248	8823
Urban open	549	637	575
Agriculture	3160	232	2397
Low density residential	3387	153	2216
Medium density residential	1017	1080	2814
High density residential	102	269	331
Transportation/communication	1053	3318	517
Rangeland	1099	1036	1087
Water/wetland	20955	4652	23214
Baseflow	5817	1544	3219
Septic tank	1685	16	1323
Point source	N/A	1444	N/A

Table 23-continue. Contribution of TN from different landuse categories in 1997

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	35693	7260	10253
Urban open	638	740	668
Agriculture	3672	269	2786
Low density residential	3935	178	2575
Medium density residential	1182	1255	3271
High density residential	118	312	385
Transportation/communication	1224	3856	601
Rangeland	1277	1204	1263
Water/wetland	24350	5406	26976
Baseflow	7148	1898	3956
Septic tank	1958	18	1537
Point source	N/A	1283	N/A

Table 23-continue. Contribution of TN from different landuse categories in 1998

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	18126	3687	5207
Urban open	324	376	339
Agriculture	1864	137	1415
Low density residential	1999	90	1308
Medium density residential	600	637	1661
High density residential	60	158	195
Transportation/communication	621	1958	305
Rangeland	649	612	641
Water/wetland	12366	2745	13699
Baseflow	3523	935	1949
Septic tank	995	9	781
Point source	N/A	576	N/A

Table 23-continue. Contribution of TN from different landuse categories in 1999

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	7975	1622	2291
Urban open	143	165	149
Agriculture	820	60	622
Low density residential	879	40	575
Medium density residential	264	280	731
High density residential	26	70	86
Transportation/communication	273	862	134
Rangeland	285	269	282
Water/wetland	5441	1207	6027
Baseflow	1495	397	828
Septic tank	437	4	344
Point source	N/A	198	N/A

Table 23-continue. Contribution of TN from different landuse categories in 2000

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	2468	502	709
Urban open	44	51	46
Agriculture	254	19	193
Low density residential	272	12	178
Medium density residential	82	88	226
High density residential	8	22	27
Transportation/communication	85	267	42
Rangeland	88	83	87
Water/wetland	1684	374	1865
Baseflow	430	114	238
Septic tank	136	1	107
Point source	N/A	325	N/A

Table 24. Contribution of TP from different landuse categories in 1996

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	1845	472	547
Urban open	53	71	55
Agriculture	458	39	348
Low density residential	369	19	241
Medium density residential	123	150	340
High density residential	16	48	51
Transportation/communication	115	426	57
Rangeland	159	172	158
Water/wetland	2095	539	2328
Baseflow	1587	421	878
Septic tank	230	3	180
Point source	N/A	185	N/A

Table 24-continue. Contribution of TP from different landuse categories in 1997

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	2144	549	636
Urban open	61	83	64
Agriculture	532	45	404
Low density residential	429	22	280
Medium density residential	143	174	395
High density residential	18	55	59
Transportation/communication	134	495	66
Rangeland	185	200	183
Water/wetland	2435	625	2706
Baseflow	1950	518	1079
Septic tank	267	3	209
Point source	N/A	158	N/A

Table 24-continue. Contribution of TP from different landuse categories in 1998

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	1089	279	323
Urban open	31	42	33
Agriculture	270	23	205
Low density residential	218	11	142
Medium density residential	72	88.6	201
High density residential	9	28	30
Transportation/communication	68	251	34
Rangeland	94	102	93
Water/wetland	1236	318	1374
Baseflow	961	255	532
Septic tank	136	2	106
Point source	N/A	165	N/A

Table 24-continue. Contribution of TP from different landuse categories in 1999

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	479	123	142
Urban open	14	18	14
Agriculture	119	10	90
Low density residential	96	5	63
Medium density residential	32	39	88
High density residential	4	12	13
Transportation/communication	30	111	15
Rangeland	41	45	41
Water/wetland	544	140	605
Baseflow	408	108	226
Septic tank	60	< 1	47
Point source	N/A	146	N/A

Table 24-continue. Contribution of TP from different landuse categories in 2000

Unit: lbs/year

	Hatchet Creek	Little Hatchet Creek	Newnans Lake
Forest/rural open	148	38	44
Urban open	4	6	4
Agriculture	37	3	28
Low density residential	30	2	19
Medium density residential	10	12	27
High density residential	1	4	4
Transportation/communication	9	34	5
Rangeland	13	14	13
Water/wetland	168	43	187
Baseflow	117	31	65
Septic tank	18	< 1	14
Point Source	N/A	159	N/A

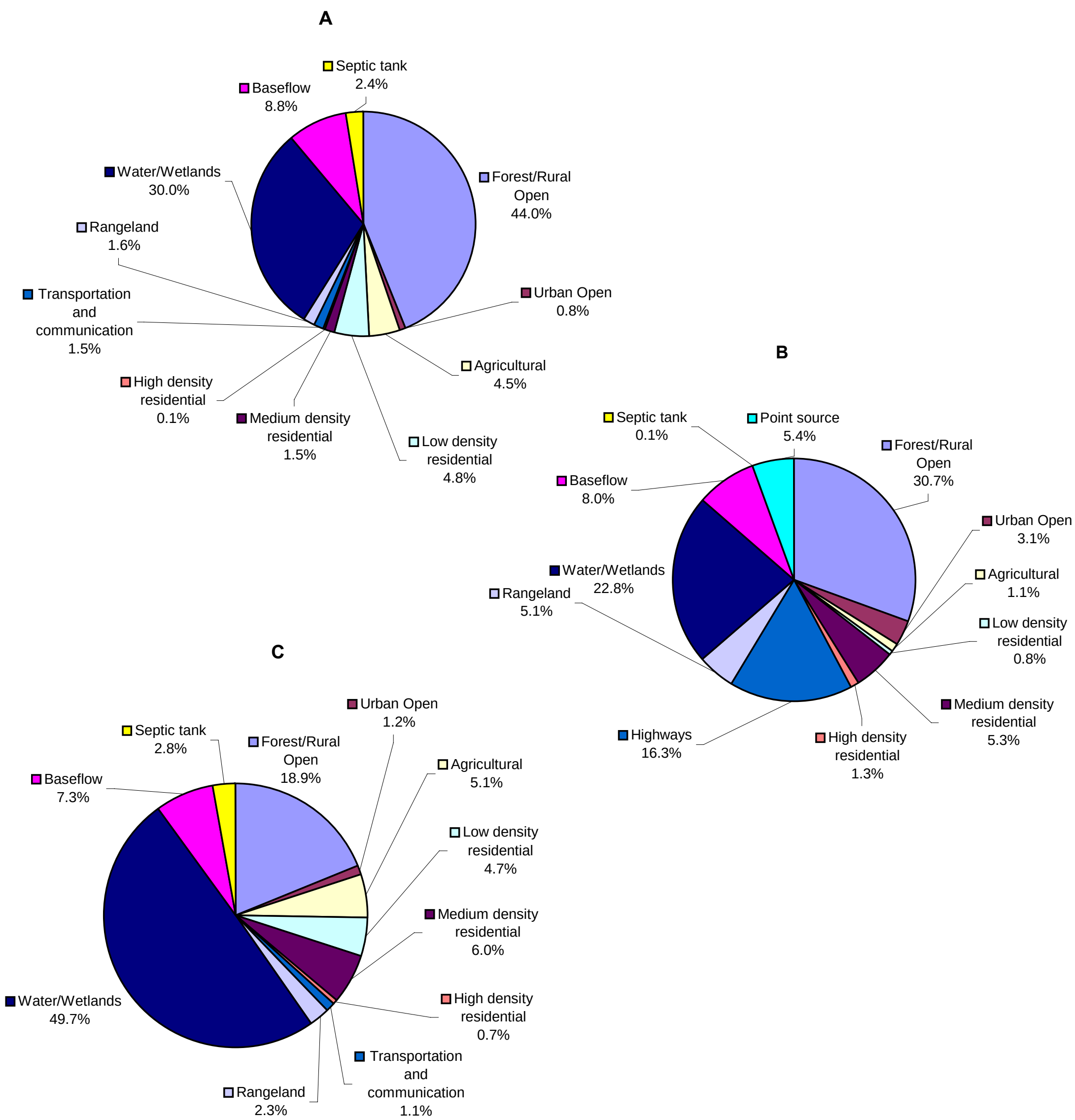


Figure 14. Percent contribution of TN from different landuse categories in 1997. A: Hatchet Creek sub-watershed; B: Little Hatchet Creek sub-watershed; C: Newnans Lake sub-watershed.

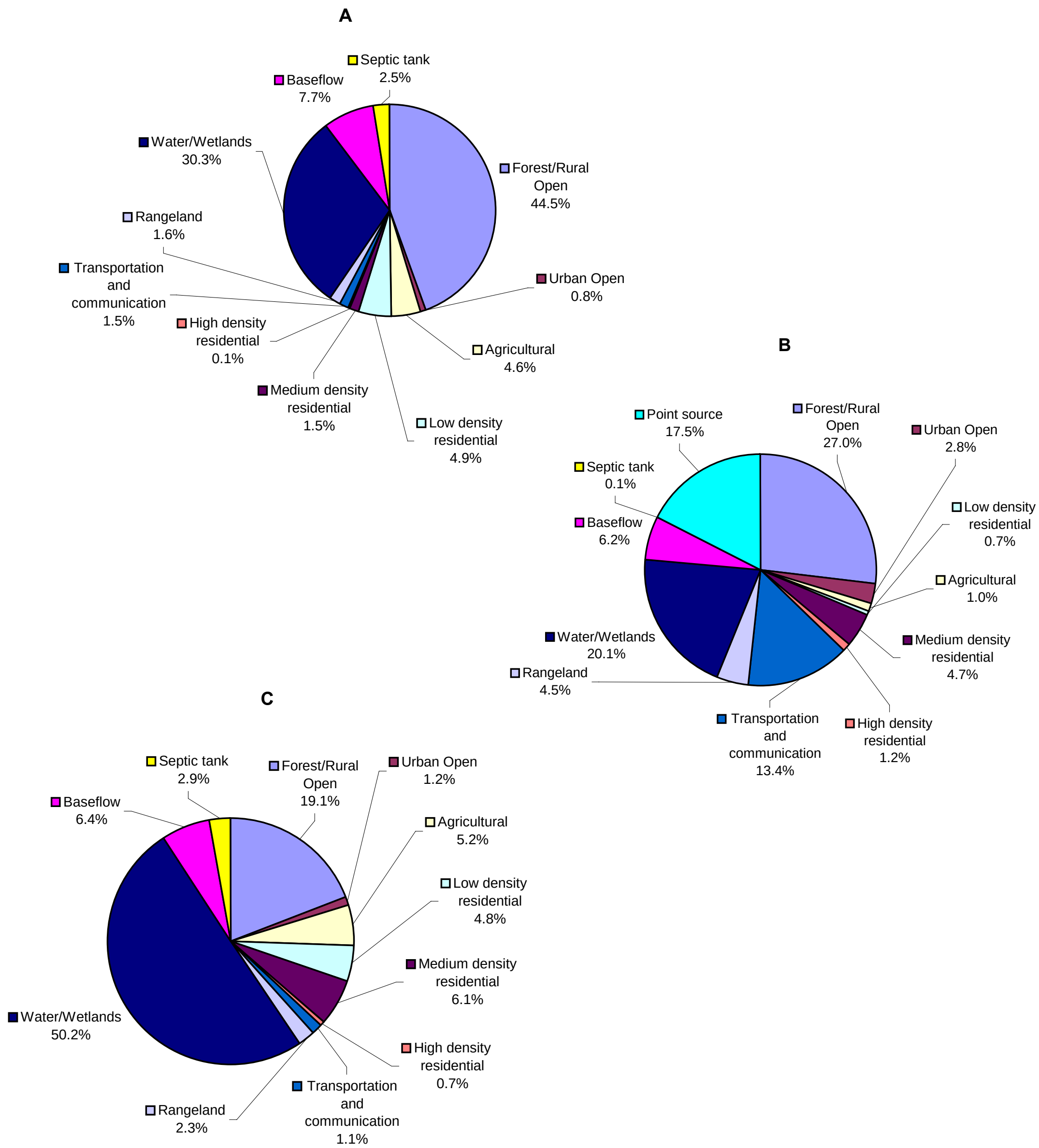


Figure 15. Percent contribution of TN from different landuse categories in 2000. A: Hatchet Creek sub-watershed; B: Little Hatchet Creek sub-watershed; C: Newnans Lake sub-watershed.

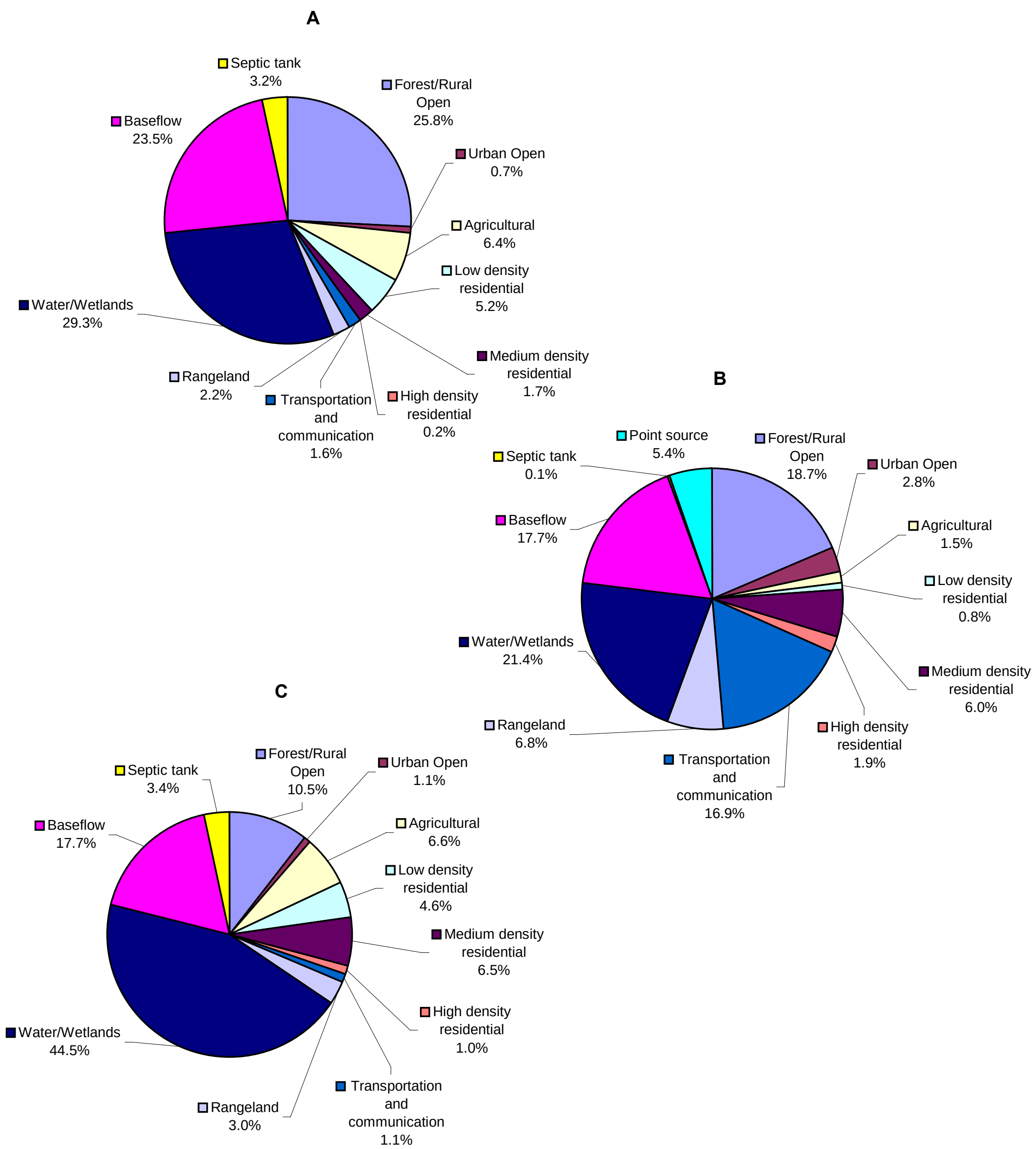


Figure 16. Percent contribution of TP from different landuse categories in 1997. A: Hatchet Creek sub-watershed; B: Little Hatchet Creek sub-watershed; C: Newnans Lake sub-watershed.

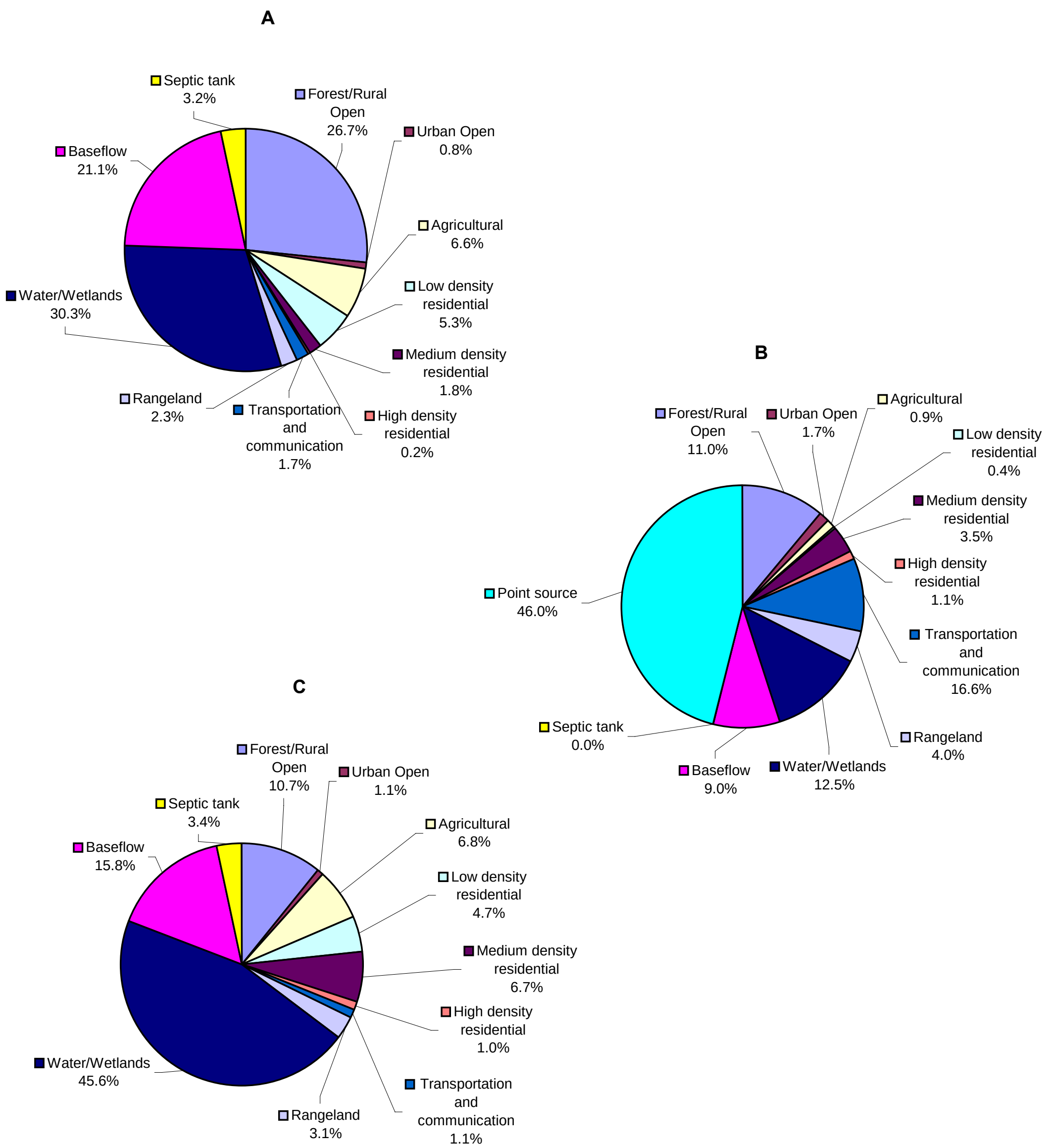


Figure 17. Percent contribution of TP from different landuse categories in 2000. A: Hatchet Creek sub-watershed; B: Little Hatchet Creek sub-watershed; C: Newnans Lake sub-watershed.

Before the percent contribution of TN and TP from each landuse category is discussed, it is important to remember that the relative TN and TP contribution by each sub-basin [Hatchet Creek (HC), Little Hatchet Creek (LHC), and Newnans Lake (NL)] were significantly different. The percent contribution of TN were 49.3% to 51.1%, 14.7% to 17.6%, and 33.0% to 34.2% for the HC, LHC, and NL sub-basins, respectively (Table 25). Annual precipitation appeared to influence the percent contribution of TN from these sub-basins. Percent TN contribution from LHC increased from about 15% to about 18%, while contributions from HC and NL sub-basins decreased from about 51% and 34% to 49% and 33%, respectively. The percent TP contribution followed the similar trend. About 42% to 48% and 31% to 35% of total TP load were from HC and NL sub-basin respectively, while 16.9% to 26.4% of the TP was from LHC sub-basin. Annual precipitation appeared to influence the percent TP contribution more than TN concentration. In the driest year 2000, the contribution of TP from LHC sub-basin increased from about 17% to 19% to about 26%, suggesting the influence from the point source.

Table 25. Percent contribution of TN and TP from HC, LHC, and NL sub-basins

	HC sub-basin		LHC sub-basin		NL sub-basin	
	TN	TP	TN	TP	TN	TP
1996	50.9%	47.7%	15.1%	17.2%	34.0%	35.1%
1997	50.9%	47.8%	15.0%	16.9%	34.1%	35.1%
1998	51.1%	47.4%	14.9%	17.7%	34.1%	34.8%
1999	51.1%	46.5%	14.7%	19.3%	34.2%	34.2%
2000	49.3%	42.4%	17.6%	26.4%	33.0%	31.3%

Non-human landuse categories appeared to dominate the TN loading in both HC and NL sub-basins. The combined percent TN contributions from Water/wetlands and Forest/rural open area accounted for between 74.0% to 74.8% of the total TN loading from HC sub-basin and between 68.6 to 69.3% from NL sub-basin. Percent TN loadings from human landuse categories, including Agriculture, Rangeland, Low, Medium, and High residential area (including septic tanks), Urban open, and Transportation and communication, accounted for 17.2% to 17.5% for HC sub-basin, and 24.1% to 24.3% for NL sub-basin. Baseflow contributed 7.7% to 8.8% TN from HC sub-basin and 6.4% to 7.3% from NL sub-basin. No active point source was identified in these two sub-basins. This explains the findings that the amount of annual precipitation did not significantly influence the percent TN distribution among non-human landuse categories, human-landuse categories, and baseflow.

Among the human landuse categories, TN loading from residential areas appears to be predominating. Residential TN loading accounted for 6.4% to 6.5% of the total TN loading in HC sub-basin and 11.4% to 11.6% in NL sub-basin. If the influence of leaking septic tanks were considered, TN loading from residential areas would account for 8.8% to 9.0% and 14.2% to 14.5% in HC and NL sub-basins, respectively. Medium density residential contributed the highest percentage of TN from residential areas in the NL sub-basin, accounting for 6.0% to 6.1% of the total TN loading. Low density residential area was the second largest residential TN contributor in NL sub-basin, accounting for 4.7% to 4.8% of the total TN loading. The largest residential TN contributor in the HC sub-basin was the low density residential area, which accounted for 4.8% to 4.9% of the total TN loading.

The largest TN contributor of non-residential human landuse category was Agriculture. It accounted for 4.5% to 4.8% of the total TN loading in both HC and NL sub-basins. The percent TN contribution from different landuse categories in HC and NL sub-basin was not significantly influenced by annual precipitation.

The distribution of percent TN loading across different landuse categories was different in LHC sub-basin from those in HC and NL sub-basins and was also significantly influenced by the annual precipitation. The combined TN loading from non-human landuse categories accounted for 53% of the total TN loading from the sub-basin in the wettest year of 1997, but decreased to 44.1% in the driest year of 2000. Percent TN contribution of baseflow was also influenced by the rainfall. In the wet year, baseflow TN loading comprised 7.9% of the total TN loading and 5.8% in the dry year. Combined TN loading from human landuse categories increased when the annual precipitation decreased, from 39.1% in the wet year to 50.1% in the dry year. The reason for the difference was the change of the percent TN loading from the point source. In the wet year, the TN loading from the point source accounted for only 6.3%, while in the dry year, the percentage increased to 22.8%.

Another large TN contributor in LHC sub-basin was the Transportation and communication landuse category. It accounted for 16.1% of the total TN loading in the wet year and 13.4% in dry year. TN loading from this landuse category was primarily from the Gainesville Regional Airport. Combined percent TN loading from all residential landuses in this basin accounted for 7.2% of the total loading in the wet year and 6.1% in the dry year. Influence from septic tanks on the TN loading appeared low. In both wet and dry years, percent TN loading from septic tanks was about 0.1%.

Percent TN loading from Agriculture was lower in LHC sub-basin than the other two sub-basins. Agriculture TN loading only accounted for 1.1% in the wet year and 0.9% in the dry year. Contributions from Rangeland and Urban open landuse categories were higher than those from the other two sub-basins. Rangeland contributed 5.0% and 4.2% TN in the wet year and dry year respectively. Urban open contributed 3.1% and 2.6% TN in wet and dry years, respectively. Although a significant change of the percent contribution from different landuse categories was observed in the LHC sub-basin, because the TN loading from this sub-basin only accounted for 15% to 17% of the TN loading from the entire Newnans Lake watershed, changes of the percent distribution within the LHC sub-basin should not influence the overall pattern of the TN loading from the watershed to the lake.

Distribution of percent TP loading from different landuse categories within all sub-basins followed the general pattern of percent TN loading (Figure 16 and 17). However, some differences are noted below. The TP loading from baseflow accounted for a significant portion of the total TP loading in all three sub-basins. In the wet year, baseflow accounted for 23.5%, 17.7%, and 17.7% for HC, LHC, and NL sub-basins respectively. In the dry year, it accounted for 21.1%, 9.0% and 15.8% for the three sub-basins respectively. Like the percent TN loading from the point source, percent TP loading from the point source comprises of a significant portion of the total TP loading in LHC sub-basin and its percentage of the total was greatly influenced by the annual precipitation. In the wet year, TP loading from the point source accounted for about 5.4% of the total TP loading from the sub-basin. In the dry year, however, the percent contribution from the point source jumped to about 46.0% and became one of the major sources of TP contributors in LHC sub-basin.

Atmospheric loading of TN and TP into Newnans Lake

One source of TN and TP loading to Newnans Lake that was not considered by WMM was the TN and TP falling directly into Newnans Lake through precipitation. In this study, atmospheric loading of TN and TP was calculated by multiplying the amount of precipitation directly falling on to the lake surface (calculated by multiplying annual precipitation by surface area of the lake) by the TN and TP concentration of the rainfall. Because no data for the TN and TP concentration of rainfall was available for the project area, published values were used in this study, which were 0.1 mg/L and 0.05 mg/L for TN and TP respectively (Stites, et al 2001). Calculated annual TN and TP loadings are tabulated in Table 26.

Table 26. Atmosphere loading of TN and TP into Newnans Lake

Unit: lbs/year

	TN	TP
1996	7802	3901
1997	8048	4024
1998	7133	3567
1999	5039	2520
2000	4208	2104
Mean	**6446**	**3223**
SE	**770**	**385**
CV	**12%**	**12%**

5.3 Establishing the relationship between TN and TP loading and in-lake TN, TP, and Chla concentrations

Input and output analysis on TN and TP dynamics of Newnans Lake

Before the Bathtub eutrophication model could be used to establish a relationship between TN and TP loadings to the lake and the in-lake TN, TP, and Chla concentrations, other possible sources of TN and TP needed to be considered. In this study, one specific concern was whether internal recycling of nutrients was significant, and as such, should be included in the model.

To address this question, the TN and TP concentrations in all the sources were analyzed and compared to the TN and TP concentration of the lake and outlet stream. If the TN and TP concentrations in all the sources were significantly lower than the in-lake and outlet concentrations, an assumption of internal recycling is warranted.

Table 27 lists TN and TP concentrations of all the sources characterized in this study and the TN and TP concentrations of the lake and the outlet stream. Among these values, concentration of the water from two inlet streams and surface runoff from NL sub-basin were model predictions. These model predictions are final results after the influence from landuse patterns, baseflow input, septic tank leakage, and point sources were taken into account. Concentrations of the precipitation directly into Newnans Lake were literature-cited values

(Stites, et al 2001). The in-lake concentration and the concentration of the outflow stream were based on measured data. Based on Table 27, TN and TP concentrations in all the sources were lower than the in-lake and outflow concentrations. Therefore, it was reasonable to include internal recycling as a process for both TN and TP in the Bathtub application.

Table 27 Comparison of TN and TP concentrations in all identified sources to the TN and TP concentrations of lake water and outflow stream. Data represent mean ± 1 SE (n=5). All the means were calculated based on either model predictions or measured data in the period from 1996 through 2000.

Unit: mg/L

	TN	TP
Hatchet Creek	0.936 ± 0.013	0.101 ± 0.001
Little Hatchet Creek	0.955 ± 0.086	0.139 ± 0.022
NL surface runoff	0.978 ± 0.012	0.111 ± 0.001
Precipitation	0.100	0.05
Newnans Lake	4.388 ± 0.887	0.158 ± 0.036
Prairie Creek	4.030 ± 1.103	0.172 ± 0.056

Data required for calibrating Bathtub eutrophication model

The relationship between TN and TP loading and the in-lake TN and TP concentrations was established through fitting the Bathtub predictions with the measured TN and TP concentrations of the lake. To calibrate the model, the following data were required:

1. Physical characteristics of the lake (surface area, mean depth, and mixed layer depth)
2. Meteorological data (precipitation and evaporation)
3. Measured water quality data (TN, TP, and Chla concentrations of the lake water)
4. Loading data (flow and TN and TP concentrations of the flow from various point and nonpoint sources).

Because Bathtub allows both error and variability analysis, whenever there were historical data, long-term average and coefficient of variance (CV) of the average was calculated and entered into the model as input. All the data that were required for model calibration are listed in Tables 28 through 31.

Table 28. Physical characteristics of Newnans Lake

	Lake surface area	Mean depth	Mixed layer depth
	(km^2)	(m)	(m)
1996	25.50	1.55	1.55
1997	24.69	1.55	1.55

1998	27.92	1.81	1.81
1999	23.47	1.16	1.16
2000	21.85	1.02	1.02
Mean	24.69	1.42	1.42
SE	1.02	0.14	0.14
CV	4%	10%	10%

Note: Because Newnans Lake is a shallow lake with a relatively large surface area, wind mixing is strong and thermal stratification does not form in the summer. Therefore, the "Mixed layer depth" was assumed equal to the mean depth of the lake.

Table 29. Precipitation and evaporation

Unit: m/year

	Precipitation	Evaporation
1996	1.388	1.330
1997	1.479	1.474
1998	1.159	1.587
1999	0.974	1.606
2000	0.874	1.661
Mean	1.175	1.532
SE	0.116	0.059
CV	10%	4%

Table 30. Measured TN, TP, and Chla concentrations of Newnans Lake

Unit: ppb

	TN	TP	Chla
1996	3803	111	272.2
1997	3813	126	261.8
1998	2364	89	120.5
1999	4262	172	269.6
2000	7700	291	298.7
Mean	4388	158	245.0
SE	888	36	32.0
CV	20%	23%	13%

Table 31. Flow and TN and TP concentrations of different sources

	Flow			TN			TP		
	mean	SE	CV	Mean	SE	CV	Mean	SE	CV
	(hm^3/yr)			(ppb)			(ppb)		
Forest/Rural Open	9.68	3.25	34%	1326.2	0.0	0%	83.00	0.001	0.0%
Urban Open	0.60	0.20	34%	823.0	0.4	0%	83.60	0.079	0.1%
Agricultural	0.96	0.32	34%	1686.1	0.3	0%	245.93	0.095	0.0%
Low density residential	1.25	0.42	34%	1288.6	0.1	0%	140.91	0.017	0.0%
Medium density residential	0.85	0.28	34%	1627.3	0.2	0%	203.13	0.046	0.0%
High density residential	0.12	0.04	34%	1684.4	0.7	0%	273.64	0.254	0.1%
Transportation, Communications, and Utilities	0.98	0.33	34%	1393.4	0.2	0%	170.48	0.045	0.0%
Rangeland	0.56	0.19	34%	1625.7	0.2	0%	246.85	0.085	0.0%
Water/Wetlands	11.86	3.98	34%	1155.0	0.0	0%	117.39	0.001	0.0%
Baseflow	13.81	4.74	34%	220.0	0.0	0%	60.00	0.000	0.0%
Point source	0.03	0.00	4%	9912	3072	31%	2182.01	41.65	1.9%

Note:

a) Bathtub does not allow direct input of loading. Therefore, data presented here are flow and TN and TP concentration of the flow.

b) Flows for each source presented are calculated by aggregating individual flows from all the three sub-basins (Hatchet Creek, Little Hatchet Creek, and Newnans Lake sub-basin) and then averaging throughout the period from 1996 to 2000.

c) TN and TP concentrations presented for each source were calculated by adding TN and TP loadings from all the three sub-basins (Hatchet Creek, Little Hatchet Creek, and Newnans Lake sub-basin), dividing the sum by the total flow over all the three sub-basins, and then averaging throughout the period from 1996 to 2000.

Calibrating the Bathtub eutrophication model

To calibrate the model, each source of TN and TP was designated as an independent tributary. Flow and TN and TP concentrations of the flow were defined for each tributary as listed in Table 30. The TN flux from the sediment is not defined in Table 30 because in Bathtub, internal recycling is characterized differently from regular point and nonpoint sources. Instead of being defined by flow and the pollutant concentration of the flow, internal recycling is expressed as a sediment releasing rate. Because information on internal recycling of TN and TP were not available for Newnans Lake, a TP rate of 0.665 mg $P/m^2/day$ determined in a study conducted at Lake Okeechobee (James and Bierman 1995) was used in this study. The TN rate used in this study was 11.3 mg $N/m^2/day$. This value was calculated by multiplying the TP rate by 17, which is the sediment TN/TP ratio of Newnans Lake characterized by Brenner and Whitmore (1998).

Bathtub provides alternative models for estimating the influence of sedimentation on the in-lake TN and TP concentrations. In this study, the settling velocity model was chosen for both TN and TP. This model assumes that the sedimentation of TN and TP is in first-order kinetics and should linearly correlate with the in-lake TN and TP concentration. The model also assumes that the sedimentation is influenced by the depth of the lake. The deeper the lake, the slower the sedimentation. This model fit the condition of Newnans Lake because the lake is relatively shallow and large in surface area. Continued wind mixing prevents the lake from forming thermal stratification, which would otherwise prevent the particles from being re-suspended once settled down to the bottom. Continued wind mixing through the entire water column also reduces particle settling rate by continuously bringing the settled particle back in to water column. These processes produce a relatively low settling rate in Newnans Lake.
Other sedimentation models provided by Bathtub assume second-order kinetics, which fit reasonably well with lakes that form thermal stratification during the summer. However, these models would overestimate the sedimentation of Newnans Lake, and in turn cause underestimation of the in-lake TN and TP concentration.

Bathtub provides two chlorophyll a responding models based on the assumption of nitrogen and phosphorus co-limitation: Model 1 and 3. Model 1 assumes that algal communities are co-limited not only by nitrogen and phosphorus, but also by light intensity. This model seemed to fit the situation for Newnans Lake because the lake had a very high chlorophyll concentration, which would be expected to lead to self-shading. However, application of this model yielded Chla concentrations much lower than the measured data. Therefore, in simulating Chla response, Model 3 was used. This model assumes that the primary production of the lake was co-limited by nitrogen and phosphorus, but not by light intensity (Walker 1999). This could be the case in Newnans Lake because the lake is large and shallow. Wind mixing could constantly stir the entire water column and bring the algal cells in the deeper water up to the surface so that no cells would be permanently shaded. Using this model, a reasonable fit between predicted and measured Chla was achieved.

Calibration factors were applied to fit TN and TP predictions to the measured data. Two calibration methods are provided by Bathtub for phosphorus and nitrogen: Method 0 calibrates decay rates and Method 1 calibrates concentration. In the first case, the calibration factors are applied to estimated sedimentation rates in computing nutrient balances. In the second case, the factors are applied to estimated concentrations. In Method 0, it is assumed that the error is attributed primarily to the sedimentation model. In Method 1, the error source is unspecified (some combination of input error and sedimentation model error). The latter may be used when predicted nutrient profiles are insensitive to errors in predicted sedimentation rate because the mass balance is dominated by inflow and outflow terms (low hydraulic residence times) (Walker 1999). In this study, because wind mixing could significant lower the sedimentation rate over the default sedimentation rate (based on data from lakes that form thermal stratification), it was assumed that the error of the model predictions came mainly from the error associated with the sedimentation model. Therefore, Method 0 was adopted in this study to calibrate the decay rate due to the sedimentation. Typical calibration factors for TN and TP recommended by the Bathtub user's manual are 0.5 – 2.0 for TP and 0.33 – 3 for TN. In this study, 0.5 and 2 were used for calibrating TP and TN, respectively. Results of model calibration are shown in Table 32.

Table 32. Bathtub calibration results

	Measured		Estimated		Error	T statistics		
	Mean	CV	mean	CV		1	2	3
TP (mg/l)	0.158	0.23	0.160	0.38	1%	-0.07	-0.06	-0.04
TN (mg/l)	4.39	0.20	4.34	0.55	1%	0.05	0.04	0.02
Chla (µg/l)	245	0.13	243	0.54	1%	0.05	0.02	0.01

Bathtub provides for statistical comparisons between observed and predicted concentrations. These are computed using three alternative measures of error: observed error only, T(1); error typical of model development data set, T(2); and observed and predicted error, T(3). Tests of model applicability are normally based upon T(2) and T(3). If their absolute values exceed 2 for the comparison of area-weighted mean concentrations, there is less than a 5% chance that nutrient sedimentation dynamics in the reservoir are typical of those in the model development data set. This assumes that input conditions have been specified in an unbiased manner. Once an appropriate sedimentation model is selected, T(1) can be used as a basis for deciding whether calibration is appropriate. If the absolute value of T(1) exceeds 2, then there is less than a 5% chance that the observed and predicted means are equal, given the error in the observed mean (Walker 1999). In this case, no T value for TN, TP and Chla predictions was higher than 2. Therefore, the model was considered calibrated properly.

<u>TSI from Bathtub predictions vs. TSI based on measured data</u>

The TSI was calculated based on Bathtub estimated TN, TP, and Chla concentrations. Because the mean values of model predictions for TN, TP, and Chla all have associated CV values estimated by Bathtub (Table 32), TSIs calculated based on model estimated TN, TP, and Chla include the mean, the maximum possible value, and the minimum possible value (Table 33).

Table 33. TSI calculated based on model predicted and measured TN, TP, and Chla concentrations

	TSI calculated based on model predictions	TSI calculated based on measured data
Mean	88	89
Maximum	95	91
Minimum	76	87

As shown in Table 33, the mean predicted TSI is very similar to measured values and the range of TSIs calculated based on model estimated TN, TP, and Chla appeared to overlap with the mean ± 1 SE of the TSIs calculated based on measured data. Therefore the model predications were considered adequate estimates of measured values. Table 33 also indicates that the TSI calculated based on model estimated TN, TP, and Chla concentrations had a range of 19 TSI units**.**

Evaluation of influence from the internal recycling on the trophic status of Newnans Lake

In addition to calibrating the model, the significance of internal recycling of TN and TP during the verified period on the trophic status of Newnans Lake was examined in this study. No data were available on sediment TN and TP levels during the verified period or on how the rate of translocation of TN and TP from the sediment into the water column correlate with sediment TN and TP in this lake over this period. Given the lack of this information, the importance of the TN and TP internal recycling was examined by comparing the current TSI to the TSI calculated under the situation that the internal recycling of TN and TP was completely eliminated. All the calibrated model parameters were kept the same during the calculation except that the TN and TP sediment flux rate was reset to 0. Additionally, when calculating the TSI, the CVs associated with the TN, TP, and Chla concentrations were all kept the same. The model estimated TN, TP, and Chla concentrations without loadings from internal recycling and the TSI calculated based on these data are listed in Table 34.

Table 34. TN, TP, Chla, and TSI values after nutrient loading from the internal recycling was eliminated

	Current model estimates		Estimate without internal recycling	
	Mean	CV	Mean	CV
TP (mg/l)	0.160	0.38	0.069	0.38
TN (mg/l)	4.34	0.55	1.00	0.55
Chla (µg/l)	243	0.54	63.4	0.54
Mean TSI	88		67.4	
Max TSI	95		74.2	
Min TSI	76		55.6	

As Table 33 shows, by completely removing the TN and TP loading from internal recycling from Bathtub, TN in the lake drops 77% from 4.34 mg/l to 1.00 mg/l. Considering the 55% CV associated with the result, the TN concentration returned to its level in the late 1980s and early 1990s. The same thing happened to the TP concentration, although in a relatively milder way. It drops about 56% from 0.160 mg/l to 0.069 mg/l, returning to its level around the late 1980s and early 1990s. The Chla concentration dropped 74%, from the current 243 µg/l to about 63.4 µg/l. The mean TSI value calculated based on the TN, TP, and Chla concentrations after the loading from internal recycling was totally removed was 67.4. Due to the CV associated with TN, TP, and Chla concentrations, the calculated TSI had a range from 55.6 to 74.2, which was not significantly different from the TSI level at late 1980s and early 1990s.

When the model simulation was run with the TN and TP loadings from internal recycling set to 0, the TN and TP ratio was checked to ensure that it did not violate the assumptions of the calibrated model. The ratio should be between 10 and 30 so that the algal community of the lake was still under the co-limitation by phosphorus and nitrogen. The TN/TP ratio after we assumed 0 loading from internal recycling was about 16, which met the model assumption. This ratio was also similar to the TN/TP ratio around late 1980s and early 1990s, indicating a situation approaching nitrogen limitation.

Evaluating the Natural Background TSI of Newnans Lake

The background TN and TP loading without the loadings generated from the existing level of human activities were estimated using the following procedures:

1. The loadings from internal recycling of TN and TP were completely removed.
2. All the man-made landuse categories (Urban open, Agricultural, Low-density residential, Medium density residential, High density residential, Transportation and communication, and Rangeland) in all the three sub-basins were evaluated as Forest/rural open. All the loadings from septic tanks and point sources were also removed.
3. TN and TP loadings through surface runoff were then estimated using the calibrated WMM, a long-term average precipitation of 13.6 inches/year (adjusted with P_0), and a long-term average areal baseflow of 1.8 inches/year.
4. Flow of Forest/rural open, Water/wetland, and baseflow from all the three sub-basins including HC, LHC, and NL were then aggregated.
5. TN and TP concentrations from Forest/rural open, Water/wetland, and baseflow were calculated by dividing the total loadings from the three sub-basins by the total flow from the three sub-basins (Table 35).

Table 35. Flow and TN and TP concentrations of surface runoff from Forest/rural open, Water/wetland, and Baseflow

	Flow	TN concentration	TP concentration
	(Hm^3/year)	(ppb)	(ppb)
Forest/rural open	13.36	1321.48	82.67
Water/wetland	11.86	1152.54	116.97
Baseflow	13.81	220.00	60.00

6. The flow and TN and TP concentration of surface runoffs from Forest/rural open, Water/wetland, and baseflow were then entered into Bathtub to estimate the in-lake TN, TP, and Chla concentrations.
7. The TSI was calculated based on the predicted TN, TP, and Chla concentrations. This TSI was considered the natural background TSI of Newnans Lake and any further reduction of the TSI of the lake by additional reductions in the loadings was not considered. The resulting TN, TP, and Chla concentration and TSI are listed in Table 36.

Table 36. TN, TP, and Chla concentrations and TSI after all the human landuse categories and loadings from internal recycling were removed

TP (mg/l)	0.060
TN (mg/l)	0.936
TN/TP	16
Chla (µg/l)	54.9
Mean TSI	65.4

Max TSI	72.1
Min TSI	53.5

As shown in Table 36, TN, TP, and Chla concentrations decreased an additional 5%, 13%, and 13%, respectively, when all the loadings from human landuse categories were removed compared to the model estimates when the loadings from internal recycling were totally removed without changing the current landuse pattern (Table 34). Mean TSI value decreased from 67.4 to 65.4, about 3% lower than before the loadings from human influences were completely removed.

Determination of Assimilative Capacity

As mentioned previously, the IWR thresholds for nutrient impairment in lakes was used as the water quality target for the lake. Rule 62-303.352(1), FAC, specifies for lakes with an average color of 60 or greater that the annual average TSI should be 60 or less, unless paleolimnological information indicates the annual average natural TSI of the lake was greater than 60. Based on results contained in Brenner and Whitmore 1998, the range of diatom-inferred TP concentrations for historical lake water quality in Newnans Lake is 0.036 to 0.077 mg/L. The paleolimnological results did not address TN and Chla concentrations so that a TSI could not be calculated from the published data. However, model estimates for the natural background annual average TSI ranged between 54.9 and 72.1 (mean of 65.4) and the predicted TP concentration for the natural background condition was 0.06 mg/L. Because the natural background TP determined by modeling is within the range of natural background TP determined by the paleolimnological study, use of the natural background TSI determined from the modeling is acceptable evidence that the natural background TSI of the lake was greater than 60. Therefore, maintaining the TSI of the Lake within the range of TSIs established as natural background became the target for the load allocation component of the TMDL.

The TN and TP loadings from major sources to Newnans Lake during the period of this study are listed in Table 38. The total annual average loadings to the Lake for the current condition are 315,510 lbs/year for TN and 25,732 lbs/year for TP. To evaluate natural background, the impact of loadings from all human based nonpoint sources were removed by resetting the landuses to Forest/open and all the loadings from septic tanks were removed. The loadings from this scenario became the natural background case. The annual TN and TP loadings to the lake dropped to 85,470 lbs/year and 10,924 lbs/year, respectively. This represents a 74% reduction of TN and a 59% reduction of TP loadings. After this loading reduction is achieved, the TSI of the lake is predicted to decrease to about 65 (with a range from 53 to 72). Because 65 is the natural background condition of the lake, no further reduction in loading was considered necessary in this study. The total allowable loading (assimilative capacity) is 10,924 lbs/year for TP and 85470 lbs/year for TN. This corresponds to reductions from the existing loadings of 74 percent for TN and 59 percent for TP.

6.0 Determination of TMDL

The objective of a TMDL is to allocate loads among all of the known pollutant sources throughout a watershed so that appropriate control measures can be implemented and water quality standards achieved. A TMDL has historically been expressed as the sum of all point source loads (Waste Load Allocations), nonpoint source loads (Load allocations), and an appropriate margin of safety (MOS), which takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$\textbf{TMDL} = \sum \textbf{WLAs} + \sum \textbf{LAs} + \textbf{MOS}$$

This equation has changed slightly in response to the evolution of the NPDES Stormwater Program, such that the WLA has been broken out into separate subcategories for wastewater discharges and stormwater discharges:

$$\textbf{TMDL} \cong \sum \textbf{WLAs}_{\textbf{wastewater}} + \sum \textbf{WLAs}_{\textbf{stormwater}} + \sum \textbf{LAs} + \textbf{MOS}$$

It should be noted that, in this modified equation, the various components of the TMDL may not sum up to the value of the TMDL because a) the WLA for stormwater is typically based on the percent reduction needed for **all** nonpoint sources and is accounted for within the LA, and b) TMDL components can be expressed in different terms [for example, the WLA for stormwater is typically expressed as a percent reduction and the WLA for wastewater is typically expressed as a mass per day].

WLAs for stormwater discharges are typically expressed as "percent reduction" because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from other nonpoint sources (given the nature of stormwater transport). The permitting of stormwater discharges is also different than the permitting of most wastewater point sources. Because stormwater discharges cannot be centrally collected, monitored and treated, they are not subject to the same types of effluent limitations as wastewater facilities and are instead required to meet a performance standard of providing treatment to the "maximum extent practical" through the implementation of Best Management Practices.

This new approach is consistent with federal regulations [40 CFR § 130.2(I)], which state that TMDLs can be expressed in terms of mass per time (e.g. pounds per day), toxicity, or **other appropriate measure**. The TMDL for Newnans Lake (Table 37) is expressed in terms of pounds per year and percent reduction.

Table 37 TMDL Components

WBID	Parameter	WLA		LA (lbs/year)	MOS	TMDL (lbs/year)	Percent Reduction
		Wastewater (lbs/year)	Stormwater				
2705B	TN	3,104	NA	82,366	Implicit	85,470	74
2705B	TP	386	NA	10,538	Implicit	10,924	59

6.1 Load Allocation

The allowable LA is 10,538 lbs/year for TP and 82,366 lbs/year for TN. This corresponds to reductions from the existing loadings of 74 percent for TN and 59 percent for TP. It should be noted that the LA allocation includes loading from stormwater discharges regulated by the

Department and the Water Management Districts that are not part of the National Pollutant Discharge Elimination System (NPDES) Stormwater Program (see Appendix A).

The Department recognizes that the absolute value of these loading numbers may be significantly different from the absolute loads calculated by other models, based on analysis using data from other sources, use of different assumptions, and/or differing interpretation of the results of other researchers. However, the Department is very confident in the relative percent load reductions required to return the lake to a healthy condition and the estimated concentrations of TN (0.97 mg/L), TP (0.062 mg/L), and Chla (57.6 ug/L) that would be expected in a healthy Newnans Lake.

6.2 WasteLoad Allocation

NPDES Stormwater Discharges

As noted in Sections 4 and 6.1, load from stormwater discharges permitted under the NPDES Stormwater Program are placed in the WLA, rather than the LA. This includes loads from municipal separate storm sewer systems (MS4). However, based on the information provided by EPA, no MS4 area was found overlapping the Newnans Lake watershed and no stormwater loads were assigned to the WLA.

NPDES Wastewater Discharges

To evaluate the impact of the point source in the basin, additional model runs were made for natural background under average, wet, and dry years with the point source added back in at the maximum permit limits and modeled as if it discharged directly to the lake. The results are shown in Table 38. Under critical conditions (dry year), the point source would increase the TSI of the lake from 62 to 64, with an increase in Chla concentrations of 6.6 ug/L (from 40.4 to 47.0 ug/L). This TSI of 64 under critical conditions for the point source is still under the mean TSI of 65.4. Under average natural background conditions, the point source would increase the TSI of the lake by less than 1 TSI unit from 65.4 to about 65.7 (rounded to 65 and 66). This would increase the Chla concentration in the lake by only 2.7 ug/L. Under wet year conditions there was no change in the TSI of the Lake by the addition of the point source and Chla only increased by 1.5 ug/L.

Given the small projected changes in TSI and Chla and that the point source was evaluated as if it discharged directly into the lake with no consideration of any assimilation that might occur in Little Hatchet Creek, the Department concluded that the facility as currently permitted will not cause or contribute to violations of state water quality standards in Newnans Lake. Therefore no reduction in the loadings from the facility are warranted. As no load reductions are proposed for the point source, Brittany Estates loadings are set at 386 lbs/year for TP and 3,104 lbs/year for TN.

6.3 Margin of Safety

By setting the target TSI as natural background, the Department is using the difference between natural background and the loading capacity as defined by EPA regulation (40 C.F.R. 130.2(f)) as part of the implicit margin of safety. EPA defines the loading capacity as the greatest amount of a pollutant that a water can receive without violating water quality standards. Additional implicit margin of safety exists due to conservative assumptions used in the modeling process. For example, it was assumed that 100 percent of the loadings from the single point source were transported by Little Hatchet Creek into the lake.

7.0 Evaluation of TMDL on Unionized Ammonia in Newnans Lake

Newnans Lake was placed on the Planning List for Unionized Ammonia following the procedures established in Rule 62-303, FAC. While not verified as impaired for this parameter, the impact on unionized ammonia of reducing TN as a part of the nutrient TMDL was examined. The mean TN concentration for the verified period is 4.34 mg/L. The annual average concentration of TN in the Lake once the TMDL is achieved has been calculated as 0.94 mg/L. The current ratio between total ammonia and TN is 0.06 (based on the quarterly means from 1989 – 2000). Based on this ratio, the annual average total ammonia concentration in the Lake after the TMDL is achieved was calculated as (0.94 * 0.06) 0.06 mg/L. The current ratio of un-ionized ammonia to TN is 0.01 (based on the quarterly means from 1989 – 2000). Based on this ratio, the annual average un-ionized ammonia concentration in the Lake after the TMDL is achieved was calculated as (0.94 * 0.01) 0.01 mg/L. This value is below the un-ionized ammonia criterion of 0.02 mg/L specified in Rule 62-302.530, FAC. This indicates that under the TMDL for TN, the Lake the annual average un-ionized ammonia concentration will meet water quality standards.

8.0 NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

Following adoption of this TMDL by rule, the next step in the TMDL process is to develop an implementation plan for the TMDL, which will be a component of the Basin Management Action Plan for the Newnans Lake Basin. This document will be developed in cooperation with local stakeholders and will attempt to reach consensus on more detailed allocations and on how load reductions will be accomplished.

The Basin Management Action Plan (B-MAP) will include:

- Allocations among the affected parties.
- A description of the load reduction activities to be undertaken.
- Timetables for project implementation and completion.
- Funding mechanisms that may be utilized.
- Any applicable signed agreements.
- Local ordinances defining actions to be taken or prohibited.
- Local water quality standards, permits, or load limitation agreements.
- Monitoring and follow-up measures.

It should be noted that TMDL development and implementation is an iterative process, and this TMDL will be re-evaluated during the BMAP development process and subsequent Watershed Management cycles. The Department acknowledges the uncertainty associated with TMDL development and allocation, particularly in estimates of nonpoint source loads and allocations for NPDES stormwater discharges, and fully expects that it may be further refined or revised over time. If any changes in the estimate of the assimilative capacity AND/OR allocation between point and nonpoint sources are required, the rule adopting this TMDL will be revised, thereby providing a point of entry for interested parties.

Table 38 Source Evaluation Critical Conditions

Average = long-term average rainfall, NB = Natural Background, @E = existing condition, PS = Point Source

	Current Condition Average	NB Average	NB + PS @E Average	**NB + PS @ Permit limits Average**	NB Wet Year	NB + PS @E Wet Year	NB + PS @Permit limits Wet Year	NB Dry Year	NB + PS @E Dry Year	NB + PS @ Permit Limits Dry Year
TP annual load (kg/year)										
Precipitation	1450	1450	1450	**1450**	1826	1826	1826	1079	1079	1079
Watershed	3997	3330	3330	**3330**	6307	6307	6307	422	422	422
Point source	66	0	66	**175**	0	66	175	0	66	175
Internal recycling	6114	0	0	**0**	0	0	0	0	0	0
total loading	11627	4780	4845	**4954**	8133	8199	8308	1501	1566	1675
TN annual Load (kg/year)										
Precipitation	2900	2900	2900	**2900**	3652	3652	3652	2158	2158	2158
Watershed	37164	34461	34461	**34461**	64932	64932	64932	4441	4441	4441
Point source	297	0	297	**1408**	0	297	1408	0	297	1408
Internal recycling	102751	0	0	**0**	0	0	0	0	0	0
total loading	143113	37361	37659	**38769**	68584	68881	69992	6599	6897	8007
Water Quality										
TP (mg/L)	0.160	0.060	0.061	**0.062**	0.063	0.063	0.064	0.040	0.042	0.044
TN (mg/L)	4.34	0.94	0.94	**0.97**	0.80	0.81	0.82	0.97	1.00	1.15
TN/TP	27	16	15	**16**	13	13	13	24	24	26

Chla	243.0	54.9	55.7	**57.6**	50.0	50.4	51.5	40.4	42.5	47.0
TSI	88	65	66	**66**	65	65	65	62	62	64

9.0 Recommendations

Prior to formally allocating nonpoint source load reductions to specific areas or landuses, additional information regarding the quality and quantity of water reaching the lake and its point of origin are needed. Additional data are required to improve model estimates of the water and nutrient budgets for the basin and the lake. The Department plans to continue to work closely with the SJRWMD and other interested parties to produce an accurate accounting of the sources of the nutrients that are currently impacting the lake before load reductions are allocated. The overall strategy should include studies and efforts that focus on determining if control or removal of loadings generated by internal recycling of TN and TP would significantly decrease the time it would take for the Lake to return to a more natural condition.

REFERENCES

Basin Status Report. 2001. Ocklawaha. Division of Water Resource Management, Florida Department of Environmental Protection

Brenner, M. and T. J. Whitmore. 1998. Historical sediment and nutrient accumulation rates and past water quality in Newnans Lake. Final Report for St. Johns. River Water Management District.

Brown, M. T. 1995. South Dade Watershed Project. University of Miami/SWFWMD

Canfield, D. E. Jr. 1981. Chemical and trophic state characteristics of lakes in relation to regional geology. Final report submitted to Coop. Fish and Wildlife Research Unit, University of Florida: 444 pp.

CDM. 1990. Point and non-point source loading assessment, phase I. Report to Sarasota Bay National Estuary Program.

Clark, W., R. Musgrove, C. Menke, and J. Cagle. 1964. Interim report on the water resources of Alachua, Bradford, Clay, and Union counties, Florida. Florida Geological Inform. Circular # 35, State Board of Conservation, Division of Geology, Tallahassee, Florida: 170 pp.

Copeland, R., T. Gardner, J. Craft, W. Schmidt, C. M. Browner, H. L. Rhodes, and C. C. Aller. 1991. Florida's ground water quality monitoring program hydrogeological framework. Department of Environmental Regulation.

Gido, K. B. 2002. Interspecific comparisons and potential importance of nutrient excretion by benthic fishes in a large reservoir. Transactions of the American Fisheries Society **131**: 260 – 270.

Gottgens, J. F. and C. L. Montague. 1987. Orange, Lochloosa and Newnans Lakes, a survey and preliminary interpretation of environmental research data. Special Publication SJ 87-SP3, Department of Environmental Engineering Sciences, A. P. Black Hall, University of Florida, Gainesville, FL.

Harper, H. H. 1994. Stormwater loading rate parameters for central and south Florida. Environmental Research & Design, Inc.

Harper, H. H. and E. H. Livingston. 1999. Everything you always wanted to know about stormwater management practices but were afraid to ask. Biennial Stormwater Research Conference, Tampa, Florida.

Holly, J. B. 1976. Stratigraphy and sedimentary history of Newnans lake. M. S. thesis, university of Florida: 102 p.

James, R. T. and V. J. Bierman Jr. 1995. A preliminary modeling analysis of water quality in lake Okeechobee, Florida: Calibration results. Water Research **29**: 2755 – 2766.

Linsley, R. U., and J. B. Franzini. 1997. Water Resources Engineering, McGrow-Hill Book Co.

Nordlie, F. G. 1976. Plankton communities of three central Florida lakes. Hydrobiologia 48 (1): 65-78

Robison, C. P., G. B. Hall, C. Ware, and R. B. Hupalo. 1997. Water management alternatives: effects on lake levels and wetlands in the Orange Creek basin. Appendixes. Page 15. Special publication SJ97-SP8. St. Johns River Water Management District.

Roehl, J. W. 1962. Sediment source areas, delivery ratios, and influencing morphological factors. International association of Scientific Hydrology. 59: 202-213. Symposium of Bari, October 1-8, 1962

Schaus, M. H., M. J. Vanni, T. E. Wissing, M. T. Bremigan, J. E. Garvey, R. A. Stein. 1997. Nitrogen and phosphorus excretion by detritivorous gizzard shad in a reservoir ecosystem. Limnology and Oceanography **42**: 1386 – 1397.

Sloto, R. A. and M. Y. Crouse. 1996. HYSEP: A computer program for streamflow hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040.

St. John River Water Management District. 2002. Assessment of pollution sources in the Newnans Lake Watershed. 99-0128.000/Report/TOC.Doc

Stites, D. L., M. Coveney, L. Battoe, E. Lowe, and V. Hoge. 2001. An external phosphorus budget for Lake Apopka, 1989-1994. Division of Environmental Sciences, Department of Water Resources, St. Johns River Water Management district, Palatka, Florida.

User's Manual: Watershed management model, Version 4.1 1998. Rouge River national wet weather demonstration project. Wayne County, Michigan. PRO-NPS-TM27.02.

Viessman, W. Jr., G. L. Lewis, and J. W. Knapp. 1989. Introduction to hydrology. 3rd edition. Harper Collins Publisher. New York. Page 160.

Walker, W. W. 1999. Simplified procedures for eutrophication assessment and prediction: User manual. Instruction Report W-96-2. U.S. Army Corps of Engineers. Washington, DC.

Appendix A

In 1982, Florida became the first state in the country to implement statewide regulations to address the issue of nonpoint source pollution by requiring new development and redevelopment to treat stormwater before it is discharged. The Stormwater Rule, as outlined in Chapter 403 Florida Statutes (F.S.), was established as a technology-based program that relies upon the implementation of BMPs that are designed to achieve a specific level of treatment (i.e., performance standards) as set forth in Chapter 62-40, Florida Administrative Code (F.A.C.).

The rule requires Water Management Districts (WMDs) to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a SWIM plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, stormwater PLRGs have been established for Tampa Bay, Lake Thonotosassa, Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka. No PLRG has been developed for Newnans Lake at the time this study was conducted.

In 1987, the U.S. Congress established section 402(p) as part of the Federal Clean Water Act Reauthorization. This section of the law amended the scope of the federal NPDES to designate certain stormwater discharges as "point sources" of pollution. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific Standard Industrial Classification (SIC) codes, construction sites disturbing five or more acres of land, and master drainage systems of local governments with a population above 100,000 [which are better known as "municipal separate storm sewer systems" (MS4s)]. However, because the master drainage systems of most local governments in Florida are interconnected, EPA has implemented the MS4 permitting program on a county-wide basis, which brings in all cities (incorporated areas), Chapter 298 urban water control districts, and the DOT (Department of Transportation) throughout the 15 counties meeting the population criteria.

An important difference between the EPA and the state stormwater permitting programs is that the EPA program covers existing discharges while the state program focuses on new discharges. Additionally, Phase 2 of the NPDES stormwater permitting program will expand the need for these permits to construction sites between one and five acres, and to local governments with as few as 10,000 people. These revised rules require that these additional activities obtain permits by 2003. While these urban stormwater discharges are now technically referred to as "point sources" for the purpose of regulation, they are still diffuse sources of pollution that can not be easily collected and treated by a central treatment facility similar to other point sources of pollution, such as domestic and industrial wastewater discharges. The DEP recently accepted delegation from EPA for the stormwater part of the NPDES program. It should be noted that most MS4 permits issued by EPA in Florida include a reopener clause that allows permit revisions to implement TMDLs once they are formally adopted by rule.