Task 3: Estimation of Nutrient Loading to Falls Lake

Cardno ENTRIX

Shaping the Future

Prepared for:

Upper Neuse River Basin Association

Prepared by:

Cardno ENTRIX
Shaping the Future

Cardno ENTRIX
5400 Glenwood Ave, Suite G03, Raleigh, NC, 27612

Table of Contents

Tables

Figures

Executive Summary

ES.1 Introduction

In 2010 the Environmental Management Commission (EMC) passed the Falls Lake Nutrient Management Strategy, requiring two stages of nutrient reductions (N.C. Rules Review Commission 2010). The Rules establish a Nutrient Management Strategy for Falls of the Neuse Reservoir aimed at attaining:

> "…the classified uses of Falls of the Neuse Reservoir set out in 15A NCAC 02B .0211 from current impaired conditions related to excess nutrient inputs; protect its classified uses as set out in 15A NCAC 02B .0216, including use as a source of water supply for drinking water; and maintain and enhance protections currently implemented by local governments in existing water supply watersheds encompassed by the watershed of Falls of the Neuse Reservoir." (15NCAC 02B .0275)

Stage I of the Nutrient Management Strategy requires "intermediate or currently achievable controls throughout the Falls watershed with the objective of reducing nitrogen and phosphorus loading, and attaining nutrient-related water quality standards in the Lower Falls Reservoir as soon as possible but no later than January 15, 2021, while also improving water quality in the Upper Falls Reservoir…." (15NCAC 02B .0275 (4) (a)). Based on modeling and evaluation by the NC Division of Water Quality (NCDWQ), Stage I will require a 20 percent and 40 percent reduction in total nitrogen and total phosphorus loading, respectively, for point sources and agriculture. For development based sources, the rules require that loading be reduced to the levels of the baseline year (2006) established by NCDWQ. Stage I requires local jurisdictions to establish requirements to control nutrient input from new development sources. Each of the jurisdictions has adopted new development requirements and these have been approved by NCDWQ and the EMC.

Stage II requires that all areas of Falls Lake achieve the nutrient-related water quality standards. Based on NCDWQ modeling and evaluation, the additional loading reductions required to achieve this goal are 40 percent and 77 percent for total nitrogen and total phosphorus, respectively, relative to the baseline year. NCDWQ reservoir monitoring data will be used to assess compliance with the goals of the Strategy and determine if additional load reductions to a particular lake segment are needed. As stated in the Rules:

> "Stage II requires implementation of additional controls in the Upper Falls Watershed beginning no later than January 15, 2021 to achieve nutrient-related water quality standards throughout Falls Reservoir by 2041 to the maximum extent technically and economically feasible…." (15NCAC 02B .0275 (4) (b))

The NCDWQ believes that the Stage II nutrient reductions are needed for all of Falls Reservoir to achieve compliance with water quality standards. The rules identify the parties (municipalities, counties, agriculture, and state and federal entities) responsible for implementing the nutrient reductions. The nutrient reductions are to be achieved by requiring stormwater controls and implementation of best management practices (BMPs) for new and existing development, point source discharges, and agricultural non-point sources.

Cardno ENTRIX is assisting the Upper Neuse River Basin Association (UNRBA) in determining the best approach to address the nutrient management rule requirements and the Consensus Principles regarding the re-examination of Stage II of the Falls Lake Nutrient Management Strategy. Four project tasks are designed to provide the UNRBA with the information needed to make informed decisions regarding the next steps to implementation of the re-examination and to develop jurisdictional loads for regulatory and program implementation purposes:

Task 1. Develop a Framework for a Re-examination of Stage II of the Falls Lake Nutrient Management Strategy

Task 2. Review Existing Data and Reports to Summarize Knowledge of Falls Lake and the Falls Lake Watershed

Task 3. Review Methods for Delivered and Jurisdictional Nutrient Loads

Task 4. Recommend Future Monitoring and Modeling

Task 3 of this project has several objectives:

> The first is to develop a process that the local governments can use to calculate their Stage I load reduction requirements. Section 2 describes two options for developing Stage I load reduction requirements and recommends an approach for the local governments to operate along a continuum ranging from the more simplified approach to a more rigorous approach to calculate their Stage I reduction requirements.

> The second objective is to compare and contrast existing watershed models with other modeling options for allocating jurisdictional loads and determining the Stage II load reduction requirements. Section 3 describes the types of models that may be used to generate Stage II loads and recommends development of both empirical and mechanistic models to estimate the watershed loading and Stage II reductions.

> The third objective of Task 3 involves describing nutrient loading from sources in the watershed that may not be specifically addressed by the existing information. Section 4 discusses loading from onsite wastewater treatment systems, atmospheric deposition, streambank erosion, and internal loading from lake sediments.

> The fourth objective is to quantify the loading from the five upper lake tributaries to Falls Lake and to compare those loads to other available estimates. This task relies heavily on the database compiled for Task 2 of the project. Section 5 compares two load estimation tools and provides summaries of loading from the five upper lake tributaries on an annual and monthly basis.

> The final objective of Task 3 is to identify gaps in knowledge related to jurisdictional and tributary load estimation and to provide suggestions for future monitoring and modeling studies which are the focus of Task 4. Section 6 identifies the gaps associated with estimating current nutrient loading to Falls Lake and calculating Stage I and Stage II nutrient load reduction requirements.

ES.2 Stage I Requirements

The Falls Lake Nutrient Management Strategy requires that NCDWQ identify the Stage I nutrient load reduction requirements from existing development for each jurisdiction in the Falls Lake watershed and to report these to the EMC in July 2013. The Stage I nutrient load reductions are equal to the increase in loading from development that occurred between January 2007 and July 2012. During meetings between NCDWQ and the UNRBA, the agency has expressed the preference to develop these load reduction requirements in cooperation with the local governments. To comply with the reporting requirements of the Falls Lake Nutrient Management Strategy, NCDWQ and the UNRBA have discussed the option of using a simple approach to calculate preliminary estimates of Stage I loads that may be revised in the future as more refined approaches are utilized.

This TM describes two options for calculating Stage I requirements: stormwater nutrient load accounting tools and areal loading rates. Stormwater nutrient load accounting tools vary in the level of detail required for their application. The local governments that are required to meet the Neuse River Basin Nutrient Sensitive Waters Strategy likely have the data available to populate the less detailed stormwater nutrient load accounting tools such as the City of Durham Nutrient Load Calculation Tool. Few of the local governments have the level of detail required to apply the Jordan Falls Lake Stormwater Nutrient Load

Accounting Tool to developments that occurred in the interim period (January 2007 through July 2012). Those local governments that are not required to participate in the Neuse River Basin Nutrient Sensitive Waters Strategy may not have begun to collect the information needed to calculate Stage I requirements.

Regardless of the method selected for calculating Stage I loads, local governments should begin compiling data that describe the land use changes that occurred between January 2007 and July 2012. This exercise may require pulling paper site development plans and permits and analyzing aerial imagery to identify the location, amount, and type of development that has occurred. Efforts should also be made to document conventional and non-conventional BMP implementation.

ES.3 Stage II Requirements

Stage II of the Falls Lake Nutrient Management Strategy requires that local governments reduce nutrient loading from existing development by 40 percent for nitrogen and 77 percent for phosphorus, relative to the 2006 baseline year. Because the Strategy does not specify how the 2006 baseline loads are to be calculated, the UNRBA has decided to review various load calculation methods. This TM describes two types of models (mechanistic and empirical) that may be used for determining nutrient load reductions and calculating jurisdictional loads and provides examples of each.

There are two existing Falls Lake watershed models: a mechanistic model, the Watershed Analysis Risk Management Framework (WARMF) model developed by NDCWQ and an empirical model, developed by the U.S. Geological Survey (USGS) Spatially Referenced Regressions on Watershed Attributes (SPARROW) model. The models produce significantly different total amounts of simulated nitrogen and phosphorus loads delivered to Falls Lake, and the nutrient loading source categories are set up differently in each model. Not only do the models not include the same source categories, but when the source categories are similar, or overlapping, the percent loading of nitrogen and phosphorus allocated to these sources is different. Of the two watershed models, the SPARROW model simulates loads to the Lake that are similar to those used to drive the Falls Lake nutrient response model.

Neither of the existing models is suitable for allocating year 2006 baseline loads to jurisdictions in the Falls Lake watershed due to the uncertainty associated with the loading estimates, the inability to assign loading to specific sources, and the financial implications of the allocations. For example, the WARMF model predicts total nitrogen loads that are within 1 percent of the Stage II nitrogen allocation and estimates total phosphorus loads that are two times lower than those used to drive the Falls Lake nutrient response model. The SPARROW model produces loading similar to other estimates (e.g., NCDWQ's Environmental Fluid Dynamics Code (EFDC) model for Falls Lake and the USGS Load Estimator (LOADEST) values presented in this TM), but the source categories are not compatible for assigning jurisdictional loads because a number of sources are not specifically defined in the output. For example, there is no allocation for forests and loading from onsite wastewater treatment systems is lumped together with the urban developed category.

The final outcome of the UNRBA's reexamination of the Stage II requirements is presently unknown. However, some level of reduction will likely be required and the data gaps that currently exist will reduce the accuracy of any watershed model that may be used to fairly allocate jurisdictional loads. In light of the current dependency of high cost ($1 billion to $2 billion) decisions on results from a single model, Cardno ENTRIX recommends that the UNRBA consider supporting the development and application of two fundamentally different models for both the watershed and the lake response. The use of multiple models for analysis is becoming a common practice in applied science (e.g., weather forecasting), including analysis for the Chesapeake Bay TMDL (e.g., Workshop on "Multiple Models for Management in the Chesapeake Bay", February 25-26, 2013).

Cardno ENTRIX recommends application of both mechanistic and empirical models for the watershed and the lake. These recommendations are described in detail in the Task 4 TM. Both types of models require the collection of additional flow and water quality data throughout the watershed, assessment of nutrient loading from specific sources, and a better understanding of nutrient fate and transport within the watershed, streams, impoundments, and Falls Lake.

ES.4 Uncertainty in Specific Loading Sources

One of the objectives of Task 3 is to describe nutrient loading from four specific sources that are not currently well defined. Information from existing models, reports, and available data indicate the following:

> Nutrient loading from onsite wastewater treatment systems is not well quantified. The type of system, underlying geology, system age, level of maintenance, and distance from a receiving water body all dictate the amount of nutrient loading contributed by each system. Additional research is needed to quantify loading from this source and to estimate credits associated with repairing, replacing, or connecting these systems to a centralized sewer system.

> Nitrogen loading from atmospheric deposition is well represented by state and local monitoring data and existing models. National and local data indicate that phosphorus loading from atmospheric deposition is minimal. No additional studies are needed to quantify loading from this source.

> Nutrient loading associated with streambank erosion is not well quantified in this watershed. Additional research is needed to quantify loading from this source and determine potential nutrient reduction credits associated with stream bank and floodplain restoration projects.

> Nutrient loading from Falls Lake sediments is not well quantified. While data compiled for Task 2 and a calculation method presented in this TM indicate that phosphorus loading from sediments is not a significant source of loading on an annual scale, monitoring data indicate that ammonia flux from the sediments may be relatively high. Additional studies are needed to measure this source of nutrient loading during different seasonal conditions (e.g., when dissolved oxygen concentrations are low) and at multiple locations in the lake.

ES.5 Estimation of Tributary Loading to Falls Lake

The estimation of nutrient loading to Falls Lake requires a combination of flow and water quality data for each tributary. These data are available at the mouths of five tributaries that drain to the western segment of Falls Lake: Eno River, Little River, Flat River, Ellerbe Creek, and Knap of Reeds Creek. While there is some water quality data at the mouths of the other tributaries in the watershed, none of the tributaries that enter Falls Lake downstream of I-85 are equipped with flow gages (See Figure ES-1). Therefore, this TM summarizes the loading from the five gaged tributaries and presents recommendations for future monitoring studies to quantify loading from the other tributaries in the watershed.

Prior to calculating the tributary loads from all five tributaries, the Eno River data was used to compare the results of two tributary loading calculation tools. As a result of this exercise, the USGS LOADEST tool was selected over the U.S. Army Corps of Engineers (USACE) BATHTUB tool because of its ability to 1) output times series loads which may be used to drive lake response models such as EFDC and 2) use model error analysis to recommend a best fit model. The LOADEST tool was then used to calculate tributary loading from the five upper lake tributaries and to assess annual and seasonal trends in the loading. Of particular focus was the comparison of the baseline 2006 loads to the other years.

For the most part, nutrient loading is correlated with stream hydrology; nutrient loading increases under higher flow conditions and decreases during lower flow periods. The years 2003 and 2009 had the highest flows and nutrient loads for the analysis period. Nutrient loading from the Ellerbe Creek and Knap of Reeds Creek subwatersheds were less affected by streamflow than other tributaries possibly because of the presence of wastewater treatment plant (WWTP) discharges that comprise a relatively high percentage of total streamflow. In addition, phosphorus loading from the Ellerbe Creek watershed has declined each year since 2006, even during 2009 which was a high flow year.

On an annual basis, the baseline year 2006 had near average flows relative to the other years considered in this loading analysis. For the six year period that each of the five upper lake tributaries were gaged, the average cumulative annual flow was 68,993 MG and in 2006 the annual flow was 65,011 MG. As a result, total nutrient loading delivered in 2006 from the upper five tributaries was also similar to the average annual loading for the 2006 to 2011 period. In 2006 total nitrogen loads were 1 percent lower than the annual average, and total phosphorus loads were 21 percent higher than the annual average.

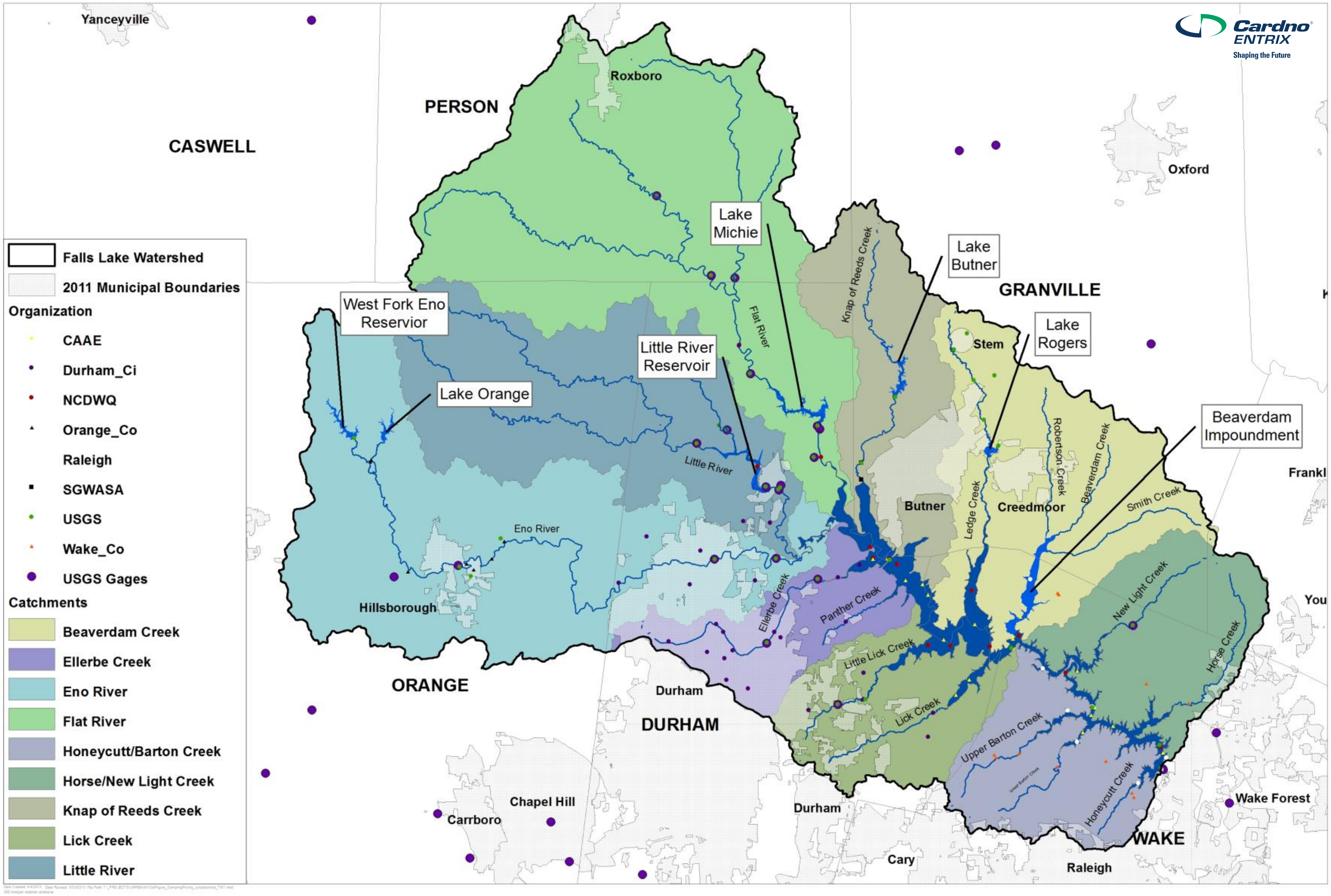

Figure ES-1 Water Quality and Flow Monitoring Stations in Falls Lake Watershed

In 2006, Tropical Storm Alberto deposited up to eight inches of rain in some parts of the watershed. To evaluate the impacts of this storm on nutrient loading to Falls Lake, the LOADEST tool was rerun for 2006 without the hydrologic inputs associated with the storm. Omitting Tropical Storm Alberto from the year 2006 loads did not significantly impact the loading from these five tributaries. However, the upper part of the watershed received much lower rainfall amounts (up to four inches with most of the area receiving approximately two inches of rainfall) compared to the lower part of the watershed during this storm. While a two to four inch storm is relatively large for this area, it is not outside the range of other high precipitation events that have occurred in the past. The significance of this storm was likely much greater in the lower part of the watershed where higher rainfall amounts occurred.

Seasonally, the summer months typically have the lowest flows and nutrient loads, while the winter and spring months have higher flows and nutrient loads. The Knap of Reeds Creek subwatershed exhibits different seasonal trends with the highest nutrient loads seen in late spring/early summer and the lowest nutrient loads observed in the fall and winter.

The most significant data gap associated with the calculation of tributary nutrient loading to Falls Lake is the lack of flow gages in the subwatersheds that enter the lake downstream of I-85 (Figure ES-1). Collection of water quality data in the tributaries near the lake is also needed. Future monitoring studies associated with these efforts will be addressed in TM 4.

ES.6 Summary

The Falls Lake Nutrient Management Strategy requires significant and costly nutrient reductions in the Falls Lake watershed over the next several years. Because of the mandated time line for development of the Strategy, NCDWQ had a limited amount of time to collect data and develop models on which to base the rules. As a result of the compressed schedule, there is significant uncertainty regarding the amount and sources of nutrient loading to Falls Lake as well as the load allocations needed to protect the lake and its designated uses. For example, the existing models developed for the watershed and the lake vary greatly in their estimation of nutrient loading to the lake. Cardno ENTRIX developed nutrient loading estimates using the USGS LOADEST tool and this approach resulted in loads similar to those used to drive the Falls Lake Nutrient Response Model.

In addition to understanding the impacts of load allocations on lake water quality and attainment of designated uses, the Strategy requires that the allowable loads be allocated fairly among the jurisdictions. However, the existing models are not well suited for this purpose: they either significantly underestimate loading to the lake (compared to others methods that are in closer agreement) or do not include source categories that are needed to allocate loads among the jurisdictions in this watershed.

For these reasons, development of additional, or revised, watershed and lake response models are needed to reduce the uncertainty associated with the load allocations and predicted lake response. The rules require a minimum of three years of data collection to support development of these models. The future monitoring and modeling studies needed to support the re-examination process are described in the Task 4 and Task 1 TMs.

1. Introduction

1.1 Purpose, Objectives, and Organization

Cardno ENTRIX is assisting the Upper Neuse River Basin Association (UNRBA) in determining the best approach to address the nutrient management rule requirements and the Consensus Principles regarding the re-examination of Stage II of the Falls Lake Nutrient Management Strategy. Four project tasks are designed to provide the UNRBA with the information needed to make informed decisions regarding the next steps to implementation of the re-examination and to develop jurisdictional loads for regulatory and program implementation purposes:

- Task 1. Develop a Framework for a Re-examination of Stage II of the Falls Lake Nutrient Management Strategy
- Task 2. Review Existing Data and Reports to Summarize Knowledge of Falls Lake and the Falls Lake Watershed
- Task 3. Review Methods for Delivered and Jurisdictional Nutrient Loads
- Task 4. Recommend Future Monitoring and Modeling

Task 3 of this project has several objectives. The first is to develop a process that the local governments can use to calculate their Stage I load reduction requirements. The second is to compare and contrast existing watershed models with other modeling options for allocating jurisdictional loads and determining the Stage II load reduction requirements. The third objective involves describing nutrient loading from sources in the watershed that may not be specifically addressed by the existing information. The fourth objective is to quantify the loading from the five upper lake tributaries to Falls Lake and to compare those loads to other available estimates. This task relies heavily on the database compiled for Task 2 of the project. The final objective of Task 3 is to identify gaps in knowledge related to jurisdictional and tributary load estimation and to provide a basis for future monitoring and modeling studies which are the focus of Task 4.

This TM is organized into several sections to address the objectives of Task 3:

- Section 2 reviews methods for calculating Stage I jurisdictional loads.
- Section 3 reviews methods for calculating Stage II jurisdictional loads.
- Section 4 assesses nutrient loading from specific sources in the watershed.
- Section 5 calculates tributary loading from the upper five tributaries to Falls Lake.
- Section 6 identifies data gaps associated with load estimates.
- Section 7 provides a list of references.

1.2 Background Information

In 2010 the Environmental Management Commission (EMC) passed the Falls Lake Nutrient Management Strategy, requiring two stages of nutrient reductions (N.C. Rules Review Commission 2010). The Rules establish a Nutrient Management Strategy for Falls of the Neuse Reservoir aimed at attaining:

> "…the classified uses of Falls of the Neuse Reservoir set out in 15A NCAC 02B .0211 from current impaired conditions related to excess nutrient inputs; protect its classified uses as set out in 15A NCAC 02B .0216, including use as a source of water supply for drinking water; and maintain and

> enhance protections currently implemented by local governments in existing water supply watersheds encompassed by the watershed of Falls of the Neuse Reservoir." (15NCAC 02B .0275)

Stage I of the Nutrient Management Strategy requires "intermediate or currently achievable controls throughout the Falls watershed with the objective of reducing nitrogen and phosphorus loading, and attaining nutrient-related water quality standards in the Lower Falls Reservoir as soon as possible but no later than January 15, 2021, while also improving water quality in the Upper Falls Reservoir…" (15NCAC 02B .0275 (4) (a)). Based on modeling and evaluation by the NC Division of Water Quality (NCDWQ), this will require a 20 percent and 40 percent reduction in total nitrogen and total phosphorus loading, respectively, for point sources and agriculture. For development based sources, the rules require that loading be reduced to the levels of the baseline year that NCDWQ established (2006). For Stage I, the rules require local jurisdictions to establish requirements to control nutrient input from new development sources as well. Each of the jurisdictions has adopted new development requirements and these have been approved by NCDWQ and the EMC.

Stage II requires that all areas of Falls Lake achieve the nutrient-related water quality standards. Based on NCDWQ modeling and evaluation, the additional loading reductions required to achieve this goal are 40 percent and 77 percent for total nitrogen and total phosphorus, respectively, relative to the baseline year. NCDWQ reservoir monitoring data will be used to assess compliance with the goals of the Strategy and determine if additional load reductions to a particular lake segment are needed. As stated in the Rules:

> "Stage II requires implementation of additional controls in the Upper Falls Watershed beginning no later than January 15, 2021 to achieve nutrient-related water quality standards throughout Falls Reservoir by 2041 to the maximum extent technically and economically feasible…" (15NCAC 02B .0275 (4) (b))

The NCDWQ believes that the Stage II nutrient reductions are needed for all of Falls Reservoir to achieve compliance with water quality standards. The rules identify the parties (municipalities, counties, agriculture, and state and federal entities) responsible for implementing the nutrient reductions, which are to be achieved by requiring stormwater controls and implementation of best management practices (BMPs) for new and existing development, point source discharges, and agricultural non-point sources.

Stage I and Stage II requirements are summarized below:

> **Existing Development Stormwater Management.** The Existing Development rules are based on when the development occurred: prior to the baseline period or between the baseline period and the implementation of the new development stormwater programs (July 2012).

  - For lands developed prior to the end of the baseline period (December 2006), there are no Stage I requirements.
  - For lands developed after the baseline period but before implementation of the new development stormwater programs, Stage I requires that "the current loading rate shall be compared to the loading rate for these lands prior to development for the acres involved, and the difference shall constitute the load reduction need in annual mass load, in pounds per year. Alternatively, a local government may assume uniform pre-development loading rates of 2.89 pounds/acre/year N and 0.63 pounds/acre/year P for these lands. The local government shall achieve this Stage I load reduction by calendar year 2020."
  - Stage II applies to all lands developed prior to the baseline period: "If a local government achieves the Stage I reduction objectives described in this Item, a local government's initial Stage II load reduction program shall, at the local government's election, either (A) achieve additional annual reductions in nitrogen and phosphorus loads from existing development greater than or equal to the average annual additional reductions achieved in the last seven years of Stage I or (B) provide for an annual expenditure that equals or exceeds the average annual amount the local government

> has spent to achieve nutrient reductions from existing development during the last seven years of Stage I. A local government's expenditures shall include all local government funds, including any state and federal grant funds used to achieve nutrient reductions from existing developed lands. The cost of achieving reductions from municipal wastewater treatment plants shall not be included in calculating a local government's expenditures….If Stage I reduction objectives are not achieved, a local government's initial Stage II load reduction program shall, at the local government's election, either (A) achieve additional annual reductions in nitrogen and phosphorus loads from existing development greater than or equal to the average annual additional reductions achieved in the highest three years of implementation of Stage I or (B) provide for an annual expenditure that equals or exceeds the average annual amount the local government has spent to achieve nutrient reductions from existing development during the highest three years of implementation of Stage I."

- **New Development Stormwater Management.** The New Development rules apply to development that occurred after implementation of the new development stormwater programs (July 2012). All local governments affected by the Strategy are required to develop stormwater management programs and limit nutrient loading from new development to 2.2 pounds per acre per year of nitrogen and 0.33 pounds per acre per year of phosphorus. All stormwater systems shall be designed to control and treat, at a minimum, the runoff generated by one inch of rainfall and shall ensure that there is no net increase in peak flow leaving the site compared to pre-development conditions for the one year, 24-hour storm event.
- **Wastewater Discharge Requirements.** For the Upper Falls Watershed, Stage I minimum nutrient control requirements have been established for point source wastewater discharges in the Falls Lake Watershed, and facility-specific nutrient allocations have been determined. Mass nitrogen and phosphorous allocations have been established for Stage II for facilities with flows <0.1 MGD and ≥ 0.1 MGD. The total Stage II allocations will be apportioned to existing dischargers based on proportion of permitted flow. By January 2027, all facilities with permitted flows ≥ 0.1 MGD in the Upper Falls Watershed must submit a plan and schedule for achieving the Stage II loadings by 2036. Requirements for new and expanding discharges have also been established in the rule. For the Lower Falls Watershed, all point sources with a permitted flow of ≥ 0.1 MGD shall meet monthly and annual average discharge limits for total nitrogen and total phosphorus by 2016. An annual mass limit of 911 pounds of total phosphorus per calendar year has been established for all facilities. The rules establish that new wastewater discharges or expansions in the Lower Falls Watershed will not be permitted.
- **Agricultural Requirements.** Stage I requires a 20 percent reduction in nitrogen loading and a 40 percent reduction in phosphorus loading (relative to 2006) by 2020 from agricultural lands. Stage II requires a 40 percent reduction in nitrogen loading and a 77 percent reduction in phosphorus loading by 2035. By January 2013, the Watershed Oversight Committee shall provide the Environmental Management Commission (EMC) with an initial assessment of the reductions that have been achieved since 2006. Annual reporting will be required. Stage II will only include requirements for individual operators if the collective Stage I reductions have not been met.
- **Adaptive Management Options.** Beginning in 2016, and every five years afterwards, NCDWQ will review all available data, such as loading reductions, best management practice effectiveness data, and instream loading estimates and determine whether any rule revisions are needed. The NCDWQ evaluations will be conducted in order to address uncertainty, changes in scientific understanding, technological advances, economic feasibility, and incorporate new information and data. In July 2025, NCDWQ will review and report to the EMC the physical, chemical, and biological conditions, and nutrient loading impacts within the Upper Falls Reservoir (defined as Falls Lake upstream of State Route 50) as well as the influence nutrient management actions have had on water quality. This report will include a re-assessment of the methodology used to determine compliance with nutrient-related water quality standards and the potential for using other methods, as well as describe the

feasibility and costs and benefits of achieving the Stage II objective. This report will also recommend to the EMC the need for alternative regulatory action such as, water quality standards revision, waterbody reclassification, or issuance of a site-specific variance.

2 Review Methods to Calculate Stage I Nutrient Load Reductions

This section discusses different methods that can be used to calculate Stage I nutrient loads for each jurisdiction. The relative level of effort and data required for each method are also identified. Because of the short time period available for determination and reporting of jurisdictional loads, one of the calculation options described is a relatively simple and rapid method that can be used to determine Stage I loads.

The Falls Lake Nutrient Management Strategy requires NCDWQ to identify the Stage I nutrient load reduction requirements for each jurisdiction in the Falls Lake watershed and to report these to the EMC in July 2013. The Stage I nutrient load reductions are equal to the increase in loading that occurred from development that was constructed between January 2007 and July 2012. During meetings between NCDWQ and the UNRBA, the agency has expressed the preference to develop these load reduction requirements in cooperation with the local governments.

2.1 Stormwater Nutrient Load Accounting Tools

Stormwater nutrient load accounting tools provide one approach to determining the nutrient loading from development that occurred during the interim period: after the baseline year and before the new development programs were in place. These tools require information about the pre-existing land uses and characteristics of the development. The level of detail required to populate these spreadsheet-based tools varies from simple to complex. Two load accounting tools are discussed in this section to provide examples.

2.1.1 Jordan Falls Lake Stormwater Nutrient Load Accounting Tool (JFLSNLAT)

Researchers at the North Carolina State University Biological and Agricultural Engineering Department developed the Jordan Falls Lake Stormwater Nutrient Load Accounting Tool (JFLSNLAT) (NCSU and NCDENR 2011) to assist local governments in their implementation of the local stormwater programs required in the Jordan Lake and Falls Lake watersheds. The JFLSNLAT accounts for local geology and local precipitation in its calculation of pre and post development runoff and uses the Simple Method (Schueler 1987) to calculate runoff (based on fraction of impervious cover and a runoff coefficient) and nutrient loads (using event mean concentrations for each land use). BMPs may be simulated in parallel or in series to estimate the reduction in nutrient loading achieved by various configurations and types of BMPs.

Watershed characteristics are entered into the JFLSNLAT for pre and post development conditions. Table 2-1 lists the data inputs for non-residential and residential land uses. Inputs are entered as area in square feet.

Table 2-1 Watershed Characteristic Inputs (square feet) for the JFLSNLAT

Non Residential Land Uses	Residential Land Uses
COMMERCIAL	PART A
Parking lot	1/8-ac lots
Roof	1/4-ac lots
Open/Landscaped	1/2-ac lots
INDUSTRIAL	1-ac lots

Non Residential Land Uses	**Residential Land Uses**
Parking Lot	2-ac lots
Roof	Multi-family
Open/Landscaped	Townhomes
TRANSPORTATION	Custom Lot Size
High Density (Interstate/Main)	PART B
Low Density (Secondary/Feeder)	Roadway
Rural	Driveway
Sidewalk	Parking Lot
PERVIOUS	Roof
Managed Pervious	Sidewalk/Patio
Unmanaged (pasture)	Lawn
Forest	Managed pervious
JURISDICTIONAL LANDS	Forest
Natural wetland	Natural wetland
Riparian buffer	Riparian buffer
Open water	Open water
LAND TAKEN UP BY BMPS	LAND TAKEN UP BY BMPS

Because the Falls Lake Nutrient Management Strategy final rules were approved in December 2010, many of the local governments were not tracking developments that occurred in the interim period with regard to the level of detail needed to populate the JFLSNLAT. Retroactively acquiring this information would require pulling paper site development plans and measuring the square footage of each of the land use categories as well as the areas draining to each BMP installed with the development. This approach would be very time intensive and difficult to achieve given the schedule and reporting requirements.

2.1.2 Tar/Pamlico and Neuse Nutrient Calculation Tools

In 1989, the EMC designated the Tar-Pamlico Basin as a Nutrient Sensitive Water (NSW). As a result, a basinwide nutrient management strategy was adopted to reduce nutrient loading throughout the watershed. In 1997, the EMC implemented the Neuse River Nutrient Sensitive Waters Strategy with the goal of reducing nitrogen loading to the Neuse Estuary. Some of the local governments in the watershed were required to demonstrate compliance with the rules and meet the nitrogen export standard of 3.6 lb-N/ac/yr: City of Durham, City of Raleigh, Durham County, Orange County, and Wake County.

To support these requirements, spreadsheet tools were developed to estimate nitrogen and phosphorus loading from new developments. The City of Durham has developed a single spreadsheet tool that allows the user to calculate the increases in both nitrogen and phosphorus in the same spreadsheet. The data input requirements for this tool are less detailed than for the JFLSNLAT. Table 2-2 lists the input requirements for pre and post development needed to populate the City of Durham Nutrient Load Calculation Tool.

Table 2-2 Watershed Characteristic Inputs (acres) for the City of Durham Nutrient Load Calculation Tool

IMPERVIOUS
Transportation - roads, driveways, parking areas, and wash pads covered by pavement, gravel, dirt, or pavers
Non-transportation - roofs and sidewalks
PERVIOUS
Managed
Wooded

Wake County developed a Hybrid Stormwater Design tool to meet requirements of the Falls, Jordan and Neuse Nutrient Management strategies, as well as Wake County's local stormwater volume control policies. This tool was submitted to and approved by the EMC as part of Wake County's New Development Program. The Wake County tool differs in format with some modifications from the Jordan/Falls Lake Stormwater Load Accounting Tool. However, the Wake County tool incorporates requirements and calculations as outlined in the JFSLAT– User's Manual and produces the same load results. An example modification is that the Wake County tool specifies each residential lot using a custom lot option rather than the general lot sizes specified for the JFSLAT.

The local governments that have been implementing the Neuse River Basin Nutrient Sensitive Waters Strategy likely have the information they need to utilize a tool such as the City of Durham Nutrient Load Calculation Tool or the Wake County Hybrid Stormwater Design Tool. Those local governments in the Falls Lake watershed that were not required to participate in the Neuse River Basin Nutrient Sensitive Waters Strategy may not have the data needed to populate even this less data-intensive calculation tool. Implementing this tool without an existing electronic database of pre and post development land use changes will require pulling paper permits and plans to delineate the areal inputs required for this tool. Depending on the amount of development that has occurred in these areas, this process may not be feasible given the time constraints.

2.2 Areal Loading Rates

Given the time constraints for reporting the Stage I nutrient load reduction requirements and the varying levels of information and detail available for each local government, the UNRBA and NCDWQ have discussed the option of using a simple method for calculating preliminary Stage I load reduction requirements. For those local governments that already have more detailed assessments such as stormwater load accounting tools, or who wish in the future to refine their estimates using such tools, they have the option of re-submitting their Stage I requirements when the refined estimates become available (i.e., now or in the future). The purpose of this simple approach is to 1) allow NCDWQ and the local governments to meet the Stage I reporting requirement deadline, 2) provide the local governments with planning level reduction requirements prior to implementing Stage I, and 3) allow the local governments to submit more accurate numbers as they become available.

To calculate the new development nutrient export goals of 2.2 lb-N/ac/yr and 0.33 lb-P/ac/yr, NCDWQ assumed that 40 percent nitrogen and 77 percent phosphorus reductions were required relative to the amount of land that was undeveloped in 2006 (Table 2-3). Each of the jurisdictions has adopted new development requirements and these have been approved by NCDWQ and the EMC.

Table 2-3 Calculation of New Development Nutrient Export Goals Using Areal Loading Rates (Provided by John Huisman with NCDWQ)

Nitrogen				
Land use	**N export rate (lb/ac/yr)**	**40% Reduction in Export Rate (lb/ac/yr)**	**Proportion of Buildable Area**	**(Reduced Export Rate) x (Area) (lb/yr)**
Agriculture: row crops	13.4	8.0	0.02	0.16
Agriculture: pasture	5.7	3.4	0.26	0.88
Forest	1.6	Not needed	0.72	1.16
Weighted Average				2.20
Phosphorus				
Land use	**P export rate (lb/ac/yr)**	**77% Reduction in Export Rate (lb/ac/yr)**	**Proportion of Buildable Area**	**(Reduced Export Rate) x (Area) (lb/yr)**
Agriculture: row crop	5.3	1.22	0.02	0.02
Agriculture: pasture	1.1	0.25	0.26	0.07
Forest	0.33	Not Needed	0.72	0.24
Weighted Average				0.33

It appears that the initial loading rates for agriculture and forest lands that NCDWQ used to calculate the new development nutrient export goals (Table 2-3) were based on the average field-scale rates generated by the Jordan Lake watershed model (Table 2-4, Tetra Tech 2003). Because these values represent field-scale export rates and not delivered loads, which may be reduced during transport across land surfaces and stream channels, these areal loading rates should provide a conservative estimate of Stage I load reduction requirements.

Table 2-4 Field-scale Areal Loading Rates from the 2003 Jordan Lake Watershed Model

Code Land Use Description	**TN (lb-N/ac/yr)**	**TP (lb-P/ac/yr)**
Barren	45.96	29.92
Commercial/Heavy Industrial	24.05	3.7
Forest	1.59	0.33
Office/Light Industrial	16.47	2.63
Pasture	5.69	1.08
Row Crop	13.37	5.32
Urban Green Space	3.57	0.61
Water	0	0
Wetland	2.2	0.4
Residential <0.25 ac per dwelling unit (sewered)	15.03	2.47
Residential - 0.25-0.5 ac per dwelling unit (sewered)	11.86	2.0
Residential - 0.5-1.0 ac per dwelling unit (sewered)	11.72	1.94

Code Land Use Description	TN (lb-N/ac/yr)	TP (lb-P/ac/yr)
Residential - 0.5-1.0 ac per dwelling unit (unsewered)	41.42	2.03
Residential - 1.0-1.5 ac per dwelling unit (sewered)	10.89	1.81
Residential - 1.0-1.5 ac per dwelling unit (unsewered)	28.71	1.86
Residential - 1.5-2 ac per dwelling unit (sewered)	9.37	1.71
Residential - 1.5-2 ac per dwelling unit (unsewered)	22.09	1.74
Residential - 2+ ac per dwelling unit (sewered)	2.49	0.6
Residential - 2+ ac per dwelling unit (unsewered)	11.4	0.63

Even the areal loading rates method will require collecting information about the pre and post development conditions for each local government. Depending on the amount and type of information that local governments have been tracking, determination of where development has occurred in the watershed during the interim period may require assessment of aerial imagery. Obtaining and analyzing satellite imagery collected around January 2007 and August 2012 will provide the information needed to determine pre and post development conditions for calculating Stage 1 load reductions in those areas where this information is unknown. An alternative to determining the pre-development land use is to apply the uniform pre-development loads rates specified in 15A NCAC 02B: 0278 (3)(a): 2.89 lb-N/ac/yr and 0.63 lb-P/ac/yr.

As part of the preliminary submittal, local governments may wish to account for BMPs that have been implemented during the interim period. BMP credits may be calculated from the reduction efficiencies reported in the NCDWQ Stormwater BMP manual or calculated using a tool such as the JFLSNLAT. These credits will result in a reduction of the Stage I requirements.

2.3 Recommendations for Calculating Stage I Reductions

Initial discussions with the UNRBA indicated a preference for all members to use the same approach for calculating Stage 1 jurisdictional loads. After closer evaluation and further discussion, it is apparent that there is a wide range in the amount of data and staff resources available to individual members. A number of the UNRBA members have spent significant time and effort creating development inventories and calculating load reduction requirements and do not want to lose this investment of resources. In response, Cardno ENTRIX recommends that each local government in the Falls Lake watershed operate along a continuum ranging from the more simplified approach to a more rigorous approach to calculate their Stage I reduction requirements. Regardless of what calculation method is ultimately selected, local governments should begin compiling the following information and making decisions on how they wish to proceed with the load calculations:

1. Gather existing information regarding interim development including acreage and location of pre and post development land use.
2. Gather existing information regarding BMP implementation that occurred during the interim period in the watershed including management strategies that are not specific to an interim development (e.g., stream restoration projects, repairing onsite wastewater treatment systems, implementing fertilizer management plans).
3. Meet with NCDWQ to discuss options for calculating Stage I requirements based on the amount and format of the existing data.
4. Calculate the Stage I requirements for interim development:
    a. Determine and quantify (acreage) of pre-development land use
        i. Use existing information (databases, permits, site plans), or

    - ii. Use aerial photography from approximately January 2007
- b. Determine pre-development export rates
    - i. Apply areal loading rates specified in Table 2-4 to pre-development land use, or
    - ii. Use uniform pre-development export rates, or
    - iii. Use the City of Durham Nutrient Load Calculation Tool, or
    - iv. Use the JFLSNLAT
- c. Determine and quantify (acreage) of post-development land use
    - i. Use existing information (databases, permits, site plans), or
    - ii. Use aerial photography from approximately July 2012
- d. Determine post-development export rates
    - i. Apply areal loading rates specified in Table 2-4 to post-development land use, or
    - ii. Use the City of Durham Nutrient Load Calculation Tool, or
    - iii. Use the JFLSNLAT
- e. Identify BMPs implemented with interim development
    - i. Use existing information (databases, permits, site plans), or
    - ii. Perform site visits, or
    - iii. Use 1-m scale aerial imagery
- f. Quantify type and/or acreage of post-development land use draining to each BMP
    - i. Use existing information (databases, permits, site plans), or
    - ii. Perform site visits, or
    - iii. Use 1-m scale digital elevation models or LIDAR contour data
- g. Calculate load reduction from each site-scale BMP
    - i. Apply the reduction efficiencies reported in the NCDWQ Stormwater BMP manual to the post-development export rates for the land draining to the BMP, or
    - ii. Use the JFLSNLAT
- h. Identify BMPs not associated with interim development and quantify nutrient credits
    - i. For conventional BMPs such as regional wet detention ponds, follow steps e, f, g
    - ii. For non-conventional BMPs
        - 1. Coordinate with NCDWQ to estimate preliminary credits
        - 2. Request credit for these BMPs following NCDWQ's determination of nutrient credits associated with non-conventional BMPs and management practices (many of these will be published in the Nutrient Scientific Advisory Board's report to the EMC in July 2013)

3 Review Methods for Calculating Stage II Nutrient Load Reductions

This section compares the theoretical basis, application, and constraints of commonly-used methods that may be used to determine Stage II jurisdictional loads including mechanistic and empirical watershed models. The relative level of effort and data required for each method are also identified. Descriptions of how each model calculates loading from specific sources such as onsite wastewater treatment systems, atmospheric deposition, and instream erosion are included, along with a discussion of how each model may be used to account for nutrient management practices that are implemented in the watershed.

Unlike the Stage I requirements, Stage II requires an estimate of the baseline (2006) nitrogen and phosphorus loads for each local government. While the stormwater load accounting tools provide an estimate of the change in loading at the development scale, they do not provide an estimation of loading at the jurisdictional level. The areal loading rates discussed in Section 2.2 may provide a conservative estimate of 2006 loading based on land use present at that time, but they are not accurate enough to calculate the Stage II load reduction requirements given the financial implications of the results.

Regarding Stage II, the Falls Lake Nutrient Management Strategy states the following:

> The objective of Stage II is to achieve and maintain nutrient-related water quality standards throughout Falls Reservoir. This is estimated to require a reduction of 40 and 77 percent in average annual mass loads of nitrogen and phosphorus, respectively, delivered from the sources named in Item (6) in the Upper Falls Watershed from a baseline of 2006. The resulting Stage II allowable loads to Falls Reservoir from the watersheds of Ellerbe Creek, Eno River, Little River, Flat River, and Knap of Reeds Creek shall be 658,000 pounds of nitrogen per year and 35,000 pounds of phosphorus per year.

Baseline loads are therefore 1,097,000 lb-N/yr and 152,000 lb-P/yr (back calculated given required reductions of 40 percent and 77 percent for nitrogen and phosphorus, respectively.) Allocation of these baseline loads will be required to implement Stage II of the Falls Lake Nutrient Management Strategy.

Because water quality and flow data are usually collected at hydrologic boundaries, not jurisdictional boundaries, and jurisdictions are comprised of multiple combinations of soil type, land use, and topography, it is difficult to accurately apportion tributary loading to the upstream jurisdictions. Watershed loading models that overlay land use, soils, topography, and jurisdictional and subwatershed boundaries are traditionally used to assign loading contributions.

Due to the requirements specified in the Falls Lake Nutrient Management Strategy (.0275 5(b)(i)), nutrient loading to Falls Lake must be evaluated and reported to the EMC every five years, beginning in 2016. However, the EMC did not specify the methodology to be used in this assessment.

3.1 Mechanistic Watershed Loading Models

Mechanistic model structures use process-based and engineering principals to link model inputs (e.g., stream flow, water quality, bathymetry, meteorological inputs) to expected pollutant concentrations or to indicators like chlorophyll *a*. Mechanistic watershed loading models generally operate on the same fundamental theories (Soil Conservation Service (SCS) Curve Number, Universal Soil Loss Equation, etc.) and rely on the same characterization datasets (land cover, soils, and topography). Time series weather data are used to drive the models which predict hydrology, sediment, and pollutant loading from processes that occur in the atmosphere, on the land surface, in groundwater zones, and in stream channels. Mechanistic watershed models vary in their level of complexity including the algorithms, time steps, and outputs they generate. This section describes the existing mechanistic watershed model developed by NCDWQ for Falls Lake using WARMF as well as alternative mechanistic models that may be useful for meeting future needs of the UNRBA.

3.1.1 WARMF

The Watershed Analysis Risk Management Framework (WARMF) was developed to support USEPA in assessing watershed management for the purpose of developing total maximum daily loads (TMDLs). WARMF simulates point sources and nonpoint sources based on land use, soil characteristics, topography, and meteorology. The model simulates reservoirs using a two dimensional reservoir model (CE-QUAL-W2) divided into approximately 30 layers that are horizontally mixed. The model simulates flow, pH, temperature, dissolved oxygen, ammonia, nitrate, phosphate, suspended sediment, coliform bacteria, major cations and anions, three algal species, and periphyton (EPRI 2001). The model has undergone two external peer reviews and several applications have been published in peer-reviewed journals (EPRI 2001). Version 6.1 of the WARMF software is available for download from the Environmental Protection Agency (http://www.epa.gov/athens/wwqtsc/html/warmf.html).

WARMF uses mass balance, heat exchange, reaction kinetics, and chemical equilibriums to dynamically simulate flow and water quality. Data sources include the U.S. Environmental Protection Agency (USEPA), U.S. Geologic Survey (USGS), National Resources Conservation Service (NRCS), National Climatic Data Center (NCDC), and National Atmospheric Deposition Program (NADP). Runoff hydrology is governed by the Integrated Lake-Watershed Acidification Study (ILWAS) model which balances precipitation, interception, infiltration, evapotranspiration, and groundwater exfiltration to calculate surface runoff. Pollutant loads from land uses in the watershed are governed by the universal soil loss equation (USLE); Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS); Storage, Treatment, Overflow, Runoff Model (SWMM); stream transport capacity; and reaction kinetics.

Land use characterization is not simulated discretely in WARMF, but rather as a percent composition within each model subwatershed. For the Falls Lake WARMF model, nutrient loading associated with land uses in the watershed are based on atmospheric deposition (Section 4.2.1), soil erosion, and application of fertilizer or manure (agriculture or wildlife), which is specified for each land use on a monthly basis using the following sources of information:

> Cropland fertilization rates were based on input from the North Carolina Division of Soil and Water Conservation which provided annual fertilization rates by crop as well as the percentage applied each month. These rates were specified on an 11 digit HUC scale.

> Manure loading rates to pasture were calculated from the number of animals in each county, manure nutrient content, and the percent of time the animals spend at pasture.

> NCDOT provided fertilizer application rates for lands in their jurisdiction in the watershed.

> Fertilization rates for developed areas are based on a study conducted in North Carolina communities including Cary, Kinston, New Bern, and Greenville (Osmond and Hardy 2004 cited in NCDENR 2009b). Annual nitrogen fertilization rates for the Knap of Reeds, Flat River, Little River, Eno River, and Ellerbe Creek watersheds were assumed 30, 111, 29, 20, and 76 (kg/ha/year), respectively, based on similarities between communities in these watersheds and communities in the Osmond and Hardy study. Monthly application was specified based on typical application patterns for fescue and warm season grasses. Phosphorus applications rates were assumed 0.01 kg/ha (the modeling report does not specify time period for this rate).

Septic system loading is assigned based on population served. Global settings are used to simulate loading from septic systems falling into one of three categories, and these settings may not be adjusted for specific subwatersheds or soil types. This source of loading is described in more detail in Section 4.1.1.

The Falls Lake WARMF report summarizes the sources of nutrient loading from the five calibrated subwatersheds: Eno River, Ellerbe Creek, Knap of Reeds Creek, Little River, and Flat River (NCDENR 2009b). Figure 3-1 and Figure 3-2 show the delivered nutrient loads from the five tributaries by source category for nitrogen and phosphorus, respectively. On an annual basis, the nitrogen loads predicted from WARMF are similar to the load allocations assigned in the Falls Lake Nutrient Management

Strategy: 663,866 lb-N/yr simulated by WARMF compared to the Stage II allocation of 658,000 lb-N/yr. WARMF predicted phosphorus loads are higher than the Stage II allocation: 57,937 lb-P/yr simulated by WARMF compared to the Stage II allocation of 35,000 lb-P/yr.

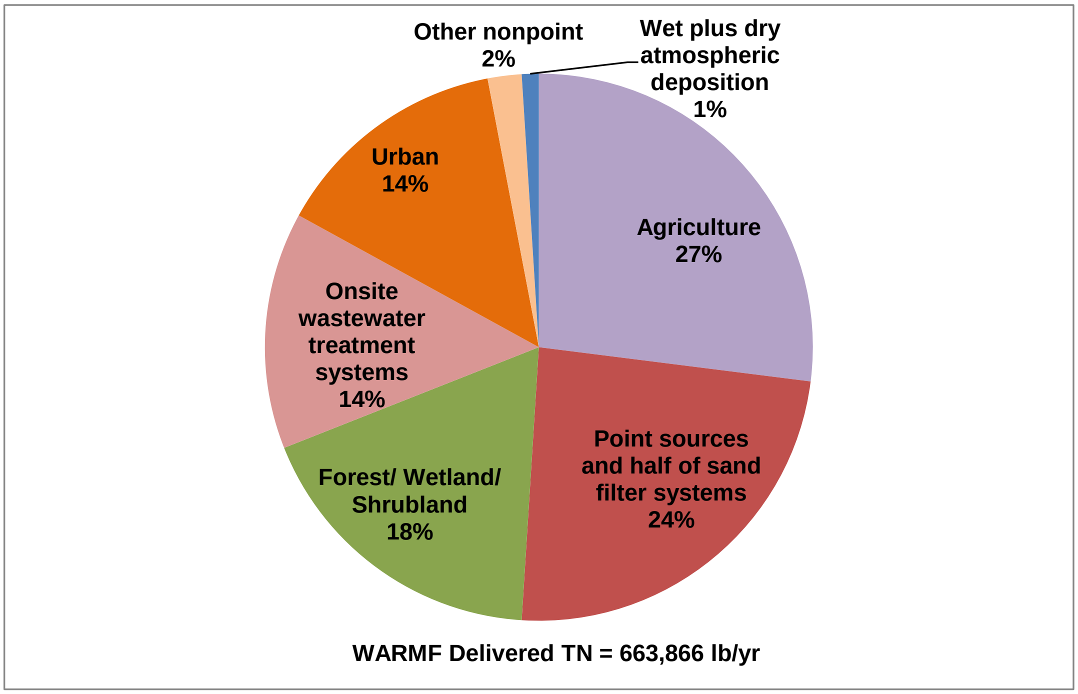

Figure 3-1 WARMF Simulated Nitrogen Loads Delivered to Falls Lake from Five Tributaries by Source

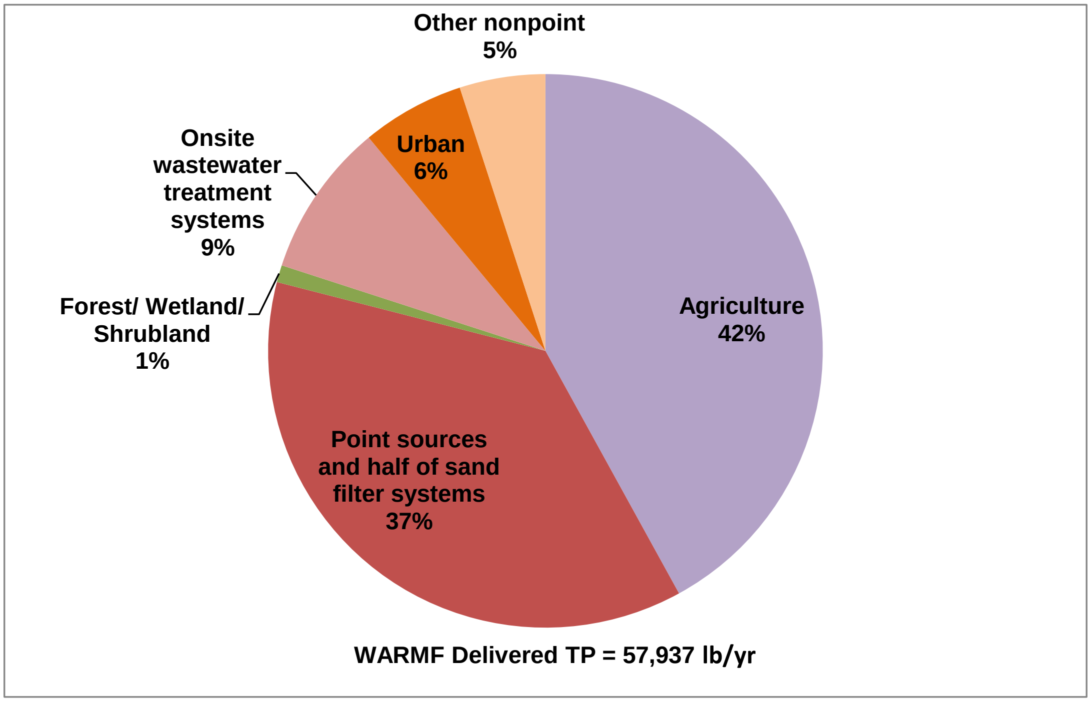

Figure 3-2 WARMF Simulated Phosphorus Loads Delivered to Falls Lake from Five Tributaries by Source

Annual average delivered total nitrogen and total phosphorus loads from the five major tributaries to Falls Lake predicted by the WARMF model are 663,866 lb-N/yr and 57,937 lb-P/yr which would require percent reductions of 1 percent and 40 percent, respectively, to achieve the Stage II goals. For comparison, the nutrient loads to Falls Lake from these five tributaries used in NCDWQ's EFDC model for year 2006 are 939,974 lb-N/yr and 116,680 lb-P/yr. These EFDC loads require percent reductions of 30 percent for total nitrogen and 70 percent for total phosphorus to achieve the Stage II goals.

In terms of calibration, the simulated flows from the WARMF model generally matched observed flows although storm peaks are often underestimated or overestimated depending on the watershed. The model generally over predicts TSS, with gross overestimates occurring at most stations relative to observed data. Total nitrogen concentrations are generally well calibrated with the exception of some modeled events that generate very large spikes in concentration that are outside of the range of realistic and observed values (20 mg/L to 50 mg/L). Total phosphorus simulations are generally within the range of those observed. For some catchments, the predicted trends in nitrogen and phosphorus do not match those observed, so when observed values are decreasing, simulated values are increasing, or vice versa.

WARMF can be used to track nutrient load reductions associated with land use conversion, point source upgrades, decreasing the failure rate of onsite wastewater treatment systems, and decreasing fertilizer and manure application rates. Load reductions associated with site scale agricultural or urban BMPs (e.g., detention ponds, filter strips, constructed wetlands) would require use of a credit accounting tool such as the urban development Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool (JFLSNLAT) and the agricultural Nitrogen Loss Estimation Worksheet (NLEW) and Phosphorus Loss Assessment Tool (PLAT).

3.1.2 Other Mechanistic Watershed Models

There are other mechanistic watershed loading models that could be developed for the Falls Lake watershed to determine jurisdictional loads. For example, the Generalized Watershed Loading Function model (GWLF, Haith et al. 1992) is a lumped parameter model that simulates runoff, sediment, and pollutant loading using the SCS Curve Number method, USLE, groundwater nutrient concentrations, rural runoff nutrient concentrations, and urban nutrient buildup-wash off rates. Septic systems are simulated with varying mass loads depending on the number of people served and the number of systems classified as properly functioning, ponding, short circuiting, or directly discharging.

The GWLF model runs at a daily time step and produces output on a monthly or annual basis (weekly output is possible but not considered accurate). The Jordan Lake watershed model developed in 2003 is an example of its application. The model is capable of determining loading rates at a jurisdictional level. Sediment delivery ratios are used to scale loads and account for uptake that occurs within each subwatershed. Instream processes are not simulated directly with GWLF. While the model is capable of providing input for empirically-based lake response models, it is not a sufficient platform to drive a time series lake response model such as EFDC. In addition, GWLF does not easily account for BMP implementation in a watershed (other than land use or agricultural operation changes). While the model inherently accounts for atmospheric deposition to the watershed, pollutant loading from other sources such as streambank erosion must be determined externally.

The Hydrological Simulation Program - FORTRAN (HSPF, Bicknell et al. 1997) is a more complex mechanistic watershed model. HSPF simulates watershed hydrologic processes as well as in stream kinetics using one dimensional channels. The HSPF model has been applied extensively throughout the United States and within North Carolina and is currently being used to refine the Jordan Lake jurisdictional loads.

The HSPF model divides a larger watershed into sub watersheds and aggregates the land uses and soil types within those subwatersheds into hydrologic response units (HRU). The behavior of sediment and nutrient loadings from each HRU can be individually calibrated to hourly loading estimates (if the calibration data exists at that level). Loadings are usually calibrated to monitoring events, which provide a single concentration value. Thus, the model output is typically valid at daily time scales. The model can also simulate instream sediment and nutrient dynamics. The land use loadings within each subwatershed can be calculated and compared with jurisdictional coverages to estimate loads from different municipalities. The time variable output from HSPF has often been used as an input to complex receiving water models, such as EFDC, and with appropriate calibration can provide accurate loading estimates to those models. The model can also be configured to represent BMPs in either a simple way by defining BMP effectiveness or by representing the BMP within the model explicitly.

3.2 Empirical Watershed Loading Models

Empirical models include regression models and probabilistic approaches that use a statistical or probabilistic approach to determine linkages between model inputs (e.g., land use) and model outputs (e.g., chlorophyll a concentrations). These models are generally more flexible in terms of the questions they can address, and because they are less parameterized than a mechanistic model, performing error analysis on the model predictions is more straightforward. Two examples of empirical watershed loading models are presented in this section.

3.2.1 SPARROW

The SPAtially Referenced Regression On Watershed attributes (SPARROW) model developed by the USGS simulates the loading, fate, and transport of sediment and nutrients in the nation’s rivers and streams. The model relies on data including erosion rates from the National Resources Inventory (NRI), 30-m resolution land cover data from the National Land Cover Data set (NLCD), reservoir data from the National Inventory of Dams (NID), soils data from the State Soil Survey Geographic (STATSGO) database, and flow and water quality data obtained through the National Water Quality Assessment (NAWQA) Program (Schwarz et al. 2003). The model outputs long-term (10-yr), mean annual fluxes of sediment and nutrients to the Enhanced River Reach (ERR) File 2.0 network (Booth et al. 2011), with more refined stream channels used to transport pollutants to the ERR channels. Upland reservoirs not located on the ERR channels are incorporated into the model and serve as sediment and nutrient sinks; point source discharges are included in the model as well.

The SPARROW model operates on a 1-km grid, with more refined data inputs (land cover, soil type, etc.) aggregated within the grid cell to represent the characteristics (Schwarz et al. 2003). The model uses nonlinear regression models that incorporate climate and basin characteristics (slope, soil pH, soil hydrologic group, etc.) as well as pollutant sources, sinks, and transport to predict pollutant loads. Long-term measurements of flow and water quality in the watershed are used to calibrate the models. SPARROW model output is available within a Decision Support System (DSS) on line at http://water.usgs.gov/nawqa/sparrow/. The DSS outputs mean annual loads, mean annual concentrations, and model uncertainty (prediction error) associated with the mean annual load (Booth et al. 2011).

Two versions of the model are available for nitrogen and phosphorus loading. The 1992 model represents the annual mean loads based on data from 1985 to 1995 and is based on modeling coefficients set at the national scale. The 2002 model is based on data collected from 1995-2005 and uses regional modeling coefficients to account for variability among the basins (Schwarz et al. 2003). While the 1992 SPARROW model uses national scale coefficients for model development, the 2002 SPARROW models use region specific coefficients to provide a more spatially accurate representation of pollutant loading (Preston et al. 2011).

Instream nitrogen and phosphorus losses in the Southeast model are correlated to travel time in the stream reach, mean discharge, and stream depth. Reservoir losses are correlated to the inverse of the hydraulic load (m/yr) calculated from mean annual flow (m^3/yr) divided by reservoir surface area (m^2). In the Southeast model, nitrogen losses are typically higher in the stream channels relative to reservoirs, while phosphorus losses are usually higher in the reservoirs (Preston et al. 2011).

Table 3-1 summarizes the nutrient loads delivered to Upper Falls Lake from the five main tributaries based on the 1992 and 2002 SPARROW models. Annual average loads reported by the 2002 model are much lower than those reported by the 1992 model. Difference in loading between these two scenarios may be due to inherent differences in the models themselves, land use changes, implementation of nutrient reduction strategies such as the ban on phosphate detergents, etc. (Garcia et al. 2011).

Table 3-1 Nutrient Loads Delivered to Falls Lake from Five Tributaries Based on the 1992 and 2002 SPARROW Models (Output from SPARROW DSS)

Nutrient	1992 Model (lb/yr)	2002 Model (lb/yr)
Nitrogen	1,751,992	1,041,250
Phosphorus	215,885	103,018

For the 2002 SPARROW models, the 1,041,250 pounds of nitrogen delivered to the Upper Lake from the five tributaries is allocated to wet deposition (49.2 percent), wastewater dischargers (14.9 percent), urban developed (15.4 percent), fertilization of agricultural lands (14.9 percent), and livestock manure application (5.5 percent). The 103,018 pounds of phosphorus delivered to the Upper Lake from the five tributaries is allocated among urban developed (29.5 percent), background-parent rock (28.1 percent), wastewater dischargers (13.2 percent), fertilization of agricultural lands (24.5 percent), and livestock manure application (4.7 percent). Figure 3-3 and Figure 3-4 show the delivered nutrient loads from the five tributaries by SPARROW source category for nitrogen and phosphorus, respectively. In the Southeast SPARROW model, nitrogen loading from background sources is assumed to comprise a small portion of the loading categorized as atmospheric deposition. For phosphorus, background loads comprise a fraction of the load categorized as background-parent rock (Preston 2011).

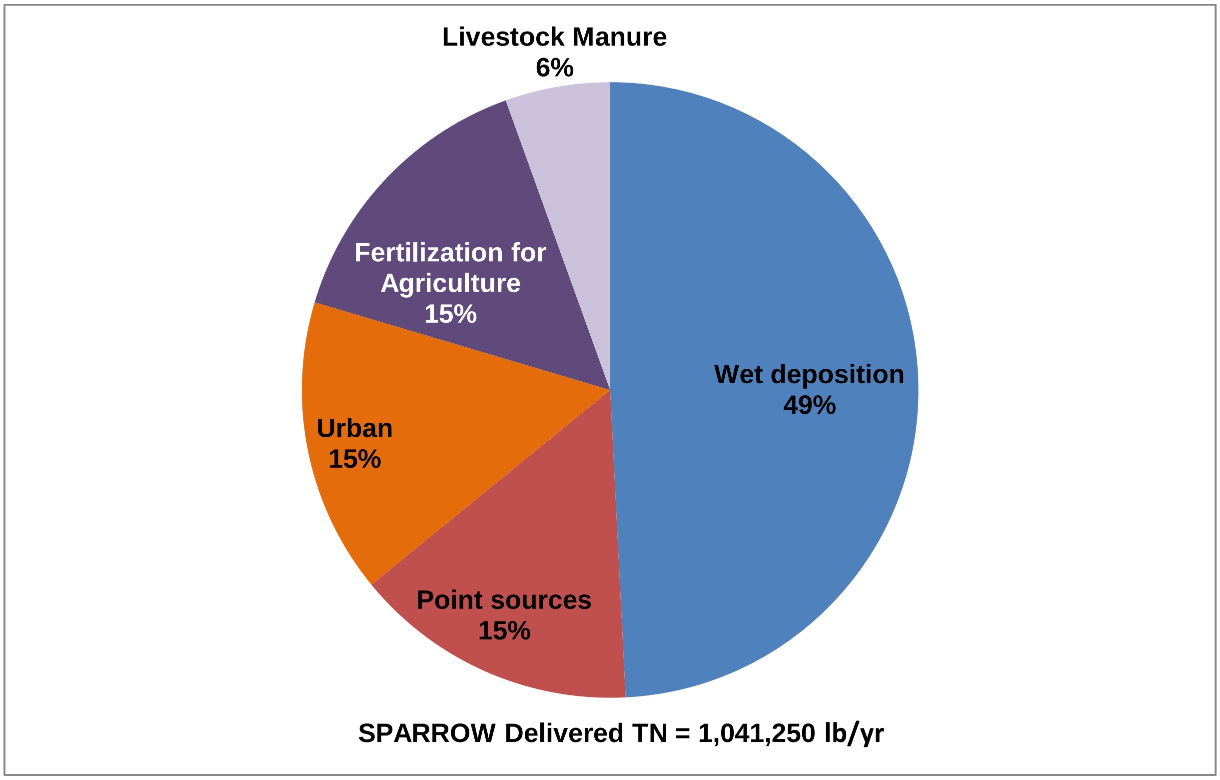

Figure 3-3 SPARROW Simulated Nitrogen Loads Delivered to Falls Lake from Five Tributaries by Source

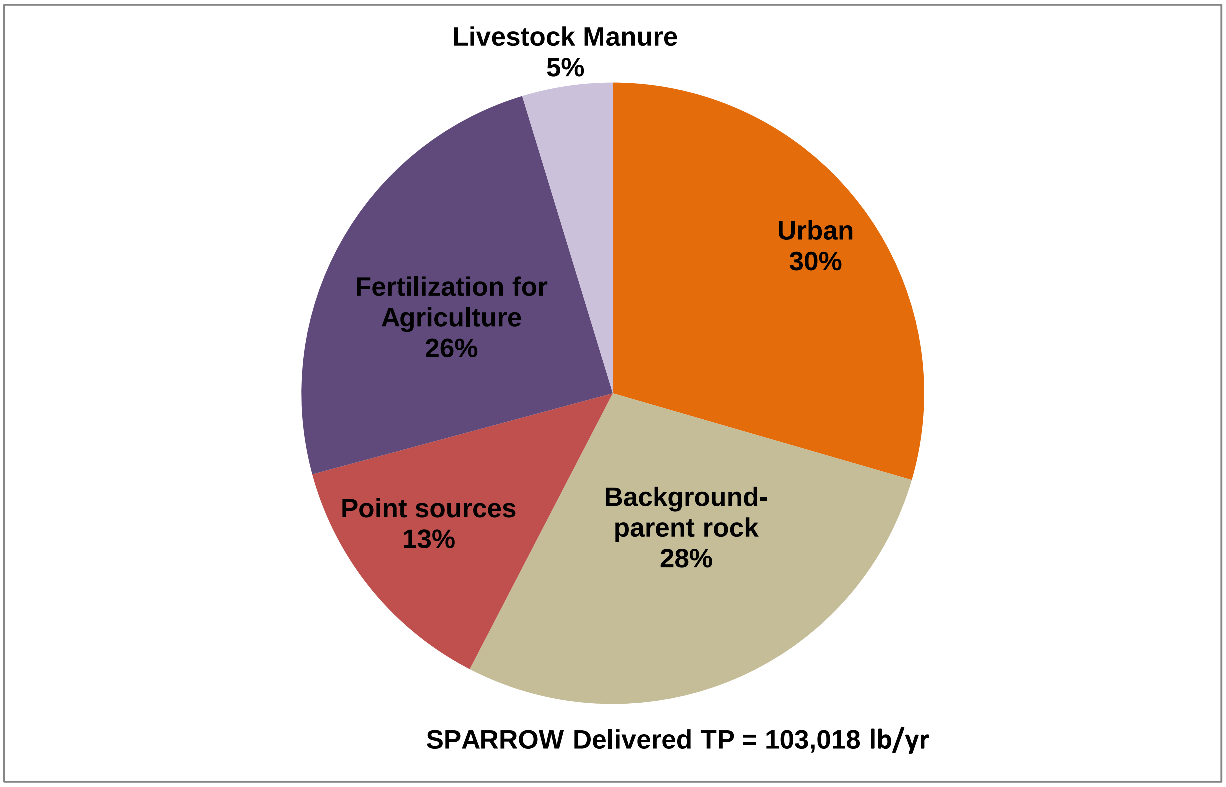

Figure 3-4 SPARROW Simulated Phosphorus Loads Delivered to Falls Lake from Five Tributaries by Source

Use of the SPARROW model output for estimation of jurisdictional loads would require some post processing prior to application. The model output for each reach segment in the watershed includes total load delivered from the mouth of the reach categorized by source. Delivered loads to Falls Lake would need to be scaled back based on the ratio of delivered load to total load (both may be output by the model, but not specified by source). In addition, sources of loading are characterized differently for nitrogen and phosphorus based on the statistical power of the sources for predicting loads. For example, the 2002 total phosphorus loads (average annual loads for 1995-2005) are allocated among wastewater discharges, urban land area, background-parent rock material (accounts for streambank erosion and legacy conditions in the southeast model), livestock manure, and fertilized land. The 2002 total nitrogen loads are allocated among wastewater discharges, wet deposition, impervious surface area, fertilizer application, and animal waste.

Loading from undisturbed areas (forest, shrub land, etc.) is not explicitly defined by the SPARROW model and this land use type makes up approximately 64 percent of the land use for the upper five tributaries. However, the wet deposition loads and background-parent rock loads can be equally distributed over the land uses in the watershed, thus allocating a portion of those loads to undisturbed areas (this approach would not account for rates of runoff and infiltration that vary by land use, and therefore likely overestimate loads from undisturbed areas). Figure 3-5 and Figure 3-6 show the redistributed loads by source under this assumption (the land use distribution for the five tributaries was taken from the WARMF modeling report (NCDENR 2009b). This allocation provides most of the source categories needed to assign jurisdictional loads, but does not explicitly assign loads to onsite wastewater treatment systems, which are still lumped in with the urban category. This approach also results in much higher loads from undisturbed areas relative to the WARMF predictions.

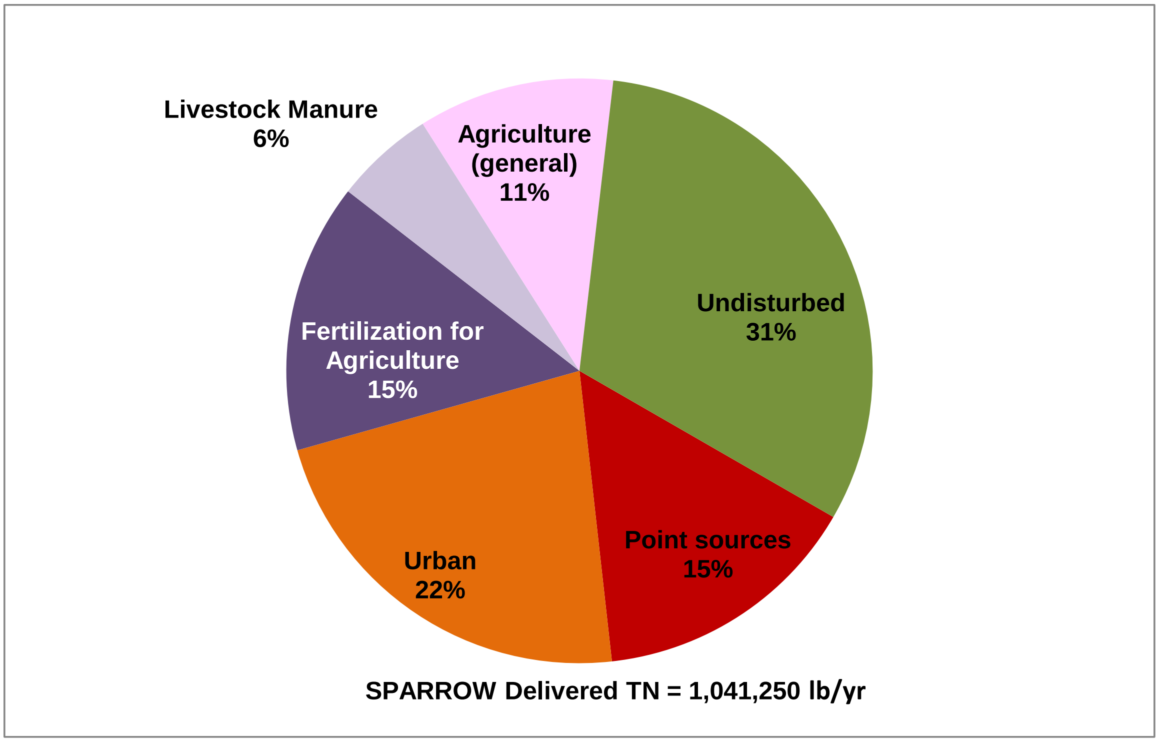

Figure 3-5 Reallocated SPARROW Simulated Nitrogen Loads Delivered to Falls Lake from Five Tributaries by Source

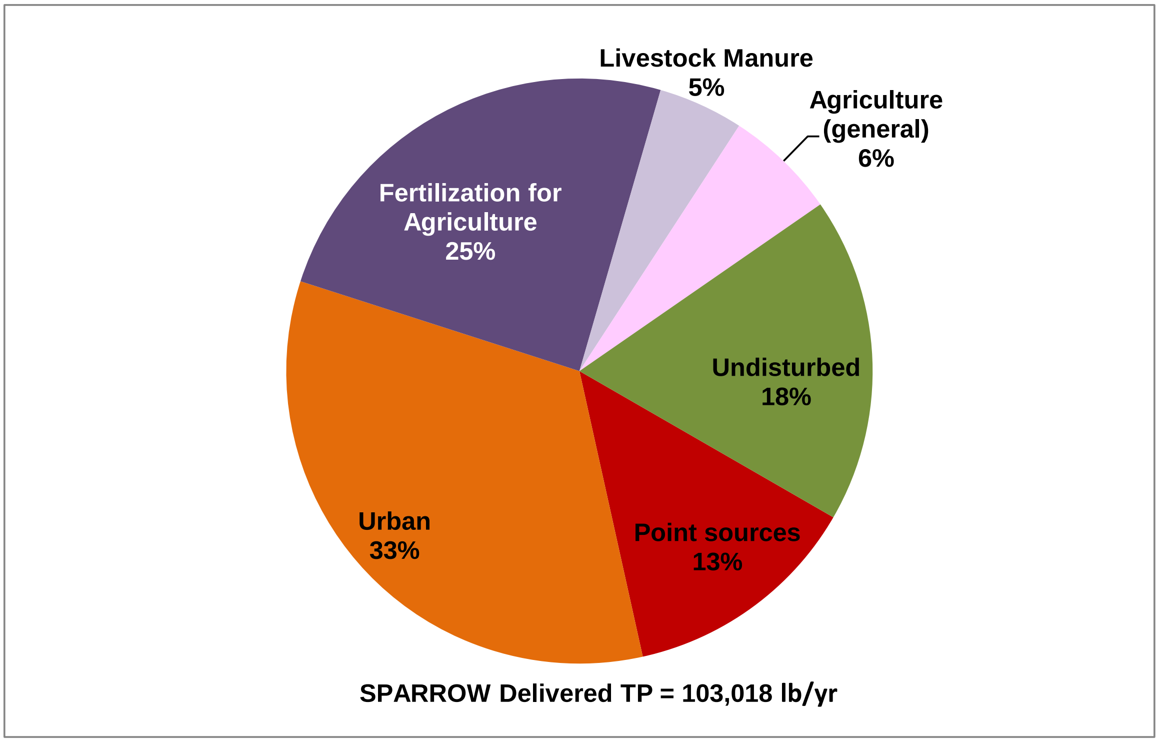

Figure 3-6 Reallocated SPARROW Simulated Phosphorus Loads Delivered to Falls Lake from Five Tributaries by Source

For comparison, the United States Forest Service (USFS) presented areal loading rates for forest on Carolina Slate Belt and Triassic Basin soils in the Piedmont of NC. Assuming that 15 percent of forest land in the watershed of the upper five tributaries is located on Triassic soils, the total loading generated from forest based on the USFS data is 365,140 lb-N/yr and 53,370 lb-P/yr. Using the delivery ratio from SPARROW for the upper watershed (0.84 for nitrogen and 0.83 for phosphorus), delivered loads from forest based on the USFS data would be 306,720 lb-N/yr and 44,300 lb-P/yr. Forest lands comprise 57 percent of the area drained by the upper five tributaries, so the reallocated SPARROW loads for forest would be 292,010 lb-N/yr and 16,500 lb-P/yr. Thus the reallocated SPARROW loads for nitrogen from forest is relatively close to those loads based on the USFS data considering the broad assumptions used to estimate the loading, but the phosphorus loads differ by a factor of 2.7. This discrepancy may be due to the background-parent rock category accounting for legacy sediment and total phosphorus resulting from historic activities.

Accounting for implementation of BMPs in the watershed with SPARROW would require use of an external calculator such as the urban development Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool (JFLSNLAT) and the agricultural Nitrogen Loss Estimation Worksheet (NLEW) and Phosphorus Loss Assessment Tool (PLAT). Post-processing of the model output would either occur in an external database or spreadsheet or be input directly into the SPARROW model using the change inputs function. The latter, however, would likely be more time consuming and difficult to maintain and track.

3.2.2 EUTROMOD

The EUTROMOD computer model (Reckhow et al. 1992) was developed to provide guidance and information for managing eutrophication in lakes and reservoirs. It is a collection of spreadsheet-based nutrient loading and lake response models which may be used to relate water quality goals to allowable nutrient inputs. The model provides information concerning the appropriate mix of point source discharges, land-use, and land management controls that result in acceptable water quality.

Lake wide, growing season average conditions in a lake are predicted as a function of annual nutrient loadings from the watershed. Annual loadings are simulated with a simple lumped watershed modeling procedure which includes the Rational Equation runoff coefficient for surface runoff, the universal soil loss equation for estimating soil loss, loading functions for nutrient export from nonpoint sources, and user-provided point source information. Lake response is predicted by a set of nonlinear regression equations from multi-lake regional data sets. These regression equations are used to estimate lake nutrient levels, chlorophyll *a* concentrations, and Secchi disc depth.

Currently EUTROMOD allows for uncertainty analysis by providing estimates of the effect of model error and hydrologic variability on the lake response variables. The model error is provided in terms of lake response estimates plus or minus one standard error, which is associated with the error term for the regression models. Year-to-year variability is addressed by utilizing an annual mean precipitation and corresponding coefficient of variation to account for hydrologic variability. This hydrologic variability is propagated by utilizing first-order error analysis and is presented as lake response estimates bounded by 90% confidence limits. Watershed model parameters include annual mean precipitation amounts and nutrient concentrations, runoff coefficients, Universal Soil Loss Equation (USLE) parameters, nutrient loading and enrichment factors by land use, trapping factors, septic system and point source information, and impoundment data including surface area, mean depth, and annual mean lake evaporation (Hession et al. 1996).

3.3 Recommendations for Calculating Stage II Reductions

Under the existing Falls Lake Nutrient Management Strategy, local governments are required to begin implementing their Stage II nutrient reduction program in 2021. Because the UNRBA has initiated a study to reexamine the Stage II rules, it may be premature to offer recommendations on how to proceed at this time because the Stage II requirements may change as a result of the reexamination. Preliminary recommendations for calculating Stage II reductions include

- In the short term, a literature review coupled with application of an empirical watershed model would provide local governments with an estimate of annual nutrient baseline loading to Falls Lake from which to calculate Stage II reductions.
- In the long term, Cardno ENTRIX recommends developing and/or updating mechanistic and empirical models to estimate loading from the watershed. The use of multiple models is described in the Task 4 TM.

4 Assessment of Relative Loading from Specific Sources

Watershed loading models generally operate on the same fundamental theories (SCS Curve Number, Universal Soil Loss Equation, etc.) and use the same datasets (land cover, soils database, topography, and meteorological inputs). Watershed loading models typically do a poor job of estimating loading from sources that do not fall neatly into specific land use categories. This section of the TM qualitatively describes the nutrient loading associated with onsite wastewater treatment systems, atmospheric deposition, streambank erosion, and internal lake loading. A comparison to the loading estimates predicted by WARMF is also provided along with a description of the accounting method used in SPARROW.

4.1 Onsite Wastewater Treatment Systems

4.1.1 WARMF Loading Estimate for Falls Lake Watershed

The WARMF model simulates onsite wastewater treatment systems as the cumulative volume of tank effluent distributed evenly over a modeling subwatershed and discharged to the subsurface (EPRI 2001). Systems may be categorized as standard, advanced, or failing, which have varying levels of pollutant concentrations in the effluent. Transport through the soil layer results in uptake, decay, nitrification, and adsorption based on the soil algorithms in the model. The model is not capable of accounting for system age, soil suitability, distance from a tributary, operation and maintenance, etc.

In the Falls Lake WARMF model developed by NCDWQ, onsite wastewater treatment systems discharging to the subsurface were simulated as either normally functioning (85 percent of systems) or poorly functioning (15 percent of systems). Per capita discharge is assumed 260 L/person/day. Poorly functioning systems have higher septic tank effluent pollutant concentrations (Table 4-1), but the discharge rate to the subsurface layer is the same as a normally functioning system. Failing systems that cause ponding and direct surface discharge are not simulated directly in WARMF; rather they are simulated using higher effluent concentrations. For sand filter systems, half were simulated as onsite wastewater systems that discharge to the subsurface and half were simulated as point sources that discharge to the land surface. Sanitary sewer overflows (SSOs) were simulated based on flow and concentration data for 138 incidents occurring throughout the watershed between 2004 and 2007.

Table 4-1 Septic Tank Effluent Nutrient Concentrations from Onsite Wastewater Treatment Systems

Parameter	Functioning System	Failing System
Ammonium (mg-N/L)	58	178
Nitrate (mg-N/L)	0.2	1.94
Organic Nitrogen (mg-N/L)	14	15
Total Nitrogen (mg-N/L)	~72	~195
Phosphate (mg-P/L)	9	21.8

NCDWQ's Falls Lake WARMF model predicts that fourteen percent of the total nitrogen load (92,941 lb/yr) delivered from the five Upper Lake tributaries is due to subsurface discharging onsite wastewater treatment systems, including half of the sand filter systems. Nine percent of the total phosphorus load (5,214 lb/yr) is attributed to these systems. The model lumps the remaining ½ of the sand filter systems in with the point source dischargers, so determining the total load due to onsite systems is not straightforward.

During the September 2012 hearing regarding a motion for a stay of newly permitted NPDES onsite wastewater discharges in the Falls Lake watershed, NCDWQ presented Exhibit 6 which showed that 7 percent of nitrogen loading delivered to Falls Lake from the upper five tributaries is due to septic systems and that sand filters contribute less than 1 percent of the load. For phosphorus, Exhibit 6 showed that 7 percent was due to septic systems and 1 percent was due to sand filter systems. The total delivered loads presented in Exhibit 6 were also different than those reported in the WARMF model documentation. The resulting loading from conventional onsite septic systems based on the Exhibit 6 percentages and daily loads are 57,342 lb-N/yr and 5,351 lb-P/yr from septic systems.

4.1.2 SPARROW Accounting Approach

The USGS's Neuse Basin SPARROW model distinguishes between nonpoint and point sources of nutrient loading from urban areas. Permitted wastewater discharges are given their own loading category, and those loads are based on data contained in the USEPA Permit Compliance System (PCS). The urban development category represents loading from nonpoint sources and includes loading associated with dry deposition of vehicle emissions (nitrogen), surface runoff concentrations, and groundwater quality affected by fertilization and onsite wastewater treatment systems (Preston et al. 2011). Thus loading from onsite wastewater treatment systems is not explicitly allocated by the SPARROW model; rather it comprises a fraction of the load categorized as urban development.

4.1.3 Local Studies

Several researchers in the North Carolina Piedmont have evaluated onsite wastewater treatment systems to determine impacts on water quality. Both conventional as well as sand filter systems have been studied. Concentrations reported in this section are not directly comparable to those presented in Section 4.1.1 (WARMF modeling of onsite systems) because the WARMF concentrations are at the point of discharge from the septic tank prior to passing through a drainfield or sand filter.

In 2010, NCDENR published its Report on the Potential Need for Improvements in Septic System Design, Operation and Siting Standards in the Falls Lake Watershed (NCDENR 2010a). The Division of Environmental Health, On-site Water Protection Section (OSWPS) reviewed the Falls Lake WARMF modeling and concluded that the loading estimates attributed to onsite wastewater treatment systems were likely high due to the assumptions used on the model and the treatment capacity of the local soils, particularly for phosphorus. For example, the WARMF modeling for the Falls Lake Watershed assumes a 15% failure rate for septic systems (Section 4.1.1), which is higher than the local observations reported by NCDENR (2010a). Based on data collected from 1982 to 2002, NCDENR indicates that Wake County has a county-wide failure rate of 9.7 percent (30 failures out of 310 inspections) and a failure rate of 6.3 percent (7 failures of 111 inspections) in the Falls Lake watershed (NCDENR 2010a). An Orange County survey indicates an observed failure rate of 4.3 percent (35 failures of 820 inspections) for systems less than eight years old, and a 9.5 percent failure rate (43 of 452 inspections) of older systems (NCDENR 2010a). The NCDENR report also noted that older systems located on smaller lots may have higher failure rates than those observed. The report concluded that properly functioning subsurface discharging systems did not contribute significantly to nutrient loading in the Falls Lake watershed, but that older systems on small lots likely have higher failure rates and surface discharging systems "pose continuing problems and contribute to increasing nutrient levels in the watershed" (NCDENR 2010a)

In 2007, AMEC prepared a Septic System Maintenance Program Study for Wake County and determined that approximately 10 percent of systems were failing (AMEC 2007). Conventional onsite wastewater systems are regularly inspected by the County; sand filter systems are inspected annually and systems with mechanical components such as pumps are inspected every three to five years. In 2005, Wake County conducted a study of field performance for onsite systems installed between 1982 and 2001 to determine rates of failure in the County (Lynn et al. 2005). Failures were defined as systems with a straight pipe from the system or ones where sewage was visible on the ground surface at the time of the survey. Failures were correlated to landscape position and soil type, with failure rates five times higher on sites located at the bottom of slopes or on the convex side slopes. Failure rates were three times higher for septic systems located on soils with lower suitability scores and this effect increased with system age. Failures were 2 to 3 times higher when vegetation above the system was not maintained or a structure was built on top of the system (Lynn et al. 2005).

Ferrell and Grimes (in review) assessed the impacts of wastewater disposal practices by assessing water quality at several locations in the Eno River watershed: one up and one downstream of the WWTP, one in a forested catchment, and six in streams draining residential areas primarily served by either centralized or onsite wastewater treatment systems. The WWTP had the greatest nutrient related impact on nitrate plus nitrite concentrations in the river. The various residential catchments had similar water quality with the exception of a catchment impacted by a broken sewer line. Total Nitrogen concentrations in the streams draining the residential catchments were generally less than 1 mg-N/L, with the exception of the catchment with the suspected broken sewer line leak.

NCDENR (2010b) collected water quality data in the Falls Lake watershed to compare nutrient concentrations in the streams of a forested catchment compared to two suburban catchments. One of the suburban catchments is primarily served by surface discharging sand filter systems, and the other is served by a centralized municipal system whose sewer lines run parallel to the stream channel. Highest mean ammonia, TKN, and total phosphorus concentrations were observed in the catchments served by surface discharging sand filter systems (0.046 mg-N/L, 0.706 mg-N/L, and 0.247 mg-P/L, respectively). The highest mean nitrate plus nitrite concentrations were observed in the sewered catchments (0.729 mg-N/L). Mean total nitrogen concentrations were similar for the two suburban categories (approximately 1 mg-N/L).

Humphrey et al. (2010) measured nitrate and ammonia concentrations for 15 months (January 2007 to March 2008) in the groundwater adjacent to16 properly functioning, conventional onsite systems located on sandy, coarse loam, or sandy clay loams in coastal NC. Median nitrate concentrations for the three soil types were 18.9 mg-N/L, 11.0 mg-N /L, and 2.6 mg-N /L, respectively. (Nitrate standards set by USEPA are 10 mg-N/L to protect infants from methemoglobinemia, or blue baby syndrome.) Ammonia concentrations in sandy or coarse loams were approximately 4 mg-N /L lower when the distance to the high water table was greater than 60 cm, compared to systems where the distance was less than 60 cm. The nitrate concentrations, however, were approximately 6.5 mg-N /L higher when the distance to the water table was greater than 60 cm. Total nitrogen concentrations were generally higher in sandy or coarse loam soils, with nitrogen speciation in the soils controlled by the distance to the water table.

Woolfolk et al. (2008) measured pollutant concentrations and discharge rates from sand filter systems in Durham County in 2000 (16 systems) and 2008 (10 systems). Total nitrogen concentrations averaged 26.1 mg/L and 40.4 mg/L, respectively, during these two studies. Total phosphorus concentrations and discharge flow rate were only measured during the 2008 study. Mean total phosphorus concentrations were 16.1 mg/L and mean discharge flow rates were less than 0.1 gallons per minute.

Exhibit 2 presented during the September 2012 hearing regarding a motion for a stay of newly permitted NPDES onsite wastewater discharges in the Falls Lake watershed showed that mean Total Kjeldahl Nitrogen (ammonia plus organic nitrogen) concentration leaving a septic tank (prior to entering a sand filter, packed media, or drain field) was 62 mg-N/L. Following treatment in a packed media or sand filter, TN concentrations averaged 28 mg-N/L to 30 mg-N/L.

4.2 Atmospheric Deposition

Nitrogen loading from atmospheric deposition is readily quantified using data collected by the National Atmospheric Deposition Program (NADP) and the associated Clean Air Status and Trends Network

(CASTNET) database. This exercise is thoroughly documented in the Falls Lake model reports (NCDENR 2009a and 2009b). In addition, the City of Durham has been conducting its own measurements of atmospheric deposition in the watershed. This section of the report compares the loads simulated in the Falls Lake WARMF and EFDC models to loads based on regional and local estimates.

4.2.1 WARMF Watershed Deposition

The NCDWQ's Falls Lake WARMF accounts for atmospheric deposition using a dry deposition equation that accounts for the pollutant depositional velocity, the ambient air concentration, the leaf area of the canopy, and gaseous and physical collection by the canopy (EPRI 2001). Chemical reactions within the leaf canopy as well as wash off by precipitation are accounted for in the model. Wet deposition is accounted for by multiplying the rainfall concentration by the rainfall volume. Wet deposition rates are based on NADP station NC41 at Finley Farms in Raleigh, NC near Lake Wheeler. Dry deposition rates are based on Clean Air Status and Trends Network (CASTNET) station PED108 (Prince Edward, Prince Edward County, Virginia). The model accounts for deposition of ammonium and nitrate to the land surface, but does not include deposition of phosphorus. Table 4-2 summarizes annual total nitrogen (ammonia and nitrate) loads from atmospheric deposition simulated in the WARMF model.

Table 4-2 Total Nitrogen Loads (lb/yr) from Atmospheric Deposition in the Falls Lake Watershed based on NCDWQ's WARMF Model

Location	Fraction	2004	2005	2006	2007
Lake Surface	Dry	34,600	73,200	61,700	59,500
	Wet	73,900	62,200	62,200	38,600
	Total	**108,500**	**135,400**	**123,900**	**98,100**
Watershed	Dry	1,260,000	2,660,000	2,240,000	2,170,000
	Wet	2,690,000	2,270,000	2,260,000	1,410,000
	Total	**3,950,000**	**4,930,000**	**4,500,000**	**3,580,000**
Total	Dry	1,294,600	2,733,200	2,301,700	2,229,500
	Wet	2,763,900	2,332,200	2,322,200	1,448,600
	Total	**4,058,500**	**5,065,400**	**4,623,900**	**3,678,100**

4.2.2 EFDC Lake Surface Deposition

The EFDC model simulates dry and wet deposition of nitrogen species (ammonium and nitrate) over the surface area of Falls Lake. Wet deposition rates are based on NADP station NC41 at Finley Farms in Wake County. Dry deposition rates are based on CASTNET station PED108 (Prince Edward, Prince Edward County, Virginia). Table 4-3 summarizes the nitrogen and phosphorus loads simulated in the Falls Lake Nutrient Response Model. Deposition rates in 2006 are 1.3 to 1.5 times higher than those in 2005 and 2007.

Table 4-3 Nitrogen Deposition Rates to the Falls Lake Surface Simulated by the EFDC Model (lb-N/yr)

Fraction	2005	2006	2007
Dry	22,200	16,700	16,400
Wet	79,900	118,000	70,000
Total	102,000	135,000	86,400

4.2.3 SPARROW Accounting Approach

The SPARROW model explicitly allocates nitrogen loading from wet atmospheric deposition by incorporating NADP data. Dry deposition of nitrogen is accounted for in the urban developed land category (Preston et al. 2011). For the five tributaries entering the Upper Lake, wet atmospheric deposition is associated with 512,409 lbs, or approximately 49 percent of the total load. Phosphorus loading associated with atmospheric deposition is not explicitly defined.

4.2.4 Regional Modeling

The USEPA Community Multiscale Air Quality (CMAQ) modeling system simulates the emission, deposition, and transformation of several airborne pollutants. CMAQ provides estimates of total nitrogen deposition at a 36 kilometer grid scale for the nation for three scenarios (2001, 2010, and 2020). For the Falls Lake watershed, total nitrogen deposition rates for these three scenarios are 10.6 lb/ac, 8.2 lb/ac, and 7.5 lb/ac, respectively (NCDENR 2009b). Total loads for the entire watershed (772 mi^2), upper watershed corresponding to the five tributaries (528 mi^2), and the lake surface (17.7 mi^2) are provided in Table 4-4. Watershed loads and loads directly deposited to the lake surface based on the CMAQ modeling are relatively similar to those simulated by WARMF and EFDC. In 2001 and 2010, simulated direct deposition to the lake surface based on CMAQ modeling accounted for 18 percent and 14 percent, respectively, of the Stage II allowable load for nitrogen. Note that these loads are gross loads, and do not account for losses that occur in the watershed or the lake.

Table 4-4 Total Nitrogen Loads to Falls Lake and in the Falls Lake Watershed based on USEPA CMAQ Model

Area	2001 (lb/yr)	2010 (lb/yr)	2020 (lb/yr)
Falls Lake Watershed	5,237,248	4,051,456	3,705,600
Upper Lake Watershed	3,581,952	2,770,944	2,534,400
Falls Lake direct deposition	119,886	92,742	84,825

4.2.5 Local Studies

The City of Durham has measured atmospheric deposition of nitrogen at two stations, one site in the Falls Lake watershed and one site in the Jordan Lake watershed. Data has been collected at the station in the Falls Lake watershed for both wet (05/2011-present) and dry (07/2011-present) deposition, while only wet deposition has been measured at the Jordan Lake station (03/2011-present). The goal is to provide data from an urban environment and compare with data from regional monitoring programs (CASTNET and NADP) that typically sample using rural stations. The City of Durham stations and the regional CASTNET and NADP stations measure rainfall, pH, wet nitrate, wet ammonia, dry nitric acid, dry nitrate, dry ammonium and meteorological parameters. The City of Durham data also include dry ammonia, wet total Kjeldahl nitrogen and wet total phosphorus data that are not measured as part of the CASTNET and NADP programs. Preliminary data was made available for this summary via presentation that covered sampling from May 2011 to June 2012.

Data collected at the City of Durham stations are consistent with data collected by other CASTNET and NADP stations. Total nitrogen deposition was 4.7 lb-N/ac/yr at the Falls Lake station and 6.3 lb-N/ac/yr at the Jordan Lake site. Deposition rates in 2009 from rural CASTNET stations ranged from 3.5 lb-N/ac/yr to 4.4 lb-N/ac/yr which does not include dry ammonia or wet organic nitrogen deposition. In the Chesapeake Bay watershed, 2010 total nitrogen deposition rates were 4.7 lb-N/ac/yr. The ratio of wet to dry deposition (75.2% to 24.8%) from the City of Durham study was comparable to data collected at other regional sites (74% to 26%). By season, ammonia and ammonium deposition was highest in the spring and summer, while nitrate and nitric acid deposition did not vary seasonally. Deposition rates of total phosphorous were not reported because all samples collected were below the 0.05 mg/L detection limit for the analysis method.

4.3 Streambank Erosion

Most watershed loading models fail to account for nutrient loading due to streambank erosion. Models that do attempt to quantify this loading either use a crude estimate (for example, 50 percent of the total sediment load originates from streambank erosion) or use regional regression equations if available. In agricultural areas, streambank erosion and associated nutrient loading can be due to animal traffic in the stream channel causing bank failure and waste deposition in the stream. In addition, straightened channels and limited stream buffers coupled with over-application of fertilizer on croplands can result in stream erosion and high delivered nutrient loads. In urban areas, increased area covered with impervious surfaces shortens the amount of time it takes for rainfall to reach a stream channel and reduces stormwater infiltration. These effects result in rapidly occurring, larger stream flow volumes during storm events than would occur under more natural or pervious watershed conditions. These higher flows produce forces that erode stream channels. The resulting erosion from the streambanks dislodges not only sediment and plant materials but also the nutrients associated with them.

4.3.1 WARMF Loading Estimate

WARMF simulates sediment transport through stream channels by comparing the load delivered from the land surface to the transport capacity of the stream (EPRI 2001). Transport capacity is a function of shear velocity, hydraulic radius, and soil characteristics. Clay and silt are assumed to remain suspended, but if the sediment load exceeds the transport capacity, the excess sediment settles out from the sand fraction. Although the model accounts for transport of sediment washed off the land surface through the stream channels, it does not account for erosion and transport of sediment from the stream banks.

4.3.2 SPARROW Accounting Approach

The Southeast SPARROW model accounts for streambank erosion in the phosphorus model as an individual category called Background-Parent Rock, which is the load associated with the phosphorus content of bed sediment in headwater streams (Preston et al. 2011, Garcia et al. 2011). For the five Upper Lake tributaries, the total phosphorus load associated with background-parent rock is 28,918 lb/yr or 28 percent of the total load. These contributions are consistent with the Southeast model as a whole, which attributes 41 percent of phosphorus loading to soil-parent rock material (Garcia et al. 2011). The model coefficient for this category is 0.037 with a 90 percent confidence interval of 0.025 to 0.050: delivered loads to the Upper Lake range from 19,540 lb/yr to 39,078 lb/yr.

4.3.3 Additional Studies

In the Piedmont of NC, studies that quantify the nutrient load associated with streambank erosion are not readily available. However, in other parts of the country, studies to quantify this nutrient source have been conducted. For example, the focus on reducing nutrient loading within the Chesapeake Bay watershed has prompted research in this topic. Walter et al. (2007) reported bank erosion rates of 0.7 ft/yr to 3.3 ft/yr (mean of 0.39 ft/yr) at the 6 sites included in their study of Piedmont streams in Pennsylvania (these sites were selected to represent reaches that are eroding at a relatively high rate and are not intended to represent Basinwide averages). The mass of sediment eroding from these streams was 400 lb/ft/yr to 1,800 lb/ft/yr with an average rate of 620 lb/ft/yr. Nutrient concentrations measured from these eroding streambanks ranged from 0.8 lb-N/ton to 4.3 lb-N/ton for nitrogen (mean of 2.3 lb-N/ton) and 0.7 lb-P/ton to 1.9 lb-P/ton for phosphorus (mean of 1.1 lb-P/ton); carbon content ranged from 11.3 lb-C/ton to 61.7 lb-C/ton (mean of 30.4 lb-C/ton).

Based on this data, 1000 feet of eroding stream bank with an average bank height of 5 feet would produce on average 72.2 cubic yards of sediment. Assuming a conversion of 1.2 tons/cubic yard yields a mass of 86.7 tons of sediment per year with an associated 200 lb-N, 100 lb-P, and 2,600 lb-C. There are over 4 million feet of stream channels in the Falls Lake watershed, so depending on the number of segments that are eroding at high rates, this could be a potentially high source of nutrient loading to the lake. If ten percent of the stream channels are actively eroding, this may contribute 80,000 lb-N, 40,000 lb-P, and over 1 million lb-C each year.

4.4 Flux from Lake Sediments

4.4.1 EFDC Falls Lake Flux Estimate

The Falls Lake Nutrient Response model used benthic flux rates of ammonia and phosphate as calibration factors for the modeling. In 2005 and 2007, flux rates for ammonia and phosphate were simulated as 0.02 g/m^2/d and 0.0023 g/m^2/d, respectively as temporally and spatially constant flux rates across the lake bottom. For year 2006, the rates were decreased to 0.01 g/m^2/d and 0.001 g/m^2/d, respectively. Table 4-5 estimates the internal lake sediment loads simulated in the Falls Lake model by multiplying the flux rate by the lake area in the EFDC model. It should be noted that the fluxes shown in Table 4-5 do not take into account the temperature correction that is accounted for in the EFDC model.

Table 4-5 Nutrient Loads from Lake Sediments Simulated with the Falls Lake Nutrient Response Model

Nutrient	2005 (lb/yr)	2006 (lb/yr)	2007 (lb/yr)
Ammonia	758,000	379,000	758,000
Phosphate	87,100	37,900	87,100

4.4.2 Local Studies

NCDWQ measured benthic flux rates of ammonia, nitrite plus nitrate, and phosphorus at two locations in Falls Lake in April 2006. Conditions in April 2006 may not have been favorable for benthic releases of nutrients, particularly phosphorus, because dissolved oxygen concentrations throughout the water column were generally greater than 5 mg/L. There appear to be single measurements of low DO sometime in April 2006 at each of the two benthic flux monitoring stations, but it is unknown whether or not those conditions occurred before or after the flux measurements were taken and whether or not anoxic conditions would have been present long enough to stimulate significant release of nutrients from lake sediment. Because the measured benthic flux rates during the April 2006 sampling were nearly zero, benthic flux rates were used as a factor to calibrate the model. Use of these parameters as calibration parameters to match observed water quality concentrations is a common modeling technique due to the difficulty and expense associated with collecting in situ measurements. However, if the watershed loading estimates are higher than actual loading and the measurements of benthic flux rates were collected in a limited period when conditions may not have been favorable for sediment release, then internal loading may be underestimated.

4.4.3 Nürnberg Method

The Nürnberg method estimates in-lake phosphorus loading due to benthic releases based on a comparison of mean growing season phosphorus concentrations in the inputs and at the outlet of each segment. In addition to water quality data, the method also requires bathymetric and average flow data for each segment. Figure 4-1 shows the three lake segments and their contributing drainage areas, USGS flow gages, and water quality monitoring stations used for this analysis. For the three Falls Lake segments analyzed, the Nürnberg calculation results in a large negative value for internal loading. This analysis indicates that on an annual basis, phosphorus losses in the lake are greater than phosphorus releases from sediments.

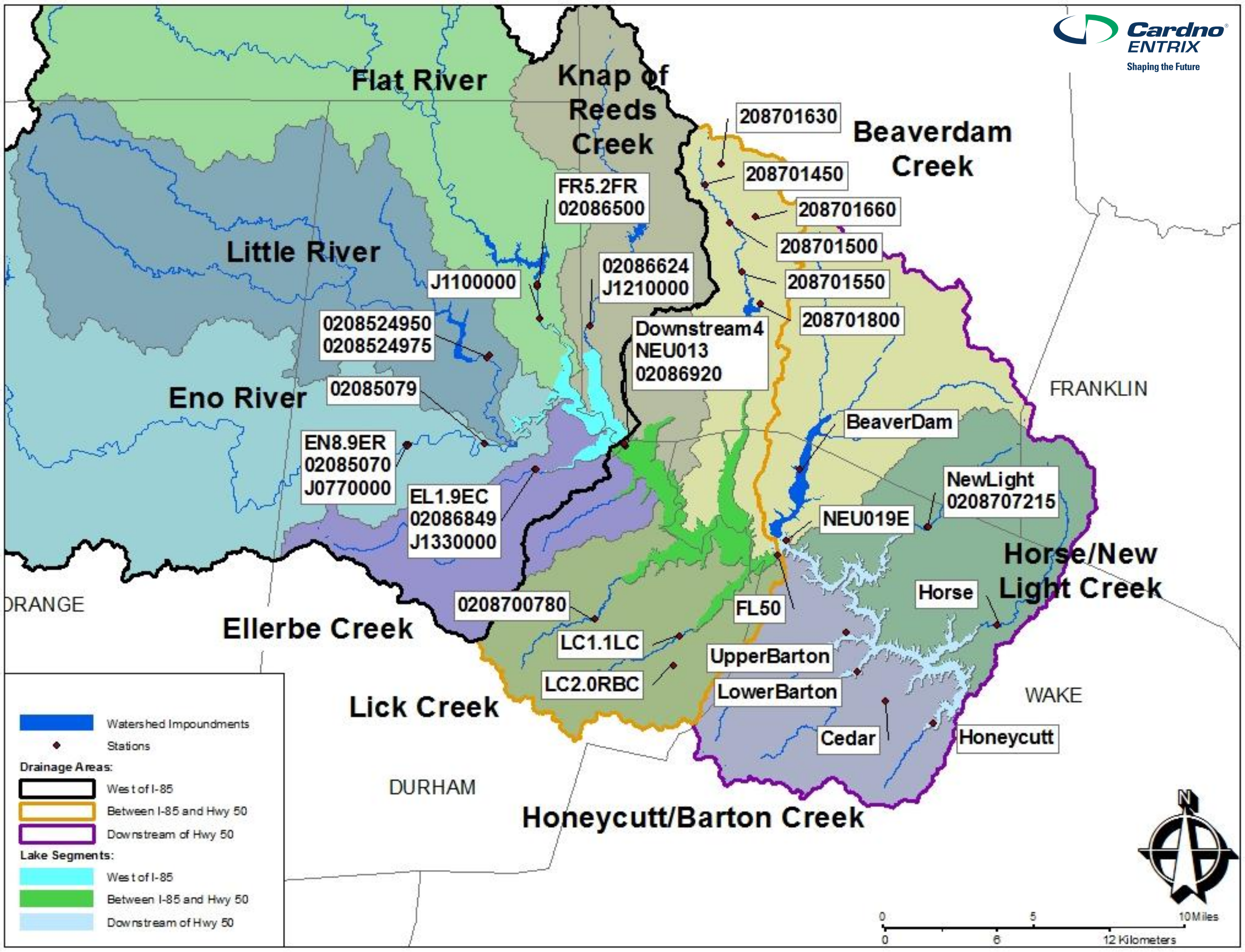

Figure 4-1 Falls Lake Flow and Water Quality Stations Used to Estimate Internal Phosphorus Loading for Three Lake Segments

4.4.3.1 Lake Morphometry

The U.S. Army Corps of Engineers (USACE) reports that normal pool elevation for Falls Lake is 251.5 ft above mean sea level (MSL), and the surface area of the entire lake including the Beaverdam Impoundment is approximately 12,400 acres (http://epec.saw.usace.army.mil/fallpert.txt). The volume of the lake at this elevation is 131,400 acre feet based on data from the USACE. Based in GIS measurements of Falls Lake, the surface area west of I-85 is approximately 2,700 acres; between I-85 and Hwy 50 is approximately 6,200 acres; and between Hwy 50 and the dam is approximately 3,400 acres. Based on the EFDC modeling grid for Falls Lake, the average depths of these three segments are 3.6 ft, 10.2 ft, and 16.4 ft, respectively. Multiplying the surface area by average depth of each segment and adding the respective volumes yields a total volume of 130,360 ac-ft. Given the approximations in morphometry, this error with respect to the USACE reported normal volume is relatively insignificant. Table 4-6 summarizes the lake characteristics assumed for each segment.

Table 4-6 Summary of Lake Morphometry at Normal Pool

Segment	Surface Area (ac)	Average Depth (ft)	Volume (ac-ft)
West of I-85	2,700	3.6	9,720
Between I-85 and Hwy 50	6,200	10.2	63,240
Between Hwy 50 and the dam (Lower Lake)	3,400	16.4	57,400
Total	**12,400**	**10.5 (calculated)**	**130,360**

4.4.3.2 Evaporative Losses and Direct Precipitation

Evaporative losses from the lake surface affect the hydraulic residence time of the lake segments by removing water from the system. For this analysis, evaporative losses are calculated from the pan evaporation data reported for the Raleigh Durham International Airport by NOAA and the Southeast Climate Consortium (54.3 inches; NOAA 1982) and the ratio of lake evaporation to pan evaporation reported by USGS for Lake Michie (0.72; Yonts et al. 1973). Segment surface area multiplied by evaporative losses in depth per time results in an annual average evaporative loss from the each segment (Table 4-7). Direct precipitation to the lake surface is assumed 42.3 inches based on data provided by the USACE (mean annual precipitation for 1999 to 2011).

Table 4-7 Average Annual Evaporative Losses from Falls Lake Segments

Segment	Pan Evaporation (inches)	Ratio of Lake Evaporation to Pan Evaporation	Segment Surface Area (ac)	Average Annual Evaporative Loss (cfs)	Average Annual Direct Precipitation (cfs)
West of I-85	54.3	0.72	2,700	12.1	13.1
I-85 to Hwy 50	54.3	0.72	6,200	27.9	30.2
Hwy 50 to Dam (Lower Lake)	54.3	0.72	3,400	15.7	17.0

4.4.3.3 Tributary Inflows

The Nürnberg method uses tributary inflows along with evaporative losses to calculate the hydraulic residence time of each lake segment. For this analysis, tributary inflows were also used to flow weight the tributary total phosphorus concentrations to estimate the mean concentration entering each segment.

4.4.3.3.1 Segment West of I-85

For the segment west of I-85, USGS flow data recorded from 2006 to 2011 was used to calculate mean annual flow for each of the five contributing tributaries. The period was selected for consistency with the Ellerbe Creek and Knap of Reeds Creek gages which were installed in 2006. Table 4-8 lists the average annual flow for each gage along with the USGS stations and drainage areas used for the analysis.

Table 4-8 Mean Annual Flows for Tributaries Draining to the Segment West of I-85

Subwatershed	USGS Gage	Gaged Drainage Area (km^2)	Drainage Area at Mouth (km^2)	Average Annual Gaged Flow (cfs)	Average Annual Flow at Mouth (cfs)
Eno	02085070	365.2	400.2	87.8	96.3
Little	0208524975	256.1	271.6	40.9	43.3
Flat	02086500	435.1	451.6	100.1	103.9
Ellerbe	02086849	56.7	92.5	40.56	66.2
Knap of Reeds	02086624	111.4	150.6	24.4	33.0
Total	**NA**	**1,224.6**	**1,366.5**	**293.8**	**342.7**

4.4.3.3.2 Segment Between I-85 and Highway 50

There are no USGS flow gages along the tributaries that drain directly to the segment between I-85 and Highway 50. For this segment, outflows from the west of I-85 segment were used along with area-weighted tributary flows (342.7 cfs / 1,366.5 km^2 * drainage are of tributary km^2) from the Lick Creek subwatershed and the portion of the Beaverdam Creek subwatershed that drains to this segment. Table 4-9 summarizes the flow inputs to this segment.

Table 4-9 Mean Annual Flows for Tributaries Draining to the Segment Between I-85 and Highway 50

Input	Contributing Drainage Area (km^2)	Average Annual Inflow (cfs)	Average Annual Evaporative Losses (cfs)	Net Average Annual Inflow (cfs)
Outlet of the West of I-85 Segment	1,366.5	342.7	12.1	330.6
Lick Creek	114.0	28.6	NA	28.6
Contributing Area of Beaverdam Creek Subwatershed	127.5	32.0	NA	32.0
Total	**1,608.0**	**403.2**	**NA**	**391.2**

4.4.3.3.3 Segment Between Highway 50 and the Dam (Lower Lake)

There are no existing USGS gages along the tributaries that drain to the Lower Lake. To estimate mean annual inflows to this segment, net outflows from the segment between I-85 and Highway 50 were added to area-weighted tributary flows (342.7 cfs / 1,366.5 km^2 * drainage area of tributary km^2) for the lower part of the watershed. Table 4-10 summarizes the flow inputs to this segment.

Table 4-10 Mean Annual Flows for Tributaries Draining to the Segment Downstream of Highway 50

Input	Contributing Drainage Area (km^2)	Average Annual Inflow (cfs)	Average Annual Evaporative Losses (cfs)	Net Average Annual Inflow (cfs)
Outlet of the I-85 to Highway 50 Segment	1,608.0	391.2	27.9	363.3
Contributing Area of Beaverdam Creek Subwatershed	99.0	24.8	NA	24.8
Honeycutt/Barton	110.6	27.7	NA	27.7
Horse/Newlight	131.0	32.9	NA	32.9
Total	**1948.6**	**476.6**	**NA**	**448.7**

4.4.3.4 Growing Season Average Tributary Total Phosphorus Concentrations

The Nürnberg method requires an estimation of mean growing season (May through September) total phosphorus concentration entering the segment. For each of the three segments analyzed for Falls Lake, multiple tributaries contribute phosphorus at varying concentrations and flows. For the five upper lake tributaries, the same water quality stations and flow gages used for the calculation of tributary loads (Section 5) were used to represent the tributary inputs for the calculation of internal lake loading. For the Lower Lake tributaries, water quality stations were selected based on the availability of total phosphorus data. For some of the subwatersheds, this required the use of stations further than 2 miles from the lake boundary.

4.4.3.4.1 Segment West of I-85

To estimate the average growing season total phosphorus concentration entering the segment west of I-85, the tributary concentrations were weighted by mean annual flow. Table 4-11 lists the water quality stations used for this analysis along with the mean growing season total phosphorus concentrations. The flow weighted growing season tributary input concentration for this segment is 0.299 mg/L.

Table 4-11 Tributary Water Quality Stations and Mean Growing Season Total Phosphorus Concentrations for the Segment West of I-85

Subwatershed	Water Quality Stations	Number of Growing Season TP observations	Growing Season Average TP (mg/L)	Average Annual Flow (cfs)	Weighted TP Concentration (mg/L)
Eno	EN8.9ER, 02085079, J0770000	82	0.073	96.3	0.021
Little	0208524950, 0208524975	92	0.100	43.3	0.013
Flat	FR5.2FR, J1100000	68	0.052	103.9	0.016
Ellerbe	J1330000, EL1.9EC	89	0.421	66.2	0.081
Knap of Reeds	J1210000	61	1.75	33.0	0.169
Total	**NA**	**392**	**0.479**	**342.7**	**0.299**

4.4.3.4.2 Segment between I-85 and Highway 50

Water quality stations located at the outlet of the West of I-85 segment were used to calculate the mean growing season total phosphorus concentration associated with this input. For the Lick Creek drainage, water quality stations located between 0 to 2 miles from the lake were used for this assessment. For the Beaverdam Creek subwatershed, the only stations with growing season total phosphorus concentrations in the portion of the subwatershed draining to this segment were located more than 2 miles from the lake boundary. Table 4-12 lists the water quality stations used for this analysis along with the mean total phosphorus concentrations.

Table 4-12 Tributary Water Quality Stations and Mean Growing Season Total Phosphorus Concentrations for the Segment Between I-85 and Highway 50

Input	Water Quality Stations	Number of Growing Season TP observations	Growing Season Average TP (mg/L)	Average Annual Flow (cfs)	Weighted TP Concentration (mg/L)
Outlet of the West of I-85 Segment	Downstream4, NEU013, 02086920	111	0.159	330.6	0.134
Lick Creek	LC1.1LC, LC2.0RBC, 0208700780	15	0.108	28.6	0.008
Contributing Area of Beaverdam Creek Subwatershed	0208701450, 0208701500, 0208701550, 0208701630, 0208701660, 0208701800	6 (each station was sampled once during the summer of 2005)	0.207	32.0	0.017
Total	**NA**	**132**	**0.158**	**391.2**	**0.159**

4.4.3.4.3 Segment Between Highway 50 and the Dam (Lower Lake)

Water quality stations located at the outlet of the segment between I-85 and Highway 50 were used to calculate the mean growing season total phosphorus concentration associated with this input. For the Beaverdam Creek subwatershed, there is only one station with total phosphorus data in the portion of the subwatershed draining to this segment. For the Honeycutt/Barton drainage, four water quality stations have growing season total phosphorus data. There are three water quality stations with total phosphorus data in the Horse/Newlight drainage. Table 4-13 lists the water quality stations used for this analysis along with the mean total phosphorus concentrations.

Table 4-13 Tributary Water Quality Stations and Mean Growing Season Total Phosphorus Concentrations for the Segment Between Highway 50 and the Dam

Input	Water Quality Stations	Number of Growing Season TP observations	Growing Season Average TP (mg/L)	Average Annual Flow (cfs)	Weighted TP Concentration (mg/L)
Outlet of the I-85 to 50 Segment	FL50, NEU019E	66	0.037	363.3	0.030
Contributing Area of Beaverdam Creek Subwatershed	Beaver	5	0.035	24.8	0.002
Honeycutt/Barton	Cedar, Honeycut, Low Bart, Up Bart	36	0.076	27.7	0.005
Horse/Newlight	Horse, New Light, 0208707215	21	0.044	32.9	0.003
Total	**NA**	**128**	**0.048**	**448.7**	**0.040**

4.4.3.5 Hydraulic Residence Time

Hydraulic residence time is the ratio of segment volume to average annual net inflow (inflows minus evaporation). Table 4-14 summarizes the hydraulic residence time for each segment.

Table 4-14 Hydraulic Residence Time for Falls Lake Segments

Segment	Volume (ac-ft)	Net Inflow (cfs)	Residence Time (yr)	Residence Time (d)
West of I-85	9,720	330.5	0.04	14.8
I-85 to Hwy 50	63,240	363.2	0.24	87.8
Hwy 50 to Dam (Lower Lake)	57,400	432.9	0.18	66.8

4.4.3.6 Growing Season Average Outflow Total Phosphorus Concentrations

Multiple water quality monitoring stations are located at the outlet of each Falls Lake segment. The mean growing season total phosphorus concentrations for these stations are provided in Table 4-15.

Table 4-15 Average Growing Season Outlet Total Phosphorus Concentrations

Segment	Water Quality Stations	Number of Growing Season TP observations	Growing Season Average TP (mg/L)
West of I-85	Downstream4, NEU013, 02086920	111	0.159
I-85 to Hwy 50	FL50, NEU019E	66	0.037
Hwy 50 to Dam (Lower Lake)	FLIN, NEU020D, 0208717595	72	0.023

4.4.3.7 Internal Phosphorus Load

The Nürnberg equation for calculating internal phosphorus loading due to benthic releases is

TPoutflow = TPinflow * (1-Rpred) + Lint / Qs

Where

TPoutflow = mean summer outflow total phosphorus concentration (µg/L)

TPinflow = mean summer tributary inflow total phosphorus concentration (µg/L)

Rpred = annual retention due to sedimentation = 15 / (18 + Qs)

Qs = mean depth over hydraulic residence time

Lint = internal phosphorus load ($mg/m^2/yr$)

For each segment of Falls Lake, the Nürnberg method predicted a negative value for internal phosphorus loading, which indicates that losses in each lake segment are greater than re-suspension from the lake sediments. While localized benthic releases may occur under certain conditions, on an annual basis the lake serves as a phosphorus sink under current conditions.

5 Estimation of Tributary Loading to Falls Lake

Due to the requirements specified in the Falls Lake Nutrient Management Strategy, (.0275 5(b)(i)), nutrient loading to Falls Lake must be evaluated and reported to the EMC every five years, beginning in 2016. Because the EMC did not specify the methodology to be used in this assessment, the UNRBA has chosen to evaluate two commonly used tributary load estimation tools: the USACE FLUX tool and the USGS LOADEST tool. This section describes these tools, compares their results for one of the gaged tributaries in the watershed, and selects one of the tools for application to the other gaged tributaries that drain to the segment of the lake west of I-85. The original plan was to test these tools on perennial and intermittent streams in the watershed. Unfortunately only one intermittent stream (in the Ellerbe Creek subwatershed) has been sampled for nutrients in the watershed, and the number of samples is insufficient for this type of application. These analyses, therefore, focus only on perennial streams in the watershed.

5.1 Review of Load Estimation Tools

Both the USACE FLUX tool and the USGS LOADEST tool use observed flows paired with water quality sampling to generate regression equations to predict nutrient loading. The equations are then applied to a daily flow series to estimate nutrient loading for a period of interest for the site being analyzed. The accuracy of both tools is restricted by the flow regimes during which water quality data are collected, and bias is introduced when sampling regimes omit the full spectrum of flows that occur at a site. This section provides a brief comparison of each tool.

5.1.1 USACE FLUX

The USACE designed the FLUX tool to generate annual or growing season nutrient loading as an input to empirical reservoir response models such as the USACE BATHTUB model. The FLUX tool provides a user-friendly graphical interface capable of generating plots and stratifying data by flow, season, or date.

FLUX applies six separate calculation methods to estimate nutrient loading. FLUX does not provide a recommendation on which of the six methods provides the best fit for the site: the user must make this determination (Walker 1999).

> Method 1 (Direct Mean Loading) can be applied if grab samples were collected randomly with respect to flow. This method can be used when concentrations are inversely related to flow, and loading does not vary with flow (e.g., downstream of a large WWTP).

> Method 2 (Flow-Weighted Concentration) uses a ratio estimate to calculate loading by multiplying flow-weighted concentrations by mean flow. This method is best applied if flows and concentrations are weakly related or unrelated.

> Method 3 (Modified Ratio Estimate) is similar to Method 2, but is modified to account for a dataset where concentrations vary with flow.

> Method 4 (Regression, First-Order) accounts for differences between instantaneous flow measurements and average total flow for the sampling period. This method is limited to datasets without a significant number of zero flows.

> Method 5 (Regression, Second-Order) modifies the regression in Method 4 adjusting for variance differences between instantaneous and total flow measurements. This method is also limited to datasets without a significant number of zero flows.

> Method 6 (Regression Applied to Individual Daily Flows) is a regression method best applied when a definite relationship between flow and concentrations exist. This method may be used to generate

daily, monthly, or annual times series of loads and requires an intensive sample data set to define the flow/concentration relationships.

5.1.2 USGS LOADEST

The USGS LOADEST tool (Runkel et al. 2004) develops and tests nine regression models for calculating nutrient loading in tributaries (Table 5-1). In addition, a user defined regression model may be applied. While LOADEST is not as user-friendly as FLUX (it uses a DOS interface that requires post processing with Microsoft® Excel or a similar program), LOADEST provides the user the option of selecting a specific model or choosing the best fit model as identified by the tool (based upon data characteristics and model error analysis). After calibration, mean load estimates, standard errors and 95% confidence intervals are generated for monthly or seasonal time periods. Daily time series may also be generated for each model. The tool is capable of analyzing data that is normally or not normally distributed, as well as data sets that contain censored data (e.g., values less than detection that have been set to one-half the detection limit).

Table 5-1 Nine Regression Models Tested by USGS LOADEST

Method Number	Equation
1	$a0 + a1 \ln Q$
2	$a0 + a1 \ln Q + a2 \ln Q2$
3	$a0 + a1 \ln Q + a2\mathit{dtime}$
4	$a0 + a1 \ln Q + a2 \sin(2\pi \mathit{dtime}) + a3 \cos(2\pi \mathit{dtime})$
5	$a0 + a1 \ln Q + a2 \ln Q2 + a3\mathit{dtime}$
6	$a0 + a1 \ln Q + a2 \ln Q2 + a3 \sin(2\pi \mathit{dtime}) + a4 \cos(2\pi \mathit{dtime})$
7	$a0 + a1 \ln Q + a2 \sin(2\pi \mathit{dtime}) + a3 \cos(2\pi \mathit{dtime}) + a4\mathit{dtime}$
8	$a0 + a1 \ln Q + a2 \ln Q2 + a3 \sin(2\pi \mathit{dtime}) + a4 \cos(2\pi \mathit{dtime}) + a5\mathit{dtime}$
9	$a0 + a1 \ln Q + a2 \ln Q2 + a3 \sin(2\pi \mathit{dtime}) + a4 \cos(2\pi \mathit{dtime}) + a5\mathit{dtime} + a6\mathit{dtime}2$

[I, Integer; $\ln Q$ = ln(streamflow) - center of ln(streamflow); dtime = decimal time - center of decimal time]

5.1.3 Falls Lake EFDC Model Input

For the five tributaries draining to the Upper Lake west of I-85, the times series inputs for the EFDC nutrient response modeling of Falls Lake were based on USGS flow data and NCDWQ ambient water quality data. To fill in days with missing water quality observations, concentrations appear to have been linearly interpolated from one observation to the next. Total nitrogen and total phosphorus loads from the upper five tributaries for each modeling year are shown in Table 5-2. Inputs for the Eno River and Little River are combined in the model as one time series because the confluence of the two rivers occurs upstream of Falls Lake.

Table 5-2 Nutrient Loading Based on the EFDC Inputs for the Falls Lake Nutrient Response Model

Subwatershed	2005 TN (lb/yr)	2006 TN (lb/yr)	2007 TN (lb/yr)	2005 TP (lb/yr)	2006 TP (lb/yr)	2007 TP (lb/yr)
Ellerbe Creek	53,581	432,293	73,855	6,559	42,731	12,318
Eno/Little River	207,702	223,301	153,559	14,675	20,127	10,176
Flat River	154,440	123,748	121,312	9,942	10,466	9,643
Knap of Reeds Creek	108,908	160,110	82,590	21,795	43,367	18,732
Total	524,630	939,453	431,316	52,971	116,690	50,869

5.2 Comparison of Load Estimates for the Eno River Subwatershed

The Eno River subwatershed was selected to compare the results of the FLUX and LOADEST tools. [EFDC time series inputs cannot be directly compared to the Eno River estimates because the EFDC input for the Eno River also includes the Little River loads.] This subwatershed was selected based on the mix of land use types (forest, agriculture, and urban) present in the drainage area and the presence of both a USGS flow gage (02085070) and water quality stations (EN8.9ER, 02085079, J0770000) near the mouth of the river (Figure 5-1). The period of record used in this analysis is 1999 to 2011.

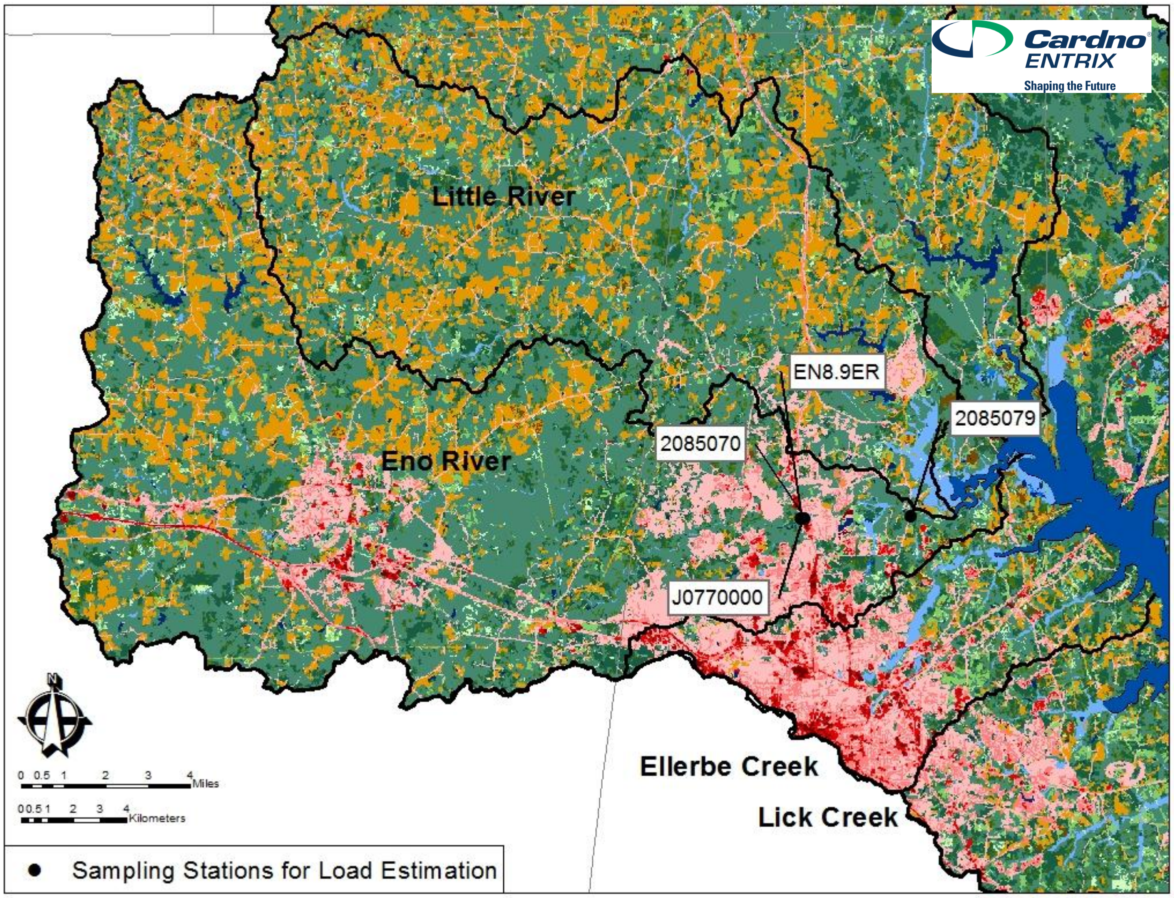

Figure 5-1 Eno River Sampling Stations used for FLUX and LOADEST comparisons

Nutrient loads were calculated for total nitrogen and total phosphorus. Because NCDWQ reported quality assurance issues with nutrient data collected at their ambient monitoring stations in 2001 (NCDENR 2011), the load calculations were performed using all of the data, as well as a subset of the data that excludes the NCDWQ data during this period. Figure 5-2 and Figure 5-3 compare the mean annual total nitrogen and total phosphorus loads predicted by FLUX and LOADEST for all of the data, as well as the subset of data that excludes the 2001 NCDWQ data. A red asterisk in the figures identifies the best fit model selected by LOADEST.

For total nitrogen, estimated mean annual loading for the Eno River subwatershed ranges from 168,020 lb-N/yr to 265,390 lb-N/yr based on the calculation method and dataset used (Figure 5-2). The FLUX methods yield more variability with respect to the method used to generate nutrient loading, and estimates vary by approximately 75,000 lb-N/yr with this tool. The LOADEST tool yields more consistent results for the nine methods tested with estimates that vary by up to 20,000 lb-N/yr. The inclusion or exclusion of the NCDWQ 2001 data has the most impact on predicted loads for FLUX method 1 and LOADEST method 9; the other methods are less affected by inclusion of the full set of data. LOADEST recommends method 1 for the Eno River data which estimates a mean annual loading of 185,137 lb-N/yr for all data and 184,669 lb-N/yr for the subset of the data.

For total phosphorus, estimates of mean annual loading range from 10,690 lb-P/yr to 30,640 lb-P/yr for the Eno River subwatershed (Figure 5-3). The FLUX tool yields more consistent results from method to method with mean annual load varying by approximately 9,000 lb-P/yr. LOADEST predictions vary by approximately 17,000 lb-P/yr. The inclusion of the 2001 NCDWQ data has a more significant impact on the LOADEST results than the FLUX results. The LOADEST model recommends method 5 for the total phosphorus data which estimates a mean annual loading of 20,797 lb-P/yr for all data and 23,668 lb-P/yr for the subset of the data.

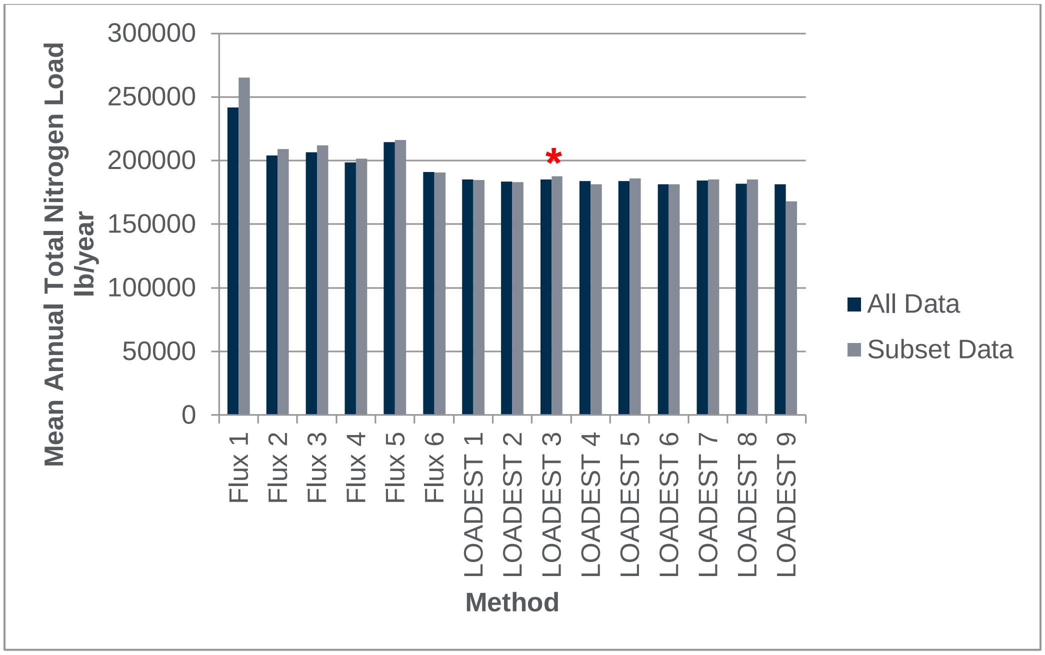

Figure 5-2 Mean Annual Total Nitrogen Loads for the Eno River (*=LOADEST "Best Fit")

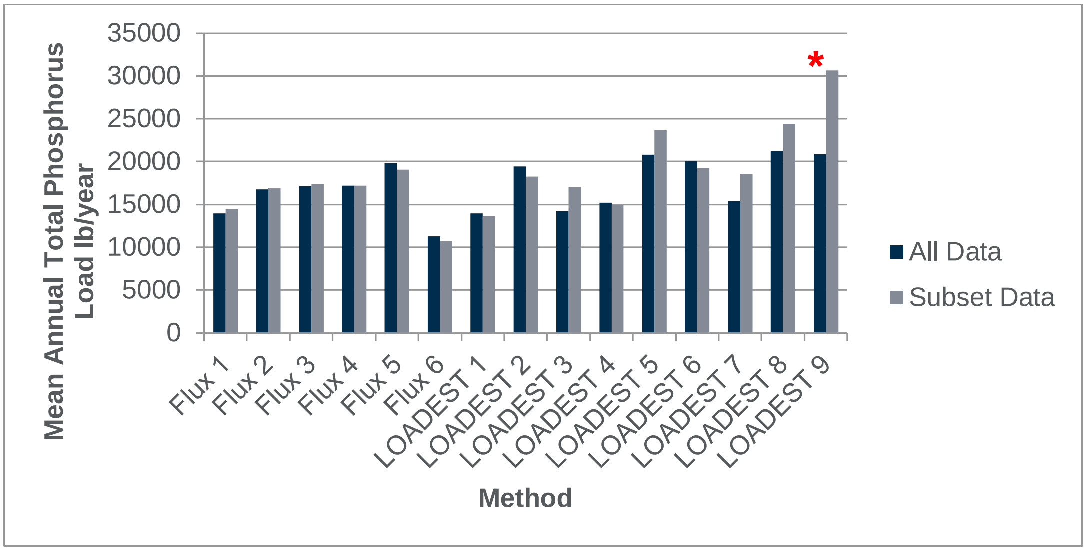

Figure 5-3 Mean Annual Total Phosphorus Loads for the Eno River (*=LOADEST "Best Fit")

The Figure 5-2 and Figure 5-3 show the mean annual nutrient loads for the Eno River based on the period 1999 to 2011. Results were also generated for 2006 which is the baseline year for the Falls Lake Nutrient Management Strategy. Both tools were run with and without the flows associated with Tropical Storm Alberto, which deposited up to eight inches of rain in some parts of the Falls Lake watershed and up to 2.85 inches in the Eno River (Figure 5-4).

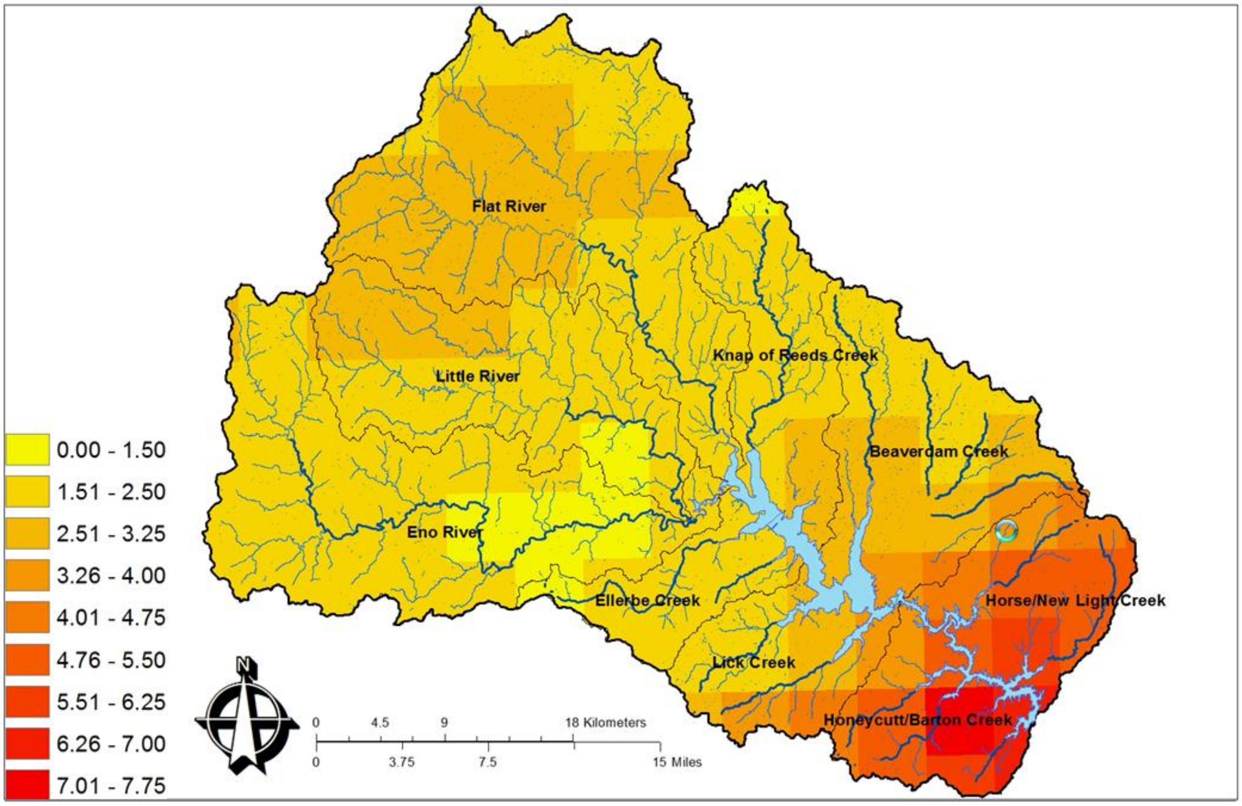

Figure 5-4 Tropical Storm Alberto Precipitation Map for the Falls Lake Watershed

Table 5-3 shows the total nitrogen and total phosphorus loads for 2006. These results exclude the pre-2001 NCDWQ data inputs, and are based on the recommended LOADEST methods. Results are provided for year 2006 with and without Tropical Storm Alberto. Total nitrogen loads in the Eno River subwatershed are slightly higher (4,4992 lb) when Tropical Storm Alberto is included. Total phosphorus loads are also higher when the storm is considered (534 lb). When the storm is not included in the load estimation, nitrogen and phosphorus loads are approximately 3.7 percent lower. As stated above, Tropical Storm Alberto deposited up to 2.85 inches of precipitation in the Eno River subwatershed. Although this is a large storm event and flows increased above their daily average (to a maximum of 656 cfs), there are numerous other high flow events recorded in the Eno River during the period of record. Average daily flow from 2001 to 2011 is approximately 105 cfs, and daily flows up to 5,360 cfs were recorded during this period. So while Tropical Storm Alberto was a large event, it was not an extreme event for this subwatershed. Although, 2006 was an average year for annual total flow in the Eno River (Section 5.3.3), both total nitrogen and total phosphorus loads for 2006 were lower than the average annual loads calculated for the 2001-2011 period (presented in Figure 5-2 and Figure 5-3).

Table 5-3 Year 2006 Annual Nutrient Loads Predicted by LOADEST (With and Without Tropical Storm Alberto

Parameter (recommended LOADEST method)	With Alberto	Without Alberto	Difference
Total Nitrogen (lb/yr) (Method 1)	149,476	144,484	4,992
Total Phosphorus (lb/yr) (Method 5)	14,770	14,236	534

5.3 Tributary Loading Estimates for Five Upper Lake Tributaries

LOADEST was selected to estimate tributary loading from the five upper lake tributaries based on 1) its ability to output times series of loads which may be used to drive models such as EFDC and 2) its use of model error analysis to recommend a best fit model. The box plots presented in this section show the distribution of daily loads by year and month. The period of record varies for each of the five tributaries, and load estimates are only analyzed for the period with available data. For example, flow data for Ellerbe Creek is available from January 2006 to the present, so daily loads are only generated and analyzed for this period. NCDWQ 2001 ambient data are not included in this analysis.

Table 5-4 summarizes the flow and water quality data available for each of the five tributaries. [The number of water quality samples used in this analysis is higher than the number used for the internal lake loading calculations (Section 4.4) which only used samples collected during the growing season.] The number of total phosphorus samples less than the detection limit is also provided. The Eno and Little River subwatersheds have the highest percentages of samples less than the detection limit (up to 20 percent). A map of the water quality monitoring stations is provided in Figure 5-5.

Table 5-4 Flow and Water Quality Data for LOADEST Tributary Nutrient Loading Estimates

Subwatershed	USGS Gage	Water Quality Stations	No. TN samples	No. TP samples	No. TP <Limit	Analyzed Date Range
Ellerbe Creek	02086849	J1330000, EL1.9EC, 02086849	147	148	2	2006-2011
Eno River	02085070	EN8.9ER, 02085079, J0770000	123	131	26	2001-2011
Flat River	02086500	FR5.2FR, J1100000	94	129	4	2003-2011

Subwatershed	USGS Gage	Water Quality Stations	No. TN samples	No. TP samples	No. TP <Limit	Analyzed Date Range
Knap of Reeds Creek	02086624	J1210000, 02086624	77	77	0	2006-2011
Little River	0208524975	0208524950, 0208524975	207	207	35	1999-2011

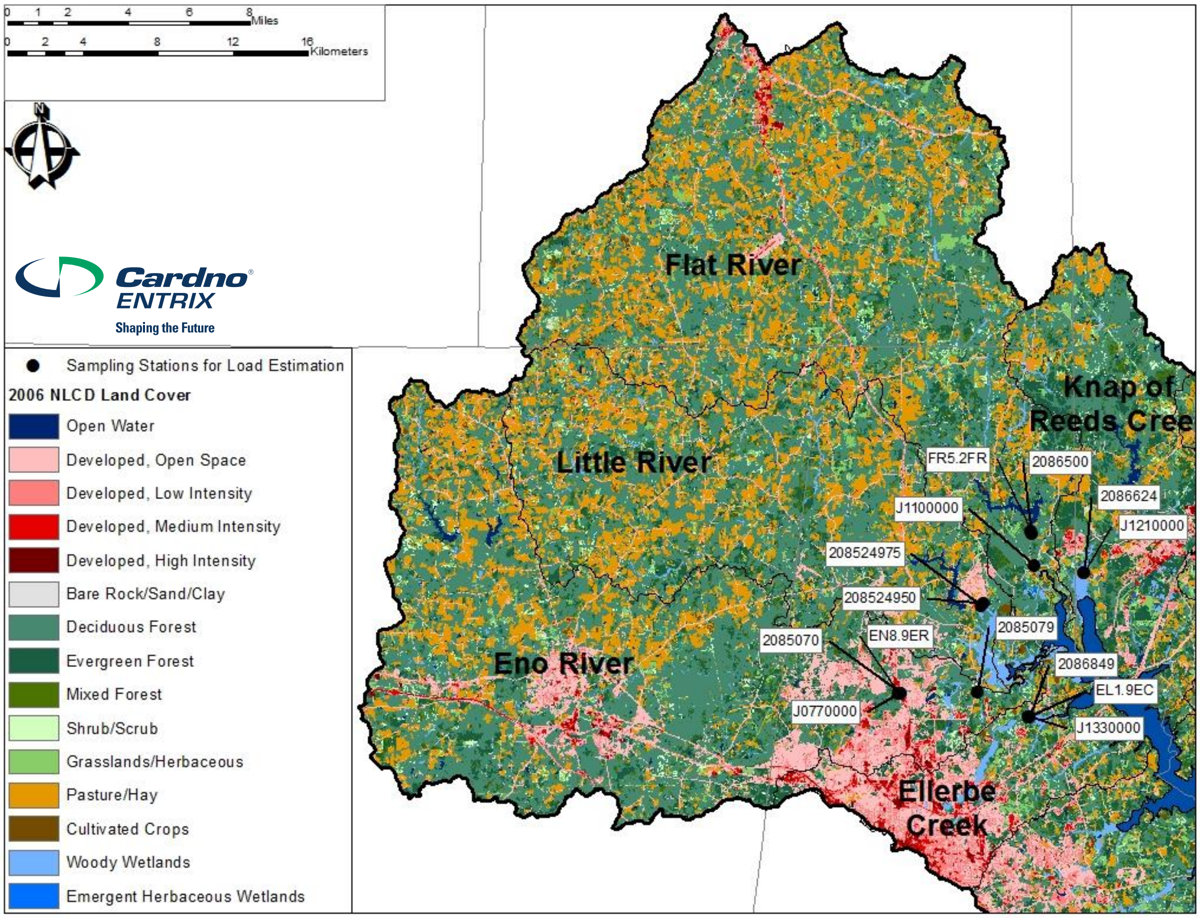

Figure 5-5 Water Quality Monitoring Stations used for the LOADEST Analysis

For this analysis, Cardno ENTRIX used the database developed during Task 2 to provide the water quality data for each station. Samples that were reported below the detection limit were assumed equal to one-half the detection limit for this analysis. The LOADEST program also includes options for dealing with less than detection values using statistical methods such as the maximum likelihood estimation (MLE) method. Cardno ENTRIX compared loading results using the assumed value of one half of detection as well as the MLE method. For total nitrogen loading from the mouth of the Eno River, the difference in loading between these two methods was less than 1 percent.

To estimate total nitrogen loading using FLUX and LOADEST, Cardno ENTRIX used the water quality database to export calculated total nitrogen concentrations and pair those with observed flows. Alternatively, the nitrogen species could have been analyzed separately and the predicted loads summed at the end of the process. Cardno ENTRIX compared the loading results for these two methods. Using the calculated total nitrogen concentration resulted in a total nitrogen load that was approximately 4 percent lower than if the load was calculated based on individual species.

5.3.1 Interpretation of Box Plots

LOADEST generates daily nutrient loads which are presented in this TM as box plots that show the distribution of daily loads by month and year. To improve the visual interpretation of the box plots, only data within the 10th to 90th percentiles are shown (when the minimum to maximum values are included, the whiskers on the plots are so long that the resulting boxes are difficult to discern on the figures). The median is equivalent to the 50th percentile where half of the measurements are less than and half are greater than that value. The mean is equivalent to the average value and is more affected by data points near the minimum and maximum values than the median; in some cases the mean is higher than the
90 percentile value because the maximum daily value is so much higher than the majority of the data. The mean is represented on the box plots as a diamond, and the median by a line within the box. The box itself illustrates the interquartile range (IQR) and extends from the 25th to 75th percentile of the data. The line at the bottom of each box extends from the 10th percentile value to the 25th percentile value where the box begins. The line at the top of the box extends from the 75th percentile value to the 90th percentile value. Figure 5-6 illustrates the 10th, 25th, mean, median, 75th and 90th percentile values that are displayed on the plots in this TM.

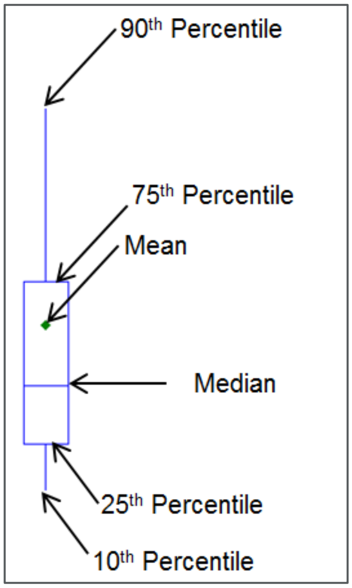

Figure 5-6 Example Box Plot Illustrating Percentiles

5.3.2 Hydrologic Inputs

USGS gages located near the mouths of the five upper lake tributaries are used to simulate the hydrologic inputs to Falls Lake. This section describes the annual and monthly distribution of mean daily flow for each subwatershed.

5.3.2.1 Annual variability in daily flows

Nutrient loading for each tributary is presented by year. A complete flow record for each subwatershed is available from 2006 to 2011. Figure 5-7 shows the annual flows for each of the five tributaries for the 2006 to 2011; cumulative annual flows for the five tributaries are shown above each series. Flows from the Eno River and Flat River are usually higher than the other three subwatersheds. In 2009, Flat River flows were approximately twice those of any other subwatershed.

Table 5-5 shows the annual flows for the period 1999 to 2011 for those subwatersheds that were monitored in the earlier period; values of NA indicate the gage was not active that year. Nutrient loading from the subwatersheds varies from year to year in terms of which subwatersheds contribute the highest level of loading, likely due to variability in flows across the watershed.

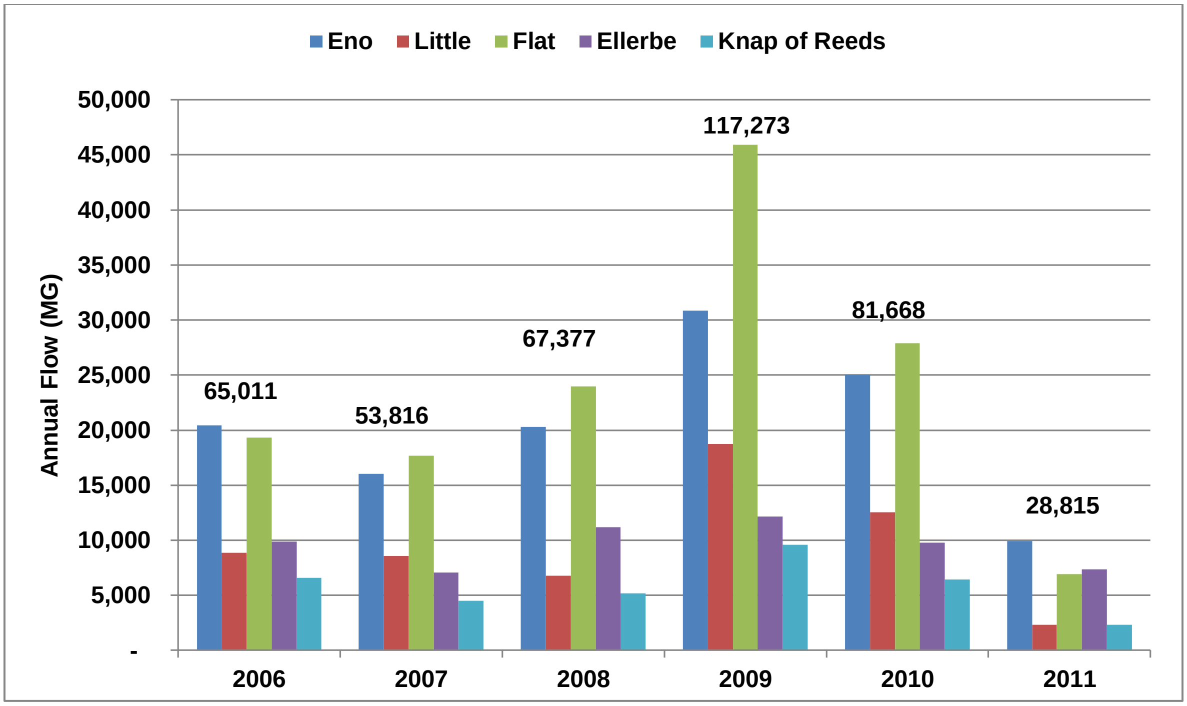

Figure 5-7 Inflows to Falls Lake from Five Upper Lake Tributaries (2006 to 2011)

Table 5-5 Annual Flow (MG) for 1999 to 2011 for Gaged Tributaries

Year	**Eno**	**Little**	**Flat**	**Ellerbe**	**Knap of Reeds**	**Total**
USGS Gage	**02085070**	**0208524975**	**02086500**	**02086849**	**02086624**	**NA**
1999	32,036	16,796	NA	NA	NA	NA
2000	27,978	13,022	NA	NA	NA	NA
2001	17,150	7,195	19,226	NA	NA	NA
2002	20,264	12,527	21,986	NA	NA	NA
2003	60,321	43,902	82,024	NA	NA	NA
2004	22,482	8,493	27,577	NA	NA	NA
2005	21,043	8,445	19,840	NA	NA	NA
2006	20,429	8,870	19,344	9,766	6,601	65,011
2007	16,018	8,587	17,669	7,054	4,489	53,816
2008	20,288	6,770	23,968	11,182	5,169	67,377
2009	30,856	18,754	45,907	12,173	9,582	117,273
2010	25,053	12,550	27,884	9,766	6,414	81,668
2011	9,932	2,302	6,912	7,337	2,332	28,815
Average of 2006 through 2011	20,429	9,639	23,614	9,546	5,764	68,993

5.3.2.2 Monthly variability in daily flows

Figure 5-8 through Figure 5-12 show the monthly distribution of daily flows for the five upper lake tributaries. A consistent y-axis scale is not used for each subwatershed due to the differences in relative size of the watersheds. Flows are generally low in the summer months and increase during the fall, winter, and spring.

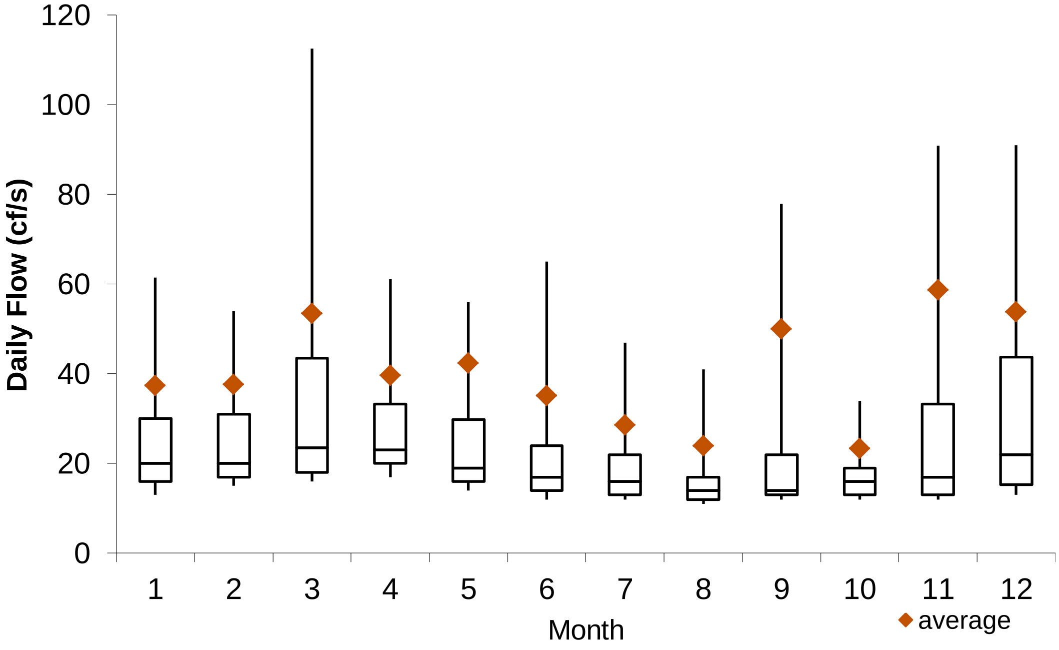

Figure 5-8 Distribution of Daily Flow by Month for the Ellerbe Creek Subwatershed (2006-2011)

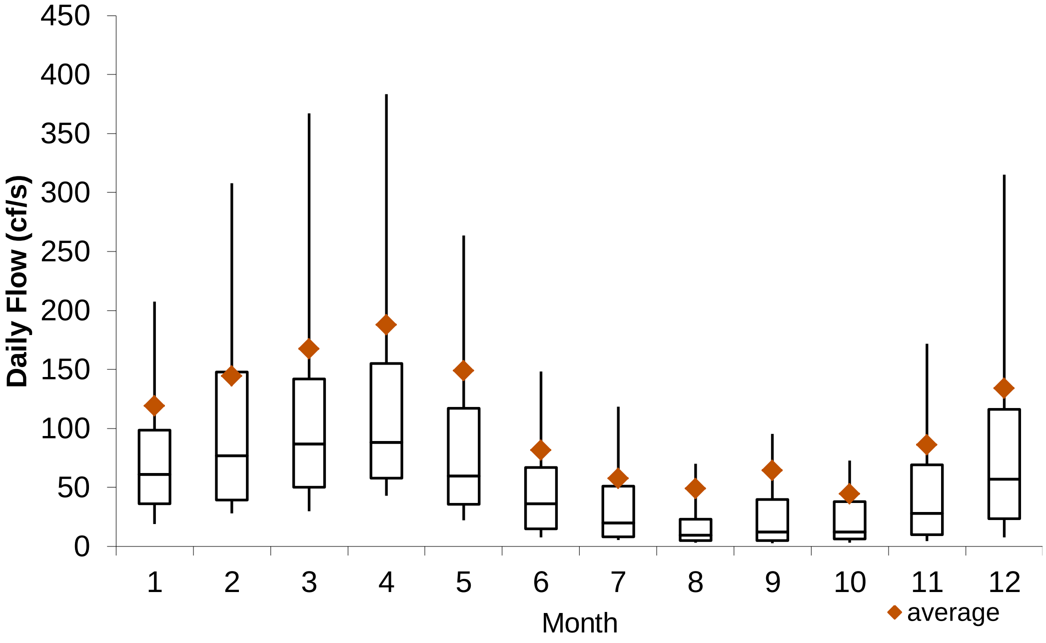

Figure 5-9 Distribution of Daily Flow by Month for the Eno River Subwatershed (2001-2011)

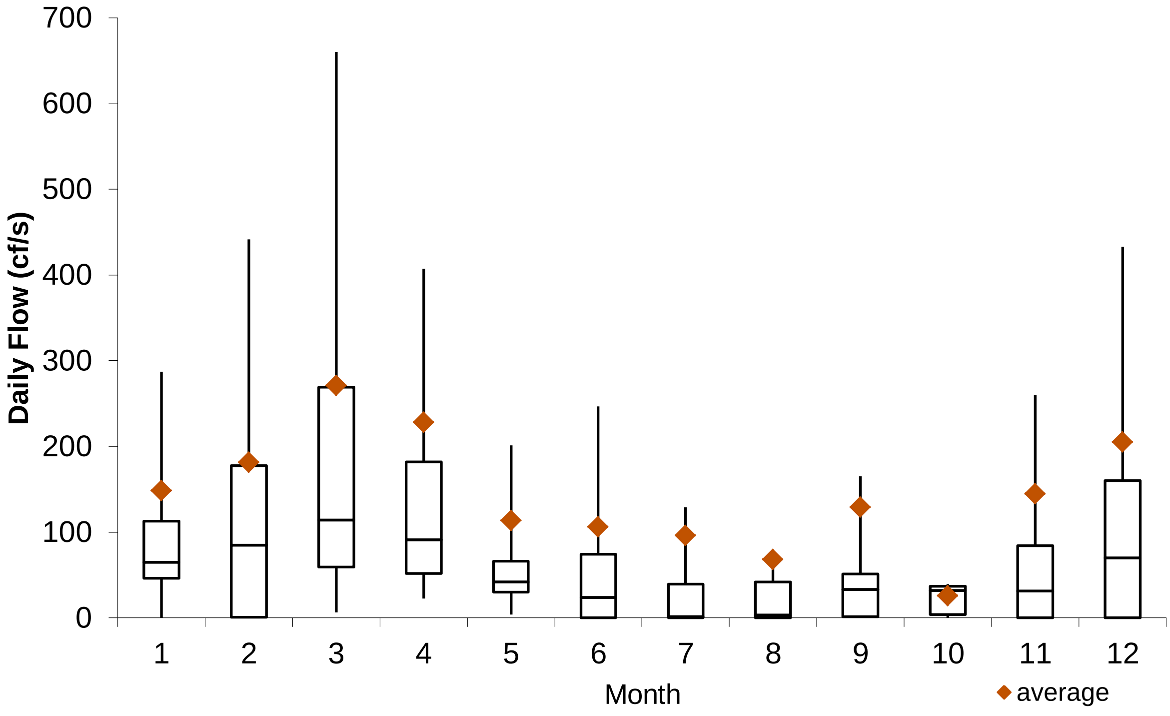

Figure 5-10 Distribution of Daily Flow by Month for the Flat River Subwatershed (2003-2011)

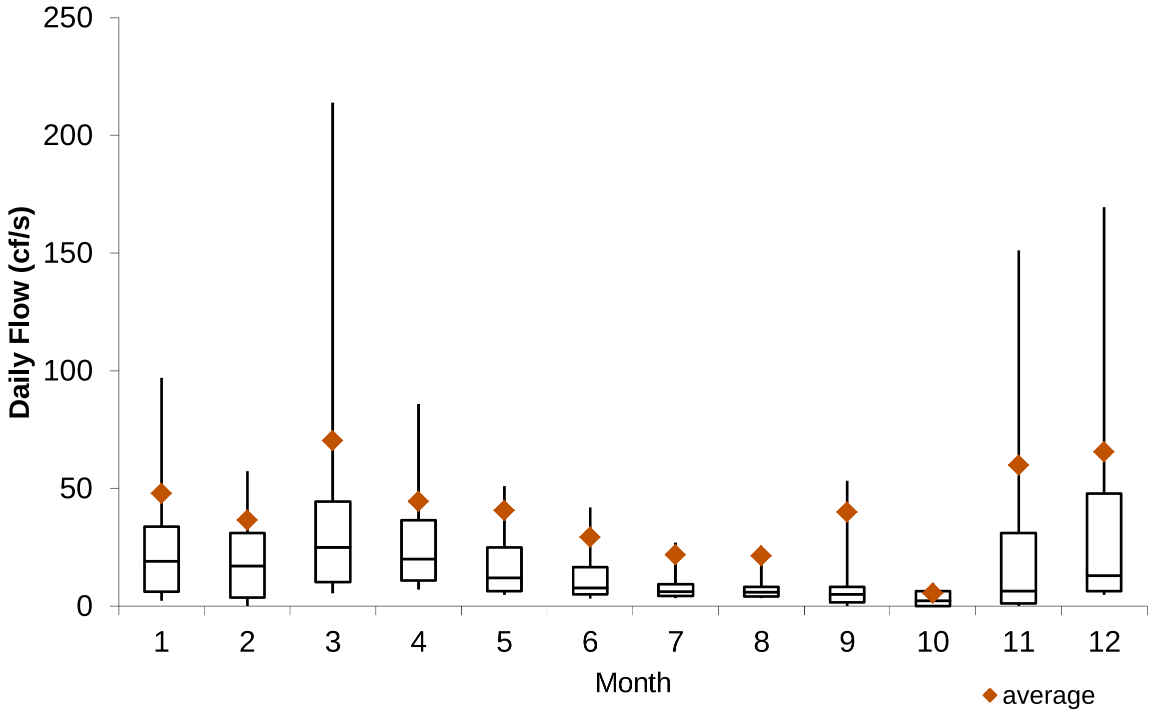

Figure 5-11 Distribution of Daily Flow by Month for the Knap of Reeds Creek Subwatershed (2006-2011)

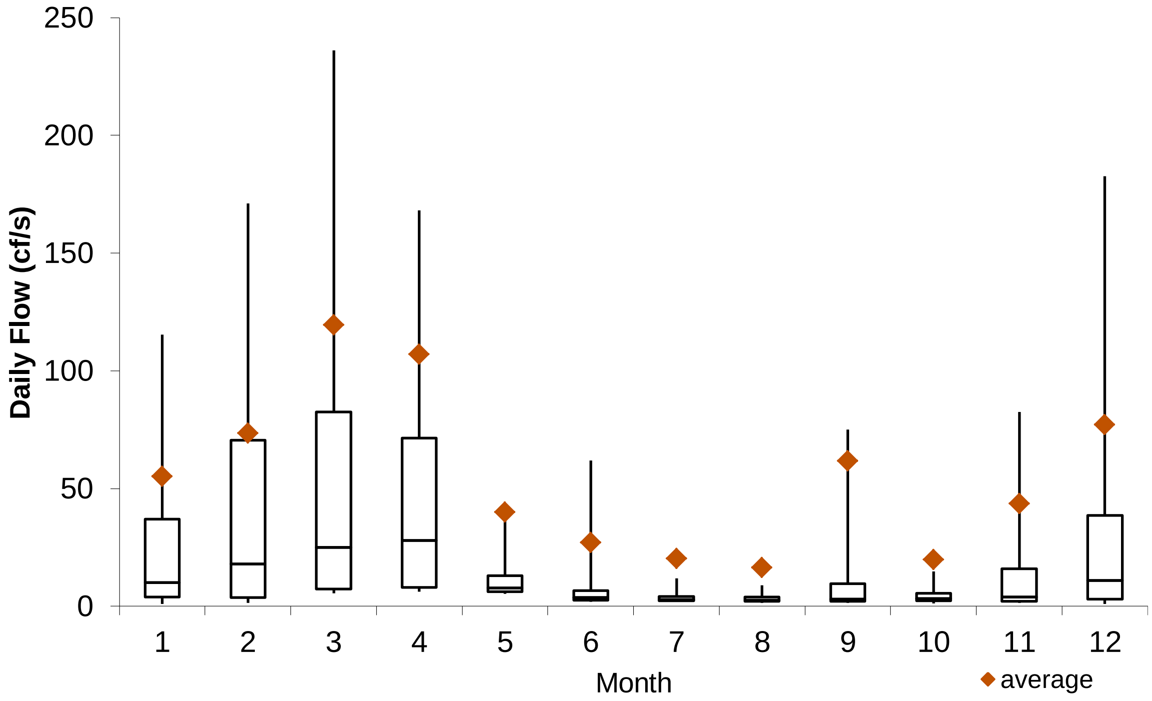

Figure 5-12 Distribution of Daily Flow by Month for the Little River Subwatershed (1999-2011)

5.3.3 Distribution of Water Quality Sampling Events with Respect to Flow

Load estimation tools calculate loading by matching observed water quality with the flow that occurred at the time of sampling and creating a regression equation to define the relationship. If only one part of the flow regime is well represented by water quality sampling, then the resulting load estimation may be biased. To determine if the existing monitoring programs capture the full range of flows observed in these subwatersheds, sampling days were plotted along with the flows displayed as frequency curves. For a given gage, the 0 percentile flow represents the minimum observed flow and the 100 percentile flow represents the maximum observed flow (for that gage's period of record that coincides with the water quality data collection period). Figure 5-13 through Figure 5-17 show the flow frequency curves for each of the five gaged subwatersheds along with the corresponding sampling events. In the each of the subwatersheds, the existing monitoring programs capture the full range of flows observed during the gaged period except for some of the highest flows.

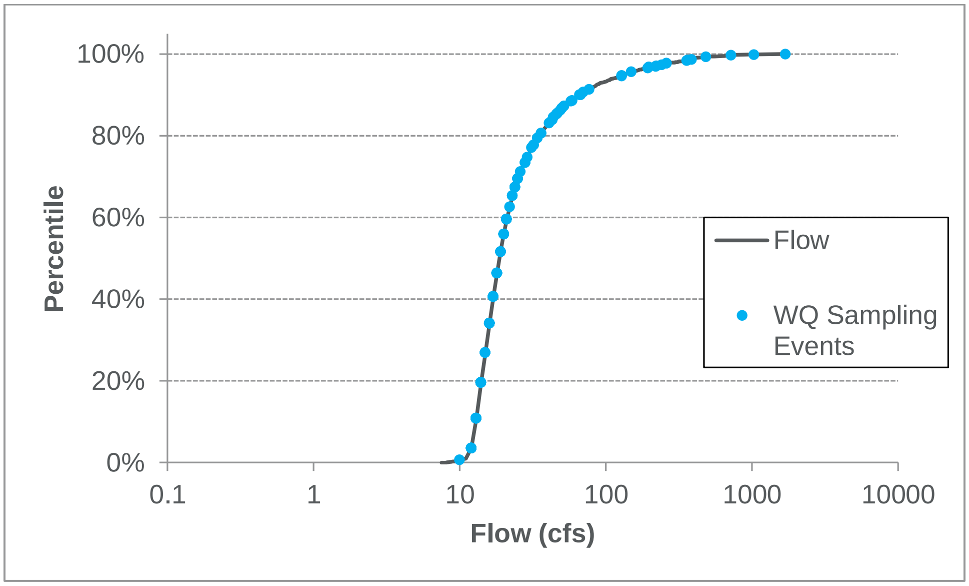

Figure 5-13 Sampling Events and Observed Flows in the Ellerbe Creek Subwatershed

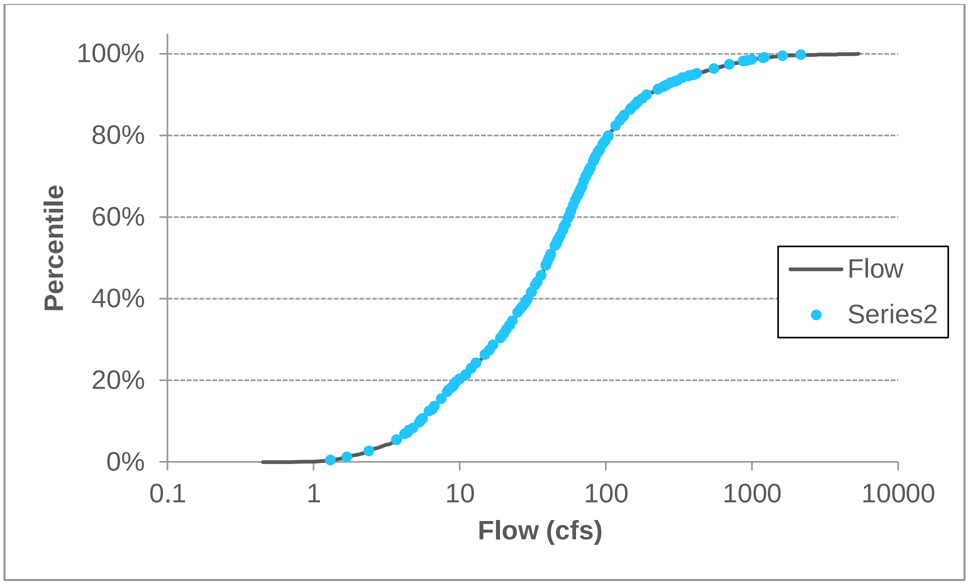

Figure 5-14 Sampling Events and Observed Flows in the Eno River Subwatershed

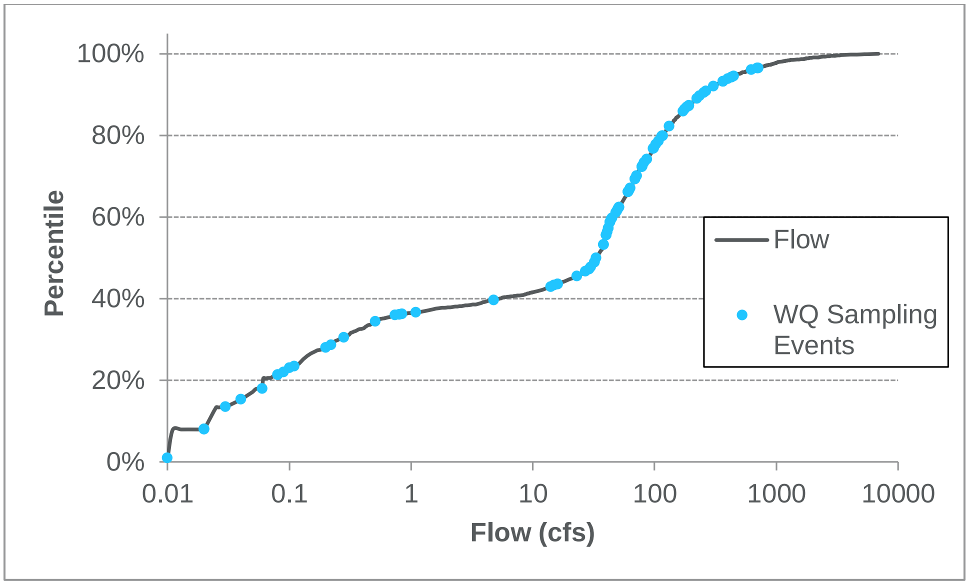

Figure 5-15 Sampling Events and Observed Flows in the Flat River Subwatershed

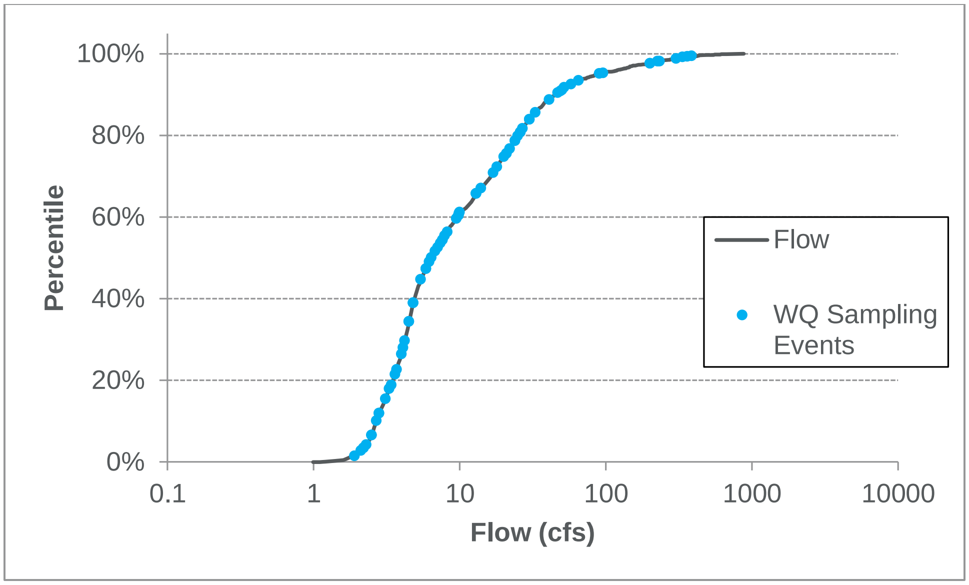

Figure 5-16 Sampling Events and Observed Flows in the Knap of Reeds Creek Subwatershed

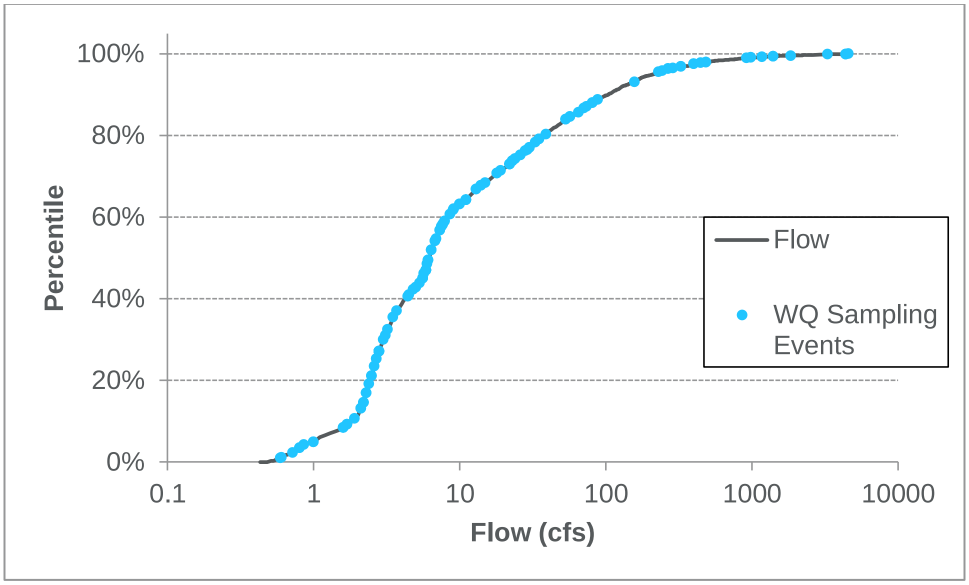

Figure 5-17 Sampling Events and Observed Flows in the Little River Subwatershed

5.3.4 Annual Nutrient Loads for the Five Upper Lake Tributaries

Table 5-6 shows the estimated total nitrogen loads for each of the five upper lake tributaries for their respective periods of record. The recommended LOADEST method used to generate these results is provided in the second row of the table. By 2006, each tributary was gaged, so total loads are presented for these years. From 2006 to 2011, the sum of total nitrogen loading to Falls Lake from these five tributaries ranged from 485,260lb-N in 2011 to 1,192,945lb-N in 2009. 2006 loads including Tropical Storm Alberto were near the average for 2006 to 2011; excluding the Tropical Storm reduced loading that year by approximately 17,800 lb-N when loads from the five tributaries are combined. For comparison, the EFDC total nitrogen loads from these five tributaries for 2006 was 939,450 lb-N.

Table 5-6 Annual Total Nitrogen (lb-N/yr) Loads Estimated by LOADEST

Year	Ellerbe Creek	Eno River	Knap of Reeds Creek	Little River Data	Flat River	Sum
Recommended LOADEST Method	7	1	6	8	6	NA
1999	NA	NA	NA	132,459	NA	NA
2000	NA	NA	NA	90,798	NA	NA
2001	NA	120,910	NA	52,628	NA	NA
2002	NA	152,824	NA	100,581	NA	NA
2003	NA	496,136	NA	349,991	565,184	NA
2004	NA	155,040	NA	67,594	179,788	NA
2005	NA	154,748	NA	62,595	136,273	NA
2006	290,686	158,678	110,276	77,286	128,435	765,361
2006 w/o Tropical Storm Alberto	279,569	153,351	113,956	74,210	126,450	747,536
2007	214,341	125,437	87,037	66,352	123,601	616,768
2008	250,050	175,885	109,740	60,724	160,997	757,396
2009	274,960	273,238	166,054	158,158	320,535	1,192,945
2010	240,964	221,740	134,740	101,265	213,412	912,121
2011	216,694	71,481	134,740	18,226	44,119	485,260
Average of 2006 through 2011	247,949	171,077	123,765	80,335	165,183	765,361

Table 5-7 shows the estimated total phosphorus loads for each of the five tributaries, along with the recommended LOADEST method used to generate the results for each subwatershed. For the complete period of record (2006 to 2011), the sum of the total phosphorus loads to the segment of the lake west of I-85 ranges from 51,703 lb-P in 2011 to 115,995 lb-P in 2009. Loads in 2006 including Tropical Storm Alberto were higher than the average load for the period; excluding the storm from the load estimation reduced the loading by 12,400 lb-P. The year 2006 loads used as input to the EFDC model for these five tributaries was 116,690 lb-P/yr.

Table 5-7 Annual Total Phosphorus (lb-P/yr) Loads Estimated by LOADEST

Year	Ellerbe Creek	Eno River	Knap of Reeds Creek	Little River Data	Flat River	Sum
Recommended LOADEST Method	9	3	4	7	8	NA
1999	NA	NA	NA	13,915	NA	NA
2000	NA	NA	NA	7,939	NA	NA
2001	NA	38,407	NA	4,774	NA	NA
2002	NA	30,851	NA	11,763	NA	NA
2003	NA	102,945	NA	33,050	62,866	NA
2004	NA	15,657	NA	7,366	17,061	NA
2005	NA	14,258	NA	5,945	11,251	NA
2006	59,307	15,806	27,626	8,635	11,127	122,501
2006 w/o Tropical Storm Alberto	50,230	15,126	25,539	8,313	10,916	110,124
2007	21,101	10,711	21,093	6,378	9,375	68,658
2008	23,492	22,266	24,368	6,621	13,394	90,141
2009	19,590	26,758	29,118	17,508	23,021	115,995
2010	17,685	41,986	24,799	10,062	14,260	108,792
2011	18,960	9,700	18,508	1,777	2,758	51,703
Average of 2006 through 2011	26,689	21,205	24,252	8,497	12,323	92,965

5.3.5 Annual Variability in Daily Loads

This section of the memorandum presents the distribution of daily total nitrogen loads and total phosphorus loads by year for each subwatershed. The years presented on each figure correspond to the period of record for that site. Comparisons of average daily loading for the most recent and complete year (2011) are provided relative to the baseline year of 2006. However, 2011 was a dry year relative to 2006 (about half of the flow volume for the upper five subwatersheds), so part of the apparent load reduction in each subwatershed is due to this reduction in hydrologic inputs. A consistent y-axis scale is not used for each subwatershed due to the differences in relative size of the watersheds.

5.3.5.1 Total Nitrogen

Figure 5-18 through Figure 5-22 show the distribution of daily total nitrogen loads for each of the five upper lake tributaries. Daily total nitrogen loads in the two subwatersheds with WWTP discharges (Ellerbe and Knap of Reeds) are less sensitive to hydrologic changes compared to the other three subwatersheds.

In the Ellerbe Creek subwatershed, the distribution of daily loads was generally consistent from 2006 to 2009, with higher average and maximum daily loads observed in 2009 (Figure 5-18). Loads decreased in 2010 and 2011. The average daily nitrogen load in the Ellerbe Creek watershed in 2011 was approximately 26 percent lower than in 2006. Average flows in 2011 were also approximately 26 percent less than in 2006.

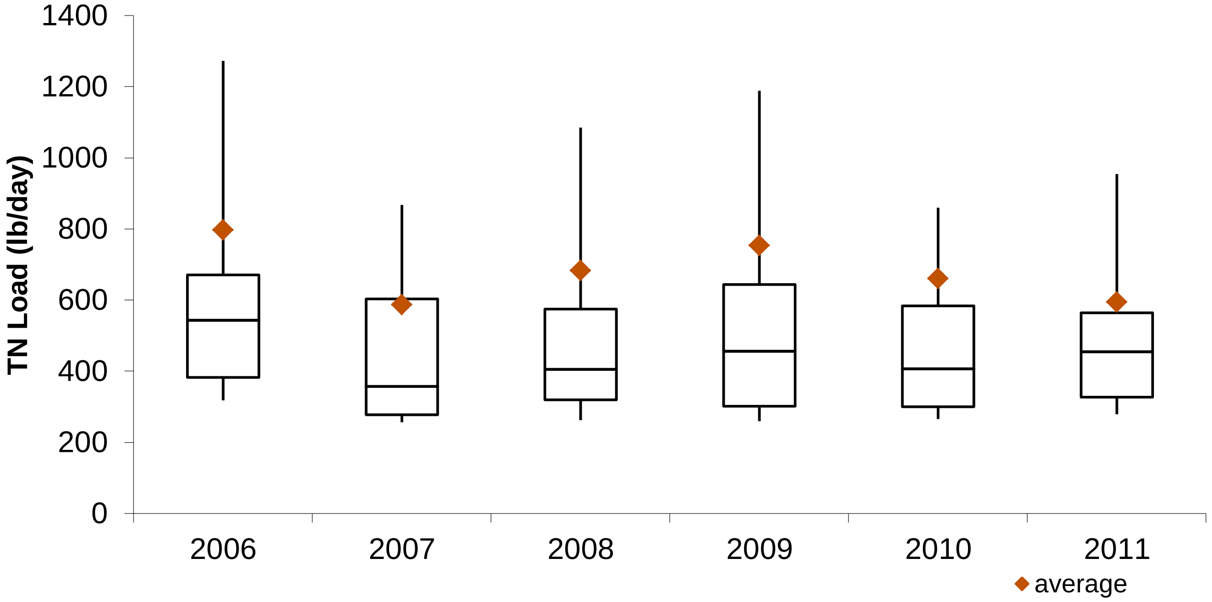

Figure 5-18 Distribution of Daily Total Nitrogen Loads by Year for the Ellerbe Creek Subwatershed

In the Eno River watershed, year 2003 had the highest distribution of total nitrogen loads due to the high flows that occurred that year; 2006 was a typical year for this subwatershed (Figure 5-19). Average daily loads in 2011 are approximately 58 percent lower than average daily loads in 2006, which is due in part to the 44 percent reduction in mean annual flow in 2011 for this subwatershed.

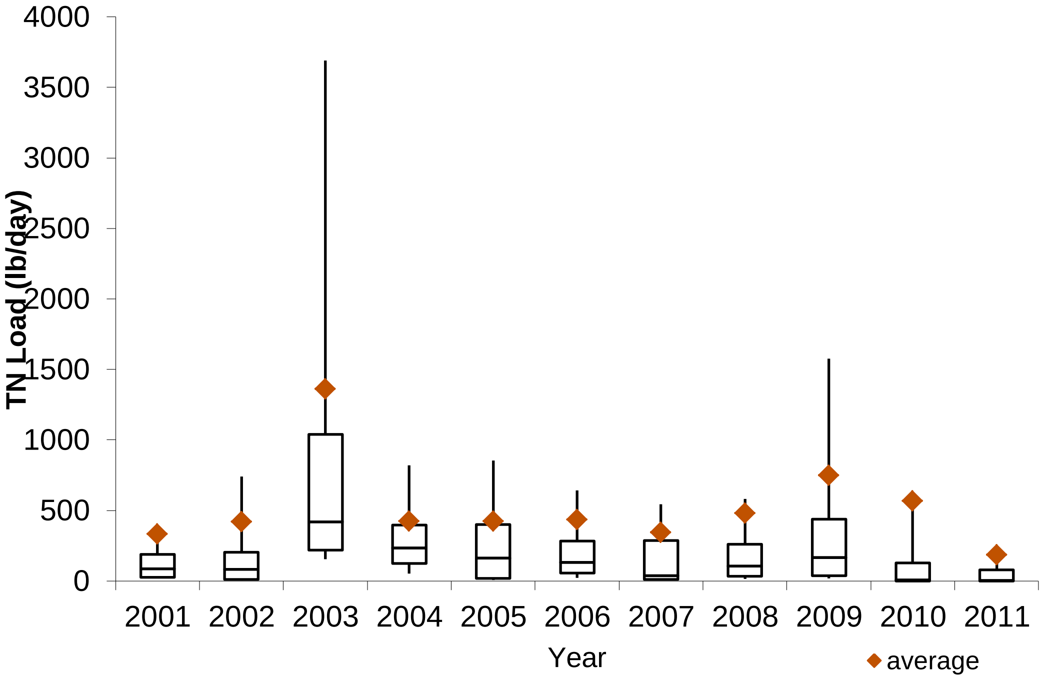

Figure 5-19 Distribution of Daily Total Nitrogen Loads by Year for the Eno River Subwatershed

In the Flat River watershed, 2003 was again the year of highest loading followed by 2009; 2006 had one of the lower distributions in daily loads (Figure 5-20). Average daily loading and flow in 2011 are 69 percent less than 2006.

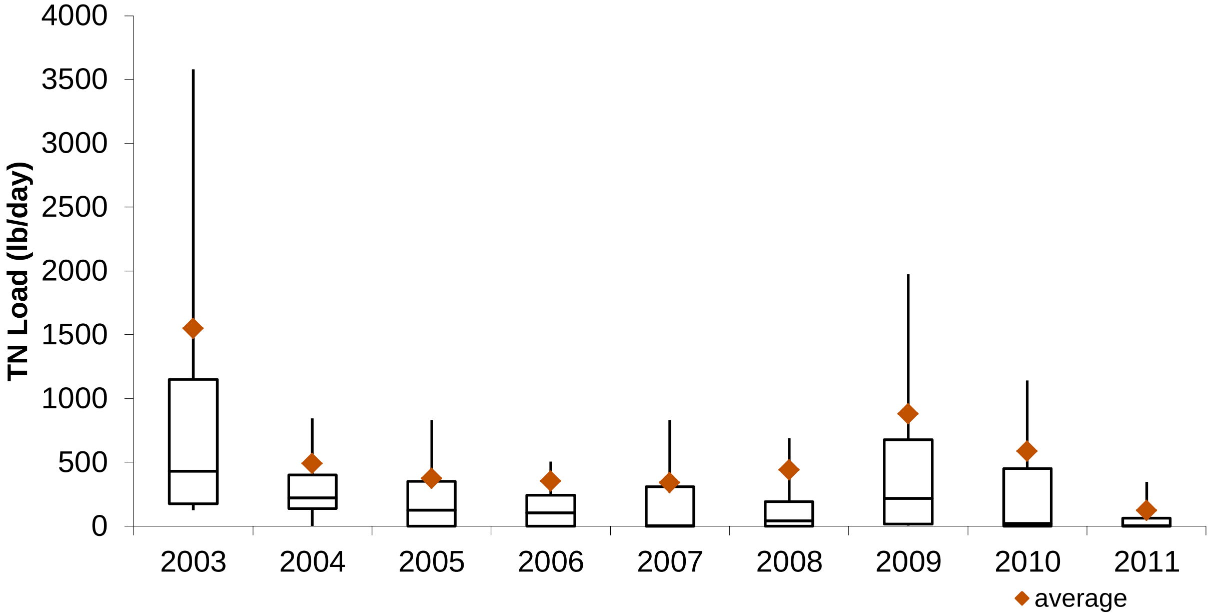

Figure 5-20 Distribution of Daily Total Nitrogen Loads by Year for the Flat River Subwatershed

In the Knap of Reeds Creek subwatershed, median daily loads in 2006 were typical, and year 2009 had the highest median and average daily loads (Figure 5-21). Average daily loads in 2011 were approximately 19 percent less than those in 2006; average flows were approximately 65 percent lower in this subwatershed.

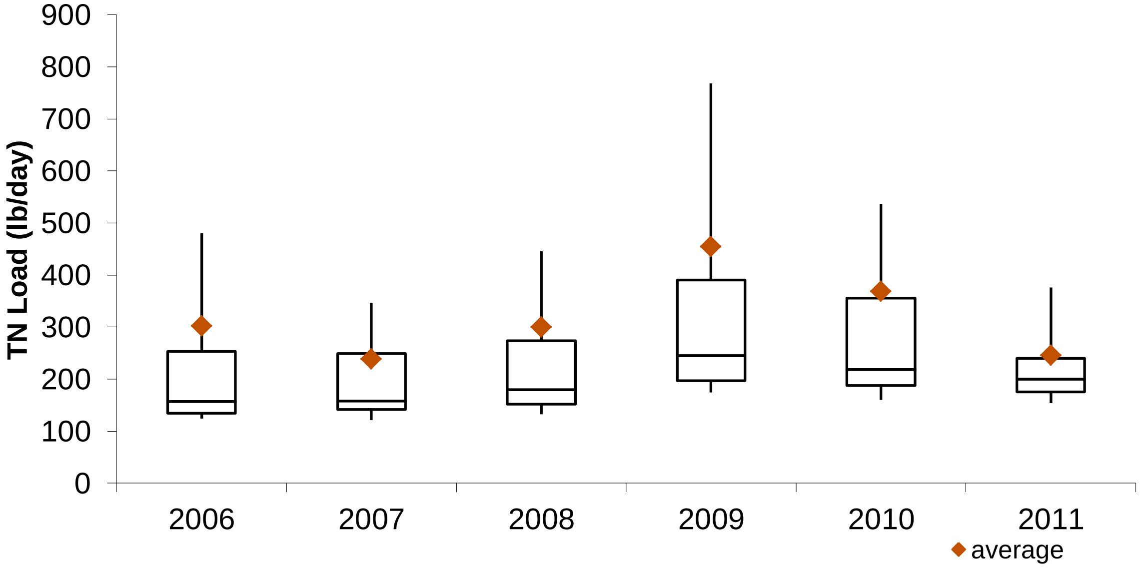

Figure 5-21 Distribution of Daily Total Nitrogen Loads by Year for the Knap of Reeds Creek Subwatershed

In the Little River subwatershed, daily loads were highly correlated to flow with years 2003 and 2009 showing the highest distributions in loading (Figure 5-22). Average total nitrogen loads in 2011 were approximately 76 less than in 2006; average flows in 2011 were 74 percent lower.

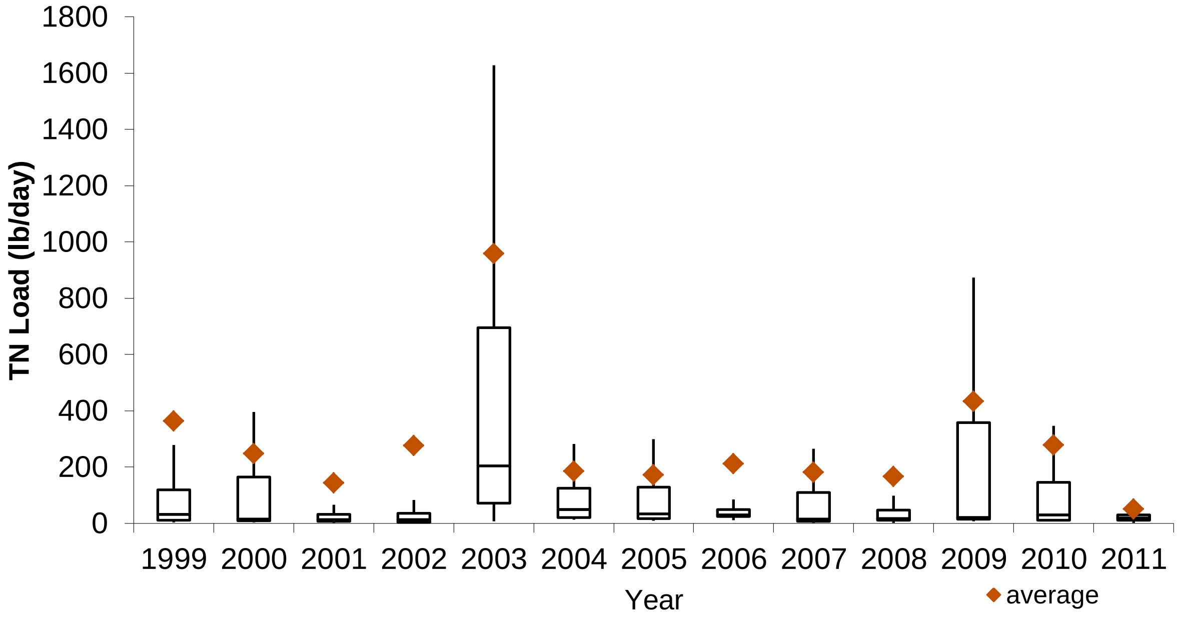

Figure 5-22 Distribution of Daily Total Nitrogen Loads by Year for the Little River Subwatershed

5.3.5.2 Total Phosphorus

Figure 5-23 through Figure 5-27 show the distribution of daily total phosphorus loads for each of the five upper lake tributaries.

For the Ellerbe Creek subwatershed, phosphorus loading shows a steady decline from 2006 to 2011 even during year 2009, which was a relatively high flow year (Figure 5-23). Average daily loads in 2011 are approximately 81 percent lower than those estimated in 2006 while average flows in 2011 were approximately 26 percent less than in 2006.

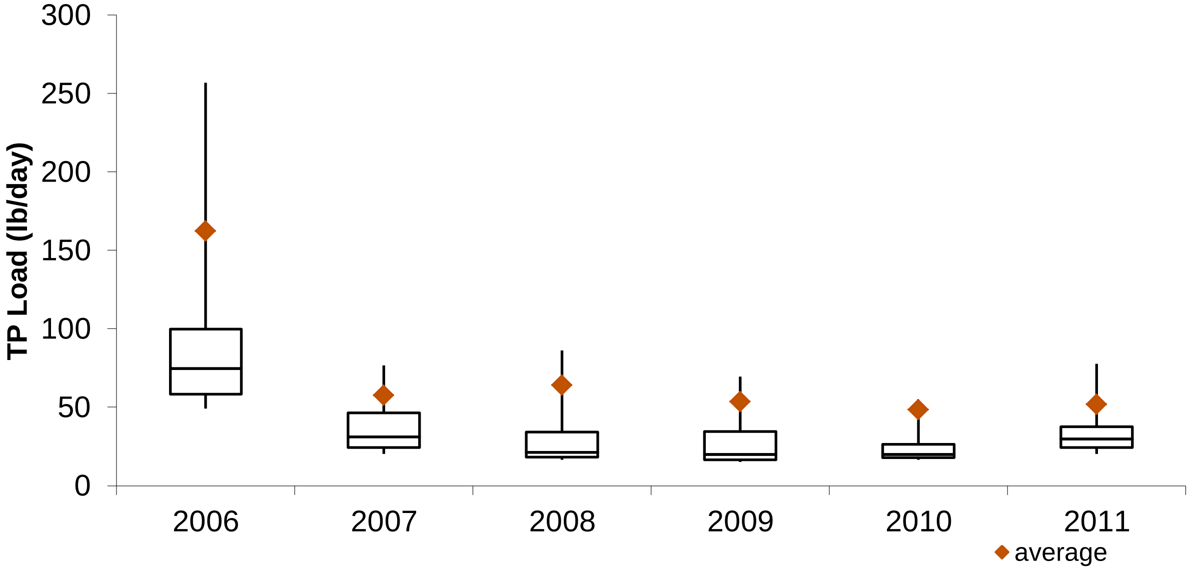

Figure 5-23 Distribution of Daily Total Phosphorus Loads by Year for the Ellerbe Creek Subwatershed

In the Eno River subwatershed, 2003 had the highest distribution in daily loads (Figure 5-24). Average daily load in 2011 was approximately 78 percent less than in 2006; average flows in 2011 were approximately 44 percent less.

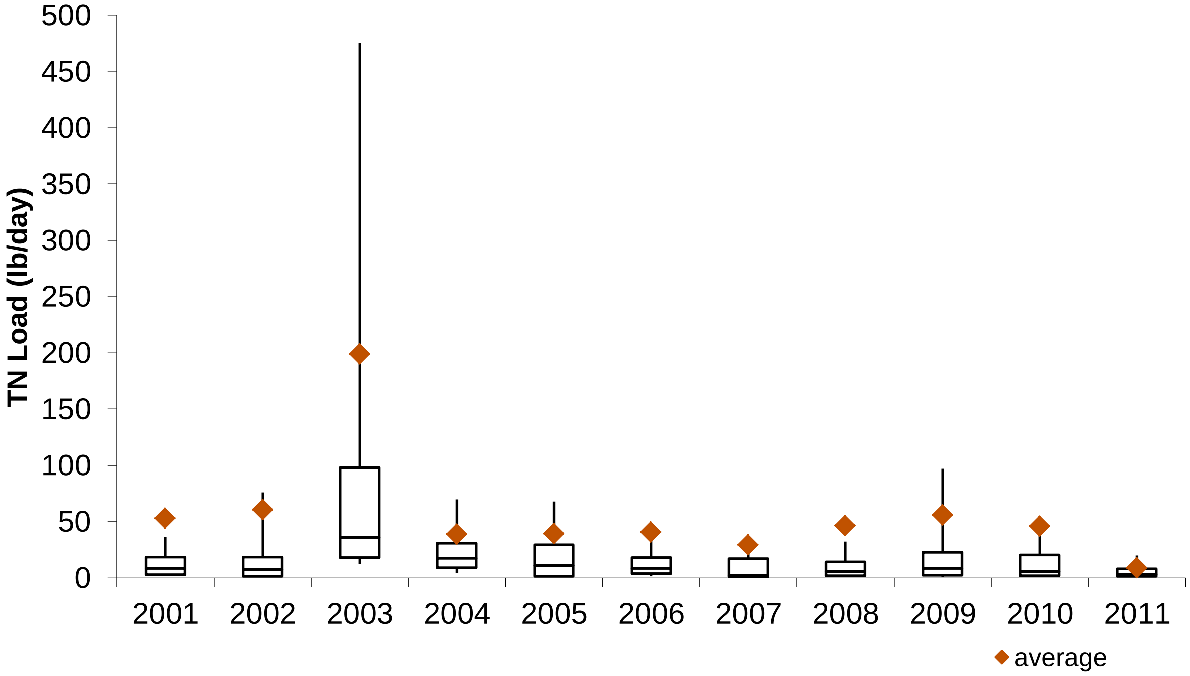

Figure 5-24 Distribution of Daily Total Phosphorus Loads by Year for the Eno River Subwatershed

In the Flat River watershed, 2003 had the highest distribution of daily loads followed by 2009 (Figure 5-25). Relative to 2006, average daily load in 2011 was approximately 83 percent lower; average flows in this subwatershed were approximately 64 percent lower.

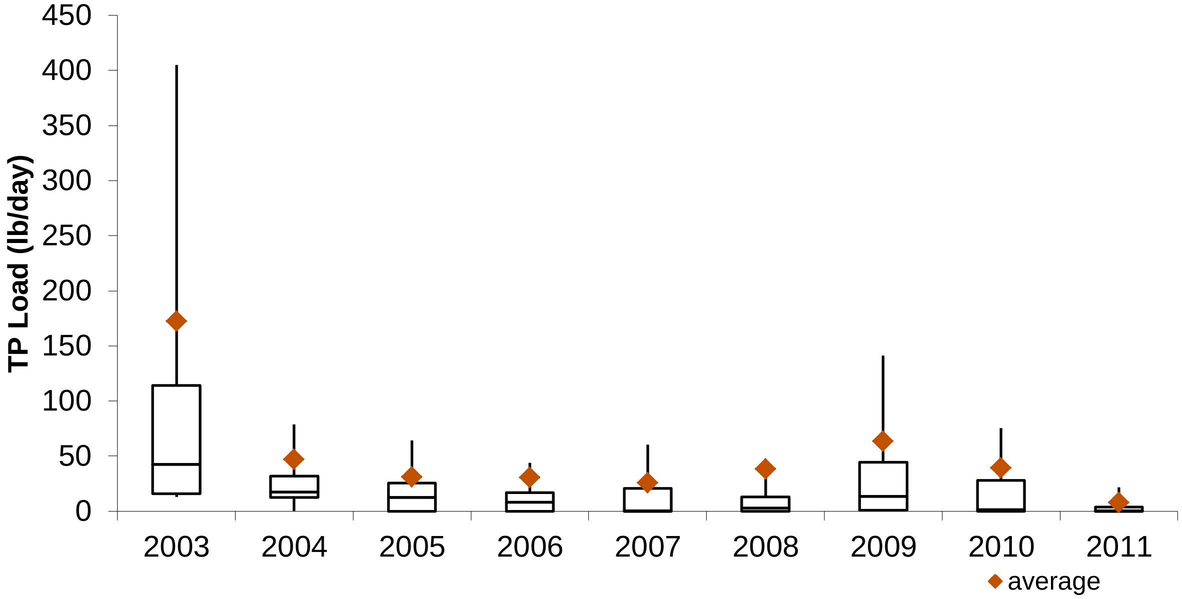

Figure 5-25 Distribution of Daily Total Phosphorus Loads by Year for the Flat River Subwatershed

In the Knap of Reeds Creek subwatershed, the distribution varies from year to year with less susceptibility to changes in hydrologic flow due to the presence of the WWTP discharge (Figure 5-26). Average daily loads in 2011 were approximately 26 percent lower than in 2006; average flows were approximately 65 percent lower.

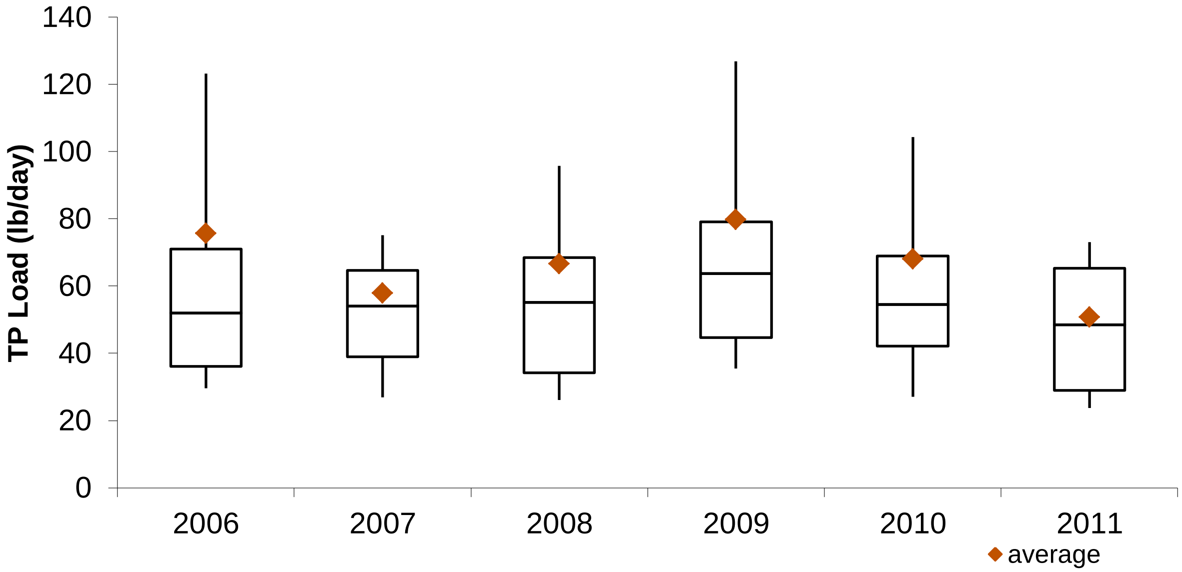

Figure 5-26 Distribution of Daily Total Phosphorus Loads by Year for the Knap of Reeds Creek Subwatershed

In the Little River subwatershed, the distribution of daily loads was highest in 2003 and 2009 (Figure 5-27). Daily average loads in 2011 were approximately 77 percent lower than in 2006; average flows were 74 percent lower.

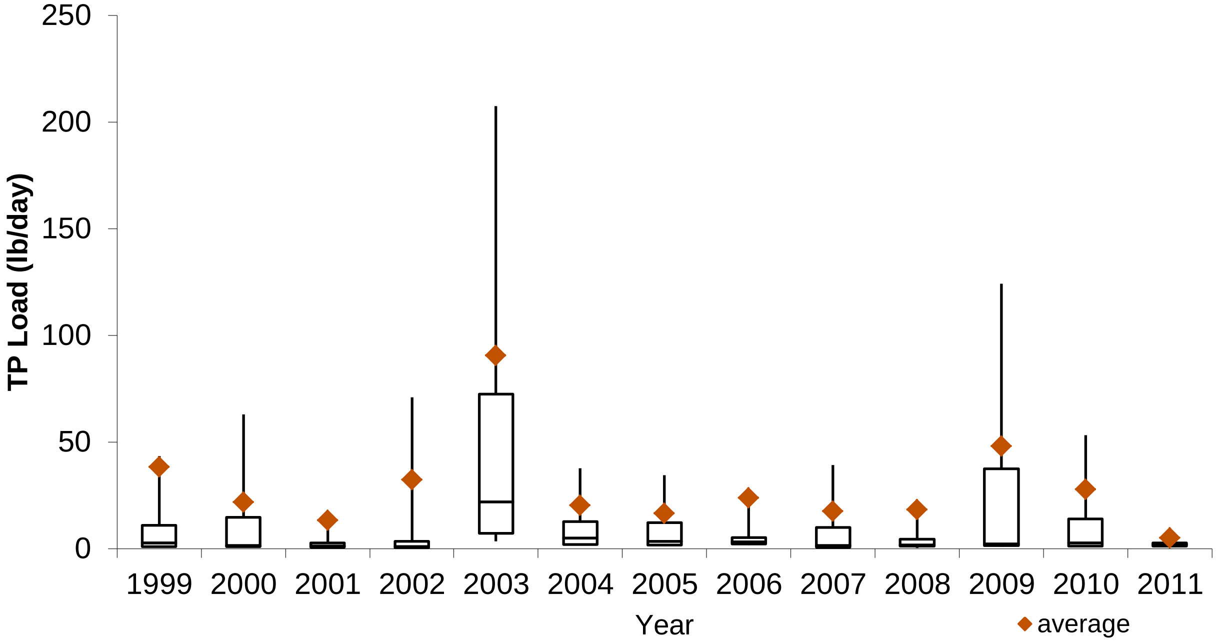

Figure 5-27 Distribution of Daily Total Phosphorus Loads by Year for the Little River Subwatershed

5.3.5.3 Monthly Variability in Daily Loads

This section of the memorandum presents the distribution of daily total nitrogen loads and total phosphorus loads by month for each subwatershed. The period of record for each subwatershed varies based on the availability of water quality and flow data.

5.3.5.4 Total Nitrogen

Figure 5-28 through Figure 5-32 show the distribution of daily total nitrogen loads for each of the five upper lake tributaries. In the Ellerbe Creek, Eno River, Flat River, and Little River subwatersheds, the distributions of daily loads tend to be highest during the late fall to early spring months. Beginning in April, the loads tend to decline for four to five months into late summer and then begin to rise again in the fall months. The Knap of Reeds subwatershed is less sensitive to seasonal effects, likely due to the presence of the WWTP discharge. In this subwatershed, the increase in loading that begins in the fall continues to late spring/early summer, followed by a slight decline during the summer months.

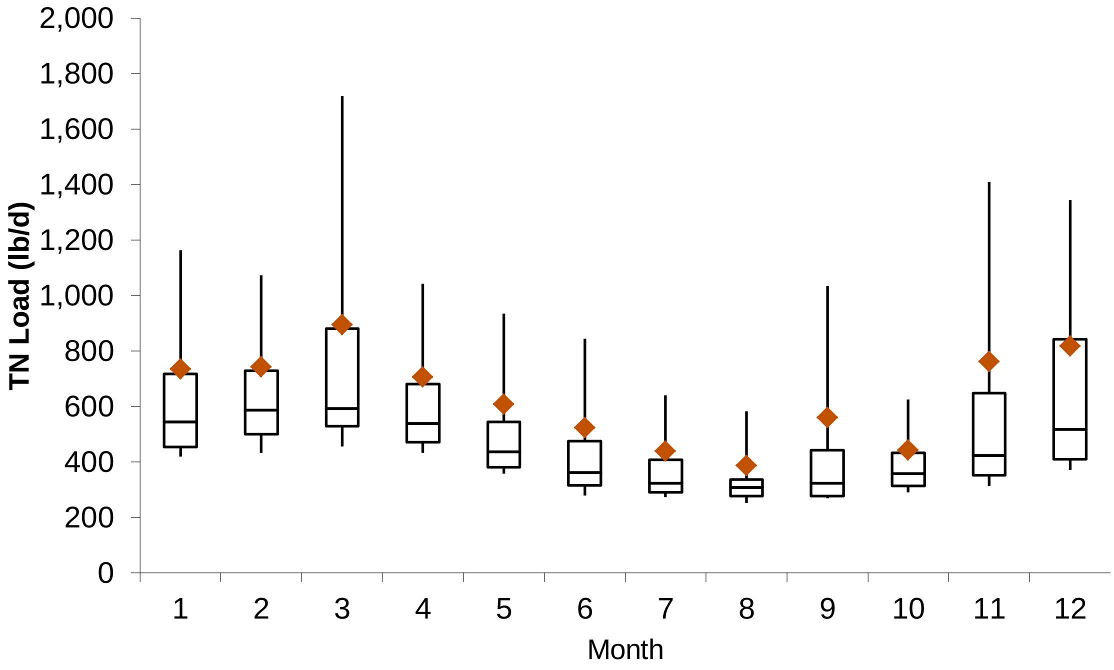

Figure 5-28 Distribution of Daily Total Nitrogen Loads by Month for the Ellerbe Creek Subwatershed (2006-2011 Flow Data)

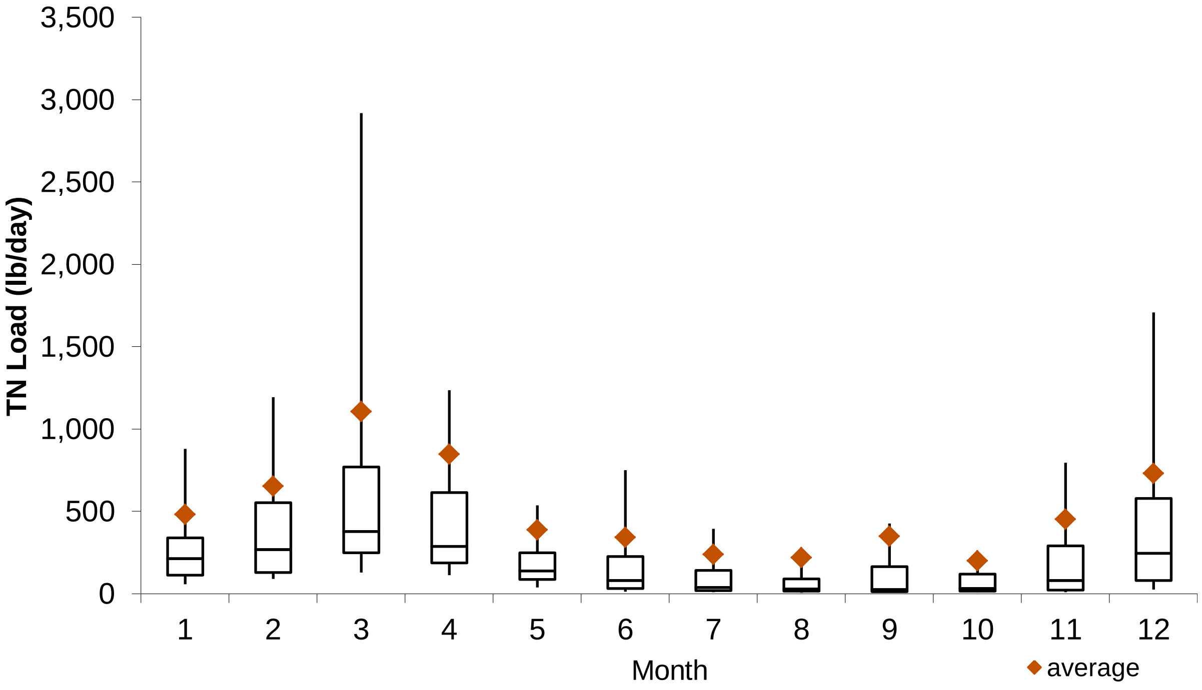

Figure 5-29 Distribution of Daily Total Nitrogen Loads by Month for the Eno River Subwatershed (2001-2011 Flow Data)

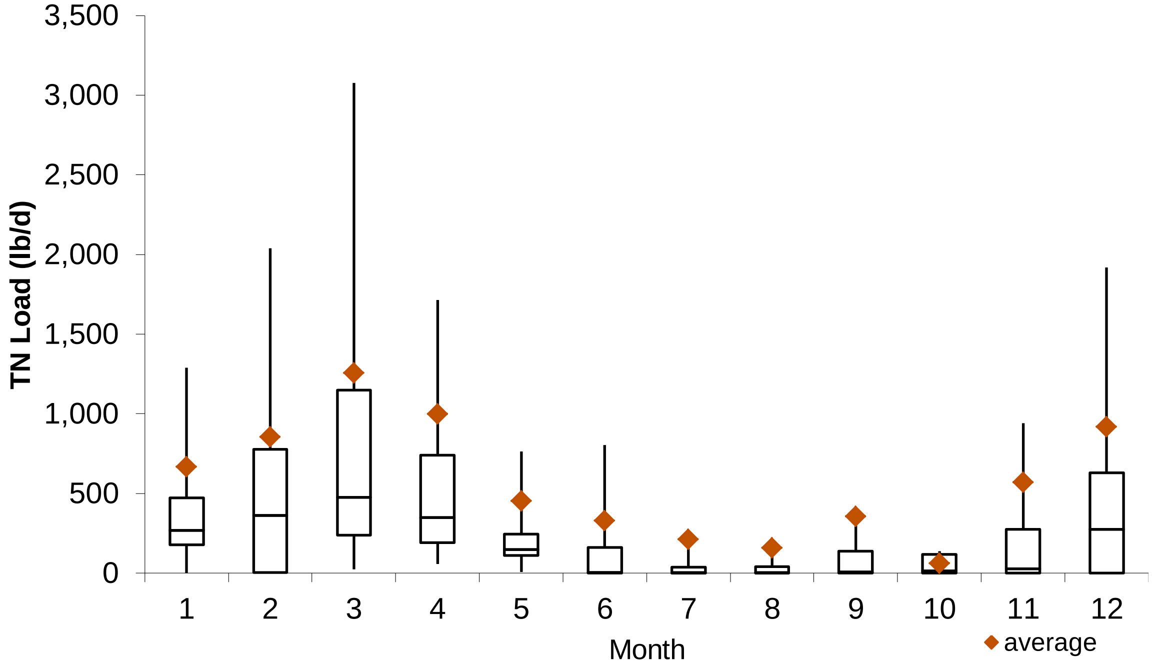

Figure 5-30 Distribution of Daily Total Nitrogen Loads by Month for the Flat River Subwatershed (2003-2011 Flow Data)

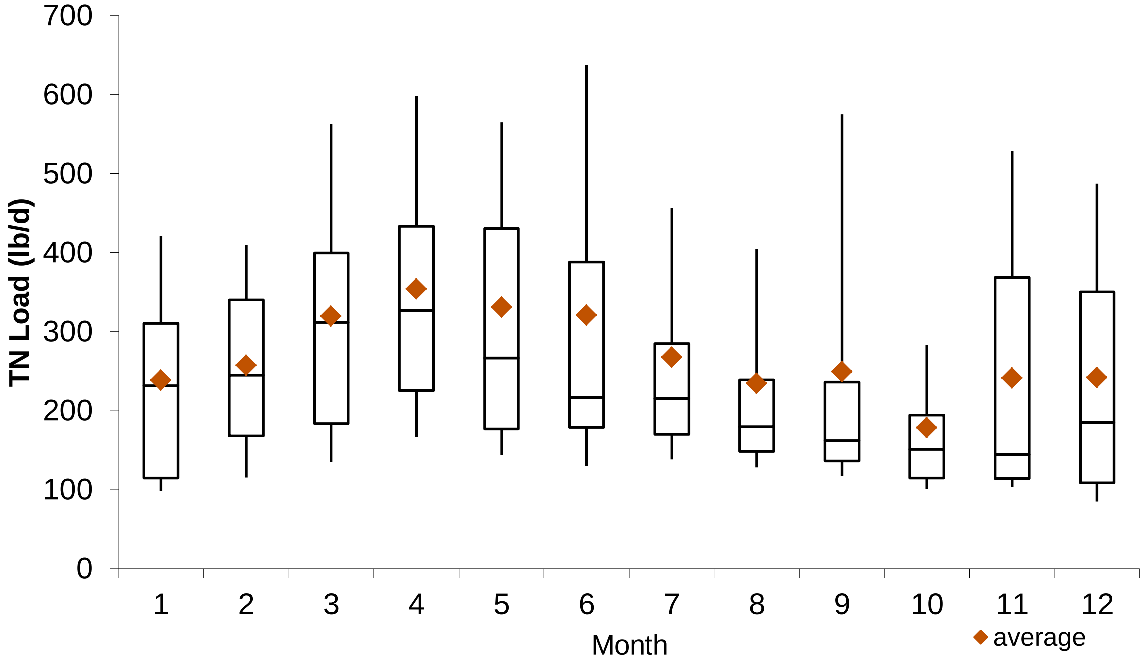

Figure 5-31 Distribution of Daily Total Nitrogen Loads by Month for the Knap of Reeds Creek Subwatershed (2006-2011 Flow Data)

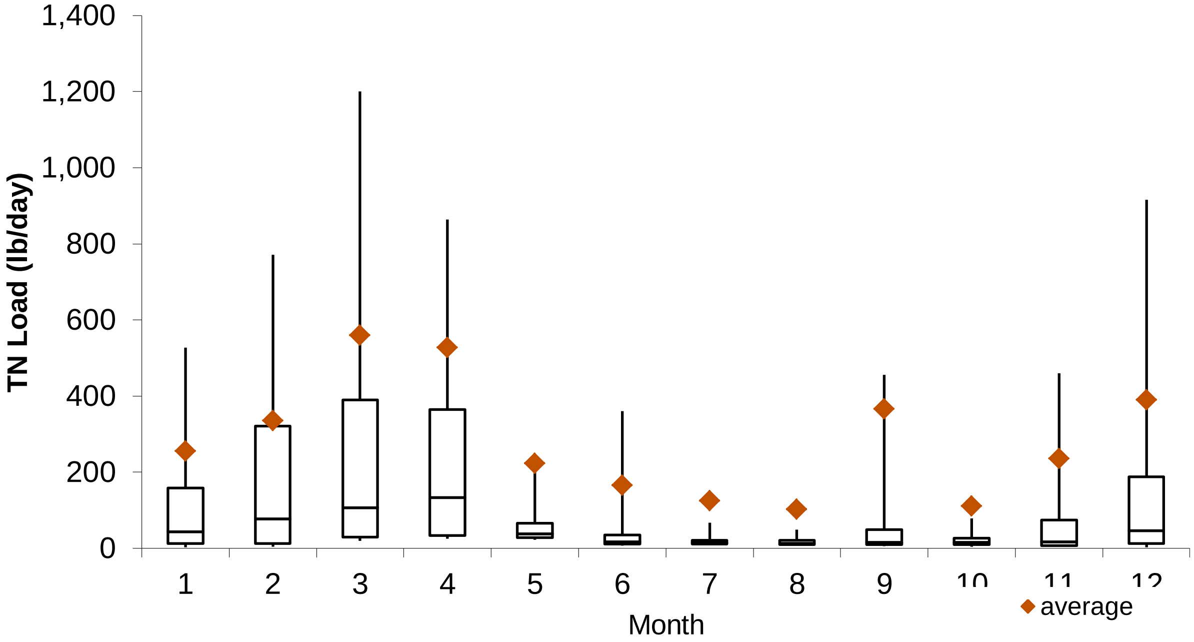

Figure 5-32 Distribution of Daily Total Nitrogen Loads by Month for the Little River Subwatershed (1999-2011 Flow Data)

5.3.5.5 Total Phosphorus

Figure 5-33 through Figure 5-37 show the distribution of daily total phosphorus loads for each of the five upper lake tributaries. In the Eno River, Flat River, and Little River subwatersheds, the distribution of daily loads tends to be highest during the late fall to early spring months. Beginning in April, the loads tend to decline for four to five months into late summer and then begin to rise again in the fall months. Daily phosphorus loads in the Ellerbe Creek subwatershed are less variable with respect to month compared to the distribution of daily nitrogen loads: the highest loads are still observed in the winter and early spring months, and lower values are observed in the summer, but the variability is less significant. The distribution of loading in the Knap of Reeds Creek subwatershed is opposite that of the other subwatersheds. Loads in the late fall to early spring are the lowest with increases occurring through the early summer and decreases beginning in in mid-summer.

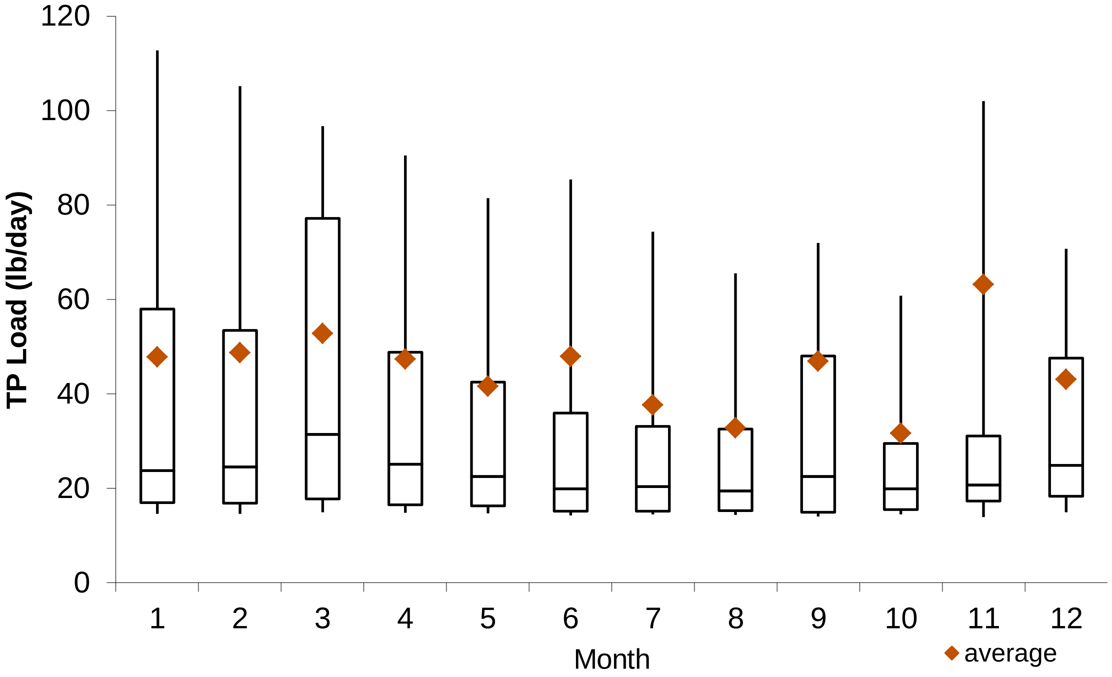

Figure 5-33 Distribution of Daily Total Phosphorus Loads by Month for the Ellerbe Creek Subwatershed (2006-2011 Flow Data)

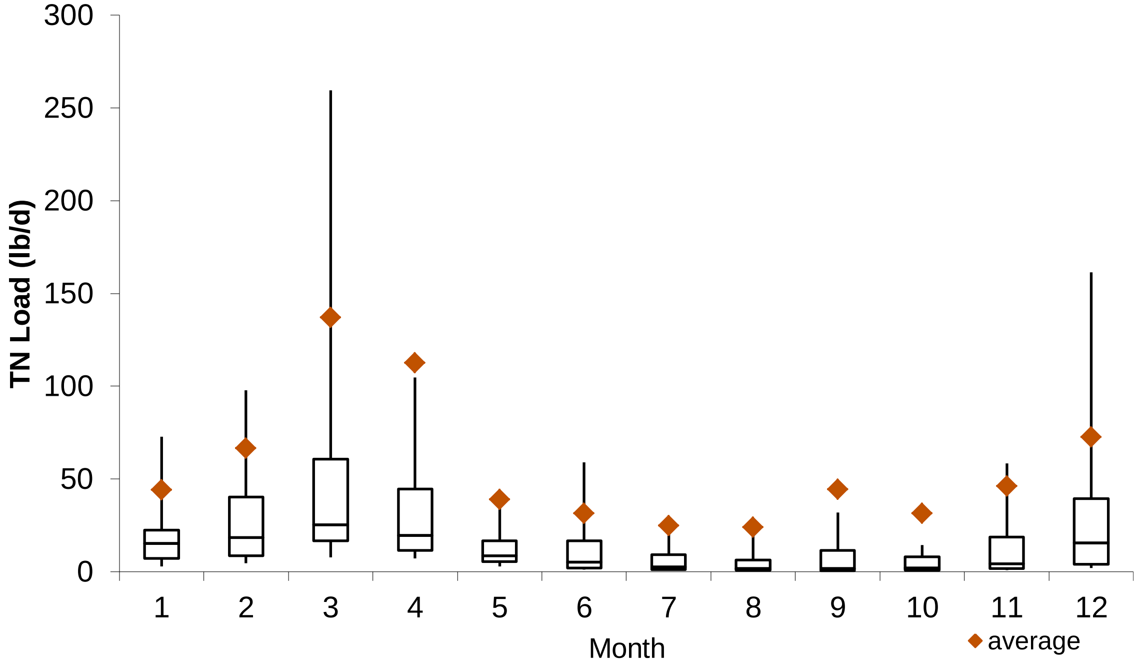

Figure 5-34 Distribution of Daily Total Phosphorus Loads by Month for the Eno River Subwatershed (2001-2011 Flow Data)

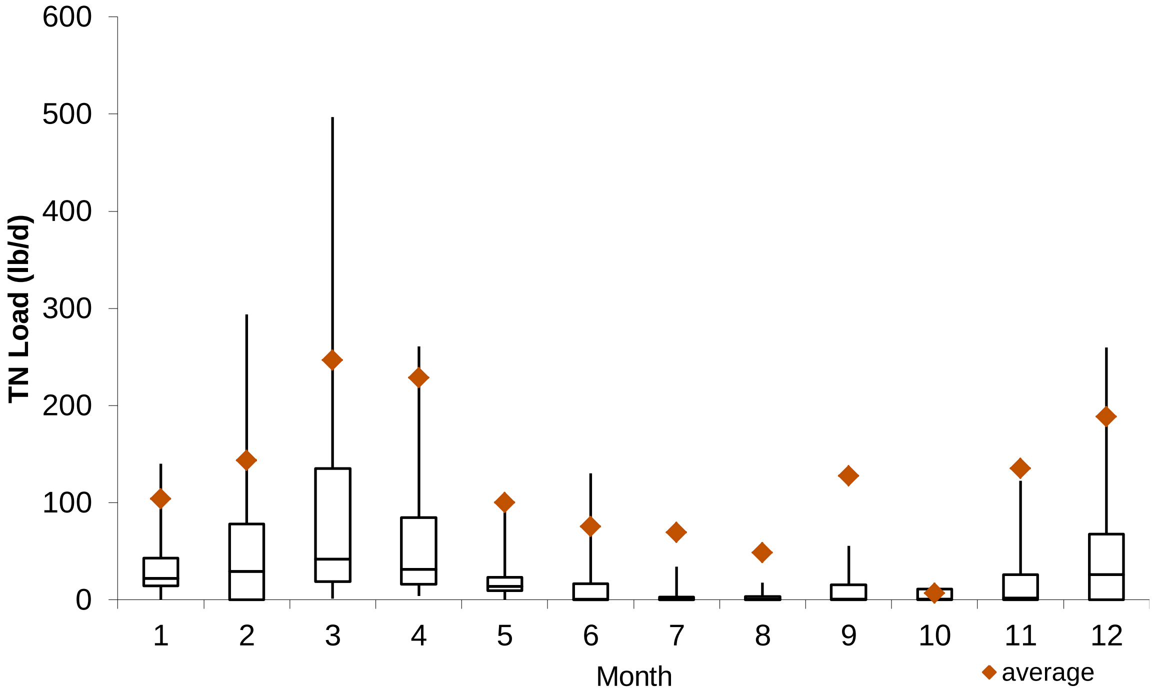

Figure 5-35 Distribution of Daily Total Phosphorus Loads by Month for the Flat River Subwatershed (2003-2011 Flow Data)

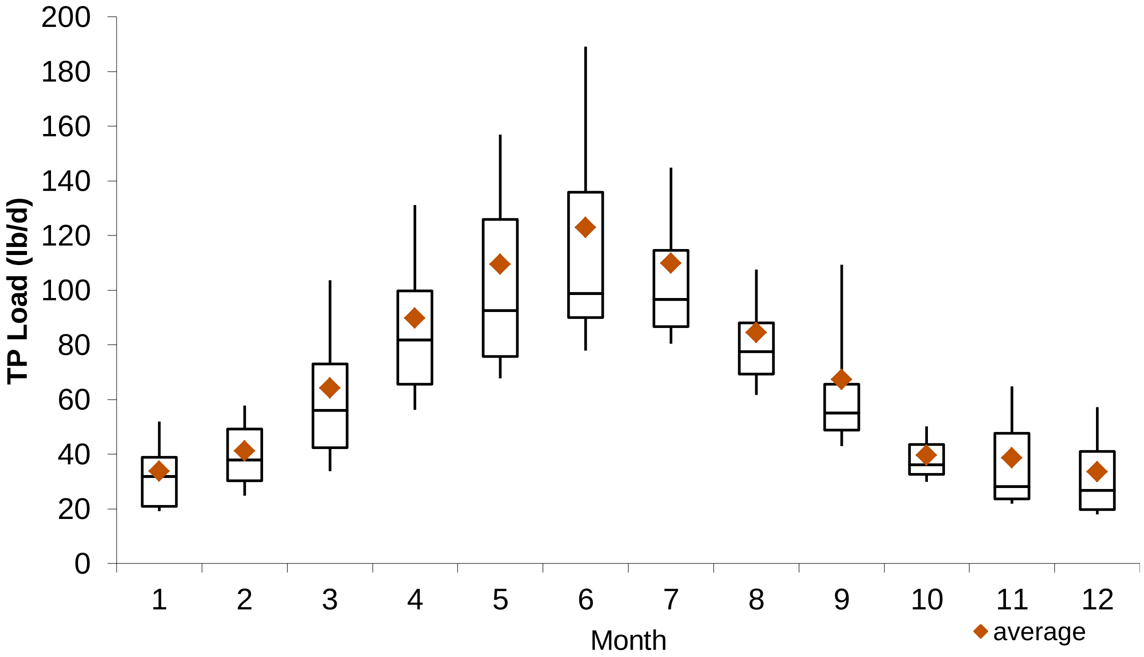

Figure 5-36 Distribution of Daily Total Phosphorus Loads by Month for the Knap of Reeds Creek Subwatershed (2006-2011 Flow Data)

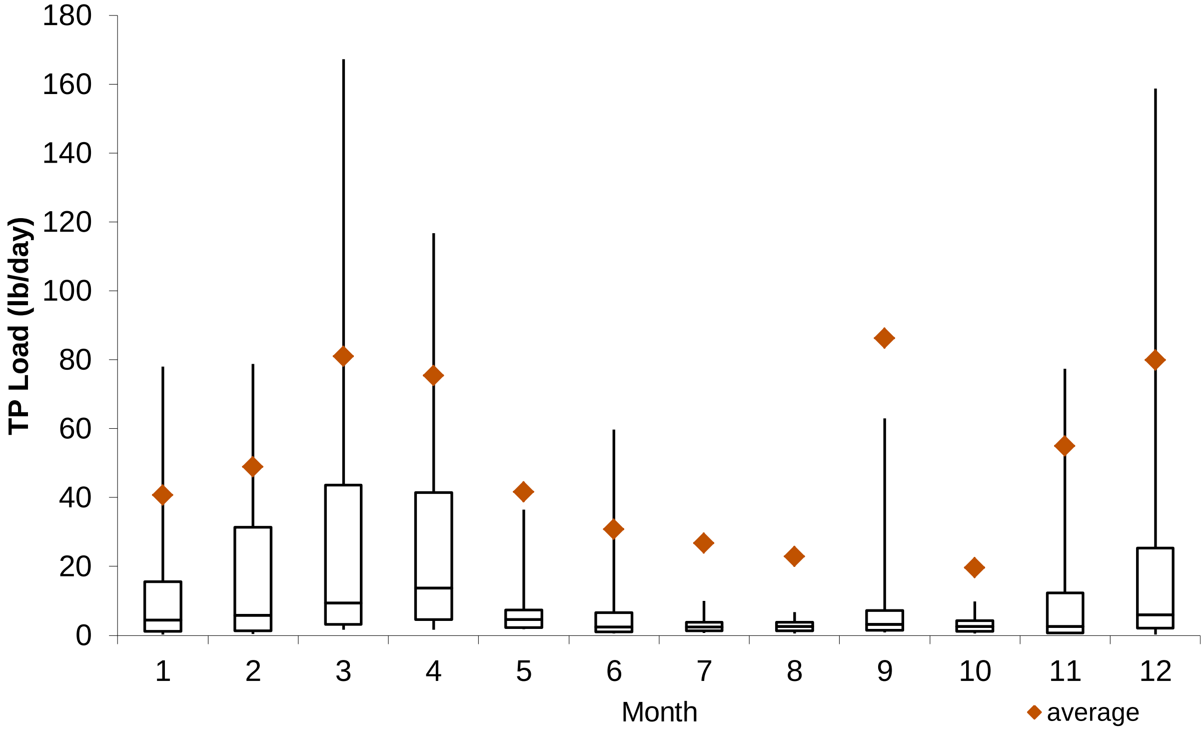

Figure 5-37 Distribution of Daily Total Phosphorus Loads by Month for the Little River Subwatershed (1999-2011 Flow Data)

6 Identification of Data Gaps Associated with Load Estimation

This section of the TM describes the gaps in knowledge associated with determining jurisdiction, tributary, and specific sources of nutrient loading to Falls Lake. These gaps are based on data analysis, input from the UNRBA, and discussions with NCDWQ.

6.1 Stage I Loads

The Stage I loads for each local government are equal to the increase in nutrient loading from development that occurred from January 2007 to July 2012. Calculation of the Stage I loads is a regulatory requirement specified in the Falls Lake Nutrient Management Strategy. While NCDWQ is ultimately responsible for calculating the Stage I loads, the rules state that “the Division shall work in cooperation with subject local governments and other watershed interests in developing this model program…” Stage I loads may be developed in coordination with NCDWQ, or solely by NCDWQ if a local government does not choose to participate.

Several of the local governments in the Falls Lake watershed have begun to analyze their Stage I load reduction requirements. The cities of Durham and Raleigh and the counties of Durham, Orange, and Wake have been tracking and calculating nutrient loading increases associated with development since the Neuse River Nutrient Sensitive Waters Strategy was adopted in 1997. These local governments likely have data in an electronic format that describes the type, amount, and location of development that has occurred. The other local governments in the watershed that were not explicitly mentioned in the Neuse River Nutrient Sensitive Waters Strategy may not have the information readily available to calculate Stage I loads in the short term. Many of these jurisdictions will need to pull paper development plans and permits and manually delineate the areas and types of development that have occurred.

This TM has described three methods for calculating Stage I loads: two are stormwater load accounting tools and one is based on conservative areal loading rates. Depending on the calculation method selected for determining Stage I loads, varying levels of detail regarding each development is needed. Even if the preliminary, simple Stage I method is selected, information regarding the geographic location, type, and size of each development is required. Additional information that would be helpful includes the pre-development land use type and descriptions of BMPs associated with each development.

As more time allows, the local governments may wish to submit more refined Stage I estimates based on one of the stormwater load accounting tools. Again, selection of the tool will dictate the level of detail needed to describe each development. If the JFLSNLAT is selected, areal inputs are in square feet with up to 12 inputs per land use category (e.g., sidewalks, lawn, rooftops). A tool similar to the City of Durham Nutrient Load Calculation Tool inputs areas in acres for four categories (transportation and non-transportation impervious, managed and wooded pervious). Those local governments that already have performed these calculations to meet the requirements of the Neuse River Nutrient Sensitive Waters Strategy may choose to submit these estimates rather than estimates based on the simple approach using conservative areal loading rates.

Whether or not the local governments account for BMPs that were implemented from January 2007 to July 2012 will also depend on the type of information that is currently available. Nutrient reduction credits may be calculated based on published reduction efficiencies or simulated in a tool such as the JFLSNLAT. Regardless of the method selected, local governments need to collect information regarding the location, size, and areas of each land use draining to the BMP.

Information regarding non-conventional BMPs are also needed. These may include repairing, replacing, or connecting onsite wastewater treatment systems; stream restoration projects; and regional scale BMPs. Descriptions of each program will be needed to determine the nutrient credits associated with these activities. Local governments may want to negotiate credits with NCDWQ in the short term or wait until the July 2013 report is issued (this report will describe nutrient reduction credits associated with some of these activities).

Filling the data gaps associated with Stage I will rely on participation from each local government to describe the locations and types of development that have occurred. Depending on the number of local governments and extent of development, it may be cost effective to use aerial images taken at the beginning and end of the interim period to assess land use changes and quantify development.

6.2 Stage II Loads and Nutrient Loading from Specific Sources

Stage II loads are based on year 2006 nutrient loads generated by each jurisdiction. The reductions required are 40 percent for nitrogen and 77 percent for phosphorus relative to the baseline year. Because the UNRBA has initiated a reexamination of Stage II, the final requirements are currently unknown.

Assuming that the Stage II load requirements will be set relative to some baseline year (even if the required reductions change), a mechanistic or empirical watershed model would be the most efficient way to determine baseline loads. However, existing data gaps will limit the development and calibration of these models:

- Flow and water quality data at jurisdictional boundaries
- Data describing nutrient loading rates from specific sources in the watershed (e.g., land uses, onsite wastewater treatment systems, streambank erosion, internal nutrient loading from lake sediments)
- Data to quantify nutrient fate and transport in the watershed and stream channels
- Flow and water quality data collected at the mouths of tributaries to provide a basis for model calibration (particularly in the Lower Lake subwatersheds)
- Flow and water quality data collected at the lake segment boundaries

Filling these data gaps may be addressed with future monitoring studies which will be described in the Task 4 TM.

6.3 Tributary Nutrient Loading to Falls Lake

To support calculation of nutrient loading to the lake, additional permanent flow monitoring gages at the mouths of ungaged tributaries are needed. It is unlikely that flow gages will be installed at each major input to the lake, particularly the smaller tributaries around the Lower Lake. Identification of representative reaches is needed to capture variations in land use, geology, presence of a WWTP, etc. In addition to supporting lake modeling, this monitoring data can be used to help identify whether or not watershed wide nutrient reduction efforts are resulting in reduced nutrient loading to the lake.

Additional water quality data is also needed to calculate tributary loading, particularly in the specific subwatersheds summarized in Table 6-1 which summarizes the available data by each parameter and segment. The segments near the lake with a small sample size relative to the other segments in the watershed are shaded. For each parameter, the smallest sample sizes are typically associated with the segment from 0 to 2 miles upstream from the lake, which are those used to estimate tributary nutrient loading. Collection of additional data in these segments will support tributary load estimation and future lake response modeling. The downstream segments (0 to 2 miles upstream from the lake) with the least amount of data include the Eno River, Horse/Barton/Cedar, Horse/Newlight, Knap of Reeds, Lick Creek, Little River, the Beaverdam Creek Subwatershed, and the Beaverdam Impoundment.

Table 6-1 Water Quality Data Availability: Sample Size by Subwatershed and Lake Segment (from the Task 2 TM)

Sub-watershed and Distance Upstream	TSS	Ammonia	NO2/NO3	Organic Nitrogen	Ortho-Phosphorus	Total Phosphorus	Chlorophyll *a*	Total Organic Carbon
BC,0-2	18	19	15	15	17	15	0	0
BC,2-10	0	30	0	30	30	30	0	0
EC,0-2	153	225	453	222	40	444	0	11
EC,2-10	216	225	214	215	3	265	0	27
ER,0-2	58	69	115	68	4	118	0	5
ER,2-10	172	184	231	182	35	237	0	5
ER>10	181	289	280	275	99	270	182	85
FR,0-2	113	201	214	199	95	248	0	1
FR,2-10	65	44	51	44	3	53	0	0
FR>10	0	1	1	1	1	1	0	0
HBC,0-2	78	78	76	76	76	76	0	0
HNL,0-2	45	50	41	42	44	41	0	0
KRC,0-2	80	137	147	136	9	147	0	10
LC,0-2	31	36	36	36	5	36	0	5
LC,2-10	57	85	85	85	29	85	0	8
LR,0-2	0	3	0	3	3	3	0	0
LR,2-10	145	426	456	424	360	504	0	53
UppLk>21	146	397	1109	917	834	621	911	161
UppLk,18-21	102	89	177	89	105	89	160	67
UppLk,13-18	206	947	699	394	410	398	433	267
BvrDmImp	23	0	56	0	0	0	120	56
LowLk,8-13	131	195	262	90	89	120	353	193
LowLk,4-8	161	284	644	276	263	277	434	637
LowLk,0-4	223	91	444	192	181	230	617	320

Note: Shaded cells indicate segments located near the lake boundary where additional data collection would be particularly useful for improving tributary loading calculations.

In addition to routine monitoring of tributaries near the lake, monitoring of water quality over the course of large storm events is needed to understand the variability in water quality associated with storm events. The five upper tributaries as well as some representative lower lake tributaries (based on land use, presence of a WWTP discharge, etc.) should be selected for this monitoring which would be conducted once per season during storm events.

Future monitoring studies, which will be described in the Task 4 TM, can be used to fill these data gaps.

7 Summary

The Falls Lake Nutrient Management Strategy requires significant and costly nutrient reductions in the Falls Lake watershed over the next several years. Because of the mandated time line for development of the Strategy, NCDWQ had a limited amount of time to collect data and develop models on which to base the rules. As a result of the compressed schedule, there is significant uncertainty regarding the amount and sources of nutrient loading to Falls Lake as well as the load allocations needed to protect the lake and its designated uses. For example, the existing models developed for the watershed and the lake vary greatly in their estimation of nutrient loading to the lake. Cardno ENTRIX developed nutrient loading estimates using the USGS LOADEST tool and this approach resulted in loads similar to those used to drive the Falls Lake Nutrient Response Model.

In addition to understanding the impacts of load allocations on lake water quality and attainment of designated uses, the Strategy requires that the allowable loads be allocated fairly among the jurisdictions. However, the existing models are not well suited for this purpose: they either significantly underestimate loading to the lake (compared to others methods that are in closer agreement) or do not include source categories that are needed to allocate loads among the jurisdictions in this watershed.

For these reasons, development of additional, or revised, watershed and lake response models are needed to reduce the uncertainty associated with the load allocations and predicted lake response. The rules require a minimum of three years of data collection to support development of these models. The future monitoring and modeling studies needed to support the re-examination process are described in the Task 4 and Task 1 TMs.

8 List of References

AMEC, 2007. Wake County Septic System Maintenance Program Study Final Report, May.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., 1997, Hydrological Simulation Program--Fortran, User's manual for version 11: U.S. Environmental Protection Agency, National Exposure Research Laboratory, Athens, Ga., EPA/600/R-97/080, 755 p.

Booth, N.L., E.J. Everman, I-L Kuo, L. Sprague and L. Murphy. 2011. A Web-Based Decision Support system for Assessing Regional Water-Quality Conditions and Management Actions. Journal of the American Water Resources Association (JWARA) 47(5):1136-1150.

EPRI. 2001. Watershed Analysis Risk Management Framework (WARMF): Update One A Decision Support System for Watershed Analysis and Total Maximum Daily Load Calculation, Allocation and Implementation. 1005181 Topical Report, October 2001.

Ferrell, G.M. and B.H. Grimes. In Review. Effects of Centralized and Onsite Wastewater Treatment on the Occurrence of Traditional and Emerging Contaminants in Streams. Journal of Environmental Health.

García, A.M., A.B. Hoos, and S. Terziotti. 2011. A Regional Modeling Framework of Phosphorus Sources and Transport in Streams of the Southeastern United States. Journal of the American Water Resources Association (JAWRA) 47(5):991-1010.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF, Generalized Watershed Loading Functions, Version 2.0, User's Manual. Dept. of Agricultural & Biological Engineering, Cornell University, Ithaca, NY.

Hession, W.C., D.E. Storm, C.T. Haan, K.H. Reckhow, and M.D. Smolen. 1996. Risk Analysis of Total Maximum Daily Loads in an Uncertain Environment Using EUTROMOD. *Lake and Reservoir Management. 12:* 331-347

Humphrey, Jr., C.P., O'Driscoll, M.A. and M.A. Zarate, 2010. Controls on groundwater nitrogen contributions from on-site wastewater systems in coastal North Carolina. Water Science and Techology, vol. 62, no. 6.

Lynn, W. E., M. T. Hoover, L. D. King, L. A. Nelson, S. M. Harris, S. W. Bristow, T. Angoli, W. Lowery and K. G. Daeke. 2005. Wake County Field Performance and Operation & Maintenance Survey of Systems Installed 1982-2002. Wake County Department of Environmental Services, Raleigh, NC.

NCDENR. 2009a. Falls Lake Nutrient Response Model Final Report. Prepared by N.C. Department of Environment and Natural Resources Division of Water Quality Planning Section Modeling/TMDL Unit November 2009.

NCDENR. 2009b. Falls Lake Watershed Analysis Risk Management Framework (WARMF) Development Final Report. Prepared by N.C. Department of Environment and Natural Resources Division of Water Quality Planning Section Modeling/TMDL Unit October 2009.

NCDENR. 2010a. Report on the potential need for improvements in septic system design, operation and siting standards in the Falls Lake watershed, October. Prepared by N.C. Department of Environment and Natural Resources.

NCDENR. 2010b. Water Quality Monitoring of Headwater Streams in the Falls Lake Watershed: A discussion of rural/forested, suburban single-family septic tank sand filters and suburban municipal sewer catchments. Falls Lake Watershed NCDENR – DWQ Surface Water Protection Raleigh Regional Office.

NCDENR. 2011. Intensive Survey Unit Standard Operating Procedures Manual: Physical and Chemical Monitoring. Version 2.0 November 2011.

North Carolina State University, Biological and Agricultural Engineering Department and North Carolina Department of Environment and Natural Resources. 2011. Jordan/Falls Lake Stormwater Nutrient Load Accounting Tool. Version 1.1. November 2011. http://portal.ncdenr.org/web/wq/ps/nps/fallslake

NOAA Technical Report NWS 34, Mean Monthly, Seasonal, and Annual Pan Evaporation for the US, R. K. Farnsworth and E. S. Thompson, Dec. 1982.

Nürnberg, G.K. 1984. The prediction of internal phosphorus load in lakes with anoxic hypolimnia. Limno. Oceanogr. 29, 111-24.

Osmond, D.L. and Hardy, D.H. (2004). Landscape and watershed processes: Characterization of turf practices in five North Carolina communities. Journal of Environmental Quality. 33, 565-575.

Preston, S.D., R.B. Alexander, G.E. Schwarz, and C.G. Crawford. 2011. Factors Affecting Stream Nutrient Loads: A Synthesis of Regional SPARROW Model Results for the Continental United States. Journal of the American Water Resources Association (JAWRA) 47(5):891-915.

Reckhow, K.H., S. Coffey, M.H. Henning, K. Smith, and R. Banting. 1992. EUTROMOD: technical guidance and spreadsheet models for nutrient loading and lake eutrophication. Draft report. Durham, NC: School of the Environment, Duke University.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load Estimator (LOADEST): A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers: U.S. Geological Survey Techniques and Methods Book 4, Chapter A5, 69 p.

Schwarz, G., R. Smith, R. Alexander, and J. Gray. 2003. Recent Progress in the Development of a SPARROW Model of Sediment for the Conterminous U.S. Proceedings of the First Interagency Conference on Research in the Watersheds, Benson, Arizona. October 27-30, 2003.

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments. Washington, DC.

Tetra Tech, Inc. 2003. B. Everett Jordan Lake TMDL Watershed Model Development. Prepared for NC DWQ. November 2003.

Walker, William W. 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. Prepared for Headquarters, U.S. Army Corps of Engineers.

Walter, Robert, Merritts, Dorothy, and Rahnis, Mike. 2007. Rates of Stream Bank Erosion of Legacy Sediment in the Piedmont and Valley and Ridge Physiographic Provinces, Southeastern and Central PA. A Report to the Pennsylvania Department of Environmental Protection. Submitted January, 2007, and Revised September 13, 2007.

Woolfolk, M., Hailey, W., Baker, J. and J. Cox, 2008. Nutrient and Bacteria Characterization of Surface Discharging Sand Filter Systems. Presented at the NC WRRI Annual Conference, October, 2008.

Yonts, W.L., Giese, G.L., and Hubbard, E.F., 1973, Evaporation from Lake Michie, North Carolina, 1961-71: U.S. Geological Survey Water-Resources Investigations 38-73, 27 p.