Task 4: Review of Existing Models and Recommendations for Future Studies DRAFT

Support of Long Term Planning and Regulatory Nutrient Activities in the Falls Lake Watershed

Cardno ENTRIX

Shaping the Future

Document Information

Prepared for	Upper Neuse River Basin Association
Project Manager	Alix Matos and Lauren Elmore
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Prepared for:

Upper Neuse River Basin Association
P.O. Box 270, Butner, NC 27509

Prepared by:

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

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Executive Summary

ES.1 Introduction

In 2010 the North Carolina 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 with the following purpose:

> "…attain 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 baseline year (2006) levels established by NCDWQ. For Stage I, the rules require local jurisdictions to establish requirements to control nutrient input from new development sources.

Stage II requires, based on NCDWQ modeling and evaluation, additional loading reductions that will result in an overall reduction of the mass of nutrients delivered to the Lake of 40 percent and 77 percent for total nitrogen and total phosphorus, respectively, relative to the baseline year. 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)).

Another important issue to the UNRBA relates to the use of Falls Lake as a water supply and the relationship between nutrient inputs, algae growth response as measured by chlorophyll *a*, and total organic carbon (TOC) levels in the Lake. TOC levels are an important factor affecting finished water quality related to secondary disinfection byproduct standards. The State's evaluation of nitrogen and phosphorus loading on "nutrient related standards" in Falls Lake does not adequately address the role that nutrients play in TOC levels, nor do the existing evaluation tools allow for an accurate prediction of how Stage II reductions (or Stage I) would affect TOC concentrations in the raw water in the reservoir. Since TOC is an important factor affecting the primary classified use of the Lake, the re-evaluation process must include efforts to collect more data related to TOC and provide better predictive tools for determining the role of nutrients in affecting TOC levels in the Lake. In addition, the duration and intensity of algal density, species variation, and chlorophyll *a* levels should be considered a regulatory decision for the Lake because they affect three of the designated uses: safe drinking water, recreation, and aquatic life.

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 for addressing the nutrient management rule requirements regarding the reexamination of Stage II of the Falls Lake Nutrient Management Strategy while continuing to support the Consensus Principles. For this project four project tasks were designed to provide the UNRBA with the information needed to make informed decisions regarding the next steps for implementation of the re-examination and to assist with development of jurisdictional loads for regulatory and program implementation purposes:

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

Task 4 has two main objectives. The first is to review the existing watershed and lake models developed by NCDWQ as the basis of the Falls Lake Nutrient Management Strategy. The second is to identify future studies that will support reexamination of the Stage II rules. Task 4 relies heavily on the database compiled for Task 2 and the load estimations performed under Task 3 to identify gaps in knowledge and data.

This Technical Memorandum (TM) 4 describes the future monitoring and modeling studies that may be needed to support the re-evaluation process. The results and conclusions from this TM will be used in conjunction with the other project work products to make a final recommendation on the suggested approach for a re-examination effort.

ES.2 Review of Existing Models

ES.2.1 Existing Watershed Model

The watershed model was developed by NCDWQ using the Watershed Analysis Risk Management Framework (WARMF) model (NCDENR 2009b). As described in the Cardno ENTRIX Task 3 TM, there is a high degree of uncertainty regarding the sources and total delivered nutrient loads estimated by the Falls Lake WARMF model. Watershed nutrient loads simulated by the WARMF model are 1.4 times and 2.0 times lower than those used as inputs to the Falls Lake Nutrient Response model developed by NCDWQ and do not correlate well with loads projected by the USGS SPAtially Referenced Regression On Watershed attributes (SPARROW) model, or with estimates predicted using LOADEST (see TM 3). The SPARROW, LOADEST, and EFDC time series nutrient loading estimates are relatively similar to each other, but the WARMF model loading estimates are much lower. Cardno ENTRIX does not recommend relying on the existing WARMF model to allocate jurisdictional loads in the watershed because there is considerable uncertainty associated with the total delivered load estimates as well as with the allocation of this load to the different sources. For example the simulated nitrogen loads derived using WARMF are nearly equivalent to the Stage II allocations calculated by NCDWQ, which indicates that either 1) the communities are already meeting their Stage II nitrogen allocations or 2) that the model underestimates nitrogen loading by about 40 percent. Section ES.4 and Section 4.1.3 recommend additional watershed modeling studies.

ES.2.2 Existing Lake Response Model

The Falls Lake Nutrient Response Model was developed using the Environmental Fluid Dynamics Code (EFDC) model (NCDENR 2009a). While measured flows and water quality data were used to estimate nutrient loading to Falls Lake upstream of I-85, fewer data were available to simulate loadings to the lower part of the lake. In addition, the modeling effort used a limited time period for establishing baseline conditions which did not provide a significant evaluation of variations in lake water quality or loading inputs over a range of hydrologic and environmental conditions. The ability to examine variation in lake response to loading that itself is variable over time gives a much better prediction of biological response and true impact to water quality in a lake environment. Unlike the Falls Lake load allocations derived by NCDWQ which are based on a single year, many TMDLs approved by EPA set nutrient load allocations based on a multi-year period that includes a range of hydrologic conditions.

Because the UNRBA has identified the need for a more complete evaluation of Lake beneficial uses and the effect of the Stage II requirements on the practical impact to established and classified uses, the ability to effectively and accurately simulate Lake quality over a wider range of conditions is needed. In addition, there needs to be a mechanism to directly link lake water quality to attainment of designated uses.

A specific concern with the existing modeling is that since chlorophyll *a* data was not collected in the tributaries upstream of Falls Lake, there was no data available to build the model input for this parameter. To fill this gap, NCDWQ assumed that tributary chlorophyll *a* concentrations were the same as those observed at nearby lake stations. This approach was also used to build the inputs for TOC. Cardno ENTRIX evaluated the sensitivity of Lake chlorophyll *a* concentrations to changes in the tributary chlorophyll *a* values. This sensitivity analysis indicated that tributary chlorophyll *a* concentrations have a significant impact on predicted compliance with the chlorophyll *a* standard. Reducing the tributary chlorophyll *a* concentrations to values more reflective of free flowing streams (10 µg/L) results in a 15 percent reduction in the simulated percent exceedance of the water quality standard at the in-Lake compliance point near I-85.

The limitations of the Falls Lake Nutrient Response Model are mostly due to limited data availability and a lack of broader coverage of season to season and year to year variations. Cardno ENTRIX recommends the collection of additional data to refine the model inputs as well as further consideration of model assumptions.

ES.3 Data Gaps Identified in Previous Tasks

This Technical Memorandum is the third in a series of TMs that have been produced to describe the data and the existing modeling of Falls Lake and its watershed. For Task 2, existing data and reports were compiled and summarized to characterize the water quality conditions of the lake. Task 3 described nutrient loading from specific sources in the watershed, discussed the existing NCDWQ WARMF model, and used a USGS tool (LOADEST) to calculate nutrient loading from tributaries to the upper lake. During the development of these tasks, several data gaps were identified:

- Chlorophyll *a* and TOC loads used to develop the input files for the EFDC lake response model developed by NCDWQ were based on in-lake concentrations, not tributary concentrations. Collection of chlorophyll *a* and TOC data in the tributaries just upstream of the lake would provide more accurate information from which to base simulations of lake response (the relative importance of this gap can be addressed with sensitivity analyses of the existing model to this input parameter).
- Limited data exists for several other parameters in the segments just upstream of the lake. The downstream segments 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. TOC and chlorophyll *a* data near the mouths of tributaries is lacking across the watershed.

The Falls Lake Rule implementation schedule requires NCDWQ to propose, and the EMC to adopt, Jurisdictional Loads (JLs) for each local government in the Falls Lake Watershed. NCDWQ is required to submit proposed JLs to the EMC in July 2013. It may be beneficial to local governments if they can develop their own data that describe the land use changes that occurred between January 2007 and July 2012. Otherwise, NCDWQ will develop load reduction requirements without local government input to meet their deadline. This exercise may require compiling site development plans and permits and analyzing aerial imagery to identify the location, area, and type of development that has occurred. Efforts should also be made to document BMP implementation that has occurred since 2006. According to key NCDWQ staff, if load reduction credits associated with BMP implementation cannot be quantified by early 2013, these may be submitted along with the revised Stage I loads.

To estimate year 2006 nutrient loads, which are the baseline for the Stage II reductions (40 percent reduction in nitrogen loading and 77 percent reduction in phosphorus loading), a watershed model will be required. 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 itself, is needed to develop and calibrate this model.

ES.4 Future Modeling Studies

Three types of models are recommended to support the reexamination of Stage II of the Falls Lake Nutrient Management Strategy:

1. A watershed model to allocate loads to the sources and jurisdictions in the watershed,
2. A lake response model to simulate lake water quality in response to various input conditions, and
3. An empirical model to link nutrient loads and lake water quality to designated uses.

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. (Section 4 describes the use of mechanistic and empirical models for Falls Lake and the watershed.) 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 also suggests developing an empirical model to link nutrient loading to lake water quality and designated uses (Section 4.4). This will allow the UNRBA to make informed decisions regarding the impacts of nutrient management measures on designated uses. For example, the empirical model may be developed to predict changes in total organic carbon, UV absorption, taste and odor, and harmful algal blooms that affect safe drinking water. Another example would be to predict the impacts of nutrient management on recreational use by assessing changes in water clarity, harmful algal blooms, taste and odor, pH, fish type and quantity. This empirical model may be directly linked to both the watershed model that predicts nutrient loads resulting from management actions as well as the lake response model that predicts changes in lake water quality.

ES.5 Future Monitoring Studies

The monitoring frequency suggested for most of the studies described in this memorandum is monthly. More intensive monitoring during storm events, coupled with installation of permanent flow gages in ungaged tributaries will reduce uncertainty with respect to nutrient loading to the lake. The majority of the recommended monitoring focuses on the watershed, rather than the lake, to support estimation of jurisdictional and tributary loading to the lake. Existing lake monitoring conducted by the local governments and agencies is likely sufficient to capture the spatial and temporal water quality trends in the lake. The recommendations for additional water quality monitoring in the lake are associated with developing linkages between water quality and designated uses.

Six objectives have been identified to support the future needs of the UNRBA:

1. Source allocation and estimation of jurisdictional loading,
2. Lake response modeling,
3. Compliance monitoring,
4. Linkage of water quality to designated uses,
5. Credit accounting/BMP effectiveness, and
6. Support of regulatory options.

Strategic planning will be required to prioritize and conduct the monitoring studies needed to meet these objectives.

ES.6 Recommendations from the NSAB Regarding Future Studies

The Nutrient Scientific Advisory Board (NSAB) released a set of recommendations for future monitoring in July 2012. These are described in more detail in Section 6, but generally include the following:

> Additional watershed monitoring is needed in smaller drainages, and in general, upstream of wastewater treatment plants (WWTPs).

> Onsite wastewater disposal systems should be simulated separately, and not lumped in with the associated land use.

> Need to account for storm events, gross solids, and seasonality.

> Monitoring efforts should be coordinated with federal, state, and local governments.

Many of the recommendations by the NSAB are consistent with the issues highlighted by the UNRBA and the monitoring recommendations described in Section 5.

ES.7 Conclusions and Recommendations for the UNRBA

The Falls Lake Nutrient Management Strategy requires phased implementation of nutrient reductions and defines a schedule for meeting various regulatory requirements. The requirements and schedule defined by the rules dictate immediate, short term, and long term time frames for conducting the various efforts.

Immediate needs are associated with the July 2013 report to the EMC that requires local governments and NCDWQ to estimate the Stage I reduction requirements for each jurisdiction. The Stage I nutrient load reductions are equal to the increase in loading from development that occurred between January 2007 and July 2012. Data collection efforts should include descriptions of the type, amount, and location of development that has occurred during this period. In addition, information regarding the location, size, and types of BMPs implemented as well as areas of each land use draining to the BMP should be collected. Stage I calculation methods include stormwater load accounting tools as well as simplified areal loading rates. Each jurisdiction will need to decide, based on existing data availability and progress to date, which method they will use for the immediate reporting requirements. Detailed descriptions of these methods and their data requirements are provided in the Task 3 TM. Phase I will be implemented in January 2014.

Short term monitoring and modeling studies should be conducted over the next three to five years to support reexamination of the Stage II rules and provide information that will support various regulatory options. The following studies are recommended during this period.

- Support refinement of the lake response model
  - Tributary monitoring (flow and water quality)
  - Storm event sampling
  - Lake bathymetry and flow data collection
  - Estimation of in-lake processes (internal loading, reaction kinetics, etc.)
- Develop preliminary estimates of baseline loads for planning purposes
  - Conduct literature review to support assignment of nutrient loading rates by land use
  - Collect morphometry and water quality data in the watershed impoundments and tributaries
  - Conduct source specific studies (e.g., streambank erosion and onsite wastewater treatment systems)
  - Develop empirical watershed model (e.g., EUTROMOD)
- Develop credits for non-conventional BMPs (NCDWQ will be determining “load reduction credits associated with various activities.”) This list of studies may need to be revised following NCDWQ submittal of the July 2013 report. For example:
  - Determine nutrient loading and estimate credits for repairing, replacing, or connecting onsite wastewater treatment systems to sewer
  - Determine the significance of streambank erosion to nutrient loading and estimate credits for restoration projects
  - Additional BMPs are identified in the Cardno ENTRIX assessment of a nutrient credit tool for the Falls Lake watershed
- Define linkage between lake water quality and designated uses.
  - Conduct monitoring studies that link water quality to attainment of designated uses.
  - Develop a preliminary Bayes Net or Structural Equation Model (SEM) to describe linkages between nutrient loading and designated uses
  - Use the preliminary model to perform uncertainty analyses on the model parameters and identify additional monitoring that may be needed to reduce uncertainty
- Track success of management actions
  - Conduct a literature review to quantify lag times associated with implementing BMPs impacted by historic nutrient loading (e.g., legacy sediments in streams and lakes, groundwater impacted by agriculture and onsite wastewater treatment systems)
  - Track BMP implementation and calculate credits
  - Conduct flow and water quality monitoring along jurisdictional boundaries
  - Conduct flow and water quality monitoring at tributary mouths
  - Update LOADEST analyses for annual reporting to the EMC

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 such as EUTROMOD would provide local governments with an estimate of annual baseline nutrient loading to Falls Lake from which to calculate Stage II reductions.

> In the long term, the EUTROMOD application could be updated as local data become available through future monitoring studies. Consistent with the recommendation that two fundamentally different modeling approaches be developed for Falls Lake and its watershed, Cardno ENTRIX recommends development of a mechanistic watershed model such as HSPF to be linked to the EFDC lake response model.

Long term monitoring and modeling studies are needed to support the Stage II requirements of the Falls Lake Nutrient Management Strategy. Because the reexamination of the Stage II rules may alter the structure of Stage II, the long-term studies should begin after the reexamination period. The list of preliminary recommendations assumes that some level of nutrient reductions will be required and that those reductions will be relative to a baseline year.

> Refine estimates of baseline loads

  - Conduct targeted areal loading rates studies for nutrients, carbon, and sediments
  - Continue monitoring flow and water quality at jurisdiction boundaries and tributary mouths
  - Conduct specific source loading studies that weren't conducted during short term studies (e.g., studies that were not funded or newly identified studies)
  - Develop refined EUTROMOD and HSPF models using local monitoring data to assign jurisdictional loads under baseline and management scenarios

Several monitoring and modeling studies have been recommended to support the reexamination of the Falls Lake rules. In general, these studies can be conducted during specific periods: immediate, short term, and long term. Given the potential costs of these studies, a strategic plan should be developed to modify existing programs to collect additional data, seek grants and cooperative funding agreements, petition agencies to conduct special studies, and combine multiple monitoring studies into coordinated sampling efforts.

It is important to note that the recommendations in this TM address the studies needed to reexamine the Falls Lake Nutrient Management Strategy as defined by the rules. There are other regulatory options that will be considered under Task 1 that may reduce the number of studies required. Task 1 will seek to compare and contrast the costs associated with various options (monitoring, modeling, litigation, required nutrient reductions) with the benefits (improvements in water quality, protection of drinking water supplies, etc.) to guide selection of the path forward.

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 reexamination 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 reexamination and to develop jurisdictional loads for regulatory and program implementation purposes:

> Task 1. Develop a Framework for a Reexamination 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 4 of this project has two main objectives. The first is to review the existing watershed and lake models developed by NCDWQ as the basis of the Falls Lake Nutrient Management Strategy. The second is to identify future studies that will support reexamination of Stage II of the Falls Lake Nutrient Management Strategy. These studies may include monitoring or modeling studies. Task 4 relies heavily on the database compiled for Task 2 of the project and the load estimation performed under Task 3 to identify gaps in knowledge and data.

The future monitoring and modeling studies described in this Technical Memorandum (TM) address the process for reexamination described in the Falls Lake Nutrient Management Strategy (collection of at least three years of data, updating modeling efforts, etc.). Based on the product from Task 1, the UNRBA may decide to pursue a path other than that laid out in the Falls Lake Nutrient Management Strategy. The final recommendations for future monitoring and modeling studies will depend on the path ultimately selected by the UNRBA.

This Technical Memorandum (TM) is organized into several sections to address the objectives of Task 4:

> Section 2 provides a review of the existing models developed by NCDWQ.

> Section 3 summarizes the data gaps identified in Tasks 2 and 3.

> Section 4 describes future modeling studies needed to support the reexamination process.

> Section 5 describes future monitoring studies needed to support the reexamination process.

> Section 6 summarizes the recommendations of the Nutrient Scientific Advisory Board with respect to future monitoring studies.

> Section 7 provides conclusions and recommendations for the UNRBA.

The overarching task for this project (Task 1) will incorporate the information compiled under Tasks 2, 3, and 4 and provides recommendations for dealing with the Stage II requirements. Task 1 will incorporate several additional sources of information including 1) consultation with legal counsel on the independent panel identified for this project, 2) coordination with the Path Forward Committee, and 3) results of meetings and discussions with NCDWQ.

1.2 Background Information

In 2010 the North Carolina 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 with the following purpose:

> "…attain 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 (2006) that NCDWQ established. For Stage I, the rules require local jurisdictions to establish requirements to control nutrient input from new development sources as well.

Stage II requires, based on NCDWQ modeling and evaluation, additional loading reductions that will result in an overall reduction of the mass of nutrients delivered to the Lake of 40 percent and 77 percent for total nitrogen and total phosphorus, respectively, relative to the baseline year. 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:

1.2.1 <u>Existing Development Stormwater Management</u>

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."

1.2.2 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.

1.2.3 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.

1.2.4 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 on agricultural lands. Stage II requires a 40 percent reduction in nitrogen loading and a 77 percent reduction in phosphorus loading by 2035. By March 2013, the Watershed Oversight Committee shall provide the 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.

1.2.5 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.

During implementation of the Falls Lake Nutrient Strategy, an interested party may submit supplemental nutrient response modeling of Falls Reservoir for approval by the EMC based on additional data collected after a period of implementation. The EMC may consider revisions to the Stage II requirements based on the following guidelines:

> (i) A person shall obtain Division review and approval of any monitoring study plan and description of the modeling framework to be used prior to commencement of such a study. The study plan and modeling framework shall meet any Division requirements for data quality and model support or design in place at that time. Within 180 days of receipt, the division shall either approve the plan and modeling framework or notify the person seeking to perform the supplemental modeling of changes to the plan and modeling framework required by the Division;
>
> (ii) Supplemental modeling shall include a minimum of three years of lake water quality data unless the person performing the modeling can provide information to the Division demonstrating that a shorter time span is sufficient;
>
> (iii) The Commission may accept modeling products and results that estimate a range of combinations of nitrogen and phosphorus percentage load reductions needed to meet the goal of the Falls nutrient strategy, along with associated allowable loads to Falls Reservoir, from the watersheds of Ellerbe Creek, Eno River, Little River, Flat River, and Knap of Reeds Creek and that otherwise comply with the requirements of this Item. Such modeling may incorporate the results of studies that provide new data on various nutrient sources such as atmospheric deposition, internal loading, and loading from tributaries other than those identified in this Sub-item. The Division shall assure that the supplemental modeling is conducted in accordance with the quality assurance requirements of the Division;
>
> (iv) The Commission shall review Stage II requirements if a party submits supplemental modeling data, products and results acceptable to the Commission for this purpose. Where supplemental modeling is accepted by the Commission, and results indicate allowable loads of nitrogen and phosphorus to Falls Reservoir from the watersheds of Ellerbe Creek, Eno River, Little River, Flat River, and Knap of Reeds Creek that are substantially different than those identified in Item (3), then the Commission may initiate rulemaking to establish those allowable loads as the revised objective of Stage II relative to their associated baseline values.

2 Review of Existing Models

NCDWQ developed two models to support development of the Falls Lake Nutrient Management Strategy. The Watershed Analysis Risk Management Framework (WARMF) model is a mechanistic model that simulates nutrient loading to Falls Lake resulting from processes that occur in the watershed. The Environmental Fluid Dynamics Code (EFDC) model was used to develop the Falls Lake Nutrient Response Model, which is a time series based mechanistic model of the processes within the lake that impact water quality. The time series used as inputs for the Falls Lake Nutrient Response Model are based on flow and water quality data collected in the watershed, and are not based on output from the WARMF model.

Much of the model background and development for the Falls Lake WARMF model was presented in the Task 3 TM. The Task 3 TM also described the SPAtially Referenced Regression On Watershed attributes (SPARROW) model developed by the USGS for the Neuse River Basin. Results from this model are described as well to provide another estimate of nutrient loading to Falls Lake.

This section of the TM describes the model development and uncertainties associated with two models used to develop the Falls Lake Nutrient Management Strategy.

2.1 Falls Lake Watershed Analysis Risk Management Framework (WARMF) Development

The Division of Water Quality (DWQ) published the results of the Falls Lake WARMF modeling to assess watershed loading of nitrogen and phosphorus to Falls Lake (NCDENR 2009b). The model was developed in cooperation with a Technical Advisory Committee (TAC) consisting of several members of the UNRBA, the North Carolina Department of Transportation (NCDOT), and the DWQ.

2.1.1 Model Development

The model inputs for the WARMF model were based on data collected from 2004 to 2007. Seven meteorology stations operated by the NC State Climate Office provided data for the weather inputs. The primary source for the land use data was the 2001 National Land Cover Data (NLCD) with enhancements based on City of Durham and NCDOT data. The WARMF model converts land use areas into percentages for each model catchment. For the Falls Lake watershed, the major land use categories are forest (58 percent), agriculture (18 percent), urban (11 percent), shrub/grassland (6 percent), water/wetlands (5 percent), and NCDOT (2 percent). Soils data were obtained from the USDA-NRCS Soil Data Mart and soil parameters were aggregated to the model catchment using weighted averages based on percent composition. Streambank erosion was accounted for in the model (NCDWQ 2009b) but loads are not explicitly reported as a source category.

Data from eight USGS flow gages were used to develop the model along with water quality data from six DWQ ambient monitoring stations and two USGS stations. Prior to March 2005, DWQ monitored the ambient stations monthly. From March 2005 to September 2007, the frequency was increased to twice per month to support the modeling studies.

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. The publicly available WARMF model was set up and calibrated by NCDWQ with some assistance from the model developers. This Falls Lake specific model application exists and can be modified.

Land use characterization is not simulated discretely in WARMF, but rather as a percent composition within each model subwatershed. Nutrient loading associated with land uses in the watershed are based on atmospheric deposition, soil erosion, and application of fertilizer or manure (agriculture or wildlife). Land application is specified for each land use on a monthly basis based on 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).

The WARMF model simulates the hydrologic and water quality impacts of nine reservoirs in the watershed. Atmospheric deposition data from NCDOT and the National Atmospheric Deposition Program were used to estimate wet and dry (NCDOT only) deposition rates of nitrogen. The land application module of WARMF was used to account for nutrient loading from fertilization or manure application on agricultural, urban, and NCDOT lands. Nutrients from biosolids are “implicitly included in the fertilizer application per crop data used in the model” (NCDWQ 2009b). WARMF simulates this application monthly.

Onsite wastewater treatment (septic and sand filter) systems were simulated as either normally functioning (85 percent of systems) or poorly functioning (15 percent of systems). Poorly functioning systems have higher pollutant concentrations, but discharge to the subsurface layer the same way as a normally functioning system. Failing systems that cause ponding and direct surface discharge are not simulated in WARMF. Half of sand filters 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 between 2004 and 2007. All permittees must report SSOs of 1,000 gallons or more and any SSO that reaches a waterbody.

2.1.2 Model Results

Falls Lake WARMF model results are presented in the Cardno ENTRIX Task 3 TM in Section 3.1.1. As described in the Task 3 TM, there is a high degree of uncertainty regarding the sources and total delivered nutrient loads estimated by the Falls Lake WARMF model. Watershed nutrient loads simulated by the WARMF model are 1.4 times and 2.0 times lower than those used as inputs to the Falls Lake Nutrient Response model developed by NCDWQ and do not correlate well with loads projected by the USGS SPAtially Referenced Regression On Watershed attributes (SPARROW) model, or with estimates predicted using LOADEST (see TM 3). For example, 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. The Stage II allocations for these parameters are 658,000 lb-N/yr and 35,000 lb-P/yr. Thus, the WARMF model results indicate that baseline nitrogen loads would require a 1 percent reduction and baseline phosphorus loads would require a 40 percent reduction to achieve the Stage II goals.

As described in TM 3, the SPARROW, LOADEST, and EFDC time series nutrient loading estimates are relatively similar to each other, but the WARMF model loading estimates are much lower. Cardno ENTRIX does not recommend relying on the existing WARMF model to allocate jurisdictional loads in the watershed, because there is considerable uncertainty associated with the total delivered load estimates as well as with the allocation of this load to the different sources.

2.1.3 Model Uncertainty

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 events with very large spikes in concentration that are outside of the range of realistic values (20 mg/L to 50 mg/L). Total phosphorus simulations are generally in the range of those observed. For some catchments, the trends in nitrogen and phosphorus do not match those observed, so when observed values are decreasing, simulated values are increasing, or vice versa.

As described in the Task 3 TM, there is a high degree of uncertainty regarding the sources and total delivered amount of nutrient loading estimated by the Falls Lake WARMF model. For example, Figure 2-1 compares the nitrogen loads simulated by the SPAtially Referenced Regression On Watershed attributes (SPARROW) model developed by the USGS (described in Section 3.2.1 of the Task 3 TM) to those predicted by the Falls Lake WARMF model. Loads predicted by both models represent the delivered loads from the upper lake tributaries (Eno River, Flat River, Little River, Knap of Reeds Creek, and Ellerbe Creek). Total nitrogen loads simulated by WARMF are approximately 64 percent of those simulated by the SPARROW model, and the sources of loading are inconsistent (see Task 3 TM for a description of the loading categories for both models). EFDC time series loads are similar to the SPARROW estimates (Figure 2-2) because these methods rely on observed flow and water quality data to estimate loads.

For total phosphorus WARMF predicted loads are approximately 56 percent of those estimated by SPARROW, and the relative contributions from the source categories differ as well (TM 3). The EFDC model estimates loading that is slightly higher than the SPARROW loads and twice those predicted by WARMF.

The discrepancies in loading between the watershed model and lake models reduce confidence in load allocations that may be assigned based on the existing modeling. The WARMF and SPARROW models are not 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 loading estimates (e.g., the EFDC model and the USGS Load Estimator (LOADEST) values presented in TM 3), 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.

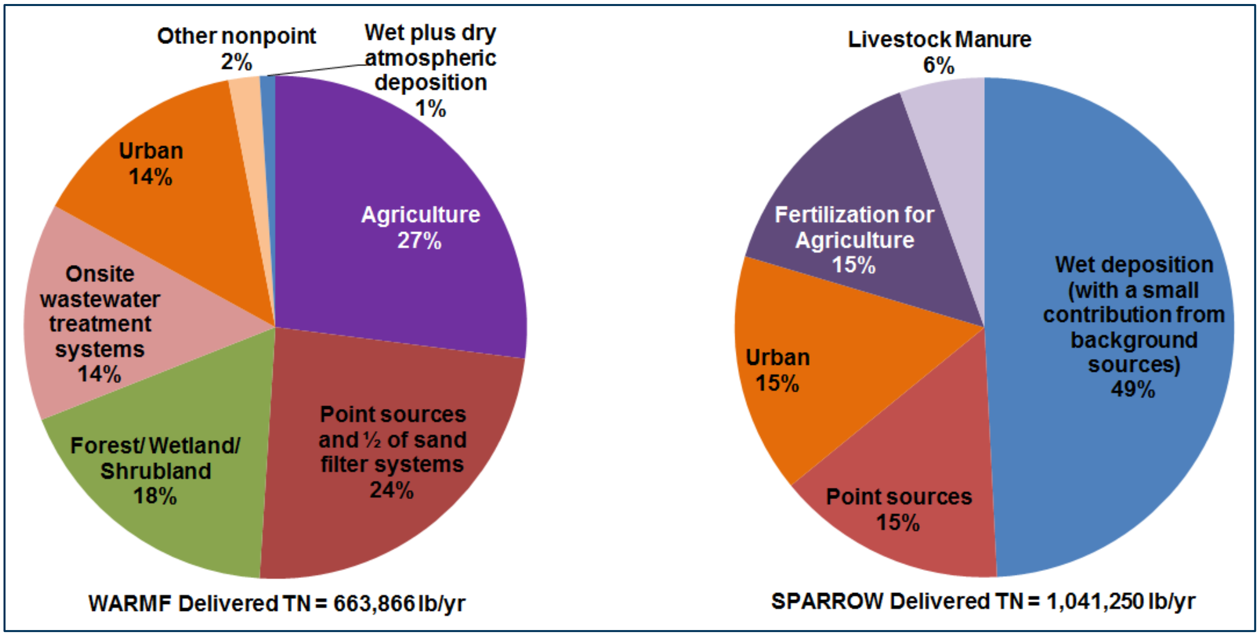


Figure 2-1 Comparison of Nitrogen Loads Predicted by the WARMF and SPARROW Models

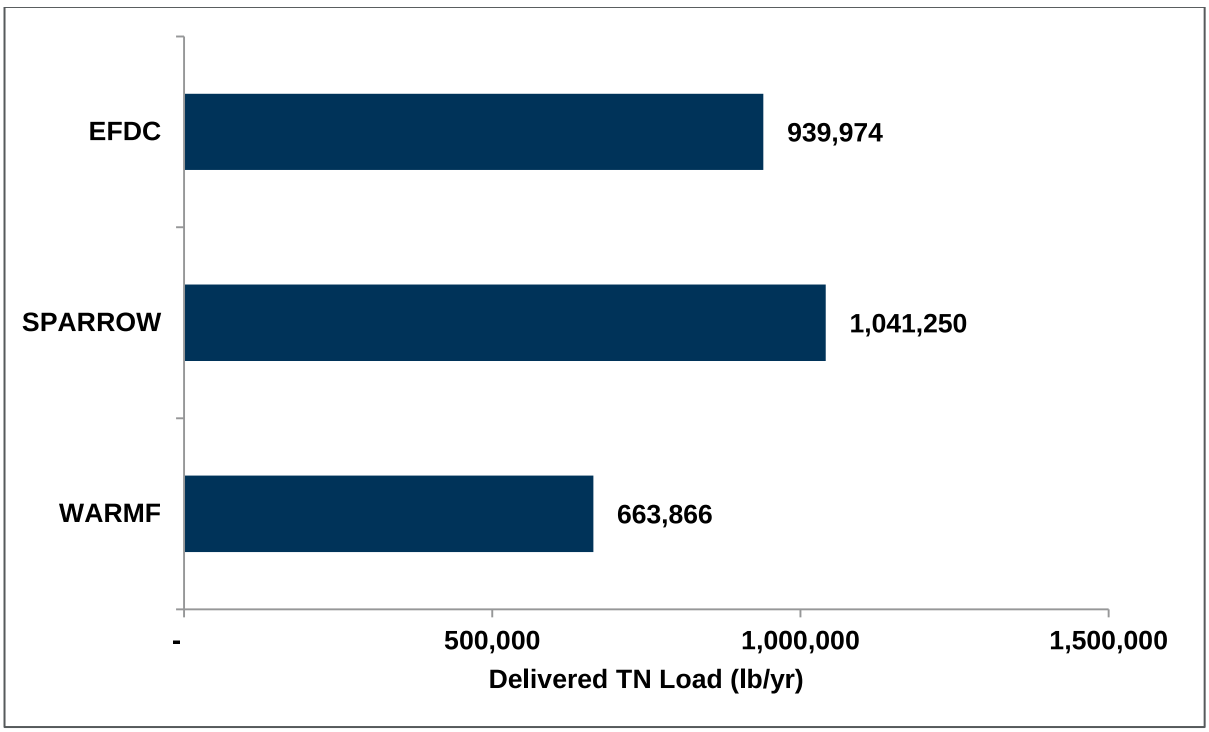


Figure 2-2 Comparison of Nitrogen Loads Predicted by the WARMF, SPARROW, and EFDC Models

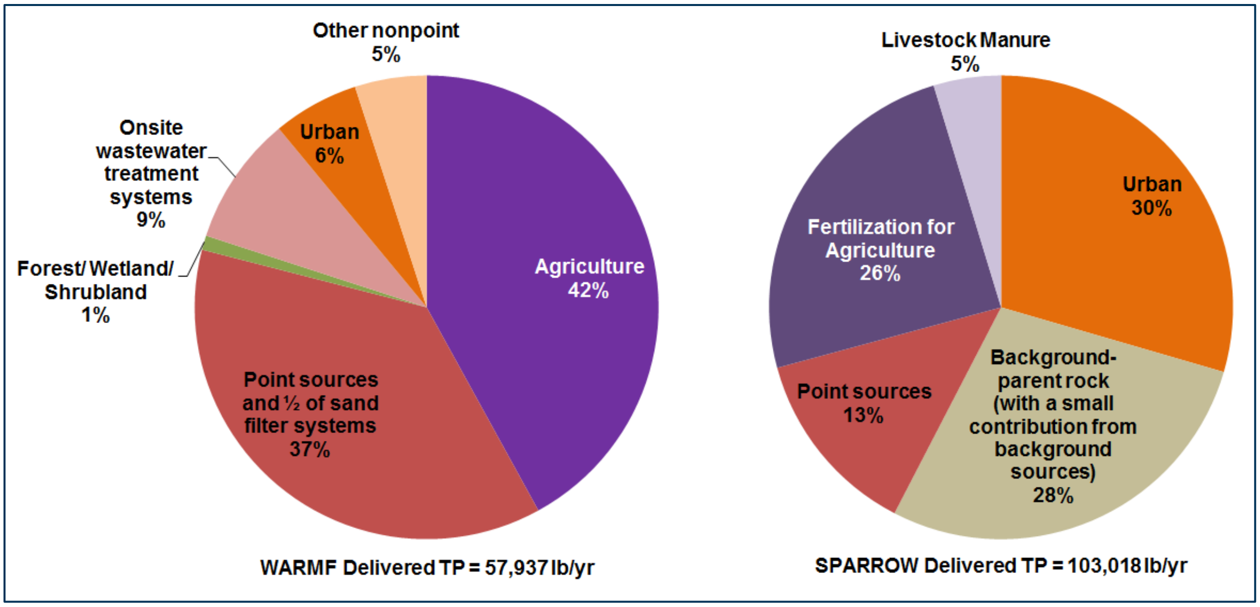


Figure 2-3 Comparison of Phosphorus Loads Predicted by the WARMF and SPARROW Models

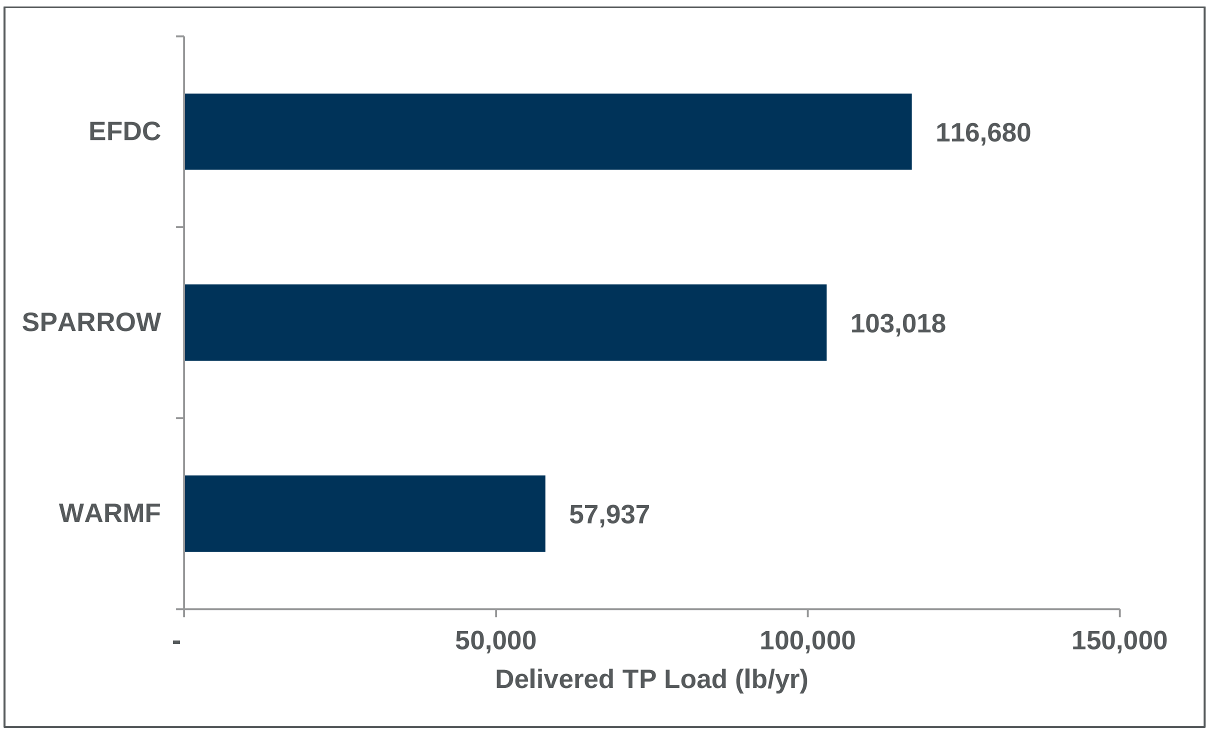


Figure 2-4 Comparison of Phosphorus Loads Predicted by the WARMF, SPARROW, and EFDC Models

2.2 Falls Lake Nutrient Response Model

To provide the basis for setting the loading targets in the Falls Lake Nutrient Management Strategy, NCDWQ developed a Falls Lake Nutrient Response Model using the Environmental Fluid Dynamics Code (EFDC) model (NCDENR 2009a). The EFDC model is a three dimensional hydrodynamic/water quality model capable of simulating eutrophication with multiple algal species including cyanobacteria, diatoms, and green algae.

2.2.1 Model Development

The model grid representing Falls Lake was developed using 519 cells and four vertical layers. Reservoir bathymetry was developed using 17 transects measured by DWQ in 2005 along with USGS 24K topography and digital elevation model data from the flood mapping program. The Falls Lake nutrient response model was developed using data collected from 2005 to 2007 from many of the same agencies used to develop the WARMF model: USGS flow and water quality data, DWQ ambient monitoring data, NC State Climate office meteorological data, and NADP atmospheric deposition data.

Flows from gaged watersheds were estimated by scaling up flows at the mouth of each tributary by the drainage area ratio for the tributary relative to the gage. For ungaged tributaries, the drainage area ratios used to derive flow were allowed to vary by plus or minus 15 percent. The ratios varied by year as well, and were determined using the judgment of the modeler through model sensitivity runs (NCDENR 2009a).

Monitoring data were used to develop the model input files developed at a 30 second time step. TSS, nitrogen, and phosphorus inputs were generated using DWQ ambient monitoring data collected in tributaries to the lake. Chlorophyll *a* and TOC inputs were generated using observations collected in the lake at the closest station to the tributary being simulated. The EFDC modeling grid and water quality monitoring stations are shown in Figure 2-5.

DWQ measured benthic flux rates of ammonia, nitrite plus nitrate, and total phosphorus in April 2006. Ammonia fluxes were observed at two locations and were approximately 0.01 and 0.05 $g/m^2/d$. Ammonia flux is also evident in the depth plots provided for the Upper and Lower Lake samples. The Task 2 TM shows that highest ammonia concentrations were observed in the bottom depths of the Upper Lake section. Measured nitrite plus nitrate and total phosphorus fluxes were insignificant, and the box plots of these parameters support the conclusion that these fluxes are negligible across the lake as a whole: surface concentrations of nitrite plus nitrate and total phosphorus are higher than middle or bottom depths (Task 2 TM). Note that the box plot summaries in the Task 2 TM include all samples and locations within the lake segment (Upper versus Lower) and that localized benthic releases would not be evident at this scale. DWQ also measured sediment oxygen demand, and the average rate observed was -1.4 $g/m^2/d$.

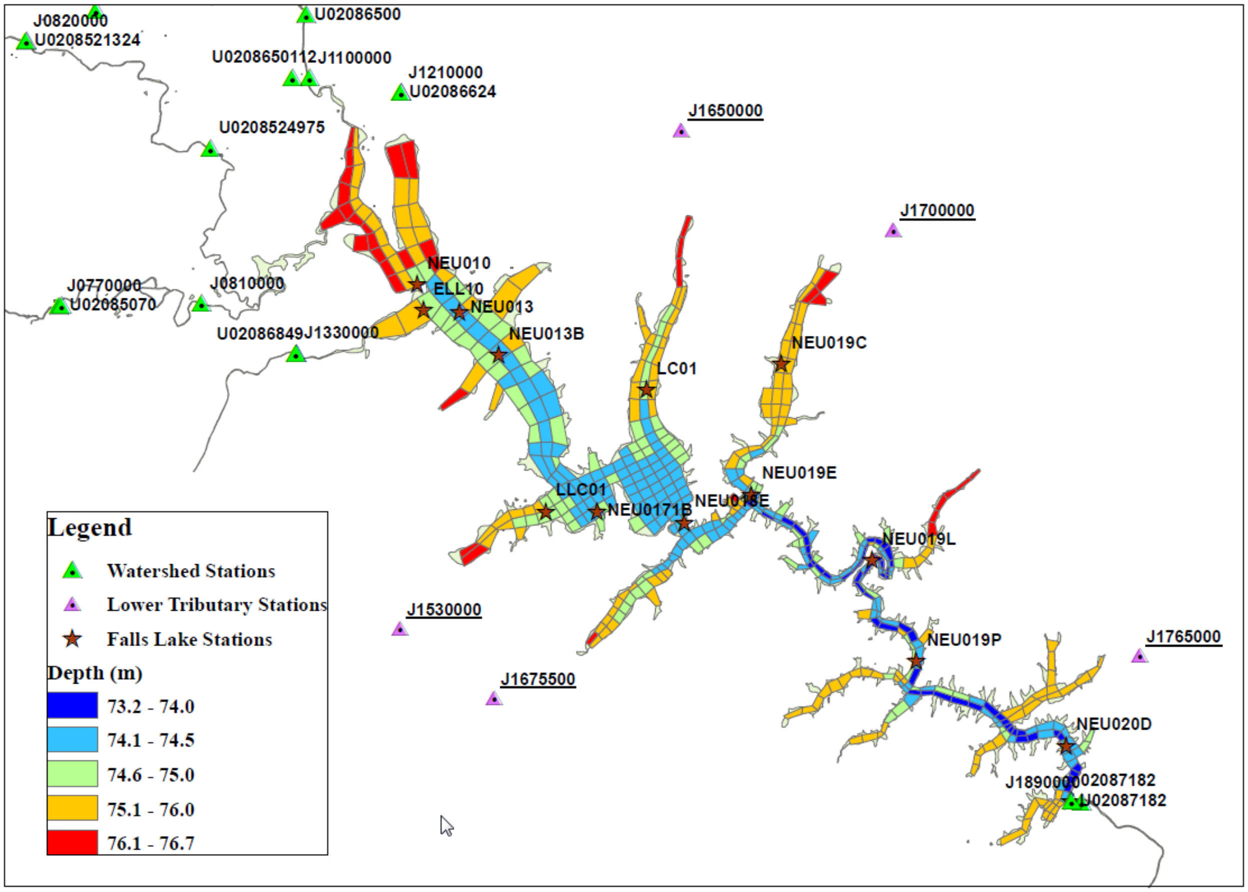


Figure 2-5 Falls Lake EFDC Modeling Grid (from NCDENR 2009a)

2.2.2 Model Uncertainty

There are several sources of uncertainty regarding the development and application of the Falls Lake EFDC model. First, simulated nutrient loads to Falls Lake from the five major tributaries for the baseline year (2006) are 939,974 lb-N/yr and 116,680 lb-P/yr. These loads are 1.4 times and 2.0 times higher than those estimated using the WARMF model (Section 2.1). Ideally, when watershed and lake response models are developed for a given waterbody, the results should be somewhat similar even if the models cannot be formally linked. In addition, simulated loading to the Lower Lake is also highly uncertain since there are no flow gages in this part of the watershed, many of these tributaries are intermittent with little to no discharge in the summer, and water quality monitoring has not occurred at the same frequency and for the same length of time as the upper lake monitoring.

Second, the Falls Lake nutrient response model was calibrated separately for years 2005 and 2006, and then validated for year 2007 using the 2005-based calibration. Thus year 2006, which was used as the basis for determining the load allocations, was never validated using an independent data set. Extending the modeling period to include a greater range in hydrologic variability will provide greater confidence in simulations of lake response.

Third, when NCDWQ developed the lake response model, there were no chlorophyll *a* data collected at the mouths of the tributaries. To provide an input for the time series for each tributary, NCDWQ assumed that the chlorophyll *a* concentration at the mouth of each tributary was equal to observations collected at the nearest lake station. This assumption not only affects model development and calibration, but also the simulated response to nutrient reductions. Additionally, as nitrogen and phosphorus reductions were assumed in the watershed as a result of Stage I and Stage II implementation, the chlorophyll *a* inputs to the lake were not altered (neither were TOC or TSS). It is expected that nutrient reductions in the tributaries would also reduce chlorophyll *a* concentrations in the tributaries. In-Lake chlorophyll *a* concentrations predicted by the model are sensitive to tributary chlorophyll *a* levels. Maintaining the baseline tributary chlorophyll *a* concentrations results in higher inlake chlorophyll *a* concentrations relative to what would be expected with reduced nutrient loading. Finally, benthic flux rates were also assumed to remain at existing levels.

To compare the impacts of the tributary chlorophyll *a* concentrations on simulated chlorophyll *a* concentrations at the compliance point (NEU013B), Cardno ENTRIX ran four scenarios with the 2006 EFDC model: baseline, Stage I reductions, baseline with tributary chlorophyll *a* concentrations set to 10 µg/L continuously, and Stage I reductions with tributary chlorophyll *a* concentrations set to 10 µg/L continuously. The results are shown in Figure 2-6. The model shows that in 2006, there was a spring bloom in early May. Through the remainder of that year, chlorophyll *a* concentrations remained above the standard 40 µg/L until late December and were greater than that standard 52 percent of the time (baseline). With Stage 1 reductions, the concentrations would have been slightly less with concentrations greater than the standard one-third of the time. If chlorophyll *a* concentrations were held to a constant 10 µg/L throughout the year at year 2006 nutrient loading levels, the standard would be exceeded at NEU013B 35 percent of the time. A combination of Stage 1 reductions and chlorophyll *a* concentrations at 10 µg/L lessened the concentration during the spring bloom and throughout the summer with the standard only consistently being exceeded starting in October. Simulated percent exceedance at the compliance point is 20 percent of the time for this scenario. Thus the model is highly sensitive to the assumption regarding tributary chlorophyll *a* concentrations, and predicted exceedance varies by 15 percent for a given loading scenario.

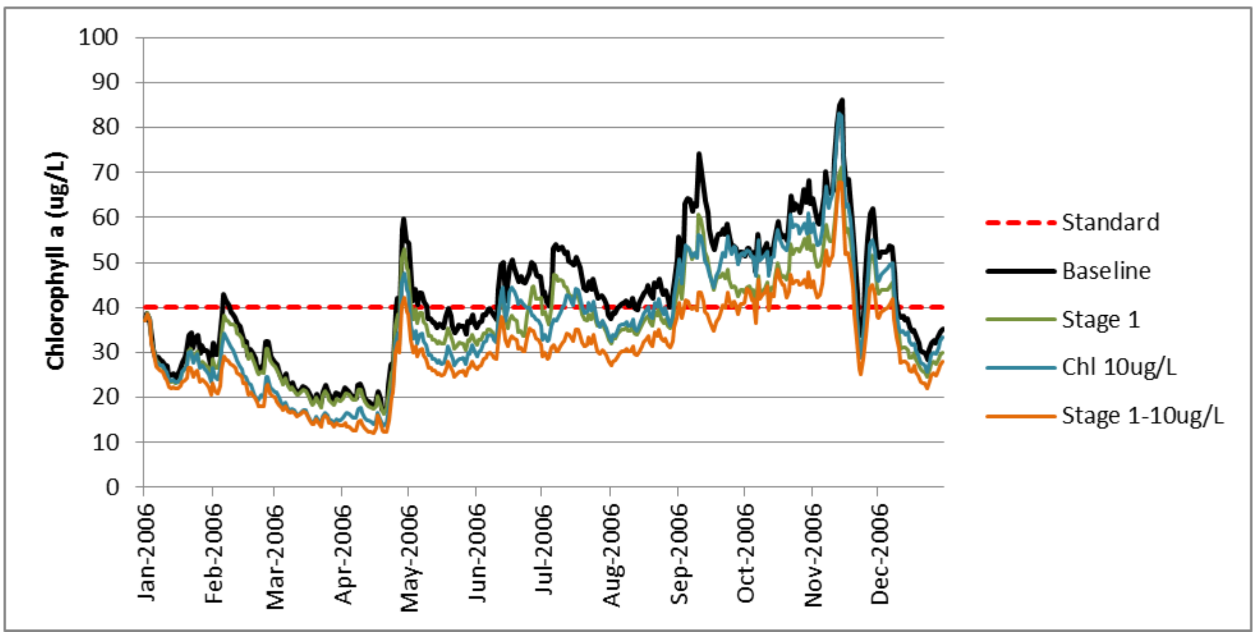


Figure 2-6 Sensitivity of the EFDC Model to Tributary Chlorophyll *a* Assumptions for Baseline and Stage I Scenarios (at NEU013B)

Fourth, the current version of the Falls Lake EFDC model assumes that lake processes do not vary spatially in the lake. For example, background light extinction, nutrient flux, and sediment oxygen demand are assumed to be the same across the entire lake and do not vary within the arms or longitudinally along the center of the lake. Given the size and loading patterns to Falls Lake, these rates likely vary spatially, but existing data are not available to characterize spatial variation.

Fifth, there is also uncertainty regarding how the model output was used to set the required nutrient load reductions. The model was used to determine the limiting factors on algal growth at various locations in the lake (Figure 2-7). With respect to nitrogen and phosphorus limitation, in the upper part of the lake, algal growth is nitrogen limited between 70 percent and 80 percent of the time, and phosphorus limited 20 to 30 percent of the time. Further down the lake, the percent of time N and P limit algal growth is more similar, but nitrogen limits algal growth more frequently than phosphorus at every location that was assessed (13 stations along the length of the lake). It is not clear why the Falls Lake Rules require much higher phosphorus load reductions relative to nitrogen when nitrogen seems to be limiting algal growth 70 percent to 80 percent of the time in the upper part of the lake.

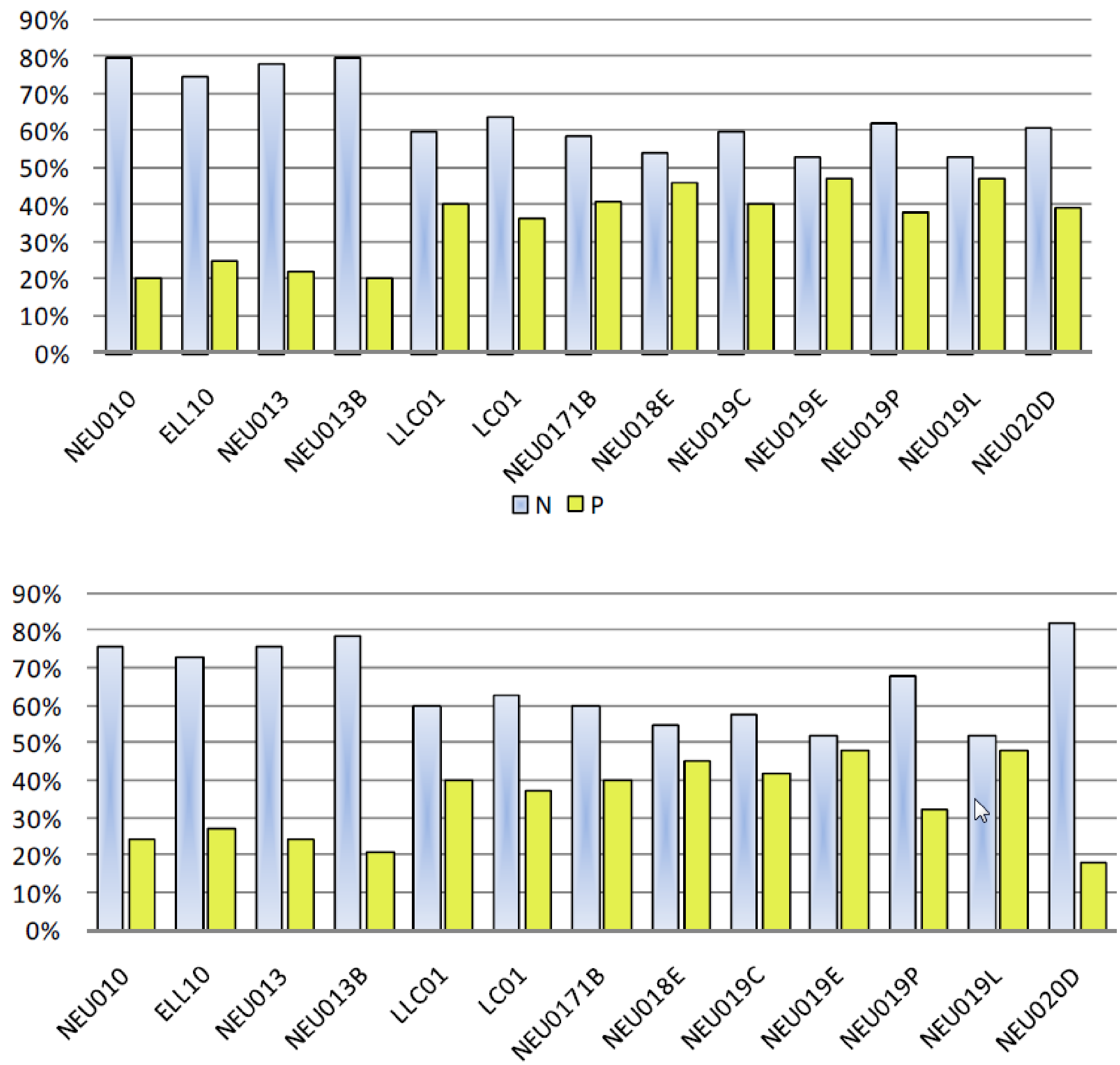


Figure 2-7 Percent of Time Algal Growth is Limited by Nitrogen or Phosphorus at the Surface Layers (Top Panel) and Bottom Layers (Bottom Panel) in Year 2006 (from NCDENR 2009a)

Sixth, there is uncertainty regarding the appropriateness of selecting year 2006 as the baseline year. Typically, load allocations such as the Falls Lake Nutrient Management Strategy are developed using multiple years to determine the load reduction requirements for a waterbody. This approach accounts for various hydrologic conditions (wet, dry, and average years) and prevents allocations based on conditions that may have been impacted by extreme events, such as hurricanes or severe droughts. For the purposes of developing the Falls Lake model, 2005 and 2007 were considered dry years and 2006 was considered a normal year based on total annual precipitation. While annual precipitation for year 2006 may be similar to the annual average, analysis of monthly totals shows that year 2006 was not an average year (Figure 2-8). Rainfall during the months of January to May was generally less than the long-term monthly averages. In June 2006, the total monthly rainfall was approximately 11 inches higher than the long-term average for that month due to Tropical Storm Alberto which deposited up to 8 inches of rainfall in the lower part of the watershed and up to 4 inches in the upper part. In November, the total monthly rainfall was approximately 3 inches higher than the long-term average.

As a result, monthly inflows to the lake were significantly impacted by the rainfall patterns. Inflows from January to May were very low compared to the long-term averages observed during those months, and these low inflow months followed a drought year (2005). Inflows in June and November of 2006 were 3 to 4 times higher than those typically observed. Also, the precipitation input for year 2006 used to drive the EFDC model for Falls Lake indicates an annual precipitation of over 88 inches. The USGS reports a total annual rainfall at Falls Lake above the dam of approximately 48 inches in 2006. It is unclear how this discrepancy in precipitation to the lake surface impacts model results.

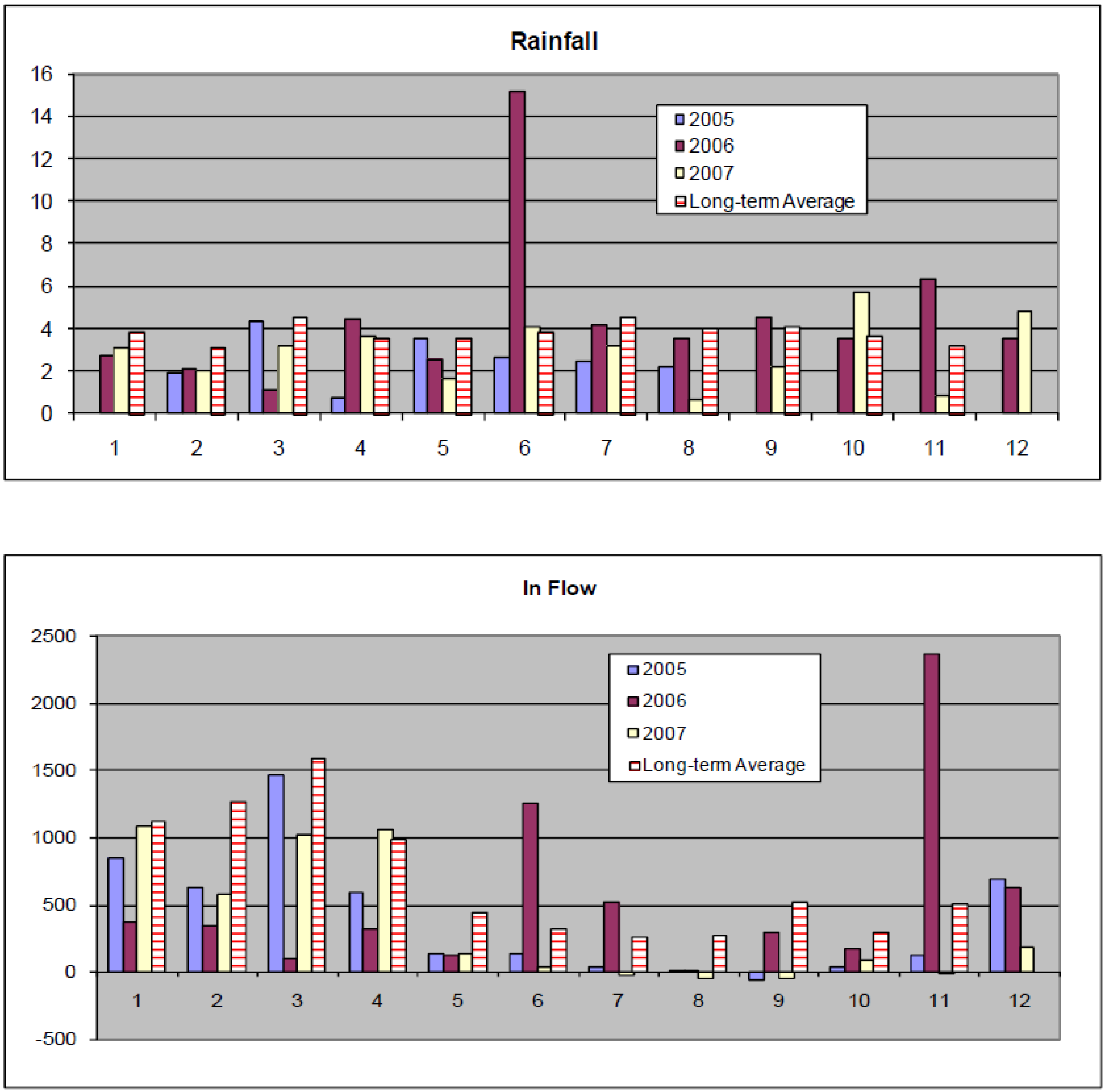


Figure 2-8 Monthly Rainfall (Top Panel, inches) and Monthly Inflow (Bottom Panel, monthly average cfs) Relative to the Longer Term Average (from NCDENR 2009a)

3 Data Gaps Identified in Task 2 and Task 3

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.

3.1 Task 2 Data Gaps

Data needs (gaps) to estimate nutrient loads and to support models are appropriately assessed using sensitivity and uncertainty analyses with the models to be applied. For nutrient loads, the model typically is a “rating curve” based on flow-concentration relations or a watershed loading model that simulates runoff and associated nutrient loads. For the reservoir and watershed, the models may be process-based (e.g., the Falls Lake Nutrient Response Model and the Falls Lake Watershed Model) or empirical (e.g., USGS SPARROW).

Identification of data needs is a “value of information analysis” (VOIA). A data gap exists if additional monitoring to fill that gap can improve knowledge and reduce uncertainty, leading to better-informed decision making at an acceptable cost. The VOIA requires a model that links management actions to desired outcomes, such as linking stormwater treatment to water quality standards compliance. Once reservoir and watershed models are selected, the model(s) can be run to determine quantitatively (using sensitivity/uncertainty analyses) what additional monitoring is most cost-effective (improves prediction at acceptable cost).

One obvious gap is the absence of measured tributary chlorophyll *a* and TOC loads for developing the input files for the EFDC lake response model. Collection of chlorophyll *a* and TOC data in the tributaries just upstream of the lake would provide more accurate information from which to base simulations of lake response (as demonstrated in Section 2.2 the EFDC model is sensitive to these inputs). Limited data exists for other parameters in the segments just upstream of the lake.

Table 3-1 summarizes the sample size for each parameter and segment. Each waterbody or lake segment is followed by a category that represents the distance upstream from the Lake or if in the Lake, the distance upstream from the dam. Highway 50 divides the Lake into upper and lower segments. For example, Upper Lake, 13-18 represents samples taken in Falls Lake upstream of Highway 50 between 13 and 18 miles upstream of the Falls Lake Dam. Eno River, 0-2 represents samples taken in the Eno River from its mouth up to 2 miles upstream of the Lake.

The segments near the lake with a small sample size relative to the other segments in the watershed are shaded in Table 3-1. For each parameter, the smallest sample sizes are typically associated with the segment from 0 to 2 miles upstream from the lake and the Beaverdam Impoundment. Collection of additional data in these segments will support refinement of tributary load estimates and future lake response modeling. The downstream segments 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. Obtaining water quality at these locations may be complicated by limited public access and extreme variations in flow that can include intermittent stream conditions.

Table 3-1 Sample Size by Subwatershed and Lake Segment

Sub-watershed and Distance Upstream[1]	TSS	Ammonia	NO2/ NO3	Organic Nitrogen	Ortho-Phosphorus	Total Phosphorus	Chlorophyll *a*	Total Organic Carbon
Beaverdam Creek, 0-2	18	19	15	15	17	15	0	0
Beaverdam Creek, 2-10	0	30	0	30	30	30	0	0
Ellerbe Creek,0-2	153	225	453	222	40	444	0	11
Ellerbe Creek, 2-10	216	225	214	215	3	265	0	27
Eno River, 0-2	58	69	115	68	4	118	0	5
Eno River, 2-10	172	184	231	182	35	237	0	5
Eno River, >10	181	289	280	275	99	270	182	85
Flat River, 0-2	113	201	214	199	95	248	0	1
Flat River, 2-10	65	44	51	44	3	53	0	0
Flat River, >10	0	1	1	1	1	1	0	0
Horse/Barton/Cedar Creeks, 0-2	78	78	76	76	76	76	0	0
Horse/Newlight Creeks, 0-2	45	50	41	42	44	41	0	0
Knap of Reeds Creek, 0-2	80	137	147	136	9	147	0	10
Lick Creek, 0-2	31	36	36	36	5	36	0	5
Lick Creek, 2-10	57	85	85	85	29	85	0	8
Little River, 0-2	0	3	0	3	3	3	0	0
Little River, 2-10	145	426	456	424	360	504	0	53
Upper Falls Lake, >21	146	397	1109	917	834	621	911	161
Upper Falls Lake, 18-21	102	89	177	89	105	89	160	67
Upper Falls Lake, 13-18	206	947	699	394	410	398	433	267
Beaver Dam Impoundment	23	0	56	0	0	0	120	56
Lower Falls Lake,8-13	131	195	262	90	89	120	353	193
Lower Falls Lake, 4-8	161	284	644	276	263	277	434	637
Lower Falls Lake ,0-4	223	91	444	192	181	230	617	320

[1] Within each geographic area or waterbody the data is presented by distance upstream from the lake or upstream from the dam.

Note: Shaded cells correspond to segments located near the lake boundary with relatively small sample sizes.

3.2 Task 3 Data Gaps

3.2.1 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. Stage I loads may be developed in coordination with NCDWQ, or solely by NCDWQ if a local government does not choose to participate. Because the Falls Lake Nutrient Management Strategy requires that Stage I loads be reported to the EMC in July 2013, NCDWQ has requested that local governments submit their estimates in the first quarter of 2013 to allow time to assimilate the information and finalize the report.

Several of the local governments in the Falls Lake watershed are well positioned to provide Stage I loading estimates to NCDWQ in the first quarter of 2013. 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.

TM 3 described three methods for calculating Stage I loads: two are stormwater load accounting tools and one is based on simplified 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, simplified 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 in early 2013 rather than estimates based on the simplified 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 is 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. Local governments will need to identify developments that were approved in the interim period but not developed prior to July 2012. These developments are not subject to the New Development Rules and will need to be allocated as part of the Stage I loading unless the development plans were terminated.

3.2.2 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 presently 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 eventual reduction 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 (conventional and sand filter 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 that are described in Section 5.

3.2.3 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 3-1. Collection of additional data in these segments will support tributary load estimation and future lake response modeling.

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 described in Section 5 may be used to fill these data gaps.

4 Future Modeling Studies

Three types of modeling studies are proposed to support the reexamination of Stage II of the Falls Lake Nutrient Management Strategy: 1) watershed modeling is needed to allocate loads to the sources and jurisdictions in the watershed, 2) lake response modeling is needed to simulate lake water quality in response to various input conditions, and 3) empirical modeling is needed to link nutrient loads and lake water quality to designated uses. This section of the TM briefly describes the types of models and their potential application for Falls Lake. The watershed models and lake models have been described in previous sections of this TM as well in TM 3.

4.1 Watershed Modeling Framework

The types and applications of watershed models were discussed in Section 3 of Task 3 TM. To summarize, there are two types of watershed models applicable for the reexamination of Stage II: empirical models and mechanistic models. There are existing models of both kinds (USGS SPARROW and WARMF, respectively), but neither are capable of assigning jurisdictional loads for the baseline year with a high degree of confidence. This section of the TM describes several types of mechanistic and empirical models that may be used for the Stage II jurisdictional load estimates. At the request of the UNRBA, the same set of models evaluated by the Nutrient Scientific Advisory Board to support the revised Jordan Lake model are included in this discussion. All of the watershed models are limited by their ability to deal with legacy nutrient loading in the simulation of sediment and water quality.

The models discussed in this section range in complexity in terms of model inputs and capabilities. The increased complexity of models such as WARMF, HSPF, and LSPC means increased data needs or additional reliance on the scientific literature to calibrate the model to a specific watershed. The additional reliance on the scientific literature may be considered a limitation for the more complex model frameworks. The more simplified models such as EUTROMOD and GWLF require less data inputs but are limited in their ability to drive time series dependent lake response models, directly simulate impacts of site level BMPs, etc.

4.1.1 <u>Mechanistic Watershed Models</u>

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 briefly describes several mechanistic models that may be used in Falls Lake. At the request of the UNRBA, the models described are consistent with those evaluated by the Nutrient Scientific Advisory Board for the modeling effort for Jordan Lake.

4.1.1.1 WARMF

NCDWQ developed a Watershed Analysis Risk Management Framework (WARMF) model of the Falls Lake watershed to support the development of the Falls Lake Nutrient Management Strategy. The WARMF model was developed by Systech Engineering to allow stakeholders to develop and evaluate water quality alternatives. The graphical user interface (GUI) of the WARMF model allows the user to switch between the model and various scenarios to calculate pollutant TMDLs. The model simulates both the watershed processes and a simplistic representation of reservoirs.

The WARMF model is a lumped model which aggregates like land uses within a subwatershed and simulates the runoff and pollutant behavior within each. The model simulates runoff through canopy interception, snow dynamics, infiltration through the soil layers, evapotranspiration, and groundwater flows to the stream. The chemistry of the model heavily emphasizes the interaction between dry deposition and the canopy. WARMF can incorporate BMP actions in the watershed such as buffer strips, street sweeping, livestock exclusion, and fertilizer reduction. The model can represent water quality kinetics in the streams and reservoirs. The WARMF model framework was applied to the Falls Lake watershed using a digital elevation model and 2001 land use data. The Falls Lake WARMF model is also undergoing upgrades by the City of Durham in order to capture City monitoring data, isolate Orange County delivered loads in the Eno River, and reduce the time step to hourly.

WARMF is a proprietary model framework that was made publically available in the EPA BASINS 3 package. During this period of public availability, several states used the model framework to develop Total Maximum Daily Loads and management strategies. WARMF is no longer made available in the EPA BASINS package. The model framework source code continues to be proprietary, although any application of WARMF, such as the Falls Lake application, is not proprietary.

The WARMF model has several limitations with respect to estimating Stage II jurisdictional loads:

> The existing model is not well calibrated to observed nutrient loads entering Falls Lake.

> The model does not account for age or distance from a stream or groundwater when calculating loads from onsite wastewater treatment systems (septic or sand filter).

> The model does not simulate legacy groundwater or legacy sediment nutrient concentrations.

> The model does not output total organic carbon.

4.1.1.2 GWLF

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 (Tetra Tech 2003). 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 nutrient processes are not simulated directly with GWLF, but the ArcView version of the model is capable of simulating sediment transport in the reaches. 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 GWLF model has several limitations with respect to estimating Stage II jurisdictional loads:

> The model does not account for age or distance from a stream or groundwater when calculating loads from onsite wastewater treatment systems.

> The model does not account for nutrient loading associated with streambank erosion.

> The model does not simulate legacy groundwater or legacy sediment nutrient concentrations.

> The model does not simulate instream transport processes or nutrient trapping in watershed impoundments.

> The model is not accurate at a daily time step (needed if watershed model is to drive a time series based lake response model).

4.1.1.3 SWAT

The Soil and Water Assessment Tool (SWAT) is a river basin or watershed model that was developed for the USDA. The model's primary focus is on the simulation of agricultural practices in large watersheds with varying soils, land use, and management conditions over long periods of time. The model is intended to study long term impacts.

The SWAT model divides a watershed into smaller subwatersheds and develops hydrologic response units for each combination of soil and vegetation type. The model simulates hydrology via runoff, infiltration, and evapotranspiration. Its emphasis is shown through its description of plant growth and water/nutrient uptake and agriculture practices (planting, tillage, irrigation, fertilization harvesting, etc.). Urbanized areas incorporate atmospheric deposition via buildup/wash off functions. The model represents instream processes (nutrient transformation, sedimentation, scour) and BMPs on daily time scales.

The SWAT model has several limitations with respect to estimating Stage II jurisdictional loads:

> The model does not account for age or distance from a stream or groundwater when calculating loads from onsite wastewater treatment systems.

> The model does not account for nutrient loading associated with streambank erosion.

> The model does not simulate legacy groundwater or legacy sediment nutrient concentrations.

> The model does not simulate nutrient trapping in watershed impoundments.

4.1.1.4 HSPF

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 coverage 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. 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.

As with the other watershed loading models, the HSPF model is not equipped to simulate legacy groundwater or legacy sediment nutrient concentrations. Most of the limitations associated with the other models can be overcome in HSPF by using the special actions portion of the model input file to develop new rules for the model (e.g., accounting for age or distance from a stream or groundwater when calculating loads from onsite wastewater treatment systems).

The HSPF model has several limitations with respect to estimating Stage II jurisdictional loads:

> The model does not directly account for nutrient loading associated with streambank erosion (it accounts for stream sediment transport capacity relative to upland sediment loads). However, it has the capacity to incorporate relationships between flow depth and sediment which would need to be calibrated using local information.

> The model does not simulate legacy groundwater or legacy sediment nutrient concentrations.

4.1.1.5 LSPC

The Loading Simulation Program in C++ (LSPC) is a watershed model that is based on HSPF but written in a more modern programming language that provides some computational benefits. By writing the model algorithms in C++, LSPC overcomes some model size limitations that are inherent in the Fortran code based HSPF. LSPC uses Microsoft Access to interface with the model and its graphical user interface (GUI).

LSPC has much of the same functionality as HSPF. Its use of C++ allows for some efficiency in developing model input files where HSPF requires binary input files. Two significant differences between HSPF and LSPC is that HSPF has the ability to route runoff between modeled land categories (e.g. across a filter strip) and special actions may be specified within HSPF to develop a set of rules to change model setup during the simulation.

As with the other watershed loading models, the LSPC model is not equipped to simulate legacy groundwater or legacy sediment nutrient concentrations. Most of the limitations associated with the other models can be overcome in HSPF by coding special actions (e.g., accounting for age or distance from a stream or groundwater when calculating loads from onsite wastewater treatment systems).

The LSPC model has several limitations with respect to estimating Stage II jurisdictional loads:

> The model does not directly account for nutrient loading associated with streambank erosion (it accounts for stream sediment transport capacity relative to upland sediment loads). However, a version of the model has been developed which develops a power relationship between depth and bank erosion. Local data would need to be collected to calibrate those model parameters

> The model does not simulate legacy groundwater or legacy sediment nutrient concentrations.

4.1.1.6 PC-SWMM/XPSWMM

The Stormwater Management Model (SWMM) is available in two versions. The EPA has a publically available version PC-SWMM and XPSoftware has a proprietary version (XPSWMM). The two models are based on the same premise of focusing on stormwater transport in an urbanized system. The model can simulate urban BMPs, hydrology, and hydraulics. The model runs at sub-hourly time scales and simulates both hydrology and water quality.

The SWMM model simulates overland water quantity and quality produced by storms in urban watersheds. Several modules or blocks are included to model a wide range of quality and quantity watershed processes. A distributed parameter sub-model (RUNOFF) describes runoff based on the concept of surface storage balance. The rainfall/runoff simulation is accomplished by the nonlinear reservoir approach. The lumped storage scheme is applied for soil/groundwater modeling. For impervious areas, a linear formulation is used to compute daily/hourly increases in particle accumulation. For pervious areas, a modified Universal Soil Loss Equation (USLE) determines sediment load. The concept of potency factors is applied to simulate pollutants other than sediment.

Infiltration is calculated using the Horton or Green-Ampt methods, at the user's choice. A version of Manning's equation is used to estimate flow rate from the subcatchment area based on a conceptual model of the subcatchment as a "nonlinear reservoir." The lumped storage scheme is applied for soil and groundwater modeling. For impervious areas, a linear formulation is used to compute daily and hourly increases in particle accumulation. For pervious areas, a modified Universal Soil Loss Equation (USLE) determines sediment load. The concept of potency factors is applied to simulate pollutants other than sediment.

Transport block has kinematic wave routing of flow and quality, base flow generation, and infiltration capabilities, and it routes flow through user-defined system ranges from natural channel to concrete pipes. The EXTRAN block carries out a numerical solution of the complete St. Venant equations for the urban drainage ways and conduits, by modeling the network as a link-node system (cf., DYNHYD). SWMM can directly be interfaced with EPA's WASP receiving water quality model.

Like the other detailed watershed models, SWMM divides a watershed into smaller catchments. Rainfall infiltration is calculated via two methods (Horton or Green-Ampt) in PC-SWMM and sediment runoff calculated via a modified USLE. XPSWMM employs ten different runoff options and has more options for subsurface and groundwater flows. Each model has a sediment scour capability within the drainage networks. Urban BMPs can be represented in either modeling environment. Model output can be produced on sub-hourly time scales

XP-SWMM is an enhanced version of SWMM coupled with the XP interface. The graphical EXPERT environment (XP) is a friendly, graphics-based environment that encompasses data entry, run-time graphics, and post-processing of results in graphical form. Drainage networks are drawn either on the screen over real-world topographical backgrounds or imported from a database. It has the ability to handle systems comprising pipes and open channels, rivers, loops, bifurcations, pumps, weirs, and ponds

In addition to EPA SWMM's Non-linear Runoff Routing, XP-SWMM has 10 additional ways to estimate surface runoff:

1. SCS Unit Hydrographs using a Curve Number with curvilinear unit hydrographs
2. SCS Unit Hydrographs using a Curve Number with triangular unit hydrographs
3. Kinematic Wave
4. Snyder Unit Hydrograph
5. Snyder (Alameda) Unit Hydrograph
6. Nash Unit Hydrograph
7. Santa Barbara Urban Hydrograph
8. Laurenson's Non-linear Runoff Routing (RAFTS)
9. Rational Method
10. Colorado Urban Hydrograph Procedure (CUHP)

The model has more capabilities in infiltration, sub-surface flow, and groundwater flow than that of EPA SWMM. In addition to SWMM capabilities, pollutant routing is available for all modules, including the Hydraulics layer. More than 30 types of conduits can be input into the model.

The SWMM models have several limitations with respect to estimating Stage II jurisdictional loads:

> The SWMM model is primarily used for urban areas and does simulate onsite wastewater treatment systems, streambank erosion, groundwater, and/or agriculture.

> The model does not simulate instream transport processes or nutrient trapping in watershed impoundments.

> The model is not accurate at a daily time step (needed if watershed model is to drive a time series based lake response model).

4.1.2 Empirical 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). Empirical models can be more flexible in terms of the questions they can address, because they have fewer parameters than mechanistic models, which make it possible to perform error analysis on the empirical model's predictions. Two examples of empirical watershed loading models are presented in this section.

4.1.2.1 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 (approximately 20 years) 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 (m3/yr) divided by reservoir surface area (m2).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).

The SPARROW model has several limitations with respect to estimating Stage II jurisdictional loads:

> Model output represents average annual loads for a ten year period, so cannot be used as a tool for annual reporting requirements.

> Model output 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).

> Sources of loading are characterized differently for nitrogen and phosphorus based on the statistical power of the sources for predicting loads. For example, 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. 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 draining to Falls Lake.

> It is not easy to simulate or track nutrient reductions associated with conventional or nonconventional BMPs.

4.1.2.2 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).

EUTROMOD may be further developed to overcome some of the limitations associated with other watershed models discussed in Section 4.1. For example, the model can be built to simulate nutrient loss in the tributaries, specify loading for onsite wastewater treatment systems by age and distance, etc. There are three remaining limitations for EUTROMOD with respect to estimating Stage II jurisdictional loads:

> The model does not simulate legacy groundwater or legacy sediment nutrient concentrations.

> The model cannot be run at a daily time step (needed if watershed model is to drive a time series based lake response model).

4.1.3 Comparison of Watershed Models

To summarize, there are two types of watershed models applicable for reexamining Stage II of the rules and calculating jurisdictional loads: mechanistic and empirical. Table 4-1 compares the applicability of two empirical models and six mechanistic models considered for the Falls Lake watershed. The number of Xs in the cells refers to the level of scientific complexity that is included in the model framework, not how well the model addresses the criteria. How well the model application addresses the criteria is dependent upon the calibration, the suitability of literature values, and the availability of site-specific data. Not appropriate (NA) indicates that the model does not address the component.

As described above, empirical models are better suited to perform uncertainty analysis. The EUTROMOD model meets more of the modeling criteria for Falls Lake compared to the USGS SPARROW model. For example, SPARROW cannot be easily modified and only addresses certain sources of loading in the watershed. EUTROMOD is flexible tool that can be set up to addresses sources of loading and parameters of interest as needed.

With respect to the deterministic watershed models needed to predict nutrient loading to Falls Lake, the HSPF, LSPC, and WARMF models meet more of the criteria than the other modeling platforms. In addition, HSPF has a feature that allows for special rules to be defined accounting for model limitations such as streambank erosion. LSPC and WARMF do not have special actions built into the modeling framework.

Simultaneous development of the HSPF and EUTROMOD models is recommended to allow a bounding of outcomes and provide a means to conduct uncertainty analysis. In addition, EUTROMOD can be developed in the short term to provide estimates of Stage II jurisdictional loads and support development of a nutrient credit accounting tool that accounts for location in the watershed in the determination of baseline loads and nutrient credits. Because EUTROMOD is capable of simulating lakes and reservoirs, it also provides a simple statistical model of Falls Lake to supplement the Falls Lake EFDC model (see Section 4.3).

Table 4-1 Evaluation Criteria for Falls Lake Stage II Watershed Models

Selection Criteria	SPARROW	EUTROMOD	WARMF	GWLF	SWAT	HSPF	LSPC	SWMM
Focus Area	Watershed	Watershed	Watershed	Watershed	Watershed/ Site Level	Watershed/ Site Level	Watershed/ Site Level	Watershed/ Site Level
Smallest accurate output time step	10-yr average	Annual	Daily	Monthly	Daily	Hourly/ subhourly	Hourly/ subhourly	Hourly/ subhourly
Type	Empirical	Empirical	Mechanistic	Mechanistic	Mechanistic	Mechanistic	Mechanistic	Mechanistic
Focus Parameters								
Flow	NA	XXX	XXX	XXX	XXX	XXX	XXX	XXX
TN	XXX	XXX	XXX	XXX	XXX	XXX	XXX	X
TP	XXX	XXX	XXX	XXX	XXX	XXX	XXX	X
TOC	XXX	X (can be added)	NA	X	X	XX	XX	X
TSS	X	X (can be added)	XXX	X (predicts total sediment)	XXX	XXX	XXX	XXX
DO	NA	XX (impoundments)	X	NA	XXX	XXX	XXX	X
pH	NA	XX (impoundments)	NA	NA		XXX	XXX	NA
Chlorophyll *a*	NA	XX (impoundments) (can model reaches with no reach-lake exchange)	X	NA	XXX	XXX	XXX	NA
Accounting								
Nutrient fate and transport in the watershed	X	XX	XX	X	XXX	XXX	XXX	X
Land to land routing	NA	NA	NA	NA	XXX	XXX	NA	XX
Extreme hydrologic events	NA	NA	XXX	XXX	XXX	XXX	XXX	XXX
Impacts of geologic formation	XXX (TP)	X	XX	XX	XXX	XXX	XXX	XX
Loading Sources								
Streambank erosion	XX (TP)	X	NA	NA	NA	XX	XX	NA
Explicit simulation of conventional onsite wastewater treatment systems	NA	XX	XX	XX	XX	XX	XX	NA

Selection Criteria	SPARROW	EUTROMOD	WARMF	GWLF	SWAT	HSPF	LSPC	SWMM
Explicit simulation of sand filter wastewater treatment systems	NA	X	X	X	X	X	X	NA
Explicit simulation of atmospheric deposition	XX (wet)	NA	XXX	NA	NA	XXX	XXX	NA)
Urban land uses	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Undisturbed land uses	NA	XXX	XXX	XXX	XXX	XXX	XXX	XX
Row crop and pasture	NA	XXX	XXX	XXX	XXX	XXX	XXX	NA
Fertilization and manure application	XXX	XXX	XXX	XXX	XXX	XXX	XXX	NA
Point sources	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Groundwater	NA	XX	XX	XX	XX	XX	XX	X
Legacy loading	NA	NA	NA	NA	NA	NA	NA	NA
Code								
Publically available	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Publically available source code	No	Yes	No	No	Yes	Yes	No	No
Applications								
Provide inputs for time series lake response model	NA	NA	XX	NA	XXX	XXX	XXX	XXX
Estimate jurisdictional loads for Stage II	X	XXX	XXX	XXX	XXX	XXX	XXX	XX
Estimate credits associated with conventional BMPs	X	XX	XXX	X (ag practices)	XXX	XXX	XXX	X
Estimate credits associated with non-conventional BMPs	NA	X	X (changes in WW disposal)	X (changes in WW disposal)	X (changes in WW disposal)	X (changes in WW disposal)	X (changes in WW disposal)	NA

XXX = rigorous and scientifically defensible assessment, XX = mid-level assessment, X = simplistic assessment approach, NA = not appropriate

4.2 Lake Response Modeling

There are several types of lake models that could be developed for Falls Lake, including both mechanistic and empirical models. NCDWQ has already developed a time series based, mechanistic nutrient response model for Falls Lake using the EFDC model, and the existing lake response model developed by NCDWQ provides a platform for predicting how watershed loading to the lake affects water quality. As with most models, the accuracy of the model is limited by data availability. Section 5 describes the monitoring studies that are recommended to reduce the uncertainty (Section 2.2.2) associated with the existing Falls Lake EFDC model.

Following collection of additional data and recalibration of the Falls Lake EFDC model, the model may be used to assess the impacts of various management strategies on water quality including dissolved oxygen, chlorophyll *a*, and TOC and to predict compliance with water quality standards. The model may also be linked to an ecosystem response model (e.g., CASM or AQUATOX) to assess how water quality affects biota in the lake. Collection of biomass data for zooplankton, benthic invertebrate, and additional fish species would be useful for developing an ecosystem response model.

Cardno ENTRIX recommends using the existing EFDC modeling platform for Falls Lake and revising it with data resulting from the future monitoring studies described in Section 5. To supplement the lake response model, the reservoir component of EUTROMOD should be developed to conduct uncertainty analyses and provide supporting evidence for the simulated lake response. The use of multiple models is described in Section 4.3. Additionally, an empirical model of the lake is recommended to provide a linkage between lake water quality and designated uses (Section 4.4).

4.3 Multiple Models

Environmental simulation models are invaluable tools for informing societal decision making. For example, we depend on hydrologic models to inform water supply/flooding decisions, water quality models for Total Maximum Daily Loads (TMDLs), and air quality models for standards compliance assessment. When multiple models are available, it is not uncommon to apply more than a single model to inform a decision, particularly if the consequences of a decision are significant, and if uncertainties are believed to be large.

Consider weather forecasting for major storms such as hurricanes. It is now common practice for a meteorologist to display the projected deterministic trajectories of the hurricane's eye based on several model forecasts; the fact that these models are based on different mathematical constructs adds to the robustness of the information about the range of storm trajectories. The use of multiple models also provides greater public awareness of possible outcomes than does a single deterministic trajectory.

The concept of using multiple models to inform critical decisions provides the UNRBA the following advantages:

> Accounts for uncertainty with model structures

> Provides better predictions and more informative uncertainty estimates

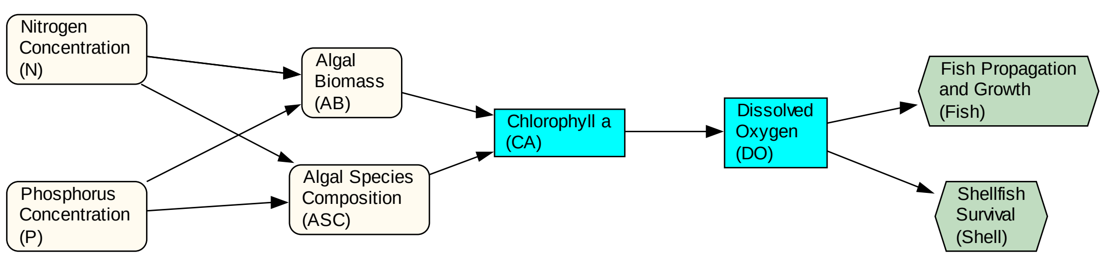
> Model disagreements may highlight research needs.

The Falls Lake EFDC model was developed and may continue to be refined by experienced water quality modelers. Yet, as a single deterministic model, EFDC shares a critical shortcoming with the most sophisticated meteorological model; both are deterministic simplifications of an extremely complex system. Thus, even the most elaborate EFDC model can be the subject of public criticism and skepticism concerning the dependency of decisions on the EFDC forecasts, particularly in the absence of uncertainty analysis or an estimate of the range of possible outcomes associated with proposed management options.

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). One modeling scheme should be simply for uncertainty analysis, and the other should focus on mechanistic details. The model developed for uncertainty analysis would be simple and statistically based. EUTROMOD provides a platform for developing a simple model for both the watershed and Falls Lake. The second modeling scheme would provide detailed characterization of the ecological process and space/time resolution. This scheme would be developed by linking a mechanistic watershed model (HSPF) to the Falls Lake Nutrient Response Model (EFDC). While the simple statistical model will not provide the ecologic/space/time resolution to provide a detailed prediction of lake response to nutrient loads, it will be probabilistic. The probabilistic nature of the statistical model means that prediction uncertainty will be estimated; this would allow extension of the model for probabilistic prediction of endpoints concerning fish and shellfish for models like those described in Section 4.4.

4.4 Empirical Models: Regression, Structural Equation Models, and Bayes Networks

Empirical models use data (and sometimes expert opinion in the case of a Bayes Network) to define linkages between management controls, chance nodes, and benefits. Regardless of the type of model (probabilistic, mechanistic, etc.), model building often begins with a graphical model that consists of boxes and arrows characterizing key relationships. As an example, consider the figure below, which presents a graphical model of the nutrient-ecological relationships in an estuarine aquatic ecosystem. In this example, nutrient concentrations in the estuary affect algal biomass and species composition which affect chlorophyll *a* and dissolved oxygen concentrations. Finally, the water quality conditions in the estuary affect fish propagation and growth as well as shellfish survival.



The graphical model above can be re-expressed as a set of equations, which are presented in the box to the right. There are three main categories of empirical models that may be developed around these equations: regression models, SEM, and Bayes networks. In this example, the first four equations presented in the box may be fit using data from the Neuse Estuary by fitting each equation separately using a regression analysis. Alternatively, a SEM can be used to fit the set of equations simultaneously. The graphical model and the equations may also be fit with a Bayesian network (BN) in which the expressions are not regression equations but conditional probability relationships (as described in Reckhow 1999).

Equations reflecting relationships in the graphical model

$$ASC = \beta_0 + \beta_1 N + \beta_2 P + \varepsilon_1$$
$$AB = \beta_4 + \beta_5 N + \beta_6 P + \varepsilon_2$$
$$CA = \beta_7 + \beta_8 ASC + \beta_9 AB + \varepsilon_3$$
$$DO = \beta_{10} + \beta_{11} CA + \varepsilon_4$$
$$Fish = \beta_{12} + \beta_{13} DO + \varepsilon_5$$
$$Shell = \beta_{14} + \beta_{15} DO + \varepsilon_6$$

The Bayes network has the added advantage in its ability to include the unmeasured but important higher food chain impairments (Fish, Shell) in the model. Expert probability elicitation is used to quantify the last two equations for this expanded Bayes network. In summary, the first step is to start with the graphical model, write a set of equations consistent with the boxes and arrows in the graphical model, and then proceed to fit the equations using regression, an SEM, and/or a BN.

A SEM is essentially a set of connected multiple regression models. However, the parameters in the equations in an SEM are estimated simultaneously, whereas the parameters in a set of multiple regression models are estimated equation by equation. Simultaneous estimation provides significant improvements for SEMs over standard regression analysis.

Typically, SEMs are linear models based on multivariate normality that require a complete data set for parameter estimation. In contrast, a Bayes net has the flexibility to express expert scientific judgment probabilistically in the model and to capture nonlinearity. A Bayes net can be thought of as a graphical model with a series of nodes linked by arrows, where the arrows in a Bayes net represent probabilities. The arrows indicate causal linkages among the nodes, and the nodes denote important system attributes. Each node is characterized by probabilities or probabilistic mathematical expressions that represent knowledge about these system attributes. The mathematical expressions may be 1) mechanistic descriptions such as chemical reaction kinetics, 2) empirical relationships such as linear regression models, or 3) relationships derived from expert judgment, depending on how much information there is about the relationships characterizing a particular node. The possible outcomes at each node are expressed probabilistically; thus a Bayes net is a set of conditional probabilities describing a set of likely system responses. The ability to incorporate mechanistic, empirical, and judgmental information makes the BN approach extremely flexible and facilitates an extension to non-traditional model endpoints (e.g., fish propagation) of public concern.

An interesting and useful aspect of structural equation models and Bayes networks is the potential to infer causality with observational data (Pearl 2000; Stow and Borsuk 2003). For example, SEMs and Bayes net can assess the linkages between water quality and designated uses in Falls Lake. A model like this could be developed using existing data for predictive and causal analyses in the near term for Falls Lake with future monitoring studies collecting targeted data to refine the relationships and reduce model uncertainty. Reckhow (1994, 1996, 1999) illustrates this in two different modeling studies. In the first application (Reckhow 1994), the EPA WASP model was applied to assess management options for eutrophication in Lake Okeechobee where an analysis was undertaken to allow a trade-off between monitoring to reduce prediction uncertainty versus the cost of that monitoring. In the second application (Reckhow 1999), a probability model for Neuse Estuary eutrophication was applied to show how measurements of high spring streamflow led to a revised predicted probability of an algal bloom.

In the figure below displaying a graphical model for structural equations or Bayes networks, the green rectangles represent decision (possible management controls) nodes, the blue rounded-corner rectangles represent uncertain chance nodes, and the pink hexagonal nodes reflect values/benefits that may be affected by changes in the management nodes.

- Drinking Water Supply: Assess the relative importance and causal nature of allochthonous versus autochthonous organic matter in the formation of total organic carbon and adsorption of UV light (a key predictor variable for the formation of disinfection byproducts; Dr. Phillip Singer, UNC Chapel Hill retired professor, personal communication) within Falls Reservoir. The figure below may be considered a candidate causal model for the effect of organic matter, UV adsorption, harmful algal blooms, taste and odor on the quality and safety of drinking water.
- Aquatic Life Use: Assess the relationships between nitrogen, phosphorus, algal biomass/species composition, dissolved oxygen, pH, and harmful algal blooms as a way to assess the levels at which nutrients and algae cause stressful conditions for aquatic organisms.
- Recreational Use: Assess the impacts of nitrogen, phosphorus, chlorophyll *a*, algal speciation, harmful algal blooms, pH, water clarity, fish type and quantity, and taste and odor on the quantity and quality of

recreational visits. Perform separate assessments for fishing, boating, swimming, and general noncontact recreation (hiking, bird watching, etc.) as chance nodes are expected to impact these final uses in different ways.

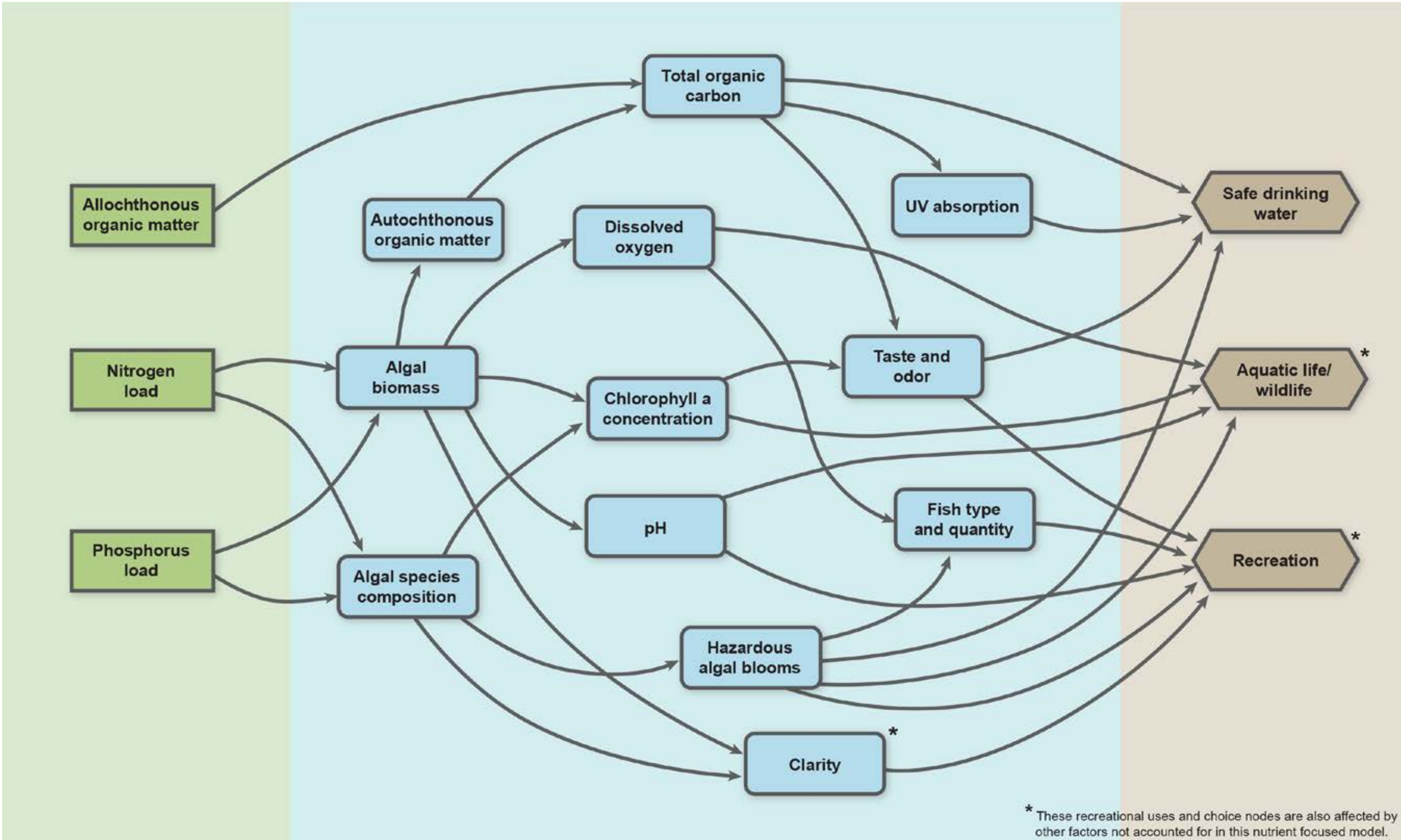


Figure 4-1 Graphical Model for Falls Lake

In water quality studies, investigators often use existing scientific knowledge to specify hypotheses or models, and then collect data at a site of interest to test the hypotheses or fit the models. If collateral data from nearby or similar sites exist, it is common practice to use this information to make a judgmental assessment of the support for and against the model/hypothesis, but otherwise not to incorporate these collateral data into the analysis in a formal way.

For example, consider the situation in which an agency (e.g., NCDWQ) has maintained an area-wide surface water quality monitoring network, and a regional agency (e.g., the UNRBA) is interested in using some of these data to assess trends in selected pollutants at sites within its area of interest. The common practice is to use the data at each site for a site-specific trend analysis, while using data from other nearby sites only in a comparative analysis or discussion. This approach persists despite the fact that if variability in water quality at a site is high, a long record of single-site observation is required to be confident in a conclusion concerning change over time at that site.

A seemingly natural question might be whether collateral data at nearby sites can contribute to the site-specific analysis other than in a comparative study. The answer often is "yes," as a consequence of exploiting the commonality among sites. On the one hand, each field site has unique features associated with forcing functions (e.g., watershed conditions and pollutant inputs) and with response functions (e.g., flow and concentration). However, the water quality sciences include common principles that should lead us to expect similarity in system response to inputs, and implied in a discussion of response at other nearby sites is often an expectation that these sites have something in common with a particular site of interest.

As a result, it should often be possible to improve (i.e., reduce error) the single-site analysis by "borrowing strength" from other similar sites; this may be accomplished using an empirical Bayes or multilevel approach. In empirical Bayes inference, collateral information (which in the above example is the assessment of trends at the other similar sites) is used to construct a "prior" probability model that characterizes this information; using Bayes Theorem, the prior probability is then combined with a probability model for the trend at the site of interest. Reckhow (1996) demonstrated this for reducing the error of IBI trends assessment at several sites in Ohio streams. In many instances, combining information using empirical Bayes methods yields smaller confidence interval estimates and thus stronger scientific inferences than would result if this information were ignored.

Cardno ENTRIX recommends development of an empirical model of Falls Lake to link nutrient loads to water quality and designated uses in Falls Lake. This platform will allow an assessment of the benefits associated with various nutrient management strategies. The following datasets should be used for this effort:

- EPA National Lakes Survey, a probability-based sampling program for 904 lakes nationwide (http://water.epa.gov/type/lakes/lakessurvey_index.cfm), which includes a large number of water quality variables.
- EPA Information Collection Rule data (http://www.epa.gov/envirofw/html/icr/index.html), which includes nationwide data on source water quality, drinking water treatment processes and effectiveness, and disinfection byproducts (DBPs).

These data can be used to develop a comprehensive statistical/probabilistic model that characterizes many of the relationships in Figure 4-1. The model would allow, for example, assessment of the impact of land use changes in the Falls Lake watershed on DBPs associated with selected drinking water treatment technologies in the Raleigh plant. Cardno ENTRIX recommends that these data be used to develop this model.

5 Future Monitoring Studies

Work completed to date on the tasks associated with this project has identified a number of data gaps that could be filled with additional monitoring efforts. This section describes the types of studies that would address the following monitoring objectives:

> Source allocation and estimation of jurisdictional loading

> Lake response modeling

> Compliance monitoring

> Linkage of water quality to designated uses

> Credit accounting/BMP effectiveness

> Support of regulatory options

The monitoring frequency suggested for most of the studies described in this technical memorandum is monthly. More intensive monitoring during storm events coupled with installation of permanent flow gages in ungaged tributaries will reduce uncertainty with respect to nutrient loading to the lake. The majority of the recommended monitoring focuses on the watershed, rather than the lake, to support estimation of jurisdictional and tributary loading to the lake. Existing lake monitoring conducted by the local governments and agencies is likely sufficient to capture the spatial and temporal water quality trends in the lake. The recommendations for additional water quality monitoring in the lake are associated with developing linkages between water quality and designated uses.

During the years that NCDWQ collected data to support development of the lake response model, monitoring frequency was increased from monthly to 2 to 3 times per month, particularly in the summer. A similar monitoring frequency was used by NCDWQ for development of the Cape Fear EFDC model. The Cape Fear monitoring also included storm event sampling to assess how pollutant concentrations change during precipitation events. The UNRBA will need to discuss sampling frequency with NCDWQ to ensure that the final sampling plan is acceptable to NCDWQ.

Current monitoring frequency for the sampling organizations in the watershed is described in

Table 5-1 (frequencies focus on monitoring of nutrient and chlorophyll *a* data). The majority of the organizations sample at least monthly, with occasional increases in frequency to 2 to 4 times per month.

Table 5-1 Summary of Current Monitoring Programs for the Organizations

Organization	Predominant Sampling Frequency based on TN, TP, and chlorophyll *a*
NCDWQ	Monthly with increased frequency (2 to 3 times per month) during 2005 to 2007
USGS	Monthly with occasional increases to 2 to 3 times per month
City of Durham	Downstream of WWTP weekly; other stations at least monthly with occasional increases to 2 to 3 times per month
City of Raleigh	Once or twice per month depending on station
CAAE	Monthly with occasional increases to 2 to 4 times per month
SGWASA	Not applicable for these parameters
Orange County	Twice per month beginning in 2010 and ending in 2011
Wake County	Monthly with occasional increases to 2 times per month

Estimated costs associated with these studies are included in the text below. These costs include labor and laboratory analysis costs, but do not include development of a sampling plan, sampling QAPP, documentation of the results of these studies, or any associated modeling or analysis of the data.

Strategic planning and prioritization will be a crucial part of developing an adaptive monitoring program that best meets the current and future needs of the UNRBA. Section 2 lists some considerations for implementing the monitoring studies described in this memorandum.

5.2 Source Allocation and Estimation of Jurisdictional Loading

In order to achieve compliance with water quality standards throughout the Lake, the State has determined that this will likely require a 40 percent reduction in nitrogen loading and a 77 percent reduction in phosphorus loading. The Falls Lake Nutrient Management Strategy 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. Due to the requirements specified in the Falls Lake Nutrient Management Strategy (.0275 5(b)(i)), nutrient loading to Falls Lake Reservoir must be evaluated and reported to the EMC every five years, beginning in 2016.

Current evaluations of the watershed model indicate that there is a high degree of uncertainty associated with the watershed loads predicted by the Falls Lake watershed loading (WARMF) model. Issues and uncertainties associated with the model are more fully described in the Task 3 Technical Memorandum as well as Section 2.1.3 of this TM. A list of key issues includes:

> The WARMF modeling was developed independently of the EFDC Falls Lake response model, and the watershed loading predicted by the two models varies by a factor of 1.4 for nitrogen to 2.0 for phosphorus.

> The nitrogen loading predicted by the WARMF modeling is nearly equivalent to the Stage II allocation.

> The WARMF model is based on several assumptions that have not been verified by field studies (e.g., the model assumes a failure rate for onsite wastewater treatment systems of 15 percent when local surveys indicate the rate is closer to 10 percent).

Targeted monitoring within the watershed will reduce uncertainties associated with specific loading sources and jurisdictional allocations. The following studies would provide data that can be used to refine the watershed loading estimates to Falls Lake and increase the accuracy of jurisdictional load allocation.

5.2.1 <u>Jurisdictional monitoring</u>

Establishment of upstream and downstream monitoring at jurisdictional boundaries can be used to 1) assess changes in loading due to jurisdictional inputs and 2) demonstrate changes in nutrient loading as BMPs are implemented. The monitoring should include collection of water quality and flow data to allow for calculation of loading. The water quality measurements should include the following parameters: ammonia (NH3), nitrate plus nitrite (NO2/NO3), total Kjeldahl nitrogen (TKN), ortho-phosphorus (Ortho-P), total Phosphorus (TP), total suspended solids (TSS), total organic carbon (TOC), and field parameters (turbidity, temperature, dissolved oxygen, pH, and conductivity).

The number of stations required to characterize jurisdictional loadings within the Falls Lake watershed, based on the intersection of specific jurisdictional boundaries and the stream network, is 30 to 40 stations (existing monitoring stations may already be located at some of these boundaries). Seventeen of these jurisdictional boundary stations would also provide the tributary loading data needed for refinement of lake loading estimates. A discussion of monitoring needed to refine lake loading is presented in Section 5.3. Additional parameters that could be included in the monitoring efforts to address other issues in the watershed, such as 303(d) impairments, are fecal coliform and five-day biochemical oxygen demand

(BOD5). Monitoring frequency should be monthly and should capture various hydrologic regimes. This monitoring program may be achieved by modifying existing local government sampling plans (station locations, parameters, frequency, etc.).

Assuming 23 distinct monitoring stations are needed for this effort, the estimated cost for water quality sampling is $95,000 per year.

5.2.2 Areal loading rates

Another approach to developing jurisdictional loading estimates is to better quantify loading by source category. This information can be used directly in spreadsheet-based loading models or used to calibrate mechanistic watershed loading models. The U.S. Forest Service (USFS) has been monitoring areal loading rates of nitrogen and phosphorus from forest lands located on Triassic Basin and Carolina Slate Belt formations to assess the variability in nutrient loading rates from forest due to geology. Similar studies could be performed for other land uses in the basin such as residential land (with variations by density and wastewater disposal method), agriculture (row crop, pasture, and pasture with manure), commercial, industrial, wetlands, and North Carolina Department of Transportation (NCDOT). Water quality parameters would include NH3, NO2/NO3, TKN, ortho-P, TP, TSS, TOC, and field parameters. Additional parameters that may be included in this assessment include fecal coliform and BOD5. The sampling plan should be based on the USFS forest study which monitors water quality at 10-minute increments during storm events using an automatic sampler and monitors baseflow with routine grab samples (TJCOG 2012).

This monitoring study is resource intensive given the number of stations needed to specify loading by land use, geology, and wastewater disposal method. Projected costs are $800,000 per year.

Preliminary numbers may also be determined with a literature review with projected costs of $25,000. The results of this literature review would likely provide a basis to prioritize the land uses requiring more detailed study. Once the targeted studies are identified, Cardno ENTRIX recommends that the UNRBA work with local universities and other interested stakeholders to conduct these studies.

5.2.3 Nutrient Fate and Transport

Regardless of the approach for determining jurisdictional loading (spreadsheet models, mechanistic models, etc.), nutrient fate and transport in the watershed should be accounted for in order to

- accurately allocate lake loading to the various jurisdictions and source categories and
- optimize placement of best management practices or other nutrient reduction efforts in order to most cost effectively meet jurisdictional load reductions and improve lake water quality.

Stream fate and transport is typically accounted for within models using reaction rates or trapping factors based on literature or simple empirical equations. Nutrient trapping by impoundments in the watershed may be accounted for based on literature, simple empirical equations, or modeling of sedimentation and uptake. The Triangle J Council of Governments has developed an Upper Neuse Water Quality Monitoring Plan which recommends nutrient fate and transport studies to assess variations associated with land use and geologic formations and to provide information to optimize BMP implementation in the watershed (TJCOG 2012). Placing additional monitoring stations within the catchments associated with the Areal Loading Rates study described above may provide the data needed to address this area of uncertainty.

Nutrient trapping in watershed impoundments should also be accounted for when allocating jurisdictional loads. Impoundments essentially function like regional scale BMPs that provide for settling and uptake of nutrients. Monitoring of inlet, outlet, and in-lake nutrient concentrations can provide the basis for assessing nutrient trapping in impoundments using empirical models such as EUTROMOD or BATHTUB. Additional water quality monitoring stations near or within the watershed impoundments will likely be needed to provide this information. Parameters should include instantaneous flow, chlorophyll *a*, turbidity, NH_3, NO_2/NO_3, TKN, Ortho-P, TP, TSS, TOC, and field parameters.

Cardno ENTRIX recommends conducting two nutrient fate and transport studies along the stream reaches at 20 locations. One study should occur during the summer season and one during a cooler period. This study would require approximately $50,000 and would not need to be repeated each year.

Collection of monitoring data in the watershed impoundments to quantify nutrient trapping should occur monthly during each year of monitoring. This study will cost approximately $65,000 per year.

5.2.4 Source Specific Studies

Determination of loading from sources such as internal lake loading, onsite wastewater treatment systems (conventional and sand filter), and streambank erosion will provide information needed to refine jurisdictional loading estimates and provide information to quantify nutrient credits associated with managing these sources. Source specific monitoring recommendations are discussed in Sections and 5.3.5 and 5.6.2.

5.3 Lake Response Modeling

The existing Falls Lake EFDC lake response model was developed based on lake and watershed data collected from 2005 to 2007. Additional monitoring studies, particularly benthic flux estimates and characterization of tributary inputs of chlorophyll *a* and total organic carbon (TOC) would reduce many of the uncertainties associated with the lake response modeling.

5.3.1 Internal Lake Loading

The assessment of nutrient loading to the lake should account for internal loading due to releases from lake sediment. Benthic flux rates should be measured for ammonia, nitrate plus nitrite, phosphate, and sediment oxygen demand (SOD). There are a small number of existing measurements of benthic flux in Falls Lake that were conducted in support of the EFDC lake response modeling. However, the number of stations and the number of sampling events did not provide sufficient information to characterize the spatial and temporal variability across the lake as whole, and the modeling assumed a single rate for each parameter across the lake. In addition, measurements were conducted in the spring when anoxic conditions at the sediment-water interface were likely not present. Anoxic conditions stimulate release of phosphorus from lake sediments, so the existing monitoring may not have adequately characterized the variability in this nutrient loading source.

Benthic nutrient flux and sediment oxygen demand may be measured in situ using sealed chambers or in a laboratory using extracted sediment cores and either deionized water or lake water. In each method, samples are extracted from the water above the sediments and changes in nutrient concentration are used to calculate flux (mass per time). Measurements are typically taken in triplicate at each site. Site locations should be selected to assess longitudinal changes in nutrient flux from the upstream end of the lake to the dam. Additional sites located downstream of tributary mouths and in the lake coves will provide information on localized releases. Monitoring frequency will depend on funding available. The TJCOG Monitoring Plan includes recommendations for monitoring nutrient flux from sediments in Falls Lake (TJCOG 2012). Depending on the monitoring objectives of the study, the number of sampling locations recommended is up to 24 and the frequency of sampling ranges from monthly to seasonally, or more frequently (1 to 4 times per day) during event sampling. Concurrent water quality sampling near the lake bottom is also recommended by the TJCOG (NH_3, NO_2/NO_3, Ortho-P, TP, TSS, TOC, and field parameters).

Given the resource constraints of the UNRBA, Cardno ENTRIX recommends performing one study at 12 locations in the lake. Projected costs are approximately $180,000. The UNRBA should consider petitioning USEPA Region 4 to conduct these studies to reduce the financial burden to the association.

5.3.2 Lake bathymetry and flow data

The bathymetry for the existing EFDC model is based on a limited number of transects conducted by NCDWQ to support the modeling effort. Additional bathymetry data and the characterization of flows between the lake segments would support future modeling refinements. A single bathymetric survey of the lake and the collection of monthly flow and water quality monitoring at lake constriction points are recommended (instantaneous flow, chlorophyll *a*, turbidity, NH_3, NO_2/NO_3, TKN, Ortho-P, TP, TSS, TOC, DOC, VSS, and field parameters). This effort may require additional water quality monitoring stations or increased monitoring frequency at existing stations (water quality monitoring stations currently exist at the constrictions at I-85 and Highway 50).

Collection of lake bathymetry data is estimated to costs $25,000 (a one-time study). Flow and water quality data collection and analysis at two constriction points will costs approximately $35,000 per year.

5.3.3 Tributary monitoring

As described in the Task 2 TM, the majority of the watersheds monitoring data have been collected in the upper watershed areas. To characterize tributary inputs to support lake modeling, paired flow and water quality monitoring is needed at the mouths of the tributaries upstream of the high-water level for the lake (i.e., stations should reflect free flowing waters). The current EFDC model setup includes 17 tributary input points. The locations should be monitored monthly, and sampling should capture various hydrologic regimes. Monitoring should include the following parameters: instantaneous flow, chlorophyll *a*, turbidity, NH_3, NO_2/NO_3, TKN, Ortho-P, TP, TSS, TOC, DOC, and field parameters.

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.

Assuming 17 distinct monitoring stations are needed for this effort, the estimated cost for water quality sampling is $85,000 per year. Five additional flow gages will cost approximately $125,000 per year.

5.3.4 Storm event sampling

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 a few 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 at 15-minute to 1 hour increments for the following parameters: instantaneous flow, chlorophyll *a*, turbidity, NH_3, NO_2/NO_3, TKN, Ortho-P, total P, TSS, TOC, DOC, and field parameters.

Projected costs for this study are $120,000 per year.

5.3.5 Inlake processes

The existing EFDC lake response model uses literature values and model calibration to approximate nutrient transformations such as algal growth and settling, background light extinction, organic hydrolysis, nitrification, sedimentation, etc. Given the long residence time of the lake, these parameters have implications for how nutrients are cycled and converted within the lake model. An understanding of the spatial variability in these processes would improve model calibration and provide the data needed to simulate these processes spatially rather than assuming that one set of factors applies in all areas of the lake.

Projected costs are $25,000 for a single lake study. These studies may also be conducted under petition to USEPA in conjunction with the internal lake loading studies.

5.4 Compliance Monitoring

The Falls Lake Nutrient Management Strategy requires local governments to develop plans to reduce nutrient loading to Falls Lake and to track progress by estimating nutrient load reductions. The monitoring data associated with better characterizing loading at jurisdictional boundaries and individual tributary monitoring efforts (as described in Section 5.2) can also be used to support documentation of compliance with regulatory requirements. Additional studies to support compliance include the following:

5.4.1 Lag time

Bringing Falls Lake into compliance with ambient water quality standards may take decades because of lag times associated with legacy pollutants within the stream channels, the lake, soils, and groundwater that may have been polluted by historic activities. A literature review focused on legacy pollutants and lag time effects may provide the UNRBA with additional information regarding realistic improvements in lake water quality. This assessment may indicate specific monitoring or modeling studies needed to better quantify legacy effects and predict lag times for lake response.

This study may be conducted with a literature review with projected costs of $25,000.

5.4.2 BMP implementation tracking

Local governments in the Falls Lake watershed are required to track BMP implementation and estimate resulting nutrient load reductions. Local governments should begin collecting data to support this requirement and provide the data needed for credit accounting tools such as the Jordan/Falls Lake Stormwater Nutrient Loading Accounting Tool (NCSU-BAE and NCDENR 2011). The following information should be collected: description of each BMP, geographic position, parcel square footage, square footage by land use draining to the BMP, and BMP inspections and maintenance performed. The NSAB is currently establishing guidance regarding data collection efforts for BMPs that will be needed to calculate credits.

5.5 Linkage of Water Quality to Designated Uses

Falls Lake is listed as impaired for chlorophyll *a* based on the water quality standard of 40 µg/L. The framework for reexamining the Falls Lake Nutrient Management Strategy relies on a linkage between water quality and designated uses: wildlife enhancement and aquatic life, recreation, drinking water supply, and flood storage. To date, little data has been collected in Falls Lake to support this linkage, and even NCDWQ staff have stated that “based on what NCDWQ staff has read in files from the 1970s, WRRI did not have a specific designated use that they were trying to protect by utilizing the 40 µg/L chlorophyll *a* criteria” (August 29, 2005 Falls of the Neuse and High Rock Lakes Combined Technical Advisory Committee meeting). Several studies are needed to provide a better linkage between water quality and designated uses, particularly with respect to the chlorophyll *a* standard.

5.5.1 Diurnal pH and DO monitoring with water quality sampling

Chlorophyll *a* is an indicator of the amount of algae present in the water column and is not itself directly toxic to aquatic organisms. An over-abundance of algae may cause diurnal variations in dissolved oxygen (DO) concentrations and pH levels as the processes of photosynthesis and respiration occur. Die-off and decay of algae also result in the consumption of DO. Diurnal sampling of DO, pH, and temperature at several locations (at multiple depths) in the lake will provide an indication of whether aquatic organisms are likely experiencing stress due to diurnal fluctuations in DO or pH. Water quality samples should be collected during these events at least once per day at multiple depths and include chlorophyll *a*, turbidity, NH_3, NO_2/NO_3, TKN, Ortho-P, total P, TSS, TOC, and BOD5. NCSU-CAAE collects field data at three hour increments at seven locations in Falls Lake with at least monthly water quality sampling. Conducting intensive water quality sampling once per month (or at least once per season) over a 3 to 4 day period at the CAAE stations would provide information that can be used to link water quality to aquatic stressors.

Projected costs for this study are $70,000 per year.

5.5.2 Fish monitoring with water quality sampling

The NC Wildlife Resources Commission (NCWRC) conducts fish monitoring in Falls Lake once per year for either largemouth bass or black crappie. The majority of the fish monitoring occurs in the Lower Lake downstream of Highway 50 (94 percent of current surveys focus on the Lower Lake). Fish monitoring in the Upper Lake would provide information on the biological health in this part of the system. Water quality sampling should be conducted near the time of the surveys to provide an indication of how water quality affects fish utilization of the lake: chlorophyll *a*, turbidity, NH3, NO2/NO3, TKN, Ortho-P, total P, TSS, TOC, and field parameters. Coordination with the NCWRC will be required to develop this sampling plan.

Projected costs for this study are $30,000 per year.

5.5.3 Terrestrial and avian species monitoring

Monitoring of terrestrial and avian species may support assessment of the wildlife enhancement designated use for Falls Lake. Linking these assessments to water quality in the lake will not be as straight forward as the fish monitoring studies discussed above. These assessments should be conducted through coordination with NCWRC and provide supporting evidence regarding Falls Lake and its designated uses. The NCWRC recommends the following surveys for lakes and reservoirs in the Piedmont: birds (Bald Eagle, Red-headed Woodpecker, Yellow-crowned Night-heron); reptiles (pond turtles, and Eastern Ribbonsnake); identification of threats to reservoir-associated birds; monitoring for shorebird migration; monitoring bald eagle breeding activity; tracking population trends of waterbirds, rails, pond turtles, and common ribbon snakes (http://www.ncwildlife.org/Learning/Habitats/Piedmont.aspx). Ongoing bird counts conducted by the Audubon Society (annual winter count since 1998) and Carolina Birding Club at Falls Lake provide a database of bird populations over time (winter, spring, and fall counts).

Projected costs for this study are $25,000 per year.

5.5.4 Recreational data and water quality sampling

Monthly recreational count data are available from the State Park Service for the period 2005 to 2011. At a monthly scale it is difficult to assess how water quality impacts people’s choices about where and when to recreate. User perception surveys conducted in association with Park Service counts can be used to assess how water quality conditions (clarity, aesthetics, odor, etc.) impact the quality of the recreational experience and dictate choices in where and when to recreate. These surveys conducted with water quality sampling (chlorophyll *a*, turbidity, NH_3, NO_2/NO_3, TKN, ortho-P, total P, TSS, TOC, and field parameters) will provide a linkage between water quality and attainment of the recreational designated uses for the reservoir. Surveys should target a mix of recreational uses including fishing, swimming, and boating to determine if water quality affects these uses in different ways. Coordination with the State Park Service will be required to develop this sampling plan.

Projected costs for this study are $125,000 per year.

5.5.5 Event based water quality sampling

Monitoring associated with events that occur in Falls Lake or the watershed will provide information on how water quality is impacted by events (e.g., hurricanes, droughts) or how water quality impacts events (e.g., fish kills, WTP disturbances, algae blooms, etc.). Collection of water quality parameters such as chlorophyll *a*, turbidity, NH_3, NO_2/NO_3, TKN, ortho-P, total P, TSS, TOC, and field parameters will support assessing the linkage between water quality and these disturbances. Sampling plans for various events should plan for synoptic sampling to assess water quality at the mouths of the main tributaries and in the different lake segments.

Projected costs for this study are $45,000 per year.

5.6 Credit Accounting / BMP Effectiveness

For many BMPs that have been or will be used in the Falls Lake watershed, local research is available to quantify pollutant removal efficiencies. The Jordan/Falls Lake Stormwater Nutrient Loading Accounting Tool estimates the removal efficiencies of BMPs such as bioretention cells, detention ponds, permeable pavement, and constructed wetlands. The Tool accounts for climate and geology in the estimation of nutrient reduction credits. Less data is available to estimate the performance of (and resulting credits for) other practices such as repairing/replacing failing onsite wastewater treatment systems (conventional and sand filter) and restoring streams and floodplains. Collection of additional data to support these assessments is needed to adequately account for less conventional management practices in the watershed.

5.6.1 Estimation of loading from onsite wastewater treatment systems

Several categories of onsite wastewater treatment systems are used in the Falls Lake watershed including conventional septic/drainfield systems and discharging sand filter systems. The former discharges to the subsurface and latter discharges to the land surface, ditch, or stream. Either type of system may be functioning properly or failing, and the nutrient loading rates are expected to vary based on the type of system (conventional and sand filter), level of functionality and the type of failure (surface ponding, short circuiting, etc.). Underlying geology, groundwater hydraulic conductivity and geochemical reactions, subsurface versus above-ground discharge, and distance to a stream channel impact the nutrient loading that is associated with these systems. The nutrient reduction credits associated with repairing, replacing, upgrading, or connecting these systems to sewer are difficult to quantify based on the available information. Research conducted by NCDENR, with additional studies proposed by TJCOG, aim to measure the differences in stream concentrations associated with catchments that drain residential areas using specific wastewater disposal methods. While these studies may indicate differences in water quality on a catchment scale, determining what loading is associated with onsite systems will be difficult unless other variables are controlled (past land use should be consistent among the catchments, fertilizer application to lawns should be controlled, etc.). Additionally, determining the loading associated with failing systems relative to functioning systems will be difficult unless the catchments are homogeneous in this respect as well. To supplement these proposed catchment scale studies, TJCOG recommends monitoring the quality of septic tank effluent, groundwater in the vicinity of the onsite systems, and surface water or land surface discharges of sand filter systems. An assessment of hydraulic conductivity is needed as well to characterize nutrient flux through the groundwater system. Groundwater and surface monitoring locations should be placed to characterize the impacts of distance to stream channel on nutrient attenuation and delivery. Studies on different geologic formations with varying degrees of system performance and age should be conducted as well. Water quality parameters should include NH_3, NO_2/NO_3, TKN, Ortho-P, TP, TSS, TOC, and field parameters.

Projected costs for this study are $125,000 per year.

5.6.2 Streambank erosion and nutrient loading

Little is known regarding the contribution of streambank erosion to nutrient loading in the Falls Lake watershed. Preliminary monitoring to measure the relative importance of this source is suggested to determine if wider scale monitoring and modeling is needed. There are several locations in the watershed with historic stream channel cross section measurements. Revisiting these sites and measuring the cross sections will provide an estimate of the mass of sediment lost. Collecting stream bank and stream bed sediment data for analysis of nutrient and carbon content will provide a corresponding estimate of loading for these parameters.

Projected costs for this study are $20,000 per year.

5.6.3 Tracking BMP inspections and repairs

In order to continue receiving nutrient loading credits from BMPs, local governments should inspect and repair BMPs on an annual basis. Documentation of these efforts in an electronic database is suggested.

5.7 Support of Regulatory Options

The Falls Lake Nutrient Management Strategy requires all local governments to reduce nutrient loading from lands in their jurisdiction to improve water quality in Falls Lake. The approach does not promote pooling of resources and optimized source reduction strategies that would allow the local governments to improve lake water quality in a more efficient manner. For example, assuming the cost to remove a pound of phosphorus is the same in two locations in the watershed, but one location is near the lake and the other is upstream of a watershed impoundment does not result in the same reduction in phosphorus loading to the lake. The pound removed upstream of an impoundment is already mitigated to some degree by the impoundment, so the reduction in loading to Falls Lake is somewhat lower. The same analogy applies to transport in streams where transformations and losses occur.

> Accounting for Nutrient Fate and Transport would provide a scientifically defensible basis to support a more efficient lake-improvement strategy that would provide greater improvements in lake water quality with fewer resources.

> Regulatory options for dealing with the Falls Lake Nutrient Management Strategy may include development of site specific criteria or conducting a use attainability analysis. Either of these options would likely focus on the differences in water quality between the Upper and Lower segments of the lake. Modeling the segments of the lake separately may be required to support these regulatory options. Each of the studies described in Section 1.1.3 would improve the understanding of the spatial variation in the lake including Internal Lake Loading, Lake bathymetry and flow data, and Inlake processes.

> Linkage of water quality to designated uses is a key component of the reexamination, particularly if the UNRBA pursues a site specific criteria or a use attainability analysis. These studies include Diurnal pH and DO monitoring with water quality sampling, Fish monitoring with water quality sampling, Terrestrial and avian species monitoring, Recreational data and water quality sampling, and Event - based water quality sampling.

Table 5-2 summarizes the objectives associated with the potential lake and watershed monitoring studies. Most of the proposed studies meet multiple objectives.

Table 5-2 Objectives for Potential Monitoring and Modeling Studies for the Falls Lake Watershed

Study	Source/ Jurisdictional Loading	Lake Response Modeling	Compliance Monitoring	Linkage of Water Quality to Designated Uses	Credit Estimation for non-Conventional BMPs	Support of Regulatory Options
Jurisdictional monitoring	X		X			X
Areal loading rates	X					
Internal Lake Loading	X	X				X
Nutrient Fate and Transport	X					X
Lake bathymetry and flow data		X				X
Tributary monitoring		X	X			X
Storm event sampling		X				
In-lake processes		X				X
Lag time			X			X
BMP implementation tracking	X		X			
Diurnal pH and DO monitoring with water quality sampling				X		X
Fish monitoring with water quality sampling				X		X
Terrestrial and avian species monitoring				X		X
Recreational data and water quality sampling				X		X
Event based water quality sampling				X		X
Estimation of loading from onsite wastewater treatment systems	X		X		X	
Streambank erosion and nutrient loading	X				X	
Tracking BMP inspections and repairs	X				X	

Table 5-3 presents preliminary estimates of the number of monitoring locations, sampling frequency and duration, and relative costs for the potential monitoring studies. These are ballpark estimates that will be refined pending input from the UNRBA, consideration of the strategies described in Section 2, and coordination with other monitoring organizations such as CAAE, NCWRC, etc.

Table 5-3 Summaries of Potential Monitoring and Modeling Studies for the Falls Lake Watershed

Study	Number of Locations	Sampling Duration	Sampling Frequency	Estimated Costs	Period
Streambank erosion and nutrient loading – scoping level assessment	10	One event	One event	$20,000	1-5
Lake bathymetry	Multiple transects	One event	One event	$25,000	1-5
Inlake processes	12	One study	One study	$25,000 [b]	1-5
Areal loading rates (literature review)	Literature review	One study	One study	$25,000	1-5
Terrestrial and avian species monitoring	Variable	One study	One study	$25,000	1-5
Recreational data and water quality sampling	6	Three years	Quarterly	$60,000 per year	1-5
Event based water quality sampling	10	Three years	Assume twice per year	$65,000 per year	1-5
Diurnal pH and DO monitoring with water quality sampling	7	Three years	Quarterly	$70,000 per year	1-5
Aquatic species monitoring with water quality sampling	10	Three years	Quarterly	$90,000 per year	1-5
Storm event monitoring	10	Three years	Once per season	$120,000 per year	1-5
Estimation of loading from onsite wastewater treatment systems	20	Three years	Monthly	$120,000 per year	1-5
Internal Lake Loading	12	One study	One study	$180,000[b]	1-5
Lag time	Literature review	One study	One study	$25,000	1-5
Lake flow and water quality data between segments	2	Three years per period	Monthly	$35,000 per year	1-5, 5-10
Tributary water quality monitoring	17	Three years per period	Monthly	$85,000 per year	1-5, 5-10
Tributary flow monitoring	5	Three years per period	Continuous	$125,000 per year	1-5, 5-10
Nutrient Fate and Transport – Impoundments	15	Three years per period	Monthly	$65,000 per year	1-5, 5-10
Jurisdictional monitoring	23	Three years	Monthly	$95,000 per year	1-5, 5-10
Nutrient Fate and Transport – Streams	20	One year	Two seasons	$85,000	5-10
Areal loading rates (monitoring)[a]	To be determined	Three years	Variable based on the number of storms	To be determined	5-10
BMP implementation tracking	Varies by local government	Indefinitely	At time of implementation of BMP	Conducted by the local governments	All
Tracking BMP inspections & repairs	Varies by local government	Indefinitely	Annually for each BMP	Conducted by the local governments	All

a. Target studies to reduce uncertainty associated with particular land uses.

b. Suggest petitioning USEPA Region 4 to conduct these studies.

5.8 Strategic Planning

Implementing all of these studies is likely to be cost prohibitive. Strategies that should be considered to reduce monitoring costs include

- Modifying existing monitoring programs to include additional information
  - Addition or relocation of sites
  - Additional parameters
  - Addition of flow measurements
  - Increased frequency or addition of special studies such as storm event sampling
- Identification of existing groundwater monitoring wells that may serve as part of the water quality sampling
- Integrating the work already conducted by TJCOC in developing monitoring plans
- Seeking grants and research opportunities to help fund monitoring (agencies, universities, etc.)
- Seeking additional interested parties to conduct studies associated with specific questions
  - WTP operators interested in linking watershed loads to lake water quality to drinking water quality
  - Local governments in the Piedmont interested in understanding the impacts of geology on nutrient fate and transport from onsite wastewater treatment systems
- Petition agencies for special studies
  - USEPA Region 4: lake benthic flux studies
  - NCWRC: expand aquatic life surveys in the entire lake
- Inclusion of additional parameters of interest (e.g., for 303(d) listed streams) to streamline monitoring efforts for local governments: fecal coliform, BOD, etc.
- Combine multiple monitoring studies into coordinated sampling efforts. For example:
  - Tributary and jurisdictional monitoring studies should be integrated
  - Discussions with NCWRC are needed to determine if CAAE diurnal studies and associated water quality sampling would provide good locations for monitoring fish in the Upper Lake.

6 Recommendations from the Nutrient Scientific Advisory Board Regarding Future Studies

In July 2012, the Nutrient Scientific Advisory Board released its Second Annual Report to the Secretary which provides guidance to local governments in the Falls Lake and Jordan Lake watersheds tasked with reducing nutrient loading to lakes. The Task 3 TM summarizes the Report and its discussions regarding the various practices that can be considered for achieving nutrient reduction credits. The costs, benefits, and feasibility associated with the practices are also included as well as the credit accounting system that may be used to calculate the credits associated with various practices.

The Report also included a set of recommendations regarding future monitoring and modeling studies, many of which are directly applicable to the Falls Lake system. The recommendations are as follows (Nutrient Scientific Advisory Board 2012):

- Calculating jurisdictional loads requires a more rigorous approach than a conventional watershed model.
- There are biases in the current ambient monitoring of tributaries in the watershed, with the majority of stations being located downstream of large municipal wastewater treatment plants. This bias may result in overestimation of nutrient loads in those subwatersheds that do not contain a WWTP discharge. The current sampling strategies may result in calibrated models that do not accurately reflect pollutant fate and transport in the smaller drainages.
- Onsite wastewater disposal systems should be simulated separately by type (conventional subsurface versus sand filter and not lumped in with other loading categories.
- There is a need to quantify the amount of pollutant loading associated with “first flush” runoff events because stormwater management practices are designed to treat only the initial part of larger storms.
- There is a need to better understand the seasonality associated with pollutant loading.
- Higher resolution land cover data is needed across the watershed to produce models that are acceptable in a regulatory context, such as assignment of jurisdictional loads.
- There is a need to develop credit accounting methods for practices other than those for which credit estimation techniques are currently available.
- Water quality monitoring and modeling do not adequately address gross solids associated with storm events (trash, leaf litter, etc.)
- Data collection efforts should be coordinated across the watershed and include Federal, State, and local governments. The Report recommends pooling resources, using uniform protocols, and coordinating efforts across the watershed.
- Tools are needed to help local governments identify constraints to successful implementation of management practices, particularly on existing development.
- The State should reconsider the regulatory barriers that currently impede construction of impoundments along smaller stream corridors to provide additional nutrient removal in systems that are already degraded: disconnected from floodplain, severely downcut, highly urbanized areas, etc.

7 Recommendations for the UNRBA

The Falls Lake Nutrient Management Strategy requires phased implementation of nutrient reductions and defines a schedule for meeting various regulatory requirements. Table 7-1 presents a modified version of the Falls Lake Existing Development (0.0278) Rule Implementation Timeline presented by NCDWQ during an October 2012 UNRBA meeting. The requirements and schedule defined by the rules dictate immediate, short term, and long term time frames for conducting various monitoring and modeling studies:

> Immediate needs are associated with the July 2013 report to the EMC.

> Short term needs include monitoring and modeling studies that should occur over the next three to five years to support reexamination of the Stage II rules.

> Long term studies should be conducted over the next five to ten years to prepare for Stage II requirements. Because the requirements and basis for Stage II may change following the reexamination process, long term studies may need to be refined during the short term period.

Table 7-1 Falls Lake Existing Development (0.0278) Rule Implementation Timeline

Date	Task
January 2013	Local governments complete inventories
March 2013	Local governments submit estimates for Stage I requirements
July 2013	NCDWQ brings model program (including Stage I requirements) to the EMC for approval
January 2014	Local governments submit local Stage I Programs for approval and begin implementing measures
March 2015	NCDWQ provides recommendations to EMC on local governments programs
September 2016	Local governments begin submitting annual reports on Stage I programs
January 2021	Local governments submit initial Stage II Programs to NCDWQ for EMC approval and begin implementation

7.2 Immediate Needs (Prior to April 2013)

The Falls Lake Nutrient Management Strategy requires that NCDWQ 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 from development that occurred between January 2007 and July 2012. As described in the Task 3 TM, the local governments that have not already been collecting data to support this assessment need to begin this process as soon as possible.

Data collection efforts should include descriptions of the type, amount, and location of development that has occurred during this period. Filling the data gaps associated with Stage I will rely on participation from each local government to describe the locations, amounts, and types of development that have occurred during the interim period. 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.

In addition, information regarding the location, size, and types of BMPs implemented as well as areas of each land use draining to the BMP should be collected. Stage I calculation methods include stormwater load accounting tools as well as conservative areal loading rates. Each jurisdiction will need to decide, based on existing data availability, which method they will use for the immediate reporting requirements. Detailed descriptions of these methods and their data requirements are provided in the Task 3 TM.

7.3 Short Term Needs (5 years)

Short term monitoring and modeling studies should be conducted over the next three to five years to support reexamination of the Stage II rules and provide information that will support various regulatory options. The following studies are recommended during this period.

- Support refinement of the lake response model
  - Tributary monitoring (flow and water quality), ($210,000 per year)
  - Storm event sampling, ($120,000 per year)
  - Lake bathymetry, ($25,000)
  - Lake water quality and flow data at I-85 and Hwy 50, ($35,000 per year)
  - Lake processes (internal loading, reaction kinetics, etc.), ($205,000 – petition USEPA)
- Develop preliminary estimates of 2006 baseline loads for planning purposes
  - Conduct literature review to assign nutrient loading rates by land use, ($25,000)
  - Conduct literature review to account for geology and stream fate and transport ($25,000)
  - Collect morphometry and water quality data in the watershed impoundments, ($65,000 per year)
  - Conduct source specific studies (e.g., streambank erosion ($20,000) and onsite wastewater treatment systems ($120,000 per year)
  - Develop preliminary empirical watershed model (e.g., EUTROMOD) ($150,000)
- Develop credits for non-conventional BMPs (NCDWQ will be determining “load reduction credits associated with various activities.” (This list of studies may need to be revised following submittal of the July 2013 report.)
  - Determine nutrient loading and estimate credits for repairing, replacing, or connecting onsite wastewater treatment systems to sewer.
  - Determine the significance of streambank erosion to nutrient loading and estimate credits for restoration projects.
- Define linkage between lake water quality and designated uses (drinking water supply, recreation, aquatic life and wildlife propagation and survival)
  - Conduct monitoring studies that link water quality to attainment of designated uses, ($310,000 per year)
  - Develop a preliminary Bayes net or SEM to describe linkages between nutrient loading and designated uses. Use the preliminary model to perform uncertainty analyses on the model parameters and identify additional monitoring that may be needed to reduce uncertainty, ($160,000).
- Track success of management actions
  - Conduct literature review to quantify lag times associated with historic impacts on sediments and groundwater ($25,000)

- Track BMP implementation and calculate credits (local governments perform)
- Conduct flow and water quality monitoring at jurisdictional boundaries, ($95,000 per year (may hold off on these studies until long term period and rely on credit accounting tools only)
- Conduct flow and water quality monitoring at tributary mouths, (no additional costs)
- Update LOADEST analyses for annual reporting to the EMC ($15,000 per year)

7.4 Long Term Needs (5 to 10 years)

Under the existing Falls Lake Nutrient Management Strategy, local governments are required to begin implementing their Stage II nutrient reduction program in 2021. Under the current version of the rules, long term monitoring and modeling studies are needed to support the Stage II requirements of the Falls Lake Nutrient Management Strategy. Because the reexamination of the Stage II rules may alter the structure of Stage II, the long term studies should begin after the reexamination period. The list of preliminary recommendations assumes that some level of reductions will be required and that those reductions will be relative to a baseline year.

> Refine estimates of baseline loads
  - Conduct targeted areal loading rates studies for nutrients, carbon, and sediments (to be determined)
  - Conduct nutrient fate and transport studies in stream reaches ($85,000)
  - Conduct specific source loading studies that weren't conducted during short term studies (e.g., studies that were not funded or newly identified studies) (variable costs)
  - Develop a refined EUTROMOD (based on monitoring studies) and an HSPF model to assign jurisdictional loads under baseline and management scenarios (variable costs)

> Continue flow and water quality assessments
  - Continue to monitoring flow and water quality at tributary mouths, ($210,000 per year)
  - Continue to collect flow and water quality measurements at jurisdictional boundaries ($95,000 per year)
  - Continue to collect morphometry and water quality data in the watershed impoundments ($65,000 per year)
  - Continue to collect lake water quality and flow data at I-85 and Hwy 50 ($35,000 per year)

7.5 Conclusions

Several monitoring and modeling studies have been recommended to support the reexamination of the Falls Lake rules. In general, these studies can be conducted during specific periods: immediate, short term, and long term.

In the short term, projected costs for annual studies ranges may reach over $1,000,000 per year. While all of the recommended short term studies provide value for the reexamination, the highest priority studies include

> Collection of flow and water quality data at the mouths of the tributaries to support refinement of the lake model. This study, estimated to cost $210,000 per year, will provide additional data to support development of time series inputs for the lake model in the upper and lower watershed. Given the sensitivity of the model with respect to compliance with the chlorophyll *a* standard, collection of this data and refinement of the lake model may significantly reduce the nutrient load reductions that are required under the current rules.

> The current rules do not account for fate and transport in the watershed, and all sources are subject to the rule requirements. Collection of bathymetry and water quality data in the watershed impoundments (approximately $65,000 per year) will provide the basis to support a more strategic nutrient management program where money is spent in areas with the most impact on lake water quality. (Similar studies in the stream segments are recommended for the long term with short term values relying on literature review).

> Develop a preliminary EUTROMOD model to provide preliminary estimates of baseline loads, prioritize future monitoring studies conducted in the long term period, and support a strategic nutrient management program including accounting for delivery factors in the watershed, ($150,000).

> Collect data to define the linkage between lake water quality and designated uses ($310,000 per year) and develop an empirical model to link nutrient management to changes in attainment of designated uses. These studies may be used to support a use attainability analysis, develop site specific criteria, and inform management decisions regarding nutrient management in the watershed and the impacts on drinking water supply, recreation, and aquatic life use.

The monitoring studies conducted during the long term period will depend on 1) the number of studies that were not funded during the short term period, 2) the prioritization of studies resulting from development of the preliminary EUTROMOD model, and 3) the outcome of the reexamination process conducted during the short term period. Many of the long term studies overlap with high priority short term studies (e.g., tributary and impoundment monitoring). If the UNRBA can fund the additional monitoring studies recommended for the long term period (nutrient fate and transport in streams and monitoring at jurisdictional boundaries) during the short term, the overall monitoring costs would decrease. The long term period could then be used to focus on source specific loading studies such as streambank erosion and onsite wastewater treatment systems and to develop the multiple models needed to simulate watershed loading and lake response (refined EUTROMOD, HSPF, and revised EFDC with updated data inputs).

Given the potential costs of these studies, a strategic plan should be developed to modify existing programs to collect additional data, seek grants and cooperative funding agreements, petition agencies to conduct special studies, and combine multiple monitoring studies into coordinated sampling efforts (for example combining lake station locations (where possible) for linking water quality to designated uses).

It is important to note that the recommendations in this TM address the studies needed to reexamine the Falls Lake Nutrient Management Strategy as defined by the existing rules. There are other regulatory options that will be considered under Task 1 that may reduce the number or intensity of studies required. Task 1 will seek to compare and contrast the costs associated with various options (monitoring, modeling, litigation, required nutrient reductions) with the benefits (improvements in water quality, protection of drinking water supplies).

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