Upper Neuse River Basin Association Submittal: Description of the Water Quality Modeling Framework under the Re-examination Provision of the Falls Lake Rules

Prepared on Behalf of the UNRBA
by: Cardno ENTRIX

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Document Information

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Project Name	UNRBA Monitoring Program Development and Implementation
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Project Manager	Lauren Elmore
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Prepared for: Forrest Westall, UNRBA Executive Director

Forrest Westall, UNRBA Executive Director
PO Box 270, Butner, NC, 27509

Prepared by:

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

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Modeling Framework Executive Summary

In 2010 the Environmental Management Commission (EMC) passed the Falls Lake Nutrient Management Strategy, requiring two stages of nutrient reductions (N.C. Rules Review Commission 2010). The Strategy recognized the uncertainty associated with the water quality modeling and the Stage II requirements and allows interested parties to re-examine the Strategy using a data collection and modeling study. The rule allowing this re-examination requires an interested party to "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."

Cardno ENTRIX developed this Technical Memorandum on behalf of the UNRBA to begin this approval process. This document should not be considered a full modeling Quality Assurance Project Plan (QAPP). The UNRBA will submit to NCDWR for review a complete modeling framework closer to the time that model revisions will begin. The revised modeling framework should be drafted by the selected modeling contractor, and the UNRBA has not yet initiated this selection process.

The purpose of this modeling framework document is to help guide the development of the UNRBA monitoring program and to describe the context of the modeling effort that the upcoming monitoring program will support. The UNRBA anticipates that a complete modeling QAPP would be submitted to NCDWR sometime in 2016.

1 Introduction

In 2010 the Environmental Management Commission (EMC) passed the Falls Lake Nutrient Management Strategy, requiring two stages of nutrient reductions (N.C. Rules Review Commission 2010). To provide the basis for setting the nutrient loading targets in the Falls Lake Nutrient Management Strategy, North Carolina Division of Water Resources (NCDWR) developed a Falls Lake Nutrient Response Model using the Environmental Fluid Dynamics Code (EFDC) model (NCDENR 2009). Cardno ENTRIX is developing a monitoring and modeling plan on behalf of the UNRBA to collect additional data that will improve upon the existing model simulations by filling data gaps and including a longer monitoring period to encompass greater hydrologic variability and loading patterns.

In a number of meetings and communications with the Division of Water Resources (DWR), UNRBA representatives have consistently noted that the Association is undertaking a re-examination of Stage II as allowed under the Falls Lake Rules. Representatives of DWR have attended UNRBA Path Forward Committee and Board Meetings where the subject of re-examination has been discussed in detail. The UNRBA in its ongoing planning and development of this re-examination process has committed to an evaluation program that will collect water quality information and perform special monitoring studies that will be specifically designed to support a lake modeling process to update the State's existing lake response model.

The rule allowing this re-examination requires an interested party to "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." This Technical Memorandum represents a "description of the modeling framework" and was completed as directed by the UNRBA as a necessary component for securing Division approval for the UNRBA monitoring program. Clearly, this description of a modeling framework is an initial commitment to a modeling process that will be developed in greater detail, including a full Quality Assurance Project Plan, at the appropriate time. The UNRBA Board has indicated its commitment to a minimum of four years of monitoring to support the re-examination, with an additional year if needed due to unusual weather patterns. The modeling framework description provided in this TM is sufficient for the development of a detailed monitoring program to support the UNRBA's re-examination process. The UNRBA has not yet identified its contractor for the actual modeling effort and will submit to DWR a complete modeling framework package for its review and approval prior to undertaking actual re-modeling activity. The UNRBA anticipates that it will seek services for the modeling component of the reexamination process in approximately two years following commencement of the monitoring program.

Through several meetings and discussions, the UNRBA and the agency agreed that the most efficient way to proceed with the submittal of information for approval under the re-examination provision is to provide DWR with portions of the Association's package as they become available. This description of a modeling framework is essential to the overall design of the proposed monitoring program. As a result, the UNRBA authorized Cardno ENTRIX to proceed with this TM for review by the Association membership and submittal to DWR for approval. As noted, the UNRBA will provide DWR with a complete modeling framework package for approval prior to undertaking the re-modeling effort.

1.1 Background

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

> "…the classified uses of Falls of the Neuse Reservoir set out in 15A NCAC 02B .0211 from current impaired conditions related to excess nutrient inputs; protect its classified uses as set out

> in 15A NCAC 02B .0216, including use as a source of water supply for drinking water; and maintain and enhance protections currently implemented by local governments in existing water supply watersheds encompassed by the watershed of Falls of the Neuse Reservoir." (15NCAC 02B .0275)

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

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

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

The NCDWR 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 nonpoint sources.

Section 5 (f) of the Falls Lake Nutrient Management Strategy recognized the uncertainty associated with the water quality modeling and the Stage II requirements:

5(f) Recognizing the uncertainty associated with model-based load reduction targets, to ensure that allowable loads to Falls Reservoir remain appropriate as implementation proceeds, a person may at any time during implementation of the Falls nutrient strategy develop and submit for Commission approval supplemental nutrient response modeling of Falls Reservoir based on additional data collected after a period of implementation. The Commission may consider revisions to the requirements of Stage II based on the results of such modeling as follows:

> (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;
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> (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.

Implementation of the Nutrient Management Strategy is estimated to cost the stakeholders in the watershed $1.5 billion (NCDWQ 2010) and requires unprecedented actions on the part of UNRBA member governments and other regulated parties. In light of the potential financial impact of these rules and the importance of Falls Lake as a resource, the UNRBA began a project in 2011 to evaluate the technical bases and regulatory framework for the Falls Rules, particularly Stage II. Although UNRBA members have initiated this evaluation project, they have committed to protecting the use of Falls Lake as a water supply.

In January 2012, the UNRBA contracted Cardno ENTRIX to conduct a technical and regulatory review of the Falls Lake Nutrient Management Strategy. Part of this effort included a review of the existing watershed and lake response models developed by NCDWR. Cardno ENTRIX (2013) recommended additional tributary data collection and revisions to the existing lake response model as important components of the re-examination process. Cardno ENTRIX also recommended that multiple models be developed to inform the re-examination of the nutrient strategy. The recommendation included the development of a model that evaluates uncertainty and provides additional model validation, such as a structural equation model or Bayesian model, and a revised version of the existing Falls Lake Nutrient Response Model using the Environmental Fluid Dynamics Code (EFDC) model framework.

The UNRBA is submitting this modeling framework as directed by the Falls Lake Nutrient Management Strategy and the modeling requirements described by NCDWR for their review of water quality models for decision making purposes. The remaining sections of this document follow the outline provided in the Division of Water Resources Guidelines for Water Quality Modeling Plans, August 20, 2013: http://portal.ncdenr.org/web/wq/ps/mtu/modeling.

1.2 Project Goals

In 2013, in order to support the Association's re-examination process and an expanded review of Lake management approaches, the UNRBA developed six objectives that additional monitoring and modeling should support. These objectives are described in the Task 4 technical memorandum (Cardno ENTRIX 2013) and are listed below:

A. Source and Jurisdictional Loading

B. Lake Response Modeling

C. Compliance Monitoring

D. Linkage of Water Quality to Designated Uses

E. Credit Estimation for non-Conventional BMPs

F. Support of Regulatory Options

This document addresses Lake Response Modeling (item B) which pertains specifically to requirements described in 15A NCAC 02B .0275 (5) (f) for the revision and update of the existing Falls Lake Nutrient Response Model using EFDC. The revision of the existing nutrient response model will allow the UNRBA to re-evaluate the Falls Lake nutrient reduction requirements using multiple years of data and provide a technical foundation for modifications to the nutrient management strategy. The remaining five objectives (A and C thru F) go beyond the scope of the reexamination process described in 15A NCAC 02B .0275 (5) (f).There are several goals associated with the monitoring program that are directly related to Lake Response Modeling. These are listed below and described in more detail in the following sections:

> Update the model with more recent water quality data

> Refine tributary loading estimates

> Recalibrate the model and evaluate various nutrient management scenarios and impacts on key parameters

1.2.1 Update Model with Additional Water Quality Data

One project goal is to update the existing Falls Lake EFDC Nutrient Response model with additional water quality data. The original Falls Lake Nutrient Response model was developed by NCDWR under a very tight schedule with limited water quality data. Since the model was originally developed, calibrated, and validated (2005 to 2007) several additional years of water quality data have been collected. In addition, many of the local governments in the watershed have implemented successful nutrient reduction programs from both point and nonpoint sources.

1.2.2 Refine Tributary Loading Estimates

Another goal is to reduce uncertainties in tributary loading estimates by collecting missing data. One key source of uncertainty in the existing model is the lack of measured chlorophyll *a* and total organic carbon (TOC) inputs from the tributaries. Because these data were not routinely collected throughout the watershed, the NCDWR version of the lake model assumed that concentrations entering the lake from the tributaries were the same as what was observed at the closest lake monitoring station. The UNRBA believes that this assumption affected the calibration of the model and the ability of the model to accurately estimate the lake's response to nutrients. In addition it appears that even under Stage II load reduction scenarios, the tributary concentrations of chlorophyll *a* and TOC were maintained in the model at the lake concentrations observed during the modeling period. This assumption may have skewed upward the model's prediction of chlorophyll *a* concentrations in the Lake and helped support higher nutrient reduction targets than what is needed to achieve water quality standards in the Lake.

Another potential area of model refinement relates to the method used to estimate daily tributary concentrations from bi-weekly or monthly water quality samples. For the current model, NCDWQ used a linear interpolation between two sampling dates to estimate daily loads. The UNRBA plans to explore the use of other existing tools such as the United States Geological Survey's (USGS) LOAD ESTimator (LOADEST) program to estimate daily concentrations of total nitrogen and total phosphorus based on relationships with flow. The USGS LOADEST program is commonly used for this purpose and provides an alternative method for predicting daily concentrations and loads. Cardno ENTRIX has developed LOADEST regressions for total nitrogen and total phosphorous for the upper five tributaries to the lake and presented corresponding r-squared values (Cardno ENTRIX 2014).

1.2.3 Recalibrate Lake Response Model and Evaluate Nutrient Management Scenarios

As described above, additional water quality data will be collected to refine tributary loading inputs. Data collected in the lake, primarily by NCDWR, will be used to calibrate the revised lake response model. The calibrated model will then be used to evaluate various nutrient management scenarios and impacts on key parameters. The key parameter of concern has been chlorophyll a because the upper part of the lake is currently considered impaired due to exceedances of the chlorophyll a standard. However, the UNRBA member governments are also concerned about total organic carbon (TOC) and related water quality conditions in Falls Lake.

1.3 Project Organization

The current Project Team for the nutrient response model revisions includes the following parties:

> UNRBA Executive Director Forrest Westall

> UNRBA QA/QC Team: Path Forward Committee Members

> Cardno ENTRIX Project Manager: Lauren Elmore

> Cardno ENTRIX Modeling Coordinator: Alix Matos, PE

> Cardno ENTRIX Lead EFDC Modeler: Drew Ackerman

> Cardno ENTRIX QA/QC Team Lead: Matt Van De Bogert, PhD

> USGS Providing Flow gaging support

> TBD Selected subcontractors as identified in the Monitoring Plan QAPP

Work on the nutrient response model will not begin for several years (e.g., 2016 or later). The future nutrient response modeling QAPP will have updated modeling team information. In addition and as noted in the introduction to this TM, the UNRBA has not at this time selected its modeling contractor. When a full modeling framework is submitted, the modeling project team will be identified.

1.4 Falls Lake Nutrient Response Modeling Plan using EFDC

The modeling plan for this project is essentially the same as that developed by NCDWQ when the original Falls Lake Nutrient Response Model was developed. This section describes the components of the modeling plan as required by NCDWR.

1.4.1 Model Geographic Scope

The model geographic scope will be based on the existing model and includes the lake itself and the tributary inputs shown in Figure 1. The model grid may be altered for this reexamination, including increasing the number of layers relative to the four that are in the current version of the model and extending the model grid further upstream into the tributaries. The updated model will be at least as spatially refined as the existing agency model.

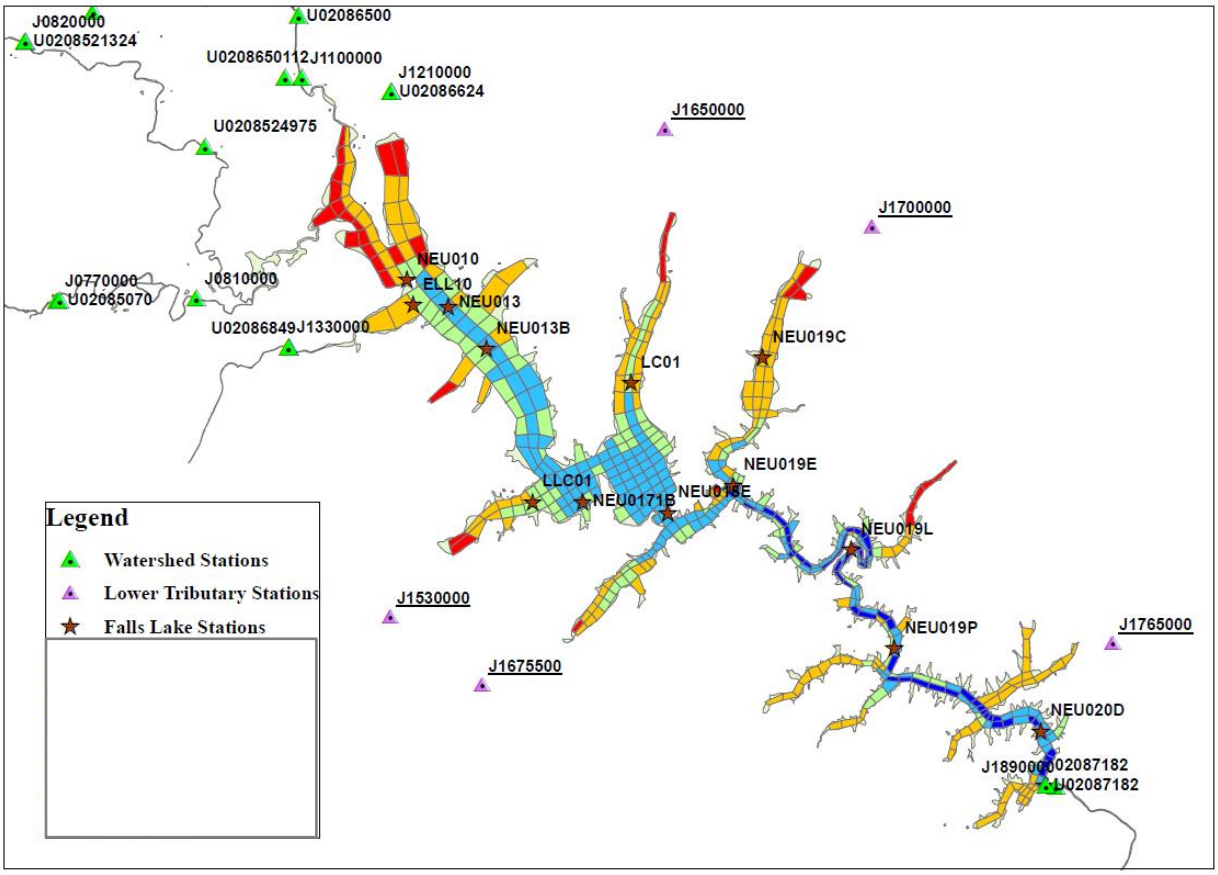

Figure 1 Geographic Scope of the Falls Lake Nutrient Response Model (from NCDENR 2009)

1.4.2 Temporal Scope

The monitoring to support revisions to the Falls Lake Nutrient Response Model will begin in 2014 and continue through 2018 or 2019. It is likely that year 2014 will be used to provide initial conditions for the model inputs and lake conditions. Model start files will be generated at the end of each year when back to back years are run. The exact calibration and corroboration years will be based on the hydrologic characteristics of the years (wet, dry, extreme events) and will be described in the modeling QAPP.

1.4.3 Model Endpoints

The primary endpoint for the model is chlorophyll *a*, with a secondary endpoint of TOC.

1.4.4 Model Selection

The existing Falls Lake model developed by NCDWR using EFDC will be used for this project as recommended by Cardno ENTRIX (2013) and approved by the UNRBA along with revised monitoring data as required under 15A NCAC 02B .0275 (5) (f). The modeling report for the Falls Lake Nutrient Response Model describes the equations, parameters, boundary conditions, grid development, and variables used by the model (NCDENR 2009). In the development of all the supporting information for the UNRBA's re-examination effort, the UNRBA and Cardno ENTRIX have had several meetings with DWR where future modeling has been discussed. The Agency has clearly indicated that for continuity and comparison purposes, DWR believes that any remodeling must employ the use of EFDC. As noted in this document, the UNRBA will provide additional modeling along with the results of the revised EFDC model.

1.4.5 Model Data Needs

The Falls Lake EFDC Nutrient Response model requires the following data:

> Climate data from the NC State Climate Office and National Oceanic and Atmospheric Administration

> Atmospheric deposition data from the National Atmospheric Deposition Program (NADP) and Clean Air Status and Trends Network (CASTNET)

> Tributary flow data from USGS

> Tributary and lake water quality data collected by USGS, NCDWR, and the UNRBA following approval of the monitoring design plan and QAPP

> Lake outflow and water surface elevation data provided by the US Army Corps of Engineers and the City of Raleigh

1.4.6 Data Gaps

Because the existing model currently predicts that large nutrient reductions are needed to comply with chlorophyll *a* criterion (stakeholder selected reduction goals of 40 percent for nitrogen and 77 percent for phosphorus), it is in the interest of the stakeholders in the watershed to reduce the uncertainty of the model inputs and predictions. Since it is typically not possible to collect site-specific data for every variable and parameter, the development of most models relies on assumptions and best professional judgment. A number of assumptions made during development of the Falls Lake model can be confirmed or replaced with actual data. The UNRBA monitoring program will be designed to fill in a number of these data gaps prior to revision of the baseline model. The monitoring program will also provide additional years of water quality data that can be used to make the model more consistent with EPA's use of multiple years when calculating load allocations. Issues and data gaps that will be addressed in the updated model include:

> The modeling period will be based on a range of typical hydrologic conditions for the watershed rather than a single year.

> Revised pollutant loading estimates for tributaries downstream of I-85.

> Use actual tributary concentrations of chlorophyll *a* and TOC collected in free flowing waters to calculate inputs to Falls Lake.

> Conduct special studies to obtain an improved understanding of the spatial variability in Falls Lake modeling parameters such as background light extinction and benthic flux rates.

The UNRBA is currently developing a monitoring plan to fill these data needs. This modeling plan is a component of the UNRBA's monitoring plan.

1.4.7 Model Calibration/Corroboration

The exact years for calibration and corroboration will be based on the hydrologic characteristics of the years monitored (wet, dry, extreme events) and the process will be described in the modeling QAPP. The model calibration points for the lake response model will be the same as in the original model developed by NCDWQ which used data collected by NCDWQ at the lake assessment points (Figure 2).

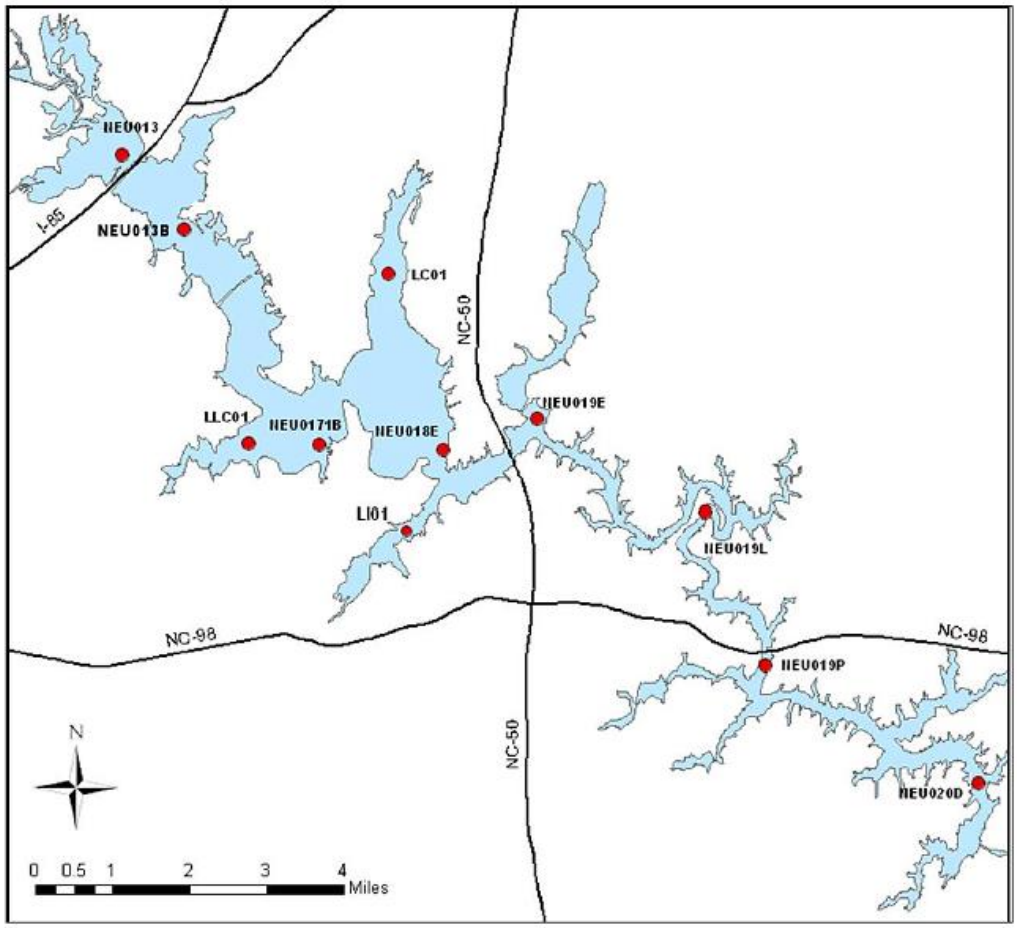

Figure 2 Division of Water Resources Falls Lake Water Quality Monitoring Locations (From NCDWQ 2011)

Parameters selected for calibration include those targeted in the original model as documented by NCDENR (2009): water level, water temperature, total suspended sediment, chlorophyll *a*, total organic carbon, total phosphorus, ammonia, nitrate plus nitrite, total Kjeldahl nitrogen, total nitrogen, and dissolved oxygen.

1.4.8 Model Performance Targets

Model performance targets and comparative statistics are described in the Falls Lake Nutrient Response Model Report (NCDENR 2009). Based on consultation with the Technical Advisory Group assembled for the DENR project, the following model performance goals and evaluation methods were established:

> Use time series plots to visually assess the comparison between observed and predicted values.

> Root mean square error for predicted hydrodynamic model variables (such as temperature) should be much less than one standard deviation of the observed data (e.g. RMSE ≤ 0.5 SD_{obs}).

> Root mean square error for chlorophyll a should be around one standard deviation of the observed data

> Average error for predicted TSS and water quality model variables (such as chlorophyll *a*, TN, and TP) should be much less than one standard deviation of the observed data (e.g. AE ≤ 0.5 SD_{obs}).

To support the reexamination of the Falls Lake Nutrient Management Strategy the revised model will be evaluated using the same performance goals. Additionally, the model should be evaluated on a monthly, or at a minimum, a seasonal basis to ensure that water quality variability in the lake is well characterized.

1.5 Data Management

Based on current information and knowledge, the software to be used for this project is described below in Table 1. This list is incomplete because work on the modeling QAPP has not yet begun. A final list will be included in the modeling QAPP. Preliminary evaluations of input data have suggested these tools will be useful for developing the inputs and outputs of the nutrient response model using EFDC.

Table 1 identifies a number of tools and programs that will likely be used for data management, input and output file generation and processing during the anticipated model revision process. This table will be updated in future modeling QAPP documentation.

Table 1 Anticipated Data Management Tools for the Revised and Updated Falls Lake Nutrient Response Model

Software name (and acronym)	Supported and Maintained by	Purpose
Environmental Fluid Dynamics Code (EFDC)	US EPA	The Environmental Fluid Dynamics Code (EFDC Hydro) is a state-of-the-art hydrodynamic model that can be used to simulate aquatic systems in one, two, and three dimensions.
EFDC-Explorer	Dynamic Solutions - International, LLC	Windows-based GUI for pre- and post- processing of the Environmental Fluid Dynamics Code (EFDC)
LOAD ESTimator (LOADEST)	USGS	Estimation of tributary nutrient concentrations based on relationships with flow, time, etc.
R statistical package	R-Core Team	Input and output file processing and results summarization as well as any statistical analyses
Intel FORTRAN	Intel Corporation	Pre and post-process model inputs and outputs
MS Excel	Microsoft	Input and output file processing and results summarization
ArcGIS	ESRI, Inc.	Spatial interpretation of data

All files will be maintained in a project directory, with input and output files stored in separate directories to simplify the execution of EFDC. Descriptions of file storage and procedures for generating and storing input and output files will be provided in the modeling QAPP.

1.6 Model Review

The Falls Lake Nutrient Response Model was developed by NCDWQ and has been previously reviewed by NCDWQ and an independent party, Tetra Tech on behalf of the North Carolina Department of Transportation. Cardno ENTRIX has reviewed the model inputs and the model's sensitivity to changes in assumed and measured input concentrations (chlorophyll a, TOC, and nutrient concentrations) on behalf of the UNRBA. The UNRBA member governments have indicated that third party review will likely occur.

1.7 Quality Assurance Plan

A QAPP will be developed prior to commencing the revised modeling using EFDC. Quality assurance of model inputs and outputs is a portion of the QAPP that will be developed. Generally, the internal quality assurance plan will include post-checks by the QA officer to examine methods and processes for

developing input and output data. The QA Officer will also ensure that the suggested model uses are appropriate to the calibration and corroboration that was performed on the revised model. Additional quality assurance will include a review by NCDWR and a third party.

1.8 Schedule

The proposed draft schedule for the model development and data collection (Figure 3).

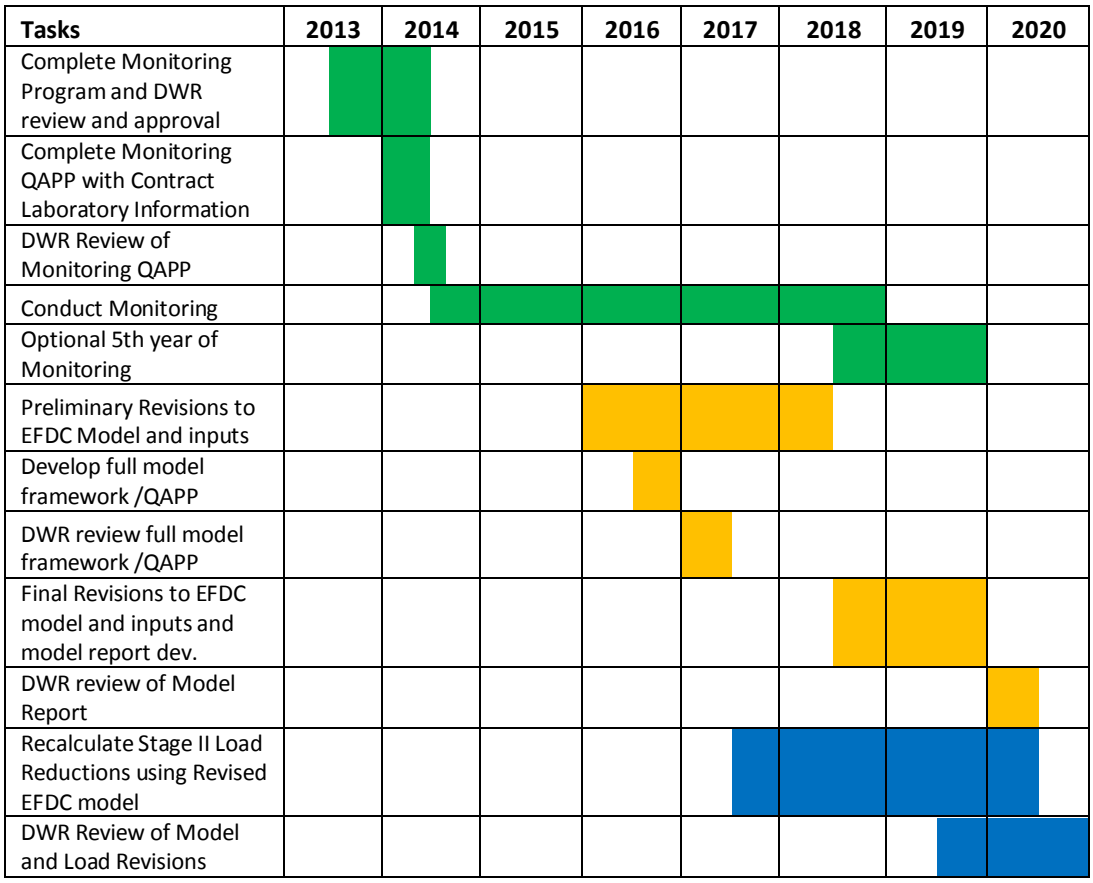

Figure 3 Potential Schedule for the nutrient response model refinements and Re-examination of Stage II of the Falls Lake Rules

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