**Upper Neuse River Basin Association**
**Special Study Plan**
**Date Issued: January 14, 2016**

## Special Study Name, ID# and Origin:

Basic Evaluation of Model Performance, SS.LR.8

This Special Study was added to the Cardno FY 2016 contract to help evaluate components of previously identified models for the reexamination of the Falls Lake Nutrient Management Strategy. This evaluation is being performed to determine whether or not the current monitoring program design is sufficient, or whether the monitoring program requires revisions to address the needs of the models. This study will focus on previously identified modeling approaches the UNRBA is planning to use for the reexamination and potential alternative regulatory approaches.

## Responsible Contractor(s):

Cardno – responsible for study planning; general management and oversight; and model evaluations, interpretations, and incorporation into the monitoring program; responsible for identifying data gaps that may be best addressed by incorporating input from experts.

## Purpose of Study:

This Special Study will support potential adaptations of the Monitoring Program by helping to ensure that the data collected is appropriate and sufficient for future modeling efforts. This study will support the evaluation of resource allocation among existing or potential monitoring studies through targeted revisions to and simulations with the multiple models identified to support the reexamination process. This study will include evaluations of tributary load estimates using USGS LOASEST, preliminary revisions to the EFDC model grid and input files, assessment of 2006 baseline EFDC model output with respect to identifying dominant factors affecting model results, and documentation of the data needs of the models. This work will also support recommendations for future model development through a review of the current EFDC model implementation (e.g., its spatial resolution, choice of model algorithms and compatibility with monitoring data) and its appropriateness to support the objectives of the Stage II reexamination. This Special Study will also include evaluation of the data needs of the empirical/probabilistic models that have been recommended to support linking water quality in Falls Lake to designated uses.

The models to be evaluated include the following:

- **USGS LOADEST:** This model includes a series of regression models that estimate tributary loads by correlating observed water quality concentrations with flow data. In the UNRBA Monitoring Plan Model Sensitivity Technical Memorandum (http://www.unrba.org/monitoring-program), Cardno evaluated the regression models generated by LOADEST for the five, large upper lake tributaries and developed loading estimates by pairing the model with the greatest accuracy to flows observed at the USGS gages on the five tributaries. Depending how the flow (hourly average, daily average, etc.) was paired with the LOADEST water quality regression resulted in a relatively large range of tributary load estimates. As part of this Model Evaluation Special Study, Cardno will use the data collected from the UNRBA Storm Event Sampling Special Study to assess the accuracy of the different load estimation methods by comparing estimated loads to observed loads during multiple storm events.

- **The 3D Falls Lake Nutrient Response Model using the Environmental Fluid Dynamics Code (EFDC):** This model was originally developed by DWR to simulate water quality in Falls Lake for 2006[1] (the baseline year), and it was used to determine the nutrient load reduction targets in the Falls Lake Nutrient Management Strategy. In previous work, Cardno identified several data gaps and issues with how the model was developed (see the Task 4 - Recommend Future Monitoring and Modeling Approaches available at http://www.unrba.org/reexamination and the UNRBA Monitoring Plan Model Sensitivity Technical Memorandum and the Description of UNRBA Model Framework available at http://www.unrba.org/monitoring-program). Given that one year of data has now been collected under the UNRBA Monitoring Program, it is timely to review the model and whether the monitoring program is gathering the appropriate data. One component of this Special Study includes preliminary assessments to evaluate three of the most resource intensive Special Studies that the UNRBA is currently conducting: Constriction Point Special Study, Storm Event Sampling, and Lake Sediment Evaluation.
- **Falls Lake Framework Tool:** This spreadsheet-based model was previously developed by Cardno to support development of the reexamination strategy (see the Task 1 - Develop a Framework for a Reexamination of Stage II of the Falls Lake Nutrient Management Strategy available at http://www.unrba.org/reexamination). This model incorporates the steady state USACE BATHTUB model in its calculations to predict lake concentrations of total nitrogen, total phosphorus, and chlorophyll a. Information from other sources was used to link lake water quality to the designated uses of Falls Lake. For example, data from the City of Raleigh regarding the amount of ferric sulfate needed to treat raw water from Falls Lake was used to determine how changing nutrient loads to the lake would affect the cost of treating the drinking water. Treatment costs were used to assess the effects of changing lake water quality on meeting the designated use of water supply for Falls Lake. The Task 1 Technical Memorandum describes how linkages to the other designated uses were coded into the Falls Lake Framework Tool. Each of the linkages in the Falls Lake Framework Tool will be evaluated for its use in the empirical/probabilistic model described in the next bullet.
- **Empirical/probabilistic model:** An empirical/probabilistic model uses mathematical relationships and probability estimates to predict how changing one parameter may affect multiple other parameters of interest. Mechanistic models (such as EFDC) simulate processes that result in specific outcomes (such as water quality concentrations), but they cannot always simulate the types of outcomes that determine whether or not a designated use is met. For example, the Falls Lake EFDC model can predict average concentrations of total organic carbon at the City of Raleigh's raw water intake, but it does not predict how well Raleigh will be able to comply with the standards in the Safe Drinking Water Act.

  Cardno recommended development of an empirical/probabilistic model of Falls Lake to predict how changing nutrient loads to the lake would affect the designated uses of the lake. The Task 1 Technical Memorandum (http://www.unrba.org/reexamination) presented a conceptual model showing the linkages that may be included in the model, which may include Bayesian modeling to incorporate input from subject matter experts to assist with model linkages that may not be easily developed from readily available data. This Special Study component will evaluate these linkages and determine if the Monitoring Program is collecting the types and quantities of data needed to fully develop the empirical/probabilistic model. The mathematical relationships in the Falls Lake Framework Tool will be also evaluated for applicability for the empirical/probabilistic model.

[1] The model was also developed for part of 2005 and part of 2007.

**This Special Study supports these objectives of the UNRBA Monitoring Program:**

- Lake response modeling
- Support of regulatory options

**Anticipated Schedule:**

This special study will be completed by April 2016 so that its findings may be used by the PFC to prioritize monitoring plans for inclusion in the FY2017 monitoring program.

**Summary of Study Methods:**

This Special Study includes preliminary assessments of the models that have been identified to support the UNRBA's reexamination of the Falls Lake Nutrient Management Strategy. As described above, the primary purpose of this Special Study is to inform revisions to the UNRBA Monitoring Program, with a particular emphasis on the most resource intensive special studies.

**USGS LOADEST Model Evaluations**

In 2015, Cardno initiated the Storm Event Sampling Special Study (http://www.unrba.org/monitoring-program) to collect water quality samples at a relatively high frequency during storm events at two tributaries in the Falls Lake Watershed. The Storm Event Sampling Special Study provides data to calculate a measured tributary load generated during a storm. As part of this Model Evaluation Special Study, Cardno will compare the measured tributary loads to those predicted by pairing LOADEST water quality regressions with flow estimates, and determine the most accurate flow-regression pairing method for future revisions to the Falls Lake EFDC model.

Evaluations of USGS LOADEST will improve the accuracy of the tributary load estimates that are used to drive the EFDC lake response model and provide information on whether or not the Storm Event Sampling Special Study should be revised. Cardno will evaluate the LOADEST regressions that were previously developed using ambient water quality data, and update the regressions by including data collected as part of the UNRBA Routine Monitoring, High Flow Event Special Study, and Storm Event Sampling Special Study. The degree of accuracy of the load estimates relative to measured loads at two tributaries (one with a wastewater treatment plant discharge and one without) will inform decisions on how the Storm Event Sampling Special Study may need to be revised, for example:

- Are the data collected as part of the Routine Monitoring and High Flow Event Special Study sufficient to develop accurate water quality regressions using LOADEST? After multiple storms have been sampled as part of the Storm Event Sampling Special Study, is this data sufficient to document the most accurate load estimation method (pairing flow and water quality regression)?
- Should the resources for the Storm Event Sampling Special Study be allocated to a different effort (e.g., collecting more High Flow Event Samples with a broader spatial coverage)?
- Is the most accurate load estimation method (pairing flow and water quality regression) the same for both of these relatively different tributaries (drainage area, land use, and size of permitted wastewater treatment plant discharges), or do they respond differently such that additional storm event data collection, possibly on a different tributary is warranted?

**EFDC Model Evaluations and Literature Review**

Evaluations of the EFDC model will focus initially on three components of the modeling:
1) adjusting the model grid at the upper lake constriction points to better simulate the flow and transport of materials (such as nutrients) through I-85 for comparison to data collected as part of the Constriction Point Study,
2) review of the 2006 model output to understand the primary sources of nutrients and carbon including tributary inputs, atmospheric deposition, releases from the sediments, and
3) documentation of the data needs associated with the sediment diagenesis module and comparison to sediment data collected in Falls Lake as part of the Lake Sediment Evaluation Special Study.
These model assessments will provide information on the data requirements, degree of uncertainty, and relative importance to model results. The evaluations will also inform decisions on potential modifications to current monitoring activities and data collection efforts.

Each evaluation of the EFDC model will focus on the upper lake segment (above I-85) which receives loads from 66 percent of the Falls Lake drainage area and three wastewater treatment plants. This segment also demonstrates the greatest response to nutrient loads in terms of algal production, has the greatest variability in observed water quality, and generally has higher chlorophyll a concentrations compared to the downstream segments. In the lower part of the lake, the water quality concentrations are relatively stable and appear to be driven mostly by processes occurring in the upper segment. By limiting the preliminary evaluations to the upper most segment (e.g., revisions to the model grid), the resources assigned to this Special Study can be used to address more types of model evaluations. At this stage of the modeling review, the goal is to evaluate whether or not the Monitoring Program is collecting the types and quantity of data needed to develop and calibrate the models. Focusing on the area of the lake with the most variability in water quality allows for an efficient use of limited resources. Future model revisions to support full model development and calibration will include the entire lake.

*Revisions to the Model Grid*

The existing Falls Lake EFDC model grid does not incorporate the flow constrictions at railroad and road causeways which may have a significant impact on the hydrodynamics and subsequent transport of material through the segments of the reservoir. Cardno will revise the grid configuration around the Railway and I-85 bridge causeways in the upper lake segment to better simulate the movement of water through these constriction points. After the grid has been revised, model simulations will be performed using the 2006 model input files to determine the impact of modeling the revised constrictions. Revising the grid using the 2006 model will not provide a direct comparison to the flow and water quality data collected as part of the Constriction Point Special Study which is likely to be carried out in 2016. However, the model results can be compared qualitatively to the data collected as part of this effort to determine if the revised model more accurately represents flow conditions in the lake and if revisions to the design of the Constriction Point Special Study are needed to better understand the hydrodynamics through constrictions. While the grid revisions will occur in early 2016, the comparisons to field measurements cannot be conducted until at least one of the sampling events of the Constriction Point Special Study has been conducted and analyzed, likely in the spring of 2016. The model sensitivity to this revision and the remaining uncertainties revealed during the model evaluation will help inform revisions to this relatively expensive Constriction Point Special Study for future years.

*Analysis of Model Outputs and Mass Balances*

This component of the work will also provide preliminary mass balance estimates for nutrients, chlorophyll-a, and organic carbon in the upper lake segments. The mass balance is an important indicator of key model processes controlling the simulated model response and will allow more robust assessment of

model uncertainty and guide Monitoring Program revisions (e.g., the potential need for more spatial resolution of monitoring and event based sampling in the lake).

*Review of Methods to Simulate Nutrient Release from Lake Sediments*

Cardno will also review EFDC options for incorporating sediment nutrient releases (including the sediment diagenesis module) and compare to the data collected as part of the Lake Sediment Evaluation Special Study. This evaluation will be conducted to determine whether the data that has been collected is sufficient to develop the model to simulate the release of nutrients from the lake sediments and to determine the key uncertainties in the model processes. This evaluation will help inform any needed alterations in the monitoring program, including monitoring coordination with USEPA to conduct in situ benthic chamber measurements of nutrient releases from lake sediments.

**Evaluations of Empirical/Probabilistic Models including the Falls Lake Framework Tool and Bayesian Models**

The empirical/probabilistic model will be developed to link water quality to the designated uses of Falls Lake and to support the reexamination of the Falls Lake Nutrient Management Strategy. Cardno previously developed a preliminary, simplified empirical model (the Falls Lake Framework Tool) and a conceptual model for the more rigorous empirical/probabilistic model that will be developed in the future to support the reexamination process. This component will evaluate the model linkages identified in the conceptual model against the existing monitoring efforts (by the UNRBA and other organizations) to determine if additional monitoring is needed to populate the empirical/probabilistic model. Identification of potential methods for developing model linkages will also be described as part of this Special Study. For example, the tributary flow data measured by USGS and the UNRBA routine monitoring, high flow event sampling, and storm event sampling will be used to estimate nitrogen and phosphorus loading to the lake. In order to predict nutrient concentrations in the lake in the empirical/probabilistic model, a mathematical expression will be needed. This prediction of lake water quality may be developed with a site-specific relationship using data collected in Falls Lake, or represented by existing regression equations that were developed based on data collected in other reservoirs (e.g., the USACE BATHTUB equations that were used to develop the Falls Lake Framework Tool). For each variable and model linkage in the empirical/probabilistic model, potential sources of information will be identified to confirm that the current Monitoring Program is providing the information necessary to build this model. In the event that gaps in data are identified, they will be presented to the PFC to inform potential revisions to the Monitoring Program.

**Quality Assurance/Quality Control:**

Cardno's modelers employ a system of quality assurance protocols to ensure that modeling scenarios and input and output files are managed with accuracy and accountability. The EFDC model provided by NC DWR comprising the executable code (FL2005.exe), FORTRAN source code files and 2006 Baseline model input files will be registered in Cardno's modeling tracking system. Adjustments to model grids and input files and the resultant model output files will be tracked through a model run register. Analysis of the output fields and data will be conducted with the Matlab software package. All Matlab scripts, functions and input (comprising data or model outputs) will be logged through the Sub Version Management system.

**Reporting/Deliverables:**

Cardno will communicate with the UNRBA Executive Director on a regular basis on the progress of this Special Study. Status updates will be provided to the UNRBA Path Forward Committee and the Board of Directors at their regular meetings.

Discussion of the status and results from this Special Study will be included in one or more technical memoranda or the Mid-Year and Annual Reports, depending on the timing of those reports being delivered to the PFC relative to the information generated by this study. Deliverables from this effort will provide recommendations on additional data types and monitoring studies (if needed) that would benefit the modeling efforts and support the re-examination. This information will largely be used to inform future revisions to the monitoring program, and the results will be summarized as recommendations for the FY 2017 Monitoring Plan, which will be presented to the PFC in April 2016.