Memorandum

Date:	November 21, 2016
To:	Forrest Westall, UNRBA
From:	Alix Matos and Matt Van de Bogert, Cardno; Chris Wallen and Katie van Werkhoven, Dynamic Solutions, LLC
RE:	Lists of Potential Model Package Selection Criteria and Model Package Selection Process for the UNRBA Modeling and Regulatory Support Project For Distribution to Watershed Stakeholders

In 2010, the Environmental Management Commission passed the Falls Lake Nutrient Management Strategy, requiring two stages of nutrient reductions for Falls Lake. The Strategy was developed on a compressed schedule with only three years to collect data, develop watershed and lake models, and adopt the rules. Because of the uncertainty associated with the model-based load reductions, the Strategy allowed for a reexamination of the required nutrient load reductions (http://portal.ncdenr.org/web/fallslake/home). Due to this uncertainty and because the Strategy is estimated to cost over $1 billion, the Upper Neuse River Basin Association (UNRBA) began planning for a reexamination in 2011. The UNRBA has been collecting water quality data in the watershed and the lake since August 2014 to support this effort.

In 2016, the UNRBA issued an RFQ and selected a team of contractors to begin the Modeling and Regulatory Support component of the reexamination. The UNRBA hosted a kickoff meeting for this project on September 28, 2016. The scope of work for Year 1 of this contract includes the following:

- Evaluation and selection of lake and watershed modeling packages
- Development of conceptual plan for the multi-modeling approach
- Development of the Modeling Quality Assurance Project Plan (QAPP)
- Development of the two-year work plan (October 2017 through September 2019)
- Revisions to the Description of Modeling Framework (previously approved by DWR in 2014)

This memorandum summarizes potential criteria for the evaluation and selection of watershed and lake modeling packages. This list was compiled from several sources:

- Monitoring and modeling goals compiled during development of the original Falls Lake Nutrient Response Modeling by the Technical Advisory Committee, the UNRBA, and the Triangle Council of Governments (TJCOG);
- Model package selection criteria documented previously in the Task 4 Technical Memorandum - Recommend Future Monitoring and Modeling Approaches available online at www.unrba.org/reexamination;
- Comments received during the September 28, 2016 kickoff meeting for the UNRBA Modeling and Regulatory Support Project.

Some comments such as evaluating emerging contaminants of concern are beyond the scope of this UNRBA project. This issue was not added to the tables of model package selection criteria.

Two types of modeling packages are being considered for this project: watershed loading and lake nutrient response. Each type of modeling package may include a complex, mechanistic model (process based) as well as a simple, empirical model (data driven). The UNRBA has proposed this multi-modeling approach (also described in the Task 4 Technical Memorandum), at a minimum for the lake nutrient response modeling and possibly for the watershed modeling, to corroborate results, evaluate modeling uncertainty, and provide a linkage between lake water quality and designated uses.

1. Watershed loading model packages. These model packages simulate the amount of pollutant generated from nonpoint sources (land uses, atmospheric deposition, onsite wastewater treatment, fertilizer application, etc.) and account for loads contributed from point sources (permitted dischargers such as wastewater treatment plants). These model packages may be empirical or mechanistic. Watershed loading models can be linked to downstream instream water quality models that predict the water quality in a receiving waterbody such as a river or lake. The primary objectives for the watershed modeling to support the UNRBA reexamination effort include the following:
    a. Determine nutrient and carbon loads from different land uses, sources, and jurisdictions in the watershed
    b. Provide inputs for the lake nutrient response model(s)
    c. Evaluate various management strategies and scenarios and the potential impacts these actions will have on loading to the lake
2. Lake nutrient response model packages. These model packages predict volume and discharge (or flow) and nutrient-related water quality in response to flows and loading from the watershed, atmosphere, and internal loads. Like watershed model packages, they may be either empirical or mechanistic. Lake response models should account for hydrologic inputs (tributary inflows, precipitation to the lake surface, point source discharges) and outputs (flow over the dam or through outlet structures, evaporation from the lake surface, and water supply withdrawals). Lake nutrient response models predict water quality attributes associated with trophic status, including growth of algae, by simulating nutrient concentrations, light availability, and hydrologic residence time. Some lake nutrient response models account for internal nutrient loading from the lake bottom sediments. The primary objectives for the lake response modeling to support the UNRBA reexamination effort include the following:
    a. Simulate nutrient, chlorophyll *a,* and total organic carbon concentrations in the lake (several of these model packages also simulate other water quality parameters, but these are of primary concern to the UNRBA)
    b. Evaluate various management strategies, regulatory options, and impacts on water quality in the lake
    c. Link water quality to designated uses in the lake
    d. Evaluate water quality standards

Conventional watershed loading and lake nutrient response model packages are often developed to predict nutrient loads and changes in water quality parameters. These model packages typically do not address attainment of designated uses or key questions of concern from the public: Is the water safe to swim in? Will the lake support a healthy fish population? The UNRBA reexamination strategy includes the development of an empirical/probabilistic/Bayesian (EPB) model to link lake water quality to designated uses and trophic conditions in the lake. Because some of the information to populate this model may be difficult or costly to measure, expert opinion is often incorporated in the model. The UNRBA has identified subject matter experts (SMEs) to support this component of the reexamination. The SMEs address the fields of water chemistry, lake processes, drinking water treatability, and evaluation of impacts to recreational uses. This model would be constructed specifically for this Falls Lake application and may incorporate empirical equations from existing modeling packages when available. For example, the EPB could incorporate equations from EUTROMOD or BATHTUB to predict lake water quality, but other relationships would have to be developed to link water quality to designated uses. The EPB is a model framework that will be evaluated as part of the suite of watershed and lake modeling packages.

Year 1 of the UNRBA Modeling and Regulatory Support contract includes an evaluation and selection of model packages that will be used to support the reexamination of Stage II of the Falls Lake Nutrient Management Strategy. Figure 1-1Table 1 list the types, names, and acronyms for the model packages being evaluated. Tables 2 and 3 list the model packages proposed for evaluation and the suggested criteria that will inform model package selection. These criteria have been identified to assist with the evaluation of the model packages to achieve the primary modeling goals listed above. Table 4 provides links to additional information available online for the modeling packages.

This list of model package selection criteria has been reviewed by the UNRBA Modeling and Regulatory Support Workgroup, the UNRBA Path Forward Committee, and staff at the Division of Water Resources Modeling and Planning Groups. This list is being distributed to the watershed stakeholders for their review as part of the ongoing effort to communicate the UNRBA's reexamination process.

Table 1 Lake and Watershed Model Packages Being Evaluated

Model Package	Acronym	Type
SPAtially Referenced Regressions On Watershed	SPARROW	Watershed
EUTROMOD	EUTROMOD	Watershed and Lake
Watershed Assessment Risk Management Framework	WARMF	Watershed and Lake
Generalized Loading Function Model	GWLF	Watershed
Soil and Water Assessment Tool	SWAT	Watershed
Hydrological Simulation Program Fortran	HSPF	Watershed
Loading Simulation Program C	LSPC	Watershed
Storm Water Management Model	SWMM	Watershed
Regional Hydro-Ecological Simulation System	RHESSys	Watershed
MIKE-SHE	MIKE-SHE	Watershed
Gridded Surface Subsurface Hydrologic Analysis	GSSHA	Watershed
Empirical Probabilistic Bayesian	EPB	Watershed and Lake
Environmental Fluid Dynamics Code	EFDC	Lake
EFDC-Water quality Analysis Simulation Program	EFDC-WASP	Lake
WARMF-LAKE	WARMF-LAKE	Lake
WARMF-CE-QUAL-W2	WARMF-CE-QUAL-W2	Lake
DELFT	DELFT	Lake
General Lake Model	GLM	Lake
BATHTUB	BATHTUB	Lake
ECOM-Row Column AESOP	ECOM-RCA	Lake
MIKE-3	MIKE-3	Lake
RMA	RMA	Lake
AQUATOX	AQUATOX	Lake
Comprehensive Aquatic Systems Model	CASM	Lake

Table 2 Evaluation Criteria for Falls Lake Watershed Model Packages

MODEL:	SPARROW	EUTROMOD	WARMF	GWLF	SWAT	HSPF	LSPC	SWMM	RHESSys	MIKE-SHE	GSSHA	EPB
Model Package Characteristics and Past Use:												
Publically available model package: Does the UNRBA have to purchase the model package to use it for the Falls watershed? Or is it free and publicly available?												
Publically available source code: Does the UNRBA have access to the computer code behind the model package? If not, can the UNRBA pay a fee for this access?												
Peer reviewed: Has the model package been used in other watersheds in the South eastern US? Has the programming for the model package been reviewed by other programmers and water resource scientists?												
EPA recommendation: EPA does or does not recommend this model be considered.												
NCDWR recommendation: NCDWR does or does not recommend this model be considered.												
Is there an existing application of this model package to the Falls Lake watershed?												
Was this model package used to develop the current Falls Lake Nutrient Management Strategy?												
Spatial resolution: Can the model package be set up to run small (~ 100 acre) to large (several square miles) drainage areas? Can the model package take advantage of 2-foot aerial imagery, or must it be 30 meter (NLCD)? Can the land use information available at a parcel level be converted to land cover?												
Smallest accurate output time step: Does the model package predict flows and nutrient loads annually? Seasonally? Monthly? Daily? Hourly? Subhourly?												
Does the model use **land use data or land cover data**?												
Type: What is the basis for the package? Empirical (based on data and simple statistics), Process-Based (based on physics and chemistry), Advanced statistics (using Bayesian theory or Structural Equation Modeling (SEM)?												
Is the model package **simple or complex**?												

MODEL:	SPARROW	EUTROMOD	WARMF	GWLF	SWAT	HSPF	LSPC	SWMM	RHESSys	MIKE-SHE	GSSHA	EPB
How many parameters are included in the model?												
Does the **UNRBA monitoring plan/member information support inputs** needed for this model (atmospheric deposition, rainfall, land application rates, land cover and land cover resolution, groundwater interactions, on-site wastewater information, point sources, locations of BMPs)?												
Does the **UNRBA monitoring plan/member information support** matching water quality information for **watershed model calibration** (relevant parameters, seasons, jurisdictional boundaries)?												
Existing GUI: Does the model package include a Graphical User Interface for pre- and post-processing?												
Can this model package incorporate advanced doppler/radar rainfall data?												
What is the relative cost of the model package per license? Is there a separate cost for the GUI?												
Model Package Selection Criteria:												
Focus Parameters:												
Flow: Can the model package simulate stream flow? Pond discharge/flow? Water volume? Water depth?												
Nitrogen: Can the model package simulate nitrogen fate and transport in the watershed, and the in-stream nitrogen cycle? Can the model package simulate nitrogen interactions with groundwater?												
Phosphorus: Can the model package simulate phosphorus fate and transport in the watershed, and the in-stream phosphorus cycle? Phosphorus contributions from groundwater?												
Carbon: Can the model package simulate the watershed carbon cycle, including carbon associated with trees and other plants?												
Total suspended solids: Can the model package simulate erosion and sediment transport from land surfaces?												
Turbidity: Can the model package simulate turbidity/light scattering in streams?												

MODEL:	SPARROW	EUTROMOD	WARMF	GWLF	SWAT	HSPF	LSPC	SWMM	RHESSys	MIKE-SHE	GSSHA	EPB
Dissolved oxygen (DO): Can the model package simulate the in-stream oxygen cycle, including multiple types of oxygen consuming wastes and temperature affects?												
pH: Can the model package simulate hydrogen ion concentrations (pH)?												
Chlorophyll *a*: Can the model package simulate chlorophyll *a* as a component of floating algae (phytoplankton)?												
Does the model simulate **additional parameters** such as bacteria and metals?												
Does the model package explicitly simulate these conditions or processes:?												
Land to land routing: Does the model package keep track of land-based pollutant sources as the pollutant is routed across other land uses?												
Extreme hydrologic events: Can the model package be used to simulate water quality during droughts and floods, including hurricanes?												
Flooded tributaries/lake backwaters: Can the model package simulate flooding in streams? Lake backwater?												
Impacts of geologic formation: Can the model package account for the different geology? Triassic? Slate Belt?												
Water quality benefits of structural (conventional) best management practices: Can the model package simulate the nutrient load and water volume changes as a result of best management practices?												
Can the model use a future conditions scenario as a baseline to **evaluate potential credits associated with land conservation**?												
Can the model **simulate green infrastructure/low impact development?**												
Can the model package **estimate pollutant load reductions associated with non-conventional BMPs** such as street sweeping, soil improvement, and buffer restoration?												
Non-water quality benefits of best management practices: Can the model package output information												

MODEL:	SPARROW	EUTROMOD	WARMF	GWLF	SWAT	HSPF	LSPC	SWMM	RHESSys	MIKE-SHE	GSSHA	EPB
that can be used to evaluate the other benefits (e.g., improved habitat) of best management practices? Recreational benefits?												
Evaluation of water quality standards: Can the model package be used to evaluate the current NC water quality standards for chlorophyll a? Turbidity? DO? pH?												
Does the model package explicitly simulate these sources?:												
Streambank erosion: Does the model package simulate erosive forces of stream flows and simulate erosion, deposition, and transport of stream sediments?												
Stream bed loads (parent rock): Does the model package account for load contributions and variable nutrient concentrations associated with the parent rock material?												
Does the model package explicitly simulate **conventional onsite wastewater treatment systems**?												
Does the model package explicitly simulate **sand filter wastewater treatment systems**?												
Does the model package explicitly simulate **atmospheric deposition**?												
Does the model package explicitly simulate **urban land uses**?												
Does the model package explicitly simulate **storm sewer systems**?												
Does the model package explicitly simulate DOT and local **roads**?												
Does the model package explicitly simulate **undisturbed land uses**?												
Does the model package explicitly simulate **row crop and pasture**?												
Does the model package explicitly simulate **variable agricultural land uses (year to year changes)**?												
Does the model package explicitly simulate **fertilization and manure application**?												

MODEL:	SPARROW	EUTROMOD	WARMF	GWLF	SWAT	HSPF	LSPC	SWMM	RHESSys	MIKE-SHE	GSSHA	EPB
Does the model package account for **point source inputs**?												
Does the model package account for **groundwater**?												
Does the model package account for **legacy loading** (e.g., sediments, groundwater)?												
Does the model package include the capability to add **miscellaneous sources** such as HVAC coil cleaning, mobile car washes, landfills, etc.?												
Applications												
Can the model package provide **time series inputs for lake response models**?												
Can the model package be used to **estimate jurisdictional loads** (including delivery to the lake)?												
Can the model package be used for scenarios such as future land use changes, BMP applications, etc.?												
Can the model be used to **evaluate nutrient management strategies based on source and subwatershed**?												

Table 3 Evaluation Criteria for Falls Lake Response Model Packages (Flow and Water Quality)

MODEL:	EFDC	EFDC-WASP	WARMF-LAKE	WARMF-CE-QUAL-W2	DELFT	GLM	BATHTUB	EUTRO-MOD	EPB	ECOM-RCA	MIKE-3	RMA	AQUA-TOX	CASM
Model Characteristics and Past Use:														
Publically available model package: Does the UNRBA have to purchase the model package to use it for the Falls watershed? Or is it free and publicly available?														
Publically available source code: Does the UNRBA have access to the computer code behind the model package? If not, can the UNRBA pay a fee for this access?														
Peer reviewed: Has the model package been used in other watersheds in the South eastern US? Has the programming for the model package been reviewed by other programmers and water resource scientists?														
EPA recommendation: EPA does or does not recommend this model be considered.														
NCDWR recommendation: NCDWR does or does not recommend this model be considered.														
Is there an existing application of this model package to the Falls Lake watershed?														
Was this model package used to develop the current Falls Lake Nutrient Management Strategy?														
Type: What is the basis for the package? Empirical (based on data and simple statistics), Process-Based (based on physics and chemistry), Advanced statistics (using Bayesian theory or SEM)?														
Is the model package **simple or complex?**														

MODEL:	EFDC	EFDC-WASP	WARMF-LAKE	WARMF-CE-QUAL-W2	DELFT	GLM	BATHTUB	EUTRO-MOD	EPB	ECOM-RCA	MIKE-3	RMA	AQUA-TOX	CASM
How many parameters are included in the model**?**														
Model dimension: Does it simulate differences in 1 dimension only (e.g., either vertical water layers or upstream to downstream), 2 dimensions (typically vertical water layers and upstream to downstream gradients), or 3 dimensions (depth, upstream to downstream, and horizontal differences)? Does it simulate water quality as a lake-segment average?														
Smallest accurate output time step: Does the model package predict flow and water quality in the lake annually? Seasonally? Monthly? Daily? Hourly? Subhourly?														
Do the **UNRBA and DWR monitoring plans support inputs** needed for this model? (atmospheric deposition, tributary inputs, rainfall, sediment interactions, direct discharges)														
Do the **UNRBA and DWR monitoring plans support** matching water quality information for **lake model calibration** (relevant parameters, seasons, spatial coverage)?														
Existing GUI: Does the model package include a Graphical User Interface for pre- and post-processing?														
What is the relative cost of the model package per license? Is there a separate cost for the GUI?														
Model Package Selection Criteria:														
Focus Parameters:														
Hydraulics/hydrodynamics: Is the movement of water based only on a mass balance? Are thermal														

MODEL:	EFDC	EFDC-WASP	WARMF-LAKE	WARMF-CE-QUAL-W2	DELFT	GLM	BATHTUB	EUTRO-MOD	EPB	ECOM-RCA	MIKE-3	RMA	AQUA-TOX	CASM
stratification and topographic features considered?														
Nitrogen: Is the in-lake nitrogen cycle represented in the model package? Does the model package predict nitrogen concentrations as the total fraction, inorganic/organic, measurable species?														
Phosphorus: Is the in-lake phosphorus cycle represented in the model package? Does the model package predict phosphorus concentrations as the total fraction, inorganic/organic, measurable species?														
Carbon: Does the model package predict in-lake carbon concentrations as the total fraction, inorganic/organic, measurable species?														
TSS: Does the model package simulate sediment transport in the lake? How many sediment classifications are defined?														
Turbidity: What components are considered in the simulation of turbidity/light scattering: algae? inorganic solids? background color?														
DO: Can the model package simulate oxygen dynamics, including multiple types of oxygen consuming wastes?														
pH: Can the model package simulate hydrogen ion concentrations (pH)?														
Chlorophyll *a*: Can the model package simulate chlorophyll *a* as a component of floating algae (phytoplankton)?														
Phytoplankton assemblages: Can the model package simulate different algal groups in the lake (i.e., are greens, diatoms, and blue-green algae simulated)?														

MODEL:	EFDC	EFDC-WASP	WARMF-LAKE	WARMF-CE-QUAL-W2	DELFT	GLM	BATHTUB	EUTRO-MOD	EPB	ECOM-RCA	MIKE-3	RMA	AQUA-TOX	CASM
Can the model package explicitly simulate these conditions or processes?														
Extreme hydrologic events: Can the model package be used to simulate water quality during droughts and floods, including impacts of hurricanes?														
Groundwater inputs: Can the model package account for flow and nutrient inputs from groundwater?														
Wetting/drying: Can the model package simulate the effects of changing lake levels on shoreline areas and tributary arms? Can the model package be used to predict the amount of shoreline exposed or inundated that would be subject to vegetative growth?														
Sediment diagenesis and benthic nutrient flux: Can the model package simulate the settling, decay, and resuspension of organic material and the subsequent release of nutrients into the water column from the lake sediments?														
Sediment resuspension: Can the model package simulate resuspension of organic material and nutrients from the sediments due to physical processes such as wind mixing, lake turn over, high tributary inflows, etc.?														
Historic channel versus floodplain: Can the model package distinguish the characteristics of the lake bottom associated with the historic Neuse River channel compared to the historic floodplain in terms of sediment chemistry and nutrient releases, thermal differences, water quality characteristics, etc.?														
Vertical stratification: Does the model package account for differences in water density due to temperature?														

MODEL:	EFDC	EFDC-WASP	WARMF-LAKE	WARMF-CE-QUAL-W2	DELFT	GLM	BATHTUB	EUTRO-MOD	EPB	ECOM-RCA	MIKE-3	RMA	AQUA-TOX	CASM
Does the model package explicitly account for **atmospheric deposition** of nitrogen and phosphorus?														
Does the model package explicitly simulate **atmospheric exchange of carbon**?														
Can the model package be used to evaluate lake **pump and treat systems**?														
Does the model package simulate flows and changes in water quality associated with **outlet control structures** in response to changing water levels?														
Applications:														
Can the model package be used to predict the nutrient assimilative capacity of Falls Lake and to **support development of nutrient management strategy**?														
Can the model package be used to **evaluate attainment of designated uses** including recreation and drinking water supply?														
Can the model package be used to **evaluate regulatory options** such as site specific criteria or use attainability analyses?														
Can the model package be used to **evaluate lag time** associated with watershed changes?														
Evaluation of water quality standards. Can the model package be used to evaluate the current NC water quality standards for chlorophyll *a*? Turbidity? DO? pH?														

Table 4 Examples of Available Information and Links to Online Resources

MODEL	Links
SPARROW	http://water.usgs.gov/nawqa/sparrow/
EUTROMOD	https://www.epa.gov/nutrient-policy-data/criteria-development-guidance-lakes-and-reservoirs
WARMF	http://www.systechwater.com/
GWLF	http://cwam.ucdavis.edu/pdfs/GWLF.pdf
SWAT	http://swat.tamu.edu/
HSPF	https://www.epa.gov/water-research/methods-models-tools-and-databases-water-research
LSPC	https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=75860&CFID=22884508&CFTOKEN=98267566
SWMM	https://www.epa.gov/water-research/methods-models-tools-and-databases-water-research
RHESSys	http://fiesta.bren.ucsb.edu/~rhessys/
MIKE-SHE	https://www.mikepoweredbydhi.com/products/mike-she
GSSHA	http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476714/gridded-surface-subsurface-hydrologic-analysis/
EPB	https://www.epa.gov/nutrient-policy-data/criteria-development-guidance-lakes-and-reservoirs
EFDC	https://www.epa.gov/water-research/methods-models-tools-and-databases-water-research
EFDC-WASP	https://www.epa.gov/water-research/methods-models-tools-and-databases-water-research
WARMF-LAKE	http://www.systechwater.com/
WARMF-CE-QUAL-W2	http://www.systechwater.com/; http://www.ce.pdx.edu/w2/
DELFT	http://oss.deltares.nl/web/delft3d
GLM	http://aed.see.uwa.edu.au/research/models/GLM/
BATHTUB	http://www.wwwalker.net/bathtub/help/bathtubWebMain.html
EUTROMOD	https://www.epa.gov/nutrient-policy-data/criteria-development-guidance-lakes-and-reservoirs
ECOM-RCA	https://www.pca.state.mn.us/sites/default/files/wq-iw9-01jd.pdf
MIKE-3	http://www.mikepoweredbydhi.com/products/mike-3
RMA	http://www.rmanet.com/about/
AQUATOX	https://www.epa.gov/exposure-assessment-models/aquatox
CASM	http://planning.usace.army.mil/toolbox/library/IWRServer/03-PS-3.pdf