# Memorandum

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| Date: | February 7, 2017 |
| To: | Forrest Westall, UNRBA |
| From: | Alix Matos and Matt Van de Bogert, Cardno;<br>Chris Wallen and Katie van Werkhoven, Dynamic Solutions, LLC |
| RE: | Evaluation and Selection of Model Packages for the UNRBA Modeling and Regulatory Support Project |

## Introduction

Falls Lake was constructed by the US Army Corps of Engineers in the late 1970s. The designated uses of Falls Lake are drinking water supply, recreation, fishing, aquatic life, and wildlife. In 2010, the Environmental Management Commission (EMC) passed the Falls Lake Nutrient Management Strategy (the Strategy) (N.C. Rules Review Commission 2010). The Strategy requires two stages of nutrient reductions for Falls Lake. The goal of Stage I is to achieve compliance with the chlorophyll *a* standard in the lower half of the lake (below Highway 50). The goal of Stage II is to comply with the chlorophyll *a* standard everywhere in the lake. The load reduction requirements to meet these goals were based on a lake nutrient response model developed by NCDWR.

The Strategy was developed by NCDWR 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. Based on NCDWR's fiscal analysis (NCDWR 2010), the cost of Stage I is expected to approach $500 million. Implementation costs for Stage II are expected to approach $1 billion. Currently, the reduction goals for Stage II are infeasible and beyond the limits of technology (NSAB 2012). For these reasons, the Upper Neuse River Basin Association (UNRBA) began planning for a reexamination of the required nutrient load reductions in 2011 (https://www.unrba.org/reexamination).

The UNRBA's reexamination will provide revised nutrient load reductions. The reexamination plan includes a comprehensive monitoring program to provide additional data in evaluating the nutrient load reductions (https://www.unrba.org/monitoring-program). The UNRBA has been collecting water quality data in the watershed and the lake since August 2014 to support this effort. The UNRBA reexamination plan also includes revised watershed modeling, revised lake nutrient response modeling, and modeling to predict how changes in lake water quality affect the drinking water, recreation, and aquatic life uses of the lake. The additional data collected from the UNRBA monitoring program will be used to develop and calibrate these models. This document describes the model selection process for the UNRBA reexamination of the nutrient load reductions for Falls Lake.

## Purposes of Modeling to Support the Reexamination

Two types of modeling packages have been considered for this project: those able to simulate watershed loading and others that can simulate the lake's nutrient response. Many models of each type exist—each with its own set of strengths and weaknesses—and many of the models could be adapted for the Upper Neuse River Basin. Although it is cost-prohibitive to develop and use every possible model, there are

advantages to developing more than one model, especially when the models are based on different underlying assumptions and model structures. The UNRBA has proposed a multi-modeling approach for the lake nutrient response modeling (lake response modeling is also described in the Task 4 Technical Memorandum (Cardno 2013b) available at https://www.unrba.org/reexamination) that includes a complex, process-based model (mechanistic model) as well as a simple, data-driven model (empirical model). Multiple models can be used to evaluate model uncertainty and the robustness of model conclusions to different sets of assumptions. The UNRBA will also develop a mechanistic watershed model.

1. Watershed loading model packages. These model packages simulate the amount of loading 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 an opportunity to use the loading results as 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 lake 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. Lake nutrient response models that include an ecosystem modeling component also predict the response of aquatic organisms higher than algae in the food web (e.g., zooplankton and various trophic levels of fish). 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 typically developed to predict nutrient loads and changes in water quality parameters. These model packages do not directly address attainment of designated uses or key questions of concern from the public. As a result, the UNRBA reexamination strategy includes the development of a designated use model. This statistical model will link water quality to designated uses. This framework will use data to derive the empirical relationships. Some of the information needed to populate the designated use model may be difficult or costly to measure. Thus, expert opinion may be incorporated in this modeling approach and applied using Bayesian techniques. The UNRBA has identified subject matter experts to support this component

of the reexamination. The subject matter experts 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 designated use model 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.

In addition to the designated use model, the UNRBA is considering development of an ecosystem model to further evaluate the linkage between lake water quality and the aquatic life designated use. Additional information is being compiled regarding the data requirements and costs associated with developing and calibrating an ecosystem model for Falls Lake. This information will be provided to the MRSW and the PFC to inform decisions regarding development of this type of model. This type of model can be developed as an independent model, or it can be driven by output from a lake nutrient response model.

These models are one component of the UNRBA's science-based approach for the reexamination (Cardno 2013a). The plan for conducting the reexamination is outlined in the Task 1 Technical Memorandum https://www.unrba.org/reexamination. As shown in Figure 1, the reexamination is a comprehensive evaluation that considers scientific analyses, feasibility, and regulatory flexibility. The revised strategy for Falls Reservoir will use a targeted, efficient approach to nutrient management.

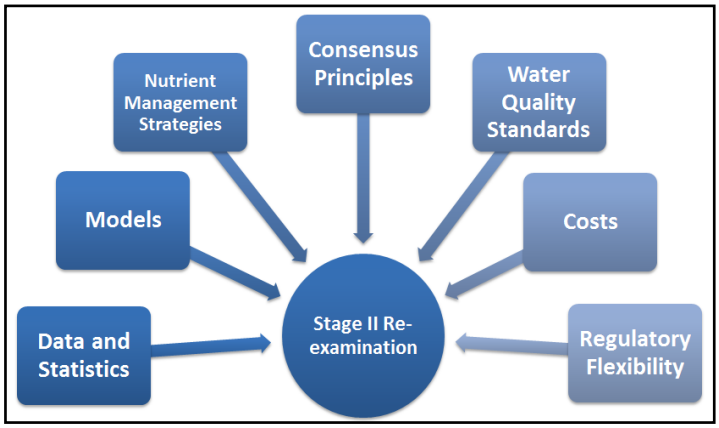


**Figure 1. Components of the Reexamination**

After the watershed and lake models are revised, the UNRBA will recalculate the load reduction requirements needed for the entire lake to meet the water quality criterion for chlorophyll *a*. A cost benefit analysis will be conducted to estimate the costs and evaluate the feasibility (financial, technical, and logistical) of meeting the required load reductions. If the revised loading targets remain beyond the limits of technology or financial resources, the UNRBA may consider regulatory options. These options may include variances, site specific criteria, or revisions to designated uses.

## Development of Model Package Selection Criteria

To facilitate the evaluation and comparison of model packages, selection criteria were developed to evaluate the specific concerns raised by the UNRBA members, staff at DWR, and the watershed stakeholders. The model package selection criteria were developed under consultation with the UNRBA Modeling and Regulatory Support Workgroup (MRSW) and the UNRBA Path Forward Committee (PFC). A memorandum dated October 19, 2016 summarizing the model selection criteria and the models to be evaluated was submitted to the UNRBA PFC and the Division of Water Resources (DWR). DWR modeling staff provided comments on the memorandum on October 27, 2016. The selection criteria and list of models to include in the evaluation were approved by the PFC at the October 28, 2016 meeting. A memorandum dated November 21, 2016 was distributed to the stakeholders to inform them of the models and model selection criteria being evaluated by the UNRBA.

The list of model package selection criteria were compiled from several sources with input from the MRSW:

- 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 which included participation from a number of external stakeholders.

## Evaluation and Selection of Model Packages

The UNRBA MRSW established a two-step process for the evaluation and selection of watershed and lake modeling packages. The first step was a quantitative analysis using numeric scores and weights applied to the model selection criteria. The scoring and weighting system was drafted and a final version established through consultation with the MRSW. Scores were assigned numeric values based on the number of potential answers with the highest value indicating the “best” value for the criteria:

- If 5 categories can be described for this criteria, values of 1 through 5 will be assigned
- If criteria generally fall into 3 categories, then values of 1, 3, and 5 are assigned
- If criteria generally fall into 2 categories, values of 2 and 4 are assigned
- Some criteria are characteristics that are included as "Informational" but not assigned a score

Weights were used to rank the importance of each criterion relative to input provided by the UNRBA members, staff at DWR, and the watershed stakeholders. Higher weights were assigned to criteria that represented or supported a primary modeling objective:

1. Criteria was identified as important by the MRSW, PFC, DWR, or stakeholders but is not related to this UNRBA project
2. Criteria supports a primary modeling objective
3. Criteria was identified as high priority by MRSW, PFC, DWR, or stakeholders and supports a primary modeling objective
4. Criteria is a primary modeling objective

Preliminary raw and weighted scores were provided to the MRSW to support Step 1 of the evaluation. Appendix A includes the raw and weighted scores for the watershed and lake modeling packages. At the bottom of each table the total scores as well as summary scores for the highest weighted criteria are provided. Step 2 of the evaluation consisted of a discussion with the MRSW on December 6, 2016. The MRSW considered the quantitative scores in their discussion of the different modeling packages. Relative costs of model licenses and interfaces were also considered. The final MRSW recommendations for the model packages were based on an overall review and open discussion of the relative strengths and weaknesses of models, how weaknesses in the highest ranked models could be addressed using other models, consideration of input from the stakeholders, and likely acceptance by the State and Federal agencies. The MRSW selected four models to recommend to the PFC to support the reexamination. An optional fifth model that provides the ability to evaluate ecological conditions in the lake is also being considered pending additional review of this modeling approach, data requirements, and monitoring costs. On December 14, 2016, the MRSW presented their recommendations for model package selection to the UNRBA PFC. During this meeting, the PFC approved the recommendations of the MRSW:

- Watershed modeling package – The MRSW recommended the WARMF modeling package for the watershed modeling. Some of the important points noted in evaluating the different modeling approaches were that the WARMF model has been used in a regulatory capacity in the Southeast, and the UNRBA has direct access to the model developers through this project if any special coding is required. There is an older model of the Falls Lake watershed using this package, and the City of Durham is developing refined WARMF models for the Ellerbe, Little Lick, and Eno River subwatersheds. The City of Durham's updated WARMF models can be incorporated into the larger Falls Lake watershed modeling effort
- Lake modeling packages –
    - The MRSW recommends the EFDC model package for the complex, mechanistic lake nutrient response model. Some key reasons that EFDC is recommended include: 1) the model provides an effective mechanistic simulation of the lake, 2) the agencies are more familiar with EFDC and 3) some stakeholders have expressed more comfort in using the same lake nutrient response modeling package that was used by the State previously to develop the Falls Lake Nutrient Management Strategy.
    - The MRSW recommends the WARMF-LAKE model package for the moderate/simple lake nutrient response model. The UNRBA previously established the need for multiple independent models to corroborate modeling results. In addition, a simpler model will have faster model run times compared to the complex model which can take several hours to run WARMF-LAKE was selected over the other moderate or simple models because if its relatively high scores and the inclusion in the WARMF model package. This direct linkage to the watershed model will allow for simulations of changes in lake water quality in response to changing watershed conditions (land use, atmospheric deposition, etc.). The WARMF model package will also provide information for the cost benefit analysis (i.e., comparing the effects of watershed management options on lake response).
- The MRSW recommends development of a statistical model link lake water quality to designated uses. Because mechanistic lake nutrient response models tend to "end" at water quality, additional analyses are required to link water quality to designated uses. The UNRBA plans to develop a designated use model to predict how changes in lake water quality affect the aquatic life use, drinking water use, and recreational uses of Falls Lake. A conceptual designated use model was included in the *September 28, 2016 Kickoff Meeting Reference Material* available at https://www.unrba.org/reexamination.

- The MRSW identified for future consideration an ecosystem model. The specific model noted is CASM which provides a mechanistic simulation of the impacts of lake water quality on the aquatic life designated use. This is a preliminary recommendation pending additional evaluation.

**Summary**

The UNRBA has been working since 2011 towards a reexamination of Stage II of the Falls Lake Nutrient Management Strategy. The UNRBA has been collecting water quality data in the watershed and the lake since August 2014 to support the reexamination. Other organizations including NCDEQ, local universities, and member governments also collect data that will be considered in the UNRBA reexamination. The additional data collected by the UNRBA and other organizations will provide the basis for the revised watershed and lake nutrient response modeling. Because the existing modeling predicts that very large nutrient reductions are needed to comply with the chlorophyll *a* criterion, it is in the interest of the stakeholders in the watershed to reduce the uncertainty of the model inputs and predictions. While all models rely on assumptions and best professional judgment in their development, and it is typically not possible to collect site-specific data for every variable and parameter, there are several key issues and data gaps that the UNRBA has been working to address. Additional information about the UNRBA Monitoring Program is available online at https://www.unrba.org/monitoring-program.

The UNRBA has selected the WARMF watershed model package and two lake nutrient response modeling packages (EFDC and WARMF-LAKE) to support the reexamination. A designated use model will also be developed to link water quality to designated uses. The UNRBA is considering an optional fifth type of model package to simulate ecosystem response as another means to evaluate the aquatic life use. After these models have been developed, calibrated, and verified, the load allocations will need to be recalculated to determine the amount of nutrient loading that the lake can receive and meet the chlorophyll *a* target of 40 µg/L. A cost benefit analysis will also be conducted to evaluate the costs and effectiveness of management strategies. The results of the revised modeling and cost benefit analysis will be used to reassess the technical and financial feasibility of the revised load allocations. The revised modeling may also be used to test the feasibility of meeting the water quality standard for chlorophyll *a* in the Upper Lake, determine whether alternative water quality standards may be sufficient to protect the existing uses, and assess the impact of the management of Falls Lake on water quality in the Upper Lake. The models will also be used to test various regulatory scenarios with respect to attainment of existing and proposed use classifications.

The UNRBA will be working closely with the agencies to develop a revised nutrient management strategy for Falls Lake. Following approval of the revised strategy, NCDEQ will continue to collect water quality data in Falls Lake. As implementation proceeds, the data will be evaluated to determine if any changes to the strategy are needed. If needed, the models may be updated with new information as it becomes available. This adaptive approach depicted in Figure 2 allows decision makers to integrate the latest information and science into their planning and management activities.

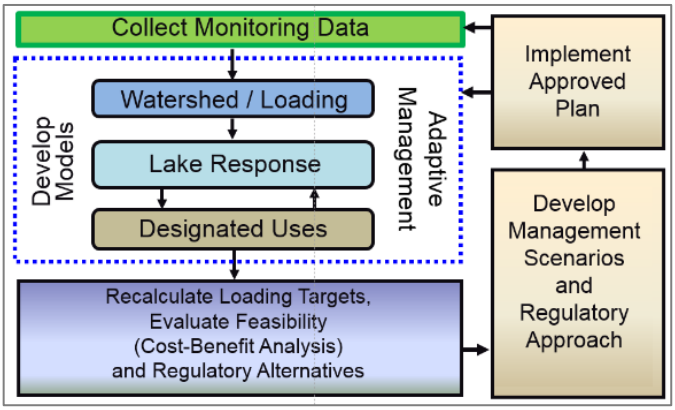


**Figure 2. Framework for the UNRBA Reexamination**

## References

Cardno [ENTRIX]. 2013a. Task 1: Framework for a Re-examination of Stage II of the Falls Nutrient Strategy. Prepared for the Upper Neuse River Basin Association.

Cardno [ENTRIX]. 2013b. Task 4: Review of Existing Models and Recommendations for Future Studies Support of Long Term Planning and Regulatory Nutrient Activities in the Falls Lake Watershed. Prepared for the Upper Neuse River Basin Association.

NSAB. 2012. Second Annual Report of the Nutrient Scientific Advisory Board.

## Appendix A. Results of the Quantitative Model Evaluation for the UNRBA Reexamination

The UNRBA MRSW established a two-step process for the evaluation and selection of watershed and lake modeling packages. The first step was a quantitative analysis using numeric scores and weights applied to the model selection criteria. The scoring and weighting system was drafted and a final version established through consultation with the MRSW. Scores were assigned numeric values based on the number of potential answers with the highest value indicating the "best" value for the criteria:

- If 5 categories can be described for this criteria, values of 1 through 5 will be assigned
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1. Criteria was identified as important by the MRSW, PFC, DWR, or stakeholders but is not related to this UNRBA project
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4. Criteria is a primary modeling objective

Preliminary raw and weighted scores were provided to the MRSW to support Step 1 of the evaluation. Table 1 through Table 4 includes the raw and weighted scores for the watershed and lake modeling packages. At the bottom of each table the total scores as well as summary scores for the highest weighted criteria are provided.

**Table 1 Raw Scores for the Evaluation of Watershed Modeling Packages**

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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? | 1 - Relatively expensive; 3 - Moderately expensive; 5 – Free | 2 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 3 | 5 | 5 | 5 |
| **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? | 1 - No access; 2 - Partial access; 3 - Paid access; 4 - Contract team has full access; 5 - Fully open access | 2 | 4 | 5 | 5 | 1 | 5 | 5 | 1 | 3 | 1 | 1 | 5 |
| **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? | 1 - Not peer reviewed and not used in SE US; 3 - Peer reviewed applied elsewhere in US; 5 - Peer reviewed and used in SE US | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Is there an existing application of this model package to the Falls Lake watershed? | 1 - No; 3 - Partial; 5 - Full watershed | 2 | 5 | 5 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 5 | 1 |
| Was this model package used to develop the current Falls Lake Nutrient Management Strategy? | Informational: No; Yes | Informational | No: (considered but not applied) | No | No | No | No | No | No | No | No | No | No |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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? | 1 - Little flexibility in drainage area size, uses course land cover data (30 m); 3 - Moderate flexibility and land cover data resolution; 5 - Highly flexible for drainage area size, capable of incorporating high resolution data (2 ft) | 2 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 3 | 3 | 1 | 3 |
| **Smallest accurate output time step:** Does the model package predict flows and nutrient loads annually? Seasonally? Monthly? Daily? Hourly? Subhourly? | 1- annually; 2 - seasonal or monthly; 3 - daily; 4 - hourly; 5 - subhourly | 3 | 5 | 4 | 5 | 5 | 5 | 3 | 5 | 5 | 2 | 1 | 1 |
| Does the model use **land use data** (e.g., residential versus commercial) **or land cover data** (e.g., impervious versus tree canopy), or both? | 1 - land cover; 3 - land use; 4 - both with limitations; 5 - both | 2 | 5 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 1 | 5 |
| **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)? | Informational: Process based (P); Nonlinear regression modeling (NLRM); Empirical (E) | Informational | P | P | P | P | P | P | P | P | P | NLRM | E |
| Is the model package simple or complex? | Informational: Complex (C); Moderate (M); Simple (S) | Informational | C | C | C | C | C | C | C | C | M | M | S |
| How many parameters are included in the model (Less than 50, 100, 500, 1000; more than 1000)? | Informational | Informational | <500 | <500 | <500 | <500 | <500 | <500 | <1000 | <250 | <250 | <150 | <100 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Does the **available information** (UNRBA monitoring plan, member, DWR, NADP, etc.) **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)? | 1- at least 10% of inputs are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 3 | 5 | 5 | 5 |
| Does the available information support model calibration (parameters, coefficients, etc.)? | 1- at least 10% of parameters are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Does the available information support matching water quality information for watershed model calibration (e.g., flows, nutrient concentrations, etc.)? | 1- at least 10% of parameters are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Existing GUI:** Does the model package include a Graphical User Interface for pre and post processing? | 1 - No GUI; 3 - Simple GUI, no additional functionality; 5 - Advanced GUI with additional functionality | 3 | 5 | 3 | 5 | 3 | 5 | 1 | 5 | 5 | 3 | 5 | 1 |
| Can this model package incorporate advanced Doppler/radar rainfall data? | 1 - No; 3 - Indirect incorporation; 5 - Direct incorporation | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 1 | 1 |
| What is the relative cost of the model package per license? Is there a separate cost for the GUI? | 1 - Relatively expensive; 3 - Moderately expensive; 5 - Free | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 3 | 5 | 5 | 5 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Package Selection Criteria: | | | | | | | | | | | | | |
| Focus Parameters: | | | | | | | | | | | | | |
| **Flow:** Can the model package simulate stream flow? Pond discharge/flow? Water volume? Water depth? | 1 - Does not simulate flow; 2 - simulates stream flow; 3 - simulates stream flow, velocity, and depth; 4 - simulates pond discharge and flow; 5 - simulates 3 and 4 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 2 | 1 | 1 |
| **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? | 1 - Simulates N loads at site level; 2 - incorporates overland fate and transport; 3 - simulates instream fate and transport or shallow groundwater inputs; 5 - simulates all | 4 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 3 | 3 | 2 |
| **Phosphorus:** Can the model package simulate phosphorus fate and transport in the watershed, and the in-stream phosphorus cycle? Phosphorus contributions from groundwater? | 1 - Simulates P loads at site level; 2 - incorporates overland fate and transport; 3 - simulates instream fate and transport or shallow groundwater inputs; 5 - simulates all | 4 | 5 | 5 | 5 | 5 | 3 | 0 | 5 | 5 | 3 | 3 | 2 |
| **Carbon:** Can the model package simulate the watershed carbon cycle, including carbon associated with trees and other plants? | 1 - Simulates C loads at site level; 2 - incorporates overland fate and transport; 3 - simulates instream fate and transport or shallow groundwater inputs; 5 - simulates all | 4 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 1 | 0 | 3 | 0 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total suspended solids:** Can the model package simulate erosion and sediment transport from land surfaces? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Turbidity:** Can the model package simulate turbidity/light scattering in streams? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 2 | 2 | 2 | 2 |
| **Dissolved oxygen (DO):** Can the model package simulate the in-stream oxygen cycle, including multiple types of oxygen consuming wastes and temperature affects? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 2 | 2 | 2 | 2 |
| **pH:** Can the model package simulate hydrogen ion concentrations (pH)? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 2 | 2 | 2 | 2 |
| **Chlorophyll *a*:** Can the model package simulate chlorophyll *a* as a component of floating algae (phytoplankton)? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 2 | 2 | 2 | 4 |
| Does the model simulate **additional parameters** such as bacteria and metals? | 2 - No; 4 - Yes | 1 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 2 | 2 | 2 | 2 |
| 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 within a catchment? | 2 - No; 4 - Yes | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 2 |
| **Extreme hydrologic events:** Can the model package be used to simulate water quality during droughts and floods, including hurricanes? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 2 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Flooded tributaries/lake backwaters:** Can the model package simulate flooding in streams? Lake backwater? | 2 - No; 4 - Yes | 3 | 2 | 2 | 2 | 2 | 4 | 2 | 4 | 4 | 2 | 2 | 2 |
| **Impacts of geologic formation:** Can the model package account for the different geology? Triassic? Slate Belt? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 |
| **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? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 2 | 2 | 2 |
| Can the model use a future conditions scenario as a baseline to **evaluate potential credits associated with land conservation**? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Can the model simulate green infrastructure/low impact development? | 1 - No; 3 - Some types 5 - Many types | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 1 | 1 | 1 |
| Can the model package **estimate pollutant load reductions associated with non-conventional BMPs** such as street sweeping, soil improvement, and buffer restoration? | 1 - No; 3 - Some types 5 - Many types | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 1 | 1 | 1 |
| **Non-water quality benefits of best management practices:** Can the model package output information that can be used to evaluate the other benefits (e.g., improved habitat) of best management practices? Recreational benefits? | 1 - No; 3 - Partial; 5 - Yes | 1 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 3 | 1 | 1 | 1 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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? | 1 - No; 2 - one parameters; 3 - two; 4 - three; 5 - four | 2 | 5 | 5 | 5 | 5 | 1 | 1 | 5 | 1 | 1 | 1 | 1 |
| 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? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 2 | 2 | 2 |
| **Stream bed loads (parent rock):** Does the model package account for load contributions and variable nutrient concentrations associated with the parent rock material? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 4 | 2 |
| Does the model package explicitly simulate conventional onsite wastewater treatment systems? | 2 - No; 4 - Yes | 3 | 4 | 4 | 2 | 2 | 2 | 4 | 2 | 2 | 4 | 2 | 2 |
| Does the model package explicitly simulate **sand filter wastewater treatment systems**? | 2 - No; 4 - Yes | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Does the model package explicitly simulate **atmospheric deposition**? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 |
| Does the model package explicitly simulate **urban land uses**? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Does the model package explicitly simulate **storm sewer systems**? | 2 - No; 4 - Yes | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 2 | 2 | 2 | 2 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Does the model package explicitly simulate DOT and local **roads**? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 2 | 2 |
| Does the model package explicitly simulate **undisturbed land uses**? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 |
| Does the model package explicitly simulate **row crop and pasture**? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 2 | 4 |
| Does the model package explicitly simulate variable agricultural land uses (year to year changes)? | 2 - No; 4 - Yes | 3 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 2 | 4 | 2 | 2 |
| Does the model package explicitly simulate **fertilization and manure application**? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 2 | 4 | 4 | 2 |
| Does the model package account for **point source inputs**? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Does the model package account for **groundwater**? | 1 - No; 3 - Shallow groundwater only; 5 - Fully integrated | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 5 | 3 | 3 | 1 | 1 |
| Does the model package account for **legacy loading** (e.g., sediments, groundwater)? | 2 - No; 4 - Yes | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Does the model package include the capability to **add miscellaneous sources** such as HVAC coil cleaning, mobile car washes, landfills, etc.? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 2 | 2 | 2 |
| Applications | | | | | | | | | | | | | |
| Can the model package provide time series inputs for lake response models? | 2 - No; 4 - Yes | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 2 | 2 | 2 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Can the model package be used to **estimate jurisdictional loads** (including delivery to the lake)? | 2 - No; 4 - Yes | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 2 | 2 | 2 |
| Can the model package be used for scenarios such as future land use changes, BMP applications, etc.? | 2 - No; 4 - Yes | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 2 | 4 |
| Can the model be used to evaluate nutrient management strategies based on source and subwatershed? | 2 - No; 4 - Yes | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 2 | 2 |
| Raw Score Summaries | | | | | | | | | | | | | |
| Model Package Characteristics and Past Use: | | | 57 | 55 | 52 | 48 | 55 | 46 | 42 | 44 | 43 | 40 | 42 |
| Focus Parameters | | | 44 | 44 | 44 | 44 | 28 | 29 | 44 | 30 | 22 | 24 | 21 |
| Explicit Processes Simulated | | | 34 | 36 | 36 | 36 | 36 | 28 | 38 | 34 | 20 | 20 | 20 |
| Explicit Sources Simulated | | | 55 | 55 | 53 | 53 | 45 | 53 | 57 | 49 | 51 | 41 | 41 |
| Applications | | | 16 | 16 | 16 | 16 | 16 | 8 | 16 | 16 | 12 | 8 | 10 |
| TOTAL RAW Score | | | 206 | 206 | 201 | 197 | 180 | 164 | 197 | 173 | 148 | 133 | 134 |

**Table 2 Weighted Scores for the Evaluation of Watershed Modeling Packages**

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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? | 1 - Relatively expensive; 3 - Moderately expensive; 5 - Free | 2 | 10 | 10 | 10 | 10 | 10 | 10 | 2 | 6 | 10 | 10 | 10 |
| **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? | 1 - No access; 2 - Partial access; 3 - Paid access; 4 - Contract team has full access; 5 - Fully open access | 2 | 8 | 10 | 10 | 2 | 10 | 10 | 2 | 6 | 2 | 2 | 10 |
| **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? | 1 - Not peer reviewed and not used in SE US; 3 - Peer reviewed applied elsewhere in US; 5 - Peer reviewed and used in SE US | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Is there an existing application of this model package to the Falls Lake watershed? | 1 - No; 3 - Partial; 5 - Full watershed | 2 | 10 | 10 | 2 | 2 | 6 | 2 | 2 | 2 | 2 | 10 | 2 |
| Was this model package used to develop the current Falls Lake Nutrient Management Strategy? | Informational: No; Yes | Informational | No (considered but not applied) | No | No | No | No | No | No | No | No | No | No |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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? | 1 - Little flexibility in drainage area size, uses course land cover data (30 m); 3 - Moderate flexibility and land cover data resolution; 5 - Highly flexible for drainage area size, capable of incorporating high resolution data (2 ft) | 2 | 10 | 10 | 6 | 10 | 10 | 10 | 10 | 6 | 6 | 2 | 6 |
| **Smallest accurate output time step:** Does the model package predict flows and nutrient loads annually? Seasonally? Monthly? Daily? Hourly? Subhourly? | 1- annually; 2 - seasonal or monthly; 3 - daily; 4 - hourly; 5 - subhourly | 3 | 15 | 12 | 15 | 15 | 15 | 9 | 15 | 15 | 6 | 3 | 3 |
| Does the model use **land use data** (e.g., residential versus commercial) **or land cover data** (e.g., impervious versus tree canopy), or both? | 1 - land cover; 3 - land use; 4 - both with limitations; 5 - both | 2 | 10 | 10 | 10 | 10 | 8 | 10 | 10 | 10 | 10 | 2 | 10 |
| **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)? | Informational: Process based (P); Nonlinear regression modeling (NLRM); Empirical (E) | Informational | P | P | P | P | P | P | P | P | P | NLRM | E |
| Is the model package simple or complex? | Informational: Complex (C); Moderate (M); Simple (S) | Informational | C | C | C | C | C | C | C | C | M | M | S |
| How many parameters are included in the model (Less than 50, 100, 500, 1000; more than 1000)? | Informational | Informational | <500 | <500 | <500 | <500 | <500 | <500 | <1000 | <250 | <250 | <150 | <100 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Does the **available information** (UNRBA monitoring plan, member, DWR, NADP, etc.) **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)? | 1- at least 10% of inputs are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 15 | 15 | 15 | 15 | 15 | 9 | 9 | 9 | 15 | 15 | 15 |
| Does the available information support model calibration (parameters, coefficients, etc.)? | 1- at least 10% of parameters are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Does the available information support matching water quality information for watershed model calibration (e.g., flows, nutrient concentrations, etc.)? | 1- at least 10% of parameters are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| **Existing GUI:** Does the model package include a Graphical User Interface for pre and post processing? | 1 - No GUI; 3 - Simple GUI, no additional functionality; 5 - Advanced GUI with additional functionality | 3 | 15 | 9 | 15 | 9 | 15 | 3 | 15 | 15 | 9 | 15 | 3 |
| Can this model package incorporate advanced Doppler/radar rainfall data? | 1 - No; 3 - Indirect incorporation; 5 - Direct incorporation | 3 | 9 | 9 | 9 | 9 | 9 | 9 | 15 | 9 | 9 | 3 | 3 |
| What is the relative cost of the model package per license? Is there a separate cost for the GUI? | 1 - Relatively expensive; 3 - Moderately expensive; 5 - Free | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 3 | 9 | 15 | 15 | 15 |
| Model Package Selection Criteria: | | | | | | | | | | | | | |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Focus Parameters: | | | | | | | | | | | | | |
| **Flow:** Can the model package simulate stream flow? Pond discharge/flow? Water volume? Water depth? | 1 - Does not simulate flow; 2 - simulates stream flow; 3 - simulates stream flow, velocity, and depth; 4 - simulates pond discharge and flow; 5 - simulates 3 and 4 | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 6 | 3 | 3 |
| **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? | 1 - Simulates N loads at site level; 2 - incorporates overland fate and transport; 3 - simulates instream fate and transport or shallow groundwater inputs; 5 - simulates all | 4 | 20 | 20 | 20 | 20 | 12 | 20 | 20 | 20 | 12 | 12 | 8 |
| **Phosphorus:** Can the model package simulate phosphorus fate and transport in the watershed, and the in-stream phosphorus cycle? Phosphorus contributions from groundwater? | 1 - Simulates P loads at site level; 2 - incorporates overland fate and transport; 3 - simulates instream fate and transport or shallow groundwater inputs; 5 - simulates all | 4 | 20 | 20 | 20 | 20 | 12 | 0 | 20 | 20 | 12 | 12 | 8 |
| **Carbon:** Can the model package simulate the watershed carbon cycle, including carbon associated with trees and other plants? | 1 - Simulates C loads at site level; 2 - incorporates overland fate and transport; 3 - simulates instream fate and transport or shallow groundwater inputs; 5 - simulates all | 4 | 20 | 20 | 20 | 20 | 12 | 20 | 20 | 4 | 0 | 12 | 0 |
| **Total suspended solids:** Can the model package simulate erosion and sediment transport from land surfaces? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | 8 | 8 | 8 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Turbidity:** Can the model package simulate turbidity/light scattering in streams? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 4 | 4 | 8 | 4 | 4 | 4 | 4 |
| **Dissolved oxygen (DO):** Can the model package simulate the in-stream oxygen cycle, including multiple types of oxygen consuming wastes and temperature affects? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 6 | 6 | 6 | 6 |
| **pH:** Can the model package simulate hydrogen ion concentrations (pH)? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 4 | 4 | 8 | 4 | 4 | 4 | 4 |
| **Chlorophyll *a*:** Can the model package simulate chlorophyll *a* as a component of floating algae (phytoplankton)? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 6 | 6 | 6 | 12 |
| Does the model simulate **additional parameters** such as bacteria and metals? | 2 - No; 4 - Yes | 1 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 2 | 2 | 2 | 2 |
| 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 within a catchment? | 2 - No; 4 - Yes | 2 | 4 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 4 | 4 | 4 |
| **Extreme hydrologic events:** Can the model package be used to simulate water quality during droughts and floods, including hurricanes? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 6 |
| **Flooded tributaries/lake backwaters:** Can the model package simulate flooding in streams? Lake backwater? | 2 - No; 4 - Yes | 3 | 6 | 6 | 6 | 6 | 12 | 6 | 12 | 12 | 6 | 6 | 6 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Impacts of geologic formation:** Can the model package account for the different geology? Triassic? Slate Belt? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 6 | 12 | 12 | 12 | 12 | 12 | 12 |
| **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? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 6 | 12 | 12 | 6 | 6 | 6 |
| Can the model use a future conditions scenario as a baseline to **evaluate potential credits associated with land conservation**? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Can the model simulate green infrastructure/low impact development? | 1 - No; 3 - Some types 5 - Many types | 3 | 9 | 9 | 9 | 9 | 15 | 9 | 9 | 9 | 3 | 3 | 3 |
| Can the model package **estimate pollutant load reductions associated with non-conventional BMPs** such as street sweeping, soil improvement, and buffer restoration? | 1 - No; 3 - Some types 5 - Many types | 3 | 9 | 9 | 9 | 9 | 15 | 9 | 9 | 9 | 3 | 3 | 3 |
| **Non-water quality benefits of best management practices:** Can the model package output information that can be used to evaluate the other benefits (e.g., improved habitat) of best management practices? Recreational benefits? | 1 - No; 3 - Partial; 5 - Yes | 1 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 3 | 1 | 1 | 1 |
| **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? | 1 - No; 2 - one parameters; 3 - two; 4 - three; 5 - four | 2 | 10 | 10 | 10 | 10 | 2 | 2 | 10 | 2 | 2 | 2 | 2 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 4 | 4 | 8 | 8 | 4 | 4 | 4 |
| **Stream bed loads (parent rock):** Does the model package account for load contributions and variable nutrient concentrations associated with the parent rock material? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 4 | 4 | 8 | 8 | 8 | 8 | 4 |
| Does the model package explicitly simulate conventional onsite wastewater treatment systems? | 2 - No; 4 - Yes | 3 | 12 | 12 | 6 | 6 | 6 | 12 | 6 | 6 | 12 | 6 | 6 |
| Does the model package explicitly simulate **sand filter wastewater treatment systems**? | 2 - No; 4 - Yes | 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Does the model package explicitly simulate **atmospheric deposition**? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 12 | 12 |
| Does the model package explicitly simulate **urban land uses**? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Does the model package explicitly simulate **storm sewer systems**? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 8 | 8 | 8 | 4 | 4 | 4 | 4 |
| Does the model package explicitly simulate DOT and local **roads**? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 12 | 6 | 6 |
| Does the model package explicitly simulate **undisturbed land uses**? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 12 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Does the model package explicitly simulate **row crop and pasture**? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 6 | 12 | 12 | 12 | 12 | 6 | 12 |
| Does the model package explicitly simulate variable agricultural land uses (year to year changes)? | 2 - No; 4 - Yes | 3 | 6 | 6 | 6 | 6 | 6 | 12 | 6 | 6 | 12 | 6 | 6 |
| Does the model package explicitly simulate **fertilization and manure application**? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 6 | 12 | 12 | 6 | 12 | 12 | 6 |
| Does the model package account for **point source inputs**? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Does the model package account for **groundwater**? | 1 - No; 3 - Shallow groundwater only; 5 - Fully integrated | 3 | 9 | 9 | 9 | 9 | 3 | 9 | 15 | 9 | 9 | 3 | 3 |
| Does the model package account for **legacy loading** (e.g., sediments, groundwater)? | 2 - No; 4 - Yes | 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Does the model package include the capability to **add miscellaneous sources** such as HVAC coil cleaning, mobile car washes, landfills, etc.? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 6 | 12 | 12 | 6 | 6 | 6 |
| Applications | | | | | | | | | | | | | |
| Can the model package provide time series inputs for lake response models? | 2 - No; 4 - Yes | 4 | 16 | 16 | 16 | 16 | 16 | 8 | 16 | 16 | 8 | 8 | 8 |
| Can the model package be used to **estimate jurisdictional loads** (including delivery to the lake)? | 2 - No; 4 - Yes | 4 | 16 | 16 | 16 | 16 | 16 | 8 | 16 | 16 | 8 | 8 | 8 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Can the model package be used for scenarios such as future land use changes, BMP applications, etc.? | 2 - No; 4 - Yes | 4 | 16 | 16 | 16 | 16 | 16 | 8 | 16 | 16 | 16 | 8 | 16 |
| Can the model be used to evaluate nutrient management strategies based on source and subwatershed? | 2 - No; 4 - Yes | 4 | 16 | 16 | 16 | 16 | 16 | 8 | 16 | 16 | 16 | 8 | 8 |

Weighted Score Summaries

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Package Characteristics and Past Use: | 147 | 140 | 137 | 127 | 143 | 117 | 113 | 117 | 114 | 107 | 107 |
| Focus Parameters | 127 | 127 | 127 | 127 | 79 | 85 | 127 | 89 | 60 | 69 | 55 |
| Explicit Processes Simulated | 89 | 93 | 93 | 93 | 97 | 77 | 99 | 91 | 55 | 55 | 55 |
| Explicit Sources Simulated | 151 | 151 | 145 | 145 | 123 | 147 | 155 | 133 | 141 | 111 | 113 |
| Applications | 64 | 64 | 64 | 64 | 64 | 32 | 64 | 64 | 48 | 32 | 40 |
| Total Weighted Score | 578 | 575 | 566 | 556 | 506 | 458 | 558 | 494 | 418 | 374 | 370 |

Sum Weighted Scores for Weight = 4

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Package Characteristics and Past Use | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Focus Parameters | 60 | 60 | 60 | 60 | 36 | 40 | 60 | 44 | 24 | 36 | 16 |
| Explicit Processes Simulated | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Explicit Sources Simulated | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | WARMF | SWAT | HSPF | LSPC | SWMM | RHESSys | MIKESHE+WQ | GSSHA | GWLF | SPARROW | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Applications | | | 64 | 64 | 64 | 64 | 64 | 32 | 64 | 64 | 48 | 32 | 40 |
| Total Scores for Weight = 4 | | | 124 | 124 | 124 | 124 | 100 | 72 | 124 | 108 | 72 | 68 | 56 |
| | | | | | | | | | | | | | |
| Sum Weighted Scores for Weight = 3 | | | | | | | | | | | | | |
| Model Package Characteristics and Past Use | | | 99 | 90 | 99 | 93 | 99 | 75 | 87 | 87 | 84 | 81 | 69 |
| Focus Parameters | | | 39 | 39 | 39 | 39 | 27 | 27 | 39 | 27 | 18 | 15 | 21 |
| Explicit Processes Simulated | | | 72 | 72 | 72 | 72 | 84 | 66 | 78 | 78 | 48 | 48 | 48 |
| Explicit Sources Simulated | | | 123 | 123 | 117 | 117 | 99 | 123 | 123 | 105 | 117 | 87 | 93 |
| Applications | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Scores for Weight = 3 | | | 333 | 324 | 327 | 321 | 309 | 291 | 327 | 297 | 267 | 231 | 231 |
| | | | | | | | | | | | | | |
| Sum Weighted Scores for Weight = 4 + 3 | | | 457 | 448 | 451 | 445 | 409 | 363 | 451 | 405 | 339 | 299 | 287 |

**Table 3 Raw Scores for the Evaluation of Lake Modeling Packages**

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHTUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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? | 1 - Relatively expensive; 3 - Moderately expensive; 5 - Free | 2 | 5 | 5 | 5 | 5 | 5 | 1 | 5 | 5 | 3 | 5 | 5 | 5 | 5 |
| **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? | 1 - No access; 2 - Partial access; 3 - Paid access; 4 - Contract team has full access; 5 - Fully open access | 2 | 5 | 5 | 5 | 5 | 5 | 1 | 1 | 3 | 4 | 4 | 5 | 1 | 5 |
| **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? | 1 - Not peer reviewed and not used in SE US; 3 - Peer reviewed applied elsewhere in US; 5 - Peer reviewed and used in SE US | 3 | 5 | 5 | 5 | 5 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 5 | 3 |
| Is there an existing application of this model package to Falls Lake? | 1 - No; 3 - Exploratory; 5 - Yes | 2 | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 | 3 | 5 | 1 |
| Was this model package used to develop the current Falls Lake Nutrient Management Strategy? | Informational | Informational | Yes | No | No | No | No | No | No | No | No | No | No | No | No |
| **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)? | Informational: Process based (P); Empirical (E) | Informational | P | P | P | P | P | P | P | P | P | P | P | E | E |
| Is the model package simple or complex? | Informational: Complex (C); Moderate (M); Simple (S) | Informational | C | C | C | C | C | C | C | C | C | M | M | S | S |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHTUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| How many parameters are included in the model (Less than 50, 100, 500, 1000; more than 1000)? | Informational | Informational | <500 | <500 | <500 | <500 | <500 | <500 | <500 | <1000 | <1000 | <100 | <500 | <50 | <50 |
| **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? | Informational: 1D; 2D; 3D; Vertical (V); Lake Segment Average (LSA) | Informational | 3D | 3D | 2D | 3D | 3D | 3D | 3D | LSA | 3D | 1D (V) | 1D (V) | LSA | LSA |
| **Smallest accurate output time step:** Does the model package predict flow and water quality in the lake annually? Seasonally? Monthly? Daily? Hourly? Subhourly? | 1- annually; 2 - seasonal or monthly; 3 - daily; 4 - hourly; 5 - subhourly | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 5 | 4 | 2 | 1 |
| Does the **available information** (UNRBA monitoring plan, member, DWR, NADP, etc.) **support inputs needed for this model** (atmospheric deposition, tributary inputs, rainfall, sediment interactions, direct discharges, bathymetry)? | 1- at least 10% of inputs are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 5 | 5 |
| Does the available information support model calibration (parameters, coefficients, etc.)? | 1- at least 10% of inputs are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| Does the **available information support matching water quality information for lake model calibration** (e.g., measured water quality constituents)? (Scores indicate what is measured, not frequency or spatial coverage.) | 1- at least 10% of parameters are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 5 | 5 | 5 | 5 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHTUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Existing GUI:** Does the model package include a Graphical User Interface for pre and post processing? | 1 - No GUI; 3 - Simple GUI, no additional functionality; 5 - Advanced GUI with additional functionality | 3 | 5 | 5 | 5 | 5 | 3 | 5 | 3 | 3 | 1 | 5 | 1 | 3 | 1 |
| What is the relative cost of the model package per license? Is there a separate cost for the GUI? | 1 - Relatively expensive; 3 - Moderately expensive; 5 - Free | 3 | 3 | 3 | 5 | 5 | 3 | 1 | 3 | 5 | 3 | 5 | 5 | 5 | 5 |
| Model Package Selection Criteria: | | | | | | | | | | | | | | | |
| Focus Parameters: | | | | | | | | | | | | | | | |
| **Hydraulics/hydrodynamics:** Is the movement of water based only on a mass balance? Are thermal stratification and topographic features considered? | 1 - Mass balance only; 3 - also simulates thermal stratification; 5 - also simulates thermal stratification and topographic features | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 3 | 3 | 3 | 1 | 0 |
| **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? | 1 - Simulates total nitrogen only; 3 - simulates inorganic/organic fractions; 5 - simulates the nitrogen cycle and measurable speciation | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 3 | 1 |
| **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? | 1 - Simulates total phosphorus only; 3 - simulates inorganic/organic fractions; 5 - simulates the phosphorus cycle and measurable speciation | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 3 | 5 | 3 | 1 |
| **Carbon:** Does the model package predict in-lake carbon concentrations as the total fraction, inorganic/organic, measurable species | 1 - Does not simulate; 2 - simulates total; 3 - simulates inorganic/organic fractions; 4 - also simulates dissolved/particulate | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 5 | 4 | 5 | 1 | 1 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHTUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | fractions; 5 - also simulates labile/refractory | | | | | | | | | | | | | | |
| **TSS:** Does the model package simulate sediment transport in the lake? How many sediment classifications are defined? | 1 - Does not simulate; 3 - simulates total; 5 - simulates at least 3 classes | 2 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 1 | 3 | 3 | 3 | 1 | 1 |
| **Turbidity:** What components are considered in the simulation of turbidity/light scattering: algae? inorganic solids? background color? | 1 - Does not simulate; 2 - simulates either algal or inorganic solids; 3 - simulates algal and inorganic solids; 5 - also simulates background color | 2 | 5 | 5 | 3 | 5 | 3 | 3 | 3 | 5 | 5 | 3 | 3 | 3 | 1 |
| **DO:** Can the model package simulate oxygen dynamics, including multiple types of oxygen consuming wastes? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 |
| **pH:** Can the model package simulate hydrogen ion concentrations (pH)? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 2 | 2 |
| **Chlorophyll *a*:** Can the model package simulate chlorophyll *a* as a component of floating algae (phytoplankton)? | 2 - No; 4 - Yes | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Phytoplankton assemblages:** Can the model package simulate different algal groups in the lake (i.e., are greens, diatoms, and blue-green algae simulated)? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 2 | 2 |
| 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? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHTUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Groundwater inputs:** Can the model package account for flow and nutrient inputs from groundwater? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 2 |
| **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? | 2 - No; 4 - Yes | 3 | 4 | 4 | 2 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 4 | 2 | 2 |
| **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? | 1 - No; 3 - Can incorporate from a separate model; 5 - Explicitly simulates | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 3 | 5 | 3 | 1 |
| **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.? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 4 | 2 | 2 |
| **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.? | 2 - No; 4 - Yes | 2 | 4 | 4 | 2 | 4 | 4 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **Vertical stratification:** Does the model package account for differences in water density due to temperature? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 2 | 2 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHTUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Does the model package explicitly account for **atmospheric deposition** of nitrogen and phosphorus? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | 4 |
| Does the model package explicitly simulate **atmospheric exchange of carbon**? | 2 - No; 4 - Yes | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 2 | 2 |
| Can the model package be used to evaluate lake **pump and treat** systems? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 |
| Does the model package simulate flows and changes in water quality associated with **outlet control structures** in response to changing water levels? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 2 | 2 |
| Applications: | | | | | | | | | | | | | | | |
| Can the model package be used to predict the nutrient assimilative capacity of Falls Lake and to **support development of nutrient management strategy**? | 2 - No; 4 - Yes | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 |
| Can the model package be used to **evaluate attainment of designated uses** including recreation and drinking water supply? | 1 - No; 2- one DU; 3- two DUs; 4- three DUs; 5- four DUs | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| Can the model package be used to **evaluate regulatory options** such as site specific criteria or use attainability analyses? | 2 - No; 4 - Yes | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 |
| Can the model package be used to **evaluate lag time** associated with watershed changes? | 2 - No; 4 - Yes | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 2 |
| **Evaluation of water quality standards**. Can the model package be used to directly evaluate the | 1 - Cannot be used; 2 - evaluates chlorophyll a; 3 - chlorophyll a plus 1 other parameter; 4 - chlorophyll a | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 2 | 2 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHTUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| current NC water quality standards for chlorophyll *a*? Turbidity? DO? pH? | +2 parameters; 5 - chlorophyll a +3 parameters | | | | | | | | | | | | | | |

Raw Score Summaries

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Package Characteristics and Past Use: | | 43 | 39 | 41 | 41 | 35 | 27 | 31 | 29 | 23 | 44 | 36 | 38 | 32 |
| Focus Parameters | | 46 | 46 | 44 | 46 | 42 | 42 | 40 | 32 | 36 | 37 | 40 | 22 | 15 |
| Explicit Processes Simulated | | 45 | 45 | 41 | 45 | 45 | 45 | 41 | 29 | 29 | 37 | 43 | 27 | 23 |
| Applications | | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 18 | 17 | 17 | 17 | 13 | 9 |
| TOTAL RAW Score | | 151 | 147 | 143 | 149 | 139 | 131 | 129 | 108 | 105 | 135 | 136 | 100 | 79 |

**Table 4 Weighted Scores for the Evaluation of Lake Modeling Packages**

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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? | 1 - Relatively expensive; 3 - Moderately expensive; 5 - Free | 2 | 10 | 10 | 10 | 10 | 10 | 2 | 10 | 10 | 6 | 10 | 10 | 10 | 10 |
| **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? | 1 - No access; 2 - Partial access; 3 - Paid access; 4 - Contract team has full access; 5 - Fully open access | 2 | 10 | 10 | 10 | 10 | 10 | 2 | 2 | 6 | 8 | 8 | 10 | 2 | 10 |
| **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? | 1 - Not peer reviewed and not used in SE US; 3 - Peer reviewed applied elsewhere in US; 5 - Peer reviewed and used in SE US | 3 | 15 | 15 | 15 | 15 | 9 | 9 | 9 | 9 | 9 | 15 | 9 | 15 | 9 |
| Is there an existing application of this model package to Falls Lake? | 1 - No; 3 - Exploratory; 5 - Yes | 2 | 10 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 10 | 6 | 10 | 2 |
| Was this model package used to develop the current Falls Lake Nutrient Management Strategy? | Informational | Informational | Yes | No | No | No | No | No | No | No | No | No | No | No | No |
| **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)? | Informational: Process based (P); Empirical (E) | Informational | P | P | P | P | P | P | P | P | P | P | P | E | E |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Is the model package simple or complex? | Informational: Complex (C); Moderate (M); Simple (S) | Informational | C | C | C | C | C | C | C | C | C | M | M | S | S |
| How many parameters are included in the model (Less than 50, 100, 500, 1000; more than 1000)? | Informational | Informational | <500 | <500 | <500 | <500 | <500 | <500 | <500 | <1000 | <1000 | <100 | <500 | <50 | <50 |
| **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? | Informational: 1D; 2D; 3D; Vertical (V); Lake Segment Average (LSA) | Informational | 3D | 3D | 2D | 3D | 3D | 3D | 3D | LSA | 3D | 1D (V) | 1D (V) | LSA | LSA |
| **Smallest accurate output time step:** Does the model package predict flow and water quality in the lake annually? Seasonally? Monthly? Daily? Hourly? Subhourly? | 1- annually; 2 - seasonal or monthly; 3 - daily; 4 - hourly; 5 - subhourly | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 9 | 9 | 15 | 12 | 6 | 3 |
| Does the **available information** (UNRBA monitoring plan, member, DWR, NADP, etc.) **support inputs needed for this model** (atmospheric deposition, tributary inputs, rainfall, sediment interactions, direct discharges, bathymetry)? | 1- at least 10% of inputs are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 12 | 15 | 15 |
| Does the available information support model calibration (parameters, coefficients, etc.)? | 1- at least 10% of inputs are supported; 2 - at least 25%; 3 - at least 50%; 4 - at least 75%; 5 - at least 90% | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 6 | 3 |
| Does the **available information support matching water quality information for lake** | 1- at least 10% of parameters are supported; 2 - at least 25%; 3 - at | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 9 | 9 | 15 | 15 | 15 | 15 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **model calibration** (e.g., measured water quality constituents)? (Scores indicate what is measured, not frequency or spatial coverage.) | least 50%; 4 - at least 75%; 5 - at least 90% | | | | | | | | | | | | | | |
| **Existing GUI:** Does the model package include a Graphical User Interface for pre and post processing? | 1 - No GUI; 3 - Simple GUI, no additional functionality; 5 - Advanced GUI with additional functionality | 3 | 15 | 15 | 15 | 15 | 9 | 15 | 9 | 9 | 3 | 15 | 3 | 9 | 3 |
| What is the relative cost of the model package per license? Is there a separate cost for the GUI? | 1 - Relatively expensive; 3 - Moderately expensive; 5 - Free | 3 | 9 | 9 | 15 | 15 | 9 | 3 | 9 | 15 | 9 | 15 | 15 | 15 | 15 |
| Model Package Selection Criteria: | | | | | | | | | | | | | | | |
| Focus Parameters: | | | | | | | | | | | | | | | |
| **Hydraulics/hydrodynamics:** Is the movement of water based only on a mass balance? Are thermal stratification and topographic features considered? | 1 - Mass balance only; 3 - also simulates thermal stratification; 5 - also simulates thermal stratification and topographic features | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 3 | 9 | 9 | 9 | 3 | 0 |
| **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? | 1 - Simulates total nitrogen only; 3 - simulates inorganic/organic fractions; 5 - simulates the nitrogen cycle and measurable speciation | 4 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 12 | 20 | 20 | 12 | 4 |
| **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? | 1 - Simulates total phosphorus only; 3 - simulates inorganic/organic fractions; 5 - simulates the phosphorus cycle and measurable speciation | 4 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 12 | 12 | 20 | 12 | 4 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carbon:** Does the model package predict in-lake carbon concentrations as the total fraction, inorganic/organic, measurable species | 1 - Does not simulate; 2 - simulates total; 3 - simulates inorganic/organic fractions; 4 - also simulates dissolved/particulate fractions; 5 - also simulates labile/refractory | 4 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 4 | 20 | 16 | 20 | 4 | 4 |
| **TSS:** Does the model package simulate sediment transport in the lake? How many sediment classifications are defined? | 1 - Does not simulate; 3 - simulates total; 5 - simulates at least 3 classes | 2 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 2 | 6 | 6 | 6 | 2 | 2 |
| **Turbidity:** What components are considered in the simulation of turbidity/light scattering: algae? inorganic solids? background color? | 1 - Does not simulate; 2 - simulates either algal or inorganic solids; 3 - simulates algal and inorganic solids; 5 - also simulates background color | 2 | 10 | 10 | 6 | 10 | 6 | 6 | 6 | 10 | 10 | 6 | 6 | 6 | 2 |
| **DO:** Can the model package simulate oxygen dynamics, including multiple types of oxygen consuming wastes? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| **pH:** Can the model package simulate hydrogen ion concentrations (pH)? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 4 | 4 | 4 | 4 | 4 | 8 | 8 | 4 | 4 |
| **Chlorophyll *a*:** Can the model package simulate chlorophyll *a* as a component of floating algae (phytoplankton)? | 2 - No; 4 - Yes | 4 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| **Phytoplankton assemblages:** Can the model package simulate different algal groups in the lake (i.e., are greens, diatoms, and blue-green algae simulated)? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | 8 | 4 | 4 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| **Groundwater inputs:** Can the model package account for flow and nutrient inputs from groundwater? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 12 | 12 | 6 |
| **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? | 2 - No; 4 - Yes | 3 | 12 | 12 | 6 | 12 | 12 | 12 | 12 | 6 | 6 | 6 | 12 | 6 | 6 |
| **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? | 1 - No; 3 - Can incorporate from a separate model; 5 - Explicitly simulates | 3 | 15 | 15 | 15 | 15 | 15 | 15 | 9 | 15 | 15 | 9 | 15 | 9 | 3 |
| **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.? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 6 | 12 | 6 | 6 |
| **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 | 2 - No; 4 - Yes | 2 | 8 | 8 | 4 | 8 | 8 | 8 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 4 | 4 | 8 | 8 | 4 | 4 |
| Does the model package explicitly account for **atmospheric deposition** of nitrogen and phosphorus? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 12 | 12 | 12 |
| Does the model package explicitly simulate **atmospheric exchange of carbon**? | 2 - No; 4 - Yes | 2 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 4 | 4 | 8 | 8 | 4 | 4 |
| Can the model package be used to evaluate lake **pump and treat** systems? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| Does the model package simulate flows and changes in water quality associated with **outlet control structures** in response to changing water levels? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 | 12 | 12 | 6 | 6 |
| Applications: | | | | | | | | | | | | | | | |
| Can the model package be used to predict the nutrient assimilative capacity of Falls Lake and to **support development of nutrient management strategy**? | 2 - No; 4 - Yes | 4 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 8 |
| Can the model package be used to **evaluate attainment of designated uses** including recreation and drinking water supply? | 1 - No; 2- one DU; 3- two DUs; 4- three DUs; 5- four DUs | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 8 | 8 | 4 | 4 | 4 | 4 |

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Can the model package be used to **evaluate regulatory options** such as site specific criteria or use attainability analyses? | 2 - No; 4 - Yes | 4 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 8 |
| Can the model package be used to **evaluate lag time** associated with watershed changes? | 2 - No; 4 - Yes | 3 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| **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? | 1 - Cannot be used; 2 - evaluates chlorophyll a; 3 - chlorophyll a plus 1 other parameter; 4 - chlorophyll a +2 parameters; 5 - chlorophyll a +3 parameters | 4 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 12 | 16 | 16 | 8 | 8 |

Weighted Score Summaries

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Package Characteristics and Past Use | | 114 | 106 | 112 | 112 | 94 | 78 | 86 | 78 | 64 | 118 | 95 | 103 | 85 | |
| Focus Parameters | | 139 | 139 | 135 | 139 | 131 | 131 | 127 | 99 | 109 | 113 | 125 | 69 | 46 | |
| Explicit Processes Simulated | | 123 | 123 | 113 | 123 | 123 | 123 | 113 | 81 | 81 | 101 | 119 | 75 | 63 | |
| Applications | | 64 | 64 | 64 | 64 | 64 | 64 | 64 | 68 | 64 | 64 | 64 | 50 | 34 | |
| Total Weighted Score | | 440 | 432 | 424 | 438 | 412 | 396 | 390 | 326 | 318 | 396 | 403 | 297 | 228 | |

Sum Weighted Scores for Weight = 4

| MODEL: | Scoring Metrics (1 - 5) | Weight (1-4) | EFDC | EFDC-WASP | CE-QUAL-W2 | DELFT | ECOM-RCA | MIKE-3 | RMA | AQUATOX | CASM | WARMF-LAKE | GLM | BATHUB | EUTROMOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Package Characteristics and Past Use | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Focus Parameters | | | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 60 | 60 | 64 | 76 | 44 | 28 |
| Explicit Processes Simulated | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Applications | | | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 56 | 52 | 52 | 52 | 44 | 28 |
| Total Scores for Weight = 4 | | | 128 | 128 | 128 | 128 | 128 | 128 | 128 | 116 | 112 | 116 | 128 | 88 | 56 |
| Sum Weighted Scores for Weight = 3 | | | | | | | | | | | | | | | |
| Model Package Characteristics and Past Use | | | 84 | 84 | 90 | 90 | 72 | 72 | 72 | 60 | 48 | 90 | 69 | 81 | 63 |
| Focus Parameters | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 15 | 21 | 21 | 21 | 9 | 6 |
| Explicit Processes Simulated | | | 99 | 99 | 93 | 99 | 99 | 99 | 93 | 69 | 69 | 81 | 99 | 63 | 51 |
| Applications | | | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 6 |
| Total Scores for Weight = 3 | | | 222 | 222 | 222 | 228 | 210 | 210 | 204 | 156 | 150 | 204 | 201 | 159 | 126 |
| Sum Weighted Scores for Weight = 4 + 3 | | | 350 | 350 | 350 | 356 | 338 | 338 | 332 | 272 | 262 | 320 | 329 | 247 | 182 |