QUALITY ASSURANCE PROJECT PLAN
for
The Upper Neuse River Basin Association
Falls Lake and Watershed Modeling

Prepared for:

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Submitted for Approval by:

NC Environmental Quality

North Carolina Department of Environmental Quality
Division of Water Resources

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ABBREVIATIONS

AFO	Animal Feeding Operation
BIMS	Basinwide Information Management System
BMP	Best management practices
BOD	UNRBA Board of Directors
CAAE	Center for Applied Aquatic Ecology
CAFO	Concentrated Animal Feeding Operation
CASTNET	Clean Air Status and Trends Network
CDL	USDA NASS Crop Data Layer
CD-ROM	Compact Disc – Read Only Memory
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
DQO	Data Quality Objective
DVD	Digital Versatile Disk
DWR	NCDEQ Division of Water Resources
EFDC	Environmental Fluid Dynamics Code
EMC	Environmental Management Commission
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FTP	File Transfer Protocol
GIS	Geographic Information System
MRSW	UNRBA Modeling and Regulatory Support Workgroup
N	Nitrogen
NADP	National Atmospheric Deposition Program
NASS	USDA's National Agricultural Statistics Service
NCDC	National Climatic Data Center
NCDEQ	N.C. Department of Environmental Quality
NC CRONOS	N.C. Climate Retrieval and Observations Network of the Southeast
NED	National Elevation Dataset
NH4-N	Ammonium as Nitrogen
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NMS	Nutrient Management Strategy
NO3-N	Nitrate as Nitrogen
NOAA	National Oceanic Atmospheric Administration
NRCS	Natural Resource Conservation Service of the USDA
NWIS	National Water Information System
OMB	Office of Management and Budget
Org-N	Organic Nitrogen
OSWD	On-Site Wastewater Disposal
PFC	UNRBA Path Forward Committee
P	Phosphorus
PM	Project Manager
PO4-P	Orthophosphate as Phosphorus
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RMSE	Root Mean Square Error

SOP	Standard Operating Procedure
STATSGO2	State Soil Geographic Dataset version 2: U.S. General Soil Map
STF	Summary tape files
STORET	EPA Storage and Retrieval System
TIGER	Topologically Integrated Geographic Encoding and Referencing
TIRS	Thermal Infrared Sensor
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
UNC	University of North Carolina at Chapel Hill
UNRBA	Upper Neuse River Basin Association
USACE	United States Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WARMF	Watershed Analysis Risk Management Framework
WOC	Watershed Oversight Committee

REVISION LOG

Upper Neuse River Basin Association, Falls Lake and Watershed Modeling
Quality Assurance Project Plan

Date	Version Edited	Section	Changes/Updates	Editor
2/28/2018	1.0	All	Initial Approved QAPP	N/A

SECTION A — PROJECT MANAGEMENT

A.1 Signature and Approval Sheet

Upper Neuse River Basin Association, Falls Lake and Watershed Modeling
Quality Assurance Project Plan, Version 1.0

Approved by:

Signature on original	March 1, 2018
Forrest Westall, UNRBA Executive Director	Date
Signature on original	March 21, 2018
Sig Hutchinson, UNRBA Chair, Board of Directors	Date
Signature on original	February 28, 2018
Michelle Woolfolk, City of Durham Chair, UNRBA Modeling and Regulatory Support Workgroup	Date
Signature on original	February 20, 2018
Kenneth Waldroup, City of Raleigh Co-Chair, UNRBA Path Forward Committee	Date
Signature on original	February 28, 2018
Lindsay Mize, South Granville Water and Sewer Authority Co-Chair, UNRBA Path Forward Committee	Date
Signature on original	March 20, 2018
Brenan Buckley, Brown and Caldwell, Principal in Charge	Date
Signature on original	March 20, 2018
Doug Durbin, Brown and Caldwell, Quality Assurance Officer	Date
Signature on original	March 20, 2018
Alix Matos, Brown and Caldwell, Project Manager	Date
Signature on original	February 23, 2018
Chris Wallen, Dynamic Solutions, LLC Lake Modeling Task Manager	Date
Signature on original	February 23, 2018
Scott Sheeder, Systech Water Resources, LLC Watershed Modeling Task Manager	Date
Signature on original	February 23, 2018
Matthew Van De Bogert, Brown and Caldwell, Statistical Modeling Task Manager	Date
Signature on original	March 1, 2018
Tom Fransen, Chief, NC Division of Water Resources Water Planning Section	Date
Signature on original	March 1, 2018
Pamela Behm, NC Division of Water Resources Chief, Modeling and Assessment Branch	Date
Signature on original	March 1, 2018
Richard Gannon, Chief, NC Division of Water Resources Nonpoint Source Planning Branch	Date

A.2 Table of Contents

A.3 Distribution List

Primary Distribution:

Upper Neuse River Basin Association
Forrest Westall, Executive Director
Sig Hutchinson, UNRBA Chair, Board of Directors
Haywood Phthisic, Assistant to Executive Director
Michelle Woolfolk, City of Durham, Chair, UNRBA Modeling and Regulatory Support Workgroup
Kenneth Waldroup, City of Raleigh, Co-Chair, UNRBA Path Forward Committee
Lindsay Mize, South Granville Water and Sewer Authority, Co-Chair, UNRBA Path Forward Committee

NC Department of Environmental Quality, Division of Water Resources
Cyndi Karoly, Chief, Water Sciences Section
Tom Fransen, Chief, Water Planning Section
Pam Behm, Chief, Modeling and Assessment Branch
Rich Gannon, Chief, Nonpoint Source Planning Branch
John Huisman, Environmental Program Consultant
Cam McNutt, Environmental Program Consultant

EPA
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Marion Hopkins, Region 4

Dynamic Solutions, LLC.
Chris Wallen, Vice President, Lake Modeling Task Manager
Andrew Stoddard, Senior Modeler
Silong Wu, Senior Modeler
Jan Mandrup-Poulson, Regulatory Support

Systech Water Resources, Inc.
Joel Herr, Watershed Modeling Code Customization
Scott Sheeder, Watershed Modeling Task Manager

Brown and Caldwell
Alix Matos, Project Manager
Douglas Durbin, Quality Assurance Officer
Brenan Buckley, Principal in Charge
Matthew Van de Bogert, Empirical/Probabilistic Modeling Task Manager
Lauren Handsel, Water Resources Engineer

*Independent consultants listed on the project organizational chart are also included in the distribution of this Modeling QAPP.

A.4 Project Organization

A.4.1 Introduction

The Upper Neuse River Basin Association (UNRBA) has contracted with Brown and Caldwell to provide water quality modeling and regulatory support for the reexamination of the Falls Lake Nutrient Management Strategy, with specific reference to Stage II of the Falls Lake Rules. Dynamic Solutions, LLC; Systech Water Resources, Inc.; and several independent consultants are subcontractors to Brown and Caldwell. This modeling project is conducted under the direction of the UNRBA. The UNRBA modeling and regulatory support project is aimed at providing support to the association's mission of developing accurate management, technical, regulatory and legal recommendations regarding development of appropriate eutrophication management strategies for Falls Lake (Box A.4.1). The purpose of this Quality Assurance Project Plan (QAPP) is to document the quality assurance planning associated with the development and application of the Falls Lake and Watershed models.

Box A.4-1 The Mission of the UNRBA

The mission of the UNRBA is to preserve the water quality of the Upper Neuse River Basin through innovative and cost-effective nutrient reduction strategies, and to constitute a forum to cooperate on water supply issues within the Upper Neuse River Basin by:

- *Forming a coalition of units of local government, public and private agencies, and other interested and affected communities, organizations, businesses and individuals to secure and pool financial resources and expertise;*
- *Collecting and analyzing information and data and developing, evaluating and implementing strategies to reduce, control and manage nutrient discharge; and*
- *Providing accurate technical, management, regulatory and legal recommendations regarding the implementation of alternate strategies for the management of the water quality of Falls Lake.*

The day-to-day operations of project management and quality assurance procedures which occur under the guidance of this QAPP will be directed by Brown and Caldwell. Dynamic Solutions, LLC. will perform the mechanistic lake modeling, and Systech Water Resources, Inc. will perform the mechanistic watershed modeling. Systech may customize changes to the watershed modeling code, and will document any changes as part of the project documentation. Brown and Caldwell will lead the statistical (empirical/probabilistic/Bayesian) modeling with the support of several technical experts. The modeling project will be overseen by the UNRBA. The UNRBA Executive Director, Forrest Westall, serves as the primary point of contact with Brown and Caldwell and its subcontractors (hereafter referred to as the Team). The UNRBA Executive Director along with the UNRBA Path Forward Committee (PFC) and the UNRBA Modeling and Regulatory Support Workgroup (MRSW) will provide general project guidance and oversight. NCDEQ Division of Water Resources (henceforth, DWR) and EPA Region 4 will be engaged throughout the process; approvals of this QAPP will be requested from both agencies. Figure A.4-1 shows the organizational chart for this project. Names of Task Managers are shown in bold font in the respective boxes.

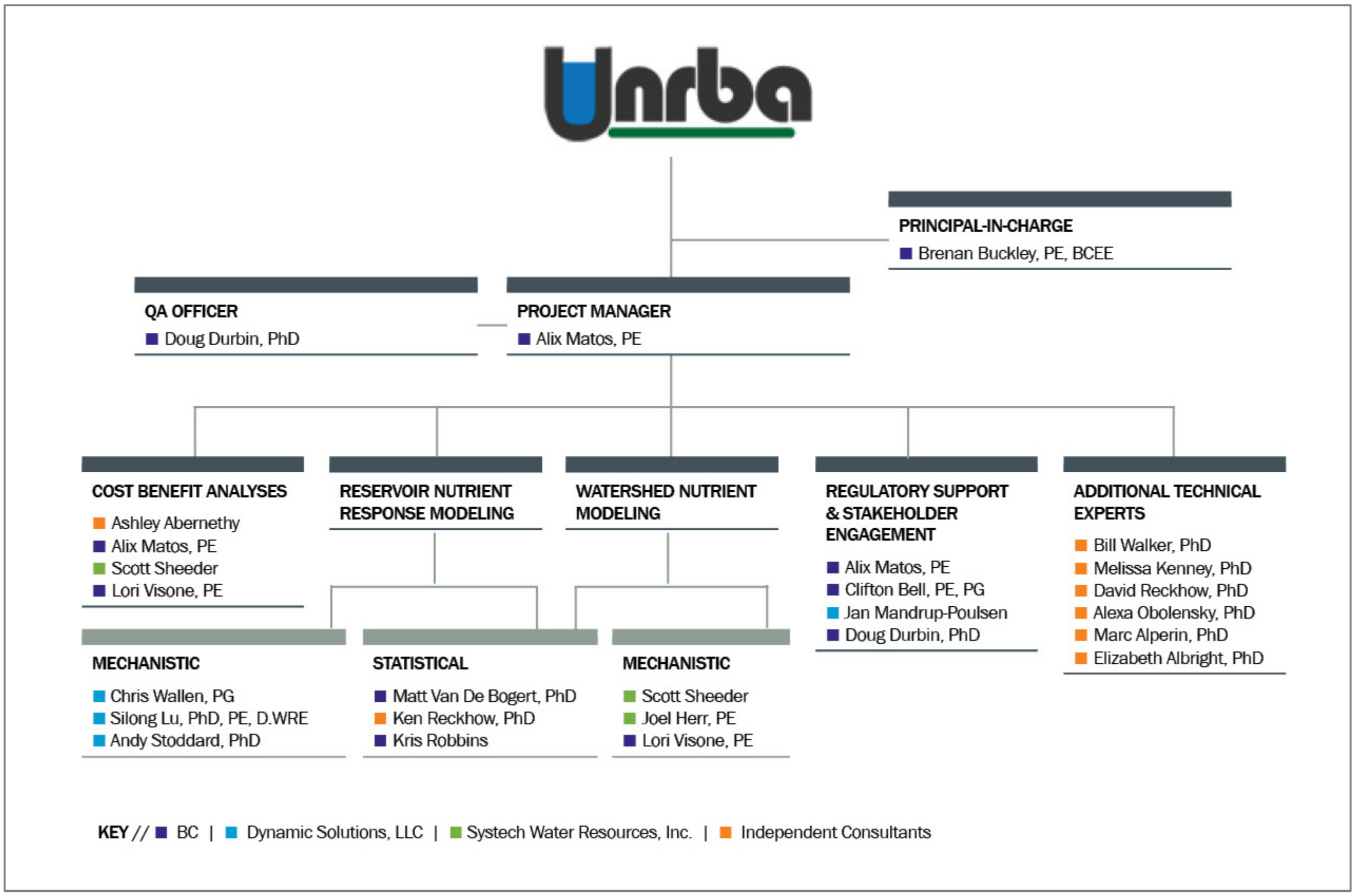

Figure A.4-1 UNRBA Monitoring Program Organizational Chart

A.4.2 Project Management and Oversight

The following team members provide project management and oversight of work associated with the development of the lake and watershed models. Other staff listed on Figure A.4-1 provide support services or are involved with tasks beyond the scope of the lake and watershed models (e.g., cost benefit analysis). All named individuals listed as either project managers, team members, task managers, additional experts, or otherwise named in this document will be furnished a copy of this approved QAPP to ensure a consistent awareness of this Project Plan and the expectations for obtaining a quality project.

Brown and Caldwell

Brenan Buckley, Principal-in-Charge for the Modeling and Regulatory Support Project

- Responsible for management oversight of the project including ensuring that adequate and appropriate resources are available to perform the work

Doug Durbin, Quality Assurance Officer for the Modeling and Regulatory Support Project

- Responsible for technical oversight of the project
- Ensures the overall performance, direction, and quality of the project are aligned with goals
- Ensures compliance with the requirements specified in this QAPP
- Responsible for ensuring that the UNRBA Monitoring Program is managed in a such a way to continue to provide high quality data to support the UNRBA Modeling and Regulatory Support Project
- Responsible for executing the tasks and other requirements of the Monitoring Program on time and with the Quality Assurance/Quality Control (QA/QC) requirements in the system as defined by the contract and in the Monitoring QAPP

Alix Matos, Project Manager (PM) for the Modeling and Regulatory Support Project

- Responsible for ensuring that the Modeling and Regulatory Support Project is conducted in accordance with all relevant QAPPs
- Reviews and approves all reports, work plans, corrective actions, QAPP, and any other major work products and their revisions
- Manages subcontracts with Dynamic Solutions, LLC., Systech Water Resources, Inc., and independent technical consultants
- In consultation with UNRBA Executive Director, approves changes to project and ensures changes comply with UNRBA goals and DWR requirements
- Reports to UNRBA Executive Director and keeps Executive Director apprised of Modeling and Regulatory Support (MRS) Project status and progress
- Presents status updates to the UNRBA Path Forward Committee (PFC) and UNRBA Board of Directors and the UNRBA Modeling and Regulatory Support Workgroup (MRSW)

Matthew Van de Bogert, Task Manager for Statistical Modeling

- Responsible for managing all support staff and independent technical experts who will be assisting with development of the statistical modeling, quality assurance of model inputs and model development, and report writing
- Responsible for submitting accurate and timely deliverables to the PM and attending conference calls, training, meetings, and related modeling project activities with the UNRBA
- Responsible for producing data and modeling products of known and acceptable quality in accordance with this QAPP
- Responsible for ensuring adequate training and supervision of all activities involved in generating data and model results, including the facilitation of audits and the implementation, documentation, verification and reporting of corrective actions to PM

Dynamic Solutions, LLC.

Chris Wallen, Task Manager for Lake Modeling

- ***Responsible for executing the tasks and other requirements of the subcontract on time and with the QA/QC requirements in the system as defined by the contract and in the Modeling QAPP***
- Responsible for submitting accurate and timely deliverables to the Brown and Caldwell PM and attending conference calls, training, meetings, and related modeling project activities with the UNRBA
- Responsible for producing data and modeling products of known and acceptable quality in accordance with this QAPP
- Responsible for ensuring adequate training and supervision of all activities involved in generating data and model results, including the facilitation of audits and the implementation, documentation, verification and reporting of corrective actions to Brown and Caldwell PM
- Responsible for managing all Dynamic Solutions, LLC staff who will be assisting with developing the Modeling QAPP, developing the Environmental Fluid Dynamics Code (EFDC) lake model, and generating the modeling report

Jan Mandrup-Poulson, Model Review and Regulatory Support

- Reviews WARMF and EFDC model development, calibration, and scenario analysis
- Responsible for providing guidance on stakeholder engagement throughout the project
- Collaborates with legal group and modeling team on revised nutrient management strategy

Systech Water Resources, Inc.

Scott Sheeder, Task Manager for Watershed Modeling

- Responsible for executing the tasks and other requirements of the subcontract on time and with the QA/QC requirements in the system as defined by the contract and in the project QAPP
- Responsible for submitting accurate and timely deliverables to the Brown and Caldwell PM and attending conference calls, training, meetings, and related modeling project activities with the UNRBA
- Responsible for producing data and modeling products of known and acceptable quality in accordance with this QAPP
- Responsible for ensuring adequate training and supervision of all activities involved in generating data and model results, including the facilitation of audits and the implementation, documentation, verification and reporting of corrective actions to Brown and Caldwell PM
- Responsible for managing all Systech Water Resources staff who will be assisting with developing the Watershed Analysis Risk Management Framework (WARMF) watershed and lake models and generating the modeling report

Joel Herr

- Responsible for customization, documentation, and quality assurance procedures associated with customized revisions to the WARMF model on an as needed basis

Independent Consultants

Several independent consultants have been identified to support the mechanistic and statistical modeling for this project. Each of these independent consultants is an expert in their field and will provide focused support to the project.

A.4.3 Primary model end-users

UNRBA

Forrest Westall, Executive Director

- Liaison between the UNRBA (primary model end-user) and Brown and Caldwell staff
- Provides oversight and monitoring of Modeling and Regulatory Support Contract and the associated Scope of Work for the project
- Receives periodic status updates from Brown and Caldwell on Modeling and Regulatory Support Project (e.g., weekly status update calls)
- Facilitates interactions between UNRBA Board of Directors, the PFC, the MRSW, and Brown and Caldwell for project status updates
- Provides input to the PM on changes needed to the modeling project as part of a continuous program assessment process

Michelle Woolfolk, Chair of the MRSW

- Provides technical input of the Modeling and Regulatory Support activities
- Coordinates activities of the MRSW
- Presents general status updates to the PFC on behalf of the MRSW
- Provides perspective on success of project in meeting goals of Consensus Principals

Kenneth Waldroup and Lindsay Mize, Co-Chairs of the PFC

- Presents general status updates to the BOD on behalf of the PFC
- Coordinates activities of the PFC
- Provides perspective on success of project in meeting goals of Consensus Principals

UNRBA Individual Jurisdictions and Utilities

- Contributes input on modeling scenarios and management scenarios to be evaluated
- Supplies local data to modeling team to improve accuracy of model representations

- Provides perspective on success of project in meeting goals of Consensus Principals
- Participates in UNRBA status update meetings (BOD and PFC) and stakeholder engagement meetings

Environmental Protection Agency (EPA Region 4)

- As requested, provides reviews and comments on the Modeling QAPP and other components of the modeling effort
- Serves as a point of reference relative to preliminary and final modeling results

NC Department of Environmental Quality (NCDEQ) Division of Water Resources (DWR)

- Reviews, provides comments, and approves Modeling QAPP and subsequent revisions
- Reviews modeling files on behalf of DEQ
- Provides input on model development, sensitivity analyses, and scenario development
- Offers comments on nutrient management strategies

Watershed Stakeholders

- Provides supplemental data to improve accuracy and representativeness of models for their sources/areas
- Participates in stakeholder meetings to provide input on comments throughout the Modeling and Regulatory Support process
- Comments on modeling scenarios and evaluation of nutrient management strategies

A.5 Problem Definition and Background

A.5.1 Background

The waters of the Upper Neuse River Basin in North Carolina have had many challenges meeting the demands of society and the current environmental standards in place for those waters. Falls Lake is the primary source of drinking water for the City of Raleigh and its 550,000 customers and is immediately downstream of several urban areas, including the City of Durham. Constructed in the early 1980's, Falls Lake is a shallow Piedmont lake with inherent difficulty meeting water quality standards for chlorophyll-a because of its geology, morphology, and its topographic location below pre-existing and established land use.

A complex set of rules, regulations, and policies governs activities in the Falls Lake watershed. The Falls Nutrient Strategy Rules overlay several previous regulations, including the Neuse River Basin Nutrient Strategy, National Pollutant Discharge Elimination System permits, and stormwater permits for Phase I and Phase II of the Clean Water Act, and state Water Supply Watershed Protection regulations.

A.5.2 Regulatory Information

In 2005, the North Carolina General Assembly enacted Session Law 2005-190 (Senate Bill 981, Clean Lakes Act), which directed the North Carolina Environmental Management Commission (EMC) to develop and adopt nutrient management strategies (NMS) to reduce nitrogen and phosphorus pollution in several water supply reservoirs by July 1, 2008 (later extended to July 1, 2009). In 2009, the General Assembly enacted Session Law 2009-486 (Senate Bill 1020, Improve Upper Neuse River Water Quality), which extended the deadline again until January 15, 2011 for the implementation of the Falls Lake NMS, allowed for a system crediting early adoption of nutrient reductions, and required stricter sedimentation and erosion control measures in the watershed.

In 2008, the DWR (formerly the Division of Water Quality, DWQ) placed Falls Lake on the Section 303(d) list because of violations of the State's water quality standards for chlorophyll-a, a proxy for algae. Falls Lake above I-85 was also 303(d) listed for turbidity in 2008.

In 2010, recognizing that complex jurisdictional (upstream/downstream) management issues concerning water quality in Falls Lake would affect their ability to solve other critical regional problems, many impacted local governments developed a set of "Consensus Principles" to help shape the proposed rules. The principles included three fundamental agreements: (1) that any rules would need to protect Falls Lake for the purpose of water supply, (2) that additional water quality monitoring would provide useful information, and (3) that North Carolina should consider new information before going beyond those actions necessary to protect Falls Lake for the purpose of water supply. The City of Durham, Durham County, Granville County, City of Raleigh, Wake County, Orange County, Person County, Butner, Creedmoor, and the South Granville Water and Sewer Authority adopted the Consensus Principles in their comments on the rules. The Consensus Principles were a major factor in shaping the Falls Lake Nutrient Management Strategy and continue to guide the UNRBA in its reexamination process. The Hearing Officers Report (NCDWQ 2010) references the Consensus Principles as a foundational component of the Strategy. Section Nine of the Consensus Principles states the following:

> "The process by which the proposed regulatory scheme has been developed relied on a limited data base which will be substantially enhanced by a more rigorous program of sampling, monitoring and analysis. In addition, it may not be feasible to attain all currently designated uses in the Upper Lake and attempting to do so may result in substantial and widespread economic and social impact. The EMC should therefore begin a re-examination of its nutrient management strategy for Falls Lake by January 1, 2018 [later changed by rule to 2021]. The re-examination should consider, among other things, (i) the physical, chemical, and biological conditions of the Lake with a focus on nutrient loading impacts and the potential for achieving the Stage I goal by 2021 [later changed in the final rule to 2024] as well as the feasibility of both achieving the Stage II reduction goals and meeting the water quality standard for chlorophyll-a in the Upper Lake, (ii) the cost of achieving, or attempting to achieve, the Stage II reduction goals and the water quality standard in the Upper Lake, (iii) the existing uses in the Upper Lake and whether alternative water quality standards would be sufficient to protect those existing uses, and (iv) the impact of the management of Falls Lake on water quality in the Upper Lake. As the first step in the re-examination, a Scientific Advisory Board should analyze and review the information identified above along with the additional monitoring and modeling data compiled since the model was approved and should present its recommendations for changes in the Nutrient Management Strategy and its implementing rules to DWQ [now DWR] and the EMC by January 1, 2019 [later changed in the final rule to 2024]. In light of the report from the Science Advisory Board, the EMC should direct the DWQ [DWR] to prepare proposed rule revisions, if any, and an updated fiscal note on Stage II by August 1, 2019 [later changed in the final rule to 2025]. In its development of any proposed rule revisions, DWQ [DWR] shall consult with the local governments and other interested parties. Except to the extent that management measures identified as a part of Stage II are required to achieve the Stage I goal, local governments should not be required to begin implementing Stage II management measures without a determination by the EMC of whether alternative goals and/or standards should be established for the Upper Lake."

On November 18, 2010, the EMC adopted the nutrient management rules for Falls Lake, with an effective date of January 15, 2011. The North Carolina Rules Review Commission approved the rules with minor technical language changes, and the rules took effect on January 15, 2011.

The rules were developed to address exceedances of the NC water quality standard for chlorophyll-a and the listing of portions of the lake as impaired. The NC chlorophyll-a standard is dimensionless in that it does not explicitly contain a time duration, frequency dimension, or a spatial dimension. Therefore, the standard has been interpreted and implemented by as an instantaneous standard.

It is the general view of the UNRBA that the designated uses (support of activities on or in the waters, raw water supply, and other uses listed under the description of the classification of these waters) of Falls Lake do not appear to be impaired. This view has been developed based on the review of existing information about the use of these waters. The USACE (2013) indicates that recreational use is limited only by the number of facilities and access, not water quality. The lake has not experienced nuisance algal blooms or fish kills (except for one caused by a fish disease) (NCDWQ, 2008). The City of Raleigh provides safe drinking water from Falls Lake to 550,000 customers. Water supply, fishing, and recreational uses of Falls Lake have continued without any indication that these uses are impaired.

As already noted, some lake monitoring results have shown exceedances of the water quality standard for chlorophyll a, and these data have been used by the State to list portions of the lake under Section 303 of the Federal Clean Water Act. It is understood that the evaluation of use-support is an activity distinctly different than the modeling effort. However, the UNRBA believes it is important to note these use-support considerations relative to its modeling effort and its description and specification of the methods and procedures it will use to produce effective and appropriate modeling tools to inform and guide its evaluation of existing and potential regulatory frameworks for eutrophication management of Falls Lake. Future application of the completed modeling tools to assist with an assessment of important use-support principles do not impact in any way the necessary quality assurance and quality control measures that are described in this document and that are necessary for effective model development. The UNRBA understands that agency approval of this document relates only to the technical components of the QAAP described herein for the development of the identified modeling tools.

The rules address the reexamination prior to implementing Stage II in section 15A NCAC 02B.0275. Section (5)(f) describes specific requirements of any stakeholder desiring to submit data or modeling to the DWR regarding Falls Lake and the requirement to reexamine the Stage II goals. This section of the rule follows:

> The UNRBA has been performing enhanced water quality monitoring in the watershed and the lake since August 2014. The UNRBA Monitoring Program is conducted under a Monitoring QAPP and Monitoring Study Plan which have both been approved by DWR as required by Section (5)(f) parts (i) and (ii). This Modeling QAPP is being submitted to DEQ by the UNRBA for approval of the modeling framework as required under part (i).

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

(i) A person shall obtain Division review and approval of any monitoring study plan and description of the modeling framework to be used prior to commencement of such a study. The study plan and modeling framework shall meet any division requirements for data quality and model support or design in place at that time. Within 180 days of receipt, the division shall either approve the plan and modeling framework or notify the person seeking to perform the supplemental modeling of changes to the plan and modeling framework required by the Division;

(ii) Supplemental modeling shall include a minimum of three years of lake water quality data unless the person performing the modeling can provide information to the Division demonstrating that a shorter time span is sufficient;

(iii)The Commission may accept modeling products and results that estimate a range of combinations of nitrogen and phosphorus percentage load reductions needed to meet the goal of the Falls nutrient strategy, along with associated allowable loads to Falls Reservoir, from the watersheds of Ellerbe Creek, Eno River, Little River, Flat River, and Knap of Reeds Creek and that otherwise comply with the requirements of this Item. Such modeling may incorporate the results of studies that provide new data on various nutrient sources such as atmospheric deposition, internal loading, and loading from tributaries other than those identified in this Sub-item. The Division shall assure that the supplemental modeling is conducted in accordance with the quality assurance requirements of the Division;

(iv) The Commission shall review Stage II requirements if a party submits supplemental modeling data, products and results acceptable to the Commission for this purpose. Where supplemental modeling is accepted by the Commission, and results indicate allowable loads of nitrogen and phosphorus to Falls Reservoir from the watersheds of Ellerbe Creek, Eno River, Little River, Flat River, and Knap of Reeds Creek that are substantially different than those identified in Item (3), then the Commission may initiate rulemaking to establish those allowable loads as the revised objective of Stage II relative to their associated baseline values;

The full text of NCAC 02B.0275 (5) also provides requirements for data development related to assessing Lake conditions and reporting to the EMC on progress in improving water quality under these rules. It is the UNRBA's objective with its monitoring program to see that all data collected can and will be used under the provisions of the Falls Lake Rules and for all State activities related to assessment of Falls Lake.

A.5.3 Project Goals

The UNRBA will develop and administer a Modeling and Regulatory Support Project that includes the objectives of updating, revising, and improving the existing lake and watershed models developed previously for Falls Lake. These updated models will support the reexamination of the current Nutrient Management Strategy, with specific reference to Stage II of the Falls Lake Rules (NCAC 15A 02B.0275(5)). The modeling is one component of the reexamination. The development of improved modeling tools supports the overall reexamination process and provides important input to the regulatory support component of the process. Goals of the modeling effort include

- Estimating nutrient, carbon, sediment, and chlorophyll-a loading to Falls Lake;
- Revising the lake response and watershed models using data that was not available at the time DWR conducted their modeling to develop the Falls Lake Nutrient Management Strategy;
- Evaluating the impacts of management strategies on water quality
- Understanding how changes in lake water quality affect the designated uses of the lake;
- Evaluating management strategies in the lake and watershed to determine the impacts to lake water quality and designated uses;
- Examining alternative chlorophyll-a criteria that include duration, frequency, spatial, and temporal components consistent with the chlorophyll-a criteria approved by EPA for states with more recent standards (North Carolina's standard was developed in the 1970s).

This QAPP is intended to cover model development and application under the administration of the UNRBA by its contractor and does not supplant any existing QAPPs of member organizations. The procedures outlined in this QAPP are intended to follow those described in the existing DWR modeling reports for the Falls Lake watershed and lake modeling (NCDWQ, 2009a and 2009b) as closely as possible so that the models developed under this modeling project meet the same Quality Assurance/Quality Control standards as models developed by DWR.

To meet requirements outlined in the Falls Lake Rules for an acceptable reexamination effort, DWR must review and approve the technical components of the monitoring study plan and modeling framework to assure that data collected under the program are acceptable for regulatory use. In 2014, DWR approved the UNRBA Monitoring Plan (Cardno 2014b), Monitoring QAPP (Cardno 2014c), and the description of the modeling framework (Cardno 2014d). The Division must approve the technical aspects of the steps and processes used for the development of the modeling components the UNRBA plans to use for its reexamination of the strategy. One important objective of this QAPP is to provide the documentation necessary to demonstrate compliance with DWR Quality Assurance standards for modeling. DWR approval of this Modeling QAPP relates only to the procedures and approaches that will be used for the development and calibration of models used to support the reexamination of the Falls Lake Nutrient Management Strategy.

This Modeling QAPP is intended to guide the model development and application for the purposes stated above. However, the results of early modeling activities and initial analyses may be used to refine the modeling project. Most modeling changes are expected to relate to the availability of new information that may become available as the models are developed (e.g., Special Studies conducted under the UNRBA Monitoring Program). Minor changes will not result in revisions of this QAPP. If models or data not included in this QAPP are proposed for inclusion in the modeling project to support efforts requiring DWR approval per the Falls Lake Rules, they will be documented in revised versions of this QAPP, cataloged in the Revision Log at the beginning of the document, and provided to DWR for review.

A.6 Project Description and Schedule

A.6.1 Overview

The overall goal of the modeling project is to accurately represent nutrient and carbon loading from the watershed and the impacts to water quality in Falls Lake. The models developed under this project will be used to evaluate management strategies in the lake and watershed to determine the impacts to lake water quality. The UNRBA Modeling and Regulatory Support Project will be a multiyear project that will rely on data collected by the UNRBA Monitoring Program. The UNRBA began data collection under its Monitoring Program in August 2014. This Program is expected to continue until at least October 2018 to capture four years of monitoring and end after the growing season. An optional fifth year of additional data collection may be approved by the UNRBA if extreme conditions affect the first four years of the program. Modeling conducted to support this project may include three types of models, each with its own set of data, parameters, model formulations, and applications:

A. Mechanistic lake modeling will simulate the response of Falls Lake (sediment, nutrients, chlorophyll-a, total organic carbon and dissolved oxygen) to changes in watershed and lake management strategies.
B. Mechanistic watershed modeling will provide estimates of nutrient and carbon loading to Falls Lake and predict changes in loading in response to watershed management strategies.
C. Statistical modeling (empirical/probabilistic/Bayesian) will predict water quality in Falls Lake and support evaluation of the impacts to designated uses (e.g., recreation, water supply, and aquatic life use).

A.6.2 Project Location

The Neuse River was impounded near the City of Raleigh in central North Carolina to form the Falls of the Neuse Reservoir (Falls Lake) at the downstream end of the Upper Neuse River Basin (Hydrologic Unit Code 03020201, Figure A.6-1). Falls Lake is a Piedmont reservoir with a contributing drainage area of 770 square miles that includes several smaller impoundments. Figure A.6-2 shows the subwatersheds and jurisdictions that comprise the watershed. The base layer for the subwatersheds is the 12-digit hydrologic unit code developed by the US Geological Survey (USGS). Slight modifications to this coverage were made to isolate areas upstream of impoundments and to separate individual tributaries to the lake.

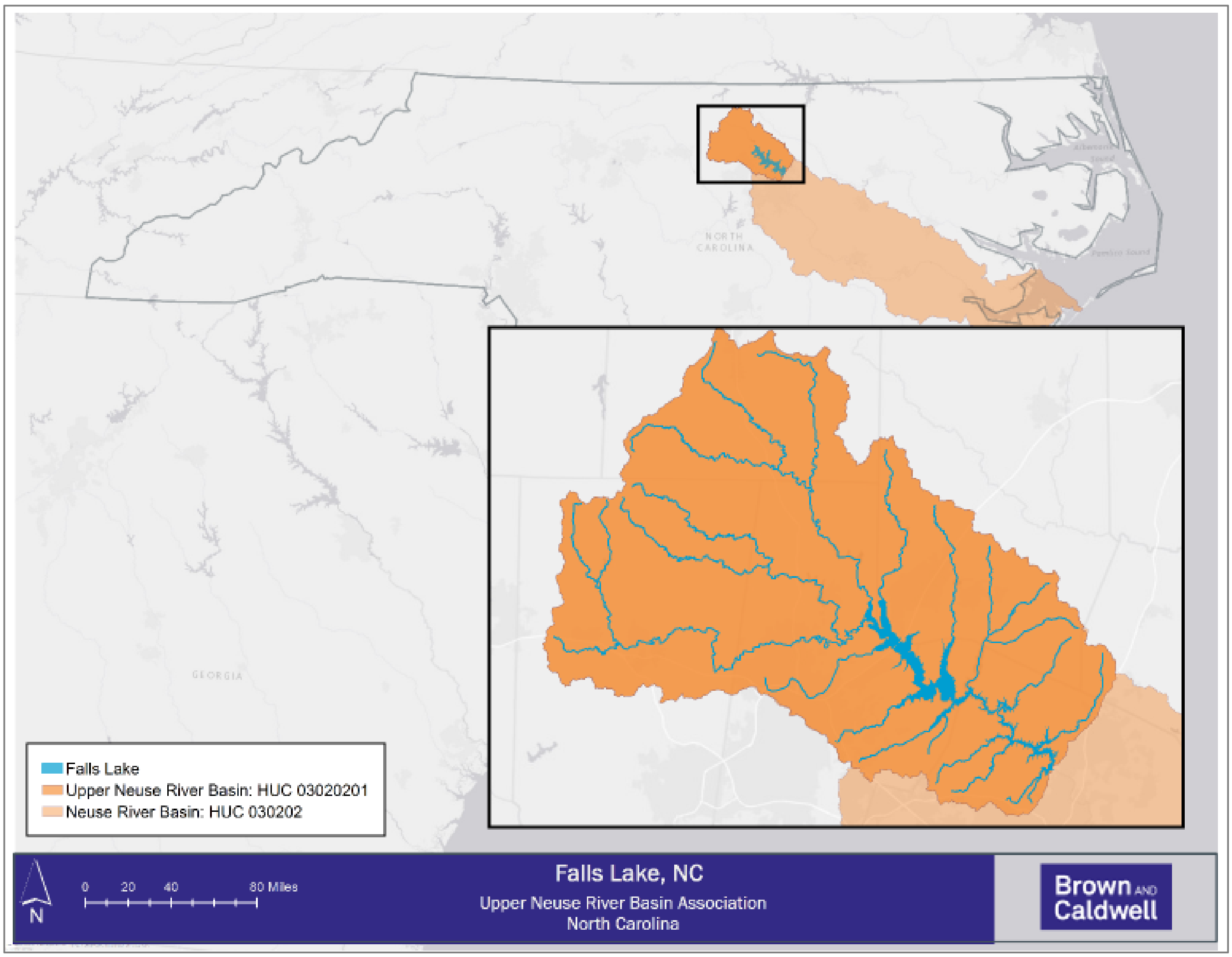

Figure A.6-1 Falls Lake, NC

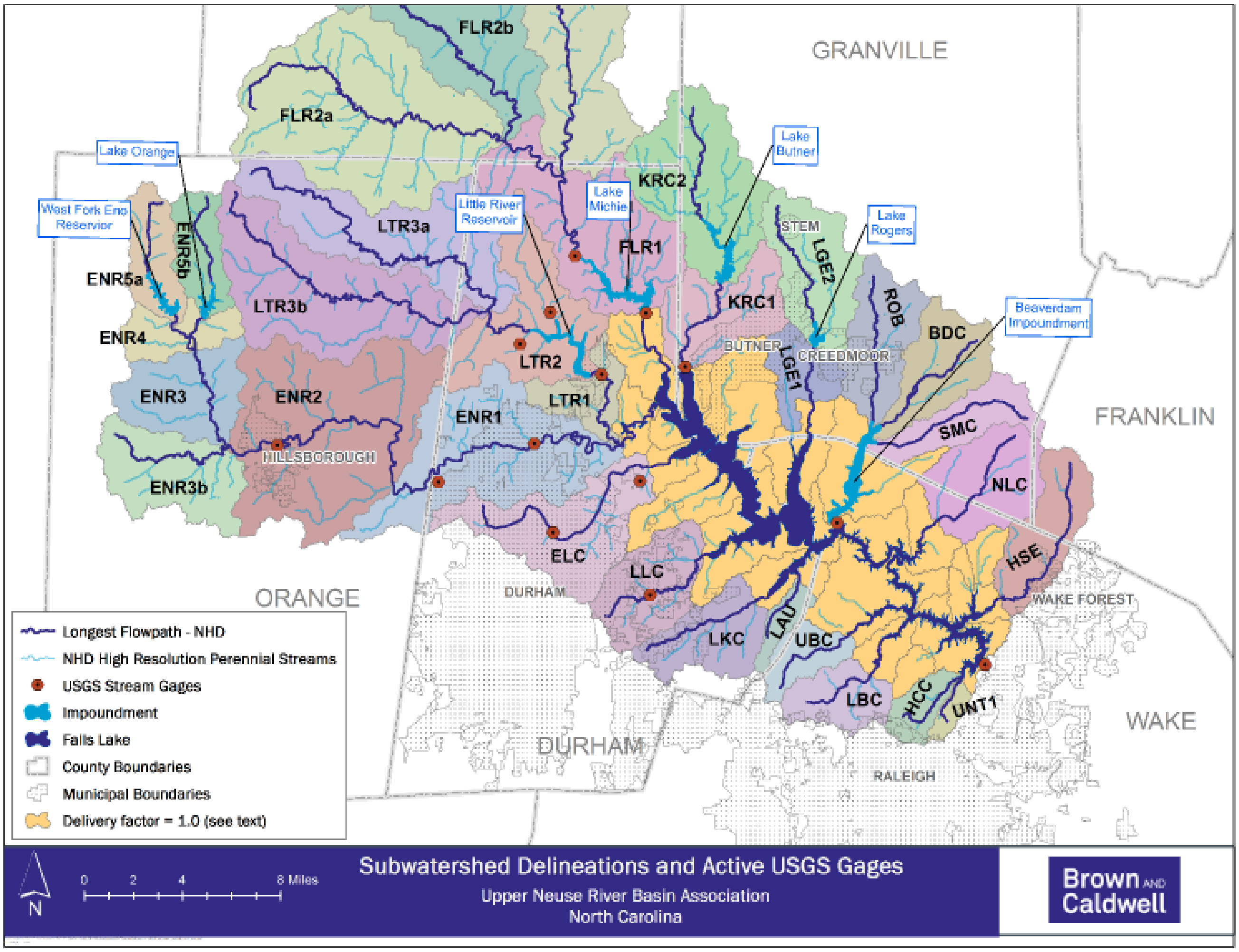

Figure A.6-2 Subwatersheds and Jurisdictions in the Falls Lake Watershed

A.6.3 Project Data

Data used for model inputs, calibration, and validation will include data collected by the UNRBA under its DWR-approved monitoring QAPP, local municipalities, universities, and state and federal agencies. These data sources and their quality objectives are outlined in section B.9 of this QAPP.

A.6.4 Project Description

In this project, watershed and water quality models for Falls Lake will be developed to support the reexamination of Stage II of the Falls Lake Nutrient Management Strategy. The models will focus on sediment, nutrients, chlorophyll-a, and total organic carbon. The models will also be used to evaluate management strategies and impacts to water quality in Falls Lake.

The Team worked with a subcommittee of the UNRBA (the Modeling and Regulatory Support Workgroup, MRSW) to select the modeling packages for the reexamination. Selection of the modeling packages was approved by the UNRBA PFC in December 2016. Documentation of this process is available at https://www.unrba.org/sites/default/files/reexam-files/ModelPackageSelection_02072017.pdf.

Two mechanistic models have been selected for the Falls Lake study: the WARMF (Watershed Analysis and Risk Management Framework) watershed and lake model and the EFDC (Environmental Fluid Dynamics Code) lake model. Both WARMF and EFDC are EPA-approved and peer-reviewed water quality modeling tools that have been successfully applied for numerous nutrient allocation studies nationwide. Both modeling packages were previously used by DWR for this lake and watershed. DWR used the EFDC model to establish the Falls Lake Nutrient Management Strategy required load reductions. The two models, WARMF and EFDC, were not linked in the DWR development of the nutrient management strategy.

WARMF has been selected as the most appropriate modeling tool for development of a watershed model of the Falls Lake Study Area. It is an EPA-approved and peer-reviewed model that has been used nationwide for water quality assessment and Total Maximum Daily Load (TMDL) development. The representations of watershed processes within WARMF are comprehensive and based on fundamental principles of physics and chemistry. It is a continuous, lumped parameter, watershed−scale model that simulates the movement of water, sediment, nutrients, and other constituents on pervious and impervious surfaces, in soil profiles, and within streams. Staff on the Team have used WARMF to develop numerous watershed model applications including projects in North and South Carolina for the Lower Catawba River Basin. The WARMF watershed model will be developed to simulate streamflow, temperature, chlorophyll-a, TSS, TOC, TN, and TP as inputs to two lake nutrient response models (WARMF and EFDC).

The WARMF lake model (one of the selected lake nutrient response models), is included as part of the WARMF model application and is internally linked to the WARMF watershed model. The WARMF lake model is a moderately complex, 1D mechanistic model that simulates vertical stratification and allows for subdivision of the lake body into multiple linked segments. The model performs a mass balance and simulates chemical/physical processes within each vertical layer of a lake segment. WARMF lake will be used to simulate water quality in Falls Lake as well as in seven smaller impoundments in the watershed. As with the WARMF watershed model, the staff on the Team have used the WARMF lake model as part of TMDL development for multiple reservoirs in the Catawba River Basin in North and South Carolina.

The EFDC model has been selected as the complex, mechanistic lake nutrient response model to be used for this study. EFDC will be used to develop a hydrodynamic, sediment transport, water quality model of Falls Lake. The sediment diagenesis model, that is an optional submodel of EFDC, may also be applied pending exploration of additional empirical formulations based on sediment cores collected in Falls Lake. EFDC is a peer reviewed and EPA-supported surface water model that has been applied for hundreds of TMDL and water quality management studies nationwide and worldwide. The Team has used EFDC to develop numerous model applications, including the Lower Tar River-Pamlico estuary in North Carolina and the Caloosahatchee River Basin and Lake Apopka in Florida. With the selection of EFDC for the Falls Lake project, the Team can provide very powerful pre- and post-processing capabilities of EFDC_Explorer that was developed by Paul Craig (2012). EFDC_Explorer will be used to facilitate processing of data for model setup and extraction of model results for visualization of time series plots, vertical profiles, longitudinal transects, animated maps, calculation of output variables, and calculation of model performance statistics.

The Team will also develop a statistical lake model using empirical, probabilistic, and Bayesian techniques. This model will use estimates of nutrient loading from the WARMF watershed model along with morphological information describing the segments of Falls Lake to predict in-lake concentrations of nutrients, carbon, and chlorophyll-a. Average annual or seasonal loads extracted from WARMF will serve as input to the statistical model, and this model will evaluate water quality on either a growing season or annual time basis. Existing formulations for predicting lake water quality will be reviewed for application in this model; site-specific regressions based on Falls Lake data will also be explored. Building the linkages from lake water quality to designated uses will require input from experts in many water quality fields. Outputs from this model will include the probability of attaining water quality standards (dissolved oxygen (DO), chlorophyll-a, and turbidity), drinking water standards, and anoxic conditions. The team will use a combination of the open-source R program, Excel, and Bayesian modeling software (e.g., Netica, AgenaRisk, Hugin, BayesiaLab) to build the statistical model. Existing empirical models that simulate lake water quality such as the United States Army Corps of Engineers (USACE) BATHTUB model or EUTROMOD may also be integrated into this model.

The watershed and lake models will be developed, calibrated, and validated by the Team to provide a technically credible set of water quality modeling tools for Falls Lake. Data collected by the USGS, DWR, UNRBA member governments, and local universities will be used to support development of the watershed and lake model for this study. Nutrient data collected in the lake by DWR, for example, will provide data for calibration. The model setup and calibration procedures are detailed in Section B.7, and descriptions of data sources used for model development and calibration are included in Section B.9 of this document.

The watershed (WARMF) and lake (WARMF, EFDC, and statistical) model frameworks that will be developed for this project will be used to evaluate various management approaches to improving water quality in the lake, including a range of selected pollutant load reduction scenarios. The watershed model will simulate changes in the loading of TSS, carbon, and nutrients to the lake resulting from a series of specific, potential management actions in the watershed aimed at reducing inputs from the watershed. The lake nutrient response models will then be used to assess the impacts of reduced watershed loading on concentrations of nutrients, chlorophyll-a, carbon, and dissolved oxygen in Falls Lake. These modeling tools can be used to evaluate the impact of potential actions on water quality. Select combinations of actions will be evaluated in a cost benefit analysis. Nutrient load reduction scenarios will be evaluated in a cost benefit analysis.

This QAPP documents the procedures for development and validation of each of the models described above. The three lake models that will be developed have very different model structures, scales, and outputs, and each has advantages and disadvantages. Developing multiple models allows for a weight of evidence approach in evaluating impacts on water quality in the lake and adds significant flexibility for the analysis of alternative management scenarios. Each model will be applied to support decision making.

Figure A.6-3 illustrates how these three models may be used to support the Reexamination of Stage II of the Falls Lake Nutrient Management Strategy.

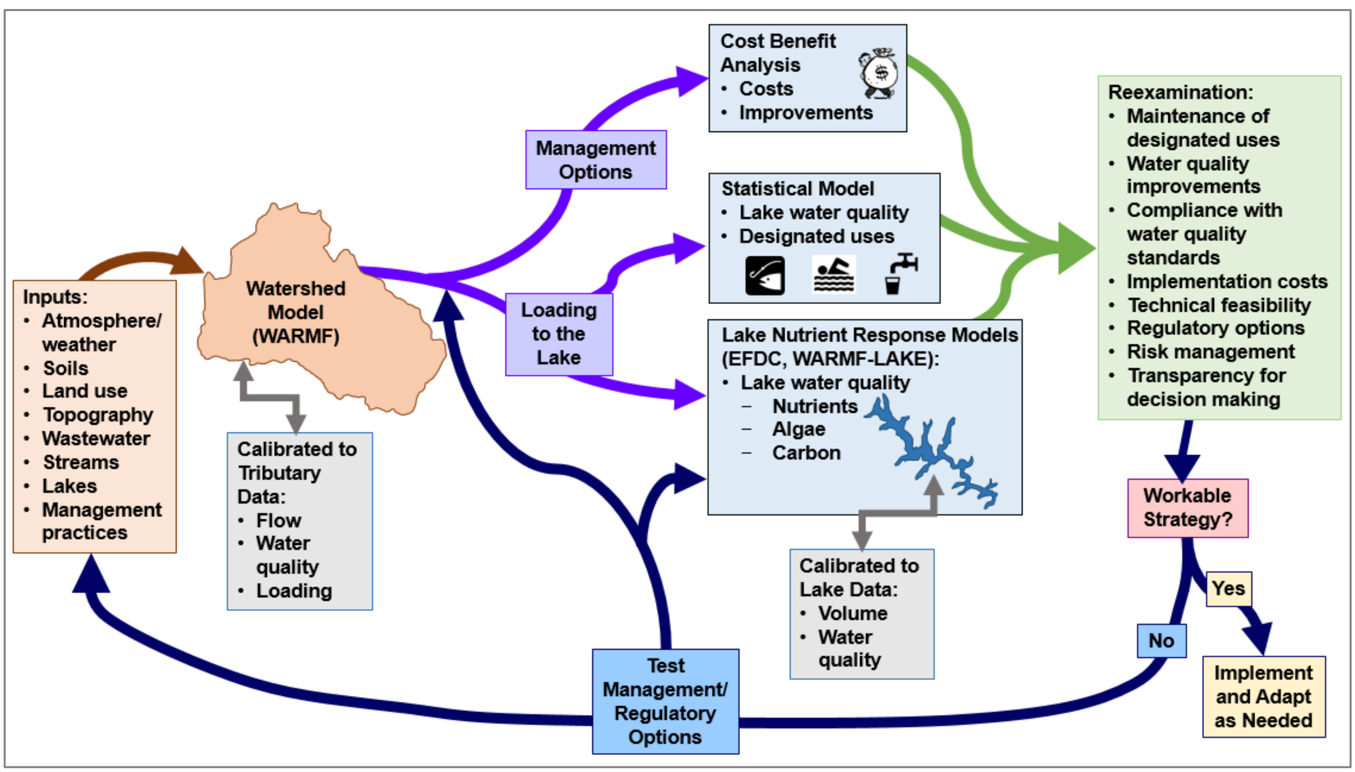

Figure A.6-3 Conceptual Modeling Plan for the Reexamination of Stage II of the Falls Lake Nutrient Management Strategy

Brown and Caldwell will be responsible for the following task areas:

- Management and quality assurance of the UNRBA Monitoring Program data
- Transfer of data and information to ensure that Systech Water Resources and Dynamic Solutions have access to and an understanding of all existing data, analyses, and special studies related to the modeling project
- Development of the statistical model as a component of the model framework
- Cost benefit analysis to quantify the costs, outcomes, and feasibility of management options
- Client communications (written, presentations, meetings) and incorporation of input from the UNRBA and DWR

Dynamic Solutions will be responsible for the following task areas:

- Development of the EFDC model for Falls Lake
- Evaluate the impacts of watershed load reductions of TN and TP on lake water quality
- Preparation of sections of the modeling report for the EFDC model

Systech will be responsible for the following task areas:

- Development of the WARMF watershed model and WARMF lake model to estimate stream flow and pollutant loadings from the watershed to Falls Lake
- Customization and documentation of WARMF model code to address specific needs for Falls Lake and its watershed
- Preparation of sections of the modeling report for WARMF watershed and WARMF lake models

The Team will execute the following phases to develop models in support of the reexamination of Stage II of the Falls Lake Nutrient Management Strategy. This schedule will allow for the collection of four years of monitoring data by the UNRBA as approved by the BOD.

Phase 1: Quality Assurance Project Plan for Watershed and Lake Models

The overall goal of this QAPP is to present the approach for (a) ensuring that datasets to be used for the watershed and lake modeling analyses meet quality criteria established for the project and (b) demonstrating the technical credibility of the selected model framework and its application for Falls Lake. Specific procedures addressed in this document relate to the evaluation of existing datasets and analyses, compilation of model input data, selection of key model parameters and coefficients, and methods used for calibration of the watershed and lake model framework. Existing datasets will include, for example, topography, land use, meteorology, streamflow, water quality, lake bathymetry, and lake levels. This modeling QAPP document is consistent with "EPA Guidance for Quality Assurance Project Plans for Modeling (G-5M)" (USEPA, 2002). The purpose of this QAPP is to clearly delineate the Team's QA policy, management structure, requirements, and procedures that are implemented to verify and calibrate the output of the modeling process associated with this project. Review of this QAPP will be performed by UNRBA, DWR, and EPA Region 4 to help ensure that the outputs and data generated for the purposes described herein are scientifically valid and legally defensible.

Phase 2: Preliminary Data Compilation and Development of Watershed and Lake Models

Data collection continues for information that will be incorporated into the modeling. Under Phase 2, preliminary, semi-static data needed for the watershed and lake models will be identified, obtained, compiled and summarized for use in setup and calibration of the models. Data collection and pre-processing under Phase 2 will include documentation of QA/QC procedures to ensure the quality of data used for model development. These datasets will include land use, soils, and topography. The Team will also begin to request and compile data from UNRBA members and watershed stakeholders for 2005 through 2007 and 2014 through 2017 including urban and agricultural land application rates, land use practices, onsite wastewater systems, wastewater treatment plant discharges, and nutrient reduction activities. Information for 2018 will be compiled during Phase 3. During Phase 2, the team will present an overview of the models to stakeholders, including a clear explanation of how the compiled data will be used within the models. Phase 2 will also include development of a data management plan as referenced in this Modeling QAPP.

In a Special Study conducted in 2017, the UNRBA collected bathymetric data in Falls Lake. Under Phase 2, this dataset will be processed and used to develop the preliminary EFDC model grid. It will also be analyzed for use in the WARMF lake model and the statistical models.

The Team will also conduct exploratory analyses of lake water quality data during Phase 2 to support later development of the statistical model. These analyses will include spatial and temporal trends for identifying proper lake segmentation and temporal scale for the modeling. The team will primarily use the R program (R Core Team 2017) for statistical analyses and modeling.

During Phase 2, the Team will provide status updates to the UNRBA during their routine PFC and BOD meetings. These are open meetings and staff from DWR and other stakeholders often attend. This provides an additional opportunity to interface with external stakeholders. In addition to these routine meetings, targeted meetings with specific stakeholders or the whole list of stakeholders will be conducted for the data compilation process and to provide opportunity for input. Stakeholders and interested parties will be provided a memorandum to review and comment on the data compilation and summary phase of the project.

Phase 2 will include a memorandum that describes the compilation and evaluations of the semi-static datasets that will be used to develop the watershed and lake models. This memorandum will be distributed to the MRSW, PFC, watershed stakeholders, and interested parties for comment prior to the beginning of Phase 3. The memorandum will also describe the development of the EFDC model grid and morphological characteristics that will be used for the WARMF lake model (lake segment averages with vertical stratification) and the statistical model (lake segment averages).

Phase 3: Development of Mechanistic and Statistical Models

The UNRBA plans to collect water quality data in the watershed and lake until at least October 2018. Extending the program to obtain a fifth year of data will depend on hydrologic, climatological, or other considerations. The description of this Phase assumes that modeling will include data collected through October 2018, which will provide four complete years of data. The UNRBA may choose to conduct additional monitoring after October 2018. This could range from targeted special studies to limited data collection to full data collection.

Under Phase 3, the Team will acquire, compile and process the watershed and lake data (flow and water quality) that corresponds to modeling periods January 2005 through December 2007 and August 2014 to December 2018. The full dataset for this period will likely not be available until March 2019 due to laboratory analyses and QA/QC procedures. Compilation will include data obtained under an approved QAPP (e.g., UNRBA, DWR, Center for Applied Aquatic Ecology (CAAE), Cities of Durham and Raleigh). This will also include data from local governments including discharge monitoring reports and watershed management actions. Data from USGS, NC Climate Retrieval and Observations Network of the Southeast (NC CRONOS), and National Oceanic and Atmospheric Administration (NOAA) will also be acquired and processed to develop model inputs.

The primary modeling period as described in this Phase is August 2014 through December 2018. This period allows for model spin up during the latter part of 2014, model calibration in 2015 and 2016, and model validation in 2017 and 2018. If the hydrologic conditions are anomalous for a year, the models may not perform as well. The original years of DWR's watershed and lake modeling (2005 through 2007) will also be used to provide a comparison to extreme drought conditions. Because the same level of monitoring data is not available for that period and because this was a historic drought for the area, the comparative statistics for the watershed and lake models may not show as strong a fit to observations. The following models will be developed under Phase 3:

- WARMF has been selected as the most appropriate modeling tool for development of a watershed model for the Falls Lake watershed shown in Figure A.6-3. Under Phase 3, the Team will setup, calibrate, and validate the WARMF watershed model for the Falls Lake watershed for the period August 2014 through December 2018 and compare to historic conditions from 2005 to 2007. The degree of change in the watershed (land use, best management practices, and agricultural practices) may limit the application for this earlier period. Sensitivity analyses and evaluations of scenarios will also be conducted to support the Reexamination. Sensitivity analyses are defined in EPA's (2002) Guidance for Quality Assurance Project Plans for Modeling as "a quantitative evaluation of the impact of variability or uncertainty in model inputs on the degree of calibration of a model and on its results or conclusions."

- EFDC has been selected as the complex, mechanistic modeling tool for development of a hydrodynamic, sediment transport and water quality model of Falls Lake. The WARMF lake model will also be developed to enable a weight of evidence approach for evaluating the water quality impacts in the lake, rather than relying on a single model. The WARMF lake model will also provide a directly linked watershed-lake model, which will add flexibility to the analysis of management scenarios and provide information for the cost benefit analysis. Under Task 3c, the Team will set up, calibrate, and validate the WARMF and EFDC lake models for Falls Lake for the period of August 2014 through December 2018 and compare to conditions from 2005 to 2007. If the revised WARMF watershed model is not able to accurately generate flows and loads to the lake during the extreme drought conditions, statistical methods may be used to generate input files for the EFDC lake model for this period. Sensitivity analyses and evaluations of scenarios will also be conducted to support the Reexamination.
- The Team will develop a statistical model to simulate lake water quality. Outputs from the WARMF watershed model will provide nutrient loading rates to the statistical model. Site specific regressions (based on data collected in Falls Lake and the watershed) or existing empirical formulations and models (e.g., USACE BATHTUB model) will be evaluated for the lake water quality component of the statistical model. Sensitivity analyses and evaluations of scenarios will also be conducted to support the Reexamination. Expert elicitation, published literature, and additional lake studies may be used to develop the linkages between lake water quality and designated uses. Alternate management strategies will be developed and evaluated for impacts to water quality.

The water quality response of the WARMF and EFDC lake models to the changes in external and internal loads will be evaluated in terms of improvement in water quality and comparison to water quality targets for dissolved oxygen and chlorophyll-a. Simulated changes in loads may be due to implementation of best management practices in the watershed, pump and treat systems in the watershed or lake, changes in lake operations or management, and may include other management approaches.

Phase 3 will also include evaluation of selected load reduction scenarios with a sediment flux model. For this evaluation, either the sediment flux model available within EFDC or an empirically-derived sediment flux model will be used. If the EFDC sediment flux model is selected, “spin-up” simulations will need to be performed prior to the evaluation. The spin-up simulations will aim to allow the sediment bed to reach new equilibrium conditions as a result of the selected scenario’s reduction in external watershed loads. This will ensure that the subsequent lake model results are based on sediment flux processes occurring at equilibrium conditions. The subsequent lake model results will be evaluated to determine if compliance with water quality targets would result from changes in loading from the watershed and/or lake sediments (e.g., dredging, capping). A maximum of one (1) additional series of sediment flux model spin-up runs will be repeated to achieve a new equilibrium condition for the sediment bed for comparison to water quality targets. The sediment flux model “spin-up” methodology is designed to facilitate convergence to equilibrium conditions on the selected load reduction scenario. The coupled water column and sediment flux model also will provide important information to UNRBA, DWR, EPA Region 4, and watershed stakeholders about the probable time scale in years for water quality improvements in the lake and the feasibility of achieving compliance with water quality targets.

During Phase 3, the Team will provide routine status updates to the UNRBA during their PFC meetings and BOD meetings. These are open meetings and staff from DWR and other stakeholders often attend. Stakeholder outreach meetings will be conducted during Phase 3 to provide status updates and receive feedback on the modeling, scenarios, etc.

Phase 3 will include a model report that describes the development, calibration, validation, sensitivity analyses, and preliminary scenario evaluations for the watershed and lake models.

Phase 4: Support the Reexamination

Concurrent with Phase 3, a cost benefit analysis will be conducted to evaluate select load reduction scenarios. Additional watershed and lake modeling and scenario analysis may be needed to evaluate various modeling options.

During Phase 4 the Team will compile cost and effectiveness data for best management practices. The technical and logistical feasibility of attaining the load reductions developed under Phase 3 will be evaluated. The societal costs will be estimated using the USEPA Preliminary Municipal Screener with additional analyses conducted as needed. The nutrient management scenarios selected in Phase 3 will be evaluated for predicted improvements to water quality and compared to water quality standards. Scenarios will also be evaluated for implementation costs and technical feasibility.

Supplemental watershed and lake modeling may also be conducted during Phase 4 to address questions raised by the UNRBA, DWR, EPA, or stakeholders including evaluating variations to nutrient reduction scenarios. Additional watershed and lake modeling scenarios may be needed based on the cost benefit analysis. The models may be used to evaluate alternative regulatory approaches such as site-specific chlorophyll-a criteria, revise designated uses, variances, etc., and support negotiations with regulators for these options.

During Phase 4, the Team will provide routine status updates to the UNRBA during their PFC meetings BOD meetings. These are open meetings and staff from DWR and other stakeholders often attend. Stakeholder outreach meetings will be conducted during Phase 4 to provide status updates and receive feedback.

Phase 4 will include a memorandum that describes the cost benefit analysis and scenario evaluations for the watershed and lake models. The memorandum will include a comparison of the impacts of management strategies on water quality and implementation costs.

Phase 5: Preparation of Final Model Documents, Report, and Stakeholder Meetings

Under Phase 5, draft and final model documents and reports for Falls Lake will be submitted as project deliverables based on compilation and updates to the technical memorandum as needed. The model documents and report will include the following:

- An inventory of data input parameters for the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models, including those parameters and values used for watershed and lake model calibration analyses.
- All watershed model input files (as WARMF input format).
- All lake model input files (as WARMF input format).
- All hydrodynamic and water quality model input files (as EFDC input format).
- All statistical regressions used to link nutrient loading to lake water quality.
- Output results generated by the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models.
- Tables of model performance statistics computed for the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models.
- Compiled executable files, code modifications, and output files for the versions of WARMF and EFDC used by Systech Water Resources and Dynamic Solutions, respectively, for application to the Falls Lake project.
- Data sources and pollutant source assessment of flow and external loads;
- Development and calibration of the WARMF watershed model, WARMF lake model, and EFDC lake model;
- Load reduction scenarios (combinations of nitrogen and phosphorus reductions) and resulting water quality conditions in Falls Lake, with a comparison to chlorophyll-a targets;
- Development and results of the statistical model, including the impacts of management scenarios on lake water quality;
- Methodology and results of the cost benefit analysis, including the evaluation of the feasibility of load reduction scenarios;

Preparation of the model report will be a collaborative effort between the Team and the UNRBA. Third party reviews of the models are anticipated by individual UNRBA members. Stakeholder input will also be sought and considered during the process to finalize the modeling report. The final steps in completing the report include review by DWR. Once DWR has received a draft of the model report, UNRBA will send it to EPA Region 4 for their review and comments. Based on the comments received, the Team will prepare and submit a revised model report that incorporates, where appropriate, revisions based on DWR's and EPA's comments. A copy of the final model report will be posted to the UNRBA website.

The Team will provide routine status updates at monthly PFC meetings and bi-monthly BOD meetings during Phase 5. Stakeholder outreach meetings will be conducted during Phase 5 to provide status updates and receive feedback.

A.6.5 Project Schedule

An anticipated schedule for the project is presented in Figure A.6-4.

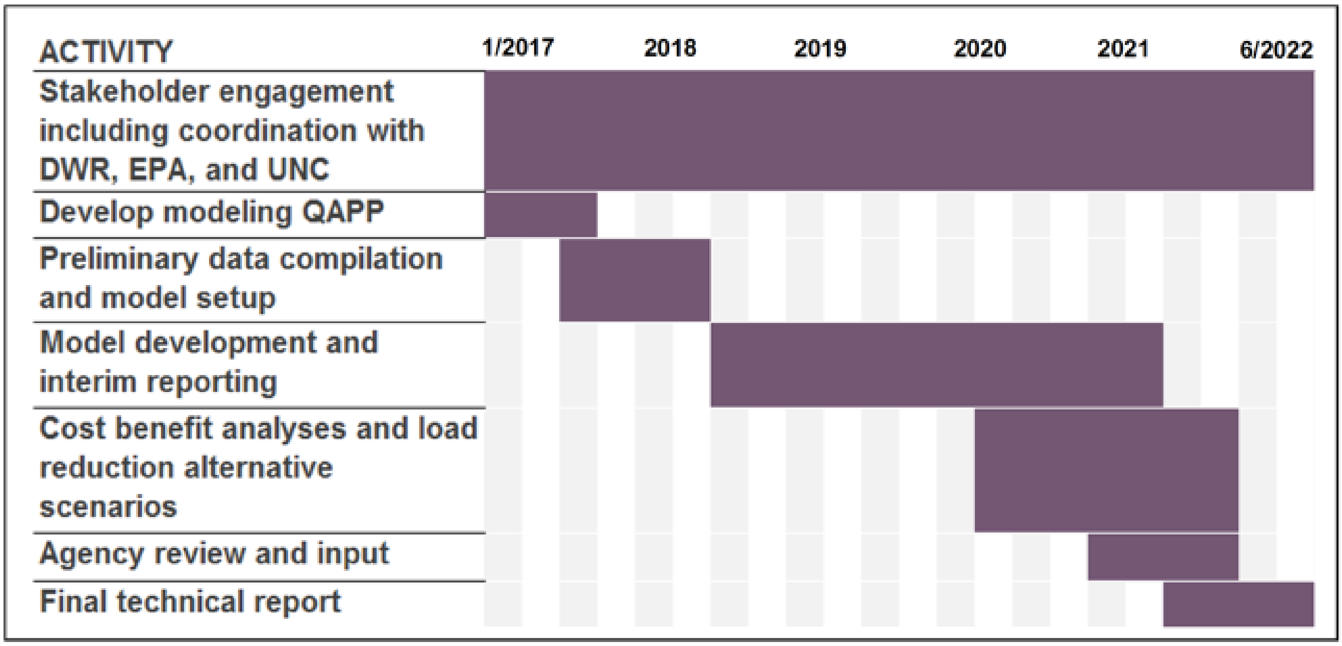

Figure A.6-4 Anticipated Schedule for the Falls Lake Modeling Project

A.7 Quality Objectives and Criteria for Model Inputs/Output

Data Quality Objectives (DQOs) are quantitative and qualitative statements that clarify the intended use of data, define the types of data needed to support a decision, identify the conditions under which the data should be collected, and specify tolerable limits on the probability of making a decision in error because of uncertainty in the data. In the case of a modeling study, DQOs apply to both the data used to develop model inputs and parameters, as well as the outputs generated by the model (i.e., the model performance). The quality and reliability of the model results depend directly on the quality and reliability of the data used to generate model inputs, among other factors. Thus, data of known and documented quality are essential components for the success of a water quality modeling study in which model results are ultimately used to support the decision-making process for lake and watershed management plans.

Falls Lake has been studied extensively over many years by the UNRBA, DWR, local governments, and academic investigators. Recent studies include an analysis of lake and watershed data collected between 1999 and 2011 (Cardno, 2012), a status update for Falls Lake (NCDWR, 2016), and a basin-wide assessment report for the Neuse River Basin (NCDWQ, 2012). Field monitoring programs conducted by agencies (such as USGS, U.S. Department of Agriculture (USDA), DWR, and USACE) and organizations with approved monitoring QAPPs (UNRBA, CAAE, and local governments) will provide the observed data used in the development of the watershed model (WARMF) and the lake models (WARMF, EFDC, and statistical) for this study. Each of the approved monitoring programs were implemented using recognized QA/QC procedures established by those agencies for sample collection and analytical chemistry. All data used in the modeling analyses will be reviewed for quality and consistency with other relevant data to determine if the observed data used for model development is, in fact, representative of Falls Lake and the watershed. The types of data used to develop the models, along with the sources and intended use, are described in Table B.9-1. Criteria for acceptance of datasets for use in model development are further discussed below in Section A.7.1

All data used for model development inherently include uncertainty stemming from measurement error, aggregation, natural variability, and other factors. When the data are used to generate model inputs, their associated uncertainty becomes lumped with model parameter and structural uncertainty, resulting in the overall uncertainty in model simulations. The process of calibration involves iterative refinement of model parameters to produce the best overall agreement between the model simulations and observed historical datasets. Uncertainties in both model simulations and historical calibration data (e.g., measured flow and concentrations) are reflected in the error between simulated and observed values throughout the calibration period. The calibration/validation process thus jointly addresses all relevant sources of uncertainty, with criteria for acceptance as described in the following section.

A.7.1 Model Performance and Acceptance Criteria

Model performance and acceptance criteria form the basis by which judgments will be made on whether the WARMF watershed model, WARMF lake model, EFDC lake model, and statistical lake model results for the Falls Lake Study Area are sufficient and adequate to support watershed and lake management planning decisions. Model performance criteria, sometimes referred to as calibration and/or validation criteria, have been contentious topics for many years, as discussed in articles by Thomann (1982), Donigian and Imhoff (2009), Oreskes et al. (1994), ASCE (1993), Legates and McCabe (1999), Fitzpatrick (2009), and Moriasi (2007). Despite the lack of consensus on performance criteria, surface water models are being applied for water quality assessment and regulatory purposes including the development of TMDLs, load allocations, and evaluations of management strategies. WARMF and EFDC have both been applied for numerous water quality management planning studies including many TMDL determinations and load analyses. Both models are peer-reviewed and accepted by the community of surface water modelers. Statistical models are also used for regulatory purposes such as TMDL development. These models may rely on site specific data to develop the formulations or use existing relationships published in the literature or coded into modeling tools. Performance criteria are defined for both mechanistic and statistical models to guide model calibration to observed conditions.

Given the limitations and lack of consensus associated with any single performance measure, a "weight of evidence" methodology is widely used and accepted for evaluating water quality models. The approach prescribes using multiple performance evaluation techniques, both visual and statistical, while recognizing the uncertainty inherent in model simulations and measured data. The following well-accepted underlying principles form the basis of the "weight of evidence" approach (Donigian 1982, Donigian and Imhoff 2009):

- Because models are approximations of natural systems, exact duplication of observed data is not a performance criterion.
- The model calibration and validation process measures, through graphical and statistical comparison, the ability of a model to simulate a system's response as represented by observed datasets.
- There is no single procedure or statistic that is widely accepted as measuring whether a model's performance is acceptable.
- A combination of graphical and statistical comparisons of model results to observed data is necessary to provide sufficient evidence to weight the decision of model acceptance or rejection.
- All model and observed data comparisons must recognize the inherent errors and uncertainty in both the model and the measurements of the observed datasets.

The "weight of evidence" approach will be used for this study to evaluate model performance and determine the end points of calibration for the Falls Lake watershed and lake models. In practical application, the approach includes the following steps: (a) visual inspection of plots of model results compared to observed datasets (e.g., station time series and vertical profiles) and (b) analysis of model-data performance statistics. The calibration process involves iterative repetition of these two steps until adjustments no longer improve results. The "weight of evidence" approach recognizes that, as a numerical model approximation of Falls Lake and the watershed, perfect agreement between observed data and model results is not expected and is not specified as a performance criterion for model calibration. Target values of model performance statistics are defined and will serve as guidelines to supplement visual inspection of model-data plots to determine appropriate endpoints for calibration of the watershed model and the lake model. These targets are treated, not as absolute criteria for acceptance, but as one of multiple tools to evaluate model performance. The "weight of evidence" approach thus acknowledges the approximate nature of surface water models, the utility of both graphical and statistical performance evaluation methods, and the inherent uncertainties in both input data and observed data (Oreskes et al., 1994).

WARMF Watershed Model Performance Evaluation

As prescribed by the "weight of evidence" approach, the watershed model performance will be evaluated by graphical comparison with statistical measures used for supplemental guidance and to aid in determining the endpoints of calibration. Methods commonly used to graphically evaluate watershed model results include

- Time series plots of observed and simulated values, at the model time step and aggregated to a larger (e.g., monthly) time step where possible depending on the frequency of observed data,
- Box-and-whisker plots (typically monthly) showing the distribution of the simulated dataset relative to the observed median value,
- Bar charts of simulated and observed annualized flow volume or mass loading,
- Scatter plots of observed versus simulated values (i.e., where all points would plot on the 45-degree line if in perfect agreement),
- Cumulative frequency distributions of observed and simulated values (e.g., flow duration curves).

The most appropriate type(s) of graphical comparison depends on the variable (flow, concentration, etc.), and observed data frequency (daily, weekly, monthly, etc.). Cumulative frequency distributions, for example, should only be used when a continuous observed data record is available, such as streamflow. An appropriate subset of the above graphical methods will be used in this study to visually assess the agreement between simulated and observed values for each calibrated variable.

In addition to graphical comparisons, statistical performance measures will be calculated to evaluate model results. Based on experience of the Team and published calibration guidance (e.g., Donigian, 2002; Moriasi, 2007; Herr and Chen, 2012), statistical evaluations for variables with observed data records that are non-continuous, consistently near zero (or the detection limit) in magnitude, or that have low to zero variability should be done with caution. Under these circumstances, there is a greater chance that statistical calculations may be skewed and not provide a meaningful representation of the model performance. If this occurs, more emphasis should be put on graphical methods than on statistical methods for model performance evaluation and a detailed explanation will be provided.

Flow and water quality monitoring sites in the watershed are shown below in Figure A.7-1. A complete flow calibration for the watershed model will be performed at the 10 USGS flow gages in the watershed where near-continuous streamflow records are available (orange circles on tributaries upstream of the lake). For these gaged locations, model results for flow will be evaluated and reported both graphically and statistically. These flow gages are all located on the five largest tributaries to the lake (Ellerbe, Eno, Little, Flat and Knap of Reeds). Flows will be estimated for the water quality monitoring sites that are not at gaged locations.

A complete water quality calibration (for each parameter) including evaluation of performance criteria and generation of documentation will be performed for a minimum of 7 locations. These locations include the lake loading stations of the five largest tributaries (ELC-3.1, ENR-8.3, LTR-1.9, FLR-5.0, and KRC-4.5). The selection of the calibration locations is based on the availability of measured data to best support a full calibration, model evaluation, and meet the objectives of the UNRBA. The model acceptance criteria described in this section will be applied at these calibration locations. Data collected at all watershed stations will be used to support calibration. Specific stations and parameters will be utilized to improve model calibration at locations where full calibration will be conducted.

For water quality monitoring sites that are not located at or near USGS flow gages, flows will be estimated. Simulation results for these locations will be compared to the estimated flow data and measured water quality data. Results will be presented graphically for all monitoring site locations.

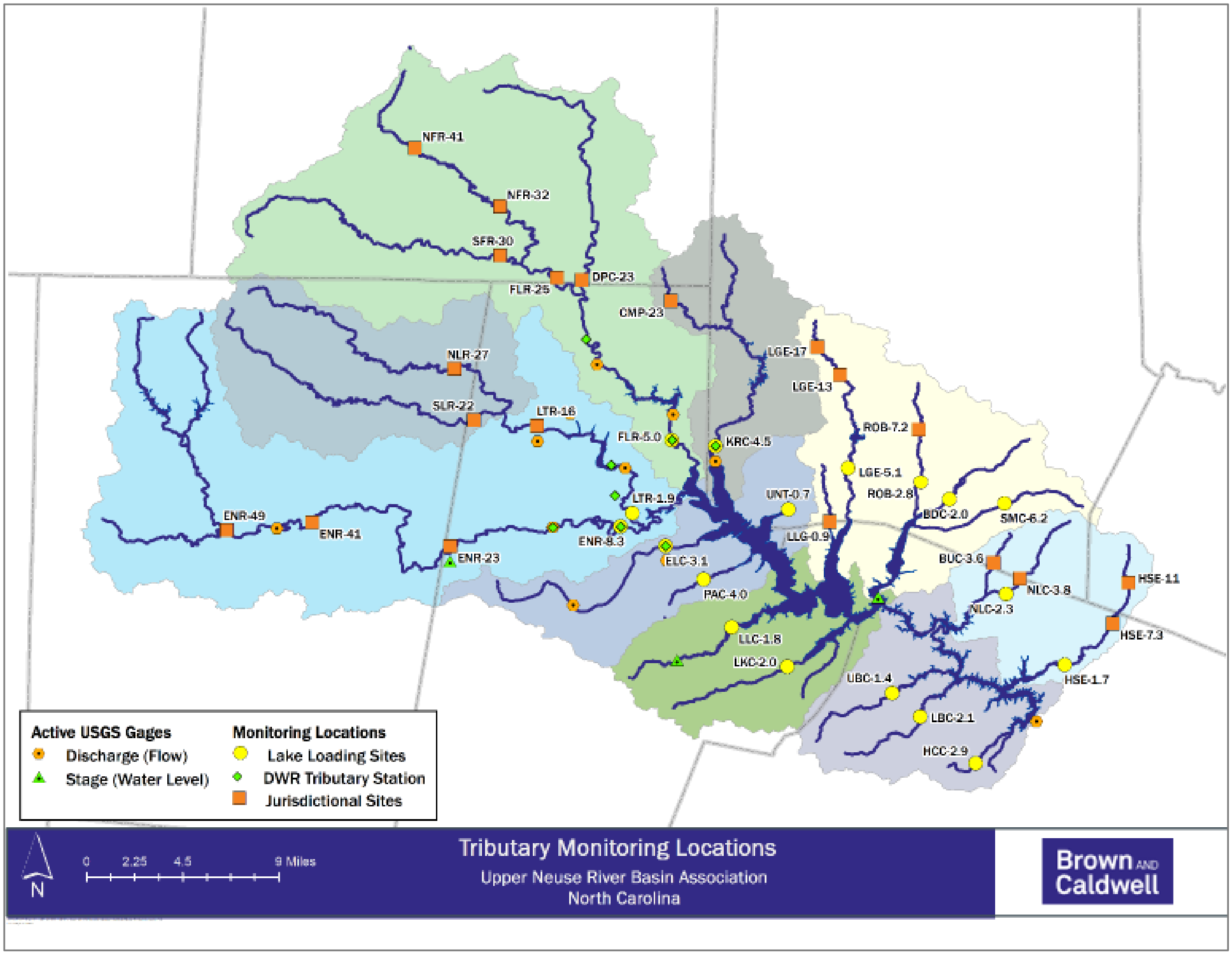

Figure A.7-1 Flow Gages and Water Quality Monitoring Sites in the Falls Lake Watershed

At the 10 locations where continuous streamflow is measured, criteria based on Lumb, et al. (1994) and Donigian (2002) will be used as targets for hydrology calibration in this study. These criteria use the percent difference in aggregated flow characteristics between simulated and observed. The percent difference (also known as percent bias) is a measure of model error relative to the observed mean and is calculated as follows:

Percent Difference:

$$\%Diff = \frac{\sum P - O}{\sum O} \times 100$$

Where,

O is the observed measurement (or aggregate of the observed)

P is the predicted model result (or aggregate of the predictions)

Target ranges are identified for very good, good or fair performance for multiple model error components as shown in

Table A.**7-1**. These criteria that will be used to guide the hydrology calibration throughout this study.

Table A.7-1 Hydrology Calibration Criteria

Prediction Error	Very Good	Good	Fair
Error in total volume	≤ 5%	5-10%	10-15%
Error in monthly flows	≤ 10%	10-15%	15-25%
Error in volume of 50% lowest flows	≤ 10%	10-15%	15-25%
Error in volume of 10% highest flows	≤ 10%	10-15%	15-25%
Seasonal volume error – Summer	≤ 15%	15-30%	30-50%
Seasonal volume error – Fall	≤ 15%	15-30%	30-50%
Seasonal volume error – Winter	≤ 15%	15-30%	30-50%
Seasonal volume error – Spring	≤ 15%	15-30%	30-50%

Additional statistics that are commonly used to evaluate streamflow simulations will also be calculated to further guide the hydrology calibration process at gaged locations. These values will be included in the final modeling report and are defined as below.

Average Error:

$$AE = \frac{\sum(P-O)}{N}$$

Where N is the number of paired records of observed measurements and model results (or aggregates)

Coefficient of Determination:

$$R^2 = \left(\frac{\sum(O-\overline{O})(P-\overline{P})}{\sqrt{\sum(O-\overline{O})^2}\sqrt{\sum(P-\overline{P})^2}} \right)^2$$

Ratio of Root Mean Square Error (RMSE) to Standard Deviation of the Observed Data ($STDEV_{obs}$):

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum(P-O)^2}}{\sqrt{\sum(O-\overline{O})^2}}$$

Nash-Sutcliffe Efficiency:

$$NSE = 1 - \left(\frac{\sum(P-O)^2}{\sum(O-\overline{O})^2} \right)$$

For water quality variables, a similar 3-tiered system of categorizing statistical performance developed by Donigian (2002) will be used for calibration guidance at the locations where statistical water quality calibration will be performed. The system is based on the percent difference measure (defined above) with the categorized values shown in Table **A.7-2**. As described previously, these statistical measures will be used to supplement graphical evaluation of the model results and aid in determining the endpoints of model calibration.

Table A.7-2 General Watershed Model Calibration Guidance

Parameter	% Difference Criteria		
	Very Good	Good	Fair
Sediment	< ± 20	± 20-30	± 30-45
Water Temperature	< ± 7	± 8-12	± 13-18
Water Quality/Nutrients	< ± 15	± 15-25	± 25-35

WARMF Lake Model Performance Evaluation

The lake models will also be evaluated following the "weight of evidence" approach, using a combination of graphical and statistical comparisons. When calibrating the WARMF lake model it is important to keep in mind that the model is one-dimensional and represents a lake segment as completely mixed (i.e. laterally-averaged) within each vertical layer. Model outputs include time series of surface layer conditions and vertical profiles for each day of the simulation. Thus, individual point measurements of water quality in the lake do not directly correspond to simulated water quality model outputs. If more than one measurement location exists within a given lake segment, the data should be aggregated (e.g., weighted average) to obtain values representing the 'observed' lateral-average condition for that portion of the lake. This process introduces additional uncertainty into the values used to calibrate the WARMF lake model, which must be taken into consideration during calibration and when evaluating the model performance. In addition, measurements collected at different depths will need to be aggregated based on the corresponding vertical layer of the model. If only one measurement location exists within a lake or lake segment, it should be assessed how representative it may or may not be for the full area of the lake (or portion of the lake) being simulated. In all cases, the model calibration and evaluation process must consider the potential discrepancies between the spatial area and depth represented by the model and by the data, as well as uncertainty in estimates of 'observed' laterally-averaged conditions.

To evaluate the WARMF lake model, a subset of the graphical methods described for the watershed model will also be used. The graphical evaluations will be supplemented by the performance criteria listed above in

The number and configuration of modeling segments for the WARMF lake model is not yet determined. Each lake segment will be calibrated and evaluated using the measured data from the lake monitoring station, or an aggregate from multiple stations, located within that segment.

EFDC Lake Model Performance Evaluation

A map of water quality monitoring locations in Falls Lake is shown in Figure A.7-2. The USACE measures water elevation in Falls Lake at the dam, and the USGS measures water elevation at the Beaverdam Impoundment dam. The EFDC lake model will be calibrated and evaluated for stage at these two locations and for water quality at the 12 DWR monitoring locations (blue circles).

At each calibration location in the lake, graphical evaluations of EFDC model results will include a visual comparison between trends in the data and model results on seasonal and annual time scales for each water quality parameter. The primary statistical criterion for the EFDC lake model that will be adopted in this study is a normalized root mean square error (RMSE) performance measure. This measure, expressed as a percentage, is computed as the ratio of the RMSE to the standard deviation in the observed data for each hydrodynamic or water quality constituent (Moriasi et al, 2007).) The equation for the RMSE– standard deviation ratio (RSR) is given below:

RMSE-$STDEV_{obs}$ Ratio (RSR):

$$RSR = \frac{RMSE}{STDEV_{obs}} \times 100 = \frac{\sqrt{\sum (P - O)^2}}{\sqrt{\sum \left(O - \overline{O}\right)^2}} \times 100$$

Where,

N is the number of paired records of observed measurements and model results

O is the observed measurement

P is the predicted model result

$STDEV_{obs}$ is the standard deviation of the observed data

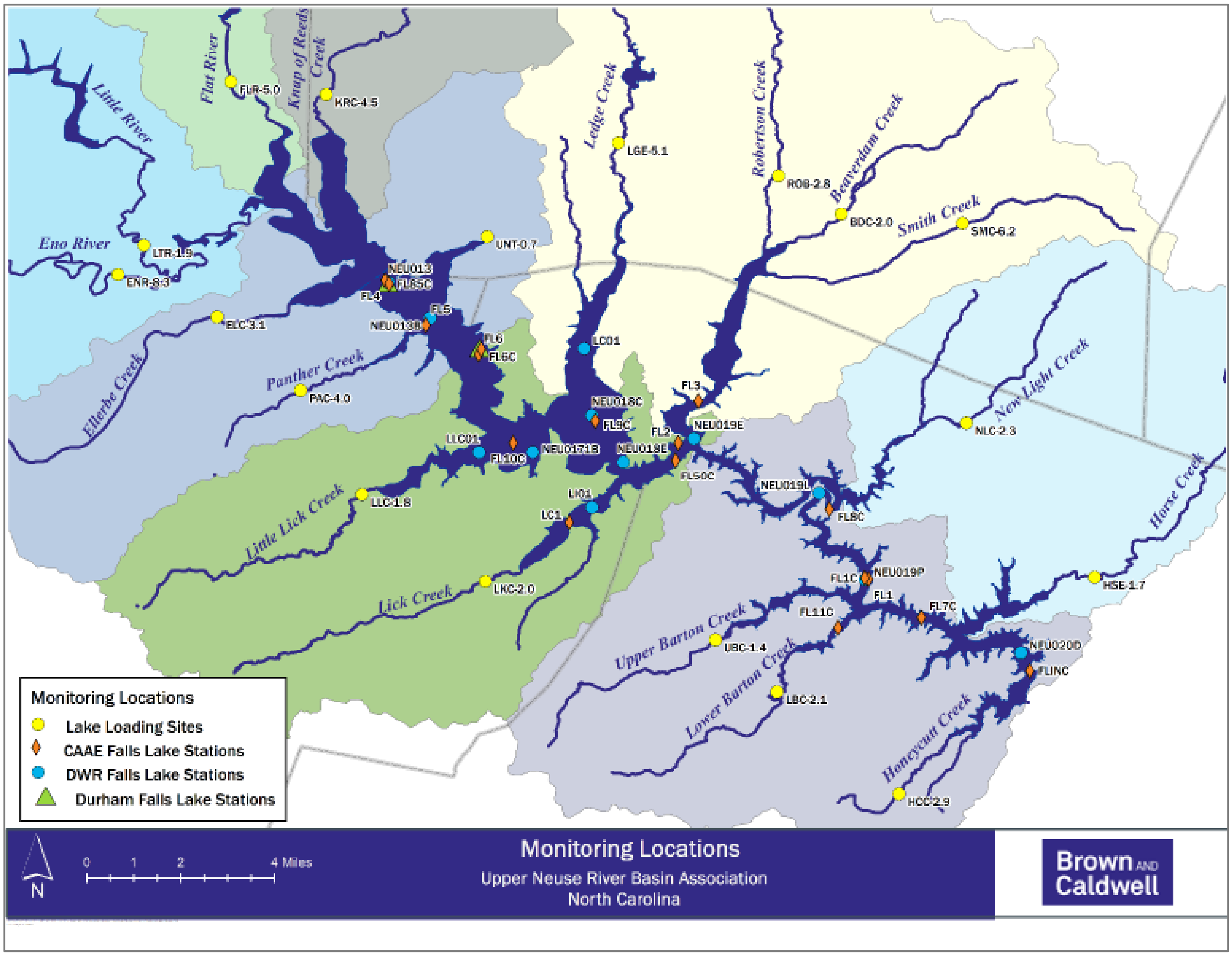

Figure A.7-2 Water Quality Monitoring Sites in Falls Lake

Different target values for the RSR are adopted for each type of variable, based on previous criteria used by DWR for the EFDC model. For hydrodynamic variables, such as water surface elevation of the lake, and water temperature, a target RSR value of 50% is adopted. For variables simulated with the EFDC water quality model, an RSR performance measure of 50% is adopted for DO and 100% for nutrients, total organic carbon, total suspended solids, and algal biomass.

Performance criteria based on either a normalized RMSE or RMSE statistic is the standard approach used for evaluation of the EFDC model as indicated by a compilation of 153 water quality modeling studies by Ahrenditis and Brett (2004), as well as others (Limnotech, 2009; Sheng and Kim, 2009; Jin and Ji, 2013). Thus, using a similar approach will provide the most consistency and comparability with the team's experience and other studies' results. Most of these studies applied a normalized RMSE statistic to evaluate the model at individual station locations in a waterbody. The previous Falls Lake EFDC model evaluation, however, was performed for a single result (assumed to be a spatial average or other calculated composite) for the entire lake using multiple statistics. To allow for comparison between this study and the previous Falls Lake EFDC model results, individual and composite statistics will be calculated and evaluated using consistent statistical measures (Percent Difference, AE, R-square, NSE as described for the watershed model).

Statistical Lake Model Performance Evaluation

The statistical lake model will also be evaluated following the "weight of evidence" approach, using a combination of graphical and statistical comparisons. The statistical lake model will represent seasonal or annual average conditions for a lake segment. Individual point measurements of water quality in the lake will be aggregated spatially and temporally within the segment to compare to simulated water quality. As with the WARMF lake model, this process introduces additional uncertainty into the values used to calibrate the model, which must be taken into consideration during calibration and when evaluating the model performance. The model calibration and evaluation process must account for the potential discrepancies between the spatial area and depth represented by the model and by the data, as well as uncertainty in estimates of 'observed' average conditions.

To evaluate the statistical lake model, simulated water quality will be compared to seasonal or annual averages using the performance criteria listed in Table A**.7-2**.

Summary of Model Performance Approach

Given the lack of a general consensus for defining quantitative model performance criteria, the inherent errors in input and observed data, and the approximate nature of model formulations, absolute criteria for model acceptance or rejection are not appropriate for studies such as the development of the WARMF watershed model, WARMF lake model, EFDC lake model, and statistical lake model for Falls Lake. The criteria presented above will be used as targets for model calibration, but not as rigid criteria for rejection or acceptance of model results.

Any model performance comparison of model results versus observed measurement yielding differences greater than the criteria listed above will trigger a re-evaluation of the watershed or lake model to determine if (a) any important processes in the lake or watershed are not well-represented in the model structure or parameterization, (b) model inputs, particularly those with large uncertainty, need to be revised (e.g., land application), or (c) if the observed datasets as used are not appropriate for comparison to model results (e.g., require unit conversion). Any revisions identified as necessary and feasible will be made and the model re-run with the objective of achieving an acceptable model calibration. A justification will be documented if data revisions are necessary.

If, after reviewing and revising the parameters, inputs and/or observed data, the performance measures of the watershed or lake models still do not meet the targets at any location, a discussion of possible explanations will be provided. The model calibration will not necessarily be considered unacceptable if model results fall outside the performance criteria. Decisions will be made jointly by the Team and the UNRBA about (a) the validity and any unresolvable issues with the input data and observed data used to construct the models, (b) the significance of poor model performance at a location for the ultimate intended use of the models and (c) the steps needed to complete or alter development of the watershed and lake models to achieve results that can be used for the Reexamination. If satisfactory performance is not achieved, then a complete discussion and explanation for the discrepancy between model results and observed data will be presented and discussed in the technical report prepared for this study.

A.7.2 Data Requirements and Criteria for Acceptance

Published reports including electronic files obtained from DWR, USEPA, NOAA, NC CRONOS, USEPA, NADP, NCDOT, US Census Bureau, USACE Wilmington District, USGS, USDA, the UNRBA, local governments, utilities, and other stakeholders will serve as the primary data sources for the project. Section B.9 presents a description of the data sources, QA/QC information, and Standard Operating Procedures (SOPs) for these organizations. Datasets that are publicly distributed by federal agencies, the State of North Carolina, or that are collected in accordance with a State-approved Monitoring QAPP are considered defensible for the purposes of this project. To further ensure the quality of data and confidence in model inputs, data from all sources will be reviewed based on the acceptance criteria outlined herein prior to use in model development.

The criteria that will be used to determine if data are acceptable for use in this study are reasonableness, completeness, and consistency. These three qualities are further described as follows:

- Data reasonableness: Datasets will be checked to ensure that all values and dates are reasonable. Graphical methods will be used to evaluate potential anomalous values that may originate from data entry or analytical errors. Frequency distribution plots may also be used to assess if the range of values is reasonable. Any values outside reasonable ranges for the variable or location will be flagged and investigated. Clear data errors (e.g., negative values for flow, concentration, etc.) will be removed and suspicious values will be confirmed with the data source agency. If appropriate, annual average or total values will be calculated to check for any long-term accumulating bias that may not be visible in point values (e.g., due to poorly calibrated instruments). In addition, queries will be used to find mistyped or unreasonable dates (e.g., 8/24/1900). Clarification from the source agency will be solicited to correct or confirm any suspicious or unreasonable data or trends. All data values removed from a record will be documented, including reason for removal and source agency confirmation if appropriate.

- Data completeness: Datasets will be checked to determine if any data are missing in the defined simulation period (August 2014 to December 2018). In any complex modeling study, data gaps are inevitable that must be filled to generate complete model inputs for the time step or spatial scale required by the model. However, some data records may be too short (e.g., too few data points or types of conditions represented) to support a valid data filling approach for certain model inputs. Thus, for this criterion it will be assessed if 1) data gaps are present 2) those gaps can be filled by a valid approach if necessary and 3) if data do not require filling (e.g., some calibration data), the data are of sufficient quantity to support its intended use. Any data gaps and the assumptions used in filling the gaps will be documented in the modeling report.
- Data consistency: Datasets will be checked to ensure consistency of location, measurement units, analytical and QA procedures, and comparability of values within the dataset and across other datasets representing the same variable. Sampling station data will be checked through queries and mapping to ensure that no mistyped geospatial data (e.g., locations outside the watershed) are inadvertently used for model development. For geospatial data, consistency checks will include verification that the datasets completely cover the project area, boundaries coincide with other data layers (e.g., state or county boundaries), and that the horizontal projection, vertical datum and units agree with their metadata. For temporal data, consistency checks will include verification of measurement units and sampling methods. Data plots will be inspected for intra- and inter-annual patterns (e.g., wet/dry seasons and years), and data will be compared across locations for similar patterns (e.g., such as to confirm a high precipitation across nearby stations or a high flow event at upstream/downstream stations). If more than one data source is available for a given variable and location, more recently produced datasets will be considered superior to older datasets. If inconsistencies are not easily remedied, an alternate data source meeting the project requirements may be identified.

In addition to the above, acceptance criteria will be obtained from existing QAPPs, sampling and analysis plans, standard operating procedures (SOPs), laboratory reports, and other correspondence for a given source of measurement data, if available. Files obtained from data sources will preferably be in electronic format with adequate documentation of file structure, data record fields, and units of parameter measurements for all files. A description of the data sources, types of data, an inventory of the availability of data, and procedures used to fill in data gaps will be included in the watershed modeling and lake modeling report.

A.8 Special Training/Certification

A.8.1 Brown and Caldwell Staff

Staff at Brown and Caldwell have been supporting the UNRBA in their planning for the Reexamination of Stage II of the Falls Lake Nutrient Management Strategy since 2012. Our team includes scientists specializing in limnology and statistical analyses, water resource engineers, and economists. Members of our team helped the UNRBA design and implement the UNRBA Monitoring Program. Our data managers maintain the UNRBA Data Portal that includes all the Routine Monitoring and Special Studies data collected to support model development and the Reexamination. Our modelers extended an EFDC hydrodynamic/water quality model of the Lower Tar/Pamlico Estuary and developed a Princeton Ocean Model for the Gulf of Mexico following the 2010 oil spill. Our staff have been involved in the development of TMDLs and implementation plans across the country including eutrophication, fecal coliform, sediment, mercury, and persistent organic pollutants.

A.8.2 Dynamic Solutions, LLC. Staff

Dynamic Solutions personnel, all of whom hold graduate degrees from universities well known for excellence and leadership in surface water modeling, are nationally recognized as experts in the field of watershed modeling and hydrodynamic and water quality modeling. Dynamic Solutions personnel all have 20+ years of professional experience developing, modifying and applying surface water models in numerous types of water bodies. Dynamic Solutions personnel have used EFDC and EFDC_Explorer to develop hydrodynamic, sediment transport and water quality models in rivers, lakes, reservoirs, estuaries and coastal waters. In addition to software development, database design, statistical analysis and numerical modeling skills, Dynamic Solutions personnel also possess extensive field experience from academic research cruises and hydrographic/water quality surveys that contributes significantly to their success with complex surface water modeling studies. Dynamic Solutions personnel can provide the high level of technical expertise required to successfully develop a calibrated EFDC lake model of the Falls Lake Study Area.

A.8.3 Systech Water Resources, Inc. Staff

The staff at Systech is composed of senior level engineers and modelers with strong backgrounds in the fundamental sciences and each with more than 17 years of diverse experience. As the developers of the WARMF decision support system, Systech has unique capabilities on projects involving the WARMF system. The firm is the sole owner of the source code, thus they can enhance both the Graphical User Interface and the underlying scientific simulation algorithms with new analysis tools and simulation options, as well as correct issues identified internally by staff or by other users. Systech has used this modeling system nationally to support water quality modeling of downstream waters and development of TMDLs and implementation plans. Systech recently developed a WARMF model of the lower Catawba River Basin under contract to the SC Department of Health and Environmental Control. SCDHEC is using the model and WARMF's TMDL tool to determine load reduction scenarios that would allow the 4-reservoir system in the SC portion of the basin to meet water quality criteria for nutrients.

A.9 Documentation and Records

Brown and Caldwell is responsible for coordinating development of modeling reports based on the watershed and lake modeling and reporting conducted by Systech Water Resources, Inc. and Dynamic Solutions, LLC. The Brown and Caldwell PM and Quality Assurance Officer will provide the oversight and review of watershed and lake model calibrations and reports. The UNRBA and member governments expect a third-party review of the models.

A.9.1 Project Documents and Reports

The project consists of the development of a watershed model (WARMF) and lake models (WARMF, EFDC, and statistical) for the Falls Lake Study Area and application of those models to reexamine Stage II of the Falls Lake Nutrient Management Strategy. The following bullets identify potential subjects and materials that may be developed in this study:

- An inventory of data input parameters for the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models, including those parameters and values used for watershed and lake model calibration analyses.
- All watershed model input files (as WARMF input format).
- All lake model input files (as WARMF input format).
- All hydrodynamic and water quality model input files (as EFDC input format).
- All statistical regressions used to link nutrient loading to lake water quality.
- Output results generated by the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models.
- Tables of model performance statistics computed for the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models.
- Compiled executable files, code modifications, and output files for the versions of WARMF and EFDC used by Systech Water Resources and Dynamic Solutions, respectively, for application to the Falls Lake project.
- Monthly status updates at PFC meetings and brief summaries of work completed accompanying monthly invoices.
- Draft and final modeling reports to document data sources, model development, model code revisions, calibration and validation of model results, and evaluation of the effectiveness of watershed load reductions to improve water quality conditions in Falls Lake.

- Technical, editorial and graphic support to UNRBA to prepare presentations for public meetings. These may include materials describing the modeling approach and/or fact sheets to present the key issues/findings related to the watershed and lake model framework and evaluation of nutrient management strategies.
- Corrective action reports (if applicable).

The draft and final modeling reports will include, but will not be limited to, the following:

- An executive summary.
- An overview of the WARMF watershed model.
- A summary of data sources and data used in development of the WARMF watershed model.
- WARMF watershed model calibration techniques and model results presented in both narrative and graphical form.
- An overview of the WARMF lake model.
- A summary of data sources and data used in development of the WARMF lake model.
- WARMF lake model calibration techniques and model results presented in both narrative and graphical form.
- An overview of the EFDC lake model.
- A summary of data sources and data used in development of the EFDC lake model.
- EFDC lake model calibration techniques and model results presented in both narrative and graphical form.
- An overview of the statistical lake model.
- A summary of data sources and data used in development of the statistical lake model.
- Statistical lake model formulations, calibration, and model results relative to performance criteria.
- An evaluation of likely improvements to lake water quality resulting from implementation of nutrient management actions in the watershed.
- A cost benefit analyses evaluation the cost of implementation of nutrient management strategies and the level of expected improvement in lake water quality.
- Water quality data used in this project documented in a technical appendix with errors and/or outliers (if applicable) clearly identified.

The Team will review and address comments received on the draft modeling report from the UNRBA, DWR, EPA, and stakeholders. The Team will discuss all substantive comments with the UNRBA, as needed, to decide on a course of action to best address the comments for incorporation into the final modeling report.

A.9.2 Data Reporting Package Format and Documentation Control

The Modeling Task Managers are responsible for retaining information as modeling tasks are completed and will do so both in electronic and hardcopy formats. Records of the project will be maintained so that another person could duplicate the work performed for development of the WARMF watershed model, WARMF lake model, the EFDC model, and the statistical lake model for the Falls Lake Study Area with a reasonable amount of effort.

All project files including WARMF and EFDC model input files, observed data files used for watershed and lake model calibration, Geographic Information System (GIS) shape files, Microsoft Excel spreadsheet files, and Microsoft Word document files will be transferred to the UNRBA in electronic format. Electronic files will be provided to the UNRBA on Digital Versatile Disk (DVD(s)), external removable hard drive media or by file transfer via the Brown and Caldwell, Systech Water Resources, or Dynamic Solutions File Transfer Protocol (FTP) sites. All files developed for the Falls Lake project will be stored permanently on Brown and Caldwell, Systech Water Resources, and Dynamic Solutions servers.

A.9.3 Data Reporting Package Archive and Retrieval

Hard copies of the QAPP documents for the Falls Lake study are retained in the files of Brown and Caldwell in Raleigh, NC; Systech Water Resources in State College, PA; and Dynamic Solutions in Knoxville, Tennessee. Electronic copies are kept on the respective Local Area Network and VPN servers. The Project Manager is responsible for distributing electronic copies of the approved QAPP to all Brown and Caldwell, Systech Water Resources, and Dynamic Solutions staff listed on the distribution list (Section A.3).

After the project, all project files will be archived on portable external hard drives for permanent storage by Brown and Caldwell, Systech Water Resources, Dynamic Solutions, and the UNRBA. A data management plan will be developed to index and manage model development and application files. This will include software files for WARMF, EFDC and EFDC_Explorer, post-processing software, original raw input data files and reformatted input data files, WARMF and EFDC model results, statistical modeling files and code, technical memorandum, modeling reports, and all other interim project deliverables. In addition to electronic records of the project, which are the natural result of a computer modeling project, the respective Task Manager will retain all working notes, modeling logs and results in hardcopy form. Three-ring binders and letter size file pockets will be used to organize modeling logs and other hard copy materials for ready access during the project as well as for the project archives for at least five (5) years after completion of the project.

A.9.4 Backup/Disaster Recovery

Brown and Caldwell Backup/Data Recovery

Brown and Caldwell uses CommVault for file backups of the local Raleigh server and personal computers. The server is backed up with a local copy and an offsite replicate copy in Phoenix, Arizona. Personal computers are backed up to a cloud-based environment. Backups occur no less than once per day. Brown and Caldwell IT staff will be responsible for restoring files from the server or personal computers in the event of failure, loss, or damage.

Systech Water Resources Backup/Data Recovery

WARMF model work will be performed either at Systech's satellite office in State College, PA or remotely on a server in Walnut Creek, CA. Both computers use software which backs up its files every night to a cloud-based environment. In the event of data loss, the files will be recovered from the cloud by Systech personnel.

Dynamic Solutions Backup/Data Recovery

Backup files for this project will be created at Dynamic Solutions on a weekly basis to prevent potential data losses. As changes are made to EFDC model input files, deliverables, and other pre- and post-processing tasks, files are backed up on a hard drive of a network computer, as needed, daily. Project files archived on hard drives of separate network computer(s) are backed up to removable media (DVD's or removable hard drives) on a weekly basis. The Modeling Task Managers will have primary responsibility for backup of the EFDC model project files, as well as ensuring that the current versions of the EFDC lake model and the EFDC_Explorer software files are backed up to both hard drives of network computers and removable electronic media. In the event of a catastrophic failure of the hard drives of the primary computers used by Dynamic Solutions for the project, backup files will be accessed and restored from either network computer hard drives and/or removable hard drives. Backup files for the project will be maintained at the Dynamic Solutions headquarters office in Knoxville, Tennessee.

SECTION B — DATA GENERATION & ACQUISITION

B.1 Sampling Process and Design

Not applicable – no new sampling data will be collected under this QAPP for this project.

B.2 Sampling Methods Requirements

Not applicable – no new sampling data will be collected under this QAPP for this project.

B.3 Sample Handling and Custody Requirements

Not applicable – No new sampling data will be collected under this QAPP for this project.

B.4 Analytical Methods Requirements

Not applicable – No new sampling data will be collected under this QAPP for this project.

B.5 Quality Control Requirements

Not applicable – No new sampling data will be collected under this QAPP for this project.

B.6 Instrument/Equipment Testing, Inspection, and Maintenance Requirements

Not applicable – no new sampling data will be collected under this QAPP for this project.

B.7 Model Setup, Calibration, and Validation

Initial model setup uses known information as a starting point to describe the system. For example, land use, topography, soils, and stream network data are used to define the spatial extent and characteristics of the watershed. Lake bathymetry data are used to develop the lake model grid. External forces such as meteorology data are used to define boundary conditions. Model parameters associated with equations that describe the watershed and lake processes are set to default values. This preliminary setup represents a starting point for model development.

Calibration is the process where the model input parameters are adjusted until the simulated results from the model match observed data. It may take many iterations during model development to adjust model parameters to get the simulated model results to match observed data. Regardless of the number of times the modeler tests different model parameter values, the whole process is considered as one calibration for a given location. Only one calibration will be performed for this project per specified calibration location (see Section A.7.1 for a map and description of calibration locations). Model calibration, in this setting, is defined as how well the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models reproduce measured or averaged values (depending on the model specificity). Validation uses a separate modeling period to test the model simulations to observed data. This process ensures a more robust model by ensuring that the model was not overly calibrated to represent just one specific period. The goal is to develop a model that simulates a wide range of conditions with a reasonable degree of accuracy. More information about model validation is provided in Section**Error! Reference source not found.**SECTION D —.

Overviews of the model setup, calibration, and validation process for the WARMF watershed, WARMF lake, EFDC lake, and statistical lake models are included in Sections B.7.1 through B.7.8 .

B.7.1 WARMF Watershed Model Setup

The WARMF watershed model represents a watershed as an interconnected network of land catchments and stream segments. Land catchments follow drainage boundaries and are characterized by different land use on the surface and multiple soil layers beneath the surface. Each land use category and soil layer in a catchment is treated as an individual model component that is assumed to have uniform characteristics, though characteristics may vary across components (e.g., different soil layers) within a catchment. Physical, chemical and biological processes are simulated for each model component, after which results (i.e., net runoff and constituent mass) are aggregated for the catchment and delivered as input to the connected stream segment. Stream segments are comprised of water column and stream bed components, each with lumped characteristics and individually simulated processes.

For a given application of WARMF, subdivision of the study area into land catchments and stream segments is determined by the user. For this project, a previously developed WARMF application for the Falls Lake watershed (NCDWQ, 2009a) will serve as the starting point for model setup and configuration. The existing catchment configuration will be reviewed and revised as necessary to correct inconsistencies based on more recent or higher resolution datasets to better capture variability in the watershed (e.g., precipitation, land management, septic systems, etc.), to subdivide at municipal or jurisdictional boundaries, or other reasons put forth by the UNRBA. Likewise, configuration of the tributary networks into model stream segments in the existing WARMF application will be thoroughly reviewed and revised where necessary. Recent updates by the City of Durham for subwatersheds in their jurisdiction will also be reviewed and incorporated into the revised WARMF model for the Falls Lake Watershed.

A significant part of model setup involves defining the model inputs (i.e., dynamic inputs or forcings) and parameters (i.e., static characteristics) for each catchment and stream segment in the revised model configuration. Dynamic inputs are those that vary in time and must be defined as an input time series to the model. For catchments, these inputs include meteorology data and atmospheric deposition. For stream segments, these inputs include gaged stream flows, point sources, sanitary sewer overflows, diversions, and return flows. Sources that will be used for these inputs are publicly available datasets from federal agencies, such as USGS (stream flow and rainfall), NOAA NCDC (meteorology), USEPA National Atmospheric Deposition Program (NADP) and Clean Air Status and Trends Network (CASTNET) (atmospheric deposition), EPA Region 4 or DWR National Pollutant Discharge Elimination System (point sources), DWR sanitary sewer overflows, and data from local governments and utilities (discharge monitoring reports for wastewater treatment facilities, City of Durham Atmospheric Deposition Monitoring Study (AMEC, 2012), etc.). These data are described further in Table B.9-1. Other sources, such as counties, municipalities, universities, and agricultural representatives will need to be investigated for supplemental data pertaining to watershed management, local land use practices, etc.

Static model parameters represent time-invariant quantities, or those that are assumed to be constant over the simulation period, such a physical land and channel characteristics. Some parameters can be calculated or estimated based on measured data (e.g., from digital elevation model (DEM) or land use data), while others must be defined by model calibration. Parameters that are estimated based on data include catchment or sewershed area and topography (average catchment slope, aspect, and shape; average channel slope and geometry), land use composition and impervious area (% of area covered by each land use or imperviousness class), septic system usage (population served and effluent type), best management practice (BMP) implementations (e.g., number and efficiency), monthly fertilizer application rates by land use, and other surface application rates of pollutants (e.g., urban areas). The above parameters are typically defined during the model setup process and not altered during the calibration, unless new information is acquired that indicates initial estimates were not representative of the catchment or stream. Some soil layer parameters can also initially be estimated from soil survey data. However, soil properties and their variation throughout a catchment are not known with precision, thus soil parameters typically require adjustment during calibration. Data sources for model parameters includes the USGS National Elevation Dataset (NED, topography), USGS National Land Cover Dataset (NLCD), USDA National Agricultural Statistics Service (NASS, land use), and USDA Soil Survey Geographic Database and the State Soil Geographic Database (STATSGO2). These sources are described further in Table B.9-1. Additional information will be collected from UNRBA members and other stakeholders within the watershed to estimate fertilizer application rates; urban land application rates; septic system usage, failure rates, and effluent characteristics; and best management practices (BMPs) in use throughout the watershed.

Once model input time series are developed and model parameters are defined, the WARMF watershed model is setup and ready to simulate hydrologic and water quality processes in the Falls Lake Watershed. Key processes accounted for by the model include surface runoff and groundwater outflow, soil erosion and transport to streams, soil adsorption and competitive cation exchange, nutrient cycling between soil and vegetation, in-stream sediment transport, streambank and bed erosion, and biochemical kinetics for nutrients, algae and DO. A mass balance is maintained through all transport and transformation processes. Key simulated variables of the WARMF watershed model include flow, water temperature, total suspended solids (TSS), total nitrogen (TN), organic nitrogen (Org-N), ammonium (NH4-N), nitrate (NO3-N), total phosphorous (TP), ortho phosphate (PO4-P), total organic carbon (TOC), DO, and chlorophyll-a.

B.7.2 WARMF Watershed Model Calibration, Validation, and Sensitivity Analyses

The primary modeling period is assumed August 2014 through December 2018. This period allows for model spin up during the latter part of 2014, model calibration in 2015 and 2016, and model validation in 2017 and 2018. If the hydrologic conditions are anomalous for a year, the models may not perform as well. The original years of DWR's watershed and lake modeling (2005 through 2007) will also be used to provide a comparison to extreme drought conditions. Because the same level of monitoring data is not available for that period and because this was a historic drought for the area, the comparative statistics for the watershed and lake models may not show as strong a fit to observations.

Constituents of concern for this study include total suspended solids (TSS), nutrients (ammonia (NH3-N), nitrate (NO3-N), total Kjeldahl nitrogen (TKN), total nitrogen (TN), phosphate (PO4-P) and total phosphorus (TP)), total organic carbon (TOC), dissolved oxygen (DO), and chlorophyll-a. The model will be calibrated to accurately simulate these constituents, along with flow and water temperature. Due to interdependencies between locations and different constituents, a systematic approach is necessary, calibrating from upstream to downstream, one constituent at a time. In-stream flow will be calibrated first since flow controls transport processes and thus affects all water quality constituents. Water temperature calibration will be performed next, since temperature affects DO saturation and decay rates of several constituents. TSS will then be calibrated as it impacts adsorption of phosphorus, ammonia, and other constituents. After flow, temperature, and TSS calibrations are finalized, in-stream water quality calibration for nutrients, TOC, chlorophyll-a, and DO will be conducted in sequence. The sequence of steps at each calibration location is as follows:

- Adjust hydrologic parameters so that the simulated long-term annual water volume is approximately equal to the observed annual water volume. This step ensures the overall water balance is reasonable and may identify if any large sources or losses of water (e.g., diversions) are missing.
- Adjust soil parameters to match the observed seasonal flow volume and shape of the hydrograph including peak flows, recession curve, and base flow.
- Refine model calibration by continuing to adjust hydrologic parameters manually or with the auto-calibration program.
- Adjust temperature related parameters so that the simulated in-stream water temperature closely follows the observed in-stream water temperature.
- Adjust overland sediment parameters so that simulated annual sediment loads per acre are reasonable for each land use.
- Adjust in-stream sediment transport parameters so that simulated TSS concentrations match the observed reasonably well.
- Adjust soil water quality parameters so that simulated soil pore water concentrations of nutrients and carbon are in dynamic steady state, with reasonable seasonable variation, unless available information indicates otherwise.
- Adjust vegetation parameters (by land use) affecting nutrients and organic carbon so that simulated fluxes (e.g., uptake, production, net load per acre) are reasonable for a given land use.
- Adjust key in-stream water quality parameters for nutrients, organic carbon, chlorophyll-a, and DO so that simulated water quality constituents match the observed data reasonably well.
- Repeat the last three steps (i.e., increase or decrease the catchment parameters then readjust in-stream water quality parameters) until additional adjustments do not improve the calibration and values of model performance metrics fall within the target ranges as described in Section A.7.

Stream locations that will be used for watershed model calibration will be identified based on monitoring locations, constituent concentrations (i.e., tributaries contributing a significant portion of the total load to the lake), and available time and resources. Comparisons of simulation results with observed data will be presented and analyzed for in-stream flow, water temperature, TSS, nutrients, TOC, DO and chlorophyll-a. Data sources of observed streamflow and in-stream water quality measurements include the USGS, UNRBA, and DWR. These data will be used to compare the model simulation results to observed data both graphically and statistically following a "weight of evidence" approach as described in Section A.7.1 The graphical methods and statistical calculations presented in Section A.7.1 will serve as tools to determine the end points of calibration. In general, calibration end points are the point of diminishing returns when further effort no longer results in measurable improvements to the calibration.

After the WARMF watershed model has been calibrated to years 2015 and 2016, the model will be used to simulate the validation period (2017 to 2018). Model output will be compared to observations collected during this period using the same graphical and statistical methods applied for calibration. The validation should generally meet the same performance criteria as the calibration period. If the calibrated model does not provide a reasonable fit for the validation period, the model calibration will be refined. The model will also be run for 2005 to 2007 to compare to historic drought conditions and the original modeling years used to develop the current Falls Lake Nutrient Management Strategy.

Sensitivity analysis is a procedure to determine how model output changes in response to changes in model input parameters. During the model calibration process a series of iterative adjustments are typically made to selected model coefficients to determine how changes in model input will affect model results. The model calibration process thus provides important insight about the sensitivity to key model parameters and coefficients. Calibration and validation results of the WARMF watershed model will be reviewed and evaluated to identify those model input parameters and kinetic coefficients to be considered for the sensitivity analyses. The watershed model sensitivity analyses will be performed using accepted modeling practice by setting up a series of model runs based on a systematic low and high adjustment of selected key model coefficients and parameters. The model calibration results are compared to the model results obtained for the low and high adjustment of model inputs to identify model sensitivity to the input variable. Key model parameters (e.g., soil infiltration rates) and model input parameters (e.g., soil nutrient concentrations) expected to have the greatest effect on the water quality response of the calibrated watershed model will be selected for review.

B.7.3 WARMF Lake Model Setup

The WARMF lake model is internally linked to the WARMF watershed model with watershed and stream loads routed to the lake per user-defined connectivity. The model represents lakes and reservoirs as either a single waterbody or as multiple linked 'segments' based on shape and water quality conditions. For example, different tributary arms of a reservoir can be treated as separate lake segments. Each lake segment is divided into approximately 30 layers to enable simulation of stratification. In each layer, principles of heat and mass balance are applied, along with biochemical transformations of nutrients, algae and DO. These calculations determine conditions within (and exchange between) layers, resulting in temperature and water quality profiles. The lake bed is also simulated as a separate model component with spatially lumped characteristics and separately simulated processes.

The lake boundaries that appear in the WARMF graphical user interface map correspond to the lake shorelines at normal pool elevation. In addition to Falls Lake, the WARMF lake model will also be used to represent seven smaller waterbodies within the watershed including Lake Michie, Lake Butner, Little River Reservoir, West Fork Eno River Reservoir, Lake Orange, Lake Rogers, and Beaverdam Lake. Five of these smaller lakes were defined in the previous WARMF application for the Falls Lake watershed (NCDWQ, 2009a). The lake boundaries will be completely reviewed and revised as necessary based on more recent data, such as the USGS NHDPlus2 dataset.

After boundaries are imported or refined, the next steps for setup of the WARMF lake model involve creating input time series and defining static model parameters based on physical characteristics or other measured data. Inputs to the lake model (in addition to internally linked watershed loads) include meteorology, atmospheric deposition, point sources discharged directly to the lake, diversions extracted directly from the lake, and controlled releases downstream. Uncontrolled (i.e., spillway) releases are an optional model input as those releases can either be simulated based on a stage-discharge relationship or defined as a time series. Discharges to the lake that also use the lake as a source (e.g., City of Durham algal turf scrubber) are defined as 'internal' point sources. The meteorology and atmospheric deposition time series that were produced for the watershed model will also be used for the lake model. Thus, no new data sources are needed for those two inputs. Data sources for the lake water balance include gaged outflows from the USGS, surface elevations from the USACE, and drinking water withdrawals from the City of Raleigh. If water surface elevation data are more complete and reliable than total release data, the option is available to define surface elevation as an input and calculate total outflow (rather than the reverse).

The lake model parameters that can be calculated from measured data include the relationship between surface area and pool elevation (from bathymetry data) for each lake segment, the stage-discharge relationship for the uncontrolled spillway (if one exists), and other physical characteristics of outlet structures, such as elevation, width, and release type. Release structure information for Falls Lake will be obtained from the USACE Wilmington District. Information on the water intake structures will be obtained from the City of Raleigh. The UNRBA conducted a bathymetric survey and sediment mapping survey of Falls Lake and Beaverdam Lake in March 2017 as a Special Study to support lake model development. A full bathymetric dataset for the six smaller impoundments is not likely available. The stage-area relationships defined in the WARMF model developed by DWR will be used as the starting point for defining these waterbodies. The Neuse River Basin Hydrologic Model developed by DWR will also be evaluated for this information. Additional information will be requested from the owners/operators of these impoundments. In June 2015, the UNRBA conducted a sediment core study that will provide guidance for initial estimates for sediment-related parameters; however, these values will also require calibration.

Once the lake model time series inputs, physical characteristics, and other parameters are defined, the WARMF lake model can simulate hydrologic and water quality processes in Falls Lake and the other impoundments. Key processes accounted for by the lake model include water and mass balance, density gradient influences on inflows and outflows, advective exchange between layers, diffusion between layers, heat conductance, reaeration, adsorption and sediment settling, sediment oxygen demand, and biochemical kinetics of nutrients, algae and DO. Key simulated variables of the WARMF lake model include surface elevation, water temperature, total suspended solids (TSS), total nitrogen (TN), total Kjeldahl nitrogen (TKN), ammonia (NH3TKia3-N), nitrate (NO3-N), total phosphorous (TP), phosphate (PO4-P), total organic carbon (TOC), DO, and chlorophyll-a.

B.7.4 WARMF Lake Model Calibration, Validation, and Sensitivity Analyses

The primary modeling period is August 2014 through December 2018. The period of 2015 and 2016 will serve as the model calibration years, and 2017 and 2018 will be used for model validation. If the hydrologic conditions are anomalous for a year, the models may not perform as well. The original years of DWR's watershed and lake modeling (2005 through 2007) will also be used to provide a comparison to extreme drought conditions. Because the same level of monitoring data is not available for that period and because this was a historic drought for the area, the comparative statistics for the watershed and lake models may not show as strong a fit to observations.

The WARMF lake model will be developed for Falls Lake for the same period (January 2005 through December 2007 and August 2014 to December 2018) and for the same water quality constituents (TSS, nutrients (N and P), TOC, DO and chlorophyll-a) as the watershed model. As described in Section A.7, it is important to keep in mind that during calibration, the model represents a lake segment as completely mixed (i.e., laterally averaged) within each vertical layer. Thus, individual point measurements of water quality in the lake do not directly correspond to simulated water quality model outputs that average conditions across each segment. Model calibration and evaluation must account for the potential discrepancies between the spatial area and depth represented by the model and by the observed data (or weighted average). With that in mind, calibration of the lake model proceeds from upstream to downstream segments (for multiple segments), one constituent at a time as follows:

- Evaluate the simulated reservoir water balance. Compare simulated to observed surface elevation or adjusted downstream releases, depending on the simulation approach. If large, consistent discrepancies exist, investigate and correct potential sources of error to the overall water balance such as missing inflows or withdrawals, accuracy of elevation-area and elevation-outflow relationships, representativeness of data (e.g., precipitation), and simulated evaporation.
- Adjust temperature related parameters so that the simulated water temperature closely follows the observed water temperature.

- Adjust sediment settling parameters so that simulated TSS concentrations match the observed concentrations reasonably well.
- Adjust key water quality parameters for nutrients, organic carbon, chlorophyll-a, and DO so that simulated water quality constituents match the observed data reasonably well. These parameters are all inter-dependent and will require iterative adjustments until acceptable results are obtained.

Comparisons of model simulation results with observed data will be presented and analyzed for surface elevation, water temperature, TSS, nutrients, TOC, DO and chlorophyll-a based on data collected by DWR and UNRBA at the 12 mainstem locations. The data source for Falls Lake and Beaverdam Lake surface elevation is the USGS. These data will be used to compare the model simulation results to observed data both graphically and statistically following a "weight of evidence" approach as described in Section A.7. The graphical methods and statistical calculations presented in Section A.7 will serve as tools to determine the end points of calibration. Data from additional sources that are collected under an approved monitoring QAPP in the mainstem including the City of Durham, City of Raleigh, and CAAE will be used as supplemental data for model development and calibration.

After the WARMF lake model has been calibrated, the model will be used to simulate the validation period (2017 to 2018). Model output will be compared to observations collected during this period using the same graphical and statistical methods applied for calibration. The validation should generally meet the same performance criteria as the calibration period. If the calibrated model does not provide a reasonable fit for the validation period, the model calibration will be refined. The model will also be run for 2005 to 2007 for comparison to historic drought conditions.

As with the WARMF watershed model, sensitivity analyses will also be performed for the WARMF lake model. Key model parameters and input parameters affecting nutrient concentrations and algal response will be selected for these analyses. Low and high adjustment of these parameters from the calibration values will be evaluated to determine the sensitivity of the model output to these ranges.

B.7.5 EFDC Lake Model Setup

The EFDC model represents waterbodies with a 3-dimensional grid to fully account for spatial variability of processes and water quality conditions. The physical domain for the computational grid of the Falls Lake model will be defined by the lake shoreline at normal pool elevation. The orthogonal curvilinear grid will be constructed using the Delft3D RGFGRID generation software (Delft, 2007). The vertical domain of the lake model is represented with ~6 to 10 layers to account for thermal stratification. The UNRBA conducted a bathymetric survey and sediment mapping survey of Falls Lake and Beaverdam Lake in 2017 as a Special Study to support lake model development.

Setup of the lake model will be completed with the assignment of initial conditions for the water column and sediment bed, water withdrawals by the City of Raleigh, local watershed and tributary stream inflows and loadings from the WARMF watershed model, and atmospheric forcing functions. Data sources for these inputs include USACE Wilmington District for lake level and reservoir releases, USGS for lake elevations in Beaverdam Lake, NOAA NCDC for meteorological data, and EPA's NADP and CASTNET for atmospheric deposition of nutrients. Flows over the dam will be simulated using a stage-discharge relationship.

Data inputs for the sediment bed model include bed characterization of organic matter (as solids, C, N, P) and porewater concentrations of ammonia, nitrate and phosphate. Data are available from the 2015 UNRBA Sediment Evaluation Special Study and the 2017 sediment mapping (part of the Bathymetry Special Study) to characterize the concentration of solids and organic matter (as C, N, P) in the sediment bed of Falls Lake. Sediment bed particle size distribution and bulk density will be estimated from literature values and consultation with Dr. Marc Alperin at the University of North Carolina at Chapel Hill (UNC) who conducted the Sediment Evaluation Special Study. If data gaps are identified for the sediment bed of Falls Lake, consultation with Dr. Alperin and data reported in the literature by Weaver (1994) for other reservoirs will be identified and used to fill in missing data. This data will be used for model setup to support the assignment of initial sediment bed conditions for the Falls Lake model.

Boundary conditions for the EFDC lake model will be established by using simulated flow and nutrient loading data from the calibrated watershed model as input to the lake model. Watershed simulated water quality species will be converted stoichiometrically to those species simulated in the lake model if necessary. Precipitation, evaporation, water withdrawals, dam discharges, and nutrient atmospheric deposition will be input to the lake model as boundary conditions as well.

Once the computational grid, model inputs, and boundary condition inputs have been developed, the EFDC lake model setup is complete and the model is ready to be calibrated to the hydrodynamic and water quality conditions in Falls Lake. Important processes accounted for by the EFDC lake model include hydrodynamic routing; seasonal stratification; circulation and mixing; atmospheric forcing; sediment transport; biochemical kinetics for nutrients, organic carbon, algae and DO; and sediment-water fluxes of nutrients and DO. State variables of the EFDC model include water level, water temperature, fine-grained cohesive sediment, nutrients (N, P), organic carbon, DO, and algal biomass. State variables of the sediment flux model include sediment bed organic matter, nutrients (N, P), and sediment-water fluxes for DO and nutrients (Di Toro, 2001).

B.7.6 EFDC Lake Model Calibration, Validation, and Sensitivity Analyses

The EFDC lake model will be developed for the period from January 2005 through December 2007 and August 2014 to December 2018. The period of 2015 and 2016 will be used for calibration and 2017 and 2018 will be used for validation. If the hydrologic conditions are anomalous for a year, the models may not perform as well. The latter part of 2014 will be used for model spin-up. The calibrated model will also be evaluated for 2005 to 2007 conditions. Depending on the validation results of the WARMF watershed model for the 2005-2007 period, the tributary inputs for the earlier period may or may not be linked to the watershed model. An alternative load estimation approach such as USGS LOADEST may be used to compare and/or generate the water quality inputs for these years. Basin proration of USGS gaged flows would provide flow inputs. Past analyses of loading using LOADEST has shown a range in predicted loads depending on the assumptions and methods used. These empirical loading estimates will be used to evaluate uncertainty and variability in loading estimates to Falls Lake.

To efficiently calibrate the lake model, the following sequence of steps will be used:

- Test hydrodynamic model water balance to calibrate stage height, lake surface area, and lake volume.
- Add heat and density effects to test ability of the hydrodynamic model to represent reasonable current velocities, water temperature, and lake stratification.
- Add sediment loading and in-lake sediment transport with cohesive parameters for critical shear stress, deposition velocity, and re-suspension rate.
- Add organic carbon, nutrient loading, and water quality kinetics (including algal growth).
- Add sediment diagenesis to couple organic matter deposition from the water column to the sediment bed for simulation of sediment oxygen demand, organic matter decomposition, and the recycling of inorganic nutrients back to the water column.

In calibrating the hydrodynamic, sediment transport, and water quality model, the accuracy of external flows, loadings, and forcing functions will be assessed by comparison to observed data for preliminary lake model runs. Key kinetic coefficients and water quality model coefficients will be adjusted, as needed, within a reasonable range of values used in other lake models developed by Dynamic Solutions and reported in the literature by Cerco and Cole (1994), Ji (2008), and Wells et al. (2008) to achieve acceptable calibration of the lake water quality model.

Calibration of the lake model will be accomplished by comparison of model results to observed data for station locations in Falls Lake. Model-data comparisons will be developed for water temperature, TSS, DO, nutrients (NO3+NO2, NH4, Organic N, TN, PO4, TP), algal biomass (as chlorophyll-a), and total organic carbon based on data collected by DWR and UNRBA at 12 locations. Data from additional sources collected in the mainstem of the lake and under a state-approved QAPP, including the City of Durham, City of Raleigh, and CAAE will be used as supplemental data for model development and calibration. The sediment flux model will be calibrated using observations and nutrient flux rates from sediment core analyses (UNC Chapel Hill) and benthic nutrient flux rates measured previously by DWR. Where data are insufficient, literature will be used to provide surrogate datasets based on results from other reservoirs for comparison to sediment flux rates simulated for Falls Lake with the EFDC lake model. Model performance will be evaluated to determine the endpoint for model calibration using a "weight of evidence" approach that has been adopted for many other modeling studies as described in Section A.7. Calibrated model results will be processed to compare water quality targets for DO and chlorophyll-a in Falls Lake.

After the EFDC lake model has been calibrated, the model will be used to simulate the validation period (2017 to 2018). Model output will be compared to observations collected during this period using the same graphical and statistical methods applied for calibration. The validation should generally meet the same performance criteria as the calibration period. If the calibrated model does not provide a reasonable fit for the validation period, the model calibration will be refined. The model will also be run for 2005 to 2007 for comparison to past conditions that formed the basis of the current Falls Lake Nutrient Management Strategy. If the WARMF watershed model is not applicable for these years because of the extreme drought conditions, then alternative methods will be used to develop EFDC lake model inputs for this earlier period. Flows may be estimated using USGS gaged flows and a basin proration technique that was explored previously (Cardno 2014a). Constituent loading to the lake may be simulated using empirical methods such as USGS LOADEST.

Calibration and validation results of the EFDC model of Falls Lake will be reviewed and evaluated to identify those model input parameters and kinetic coefficients to be considered for the sensitivity analyses. The lake model sensitivity analyses will be performed using a systematic low and high adjustment of selected key model coefficients and parameters. The model calibration results will be compared to the model results obtained for the range of model inputs to identify model sensitivity to the input variable. Key kinetic coefficients (e.g., algae growth rate) and model input parameters (e.g., settling velocity) expected to have the greatest effect on the water quality response of the calibrated EFDC lake model will be selected for review.

B.7.7 Statistical Lake Model Setup

The statistical lake model will be developed as a series of lake segments using the bathymetry data collected in March 2017 by the UNRBA. Morphological characteristics (e.g., depth, volume) will be described based on the results of the UNRBA's 2017 bathymetric survey. The models will be developed to represent average conditions in each segment. Annual nutrient loads and flows from the tributaries may be based on aggregated output from the WARMF watershed model or an alternative statistical model derived from data collected during the monitoring period. Other years may be considered using observed and prorated flows and loads simulated using an empirical method such as LOADEST. The temporal scale for the model predictions (growing season average or annual average) will be determined following an analysis of the lake data. An evaluation of the nutrient turnover ratio described by Walker (1996) will be used to justify development of an annual average or growing season average model. Existing published empirical relationships describing lake nutrient processes will be evaluated for applicability to Falls Lake. If these relationships do not accurately predict average conditions in the Falls Lake segments within the normal range of model parameters, site-specific relationships will be developed using Falls Lake data.

B.7.8 Statistical Lake Model Calibration, Validation, Sensitivity Analyses

After the statistical lake model is set up for the series of lake segments, the model coefficients will be calibrated to observed data. Depending on the empirical formulations selected or developed for this model, these may include nutrient sedimentation rates, light extinction coefficients, algal production rates, etc. The statistical lake model will be calibrated to simulate average total nitrogen, total phosphorus, TOC, and chlorophyll-a concentrations in each lake segment. Sensitivity analyses on key model parameters will be evaluated to determine the impacts on model output.

If resources allow for the development of model inputs for years prior to 2015 (using basin proration and an empirical load estimation method), the model will be calibrated to include years prior to 2015 and 2016. Years 2017 and 2018 will serve as validation years. If the hydrologic conditions are anomalous for a year, the models may not perform as well. 2006 will serve as a pseudo-validation year and will be set up regardless of whether the basin proration and load estimate methods are funded. Aggregated inputs from the EFDC lake model (flows and constituent loading) will be used to define the inputs for 2006.

B.8 Inspection/Acceptance Requirements for Supplies and Consumables

Not applicable – no new sampling data will be collected during this project.

B.9 Non-direct measurements

B.9.1 Data Sources

The available data sources that provide input parameters for the watershed and lake models include both geospatial data sources, such as land use data or elevation grids, as well as time-varying data such as meteorology or streamflow measurements. The key data sources that will be investigated and compiled to support model development and calibration are listed in Table B.9-1. These data sources are the industry standard for identifying, characterizing, and displaying pollutant sources and conducting water quality assessments. If measured data are not available for a sub-watershed, model inputs will be selected and adjusted based on calibration in similar sub-watersheds.

B.9.2 Quality of Data

Data that will be used for this project are collected by federal, state, and local organizations under approved QAPPs. Data have been compiled and subjected to QA/QC procedures for field data collection, laboratory analysis, data processing, etc.

Error! Reference source not found. summarizes the different types of datasets needed for development of the WARMF watershed model, the WARMF lake model, the EFDC lake model, and the statistical lake model. Links to the data sources and their QA/QC procedures and/or SOPs are also provided in Table B.9-1 where available. These data sources will be identified in all deliverables and will be evaluated based on the criteria listed in Section A.7 (Data Quality Objectives & Criteria). Additional information on data acceptance and validation are provided in **Error! Reference source not found.**.

B.9.3 Limitations of Available Data Sources

The following inherent limitations associated with available data sources do not preclude their use in watershed and lake model development:

- Datasets have variable periods of record.
- Each dataset or source has different acceptance criteria and methods of QA/QC applied prior to its release for general use.
- Most datasets are not available on a watershed basis and need to be converted and clipped to watersheds for further spatial analysis.

B.9.4 Quality and Limitations of WARMF Model Data

WARMF is a peer-reviewed watershed and lake model that has been widely used for water quality assessment and TMDL development. The WARMF model, like any other surface water model, is only an approximation, or a simplified representation, of complex natural systems. Therefore, there will always be inherent uncertainties and limitations within the model itself.

It is not currently possible to comprehensively quantify the error associated with WARMF model predictions. It is possible, however, to list model limitations. Model limitations may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. The following is a list of notable WARMF model limitations:

- **Observed Data:** Observed data are considered accurate. However, they only capture the moment in time and space when the samples or data were collected at limited locations in the watershed.
- **Meteorology:** Meteorology is the driving force for any hydrologic model. Meteorological data collected at a few points are applied to an area of hundreds of square miles. Sometimes, there is no meteorology station within a sub-catchment or even the entire study area. In such cases, meteorology data from nearby stations must be used. Rainfall can be quite variable, especially in the spring when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a one station and be completely dry a short distance away. On an average annual or average monthly basis, these errors may cancel. This limitation among others, must be considered when using hourly or daily model output.
- **Radical Parameter Changes:** Scenarios involving radical differences in model forcing or watershed characteristics result in greater uncertainty. The WARMF model is calibrated using estimates of

conditions in the basin during the calibration period. Large departures from these conditions increase the level of uncertainty in watershed model predictions.

- **Small Area Land Covers:** Land uses that cover very small areas and are not depicted in available land use/land cover datasets are not represented in the WARMF model unless reliable data describing the location and acreage of those areas are available. Land uses that occupy limited areas such as unpaved roads, bare areas, and construction sites may not be simulated, particularly if such sites are temporary.
- **Land Management Uncertainty:** There is a great deal of uncertainty associated with pasture and other agricultural land management practices. Management varies significantly from field to field as well as seasonally. It is not possible to easily determine what types of specific agricultural activities are happening where or to simulate all agricultural activities in the model. Therefore, categories are created to cover reasonable management choices only. There is temporal uncertainty for other land uses as well; land use may change over time and differ at the time of model development to the time(s) at which the data were collected.
- **Unidentified Sources and Withdrawals:** Point source contributions and withdrawals in each sub-watershed may or may not be significant. Potential point sources include CAFOs and industrial and municipal wastewater dischargers. Undocumented point sources and withdrawals may exist and affect water quality conditions in the watershed. Without supporting information, undocumented point sources and withdrawals are not represented in the model.

Table B.9-1 Data Sources for the Falls Lake and Watershed Models

Dataset	Description and Source	URLs and QA/SOP Information	Application
Streams: NHDPlus Version 2 (2012) National Hydrography Dataset (NHD) Watershed Boundary Dataset)	2012 version of the medium resolution 1:100K NHD. NHD is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. This dataset will be used to verify river segments in the existing WARMF watershed model. Dataset incorporates hydrographic features from USEPA Reach File 3 the Watershed Boundary Dataset, as well as USGS digital line graphs and small streams. Local government stream data will be incorporated where available.	www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php (USGS, USEPA and Horizon Systems 2012) Industry standard, public domain data source that can provide resolution necessary to conduct watershed modeling. The USGS Information Quality Guidelines can be found at www.usgs.gov/info_qual/. An evaluation of the accuracy and data quality of NED is available here: http://pubs.usgs.gov/of/2014/1008/pdf/ofr2014-1008.pdf. Standards and specifications for the National Geospatial Program are available here: https://nationalmap.gov/standards/index.html. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	Verification of sub-watershed and stream segment configuration in WARMF Development of study area background information
Streambank Erosion	Local governments, state agencies, university researchers, and the USGS will be consulted for data and information on measured or estimated rates of streambank erosion in the watershed.	Each local government and utility is responsible for ensuring the accuracy of the information and data provided. The USGS Information Quality Guidelines can be found at www.usgs.gov/info_qual/.	Verification of simulated sediment, nutrient, and carbon loading in the Falls Lake Watershed including loading from streambank erosion. Development of study area background

Dataset	Description and Source	URLs and QA/SOP Information	Application
Lake Bathymetry: UNRBA Special Study (March 2017)	The UNRBA collected depth-sounding data using a boat-mounted echo-sounder coupled with a global positioning system device. Data was collected along parallel transect lines spaced approximately 500 feet apart over the surface of Falls Lake. In addition, data along several lines from the upstream to downstream end of the reservoir were collected as cross-checks to the transect data. This Special Study was conducted with support from the USACE.	The UNRBA Bathymetry and Sediment Mapping Study Plan describes the study methods for this study: https://www.unrba.org/monitoring-program	Data from this survey effort will be processed to produce tables and graphics showing the relationship between stage and both water volume and surface area as well as maps showing depth contours and locations of sediment accumulation.
Topography: NHDPlus Version 2 (2012) National Elevation Dataset (NED)	The NED is the primary elevation data product of the USGS. NED serves as the elevation data layer for the WARMF watershed model. The National Map is available at a 10-meter resolution digital elevation model (DEM) for the Falls Lake watershed. Local government elevation data will be incorporated where available.	www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php (USGS, USEPA and Horizon Systems 2012) Industry standard, public domain data source that can provide resolution necessary to conduct watershed modeling. The USGS Information Quality Guidelines can be found at www.usgs.gov/info_qual/. An evaluation of the accuracy and data quality of NED is available here: http://pubs.usgs.gov/of/2014/1008/pdf/ofr2014-1008.pdf. Standards and specifications for the National Geospatial Program are available here: https://nationalmap.gov/standards/index.html. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	This resolution is sufficient to support watershed scale modeling. It will be used to calculate topography-based model input parameters. Derivatives of this dataset will be used to verify (and update if necessary) the contributing watershed area and subcatchment boundaries for the Falls Lake watershed. Derivative datasets from the elevation grid include flow direction & flow accumulation grids, as well as the Watershed Boundary Dataset.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Land Use, Land Cover, and Impervious Cover	NLCD is a Landsat satellite-based landcover database converted to a 30-meter resolution grid, with several independent data layers, that allows users a wide variety of applications. This has been applied consistently across the conterminous United States at a spatial resolution of 30 meters. The database includes: • 16 classes of land-cover data derived from the imagery, ancillary data and derivatives using a decision tree • Classification rules, confidence estimates and metadata from the land cover classification This dataset is currently the best available statewide land use coverage. The NLCD land use scheme will be re-classified in WARMF to provide simplified land use categories that are more meaningful in terms of estimating pollutant loading rates. Local government, state agency, and agricultural groups will be consulted for additional land use and imperviousness data, and input will be incorporated where available.	USGS NLCD Dataset (2006 and 2011) Multi-Resolution Land Characteristics Consortium www.mrlc.gov/index.php Industry standard, public domain data source that provides resolution necessary to conduct GIS mapping and watershed modeling. The latest version of NLCD database will be used for Falls Lake study. A list of the rigorous thematic land cover product accuracy assessments that have been completed for NLCD can be found at: pubs.usgs.gov/fs/2012/3020/fs2012-3020.pdf. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	Definition of land use parameters for WARMF sub-watersheds Development of study area background information.

Dataset	Description and Source	URLs and QA/SOP Information	Application
USDA NASS Cropland Data Layer	The USDA, NASS Cropland Data Layer (CDL) is a raster, geo-referenced, crop-specific land cover data layer. For NC, the CDL is available each year from 2008. The 2016 CDL has a ground resolution of 30 meters. The CDL is produced using satellite imagery from the Landsat 8 OLI/TIRS sensor and the Disaster Monitoring Constellation (DMC) DEIMOS-1 and UK2 sensors collected during the current growing season. Some CDL states used additional satellite imagery and ancillary inputs to supplement and improve the classification. These additional sources can include the USGS NED and the imperviousness and canopy data layers from the USGS National Land Cover Database 2011 (USGS, 2011). The Falls Lake Watershed Oversight Committee (WOC), the NC Department of Agriculture and Consumer Services, and the Division of Soil and Water Conservation will be consulted for additional land use data.	https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.php Information quality guidelines for USDA NASS are available at www.nass.usda.gov/About_NASS/Information_Quality_Guidelines/index.asp. Data product quality standards are available at www.ers.usda.gov/about-ers/ers-data-product-quality/ers-data-product-quality-standards.aspx#.VEFDtmddXy0. The WOC, NC Department of Agriculture and Consumer Services, NC Division of Agriculture, and Division of Soil and Water Conservation include representatives from local, state, and federal agencies and university researchers. Data compilation and analysis is conducted by these individuals and submitted to DWR for annual reporting. Data and reporting from these groups is assumed high quality for the purposes of this modeling study.	The CDL will be used to refine NLCD land use classifications for agricultural areas to allow for more specific model parameterization. The CDL will be evaluated for differences from one model year to the next to evaluate variations in crop production from year to year.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Agricultural Practices and Land Management	The WOC provides annual status reports for compliance with Stage I of the Falls Lake Nutrient Management Strategy. The report includes watershed-level information on reduction of area used for agricultural production, the area of buffers installed, nitrogen and phosphorus fertilization rates by crop type, acreage of crops grown. The report also estimates changes to nitrogen loss and phosphorus trends in the Falls Lake Watershed. The Team will work with the WOC, NC Department of Agriculture and Consumer Services, and Division of Soil and Water Conservation to determine if county-level information can be provided for those items in the report where only watershed-scale values are provided and to obtain additional agricultural information not included in the WOC reports.	http://www.ncagr.gov/SWC/watershed/NSW_strategies_FallsLake-oversight.html The WOC, NC Department of Agriculture and Consumer Services, and Division of Soil and Water Conservation include representatives from local, state, and federal agencies and university researchers. Data compilation and analysis is conducted by these individuals and submitted to DWR for annual reporting. Data and reporting from these groups is assumed high quality for the purposes of this modeling study.	Characterize agricultural land use and management for watershed modeling.
Soil General Map Unit Boundary and Properties from the Natural Resources Conservation Service	STATSGO2 (State Soil Geographic 2) dataset includes soil formation, type and distribution, which directly impact watershed hydrology and constituent loads. The Digital General Soil Map of the United States or STATSGO2 is a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped of 1:250,000 in the continental U.S., Hawaii, Puerto Rico, and the Virgin Islands and 1:1,000,000 in Alaska.	www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053629 https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627 Industry standard, public domain data sources that can provide resolution necessary to conduct GIS mapping and modeling. The Mid-Atlantic and Caribbean Area Soil Survey Region 3, as part of the National Cooperative Soil Survey Program, provides quality assurance for most of North Carolina and the Mid-Atlantic states. The Central Appalachian Interior	Guidance for initial soil parameters for WARMF sub-watersheds Development of study area background information.

Dataset	Description and Source	URLs and QA/SOP Information	Application
	The level of mapping is designed for broad planning and management uses covering state, regional, and multi-state areas. The U.S. General Soil Map is comprised of general soil association units and is maintained and distributed as a spatial and tabular dataset. The U.S. General Soil Map was developed by the National Cooperative Soil Survey and supersedes the previous STATSGO dataset. More refined soil maps are available through the SSURGO database at scales ranging from 1:12,000 to 1:63,360. Both datasets will be evaluated for appropriateness of scale for this modeling project.	Mountains and Plateaus Region Soil Survey Region (SSR6) also covers part of North Carolina. Information quality guidelines for USDA NASS are available at www.nass.usda.gov/About_NASS/Information_Quality_Guidelines/index.asp. Data product quality standards are available at www.ers.usda.gov/about-ers/ers-data-product-quality/ers-data-product-quality-standards.aspx#.VEFDtmddXy0.	

Dataset	Description and Source	URLs and QA/SOP Information	Application
Stream Water Quality Data	Water quality data in the tributaries to Falls Lake are collected by the UNRBA, DWR, and USGS. UNRBA tributary monitoring data are collected under an approved QAPP and are stored in the UNRBA data portal. DWR data are compiled from STORET. USGS data are available from the NWIS data portal.	Compilation of Water Quality Data Collected under an Approved QAPP by UNRBA, DEQ, USGS, CAAE, City of Durham, and City of Raleigh is available through the UNRBA Data Portal: https://www.unrba.org/monitoring-program QAPPs and SOPs are available at the following URLs: UNRBA – https://www.unrba.org/monitoring-program DWR - https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/microbiology-inorganics-branch/methods-pqls-qa USGS - The USGS Information Quality Guidelines can be found at www.usgs.gov/info_qual/. The USGS' *Branch of Quality Systems* (https://bqs.usgs.gov/) operates seven blind sample quality assurance projects or programs to benefit the USGS Water Science Centers, the USGS laboratories, and to assure USGS analytical data quality. Documents from the other organizations are not posted online.	Stream water quality data used for WARMF water quality calibration.
Stream Gage Data	The USGS collects flow and stage data at several gages in the watershed. Depending on the gage, data are available as either sub-hourly or daily flow estimates. Historical flow records will be obtained directly from the USGS for this project.	USGS NWIS Water Data for NC: waterdata.usgs.gov/nc/nwis/nwis The USGS Information Quality Guidelines can be found at www.usgs.gov/info_qual/.	Stream gage data used for WARMF hydrologic calibration.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Falls Lake Elevation, Inflow, Outflow and Precipitation Data	For Falls Lake, daily estimates of lake elevation, inflow to the lake, release from the lake, and precipitation data will be obtained from the USACE. This data also includes monthly withdrawal volume for water supply.	http://epec.saw.usace.army.mil/fall.htm. Information quality guidelines for the USACE are available at http://www.usace.army.mil/Information-Quality-Act/.	Model development and calibration for lake models.
Water Supply Withdrawals, Returns, and Routing through Smaller Impoundments	In 2009, DWR developed the Neuse River Basin Hydrologic Model. This mass balance model accounts for tributary background flows, withdrawals, point sources, and routing through impoundments. The routing equations will be evaluated for application to the WARMF watershed simulation of the impoundments in the Falls Lake watershed.	https://deq.nc.gov/about/divisions/water-resources/planning/basin-planning/map-page/neuse-river-basin/neuse-river-basin-model The Neuse River Basin Hydrologic Model was developed by DWR and their consultants. Model inputs and outputs from this assessment are assumed high quality for the purposes of this modeling study. Supplemental information, for water withdrawals and returns, will be requested from stakeholders in the Falls Lake Watershed including drinking water utilities.	WARMF watershed model inputs to characterize water withdrawals and returns in the watershed as well as hydrologic routing in upland impoundments.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Lake Monitoring Data and Locations	Several organizations collect and analyze water quality, biological, and field parameter data in Falls Lake including the UNRBA, DWR, CAAE, City of Durham, and City of Raleigh. All Falls Lake monitoring data collected under an approved QAPP are stored in the UNRBA data portal. DWR data are compiled from STORET. Data from other organizations are obtained from staff for compilation in the UNRBA database. Data include water quality data and measurements of velocity measurements at two bridge causeways following wet weather events. These organizations and local governments will be consulted for water quality data available for the smaller impoundments in the watershed.	Compilation of Water Quality Data Collected under an Approved QAPP by UNRBA, DEQ, CAAE, City of Durham, and City of Raleigh: https://www.unrba.org/monitoring-program QAPPs and SOPs are available at the following URLs: UNRBA – https://www.unrba.org/monitoring-program DWR - https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/microbiology-inorganics-branch/methods-pqls-qa Documents from the other organizations are not posted online.	Calibration of lake models Development of study area background information.
UNRBA Lake Sediment Evaluation and Sediment Mapping	Benthic flux estimates for nitrogen and phosphorus are based on modeling and sediment core data collected by Dr. Mark Alperin (UNC) under contract to the UNRBA. In March 2017, as part of the UNRBA Bathymetry Special Study, dual frequency echo-sounder data was collected to estimate the depth of unconsolidated sediment across the bottom of Falls Lake. This sediment mapping data will be used to improve estimates of nutrient releases from lake sediments by identifying the proportion of the lake bottom with unconsolidated sediments.	The UNRBA Lake Sediment Evaluation Study Plan and the Bathymetry and Sediment Mapping Study Plan describe the methods for these two special studies: https://www.unrba.org/monitoring-program	Provide sediment characterization model inputs for the EFDC sediment diagenesis model Support model development and calibration estimates for nutrient releases from lake sediments

Dataset	Description and Source	URLs and QA/SOP Information	Application
Census Data	Human population and financial demographic data by census block.	www.census.gov/2010census/popmap/ipmtext.php?fl=40 Industry standard, public domain data source. Provides resolution necessary to conduct GIS mapping and modeling. In accordance with the Information Quality Act, the Census Bureau Information Quality web site (www.census.gov/quality/) contains the Census Bureau's Statistical Quality Standards, information quality guidelines, and procedures to seek correction of information that does not comply with the information quality guidelines.	Development of study area background information.
Urban Nutrient Application	Application of fertilizer to residential lawns and public and private open spaces.	Information from local governments and university researchers will be used to develop inputs for rates, timing, and forms of urban nutrient application (i.e., lawn fertilization). Each local government is responsible for ensuring the accuracy of the information describing the practices and their nutrient credits. Researches at NCSU have published studies on fertilizer use in residential areas near the Falls Lake watershed. These researchers will be consulted regarding the application of fertilizer to urban areas.	Provide inputs to the watershed model.
Implementation of Best Management Practices by Local Governments	The UNRBA is developing the UNRBA Credit Tool to track progress towards compliance with required nutrient load reductions in the Falls Lake watershed. Once this Tool is finalized (summer 2017), each local government or utility will be able to import or input data on practices that have been implemented in the watershed.	Data will be compiled from member local governments and utilities using the UNRBA Credit Tool. Each local government is responsible for ensuring the accuracy of the information describing the practices and their nutrient credits.	Provide general characterization of watershed conditions and nutrient management activities for WARMF watershed model.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Onsight Wastewater Management Data and Information from Local Governments and DEQ	Inventories of onsite wastewater treatment systems and sand filter systems will be compiled from DEQ and the local governments in the watershed. If spatial datasets are not available, sewer line coverages will be obtained to estimate the density of onsite systems for residential areas.	Data and information will be compiled from member local governments, utilities, and DEQ. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	Provide characterization of watershed conditions management activities for WARMF watershed model.
Point Source Wastewater Discharges	Self-reporting monthly Discharge Monitoring Report (DMR) data and National Pollutant Discharge Elimination System permit limits for all permittees in the study area for the period of record. Data to be obtained include daily effluent flow rates, and corresponding solids, organic carbon, phosphorous, and nitrogen concentrations.	USEPA DMR Pollutant Loading Tool: cfpub.epa.gov/dmr/facility_search.cfm NCDEQ eDMR: https://deq.nc.gov/about/divisions/water-resources/edmr Data from State and Federal agencies is assumed high quality for the purposes of this modeling study. Additional data and information will be compiled from member local governments and utilities. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	Input into WARMF Development of study area background information.
Sewage Disposal Method	Septic system data and studies available from local governments, utilities, and DEQ will be prioritized for model development. Supplemental information from the 1990 federal census data will be used to estimate the occurrence of sewage disposal methods [sanitary sewer, onsite sewage facility, or other] in each modeling area. This information was provided in STF (summary tape file) 3C with over 3,300 cells/items of sample population and housing characteristics	Each local government and utility is responsible for ensuring the accuracy of the information and data provided. STF-3C from the U.S. Census Bureau: www.census.gov/mp/www/cat/decennial_census_1990/ The 1990 Detailed Housing Characteristics for North Carolina: https://www.census.gov/library/publications/1993/dec/ch-2.html Industry standard, public domain	Estimation of input parameters for WARMF watershed model Development of study area background information

Dataset	Description and Source	URLs and QA/SOP Information	Application
	for each geographic area, and tables at block group resolution in 1990. However, it is not available for the 2000 or 2010 census. Geospatial resolution of data is only available at county level so quantifying onsite sewage facilities within watershed boundaries can only be estimated.	data source that can provide resolution necessary to conduct GIS mapping and modeling. In accordance with the Information Quality Act, the Census Bureau Information Quality web site (www.census.gov/quality/) contains the Census Bureau's Statistical Quality Standards, information quality guidelines, and procedures to seek correction of information that does not comply with the information quality guidelines.	
Non-discharge Permits	The NCDEQ Non-Discharge Permitting Unit permits and monitors compliance for residual and wastewater effluent land application facilities as well as reclaimed water systems. Stakeholders and local governments in the watershed will also be consulted for this information.	https://deq.nc.gov/about/divisions/water-resources/water-resources-permits/wastewater-branch/non-discharge-permitting Available information will be acquired from staff in this Unit. Data from State agencies is assumed high quality for the purposes of this modeling study. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	Characterization of model inputs for the WARMF watershed model.
Sanitary Sewer Overflows	NCDEQ maintains the Basinwide Information Management System (BIMS) for bypasses, complaints, Sanitary Sewer Overflows, and spills. Utilities and local governments in the watershed will also be consulted for this information.	https://deq.nc.gov/about/divisions/water-resources/bims Data from State agencies is assumed high quality for the purposes of this modeling study. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	Model inputs for WARMF watershed.
On-Site Wastewater Disposal Complaint Data	Location or narrative information describing specific sites that have demonstrated unauthorized seepage or discharge to land or receiving waters. Utilities and local governments in the watershed will also be consulted for this information.	NCDEQ BIMS: https://deq.nc.gov/about/divisions/water-resources/bims Supplemental information may be obtained from State and county health departments. Data from State and local health departments is assumed high quality for the purposes of this modeling study.	Estimation of input parameters for WARMF watershed model Development of study area background information

Dataset	Description and Source	URLs and QA/SOP Information	Application
		Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	
North Carolina Agricultural Census Data	Total population estimates for various livestock species derived from the Agricultural Census at a county level. In addition to cattle, swine, and poultry, population estimates for other types of livestock are provided. This data will be supplemented by information from the Falls Lake WOC, NC Department of Agriculture and Consumer Services, and Division of Soil and Water Conservation.	https://www.nass.usda.gov/Statistics_by_State/North_Carolina/index.php This Census data is compiled by the U.S. Department of Agriculture every five years. It is the only source of consistent, comparable, and detailed agricultural data for every county in America (USDA). This is the best source of public domain data that provides data necessary for assessment. Information quality guidelines for USDA NASS are available at www.nass.usda.gov/About_NASS/Information_Quality_Guidelines/index.asp. Data product quality standards are available at www.ers.usda.gov/about-ers/ers-data-product-quality/ers-data-product-quality-standards.aspx#.VEFDtmddXy0. The WOC, NC Department of Agriculture and Consumer Services, and Division of Soil and Water Conservation include representatives from local, state, and federal agencies and university researchers. Data compilation and analysis is conducted by these individuals and submitted to DWR for annual reporting. Data and reporting from these groups is assumed high quality for the purposes of this modeling study.	Estimation of parameters for WARMF input files.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Animal Feeding Operation Locations	Locations of Animal Feeding Operations (AFOs) and Confined Animal Feeding Operations (CAFOs), as well as the type, and maximum number of dairy cattle, beef cattle, swine, and chickens for each location. Staff at DEQ will be consulted to refine the average number of animals at AFOs/CAFOs based on annual inspection reports compiled by DEQ. This data may also be supplemented with information from the Falls Lake WOC, NC Department of Agriculture and Consumer Services, and Division of Soil and Water Conservation.	NC DEQ CAFO database and map: https://deq.nc.gov/cafo-map Supplementary information may be acquired from the Falls Lake WOC. The DEQ, WOC, NC Department of Agriculture and Consumer Services, and Division of Soil and Water Conservation include representatives from local, state, and federal agencies and university researchers. Data compilation and analysis is conducted by these individuals and submitted to DWR for annual reporting. Data and reporting from these groups is assumed high quality for the purposes of this modeling study.	Input parameters for WARMF watershed model Development of study area background information
Meteorological Data	Daily precipitation, maximum and minimum daily temperature, wind speed, dew point, cloud cover, and air pressure recorded at stations in the modeled watersheds for the model period. Annual average precipitation will also be established using daily records. Estimates of solar radiation are available from the NC Climate Retrieval and Observations Network of the Southeast (NC CRONOS) Database. NC CRONOS provides hourly or aggregated data for the meteorological inputs required by the watershed and lake models.	NOAA National Climatic Data Center (NCDC): www.ncdc.noaa.gov NOAA is a public domain data source. Information quality for this agency is available at http://www.cio.noaa.gov/services_programs/info_quality.html. NC CRONOS: http://climate.ncsu.edu/cronos NC CRONOS is operated out of North Carolina State University. Data and information from this source are assumed high quality for the purposes of this study. USGS NWIS Water Data for NC: waterdata.usgs.gov/nc/nwis/nwis The USGS Information Quality Guidelines can be found at www.usgs.gov/info_qual/.	WARMF and EFDC inputs. Development of study area background.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Nutrient Atmospheric Loads	Estimated phosphorus and nitrogen air deposition fluxes will be input as direct sources to the watershed and the lake.	National Atmospheric Deposition Program (NADP): http://nadp.sws.uiuc.edu/data/ Quality assurance information for NADP are available at nadp.sws.uiuc.edu/QA/. Clean Air Status and Trends Network (CASTNET): java.epa.gov/castnet/epa_jsp/sites.jsp Quality assurance information for CASTNET are available at http://epa.gov/castnet/javaweb/docs/qapp_v8-2_Main_body.pdf. Community Multi-Scale Air Quality (CMAQ) Modeling System for Air Quality Management: https://www.epa.gov/air-research/community-multi-scale-air-quality-cmaq-modeling-system-air-quality-management Information on the CMAQ Review Process is available at https://www.cmascenter.org/cmaq/. City of Durham Atmospheric Deposition Monitoring Study (AMEC, 2012).	WARMF and EFDC model input files
DEQ Integrated Report Files	Contains information on water quality status, surface water classifications, and support assessments for NC waterbodies.	https://deq.nc.gov/about/divisions/water-resources/planning/modeling-assessment/water-quality-data-assessment/integrated-report-files Industry standard, public domain data source that can provide resolution necessary to conduct GIS mapping and modeling. Data from State agencies are assumed high quality for the purposes of this study.	Provides background information for the lake and watershed.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Public Park and Recreation Facilities Adjacent to Lakes	Several organizations maintain recreational facilities on Falls Lake including Wake County, City of Raleigh, North Carolina Wildlife Resource Commission, North Carolina Division of Parks and Recreation, and the USACE. A summary of the information collected by each organization was provided in the UNRBA 2016 Annual Monitoring Report available at https://unrba.org/monitoring-program. Local governments in the watershed will also be consulted for this information for the smaller impoundments in the watershed. .	The UNRBA 2016 Annual Monitoring Report summarizes the available information. A copy of this report is available at https://unrba.org/monitoring-program. The Team will update this information as needed by contacting representatives from each organization. Each local government and utility is responsible for ensuring the accuracy of the information and data provided.	Provides geographic orientation and background information
Roads and County Boundaries	Road and county boundary GIS datasets for the study area. This study will use Topologically Integrated Geographic En coding and Referencing (TIGER) shapefiles from the U.S. Census Bureau and data from the NC Department of Transportation (NCDOT). TIGER products are spatial extracts from the Census Bureau's Master Address File TIGER database, containing features such as roads, railroads, rivers, as well as legal and statistical geographic areas.	Industry standard that can provide resolution necessary to conduct GIS mapping and modeling. www.census.gov/geo/maps-data/data/tiger.html Tiger data is found at the following webpage: www.census.gov/geo/maps-data/data/tiger.html In accordance with the Information Quality Act, the Census Bureau Information Quality web site (www.census.gov/quality/) contains the Census Bureau's Statistical Quality Standards, information quality guidelines, and procedures to seek correction of information that does not comply with the information quality guidelines. Supplemental information from NCDOT and local governments in the watershed will be requested during the data compilation process. Information may include refined roadway characterization, best management practices, and right of way information.	Provides geographic orientation and background information for figures and maps. Provides refined land use characterization for roads and highways.

Dataset	Description and Source	URLs and QA/SOP Information	Application
Ecoregions Level III and IV	Geospatial data delineating ecoregions which denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components.	USEPA Ecoregions of North Carolina webpage: https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states Industry standard, public domain data source that can provide resolution necessary to conduct GIS mapping and modeling. Data from federal agencies are assumed high quality for the purposes of this study.	Provides geographic orientation and background information

B.9.5 Quality and Limitations of EFDC Lake Model Data

Originally developed at the Virginia Institute of Marine Science by Hamrick (1992, 1996), EFDC is now supported by USEPA as a public domain surface water model for use in TMDL and other water quality management planning studies (USEPA, 2014b). EFDC is an advanced and peer-reviewed hydrodynamic, sediment transport, and water quality model that can be used to simulate aquatic systems in one, two, and three dimensions. EFDC has evolved over the past two decades to become one of the most widely used and technically defensible hydrodynamic, sediment transport, and water quality models in the world (Ji, 2008). EFDC is a robust dynamic model. However, just like any other water quality model, an EFDC model of a waterbody approximates a complex natural system. Thus, there are inherent uncertainties within the EFDC model itself.

The following are limitations of the EFDC lake model:

- **Observed data:** Same limitations as for the WARMF model also exist for the EFDC model
- **Meteorology:** Same limitations for the WARMF model also exist for the EFDC model.
- **Radical Parameter Changes:** Same limitations as for the WARMF model exist for the EFDC model. Large departures from model calibration conditions increase the level of uncertainty for lake model predictions.
- **Sediment Bed Data:** Sediment bed data are needed for setup of the sediment transport and the sediment flux sub-models of the EFDC lake model. Bed solids content and bed porosity are assigned for the sediment transport model. Bed organic content (as carbon, nitrogen and phosphorus) and inorganic porewater nutrient concentrations are assigned for the sediment flux model. Data are available from the UNRBA Sediment Evaluation Special Study to characterize the concentrations of solids and organic matter (as C, N, P) in the sediment bed of Falls Lake. Data from this study will be used for model setup to develop initial sediment bed conditions for the Falls Lake model. Published literature and data measured in other reservoirs may be referenced to support calibration of the EFDC lake model for Falls Lake.

B.10 Data Management

B.10.1 Personnel

The Modeling Task Managers will have primary responsibility for performing all tasks related to data management for modeling purposes through completion of the Falls Lake Reexamination Study. They will coordinate closely with the PM who will obtain data files needed for the project and to ensure that the data provided in the source files is accurate and unambiguous. The Modeling Task Managers will be assisted, on an as needed basis, by other staff from Dynamic Solutions or Brown and Caldwell with review by the QA Officer and the PM.

B.10.2 Hardware and Software Requirements

Hardware

The data processing equipment that will be required for the development of the watershed and lake models for the Falls Lake Study Area are PC-based desktop and laptop computers.

The computers used at Brown and Caldwell and Dynamic Solutions are Dell computers with Microsoft® Windows 7 and/or Windows 10 Professional operating systems. These computers are equipped with the Microsoft® Office Professional Plus 2016 which includes Microsoft® Excel and Microsoft® Access. Access to computers is username and password protected.

All the electronic data is maintained on Windows-based file servers at Brown and Caldwell and Dynamic Solutions. File servers consist of Dell PowerEdge servers, running Microsoft® Windows Server software, providing storage, database access, as well as file and print services to an Ethernet network. Storage devices are running in a virtualized RAID-5 environment and distributed among several physical units. All the Brown and Caldwell computerized data are physically located at their office in Raleigh, NC and backed up to off-site servers in Austin, TX daily. Dynamic Solutions computerized data in Knoxville, TN and backed up to offsite servers daily.

Software

When data series from more than one source need to be compiled, statistical tests will be performed prior to merging the sets. Custom software or model code developed by Brown and Caldwell, and/or Dynamic Solutions using Microsoft Excel or R will be used for this purpose. GIS processing will be completed using ArcGIS 10 (ESRI, 2010a; 2010b).

The WARMF model (watershed and lake model) Version 6.7q will be used for this project (Chen et al., 1999). WARMF models require an IBM compatible PC, at least 64 MB RAM and a Windows operating system (XP or more recent). A faster processor and more RAM will provide more efficient performance and may be required for complex simulations on a short time step, such as for this study. The WARMF model is EPA-approved and public domain, which means the model executables and supporting documents can be freely downloaded and used by the public. All equations and algorithms are well documented and can be fully reviewed in the model documentation; however, the source code itself is proprietary, owned by Systech Water Resources, Inc.

The EFDC lake model is executed from EFDC_Explorer in an MS-DOS window and requires a dual core 2.66 GHz Pentium processor, a 32-bit processor with 2 GB RAM, and more than 10 GB available as hard disk space to achieve efficient runtimes. EFDC_Explorer (Version 8) will be used to support EFDC model setup and model calibration for Falls Lake. The EFDC model is EPA-approved, public domain and open source. EFDC_Explorer is proprietary software. However, a 30-day trial version of EFDC_Explorer can be obtained from Dynamic Solutions free of charge. No other proprietary models or software will be used to support this project.

B.10.3 Data Management Process

To facilitate UNRBA's data management needs associated with the UNRBA Monitoring Program, Brown and Caldwell has created and maintains a database that includes data generated under Sections B.1 through B.8 of the UNRBA Monitoring Program QAPP. The database also includes data collected by federal, state, and/or local agencies as described in section B.9 of the UNRBA Monitoring Program QAPP. All database entries are tracked per the data-generating organization. Data included in the database are limited to data collected within Falls Lake and at watershed sites defined as lake loading sites or jurisdictional boundary sites in the UNRBA Monitoring Plan. It also includes any Special Studies conducted under the Monitoring Plan. The database does not include data collected by UNRBA member jurisdictions at sites other than those specified in the UNRBA Monitoring Plan. This database will serve as the primary repository for data that will be used to develop model input files and support model development.

Consistent data management procedures will be used during all stages of the project, and a data management plan will be developed. The available data sources that will be used to develop the watershed model and lake models include geospatial data (e.g., land use data or elevation grids) and time-varying data (e.g., meteorology, flow, and water quality time-series). The various data sources described in Section B.9.1 will be compiled and converted to the input formats required by the WARMF and EFDC models. The original datasets are obtained in a variety of electronic and hardcopy formats. All original data sources will be documented to identify contact information, formats, measurement units, and filenames of data obtained.

Location data originally reported as either geographic (latitude, longitude) or North Carolina State Plane coordinates will be transformed to Universal Transverse Mercator Easting and Northing coordinates (as meters) with the horizontal projection based on North American Datum of 1983 for Zone 17. Topographic and bathymetric elevation data will be transformed to North American Vertical Datum of 1988 in meters as the reference vertical datum if the original data are provided as a vertical datum based on the National Geodetic Vertical Datum of 1929. The USACE software utility (CorpsCon6) will be used to convert vertical datum of elevation data to North American Vertical Datum of 1988. Consistent Universal Transverse Mercator coordinates are used for development of the EFDC computational grid, georeferenced maps, locations of stream and lake monitoring stations and other geographic landmarks for generating maps for the project. Spatial data to be imported to the WARMF model must be converted to geographic coordinates, including updated catchment boundaries, stations locations, stream reaches, county boundaries, or other reference data for the graphical user interface.

Date and time (as local Eastern Standard Time, EST), which are used directly for the WARMF model, are converted to decimal Julian days relative to January 1, 1990 for EFDC lake model setup and calibration. This space, depth, and time coordinate convention has been adopted for all Dynamic Solutions surface water modeling projects to facilitate a consistent pre-processing procedure for compilation of data obtained from a wide variety of original sources files. Original data sources, data filenames, and units of measurement for datasets are recorded in project notebooks and any software codes written to process original data sources. Any manipulations, transformations, conversions, assumptions, or methods used to fill in or flag missing data needed to write the original data into the standard database format are recorded for each data source in project notebooks as well as e-mails or documentation notes in any program code written for pre-processing purposes. Details about the back up plans for electronic data were included in Section A.9.4

B.10.4 Spatial Processing of Data

The data sources in Section B.9 are used to conduct GIS mapping and modeling in this project. ArcGIS is the GIS platform that will be used. GIS maps combine powerful visualization with a strong analytic and modeling framework. ArcGIS contains a comprehensive collection of spatial analysis tools for modeling various situations. The management of digital data demands the use of QA/QC parameters throughout the project to maintain data integrity. With the increased dissemination of digital data, this aspect of GIS management is most important. The quality of digital data can be ensured with management focused in three fundamental areas. The initial project management component is the first phase. Maintenance of QA/QC procedures throughout the project is the second phase, followed by a final quality assurance checks prior to data delivery.

Managing a GIS project can be difficult without QA/QC. Since there can be subtasks, multiple workers, and various forms of output, the margin for error can be quite large. The often poorly defined QA/QC protocol contributes to inconsistencies in data management. From conception to data delivery, a project should pass through a series of checks which are established control measures. The range of acceptable values sought by the control measures are quality assurance parameters. Project progress is directly proportional to the level of confidence in the data.

To produce high-quality map products and perform accurate data analysis, the source database must be of high quality and well maintained. ArcGIS includes Data Reviewer which is the QC tool for ArcGIS data. ArcGIS Data Reviewer allows the management of quality control and data analysis.[1] Data Reviewer provides a complete system for automating and simplifying data quality control, which can quickly improve the integrity of the data.

ArcGIS Data Reviewer consists of a series of tools that support both automated and visual analysis of data.[2] Data Reviewer can be used to detect anomalies with features, attributes, and relationships in databases. Data checks contain the analysis rules and can be scheduled to run automatically or run as necessary. Results of the analysis are logged in a Reviewer session, which is used to manage the life cycle of the analysis. Depending on the type of analysis being performed, the anomaly can be corrected as part of database maintenance or investigated further. The ArcGIS data analysis consists of:

- **Spatial checks:** Spatial checks analyze the spatial relationships of features.
- **Attribute checks:** Attribute checks analyze the attribute values of features and tables. This can be simple field validation like a geodatabase domain or with more complex attribute dependencies.
- **Feature integrity checks:** Feature integrity checks analyze the properties of features. Feature integrity checks ensure that the collection rules are followed for each feature class.

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[1] ArcGIS Resources: Understanding the Quality Control Life Cycle: http://blogs.esri.com/esri/arcgis/2010/08/20/understanding-the-quality-control-life-cycle/

[2] ArcGIS Resource Center; Desktop 10: http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/What_is_Data_Reviewer/01020000003p000000/

- **Metadata checks:** Metadata checks analyze the metadata information of the feature datasets and feature classes. Metadata can contain critical information about the source used to collect the derived data which can significantly impact the reliability of the data.
- **Managed data reviews:** Managed review of data is essential to complete data analysis. Whether reviewing the data through automated checks or visually, it is essential to understand the integrity of the entire database.

B.10.5 Migration/Transfer/Conversion

The Team routinely prepares and exchanges data and reports electronically in a variety of formats including any format available in Microsoft Word 2010/2013 (doc/docx), Microsoft Excel (XLS/XLSX, CSV, TXT, DBF, etc.), and Portable Document Format (pdf) files using Adobe Acrobat. The Team also processes data from the EPA's STORET database, USGS databases, and many other state and local agency database sources to acquire and use data necessary in a modeling project. During the project, input files, model results files, and deliverables will be uploaded to the Brown and Caldwell, Systech Water Resources, or Dynamic Solutions FTP site or VPN server. The Team maintains a modern e-mail system and dedicated FTP sites to facilitate secure data exchange with clients and other authorized people needing access to the large electronic files typical of our watershed and lake modeling projects. The Team Modeling Task Managers will have primary responsibility for performing tasks related to the transfer of modeling project files to the FTP site.

B.10.6 Information Dissemination

Project updates will be provided to the UNRBA in periodic telephone discussions, e-mail communications, and monthly progress reports associated with project invoices, and status reports at PFC and BOD meetings. Input data and model outputs resulting from the project described in this QAPP will be accessible to interested stakeholders and the public by written request to the UNRBA Executive Director. Key findings that result from the watershed and lake models used to support the determination of load allocations for the Falls Lake Study Area may be summarized in "fact sheets" prepared and distributed by UNRBA.

B.10.7 Data Delivery

Copies of all derived input and output datasets will be provided by the Team to the UNRBA and DWR. The original raw datasets, executable files from the WARMF and EFDC models, EFDC_Explorer files, post-processing codes, reformatted files, watershed and lake model results, and the modeling report will be uploaded to the Brown and Caldwell, Systech Water Resources, or Dynamic Solutions FTP site for download.

After the project, the Team will provide technical assistance to the UNRBA to ensure that the current versions of WARMF and EFDC models and input/output files for model calibration runs can be installed and operated properly on UNRBA computers. All components will also be burned onto read only disks by The Team and sent to the UNRBA by U.S. mail or express carrier. Another copy of project files will be archived at the Dynamic Solutions headquarters office in Knoxville, Tennessee; the Systech Water Resources office in Walnut Creek, CA; and the Brown and Caldwell office in Raleigh, North Carolina.

SECTION C — ASSESSMENT AND OVERSIGHT

C.1 Assessments and Response Actions

Assessment and response actions for data review, model calibration, and software errors are described below. A summary of tasks, responsibilities, and actions are provided in Table C.1-1.

C.1.1 Data Review

Most of the data used in this project have been produced under well-documented quality conditions. To further assure the quality of data used for model development and calibration, all data will be assessed (based on metadata and thorough review) to determine if it meets the project requirements for consistency and other acceptance criteria as described under Section A.7. The Team will evaluate geospatial data, meteorological data, hydrological data, and water quality data to be used in calibration and as model input. Any concerns with respect to data quality and usability will be brought to the attention of the data source agency. Direction and routine supervision of data tasks will be provided in a team effort by the Lead Modeler for each task, Quality Assurance Manager, and PM.

C.1.2 Model Calibration

The model calibration procedures and criteria for acceptable outcomes are provided in Section A.7 (Quality Objectives and Criteria) and B.7 (Model Setup and Calibration). Results will be reported to the Team QA Officer and PM. If agreement is not achieved between the model calibration performance standards and the predicted values, corrective action will be taken by the lead modeler to assure that the correct files are read appropriately, and the test is repeated to document compliance. If the predicted value cannot be brought within model calibration performance standards, the project PM will work with the UNRBA to arrive at an agreeable compromise.

C.1.3 Software Errors

Software requirements, software design, or code are examined to detect faults, programming errors, violations of development standards, or other problems. All errors found are recorded at the time of inspection, with later verification that all errors found have been successfully corrected. Software used to compute model predictions are tested to assess its performance relative to specific response times, computer processing usage, run time, convergence to solution, stability of the solution algorithms, the absence of terminal failures, and other quantitative aspects of computer operation. Any unresolved errors will be discussed with the UNRBA personnel listed in Section A.4 (Project Task/Organization) and the MRSW and documented in the monthly reports to the UNRBA by the PM.

Table C.1-1 Assessments and Response Actions

Assessment Activity	Responsible Party	Scope	Response Requirements
Status monitoring, oversight, etc.	Project Manager	Perform continuous monitoring of the project status and records to ensure requirements are being fulfilled	Team PM report to UNRBA in monthly report
Received geospatial data	GIS Specialist	Consistency check	Changes in data sources documented by PM in monthly report
Statistical analysis of temporal datasets	Lead Modelers & QA Officer, PM	Consistency check	Changes in data sources or exclusion of data documented by PM in monthly report
Processing of spatial and temporal data	Lead Modelers, QA Officer, PM	Development of model input data series	Unresolvable issues or changes in data sources are documented by PM in monthly report
Model calibration	Lead Modelers, QA Officer, PM	Verify that model results meet acceptable criteria	Acceptance of model results

C.2 Reports to Management

All the following reports are contract deliverables and will be delivered electronically to the UNRBA. The Team PM will coordinate the delivery of all reports to the UNRBA.

C.2.1 Progress Report

Monthly progress reports provide a summary of activities that outlines the status of each task; reports any problems, delays, quality issues, or corrective actions; identifies anticipated future activities; and highlights the budget status.

C.2.2 Corrective Action Report

Identifies any deficiencies and nonconformities. Report is submitted to the UNRBA after the deficiencies and/or nonconformance are identified. A template of the Corrective Action Form is provided in Appendix F.1.

C.2.3 Modeling Report

Preliminary and final draft modeling reports for both the WARMF and EFDC applications will be provided to the UNRBA for review and comment. Reports will be submitted for review to DWR and EPA Region 4 after review and approval by the UNRBA.

SECTION D — DATA VALIDATION AND USABILITY

D.1 Data Review, Verification, and Validation

The outcome of the project being addressed with this QAPP is the development of mechanistic and statistical models for the Falls Lake Watershed and Lake to support the Reexamination of the Falls Lake Rules Nutrient Management Strategy. This section of the QAPP defines the verification and validation steps necessary to determine if the developed models will be usable for their intended purpose. Verification of the models is the confirmation that all steps of the model development process were completed by approved, scientifically defensible methods. Validation of the models is the confirmation that model results are acceptable and reasonable for Falls Lake and the watershed, within the known limitations of the models, and as defined by predetermined performance criteria. Verification and validation will be performed for the fully developed and calibrated WARMF watershed model, WARMF lake model, EFDC lake model, and statistical lake to determine if the models can be used for their intended purpose of developing nutrient load reduction scenarios for the Reexamination.

D.2 Verification and Validation Methods

Verification of the methods used for model development (including all data processing, development of model inputs, and model calibration) will be accomplished as tasks and results are reported by the Modeling Task Managers and reviewed by the Team QA Officer, the PM, and the UNRBA.

Validation of the calibrated watershed and lake models will be accomplished by a standard model validation procedure by which the model will be run for a period that was not part of the calibration period. Results will be evaluated based on the performance criteria (Section A.7, Model Performance and Acceptance Criteria). The validation process will be conducted by the Modeling Task Managers and evaluated by the QA Officer and the PM. The UNRBA, as the end user of the watershed and lake model results, will also evaluate the performance of the models as results are reported in monthly reports and technical memoranda.

Validation of the external data sources used for development of model inputs and for model calibration will be accomplished by reviewing the data for integrity, consistency, reasonableness, and conformance to project requirements. The criteria for data acceptance and process of data validation were outlined in Section A.7. Only those data that are supported by appropriate QC procedures and meet the acceptance criteria will be considered suitable for use in this project. The Modeling Task Managers, QA Officer, and the PM are collectively responsible for ensuring that datasets are properly reviewed, verified, and converted to the required format for the intended use in the project.

Table B.9-1 presents information about selected Federal and State agency QA information and SOPs for the type of data and information that will be used to develop the watershed and lake model for the Falls Lake Study Area. Data publicly distributed by the USGS, other Federal agencies, or by the State of North Carolina are considered defensible for the purposes of this project. In addition to those agencies' rigorous QA/QC procedures, this assumption is based in part on the fact that in 2002 the United States Office of Management and Budget (OMB, 2002) issued Information Quality Guidelines directing all federal agencies to develop their own information quality guidelines. OMB guidelines require agencies to develop a process for reviewing the quality of information before it is disseminated to the public to ensure that it meets OMB's standards for objectivity, utility, and integrity.

D.2.1 Verification, Validation and Acceptance of the Watershed and Lake Models

The WARMF watershed and lake models have been well validated and widely used across the country. Detailed information about the WARMF watershed and lake model structures, scientific basis, and example applications and validation of the model are available in Chen et al. (1996, 1997, 1999, 2001, 2004, 2005, 2008); Herr et al. (2001, 2003, 2012); Geza and McCray (2007); Keller et al. (2014); McCray (2006); NCDWQ (2009a); Quinn et al. (2010, 2013); SC DHEC (2016); Stringfellow et al. (2009, 2014); Systech Water Resources, Inc. (2014); Vijayaraghavan et al. (2010); and Weintraub et al., (2004). The model has undergone a rigorous, external peer review process following the USEPA “Guidance for Conducting External Peer Review of Environmental Regulatory Models" (EPA 100-B-94-001) (Keller, 2000). The underlying algorithms within WARMF are adapted from established simulation codes. Thus, acceptance and validation for those models serve to further verify the scientific simulation approach within WARMF. These include the Storm Water Management Model (SWMM; Chen and Shubinski, 1971), Integrated Lake Watershed Acidification Study model (ILWAS; Gherini et al., 1985), Areal Non-Point Source Watershed Environment Response Simulation (ANSWERS, Beasley and Huggins, 1991), and the Lake Ecological Model (LAKECO; Chen and Orlob, 1973).

The EFDC lake model is an EPA-supported model which has been validated using analytical solutions, simulations of laboratory experiments, and verified prototype applications. The ongoing evolution of the EFDC modeling system has been driven by a diverse group of EFDC users in the academic, governmental, and private sectors. QA/QC information for the EFDC model is given in USEPA (2014a). An extensive bibliography of peer-reviewed journal and conference proceedings articles exist for the EFDC model (USEPA, 2014c).

The statistical lake model will be developed using pre-existing formulations or site-specific regressions for Falls Lake. The pre-existing formulas to be evaluated for this component of the modeling include EUTROMOD and BATHTUB which are well studied and have been applied for regulatory purposes (WERF 2010). Site-specific regressions, if needed, will be developed using established techniques including multiple regression modeling, structural equation modeling, and Bayesian statistics as described by Cardno (2013).

D.3 Reconciliation with Data Quality Objectives

The Team QA Officer, Modeling Task Managers, PM, and the UNRBA and DWR will review and evaluate the draft modeling report and calculations for consistency with the requirements of Sections B.7, D.1, and D.2 above. Necessary revisions and refinements will be made to the draft modeling report based on comments from the reviewers. Any significant limitations on the data used or modeling results shall be communicated between the project personnel listed in this subsection and documented in the modeling report.

The modeling framework developed for this project will be used to evaluate flow and watershed pollutant loadings to Falls Lake using the WARMF watershed model which will provide input data to the WARMF lake, EFDC lake, and statistical lake models to predict resulting concentrations of DO, nutrients, TOC, TSS, and chlorophyll-a, as well as loading reductions scenarios.

Using the approach and criteria discussed in Section A.7 Quality Objectives and Criteria, a determination will be made of the overall technical credibility of the methodology for evaluating water quality in Falls Lake. If model outputs show that they can meet the evaluation criteria specified in Section A.7, then they will be considered technically defensible, and therefore useable, to provide water quality results for the Falls Lake Reexamination. If performance measures of the WARMF, EFDC, and/or statistical models do not meet the project’s requirements for DQOs, the datasets used to construct the model and the assignment of model parameters will be re-evaluated to identify possible reasons for failure to meet the model performance criteria. Decisions will be made jointly by the Team and the UNRBA about (a) the validity of, and any unresolvable issues with, the input data and observed data used to construct the models, (b) the significance of below-target model performance at a location for the ultimate intended use of the models, and (c) the steps needed to complete or alter development of the watershed and lake models to achieve results that can be used for the Reexamination. If satisfactory performance is not achieved, then a complete discussion and explanation for the discrepancy between model results and observed data will be presented and discussed in the technical report prepared for this study.

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SECTION F — APPENDICES

F.1 Corrective Action Form

DATE:		CAF Number:	
What is the problem? Describe below.			
Would you describe this as a Major or Minor problem? **Major ➢ ☐ Minor ➢ ☐**			
What are the causes of the problem?			
Recommended Corrective Actions			
What is the justification for the proposed corrective action?			
Corrective Action Taken			
Submitted by:		**Date:**	
Approved by:		**Date:**	
Follow-up			
Was the problem solved? Describe.			
Project Manager Approval:		**Date:**	
QA Officer Review:		**Date:**	