UNRBA Monitoring Program Interim Report

UNRBA Monitoring FY 2016

October 2015

E213006402

Cardno
Shaping the Future

Document Information

Prepared for	Upper Neuse River Basin Association
Project Name	UNRBA Monitoring Program FY 2016
Project Number	E213006402
Project Manager	Douglas J. Durbin, Ph.D.
Date	October 2015

Prepared for:

Upper Neuse River Basin Association

P.O. Box 270, Butner, NC 27509

Prepared by:

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

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1 Purpose of the UNRBA Monitoring Program

1.1 Introduction

The UNRBA monitoring program is primarily composed of two categories of water quality monitoring. The first category is defined as Routine Monitoring. Routine Monitoring is the repeated testing of water quality variables at fixed locations over many months. Routine Monitoring provides insight into the seasonal and annual variation of nitrogen, phosphorus, and other parameters over time. The second category is defined as Special Studies. Special Studies are typically focused evaluations conducted in a time-limited effort to inform water quality modeling development and calibration so that baseline and management scenarios can be more accurately simulated. UNRBA Routine Monitoring began in August 2014. Cardno is required to produce an Interim and Annual Report on the nature of the monitoring results, and to assist the UNRBA in setting the scope and budget for the following monitoring year. Interim Reports are prepared in the fall, and Annual Reports are prepared in the spring.

This report provides an interim status review of the UNRBA Monitoring Program from August 2014 through June 2015. The data summarized comprises Year 1 of the Program. This report does not make specific recommendations for refinements to the Monitoring Program, but points to several areas under consideration for possible monitoring plan revisions in the future. An Annual Report will be prepared for submittal in April 2016 which will provide additional analyses and discussion for data collected through the end of 2015, as well as recommendations for adjustments to optimize the value of the Monitoring Program. The UNRBA Monitoring Plan and Quality Assurance Project Plan has been approved by the North Carolina Department of Environment and Natural Resources' Division of Water Resources (DWR).

1.2 Regulatory Background

The North Carolina Environmental Management Commission (EMC) passed the Falls Lake Nutrient Management Strategy ("the Rules"), requiring two stages of nutrient reductions within the Falls of the Neuse Reservoir watershed (N.C. Rules Review Commission 2010); http://portal.ncdenr.org/web/fallslake/home. The Rules establish a Nutrient Management Strategy for the lake to be implemented in two stages: Stage I is described in 15NCAC 02B .0275 (4) (a), and Stage II is described in 15NCAC 02B .0275 (4) (b). The Rules recognize there is uncertainty associated with the water quality modeling used to establish the Stage II requirements, and therefore, allow for re-examination of the Stage II nutrient loading reduction requirements after additional data collection, as specified in Section 5(f) of the Rules. The UNRBA Monitoring Program was specifically designed to reduce the uncertainty and to re-examine the scientific assessment and modeling predictions used by the state to support these rules.

1.3 UNRBA Re-examination Strategy

In 2011, the Upper Neuse River Basin Association (UNRBA) began a re-examination process of the regulatory framework for Stage II of the Rules. Full implementation of the nutrient reduction strategy, which is more stringent than any others implemented in the State, requires extremely costly actions on the part of UNRBA member governments and other regulated parties, and there is uncertainty as to the practical ability to achieve the mandated reductions. In light of this uncertainty and the potential financial impact of these rules and the importance of Falls Lake as a resource, the UNRBA began examination of the technical bases and regulatory framework for Stage II of the Falls Lake Strategy. Local governments within the UNRBA agree that protecting Falls Lake as a water supply is paramount, but they want to ensure that the rules applied to the watershed sufficiently reflect the Lake's uses and that control requirements are reasonable, fiscally responsible, and efficaciously improve the water quality of this resource. Based on a review conducted by Cardno (2013), the Stage II Rules are not technically, logistically, or financially feasible.

Given the high cost of implementing Stage II (approximately $945 million (NCDWQ 2010)) and the uncertainty of whether the prescribed nutrient reduction would yield the targeted chlorophyll *a* concentration. The overall scientific re-examination process relies on additional data collection and new modeling efforts. These efforts will support revised lake response modeling, as well as evaluations of various regulatory options.

In 2014, the UNRBA and Cardno developed a Monitoring Plan to describe the locations, parameters, frequencies, and duration of the Monitoring Program (Cardno 2014b; http://www.unrba.org/monitoring-program). As established in Section 5 (f) of the Falls Lake Nutrient Management Strategy, the UNRBA Monitoring Plan was approved by DWR on July 16, 2014. The UNRBA Monitoring Quality Assurance Project Plan (QAPP), which describes the protocols and methodologies to be followed by field and laboratory staff to ensure data precision and accuracy, was approved by DWR on July 30, 2014.

1.4 Objectives of the UNRBA Monitoring Program

The UNRBA Monitoring Program is designed to support the UNRBA's three main goals, as prioritized by the UNRBA Path Forward Committee:

1. Revise lake response modeling,
2. Support alternative regulatory options as needed, and
3. Allocate loads to sources and jurisdictions.

The sections below provide an overview of the current components of the monitoring program and of the data obtained under the program through June 2015.

2 Overview of UNRBA Monitoring Program

This Interim Report addresses eleven months of data, from August 2014 through June 2015. During this period, the UNRBA Monitoring Program focused on Routine Monitoring and three Special Studies. Additional information about the Routine Monitoring and Special Studies are provided in the Monitoring Plan (Cardno 2014b; http://www.unrba.org/monitoring-program).

2.1 Routine Monitoring

The UNRBA Routine Monitoring Program includes Lake Loading stations and Jurisdictional Boundary stations (Table 2.1 and Figure 2.1). The Routine Monitoring component has been established to characterize the spatial and temporal variability of water quality in the Falls Lake Watershed. Table 2.1 briefly outlines the Routine Monitoring effort, and Table 2.2 illustrates locations of tributary stations where Routine Monitoring is conducted.

2.1.1 Lake Loading Stations on Tributaries in the Falls Lake Watershed

To characterize the tributary inputs to Falls Lake, and to support lake response modeling, flow and water quality data are needed at the mouth (point of entry) for each of the lake's 18 tributaries. Water quality and USGS flow gage locations are shown on Figure 2.1. The USGS maintains ten flow gages and one stage gage in the watershed. Site characteristics for these gages are provided in the Flow Estimation TM (Cardno 2014a) available at (http://www.unrba.org/monitoring-program).

Water quality sampling occurs twice a month at the five upper lake tributaries which, based on previous information, generally contribute roughly 75 percent of the flows to Falls Lake. It is important to have high confidence in nutrient loading for these tributaries because water and nutrient contributions from the tributaries to the lake drive much of the lake's excessive chlorophyll response. The program also includes collection of total and volatile suspended solids, total and dissolved organic carbon, and chlorophyll *a* concentrations from the tributaries to provide data that was not available when DWR developed the model. Correctly representing the tributary inputs of these parameters will be important for future modeling efforts.

The parameters selected for Routine Monitoring at lake loading sites were based on the requirements of the EFDC model, along with input from the UNRBA member organizations. In subsequent monitoring years, the UNRBA Monitoring Program may be revised to modify parameter coverage, frequencies, and sampling locations to optimize data collection for the UNRBA's needs.

2.1.2 Jurisdictional Stations on Tributaries in the Falls Lake Watershed

The Rules specify that loading from the various governmental jurisdictions in the Falls Lake watershed must be reduced. Establishment of water quality monitoring stations between the jurisdictions and at key loading points such as the outlets of major tributaries within a jurisdiction can be used to 1) provide water quality data from multiple areas within all member jurisdictions, 2) prioritize best management practice (BMP) implementation in areas with the highest nutrient loading, 3) calibrate watershed models and, 4) potentially assess changes in loading over time. Twenty stations (Figure 2.1) were identified based on input from the UNRBA Path Forward Committee (PFC) and are being monitored monthly to characterize water quality near jurisdictional boundaries (excluding those covered under the lake loading stations). In subsequent monitoring years, based on a careful evaluation of the results and review by the PFC, data collection efforts at jurisdictional sites may be revised to optimize data value for the UNRBA.

2.1.3 Falls Lake Monitoring

Monitoring results of water quality samples taken from Falls Lake will be used for calibration and validation of a revised Falls Lake water quality model. Additional monitoring of physical, chemical and biological processes increases the understanding of the lake's behavior, reduces uncertainty, and improves model performance.

Ongoing monitoring by DWR, the Center for Applied Aquatic Ecology (CAAE), and local governments also provides data that can be considered for these efforts. At UNRBA's request, DWR added a monitoring station and several parameters to their routine lake monitoring beginning in October 2014. Figure 2.2 shows the DWR monitoring stations on Falls Lake. Data summaries for the parameters that DWR analyzes may be accessed through the DWR website (http://portal.ncdenr.org/web/wq/fallsjordan).

Table 2.1 Overview of Routine Monitoring Components of the UNRBA Monitoring Program

Monitoring Program Component	Primary Data Use	Parameters Collected	Years 1 and 2	Years 3, 4 and 5 (optional)
18 Lake Loading tributary stations (names and locations provided in Table 2)	To quantify lake loading inputs to Falls Lake EFDC model UNRBA Objective Supported: Revised Lake response modeling	Water temperature Specific conductance Dissolved Oxygen pH Total Kjeldahl nitrogen Soluble Kjeldahl nitrogen Nitrate + nitrite Ammonia Total phosphorus Total soluble phosphorus Orthophosphate Total organic carbon Dissolved organic carbon Chlorophyll *a* Total suspended solids Color UV absorbance (at 254nm) Carbonaceous biochemical oxygen demand (CBOD5)	Twice a month Ellerbe Creek Eno River Little River Flat River Knap of Reeds Creek Monthly All other locations.	Twice a month Ellerbe Creek Eno River Little River Flat River Knap of Reeds Creek Monthly Little Lick Creek Lick Creek Ledge Creek New Light Creek Upper Barton Creek Monthly or Quarterly Frequency to be determined for specific locations following statistical analyses
20 Jurisdictional Boundary tributary stations (names and locations provided in Table 2)	Demonstrate water quality at multiple locations for all UNRBA member organizations UNRBA Objective Supported: Source allocation and estimation of jurisdictional loading	Water temperature Specific conductance Dissolved oxygen pH Total Kjeldahl nitrogen Nitrate + nitrite Ammonia Total phosphorus Total organic carbon Total suspended solids	Monthly All locations	Monthly or Quarterly Frequency to be determined for specific locations following statistical analyses

Table 2.2 UNRBA Routine Monitoring Tributary Stations and Sampling Frequency

Name[1] (Station Type[2])	Subwatershed	Stream Name	County	Drainage Area (mi^2)	Sampling Frequency
NFR-41 (JB)[3]	Flat	North Flat	Person	12.7	Monthly
NFR-37(JB)	Flat	North Flat	Person	15.8	Monthly
NFR-32(JB)	Flat	North Flat	Person	32.8	Monthly
SFR-30(JB)	Flat	South Flat	Person	54.4	Monthly
FLR-25(JB)	Flat	Flat	Person	102	Monthly
DPC-23(JB)	Flat	Deep	Person	32.1	Monthly
FLR-5.0(LL)	Flat	Flat	Durham	169	Twice monthly
NLR-27(JB)	Little	North Fork Little	Orange	21.9	Monthly
SLR-22(JB)	Little	South Fork Little	Durham	37.4	Monthly
LTR-16(JB)	Little	Little	Durham	78.3	Monthly
LTR-1.9(LL)	Little	Little	Durham	104	Twice monthly
ENR-49(JB)	Eno	Eno	Orange	60.5	Monthly
ENR-41(JB)	Eno	Eno	Orange	73.2	Monthly
ENR-23(JB)	Eno	Eno	Durham	121	Monthly
ENR-8.3(LL)	Eno	Eno	Durham	149	Twice monthly
CMP-23(JB)	Knap of Reeds	Camp	Durham	1.99	Monthly
KRC-4.5(LL)	Knap of Reeds	Knap of Reeds	Granville	41.9	Twice monthly
UNT-0.7(LL)	Unnamed	Unnamed	Granville	3.43	Monthly
ELC-3.1(LL)	Ellerbe	Ellerbe	Durham	21.9	Twice monthly
LKC-2.0(LL)	Lick	Lick	Durham	10.8	Monthly
LLC-1.8(LL)	Little Lick	Little Lick	Durham	13.8	Monthly
PAC-4.0(LL)	Panther	Panther	Durham	3.24	Monthly
LGE-17(JB)	Ledge	Ledge	Granville	1.79	Monthly
LGE-13(JB)	Ledge	Ledge	Granville	3.49	Monthly
LGE-5.1(LL)	Ledge	Ledge	Granville	20.3	Monthly
LLG-0.9(JB)	Little Ledge	Little Ledge	Granville	3.74	Monthly
BDC-2.0(LL)	Beaverdam	Beaverdam	Granville	12.7	Monthly
ROB-7.2(JB)	Robertson	Robertson	Granville	4.43	Monthly
ROB-2.8(LL)	Robertson	Robertson	Granville	12	Monthly
SMC-6.2(LL)	Smith	Smith	Granville	6.3	Monthly
HSE-11(JB)	Horse	Horse	Franklin	3.88	Monthly
HSE-7.3(JB)	Horse	Horse	Wake	7.11	Monthly
HSE-5.7 (JB)[4]	Horse	Horse	Wake	9.6	Monthly
HSE-1.7(LL)	Horse	Horse	Wake	11.9	Monthly
NLC-3.8(JB)	New Light	New Light	Wake	9.9	Monthly
BUC-3.6(JB)	New Light	Buckhorn	Granville	1.21	Monthly
NLC-2.3(LL)	New Light	New Light	Wake	12.3	Monthly
HCC-2.9(LL)	Honeycutt	Honeycutt	Wake	2.76	Monthly

[1]Name combines an abbreviation for the stream with the approximate distance from the station to Falls Lake (km).

[2]JB refers to a Jurisdictional Boundary station and LL refers to a Lake Loading station.

[3] NFR-41 was added in July, 2015 to replace site NFR-37 due to concerns about safety and accessibility at NFR-37.

[4] HSE-5.7 was used as an alternate for HSE-7.3 in May-June, 2015 while HSE-7.3 was inaccessible due to construction.

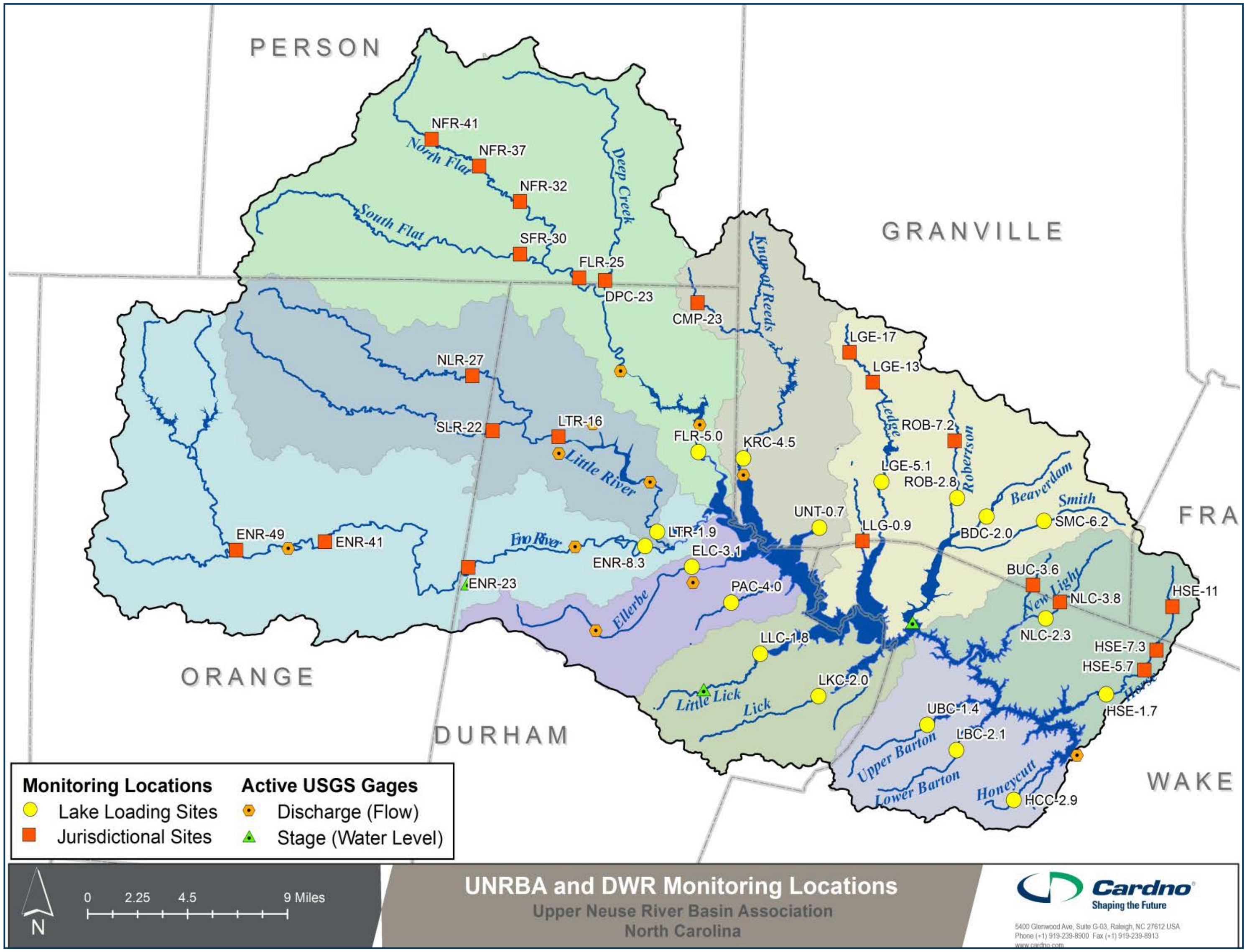

Figure 2.1 **UNRBA Lake Loading and Jurisdictional Monitoring Locations (see Table 2 for station details) and Existing USGS Gages**

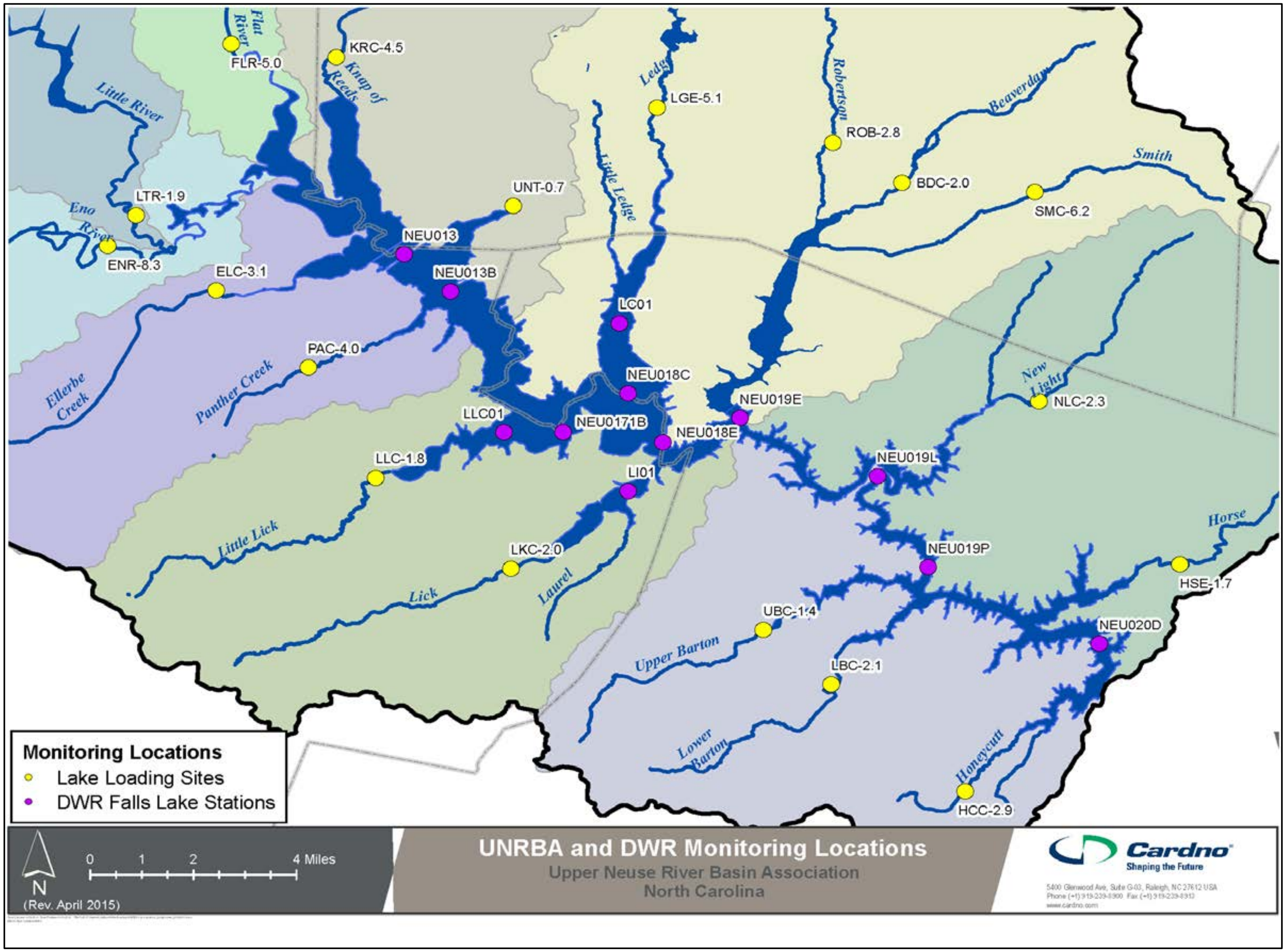

Figure 2.2 Falls Lake DWR Monitoring Locations shown with UNRBA Lake Loading Stations

2.2 Special Studies

The UNRBA Monitoring Program includes special studies designed to address specific questions. Table 2.3 briefly summarizes the studies under way. Each Special Study Plan was developed by Cardno, and four have been approved by the UNRBA Executive Director; three plans are still in development. These plans include details on the sampling methods and quality assurance protocols and are available on the UNRBA website (http://unrba.org/monitoring-program). Information about Special Studies conducted through June 2015 is provided in Section 3.4.

Table 2.3 Summary of UNRBA Special Studies under Way in Year 1 and Year 2

Monitoring Program Component	Purpose
Storm Event Sampling (initiated in Year 1)	Obtain water quality data throughout the elevated flow period associated with storms to improve loading estimates to Falls Lake. These data will be used to help verify the accuracy of methods used to develop the tributary loading input files for the EFDC model.
High Flow Monitoring at Eight Tributary Stations (initiated in Year 1)	Obtain additional water quality data when there is elevated flow at select Lake Loading stations that are frequently slow-flowing or stagnant. These data will be used to determine if water quality in these areas is different when flows are elevated and thus conveying water and loading to the lake. These data will be used to ensure that loading estimates from these slow-flowing tributaries are representative of delivered loads, and not misrepresented by localized stagnant conditions.
Falls Lake Sediment Sampling (initiated in Year 1)	Evaluate nutrient concentrations in Falls Lake sediments to improve estimates of internal loading of nutrients from the lake sediments. These data will be used to evaluate sediment models that may be used to estimate nutrient loading and to provide information to facilitate planning for a potential EPA study of in situ sediment nutrient releases.
Falls Lake Constriction Point Flux Assessment (initiated in Year 2)	Obtain water quality and velocity measurements through primary constriction points within Falls Lake to 1) provide data at a finer temporal scale than the routine DWR monitoring, 2) quantify how material moves from one lake segment to the next, and 3) provide data to constrain future model calibration to ensure that the model is accurately representing changing conditions at time steps that more closely match the "drivers" of lake response.
Light Extinction Data Collection (initiated in Year 2)	Evaluate historic light extinction data collected in Falls Lake to determine the relationship between actual light extinction measurements and Secchi depth. Light penetration is an important parameter for estimating algal production and this evaluation will help determine whether Secchi depth data can fulfill the data requirements for future updates to and calibration of the EFDC lake response model and other data analysis approaches.
Basic Evaluation of Model Performance (initiated in Year 2)	Use the existing models (EFDC, BATHUB, and the Falls Lake Framework Tool) and the conceptual empirical/probabilistic model to support the ongoing evaluation of and potential adaptations to the Monitoring Program by helping to ensure that data collected through the Program is appropriate and sufficient for future modeling efforts.
Recreational Use Assessment (initiated in Year 2)	Conduct background research on recreational use evaluations on other lakes and reservoirs in the Southeastern U.S. and elsewhere to 1) assess the current status of the recreational use of Falls Lake and 2) support discussions with NCDWR and EPA on the need for additional recreational studies.

2.2.1 <u>Storm Event Sampling</u>

This special study is focused on obtaining additional water quality data from major tributaries to Falls Lake under varying storm conditions over time. In contrast to the twice monthly grab samples taken under the Routine Monitoring process, this data collection effort employs automated sampling equipment to collect multiple discrete samples over time as stream flows rise and then fall during and following a storm event. Such data allow for a better understanding of the contribution of nutrients and related parameters associated with storm events. Data from this study will be used to better inform model development and calibration for simulating water quality conditions in Falls Lake.

Two back-to-back storms were sampled on Ellerbe Creek and Eno River in April of 2015. Parameters sampled during these events include total Kjeldahl nitrogen, ammonia, nitrate plus nitrite, total nitrogen (calculated from total Kjeldahl nitrogen and nitrate plus nitrite), total phosphorus, total organic carbon and total suspended solids. An overview of the data collected during these events is provided in Section 3: Summary of Data Collected in Year 1.

2.2.2 High-Flow Event Sampling

This Special Study is used to obtain supplementary water quality data from select tributaries to Falls Lake under high flow conditions which may be under-represented by routine monitoring. High flow conditions are qualitatively defined for this study as periods when stream flow increases markedly above normal flows in response to a rain event, generally characterized by faster water velocity, higher water levels and/or increased turbidity. This supplemental effort helps to ensure that data are available for locations expected to reflect substantially different pollutant loading during periods of high flows. Data from this study will help to inform the updated modeling of Falls Lake, as well as providing general insight into water quality characteristics during typically under-represented sampling conditions. This study is different from the Storm Event Sampling (Section 3.4.1) which uses automated samplers at two locations in the watershed to collect multiple samples over the course of a storm. Stations monitored during the High-flow Event Sampling cover more area by collecting data from more stations, but only one sample is collected during each event.

High flow samples were collected twice in FY2015 from eight of the Lake Loading Stations (Table 2.4). These stations include some significant loading contributors to Falls Lake, along with wetland dominated and/or stagnant stations observed to have low flow under most routine monitoring conditions. Parameters analyzed were the same as those measured for the Routine Monitoring of Lake Loading stations. Four streams involved in High Flow Event Sampling have USGS gaging stations upstream of the sampling location, so water quality results can be linked to gaged flows or height; the other four are not gaged. An overview of high flow monitoring results is presented in Section 3: Summary of Data Collected in Year 1.

Table 2.4 High Flow Event Monitoring Stations

Station ID	Waterbody	Location Description	Gaged Flow
FLR-5.0	Flat River	at Old Oxford Highway	Yes
LTR-1.9	Little River	at Old Oxford Road	Yes
ENR-8.3	Eno River	at Old Oxford Highway	Yes
LLC-1.8	Little Lick Creek	at Patterson Road	Stage only
UNT-0.7	Unnamed Tributary	at Northside Road	No
LGE-5.1	Ledge Creek	at Highway 15	No
ROB-2.8	Robertson Creek	at Brassfield Road	No
BDC-2.0	Beaverdam Creek	at Horseshoe Road	No

2.2.3 Lake Sediment Evaluation

This Special Study will quantify the nutrient and organic carbon content of sediment samples from Falls Lake. These data will help develop a more precise understanding of the spatial variability of sediment characteristics, bottom water and pore water nutrient concentrations, and benthic nutrient flux rates in Falls Lake. This evaluation will provide site-specific information which can be used to simulate spatial variability in benthic nutrient flux. The existing version of the Falls Lake Nutrient Response Model assumed uniform nutrient flux conditions throughout the lake and thus used a single set of model calibration factors. Information from this study will help develop a better understanding of the importance of internal nutrient loads to the waters of Falls Lake. Data collection for this special study was conducted at the end of FY2015 and results and evaluation of this information will be forthcoming later in FY2016.

2.2.4 Falls Lake Constriction Point Study

Water quality in Falls Lake is driven by some processes that occur at relatively short time steps (e.g., sunlight and cloud cover, wind, tributary flows and nutrient loading). NCDWR samples water quality in Falls Lake at 12 locations each month. These data characterize the overall water quality in the lake and is used for assessment purposes, but it does not provide data on how the lake responds to rapidly changing conditions such as a large storm event.

This study was added to the Year 2 monitoring program to provide data at a refined temporal scale to characterize how the lake responds during changing conditions. Because the lake is segmented by several bridge causeways (i.e., constrictions), it is beneficial to understand how material moves from one basin to next. The bridge constrictions are points of concentrated flow and are an efficient location to monitor the downstream transport of water and material. For some of the lake segments, the material entering from the upstream segment represents the majority of the flow and nutrient loading.

The data collected as part of this Constriction Point Study will measure the velocity of the water as it moves through the bridge constrictions, and will measure water quality at multiple points across the constriction. Collecting velocity and water quality data at these locations over multiday periods when flows are changing in response to storm events will provide multiple points in time to calibrate the model. These data will be compared with the output of the current lake model (the 2006 DWR version) and will assist in model calibration in the future when the model is revised as part of the re-examination strategy. Without these data, model calibration is limited to monthly, or twice monthly samples, that are difficult to extrapolate beyond the day and time during which they were collected. During FY2016, two sampling events are planned. Characterizing events occurring in different seasons will help ensure that the calibrated model is more robust and is not calibrated to just one event with a high degree of accuracy, at the expense of misrepresenting conditions outside of that period.

Cardno conducted a reconnaissance trip in August 2015 to test the equipment that will be used to measure the water velocities through the constriction points during the sampling events (an Acoustic Doppler Current Profiler). Selected water quality parameters (e.g., temperature and conductivity profiles and water samples for total nitrogen, total phosphorus, total suspended solids, and total organic carbon) were also sampled during this reconnaissance event across the Highway 50 constriction to evaluate the spatial variability of example water quality parameters at discrete water depths. These parameters are a subset of the parameters that will be collected during the actual sampling events. Lab analysis indicated that there is some vertical variability in the water quality between the deep and shallow zones, but that water quality within the first four meters from the surface was not highly variable.

Sampling will be conducted at the I-85 crossing and the Hwy 50 crossing, and at the Fish Dam Road crossing if time allows within the suitable sampling window. A broader list of parameters will be sampled during the actual sampling events (total organic carbon, total and volatile suspended solids, chlorophyll *a* (1-meter samples only), total phosphorus, total Kjeldahl nitrogen, ammonia, nitrate plus nitrite, Secchi depth and temperature and dissolved oxygen profiles).

2.2.5 Light Extinction Data

The availability of light for photosynthesis can strongly influence algal biomass and species composition in lakes and is therefore an important parameter in aquatic ecosystem models. Light extinction in the water column can be measured using sophisticated underwater light meters, but it is more typically estimated using the simple measurement of Secchi depth. This Special Study comprises a minor effort to analyze available historical data on light extinction from Falls Lake and to determine the strength of the relationship between actual light extinction measurements and Secchi depth. This evaluation can help to identify the degree of uncertainty resulting from using Secchi depth data as a proxy for light extinction measurements in future updates to and calibration of the EFDC lake response model and other data analysis approaches.

Cardno obtained historic light extinction data collected on Falls Lake from the mid 1980's to early 1990s from the EPA STORET database. Ten Falls Lake stations had measurements of light extinction coincident with Secchi depth (Table 2.5, Figure 2.3). A simple linear regression model was built to assess whether Secchi depth was a good approximation of the depth of 99% light attenuation during this period. The resulting model (below) was statistically significant with an R^2 value of 0.77 and a p-value < 0.001, however the scatter around the regression indicates Secchi Depth can predict depth of 99% light extinction typically within approximately +/- 0.5 meters (Figure 2.4).

$$\text{Depth of 99\% light attenuation} = 0.15 + 2.07 \times \text{Secchi depth}$$

Table 2.5 Locations with Historic Light Extinction/Secchi Depth Data

Station ID	Location
J1727000	Falls Lake at Hwy 98 near Bayleaf
J1725000	Falls Lake at Channel Marker #6 near Bayleaf
J1715000	Falls Lake at the mouth of Beaverdam Creek near Marker #10
J1675000	Falls Lake at the mouth of Ledge Creek near Creedmoor
J1590000	Falls Lake at the mouth of Little Lick Creek near Marker #13
J1370000	Falls Lake at I 85 near Northside
J1250000	Falls Lake at Southern Rr near Durham
J1740000	Falls Lake at Marker #1 near Bayleaf
J1430000	Falls Lake at Marker #16 near Redwood
J1710000	Beaverdam Lake near Sandy Plain

When the UNRBA expressed interest in the collection of light extinction data, DWR agreed to begin collecting this parameter in Falls Lake on a monthly basis at each lake monitoring location beginning in the fall of 2015. These new data will provide direct measurements of light extinction which can be used to assess the relationship between light extinction and Secchi depth. The new data may show a different relationship between light extinction and Secchi Depth, because in-lake conditions present now - 40 years after the lake was filled - may be quite different than those a few years after construction. Results of the new data acquisition and analysis will be presented in future reports.

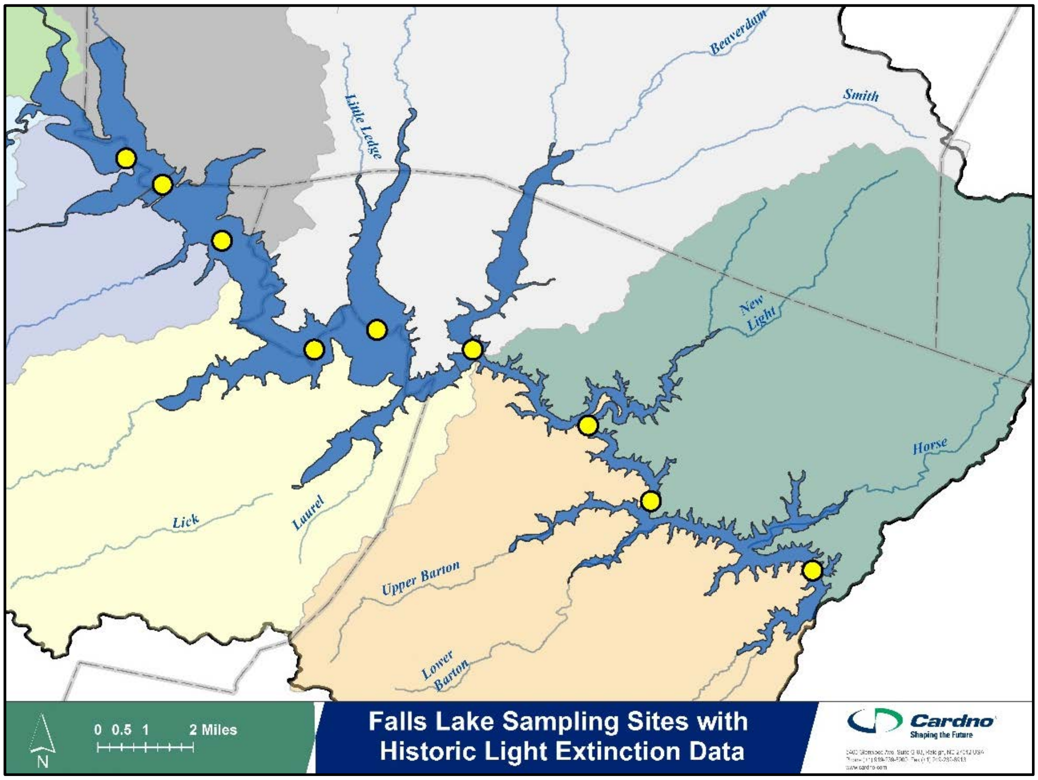

Figure 2.3 Map of Locations with Historic Light Extinction/Secchi Depth Data

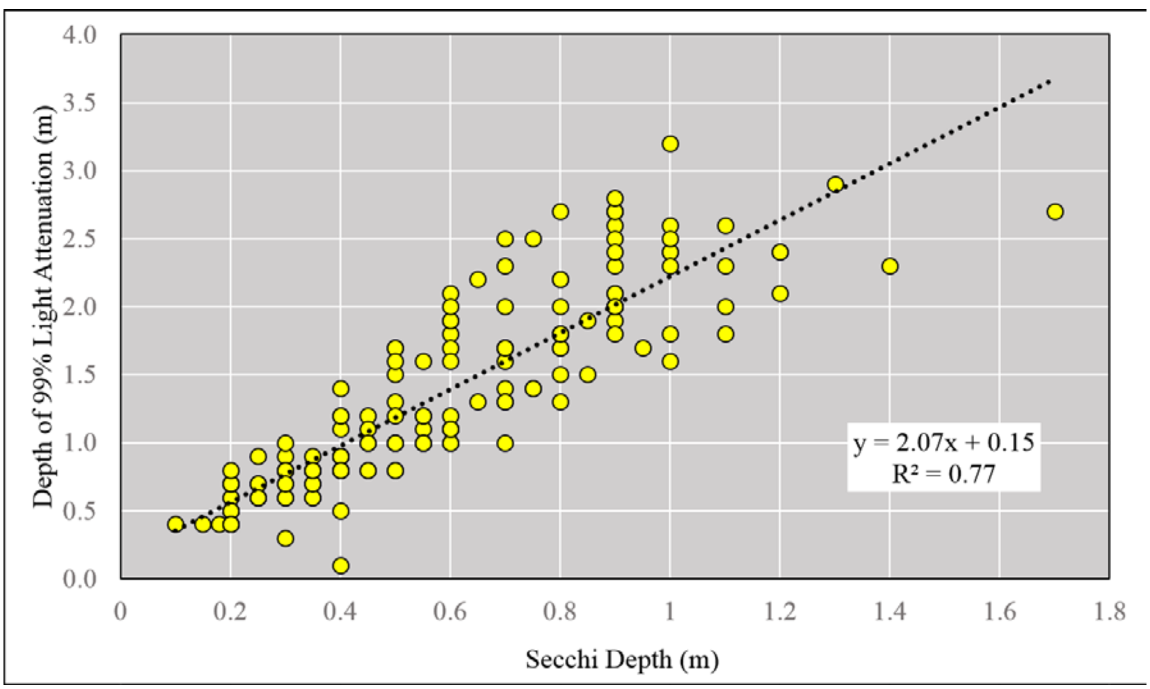

Figure 2.4 Depth of 99% light attenuation versus Secchi depth based data from Falls Lake in the 1980s and 1990s.

2.2.6 Basic Evaluation of Model Performance

This Special Study will support potential future adaptations of the Monitoring Program by helping to ensure that data collected is appropriate and sufficient for future modeling efforts. This study supports the evaluation of resource allocation among existing or potential monitoring studies through targeted sensitivity analyses, review and analyses of monitoring data with respect to uncertainty and resolution compared to model requirements, and documentation of the data needs of empirical/probabilistic models that are being developed. It also offers the opportunity to consider future model development decisions and scenarios to optimize the pairing of appropriate data and suitable modeling approaches for the re-examination effort and to better compare alternate water quality management approaches for Falls Lake.

2.2.7 Recreational Use Evaluation

This Special Study is intended to evaluate recreational uses associated with Falls Lake that may be related to the attainment of water quality standards. Falls Lake is classified by the State of North Carolina as WS-IV as a result of its use as a public water supply, but that classification also carries the protection afforded Class C waters, which includes consideration of fishing, fish consumption, wildlife, and secondary recreation, defined as “wading, boating and other uses involving human body contact with water where such activities take place in an infrequent, unorganized or incidental manner.”

Cardno included consideration of recreational uses in its Falls Lake Framework Tool developed for the UNRBA in 2013, which allowed for a very general association between recreational use and water quality. The general basis of that relationship was drawn from a study conducted by researchers at North Carolina State University looking at associations between residential land development and water quality in Wake County.

This Special Study will address these questions:

- Is Falls Lake impaired with respect to certain recreational uses?
- If so, are the recreational impairments the result of water quality conditions or impairments?
- In what manner, and to what extent, might recreational use data inform the development of alternative regulatory approaches for nutrient management in Falls Lake?

Findings from the study may help inform the re-evaluation process with respect to aligning nutrient management efforts with maintenance of designated recreational uses. They may also support discussions of alternative regulatory approaches where attainment of recreational uses is considered among the targets for adjusting water quality criteria or standards.

3 Summary of Data Collected in Year One

This report summarizes the data collected through the end of June 2015. Approximately 7,425 water quality data values have been generated from the Lake Loading, Jurisdictional Boundary, and Falls Lake stations during this period.

Data Available Online:

This report does not include raw data. The reader may access raw data online after setting up a user account at http://unrba-wqp.cardno.com/

3.1 Overview of Hydrologic Conditions for Year 1 Monitoring

Water quality in Falls Lake is highly dependent on the flows and loads that enter the lake from the tributaries and surrounding watershed. These inputs vary daily, seasonally, and annually with dry periods delivering less loading and wet periods delivering more. Figure 3.1 shows the daily precipitation that occurred during this monitoring period, along with the timing of the Routine Monitoring events.

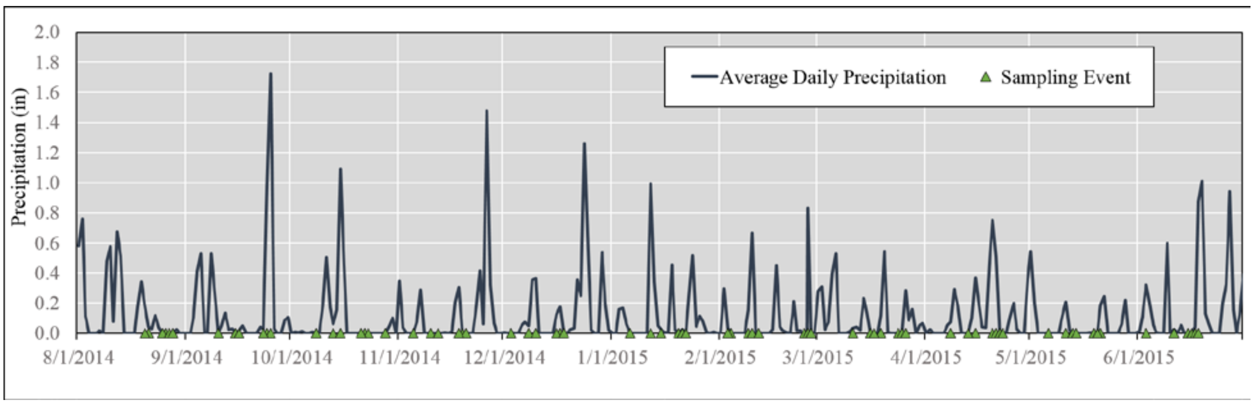

Figure 3.1 Daily Precipitation Observed in Durham, NC from August to December 2014

To illustrate the overall hydrologic conditions for Year 1 of the Monitoring Program, Cardno evaluated precipitation patterns in the Falls Lake watershed and the resulting Falls Lake elevation and compared the values from FY2015 to historical averages to assess whether the monitoring year was substantially wetter or drier than average or exhibited unusual seasonal patterns. For this interim report, these analyses are primarily meant to provide a qualitative view of the conditions in the watershed during the monitored period.

Precipitation data was obtained for six National Climatic Data Center (NCDC) rain gages and six USGS rain gages in the Upper Neuse Basin. Annual and monthly precipitation totals were calculated for each gage and results compared among gages to identify the degree of spatial variability present in the watershed and compared to 30-year normal values for the region.

Annual precipitation from August 2014 through June 2015 ranged from 35 to 52 inches across the watershed with a mean of 40.8 inches. The mean precipitation in the watershed was very similar to the 30-year average for the region of 41 inches for the same 11-month period.

In addition to total precipitation, timing of rainfall can also be important. For example, particularly wet springs can deliver large amounts of nutrients which then can fuel algae blooms throughout the summer. In 2006 which was selected as the baseline year to develop the Falls Lake Nutrient Management Strategy, drought conditions were present for much of the year, but two storm events late in the year brought the annual precipitation up to normal. Extreme patterns such as these affect water quality much differently than if the same amount of rain were delivered evenly over the course of a year.

To assess whether monthly rainfall patterns were different from typical values over the past 30 years, Cardno examined precipitation totals by month to identify months or seasons which were unusual. Figure 3.2 shows how the monthly precipitation from rain gages differs from the 30-year average for the watershed. Values above zero show periods with more rain than average and values below zero indicate drier periods. The darker shaded region shows the range of the middle 50% of precipitation values over the last 30 years and can be considered as a reference range for typical precipitation amounts. Precipitation is not uniform over the watershed and the spatial variation in total precipitation for each month is shown by the boxes in Figure 3.2. The boxes show the 25th, 50th, and 75th percentiles of precipitation over the region with whiskers extending to the full range of values observed. Measurements which are considered statistical outliers are shown as black dots.

For most months, the majority of the monitoring stations had precipitation within the typical range. In general, Year 1 appears to have been a fairly normal year in terms of precipitation, with only the month of May being notably drier than normal.

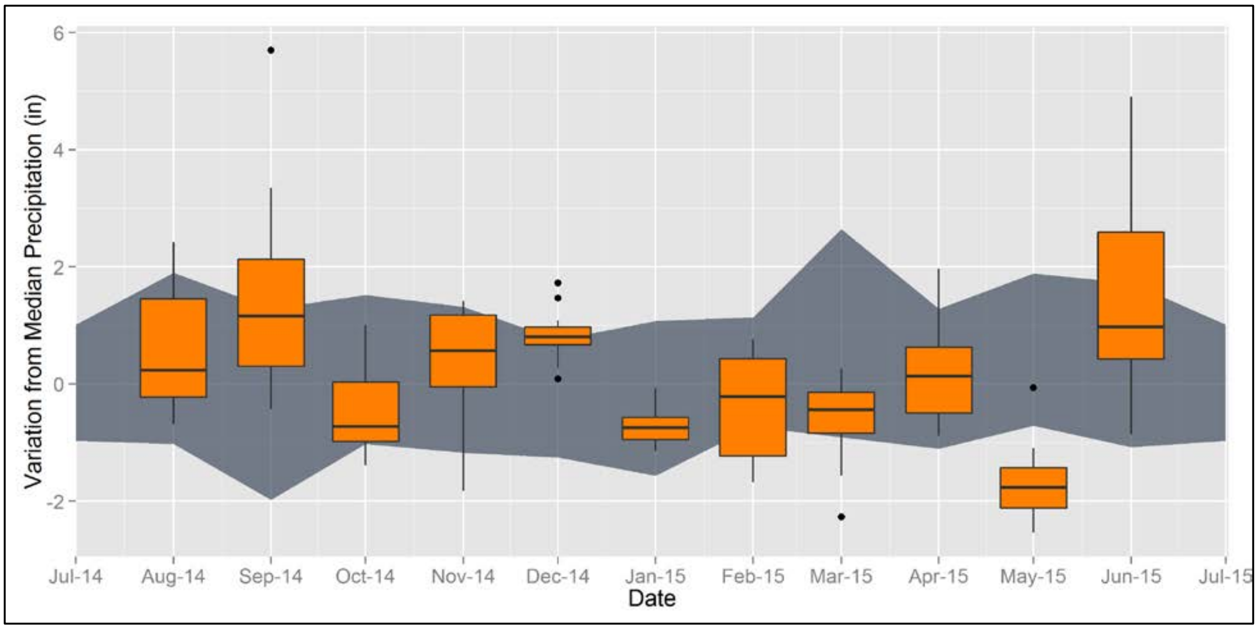

Figure 3.2 Boxplots Representing Variation from 30-Year Normal Monthly Precipitation Totals at Monitoring Stations in the Falls Lake Watershed. The darker shaded region contains the 25th to 75th percentile range of monthly precipitation over the preceding 30 years. The orange boxes display the 75th (top), median (horizontal line), and 25th percentiles (bottom) of precipitation among the 12 gages included in the data summary. Whiskers extend to the range of observed values; statistical outliers are displayed as black circles.

A similar analysis was conducted on the water level (stage) of Falls Lake based on daily data collected by the USACE (see Figure 3.3). For this analysis, median values (dashed line) are based on data reported from 1987 to present. From August 2014 to March 2015, the observed stage (orange line) in Falls Lake was higher than normal (above the 75th percentile much of the time). From April to August 2015, lake levels were very close to the median value. Once DWR posts the lake data for 2015 to the STORET

Water Quality Database (anticipated in March 2016), a general assessment of lake water quality compared to lake hydrology will be summarized in a subsequent Annual Report.

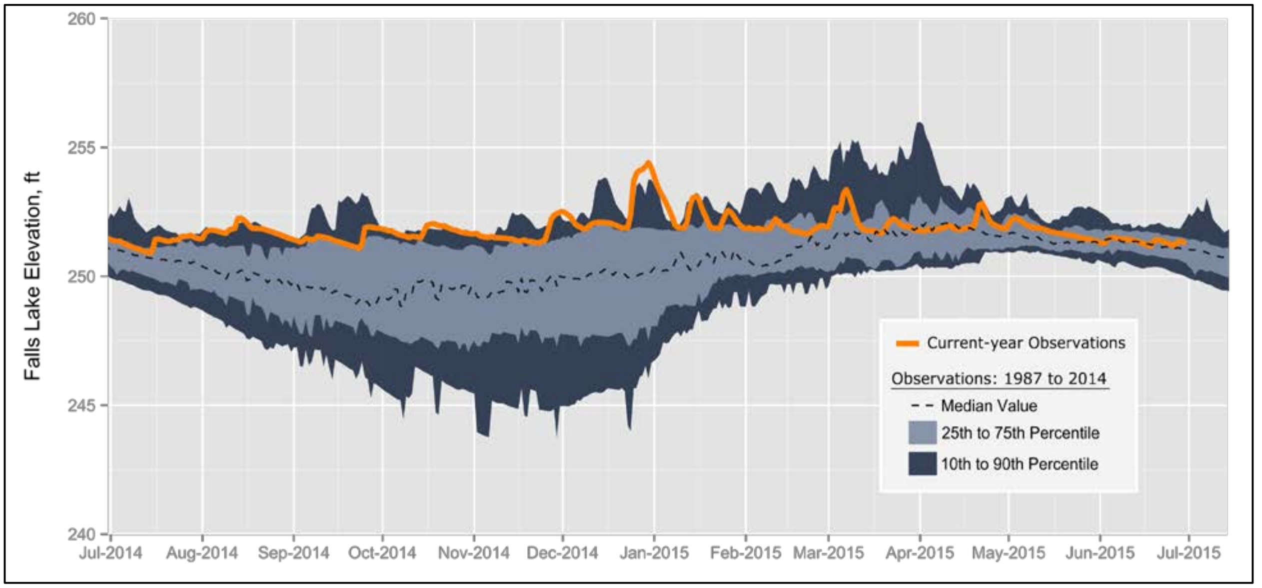

Figure 3.3 Falls Lake Elevation from July 2014 through June 2015

3.2 Routine Monitoring

3.2.1 <u>Tributary Stations</u>

The UNRBA currently monitors 20 parameters through its Routine Monitoring. This report presents measured values for the key parameters of interest to the UNRBA due to compliance or regulatory issues: total nitrogen, total phosphorus, chlorophyll *a*, and total organic carbon. The complete UNRBA database, including data for other monitored parameters, can be accessed online after setting up a user account at http://unrba-wqp.cardno.com/index.php. With a UNRBA database account users can review raw data, generate summary statistics, and obtain detailed station information. Other parameters will be presented and discussed in the Annual Report as warranted.

The majority of the data values from samples analyzed by the UNRBA contract laboratory are reported as concentrations. Concentrations represent the amount of a substance present in a specific volume of water at the time the sample was collected. Concentrations are expressed as milligrams per liter or micrograms per liter.

With only eleven months of data, it is premature to draw extensive conclusions. The graphics and comments offered below are intended to provide a general understanding of the water quality parameters and their context based on data observations during Year 1. In addition to displaying figures of individual water quality measurements, preliminary comparisons of water quality related to compliance with water quality standards, site type (jurisdictional versus lake loading), land use, presence of a wastewater treatment plant, and hydrologic soil group are also provided. Again, these comparisons only represent eleven months of data, and are not intended to draw definitive conclusions. They should be viewed as exploratory in nature.

3.2.1.1 Water Quality Data by Station

The UNRBA collected data on 20 water quality parameters in the Falls Lake Watershed. For this report, graphical representations of data for four key parameters are included to provide an overview of water quality in the watershed and how it varies across the watershed (total nitrogen, total phosphorus, TOC, and chlorophyll *a*). Three parameters monitored by the UNRBA have numeric water quality standards (chlorophyll *a*, dissolved oxygen, and pH). This section presents plots of raw data collected for the four key parameters and tables that summarize compliance with water quality standards for three parameters.

The data plots in this section present the measured values for particular parameters for routine and high flow sampling events between August 2014 and June 2015. These plots are meant to provide a quick overview of the data and several qualitative tools (grouping of stations and symbol shapes and coloring) were added to help with interpretation of the values.

First, the data are grouped by subwatersheds and within each group, stations on the same tributary are displayed from most upstream to most downstream location. Station labels with "(LL)" indicate lake loading stations and stations labeled with "(JB)" indicate jurisdictional stations. This arrangement allows quick inspection of whether spatial patterns may be emerging and allows consideration of the following questions: 1) Are jurisdictional stations located upstream in the watershed different from the lake loading stations closest to the lake? 2) Are there particular subwatersheds with higher or lower concentrations than the others? Table 2.2 (Section 2) provides a list of all tributary stations including the station identifiers used in these plots.

Second, because some water quality parameters exhibit seasonal patterns, the values are color coded according to season. This coding allows the reader to quickly assess whether higher values tend to occur in a particular season or seasons.

Finally, because rain events can affect water quality measurements, values from samples collected within two days of receiving at least ¼ inch of rain in the watershed are displayed as triangles. The choice of rainfall amount is arbitrary, but was selected as a lower threshold for precipitation events which typically induce some measurable response in streamflow.

These visual tools are intended to organize the data in ways that help explore potential patterns in the data but are not intended to imply any statistical significance of these patterns.

The following six parameters are summarized on the data plots or discussed relative to compliance with water quality standards:

- Nitrogen is an essential nutrient for all forms of life. Nitrogen in watersheds generally comes from sources such as atmospheric deposition, surface runoff of rainwater, shallow groundwater, discharge from wastewater treatment plants or onsite disposal systems, residential or agricultural fertilizer, and manure. Total nitrogen, as reflected in Figure 3.4, is calculated as the sum of several different forms of nitrogen found in the environment.
- Phosphorus, also an essential nutrient, often enters water bodies in association with soil, because phosphorus tends to bind with certain types of soil particles (particularly with clay soils common in the Piedmont). It is also a component of stormwater surface runoff, shallow groundwater, discharge from wastewater treatment plants or onsite disposal systems, fertilizers, and manure. Total phosphorus includes organic and inorganic forms. Figure 3.5 shows the total phosphorus data collected in the tributaries of Falls Lake.
- Carbon is considered the primary building block of all living things. Total organic carbon (TOC) is the amount of carbon bound in an organic compound, and it is often used as a non-specific indicator of water quality. Total organic carbon in a water sample includes algae (if present) and other microorganisms, small fragments of decaying animal or plant material, and animal waste. Figure 3.6 shows the TOC data collected in tributaries of Falls Lake. The amount of TOC in raw water affects treatment costs and compliance with the Safe Drinking Water Act.
- Chlorophyll *a* is a green pigment in algae that allows them to use energy from the sun to build living tissue through photosynthesis. Chlorophyll *a* content in a sample is an indication of how much algae is present in the water. While algae is an important component of aquatic ecosystems, too much

algae can cause problems with water treatability for drinking water, taste and odor problems, or drastic fluctuations in dissolved oxygen and/or pH that can cause problems for aquatic organisms. Under North Carolina water quality standards, the Falls Lake watershed should have chlorophyll *a* levels no greater than 40 µg/L. Figure 3.7 shows the chlorophyll *a* data collected in the tributaries of the Falls Lake Watershed. Of 238 chlorophyll *a* values measured, 225 (96 percent) were below the 40 ug/L water quality standard. Only 13 observations from the watershed exceeded 40 µg/L, representing only five of the monitored tributary stations, as listed in Table 3.1.

Table 3.1 Stations with Chlorophyll *a* Measured above the NC State Standard

Subwatershed	Station ID	Chlorophyll *a* > 40 ug/L*
Beaverdam Creek	BDC-2.0 (LL)	1/12 (8%)
Eno River	ENR-8.3 (LL)	1/23 (4%)
Flat River	FLR-5.0 (LL)	2/20 (10%)
Ledge Creek	LGE-5.1 (LL)	1/11 (9%)
Robertson Creek	ROB-2.8 (LL)	3/12 (25%)
Unnamed	UNT-0.7 (LL)	2/12 (17%)
	All Sites	**10/240 (4%)**

*Values shown are: Number of measured values below the standard / Total Number Measurements, and (Percent of measurements below the standard).

> <u>Dissolved oxygen</u> (DO) is commonly measured in water resource monitoring, and represents the amount of oxygen in the water and available for respiration by many aquatic organisms. North Carolina water quality standards applicable to the Falls Lake watershed specify that DO is to be no less than 4 mg/L at any time. In the Falls Lake watershed, dissolved oxygen concentrations tend to be lower in monitored locations with slow-moving or stagnant water, or large wetland complexes, including Beaverdam Creek, Robertson Creek, Unnamed Tributary, and Panther Creek. Of 427 total DO measurements, approximately 93 percent were above the standard and 7 percent fell below 4 mg/L, with all of those occurring at eleven of the monitored stations, as listed in Table 3.2. These stations tend to be in areas with low slopes and stagnant flows, and many are within wetland-dominated areas.

Table 3.2 Stations with Dissolved Oxygen Measurements below the NC State Standard

Subwatershed	Station ID	DO < 4 mg/L*
Beaverdam Creek	BDC-2.0 (LL)	4/12 (33%)
Flat River	FLR-5.0 (LL)	5/20 (25%)
Ledge Creek	LGE-5.1 (LL)	2/11 (18%)
Lick Creek	LKC-2.0 (LL)	1/10 (10%)
Little Lick Creek	LLC-1.8 (LL)	2/12 (17%)
Little Ledge Creek	LLG-0.9 (JB)	4/10 (40%)
Little River	LTR-1.9 (LL)	1/22 (5%)
Panther Creek	PAC-4.0 (LL)	3/11 (27%)
Robertson Creek	ROB-7.2 (JB)	1/7 (14%)
Robertson Creek	ROB-2.8 (LL)	2/12 (17%)
Unnamed	UNT-0.7 (LL)	3/12 (25%)
	All Sites	**28/443 (6%)**

* Values shown are: Number of measured values below the standard / Total Number Measurements, and (Percent of measurements below the standard).

> A measure of acidity or alkalinity is pH, using a scale of 0 to 14, and pH can affect various metabolic functions of aquatic organisms, as well as biogeochemical processes and the chemical behavior of certain metals. Most water bodies have pH levels near the middle of the pH scale (7), and the North Carolina water quality standard applicable to the Falls Lake watershed requires that pH be between 6 and 9. Data collected from August 2014 through June 2015 showed 99 percent compliance with this standard. Six stations had single pH values below 6 (Table 3.3); no station had a value greater than 9.

Table 3.3 Stations with pH Observed below the NC State Standard

Subwatershed	Station ID	pH < 6 *
Buckhorn Creek	BUC-3.6 (JB)	1/11 (9%)
Camp Creek	CMP-23 (JB)	1/9 (11%)
Horse Creek	HSE-11 (JB)	1/10 (10%)
Ledge Creek	LGE-13 (JB)	1/5 (20%)
Ledge Creek	LGE-17 (JB)	1/8 (13%)
New Light Creek	NLC-3.8 (JB)	1/11 (9%)
	All Sites	**6/443 (1%)**

* Values shown are: Number of measured values below the standard / Total Number Measurements, and (Percent of measurements below the standard).

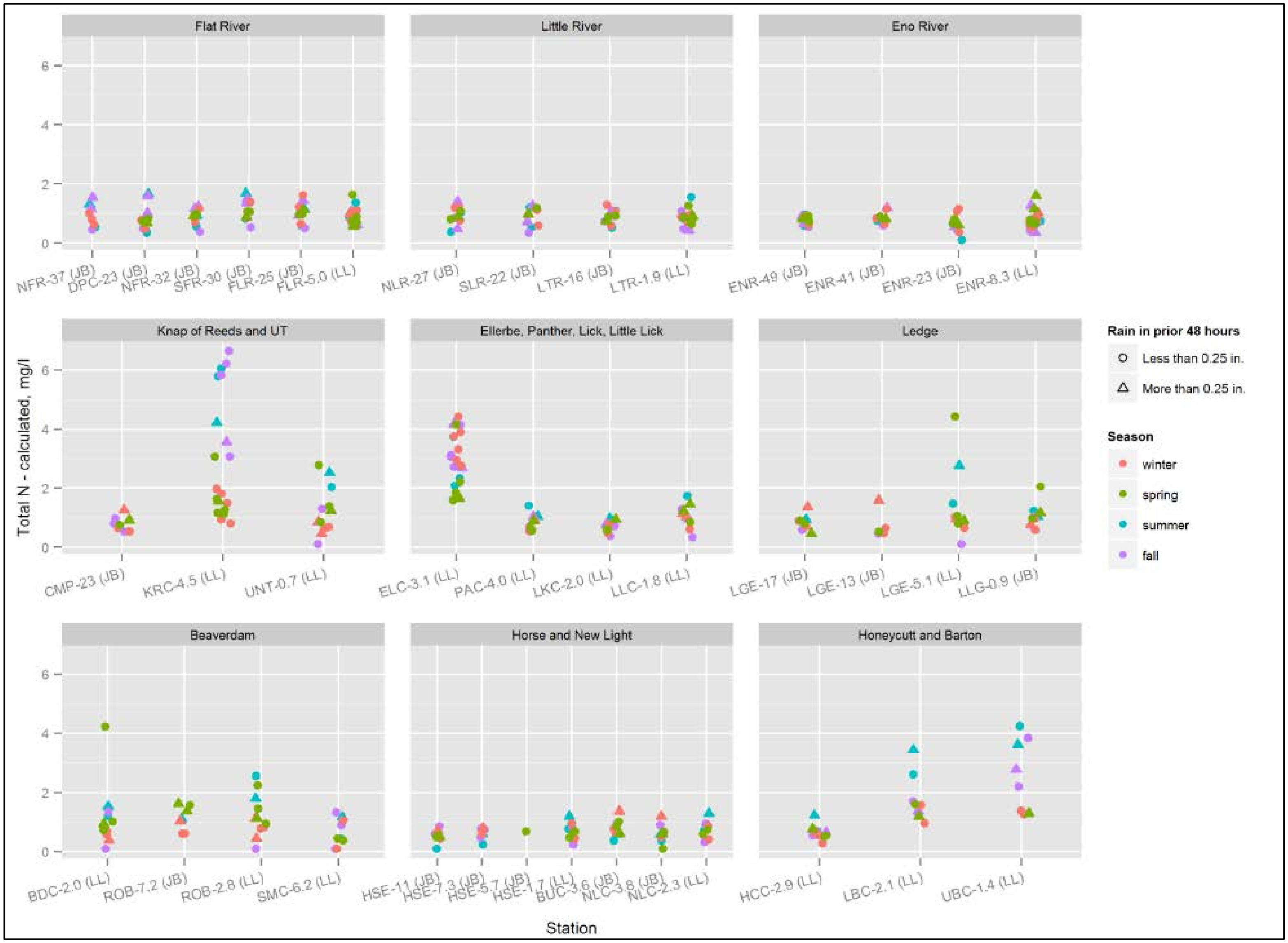

Figure 3.4 Total Nitrogen Concentrations in Tributary Samples from August 2014 to June 2015

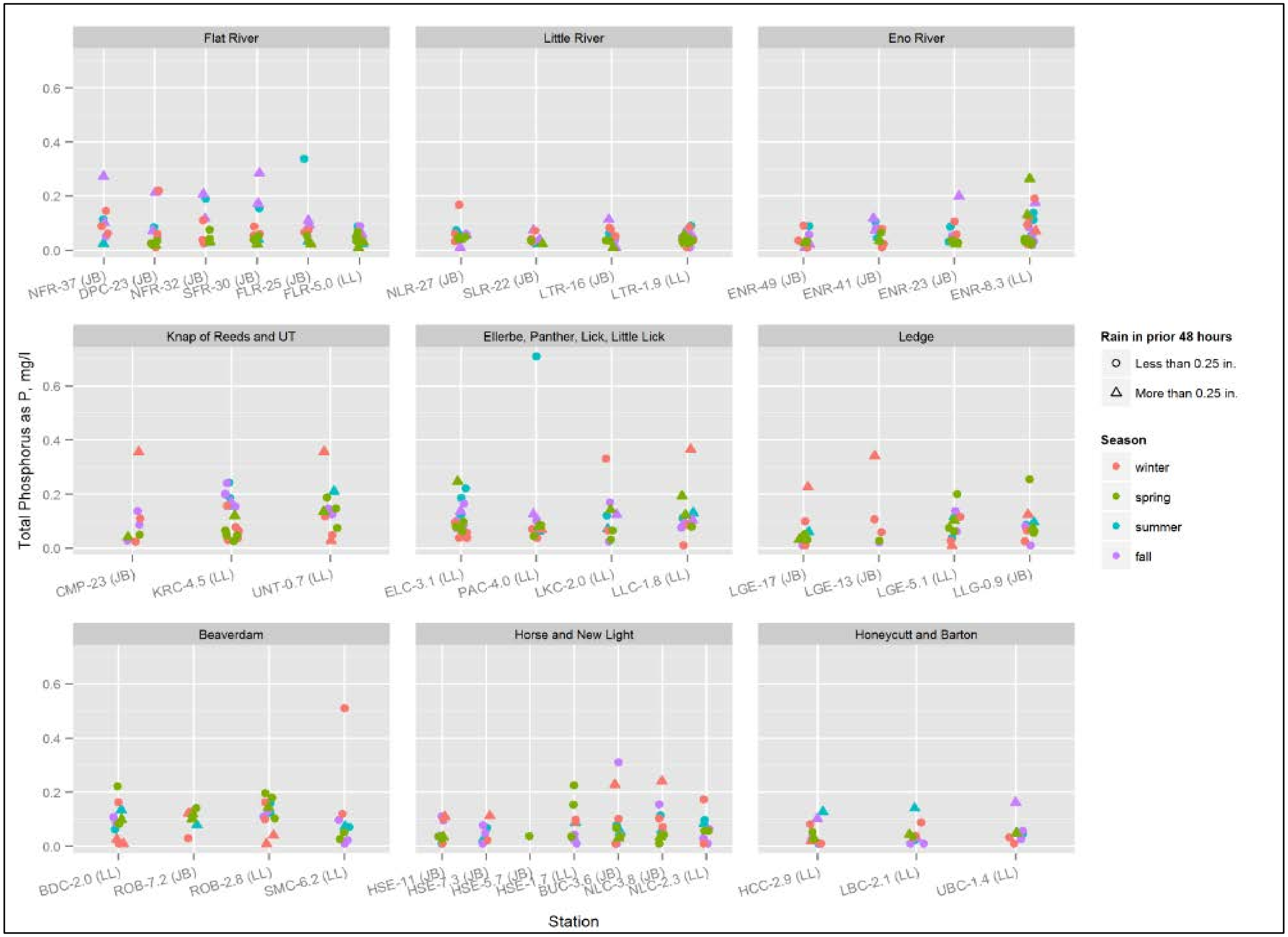

Figure 3.5 Total Phosphorus Concentrations in Tributary Samples from August 2014 to June 2015

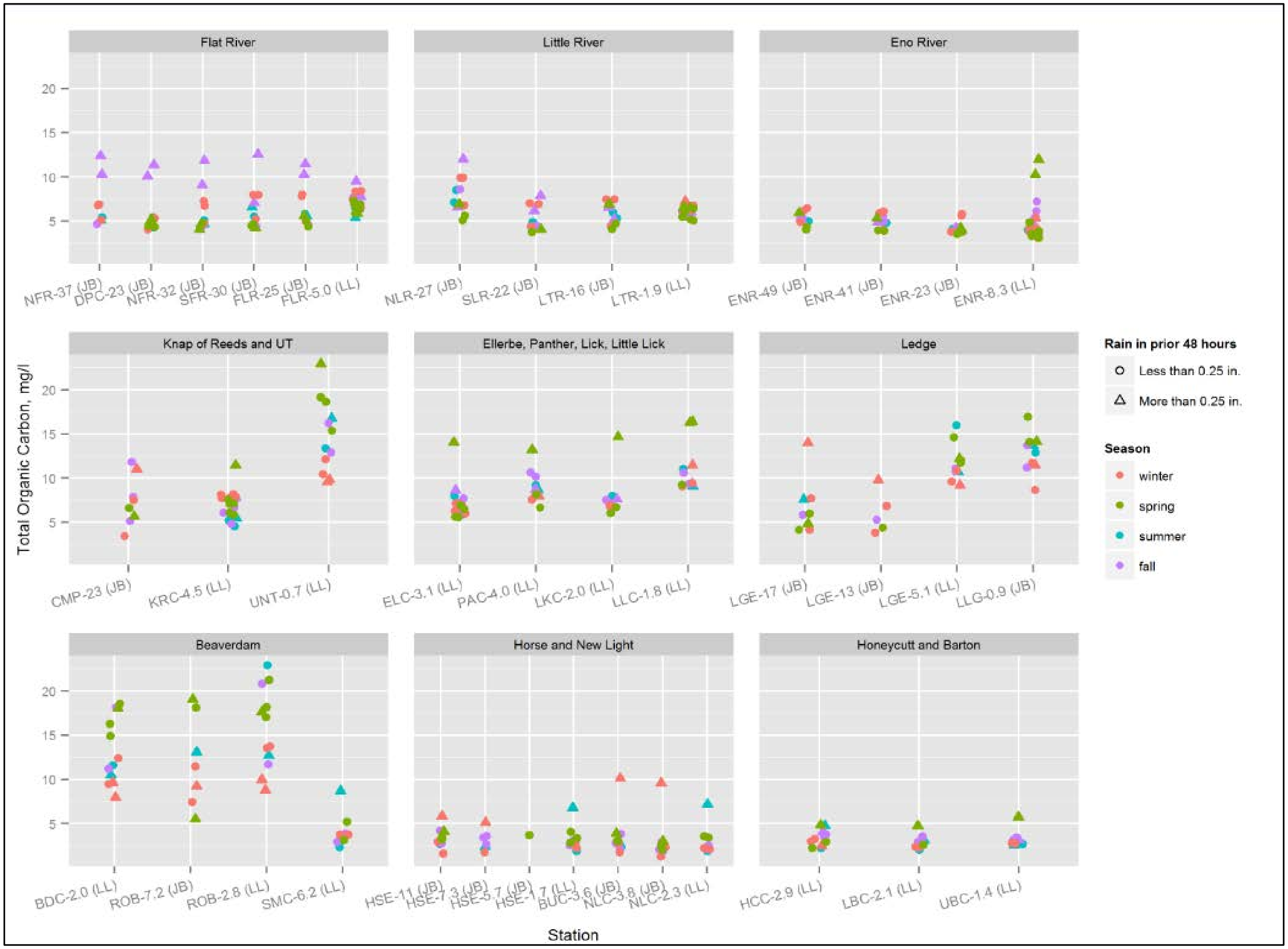

Figure 3.6 Total Organic Carbon Concentrations in Tributary Samples from August 2014 to June 2015

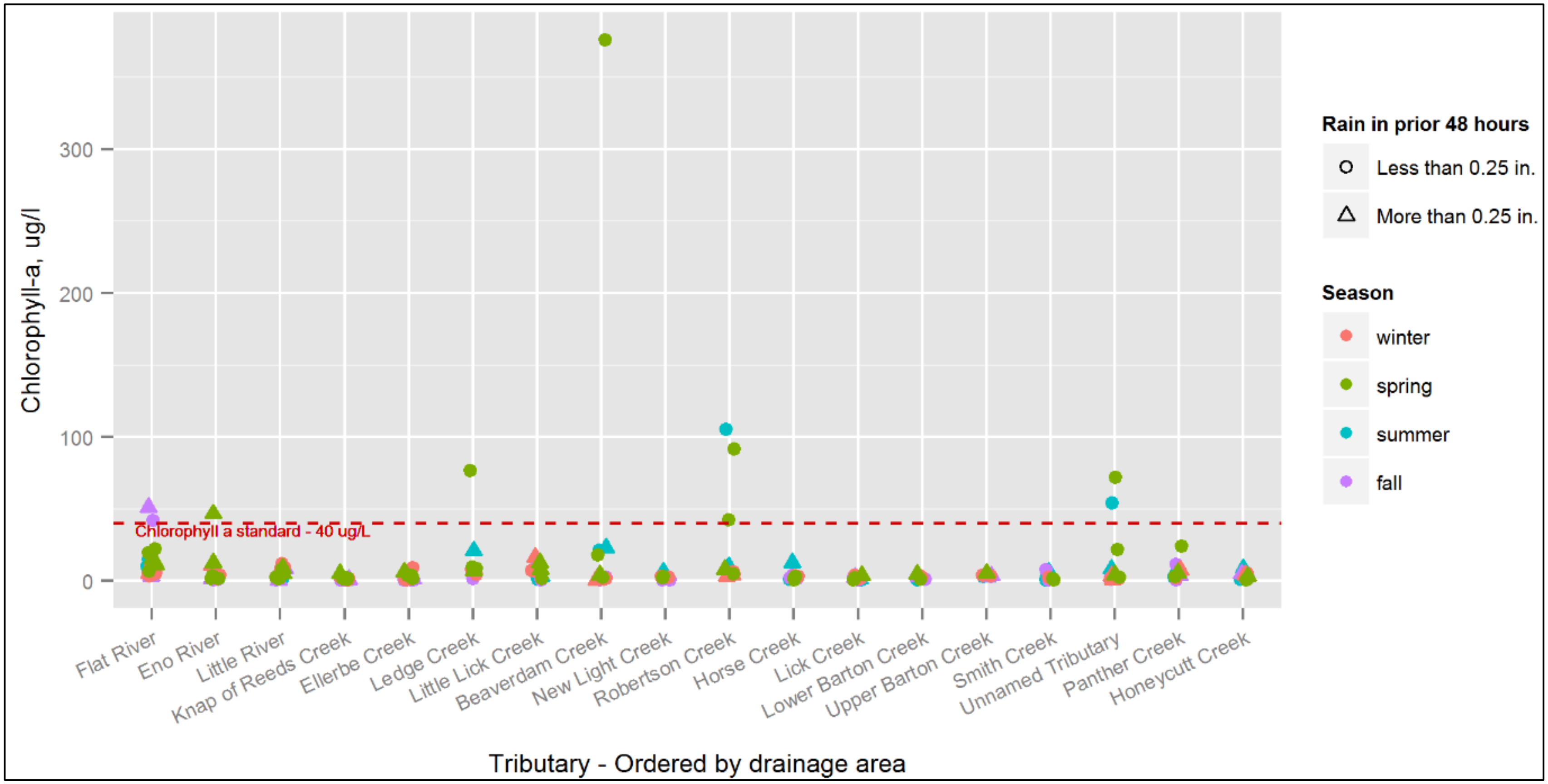

Figure 3.7 Chlorophyll *a* Concentrations at Tributary Lake Loading Stations from August 2014 to June 2015. Tributaries are listed in order from largest to smallest drainage areas.

3.2.1.2 Spatial Patterns

The Falls Lake Watershed is mostly rural, with much of the land use comprised of forest, grassland, and pasture. There are some areas of concentrated urban development around the City of Durham, Butner, Creedmoor, and Hillsborough, and these urban areas also have a number of nearby wastewater treatment plants (WWTP). Table 3.4 summarizes the land use distribution for each of the monitoring stations based on the 2011 National Land Cover Dataset (NLCD) and provides the mean concentrations for four water quality parameters. There is not a significant statistical relationship between water quality concentrations and any single land use in the watershed. Appendix A includes figures that show the spatial distribution of mean water quality concentrations relative to the land uses, jurisdictions, and presence of a major (> 1 million gallons per day) or minor (< 1 million gallons per day) WWTP.

Mean total nitrogen concentrations tend to be higher downstream of WWTPs on Knap of Reeds Creek, Ellerbe Creek, and Upper and Lower Barton Creeks. For total phosphorus, higher concentrations are observed downstream of WWTPs as well as in areas of the watershed that contain a large proportion of wetlands and non-flowing waterbodies. Given the resolution of the land use map, the wetlands are difficult to distinguish, but they generally occur along Ledge, Beaverdam, Robertson, Unnamed tributary, Lick, and Little Lick Creeks. TOC is also higher in wetland dominated areas, but presence of a WWTP does not seem to have a significant effect on observed concentrations. Chlorophyll *a* concentrations are only collected at lake loading sites, and the higher concentrations tend to occur in the non-flowing, wetland dominated areas. For most of the lake loading stations, chlorophyll *a* concentrations are less than 10 µg/L. Higher concentrations tend to occur during stagnant flows at locations with relatively low slopes and/or dominated by wetlands, but concentrations at these stations decrease when flows are elevated and discharge to the lake occurs. Understanding these patterns will be important when the DWR version of the EFDC lake model is revised: the DWR model assumed that concentrations entering from tributaries was equivalent to the nearest lake location, and the monitoring data indicate that assumption is inaccurate.

Table 3.4 Land Use Distribution and Mean Concentrations (August 2014 to June 2015). Monitoring stations are sorted in order from lowest to highest total nitrogen concentrations.

Station Name	Land Cover, % (2011 NLCD)				Water Quality (mean FY2015)			
	Developed	Forest	Grassland	Wetlands	Total Phosphorus, mg/l	Total Organic Carbon, mg/l	Total Nitrogen, mg/l	Chlorophyll *a*, µg/l
HSE-11	17	61	21	1.4	0.06	3.4	0.53	NS
ENR-23	13	60	25	0.5	0.06	4.2	0.57	NS
HSE-7.3	16	61	21	2.4	0.06	3.1	0.60	NS
NLC-3.8	11	66	21	1.5	0.07	2.9	0.61	NS
HCC-2.9	42	50	6	0.2	0.05	3.4	0.64	3.2
LGE-13	9	55	36	0.2	0.10	5.8	0.64	NS
SMC-6.2	7	71	19	2.5	0.11	4.1	0.66	2.4
HSE-1.7	26	56	16	1.6	0.08	3.3	0.67	3.3
HSE-5.7	24	55	18	2	0.04	3.7	0.68	NS
LKC-2.0	16	59	18	5.8	0.12	7.9	0.72	2.0
ENR-8.3	20	57	21	0.7	0.07	4.6	0.73	2.8
CMP-23	6	50	38	3.6	0.10	7.4	0.73	NS
BUC-3.6	8	38	18	34.6	0.09	3.5	0.75	NS
PAC-4.0	26	49	23	2.4	0.13	9.1	0.76	6.9
NLC-2.3	10	66	22	1.5	0.06	3.0	0.76	2.5
LTR-16	6	59	33	1	0.05	6.1	0.80	NS
ENR-49	9	57	32	0.7	0.04	5.2	0.81	NS
ENR-41	14	55	28	0.7	0.06	5.0	0.85	NS
LGE-17	11	54	35	0	0.06	6.5	0.85	NS
DPC-23	4	57	36	1.3	0.07	5.8	0.85	NS
LTR-1.9	9	57	31	1.6	0.05	5.6	0.86	4.5
NFR-32	13	48	37	0.7	0.08	6.1	0.90	NS
FLR-25	8	51	38	0.5	0.08	6.5	0.91	NS
FLR-5.0	7	55	36	0.9	0.05	7.1	0.96	16.7
NLR-27	6	54	38	1.1	0.06	8.1	0.97	NS
SLR-22	5	57	36	0.8	0.04	5.5	0.99	NS
LLG-0.9	20	43	28	3.2	0.09	13	1.03	NS
NFR-37	16	50	33	0.3	0.10	6.9	1.03	NS
LLC-1.8	52	34	10	2.4	0.09	10.4	1.14	4.7

Station Name	Land Cover, % (2011 NLCD)				Water Quality (mean FY2015)			
	Developed	Forest	Grassland	Wetlands	Total Phosphorus, mg/l	Total Organic Carbon, mg/l	Total Nitrogen, mg/l	Chlorophyll *a*, µg/l
ROB-7.2	7	56	29	2	0.10	12.0	1.14	NS
BDC-2.0	5	56	31	5.3	0.10	13.1	1.18	44.8
SFR-30	5	52	40	0.3	0.09	7.0	1.20	NS
UNT-0.7	13	52	29	2.8	0.12	14.3	1.23	17.6
ROB-2.8	13	55	24	3.9	0.13	15.9	1.23	30.3
LGE-5.1	13	52	28	3.9	0.09	11.9	1.35	15.0
LBC-2.1	41	51	5	2.3	0.05	3.0	1.75	2.5
UBC-1.4	28	62	7	2.2	0.05	3.2	2.77	3.6
ELC-3.1	74	16	6	3.8	0.10	7.2	2.96	2.2
KRC-4.5	9	65	22	1.6	0.12	6.9	3.17	1.4

3.2.1.3 Lake Loading versus Jurisdictional Sites

One of the exploratory analyses conducted using the Year 1 data is a comparison of three key water quality parameters for lake loading sites compared to jurisdictional sites. Figure 3.8 shows the distribution of total phosphorus, total nitrogen, and TOC concentrations for these sets of stations; chlorophyll *a* is not collected at jurisdictional sites, so this comparison could not be made. For each of these parameters, the majority of the samples at jurisdictional sites and lake loading sites are similar (the boxes overlap). However, there is more variability at the lake loading sites, which are generally larger drainage area that have a broader mix of watershed characteristics compared to sites further up in the watershed. Lake Loading stations are also more likely to be downstream of wastewater treatment plants (with the exception of jurisdictional stations on the Eno River downstream of Hillsborough).

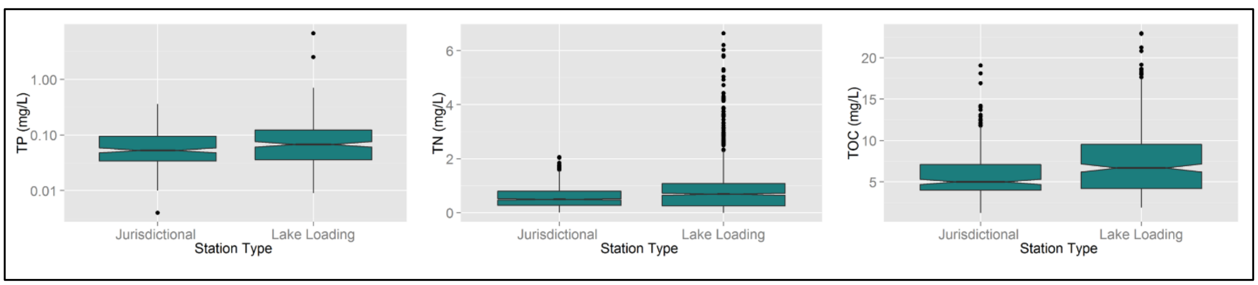

Figure 3.8 **Distribution of Water Quality Parameters by Station Type.** TP is shown on a logarithmic scale.

3.2.1.4 Sites Upstream or Downstream of Wastewater Treatment Plants

Stations were also categorized by the presence of an upstream wastewater treatment plant (WWTP) categorized as either a major facility (>1 million gallon per day) or a minor facility (i.e., a package plant) (Figure 3.9). In the Falls Lake watershed, total nitrogen concentrations collected during Year 1 tend to be higher downstream of major wastewater treatment plants; for total phosphorus, the concentrations are similar across the three groups, which may be due to recent upgrades at the Durham and SGWASA

WWTPs. TOC concentrations are fairly similar at sites with major and minor WWTPs; sites without WWTPs tend to have more variability in this parameter and the highest concentrations are observed at stations without WWTPs (these higher concentrations may be associated with non-flowing, wetland dominated areas). Chlorophyll *a* concentrations tend to be lower downstream of major WWTPs, which may be due to the increased flow rates that prevent low-flow conditions and the associated higher algal densities. Based on the Routine Monitoring conducted over the past eleven months, chlorophyll *a* concentrations at stations with flow are usually lower than levels measured under non-flowing conditions.

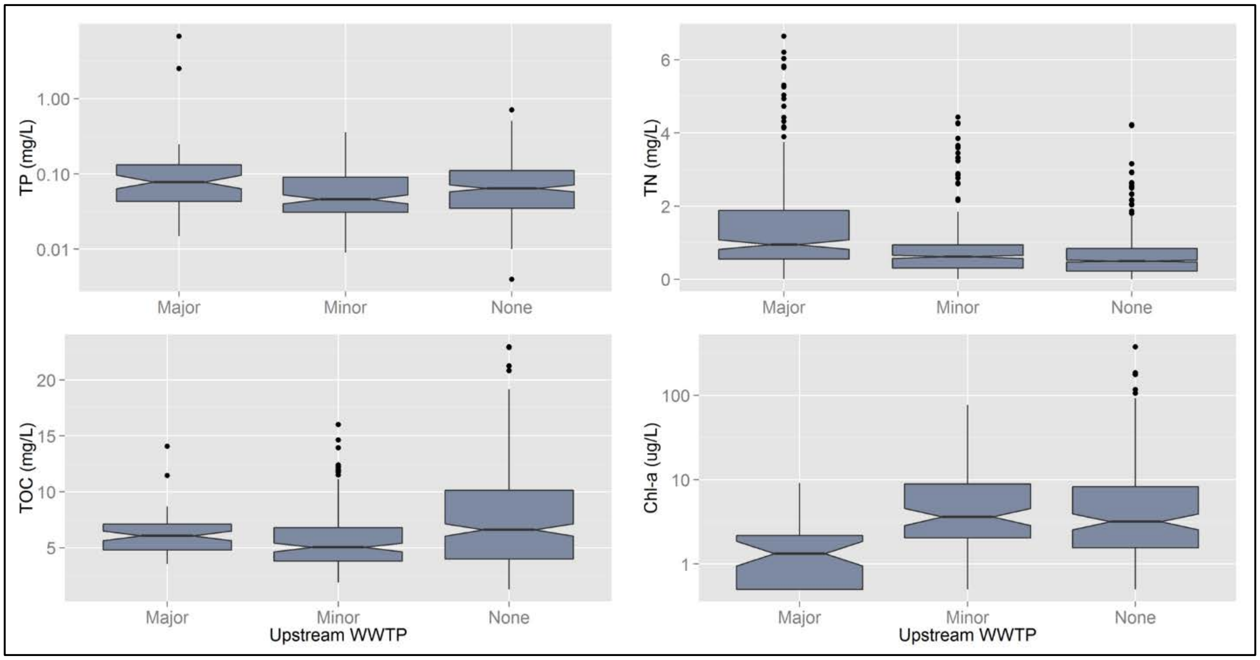

Figure 3.9 Comparison of Water Quality Parameters Relative to the Presence of a Major or Minor (Package Plant) Wastewater Treatment Plant. Note that TP and Chl-*a* plots are shown on a logarithmic scale.

3.2.1.5 Hydrologic Soil Group Patterns

As noted above, the Routine Monitoring conducted over the past eleven months indicates that stations located in non-flowing, wetland dominated areas tend to have higher concentrations of total phosphorus, TOC, and chlorophyll *a* and lower concentrations of dissolved oxygen. Wetlands tend to have different hydrologic and water quality characteristics than other undisturbed land uses in a watershed, and understanding how wetlands may affect the water quality characteristics of the tributaries and the lake will be an important consideration for the re-examination strategy and nutrient management plans that are developed for the watershed.

Wetlands are often located in areas with poor draining soils, and the NRCS classifies soils into hydrologic soil groups (HSG) based on their drainage characteristics. Figure 3.10 shows a map of HSGs in the watershed relative to the location of the UNRBA monitoring stations. Soils in the watershed range from those with moderately high infiltration rates (HSG B) to those with low infiltration rates (Group D). Due to the poor drainage characteristics of HSG D soils, they are often associated with the presence of wetlands. Figure 3.11 shows the distribution of water quality parameters based on the underlying HSG at each monitoring station. For total phosphorus and total nitrogen, concentrations at sites with HSG D soils tend to be somewhat higher than those with HSG B or C soils. For TOC, concentrations tend to increase as infiltration rates decrease, with HSG D soils having the highest concentrations of TOC observed in the watershed. For chlorophyll *a*, HSG B tends to have lower concentrations than many sites located on HSG C or D soils.

Figure 3.10 Hydrologic Soil Groups in the Falls Lake Watershed

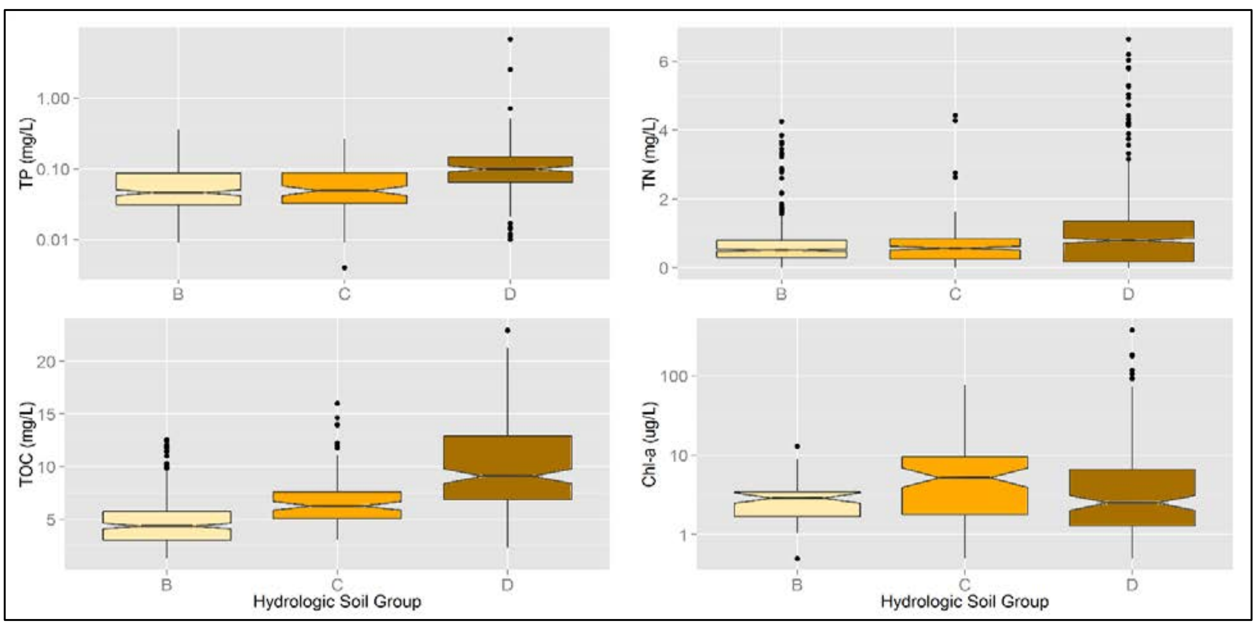

Figure 3.11 Distribution of Water Quality Parameters by Hydrologic Soil Group in the Falls Lake Watershed. Note that TP and Chl-*a* plots are shown on a logarithmic scale.

3.3 Quality Assurance Considerations for Data Collected Through June 2015

All collected data has been validated and evaluated for compliance with the quality objectives outlined in the Quality Assurance Project Plan. In addition, quality assurance evaluations of data accuracy, precision, and completeness have been performed for each monitored event.

3.3.1 Summary of Missing Data

From August 2014 to June 2015, the UNRBA collected about 90 percent of the data and samples programed in the monitoring plan. Approximately 10 percent did not result in sample collection. The majority of these occurred prior to December 2014 because the monitoring protocol at that time stated that samples should not be collected if streams are not visibly flowing. As a result, a higher percentage (approximately 13 percent) of samples were not collected in the summer/fall months of 2014 due to low flow conditions. A subsequent change to the monitoring protocol allowed for the collection of water samples regardless of flow and, as a result, only 8 percent of samples were not collected between December 2014 and June 2015. The majority of these missed samples were due to unsafe sampling conditions such inclement weather or bridge construction. Several sites were missed in February due to ice storms, despite several attempts at collection.

3.3.2 Summary of Accuracy and Precision

Accuracy and precision of results were assessed by monitoring reported blank concentrations and analyzing the percent difference between field duplicate pairs. From August 2014 to June 2015, duplicate pair replicability issues most commonly occurred during the measurement of ammonia, nitrate/nitrite, total Kjeldahl nitrogen, and total phosphorous concentrations. High field blank concentrations were reported with ammonia and phosphorous measurements. Additional quality control measures were requested of the laboratory in April 2015 and were implemented in July 2015. Field blanks were immediately improved and are continually being monitored.

3.4 Special Studies

Three special studies were initiated during Year 1 of the Monitoring Program. Preliminary data from these studies are provided below. Additional analyses and data collected through December 2015 will be summarized in the Annual Report that will be developed in the spring of 2016.

3.4.1 Storm Event Sampling

In April 2015, the UNRBA conducted storm event sampling on the Eno River and on Ellerbe Creek. Figure 3.12 shows the hydrographs at each monitoring location and the distribution of water quality samples that were collected and analyzed as part of this event. The water quality concentrations that were measured in each of these samples is provided in Figure 3.13 for Ellerbe Creek and Figure 3.14 for Eno River. The stream hydrographs are shown on the concentration plots to indicate rising and falling stream flows, but are not presented in these figures with flow units.

For most of the parameters, concentrations increased with increasing stream flows. The highest concentrations corresponded to the flow peaks, or showed a time lag relative to the peaks in flow which may be due to treatment issues at the WWTPs that may become overwhelmed during storm events or export of material associated with saturated shallow groundwater zones. At Ellerbe Creek, several parameters showed a third peak following the April storms, which may be related to the WWTP just upstream of the monitoring location. At Eno River, most of the parameters followed the general trend of higher concentrations with higher flows. Nitrate, however, continued to increase after the storm, which may be indicative of increased contribution from the shallow groundwater zone which became saturated during the storms.

Additional storms were monitored at these locations in September 2015, and two additional storms are targeted for sampling before June 2016. More detailed analysis of data from these storms will be presented in the spring 2016 Annual Report. These studies will help inform future model revisions by providing data to verify the accuracy of the loading estimates from the tributaries. As part of the model performance evaluation being conducted in FY 2016 (Section 2.2.6), preliminary model runs will be conducted to evaluate the impact of revised tributary loading estimates on simulated lake water quality.

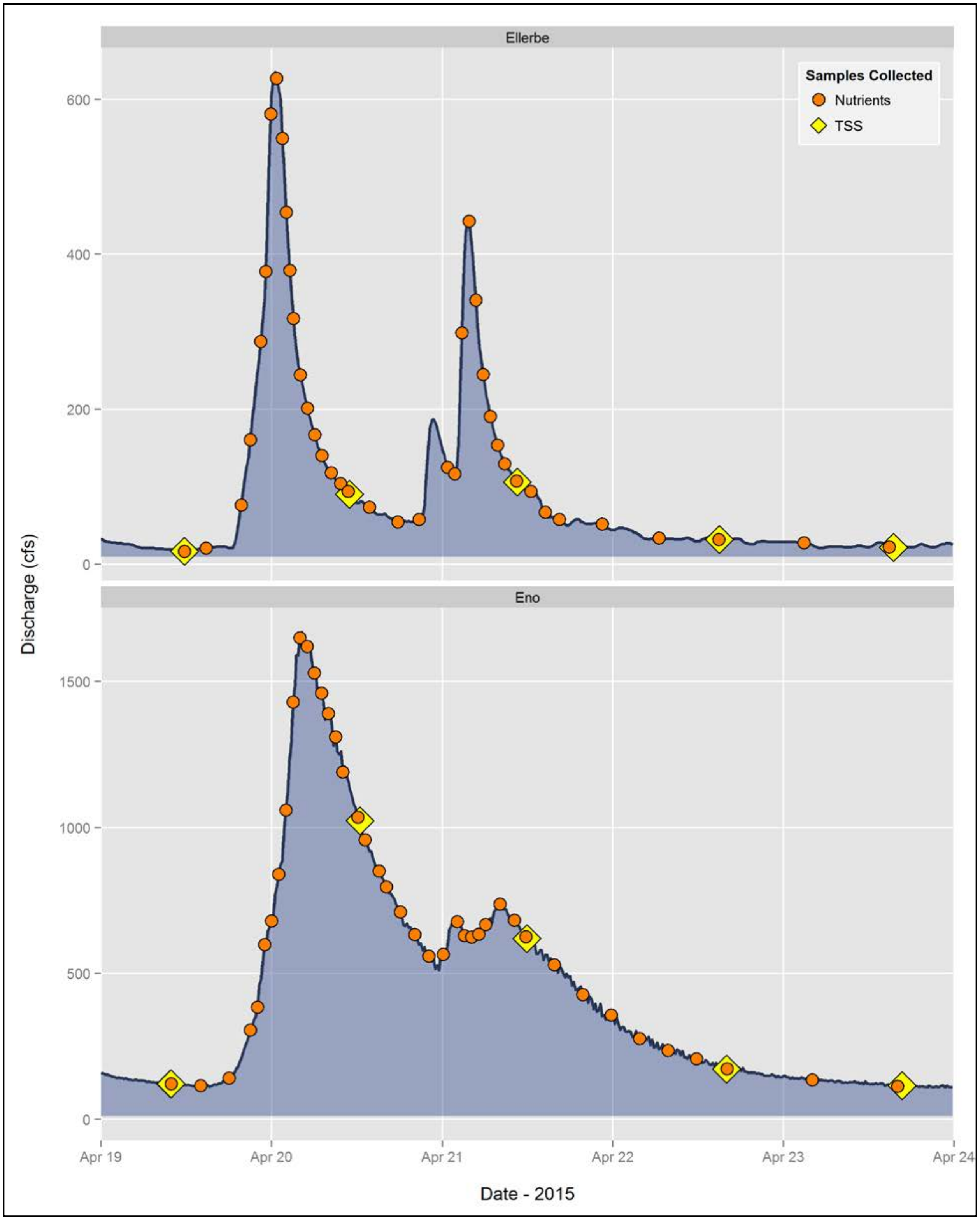

Figure 3.12 Hydrographs and Water Quality Samples Collected during the April 2015 Storm Event

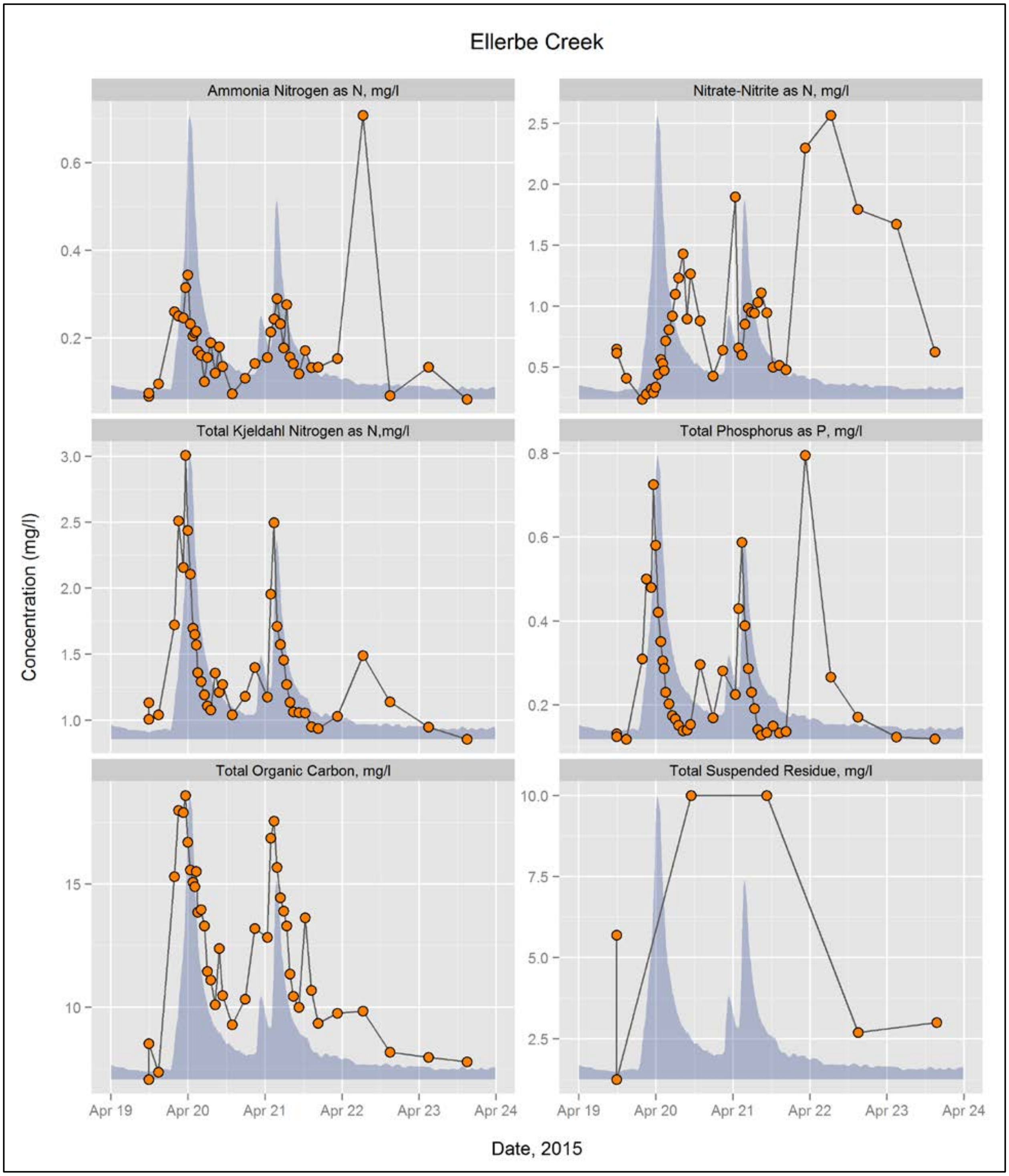

Figure 3.13 Water Quality Concentrations Observed in Ellerbe Creek during the April 2015 Storm Event

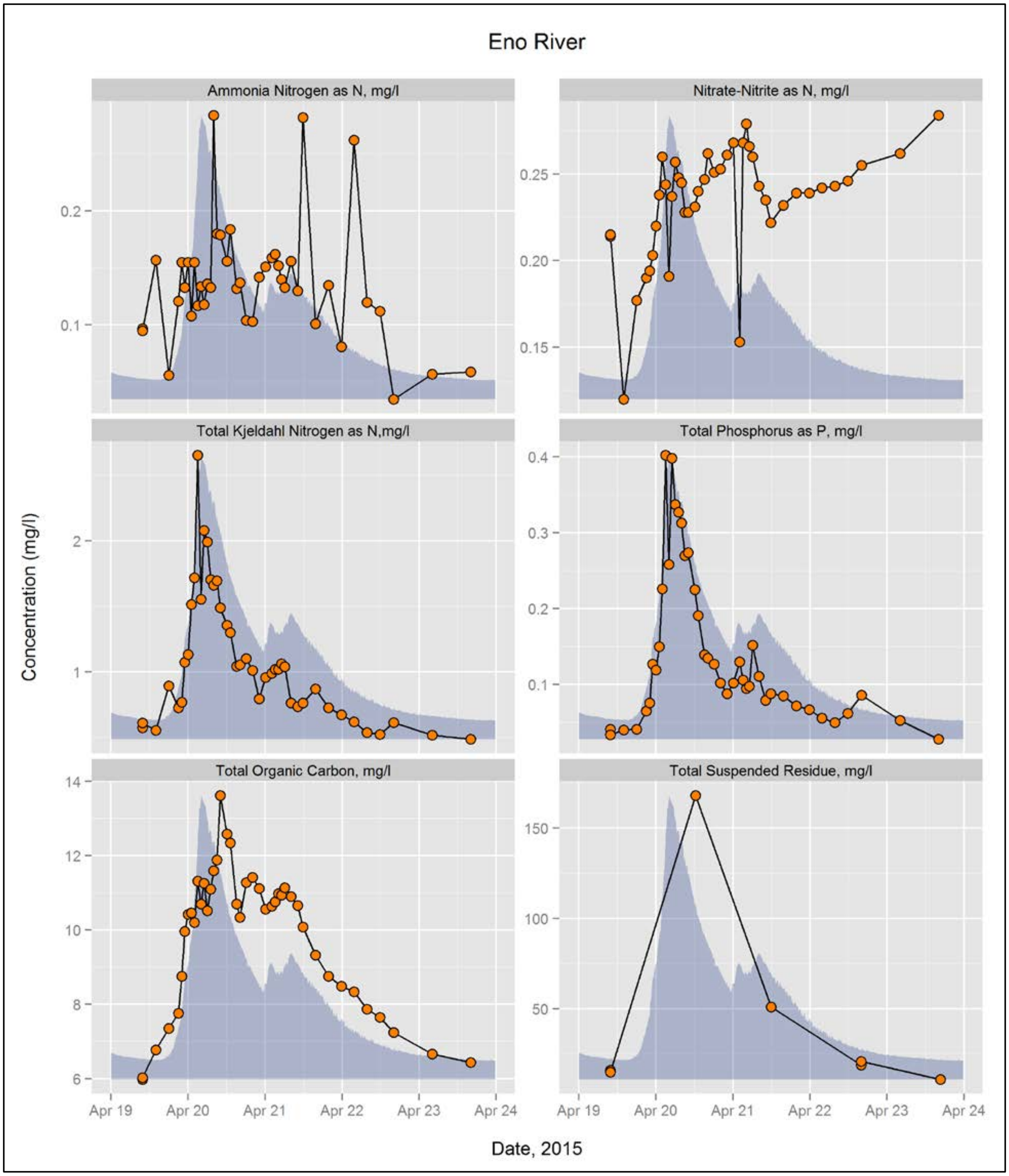

Figure 3.14 Water Quality Concentrations Observed in Eno River during the April 2015 Storm Event

3.4.2 High Flow Event Sampling

High flow conditions were sampled on February 10, 2015 and April 20, 2015 at eight lake loading stations in the Falls Lake watershed. The high flow sampling events are intended to measure water quality during elevated flows which are not captured by routine monitoring but contribute relatively large volumes of water to Falls Lake. Figure 3.15 illustrates that the high flow sampling events (orange triangles) did occur during flows which were not routinely captured (routine sampling indicated by blue circles). The flow estimates shown in Figure 3.15 are based on direct USGS gage measurements where available and on basin-area proration techniques elsewhere (flow estimation techniques are described in the Flow Estimation TM (Cardno 2014a) available at (http://www.unrba.org/monitoring-program). Flows are shown on the y-axis in cubic feet per second (cfs), and the x-axis shows the proportion of the year that flow was less than a certain value. The highest estimated flow at a station corresponds to a 1 on the x-axis because flows were less than or equal to the value 100 percent of the time; the lowest flows have a 0 value because no estimated flows were less than this value. Figure 3.16 indicates that the high flow event sampling adequately captured high flow conditions at each high flow event monitoring station. At the three stations which are sampled twice monthly (ENR-8.3, FLR-5.0, and LTR-1.9), the routine monitoring also resulted in samples that occurred during relatively high flows.

Elevated flows can influence water quality in different ways. Figure 3.16 shows how water quality concentrations varied with flow at three sites which illustrate the different types of patterns observed during these events (ENR-8.3, LTR-1.9, and ROB-2.8). At this point, with only two high flow event samples, these plots can be used to assess general patterns, but there are not enough data to draw definitive conclusions. Each plot shows the log of flow on the x-axis and observed concentrations of six water quality parameters on the y-axis.

At the Eno River site (ENR-8.3), chlorophyll *a*, total nitrogen, TOC, total phosphorus, and TSS concentrations were highest under elevated flows. The Robertson Creek site (ROB-2.8) shows the opposite trend for several parameters, with chlorophyll *a*, total nitrogen, TOC, and total phosphorus often lower under high flow conditions. This site is a wetland influenced site with low flow and nearly stagnant conditions much of the time. Decreased nutrient and carbon concentrations during high flows at this site may be the result of runoff diluting the higher concentrations which have built up from organic matter decomposition during non-flowing periods. At the Little River site (LTR-1.9), with the exception of a single TSS sample, the water quality observed during high flows appears similar to that observed under lower flows. The consistency in water quality observed at this site may be due to the Little River Reservoir located upstream. For all of the sites, dissolved oxygen concentrations under high flow conditions are within the range observed under lower flows (note this parameter is measured in the field and does not incur laboratory analysis fees). These sites demonstrate the variability in response to high flow conditions, and data will continue to be analyzed as the additional high flow events are conducted to inform potential revisions to this Special Study for FY2017.

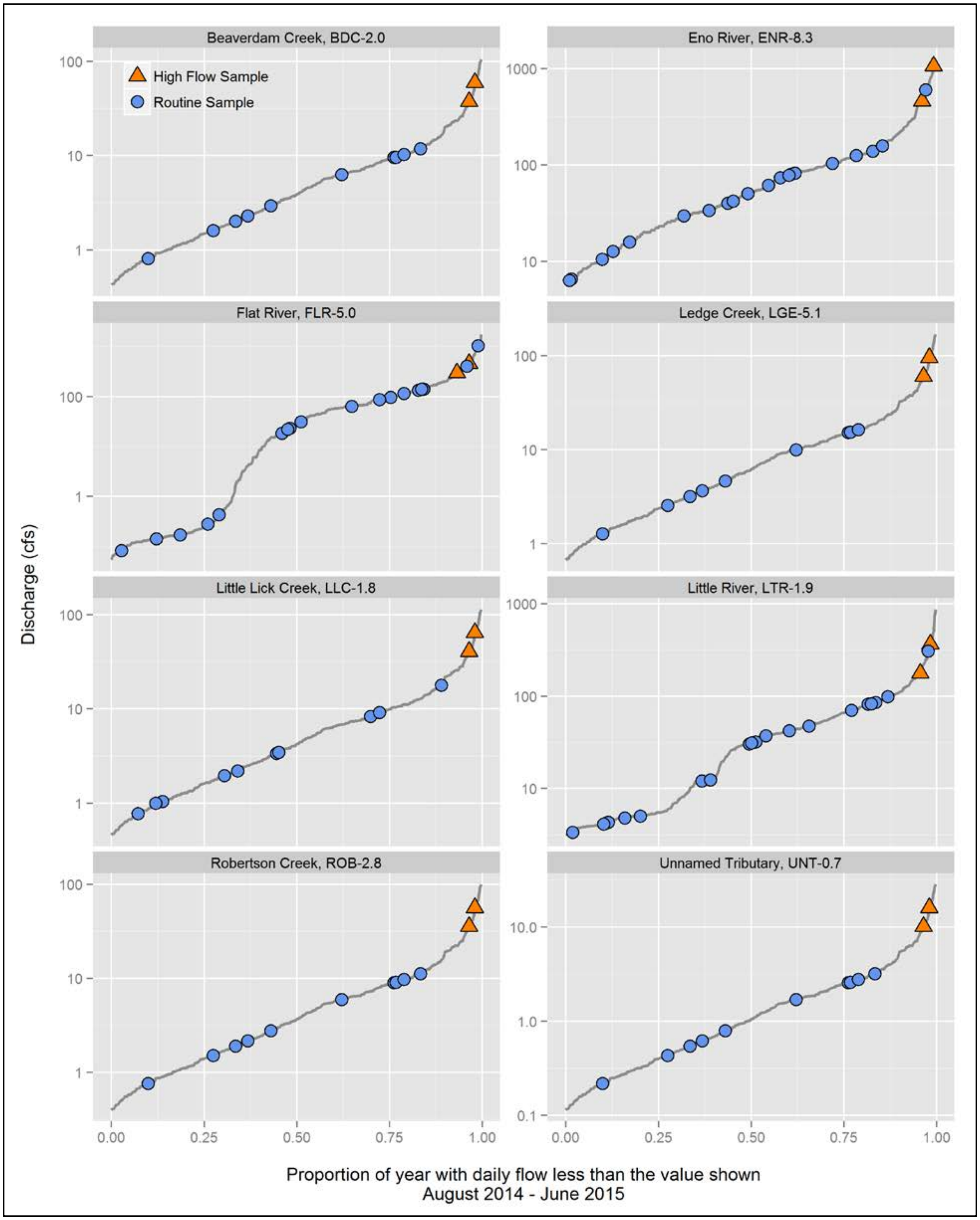

Figure 3.15 Sampling Events Compared to Flow at the Eight High Flow Event Sampling Stations

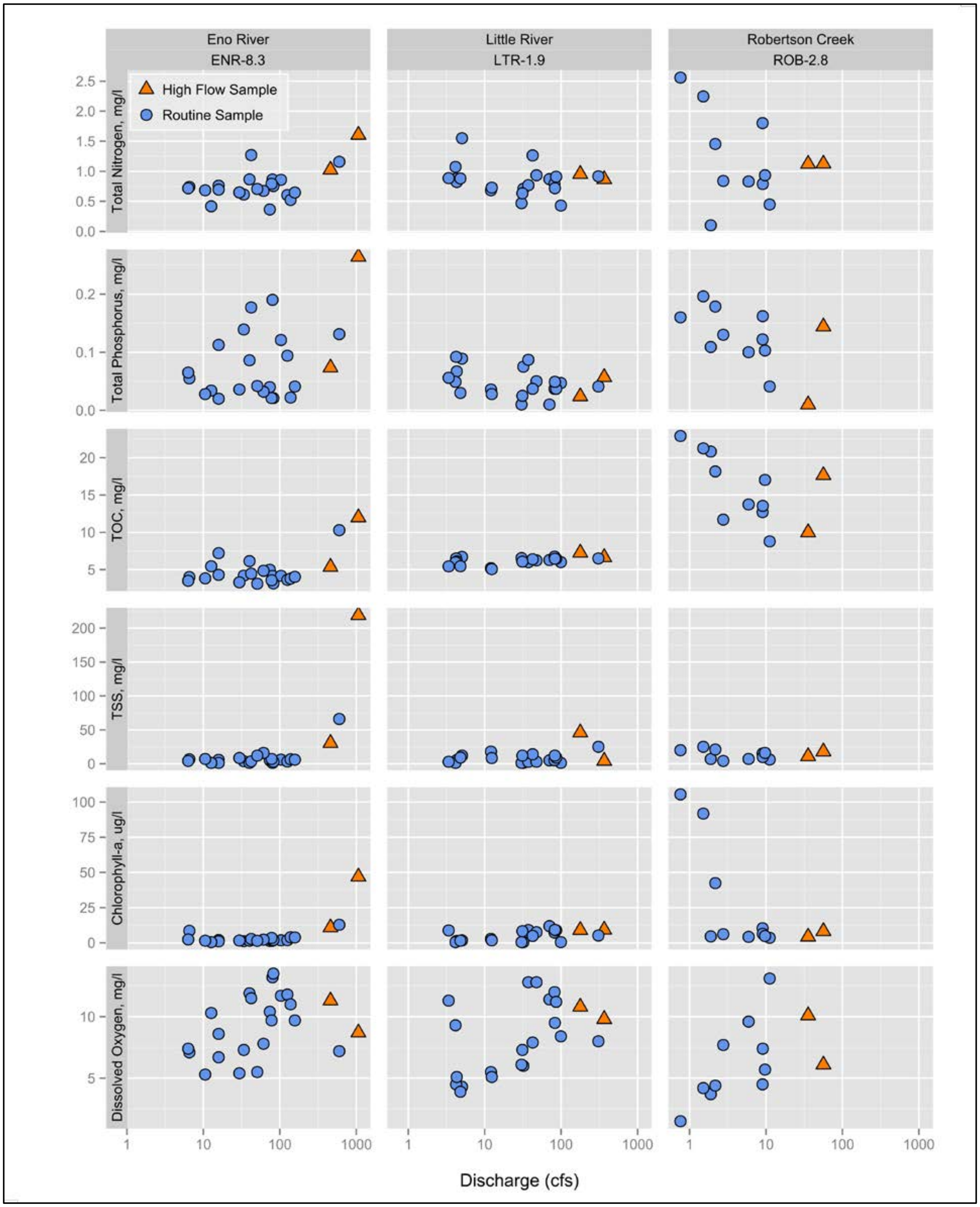

Figure 3.16 Water Quality Concentrations versus Flow at Three High Flow Event Sampling Stations

3.4.3 Falls Lake Sediment Evaluation

In the 2006 version of the EFDC model for Falls Lake, DWR assumed constant nutrient releases (fluxes) from the lake sediments that did not vary spatially or temporally; the rates of flux only varied with temperature. To assess the accuracy of this assumption, Cardno partnered with Dr. Marc Alperin from the University of North Carolina to evaluate the spatial variability of the sediments in Falls Lake and to collect data to support using the sediment diagenesis module of EFDC. Field reconnaissance for the sediment evaluation took place in May 2015 and revealed considerable variability in sediment properties throughout Falls Lake. In addition to differences between upper lake and lower lake conditions, multiple test cores indicated that drowned creek and river channels contained the thickest deposits of unconsolidated sediments and shallower areas (e.g. historic floodplains) often showed little or no unconsolidated sediment, instead having hard clay or rock at or very near the substrate surface. This variability in sediment composition can have significant impact on estimates of benthic flux in Falls Lake and therefore is an important factor in sample design.

To capture the spatial variability along the length of Falls Lake, sediment cores were collected at all 12 of DWR's Falls Lake monitoring locations and additionally downstream of Ellerbe Creek, Eno River, and Knap of Reeds Creek in the upper basin. Additionally, at each monitoring location, lateral variability was captured via cores taken from the deepest part of the pre-dam river channel and one or two places between the channel and current shoreline from what was floodplain before the dam was constructed. Downstream of the confluence of Beaverdam Creek with Falls Lake, the reservoir is more narrow and riverine and only one or two cores were collected at each of the three locations in this segment of the lake (Figure 3.17). Selection of coring locations was facilitated with a sonar depth finder.

Sediment cores were collected by hand (in shallow locations that did not have a layer of soft sediment) or by using a gravity corer. Sediment samples are being analyzed for porosity, loss on ignition, carbon content, and nutrient content. Pore-water extracted from the sediments and water samples from just above the sediments are being analyzed for ammonia, phosphate, and nitrate plus nitrite.

Results of nutrient analyses and benthic flux estimates are not yet complete; however, physical properties of the sediments have been analyzed and the results confirm the spatial patterns observed in the field. Measures of porosity (a measure of sediment coarseness) and loss on ignition (LOI, weight lost after combustion) tend to be correlated with organic matter content and nutrient flux potential. Sediment with high porosity is most likely to have high organic matter content and the greatest nutrient flux potential. In Falls Lake, porosity was greatest in sediments within the pre-dam river channel and increased from upstream to downstream indicating the highest potential benthic flux is confined to a relatively narrow spatial area within the Falls Lake sediment bed. LOI also increased from the upstream to downstream sites and showed interesting patters with sediment core depth. Constant LOI over the depth of a core suggests that the organic matter in the sediment is refractory, or resistant to decay by microbial activity. When LOI declines with depth in a core, remineralization is likely occurring and the potential for release of ammonium and phosphate from the sediments is higher. In Falls Lake, LOI was constant with depth in the upper basin suggesting presence of organic matter relatively resistant to decay (and potentially lower release of nutrients to the overlying water column) compared with a declining LOI in sediments downstream of the I-85 bridge which suggest higher decay in the sediments and likely release of nutrients to the overlying water column.

These physical measures are relatively inexpensive and, if the correlation with nutrient analyses and sediment nutrient flux estimates holds, may prove to be an efficient means to further assess the spatial variability of benthic flux in Falls Lake in the future.

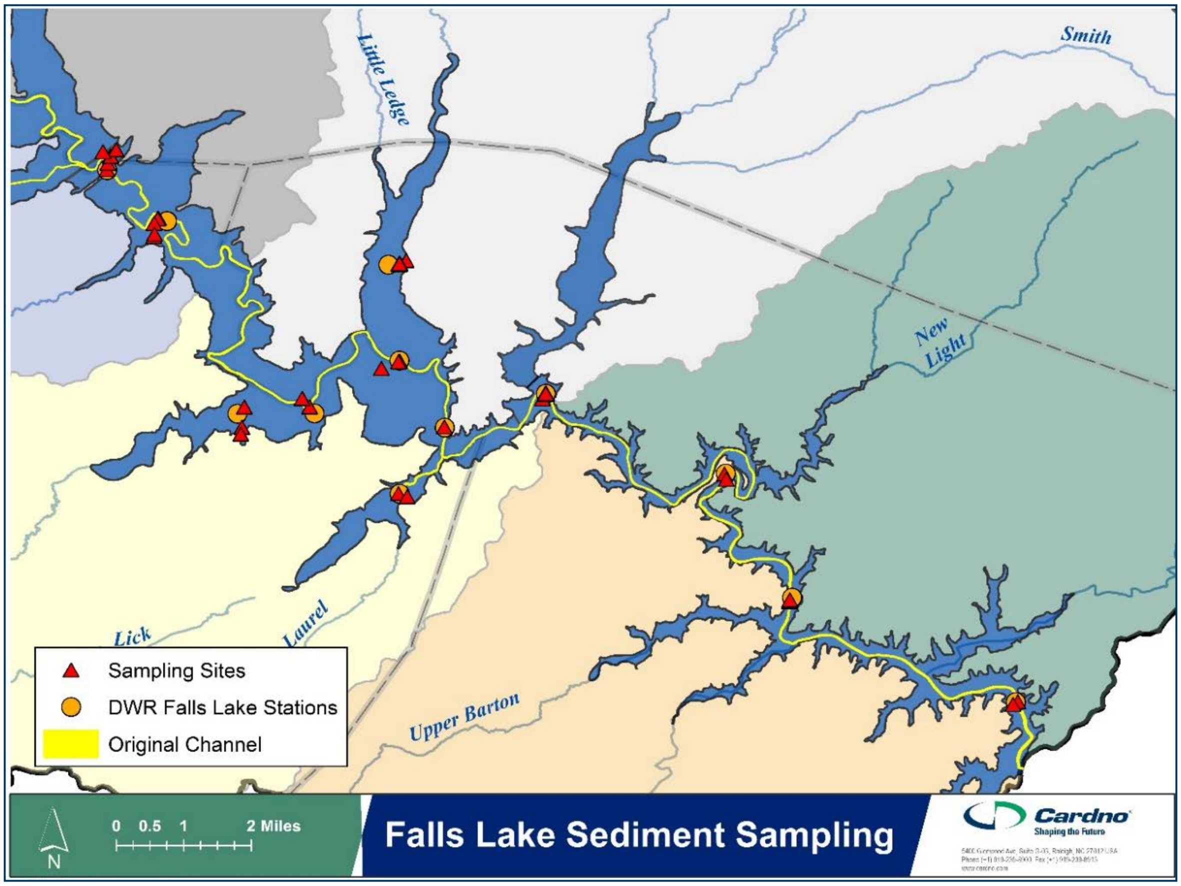

Figure 3.17 Locations of Sediment Core in Falls Lake Compared to DWR Lake Sampling Locations

3.5 Falls Lake Stations (DWR Monitoring Program)

NCDWR conducts water quality monitoring in Falls Lake at 12 stations on a monthly basis. Data is uploaded by NCDWR to the EPA STORET Water Quality Database as calendar year data sets. The 2015 UNRBA Monitoring Program Annual Report provided a brief summary of the lake data through December 2014. Additional data has not yet been uploaded by NCDWR, but it is anticipated that 2015 data will be available for consideration in the spring 2016 UNRBA Annual Report.

4 Summary and Recommendations

This Interim Report summarizes UNRBA data from August 2014 to June 2015. With the exception of May 2015, which was relatively dry, the average precipitation measured in the watershed was 40.8 inches, virtually the same as the 30-year average for the region of 41 inches for the same 11-month period. From August 2014 to March 2015, the observed stage (water level) in Falls Lake was higher than normal, and from April to August 2015, the lake levels were very close to the median value.

During this period, the UNRBA has accomplished the following:

> Collected about 90 percent of the data and samples programed in the monitoring plan (10 percent were missed due to weather and safety issues

> Improved quality assurance protocols and enhanced data turn around

> Created a public database with graphics and developed a guidance document to help users access the data

> Developed and posted plans of study for three Special Studies to the UNRBA monitoring website; three more are currently being developed

> Maintain a continual improvement in the monitoring process

4.1 Routine Monitoring

Routine Monitoring was conducted on a monthly or twice monthly basis at 38 monitoring stations in the watershed. Raw data measured under this program are available online at http://www.unrba.org/monitoring-program. This Interim Report provides graphic displays and data summaries for six key parameters that are of interest to the UNRBA members. Based on this first year of monitoring, preliminary observations for these six parameters include the following:

> Total nitrogen concentrations are generally higher at stations that are downstream of major WWTPs (> 1 MGD) or located on poorly draining soils (Hydrologic Soil Group D).

> Total phosphorus concentrations are generally higher at stations located on poorly draining soils (HSG D), the presence of an upstream WWTP did not seem to impact concentrations to the same degree as for total nitrogen. The City of Durham and SGWASA have recently upgraded their WWTPs, and the data may reflect these improvements.

> Chlorophyll *a* concentrations tend to be higher in wetland-dominated areas with stagnant flows and poor drainage characteristics (Hydrologic Soil Groups C and D). Algae can grow at these sites while they are stagnant, but since the flow is nearly zero when chlorophyll is high, these sites may not to be contributing significant algal biomass to Falls Lake. When wetland-dominated sites have been sampled during higher flow, chlorophyll concentrations have been well below the standard of 40 µg/L. Concentrations are often lower downstream of WWTPs, which may be due to increased effluent flows which limit stagnation and algal growth. Ninety-six percent of the chlorophyll *a* concentrations were lower than the water quality standard; four percent were noncompliant with the standard.

> TOC concentrations tend to be higher in areas dominated by wetlands with little or no flow, and there appears to be an increase in TOC concentrations in soils with poor drainage (i.e., higher TOC in HSG D).

> Dissolved oxygen concentrations tend to be lower in monitored locations with slow-moving or stagnant water, or large wetland complexes. Ninety-three percent of the dissolved oxygen concentrations were greater than the water quality standard of 4 mg/L; seven percent were noncompliant with the standard.

> For pH, 99 percent of measurements were compliant with the standard (6-9). Six stations had single pH values below 6, and no station had a value greater than 9.

No programmatic changes are suggested for this component of the Monitoring Program at this time.

4.2 Special Studies

Special Studies initiated during Year 1 of the Monitoring Program include Storm Event Sampling, High Flow Event Sampling, and the Falls Lake Sediment Evaluation. These three Special Studies have not been completed and additional data analyses and sampling events are being conducted through June 2016. Status updates for these evaluations will be summarized in the spring 2016 Annual Report.

4.2.1 Storm Event Sampling

Storm event sampling was conducted at Eno River and Ellerbe Creek in April 2015 (two storms in series) using automated sampling equipment. These automated samplers are programmed to collect water quality samples during rising and falling stream flows. For most of the parameters, concentrations increased with increasing stream flows. The highest concentrations corresponded to the flow peaks, or showed a time lag relative to the peaks in flow which may be due to treatment issues at the WWTPs that may become overwhelmed during storm events or export of material associated with saturated shallow groundwater zones. Storm event sampling was again conducted in August, September, and October 2015, and additional storm event sampling is planned for the winter and spring of FY 2016. These studies will help inform future model revisions by providing data to verify the accuracy of the loading estimates from the tributaries. As part of the model performance evaluation being conducted in FY 2016 (Section 2.2.6), preliminary model runs will be conducted to evaluate the impact of revised tributary loading estimates on simulated lake water quality.

4.2.2 High Flow Event Sampling

High flow event sampling was conducted at eight lake loading stations by manual grab techniques on February 10, 2015 and April 20, 2015. Different stations and parameters showed different responses to changing flows with some concentrations increasing with flows, some concentrations decreasing with flows, and some concentrations relatively similar regardless of flow. The variation in how high flows affect stream water quality may be a function of site-specific hydrology and antecedent conditions prior to the rain event. The observed patterns at the high flow monitoring stations appear to either increase concentrations with the delivery of additional material from upland areas and streambank erosion (nutrients and sediment) or decrease concentrations by diluting the high concentrations of nutrients, chlorophyll *a*, and carbon resulting from stagnant conditions. Two additional high flow events are scheduled for FY 2016.

4.2.3 Lake Sediment Evaluation

Reconnaissance for Falls Lake sediment sampling was conducted in May 2015. Test cores obtained during this trip indicated significant variability in the deposits of unconsolidated sediments in and out of the historic river and tributary channels. Variability was also evident in test cores collected in the upper versus lower part of the lake. In June 2015, sediment cores were collected at all 12 of DWR's Falls Lake monitoring locations. Additional samples were collected downstream of Ellerbe Creek, Eno River, and Knap of Reeds Creek in the upper lake basin. Preliminary analyses of sediment porosity and loss on ignition confirm the spatial patterns observed during reconnaissance. Sediment samples are now being analyzed for nutrient content, and the results of these analyses will be summarized in the spring 2016 Annual Report.

4.3 Recommendations

An important component of the UNRBA Monitoring Program is the ability to adapt monitoring plans as new information is accumulated. Any changes to the monitoring program must balance cost with the purpose and value of information gained or lost by the revision. Because the current information spans a period of only eleven months substantive changes to the UNRBA Monitoring Program are not recommended at this time. Cardno continues to evaluate potential future modifications which may lead to recommendations for station coverage and frequency changes and improved monitoring efficiency. Examples include:

- High-flow event sampling may be modified by eliminating stations or parameters where concentrations observed during high-flow events are similar to those collected during Routine Monitoring.
- Low dissolved oxygen and high chlorophyll *a* at non-flowing locations could misrepresent or bias larger-scale averages for the lake
- Parameters that are routinely at or below detection limit could be eliminated or reduced to provide cost savings (e.g., 5-day carbonaceous biochemical oxygen demand)
- Parameters that are highly correlated may not be providing additional valuable information (e.g., collection of both dissolved and total organic carbon)
- Revisions to the QAPP may be necessary to address quality assurance issues.
- Additional collection of supplemental data within Falls Lake may be advantageous based on evaluation of model performance

5 List of References

Cardno [ENTRIX]. 2012. Task 2: Review Existing Data and Reports for Falls Lake and the Watershed. Support of Long Term Planning and Regulatory Nutrient Activities in the Falls Lake Watershed. Prepared for the Upper Neuse River Basin Association.

Cardno [ENTRIX]. 2013. Task 1: Framework for a Re-examination of Stage II of the Falls Nutrient Strategy. Support of Long Term Planning and Regulatory Nutrient Activities in the Falls Lake Watershed. Prepared for the Upper Neuse River Basin Association.

Cardno [ENTRIX]. 2014a. Comparison of Flow Estimation Methods. Prepared for the Upper Neuse River Basin Association.

Cardno [ENTRIX]. 2014b. Final UNRBA Monitoring Plan for Submission to the North Carolina Department of Environment and Natural Resources, Division of Water Resources. Approved by DWR July 16, 2014.

N.C. Rules Review Commission. 2010. Falls Nutrient Strategy Rules Approved by the RRC on December 16, 2010. Effective Date - January 15, 2011.

NCDWQ. 2010. Fiscal Analysis for Proposed Nutrient Strategy for Falls of Neuse Reservoir.

UNRBA Monitoring FY 2016

APPENDIX

A

WATER QUALITY CONCENTRATIONS RELATIVE TO LAND USE AND PRESENCE OF WWTP IN THE FALLS LAKE WATERSHED

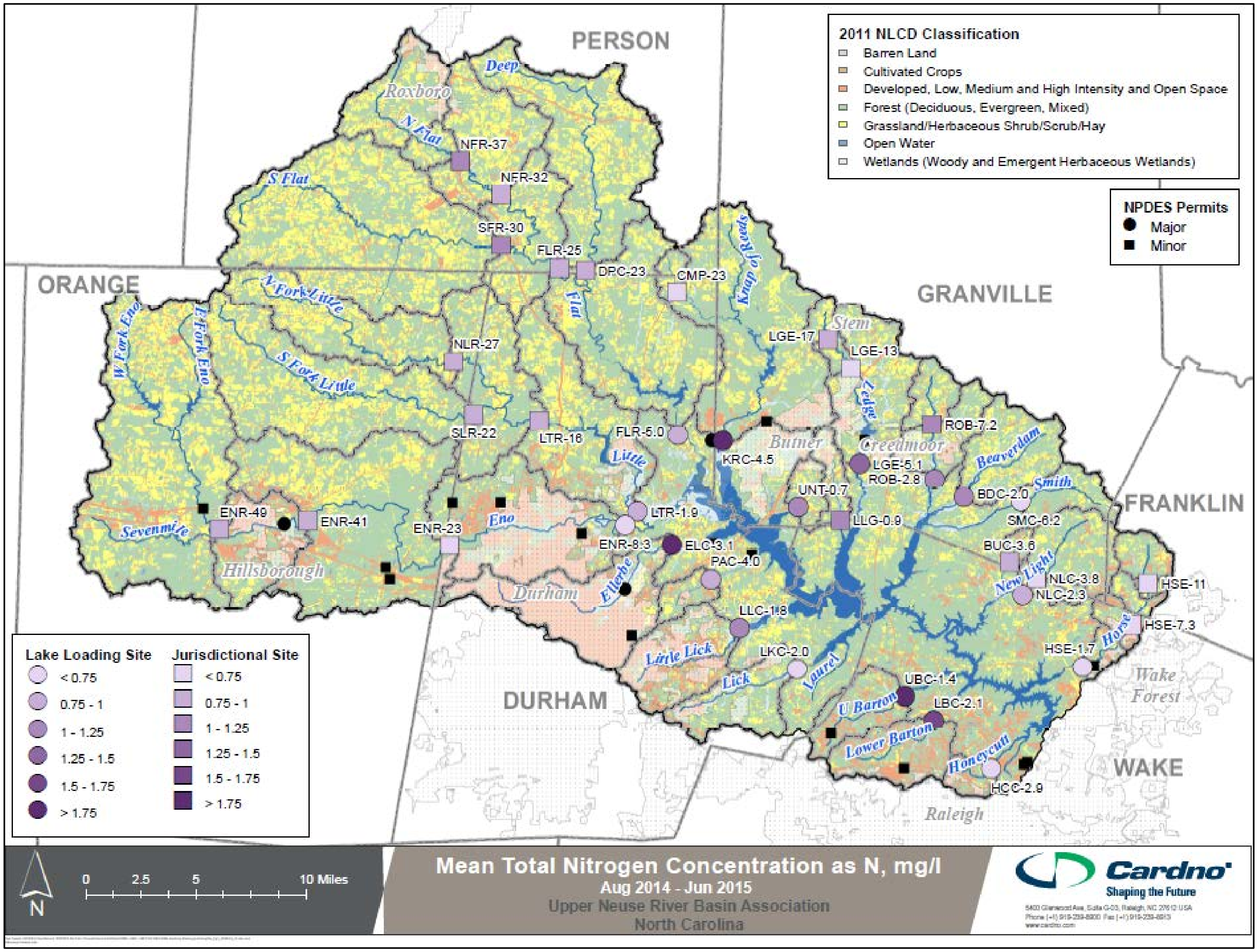

Figure A.1 Total Nitrogen Concentrations Relative to Land Use and Wastewater Facilities in the Falls Lake Watershed

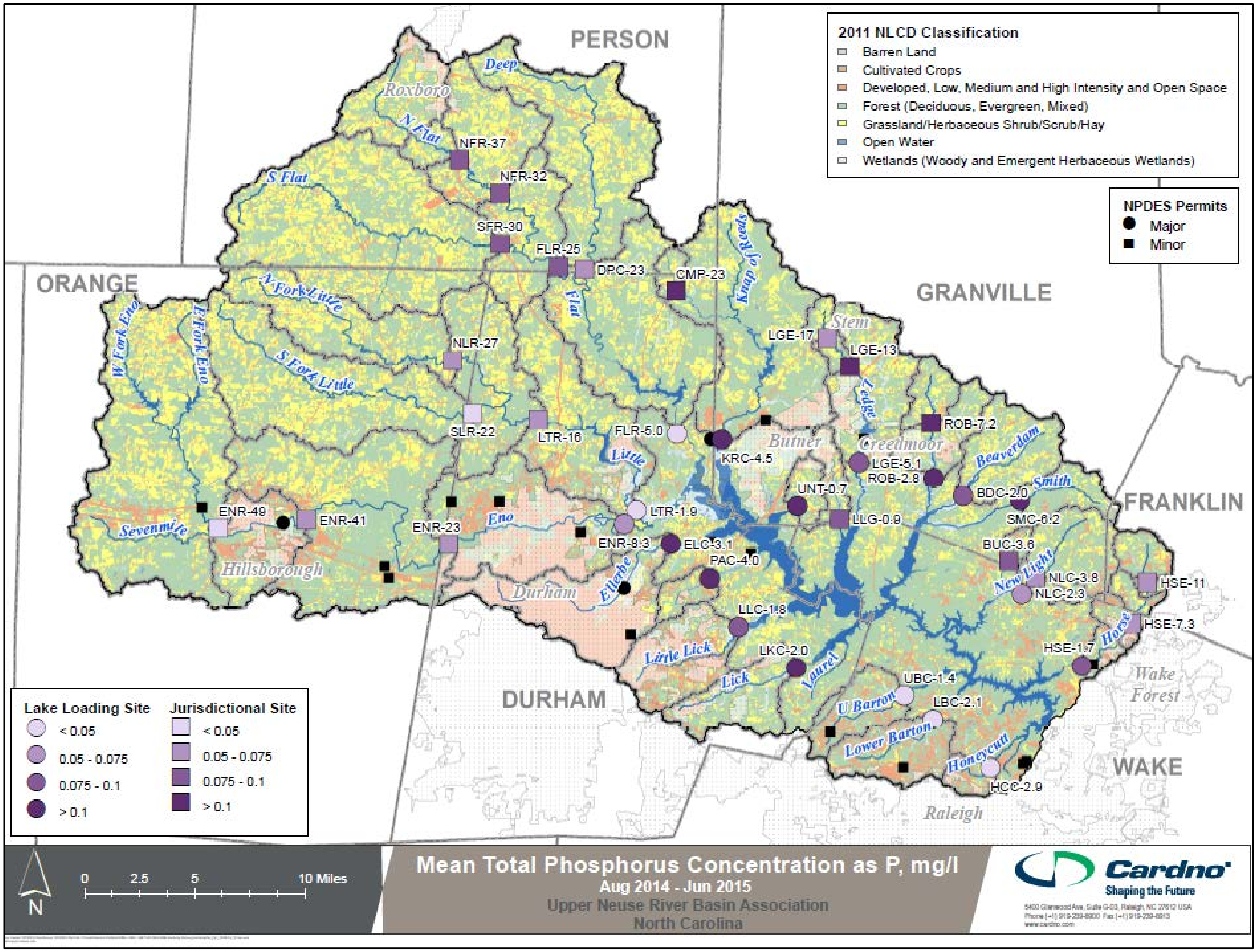

Figure A.2 Total Phosphorus Concentrations Relative to Land Use and Wastewater Facilities in the Falls Lake Watershed

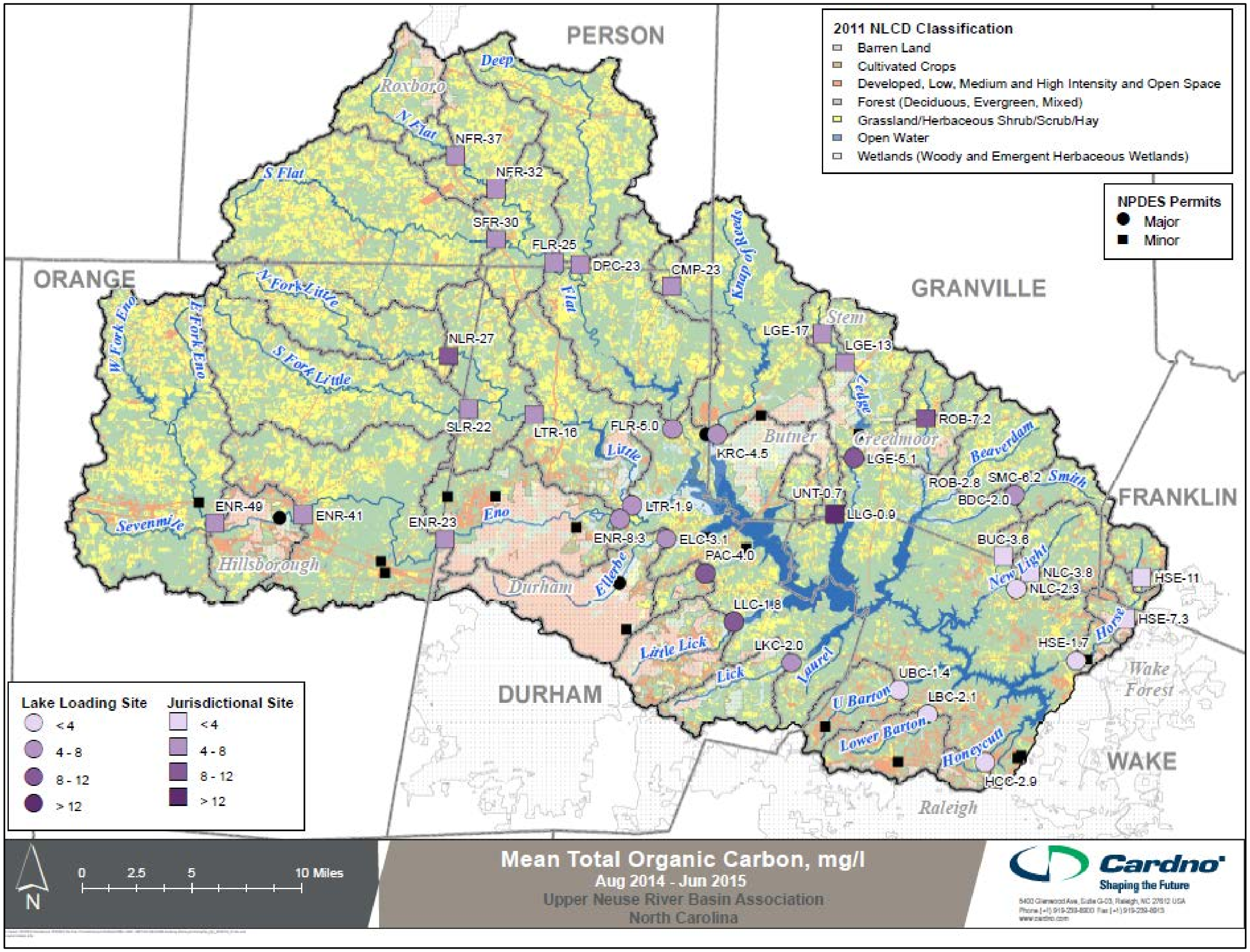

Figure A.3 Total Organic Carbon Concentrations Relative to Land Use and Wastewater Facilities in the Falls Lake Watershed

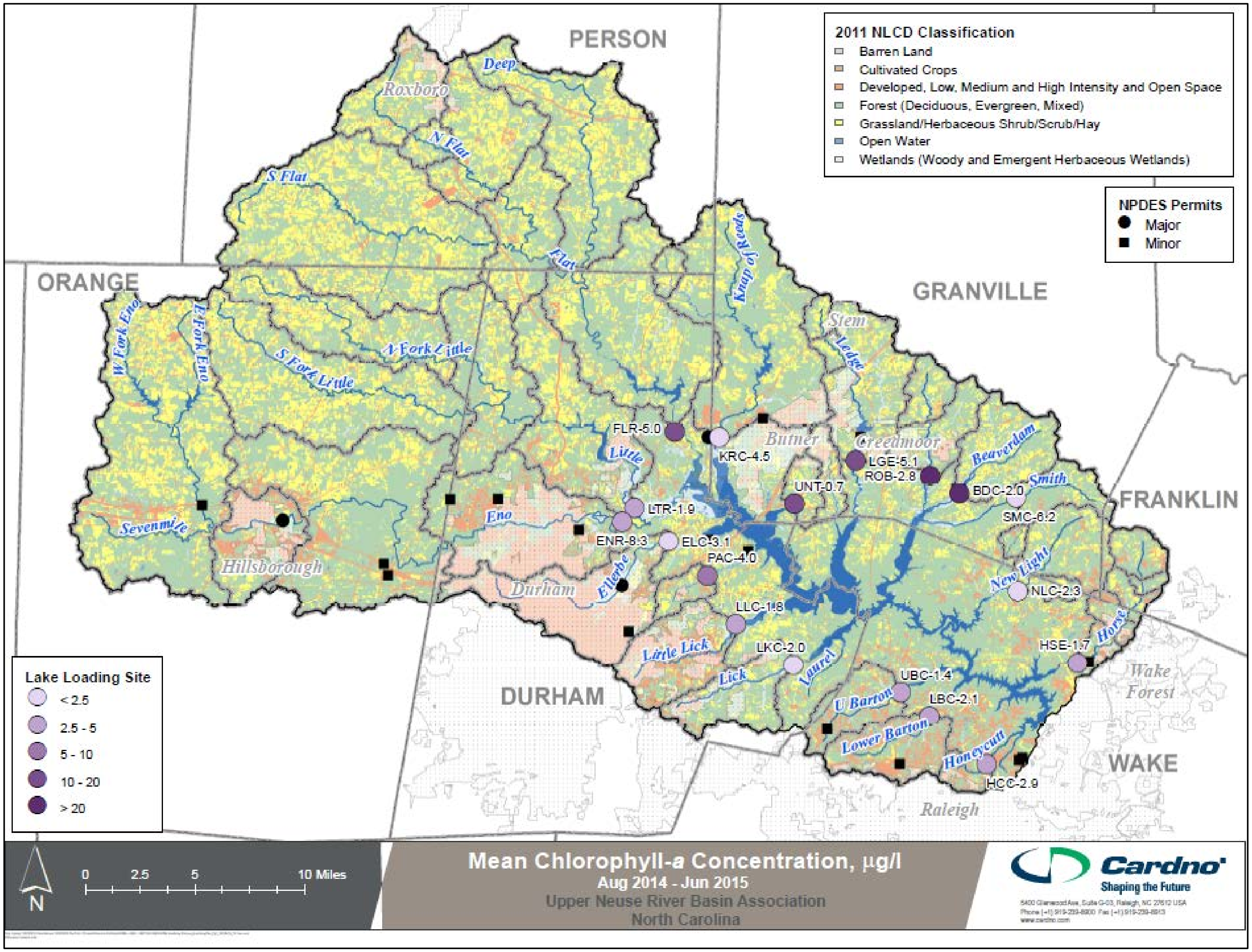

Figure A.4 Chlorophyll *a* Concentrations Relative to Land Use and Wastewater Facilities in the Falls Lake Watershed