UNRBA Monitoring Program Annual Report

UNRBA Monitoring FY 2016

May 2016

E213006402

Shaping the Future

Document Information

Prepared for	Upper Neuse River Basin Association
Project Name	UNRBA Monitoring Program FY 2016
Project Number	E213006402
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Date	May 2016

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Table of Contents

1 Purpose of the UNRBA Monitoring Program 1-1
1.1 Introduction 1-1
1.2 Regulatory Background 1-1
1.3 UNRBA Re-examination Strategy 1-2
1.4 Objectives of the UNRBA Monitoring Program 1-2
2 Overview of UNRBA Monitoring Program 2-1
2.1 Routine Monitoring 2-1
2.1.1 Lake Loading Stations on Tributaries in the Falls Lake Watershed 2-1
2.1.2 Jurisdictional Boundary Stations on Tributaries in the Falls Lake Watershed .. 2-1
2.1.3 Falls Lake Monitoring 2-2
2.1.4 Modifications to Routine Monitoring Since 2015 Interim Report 2-8
2.2 Special Studies 2-8
2.2.1 Storm Event Sampling 2-8
2.2.2 High-Flow Sampling 2-8
2.2.3 Lake Sediment Evaluation 2-10
2.2.4 Support Development of Alternative Nutrient Strategy 2-10
2.2.5 Constriction Point Study 2-10
2.2.6 Collect Volatile Suspended Solids (VSS) Data 2-11
2.2.7 Light Extinction Data 2-11
2.2.8 Basic Evaluation of Model Performance 2-11
2.2.9 Recreational Use Evaluation 2-11
3 Results and Discussion of Routine Monitoring Through December 2015 3-1
3.1 Overview of Hydrologic Conditions 3-1
3.2 Routine Monitoring 3-4
3.2.1 Lake Loading Stations 3-4
3.2.2 Jurisdictional Boundary Stations 3-27
3.2.3 Tributary Loading 3-42
3.3 Quality Assurance Considerations 3-43
3.3.1 Field and Laboratory Oversight 3-43
3.3.2 Representativeness and Completeness 3-43
3.3.3 Accuracy and Precision 3-43
4 Special Studies Status and Results 4-1
4.1 Storm Event Sampling 4-1
4.2 High Flow Sampling 4-6
4.3 Sediment Evaluation 4-9
4.4 Development of Alternative Regulatory Approaches 4-11
4.5 Constriction Point Study 4-12
4.6 Volatile Suspended Solids Data (VSS) 4-17
4.7 Light Extinction Data 4-17
4.8 Basic Evaluation of Model Performance 4-18

4.9 Recreational Use Evaluation 4-19
    4.9.1 Major Categories of Water-Based Recreation 4-22
    4.9.2 Comparison of Water Quality to Recreational User Counts 4-24
    4.9.3 Comparison of Other Factors to Recreational User Counts 4-27
    4.9.4 Recreational Use Support Assessment 4-28

5 Summary and Recommendations 5-1
5.1 Routine Monitoring 5-1
5.2 Special Studies 5-2
    5.2.1 Storm Event Sampling 5-3
    5.2.2 High Flow Sampling 5-3
    5.2.3 Lake Sediment Evaluation 5-3
    5.2.4 Support Development of Alternative Regulatory Approaches 5-3
    5.2.5 Falls Lake Constriction Point Study 5-3
    5.2.6 Volatile Suspended Solids Data 5-4
    5.2.7 Light Extinction Data 5-4
    5.2.8 Basic Evaluation of Model Performance 5-4
    5.2.9 Recreational Use Evaluation 5-5
5.3 Recommendations 5-5

6 List of References 6-1

Tables

Table 2.1 Overview of Routine Monitoring Components of the UNRBA Monitoring Program 2-3
Table 2.2 UNRBA Routine Monitoring Tributary Stations and Sampling Frequency 2-3
Table 2.3 Falls Lake Sampling by DWR and City of Durham 2-5
Table 2.4 Summary of UNRBA Special Studies under Way in Fiscal Years 1 and 2 2-9
Table 2.5 High Flow Event Monitoring Stations 2-10
Table 3.1 Stations with Chlorophyll *a* Measured above the NC State Standard (August 2014 to December 2015) 3-11
Table 3.2 Stations with Dissolved Oxygen Measurements below the NC State Standard (August 2014 to December 2015) 3-29
Table 3.3 Stations with pH Observed below the NC State Standard (August 2014 to December 2015) 3-29
Table 4.1 Discharge at Falls Lake through Two Constrictions and Released from the Dam 4-12
Table 4.2 Annual Visitation to Falls Lake (USACE 2013) 4-21
Table 4.3 Water-Based Visitation to Falls Lake (2005 to 2011), from NCDPR Records 4-24

Figures

Figure 2.1 UNRBA Lake Loading and Jurisdictional Monitoring Locations (see Table 2.2 for station details) and Existing USGS Gages 2-6
Figure 2.2 Falls Lake DWR and City of Durham Monitoring Locations, along with UNRBA Lake Loading Stations 2-7

Figure 3.1 Boxplots Representing Variation from 30-Year Normal Monthly Precipitation Totals at Monitoring Stations in the Falls Lake Watershed. 3-2

Figure 3.2 Falls Lake Elevation from January 2014 through December 2015 (median values (dashed line) and percentiles are based on data 1987 to present) 3-3

Figure 3.3 Falls Lake Elevation (stage) in Feet Above Mean Sea Level for the Period of DWR's EFDC Model Years 2005 through 2007 (Orange Line). 3-4

Figure 3.4 Temperature in Lake Loading and DWR Lake Samples from August 2014 to December 2015. 3-6

Figure 3.5 Dissolved Oxygen in Lake Loading and Lake Samples from August 2014 to December 2015 3-7

Figure 3.6 pH in Lake Loading and Lake Samples from August 2014 to December 2015 3-8

Figure 3.7 Specific Conductance in Lake Loading and Lake Samples from August 2014 to December 2015 3-9

Figure 3.8 Total Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2015 3-13

Figure 3.9 Nitrate plus Nitrite in Lake Loading and Lake Samples from August 2014 to December 2015 3-14

Figure 3.10 Ammonia in Lake Loading and Lake Samples from August 2014 to December 2015 3-15

Figure 3.11 Organic Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2015 3-16

Figure 3.12 Total Phosphorus in Lake Loading and Lake Samples from August 2014 to December 2015 3-17

Figure 3.13 Soluble Ortho-phosphate in Lake Loading Samples from August 2014 to December 2015 3-18

Figure 3.14 Chlorophyll *a* in Lake Loading and Lake Samples from August 2014 to December 2015 3-19

Figure 3.15 Total suspended solids (TSS) in Lake Loading and Lake Samples from August 2014 to December 2015 3-20

Figure 3.16 Volatile suspended solids (VSS) in Lake Loading and Lake Samples from August 2014 to December 2015 3-21

Figure 3.17 $CBOD_5$ in Lake Loading and Lake Samples from August 2014 to December 2015.. 3-22

Figure 3.18 Total Organic Carbon (TOC) in Lake Loading and Lake Samples from August 2014 to December 2015 3-23

Figure 3.19 Color (Platinum-Cobalt method) in Lake Loading Samples from August 2014 to December 2015 3-24

Figure 3.20 Color (absorbance at 440nm) in Lake Loading and Lake Samples from August 2014 to December 2015 3-25

Figure 3.21 Absorbance at 254nm in Lake Loading and Lake Samples from August 2014 to December 2015 3-26

Figure 3.22 Correlation between TOC and DOC in Lake Loading Samples from August 2014 to December 2015 3-27

Figure 3.23 Temperature in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.. 3-30

Figure 3.24 Dissolved Oxygen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015. 3-31

Figure 3.25 pH in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015. 3-32

Figure 3.26 Specific Conductance in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015. 3-33

Figure 3.27 Total Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.. 3-35

Figure 3.28 Nitrate plus Nitrite in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.. 3-36

Figure 3.29 Ammonia in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.. 3-37

Figure 3.30 Organic Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.. 3-38

Figure 3.31 Total Phosphorus (TP) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.. 3-39

Figure 3.32 Total suspended solids (TSS) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015. 3-40

Figure 3.33 Total Organic Carbon (TOC) in Jurisdiction Boundary and Lake Loading Samples from August 2014 to December 2015.. 3-41

Figure 3.34 The Contribution of each Tributary to the Total Water Load to Falls Lake during the Monitoring Period of August 2014 through December 2015. 3-42

Figure 4.1 Hydrographs and Water Quality Samples Collected from Ellerbe Creek during the Spring and Fall Storm Events 4-2

Figure 4.2 Hydrographs and Water Quality Samples Collected from Eno River during the Spring and Fall Storm Events 4-3

Figure 4.3 Water Quality Concentrations versus Flow Observed in Ellerbe Creek during the 2015 Spring and Fall Storm Events 4-4

Figure 4.4 Water Quality Concentrations versus Flow Observed in Eno River during the 2015 Spring and Fall Storm Events 4-5

Figure 4.5 Percent of Samples Collected during each Quintile of Water Load to Falls Lake from the Five Largest Tributaries with USGS Gaged Flow. 4-6

Figure 4.6 Sampling Events Compared to Flow at the Eight High Flow Event Sampling Stations 4-8

Figure 4.7 Water Quality Concentrations versus Flow at Three High Flow Event Sampling Stations 4-9

Figure 4.8 Sediment Core Sampling Locations in Falls Lake Compared to DWR Lake Sampling Stations 4-11

Figure 4.9 Comparison of Estimated and Measured Discharge for the January Constriction Point Study for Hwy 50 and I-85. 4-13

Figure 4.10 Example Water Quality Sampling Configuration for Constriction Point Study 4-14

Figure 4.11 Parameter Concentrations by Date Measured at the Interstate 85 Constriction Point Site.. 4-15
Figure 4.12 Parameter Concentrations by Date Measured at the Highway 50 Constriction Point Site.. 4-16
Figure 4.13 Map of Locations with Historic Light Extinction/Secchi Depth Data 4-17
Figure 4.14 Depth of 99% Light Attenuation versus Secchi Depth with 2015 Compared to Historic Data 4-18
Figure 4.15 Recreational Facilities of Falls Lake (from North Carolina State Parks) 4-20
Figure 4.16 Comparison of Water Based Visitation to Lake Water Quality Parameters 4-26

1 Purpose of the UNRBA Monitoring Program

1.1 Introduction

The Upper Neuse River Basin Association (UNRBA) Monitoring Program is primarily composed of two categories of water quality monitoring. The first category is Routine Monitoring, which 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, chlorophyll and other parameters over time. UNRBA Routine Monitoring began in August 2014. The second category, Special Studies, are focused evaluations conducted within a limited timeframe. Most Special Studies are intended to inform water quality modeling development and calibration so that baseline and management scenarios can be more accurately simulated. Special Studies are also used to assist the UNRBA in its efforts to explore and examine water quality and nutrient management programs, policies and regulations. Each Special Study is evaluated at the end of each monitoring year to determine whether it should be continued, modified, suspended, or replaced with another effort in the subsequent year.

In 2014, the UNRBA and Cardno initiated the Monitoring Plan that described the locations, parameters, frequencies, and duration program (Cardno 2014b; http://www.unrba.org/monitoring-program). The Monitoring Plan is maintained and updated by Cardno to reflect changes in the program over time. As established in Section 5 (f) of the Falls Lake Nutrient Management Strategy http://portal.ncdenr.org/web/fallslake/home, the UNRBA Monitoring Plan was initially approved by DWR on July 16, 2014. The UNRBA Monitoring Quality Assurance Project Plan (QAPP) was developed specifically for the program to ensure that data are reliable and suitable for consideration for regulatory purposes. The QAPP describes the protocols and methodologies to be followed by field and laboratory staff to ensure data precision and accuracy. It was initially approved by the North Carolina Department of Environmental Quality (NCDEQ) Division of Water Resources (DWR) on July 30, 2014.

Cardno is required to produce an Interim and Annual Report on the progress and nature of the monitoring results, and to assist the UNRBA in setting the scope and budget for the following year. Interim Reports are prepared each fall, and Annual Reports are prepared in the spring. The Monitoring Program scope and budget coincide with the UNRBA's Fiscal Year, which runs from July 1 through June 30.

This Annual Report provides a status review of the UNRBA Monitoring Program from August 2014 through December 2015. This report represents Year 1 and Year 2 (Calendar Years 2014 and 2015) of the Program. This report presents results and observed patterns and relationships in the data. The report includes specific recommendations for refinements to the Monitoring Program to optimize efficiency and value.

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). The Rules establish a Nutrient Management Strategy 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 performed by DWR 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 DWR to support these rules.

1.3 UNRBA Re-examination Strategy

In 2011, the 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 other nutrient strategy implemented in the State, will require 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 and public resource 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 the 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 scientific re-examination process relies on additional data collection and new modeling efforts to support revised lake response modeling, as well as evaluation of various regulatory options.

The Rules require that NCDEQ issue a status update for the Falls Lake Nutrient Management Strategy every five years, beginning in 2016. The final version of that update report was issued in March 2016 and is available on the NCDEQ website (http://portal.ncdenr.org/web/fallslake/rules-implementation-information). The report summarizes progress toward implementation of the Rules and describes changes in nutrient loading to the lake and lake water quality. The 2016 status report highlights the improvements (reductions) in chlorophyll *a* concentrations observed throughout the lake. The report also acknowledges the UNRBA as a collaborative partner to further the science with respect to reducing the uncertainty associated with the lake modeling, expanding the "toolbox" of best management practices that may be used for compliance, and employing conventional and innovative nutrient control measures to improve water quality in the lake (NCDEQ 2016).

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 December 2015.

2 Overview of UNRBA Monitoring Program

This Annual Report addresses monitoring efforts from August 2014 through December 2015. During this period, the UNRBA Monitoring Program focused on Routine Monitoring and a series of Special Studies. Additional information about the general nature of the Routine Monitoring and Special Studies efforts are provided in the Monitoring Plan and in the Plan of Study for each Special Study (https://unrba.org/monitoring-program).

2.1 Routine Monitoring

The Routine Monitoring Program was established to characterize the spatial and temporal variability of water quality in the Falls Lake Watershed. It includes Lake Loading stations and Jurisdictional Boundary stations located on tributaries to the lake. Data collection is managed by Cardno. The Monitoring Program contract and any major changes to the program are synchronized with the UNRBA fiscal year from July through June. Table 2.1 outlines the Routine Monitoring efforts on the tributaries, and Table 2.2 lists the tributary stations and monitoring frequency. Routine Monitoring also includes coordination with DWR, which conducts monthly monitoring at long-term stations located on the Falls Lake Reservoir.

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 from locations as near as possible to 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 Technical Memorandum (Cardno 2014a) available at (http://www.unrba.org/monitoring-program).

In addition to the monthly sampling at the 18 Lake Loading Stations, water quality sampling occurs twice a month on five of those tributaries to the upper lake which are estimated to contribute roughly 75 percent of the inflow quantity 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 are presumed to drive much of the lake's 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 in support of the Rules.

The parameters selected for Routine Monitoring at Lake Loading stations were generally based on the requirements of the Environment Fluid Dynamics Code (EFDC) model originally used by DWR for Falls Lake, 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 Boundary 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 between the UNRBA member governments. As with the Lake Loading Stations, data collection efforts at Jurisdictional Boundary stations may be modified in the future to optimize data value for the UNRBA.

2.1.3 Falls Lake Monitoring

Monitoring of the Falls Lake Reservoir provides data on ambient water quality conditions, as well as for calibration and validation of updated lake models. Ongoing monitoring by DWR, local governments (City of Raleigh and City of Durham), and North Carolina State University's Center for Applied Aquatic Ecology (NCSU CAAE) provides data that may be used. Table 2.3 summarizes the monitoring efforts of DWR and the City of Durham, whose data are presented in this report. Locations of monitoring stations are displayed on Figure 2.2. Data were not provided by the City of Raleigh or NCSU CAAE for consideration in this report, but may be included in future reports.

At the request of the UNRBA, DWR added a station in Falls Lake downstream of Ledge Creek in 2014 and added the following parameters to all of their monitoring stations: total suspended solids (TSS), volatile suspended solids (VSS), 5-day carbonaceous biochemical oxygen demand (CBOD5), and dissolved organic carbon (DOC). DWR also collects samples that the UNRBA has analyzed by a contract laboratory for color and specific UV absorbance (SUVA). Data summaries for the parameters that DWR analyzes may be accessed through the DWR website (https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/intensive-survey-branch/falls-jordan-lakes-monitoring).

The City of Durham collects water quality samples from two stations on Falls Lake. These stations (Cheek Road and I-85) are sampled weekly from April to October as photic zone composites. City of Durham data are available online at http://www.durhamwaterquality.org/. Data from the City of Durham is reflected in several of the graphics in Section 3.

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

Monitoring Program Component	Parameters Collected during Fiscal Years 1 and 2	Frequency of Collection in Fiscal Years 1 and 2	Frequency of Collection in Fiscal Years 4 and 5 (optional)
18 Lake Loading tributary stations (names and locations provided in Table 2.2)	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 (Pt Co units) Color (absorbance at 44nm) 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 2.2)	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	discontinued
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

Name[1] (Station Type[2])	Subwatershed	Stream Name	County	Drainage Area (mi^2)	Sampling Frequency
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
ELC-3.1(LL)	Ellerbe	Ellerbe	Durham	21.9	Twice monthly
UNT-0.7(LL)	Unnamed	Unnamed	Granville	3.43	Monthly
PAC-4.0(LL)	Panther	Panther	Durham	3.24	Monthly
LLC-1.8(LL)	Little Lick	Little Lick	Durham	13.8	Monthly
LLG-0.9(JB)	Little Ledge	Little Ledge	Granville	3.74	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
LKC-2.0(LL)	Lick	Lick	Durham	10.8	Monthly
ROB-7.2(JB)	Robertson	Robertson	Granville	4.43	Monthly
ROB-2.8(LL)	Robertson	Robertson	Granville	12.0	Monthly
BDC-2.0(LL)	Beaverdam	Beaverdam	Granville	12.7	Monthly
SMC-6.2(LL)	Smith	Smith	Granville	6.3	Monthly
BUC-3.6(JB)	New Light	Buckhorn	Granville	1.21	Monthly
NLC-3.8(JB)	New Light	New Light	Wake	9.90	Monthly
NLC-2.3(LL)	New Light	New Light	Wake	12.3	Monthly
UBC-1.4 (LL)	Upper Barton	Upper Barton	Wake	8.26	Monthly
LBC-2.1 (LL)	Lower Barton	Lower Barton	Wake	10.4	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	9.60	alternate site
HSE-1.7(LL)	Horse	Horse	Wake	11.9	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.

Table 2.3 Falls Lake Sampling by DWR and City of Durham

Parameter	Collection Method	DWR Sampling Frequency (12 Stations)	City of Durham Sampling Frequency (2 stations)
TOC	Photic Zone Composite	Monthly	Weekly (Apr – Oct)
DOC	Photic Zone Composite	Monthly	--
CBOD5	Photic Zone Composite	Monthly	--
Chlorophyll a	Photic Zone Composite	Monthly	Weekly (Apr – Oct)
TN	Photic Zone Composite	Monthly	Weekly (Apr – Oct)
TKN	Photic Zone Composite	Monthly	Weekly (Apr – Oct)
NO2 + NO3	Photic Zone Composite	Monthly	Weekly (Apr – Oct)
NH3	Photic Zone Composite	Monthly	Weekly (Apr – Oct)
TP	Photic Zone Composite	Monthly	Weekly (Apr – Oct)
Ortho-phosphorus	Photic Zone Composite	--	Weekly (Apr – Oct)
Turbidity	Photic Zone Composite	Monthly	Weekly (Apr - Oct)
TSS	Photic Zone Composite	Monthly	--
VSS	Photic Zone Composite	Monthly	--
pH	Depth Stratified	Monthly	Weekly (Apr – Oct)
Conductivity	Depth Stratified	Monthly	Weekly (Apr – Oct)
Dissolved oxygen	Depth Stratified	Monthly	Weekly (Apr – Oct)
Temperature	Depth Stratified	Monthly	Weekly (Apr – Oct)
Secchi Depth		Monthly	Weekly (Aprl – Oct)

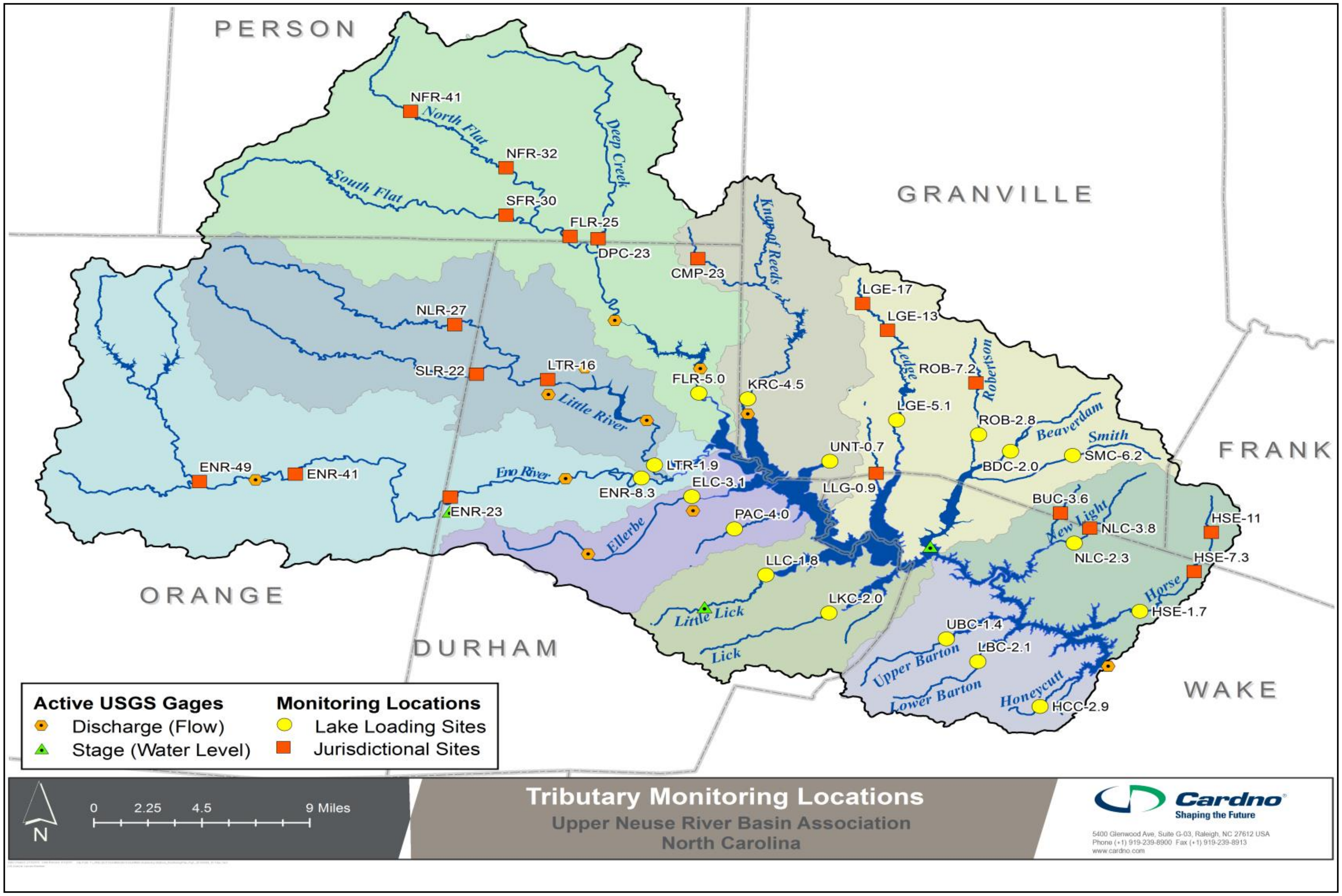

Figure 2.1 UNRBA Lake Loading and Jurisdictional Monitoring Locations (see Table 2.2 for station details) and Existing USGS Gages

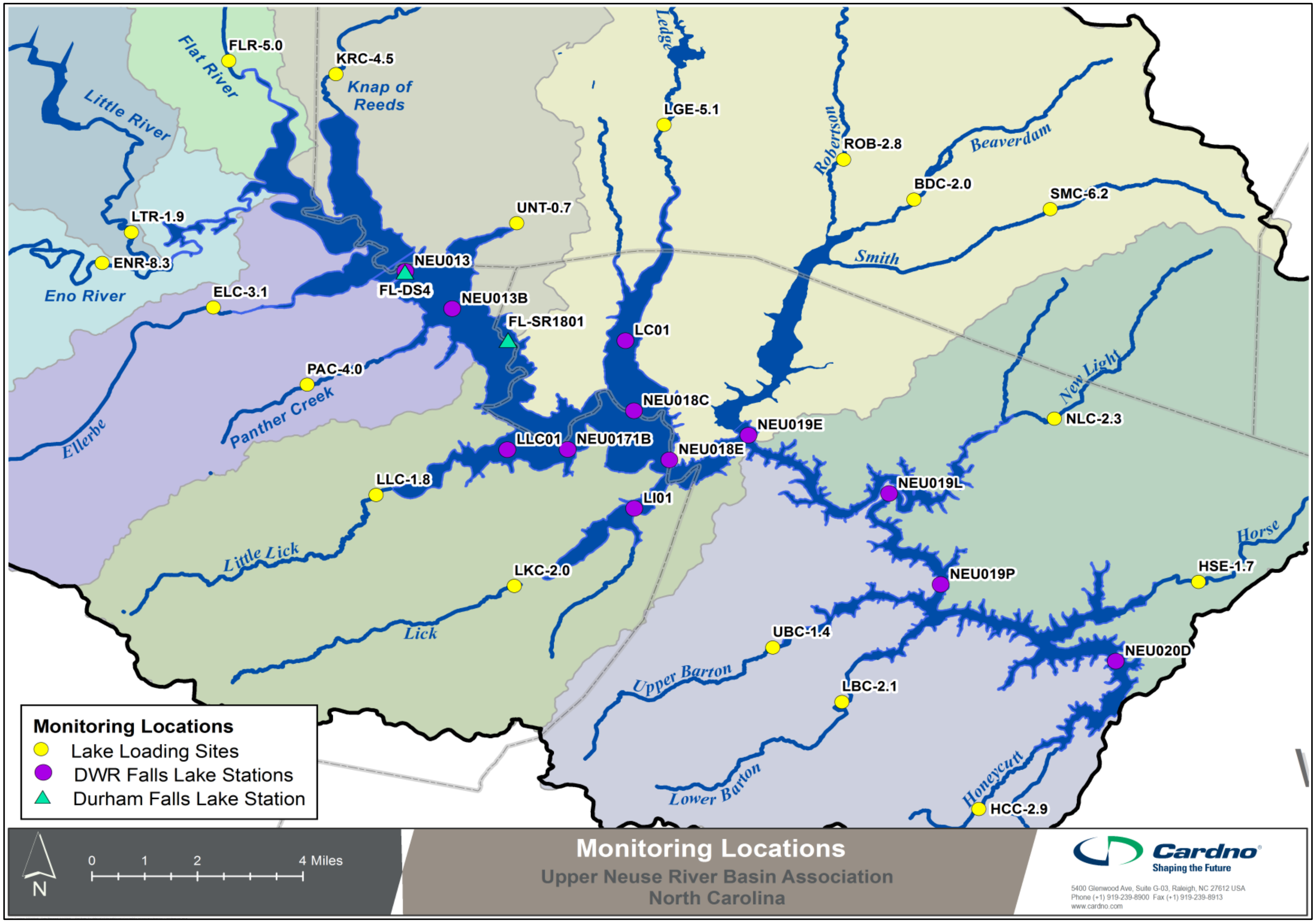

Figure 2.2 Falls Lake DWR and City of Durham Monitoring Locations, along with UNRBA Lake Loading Stations

2.1.4 Modifications to Routine Monitoring Since 2015 Interim Report

There have been no changes to the Routine Monitoring since the Interim Report was published in October 2015. A copy of the 2015 Interim Report is available at https://www.unrba.org/monitoring-program.

2.2 Special Studies

The UNRBA Monitoring Program includes Special Studies designed to address specific questions. Table 2.4 briefly summarizes the Special Studies under way. Each Special Study Plan was developed by Cardno, and has been approved by the UNRBA Executive Director. 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 December 2015 is provided in Section 4.

2.2.1 Storm Event Sampling

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, three storm peaks were sampled in late September/early October 2015, and another storm event was sampled in February 2016. 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 the 2015 events is provided in Section 3. An additional event is planned for spring 2016.

2.2.2 High-Flow 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 periods when stream flow increases markedly above normal flows in response to a rain event. 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 modeling of Falls Lake and provide water quality data under-represented by routine monitoring.

High flow samples were collected from eight of the Lake Loading Stations (Table 2.5). 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 consistent with Lake Loading stations. An overview of High Flow results is presented in Section 3.

Table 2.4 Summary of UNRBA Special Studies under Way in Fiscal Years 1 and 2

Monitoring Program Component	Purpose
Storm Event Sampling (initiated in Fiscal 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 modeling efforts.
High Flow Sampling (initiated in Fiscal Year 1)	Obtain additional water quality data when there is elevated flow at select Lake Loading stations. These data will be used to determine if water quality in these areas is different when flows are elevated and thus conveying more water and loading to the lake. These data will be used to ensure that loading estimates from these tributaries are representative of delivered loads, and not misrepresented by base flow conditions.
Falls Lake Sediment Sampling (initiated in Fiscal 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.
Support Development of Alternative Nutrient Strategy (initiated in Fiscal Year 1)	Meetings with regulators (DEQ and EPA) to discuss alternative regulatory strategies for Stage II of the Falls Lake Nutrient Management Strategy. These meetings will be used to identify their study expectations for support of alternate regulatory approaches and be sure the UNRBA monitoring program collects or has access to this information.
Falls Lake Constriction Point Flux Assessment (initiated in Fiscal 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 for future model calibration to ensure that the model is accurately representing changing conditions at time steps that match short-term lake response.
Measure VSS at Lake Loading and inlake stations (initiated in Fiscal Year 2)	Include monitoring of VSS at Lake Loading and lake monitoring stations so that the TSS output by the Falls Lake model (which includes only the inorganic fraction) can be compared directly to laboratory measurements which are calculated as TSS - VSS. DWR agreed to add this parameter to their lake monitoring, and the program now covers this parameter within Routine Monitoring.
Light Extinction Data Collection (initiated in Fiscal 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 Fiscal 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 Fiscal Year 2)	Compile available recreational data for Falls Lake and 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.

Table 2.5 High Flow Event Monitoring Stations

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

2.2.3 Lake Sediment Evaluation

This Special Study examines the nutrient and organic carbon content of sediment samples from Falls Lake. These data will support 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 provides information 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. 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 in June 2015 and results are presented in Section 3.

2.2.4 Support Development of Alternative Nutrient Strategy

This future activity will help identify and define studies needed for supporting alternate regulatory submissions by the UNRBA. For this Special Study, Cardno is available to the UNRBA to respond to various regulatory issues as they arise and to assist preparing a strategy and presentation materials for meetings and discussions with regulators (EPA and DWR). The goal of these meetings will be to discuss agency positions concerning alternative regulatory approaches and to help identify the kinds of data that may be needed to support such approaches.

2.2.5 Constriction Point Study

Water quality in Falls Lake may be driven by processes that occur at relatively short time steps (e.g., sunlight and cloud cover, wind, and variable tributary flows). NCDWR samples water quality in Falls Lake at 12 locations monthly. Thus the DWR data is suitable to characterize the overall water quality in the lake and can be used for regulatory assessment purposes, but it does not provide insight to inlake dynamics during rapidly changing conditions such as a large storm event.

This Special Study was added 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 segment to the next. The bridge constrictions are points of concentrated flow and are an efficient location to monitor the downstream transport of water and material.

Collecting velocity and water quality data at these locations over multiday periods when flows are changing in response to storm events will provide enhancements for model calibration 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. Two data collection events are budgeted for FY2016; the first took place in January 2016, and the second is expected to be conducted in the spring.

2.2.6 Collect Volatile Suspended Solids (VSS) Data

This small Special Study was added in FY 2016 to include monitoring of VSS at Lake Loading and inlake stations so that the Total Suspended Solids output values generated by the Falls Lake EFDC model (which represents only the inorganic fraction) could be compared directly to laboratory measurements which are calculated as TSS minus VSS. VSS is measured in the Lake Loading stations samples by the UNRBA contract laboratory, and DWR agreed to collect samples. This small effort is now contained within the Routine Monitoring program.

2.2.7 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 for modeling. 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 modeling uncertainty resulting from using Secchi depth data as a proxy for light extinction measurements.

2.2.8 Basic Evaluation of Model Performance

This Special Study was added to help evaluate models for the re-examination of the Falls Lake Nutrient Management Strategy. This evaluation is being performed to determine whether or not the current monitoring program design is sufficient, or whether the program requires revisions to address modeling needs. This study focuses on modeling approaches the UNRBA may use for the re-examination and potential alternative regulatory approaches. A summary of the preliminary results of this evaluation are provided in Section 3. A separate technical memorandum is in preparation to describe the methods and results of this evaluation in detail.

2.2.9 Recreational Use Evaluation

This Special Study is intended to evaluate recreational uses associated with Falls Lake that may relate to the attainment of water quality standards. Falls Lake is classified to protect recreational uses, 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.

Findings from the study may help inform the re-evaluation process with respect to aligning nutrient management efforts with maintenance of designated recreational uses. The study can 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 Results and Discussion of Routine Monitoring Through December 2015

This section presents and discusses the Routine Monitoring data collected through the end of December 2015. Where possible, patterns and trends observed in the data are noted, although it is not possible to rigorously assess temporal patterns with only 17 months of monitoring effort.

Data Available Online:

This report does not include raw data. The complete UNRBA database can be accessed online after setting up a user account at http://unrba-wqp.cardno.com/index.php. Users can review raw data, generate summary statistics, and obtain detailed station information.

3.1 Overview of Hydrologic Conditions

The UNRBA Monitoring Program does not provide for any direct collection of hydrologic data. The brief analysis in this section uses data from public sources to provide hydrologic context for the overall Monitoring Program.

To illustrate the overall hydrologic conditions for the monitoring period, Cardno evaluated precipitation patterns in the Falls Lake watershed and the resulting Falls Lake water levels and by comparing the observed values to historical averages to assess whether the monitoring period was substantially wetter or drier than average or exhibited unusual seasonal patterns. For this annual report, these analyses are primarily meant to provide a qualitative view of the monitoring period.

Precipitation data was obtained for five 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 spatial variability and comparisons to the 30-year normal values for the region.

Total rainfall in both 2014 and 2015 was similar to the 30-year annual average for the region of 43 inches. Total precipitation in 2014 ranged from 41 to 62 inches across the watershed with a mean of 49 inches. In 2015, total precipitation ranged from 38 to 58 inches with a mean of 48 inches. Though slightly wetter than average, both years' values fall within the middle 50% of historical annual totals since 1985.

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 back up to the typical range. 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 3.1 shows how the monthly precipitation from rain gages differs from the 30-year average for the watershed. Zero thus represents the 30-year average. 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 (i.e. the shaded band can be qualitatively viewed as representing "normal" conditions). Precipitation is not uniform over the watershed and the spatial variation in total precipitation for each month is shown by the orange boxes in Figure 3.1. The boxes show the 25th, 50th, and 75th percentiles of precipitation over the region with whiskers extending to the full range of values observed at the various rain gauges. 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, the monitoring period appears to have been fairly normal in terms of precipitation. However, in 2015 the months of May and August were notably drier than normal while the months of November and December were wetter than normal.

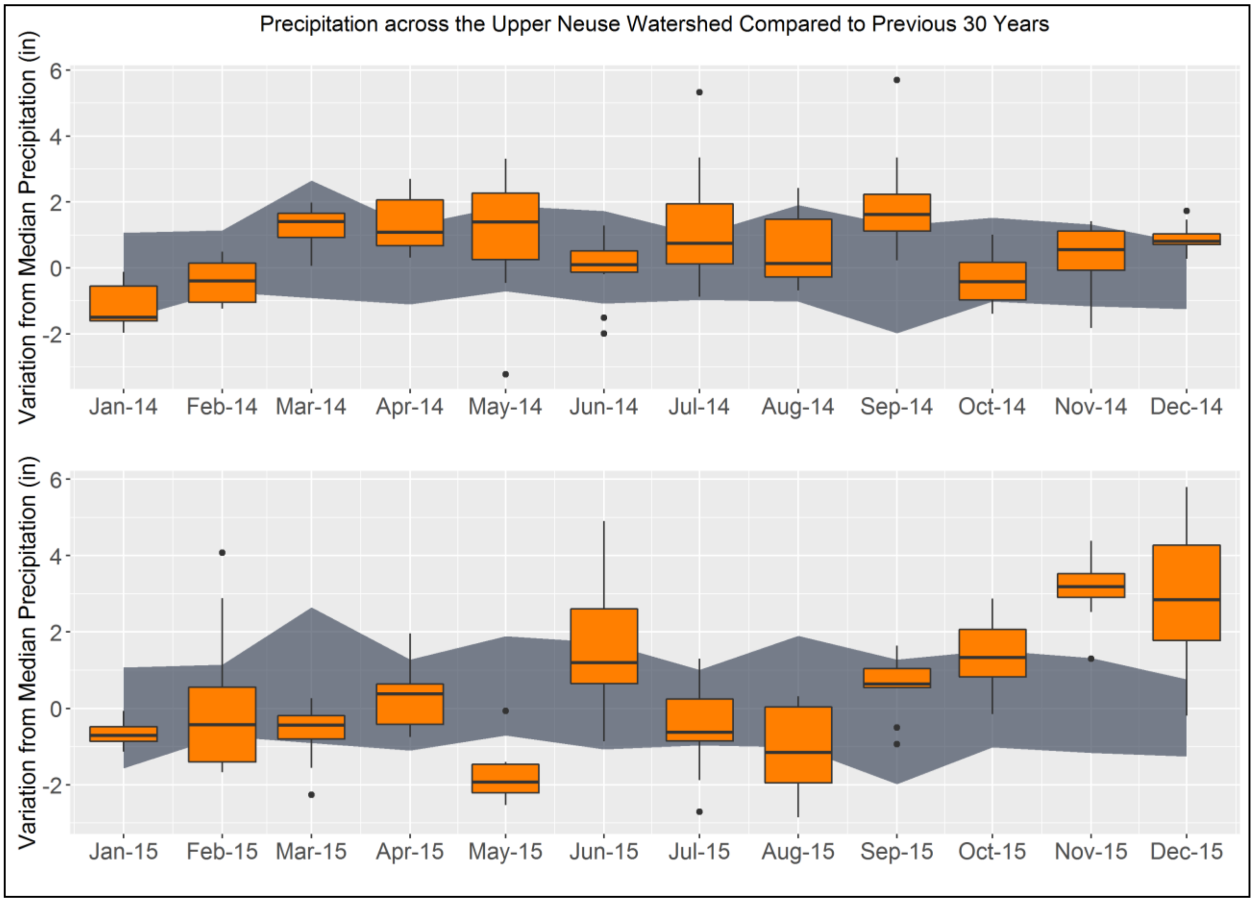

Figure 3.1 **Boxplots Representing Variation from 30-Year Normal Monthly Precipitation Totals at Monitoring Stations in the Falls Lake Watershed.** The darker shaded region contains the 25th to 75th percentile range of monthly precipitation over the preceding 30 years. The orange boxes display the 75th (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[10] are displayed as black circles. Actual long-term median monthly rainfall totals range from 2.9 (February) to 4.4 (July) inches, with 10 months of the year having long-term median rainfall between 3.0 and 4.0 inches.

A related analysis was conducted on the water level (stage) of Falls Lake based on daily data collected by the USACE (see Figure 3.2). For this analysis, median values (dashed line) are based on data reported from 1987 to present. From January 2014 to March 2015, the observed stage (orange line) in Falls Lake

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[10] By convention, statistical outliers for these plots are values that fall below the 25th percentile (lower quartile) or above the 75th percentile (upper quartile) by more than 1.5 times the difference between the upper and lower quartile values.

was generally higher than normal (above the 75th percentile much of the time). From April 2015 to October 2015, lake levels were very close to the median value. From October 2015 through December 2015, lake levels were relatively high (generally above the 75th percentile for most of this time and exceeding the 95th percentile towards the end of December).

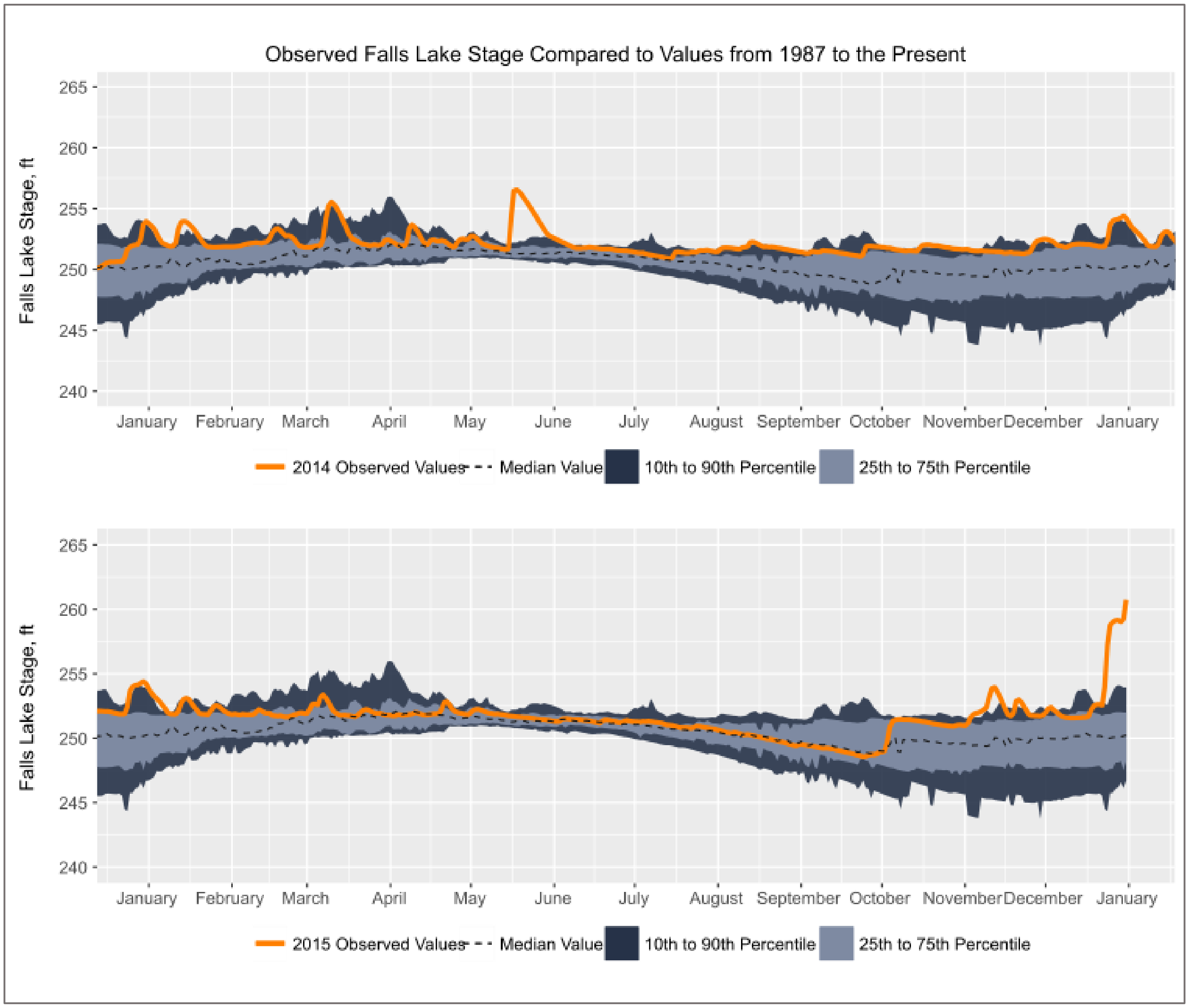


Figure 3.2 **Falls Lake Elevation from January 2014 through December 2015**
(median values (dashed line) and percentiles are based on data 1987 to present)

The UNRBA Path Forward Committee expressed interest in seeing the relationship between long-term lake levels and those assessed by DWR in its EFDC modeling effort. Figure 3.3 shows lake levels for the DWR modeling period (March 2005 through September 2007), but the baseline year used to set the Falls Lake Nutrient Management Strategy nutrient load reduction targets was limited to 2006. The region was experiencing a relatively severe drought during the modeling period, and lake levels were at or below median values from March 2005 through May 2006 and from May 2007 through December 2007. A small number of large storms, including Tropical Storm Alberto in June 2006, brought the lake levels up from June 2006 through April 2007. Because lake levels preceding these events were relatively low, much of the nutrient loading delivered to the lake from these storms was stored for long periods of time and likely contributed to some of the highest chlorophyll *a* concentrations measured in the lake over the past two decades. When lake levels are at or above normal, as with the more recent monitoring period, the residence time in the lake is generally shorter and algal concentrations tend to be lower.

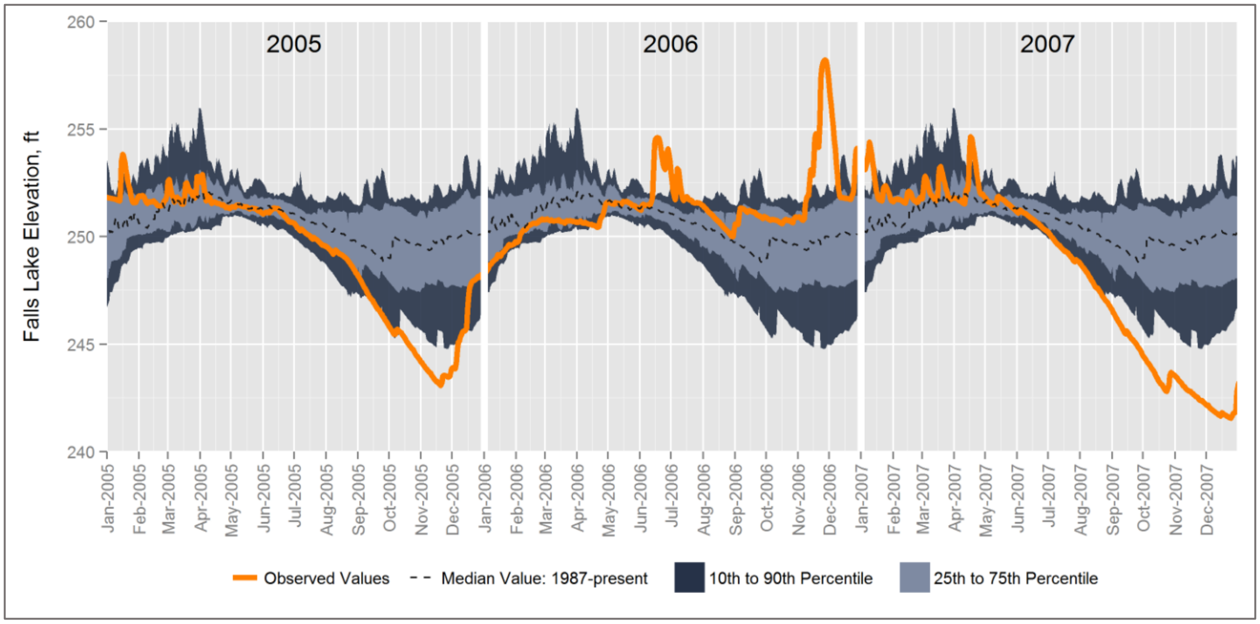


Figure 3.3 **Falls Lake Elevation (stage) in Feet Above Mean Sea Level for the Period of DWR's EFDC Model Years 2005 through 2007 (Orange Line).** The historical median (dashed line) and reference ranges (shaded regions) for each day of the year are shown for 1987 through the present.

3.2 Routine Monitoring

This section offers a concise presentation of data for most of the parameters in the Monitoring Program. The majority of the data values are reported as concentrations, which are expressed as milligrams per liter (mg/L) or micrograms per liter (ug/L).

With only seventeen months of data, it is premature to draw extensive conclusions at this time. 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 the monitoring period. In addition to displaying figures of individual water quality measurements, preliminary comparisons of water quality related to compliance with water quality standards, and statistical correlations among key parameters are also provided. While these comparisons only represent seventeen months of data, and are not intended to draw definitive conclusions, they may highlight certain patterns and observations that may warrant modifications to the Monitoring Program.

3.2.1 Lake Loading Stations

A series of graphics below provide a concise view of the data from the Lake Loading stations between August 2014 and December 2015. Box and whisker plots represent the statistical summary of the data, but each data point is also superimposed. All results reported by the lab as below reporting limits are displayed as ½ of the reporting limit. For comparative purposes, the graphs also reflect data collected in Falls Lake by DWR and the City of Durham. Thus, they provide an overview of water quality for water entering the lake, and within the lake itself. The DWR lake data consist of monthly values from the same monitoring period as the lake loading stations. The City of Durham data are included for comparison, but consist of weekly measurements from April through October and only for the year 2015 when their Quality Assurance Project Plan was reviewed and approved by DWR.

To help with visual interpretation, monitoring stations are generally presented from the top of the lake on the left side of the figures to the dam on the right side of the figures. DWR and Durham stations are inserted between the nearest up-lake and down-lake loading stations and are shaded in colors distinct from that of the Lake Loading stations. This layout allows quick inspection of spatial patterns.

Three parameters monitored by the UNRBA have numeric water quality standards (chlorophyll *a*, dissolved oxygen, and pH). Graphs for these parameters show the numerical state standard for the parameter.

A graphic for each parameter measured at the Lake Loading stations and, when applicable, by DWR and the City of Durham, is presented below, along with a brief description of the parameter and general observation on patterns noted in the graphs.

- Temperature is a field measurement of the heat content of the water (Figure 3.4). It is heavily influenced by season and climate patterns, and shallow, open areas tend to have higher temperatures than shaded, deeper or faster-moving waters. Temperatures at the Lake Loading stations were generally lower than the inlake stations. Temperature distributions for the lake data reported by the City of Durham are higher than those reported by DWR because Durham only samples the lake from April to October.
- Dissolved oxygen (DO) represents the amount of oxygen in the water and available for respiration by aquatic organisms. Field measurements of DO are provided in Figure 3.5. Oxygen concentrations in surface waters naturally range from 0 to 10 mg/L or higher, but human environmental impacts can result in changes to DO, with extreme reductions or increases generally associated with negative responses. North Carolina water quality standards specify that DO is to be no less than 4 mg/L at any time. DO concentrations in the lake and at most of the Lake Loading stations are usually well above the standard. The Lake Loading stations in stagnant areas dominated by wetlands tends to have concentrations that are sometimes lower than the standard.
- pH is a measure of acidity or alkalinity using a log scale of 0 to 14, and pH can affect various metabolic functions of aquatic organisms, as well as biogeochemical processes. Most fresh water bodies have pH levels near the middle of the pH scale (7), and the North Carolina water quality standard requires that pH be between 6 and 9. The majority of the data falls within the range of 6 to 9 (Figure 3.6). Field measured values of pH at the Lake Loading stations were generally lower than the inlake stations.
- Specific conductance is a measurement of the ability of water to conduct electricity and is commonly used as a surrogate for the amount of dissolved ionic substances in the water. Specific conductance values at the Lake Loading stations were generally similar to the inlake stations except for stations downstream of major WWTPs and package plants (Figure 3.7).

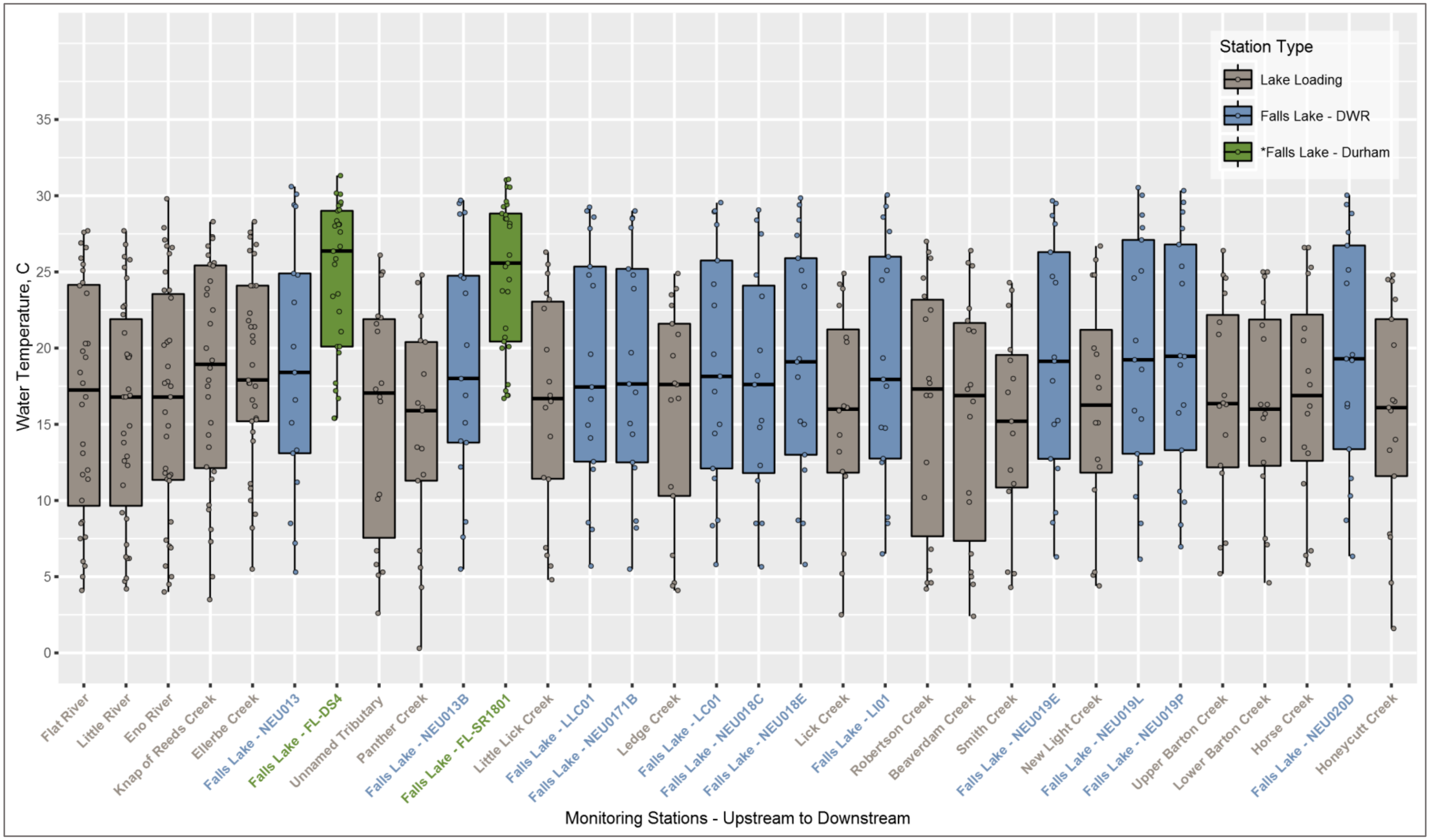


Figure 3.4 **Temperature in Lake Loading and DWR Lake Samples from August 2014 to December 2015.** Data collected by the City of Durham includes only the period of April through October 2015. The exclusion of winter months explains why these stations have higher values than adjacent lake stations.

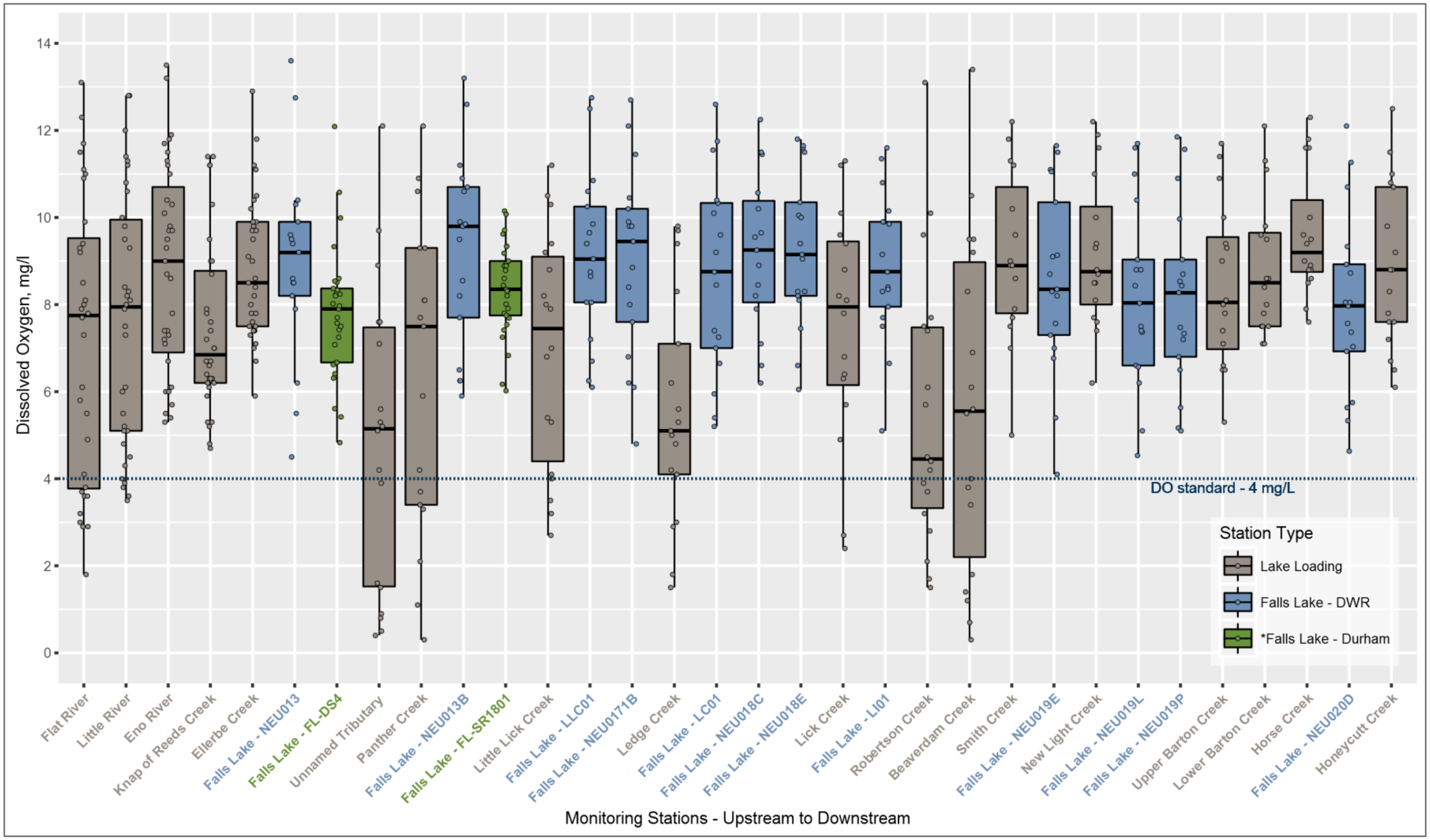


Figure 3.5 **Dissolved Oxygen in Lake Loading and Lake Samples from August 2014 to December 2015**

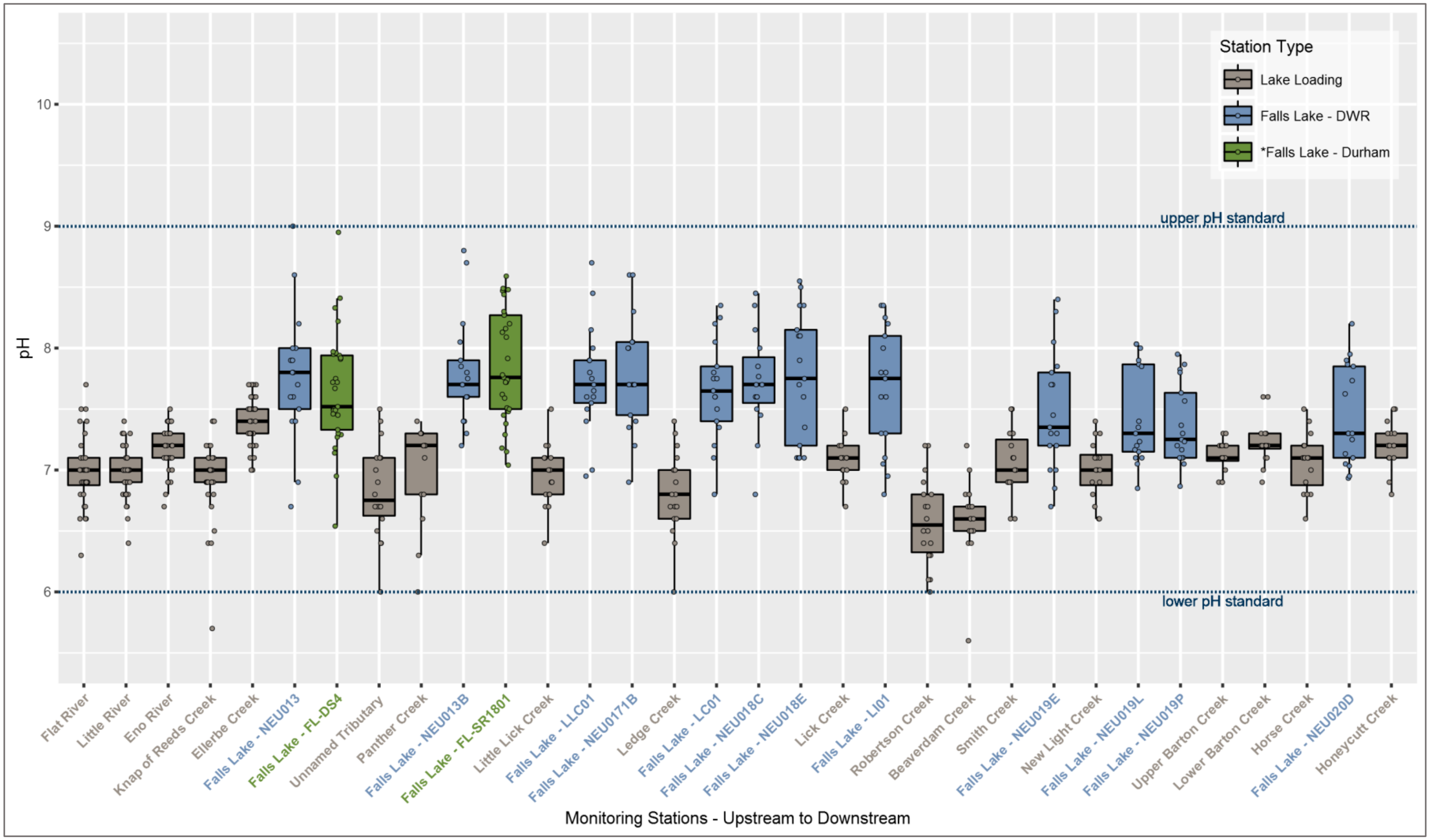


Figure 3.6 pH in Lake Loading and Lake Samples from August 2014 to December 2015

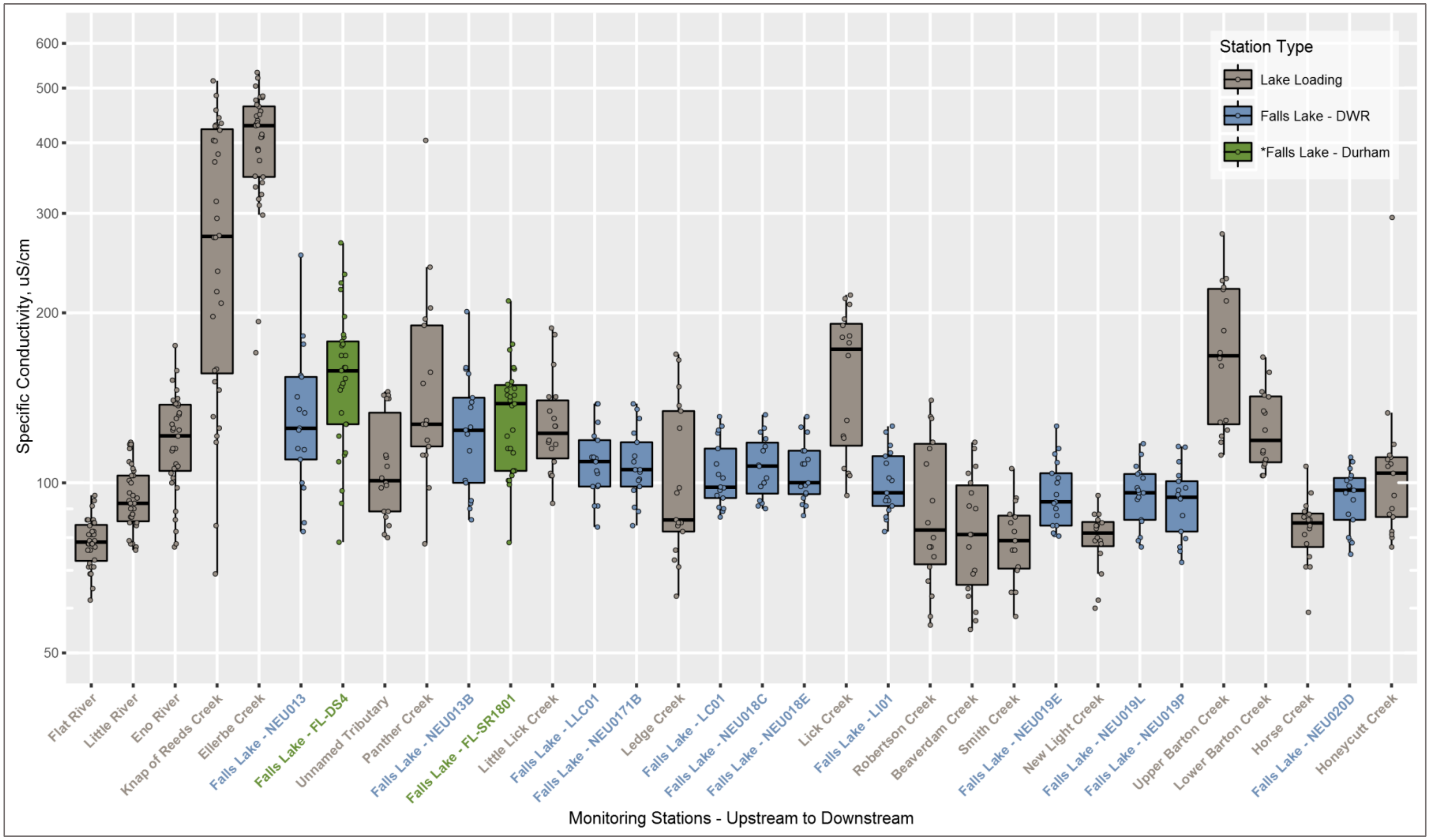


Figure 3.7 **Specific Conductance in Lake Loading and Lake Samples from August 2014 to December 2015**

> Nitrogen is an essential nutrient for all forms of life. Nitrogen 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. The various forms of nitrogen are presented in Figures 3.8 thru 3.11. Total nitrogen cannot be measured directly, but instead is calculated as the sum of measured concentrations of total Kjeldahl nitrogen (TKN) and nitrate+nitrite. TKN is comprised of ammonia, which can also be measured directly by the laboratory, and organic nitrogen. Inorganic forms of nitrogen (ammonia and nitrate+nitrite) are generally more available for assimilation by algae than organic forms. Concentrations of ammonia in the lake and watershed are generally less than 0.1 mg/L, and concentrations tend to be higher at the Lake Loading stations compared to the inlake stations because this form of nitrogen is readily used up by algae in the lake. Ammonia concentrations in the lake at City of Durham stations appear higher, but this is due to higher reporting limits relative to DWR analyses; all but the highest sample at each of Durham’s monitoring stations are below their reporting limits. Concentrations of nitrate plus nitrite are similar at the Lake Loading and inlake stations, except for stations downstream of major WWTP and small package plants where concentrations tend to be higher. Organic nitrogen concentrations are also similar at the Lake Loading and inlake stations, but the higher concentrations tend to occur downstream of major WWTPs and in stagnant areas dominated by wetlands. Concentrations of total nitrogen are generally higher and more variable in the tributaries than in the lake.

> Phosphorus is also an essential nutrient that often enters water bodies in association with soil, because phosphorus tends to bind with 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 (Figure 3.12) includes the ortho-phosphate fraction which is the most available form for primary production. Total phosphorus concentrations at the Lake Loading stations are generally higher and more variable than the inlake stations, with the sites downstream of major WWTP or located in stagnant, wetland areas having the highest concentrations. Soluble ortho-phosphate concentrations (Figure 3.13) are only shown for Lake Loading stations. DWR does not collect this parameter because past measurements of ortho-phosphate have indicated concentrations in the lake are typically below reporting limits. Indeed all of the City of Durham’s measurements of total ortho-phosphate in the lake were below their reporting limit. Concentrations of ortho-phosphate at the Lake Loading stations tend to be higher downstream of WWTPs.

> 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 is an indication of how much algae is present in the water. While algae is an important component of healthy aquatic ecosystems, too much algae can cause problems with treatability for drinking water, taste and odor problems, or drastic fluctuations in dissolved oxygen and/or pH that can cause problems for aquatic organisms. Figure 3.14 shows chlorophyll *a* data collected at Lake Loading and inlake stations. Concentrations in the lake are generally higher than those collected in the tributaries, with the exception of some elevated concentrations observed in sluggish, wetland areas. Of 372 chlorophyll *a* values measured at the lake loading stations, 350 (94 percent) were below the 40 ug/L water quality standard. Only 22 observations from the watershed exceeded 40 µg/L, representing only seven of the monitored tributary stations, as listed in Table 3.1, and the majority of these elevated values occurred during times of below average streamflow. For Unnamed Tributary and Beaverdam Ledge, Panther, and Robertson Creeks, all observed chlorophyll concentrations above 40 ug/L occurred during times when field-measured surface velocities were less than 0.01 feet per second and discharge estimates based on basin proration of nearby USGS gages were less than 3 cfs. Algal proliferation is not unexpected in shallow, sluggish water bodies, including wetlands. North Carolina water quality standards include a provision that “Water quality standards will not be considered violated when values outside the normal range are caused by natural conditions” (15A

NCAC 02B .0205). Note that collection of chlorophyll *a* data by the UNRBA is for the purpose of informing analytical efforts for the re-evaluation process; it is not intended to produce information for regulatory use attainment purposes.

Table 3.1 Stations with Chlorophyll *a* Measured above the NC State Standard (August 2014 to December 2015)

Subwatershed	Station ID	Number of Chl *a* Values Measured	Chl *a* Values Reported above 40 ug/L	Fraction of Total Values above 40 ug/L
Beaverdam Creek	BDC-2.0 (LL)	18	4	22%
Eno River	ENR-8.3 (LL)	35	1	3%
Flat River	FLR-5.0 (LL)	32	4	13%
Ledge Creek	LGE-5.1 (LL)	17	2	12%
Panther Creek	PAC-4.0 (LL)	17	1	6%
Robertson Creek	ROB-2.8 (LL)	18	5	28%
Unnamed	UNT-0.7 (LL)	18	5	28%
All Lake Loading Stations		**372**	**22**	**6%**

- Total suspended solids (TSS) (Figure 3.15) measures the amount of particulate material suspended in the water column. Volatile suspended solids (VSS) (Figure 3.16) represents the fraction associated with organic material; monitoring VSS began in July of 2015. TSS and VSS concentrations observed in the upper five tributaries (discharging upstream of I-85) and the lower part of the watershed (mostly downstream of Highway 50) are generally lower than those observed in middle tributaries and in the lake itself. In general, VSS in the tributaries is lower than in the lake, where algal productivity may contribute to higher concentrations.
- Carbonaceous biochemical oxygen demand ($CBOD_5$) measures the amount of oxygen consumed by the decay of the carbon-based organic material in a water sample. $CBOD_5$ is often measured downstream of wastewater treatment plants to model dissolved oxygen downstream of the facility and to set waste load allocations. Figure 3.17 shows the $CBOD_5$ data collected at the Lake Loading and inlake stations, with the large majority of the measured values in the watershed near or below the laboratory reporting limit of 2 mg/L. Concentrations tend to be higher in the lake, and at Lake Loading stations associated with stagnant, wetland areas where algae and other organic matter is more abundant.

$CBOD_5$ was originally included in the UNRBA Monitoring Program at Lake Loading stations to provide supplemental information regarding the lability of particulate organic carbon (POC) entering Falls Lake from its tributaries. The lability of POC was an assumed parameter for DWR's 2006 EFDC model along with the assumption that 50 percent of all incoming carbon was delivered in particulate form. Routine Monitoring has since shown that POC accounts for only about 5 percent of the organic carbon entering Falls Lake. As part of the Model Evaluation Special Study, Cardno tested the sensitivity of EFDC model predictions to assumptions about tributary POC lability and found that when POC makes up only 5 percent of the incoming carbon, its lability has a negligible impact on modeled chlorophyll and carbon concentrations). Furthermore, most samples show $CBOD_5$ at levels below the laboratory reporting limit (Figure 3.17) which reduces the utility of $CBOD_5$ for resolving differences in lability among samples. Therefore, Cardno recommends the UNRBA consider discontinuing collection of $CBOD_5$ at Lake Loading stations in FY2017, which would save the UNRBA approximately $11,500 per year.

> Carbon is considered the primary building block of all living things. The Monitoring Program currently includes collection of both DOC and TOC at the Lake Loading stations. Total organic carbon (TOC) is the total amount of carbon bound in an organic compound. Dissolved organic carbon (DOC) is the amount in a filtered sample. TOC is often used as a non-specific indicator of water quality. TOC in a water sample includes algae and other microorganisms, small fragments of decaying animal or plant material, and animal waste. The amount of TOC can affect treatment costs. Figure 3.18 shows the TOC data collected at the Lake Loading and inlake stations. Concentrations at Lake Loading stations in the lower part of the watershed (mostly downstream of Highway 50) are generally lower than those observed at the other Lake Loading stations and in the lake. The highest concentrations are observed at Lake Loading stations that are dominated by wetland complexes and/or stagnant flow conditions.

DOC is not represented in a separate graph here because its distribution is nearly identical to that of TOC. Figure 3.18 shows the strong correlation between these two parameters at the Lake Loading stations. The linear regression (blue line) is nearly parallel and just below the 1:1 line which indicates that the vast majority of the TOC entering Falls Lake is in the dissolved form. The remaining fraction – about 5% - is particulate organic carbon (POC). The statistical correlation between DOC and TOC is nearly 1, which indicates that one parameter can be readily predicted from the other with a high degree of confidence.

Because TOC is a parameter of concern for the City of Raleigh for compliance the Safe Drinking Water Act, it is important for the ongoing monitoring effort. However, because DOC can be accurately estimated from TOC measurements, and since it is a relatively expensive parameter to collect ($17,400 per year at the Lake Loading stations), Cardno recommends the UNRBA consider dropping DOC from the list of parameters collected at Lake Loading stations in FY2017.

> Dissolved humic matter can impart a visible color to water which can reduce the amount of light available to algae, and color is therefore a parameter of interest in water quality modeling. Color can be measured by visually comparing filtered water samples with known Platinum-Cobalt standards (Pt-Co). Absorbance of visible light at 440nm can also be used as an indicator of color as it specifically targets the yellow or brown material typical of humic substances. Color results as measured by the Platinum-Cobalt method are presented in Figure 3.19, and results of the absorbance at 440nm method are shown in Figure 3.20. DWR does not monitor color at the inlake stations, however the UNRBA measures the absorbance at 440nm on lake samples collected by DWR. Both approaches for measuring color show that color is highest on those tributaries that are slow-moving and most influenced by wetlands.

To date, measurements of Pt-Co color and absorbance at 440nm at the Lake Loading stations are correlated with an R^2 of 0.73. Since two methods are currently being used to quantify color, with absorbance at 440nm being the less expensive and more precise, Cardno recommends the UNRBA consider dropping the Platinum-Cobalt method from the list of monitored parameters in FY2017, which would save about $5,000 annually.

> UV Absorbance at 254nm can be combined with measurements of DOC to measure carbon-specific UV-absorbance (SUVA) which is an indicator of the concentration of humic substances in water and can be used to estimate how labile or refractory the carbon pool is (how easily can it be broken down by micro-organisms?) and how much of the organic matter may come from terrestrial sources versus other sources such as aquatic primary production. Distinction between labile and refractory carbon fractions can inform water quality modeling. UV absorbance at 254nm is presented in Figure 3.21 and indicates that humic matter is most prevalent in the tributaries with substantial wetland influence.

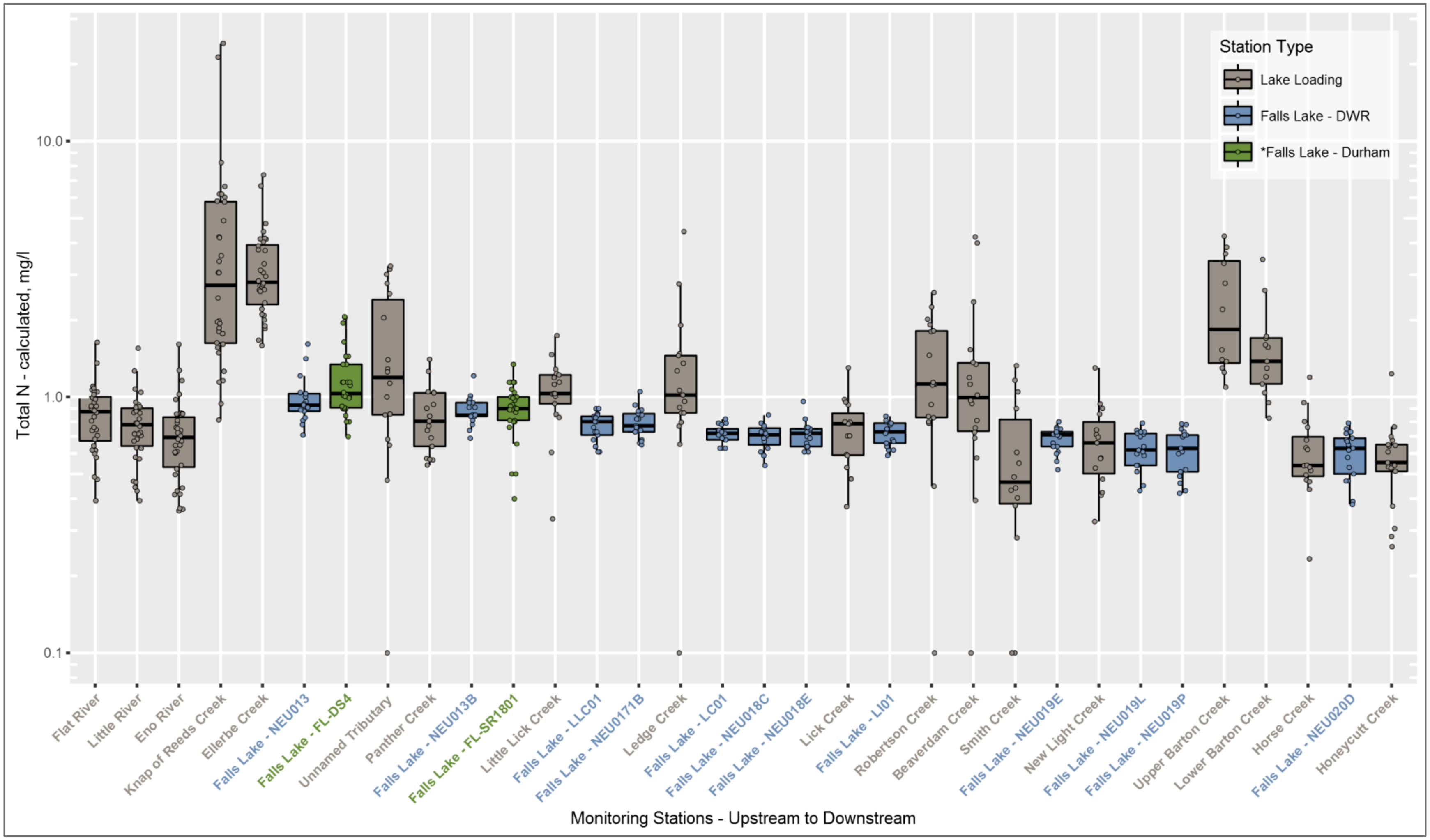


Figure 3.8 **Total Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2015**

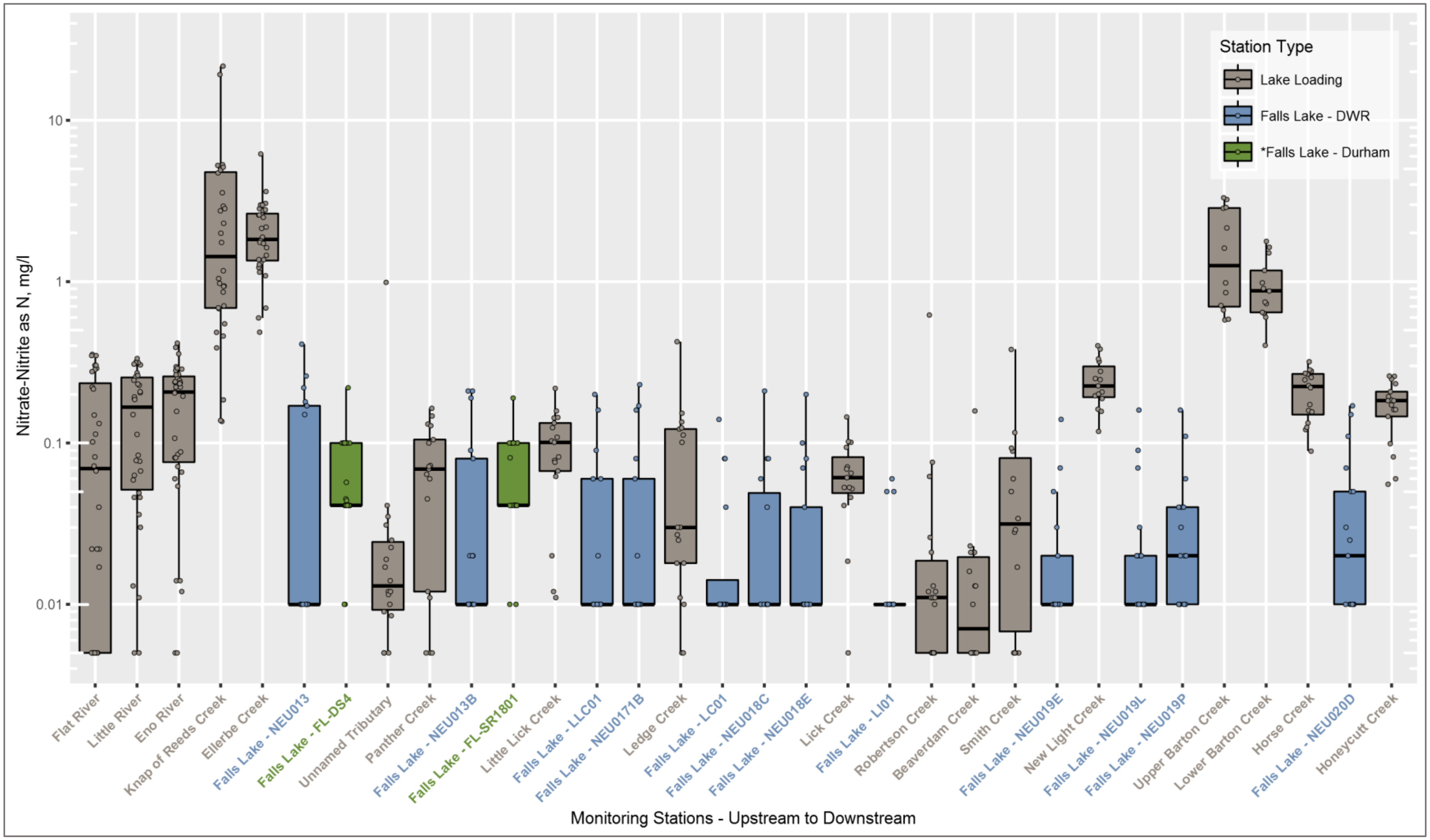


Figure 3.9 **Nitrate plus Nitrite in Lake Loading and Lake Samples from August 2014 to December 2015**

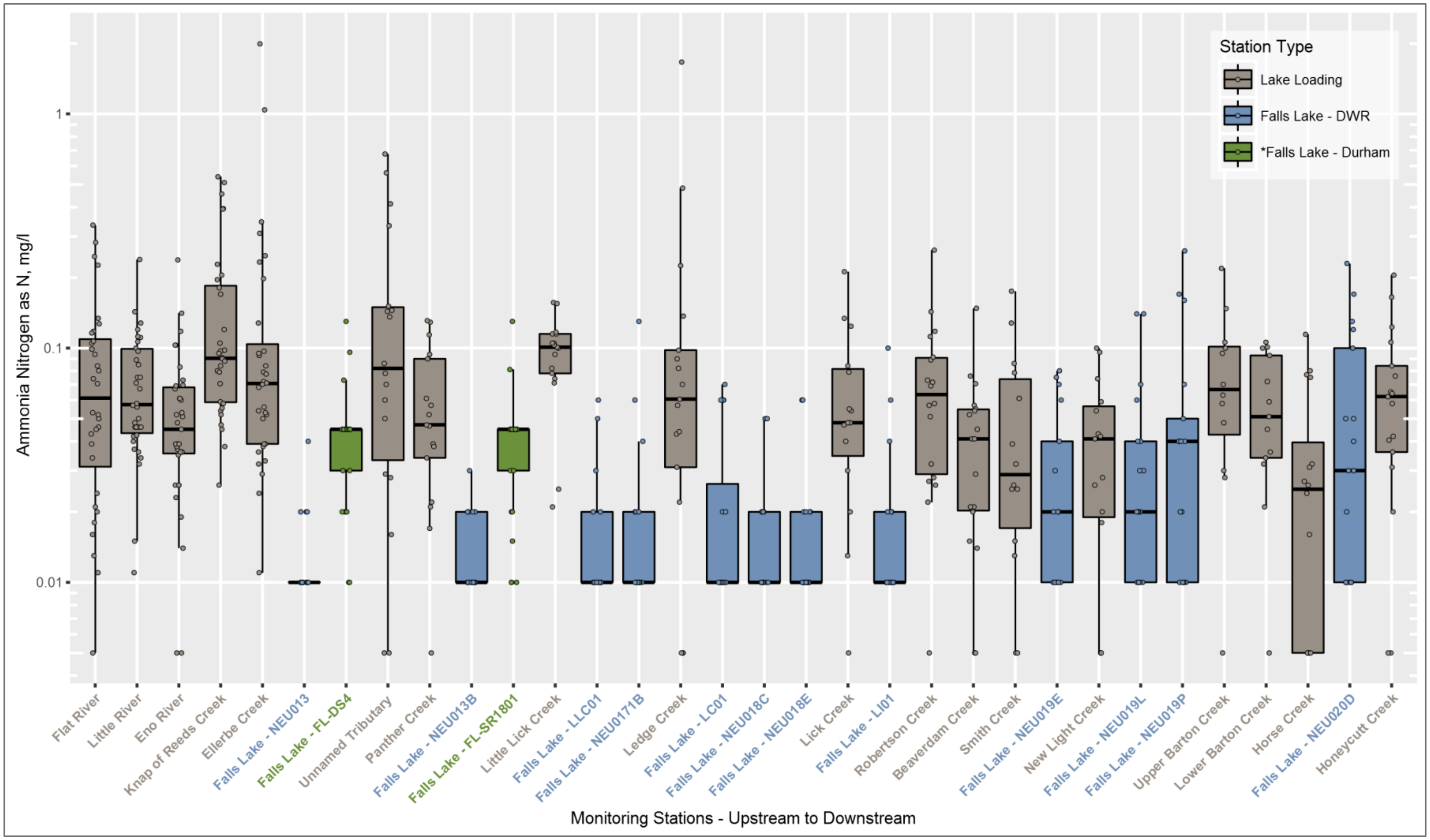


Figure 3.10 Ammonia in Lake Loading and Lake Samples from August 2014 to December 2015

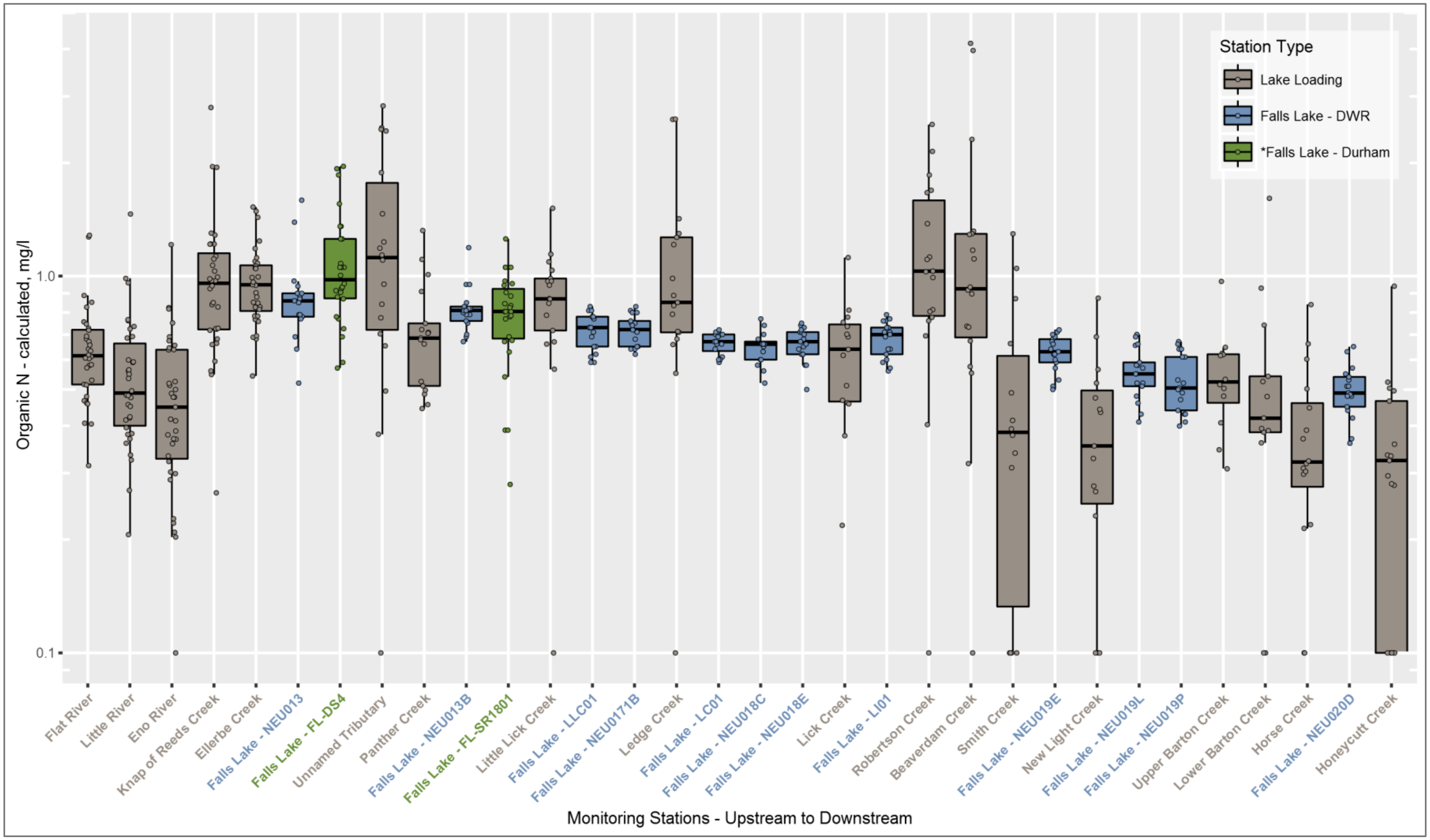


Figure 3.11 **Organic Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2015**

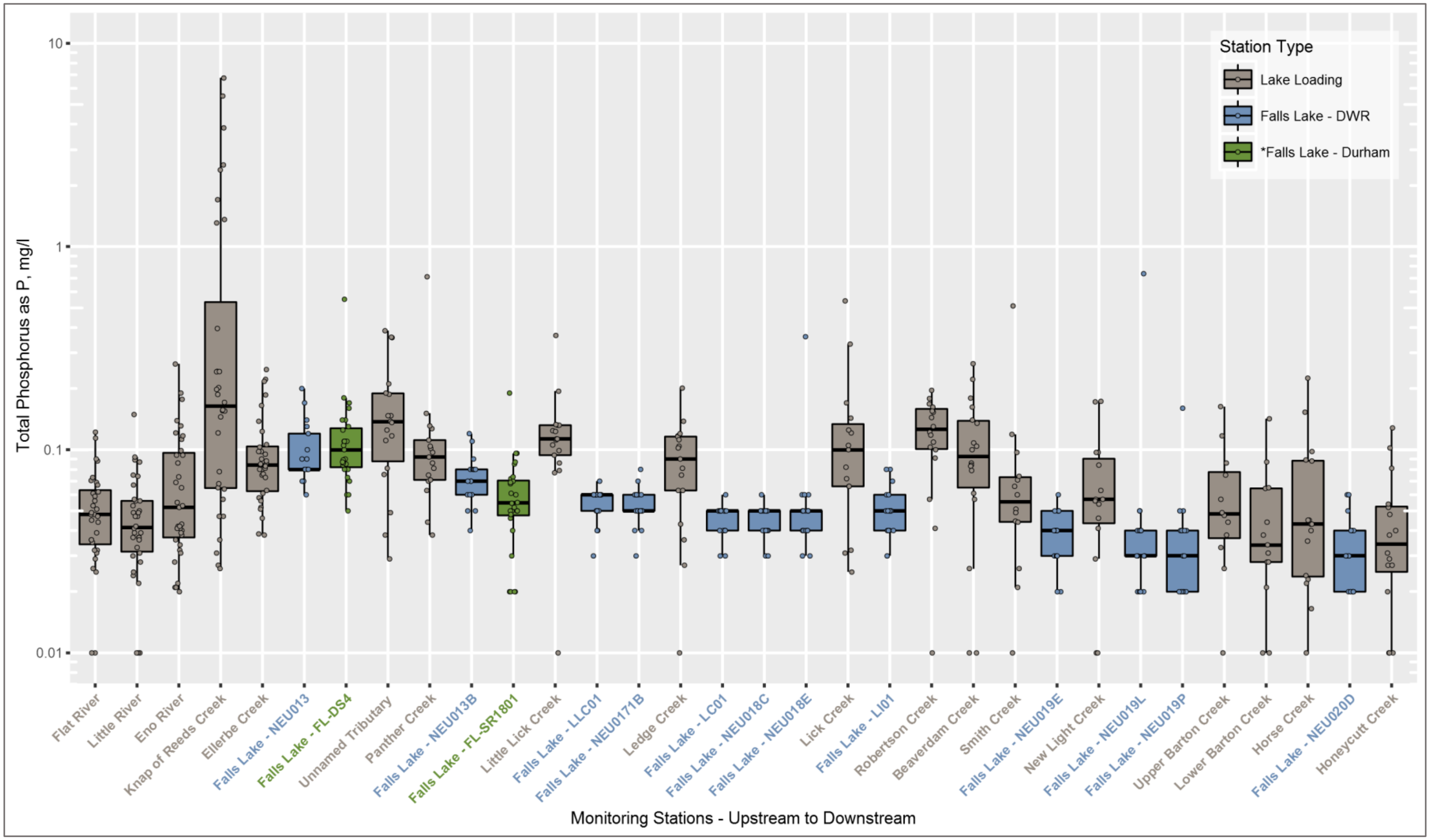


Figure 3.12 Total Phosphorus in Lake Loading and Lake Samples from August 2014 to December 2015

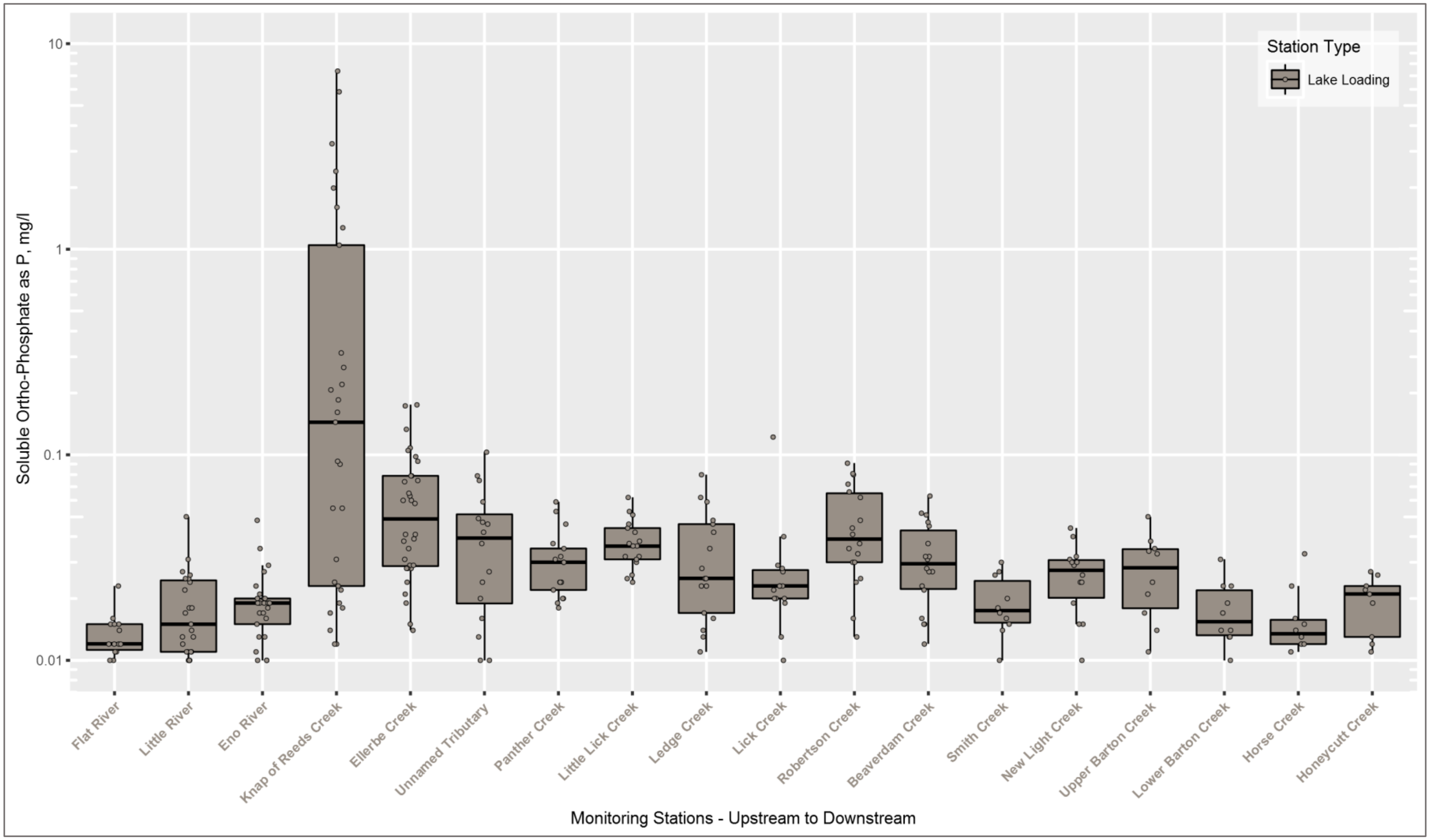


Figure 3.13 **Soluble Ortho-phosphate in Lake Loading Samples from August 2014 to December 2015**

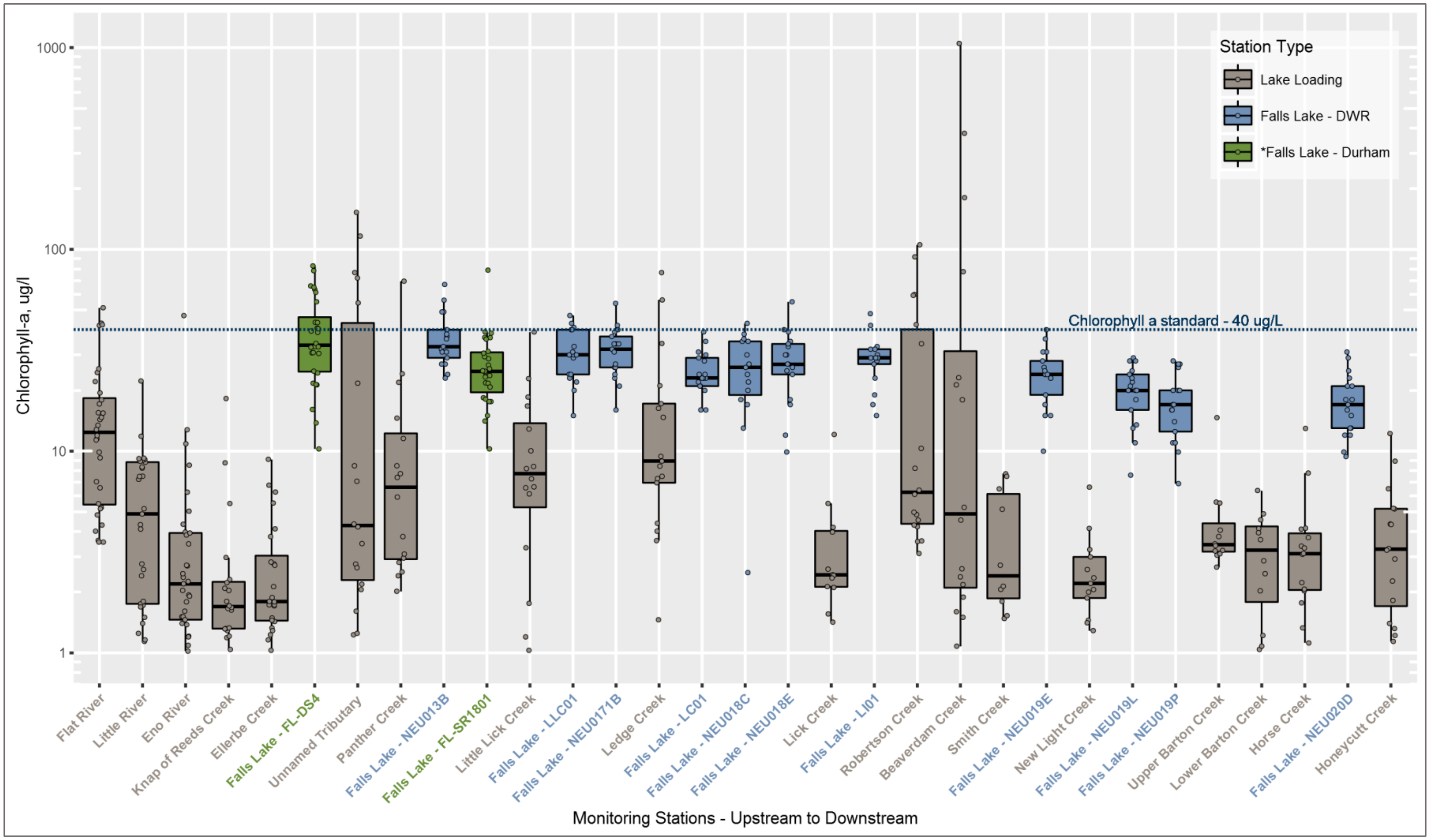


Figure 3.14 **Chlorophyll *a* in Lake Loading and Lake Samples from August 2014 to December 2015**

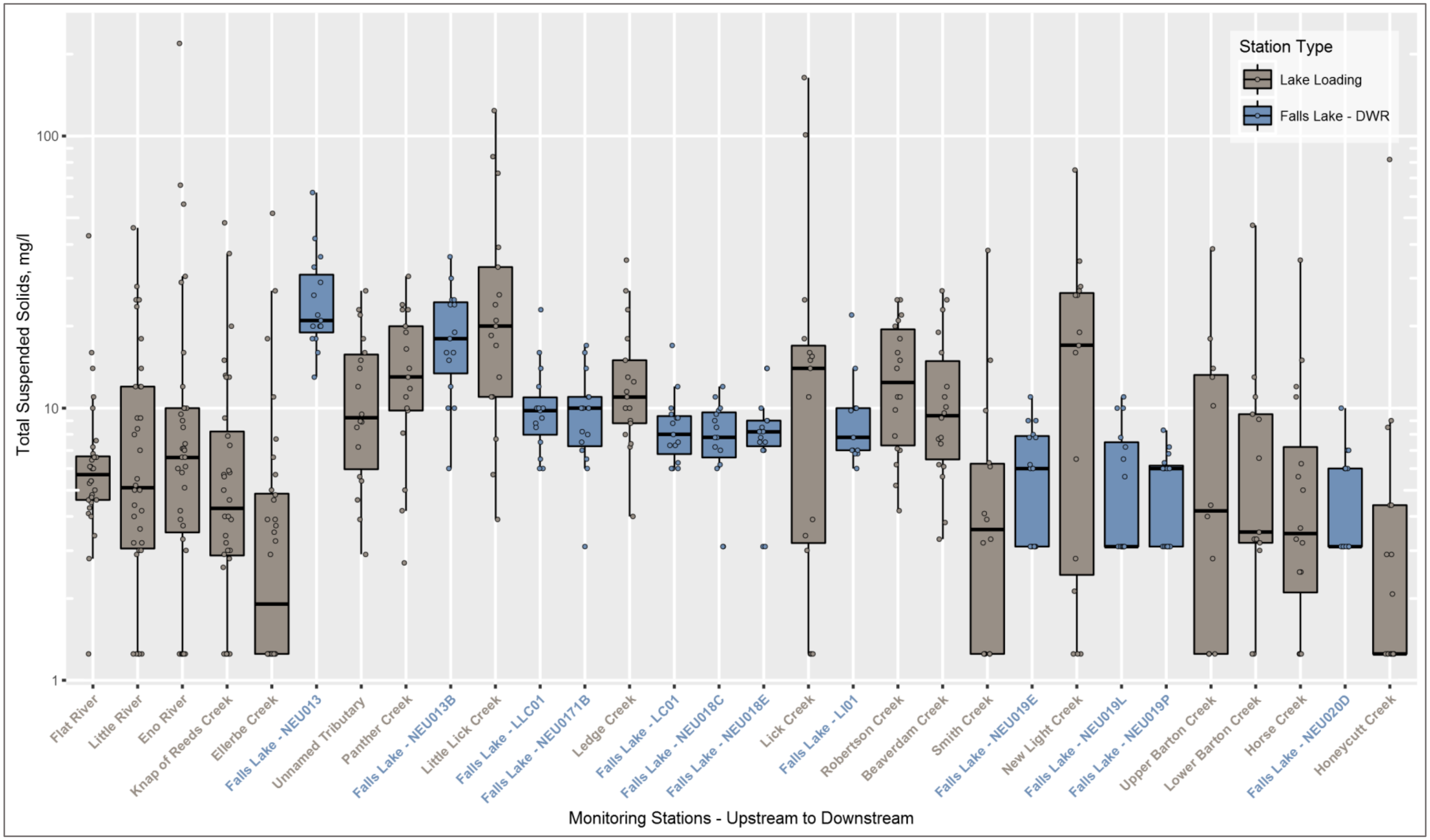


Figure 3.15 **Total suspended solids (TSS) in Lake Loading and Lake Samples from August 2014 to December 2015**

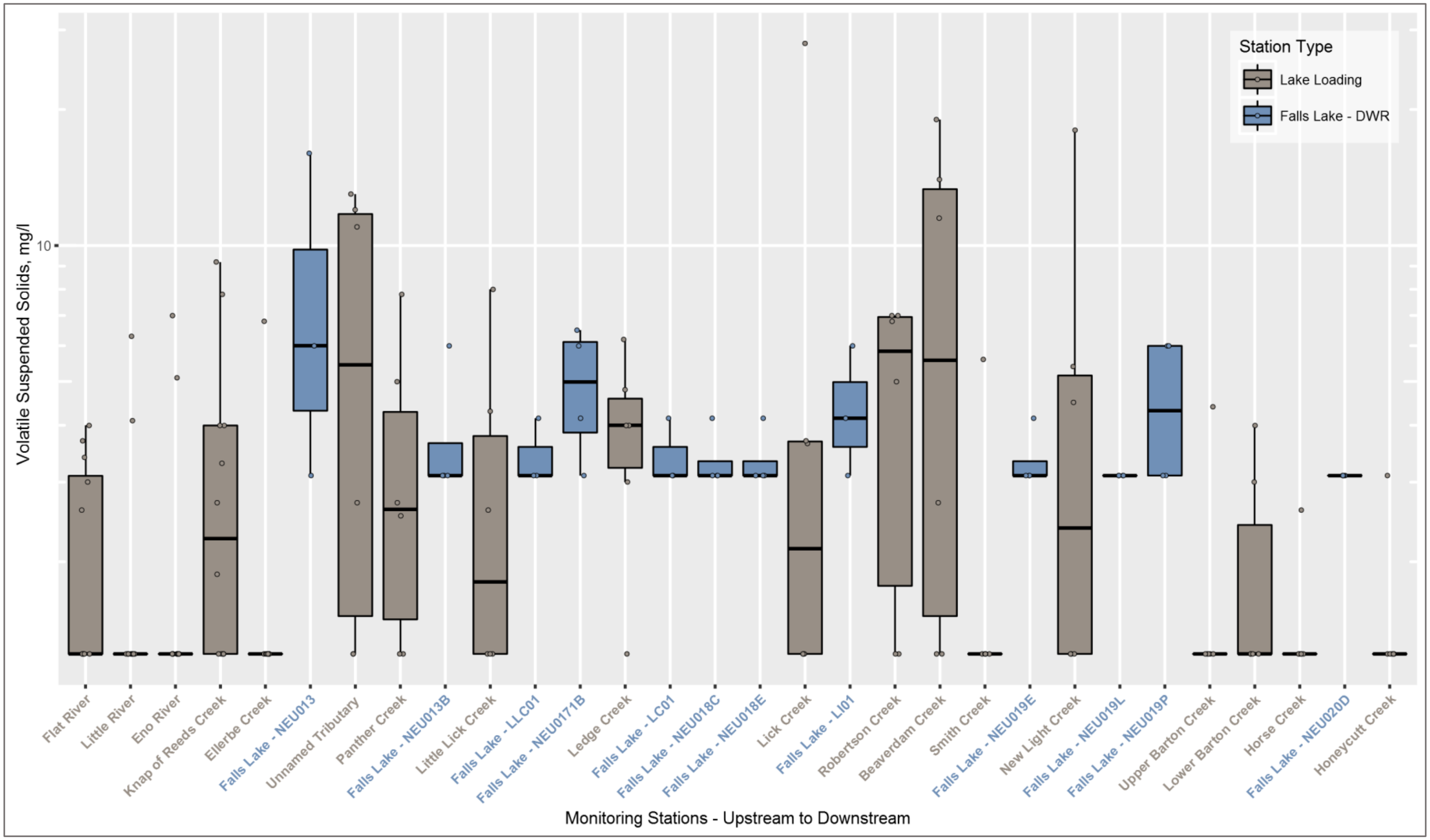


Figure 3.16 Volatile suspended solids (VSS) in Lake Loading and Lake Samples from August 2014 to December 2015

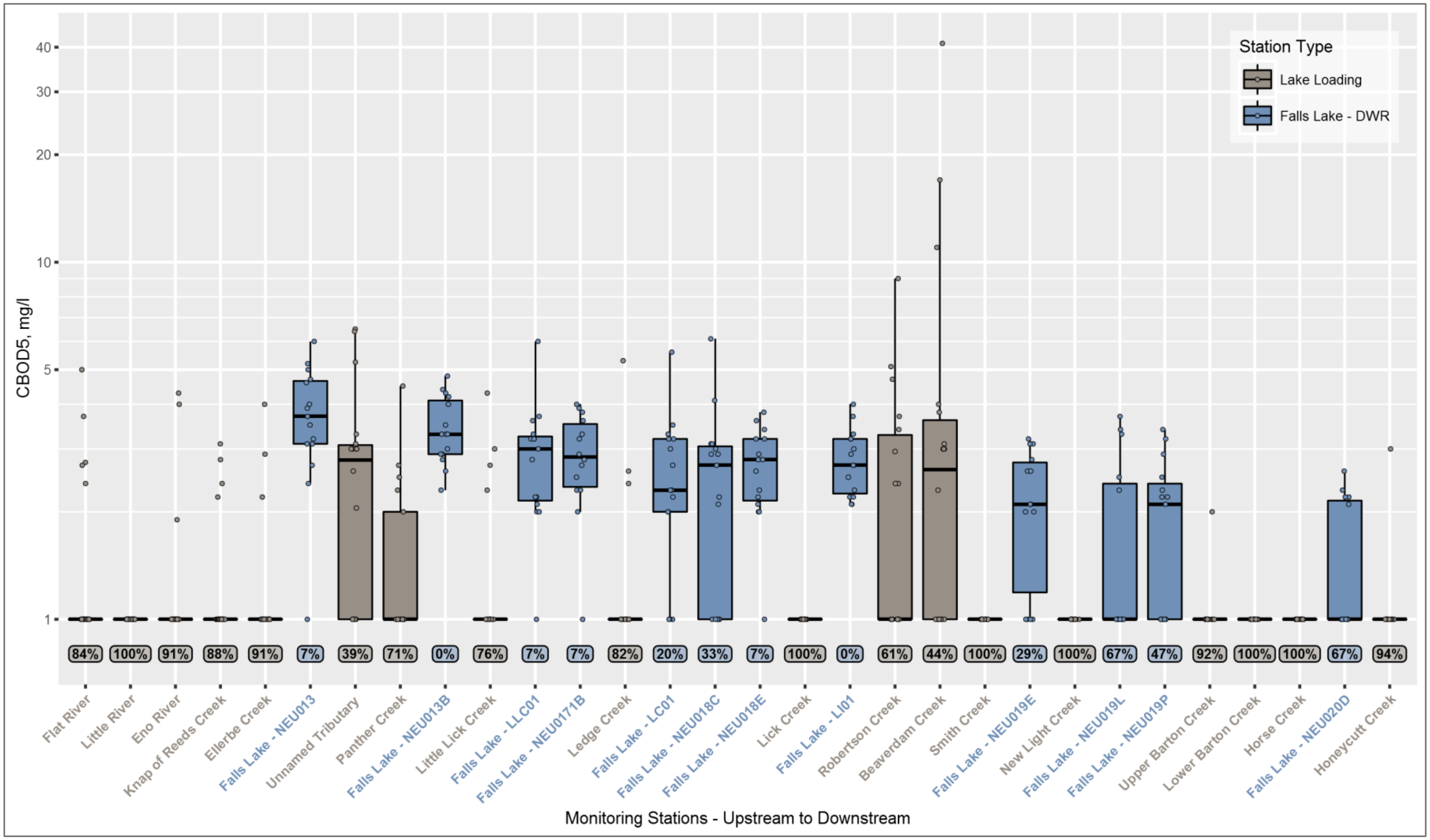


Figure 3.17 **$CBOD_5$ in Lake Loading and Lake Samples from August 2014 to December 2015.** The percentage of collected samples which had $CBOD_5$ values below reporting limits is shown at the bottom of the graph for each station.

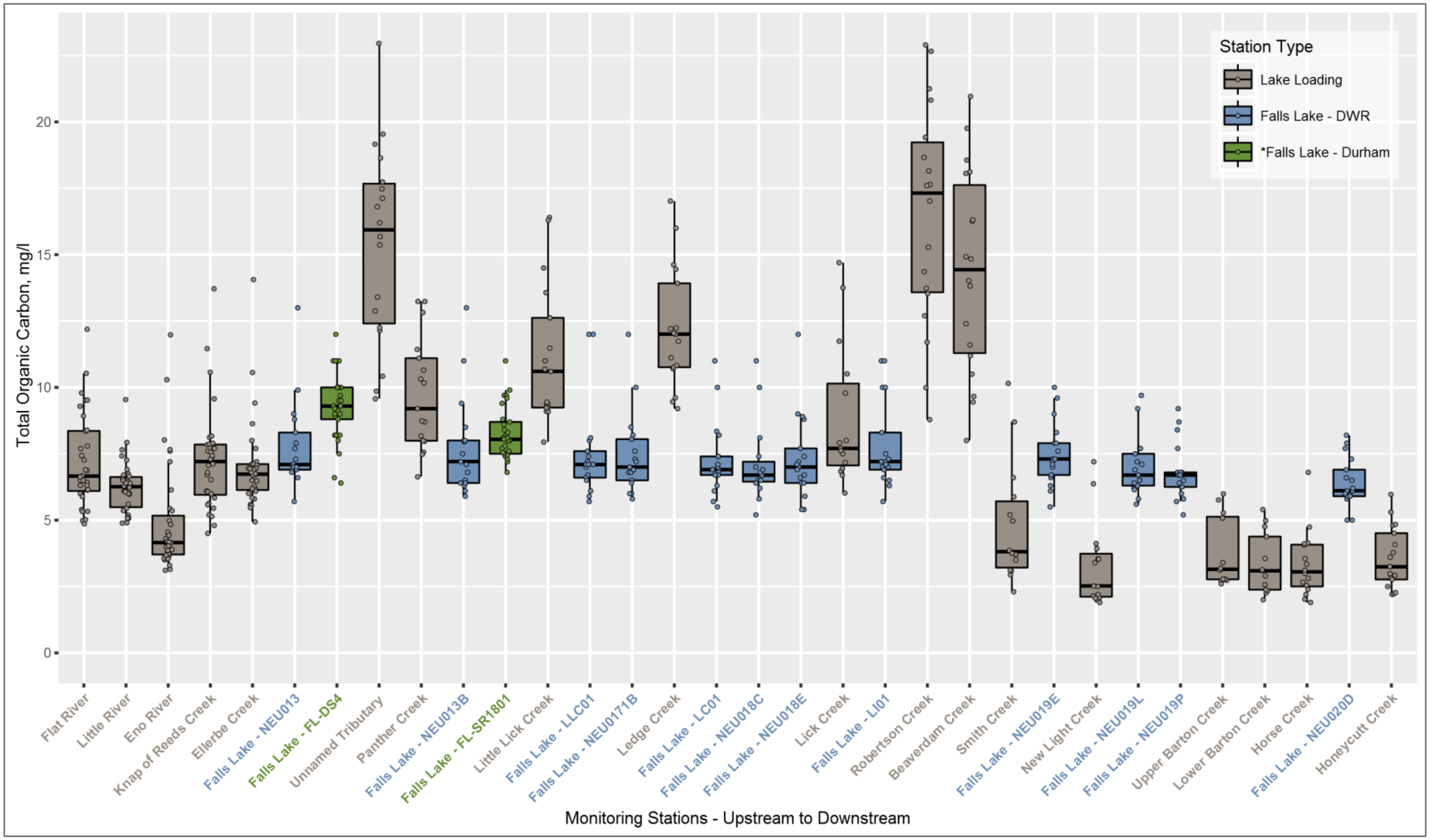


Figure 3.18 **Total Organic Carbon (TOC) in Lake Loading and Lake Samples from August 2014 to December 2015**

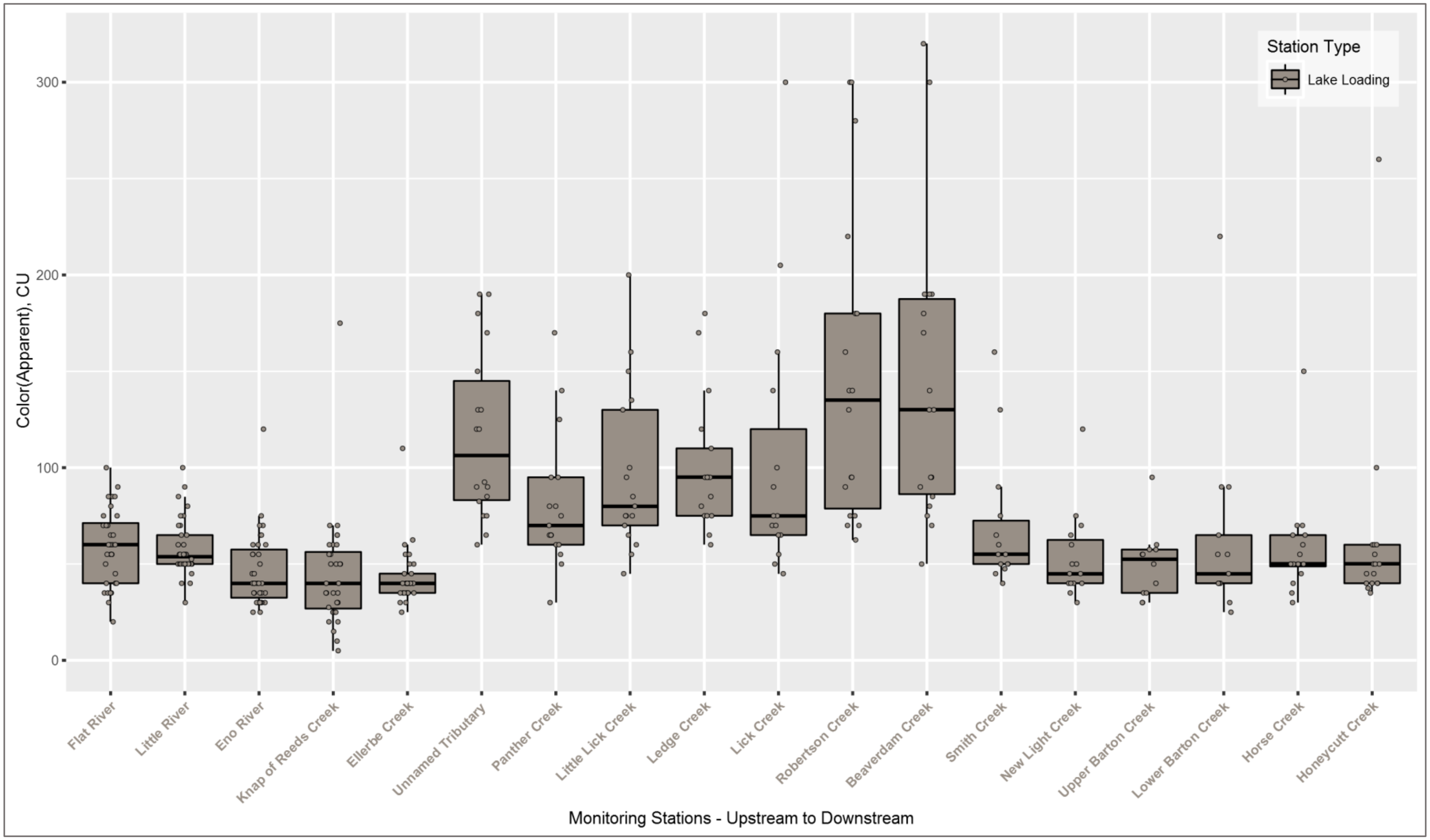


Figure 3.19 Color (Platinum-Cobalt method) in Lake Loading Samples from August 2014 to December 2015

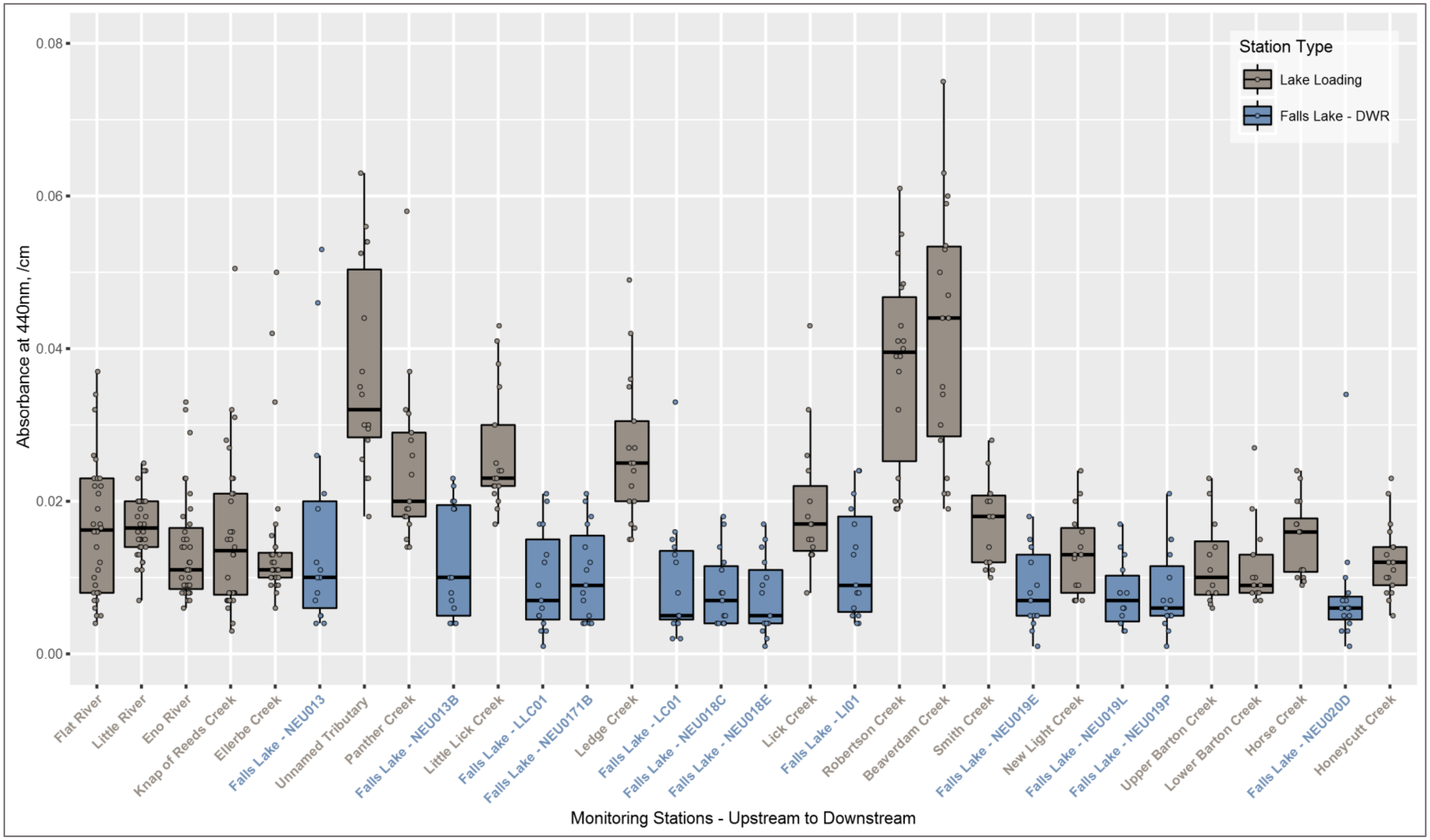


Figure 3.20 Color (absorbance at 440nm) in Lake Loading and Lake Samples from August 2014 to December 2015

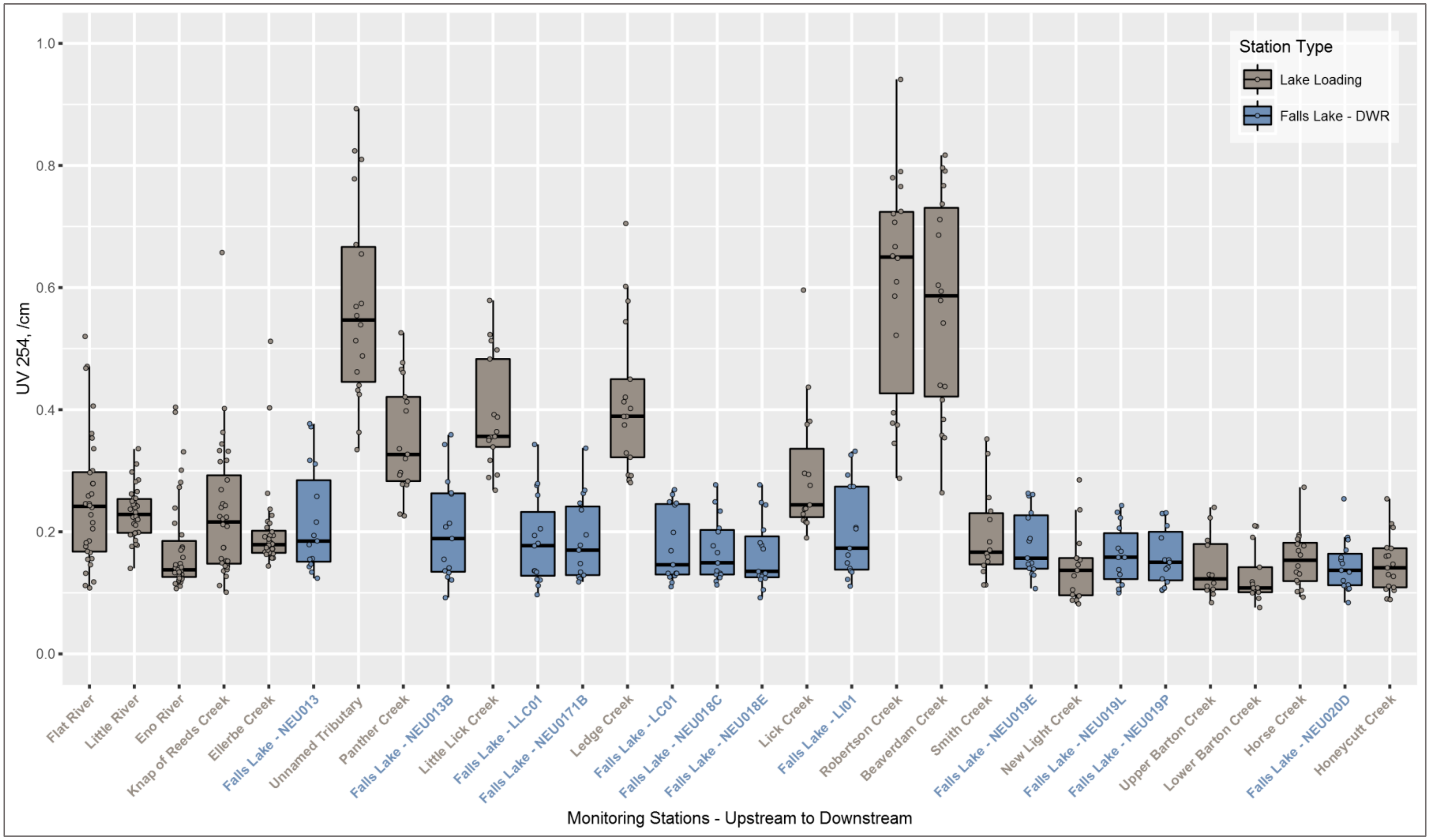


Figure 3.21 **Absorbance at 254nm in Lake Loading and Lake Samples from August 2014 to December 2015**

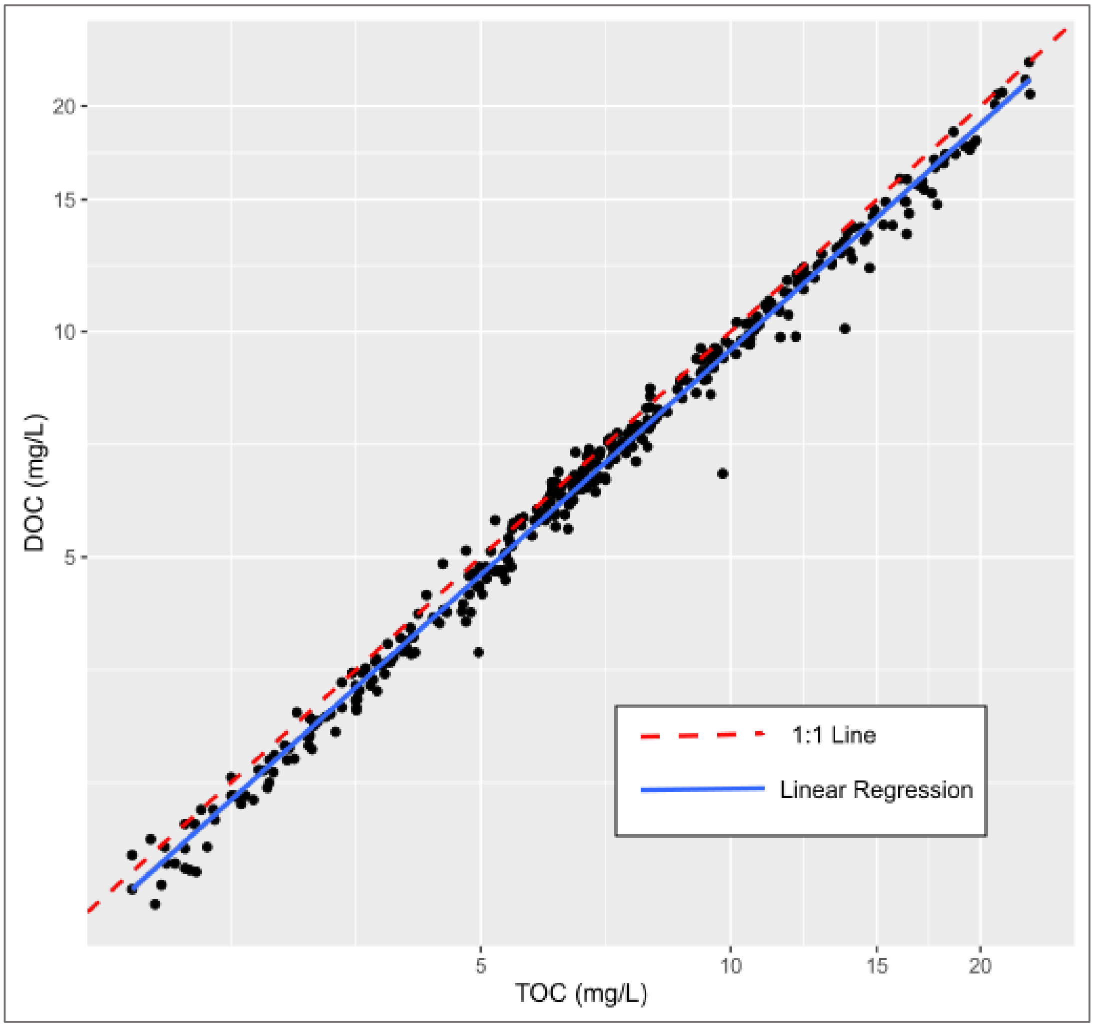


Figure 3.22 **Correlation between TOC and DOC in Lake Loading Samples from August 2014 to December 2015**

3.2.2 Jurisdictional Boundary Stations

The series of graphics below provides a concise view of data from the Jurisdictional Boundary stations between August 2014 and December 2015. Box and whisker plots represent a statistical summary of the data, but each data point is also superimposed to indicate the full distribution of the data. For comparative purposes, the graphs also provide data from each Lake Loading station. Thus, these figures provide an overview of water quality in tributaries throughout the watershed.

Data are grouped by subwatershed. Within each group, stations on the same tributary are displayed from the most upstream to the most downstream location and Jurisdictional Boundary stations are shown with a light shading while Lake Loading stations are shown with a dark shading. This arrangement allows quick inspection of whether spatial patterns are present. Station labels with “(LL)” indicate Lake Loading stations and stations labeled with “(JB)” indicate Jurisdictional Boundary stations. Table 2.2 (Section 2.1.3) provides a list of all tributary stations using same station identifiers. All stations represent data collected over the full monitoring period, except in the Flat River watershed where monitoring at station NFR-37 was suspended in June 2015 due to access and safety concerns and replacement station NFR-41 began in July 2015.

Each parameter is presented below, along with general observations of patterns noted. In a few cases, additional comments are provided on the value of ongoing data collection for certain parameters. Two parameters monitored by the UNRBA at Jurisdictional Boundary stations have numeric water quality standards (dissolved oxygen, and pH). Graphs and tables for these parameters show the level of the applicable state standard for each parameter.

> Temperature - Most variability associated with this parameter is due to seasonal changes rather than location in the watershed. Temperatures at the Jurisdictional and Lake Loading stations are generally similar though some of the sampling locations with smaller drainage areas tend to have cooler temperatures (Figure 3.23). This may be because these locations do not always have sufficient water to sample, and when data are collected it occurs following precipitation events, as opposed to other sites where water may be present and exposed to solar radiation for longer periods.

> Dissolved oxygen (DO) - Field measurements of DO are provided in Figure 3.24. DO concentrations tend to be lower at locations with slow-moving or stagnant water, or large wetland complexes, including Beaverdam Creek, Robertson Creek, Unnamed Tributary, and Panther Creek. North Carolina water quality standards specify that DO is to be no less than 4 mg/L. Of 667 total DO measurements, approximately 91 percent were above the standard and 9 percent fell below 4 mg/L, with all of those occurring at 13 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. North Carolina water quality standards include a provision that DO levels in “swamp waters, lake coves or backwaters, and lake bottom waters may have lower values if caused by natural conditions,” and further provide that “Water quality standards will not be considered violated when values outside the normal range are caused by natural conditions” (15A NCAC 02B .0205).

pH - The North Carolina water quality standard applicable to the Falls Lake watershed requires pH be between 6 and 9. Field measured values of pH at the Jurisdictional and Lake stations are almost always within this range, with most values falling between 6.5 and 7.5 (Figure 3.25). Data collected from August 2014 through December 2015 showed approximately 98 percent compliance with the standard. Ten stations had one or two pH values below 6 (

> Table 3.3); only one station had a single value greater than 8. North Carolina water quality standards include a provision that pH levels in “swamp waters may have a pH as low as 4.3 if it is the result of natural conditions” (15A NCAC 02B .0211(14)), and further provide that “Water quality standards will not be considered violated when values outside the normal range are caused by natural conditions” (15A NCAC 02B .0205).

> Specific conductance - Field-measured specific conductance values at the Jurisdictional and Lake Loading stations are generally consistent throughout the watershed. The higher ranges of values tend to occur downstream of major wastewater treatment plants and small package plants (Figure 3.26).

Table 3.2 Stations with Dissolved Oxygen Measurements below the NC State Standard (August 2014 to December 2015)

Subwatershed	Station ID	Number of DO Values Measured	DO Values Reported below 4 mg/L	Fraction of Total Values below 4 mg/L
Beaverdam Creek	BDC-2.0 (LL)	18	7	39%
Camp Creek	CMP-23 (JB)	13	1	8%
Flat River	FLR-5.0 (LL)	32	9	28%
Ledge Creek	LGE-5.1 (LL)	17	4	24%
Lick Creek	LKC-2.0 (LL)	16	2	13%
Little Lick Creek	LLC-1.8 (LL)	18	3	17%
Little Ledge Creek	LLG-0.9 (JB)	16	7	44%
Little River	LTR-1.9 (LL)	34	4	12%
North Flat River	NFR-41 (JB)	6	2	33%
Panther Creek	PAC-4.0 (LL)	17	6	35%
Robertson Creek	ROB-7.2 (JB)	11	2	18%
Robertson Creek	ROB-2.8 (LL)	18	7	39%
Unnamed	UNT-0.7 (LL)	18	7	39%
All Monitored Stations		**667**	**61**	**9%**

Table 3.3 Stations with pH Observed below the NC State Standard (August 2014 to December 2015)

Subwatershed	Station ID	Number of pH Values Measured	pH Values Reported below 6.0	Fraction of Total Values below 6.0
Beaverdam Creek	BDC-2.0 (LL)	18	1	6%
Buckhorn Creek	BUC-3.6 (JB)	15	1	7%
Camp Creek	CMP-23 (JB)	13	2	15%
Horse Creek	HSE-11 (JB)	16	1	6%
Horse Creek	HSE-5.7 (JB)	2	1	50%
Knap of Reeds Creek	KRC-4.5 (LL)	32	1	3%
Ledge Creek	LGE-13 (JB)	9	2	22%
Ledge Creek	LGE-17 (JB)	11	1	9%
New Light Creek	NLC-3.8 (JB)	17	1	6%
Robertson Creek	ROB-7.2 (JB)	11	1	9%
All Monitoring Stations		**667**	12	2%

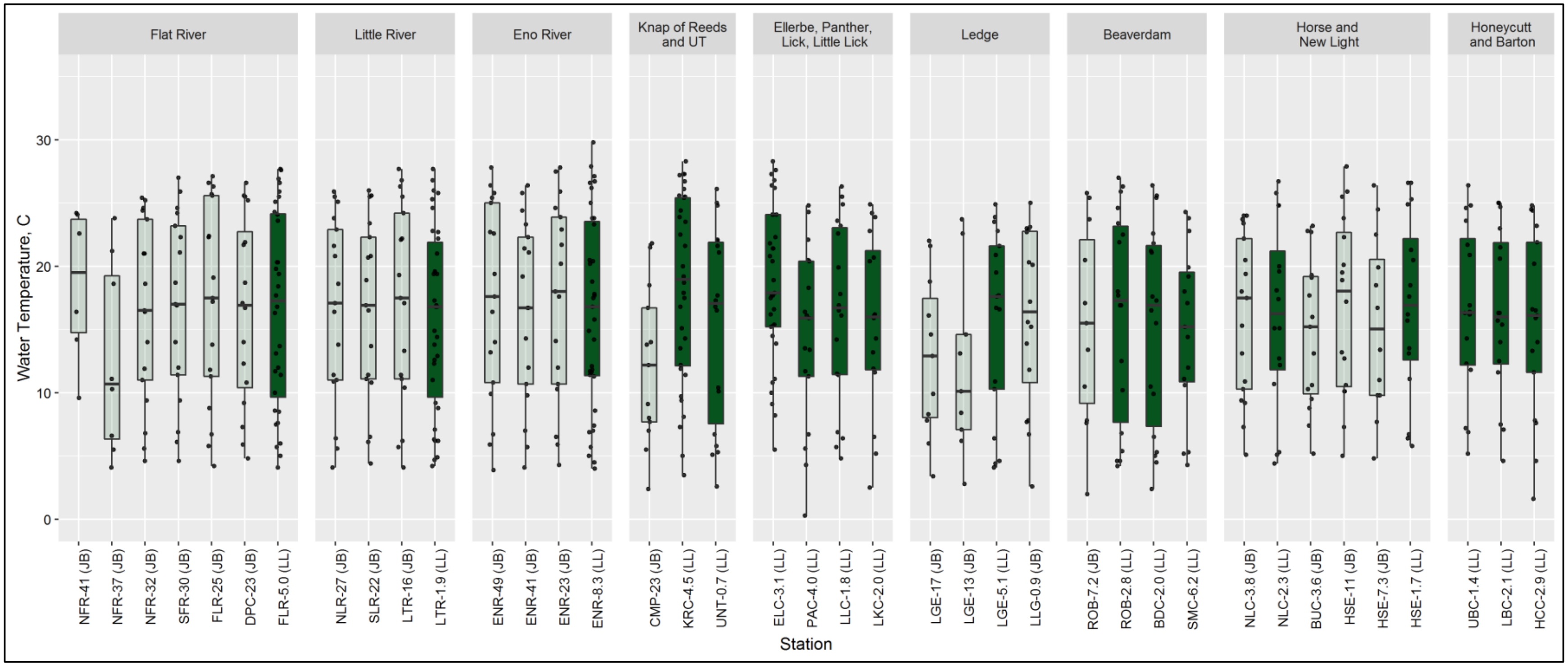


Figure 3.23 **Temperature in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

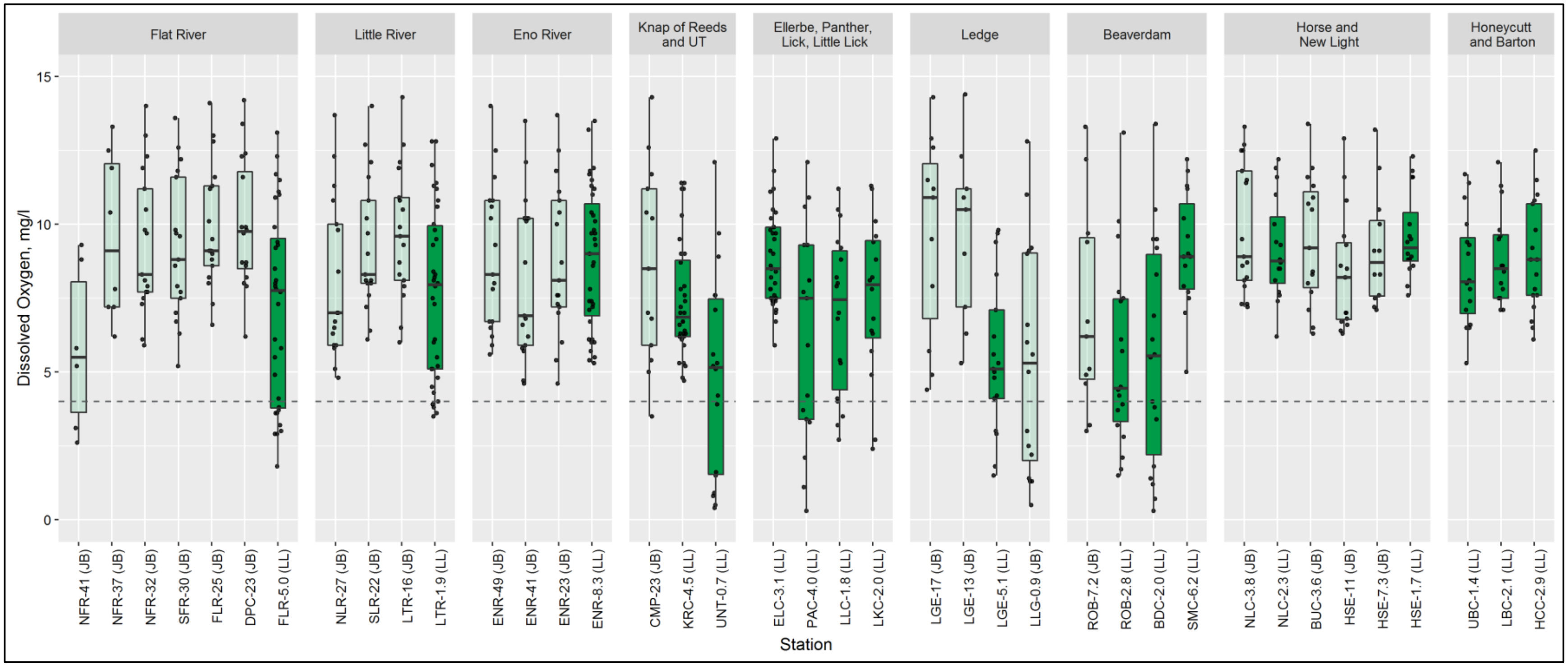


Figure 3.24 **Dissolved Oxygen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** The State's instantaneous dissolved oxygen standard of 4 mg/L is shown as a horizontal dashed line. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

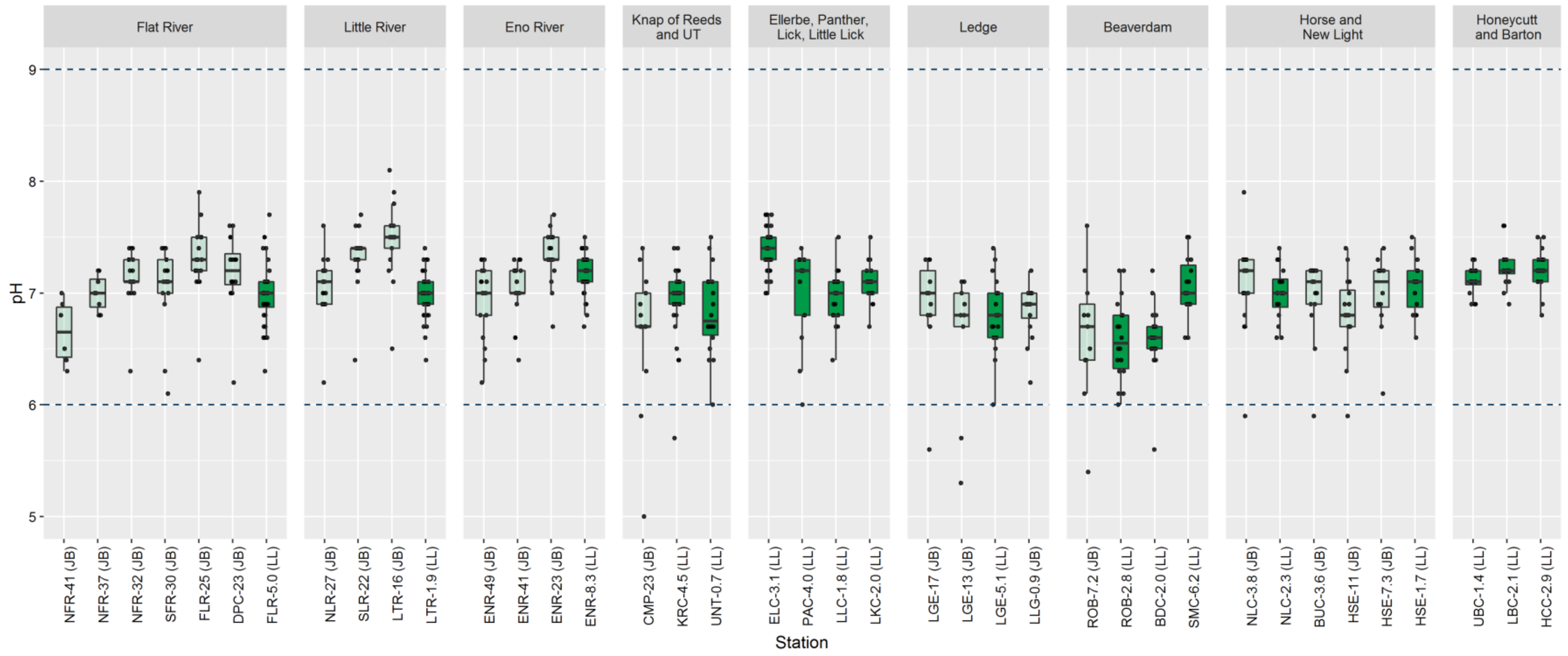


Figure 3.25 **pH in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** The State’s upper and lower pH standards are shown as horizontal dashed lines at values of 9 and 6. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

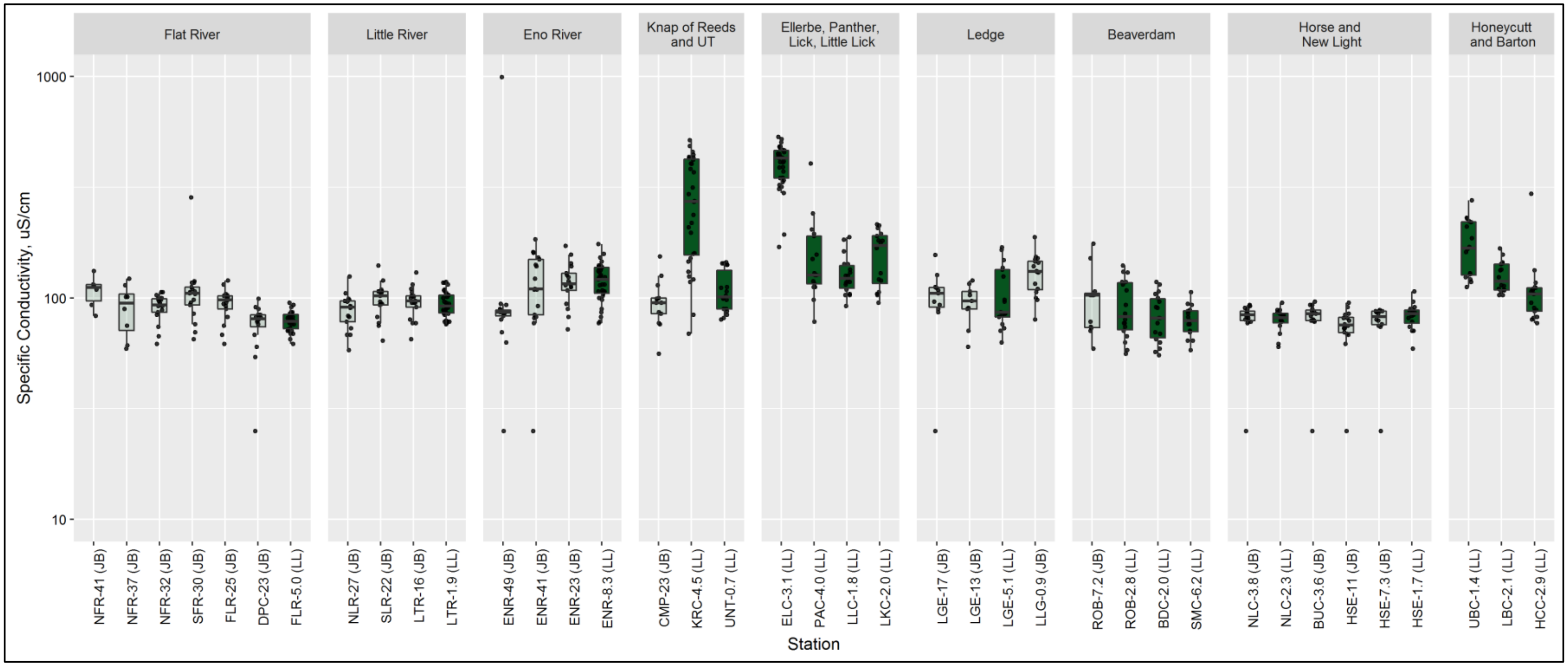


Figure 3.26 **Specific Conductance in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

> Total nitrogen measured at tributary stations is presented in Figure 3.27, nitrate + nitrite is in Figure 3.28, ammonia is in Figure 3.29, and organic nitrogen is in Figure 3.30. The higher ranges of values of nitrate + nitrite and total nitrogen tend to occur downstream of major wastewater treatment plants and small package plants; higher values of ammonia and organic nitrogen occur downstream of these facilities and in areas dominated by stagnant, wetland conditions.

> Total phosphorus in the watershed (Figure 3.31) tends be higher downstream of major wastewater treatment plants and in areas dominated by stagnant, wetland conditions. The highest concentrations have been observed downstream of the SGWASA WWTP; part of the distribution for site KRC-4.5, including the maximum value (3.8 mg/L) and 75th percentile value (0.625 mg/L), has been cutoff of the figure to scale the axes. SGWASA has been undergoing WWTP upgrades and have experienced some operational disruptions that resulted in relatively high concentrations. Following upgrades at the North Durham Water Reclamation Facility, which discharges to Ellerbe Creek, values at station ELC-3.1 are similar to other stations in the watershed. It is anticipated that as the SGWASA WWTP stabilizes following operational changes and upgrades, that concentrations at this location will decline relative to what was observed during this monitoring period.

> Total suspended solids (TSS) levels are generally consistent among the Jurisdictional and Lake Loading stations in a subwatershed (Figure 3.32). Stations draining relatively small watersheds and those located in stagnant areas tend to have higher concentrations of TSS.

> Total organic carbon (TOC) shows the TOC data collected in tributaries of Falls Lake (Figure 3.33). The highest concentrations of TOC tend to occur in areas dominated by stagnant conditions and wetland complexes. The UNRBA Monitoring Program currently includes collection of TOC at Jurisdictional Boundary stations and Lake Loading stations. At the end of the current fiscal year, this will have resulted in 23 months of data from 38 tributary stations. Cardno recommends continuing to collect TOC at the Lake Loading stations because of the value of such data for lake response modeling. However, collection of additional TOC data from the Jurisdictional Boundary stations would not provide substantive benefit for lake modeling efforts. Because the UNRBA is considering conducting watershed modeling, it may beneficial to continue collecting this parameter at Jurisdictional stations to support these efforts, but at a reduced frequency. Cardno recommends that the UNRBA consider this parameter on a quarterly basis, rather than monthly. The UNRBA currently spends $11,300 collecting TOC at jurisdictional stations and this reduction in frequency would save approximately $7,500 annually.

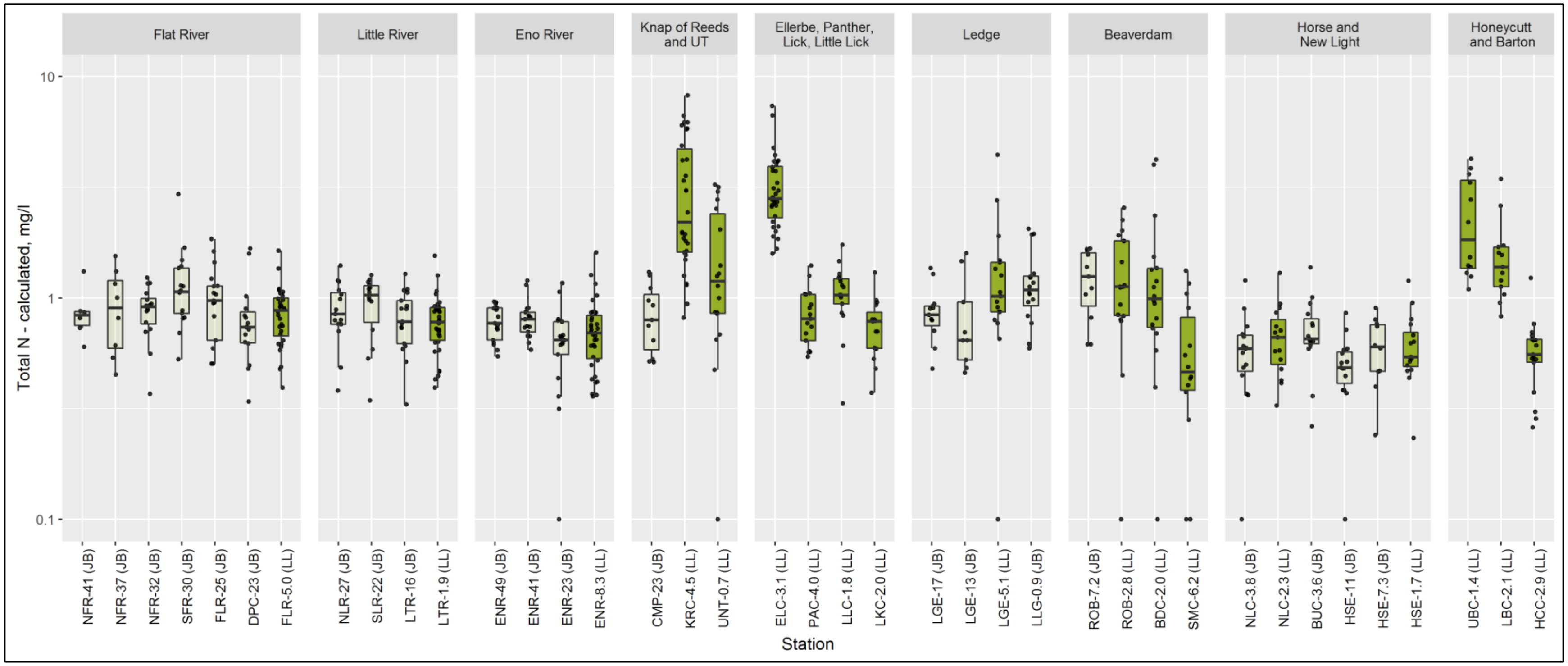


Figure 3.27 Total Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

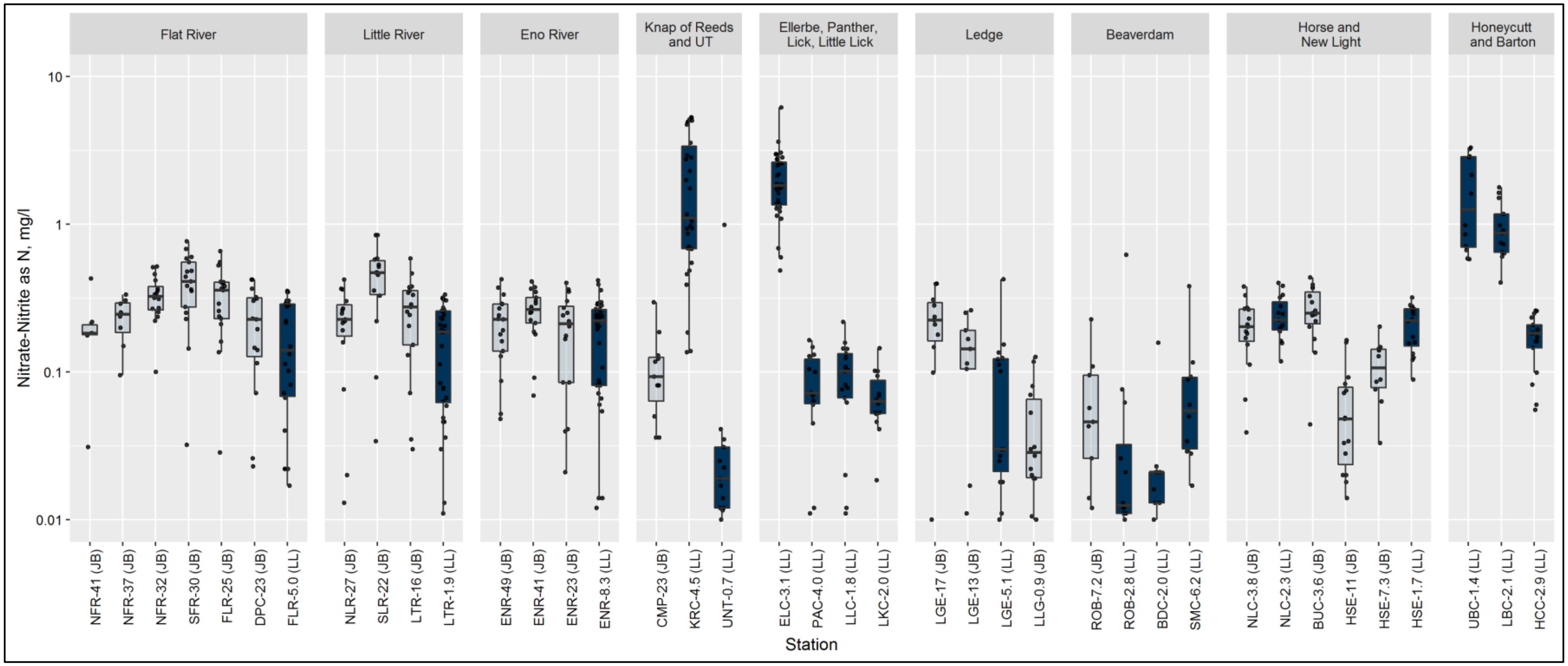


Figure 3.28 **Nitrate plus Nitrite in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

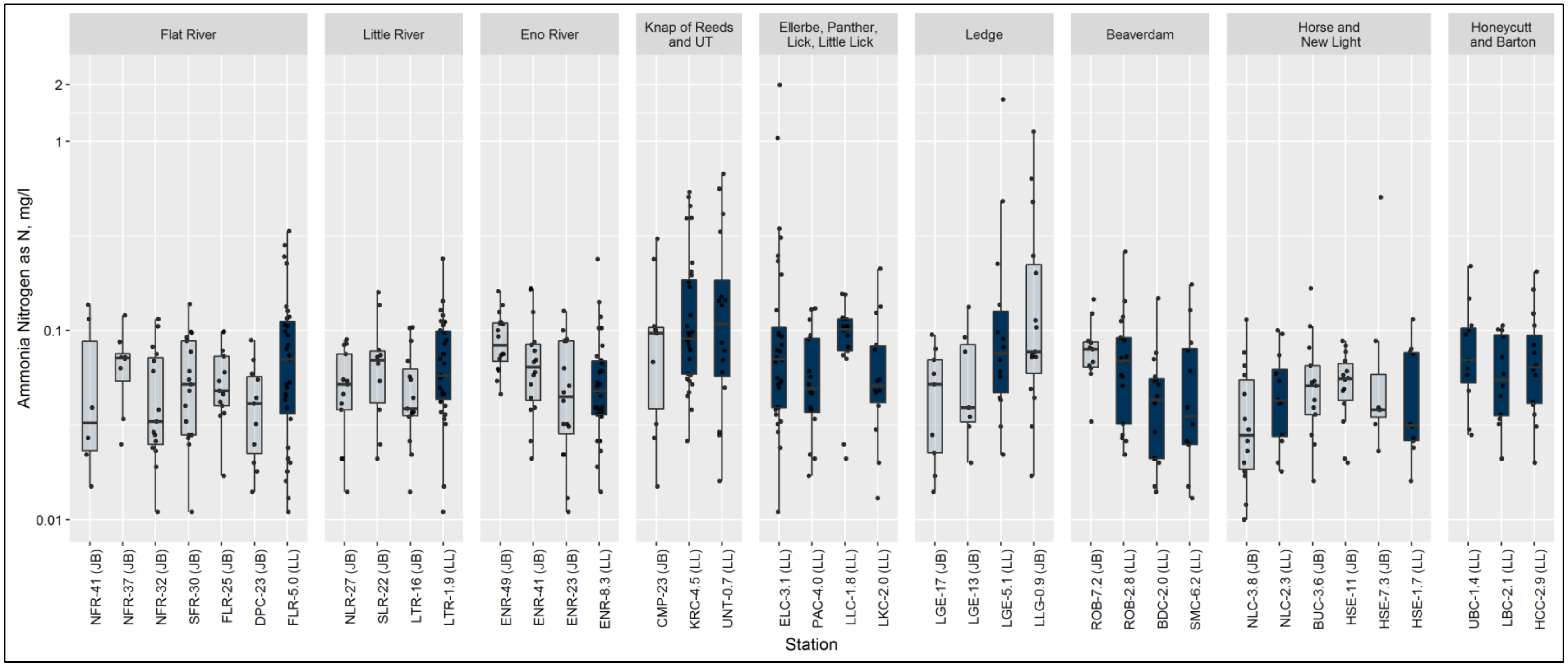


Figure 3.29 **Ammonia in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

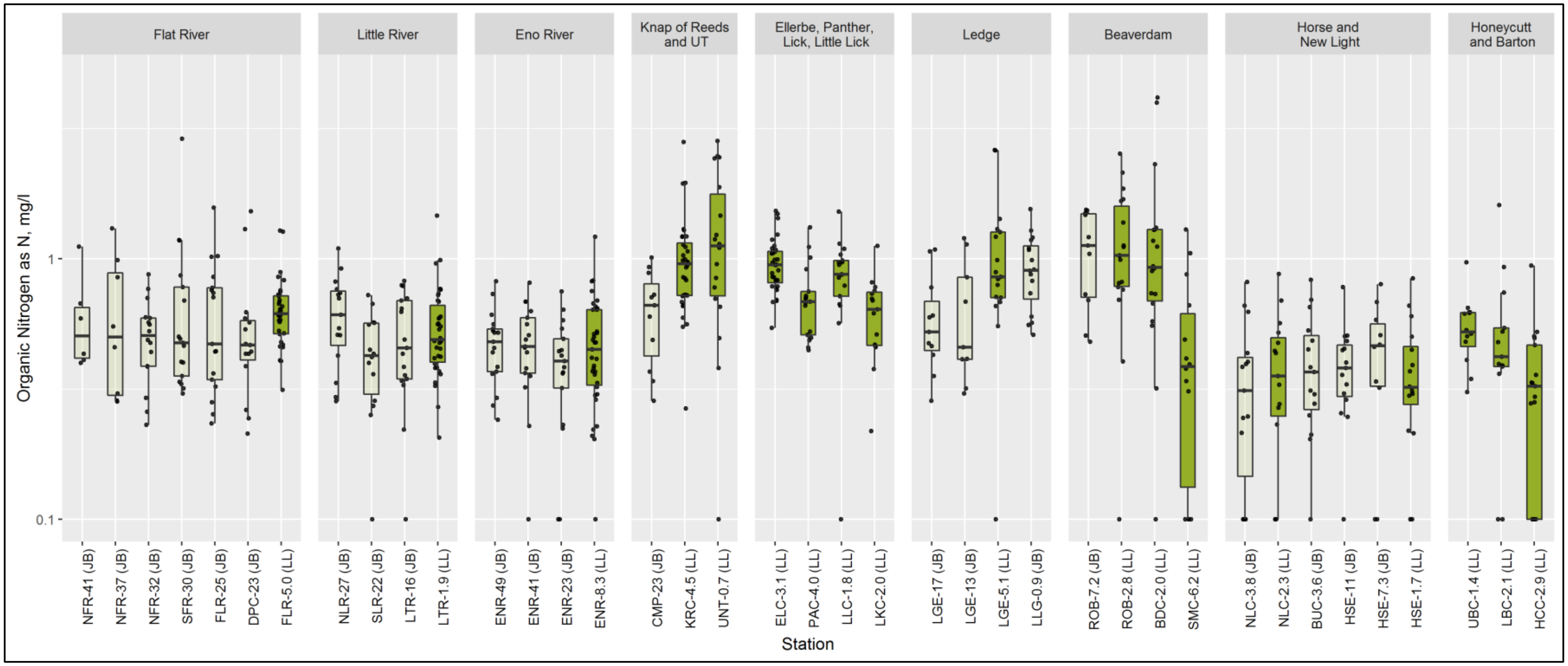


Figure 3.30 **Organic Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

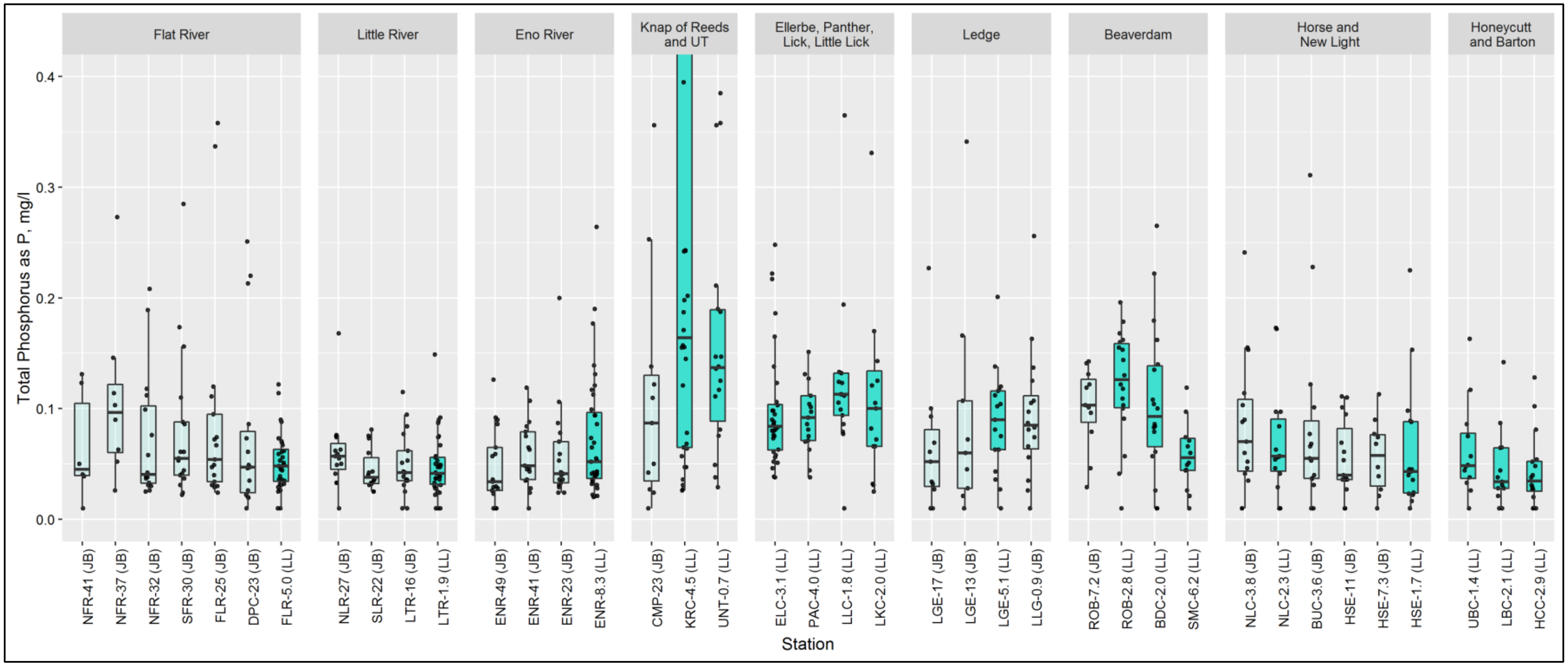


Figure 3.31 **Total Phosphorus (TP) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** In order to more clearly show the variability in observations in Jurisdictional sites, the vertical axis scale has been truncated at 0.4 mg/L which hides 8 values between 1.3 and 6.8 mg/L on Knap of Reeds Creek (KRC-4.5 (LL)). These elevated TP values occurred between July and October 2015 and are visible on the Lake Loading version of the TP graph (Figure 3.12). Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

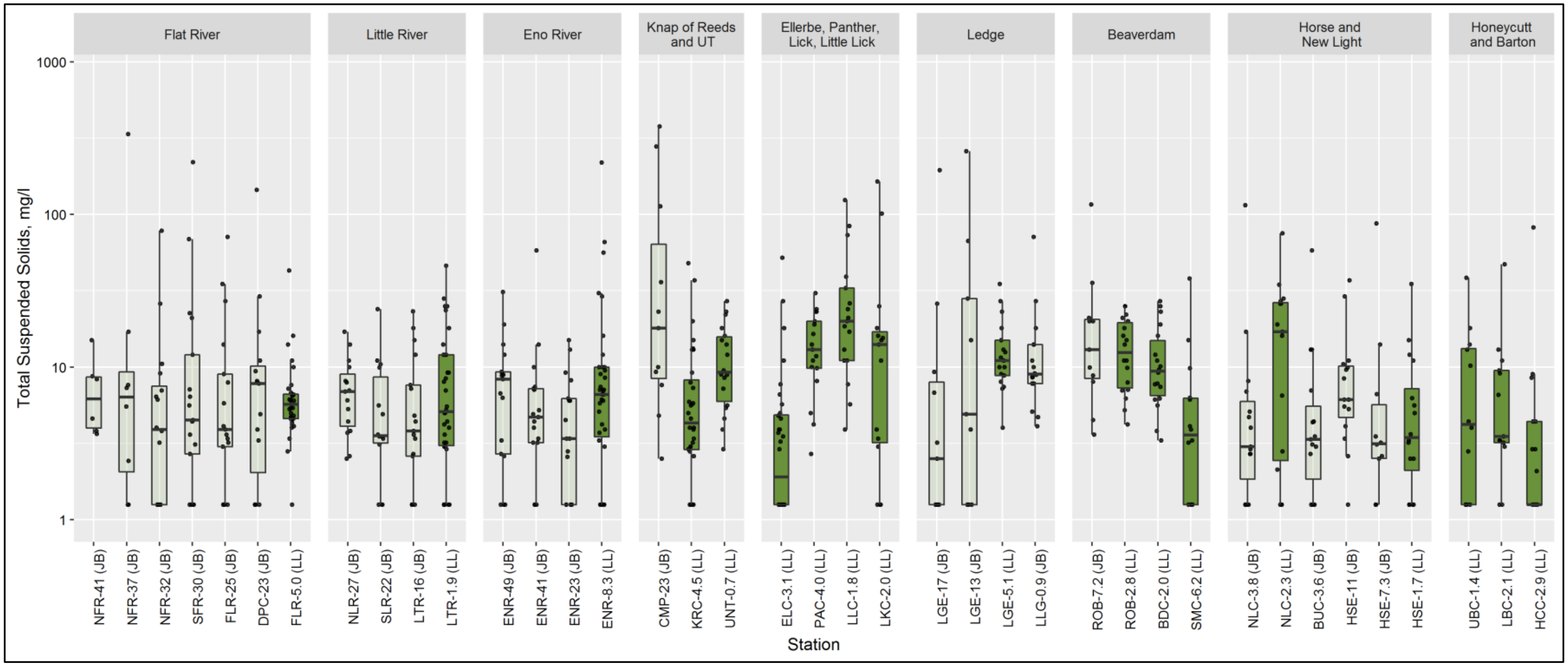


Figure 3.32 **Total suspended solids (TSS) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2015.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

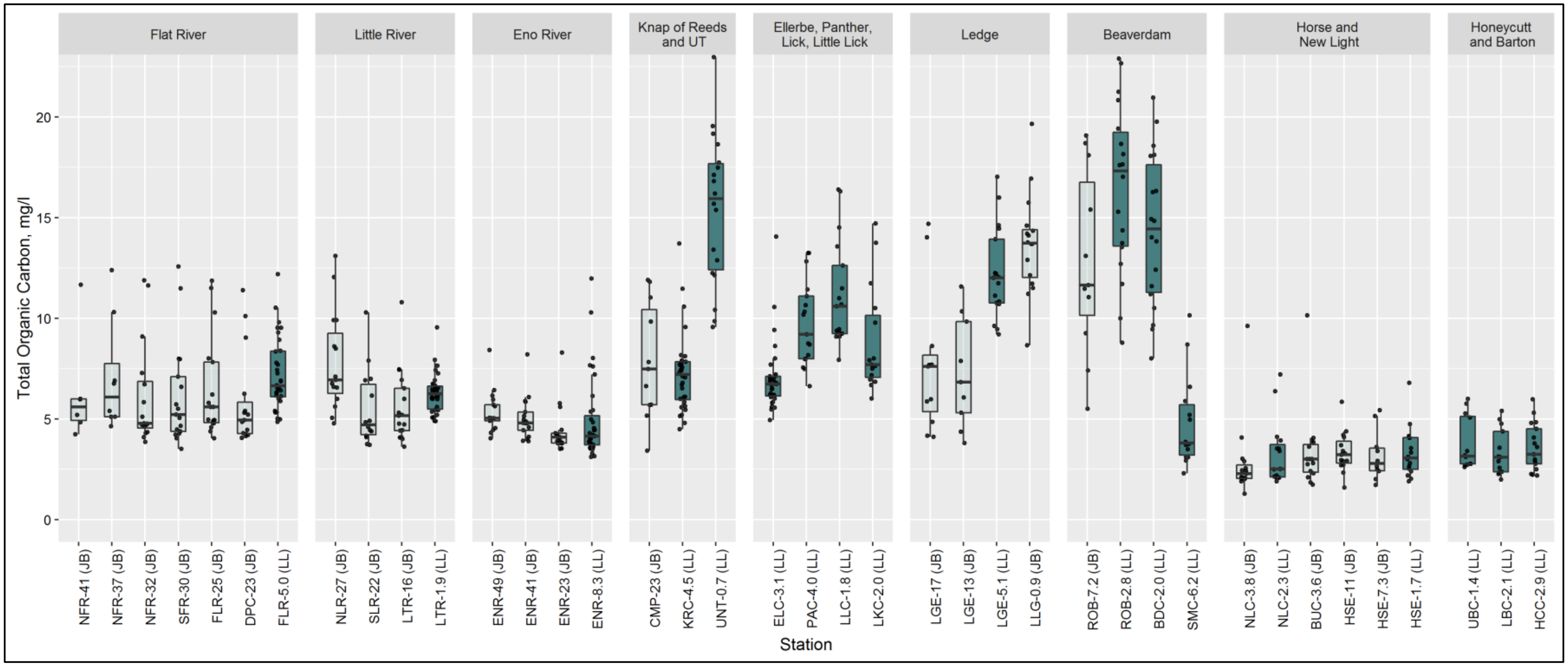


Figure 3.33 **Total Organic Carbon (TOC) in Jurisdiction Boundary and Lake Loading Samples from August 2014 to December 2015.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading.

3.2.3 Tributary Loading

The figures presented in Sections 3.2.1 and 3.2.2 display results in terms of the concentrations present at the time of measurement. Concentrations, however, are not indicative of how much of any particular substance is actually moving downstream. If high concentrations of a constituent are measured in a stream with very little moving water, the total amount of constituent delivered to Falls Lake will be low despite the high concentrations observed. Therefore, it is important to look at the total load which depends on both concentration and the volume of water delivered by each tributary.

Figure 3.34 shows the total water load of each tributary to Falls Lake based on estimates made using the basin proration method which Cardno previously evaluated for the UNRBA (Cardno 2014a). The lake loading stations in the figure are ordered left to right from highest to lowest drainage area. The stations with the two largest drainage areas (Flat and Eno Rivers) together account for more than 50 percent of the water delivered to Falls Lake. The five largest tributaries together account for almost 80 percent of the water delivered to Falls Lake. In contrast, the six smallest tributaries together account for less than 5 percent of the water delivered to Falls Lake. The influence of elevated constituent concentrations is greatest when they occur on tributaries delivering the most water to Falls Lake. Elevated concentrations on small tributaries could, however, contribute to spatial variation within the lake or localized regions of higher concentrations near stream outlets.

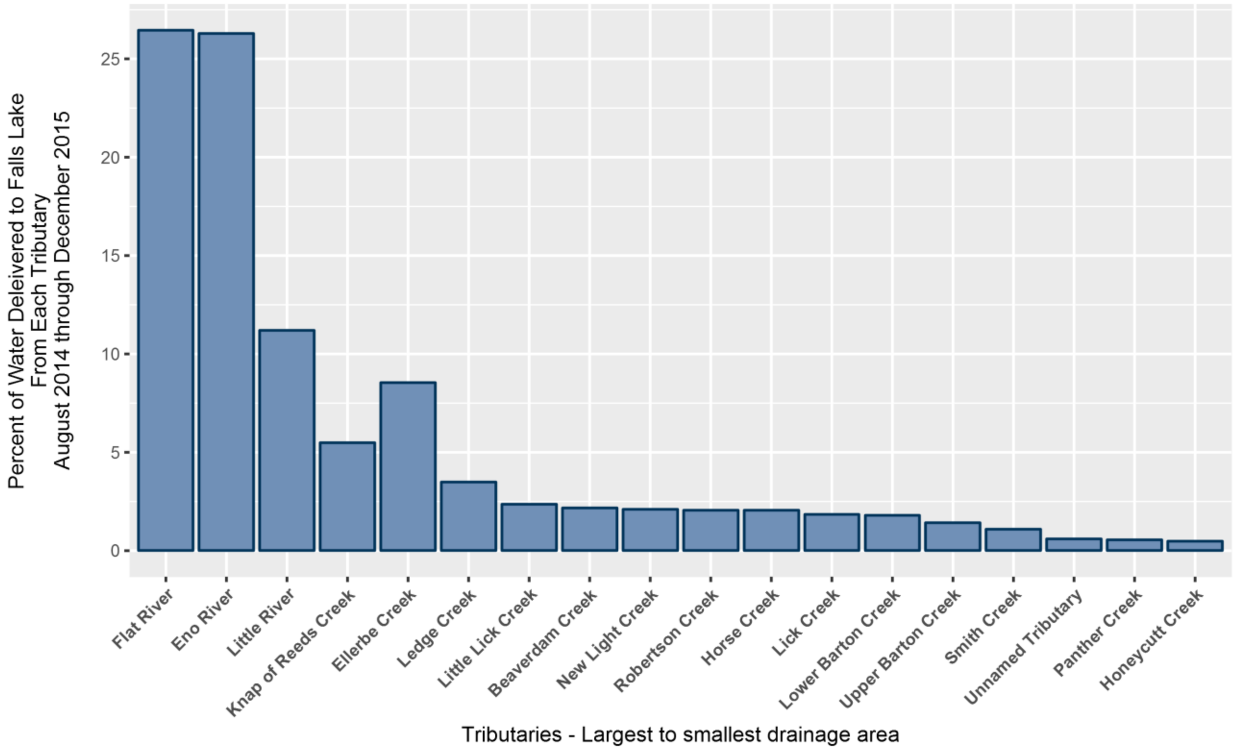


Figure 3.34 The Contribution of each Tributary to the Total Water Load to Falls Lake during the Monitoring Period of August 2014 through December 2015. The contribution is provided as the percentage of total water delivered to Falls Lake coming from each tributary. Tributaries are ordered from largest to smallest drainage area (left to right).

Ultimately, lake models require estimates of tributary loading through time which in turn require interpolation of concentrations between the times when samples were collected (monthly or twice-monthly). Several techniques can be used to interpolate between measurements, and the choice of technique can impact the load estimates. The modelers who developed DWR's version of the Falls Lake

Nutrient Response Model used a straight-line interpolation between monthly samples. Other approaches involve more complicated techniques to more accurately represent relationships between concentration and flow. The ultimate choice of load estimation method will depend on what is best supported by the data itself. Cardno is evaluating load estimation techniques as part of the Model Evaluation Special Study, however, ultimately the best estimation of lake loadings will be a component of the lake modeling process.

3.3 Quality Assurance Considerations

All analytical data collected through the UNRBA monitoring program (both from Routine Monitoring and from Special Studies) are evaluated for compliance with the quality objectives outlined in the UNRBA Quality Assurance Project Plan (QAPP). Data accuracy, precision, and completeness reviews are performed following each monitoring event and reviews of field and laboratory practices are performed on a routine basis. Note that data collection efforts associated with Special Studies are subject to the same general QA/QC considerations and scrutiny as for the Routine Monitoring.

3.3.1 Field and Laboratory Oversight

Cardno reviews field and laboratory data monthly to ensure that the representativeness, accuracy and precision of data collection efforts meet the criteria set forth in the UNRBA's QAPP. In addition, field audits were conducted in July and December of 2015 to verify field staff were using approved methods consistent with the requirements of the QAPP. Cardno conducted a detailed audit of the contract laboratory in April 2015 and initiated or revised a number of additional laboratory QA/QC procedures based on that audit. Additional efforts included procedures to reduce blank contamination and to provide QA/QC checks in concentration ranges more closely reflecting ambient concentrations of several nutrient parameters. Since those changes were initiated in July 2015, Cardno has been reviewing matrix spike and matrix spike duplicate results and calibration curves for all nutrient parameters monthly. The contracted laboratory was also the subject of a routine audit from NC-DEQ's Division of Water Resources (DWR) in August, 2015 and received an initial audit report from DWR on December 23, 2015. The laboratory and DWR are still in the iterations of responding to and revising the detailed audit report. Cardno will review the final report and address any concerns which relate to parameters collected by the UNRBA. Cardno's second annual laboratory audit will be completed in the spring of 2016.

3.3.2 Representativeness and Completeness

The UNRBA Routine Monitoring program was designed to collect data from representative sites in the Falls Lake basin and at regular time intervals in order to capture data during conditions representing the entire monitoring period. All efforts are made to adhere to this sampling plan; however some samples are understandably missed due to factors such as dry stream conditions, extreme weather, site access limitations, equipment malfunction, or staffing issues.

From August 2014 to December 2015, the UNRBA collected about 91 percent of the samples and data points anticipated in the monitoring plan. No sites have been missed due to equipment or staffing issues. Most of the missed data collection (75%) has been attributable to dry conditions which prevented sample collection from some sites. This was typically because of dry streambeds or the presence of only a disconnected pool at the sampling location. In some instances, the water was too shallow across the entire channel to obtain a clean sample uncontaminated by sediment material. Ice storms in February 2015 accounted for eleven percent of the missed samples, despite multiple collection attempts. Site access issues, typically from construction efforts, were the cause of the remaining missed samples.

3.3.3 Accuracy and Precision

Accuracy and precision of measurements are continually assessed through the review of field, trip, and bottle blank concentrations, field and laboratory duplicate samples, and matrix spike recoveries. As discussed in the QAPP, accuracy can be assessed through a variety of measurements including blank samples, laboratory control samples, and matrix spike samples. There have been no issues with laboratory control samples and only a few occurrences of matrix spike recoveries outside of the QAPP criteria (<5%). Cardno will continue to monitor and log accuracy through matrix spike recoveries; per EPA guidance, matrix spike recoveries outside of the designated recovery range do not indicate a systemic problem as long as laboratory control samples are otherwise in control.

As reported in the previous interim report, Cardno initially had concerns with elevated field blanks for some nutrient parameters (ammonia, nitrate + nitrite, total Kjeldahl nitrogen, and total phosphorus) and immediately worked with the laboratory on resolving these concerns. Since November 2014, there have been zero blank exceedances for nitrate+nitrite and total Kjeldahl nitrogen. Additional procedures were put into place with the laboratory in July and August 2015 to resolve continuing concerns with ammonia and total phosphorus; since September 2015 there have been no blank exceedances for ammonia or total phosphorus.

Precision describes the reproducibility of measurements and is assessed through field and laboratory duplicate samples. The UNRBA QAPP specifies specific criteria for the precision of laboratory measurements as determined by the relative percent difference (RPD) between matrix spike or laboratory duplicate samples. These precision criteria have consistently been met for all parameters. The QAPP additionally sets RPD precision criteria for field duplicate samples. Field duplicates generally meet these targets for field precision, however in some cases applying a relative percent difference (RPD) criteria to samples with low concentrations of analyte have resulted in RPD values above the specified targets.

Cardno evaluates and logs both relative and absolute differences between field duplicate samples and matrix spike duplicate samples in order to quantify and track the degree of uncertainty associated with field measurements for each parameter throughout the monitoring program. This will ultimately provide the end user with the information needed to quantify the uncertainty associated with field measurements.

4 Special Studies Status and Results

This section provides information on the ten special studies that have been initiated as part of the UNRBA Monitoring Program to address specific questions related to modeling or linking water quality with Designated Uses. The status and currently available results from these studies are provided below.

4.1 Storm Event Sampling

Storm Event Sampling was conducted in April, September, and October 2015 on Ellerbe Creek and Eno River capturing four or more distinct storm peaks for each tributary. Figure 4.1 and Figure 4.2 show the hydrographs at these monitoring locations and the distribution of water quality samples that were collected and analyzed as part of this event. Parameter concentrations measured in the samples are presented in relation to synoptically gaged flows in Figure 4.3 for Ellerbe Creek and Figure 4.4 for Eno River. In the Eno River, most of the parameters show a pattern of increasing concentration with river flow, except for nitrate plus nitrite which remains relatively stable once flows exceed 200 cfs. For ammonia, the relationship with flow was relatively strong during the fall events (September and October) but weaker during the spring events (April). In Ellerbe Creek, there is much more variability in parameter concentrations, particularly at low flows when the WWTP discharge comprises a greater portion of the flow. At higher flows, much of the observed variability with discharge is attributable to higher concentrations on the rising portions of the hydrograph than on the falling portions. For this tributary, accurate predictive loading models will likely need to consider both stream flow and discharge monitoring data reported by the facility.

Patterns observed clearly demonstrate the variability in parameter concentrations associated with changes in flow. Of particular value is knowledge that the upper range of flows generally is associated with different water quality characteristics than the lower flows, which will benefit future modeling work. Additional investment may be warranted to obtain more water quality data during high flow periods.

An additional storm event was monitored in February 2016 but data were not available in time for inclusion here. Another suitable storm will be targeted for sampling before June 2016 to complete the budgeted efforts for the current fiscal year. These events, along with those conducted in 2015, will help inform future model revisions by providing data to verify the accuracy of the loading estimates from the tributaries. More detailed analyses will be conducted as additional Storm Event data become available. As part of the model performance evaluation being conducted in FY 2016 (Section 2.2.8 and Section 4.8), evaluations of the load estimation methods will be compared to the available storm event data to assess the accuracy of the methods to support future lake modeling.

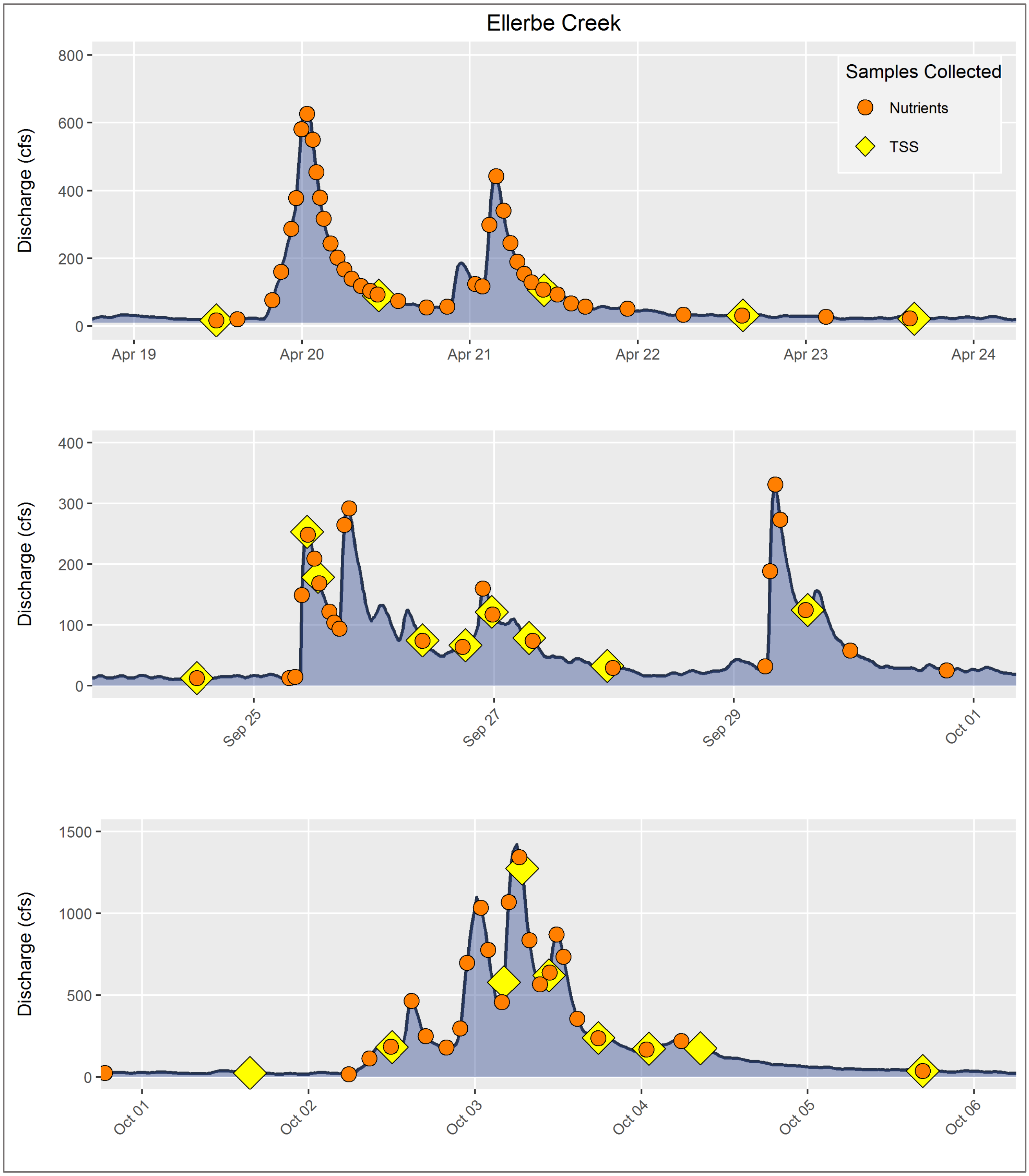


Figure 4.1 **Hydrographs and Water Quality Samples Collected from Ellerbe Creek during the Spring and Fall Storm Events** (symbols for Samples Collected only reflect the time of sample collection and not the magnitude of chemical analysis results)

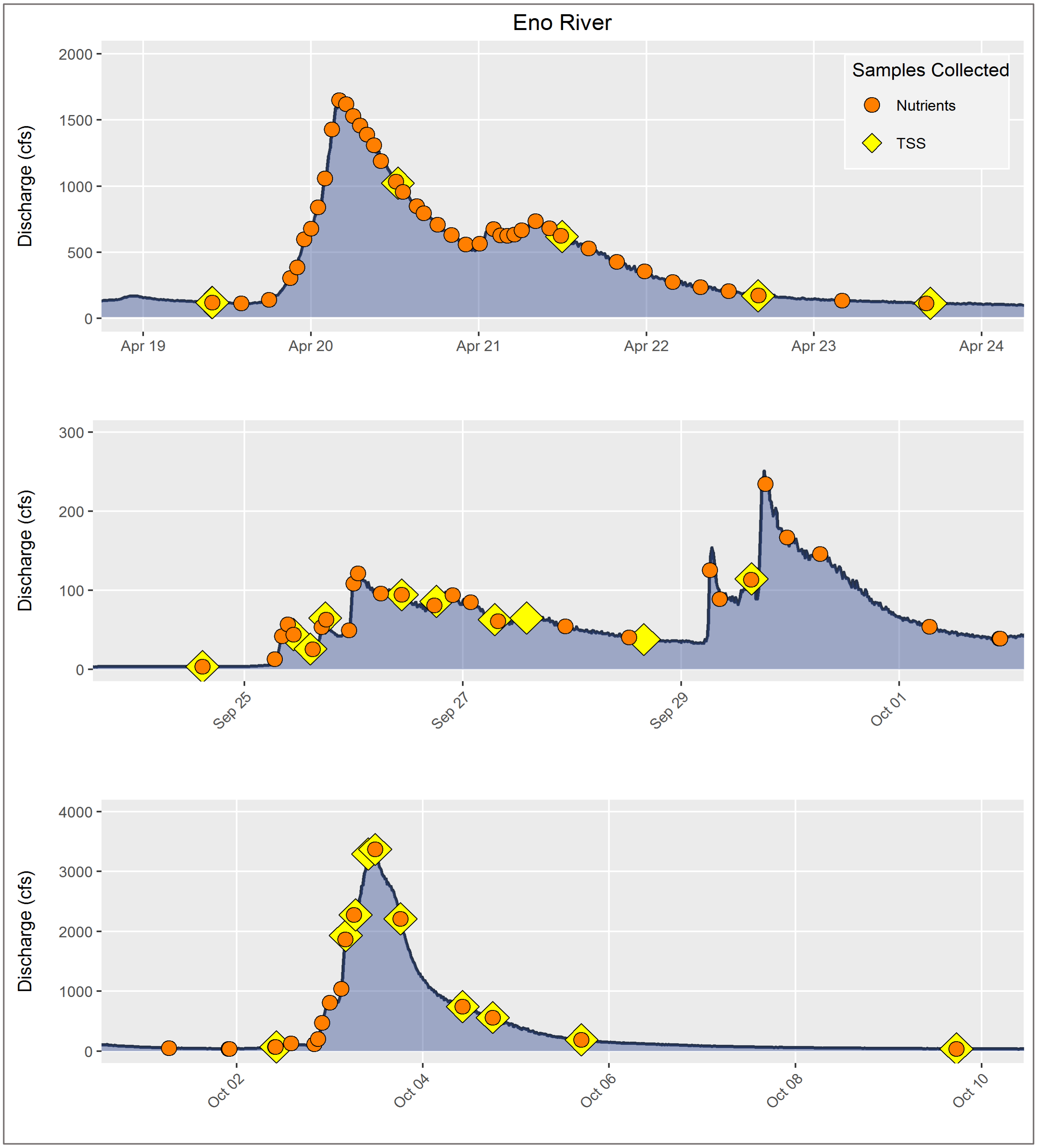


Figure 4.2 **Hydrographs and Water Quality Samples Collected from Eno River during the Spring and Fall Storm Events** (symbols for Samples Collected only reflect the time of sample collection and not the magnitude of chemical analysis results)

Figure 4.3 **Water Quality Concentrations versus Flow Observed in Ellerbe Creek during the 2015 Spring and Fall Storm Events**

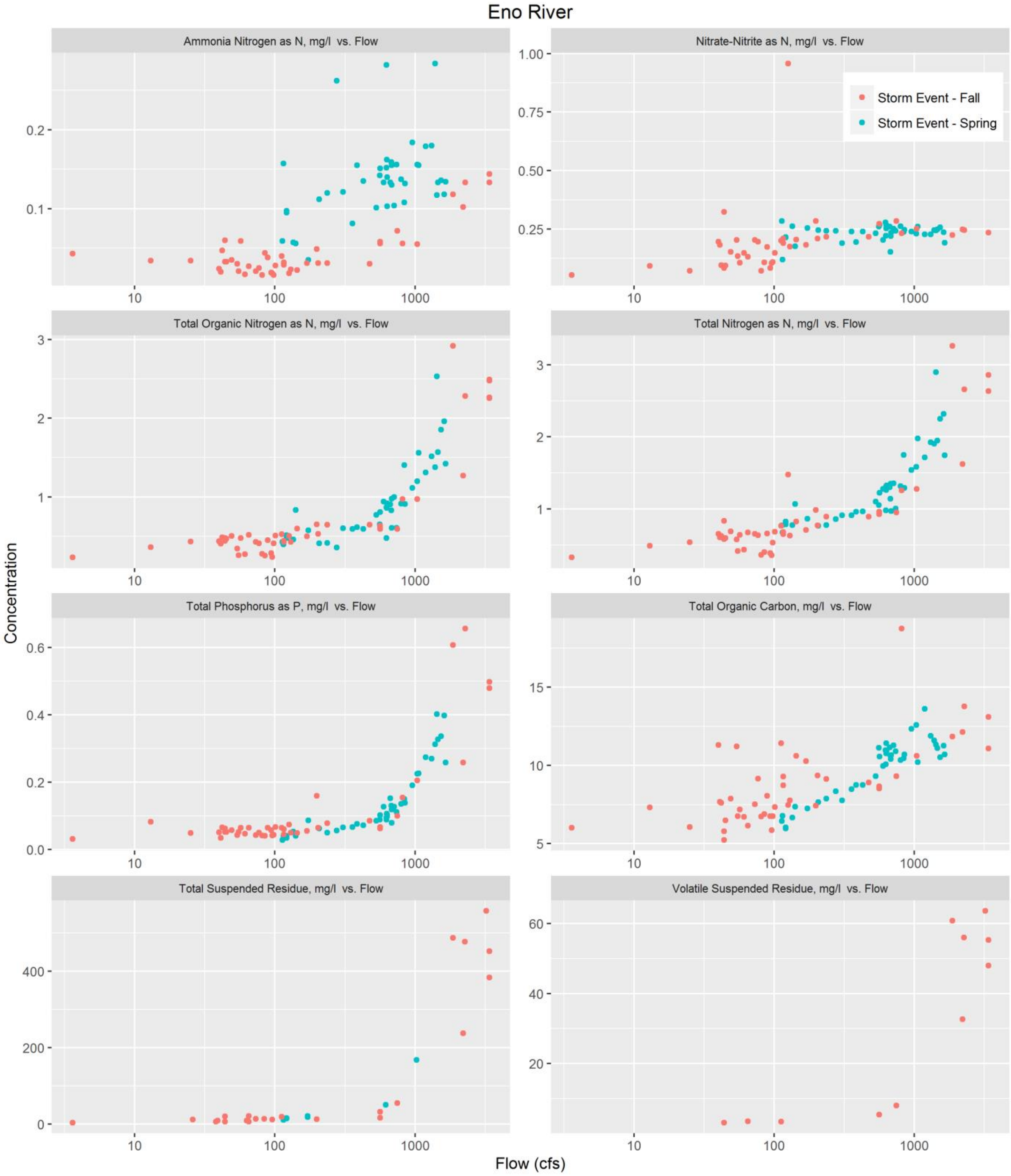


Figure 4.4 Water Quality Concentrations versus Flow Observed in Eno River during the 2015 Spring and Fall Storm Events

4.2 High Flow Sampling

High flow sampling events are intended to measure water quality during elevated flows not typically captured by Routine Monitoring, but that contribute relatively large volumes of water to Falls Lake. For example, for the five largest tributaries, about 20 percent of the water delivered to Falls Lake comes from flows which occur during just one percent of the time, and 40 percent of the water delivered comes during about 5 percent of the time. This imbalance between water delivery and the time during which it occurs leads to an over-representation of low-flow conditions and an under-representation of high flow conditions when sampling occurs based on time intervals instead of flow intervals. For the Flat, Eno, and Little Rivers and Knap of Reeds and Ellerbe Creeks (which together contributed nearly 80 percent of the water delivered to Falls Lake over the monitoring period), 50 to over 70 percent of samples have been collected during flow conditions which represent of just 20 percent of the water delivered to Falls Lake (Figure 4.5). Flow conditions representing the upper 20 percent of the load are either not represented by samples or have only been sampled only once. Because these high flow conditions occur so rarely (around one percent of the time), it is expected that routine sampling may not capture them. High flow sampling under this Special Study has resulted in the collection of more samples under high flow conditions than would be expected based on the duration of those flow conditions, however, high flows remain under-sampled when considered from the perspective of the water volume delivered to Falls Lake. Expanded high flow sampling, especially in the largest tributaries, would facilitate obtaining more samples when and where the most water is being delivered to the lake.

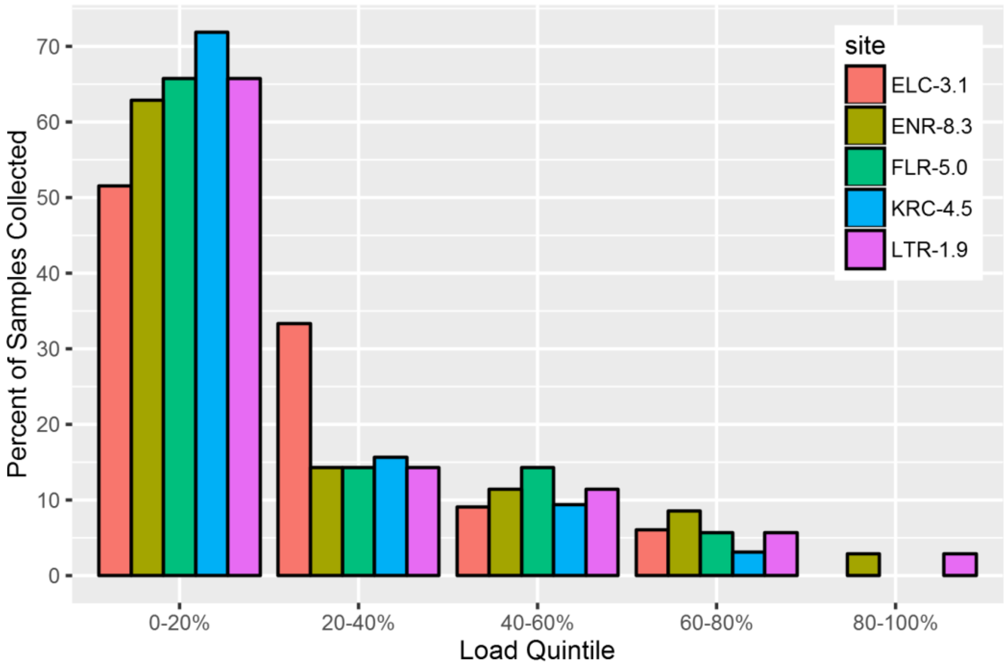


Figure 4.5 **Percent of Samples Collected during each Quintile of Water Load to Falls Lake from the Five Largest Tributaries with USGS Gaged Flow.**

High flow conditions were targeted by sampling on February 10, 2015 and April 20, 2015 at eight Lake Loading stations. Figure 4.6 illustrates that not only were high flow conditions sampled during those events (orange triangles) but due to the particularly wet conditions of Fall 2015, samples were also captured at elevated flows during routine monthly sampling (yellow circles). Flow estimates shown in Figure 4.6 are based on direct USGS gage measurements where available and on basin-area proration techniques elsewhere (see the Flow Estimation Technical Memorandum (Cardno 2014a at http://www.unrba.org/monitoring-program). Flows are shown on the y-axis in cubic feet per second, 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 that value 100 percent of the time; the lowest flows have a 0 value because no estimated flows were below this value. For Years 1 and 2, this has been a relatively small effort (triangular orange symbols on Figure 4.6 and Figure 4.7 represent data obtained through this Special Study) capturing samples in most regions of the flow duration curves. Note that each graph indicates flows above the highest level that samples were collected (see the “tail” on the line at the top of each graph), indicating there is still a portion of the flow regime for which water quality data have still not been collected. Although the number of days per year with flows greater than the highest measured value is not large (between 2 and 12 percent), because of the high flow rates, the amount of water delivered to Falls Lake during these times ranges from 14 to 34 percent of the annual load. As noted above, future efforts should be targeted to acquire samples during those peak flows.

Figure 4.7 shows how water quality parameter concentrations varied with flow at three sites representing the range of patterns observed (ENR-8.3, LTR-1.9, and ROB-2.8). While there are not yet enough data to draw definitive conclusions, these graphs can be used to assess general patterns. Each figure 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), the highest measurements of chlorophyll *a*, total nitrogen, TOC, total phosphorus, and TSS concentrations occurred under the highest 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 buffering effect of 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.

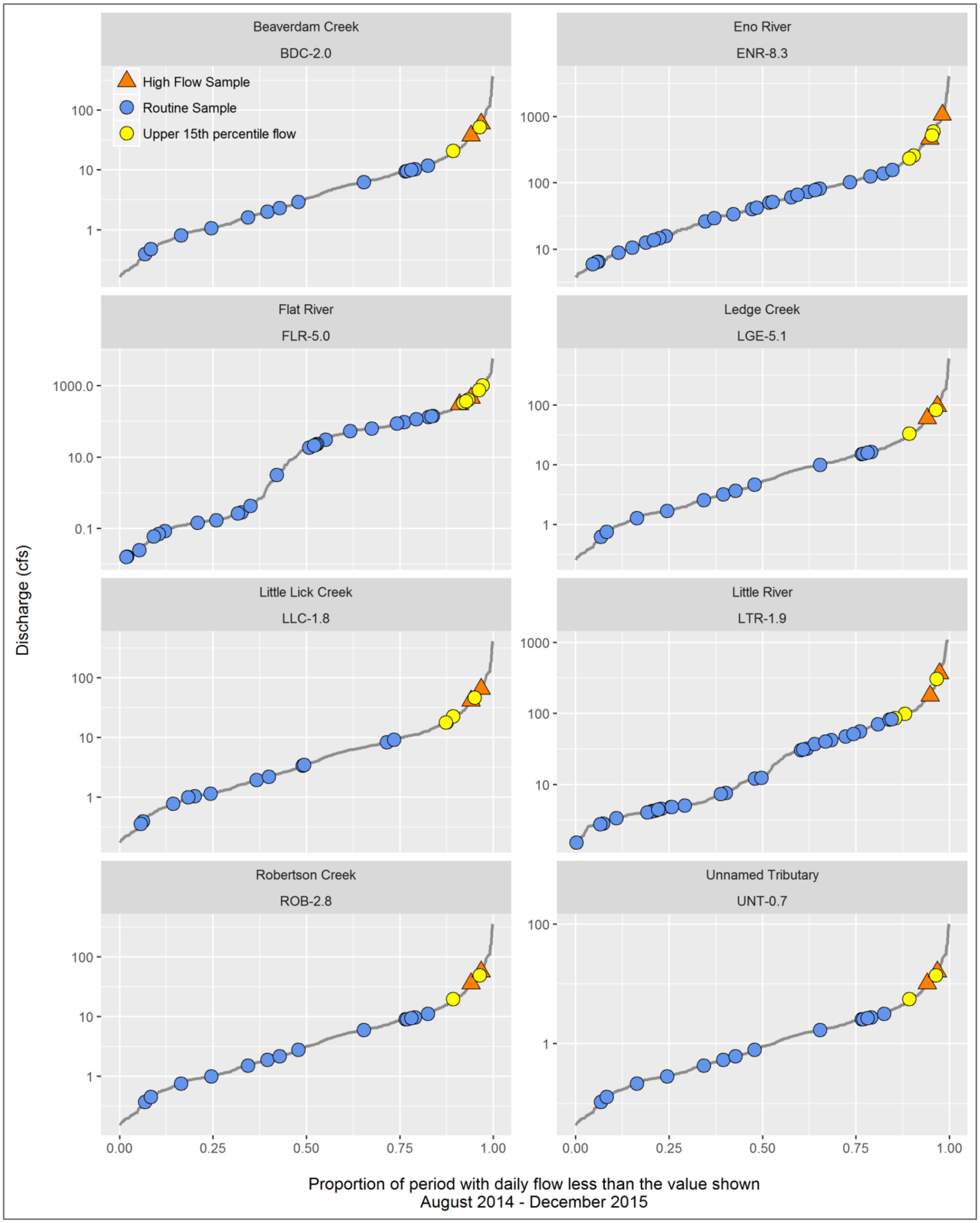


Figure 4.6 **Sampling Events Compared to Flow at the Eight High Flow Event Sampling Stations** (symbols for Samples Collected only reflect the flow magnitude associated with sample collection and not the magnitude of chemical analysis results)

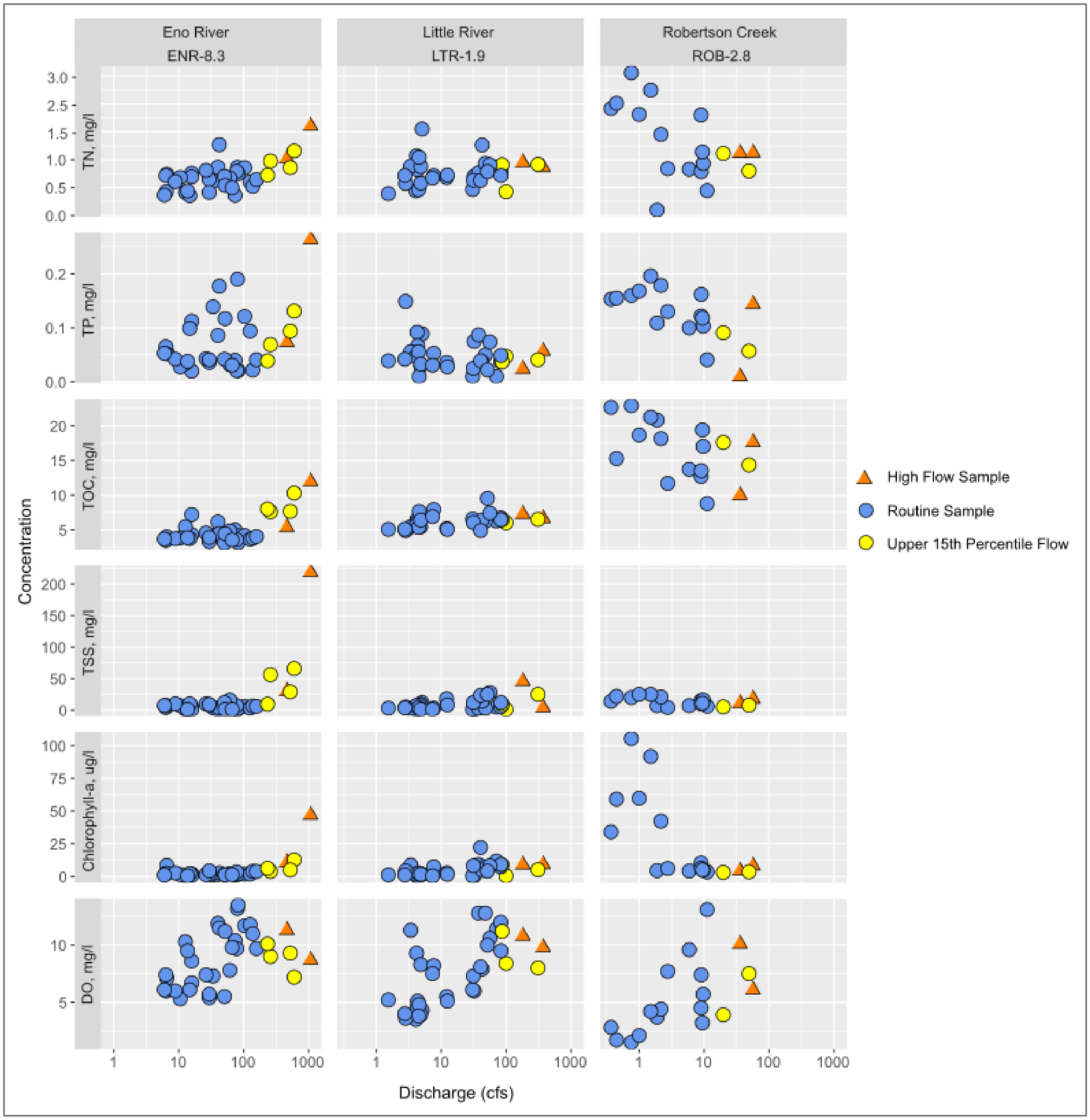


Figure 4.7 **Water Quality Concentrations versus Flow at Three High Flow Event Sampling Stations**

4.3 Sediment Evaluation

In the 2006 version of the EFDC model for Falls Lake, DWR assumed constant nutrient releases (fluxes) from the lake sediments to the water column that did not vary spatially or temporally; the rates of flux only varied with temperature. To assess the accuracy of this assumption, Dr. Marc Alperin from the University of North Carolina was engaged to evaluate the nature and spatial variability of the sediments in Falls Lake and to collect data to support using the sediment diagenesis module of EFDC or other models. Field reconnaissance in May 2015 suggested considerable variability in sediment distribution 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 in the vicinity of 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 (Figure 4.8). 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. 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.

Physical properties of the sediments have been analyzed and the results generally confirm the spatial patterns observed in the field. Measures of porosity (an indicator 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. Porosity was greatest in sediments within the historic river channel and increased from upstream to downstream suggesting the area with the highest potential benthic flux is confined to a relatively narrow spatial area within reservoir. LOI also generally increased from upstream to downstream and showed interesting patterns 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 segment of the lake, suggesting the 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, if warranted.

Results of nutrient analyses and benthic flux estimates are not yet complete; however, a portion of the samples have been analyzed and offer the ability to make some preliminary statements. Benthic ammonia flux was calculated from bottom water and the surficial layer of core samples collected near each of the 12 DWR lake monitoring stations in June 2015. At each of those stations, samples were collected from the deepest location (i.e., the historic Neuse River channel or tributary channel) and, for 9 of those stations, from a second location between the historic channel and the shoreline (i.e., on the historic floodplain). Preliminary estimates of benthic ammonia flux range from 0.001 to 0.066 grams of nitrogen per square meter per day (g-N/m^2/d). The average flux from channel samples of 0.023 g-N/m^2/d is approximately twice as high as the average flux measured on the historic floodplain (0.011 g-N/m^2/d), although there is substantial variability among stations, as is common with sediment analyses. Notwithstanding this spatial variability, the average values are generally in agreement with the values used in the State's EFDC model runs for the years 2005 through 2007 (0.01 to 0.02 g-N/m^2/d).

Tables and graphics presenting the data described above are not yet available from Dr. Alperin, as he is awaiting completion of laboratory analyses before finalizing his deliverables. Such information will be provided in a future report.

At this time, Cardno does not recommend allocating funds to the FY2017 monitoring effort for the collection of additional sediment data. However, the UNRBA modeling effort is expected to include consideration of sediment dynamics, and the US EPA may conduct an *in situ* sediment analysis on Falls Lake. Thus, it would be prudent to have a small amount of budget in FY2017 dedicated to further consideration of sediment issues in the coming fiscal year, as the modeling effort is initiated.

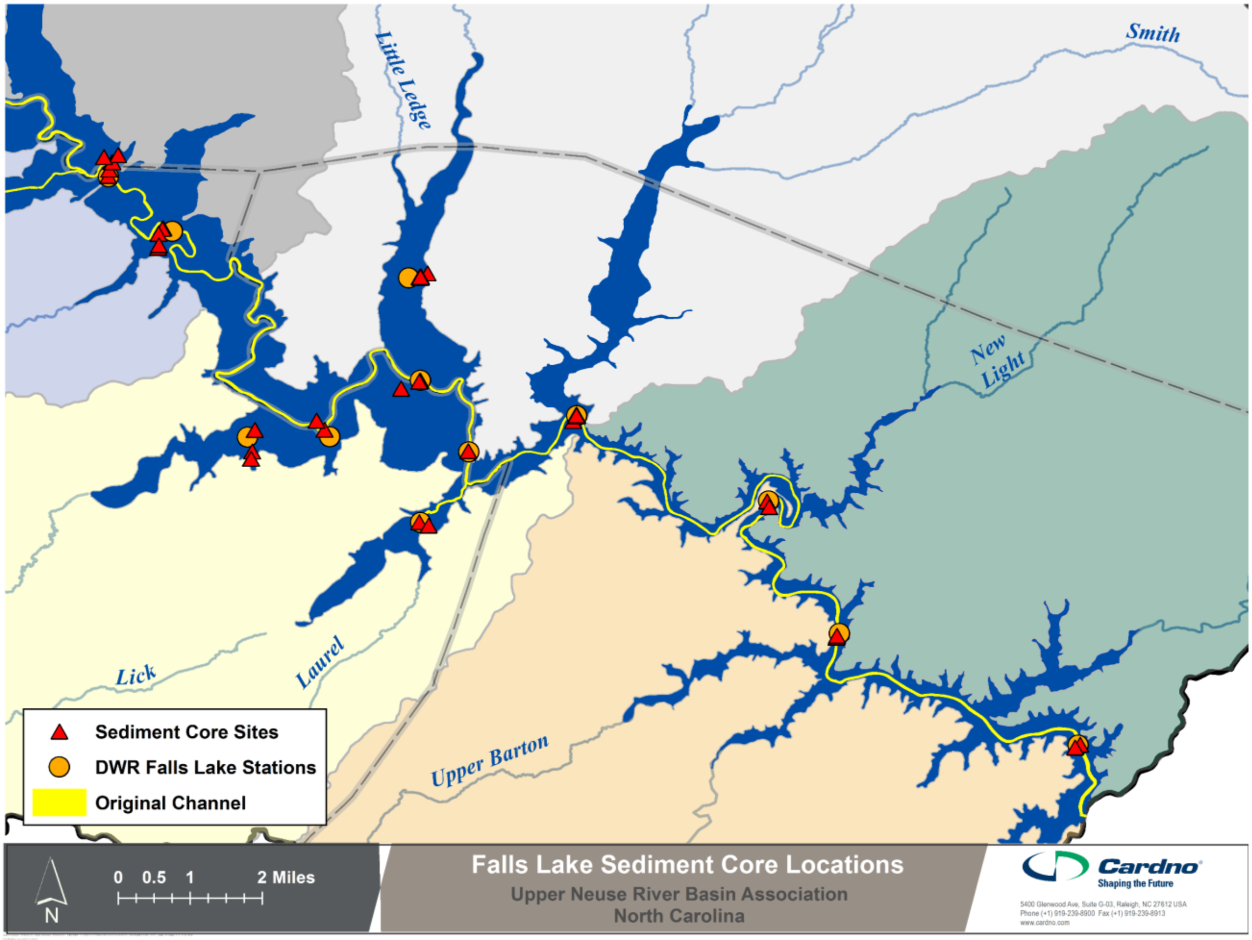


Figure 4.8 **Sediment Core Sampling Locations in Falls Lake Compared to DWR Lake Sampling Stations**

4.4 Development of Alternative Regulatory Approaches

Initial funding for this Special Study was allocated in the FY2015 Monitoring Program for Cardno to provide support to the UNRBA regarding regulatory issues, particularly preparing for meetings with the regulators to discuss alternative regulatory approaches. To date, approximately one-half of the FY2015 budget has been spent, mostly because the meetings have not yet been scheduled. A portion of the budget has been spent on initial pre-planning meetings with the UNRBA Executive Director and Subject Matter Experts. A portion of this budget has also been used to support the UNRBA in its response to various legislative actions, proposed rule revisions, and other agency documents regarding Falls Lake.

Cardno anticipates that the level of effort for this Special Study will increase incrementally in subsequent years as the UNRBA initiates the meetings with the regulators to discuss the alternative regulatory approaches and begins the modeling effort that will support the re-examination of Stage II of the Falls Lake Management Strategy, as well as any proposed alternative regulatory options. Peripheral activities are anticipated as well, such as those that arose during FY2016 (e.g., the Rules Review Process and development of the DWR Falls Lake status report).

4.5 Constriction Point Study

The first constriction point sampling event was conducted in January 2016. Data were collected at the I-85 and the Hwy 50 bridge crossings.

Cardno measured velocities through the constrictions using a SonTek® RiverSurveyor M9 acoustic Doppler current profiler (ADCP). Table 4.1 provides the water discharge estimated through each constriction based on the measured velocities and cross sectional area of each constriction. Coefficients of variation of four replicate ADCP transects during each sampling day are provided in parentheses. ADCP measurements were conducted daily between 10:00 and 12:00 at Highway 50 and between 13:00 and 15:00 at I-85 during the January event. Discharges from the dam are reported by USGS based on values recorded at noon each day.

Table 4.1 Discharge at Falls Lake through Two Constrictions and Released from the Dam

Date	Discharge measured via ADCP (cfs)		Falls Lake Dam
	Interstate 85	Highway 50	(USGS 02087183)
January 8, 2016	1050 (6%)	3170 (9%)	5010
January 11, 2016	1280 (6%)	3050 (5%)	4940
January 14, 2016	980 (5%)	2890 (4%)	4130
January 18, 2016	660 (20%)	2410 (11%)	3380

For this event, daily flowrates through the constrictions were estimated based on changes in lake surface elevation, rainfall amounts, tributary inflows, and evaporation estimates. These estimates provided for comparisons to the ADCP measurements. If the ADCP results align well with estimates using a mass balance approach, then future data collection efforts of this type may not need to incorporate ADCP units, which reduces the time and cost substantially. At this time, only one of the two constriction point studies that were funded for Fiscal Year 2 has been completed, and altering the protocol would not be prudent until both FY 2016 portions have been performed and the entire data set is reviewed.

Figure 4.9 compares the estimated flow rates to the measured flow rates. ADCP measurements of discharge through the constriction points are shown as black triangles for the I-85 and Hwy 50 constrictions, and gaged outflow at the dam is shown as black triangles in the top panel. Daily average estimates of discharge using the water mass balance approach are shown as colored circles joined by solid lines. Uncertainty based on typical USGS gage error, spatial variation in rainfall measurements, and in the basin proration technique for estimated stream flow is shown as a dark shaded region above and below each line. Variability in the ADCP measurements (i.e., the range observed over the four repeated measurements) is shown as a vertical, colored line across each triangle). Based on this first sampling event, ADCP measurements of discharge match estimates based on water mass balance fairly closely. Additionally, a preliminary analysis showed that ADCP-measured discharge at both constriction points was highly correlated with the simultaneous discharge at the Falls Lake dam, providing an additional means of estimating flow at the constriction points.

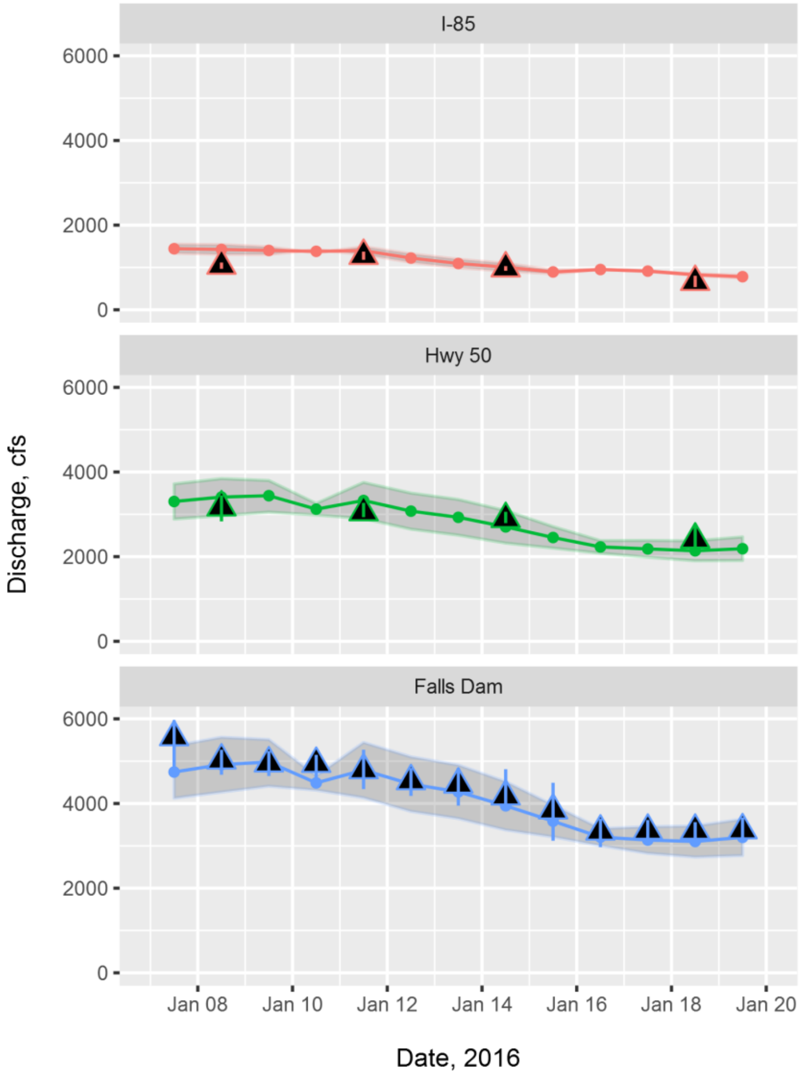


Figure 4.9 **Comparison of Estimated and Measured Discharge for the January Constriction Point Study for Hwy 50 and I-85.** For the I-85 and Hwy 50 constrictions, black triangles represent ADCP measurements with the range of 4 repeated measurements shown as vertical lines. For the Falls Dam graph, triangles represent the average USGS flow with the daily range shown as vertical lines. Estimates of daily average discharge using a mass balance approach are shown as solid circles with uncertainty shown as a shaded region above and below the circles (see text).

Grab samples were collected at three locations across each constriction point: (1) at 1 meter below the surface over the deepest portion of the historic river channel, (2) at 1 meter above the bottom at the deepest portion of the river channel, and (3) at 1 meter below the surface midway between the river channel and the shoreline (see example in Figure 4.10). A sample was collected from each of these three places at each constriction point on each of four sampling dates (i.e., a total of 12 samples from each bridge crossing for this overall event). Samples were analyzed for total organic carbon, total and volatile suspended solids, total phosphorus, total Kjeldahl nitrogen, ammonia, nitrate plus nitrite and chlorophyll *a* (1-meter samples only). Temperature and DO profiles and Secchi depth were measured in the field.

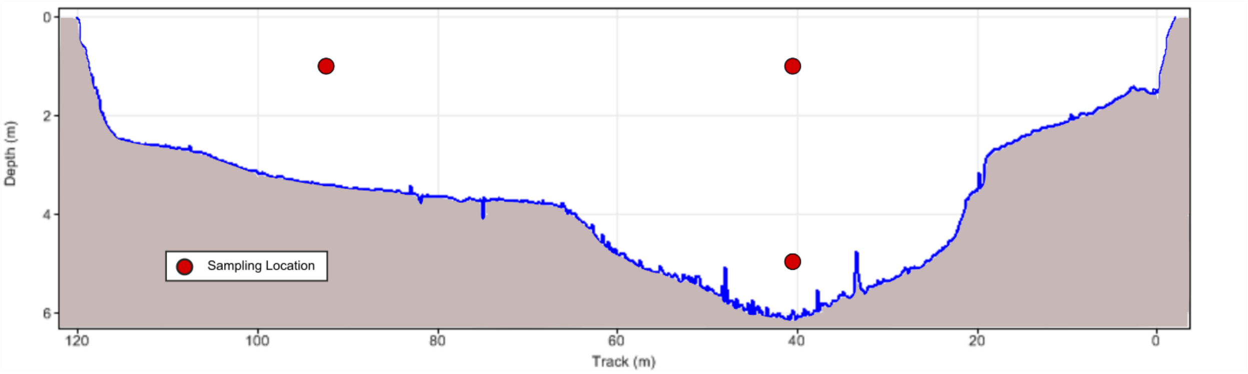


Figure 4.10 Example Water Quality Sampling Configuration for Constriction Point Study

Figure 4.11 and Figure 4.12 show the concentrations measured during the January event at the Interstate 85 and Highway 50 constrictions, respectively. For the most part, concentrations are relatively similar across the sampling points and throughout the sampling event. However, some parameters showed a distinct change in concentration over the four sampling days (e.g., ammonia and total nitrogen), while others were essentially constant (e.g., total phosphorus and chlorophyll a). Interestingly, nitrate+nitrate was very constant at Hwy 50 over the sampling period, but doubled in concentration at I-85.

For comparative purposes, these graphs also reflect the upper and lower quartiles and the minimum and maximum values for each parameter as derived from the 2015 DWR data set for the stations nearest to each respective constriction. Those lines on the graphs facilitate seeing which parameters had values from the constriction point sampling that were outside the general range of DWR monthly sampling (e.g., ammonia and chlorophyll *a*), and which parameters were in the same general range (e.g., total phosphorus).

Patterns in the data like those noted here can be an important consideration during model development, when conditions during changing flows, or during relatively rapid movement of water through the reservoir, are not detected in a monthly monitoring program.

Cardno will continue to evaluate this data, as well data collected during the second constriction point event, to inform potential revisions to this Special Study. In addition, this data will be used to inform model development and calibration of the Falls Lake water quality models that will be used to support re-examination Stage II of the Nutrient Management Strategy.

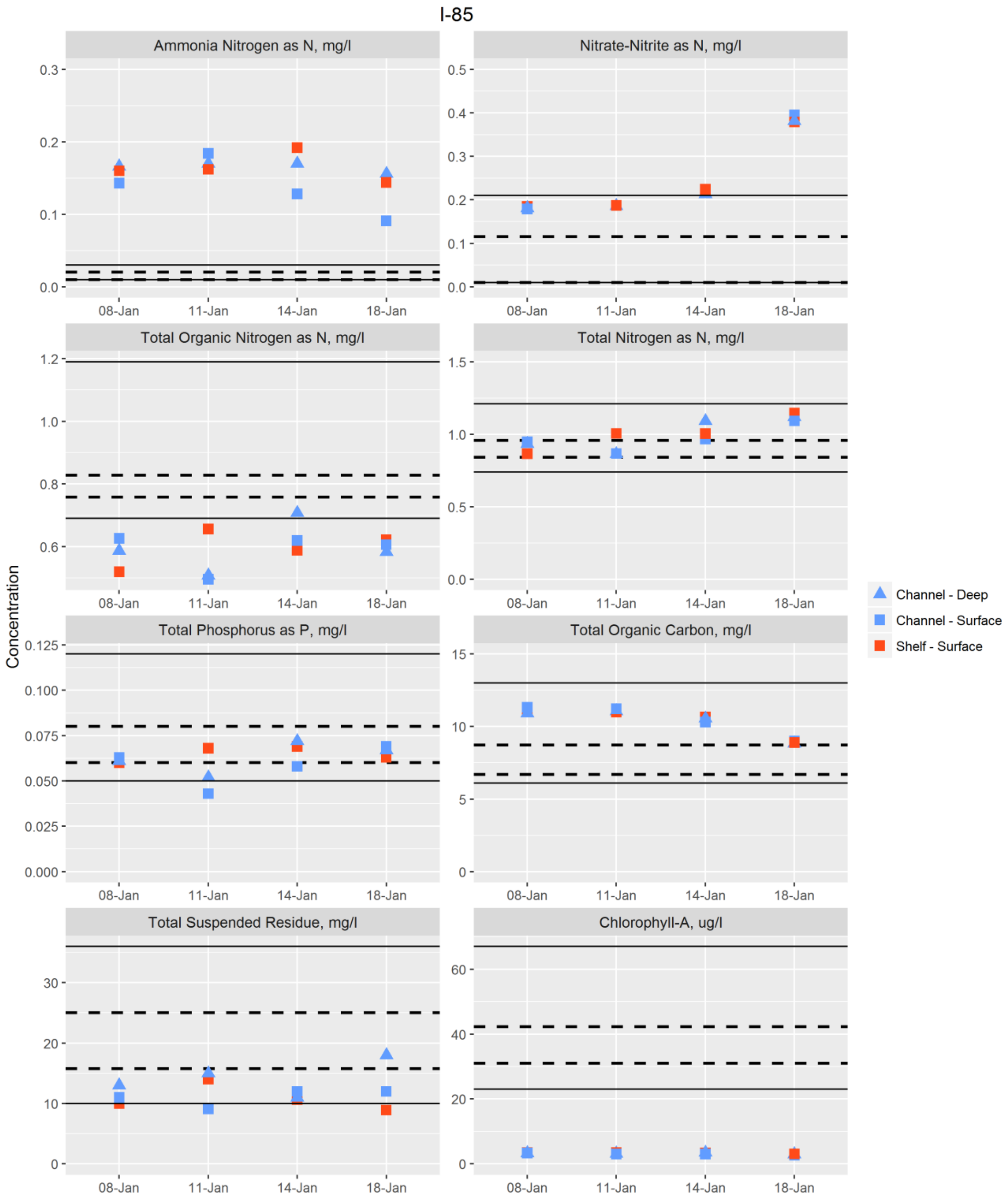


Figure 4.11 **Parameter Concentrations by Date Measured at the Interstate 85 Constriction Point Site.** Blue symbols designate samples collected along the deepest part of the lake while red symbols indicate samples collected from a more shallow 'shelf' location. Dashed lines represent the 25th and 75th percentiles of 2015 lake data collected by DWR at the station nearest the constriction point, and solid lines represent the min and max concentrations of 2015 lake data collected by DWR.

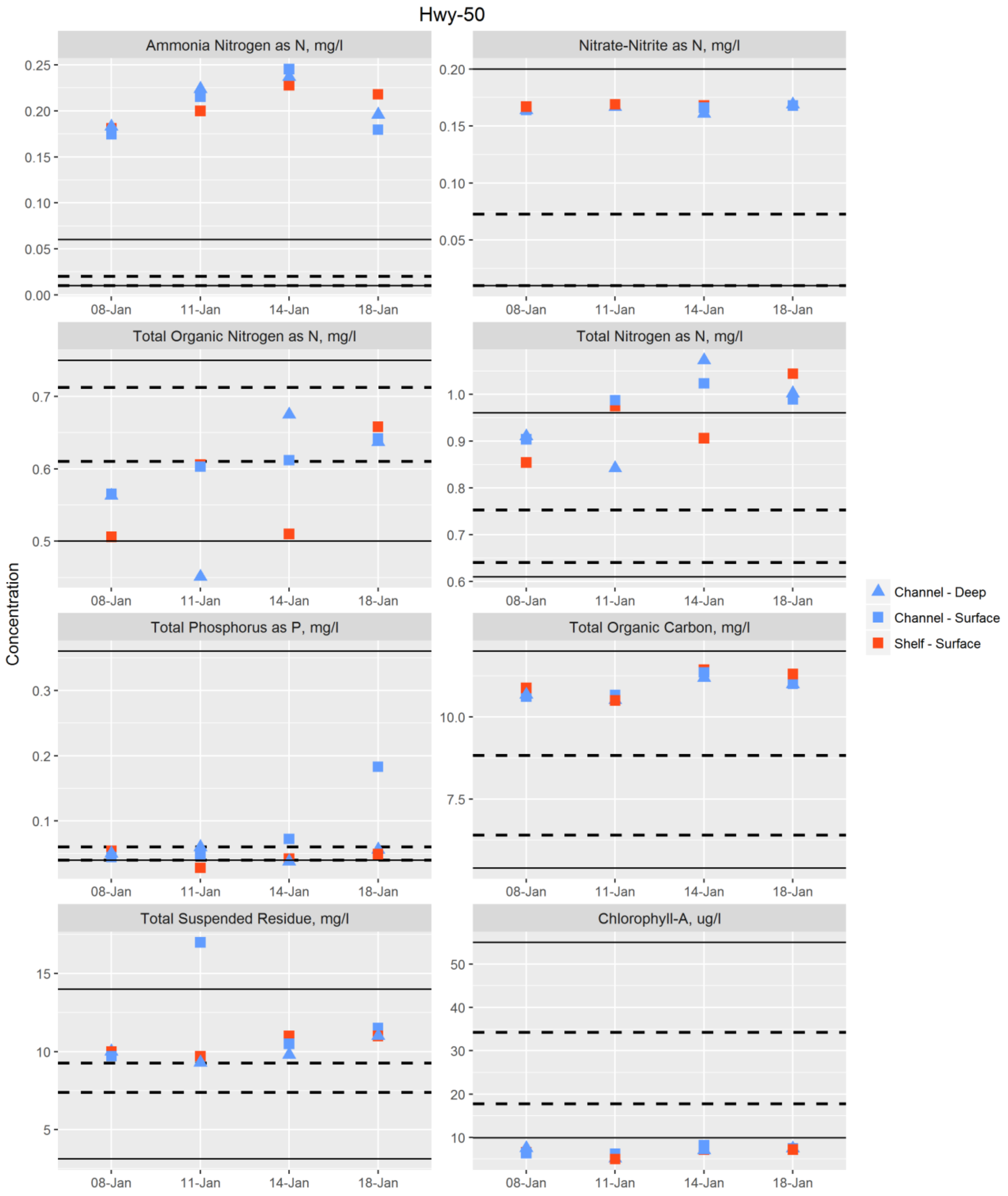


Figure 4.12 **Parameter Concentrations by Date Measured at the Highway 50 Constriction Point Site.** Blue symbols designate samples collected along the deepest part of the lake while red symbols indicate samples collected from a more shallow 'shelf' location. Dashed lines represent the 25th and 75th percentiles of 2015 lake data collected by DWR at the station nearest the constriction point, and solid lines represent the min and max concentrations of 2015 lake data collected by DWR.

4.6 Volatile Suspended Solids Data (VSS)

As noted in Section 2, this small Special Study was added in FY 2016 to add monitoring of VSS at Lake Loading and inlake stations. That effort has been folded into the Routine Monitoring process, and data are therefore provided in Section 3. Future reports will no longer address VSS data collection as a Special Study.

4.7 Light Extinction Data

Cardno obtained historic light extinction data collected on Falls Lake from the mid 1980's to early 1990s from the EPA STORET database. Ten stations had measurements of light extinction coincident with Secchi depth (Figure 4.13).

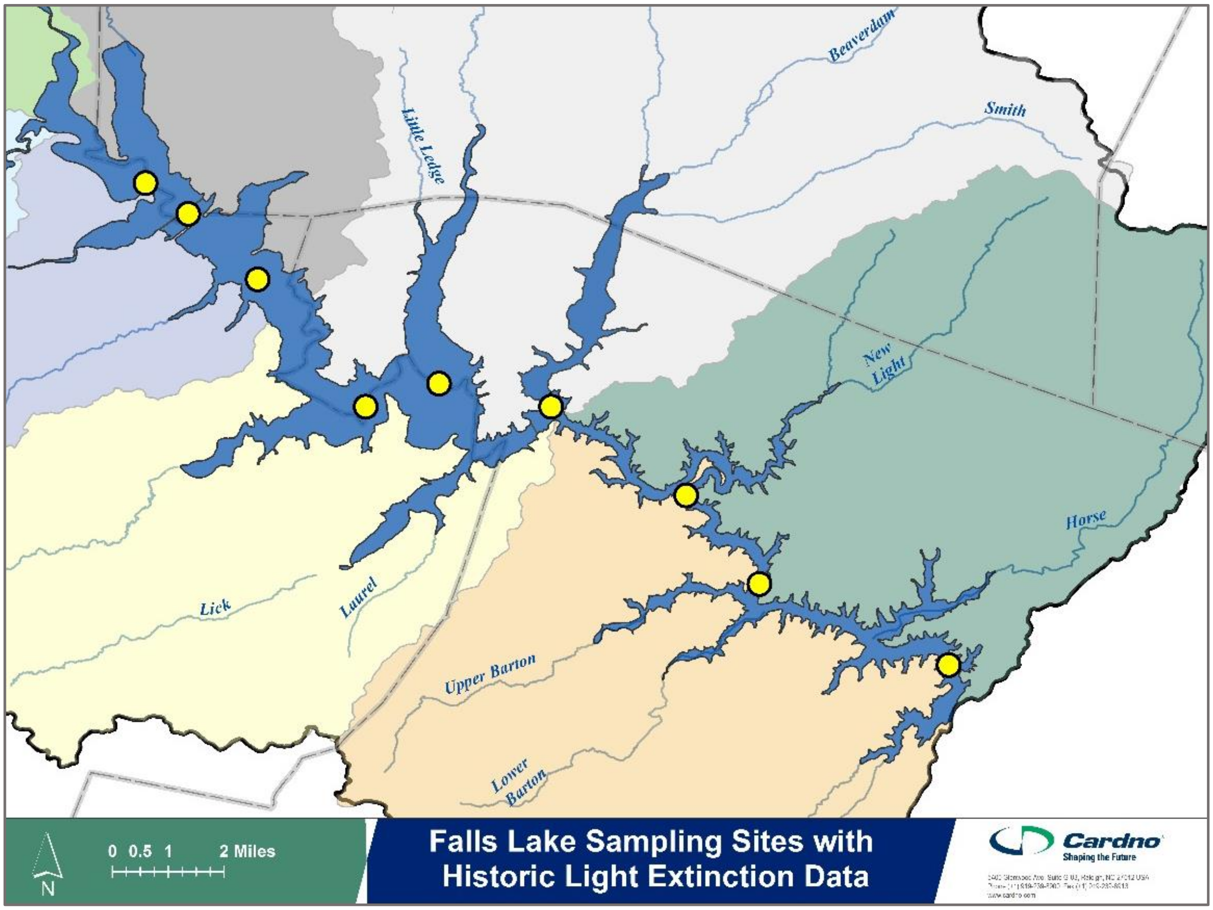


Figure 4.13 Map of Locations with Historic Light Extinction/Secchi Depth Data

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.

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

When the UNRBA expressed interest in the collection of light extinction data, DWR agreed to collect additional paired measurements of light extinction using a PAR and Secchi depth measurements. These new data provide direct measurements of light extinction which can be used to assess the relationship between light extinction and Secchi depth and evaluate the relationships relative to historic data. Results of the data that DEQ collected in October 2015 are provided in Figure 4.14, which shows the results of the recent sampling compared to the historic samples. All three DEQ measurements fall within the statistical 95% prediction interval based on the historic data.

The relationship between Secchi depth and light extinction measurements appears sufficiently strong to meet the needs of mechanistic modeling, therefore Cardno does not recommend additional resources be allocated to the collection of additional light extinction data.

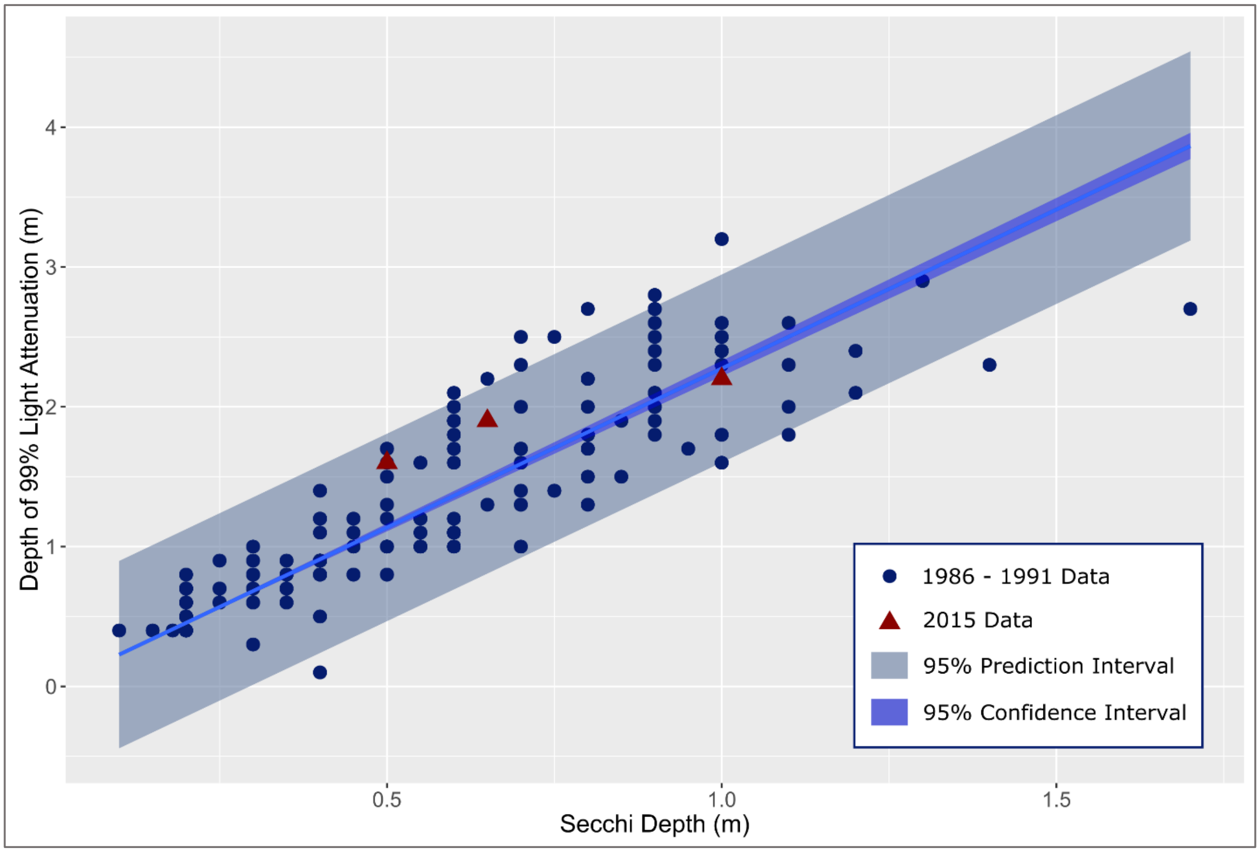


Figure 4.14 **Depth of 99% Light Attenuation versus Secchi Depth with 2015 Compared to Historic Data**

4.8 Basic Evaluation of Model Performance

This Special Study helps to ensure that the monitoring data being collected is appropriate and sufficient for anticipated modeling efforts. It generally evaluates resource allocation among existing or potential monitoring efforts by considering the needs of the various model types that could support the re-examination process.

This effort included a review and assessment of the 2006 baseline EFDC model to identify dominant factors affecting model output, and consideration of the data needs of that model. The EFDC review included preliminary revisions to the existing EFDC model grid and to certain input files that were developed by the State to investigate primary factors in simulating lake behavior. The effort also included evaluations of tributary load estimates using USGS LOADEST, which is one possible source of input to EFDC and other models to relate water quality and discharge from tributaries to the lake.

This Special Study also included evaluation of the data needs of the empirical/probabilistic models that have been recommended to support linking water quality in Falls Lake to designated uses.

A separate technical memorandum is in preparation to describe this evaluation in more detail. Several particularly pertinent findings to the monitoring effort are briefly summarized below:

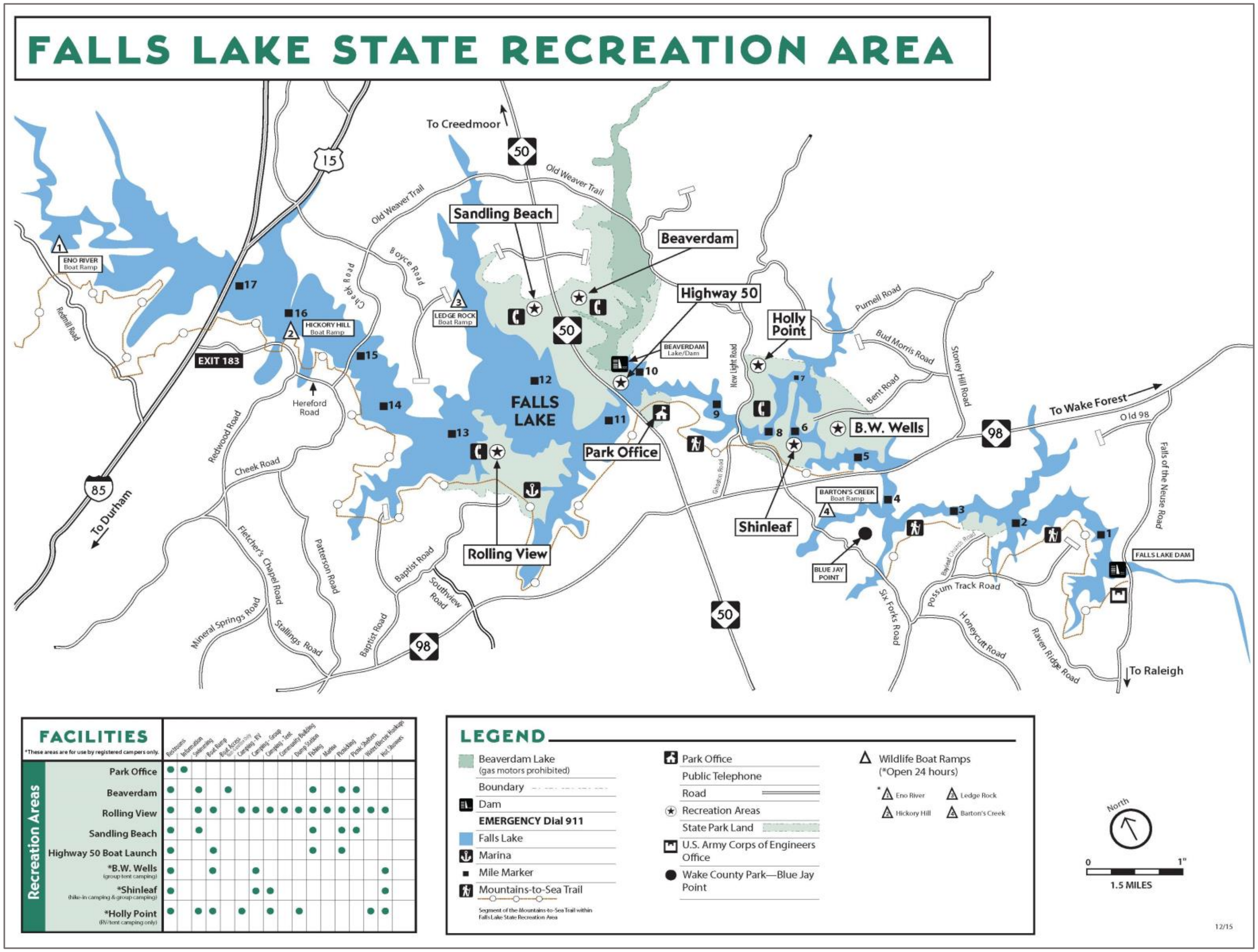
> Evaluations of tributary loading estimates using available USGS LOADEST regressions were compared to measured loads on Ellerbe Creek and Eno River using the Storm Event Sampling results. Storm Event Sampling has revealed water quality dynamics in selected large tributaries to the lake. Adapting and augmenting the High Flow sampling effort in the next fiscal year could provide data on more of the tributaries at the upper end of the flow regime.

> Two years of $CBOD_5$ data is sufficient for anticipated modeling needs. Most laboratory results to date have been below the reporting limit, and sensitivity analyses have shown that the EFDC model is relatively insensitive to the fraction of the particulate carbon pool that is labile (easily digestible) given the Routine Monitoring findings that only five percent of the total carbon load is particulate. Since this was the primary model need indicating the collection of the $CBOD_5$ data, the funding currently put toward this parameter may be better invested elsewhere.

> Cardno conducted sensitivity analyses to evaluate how adjusting the light extinction parameters would affect simulated chlorophyll *a* concentrations using the existing version of the EFDC model. These analyses indicate that predicted chlorophyll *a* concentrations are not particularly sensitive to those parameters, and existing light extinction data are suitable for modeling purposes. Given that the results of the recent data collection effort conducted by DWR in October 2015 are similar to historical measurements, and that the model response using the current version of the EFDC model is relatively insensitive to changes to light extinction parameters, Cardno does not recommend collecting additional paired studies at this time. This recommendation may be reconsidered in future years based on the results of the updated lake models if the degree of sensitivity is much greater following model revisions.

4.9 Recreational Use Evaluation

Falls Lake is a multi-use, multi-agency area owned by the United States Army Corp of Engineers (USACE). This comprises the 12,400-acre Falls Lake Reservoir and some 25,600 acres of surrounding lands. According to the USACE Falls Lake Master Plan (USACE 2013): "*USACE provides and manages recreation facilities on the lands it actively manages at Falls Lake. The area immediately surrounding the Visitor Assistance Center, dam, and tailrace includes restrooms, picnic tables, playground equipment, hiking trails, bank fishing access, and trail access to hunters using the adjacent game lands." The Master Plan also states that the North Carolina Division of Parks and Recreation "operates the majority of developed recreation facilities at Falls Lake as part of the North Carolina State Parks System. Collectively, these facilities comprise the Falls Lake State Recreation Area (SRA). NCDPR operates a total of eight developed areas around the reservoir, with most of the facilities concentrated in the middle sections of the reservoir. Facilities provide amenities for camping (walk-in, RV, vehicle; some with electric and water hook ups), swim beaches, picnic areas, hiking trails, community building, boat ramps, playgrounds, and mountain biking trails.*" Figure 4.15 shows the location of the recreational facilities on the lake.



FACILITIES

*These areas are for use by registered campers only.

Recreation Areas	Restrooms	Information	Swimming	Boat Ramp	Boat Access Non-Gasoline only	Camping - RV	Camping - Group	Camping - Tent	Community Building	Dump Station	Fishing	Marina	Picnicking	Picnic Shelters	Water/Electric Hookups	Hot Showers
Park Office	●	●														
Beaverdam	●		●		●						●		●	●		
Rolling View	●		●	●		●	●	●	●	●	●	●	●	●	●	●
Sandling Beach	●		●								●		●	●		
Highway 50 Boat Launch	●			●							●		●			
*B.W. Wells (group tent camping)	●			●			●									●
*Shinleaf (hike-in camping & group camping)	●						●	●								●
*Holly Point (RV/tent camping only)	●		●	●		●		●		●					●	●

Figure 4.15 Recreational Facilities of Falls Lake (from North Carolina State Parks)

The USACE compiles data on recreational uses provided by Falls Lake, as well as estimates of total annual visitation in their Master Plan documents that are released periodically (USACE 2013). Based on estimates of total annual visitation to Falls Lake reported in the 2013 Master Plan (**Error! Reference source not found.**), an average of 1.63 million individual visits occur each year to Falls Lake.

Table 4.2 Annual Visitation to Falls Lake (USACE 2013)

Year	Total Visitation
1999	1,615,951
2000	2,086,464
2001	1,721,402
2002	1,611,391
2003	1,573,484
2004	1,520,357
2005	1,717,857
2006	1,726,848
2007	1,807,284
2008	1,501,192
2009	1,449,360
2010	1,304,874
2011	1,566,692
2012	1,610,294
Average	1,629,532

The 2013 Master Plan indicates that the carrying capacity of Falls Lake limits annual visitation, but that water quality is not a limiting factor: According to that plan, “The quality of surface water within the reservoir is influenced by conditions throughout its watershed, including land use patterns and the presence of pollution sources. Despite water quality concerns throughout the watershed, water quality in the reservoir allows for all forms of recreational use to continue.” The plan also states, “Recreational facilities at Falls Lake currently meet the most popular recreational activities highlighted in the SCORP[11]. In some cases, such as with motorized boating, the resources at Falls Lake have met their carrying capacity to support certain recreational activities. Monitoring regional demands and the ability of the Falls Lake resources to meet these needs will allow USACE, North Carolina, and the other management partners to provide natural resource-based recreational opportunities in the future.”

The North Carolina classification applied to Falls Lake (15A NCAC 02b 0315) assigns four designated uses to the reservoir (15A NCAC 02B .0301): aquatic life, recreation, fish consumption, and water supply. To support the use of the lake as a recreational resource, the USACE (2013) leases the land to four other public agencies responsible for the management of their individual areas on Falls Lake.

Cardno identified sources of public and private recreation data on Falls Lake. There are five potential public sources of data collection for Falls Lake: Wake County, City of Raleigh, North Carolina Wildlife Resource Commission, North Carolina Division of Parks and Recreation, and the USACE.

> The USACE maintains and collects data from all traffic counters across management areas on Falls Lake. Additionally, each of the other four public agencies that lease land from the USACE

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[11] North Carolina State Comprehensive Outdoor Recreation Plan

may also collect data from these traffic counters in the areas they manage independent of the USACE's data collection. This results in overlap of data collection between USACE and the other management agencies, and this overlap of data collection may not be uniform across agencies. Each agency may use different methods of collection as it relates to weighting the raw counts from the traffic counters.

- The USACE is responsible for the management of Falls Dam, the Tailrace Area (below the dam), and the Falls Lake Visitor Center. Visitation data for these facilities is currently limited to annual estimates from 1999 to 2012. The USACE is currently revising its system and methods of data collection and analysis. Raw counts of data over the period of interest may be available in the future, but the staff at USACE at Falls Lake were not comfortable sharing the raw data.
- Wake County manages Blue Jay Point County Park on Falls Lake. Wake County collects data for the park at the monthly level as total visitation (i.e., not specified by the type of recreation) and provided data from July 2004 to January 2016.
- The City of Raleigh manages the Neuse River Greenway and a canoe launch on the lake. The City of Raleigh does not maintain counts of its management areas.
- North Carolina State Parks manages Falls Lake State Recreation Area and compiles monthly data in accordance with the North Carolina State Comprehensive Outdoor Recreation Plan (SCORP). Data is reported at the level of recreational activity including camping, boating, fishing, hiking, swimming picnicking, and biking. NC State Parks provided data from January 2005 to December 2015. NC State Parks does not manage the registration of campgrounds, or the boat ramps in the State Recreation Area. Per state legislation, NC State Parks has updated its database as of 2015. Counts of visitors are now available at a daily level from 2015 forward.
- The North Carolina Wildlife Resource Commission (NCWRC) manages four boat ramps within the Falls Lake State Recreation Area: Eno River, Hickory Hill, Ledge Rock, and Upper Barton's Creek. NCWRC does not collect any user data for these boat ramps.
- There are also three privately-run recreational facilities identified on Falls Lake: Rollingview Marina, Reserve America, and Motor Boatin', LLC. Rollingview Marina manages private boat slips on Falls Lake. They record the annual occupancy rate for the marina and are willing to make this data available (Cardno did not request this data). Reserve America manages campground registrations and reservations across the country. They are responsible for registration and reservations of campgrounds in Falls Lake State Recreation Area. They are not willing to make available counts they may have. Motor Boatin' LLC. is a pontoon boat rental company located on Falls Lake. Operations of Motor Boatin' LLC. appear to be seasonal. No response was provided to inquiries.

4.9.1 Major Categories of Water-Based Recreation

Fishing accounts for the highest proportion of recreational visits to the lake, estimated at nearly 600,000 visits in 2011 (38 percent of all visits in 2011) (USACE 2013). Anglers fish for bass, crappie, catfish, and bluegill. NCWRC maintains artificial reefs and fish shelters to help support fish populations. NCWRC conducts fisheries monitoring of the reservoir, as part of a statewide monitoring program. Electrofishing is used to sample the largemouth bass population, and trap nets are employed to survey black crappie. Cardno obtained fisheries monitoring data from NCWRC (Kirk Rundle, pers. comm.). The data provided was for bass monitoring conducted in 2009, 2011, 2013 and 2015 (generally in May), and crappie sampling in October of 2006, 2008, 2010, 2012 and 2013.

Each bass sampling event resulted in the capture and measurement of dozens to hundreds of individual fish. A key metric calculated for each captured fish is Relative Weight, where a value of 100 represents the ideal weight for a fish of a given length, but any value above 80 is indicative of a healthy fishery, with ample forage/food available. Average Relative Weights for bass sampling events ranged from the high

80’s to the upper 90’s. Each crappie sampling event resulted in the capture of several hundred individuals, with average Relative Weight values from the low 80’s (2010 only) to the high 90’s. Thus, the NCWRC monitoring indicates a quite healthy fishery in Falls Lake. Virtually all accessible parts of the lake are used by anglers, from boaters in open water and on the historic river channel, to shoreline fishing at numerous access points around the lake. Deeper waters may hold large schools of crappie in early spring, while shorelines are likely largemouth bass habitat for much of the year. The upper segment of the lake is known for a white bass run each spring. There are no creel census or angler survey data available with which to assess angling success.

Boating is also a very popular activity on Falls Lake, accounting for nearly 330,000 visits or about 20 percent of recreational uses in 2011 (USACE 2013), The North Carolina Wildlife Resources Commission manages four public boat ramps: Upper Barton, Ledge Rock, Hickory Hill and Eno River. Unfortunately, no user data are collected for those ramps. NCDPR manages a public ramp at Highway 50, and Rollingview Marina has a private ramp adjacent to the marina area. Several canoe launches are also present on the lake.

A study conducted by Colorado State University for the USACE in 2000 identified a concern over exceeding the lake’s carrying capacity for motorized vessels, and as a result, the USACE and State of North Carolina placed a moratorium any further development that would add more capacity for motorboat access to the lake (USACE 2013). As a result, no new marinas, motor boat launch areas or motor boat trailer parking will be permitted on Falls Lake lands.

Water access for motorized vessels is available via boat ramps in each segment of the lake below I-85. The Eno River Boat Launch is the only public access point above I-85, and is generally restricted to canoes and kayaks. There is signage on the lake from approximately Marker 13 and above warning boaters of shallow water hazards, particularly above I-85. Also, motorized vessels are prohibited in the Beaverdam Reservoir portion of the lake. As a result of the limited access and predominantly shallow water, the segment of the lake above I-85, and Beaverdam Reservoir can be assumed to have less availability for the full range of recreational uses than other portions of the lake.

In 2011, USACE visitor data showed approximately 250,000 visits for swimming (16 percent of the total visits) (USACE 2013). Sandling Beach, Rollingview Beach and the Beaverdam beach area provide sandy swimming beaches and the Holly Point campground has a beach for registered campers. In addition, some users swim at points accessed from various trails around the lake, or from boats anchored in coves or along shorelines. Some beach areas are open year-round (Rollingview and Beaverdam), while others are closed during the cooler months (Holly Point and Sandling Beach). While individuals have different water temperature preferences and tolerances for swimming, the vast majority of swimming activity on Falls Lake happens during the warmer-weather months, from May through September.

Table 4.3 provides visitation to the Falls Lake State Recreation Area from the SCORP for water-based activities from 2005 to 2015. Counts for the individual activities were calculated from the totals using percentages in the SCORP. Based on the SCORP activities, water-based visitation to the lake was highest in 2006 (over 630,000 visitors) and lowest in 2013 (under 470,000 visitors).

Table 4.3 Water-Based Visitation to Falls Lake (2005 to 2011), from NCDPR Records

Year	Boating	Fishing	Swimming	Total Water-Based Visitation
2005	225,509	151,409	186,635	563,553
2006	242,437	175,095	212,874	630,406
2007	221,916	153,583	182,625	558,124
2008	204,820	144,819	148,715	498,354
2009	227,700	156,808	191,575	576,083
2010	199,232	151,433	170,984	521,649
2011	238,192	138,636	168,163	544,991
2012	260,904	149,825	74475	485,204
2013	218,153	142,122	108,302	468,577
2014	239,071	161,750	151,841	552,662
2015	215,873	143,686	147,658	507,217

4.9.2 Comparison of Water Quality to Recreational User Counts

Cardno evaluated recreational user counts along with user-perceivable water quality conditions. This analysis is limited to years 2005 to 2015 to inspect the period of overlap with monthly water quality samples collected in Falls Lake and monthly visitation estimates available from NCDRP that compiles visitation records by recreational activity. The review is limited to the water-based recreation categories (boating, fishing and swimming) because non-water-dependent activities are less likely to be affected by lake water quality, and to water quality parameters that are generally perceptible to typical users (turbidity, Secchi depth and chlorophyll a levels). This analysis includes only the NCDPR data and NCDWR water quality data.

Cardno evaluated the water-based recreation data by visually comparing counts of lake-wide recreation to average annual lake water quality**Error! Reference source not found.**. Lake-wide averages were used for this comparison because visitation estimates for Falls Lake are not specified spatially, and most of the recreational facilities providing water access are located between Highway 50 and Highway 98. Secchi depth and turbidity were selected to represent water quality because these parameters measure water clarity, which can affect aesthetics. Chlorophyll *a* was also selected because high levels can result in water having a green appearance which may also be unaesthetic to some users, and because chlorophyll *a* concentrations are associated with noncompliance with water quality standards in some parts of the lake.

For the period 2005 - 2015, swimming visitation was the most variable from year to year (with differences between the minimum and maximum visitation of approximately 138 thousand); followed by boating (62 thousand), and then fishing (36 thousand). The following observations can be made:

- Secchi depth is a measure of water clarity, and higher values indicate clearer water. While Secchi depth was greatest in 2008, recreation across the water-based categories was relatively low during this year. Secchi depth was relatively similar across the other years and does not have an apparent relationship to water-based visitation at the level of resolution possible with available data.
- Turbidity generally decreased between 2005 and 2009. Between 2009 and 2015, turbidity has gradually increased. There is no apparent or established relationship between water-based visitation and this parameter.

- Chlorophyll *a* concentrations were highest in 2007 and lowest in 2010, but the visitation associated with water-based recreation was similar for these two years.

In addition to the visual assessment discussed above, Cardno also performed a regression analysis on the monthly recreational use counts and the monthly average water quality values. This analysis was done using only May-September data, representing the months when all three categories of water-based recreational use are present in the lake. Separate regression analysis was performed using both total monthly recreational use counts as well as monthly counts of each recreation type (boating, fishing, and swimming).The regressions showed no statistically significant relationship between the water quality parameters and user counts. Based on this assessment of available data, water-based recreation in Falls Lake does not appear to be linked with the lake water quality parameters commonly associated with clarity and aesthetics.

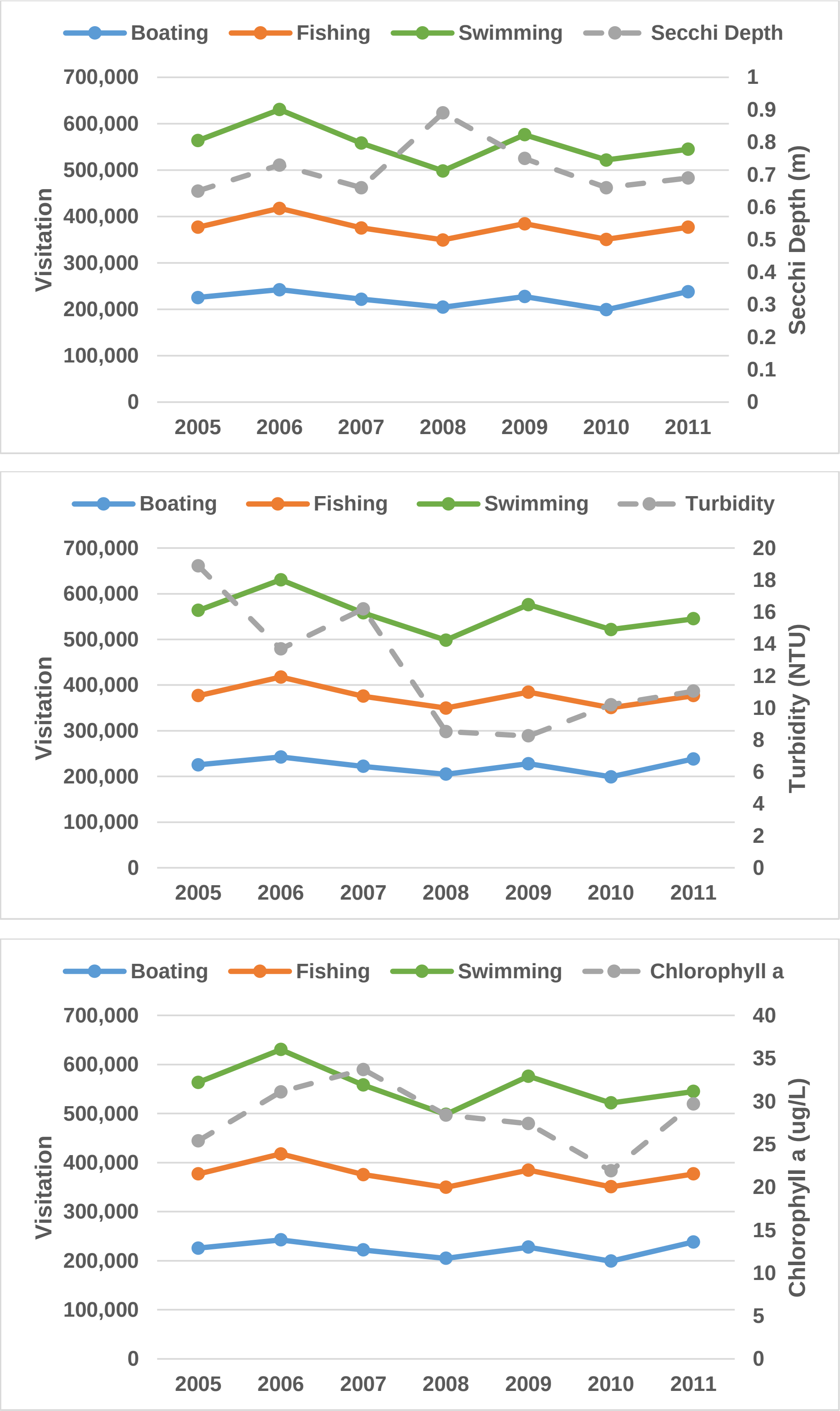

Figure 4.16 **Comparison of Water Based Visitation to Lake Water Quality Parameters**

4.9.3 Comparison of Other Factors to Recreational User Counts

Cardno examined several other factors that could reasonably be expected to have an effect on recreational uses including bacteria data, drought conditions which affect water levels in the lake, rates of unemployment (which could impact the amount of expendable income available for recreation), and fish consumption advisories. For these comparisons, records of water based recreation were extended back to 2000 because the comparisons are not limited to parameters that DWR began collecting data on in the mid-2000s.

NCDWR collected fecal coliform data on Falls Lake beginning in 1983 (with gaps in the record) at 16 monitoring locations. The majority of samples were collected in the mid to late 1980s, and the State no longer analyzes this parameter. Wake County has collected *E. coli* and Enterococci data in Falls Lake at four public swimming areas since 2009. Each area is sampled at multiple locations during the swimming season. Prior to 2015, exceedances of acceptable concentrations of either *E. coli* or Enterococci at any sampling location resulted in a closure of the swimming area. Overall, at these four access areas from 2009 through 2014, less than two percent of all bacterial samples resulted in a beach closure. Beginning in 2015, consistent with revised guidance from EPA, Wake County now posts advisories for minor exceedences of the criteria, and closures would only occur in response to very high bacterial levels. There are various sources of these bacteria in surface waters, including birds and mammals on the lake and in the watershed. *E. coli* and Enterococci are not generally linked with, or affected by, nutrients in surface waters, and are therefore not associated with the nutrient management strategy for Falls Lake

Recreation in Falls Lake may also be affected by climatic conditions such as droughts which lower the water level of the lake and limit access to the lake (e.g., boat ramps and beaches) or which might increase the number of people seeking water-based recreation opportunities. The North Carolina Drought Management Advisory Council (NCDMAC) maintains a database of drought conditions recorded weekly starting in January 2000. Figure 4.17 shows the relationship between drought condition records for each year (weeks with drought conditions in the categories of Abnormally Dry, Moderate Drought, Severe Drought, Extreme Drought, and Exceptional Drought) and the total number of water based recreational users. These data do not suggest a negative effect of drought on lake use; instead there is a slight positive relationship suggesting increased lake use during dry or drought years.

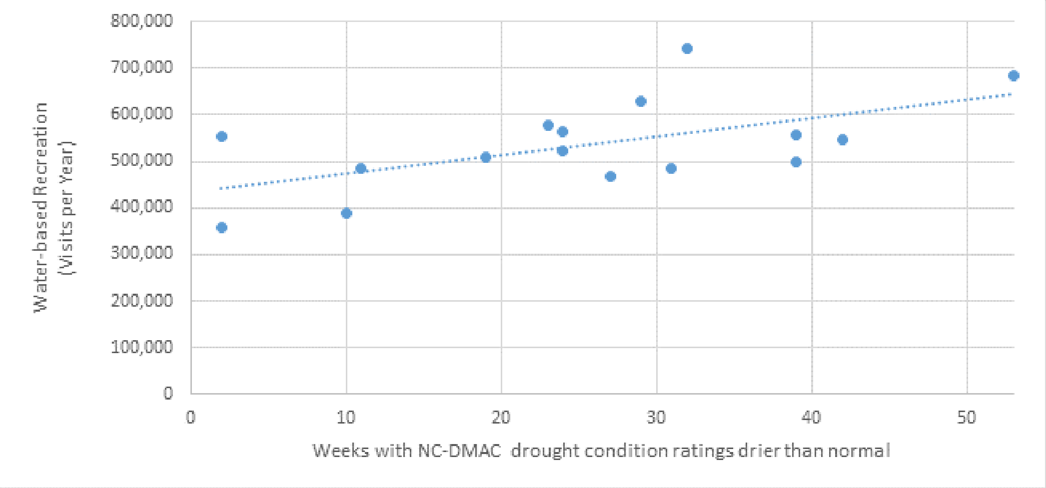

Figure 4.17 The Relationship between Water-Based Recreational Visits to Falls Lake and the North Carolina Drought Management Advisory Council's (NC-DMAC) Weekly Drought Records. Each point on the figure represents a year between 2000 and 2015 with the horizontal axis representing the number of weeks per year with NC-DMAC ratings between Abnormally Dry and Exceptional Drought. Drier conditions are weakly correlated with increased visits to the lake (R2 = 0.34, p=0.02).

It is reasonable to assume that economic factors may also affect recreational use, with fewer individuals able to spend resources for recreation as expendable income declines. The statewide annual unemployment figures were used as a surrogate for overall economic conditions, and evaluated relative to the total water-based recreational user visits to Falls Lake. Between 2000 and 2015, the unemployment rate varied from 3.69 percent (2000) to 10.73 percent (2010), while water-based recreational visits ranged from about 358,000 (2004) to nearly 742,000 (2001). However, there does not appear to be a consistent relationship indicating that better economic conditions increase recreational use of the lake, and in fact, the highest rates of unemployment (>9%) were during years when water-based recreation was at generally moderate levels.

Health concerns related to fish consumption may also have an impact on recreation in Falls Lake. In January of 2012, all 13,123 waters in North Carolina were included in the category 5-303(d) list of impaired waters due to a statewide fish consumption advisory for several fish species containing mercury. As a result, women of childbearing age, pregnant women, and children have been advised to avoid eating certain fish that contain high levels of mercury. All other individuals have been advised to limit consumption to one meal per week. Black crappie, largemouth bass, and catfish were among the freshwater fish listed as containing high levels of mercury in the state. Aside from slight decreases in fishing between 2012 and 2013 and between 2014 and 2015, fishing in Falls Lake does not appear to have been drastically influenced by the consumption advisory (**Error! Reference source not found.**). Mercury levels in Falls Lake are not associated with the nutrient management strategy for Falls Lake.

4.9.4 Recreational Use Support Assessment

Cardno also reviewed published information from Falls Lake support assessments developed by NCDEQ to assess whether recreational uses may be impaired on Falls Lake as a result of water quality. From the confluence of the Eno and the Flat Rivers to the Interstate 85 Bridge, Falls Lake is classified by the State of North Carolina as a WS-IV public water supply, which also carries the protection afforded to Class C waters, including 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.” Downstream from the Interstate 85 Bridge to the Falls Lake dam, the Lake has both a WS-IV Classification and a Class B designation, which conveys protection for primary recreation, defined as including “swimming, skin diving, water skiing and similar uses involving human body contact with water where such activities take place in an organized manner on a frequent basis”. Thus, most of the lake is used for public water supply, primary recreation and other uses suitable for Class C waters.

The 2014 NC Water Quality Assessment for 305(b) (NCDEQ 2014) contains the most recent assessment of Falls Lake as required through Section 305(b) of the Clean Water Act. Review of that report provides no indication that parameters of concern under the Falls Rules (i.e., nutrients, chlorophyll *a* and associated parameters) have resulted in non-attainment of recreational use standards in Falls Lake. Therefore, it can be concluded that Falls Lake allows for the full range of recreational uses prescribed by its Designated Uses, with respect to water quality parameters of concern to the UNRBA.[12]

This conclusion may be important in evaluating alternative regulatory solutions. Certain regulatory approaches may warrant, or require, consideration of recreational uses and their value to the Falls Lake resource. For example, a conclusion that existing conditions in the lake are not preventing or impairing recreational uses means there would not need to be a formal evaluation of the economic or societal “loss” of such uses as part of a Use Attainability Assessment or site specific criteria that were developed to either “hold the line” or continue to improve water quality within the alternative regulatory framework. Based on this review, and NCDENR’s use support status, Falls Lake appears to be meeting its

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[12] Note that exceedences of certain parameters not associated with the Falls Rules may result in some degree of limitation of recreational uses at some time in Falls Lake (e.g., mercury and bacteria).

designated use for recreation with respect to issues of concern under the Falls Rules (NCDENR 2014), and lake visitation is limited to the carrying capacity of the lake, not based on water quality (USACE 2013). Therefore, Cardno does not recommend that the UNRBA invest additional resources evaluating recreational uses in the coming fiscal year.

In light of these results, Cardno recommends that the UNRBA suspend the investment of additional resources to evaluate recreational uses in the coming fiscal year. However, we also recommend that the UNRBA communicate with NCDEQ and the U.S. EPA regarding the types of recreational use data and analyses they may have accepted as part of the process of developing or revising regulations for water resource management. Based on feedback from the agencies, further data collection and/or analyses may be warranted in future years.

5 Summary and Recommendations

The UNRBA Monitoring Program is designed to support the UNRBA's re-examination of Stage II of the Falls Lake Nutrient Management Strategy. The Monitoring Program is organized into two categories. The first is Routine Monitoring, which is the repeated testing of water quality parameters at fixed locations over many months. The second category, Special Studies, is a series of focused evaluations conducted within a limited timeframe to obtain specific information not provided by the Routine Monitoring. For the benefit of efficient resource allocation, each Special Study is evaluated at the end of each monitoring year to determine whether it should be continued, modified, suspended, or replaced with another effort in the subsequent year. The Routine Monitoring and Special Studies are designed to support the UNRBA's re-examination of Stage II of the Falls Lake Nutrient Management Strategy.

Data collection under the UNRBA Monitoring Program began in August 2014, and this report summarizes data collected through the end of calendar year 2015. This time period represents the end of the second calendar year of monitoring, and the midpoint of the second fiscal year of the program.

During this period, the program has:

- Routine Monitoring has collected more than 14,000 water quality observations from 38 stations on tributaries throughout the watershed.
- Incorporated analysis of DWR monthly monitoring at 12 stations in the Falls Lake Reservoir.
- Successfully collected and analyzed more than 90 percent of samples anticipated in the sampling design.
- Created an online database including a guidance document and graphics generator to help users access the data and visualize results.
- Developed Study Plans for six Special Studies which were posted to the UNRBA monitoring website.
- Significantly improved laboratory quality assurance protocols and data turnaround times
- Significantly improved efficiency in the monitoring and reporting process

5.1 Routine Monitoring

Annual precipitation totals for 2014 and 2015 were slightly higher than the 30-year average but were not outside of a range that would be considered typical. This resulted in the reservoir remaining near or above normal water levels throughout the monitoring period. November and December of 2015 saw about 6 more inches of rain than the long-term average for those months. The reservoir was significantly above typical levels at the end of 2015 and into January 2016.

Routine Monitoring was conducted on a monthly or twice monthly basis at 38 monitoring stations in the watershed. Raw data from this program are available online at http://www.unrba.org/monitoring-program. This report provides graphical summaries of monitored parameters to illustrate the magnitude and variability of water quality in the reservoir and its tributaries. These plots also allow for general comparison between the tributaries and the lake, and within and among the subwatersheds. Two primary factors affecting many parameters are whether a tributary station is located in an area with wetland characteristics or whether a tributary station lies downstream of a wastewater treatment facility.

Monitoring efficiencies and potential savings could be realized by eliminating water quality parameters with costs that may exceed future value of the data. This evaluation included sensitivity analyses with the EFDC model used by DWR in developing the Rules. Based on this first two years of monitoring, a few parameters were identified that could be discontinued in future monitoring years with negligible impact to modeling or other analytical efforts in the re-examination process. Additional parameters are under consideration that suggested the possibility for potential changes to the program in the future.

Suggestions to potentially improve the efficiency of the Monitoring Program are briefly discussed below. Note that dollar amounts are approximate and should not be considered exact values for budget development purposes.

> DOC and TOC are currently measured at Lake Loading locations, and there is a strong correlation between these measurements (R2 = 0.99). Given the ability to predict one parameter from the other with a high degree of confidence, Cardno recommends the UNRBA consider suspending collection of DOC at Lake Loading stations, which would result in an annual savings of approximately $17,400.

> Cardno recommends continuing to measure TOC at Lake Loading stations, but recommends reducing sampling frequency from monthly to quarterly at Jurisdictional Boundary stations. Collection of TOC at Jurisdictional Boundary stations would not provide substantive benefit to lake modeling efforts. Watershed modeling efforts should be amply supported by the 23 months of data which will have been collected by the end of this Fiscal Year, and by the ongoing TOC collection at Lake Loading stations. This reduction could result in annual savings of approximately $7,500 annually.

> CBOD5 is currently measured at Lake Loading stations to support revisions to the EFDC lake model. While this parameter is not a direct model input, it can be used to help discern the fractions of labile and refractory particulate organic carbon. Approximately 95 percent of the organic material entering Falls Lake is in the dissolved form, and model sensitivity analyses do not predict significant impacts to simulated chlorophyll a or TOC concentrations in the lake, thus Cardno recommends the UNRBA consider discontinuing collection of CBOD5 at Lake Loading stations. This could result in an annual savings of approximately $11,500.

> Two methods are currently used to evaluate color at Lake Loading stations: the Platinum-Cobalt method and absorbance at 440nm at the Lake Loading stations. Monitoring results from these methods are strongly correlated with an R2 of 0.73. Measurement of absorbance at 440nm is less expensive and more precise than the Co-Pt method, and EFDC sensitivity tests have shown little influence from reasonable variations in light extinction parameters; therefore, Cardno recommends the UNRBA consider eliminating the Pt-Co method from the list of monitored parameters in FY2017, which would save about $5,000 annually.

5.2 Special Studies

Special Studies initiated during Year 1 and Year 2 of the Monitoring Program are:

> Storm Event Sampling

> High Flow Event Sampling

> Falls Lake Sediment Evaluation

> Support Development of Alternative Nutrient Strategy

> Falls Lake Constriction Point Study

> Measure Volatile Suspended Solids at in-lake and Lake Loading stations

> Evaluation of Light Extinction Data

> Basic Evaluation of Model Performance

> Recreational Uses Evaluation

Status summaries for these Special Studies are provided below.

5.2.1 Storm Event Sampling

Storm event automated sampling was conducted at Eno River and Ellerbe Creek in April, August, September, and October 2015 and in February 2016. An additional storm event sampling is planned for the spring of FY 2016, if a suitable rain event occurs. The information learned from this Special Study has been very useful in determining the types of data needed to accurately characterize tributary inputs during storm events. Rather than collect numerous water quality samples over the course of a few storms at two locations, Cardno recommends suspending the Storm Event Special Study and reallocating those resources to an expanded version of the High Flow Sampling Special Study, as outlined below.

5.2.2 High Flow Sampling

High flow event, manual grab sampling, was conducted at eight Lake Loading stations on February 10, 2015 and April 20, 2015. Additional high flow events were fortunately obtained during October, November, and December Routine Monitoring collections. Cardno recommends the UNRBA consider expanding the High Flow sampling to include more tributaries and capture more high flow conditions at Lake Loading stations throughout the year. Cardno also recommends discontinuing analyses of parameters that require field filtering to focus analysis on total fractions (i.e., discontinuing soluble Kjeldahl nitrogen, total soluble phosphorus, dissolved organic carbon). Consistent with recommendations for changes to the Lake Loading Routine Monitoring, Cardno also recommends discontinuing analysis of carbonaceous biochemical oxygen demand ($CBOD_5$) during High Flow Events to avoid the cost of collecting data which affords little or no value to future analytical efforts.

5.2.3 Lake Sediment Evaluation

Sediment sampling was conducted near all 12 of DWR’s Falls Lake monitoring locations in June 2015. Sample analysis and data interpretation are still under way, but preliminary results suggest that sediments associated with the historic river channel have a higher potential to release nutrients to the overlying water column than sediments in shallower areas of the lake away from the channel. Cardno does not recommend allocating funds to the FY2017 monitoring budget to collect additional sediment data. However, the US EPA may conduct an *in situ* sediment evaluation, and the UNRBA modeling effort is expected to include substantial consideration of sediment dynamics. Thus, it is prudent to have a small amount of budget dedicated to ongoing consideration of sediment issues in the coming fiscal year. Additional data collection would be possible in the future if evolving analytical needs dictate.

5.2.4 Support Development of Alternative Regulatory Approaches

This Special Study does not entail data collection, but rather support for identifying and evaluating regulatory and resource management alternatives to protect Falls Lake while minimizing the fiscal impact on UNRBA members. A portion of the FY 2015 budget has been spent on initial pre-planning meetings with the UNRBA Executive Director and Subject Matter Experts. A portion of this budget has also been used to support the UNRBA in its response to various legislative actions, proposed rule revisions, and other agency documents regarding Falls Lake. The FY 2016 budget does not provide funding for this Special Study. Cardno anticipates that the level of effort associated with alternative regulatory approaches will increase in future years as the UNRBA initiates the meetings with regulators. Therefore, Cardno recommends the FY 2017 budget include an additional small allocation for this Special Study.

5.2.5 Falls Lake Constriction Point Study

The first constriction point data collection event occurred in January 2016 following a very large rain event. Water movement was measured and water quality samples were collected over a two-week period at three locations in the water column at each of two bridge constrictions (Interstate 85 and Highway 50). Data revealed that water quality, when water is moving rapidly through the constriction points, is substantially different than typical values measured in DWR's monthly sampling for some parameters. Cardno recommends extending this Special Study into FY 2017, perhaps with some adjustments to the protocol to improve efficiency. The second FY 2016 planned sampling event should be completed before determining whether to modify the protocol thereafter.

5.2.6 Volatile Suspended Solids Data

This small Special Study was added in FY 2016 to provide for monitoring of VSS at Lake Loading and inlake stations. That effort has been folded into the Routine Monitoring process, and data are therefore provided in Section 3. Future reports will no longer address VSS data collection as a Special Study.

5.2.7 Light Extinction Data

NCDEQ collected light extinction data in Falls Lake in October 2015. The data from this event are within the range of observations collected in the 1980s and 1990s. As with the historic data, light extinction data indicates that 99 percent of light is attenuated over twice the Secchi depth (R^2=0.77). Given that the results of the recent study are similar to historical measurements, and given that the model response using the current version of the EFDC model is relatively insensitive to this parameter, Cardno does not recommend allocating resources to additional paired studies at this time. This recommendation can be reconsidered in future years based on the evolving needs of modeling efforts.

5.2.8 Basic Evaluation of Model Performance

In FY2016, Cardno began a preliminary evaluation of models to determine if revisions to the Monitoring Program were needed to provide specific inputs to the models that had a relatively high degree of uncertainty and were key drivers of simulated lake water quality. Key findings of this evaluation related to recommendations presented in this Annual Report for revisions to the Monitoring Program are summarized below:

- Based on comparison of load estimates using USGS LOADEST to measured loads during storm events on two tributaries, estimated nutrient loading to Falls Lake is likely underestimated during storm events when Routine Monitoring is the sole source of water quality data used for the analysis. Because there are typically an insufficient number of water quality samples that have been collected during high flow events, routine monitoring tends to miss some of the higher concentrations that occur high flow conditions. Cardno recommends expanding the High Flow Event sampling to cover more Lake Loading stations and to collect data more frequently than twice per year as currently included in the Monitoring Program.
- Based on model sensitivity analyses on the labile and refractory fractions of particulate organic carbon, Cardno recommends discontinuing analysis of CBOD5 at the Lake Loading stations. The model is relatively insensitive to this parameter because very little of the organic carbon entering the lake is in the particulate form for which EFDC assigns lability (EFDC does not designate lability for the dissolved fraction which comprises approximately 95 percent of the organic carbon load from the tributaries).
- Cardno does not recommend the collection of additional paired light attenuation data using a PAR meter with simultaneous measurements of Secchi depth.

The UNRBA plans to initiate a modeling effort outside of Cardno's Monitoring Program contract during FY 2017. Therefore, Cardno does not recommend continuing this Special Study in FY 2017. Analyses and related efforts to support the modeling work can be provided within the data analysis component of the Routine Monitoring budget, or within the budgets of the other Special Studies. This recommendation can be revisited in future years, as the modeling efforts proceed.

5.2.9 Recreational Use Evaluation

Cardno compiled information from public sources on recreational use of Falls Lake. Records were evaluated along with data on water quality parameters that may affect some user tendencies to visit Falls Lake (i.e., water clarity and chlorophyll *a* levels). Cardno also reviewed NCDENR documentation of water quality exceedances in the 2014 305(b) Report. Based on this review, it appears that Falls Lake is meeting its designated use for recreation with respect to issues of concern under the Falls Rules (NCDENR 2014), and lake visitation is not limited by water quality conditions.

In light of these results, Cardno recommends that the UNRBA suspend the investment of additional resources to evaluate recreational uses in the coming fiscal year. However, we also recommend that the UNRBA communicate with NCDEQ and the U.S. EPA regarding the types of recreational use data and analyses they may have accepted as part of the process of developing or revising regulations for water resource management. Based on feedback from the agencies, further data collection and/or analyses may be warranted in future years.

5.3 Recommendations

An important component of the UNRBA Monitoring Program is the ability to adapt the data collection as 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 seventeen months, extensive changes to the UNRBA Monitoring Program in terms of reduced sampling frequency or change in number of stations are not recommended at this time.

Cardno recommends the UNRBA consider these modifications for Fiscal Year 2017:

Routine Monitoring

- Suspend collection of Dissolved Organic Carbon at Lake Loading stations.
- Suspend collection of Platinum-Cobalt color at Lake Loading stations.
- Suspend collection of CBOD5 at Lake Loading stations.
- The frequency of collection of Total Organic Carbon at Jurisdictional Boundary stations to quarterly.

Special Studies

- Suspend the Storm Event Special Study in its current form (but potentially carry forward encumbered funding for the remaining FY 2016 event if a suitable rain event does not occur before June 30)
- Adapt the High Flow Sampling Special Study to increase the number of stations and sampling frequency of events, and suspend the analysis of CBOD5 and dissolved fractions of parameters
- Allocate a small portion of the overall program budget for ongoing consideration of sediment issues, but do not budget for additional sediment data collection during FY 2017.
- Allocate a small portion of the overall program budget to continue planning and preparation for discussions with regulators to ensure that the data and studies being conducted by the UNRBA will address agency concerns over proposed re-examination strategies in the future. Include sufficient funding for travel and attendance at a small number of agency meetings in FY 2017.
- Continue the Constriction Point Special Study into FY 2017, with potential adaptation to the protocol based on findings from both sampling events in FY 2016.
- Suspend consideration of volatile suspended solids data collection as a Special Study, and instead consider it a component of Routine Monitoring.
- Suspend consideration of further collection of light extinction data in FY 2017

- Suspend the Basic Evaluation of Model Performance Special Study in FY 2017, but provide adequate funding in data analysis portions of Routine Monitoring and Special Studies to allow support of the initiation of modeling efforts.
- Suspend further assessment of recreational uses with respect to water quality in FY 2017.

6 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.

EPA, 2012a. “Recreational Water Quality Criteria.” Office of Water 820-F-12-058. Accessed April 8, 2016 https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf

EPA, 2012b. “2012 Recreational Water Quality Criteria (Fact Sheet).” US EPA Office of Water 820-F-12-061. Accessed April 8, 2016 https://www.epa.gov/sites/production/files/2015-10/documents/rec-factsheet-2012.pdf

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

NCDEQ. 2016. 2016 Status Report Fall Lake Nutrient Strategy. Developed by the N.C. Division of Water Resources Nonpoint Source Planning Branch.

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

NCDENR. 2014. 2014 NC Water Quality Assessment for 305(b). https://ncdenr.s3.amazonaws.com/s3fs-public/Water%20Quality/Planning/TMDL/ 303d/2014v2/2014_NC_WQ_Asmnt2.16.15.pdf

USACE. 2013. Falls Lake Master Plan Neuse River Basin. May 2013.