UNRBA Monitoring Program Annual Report

UNRBA Monitoring FY 2017

Monitoring Period August 2014 through December 2016

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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 and again on January 18, 2017.

Cardno is required to produce an Interim and an 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 2016 and presents results and general patterns and relationships observed in the data. Annual Reports may also include 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. In addition, the practical ability to achieve the mandated reductions is uncertain. In light of the financial impact of the Rules and the importance of Falls Lake as a resource, the UNRBA began examining the technical bases and regulatory framework of Stage II. Local governments within the UNRBA agree that protecting Falls Lake as a water supply and public resource is paramount. The members want to ensure that the rules applied to the watershed sufficiently reflect the lake's uses. Control requirements should be 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 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 2016.

2 Overview of UNRBA Monitoring Program

This Annual Report addresses monitoring efforts from August 2014 through December 2016. 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 7 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 during Years 1 and 2 of the program, water quality sampling occurred twice a month on five of those tributaries to the upper lake. These five tributaries are estimated to contribute roughly 75 percent of the inflow quantity to Falls Lake. In Year 3, these five tributaries were targeted under the High Flow Event Special Study, and routine monitoring was reduced to monthly. This change was made to ensure collection of water quality across a wide range of hydrologic conditions. It is important to have high confidence in nutrient loading for these tributaries because their water and nutrient contributions to the lake are presumed to drive much of the lake's chlorophyll response.

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. The program has included collection of total and volatile suspended solids, total and dissolved organic carbon, and chlorophyll a concentrations from the 18 tributaries to provide data that was not available when DWR developed the model in support of the Rules. Over the course of the UNRBA Monitoring Program, parameter coverage, frequencies, and sampling locations have been revised to optimize data collection for the UNRBA's needs. For example, the first two years of monitoring showed a high correlation between total organic carbon (TOC) and dissolved organic carbon (DOC) ($R^2 = 0.99$). Given the ability to predict DOC from TOC with a high degree of confidence and its relatively high cost, the UNRBA ceased collection of DOC from lake loading stations in June 2016. Collection of $CBOD_5$ and Platinum-Cobalt color analysis also ceased in June 2016 as explained in the 2015 UNRBA Annual Monitoring Report.

2.1.2 Jurisdictional Boundary Stations on Tributaries in the Falls Lake Watershed

The Rules specify that nutrient 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 are reviewed to optimize value for the UNRBA. Monitoring at Jurisdictional Stations has only been slightly modified since the beginning of the program: beginning in July 2016, the frequency of TOC collection at jurisdictional stations was reduced from monthly to quarterly while monthly collection continued at the lake loading station for each tributary.

2.1.3 Falls Lake Monitoring

Monitoring of Falls Lake provides data that can be used for assessing ambient water quality as well as for calibration and validation of updated lake models. Data for Falls Lake are collected by DWR, the City of Durham, the City of Raleigh, and North Carolina State University's Center for Applied Aquatic Ecology (CAAE) at 30 monitoring stations (Figure 2.2) in 22 distinct locations on the lake (some locations are monitored by more than one organization.

Prior to October 26, 2016, the City of Raleigh collected its nutrient and chlorophyll data at discrete depths. Because the graphical comparisons in this report show photic zone composite values, data from the City of Raleigh are not included in this report. Beginning in October 2016, Raleigh revised their protocols to include samples collected as photic zone composites. Data from this point forward will be included in future reports.

Field data along with nutrient, carbon and suspended sediment data obtained from photic zone composite water samples are obtained from the monitoring entities and compiled annually for inclusion in the UNRBA database and Annual Report. Results from samples collected at discrete depths do not follow DWR's sampling protocol for assessment purposes and introduce complexities in making comparisons across data sets. Therefore such data are archived separately and not included in the Annual Reports.

DWR collects samples monthly at 12 stations throughout Falls Lake and all parameters except field parameters are collected as photic zone composites. Annual data summaries for the parameters that DWR collects 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 (at Cheek Road and I-85) are sampled weekly from April to October as photic zone composites. In addition to residing in the UNRBA database, 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, although the time period represented by the City of Durham data is not directly comparable to the other stations.

CAAE has collected chlorophyll *a* samples as photic zone composites from 10 sites since before the UNRBA Monitoring Program began. Three of these sites are co-located with CAAE's automated sampling profilers at I-85, Hwy 50, and the intake structure, and have chlorophyll data 2-3 times per month. The remaining seven sites (the "C"-sites: 1C, 6C-11C) have monthly chlorophyll *a* data as photic zone composite samples. Beginning in April 2016, six sites added monthly photic zone chlorophyll *a* sampling (sites 1-6). Photic zone samples for nitrogen, phosphorus, carbon and TSS parameters began being collected twice-monthly at CAAE's three profiler sites and sites 1-6. Field parameters are collected twice-monthly at the profiler sites and monthly at sites 1-6.

Specific parameters and their frequency of measurement by each of the monitoring organizations since the start of the UNRBA monitoring program (August 2014) are summarized in Table 2.3 and Table 2.4.

In addition to the chemical analyses above, DWR has collected data on the species abundance and biovolume estimates of algae at three stations in Falls Lake since 2011. This dataset provides information on how populations of different algal groups change and cycle through time. Mechanistic models like EFDC track and predict the mass of different algal groups in response to changing environmental conditions, and DWR's algal dataset can provide a useful point of comparison for model calibration or validation. In this annual report, algal biovolumes are aggregated into eight broad groups (e.g. green algae, diatoms, cyanobacteria, etc.) and graphed to provide a visual overview of the available data. Algal biovolume is a measure of biomass that combines both the number of cells present as well as their average size.

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

Parameter	Start Date	End Date	Stations
Field Measurements:			
Air temperature	Aug, 2014	**Aug, 2015**	All
Water temperature	Aug, 2014	Ongoing	All
Specific conductance	Aug, 2014	Ongoing	All
Dissolved Oxygen	Aug, 2014	Ongoing	All
pH	Aug, 2014	Ongoing	All
Reference-point tape-down	**Jan, 2015**	Ongoing	All
Dye velocity	**Jan, 2015**	Ongoing	All
Laboratory Analyses:			
Total Kjeldahl nitrogen	Aug, 2014	Ongoing	All
Soluble Kjeldahl nitrogen	Aug, 2014	Ongoing	Lake Loading
Nitrate + nitrite	Aug, 2014	Ongoing	All
Ammonia	Aug, 2014	Ongoing	All
Total phosphorus	Aug, 2014	Ongoing	All
Total soluble phosphorus	Aug, 2014	Ongoing	Lake Loading
Orthophosphate	Aug, 2014	Ongoing	Lake Loading
Total organic carbon	Aug, 2014	Ongoing	All[†]
Dissolved organic carbon	Aug, 2014	**Jun, 2016**	Lake Loading
Chlorophyll *a*	Aug, 2014	Ongoing	Lake Loading
Total suspended solids	Aug, 2014	Ongoing	All
Volatile suspended solids	**Jul, 2015**	Ongoing	Lake Loading
Color (platinum cobalt)	Aug, 2014	**Jun, 2016**	Lake Loading
Visible absorbance at 440nm	Aug, 2014	Ongoing	Lake Loading
UV absorbance at 254nm	Aug, 2014	Ongoing	Lake Loading
5-day carbonaceous biochemical oxygen demand	Aug, 2014	**Jun, 2016**	Lake Loading

[†] Beginning in July 2016, TOC samples have been collected quarterly at jurisdictional sites and monthly at lake loading sites.

Table 2.2 UNRBA Tributary Routine Monitoring 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) [3]	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	Monthly[5]
NLR-27(JB)	Little	North Fork Little	Orange	21.9	Monthly
SLR-22(JB)	Little	South Fork Little	Durham	37.4	Monthly
LTR-16(JB)	Little	Little	Durham	78.3	Monthly
LTR-1.9(LL)	Little	Little	Durham	104	Monthly[5]
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	Monthly[5]
CMP-23(JB)	Knap of Reeds	Camp	Durham	1.99	Monthly
KRC-4.5(LL)	Knap of Reeds	Knap of Reeds	Granville	41.9	Monthly[5]
ELC-3.1(LL)	Ellerbe	Ellerbe	Durham	21.9	Monthly[5]
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.

[5] Prior to July 1, 2016, samples were collected twice monthly at these stations.

Table 2.3 Falls Lake Sampling frequencies for stations and parameters monitored by DWR and the City of Durham. Frequency of sampling by CAAE is further dependent on monitoring station and these are summarized in Table 2.4

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 (Apr – Oct)

Table 2.4. Stations and approximate sampling frequencies for stations monitored by the Center for Applied Aquatic Ecology (CAAE) at NCSU from August 2014 through December 2016. Monitoring stations are listed in order from upstream to downstream and individual locations are shown on Figure 2.2. Except for field parameters, only samples collected as photic zone composites are included in this table. (Photic zone is functionally defined as the region between the surface and a depth equal to twice the measured Secchi depth.)

Station ID	Chlorophyll *a*	TOC	Nitrogen (TN, TKN, NOx, NH3)	TP	TSS	Field Parameters (Temp, DO, pH, Conductivity)	Secchi Depth
FL4	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly	Monthly
FL85C (Interstate 85)	Weekly	2x per month	2x per month	2x per month	2x per month	2x per month	Weekly
FL5	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly	Monthly
FL6C	Monthly	-	-	-	-	-	Monthly
FL6	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly	Monthly
FL10C	Monthly	-	-	-	-	-	Monthly
FL9C	Monthly	-	-	-	-	-	Monthly
FL50C (Highway 50)	Weekly	2x per month	2x per month	2x per month	2x per month	2x per month	Weekly
FL2	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly	Monthly
FL3	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly	Monthly
FL8C	Monthly	-	-	-	-	-	Monthly
FL1C	Monthly	-	-	-	-	-	Monthly
FL1	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly[1]	Monthly	Monthly
FL11C	Monthly	-	-	-	-	-	Monthly
FL7C	Monthly	-	-	-	-	-	Monthly
FLINC (Intake Structure)	Weekly	2x per month	2x per month	2x per month	2x per month	2x per month	Weekly

[1] Samples for this station and parameter combination began to be collected as photic zone composites in April 2016.

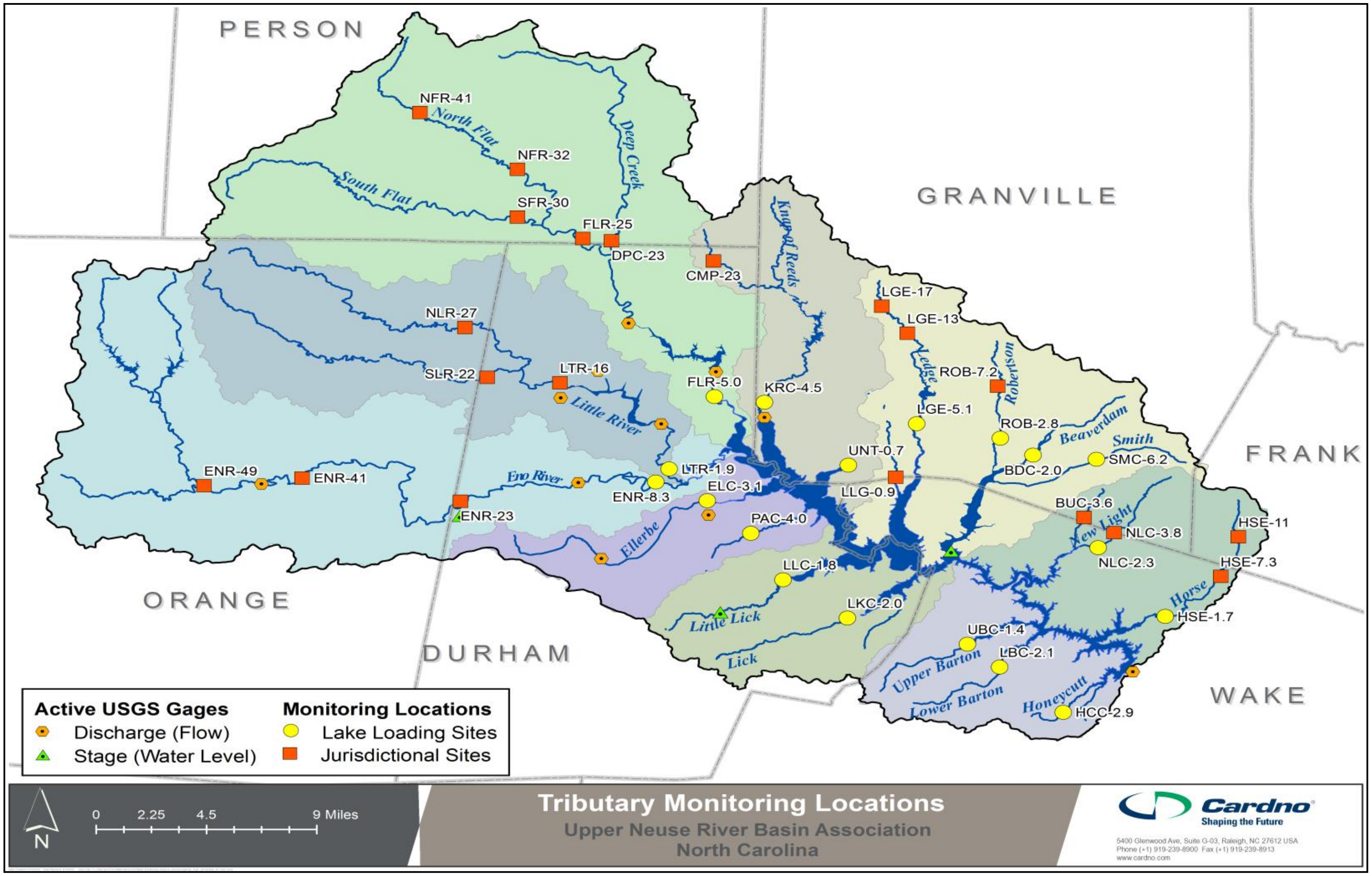

Figure 2.1 UNRBA Lake Loading and Jurisdictional Monitoring Locations (see Table 2.2 for station details) and Existing USGS Gages

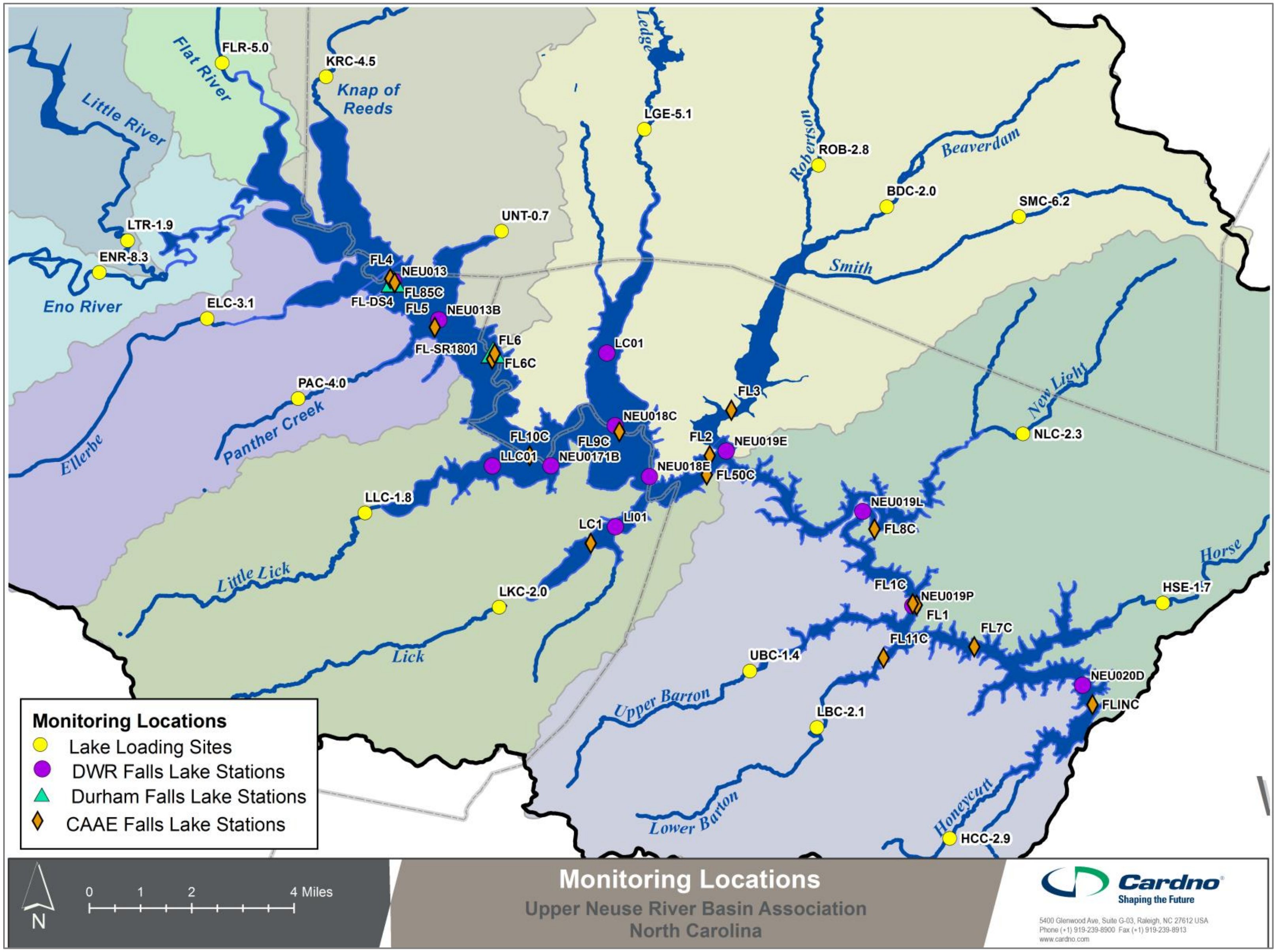

Figure 2.2 Falls Lake DWR, CAAE, and City of Durham Monitoring Locations, along with UNRBA Lake Loading Stations.

2.1.4 Modifications to Routine Monitoring Since 2016 Interim Report

There have been no changes to the Routine Monitoring since the Interim Report was published in October 2016. A copy of the 2016 Interim Report is available at https://www.unrba.org/monitoring-program. Changes that began prior to the release of the 2016 Interim Report are noted above.

2.2 Special Studies

The UNRBA Monitoring Program includes Special Studies designed to address specific questions. This section briefly summarizes the Special Studies which have been implemented as a part of the UNRBA's Monitoring Program. Each Special Study is guided by a Study Plan developed by Cardno and approved by the UNRBA Executive Director. These plans include details on data acquisition and quality assurance protocols and are available on the UNRBA website (http://unrba.org/monitoring-program). Special Studies results obtained since the previous Annual Report are presented in Section 4.

Table 2.4 Summary of UNRBA Special Studies

Monitoring Program Component	Purpose
High Flow Sampling (Active study - initiated in Fiscal Year 2015)	Obtain additional water quality grab samples 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.
Lake Bathymetry and Sediment Mapping (This study is currently underway and results will be presented in a subsequent report)	Obtain underwater topographic data for Falls Lake to improve representation by lake models. Collect data to estimate the depth of unconsolidated sediments to aid in the interpretation of the lake sediment samples collected during Fiscal Year 2015.
Falls Lake Constriction Point Flux Assessment (Completed study - initiated in Fiscal Year 2016 and concluded in Fiscal Year 2017)	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.
Falls Lake Sediment Sampling (Active study - initiated in Fiscal Year 2015, data analysis is ongoing.)	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.
Storm Event Sampling (Completed study - initiated in Fiscal Year 2015 and concluded in Fiscal Year 2016)	Obtain water quality data with automated samplers 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 tributary loading input files for modeling efforts.
Light Extinction Data Collection (Completed study - initiated and concluded in Fiscal Year 2016)	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 how well 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 (Completed study - initiated and concluded in Fiscal Year 2016)	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.

Monitoring Program Component	Purpose
Recreational Use Assessment (Completed study - initiated and concluded in Fiscal Year 2016)	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.
Support Development of Alternative Regulatory Options (Funded in Fiscal Year 2015. Continuing activities are expected to be part of the Modeling and Regulatory Support efforts.)	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 to be sure the UNRBA monitoring program collects or has access to this information.

2.2.1 Current Special Studies

The UNRBA currently has four special studies in various stages of data collection, analysis, and reporting. This section briefly describes each of these studies. The results for these current studies are provided in Section 4.

2.2.1.1 High Flow Sampling

This Special Study is used to obtain supplementary water quality grab samples 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 when loading to the lake is high. Data from this study will help to inform the development of watershed and lake models for Falls Lake.

This Special Study began in Fiscal Year 2015. Modifications to this special study were initiated in July 2016 to provide more frequent data collection from the largest tributaries under high flow conditions, as outlined in the FY2017 Monitoring Plan and the High Flow Study Plan. Results from this study are presented in Section 4.1.

2.2.1.2 Constriction Point Study

Water quality in Falls Lake may be driven by processes that occur at relatively short time steps. NCDWR samples water quality in Falls Lake at 12 locations monthly, but these data do not provide insight to in-lake dynamics during rapidly changing conditions such as following a large storm event.

The Constriction Point Special Study was developed to characterize conditions when water is moving at greater than usual rates between partially isolated portions of the reservoir. 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 can provide enhanced understanding for model calibration as part of the re-examination strategy. Two data collection events were provided for in the FY2016 budget. The first took place in January 2016, and results from this study were presented in the 2015 Annual Report available online at https://www.unrba.org/monitoring-program. The second event occurred in October 2016, and results from this event are provided in Section 4.2.

2.2.1.3 Lake Sediment Evaluation

The Lake Sediment 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 preliminary results of this study can be found in the 2015 Annual Report available online at https://www.unrba.org/monitoring-program. The full technical report will be released as a separate document.

2.2.1.4 Lake Bathymetry and Sediment Mapping

The goal of this special study is to improve the accuracy of lake models by providing data on the morphometric characteristics of the lake. The bathymetry component of this special study will map out the underwater topography of Falls Lake for a better understanding of volume, depth, and shape of the lake segments. Depth data are collected along closely-spaced transects from the upstream to downstream end of the lake. When DWR developed the original Falls Lake Nutrient Response Model, only 17 depth transects were available. The bathymetric data collected under this special study should greatly improve the accuracy of the model grid that will be developed as part of the revised lake modeling.

The sediment mapping component of this study is conducted concurrently with the bathymetric survey. The goal of sediment mapping is to identify the extent of the lake bottom which has accumulated sediment compared to areas of packed clay, sand and gravel, or even bedrock. These data will improve confidence in benthic flux estimates for use in model development. The Lake Sediment Evaluation study (Section 2.2.1.3) conducted in the summer of 2015 revealed significant nutrient flux from sediment cores, but also revealed some locations where cores could not be collected because the lake bed was hard-packed clay or rock. These locations are not expected to have the same elevated flux of nutrients, however the spatial extent that these areas cover is unknown. A dual-frequency echo-sounder is used to identify the top of the sediment and the depth of any compact surface under loose sediment. Places where these two depths are the same identify areas which do not have an accumulation of loose sediment. This information will be useful in scaling up estimates of benthic flux obtained from sediment cores.

This study is currently underway and results will be presented in a subsequent report.

2.2.2 Completed Special Studies

During previous monitoring years, the UNRBA completed several additional special studies. This section provides a brief description of each study and includes a link to the latest report with the results of the study.

2.2.2.1 Storm Event Sampling

The Storm Event Sampling Special Study focused on obtaining additional water quality data from major tributaries to Falls Lake under varying streamflow conditions over time. In contrast to the grab samples taken under the Routine Monitoring, this storm event data collection employs automated sampling equipment to collect multiple discrete samples 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 across the entire hydrograph of associated storm events. Data from this study will be used to better inform model development and calibration for simulating water quality conditions in Falls Lake and its watershed.

This special study was initiated in Fiscal Year 2015 and completed in Fiscal Year 2016. Results of this study are described in the 2016 Interim Report available online at https://www.unrba.org/monitoring-program.

2.2.2.2 Light Extinction Data

This Special Study comprised a minor effort to analyze available 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. The historical data included measurements collected from the mid 1980's to the early 1990's. To support this evaluation, the UNRBA requested that DWR collect additional data to ensure the historic data was a reasonable representation of the light extinction/Secchi depth relationship under current conditions. The results of this study were presented in the 2015 Annual Report available online at https://www.unrba.org/monitoring-program.

2.2.2.3 Basic Evaluation of Model Performance

This Special Study was included in Fiscal Year 2016 to help evaluate models for the re-examination of the Falls Lake Nutrient Management Strategy and determine whether or not the Monitoring Program design was sufficient or required revisions to address modeling needs. This study focused on modeling approaches the UNRBA would likely use for the re-examination and potential alternative regulatory approaches that may be evaluated. The Model Performance Evaluation technical memorandum summarizes the study results. This document is available online at https://www.unrba.org/monitoring-program.

2.2.2.4 Recreational Use Assessment

This Special Study evaluated 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." Findings from this study may help inform the re-examination 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. The results of this study were presented in the 2015 Annual Report available online at https://www.unrba.org/monitoring-program.

2.2.2.5 Support Development of Alternative Regulatory Options

Initial funding for this Special Study was allocated in the 2015 Fiscal Year 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, only about one-half of the FY2015 budget has been spent, mostly because the meetings have not yet been scheduled. A portion of the budget was spent on initial pre-planning meetings with the UNRBA Executive Director and Subject Matter Experts. A portion of this budget was also used to support the UNRBA in its response to various legislative actions, proposed rule revisions, and other agency documents regarding Falls Lake. Future budgeting for such activities is expected to primarily be part of the Modeling and Regulatory Support Contract that was initiated in September 2016.

3 Results and Discussion of Routine Monitoring Through December 2016

This section presents and discusses the Routine Monitoring data collected through the end of December 2016. Where possible, the data collected by the UNRBA are compared to those collected by other entities.

> **Data Available Online:**
> This report does not include raw data. The complete UNRBA database can be accessed online through the links at https://unrba.org/monitoring-program. After registering for a free account, 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.

The average annual rainfall totals across all 11 gaged locations were 49, 48, and 47 inches for 2014, 2015, and 2016 respectively. These amounts reflect values above the 30-year average for the region of 43 inches by 14%, 12%, and 9% respectively. Total precipitation can vary substantially within the watershed. For example, total rainfall from the 11 stations within the watershed ranged from 41 to 62 inches in 2014, 38 to 58 inches in 2015, and 33 to 77 inches in 2016. Although each of these years were slightly wetter than average, the annual totals fall within the middle 50% of all 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 normal in terms of precipitation with just a few months having two inches or more above or below long term averages. In 2015 the May was drier than normal while the months of November and December were wetter than normal. In 2016, June had slightly more rain than normal, while the months of January, August, November, and December each had around two inches less rain than normal.

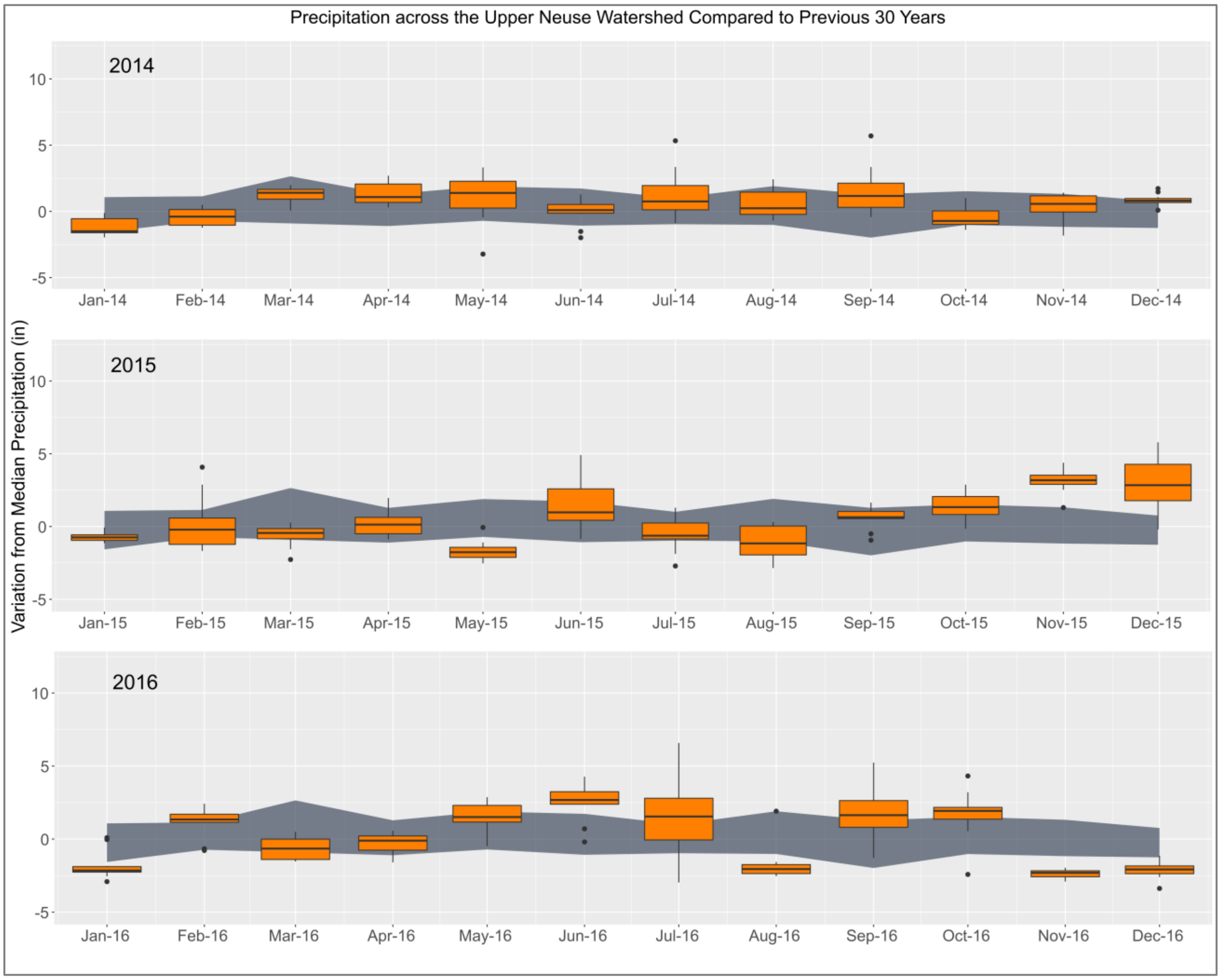

Figure 3.1 Boxplots Representing Variation from 30-Year Normal Monthly Precipitation Totals at Monitoring Stations in the Falls Lake Watershed. The darker shaded region contains the 25th to 75th percentile range of monthly precipitation over the preceding 30 years. The orange boxes display the 75th (top), 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. Long-term median monthly rainfall totals range from 2.9 inches in February to 4.4 inches in July.

A related analysis was conducted on the water level (stage) of Falls Lake based on daily data collected by the USACE (Figure 3.2). For this analysis, median values (dashed line) are based on data reported from 1987 to present. The range of the middle 50 percent of values are shown in the light blue region, while the region between the 10th to 90th percentiles are shown in dark blue. For all three years, reservoir levels have generally remained at or above median levels.

[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.

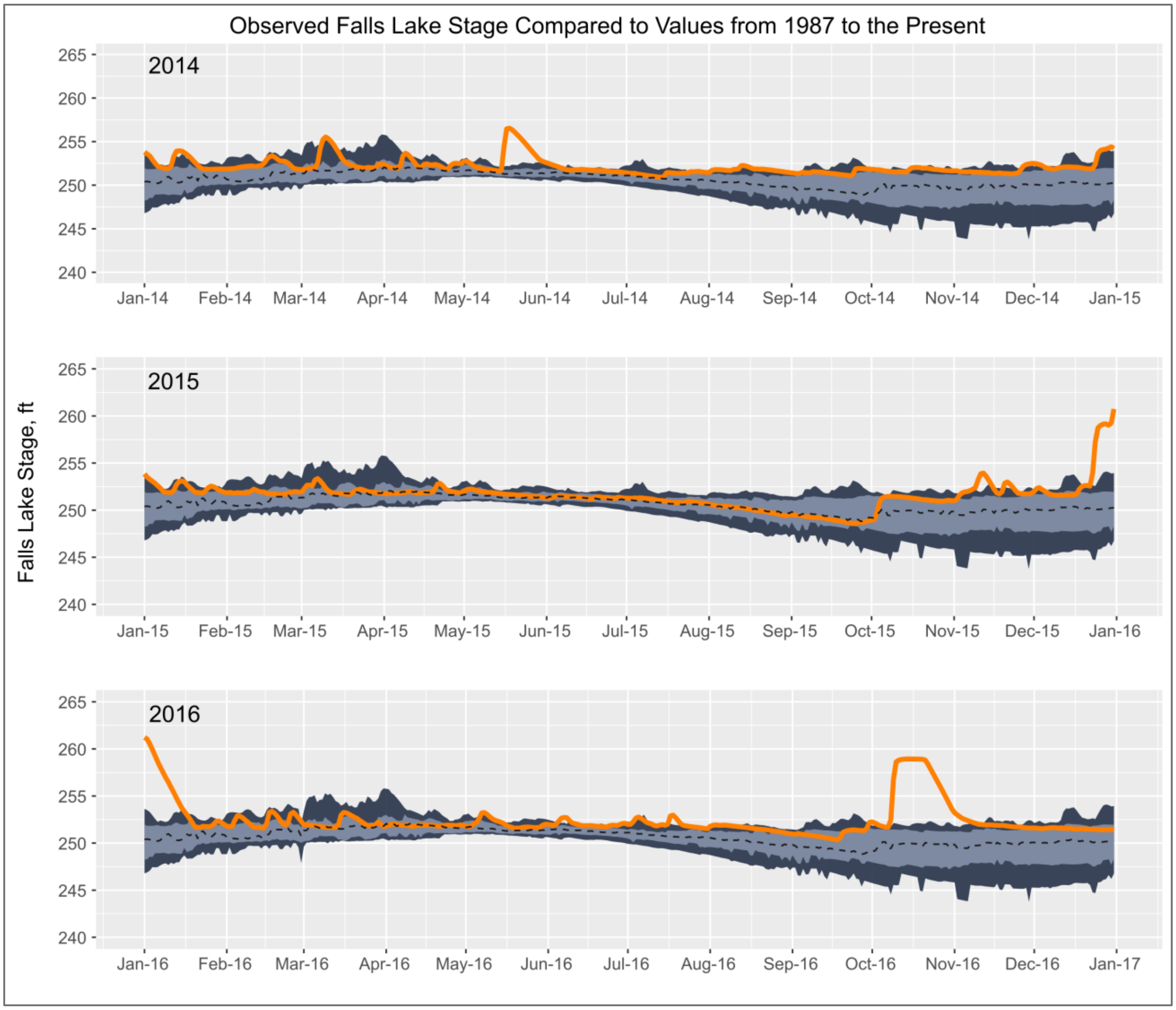

Figure 3.2 Falls Lake Elevation from January 2014 through December 2016
(median values (dashed line) and percentiles are based on data 1987 to present)

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.

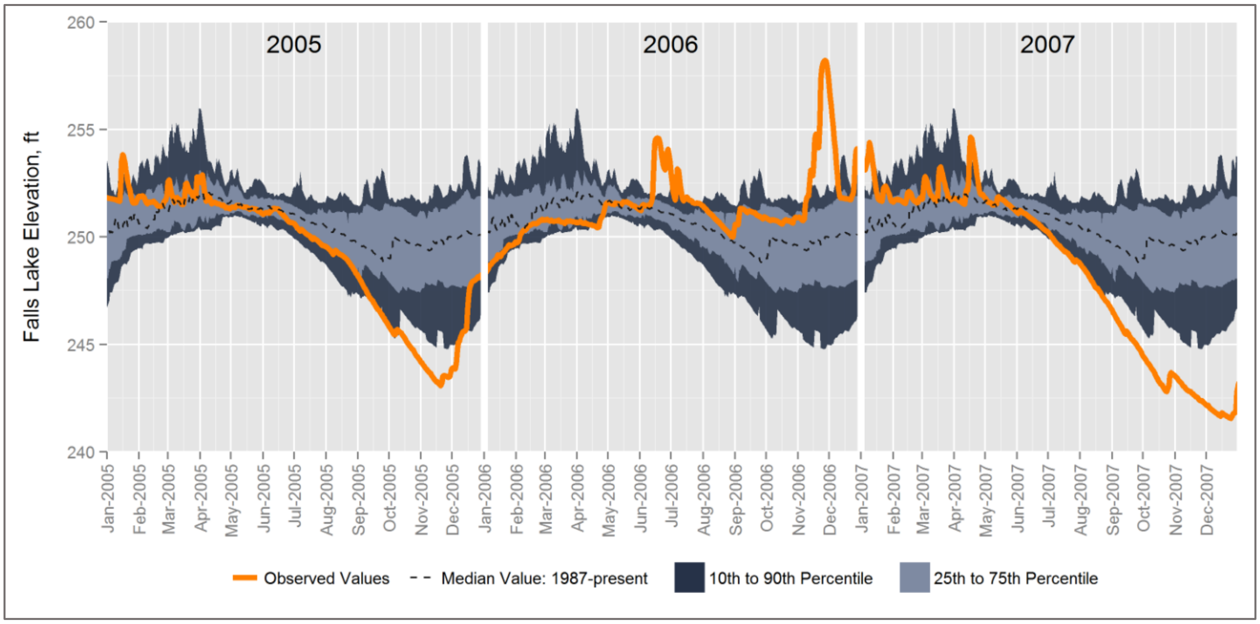

Figure 3.3 Falls Lake Elevation (stage) in Feet Above Mean Sea Level for the Period of DWR's EFDC Model Years 2005 through 2007 (Orange Line). The historical median (dashed line) and reference ranges (shaded regions) for each day of the year are shown for 1987 through the present.

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 (µg/L).

The graphics and text 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 the first section, data are presented for all tributary stations, placing the jurisdictional stations in context with corresponding downstream lake loading stations. Section 3.2.2 also displays data from the lake loading stations, but instead places it in the context of Falls Lake water quality. In addition to displaying figures of individual water quality measurements and summary statistics, preliminary comparisons of water quality related to compliance with water quality standards are also provided.

3.2.1 Tributary Stations

The series of graphics below provides a concise view of data from the jurisdictional and lake loading monitoring stations between August 2014 and December 2016. 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. To highlight data collected since the previous annual report, results from samples collected in 2016 are shown in yellow, while previous results are shown in black. Note that some of the graphics have a logarithmic Y-axis to allow the depiction of a broader range of concentrations on a reasonable sized chart. As a guide for interpreting the box and whisker figures, an example is shown below (Figure 3.4) with meanings of each component labeled.

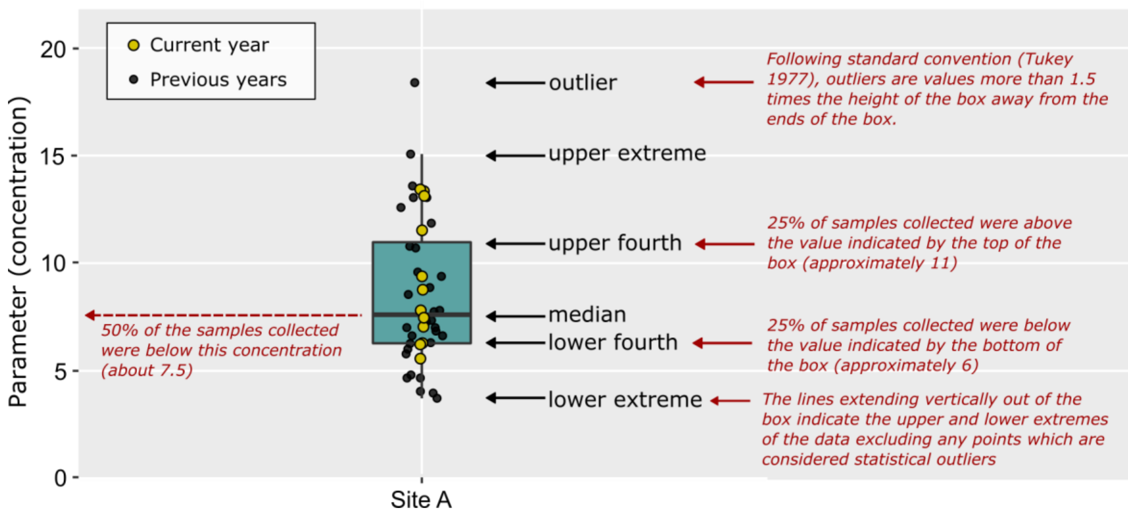

Figure 3.4. An example box and whisker figure as used in this report and the meaning of figure components. Data points (black and yellow points) are randomly spread horizontally to better show points which would otherwise overlap. By statistical convention, the upper and lower extremes represented by the vertical lines extending out of the boxes show the range of values that fall below the 25th percentile (lower quartile) or above the 75th percentile (upper quartile) by up to 1.5 times the difference between the upper and lower quartile values.

Within each figure, data are grouped by subwatershed. Within each group, stations on the same tributary are displayed from the most upstream to the most downstream location. Jurisdictional Boundary stations are shown with a light shading while downstream 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.

(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.

> <u>Dissolved oxygen</u> (DO) - Field measurements of DO are provided in Figure 3.5.**Error! Reference source not found.** 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 1,168 total DO measurements, approximately 93 percent were above the standard and 7 percent fell below 4 mg/L, as listed in Table 3.1.

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 that pH be between 6 and 9. Field measured values of pH at the Jurisdictional and Lake Loading stations are almost always within this range, with most values falling between 6.5 and 7.5 (Figure 3.6). Data collected from August 2014 through December 2016 showed approximately 98 percent compliance with the standard. 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 3.7).

Table 3.1 Stations with dissolved oxygen measurements below the NC state standard between August 2014 and December 2016.

Subwatershed	Station ID	Number of DO Values Measured	DO Values Reported below 4 mg/L	Percentage of Values below 4 mg/L
Beaverdam Creek	BDC-2.0 (LL)	30	10	33
Camp Creek	CMP-23 (JB)	25	3	12
Flat River	FLR-5.0 (LL)	50	11	22
Ledge Creek	LGE-5.1 (LL)	20	1	5
Lick Creek	LKC-2.0 (LL)	28	3	10
Little Lick Creek	LLC-1.8 (LL)	30	5	17
Little Ledge Creek	LLG-0.9 (JB)	28	11	39
Little River	LTR-1.9 (LL)	52	5	10
North Flat River	NFR-41 (JB)	18	2	11
Panther Creek	PAC-4.0 (LL)	29	7	24
Robertson Creek	ROB-7.2 (JB)	23	4	17
Robertson Creek	ROB-2.8 (LL)	30	10	33
Unnamed	UNT-0.7 (LL)	29	11	38
All Monitored Stations		**1,168**	**83**	**7**

Table 3.2 Stations with pH observed below the NC state standard between August 2014 and December 2016.

Subwatershed	Station ID	Number of pH Values Measured	pH Values Reported below 6.0	pH Values Reported above 9.0
Beaverdam Creek	BDC-2.0 (LL)	30	2 (7%)	-
Buckhorn Creek	BUC-3.6 (JB)	27	1 (4%)	-
Camp Creek	CMP-23 (JB)	25	3 (12%)	-
Horse Creek	HSE-11 (JB)	28	2 (7%)	-
Horse Creek	HSE-7.3 (JB) & HSE-5.7 (alternate)	26	2 (8%)	-
Knap of Reeds Creek	KRC-4.5 (LL)	49	1 (2%)	1 (2%)
Ledge Creek	LGE-13 (JB)	20	2 (10%)	-
Ledge Creek	LGE-17 (JB)	23	1 (4%)	-
New Light Creek	NLC-3.8 (JB)	29	1 (4%)	-
Robertson Creek	ROB-7.2 (JB)	23	2 (9%)	-
All Monitoring Stations		**1,168**	**17 (2%)**	**1 (0.1%)**

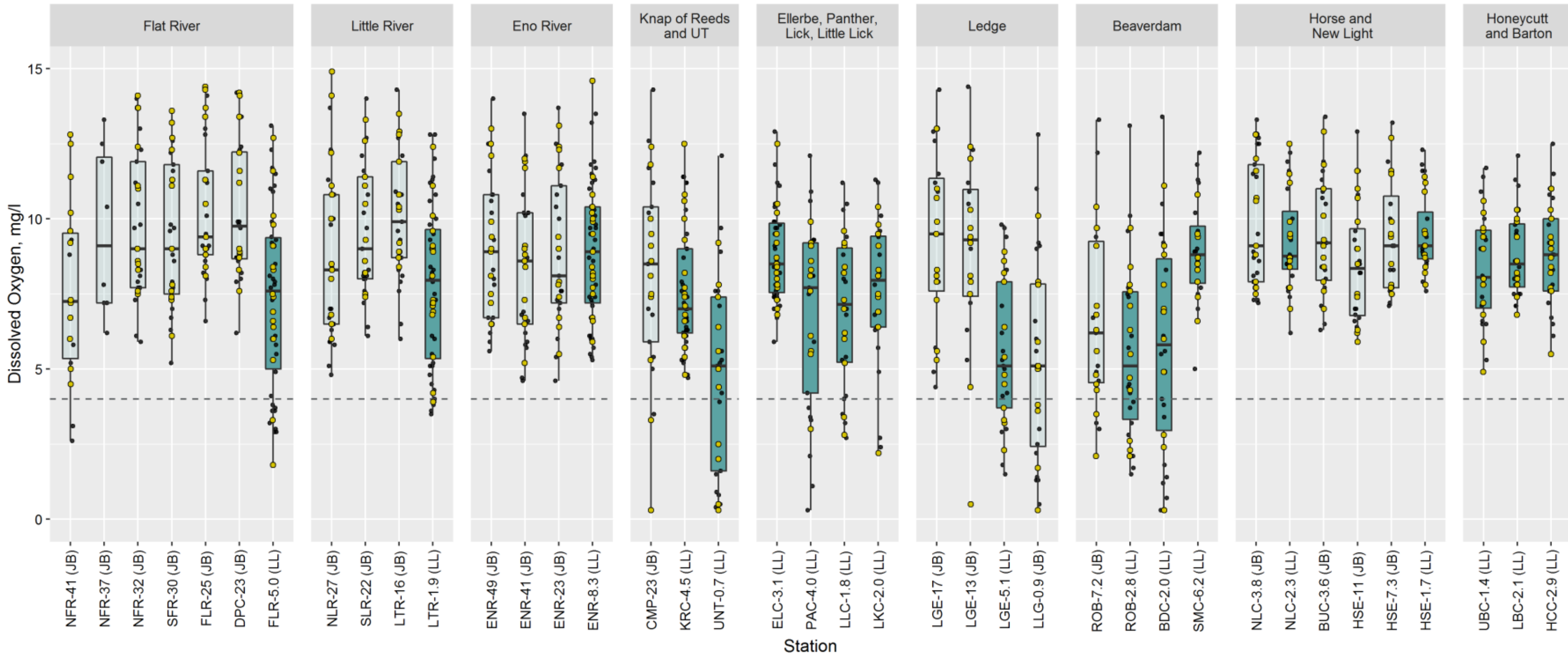

Figure 3.5 Dissolved Oxygen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016. The State's instantaneous dissolved oxygen standard of 4 mg/L is shown as a horizontal dashed line. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow. Dissolved oxygen values are lowest at locations which often have slow-moving or stagnant water and are influenced by wetlands.

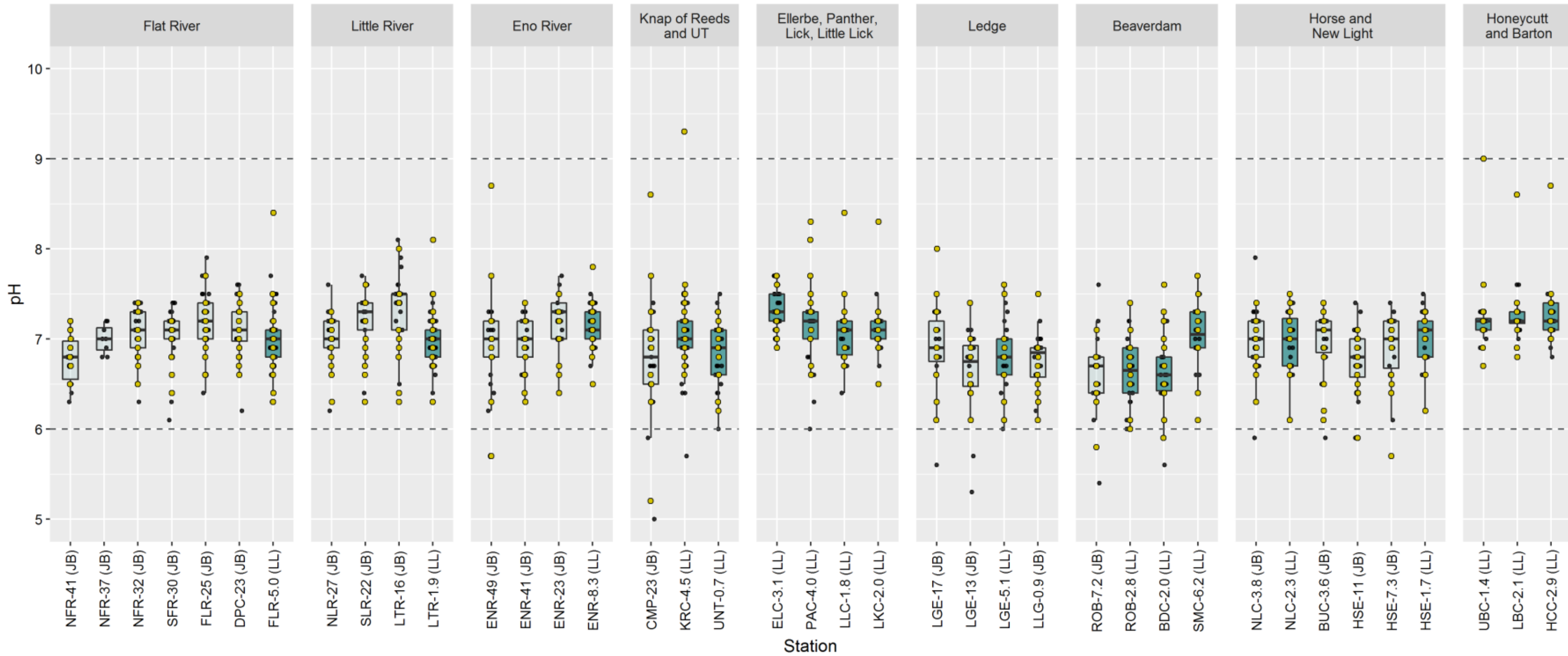

Figure 3.6 **pH in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016.** The State's upper and lower pH standards are shown as horizontal dashed lines at values of 9 and 6. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow.

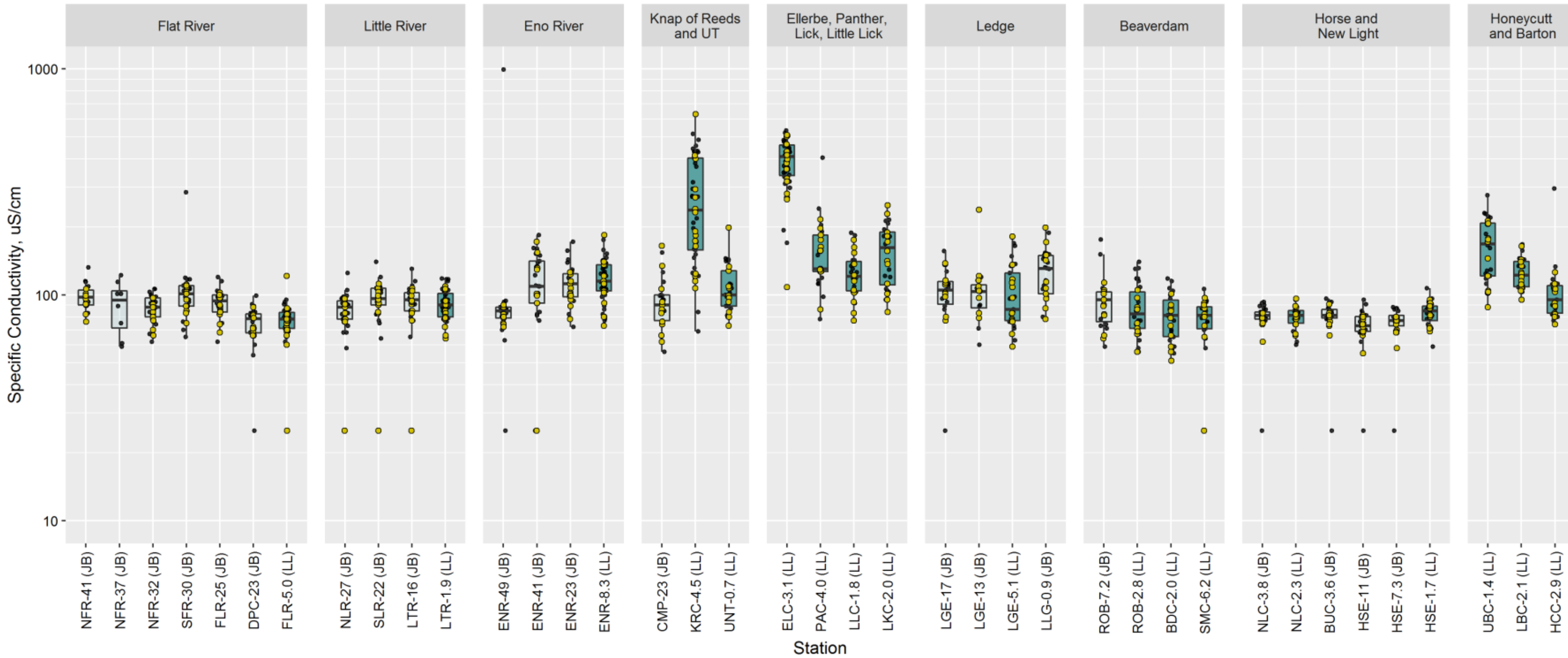

Figure 3.7 Specific Conductivity in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow. Stations downstream from wastewater treatment plants show the highest values (e.g. Knap of Reeds, Ellerbe, and Upper Barton creeks).

- Total nitrogen measured at tributary stations is presented in Figure 3.8, nitrate + nitrite is in Figure 3.9, ammonia is in Figure 3.10, and organic nitrogen is in Figure 3.11. 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 tends be higher downstream of major wastewater treatment plants and in areas dominated by stagnant, wetland conditions (Figure 3.12). The highest concentrations were observed downstream of the SGWASA WWTP (KRC-4.5) in 2015; SGWASA had been undergoing WWTP upgrades and experienced some operational disruptions that resulted in relatively high concentrations. Data collected in 2016 did not have similarly high values.
- Total suspended solids (TSS) levels are generally consistent among the Jurisdictional and Lake Loading stations in a subwatershed (Figure 3.13). 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 3.14). The highest concentrations of TOC tend to occur in areas dominated by stagnant conditions and wetland complexes. The UNRBA Monitoring Program includes collection of TOC at Jurisdictional Boundary stations and Lake Loading stations. In the 2015 Annual Report, Cardno recommended that the UNRBA decrease the frequency of monitoring this parameter to quarterly at jurisdictional stations to save approximately $7,500 annually. Cardno recommended continued monthly sampling of TOC at the Lake Loading stations because of the value of this data for lake response modeling. The UNRBA approved this change and this change was incorporated starting in July 2016.

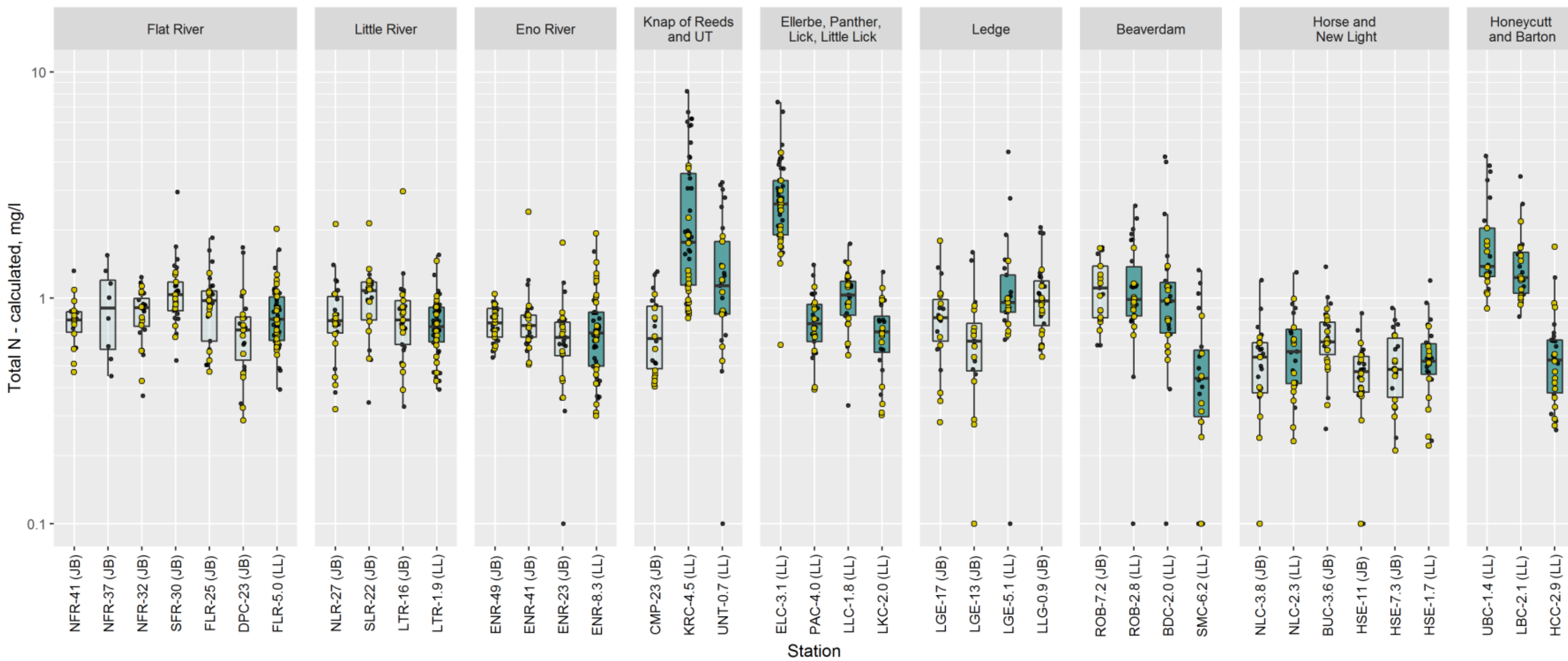

Figure 3.8 **Total Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow. Highest concentrations of total nitrogen have been observed downstream of wastewater treatment plants and package plants (i.e. Knap of Reeds, Ellerbe, Upper Barton, and Lower Barton Creeks).

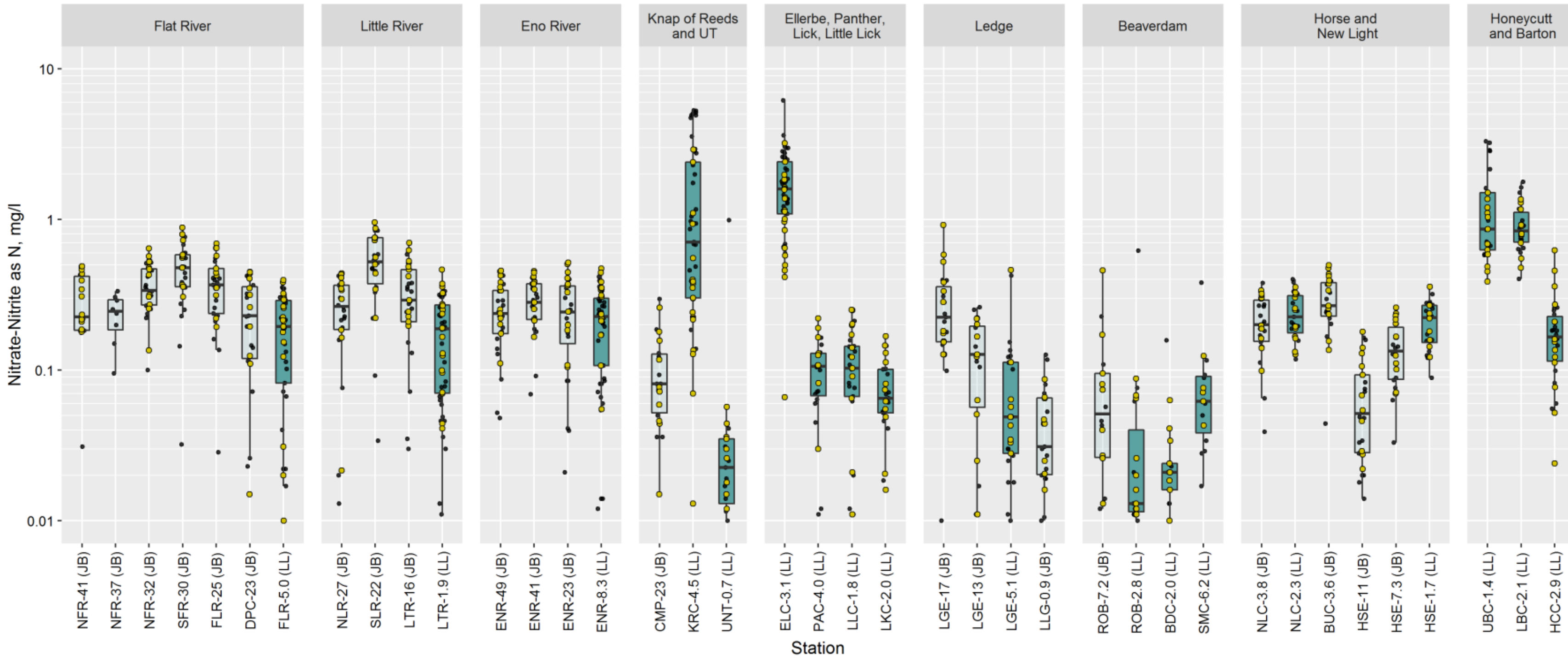

Figure 3.9 **Nitrate plus Nitrite in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow. Inorganic forms of nitrogen (including nitrate and ammonia) represent nutrient sources that are easily used by organisms and therefore these forms can fairly quickly stimulate production when provided to a nitrogen-limited system. Like total nitrogen above, concentrations of nitrate + nitrite are highest downstream of wastewater treatment plants and package plants.

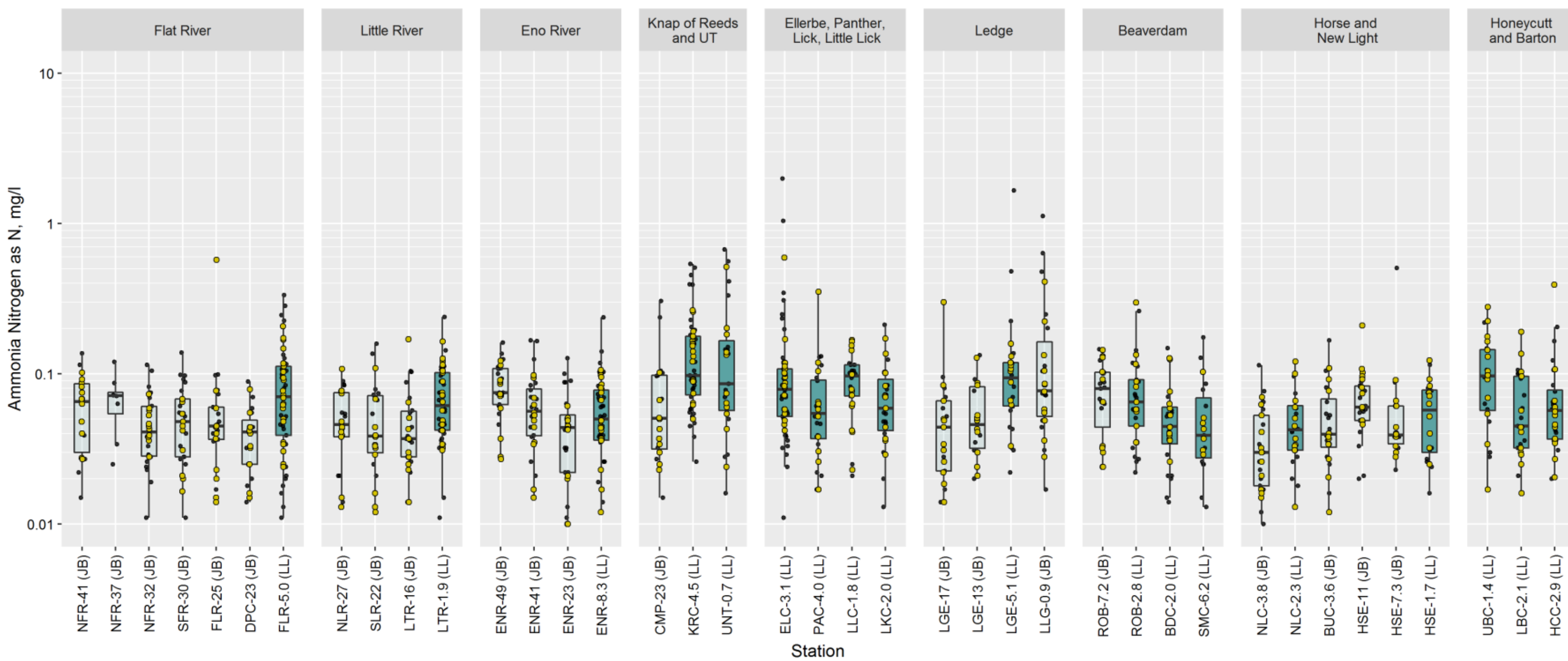

Figure 3.10 Ammonia in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow.

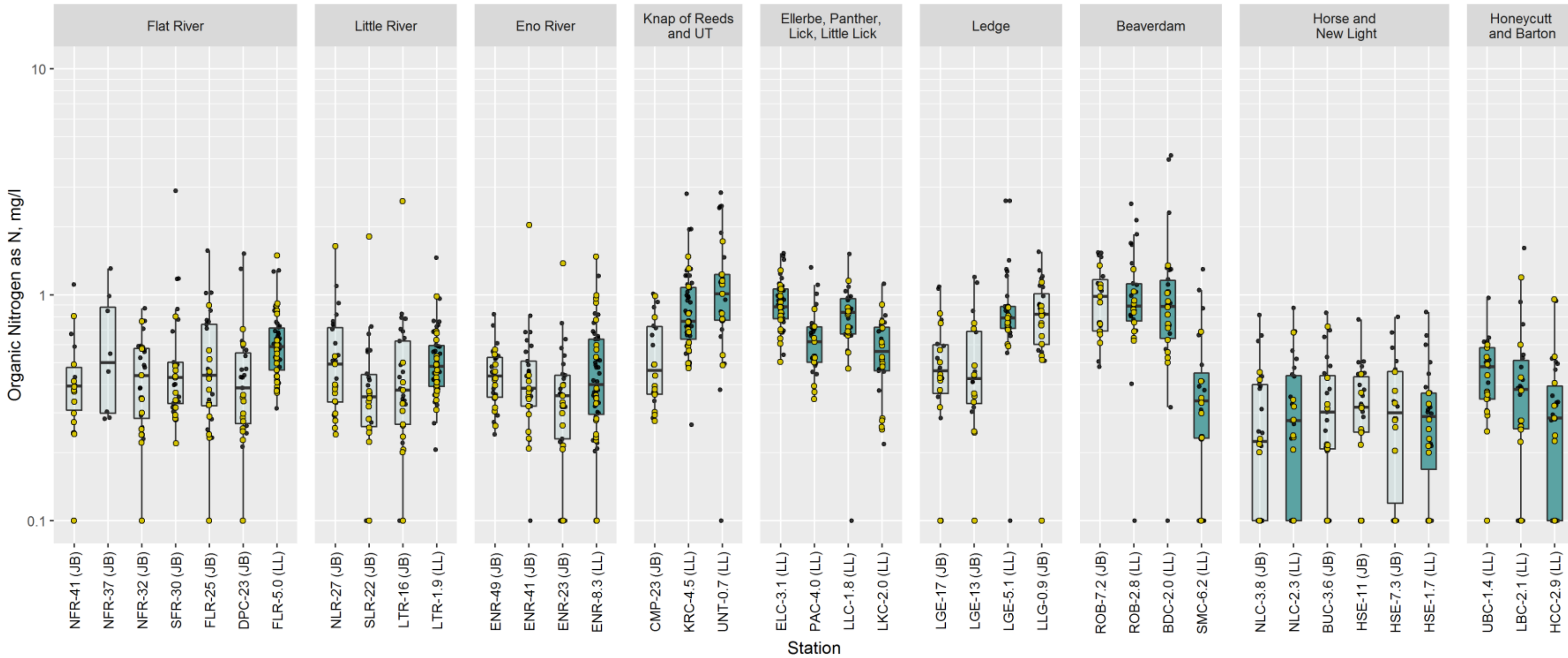

Figure 3.11 Organic Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow. Organic nitrogen is the difference between total nitrogen and the inorganic forms (ammonia and nitrate + nitrite) found in aquatic systems and is the nitrogen that is bound in living and decomposing organisms. Organic nitrogen is generally less available for rapid use since it must be broken down into inorganic forms first.

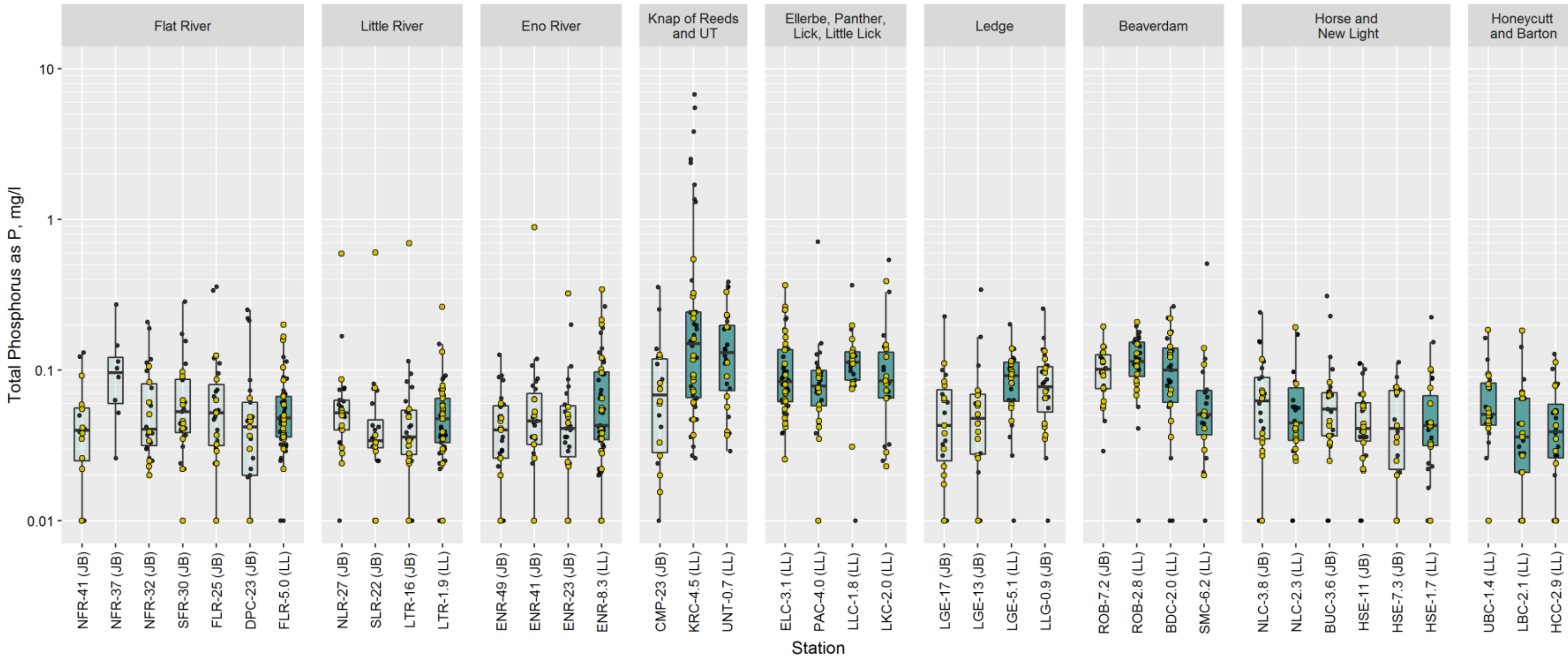

Figure 3.12 Total Phosphorus (TP) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow. Measurements of total phosphorus include organic phosphorus (or phosphorus bound to living or once-living organisms), inorganic phosphorus that can be tightly held by sediment and suspended particles, and dissolved inorganic phosphorus that is thought to be freely available to organisms. Although there do not appear to be large variations in phosphorus concentrations among sites, there is a general pattern of the highest concentrations being either downstream of WWTPs or slow-moving wetland areas.

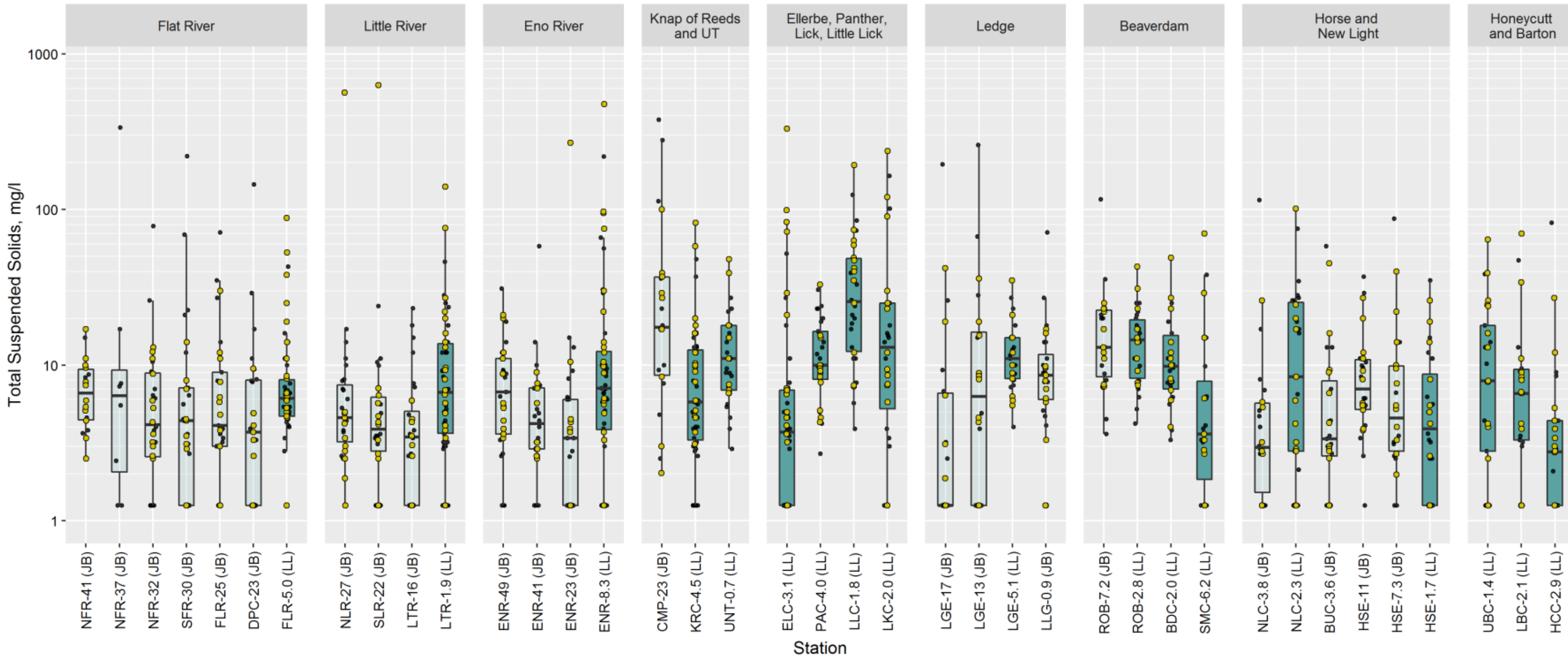

Figure 3.13 **Total suspended solids (TSS) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2016.** Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow.

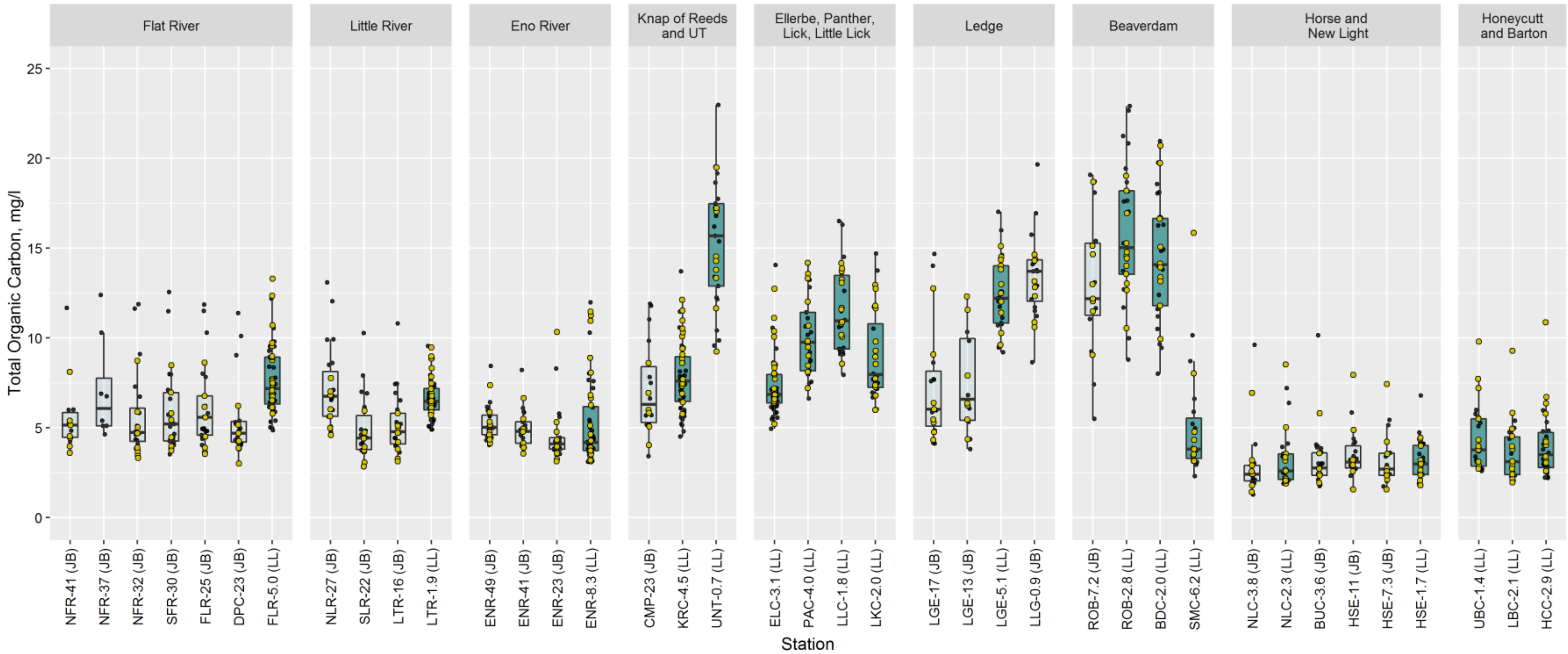

Figure 3.14 Total Organic Carbon (TOC) in Jurisdiction Boundary and Lake Loading Samples from August 2014 to December 2016. Jurisdictional Boundary stations are displayed with a light shading and Lake Loading stations are displayed with dark shading and data points from 2016 are highlighted in yellow. The highest TOC values are associated with tributaries influenced by wetlands and which generally have low elevation gradients and slow-moving water such as the Unnamed Tributary, Ledge and Little Ledge Creeks, and Robertson and Beaverdam Creeks.

3.2.2 Lake Loading and Lake Water Quality Stations

The series of graphics below provides a concise view of the data from the Lake Loading stations between August 2014 and December 2016. Box and whisker plots represent the statistical summary of the data, with each data point superimposed. Data points from 2016 are distinguished from prior samples to provide a visual assessment of any substantial changes in 2016. For comparative purposes, the graphs also reflect data collected in Falls Lake by DWR as well as the City of Durham and CAAE when available. Thus, they provide an overview of water quality for water entering the lake, and within the lake itself. Lake data come from photic zone composite samples. 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 years 2015 and 2016 when their Quality Assurance Project Plan had been reviewed and approved by DWR. Nutrient data from CAAE are limited to samples collected since April 2016 when they began collecting samples as photic zone composites at a subset of their sampling sites. Chlorophyll *a* data include data since August 2014 for the set of sites at which CAAE collected samples as photic zone composites and since April 2016 at an additional six stations.

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. Tributary (Lake Loading) stations are grouped together on the left side of figures and in-lake stations are grouped together on the right side of figures. This layout allows quick assessment of spatial patterns among the tributaries or from upstream to downstream in the lake as well as an overview of any major differences between tributary concentrations and lake concentrations. In these figures, only stations that have data for the specified parameter are displayed; therefore, among the graphics that follow, there will be some variation in the number of monitoring stations displayed on each.

All results reported by the lab as below reporting limits are displayed as the reporting limit. Reporting limits are set by individual laboratories and monitoring projects and thus may be different across the stations displayed. These differences are highlighted by the distinct markings of data below the reporting limits (red crosses) and by a horizontal bar representing the reporting limit under the box for each site. Because box and whisker plots show statistics that use the rank order of data (e.g. median and specific percentiles), the elements of the boxes and whiskers above the reporting limit are not affected by the differences in reporting limits. Thus, median values shown on the boxes can be compared across all stations. When more than half of the measured values fall below the reporting limit, the median is displayed at the reporting limit and indicates that the median is at *or below* the specified limit.

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, the City of Durham, and CAAE is presented below, along with a brief description of the parameter and general observation on patterns noted in the graphs.

> <u>Dissolved oxygen</u> (DO) represents the amount of oxygen in the water and available for respiration by aquatic organisms. Field measurements of DO are provided in Figure 3.15. 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 tend to have concentrations that are sometimes lower than the standard due to the combination of slow-moving water and decomposition of organic matter (which consumes oxygen).

- 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 3.16). Field measured values of pH at the Lake Loading stations were generally lower than the in-lake stations.
- Specific conductivity 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 such as sodium, chloride, magnesium, potassium, calcium, and others. These minerals occur naturally in water due to weathering of soils. Specific conductivity at the Lake Loading stations is generally similar to the in-lake stations except for stations downstream of major WWTPs and package plants (Figure 3.17).

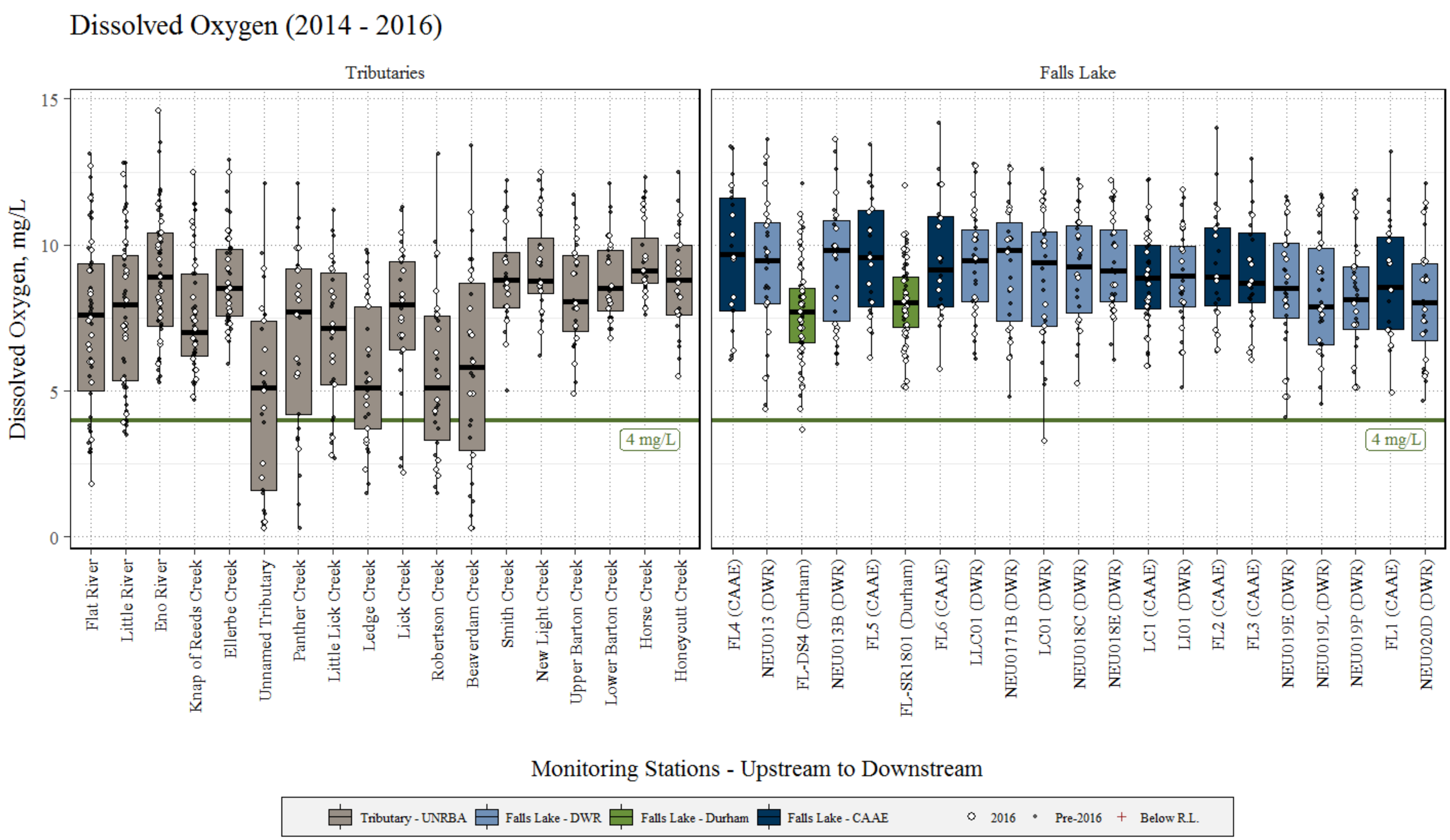

Figure 3.15 Dissolved Oxygen in Lake Loading and Lake Samples from August 2014 to December 2016. The State of North Carolina has established an instantaneous dissolved oxygen (DO) standard of 4 mg/L (shown as green line above). Tributaries which have low elevation gradients, are typically slow moving, and often are dominated by wetlands occasionally have DO values below the state standard. Values from 2016 do not appear to be substantially different from prior years. (City of Durham data are collected only during the growing season when warmer temperatures mean water can hold less dissolved oxygen.)

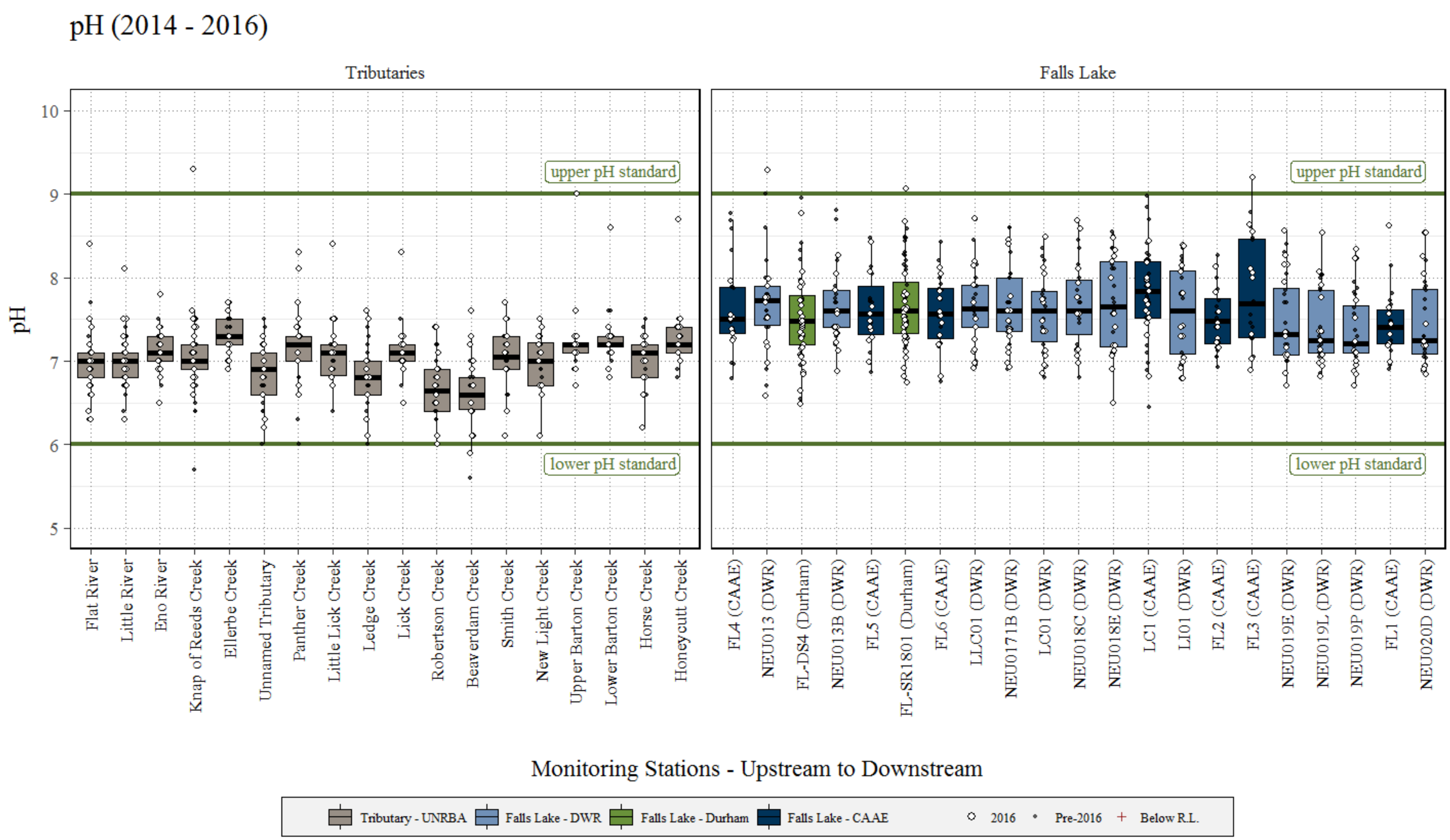

Figure 3.16 **pH in Lake Loading and Lake Samples from August 2014 to December 2016.** pH is generally lower in tributary locations than in the lake. The higher pH in the lake is likely the effect of algal photosynthesis which acts to raise the pH of water. Lower pH is seen in tributaries with low elevation gradients and slow moving water as a result of the natural organic acids which are prevalent in wetlands and slow moving water as a result of the decay and breakdown of once living matter. There are no persistent problems with pH not meeting State of NC standards and values from 2016 do not look substantially different from prior years. City of Durham data reflect growing season measurements only (April through October).

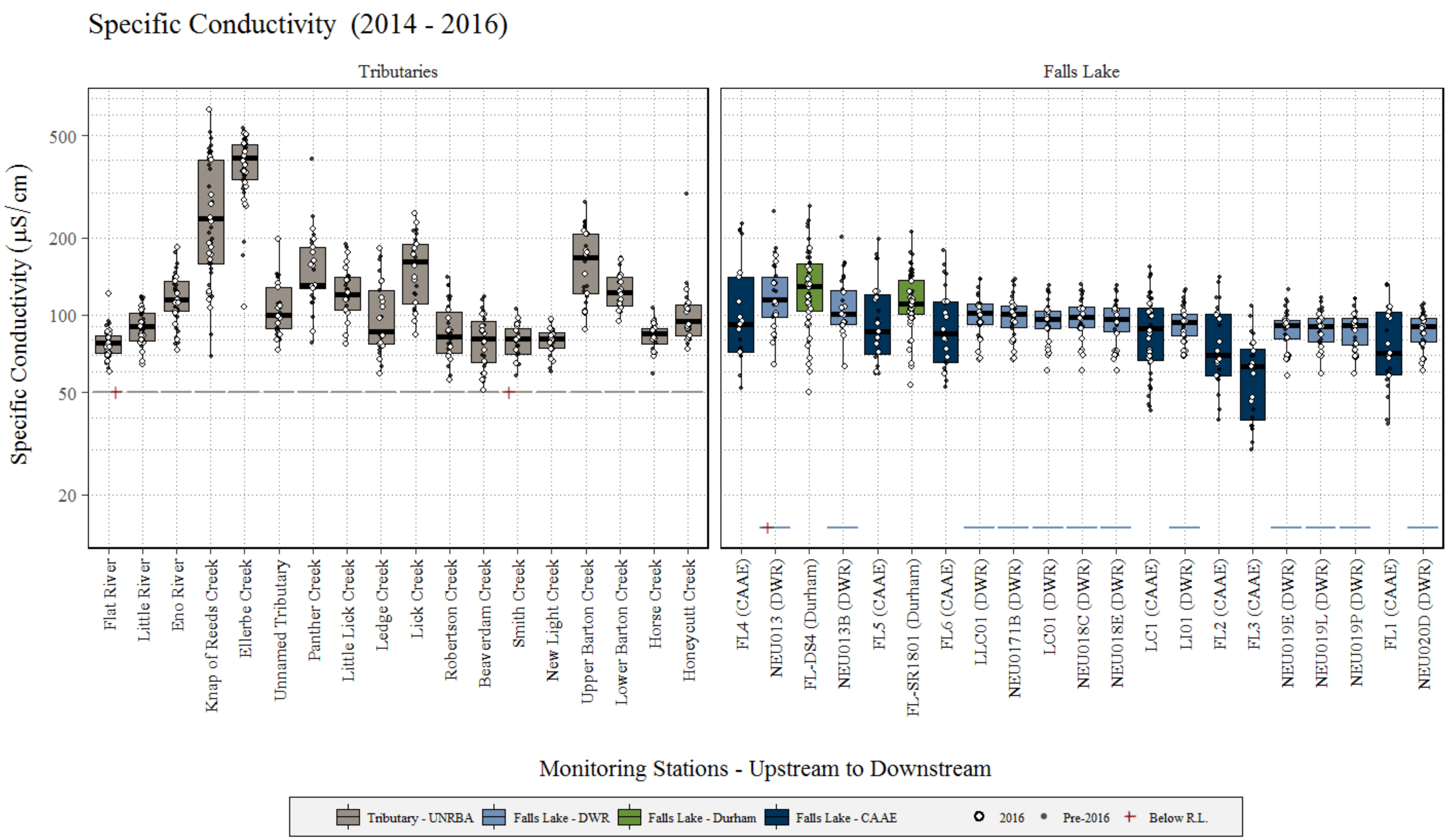

Figure 3.17 **Specific Conductivity in Lake Loading and Lake Samples from August 2014 to December 2016.** Specific conductivity is an indicator of the amount of dissolved ions in the water such as sodium, chlorides, magnesium, calcium, potassium, and others. These occur naturally due to weathering of soils. Sites downstream of wastewater treatment or package plants tend to have higher conductivity than others. Within the lake, conductivity appears to be lower at the downstream end than the upstream end. On this and subsequent figures, reporting limits are shown as horizontal lines under the bar charts when available. Observations below the reporting limits are shown as a red + symbol at the reporting limit. On this figure, note the difference in reporting limits between the tributary stations (50 us/cm) and the DWR lake stations (14.9 us/cm). Only two tributary measurements have been below reporting levels, as indicated by the red plus symbols on the reporting limit line for Flat River and Smith Creek. City of Durham data reflect growing season measurements only (April through October).

> 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. Nitrogen occurs in water in organic and inorganic forms. Organic nitrogen includes nitrogen in living organisms (including algae) and decomposing organic matter. Inorganic forms of nitrogen include ammonia, nitrate, and nitrite and are more easily used by algae than organic forms. 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. The various forms of nitrogen are presented in Figure 3.18 through Figure 3.21.

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 tributary stations compared to the in-lake stations. Concentrations of ammonia in the upper lake stations rarely have ammonia concentrations above reporting limits despite being downstream from the tributaries often with the highest concentrations of ammonia. This indicates algae are very rapidly assimilating this resource as it enters the lake. Ammonia concentrations in the downstream end of the lake are more often above detection limits, suggesting there are periods of time when algal production in this region is limited by some other resource.

Concentrations of nitrate plus nitrite are highest at tributary stations downstream of major wastewater treatment plants and small package plants. As with ammonia, concentrations within the lake are generally lower than in the tributaries, indicating this resource is also quickly assimilated by algae.

Organic nitrogen concentrations decline from the upper end of the lake to near the dam in an amount which closely corresponds to a similar decline in median chlorophyll *a* concentrations. Within the lake, total nitrogen concentrations are very similar to the concentrations of organic nitrogen, indicating that most of the nitrogen in the lake is bound within living (or once living) organisms. For tributaries, organic nitrogen still contributes the majority of the total nitrogen (except for downstream from wastewater treatment and package plants) but inorganic forms of nitrogen make up a slightly larger portion of total than within 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 runoff, shallow groundwater, discharge from wastewater treatment plants or onsite disposal systems, fertilizers, and manure. Total phosphorus (Figure 3.22) includes the ortho-phosphate fraction which is the most available form for primary production. Total phosphorus concentrations at the Lake Loading tributary stations are generally higher and more variable than the in-lake stations, with the sites downstream of major WWTP or located in stagnant, wetland areas having the highest concentrations. Within the lake, phosphorus concentrations show a steady decline from the upstream stations to the downstream stations. This suggests the lake is assimilating and storing phosphorus in its sediments.

Ortho-phosphate concentrations (Figure 3.23) are shown for Lake Loading stations and the City of Durham stations. DWR does not collect this parameter in the lake because past measurements have indicated concentrations are typically below their reporting limit of 0.02 mg/L. The City of Durham's measurements of total ortho-phosphate all fall below their reporting limit of 0.16 mg/L. Concentrations of ortho-phosphate at the Lake Loading stations tend to be higher downstream of WWTPs than at other sites.

> 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.

Chlorophyll *a* data collected from tributary and in-lake stations are presented in Figure 3.24. Concentrations in tributaries (left panel of figure) are generally lower than those observed in the lake (right panel), with the exception of some elevated concentrations observed in sluggish, wetland areas. Streams with fast moving water generally do not support large populations of free-floating algae (called phytoplankton); rather, algae in these streams is typically found in forms attached to rocks and debris and therefore not collected within a chlorophyll *a* water sample. When streams are slow-moving, phytoplankton may become more abundant. Of 632 chlorophyll *a* values measured at the lake loading tributary stations from August 2014 to December 2016, 606 (96 percent) were below the 40 µg/L water quality standard. In 2016, 256 out of 260 (98.5 percent) tributary measurements were below the standard. Only 26 observations exceeded 40 µg/L, representing only seven of the monitored tributary stations, as listed in **Table 3.3**. The majority of these elevated values occurred during times of below average streamflow. For the Unnamed Tributary, Beaverdam, Ledge, Panther, and Robertson Creeks, all observed chlorophyll *a* concentrations above 40 µg/L occurred during times when field-measured surface velocities were less than 0.2 feet per second and discharge estimates based on basin proration of nearby USGS gages were less than 7 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).

Table 3.3 Tributary stations with chlorophyll *a* measured above the NC state standard between August 2014 and December 2016. Data specifically for calendar year 2016 are given in parentheses.

Subwatershed	Station ID	Number of Chl *a* Values Measured	Chl *a* Values Reported above 40 µg/L	Percent of Total Values above 40 µg/L
Beaverdam Creek	BDC-2.0	30 (12)	6 (2)	20 (17)
Eno River	ENR-8.3	56 (21)	1 (0)	2 (0)
Flat River	FLR-5.0	54 (22)	4 (0)	7 (0)
Ledge Creek	LGE-5.1	29 (12)	3 (1)	10 (8)
Panther Creek	PAC-4.0	29 (12)	1 (0)	3 (0)
Robertson Creek	ROB-2.8	30 (12)	5 (0)	17 (0)
Unnamed	UNT-0.7	29 (11)	6 (1)	21 (9)
All Lake Loading Stations		**632 (260)**	**26 (4)**	**4 (2)**

Within Falls Lake, chlorophyll *a* concentrations decrease from upstream to downstream, with concentrations in areas of the lake downstream from the Highway 50 Bridge meeting State water quality standards since the UNRBA monitoring program began in August 2014. Of the 315 samples collected by DWR and CAAE below Highway 50 and in the main stem of the reservoir, none exceeded 40 µg/L during the period covered by this report. Of 29 samples collected from tributary arms of the lake (Lower Barton Creek), two exceeded 40 µg/L (7%) which does not exceed the criterion of 10% of samples exceeding 40 µg/L with 90% confidence (10% / 90% criterion).

Summaries of chlorophyll *a* concentrations for monitoring years 2015 and 2016 are provided in

Table 3.4 and Table 3.5. These tables show the number of samples collected at each station for the year, the number (and percentage) of those samples with concentrations above 40 µg/L, and the confidence that at least 10% of measurements were above 40 µg/L. Stations which exceed the 10% / 90% criteria for a given year are displayed in green font. The table presents additional summary metrics for chlorophyll *a* including the annual mean, the growing season mean, the annual geometric mean, and the growing season geometric mean. Each of these has been used or considered by other states for assessment methodologies.

Table 3.4. 2015 chlorophyll *a* summary metrics for each Falls Lake monitoring location. Stations are ordered from upstream to downstream and locations which exceed the current criterion of 90% confidence that 10% or more of measurements are greater than 40 µg/L are shown in green typeface. The growing season was defined as April through October for these calculations. The City of Durham collects data only during the growing season; annual averages are not possible for their two stations.

	Location	n	n (%) > 40 µg/L	Confidence > 10% above 40 µg/L	Chlorophyll a, µg/L			
					Mean (Annual)	Mean (Growing Season)	Geometric Mean (Annual)	Geometric Mean (Growing Season)
Above Highway 50	Durham - FL-DS4	28	11 (39%)	> 99%	-	39	-	35
	CAAE - FL85C	35	20 (57%)	> 99%	44	56	37	52
	DWR - NEU013B	12	3 (25%)	97%	38	41	37	38
	CAAE - FL6C	12	3 (25%)	97%	35	36	32	34
	Durham - FL-SR1801	27	1 (4%)		-	27	-	25
	DWR - LLC01	12	2 (17%)	89%	31	32	30	30
	CAAE - FL10C	12	4 (33%)	> 99%	33	34	31	32
	DWR - NEU0171B	12	2 (17%)	89%	33	32	32	30
	DWR - LC01	12	0 (0%)		25	26	24	25
	CAAE - FL9C	12	2 (17%)	89%	31	33	29	30
	DWR - NEU018C	12	1 (8%)		26	28	22	26
	DWR - NEU018E	12	1 (8%)		27	26	25	22
	DWR - LI01	12	2 (17%)	89%	29	28	28	27
	CAAE - FL50C	35	3 (9%)		27	26	25	24
Below Highway 50	DWR - NEU019E	12	0 (0%)		23	21	22	19
	CAAE - FL8C	12	0 (0%)		21	18	20	16
	DWR - NEU019L	12	0 (0%)		20	17	19	15
	CAAE - FL1C	12	0 (0%)		20	15	18	14
	DWR - NEU019P	12	0 (0%)		19	14	17	13
	CAAE - FL11C	12	0 (0%)		23	22	22	21
	CAAE - FL7C	12	0 (0%)		19	15	18	15
	DWR - NEU020D	12	0 (0%)		19	16	18	15
	CAAE - FLINC	35	0 (0%)		17	14	16	13

Table 3.5. 2016 chlorophyll *a* summary metrics for each Falls Lake monitoring location. Stations are ordered from upstream to downstream and locations which exceed the current criterion of 90% confidence that 10% or more of measurements are greater than 40 µg/L are shown in green typeface. The growing season was defined as April through October for these calculations. The City of Durham collects data only during the growing season; annual averages are not possible for their two stations.

	Location	n	n (%) > 40 µg/L	Confidence > 10% above 40 µg/L	Chlorophyll a, µg/L			
					Mean (Annual)	Mean (Growing Season)	Geometric Mean (Annual)	Geometric Mean (Growing Season)
Above Highway 50	CAAE - FL4	9	7 (78%)	> 99%	51	51	50	49
Above Highway 50	Durham - FL-DS4	31	5 (16%)	92%	-	29	-	26
Above Highway 50	CAAE - FL85C	32	16 (50%)	> 99%	40	46	33	44
Above Highway 50	DWR - NEU013B	13	3 (23%)	97%	29	41	24	40
Above Highway 50	CAAE - FL5	9	3 (33%)	99%	43	42	42	42
Above Highway 50	CAAE - FL6C	12	3 (25%)	97%	30	38	24	38
Above Highway 50	Durham - FL-SR1801	31	2 (6%)	-	-	25	-	24
Above Highway 50	CAAE - FL6	9	2 (22%)	95%	35	35	34	34
Above Highway 50	DWR - LLC01	14	2 (14%)	84%	28	33	25	32
Above Highway 50	CAAE - FL10C	12	1 (8%)	-	28	33	24	32
Above Highway 50	DWR - NEU0171B	14	2 (14%)	84%	27	34	24	32
Above Highway 50	DWR - LC01	12	0 (0%)	-	24	26	22	26
Above Highway 50	CAAE - FL9C	12	2 (17%)	89%	25	27	22	27
Above Highway 50	DWR - NEU018C	12	0 (0%)	-	24	28	22	27
Above Highway 50	DWR - NEU018E	13	1 (8%)	-	28	33	25	31
Above Highway 50	DWR - LI01	13	2 (15%)	87%	29	30	27	29
Above Highway 50	CAAE - FL50C	32	5 (16%)	91%	28	28	24	27
Below Highway 50	CAAE - FL2	9	0 (0%)	-	26	25	25	25
Below Highway 50	CAAE - FL3	9	0 (0%)	-	25	24	24	23
Below Highway 50	DWR - NEU019E	13	0 (0%)	-	25	27	23	26
Below Highway 50	CAAE - FL8C	12	0 (0%)	-	20	22	19	22
Below Highway 50	DWR - NEU019L	13	0 (0%)	-	20	23	19	23
Below Highway 50	CAAE - FL1C	12	0 (0%)	-	17	20	16	19
Below Highway 50	DWR - NEU019P	13	0 (0%)	-	20	22	19	22
Below Highway 50	CAAE - FL1	9	0 (0%)	-	20	21	20	20
Below Highway 50	CAAE - FL11C	12	2 (17%)	89%	25	25	22	24
Below Highway 50	CAAE - FL7C	12	0 (0%)	-	17	19	16	18
Below Highway 50	DWR - NEU020D	13	0 (0%)	-	17	19	17	18
Below Highway 50	CAAE - FLINC	32	0 (0%)	-	16	18	16	17

> Total suspended solids (TSS) (Figure 3.25) measures the amount of particulate material suspended in the water column. Volatile suspended solids (VSS) (Figure 3.26) represents the fraction of suspended solids associated with combustible (organic) material; monitoring VSS began in July of 2015 in response to a model-specific review of the monitoring program. VSS is a measure that includes organisms such as algae and zooplankton as well as dead and decaying material which could be used to support model parameterization and calibration.

TSS varies more over time within each tributary than within any lake site. That variation is a result of tributary flow conditions with high flows capable of carrying more material and keeping it suspended longer than low flow conditions. Median TSS concentrations observed in the upper five tributaries (discharging upstream of I-85) are lower than those observed in the lake itself, although values during high flow conditions can be several-fold higher than median lake values. The wide and shallow shape of the upper lake allows for frequent resuspension of sediment, thus keeping TSS concentrations elevated even when inflows from tributaries have low TSS.

Within the lake, TSS declines from median values around 20 mg/L near the Highway 85 Bridge to values less than 5 mg/L near the dam. This difference indicates a loss of TSS to the sediments as water travels downstream; the narrow, deeper shape of the lower part of the lake generally inhibits resuspension.

Within the lake, VSS is typically below DWR’s quantitation limit except for the most upstream site near Interstate 85. Here, high chlorophyll *a* concentrations and frequent resuspension of organic sediments likely contribute to measurable concentrations of VSS. In all tributaries except Little Lick Creek, more than half of VSS measurements were below reporting limits. Comparing the relatively low or undetectable VSS concentrations to TSS in the tributaries supports the idea that most of the suspended material entering the lake is not organic.

Aside from measuring VSS, particulate organic matter can also be estimated using more sensitive analytical measurements of organic carbon in the water. Measurements of dissolved organic carbon can be subtracted from total organic carbon to estimate particulate organic carbon. These are both measured as a part of the lake monitoring (see below) and we have over a year of data for the tributaries showing that the organic matter is almost entirely present in the dissolved form (around 95%). Given these more precise measurements of organic matter and the fact that VSS concentrations in Falls Lake are typically lower than what can be quantified, VSS is a parameter that could be considered for suspension as the monitoring program enters its next year.

> Carbon is considered the primary building block of all living things. For the first two years, the Monitoring Program included collection of both DOC and TOC at the Lake Loading stations. Total organic carbon (TOC) is the total amount of carbon bound in organic compounds (as opposed to inorganic forms such as carbon dioxide). Dissolved organic carbon (DOC) is the amount that can pass from a sample through a filter. 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 and characteristics of TOC can affect water treatment costs.

Figure 3.27 shows the TOC data collected at the Lake Loading and in-lake stations. Concentrations at Lake Loading stations in the lower part of the watershed (mostly downstream of Beaverdam Impoundment) 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.

The UNRBA monitoring program stopped collecting DOC from tributaries at the beginning of July 2016. Previous data showed that DOC was very tightly correlated with TOC accounting for approximately 95% of the TOC across all tributary sites. Because DOC can be accurately estimated from TOC measurements, and since it is a relatively expensive parameter to collect, Cardno recommended the UNRBA consider dropping DOC from the list of parameters collected at Lake Loading stations in FY2017. The UNRBA approved this change and this parameter was not collected after June 2016.

DWR collects both TOC and DOC at the in-lake monitoring stations. The correlation between these two parameters in the lake is not as strong as at the lake loading tributary stations. Also, collection of DOC is used along with UV Absorbance at 254nm to measure carbon-specific UV-absorbance (SUVA). SUVA provides information on the characteristics of the dissolved organic matter which is being explored for its utility in understanding treatment needs and the potential for formation of disinfection byproducts in the water treatment process.

> Humic matter (the major organic constituent of soil) dissolved in water can impart a visible tannic <u>color</u> to water which can reduce the amount of light available to algae for photosynthesis. 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 (Figure 3.28) can also be used as an indicator of color since it specifically targets the yellow or brown material typical of humic substances. Both approaches for measuring color show that color is highest on those tributaries that are slow-moving and most influenced by wetlands.

Because results from the two methods were well correlated, the UNRBA stopped using the more expensive and less precise Platinum-Cobalt method in FY2017.

> <u>UV Absorbance at 254nm</u> 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 it can be eaten by micro-organisms) and how much of the organic matter may come the watershed versus within-lake aquatic primary production. Distinction between labile and refractory carbon fractions can inform water quality modeling. UV absorbance at 254nm is presented in Figure 3.29 and indicates that humic matter is most prevalent in the tributaries with substantial wetland influence.

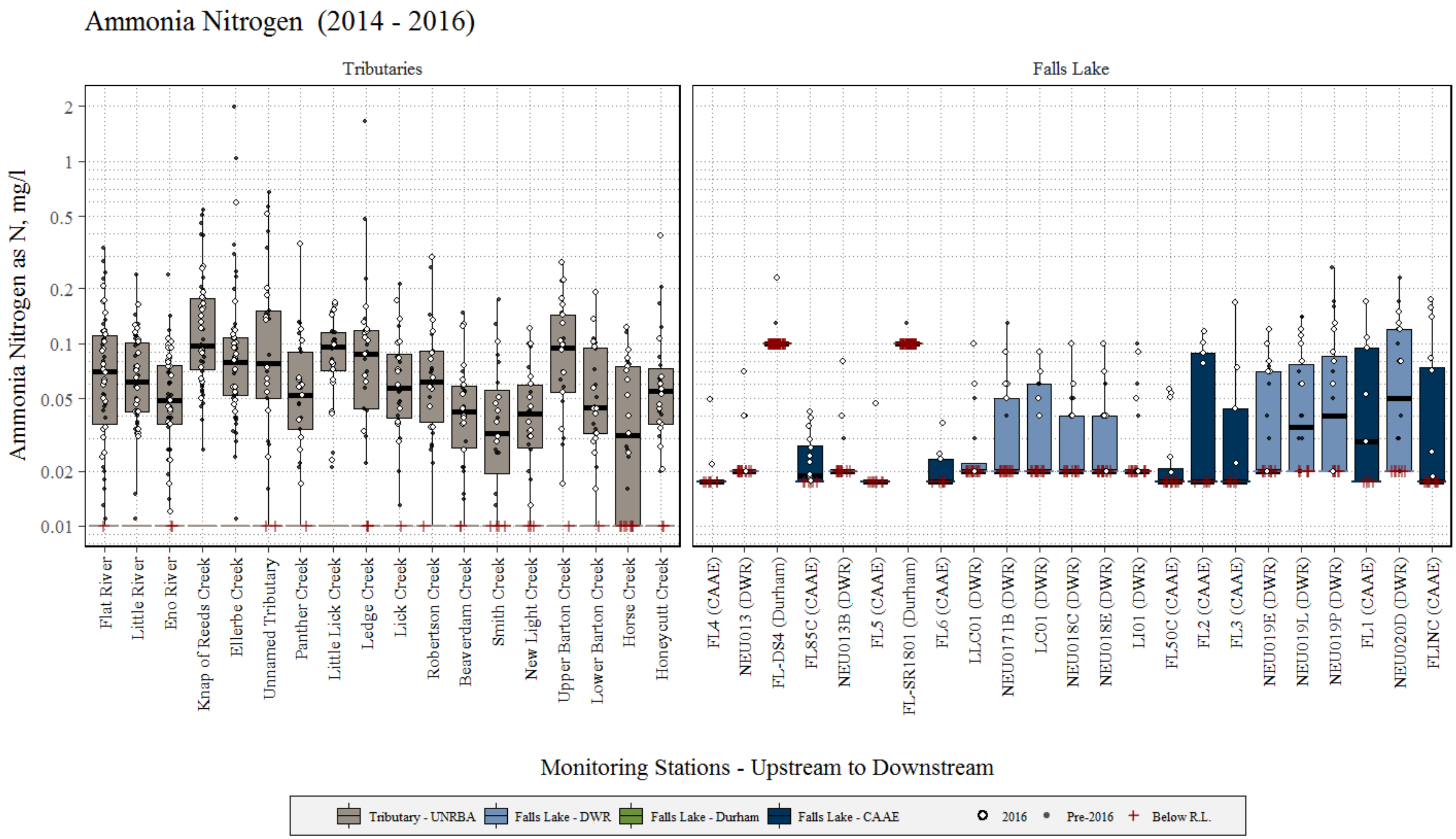

Figure 3.18 Ammonia in Lake Loading and Lake Samples from August 2014 to December 2016. In the upper stations of the lake, ammonia is rarely above detection limits, despite being downstream from tributaries often with the highest concentrations. This suggests that the ammonia entering the lake is rapidly taken up by algae. Downstream sites generally have relatively higher concentrations (though still less than detection limits > 25% of the time). Note the different reporting limits among monitoring organizations (0.1 for the City of Durham, 0.02, for DWR, 0.0175 for CAAE, and 0.01 for UNRBA).

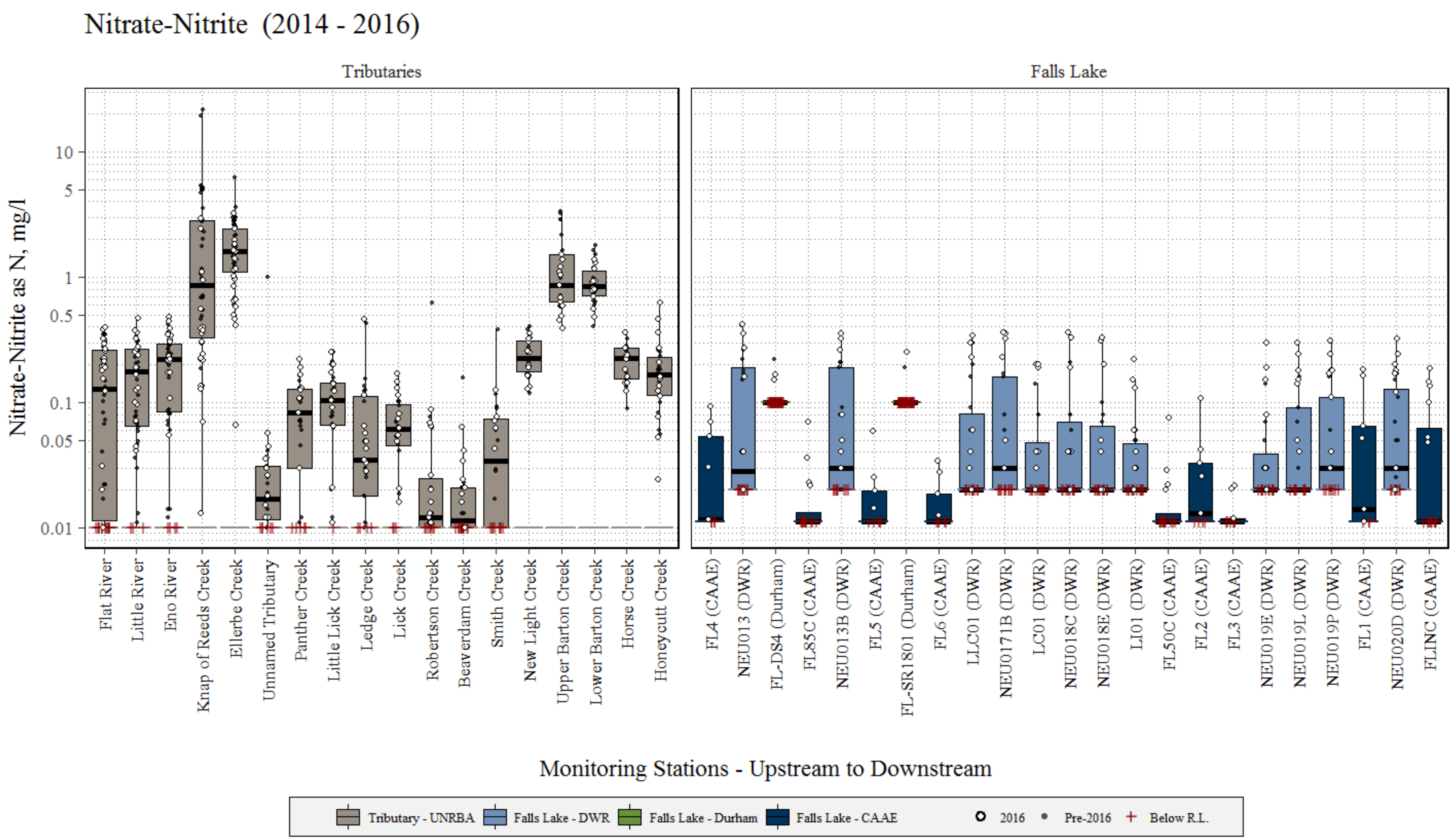

Figure 3.19 Nitrate plus Nitrite in Lake Loading and Lake Samples from August 2014 to December 2016. Concentrations of nitrate plus nitrite are highest at tributary stations downstream of major wastewater treatment plants and small package plants. As with ammonia, concentrations within the lake are generally lower than in the tributaries, suggesting this resource is quickly assimilated by algae. Different monitoring organizations have different laboratory reporting limits as seen by the different locations of the red symbols. Each red symbol indicates an observation below the respective laboratory reporting limit.

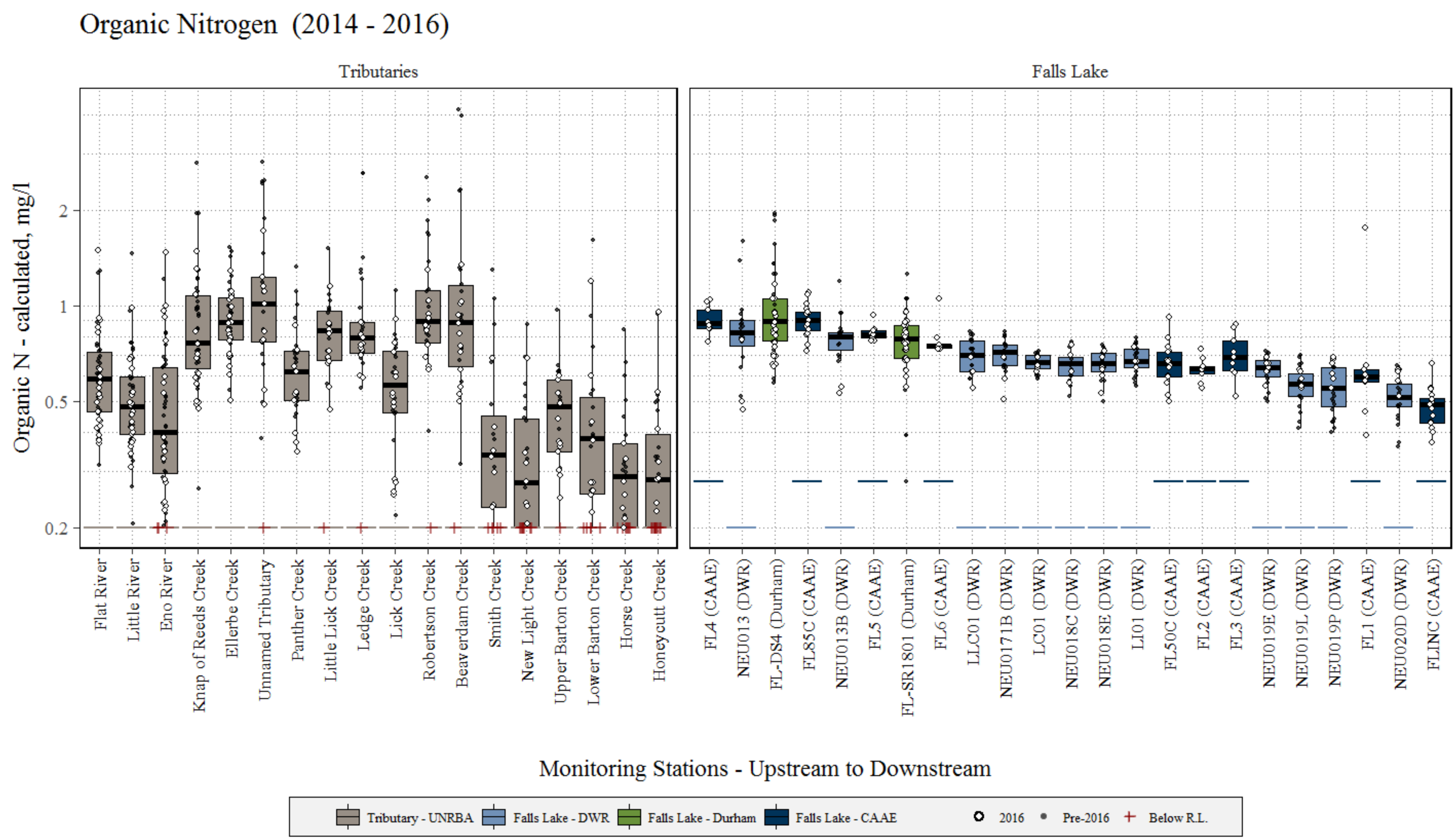

Figure 3.20 **Organic Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2016.** Tributary concentrations of organic nitrogen are highest downstream of the major WWTPs and sites often observed to have stagnant or slow-moving water conditions (Robertson and Beaverdam Creeks and the Unnamed Tributary). In the lake, median organic nitrogen concentrations decline from the upper end to near the dam in an amount which predictably corresponds to a decline in median chlorophyll *a* concentrations. The City of Durham data represent observations from the growing season only (April through October).

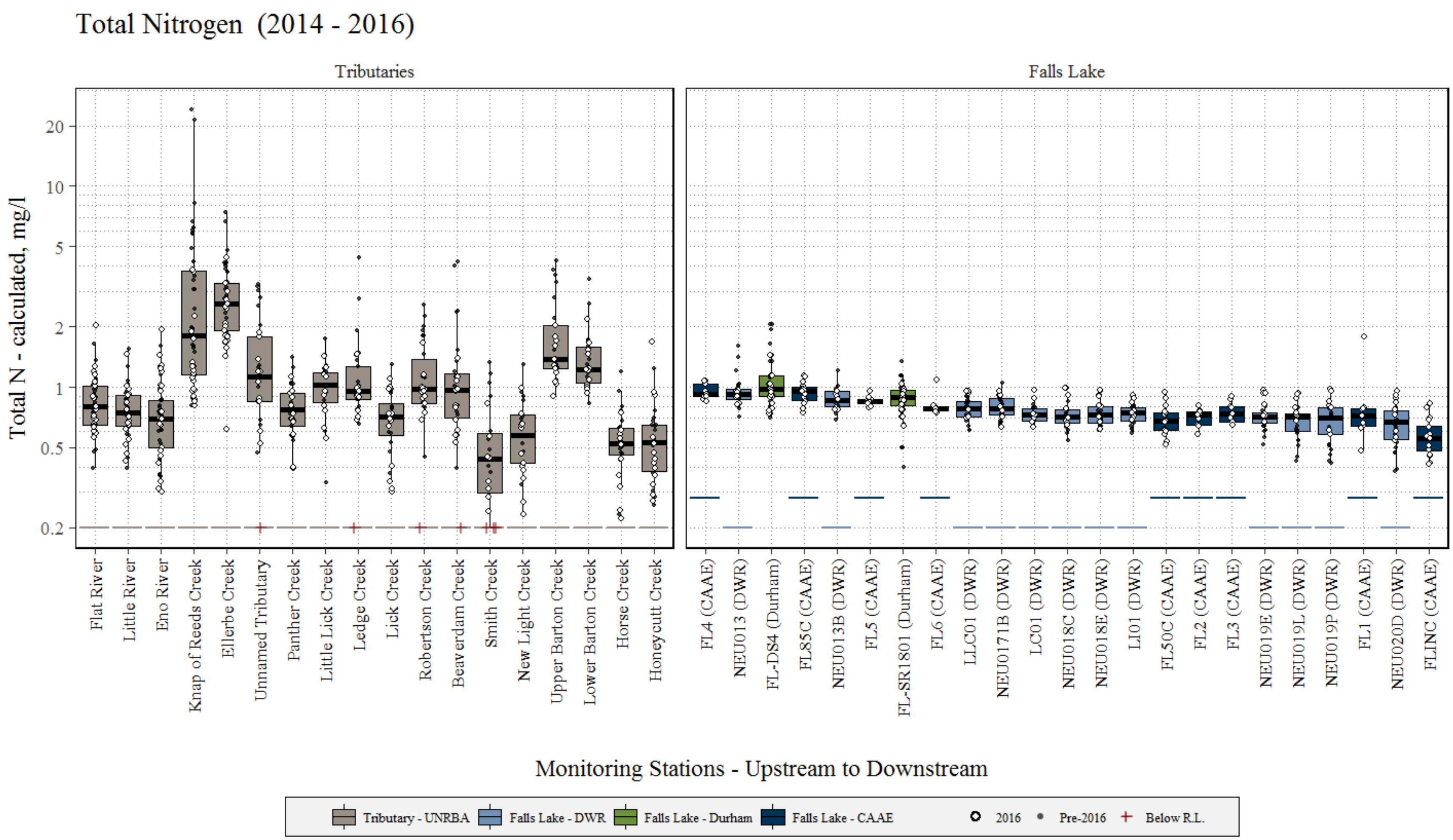

Figure 3.21 **Total Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2016.** Total nitrogen concentrations in tributaries are greatest downstream of major WWTPs and package plants, and in areas often observed to have slow moving or stagnant conditions. In these slow moving areas, the nitrogen is primarily in the form of organic nitrogen. Within the lake, total nitrogen decreases from upstream to downstream. The City of Durham data represent observations from the growing season only (April through October).

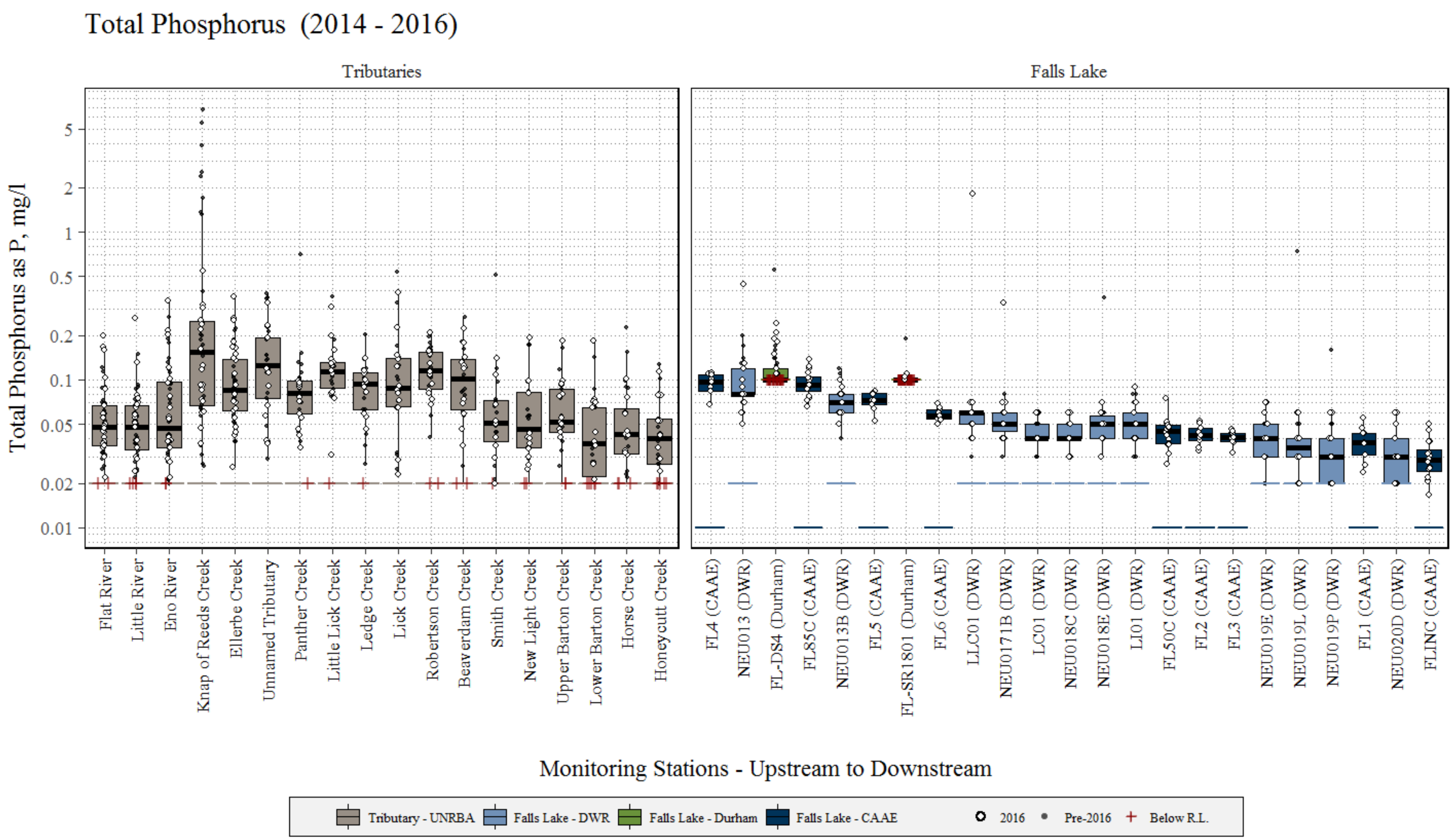

Figure 3.22 Total Phosphorus in Lake Loading and Lake Samples from August 2014 to December 2016. Like total nitrogen, TP concentrations in tributaries are greatest downstream of major WWTPs and in areas often observed to have slow moving or stagnant conditions. Within the lake, total phosphorus decreases from upstream to downstream. The City of Durham data represent observations from the growing season only (April through October) and also have a higher reporting limit than DWR and CAAE laboratories.

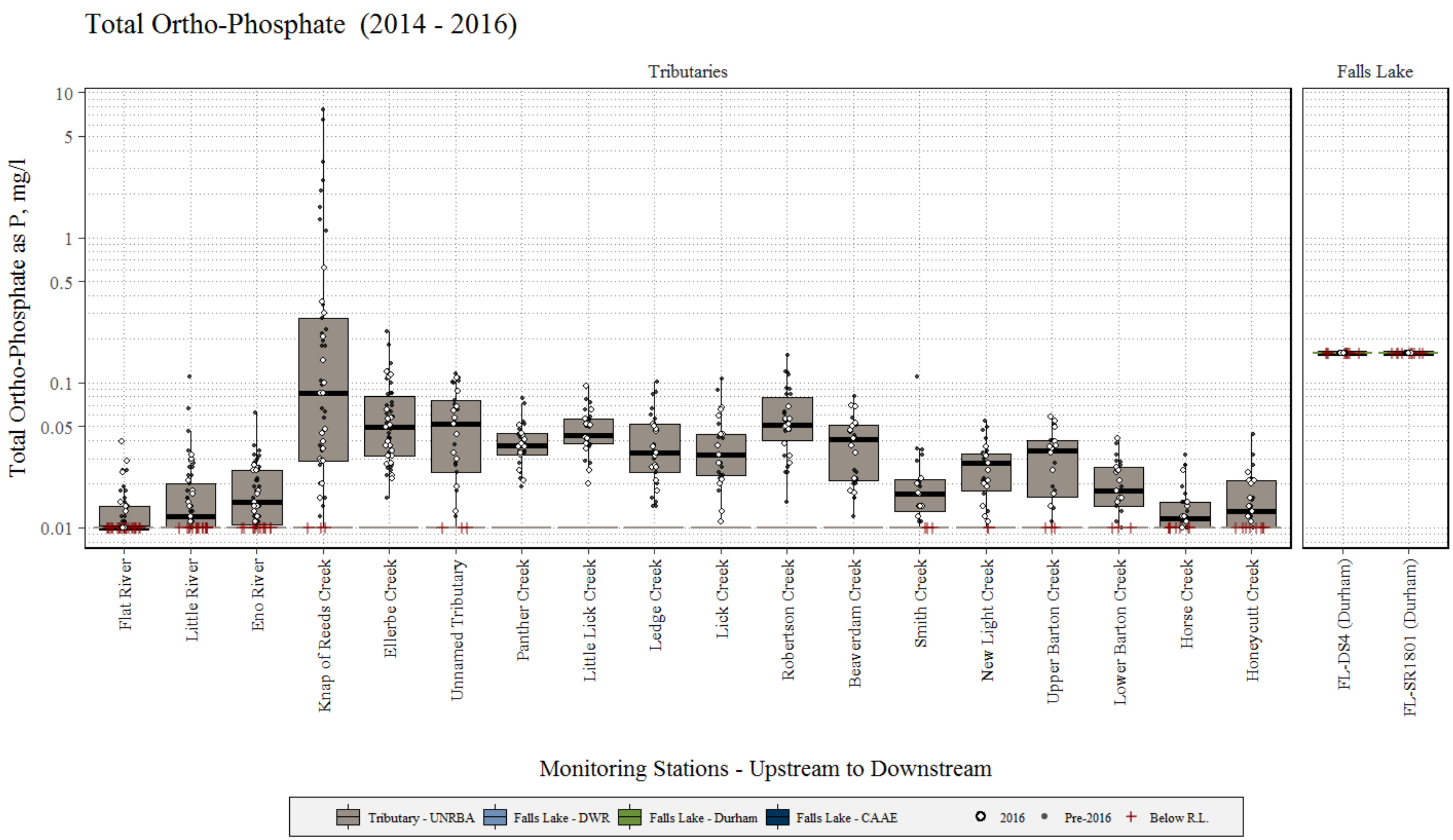

Figure 3.23 **Ortho-phosphate in Lake Loading Samples from August 2014 to December 2016.** Ortho-phosphate tends to be highest downstream from WWTPs, package plants, and wetland areas. Lake samples are only available for the City of Durham (April through October), and all of their measurements fall below their reporting limit of 0.16 mg/L. DWR does not collect ortho-phosphate data from the lake because results from prior years were mostly below their detection limit of 0.02 mg/L.

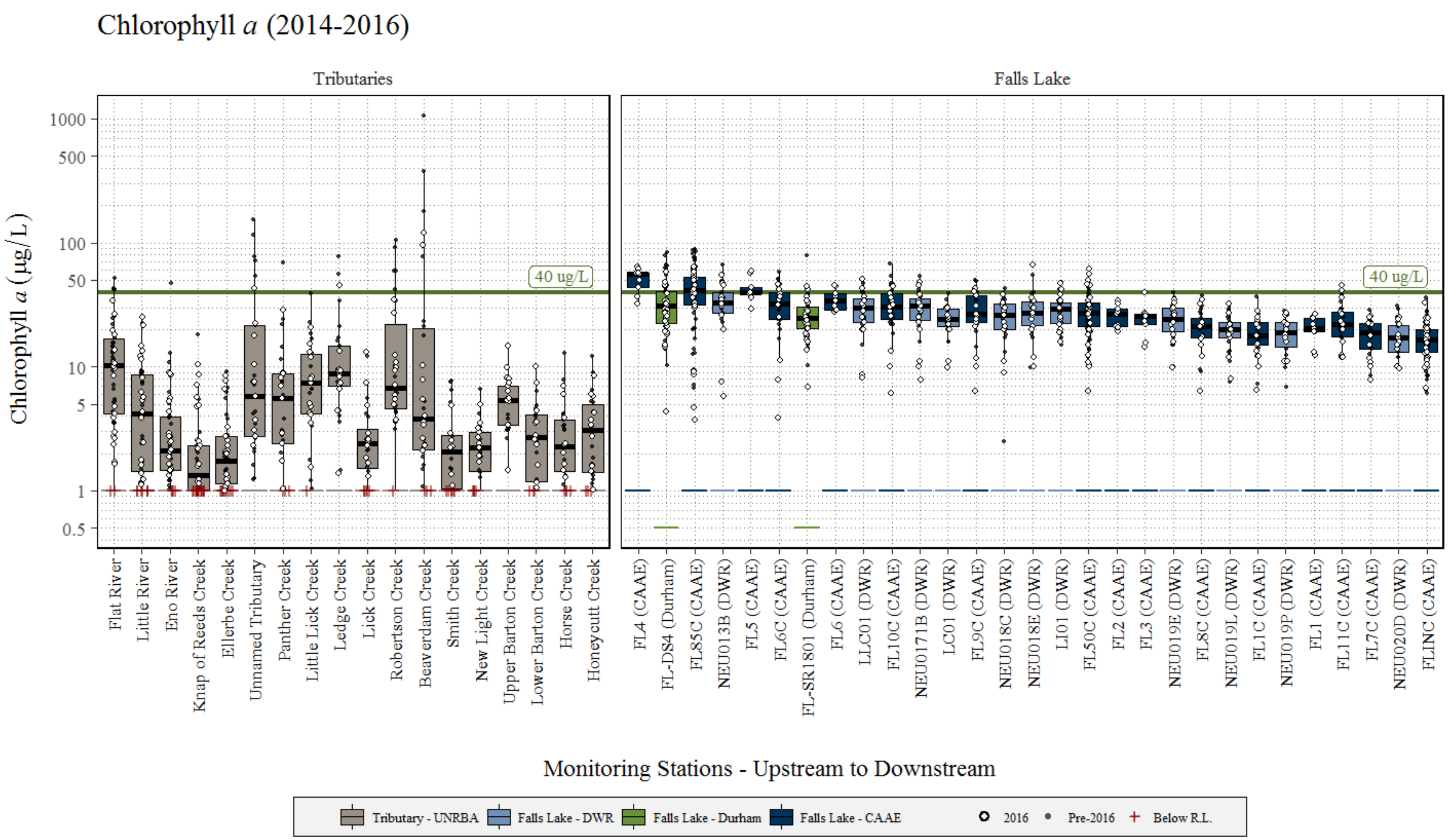

Figure 3.24 **Chlorophyll *a* in Lake Loading and Lake Samples from August 2014 to December 2016.** Median chlorophyll concentrations in the tributaries are lower than those measured at the in-lake sites. Streams, unlike reservoirs, generally do not support large populations of free-floating algae. Most algae in streams is found attached to rocks and woody debris and is not normally collected within a chlorophyll *a* sample. In 2016, just four tributary measurements were above 40 µg/L (1.5% of samples). Within the lake, chlorophyll *a* concentrations decrease from the upstream to the downstream end. Of 315 observations collected by DWR and CAAE below Highway 50 and within the main channel of the reservoir, none exceeded 40 µg/L. Of 29 observations in tributary arms of the lake below Highway 50, only two (7%) were above 40 µg/L (downstream of Lower Barton Creek, CAAE-FL11C).

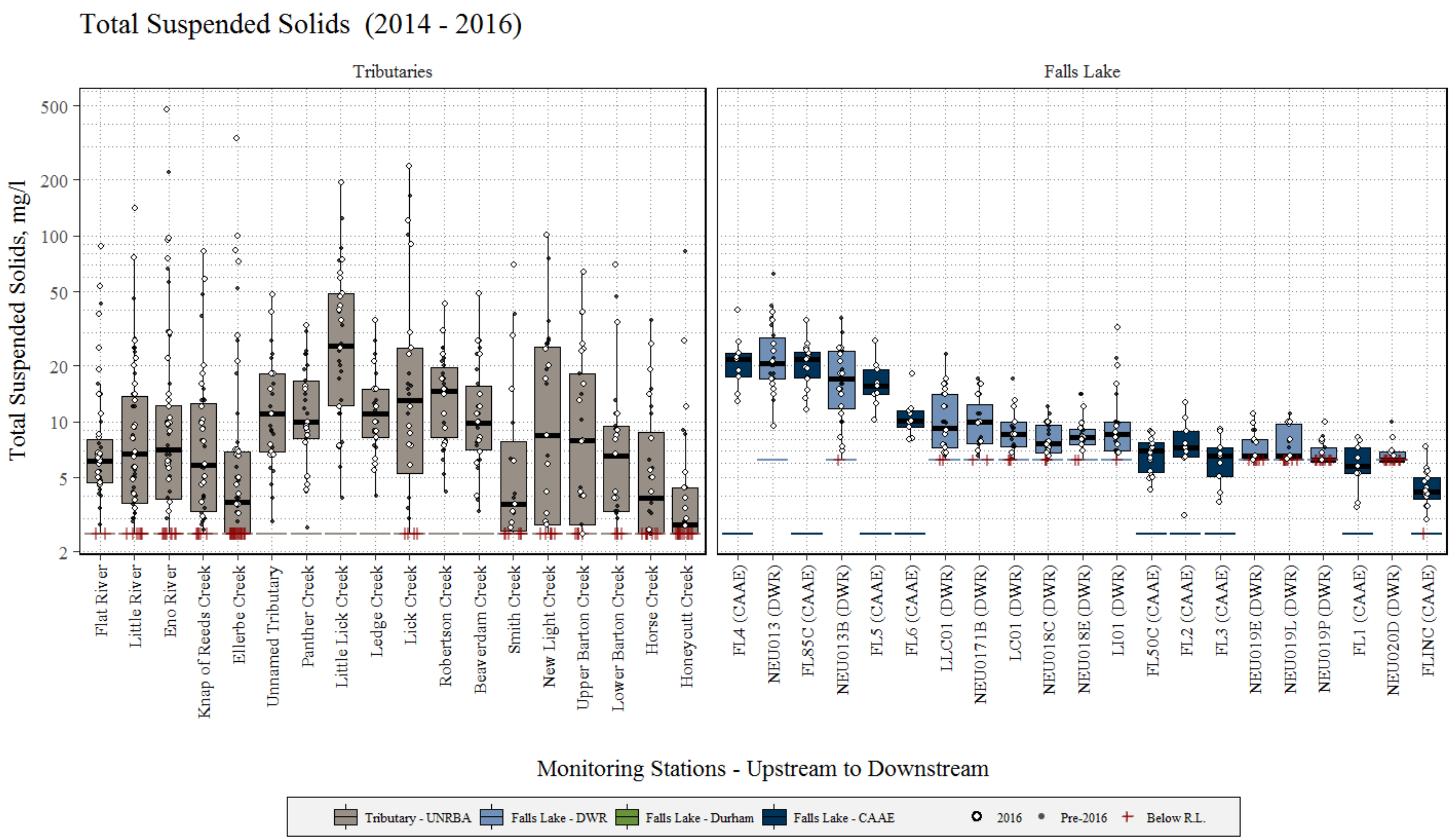

Figure 3.25 **Total suspended solids (TSS) in Lake Loading and Lake Samples from August 2014 to December 2016.** Tributaries have larger ranges of TSS concentrations than the lake sites largely due to variable flow conditions. The wide and shallow shape of the upper lake provides for frequent resuspension of sediment. TSS declines as water moves downstream due to sedimentation and a deeper, narrower channel which inhibits resuspension of sediments once deposited to deeper water.

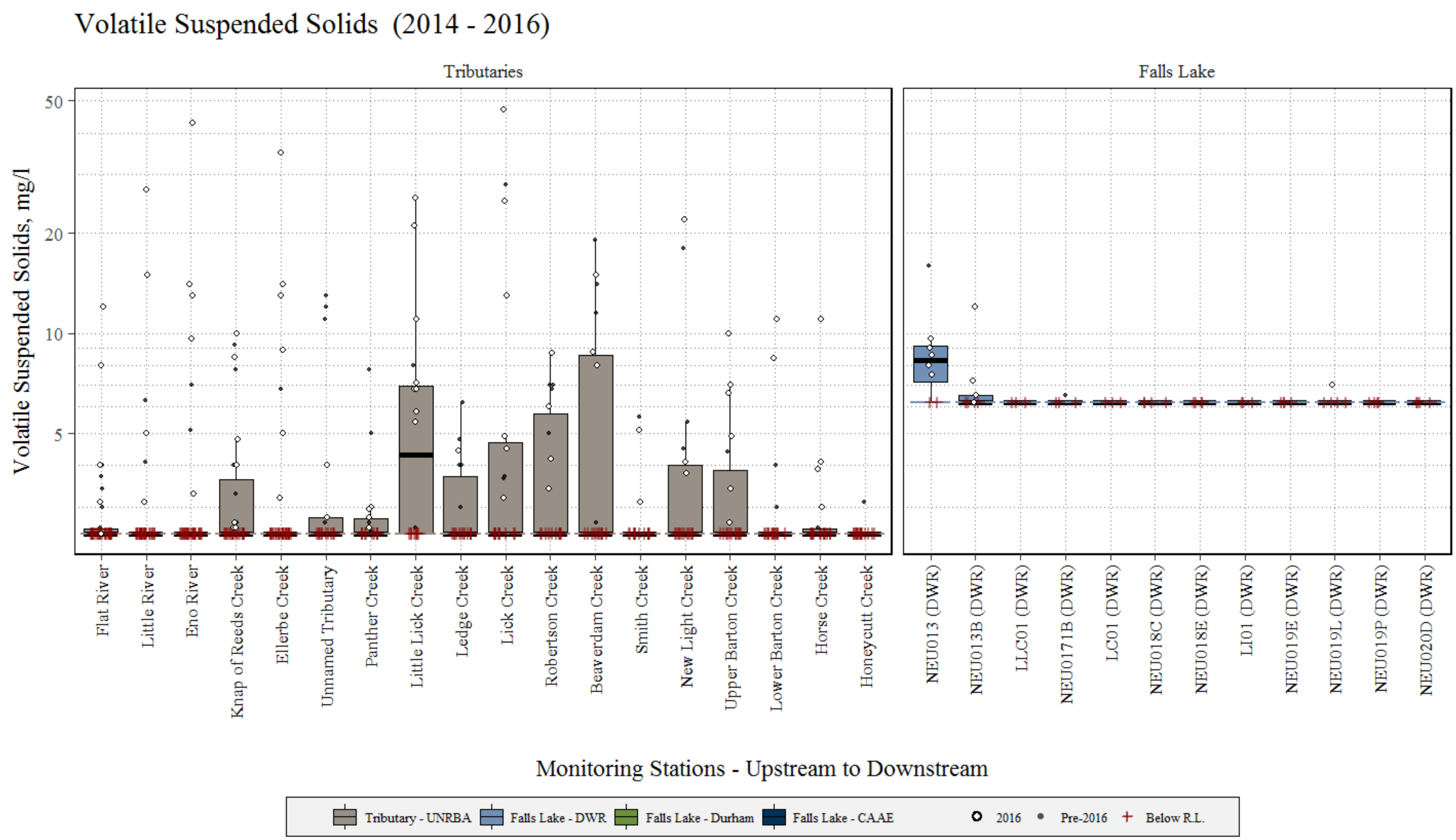

Figure 3.26 **Volatile suspended solids (VSS) in Lake Loading and Lake Samples from August 2014 to December 2016.** VSS is typically below DWR's quantitation limit in lake samples except for the site near Interstate 85. Here, chlorophyll *a* concentrations and resuspension of organic sediments likely contribute to elevated VSS. In all tributaries except Little Lick Creek, more than half of VSS measurements were below reporting limits. The VSS method is insensitive to the relatively small amounts of particulate organic matter usually present within Falls Lake and its tributaries.

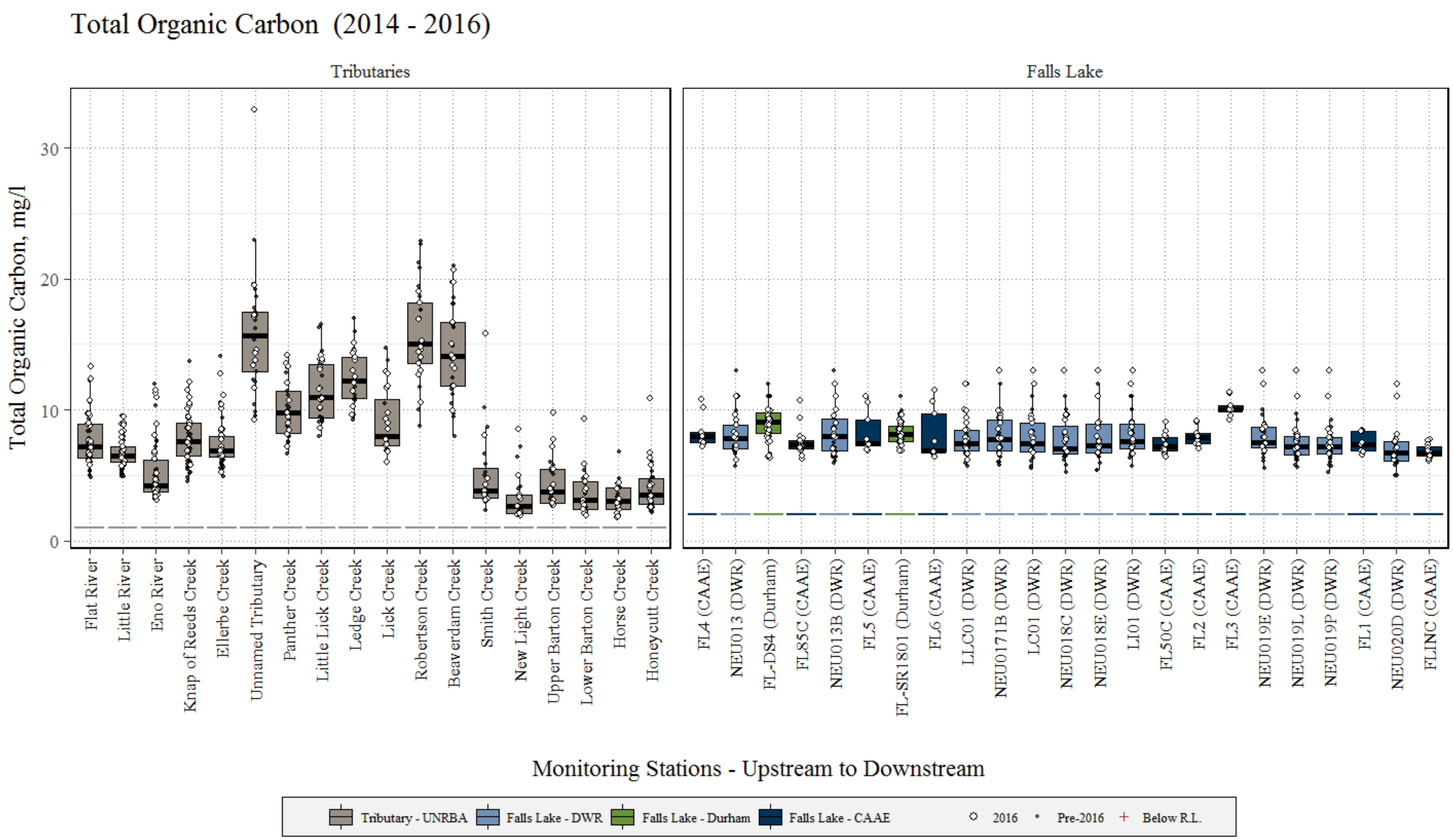

Figure 3.27 Total Organic Carbon (TOC) in Lake Loading and Lake Samples from August 2014 to December 2016. TOC is a measurement of the total organic carbon in a water sample—living and non-living, particulate and dissolved. TOC within the lake is much less variable among sites than it is among tributary sites, where TOC is generally highest downstream of wetland, sluggish waters and lowest in fast-moving waters. The City of Durham data represent observations from the growing season only (April through October).

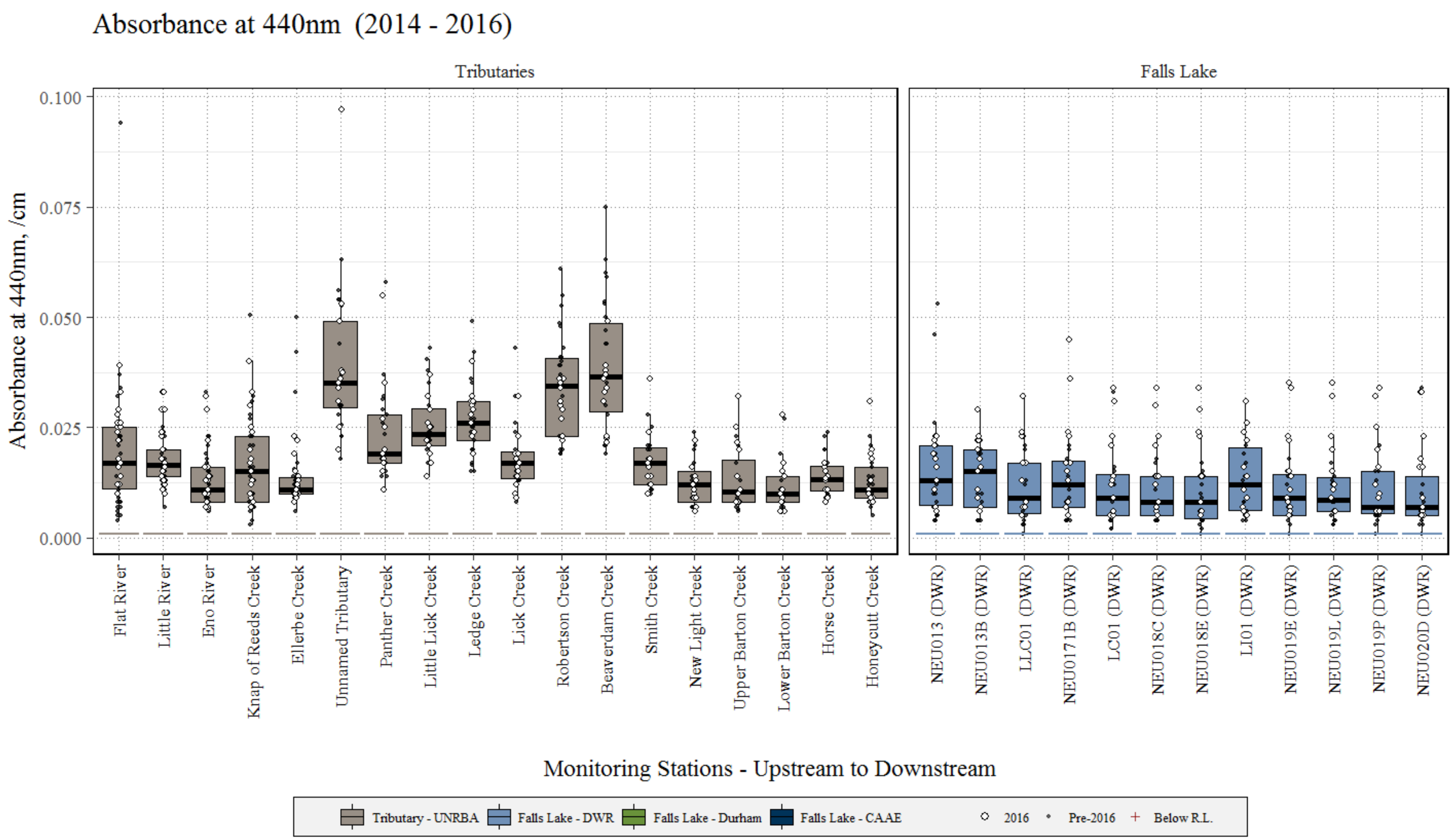

Figure 3.28 **Color (absorbance at 440nm) in Lake Loading and Lake Samples from August 2014 to December 2016.** Absorbance is a measure of how darkly colored the water is. This can be important in understanding how light penetrates the water column and influences availability for photosynthesis. Among tributary sites, those areas in or downstream from wetlands have higher absorbance indicating a darker, or more brown-colored water. Among lake sites, there is a slight declining trend from upstream locations to downstream locations, indicating clearer water (and deeper light penetration) near the dam than at I-85.

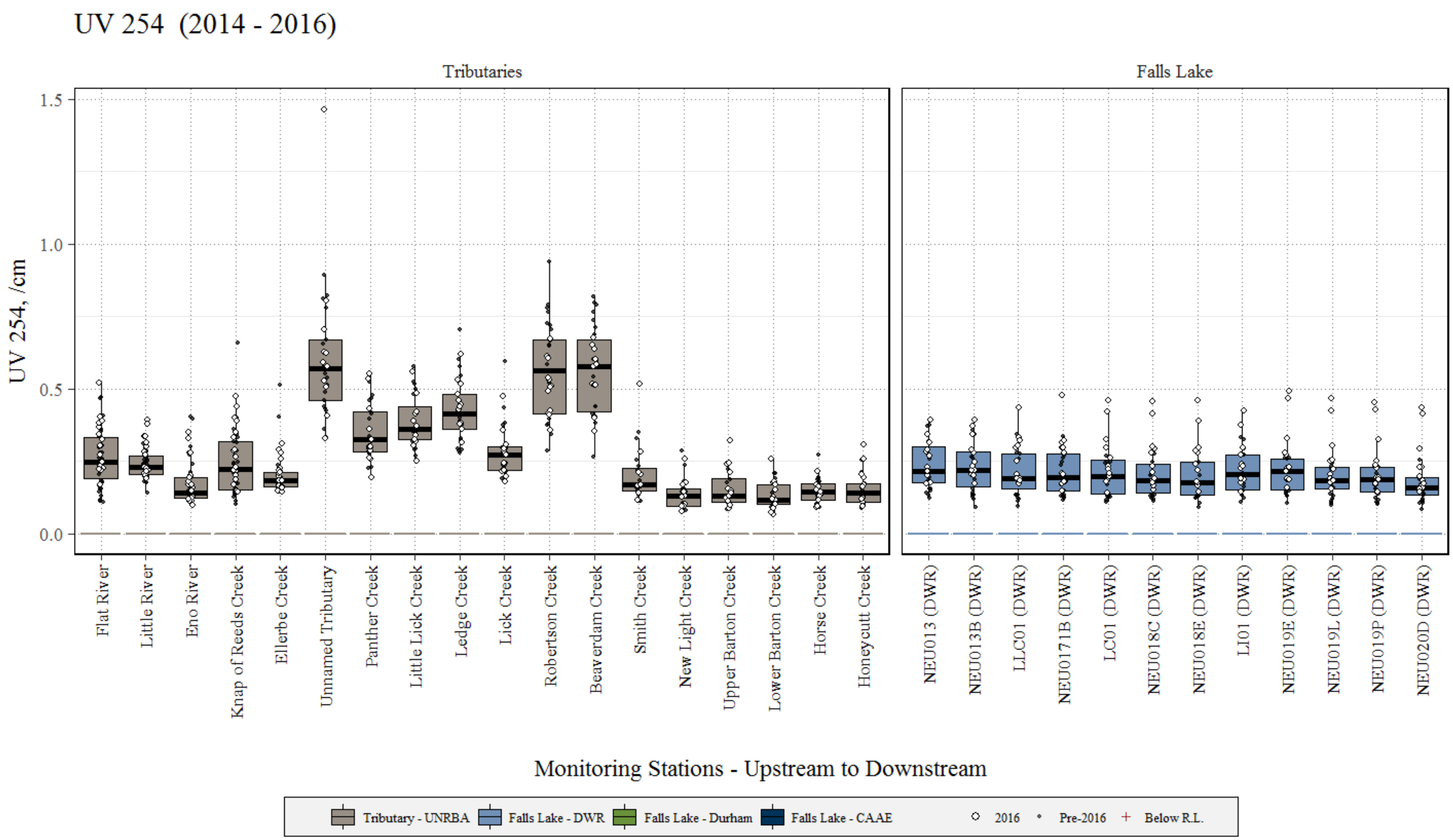

Figure 3.29 **Absorbance at 254nm in Lake Loading and Lake Samples from August 2014 to December 2016.** UV absorbance follows a similar pattern to absorbance at 440nm with highest values downstream from wetland or slow-moving sites. Values within the lake show a slight downward trend from upstream to downstream locations. This measurement is used in conjunction with DOC values to measure the Specific UV Absorbance (SUVA).

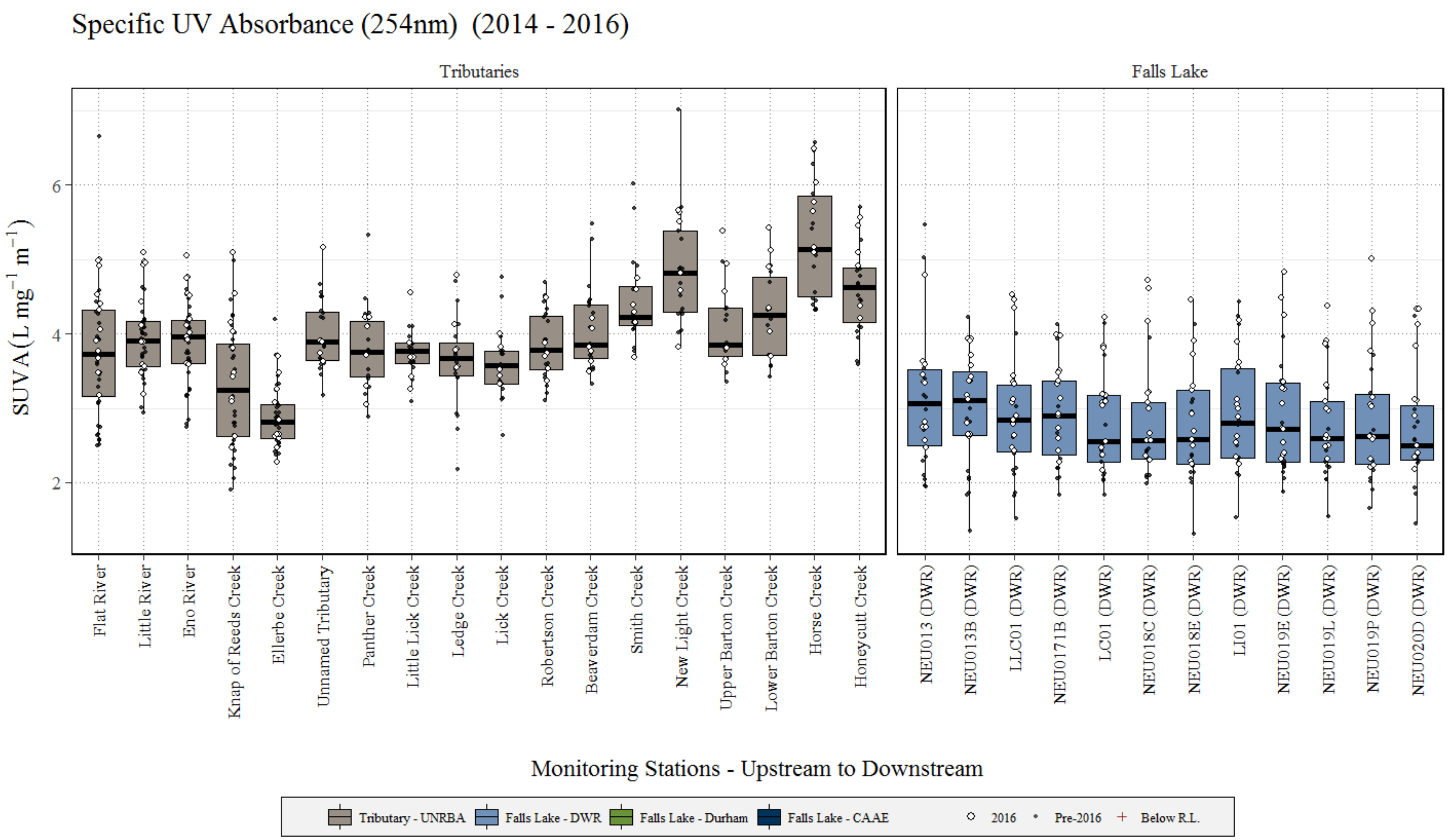

Figure 3.30 Specific UV Absorbance in Lake Loading and Lake Samples from August 2014 to December 2016. Specific UV Absorbance is a metric of the molecular complexity of the dissolved organic matter in a water sample which reflects how easily it can be digested by microorganisms. It is also correlated with the potential formation of disinfection by-products from water treatment. The SUVA in the lake samples is lower (less complex forms of organic matter), consistent with algal production being a major source of this material. Tributaries tend have higher (more complex) values, consistent with older, refractory terrestrial organic matter, although sites downstream from wastewater treatment plants also have lower values.

> Algal Assemblage Data Collected by DWR.

In addition to water quality measurements, DWR also conducts evaluations of algal assemblages from three locations in Falls Lake to assess changes over time (year-to-year and month-to-month). DWR has provided this data set and it is included in the UNRBA database. This section is primarily intended to provide a graphical overview of this dataset which shows the kind of information available rather than an in-depth analysis of algal dynamics in Falls Lake.

Figure 3.31 through Figure 3.33 show the estimated biovolume data for eight algal groups at the upstream (NEU013B), midlake (NEU018E), and downstream (NEU019P) monitoring stations. The figures illustrate the substantial differences among these phytoplankton groups with respect to estimated biovolume, as well as the dynamic shifts in abundance within most of the groups through time. Visual comparison across the figures shows variation within the same algal group from one location in the lake to another, indicating that algal abundance is not uniform among segments of the lake at a given time. For all three locations, the three taxa with the largest estimated biovolume are Blue-green Algae, Diatoms, and Prymnesiophytes (haptophytes). Aside from the chlorophyll *a* present in the algae, there are no regulatory standards or formal guidance regarding algal biovolumes in North Carolina. At least some of these data may provide value for the lake modeling efforts, since EFDC has algorithms to simulate production of diatoms, and blue-green and green algae. Analysis of algal dynamics as related to various water quality parameters may reveal relationships that could be of interest during the empirical modeling efforts as well.

Figure 3.31 Algal Biovolumes at Station NEU013B (near Interstate 85). Clear seasonal cycles of blue-green algal biovolume are apparent at this station. Samples are collected monthly and only samples with these taxa present are shown—a data point on this figure means the taxa was present. The vertical scale is held constant for each algal group and across all three stations (Figures 3.31 through 3.33) for ease of comparison.

Figure 3.32 Algal Biovolumes at Station NEU018E (mid-lake, just upstream of where Lick Creek joins Falls Lake). Annual cycles of elevated summer and fall blue-green algae populations are apparent in this figure. The vertical scale is held constant for each algal group and across all three stations (Figures 3.31 through 3.33) for ease of comparison.

Figure 3.33 Algal Biovolumes at Station NEU019P (just upstream of where Upper Barton Creek joins Falls Lake). The vertical scale is held constant for each algal group and across all three stations (Figures 3.31 through 3.33) for ease of comparison.

3.2.3 Tributary Loading

The figures previously presented display results in terms of the concentrations present at the time of measurement. Concentrations, however, are not indicative of how much of a 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 (i.e. mass delivered) which depends on both concentration and the volume of water delivered by each tributary.

Figure 3.31 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 constituent concentrations is greatest when they occur on tributaries delivering the most water to Falls Lake. Elevated concentrations on small tributaries could contribute to localized regions of higher concentrations near stream outlets.

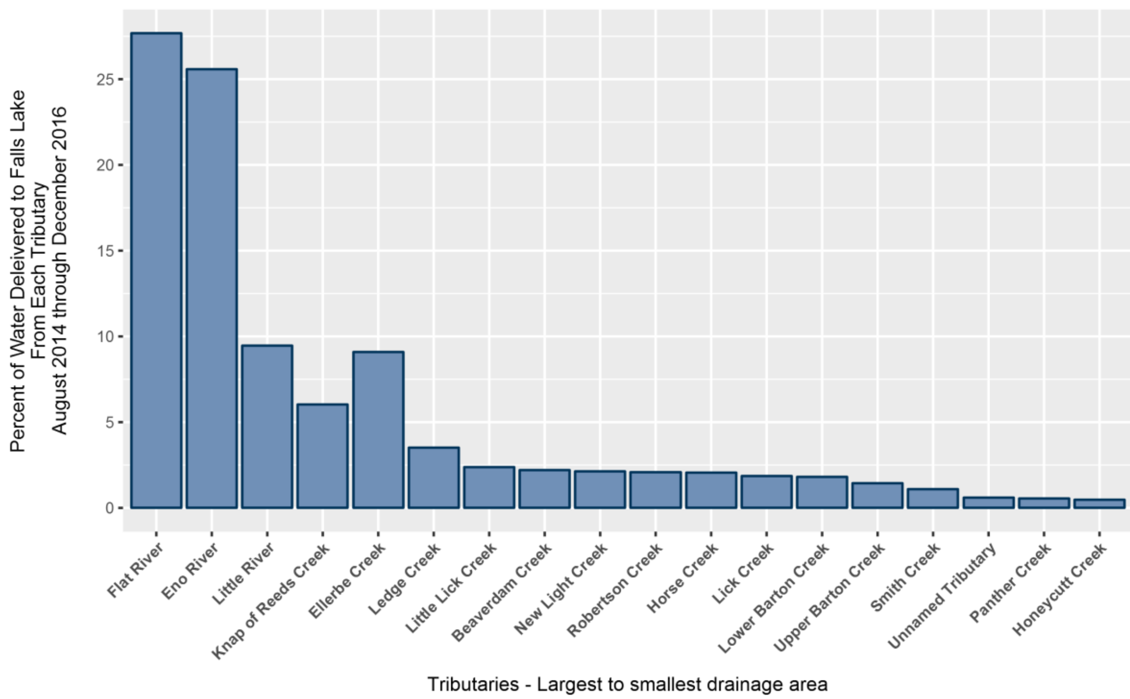

Figure 3.31 The Contribution of each Tributary to the Total Water Load to Falls Lake during the Monitoring Period of August 2014 through December 2016. The contribution is provided as the percentage of total water delivered to Falls Lake coming from each tributary. Tributaries are ordered from largest 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. 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 represent relationships between concentration and flow. The ultimate choice of load estimation method will depend on what is best supported by the data itself and will be evaluated as a component of the modeling process.

4 Special Studies Status

4.1 High Flow Sampling

High flow sampling events are intended to measure water quality during elevated flows not typically captured by Routine Monitoring. These events can contribute relatively large volumes of water to Falls Lake and thus perhaps large loads of nutrients. 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, such as monthly monitoring, instead of flow intervals.

The Flat, Eno, and Little Rivers and Knap of Reeds and Ellerbe Creeks together contribute nearly 80 percent of the water delivered to Falls Lake. During the first two years of the UNRBA Monitoring Program, 50 to over 70 percent of samples were collected during flow conditions which represent just 20 percent of the water delivered to Falls Lake. In the 2015 Annual Report, Cardno recommended an expanded high flow sampling special study to target high flows in these five tributaries approximately monthly, when conditions permit. The UNRBA approved this change and this special study was expanded beginning in July 2016.

Between July and December 2016, just three out of the six months had flow conditions and timing which had sampleable high flow conditions. Samples were collected at Flat River and Ellerbe Creek in August and at all five of the largest tributaries in September and October. Samples were also collected at Honeycutt, Lower Barton, Upper Barton, Little Lick, and Lick Creeks during the October sampling event following Hurricane Matthew. Data from these events are stored in the UNRBA database as targeted high flow samples and will be used in the development of the watershed models and will allow the calibration of models to include these influential periods of high flow.

4.2 Constriction Point Study

Constriction point sampling events were conducted in January and October 2016. Water velocity and water quality data were collected at the I-85 and the Hwy 50 bridge crossings during both events. The results of the January 2016 event were presented in the 2015 Annual Report available online at https://www.unrba.org/monitoring-program. Results of the second event are presented below. Hydrodynamics form the backbone of lake-response models like the EFDC model and the water velocity data collected as part of this effort will provide a way to verify the performance of the hydrodynamic models and will add confidence in the model outcome. Water quality data from these events will be used to inform development and calibration of the lake response models with respect to temporal patterns; however, these data were not collected as photic zone composite samples and are likely not temporally independent and therefore are not intended to be used for regulatory assessment purposes.

Velocities through the constrictions were measured 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. The standard deviation among four to six replicate ADCP transects during each sampling day is also provided. ADCP measurements were conducted between 10:00 and 11:00 AM at Highway 50 and between 13:00 and 14:00 at I-85. Discharges from the dam are the average values for each day with the standard deviation among measurements recorded every 15 minutes at the USGS gage.

Table 4.1 Discharge at Falls Lake through Two Constrictions and Released from the Dam. ADCP values are the averages and standard deviation of four to six replicate measurements Discharge from the dam is the average and standard deviation of values recorded every 15 minutes at USGS gage 02087183.

Date	Discharge measured via ADCP (cfs)		Falls Lake Dam
	Interstate 85	Highway 50	(USGS 02087183)
October 21, 2016	1146 ± 105	1241 ± 74	2096 ± 1659
October 25, 2015	995 ± 106	2311 ± 187	3704 ± 125
October 28, 2016	603 ± 102	2445 ± 143	3641 ± 113
November 1, 2016	-135 ± 110	1753 ± 158	1955 ± 639

For these events, daily flow rates through the constrictions were also estimated based on changes in lake surface elevation, rainfall amounts, tributary inflows, and evaporation estimates. 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. Additionally, ADCP results which corroborate mass balance calculations provide validation that models can predict flow through these constriction points with reasonable accuracy.

Figure 4.1 compares the measured discharge to mass balance estimates. ADCP measurements of discharge through the I-85 and Highway 50 constriction points are shown as black triangles and gaged outflow at the dam is also shown as black triangles in the bottom panel. Daily average estimates of discharge using the water mass balance approach are shown as colored circles, joined by solid lines, and surrounded by a shaded uncertainty region based on typical USGS gage error, spatial variation in rainfall measurements, and in the basin proration technique for estimated stream flow. Additional uncertainty resulting from bathymetry approximations contributes some error, but it is not quantified. The bathymetric mapping study currently underway will provide better approximations of the change in water storage with water surface elevation changes. Variability in the ADCP measurements (i.e., the range observed over the four to six repeated measurements) is shown as a vertical, colored line across each triangle). Based on both the January and October events in 2016, ADCP measurements of discharge closely match estimates based on water mass balance ($R^2 > 0.9$, $p < 0.0001$).

In addition to measuring the water movement through the constrictions, water samples were also collected to characterize water quality and the movement of nutrients, suspended solids, and chlorophyll moving through the constrictions at times of high flow. In contrast to the once per month routine sampling of Falls Lake, these data provide information on short-term changes in water quality as well as spatial variation over relatively short distances. This information will be used during the model development and calibration process. Water samples were analyzed for total organic carbon, total suspended solids, total phosphorus, total Kjeldahl nitrogen, ammonia, nitrate plus nitrite and chlorophyll *a*. Figure 4.2 contrasts the water quality results from the two constriction locations.

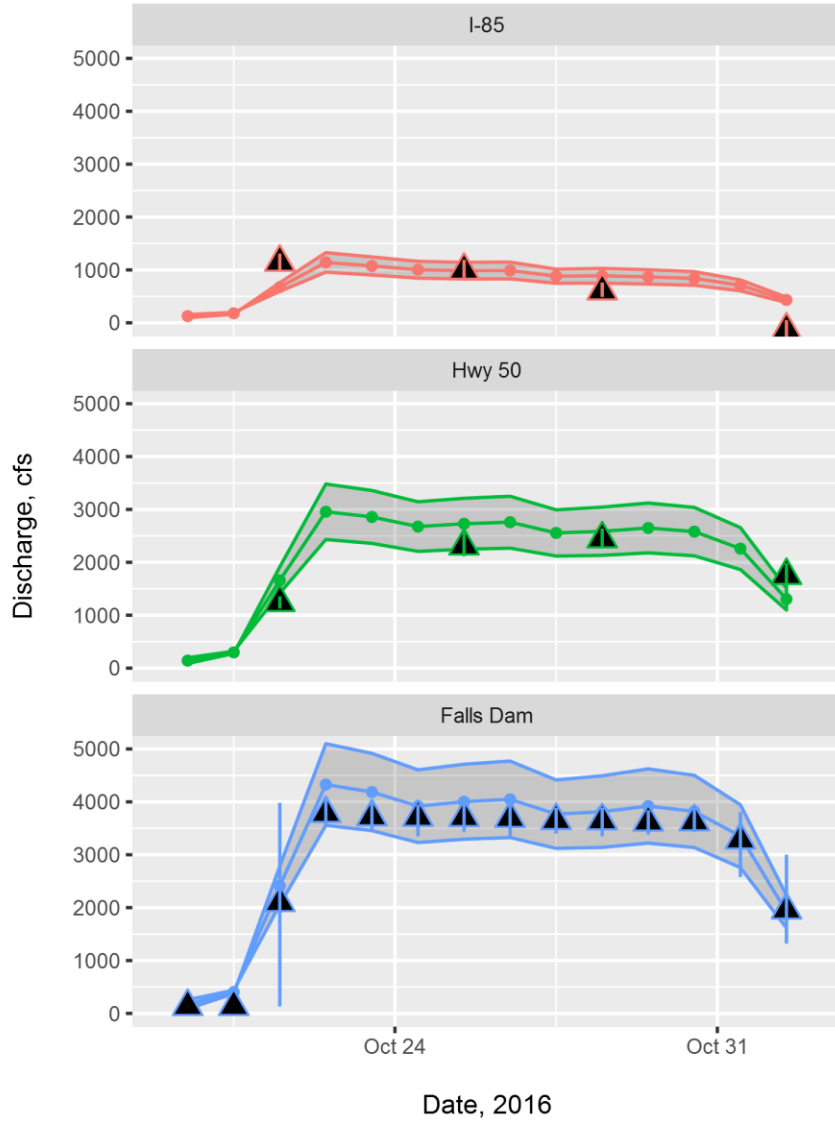

Figure 4.1 Comparison of Estimated and Measured Discharge for the October Constriction Point Study for Hwy 50 and I-85. For the I-85 and Hwy 50 constrictions, black triangles represent ADCP measurements with the range of four to six repeated measurements shown as vertical lines. For the Falls Dam panel, triangles represent the average observed flow from the USGS with the daily range shown as vertical lines. Mass-balance estimates of daily average discharge and associated uncertainty are shown as solid circles and a shaded region.

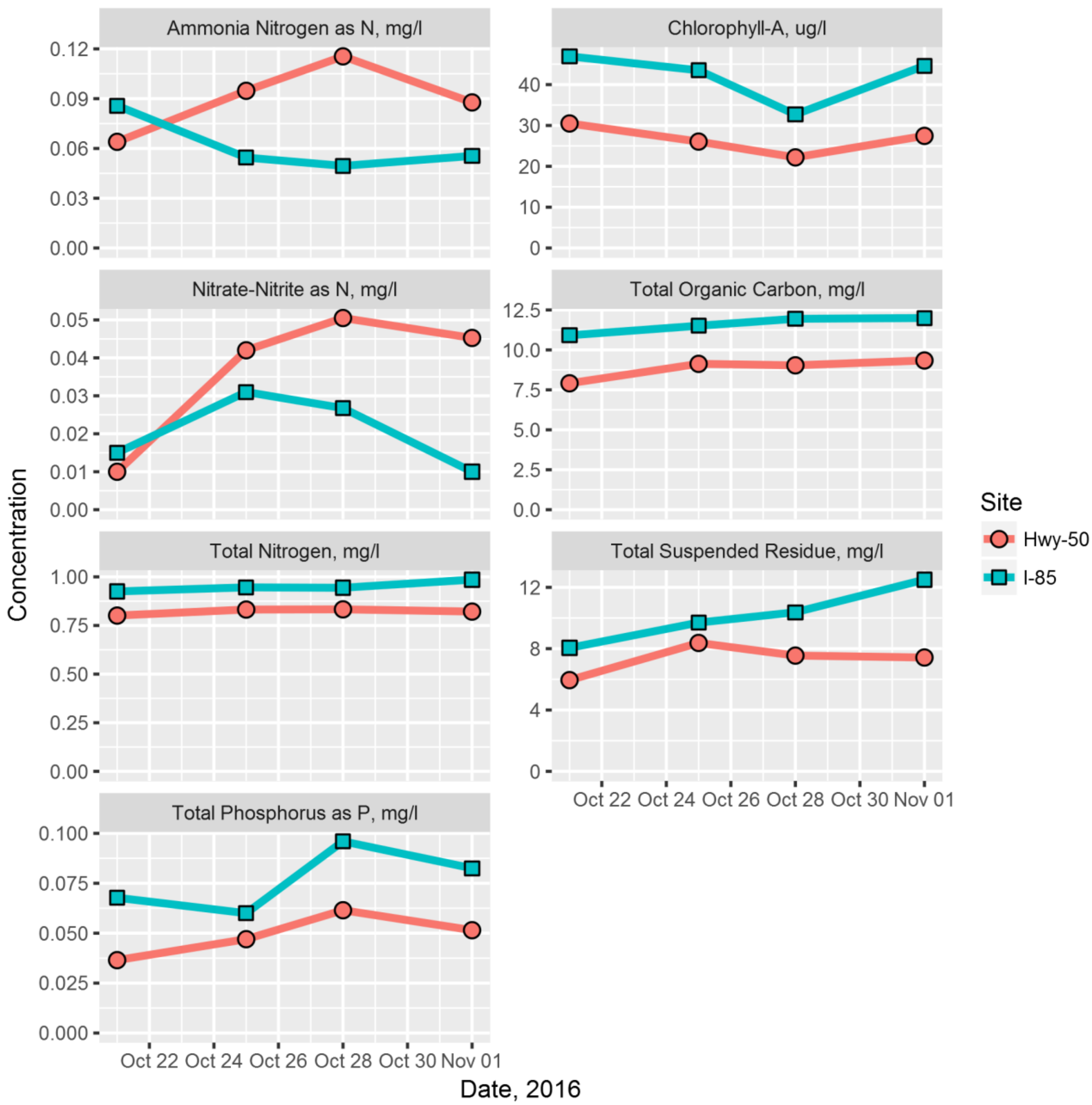

Figure 4.2 Water Quality from two constriction points following Hurricane Matthew (October 2016). Values shown are the averages of two samples collected at 1 meter depth along the width of the constriction. Total nitrogen, total phosphorus, total organic carbon and total suspended residue all appear to either hold steady or increase modestly during the time following Hurricane Matthew with concentrations slightly higher upstream at I-85 than at Hwy 50.

4.3 Lake Sediment Evaluation

When compared to the estimated nutrient loads used in the state's EFDC model, results from benthic flux chamber measurements made by DWR in 2006 suggest that nutrient releases from the sediment could account for a significant proportion of the nutrients supporting algal growth. However, these data were limited to one measurement at each of two locations in Falls Lake and these measurements differed by a factor of two. Because of this limited dataset, DWR's EFDC model assumed that nutrient releases (fluxes) from the sediments were identical throughout the lake. Because of the lack of benthic flux data, large difference between the two existing measurements, and unknown spatial patterns all coupled with the potential significance of this nutrient source for algal growth, the UNRBA funded a special study to narrow this knowledge gap. The Sediment Evaluation study provides funding to work with Dr. Marc Alperin from the University of North Carolina to collect data to assess model assumptions and to support a more sophisticated representation of this nutrient source in model development if necessary. 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 near 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 4.3). At several monitoring locations, lateral variability was captured via two to three cores, one taken from the deepest part of the pre-dam river channel and one or two cores spaced 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 samples have been 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 have been analyzed for ammonia, phosphate, and nitrate plus nitrite. Using this data, Dr. Alperin has calculated preliminary sediment flux estimates and has found that, in some locations, 'bio-irrigation' or tunnels produced by organisms living in the sediment can provide an accelerated pathway for nutrients to enter the water column from the sediment. This finding has led Dr. Alperin to further extend his analysis to include modeling of this 'bio-irrigation' effect and this modeling is still underway. A final report from Dr. Alperin is forthcoming.

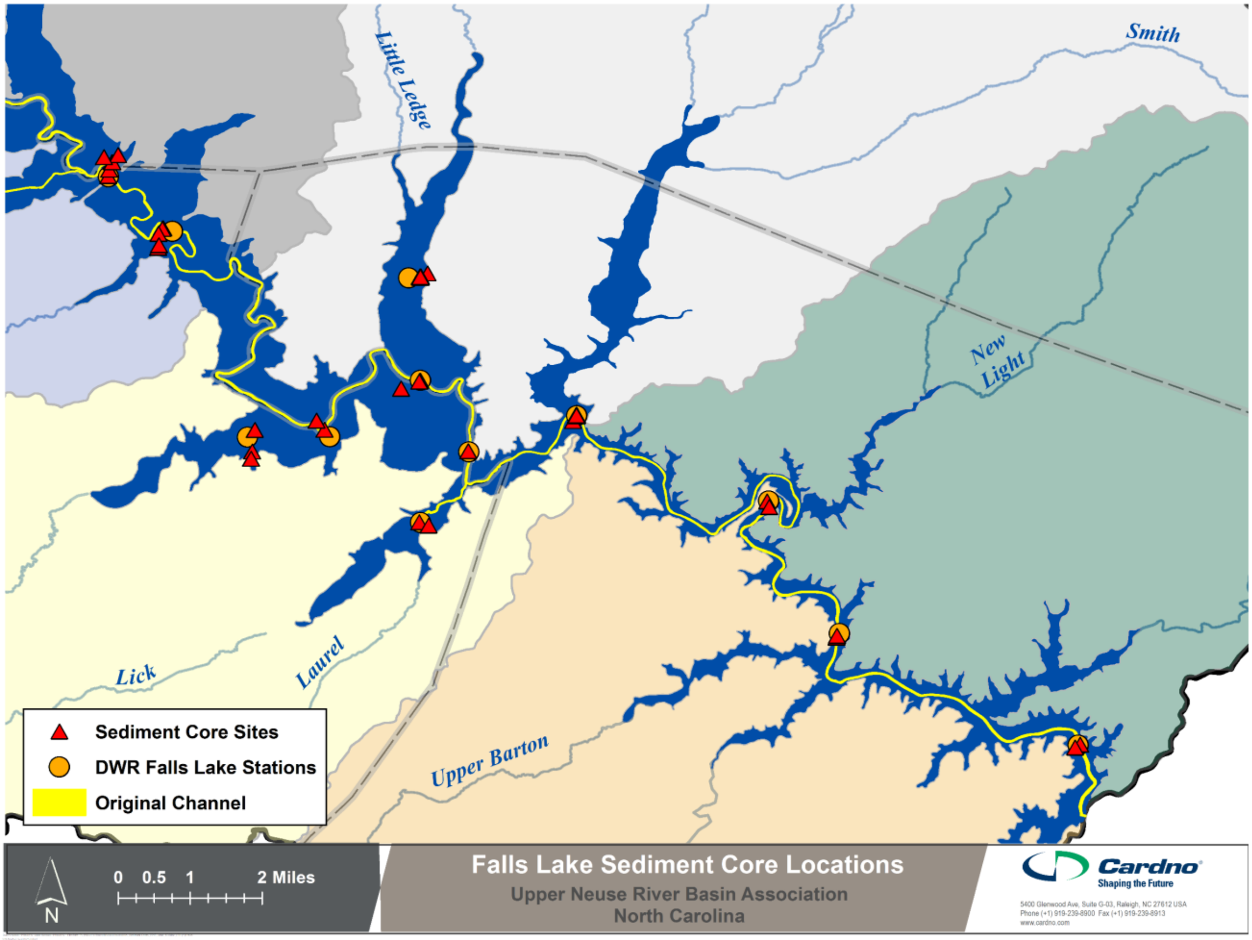

Figure 4.3 Sediment Core Sampling Locations in Falls Lake Compared to DWR Lake Sampling Stations

4.4 Lake Bathymetry and Sediment Mapping

This special study is currently underway. Field data collection was completed in April 2017 and data review, analysis, and map production are to be completed in the summer of 2017.

5 Summary and Recommendations

The UNRBA Monitoring Program is designed to support the UNRBA's reexamination 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. Data collection under the UNRBA Monitoring Program began in August 2014, and this report presents the data collected through the end of calendar year 2016.

During this period, the monitoring program has achieved the following:

- Completed sampling for 95% of 1,212 planned sampling events at 38 tributary stations
  - 3% of planned sampling events prevented due to dry streams
  - 1% were missed due to construction activities at monitoring locations (bridges, WWTP upgrades)
  - 1% were missed due to safety concerns (icy roads or banks, flood conditions)
- Collected more than 24,000 water quality observations from 38 stations on tributaries throughout the watershed.
- Collected data from other monitoring organizations and incorporated into UNRBA database (Durham, Raleigh, CAAE, DWR)
- Completed five special studies
- Completed more than two years of high flow sampling
- Collected data on the bathymetry of Falls Lake with transects generally covering every 500 to 1000 feet.
- Established and complied with a rigorous monitoring and laboratory quality assurance project plan
- Established and followed procedures for collecting quantitative information from laboratory in order to track variability of analytical results and certainty estimates for observations
- Identified opportunities for increasing cost efficiencies with respect to monitored parameters and frequency of sampling

5.1 Recommendations

The UNRBA Board of Directors has committed to a minimum of four years of routine monitoring with a possible fifth year to be considered. The data represented in this annual report spans a period of 29 months, which is just over half of the minimum monitoring period anticipated by the UNRBA (four years). Several adjustments were made to the Monitoring Program at the beginning of FY2017 to reduce or eliminate aspects deemed to be of little additional value going forward. The cost savings from those adjustments, along with completion of several Special Studies as discussed above, allowed for some funding to be redirected from the Monitoring Program to the Modeling and Regulatory Support effort. In order to fulfill four full years of monitoring, substantial reductions to the routine monitoring program are not recommended. However, minor revisions discussed earlier in this report, such as eliminating the measurement of volatile suspended solids, may be warranted.

Because the fourth monitoring year begins in FY2018, this next year is an opportune time to explore whether continued monitoring in some form may be warranted or useful, and if so, whether there are additional cost saving measures that make sense after the four-year monitoring period is complete. The next UNRBA Annual Report will be important for exploring these questions through analyses of existing data.

Moving into FY 2018, Cardno recommends the UNRBA consider the following changes and monitoring priorities:

<u>Routine Monitoring</u>

- In order to largely keep the fourth monitoring year consistent with previous routine monitoring, there are not a lot of areas that can streamlined. However, based on the graphics presented earlier in this report, VSS observations are typically below the laboratory reporting limit. This parameter could be eliminated in order to reallocate a small amount of money to modeling and regulatory support.
- We recommend the development and subsequent implementation of an approach to consider and prioritize what (if any) substantial changes or reductions to the monitoring program may be warranted after the requisite number of baseline monitoring years have been completed.

<u>Special Studies</u>

- Because of dry conditions during some months of the past year, not all of the currently allocated high flow budget will be spent this FY. Cardno recommends high flow sampling continue and that budget is allocated to be able to capture monthly high flow events if and when they occur.

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.