Upper Neuse River Basin Association Monitoring Program Annual Report

Prepared for
Upper Neuse River Basin Association, NC
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Executive Summary

The Upper Neuse River Basin Association (UNRBA) made a commitment to undergo a comprehensive and rigorous data acquisition effort. The main purpose of the UNRBA Monitoring Program is to support the Association's reexamination of Stage II of the Falls Lake Nutrient Management Strategy and in a broader sense the overall management strategy for the Lake moving into the future. The current Strategy requires the greatest percentage of nutrient loading reductions ever adopted in North Carolina. The Monitoring Program aims to reduce the uncertainties associated with prior analysis efforts through the collection of extensive and detailed water quality data and information. Results from UNRBA monitoring efforts will be used to develop new lake-response and watershed models. The revised models will be used to project impacts from nutrient loading from sources and jurisdictions, evaluate alternate nutrient management strategies, and support the development of a range of potential alternative regulatory options for consideration.

The UNRBA has been collecting and analyzing water quality data in Falls Lake and its watershed since August 2014. Documents that govern the UNRBA Monitoring Program are available online at http://www.unrba.org/monitoring-program. These include the Monitoring Plan and the Monitoring Quality Assurance Project Plan. Both documents have been approved by the North Carolina Division of Water Resources. Data collected by the UNRBA, and compiled by the UNRBA from other sources, are also available on the UNRBA's website.

Data collected or compiled by the UNRBA are available online:

http://data.unrba.org/index.php

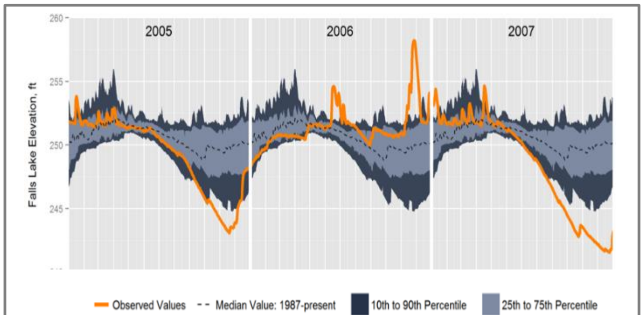
This Annual Report addresses UNRBA monitoring efforts from August 2014 through December 2017 (41 months of data). The Routine Monitoring portion of the program collected data for 20 water quality parameters from 38 tributary stations in the watershed at least monthly. Additional data have been acquired from the North Carolina Division of Water Resources (DWR) and several other entities, including the City of Durham and the NC State University Center for Applied Aquatic Ecology. Routine UNRBA Monitoring is expected to continue in the same manner through October 2018 to provide data through four full years (48 months) and four complete growing seasons. Thus, another 10 months of Routine Monitoring data are to be collected, adding 25 percent to the data summarized in this report. The full 51 months of Routine Monitoring data will be included in a Final Report to be completed in early 2019.

The Monitoring Program has also included to this point nine different Special Studies to fill data gaps and explore facets of Falls Lake not addressed through the Routine Monitoring. Results from three Special Studies not previously reported on are presented within this report: High Flow Sampling, Lake Sediment Evaluation, and Lake Bathymetry-Sediment Mapping.

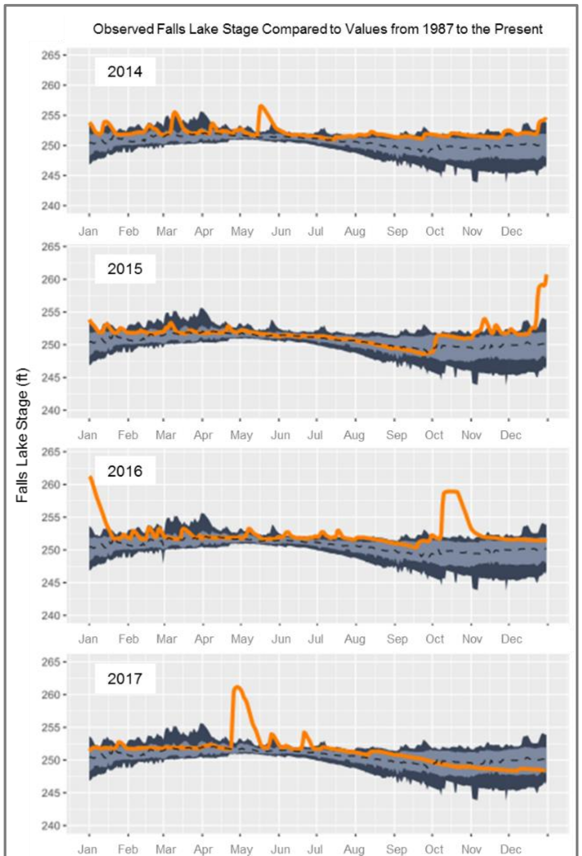
After October 2018, the Monitoring Program is expected to be substantially modified. The revised monitoring program will allow UNRBA funding to shift toward a modeling and analytical effort. The Executive Director is convening a workgroup within the UNRBA to develop recommendations for the Program moving forward.

Hydrologic Conditions

The Monitoring Program also uses data acquired by the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and U.S. Army Corps of Engineers (USACE). These organizations collected data on rainfall, streamflow, and reservoir stage. Annual precipitation patterns since the program began in August 2014 have been normal to wet. The DWR modeling effort conducted to develop the Falls Lake Nutrient Management Strategy (2009) included data from a period that included extremely low and high reservoir elevations (2005-2007). The majority of the UNRBA monitoring period exhibited conditions within the “normal” range. However, as illustrated, this period was punctuated by a few flood events and a somewhat dry period at the end of 2017. Between the monitoring conducted previously by DWR and the data acquired recently by the UNRBA, the watershed has been monitored across a reasonable and average range of hydrologic conditions. This is expected to benefit the UNRBA modeling analysis relative to the DWR assessment period, which only had data from years including either relatively high or extremely low lake levels.



Falls Lake water levels were highly variable during the DWR Modeling Period.

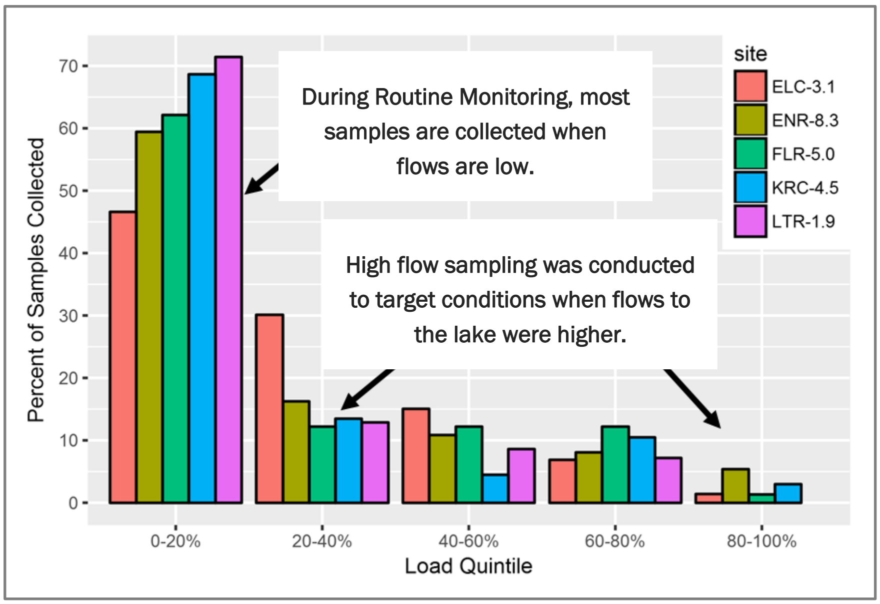


Falls Lake levels were closer to normal during the UNRBA Monitoring Period.

The timing and amount of inputs of water to Falls Lake Reservoir are largely controlled by rainfall patterns in the watershed. Release of water to the Neuse River is controlled by the USACE to mitigate flooding downstream and to preserve downstream ecological systems, especially during spawning season. The dynamic interaction of these two processes results in substantial abrupt changes to the lake’s residence time (i.e., the number of days an average parcel of water stays in the lake). Residence time varies from as short as about 20 days (when the dam is operated to drop the lake level quickly) to several hundred days (when the release at the dam is very small to retain water in the reservoir). Since the USACE actively regulates reservoir discharges (and therefore residence time), any water quality parameter that is positively or negatively correlated with residence time is subject to a water resource management program generally outside the influence of the UNRBA members. This should be considered when exploring nutrient management alternatives for the reservoir.

Of the 18 UNRBA-monitored tributaries, five contribute more than 75 percent of the water entering the lake: Flat River, Eno River, Little River, Knap of Reeds Creek, and Ellerbe Creek. Just the Flat and Eno Rivers together account for more than half of the lake's inflows. This means, in general, that flow and loading contributions from these five tributaries have a much greater potential to affect overall water quality in the lake than the remaining streams. Aside from these five, no other tributary delivers more than 3 percent of the annual inflow to the reservoir. This is an important consideration for both the lake-response and the watershed modeling efforts.

Storm events can contribute relatively large volumes of water to Falls Lake in a short time and potentially contribute large loads of nutrients during these periods. For the largest five streams, about 20 percent of the water delivered to Falls Lake comes from flows which occur during just 1 percent of the time; 40 percent of the water is delivered during 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 (less than 20th percentile) and an under-representation of higher flow conditions when sampling occurs based on static time intervals (like routine monthly monitoring). Because of this consideration, targeted High Flow Sampling has been conducted on the largest tributaries to document the levels of nutrients and other parameters during higher flows not generally captured by the Routine Monitoring. Results from this high flow monitoring have generally shown higher levels of total phosphorus, organic nitrogen, chlorophyll-a and TOC in high flows than in low-flow conditions. The multiplicative combination of higher concentrations and higher flows is valuable knowledge for inclusion in both the watershed and lake response modeling efforts. This information is very useful in tracking these short-term impacts and how they impact the lake immediately and in the period following such events.

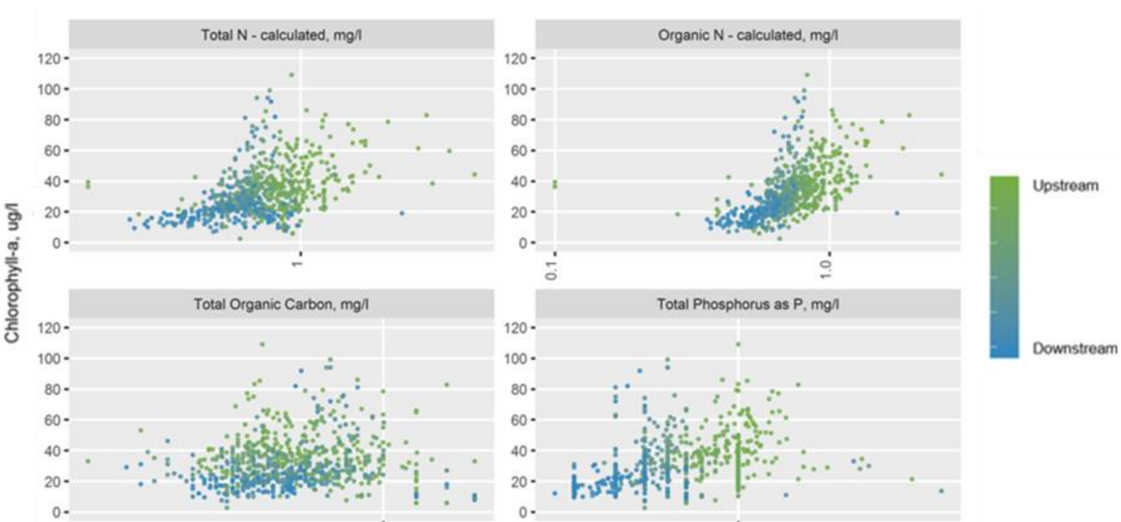


Water Quality Relationships

The Results and Discussion section of this report provides an update to prior Annual Reports, with data collected in 2017 generally falling within the ranges seen in 2014-2016. Most water quality parameters tend to be more variable both within and among the tributary stations than in the lake itself. For example, total nitrogen ranged from less than 0.2 mg/L to more than 2 mg/L across the tributary stations, but was rarely outside the range of 0.5 to 1 mg/L at the lake stations. A similar pattern is seen for total phosphorus. Chlorophyll-a is generally much lower (and more variable), in tributaries than in the lake. The tributary chlorophyll-a data collected by the UNRBA is important for the modeling effort as DWR did not have this data available to guide their model development effort. Many previous UNRBA reports have reflected this concern.

Data from in-lake stations in 2017 also show conditions largely consistent with prior years. Several parameters exhibit a clear trend from the upper lake toward the dam. Specific conductance, organic and total nitrogen, total phosphorus, chlorophyll-a, total suspended solids and color each show a distinct decrease from the upper reservoir to the lower reservoir. Such longitudinal trends were predicted prior to the construction of the reservoir. In contrast, total organic carbon (TOC) shows no apparent change from the upper lake to the dam, and very little variability within the monitored stations. The City of Raleigh closely monitors TOC in the lake, as higher concentrations may require supplemental treatment for drinking water.

Organic nitrogen comprises the majority of the total nitrogen in the lake. Most organic nitrogen is assumed to be within algal cells (phytoplankton) or other organisms suspended in the water column. Similarly, much of the total phosphorus measured in lake samples is generally assumed to be assimilated within planktonic organisms, rather than dissolved in the lake water. In contrast, total organic carbon shows no apparent relationship to chlorophyll a on a lake-wide basis during the period of monitoring. These observations will be supplemented and re-examined based on data collected during 2018. A final monitoring report of all the data collected to support the UNRBA's modeling effort will be done following collections through October 2018.

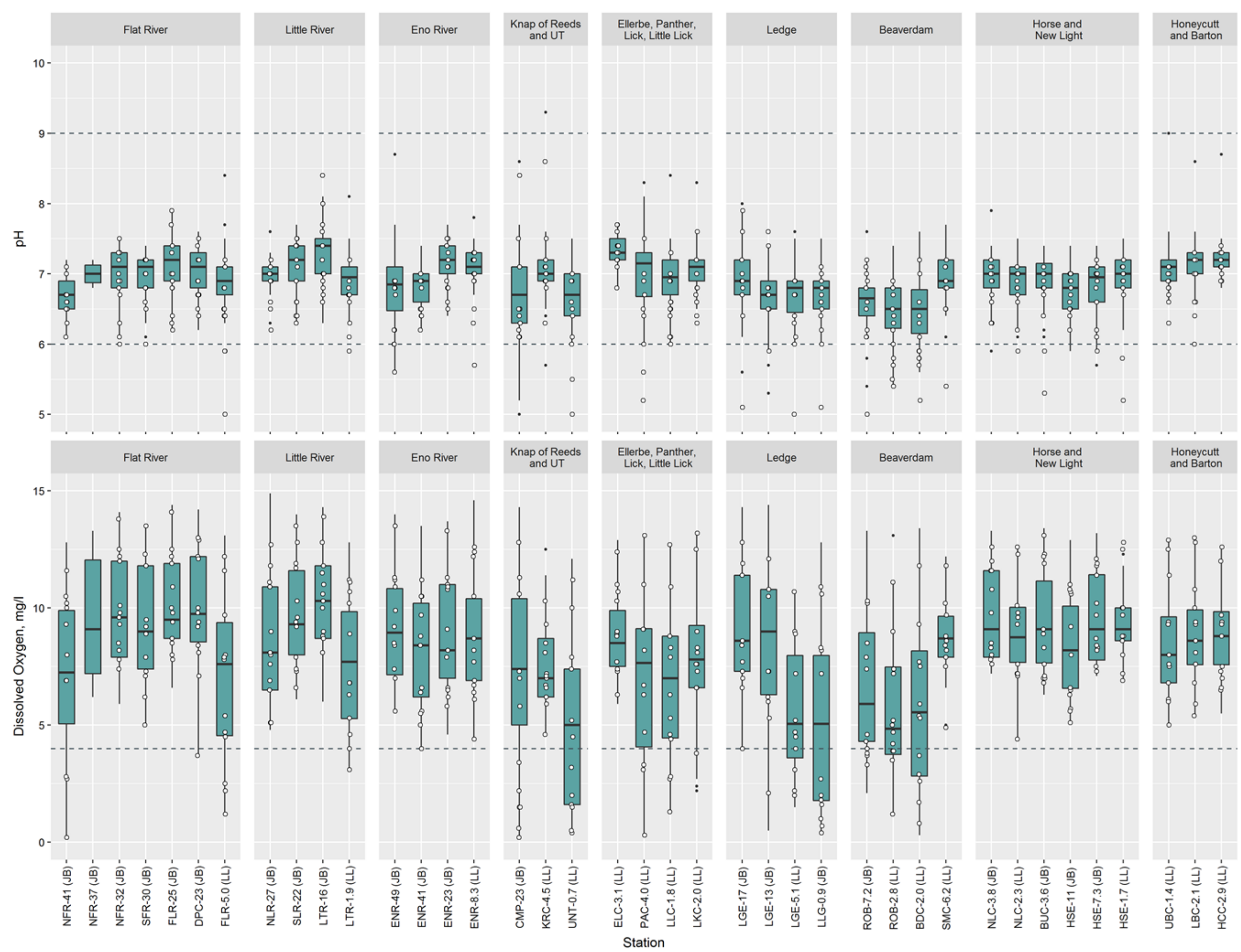


Scatter plots show a strong correlation of chlorophyll-a to organic and total nitrogen. Relationships with total organic carbon and total phosphorus are less evident.

Correlation statistics were developed to explore potential relationships between land use composition and water quality measurements for stations monitored by the UNRBA in the watershed. Specific conductance (i.e., amount of dissolved ionic substances) tends to be higher in watersheds with more developed land and lower in areas with more forested land. TOC is generally higher in basins with herbaceous land (i.e., grassland, pasture and wetlands). Basins with more wetland area tend to have streams with higher TOC and total Kjeldahl nitrogen and lower dissolved oxygen.

Routine Monitoring data indicates that stations located within non-flowing, wetland dominated areas tend to have higher concentrations of total phosphorus, TOC, and chlorophyll-a and lower concentrations of dissolved oxygen. These conditions do not appear to significantly influence water quality within the lake. These conditions represent very small volumes of water relative to storm event flows which have better water quality. Water quality in these areas is also masked by inflows from other tributaries. These relationships were also evident when the predominant hydrologic soil groups were evaluated. Water quality in sub-basins with soils having very low infiltration rates (a characteristic of wetlands) tend to show higher total phosphorus, organic nitrogen and TOC, and lower levels of nitrate-nitrite.

Tributary monitoring data include some observations of pH and dissolved oxygen (DO) that are outside the NC water quality criteria. Overall, less than 10 percent of all DO measurements were below the criterion. Only about 3 percent of pH measurements were below the criterion. Many of the exceedances are associated with slow-moving, wetland-like conditions at the corresponding tributary sampling stations. Such waters tend to have lower pH and oxygen levels due to natural processes.



Observations of pH in the tributaries of Falls Lake are typically within the water quality criteria for this parameter (6-9). Dissolved oxygen concentrations are typically above the criterion of 4 mg/L.

Tributary stations downstream of wastewater treatment facilities, including small package plants, tend to show higher levels of specific conductance, nitrogen, and phosphorus. TOC does not appear to be influenced by the presence of an upstream treatment facility. Chlorophyll-a concentrations are usually lower in streams with major treatment facilities. Nitrogen and phosphorus levels in Knap of Reeds Creek were substantially elevated in some 2015 samples due to operational issues at the upstream wastewater treatment facility. Data from 2016 and 2017 in Knap of Reeds Creek did not show similarly elevated levels. Collection of additional monitoring data through October 2018 will likely result in a lowering of the overall median nutrient levels for this stream, as the earlier, higher levels will be moderated by the more recent, lower levels.

Relationships between water quality and land uses, soil types, and presence of wastewater treatment plants are of value in developing and/or interpreting the watershed model.

Chlorophyll-a

This report provides an extended analysis of several facets of the Monitoring Program data including chlorophyll-a. Chlorophyll-a is a central focus of concern for the Falls Lake re-examination process because the lake was previously identified on North Carolina's Clean Water Act Section 303(d) list of waters not attaining the state's water quality criterion of 40 µg/L (15A NCAC 02B .0211(4)). Monitoring data clearly indicate that the upper portion of the lake experiences higher chlorophyll-a levels than the lower lake. In contrast with prior years, there were two distinctly elevated peaks in chlorophyll-a throughout the lake in 2017, one in February and the other in May. In both cases, levels dropped rapidly to more typical levels by the following monthly monitoring event. There was a smaller peak September 2017, but it did not involve all stations. The cause of these episodes is unclear, but may be partially related to a bloom of one or more algal taxa responding to optimal growing conditions over a brief period. One of the episodes followed a large rain event by several weeks and may have been triggered by inputs of nutrients from that event.

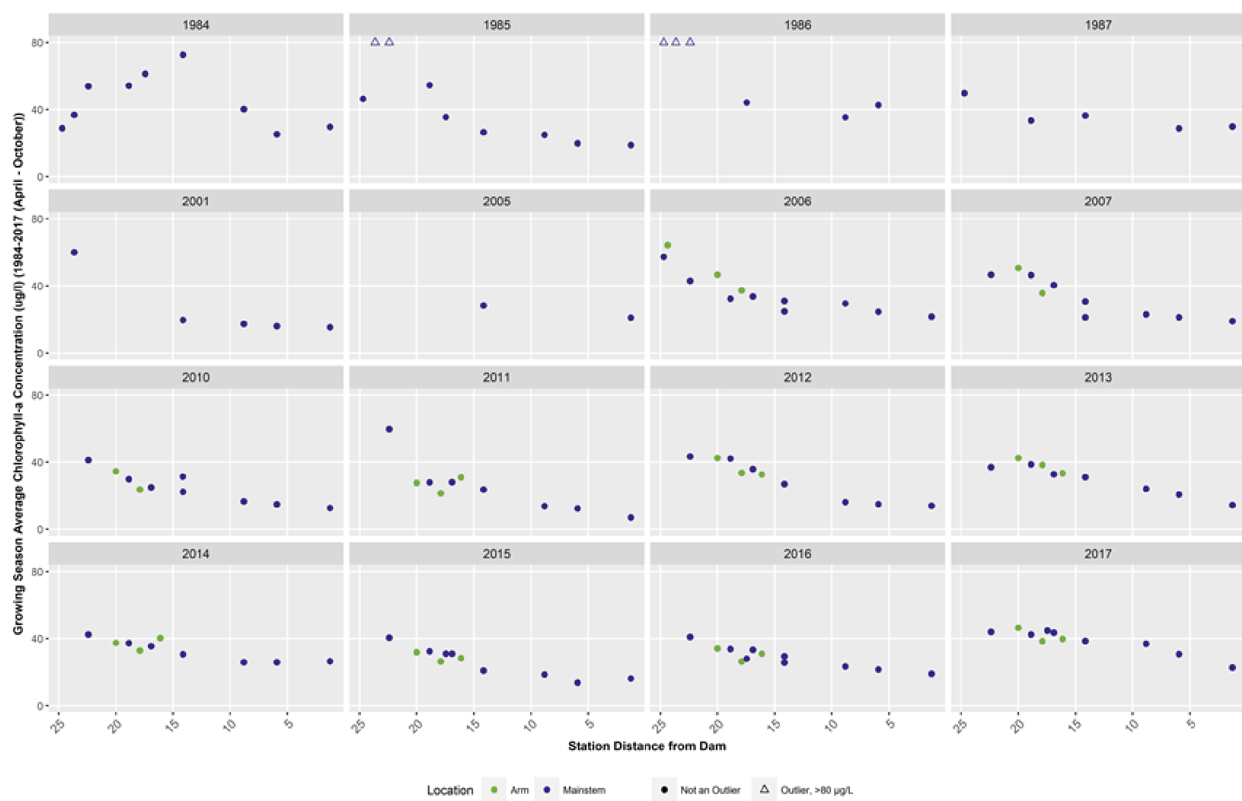
Previously, the chlorophyll-a water quality assessment 303(d) methodology was not to exceed the 40 µg/L criteria in more than 10 percent of the observations, with a statistical confidence of 90 percent. The North Carolina Environmental Management Commission has recently (March 2018) approved changes to the listing and delisting procedures for chlorophyll-a, making the listing and delisting process more rigorous. The table below summarizes chlorophyll-a data collection by NC DWR, indicating the number of measurements where levels exceeded 40 µg/L in lake samples. The higher rates of exceedance in 2017 are at least partially attributable to the two chlorophyll-a peaks noted above.

Table ES-1. Summary of Chlorophyll-a Measurements in Falls Lake Relative to NC Water Quality Criterion August 2014 – December 2017

	Falls Lake Above Hwy 50			Falls Lake Below Hwy 50		
Year	Total Observations	Observations >40 µg/L	% >40 µg/L	Total Observations	Observations >40 µg/L	% >40 µg/L
2014	72	17	24%	48	8	17%
2015	84	11	13%	48	0	0%
2016	84	10	12%	48	0	0%
2017	84	31	37%	48	12	25%
Overall	324	69	21%	192	20	10%

This report explores the use of both arithmetic and geometric means of chlorophyll-a for both annual and growing season (April-October) periods. Similar analytical approaches are becoming more common in nutrient and chlorophyll criteria development across the country. Results of the analyses will be of interest for exploring future regulatory options for Falls Lake.

Chlorophyll-a data are available from DWR back to the mid-1980s. Examination of those data indicates that chlorophyll-a levels have always been higher at the upper end of the lake than the lower end. Data from years shortly after the reservoir was impounded also indicate substantially higher growing season average chlorophyll-a concentrations in the upper lake than have been observed in recent years. While analysis methods have changed over time, the relative values and spatial patterns are indicative of a longitudinal improvement in water quality from upstream to downstream.

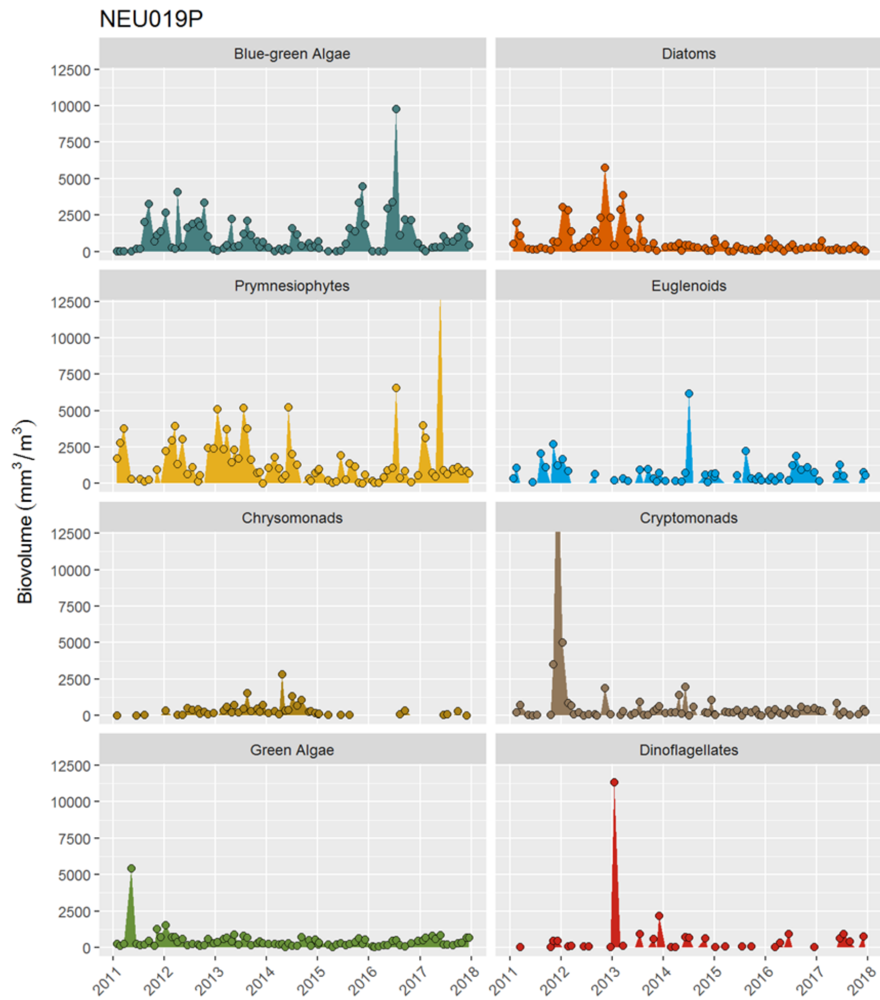


Growing Season Average Chlorophyll-a Data Collected in Falls Lake through Time

Algal Dynamics

DWR analyzes samples from three of its in-lake stations for phytoplankton content. This report summarizes phytoplankton data from 2011-2017. The data indicate high variability in algal biovolume within eight major taxonomic groups. Bluegreen algae show the strongest annual pattern, generally peaking in the latter half of the year and declining to low levels in the winter. Other algal groups either show less consistent patterns from year-to-year (e.g., diatoms) or relatively consistent low levels of biomass (e.g., green algae).

Like many reservoirs in the Southeastern U.S., Falls Lake is considered eutrophic from a nutrient enrichment standpoint, meaning it is relatively nutrient-rich and can support a relatively abundant fish and algal community. It is common to find algae growth in lakes to be limited by nutrients - either nitrogen or phosphorus, or sometimes by both. Even if nitrogen or phosphorus is shown to be “limiting,” it does not mean algae may not be abundant. It simply means that under specific conditions any additional increase in the phytoplankton population would be controlled by the supply of the limiting nutrient. Information compiled by the UNRBA suggests that phosphorus is the limiting nutrient in the lower portion of the lake, but algae in the upper lake may be co-limited for both nutrients. From a practical perspective, this means nutrient management of the lake likely needs to include consideration of both nitrogen and phosphorus. This is a question that will need to be evaluated further as the UNRBA moves through its evaluation of the existing management strategies and in developing, for consideration, alternate approaches.

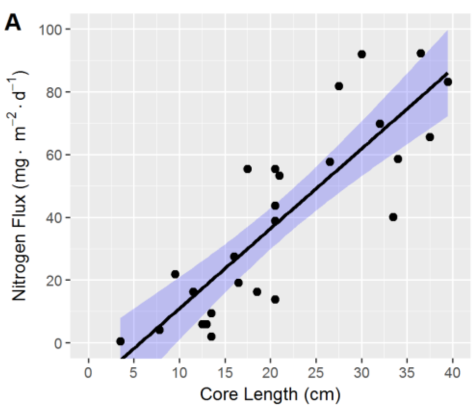


Different types of algae are present in Falls Lake.

Some species of blue-green algae produce toxic substances under environmental conditions that are not well-understood. Studies across the nation have shown that the species able to produce these toxins are common in natural lakes and man-made reservoirs. The City of Raleigh conducts monitoring for several algal toxins in association with its water intake from Falls Lake. Data from recent years reflects that, even though microcystins are sometimes present in Falls Lake, they have not been reported at levels above the World Health Organization or U.S. EPA guidelines.

Lake Sediment Quality

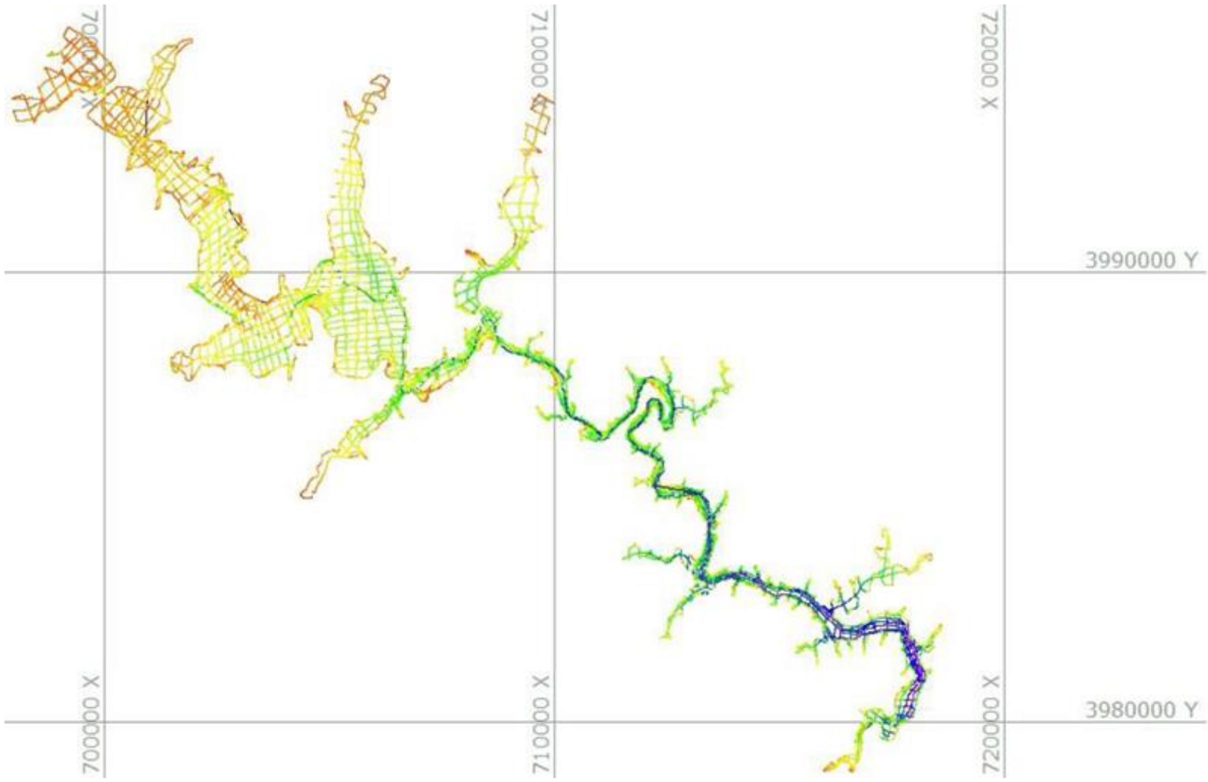
A Special Study led by Dr. Marc Alperin of the University of North Carolina's Marine Science Department was initiated in 2016 to evaluate sediments in Falls Lake. Dr. Alperin is still finalizing his report of the sediment evaluation, which will be provided to the PFC and posted to the UNRBA website at completion. This study looked at sediment cores collected from 24 locations along the lake and analyzed for a suite of parameters. This data provides information on the characteristics of the lake sediments which will help better define the role of bottom sediments on lake water quality and support the UNRBA modeling effort. Lake sediments include both historic deposition and legacy nutrients in the deeper layers as well as "younger" sediments near the surface. An important observation from the core samples was the variability in the thickness of the unconsolidated sediment layer (muck) among the locations. In general, the river and tributary channels had substantial accumulated sediment, but areas along the historic floodplain typically had much less sediment. In fact, some shelf areas had little to no sediment, where the core collection device simply contacted hard clay, sand or gravel. Dr. Alperin developed a model to estimate nutrient flux from the sediment. Some of his modeled estimates of ammonia flux from the sediment are similar to those used by DWR in its modeling of Falls Lake (ammonia is a preferred form of nitrogen for algae). However, his work showed much greater variability among sampled locations, ranging over at least an order of magnitude. For example, on the average, ammonia fluxes from cores collected within the historic river channel were more than three times higher than cores collected nearby, but outside of the channel. For the full set of cores collected within Falls Lake, the best predictor of nitrogen flux was the sediment thickness. Such findings are important because the UNRBA's lake modeling can now include spatial consideration of sediment nutrient flux variability, which was not part of the DWR modeling effort.



Nitrogen release rates from lake sediments are correlated to the thickness of the sediment measured by the core sampler.

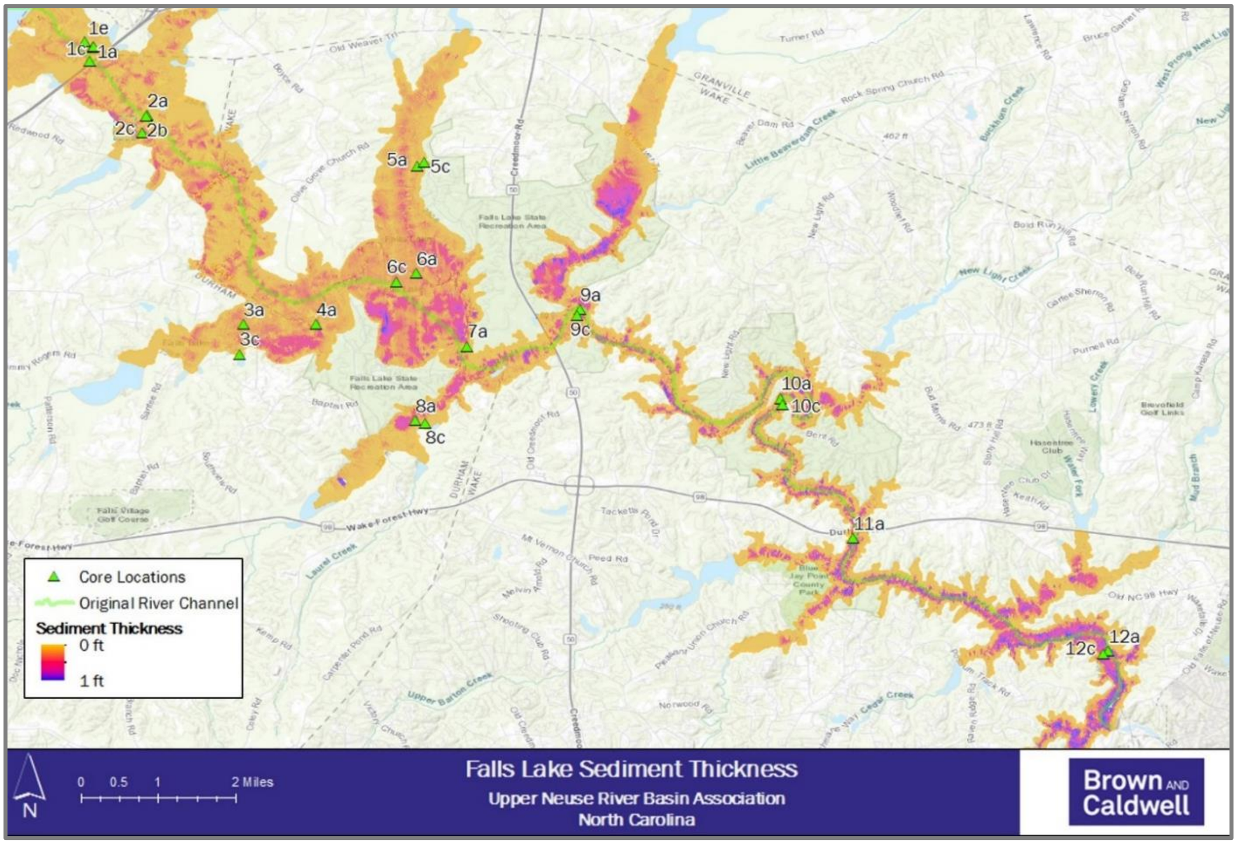
Lake Bathymetry

The UNRBA conducted a bathymetric survey and sediment mapping study of Falls Lake in FY2017. These surveys used dual-sonar frequency technology along track lines across much of the lake. Underwater topography (bathymetry) influences the retention and movement of water and thus partially controls the biological processing of nutrients that can affect the growth of algae. An accurate representation of bathymetry and flow restrictions is an essential element in understanding the volume of water within each segmented portion of Falls Lake. Before this UNRBA study, there were essentially no data on the bathymetry of Falls Lake other than pre-reservoir USGS topographic maps and 17 transects collected by DWR to support their modeling.



The UNRBA has collected significantly more bathymetric and sediment mapping data than was available during DWR's modeling effort. Data collection track lines throughout the lake are shown above.

Data produced by this mapping effort is now being used by the UNRBA modeling team to refine the grid for the hydrodynamic model. The bathymetric data show that Falls Lake at its normal elevation contains very similar water volumes above and below Highway 50 (upper and lower lake), with broad, shallow areas above Hwy 50, and narrow, deep areas in the lower lake. A second goal of this study was to generate data on the thickness of the sediment layer throughout Falls Lake. As noted above, the sediment evaluation saw significant variability in sediment thickness, with substantial areas of the lake bottom having little to no accumulated sediment. The sediment mapping effort showed that sediment accumulation in the upper portion of the lake is much less than in the lower half of the lake. The combination of the Sediment Evaluation and the Sediment Mapping provides the ability to estimate sediment nutrient flux throughout the lake, based on an empirical flux model. This information will support the lake response model by providing initial conditions for the sediment quality and providing an independent estimate for comparison to the fluxes predicted by the sediment diagenesis model (part of the lake response model). Although not a primary goal of the mapping effort, the sediment survey results can also provide a point of comparison with past and future surveys to estimate sedimentation rates. The USACE has shown a keen interest in this data.



Quality Assurance

Quality assurance and quality control (QAQC) are primary considerations for the UNRBA Monitoring Program. Data accuracy, precision, and completeness reviews are performed following each monitoring event. Reviews of field and laboratory practices are performed on a routine basis. Since the beginning of the UNRBA monitoring program, more than 98 percent of all planned sampling events in which the sampling location had flowing water were completed as planned. Through the end of 2017, there have been no cases of samples where results for Laboratory Control Sample (samples of known concentration analyzed along with field samples) associated with UNRBA data were out of compliance with method criteria. The UNRBA program calls for relatively low laboratory reporting limits for some parameters (e.g., nutrients). Low reporting limits can increase the risk of having analytical results fall within the range of uncertainty for some methods. Total phosphorus and ammonia each saw more than five percent of field blanks (sample vessels filled in the field with water presumed to have none of the target analyte present) with results above the reporting limit. This means there is an increased chance that some actual stream samples with levels near or below the reporting limit may have less than the concentration reported. However, most stream samples showed concentrations well above the reporting limits, so the error associated with very low levels is not meaningful in the modeling and related analytical efforts. The QAQC section provides confidence levels for the analyzed parameters. This type of information allows users of the data to estimate the degree of uncertainty associated with laboratory values.

Moving Forward

The UNRBA Monitoring Program was designed to support the UNRBA's re-examination of the Falls Lake Nutrient Management Strategy. Based on input from the contractor and the Executive Director of the Path Forward Committee, in recent months, recommended continuing the Routine Monitoring at least to the end of the 2018 growing season. Once this sampling is completed, this effort will constitute four full years and four growing seasons of data collection. Therefore, data acquisition for the modeling effort is scheduled to continue through October 2018. Members of the watershed modeling, lake modeling, and statistical modeling team provided consistent feedback when asked to review the Monitoring Program and the plan to continue through October 2018. All reviewers indicated that sample collection under the current plan through October would result in (1) sufficient data for effective development and calibration of the models, and (2) that a fifth year of data collection would likely yield diminishing returns in terms of additional information for modeling purposes. Additionally, as noted, since funding available for the modeling work is dependent on the level of monitoring, it is believed that the additional funding due to a reduced monitoring effort is a more effective use of resources. Thus, it is recommended that the UNRBAUNRBAUNRBA complete data collection, laboratory analyses, and evaluation of results in accordance with the current program plan for modeling support through the end of the 2018 growing season. Specific recommendations are:

- The current routine monitoring program should be continued through October 2018.
- Data acquisition for modeling support should be considered complete at that time.
- A final monitoring report for modeling use should be completed in 2019 (February-March).

The UNRBA has not yet determined monitoring objectives beyond October 2018.

The UNRBA Executive Director will establish a work group to consider the potential costs and benefits of a water quality monitoring program beyond October 2018.

The work group will examine specific objectives for any future monitoring that may be important for the UNRBA to consider.

Section 1

Purpose of 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-a 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 initiated the Monitoring Plan that described the locations, parameters, frequencies, and other program elements (Cardno 2014b; http://www.unrba.org/monitoring-program). The Monitoring Plan is maintained and updated by the UNRBA monitoring service provider 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 North Carolina Division of Water Resources (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 Division of Water Resources (DWR) on July 30, 2014 and again on January 18, 2017.

As part of the 2018 Fiscal Year contract, the UNRBA monitoring service provider is required to produce 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. 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 2017 and presents results and general patterns and relationships observed in the data. This Annual Report includes specific recommendations for refinements to the Monitoring Program to optimize efficiency and value and to accommodate UNRBA needs for resource allocation.

1.2 Regulatory Background

Falls Lake Reservoir was created by the U.S. Army Corps of Engineers (USACE) when a dam was completed at the Falls of the Neuse River in 1981. 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 regional importance of Falls Lake, the UNRBA began examining the technical bases and regulatory framework of Stage II requirements. 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 beneficial uses. Control requirements should be reasonable, fiscally responsible, and efficaciously improve the water quality of the resource. Based on a review conducted in 2013 (Cardno, 2013), the Stage II Rules are not technically, logistically, or financially feasible. Given the high cost (approximately one billion dollars) of implementing Stage II and the uncertainty of achieving the chlorophyll-a current water quality standard, the scientific re-examination process relies on additional data collection and new modeling efforts to support revised lake response modeling, as well as the 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 status 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 lake modeling uncertainty, expanding the best management practices "toolbox" used for compliance and 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 2017.

Section 2

Overview of the UNRBA Monitoring Program

This Annual Report addresses monitoring efforts from August 2014 through December 2017. 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 the UNRBA monitoring service provider. 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 seven long-term stations located on the Falls Lake Reservoir.

Table 2-1. Overview of Tributary Routine Monitoring Components of the UNRBA 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 [a] (Station Type [b])	Subwatershed	Stream Name	County	Drainage Area (mi^2)	Sampling Frequency
NFR-41 (JB) [c]	Flat	North Flat	Person	12.7	Monthly
NFR-37 (JB) [c]	Flat	North Flat	Person	15.8	Replaced with NFR-41
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 [e]
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 [e]
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 [e]
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 [e]
ELC-3.1 (LL)	Ellerbe	Ellerbe	Durham	21.9	Monthly [e]
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

Table 2-2. UNRBA Tributary Routine Monitoring Stations and Sampling Frequency

Name [a] (Station Type [b])	Subwatershed	Stream Name	County	Drainage Area (mi^2)	Sampling Frequency
HSE-11 (JB)	Horse	Horse	Franklin	3.88	Monthly
HSE-7.3 (JB)	Horse	Horse	Wake	7.11	Monthly
HSE-5.7 (JB) [d]	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

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

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

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

[d] *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.*

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

2.1.1 Lake Loading Stations on Tributaries in the Falls Lake Watershed

To characterize the tributary inputs to Falls Lake and to support watershed and 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. UNRBA monitoring locations 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 Comparison of Flow Estimation Methods Technical Memorandum (Cardno 2014a) available at https://www.unrba.org/sites/default/files/news-files/FlowEstimationTM_March28_Final.pdf

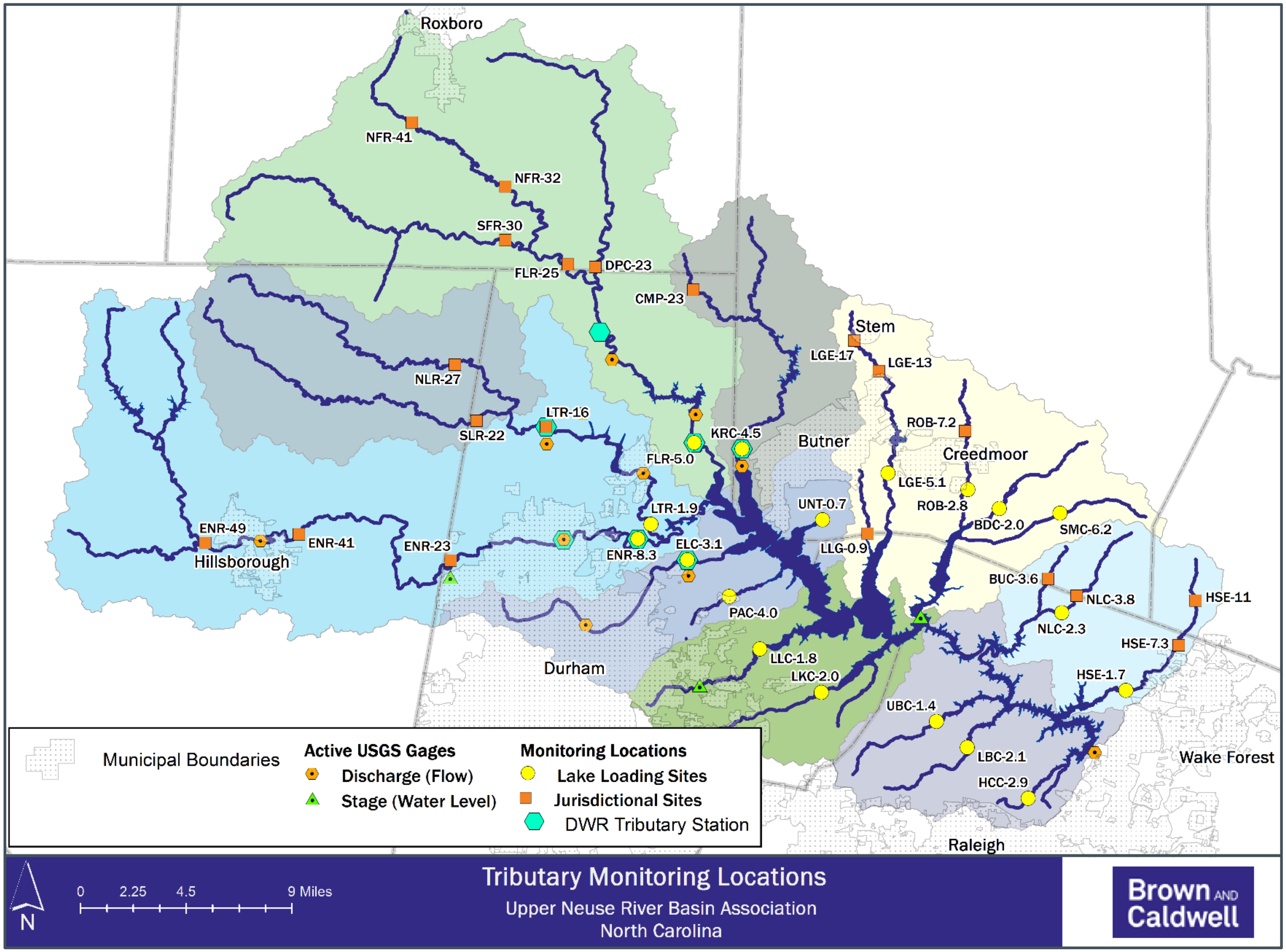


Figure 2-1. UNRBA Lake Loading and Jurisdictional Monitoring Locations (see Table 2-2 for station details) and Existing USGS Gages

In addition to 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 major 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 have the potential to drive much of the lake's chlorophyll response. Parameters selected for Routine Monitoring at Lake Loading stations were generally based on the requirements of the Watershed Analysis Risk Management Framework (WARMF) and 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. Parameter coverage, frequencies, and sampling locations have been revised occasionally 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 estimate DOC from TOC with a high degree of confidence and its relatively high cost of laboratory analysis, the UNRBA ceased collection of DOC from lake loading stations in June 2016. Collection of CBOD5 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 governmental jurisdictions in the Falls Lake watershed must be reduced. Stations located between the jurisdictions and at key loading points such as outlets of major tributaries within a jurisdiction can be used to 1) provide water quality data from points within all member jurisdictions, 2) prioritize best management practice (BMP) implementation in areas with the highest nutrient loading, 3) calibrate watershed models and, 4) 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 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 within Falls Lake itself provides data 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). Data are collected under a DWR-approved QAPP at 30 monitoring stations (Figure 2-2) in 22 distinct locations on the lake (some locations are monitored by more than one organization.

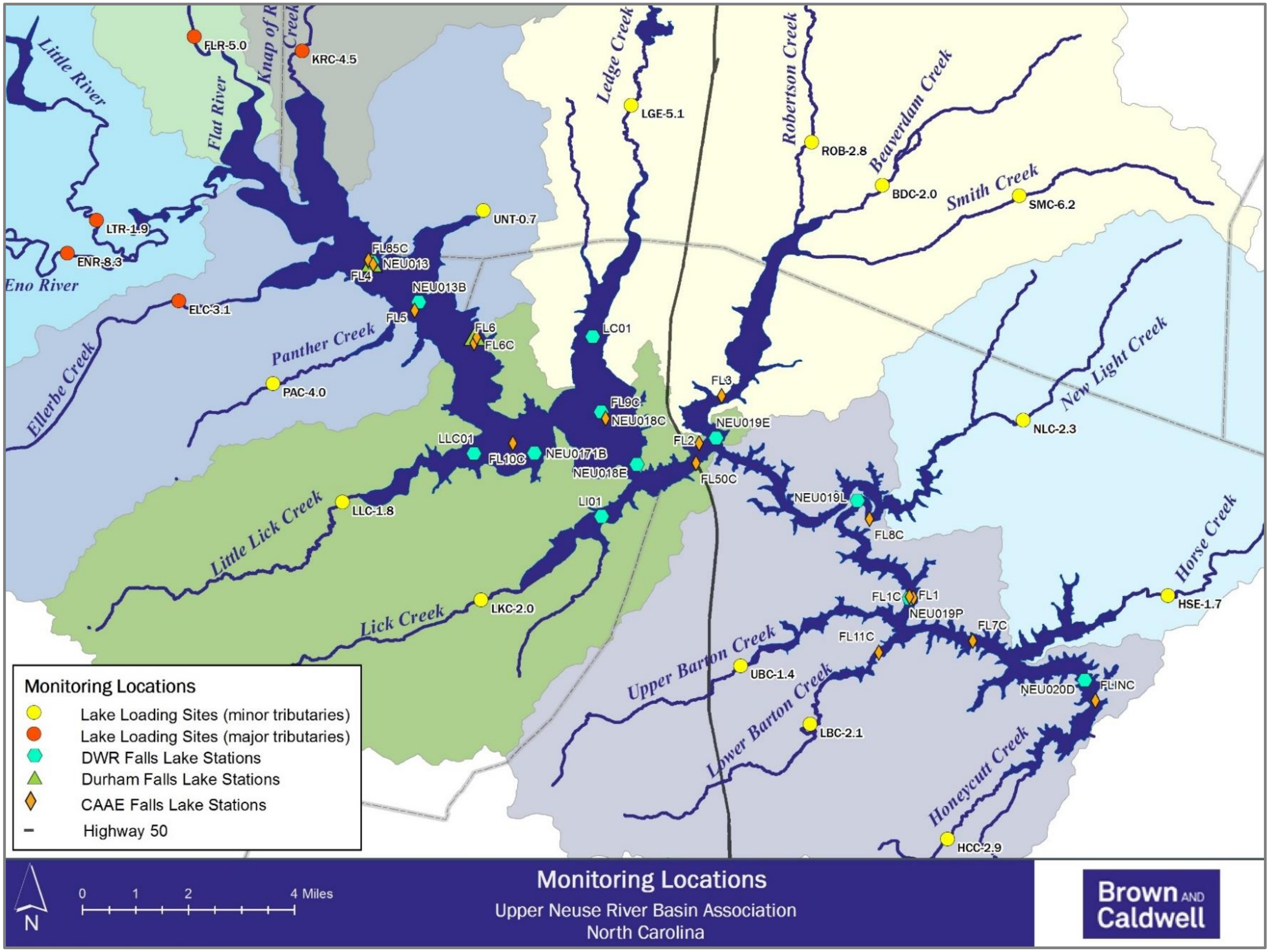


Figure 2-2. Falls Lake DWR, CAAE, and City of Durham Monitoring Locations, along with UNRBA Lake Loading Stations

Field data along with nutrient, chlorophyll-a, 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 discussed in this report 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 because Durham conducts monitoring at a greater frequency during the growing season as opposed to monthly throughout the year as performed by the other organizations.

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 two to three 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 2-3. 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 2017							
Monitoring stations are listed in order from upstream to downstream.							
Station ID	Chlorophyll-a	TOC	Nitrogen (TN, TKN, NOx, NH3)	TP	TSS	Field Parameters (Temp, DO, pH, Conductivity)	Secchi Depth
FL4	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly	Monthly
FL85C (Interstate 85)	Weekly	2x per month	2x per month	2x per month	2x per month	2x per month	Weekly
FL5	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly	Monthly
FL6C	Monthly	-	-	-	-	-	Monthly
FL6	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	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 [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly	Monthly
FL3	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly	Monthly
FL8C	Monthly	-	-	-	-	-	Monthly
FL1C	Monthly	-	-	-	-	-	Monthly
FL1	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	Monthly [a]	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

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

2.1.4 Modifications to Routine Monitoring since 2017 Annual Report

UNRBA Routine Monitoring continued through calendar year 2017 without any substantive changes in monitoring, data management, or reporting protocols from 2016. The UNRBA released a Request for Qualifications in May 2017, which resulted in a change in the UNRBA Monitoring Program service provider from Cardno Inc. to Brown and Caldwell (BC) at the beginning of FY2018. Because several key individuals had moved from the former firm to the latter, key program staff have remained consistent throughout the monitoring project. An addendum to the Monitoring QAPP was executed and provided to DEQ to document this change. The same Certified Laboratory (Environment 1) remained engaged through this transition. As part of the UNRBA service provider transition, the monitoring database was migrated from Cardno Inc's domain to the UNRBA webmaster's domain.

2.2 Special Studies

The UNRBA Monitoring Program includes Special Studies designed to address specific questions and information gaps. This section briefly summarizes Special Studies implemented as a part of the UNRBA's Monitoring Program (see Table 2-5). Each Special Study is guided by a Study Plan 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 5.

2.2.1 Current Special Studies

The UNRBA currently has three special studies in various stages of data collection, analysis, and reporting. This section briefly describes each of these studies. Results for these studies are addressed in Section 5.1.

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 5.1.

2.2.1.2 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 results of this study are summarized in Section 5.2.

Table 2-5. 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. Results of this study will be presented in Section 5.
Lake Bathymetry and Sediment Mapping (Completed study - concluded in Fiscal Year 2017)	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. Results of this study will be presented in Section 5.
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. Results from this study were presented in the 2015 and 2016 Annual Reports available online at http://unrba.org/monitoring-program.
Falls Lake Sediment Evaluation (Completed study – to be concluded in Fiscal Year 2018)	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. Results of this study will be presented in Section 5.
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. Results of this study are described in the 2016 Interim Report available online at http://unrba.org/monitoring-program.
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. The results of this study were presented in the 2015 Annual Report available online at http://unrba.org/monitoring-program.
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. The Model Performance Evaluation technical memorandum summarizes the study results available online at http://unrba.org/monitoring-program.
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. The results of this study were presented in the 2015 Annual Report available online at http://unrba.org/monitoring-program.
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. Future budgeting for such activities is expected to primarily be part of the Modeling and Regulatory Support Contract that was initiated in September 2016 available online at http://unrba.org/monitoring-program.

2.2.1.3 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 accuracy of a model grid for the purposes of hydrodynamic modeling is critical for simulating the fate and transport of materials in the lake including the cycling of nutrients and growth of algae.

The sediment mapping component of this study was 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 was unknown. A dual-frequency echo-sounder was 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 was completed in 2017 and the results are presented in Section 5.3.

Section 3

Results and Discussion of Routine Monitoring through December 2017

This section presents and discusses the Routine Monitoring data collected through the end of December 2017. Where possible, 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 after setting up a user account at http://data.unrba.org/index.php . Users can review raw data, generate summary statistics, and obtain detailed station information.

In addition to ensuring the raw data are available online, the UNRBA monitoring service provider will coordinate directly with the UNRBA's modeling contractors to assist in preparing, screening and providing data files for model development.

3.1 Overview of Hydrologic Conditions

The UNRBA Monitoring Program does not collect hydrologic data, but relies on data from other public sources. The brief analysis in this section examines that data to provide hydrologic context for the overall Monitoring Program.

To illustrate the overall hydrologic conditions for the monitoring period precipitation patterns in the Falls Lake watershed and the resulting Falls Lake water levels were evaluated. Observed values were then compared 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. For the UNRBA monitoring period (2014 to 2017), the annual average rainfall total was 7 to 14 percent higher than the 30-year average. Although each of these years were slightly wetter than average, the annual totals fall within the middle 50 percent of annual totals since 1985. It is important to note that while a given year may be wetter than normal, specific months can be relatively dry. For example, in 2017, only three months (April-Jun) out of the year had higher than normal rainfall totals whereas six months showed lower than normal rainfall totals. Total precipitation can vary substantially within the watershed. Across the 11 stations, the recorded annual rainfall varied by up to 22 inches (2014) or by as little as 13 inches (2017).

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, precipitation totals by month were examined 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 percent 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 so in general, the monitoring period appears to have been fairly normal in terms of precipitation. However, in 2015 the months of May and August were notably drier than normal while the months of November and December were wetter than normal. In 2016, the summer and early fall were wetter than average, while January was dryer than average. In 2017, the spring was much wetter than normal while the remainder of the year was close to normal or drier than normal.

A related analysis was conducted on the water level (stage) of Falls Lake based on daily data collected by the USACE (see Figure 3-2). For this analysis, median values (dashed line) are based on data reported from 1987 to present. From January 2014 to March 2015, the observed stage (orange line) in Falls Lake was generally higher than normal (above the 75th percentile much of the time). From April 2015 to October 2015, lake levels were very close to the median value. From October 2015 through January 2016, lake levels were relatively high (generally above the 75th percentile for most of this time and exceeding the 95th percentile towards the end of December). In October 2016, lake levels again rose as a result of excess precipitation from Hurricane Matthew. In 2017, lake levels rose due to a particularly rainy spring and then gradually fell to below normal values that fall and winter.

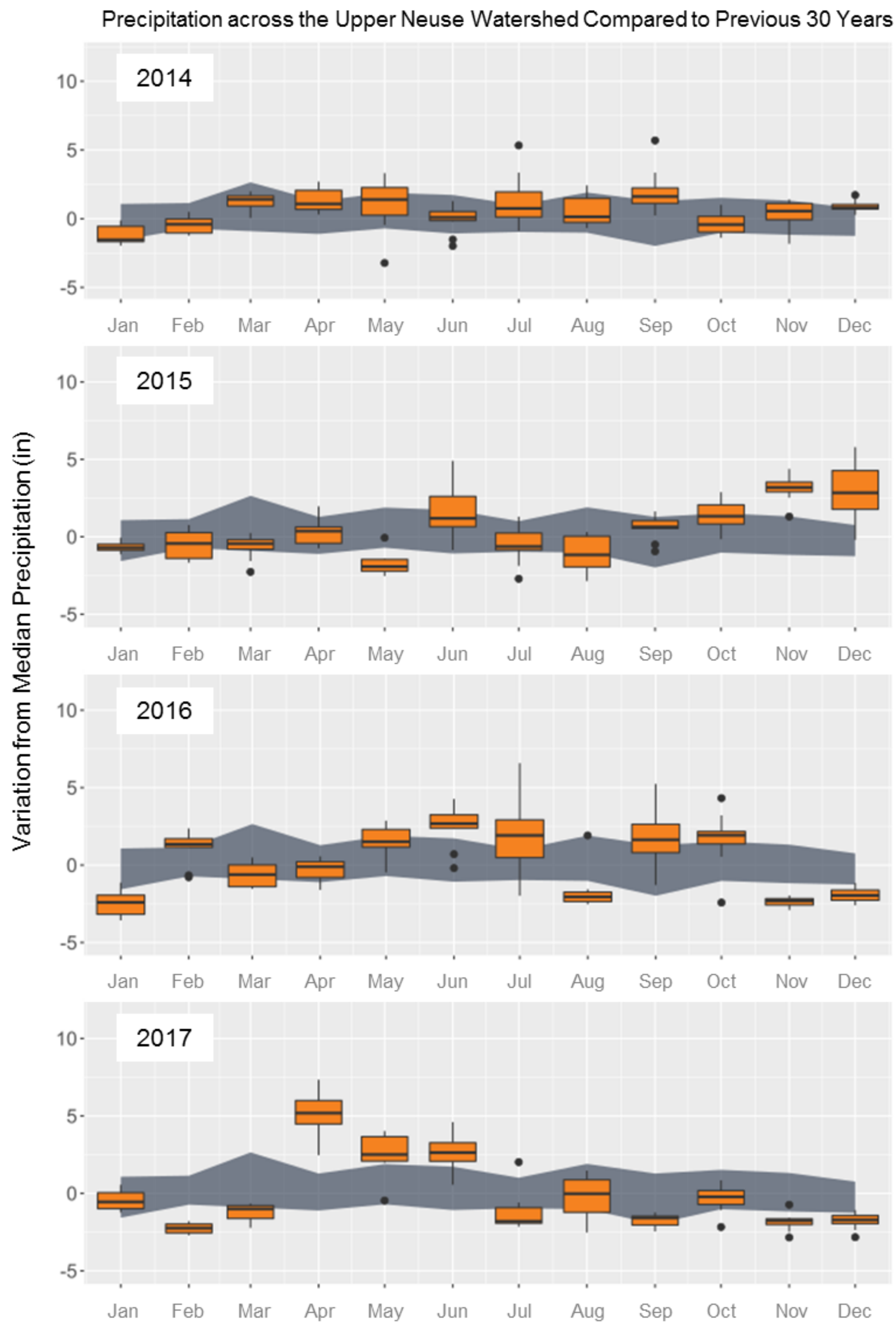


Figure 3-1. Boxplots Representing Variation from 30-Year Normal Monthly Precipitation Totals at Monitoring Stations in the Falls Lake Watershed

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 8-10 gages included in the data summary. Whiskers extend to the range of observed values; statistical outliers are displayed as black circles. Long-term median monthly rainfall totals range from 2.9 inches in February to 4.4 inches in July.

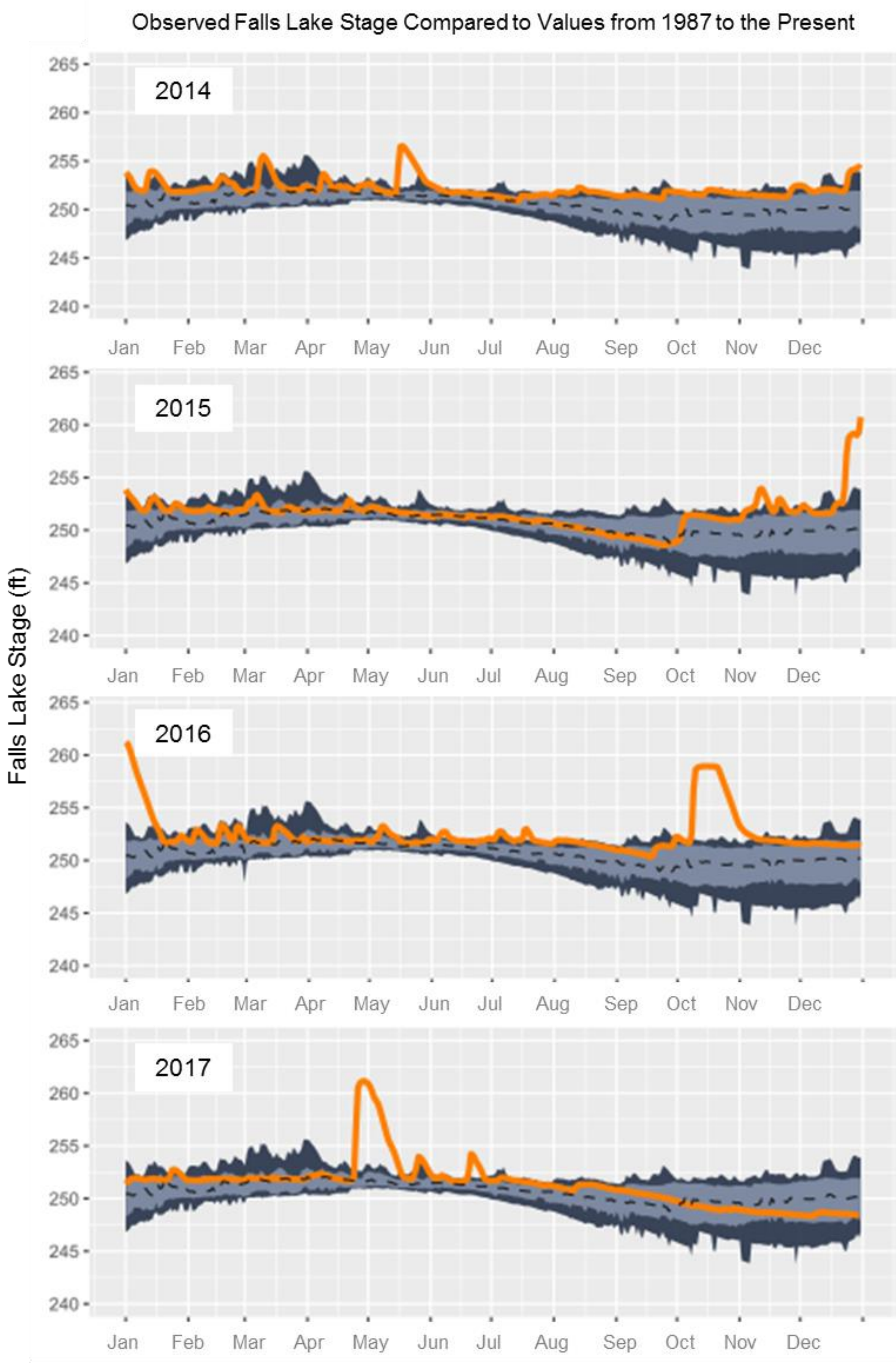


Figure 3-2. Falls Lake Elevation from January 2014 through December 2017

(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 extended 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 (because the USACE typically opens the spillway more at the dam) and algal concentrations tend to be lower.

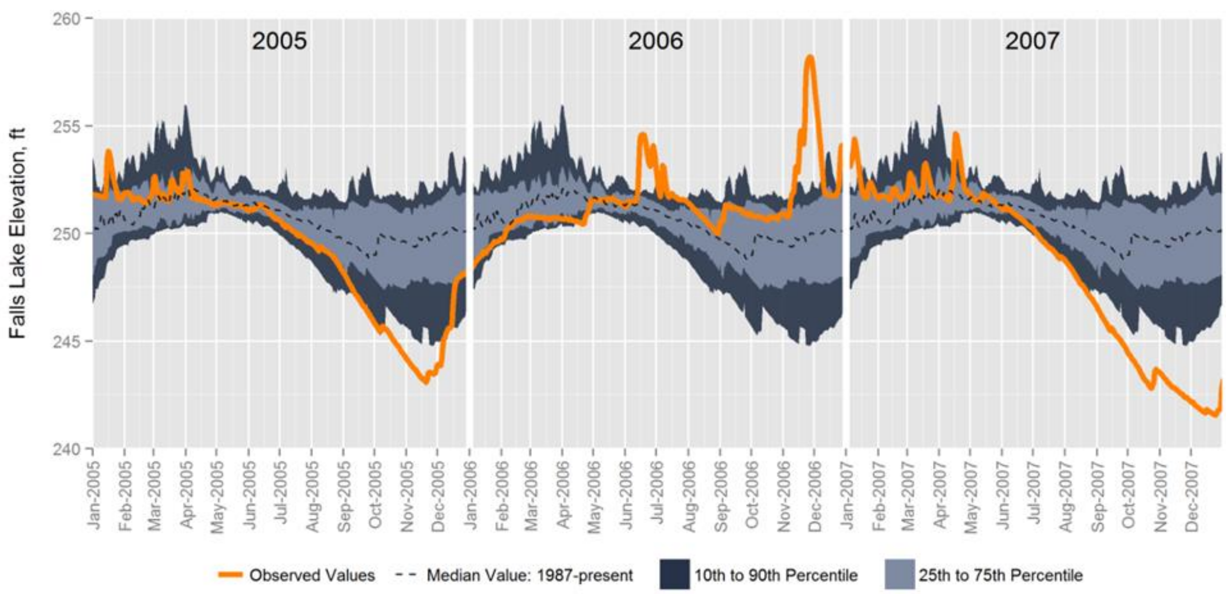


Figure 3-3. Falls Lake Elevation (stage) in Feet Above Mean Sea Level for the Period of DWR's EFDC Model Years 2005 through 2007 (Orange Line)

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 Overview of Routine Monitoring Results

This section offers a concise presentation of data for most of the parameters in the Monitoring Program. Most 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. Thus, jurisdictional stations are placed 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 the Lake Loading monitoring stations between August 2014 and December 2017. 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 2017 are shown in white, while outliers from previous results are shown in black. Observations below each parameter's reporting limits are shown as a red + symbol at the reporting limit. Note that some of the graphics have a logarithmic Y-axis to allow the depiction of a broader range of concentrations on a reasonably-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.

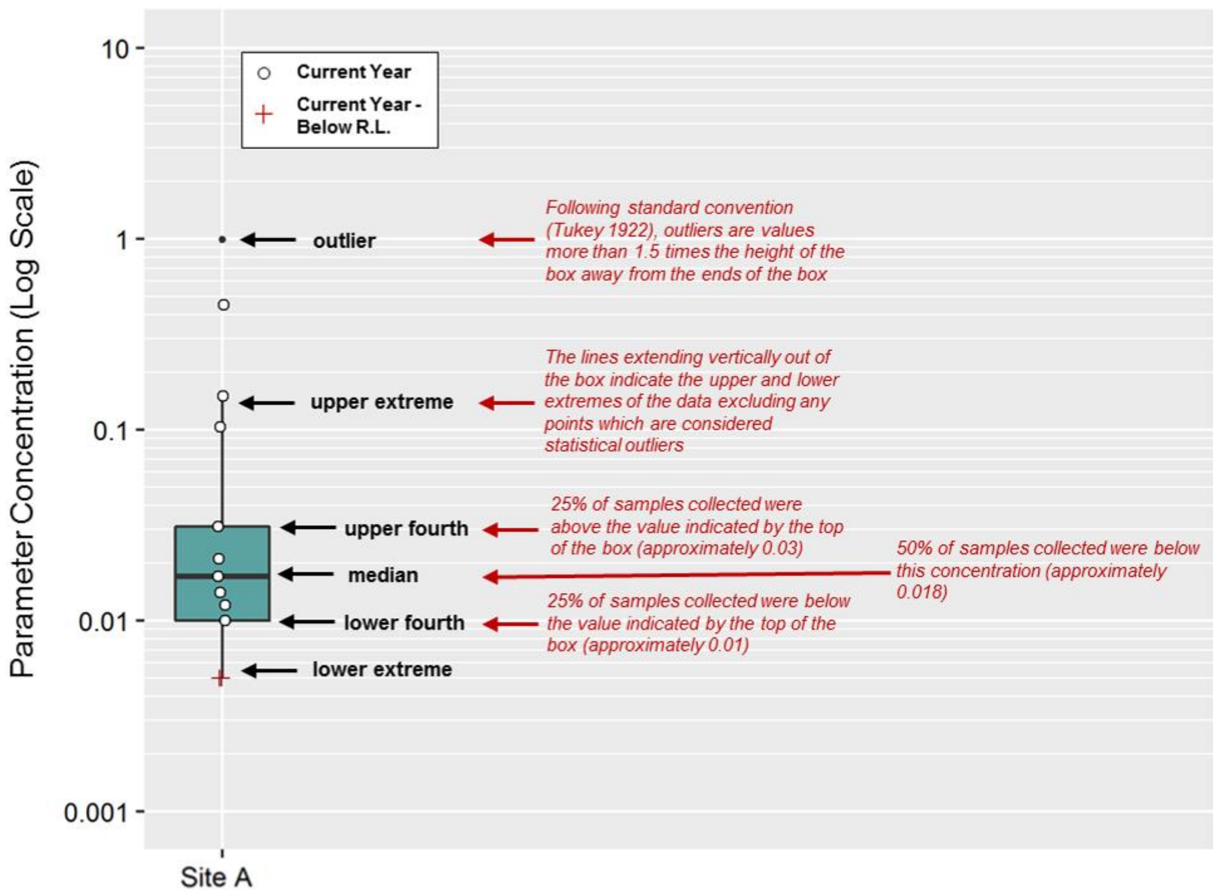


Figure 3-4. An example box and whisker figure as used in this report and the meaning of figure components

Data points (black and white 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. This arrangement allows quick inspection of whether spatial patterns are present. Station labels with "(LL)" indicate Lake Loading stations and stations labeled with "(JB)" indicate Jurisdictional Boundary stations. Table 2-2 provides a list of all tributary stations using the same station identifiers. All stations have had 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. Two parameters (dissolved oxygen and pH) monitored by the UNRBA at Jurisdictional Boundary stations have numeric water quality criteria. The graphs below for those parameters indicate the level of the applicable state criterion for each parameter.

- Dissolved oxygen (DO) represents the amount of oxygen in the water available for respiration by aquatic organisms. Oxygen concentrations in surface waters can naturally range from 0 to 15 mg/L or higher. Observed oxygen concentrations are typically the result of a combination of physical and biological features. On the physical side, water temperature constrains the capacity of water to hold on to oxygen. Water can hold more than 14 mg/L of oxygen near freezing, but at 60 F°, that is reduced to 10 mg/L, and at 78 °F, water is saturated with oxygen at just 8 mg/L. Oxygen molecules exchange between the air and water such that, absent other factors, the oxygen concentration in the water approaches its temperature-based equilibrium. But, algae, bacteria, and other aquatic organisms can cause DO levels to rise above or fall below these saturation values through photosynthesis and respiration. As the concentration diverges from the waterbody's saturation point, physical processes work toward bringing the dissolved oxygen concentration back into equilibrium with the atmosphere. The aeration from fast moving, turbulent streams can bring the water back to equilibrium relatively quickly, but in the case of calm or even stagnant water, the oxygen exchange across the water surface can happen very slowly leaving the concentration to be driven primarily by biology. Bacteria breaking down decaying organic matter can draw oxygen levels down to very low levels. If atmospheric exchange is slow (as in the case of stagnant water), these depleted oxygen concentrations can persist for long periods of time unless replenished through photosynthesis by algae and plants, or a hydrologic event flushes the system. This ongoing give-and-take between physical and biological factors drives the variability observed among streams and within different areas of the reservoir.

  Measured oxygen values are presented in Figure 3-5. The vast majority of DO concentrations were between 5 and 12 mg/L, but tended to be lower at locations with slower-moving water or large wetland complexes, including Beaverdam Creek, Robertson Creek, Unnamed Tributary to Falls Lake, and Ledge Creek. The wide range of values observed within single stations is also explained by the underlying physical and biological factors described above. Nearly all the oxygen concentrations above 10 mg/L occurred during cold months with water temperatures below 60°C. The lower values tended to be observed in summer and fall when water temperatures were at their highest and the capacity of water to hold oxygen was at its lowest. Already low oxygen concentrations were exacerbated by warm and dry conditions which caused discharge from the creeks listed above to slow drastically. As a result, there were times when these monitoring locations were essentially stagnant pools of warm water in which bacterial decomposition of organic matter (which uses oxygen) could flourish.

  Within some tributaries, an interesting difference was observed between the Jurisdictional and Lake Loading stations. Compared to upstream Jurisdictional stations, the Lake Loading stations on Flat River, Little River, and Ledge Creek all had lower DO concentrations than stations upstream on the same tributary network. For all three of these tributaries, the Lake Loading stations are located below reservoirs (Lake Michie, Little River Reservoir, and Lake Rogers, respectively) and the Jurisdictional stations are above the reservoirs. Compared to the contributing streams, the reservoirs offer a different set of factors affecting oxygen concentrations, including physically slowed water, reduced turbulence, and an ecosystem capable of supporting more stable communities of algae and other planktonic organisms. These differences could have contributed to the lower dissolved oxygen observed downstream of the reservoirs. Alternatively (or in conjunction), reduced discharge from some reservoirs as they captured the water from upstream could have caused downstream conditions to become drier with slower moving water, also capable of leading to reduced oxygen concentrations. Monitoring stations which are not separated by reservoirs appear to have very similar dissolved oxygen concentrations (e.g., stations upstream of Lake Michie on the Flat River and its tributaries, Eno River, and the Horse Creek stations).

- **pH** is a measure of acidity or alkalinity using a log scale of 0 to 14. Various metabolic functions of aquatic organisms, as well as biogeochemical processes, can be affected by pH. Most fresh water bodies have pH levels near the middle of the pH scale (7), and North Carolina water quality criteria 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).
- **Specific conductance** is a measure 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. Field-measured specific conductance values at the Jurisdictional and Lake Loading stations are generally consistent throughout the watershed (Figure 3-7), with most values lying between 75 and 200 µS/cm. Higher ranges of values tend to occur downstream of major wastewater treatment plants (WWTPs) and small package plants (e.g., Knap of Reeds, Ellerbe, and Upper Barton creeks).

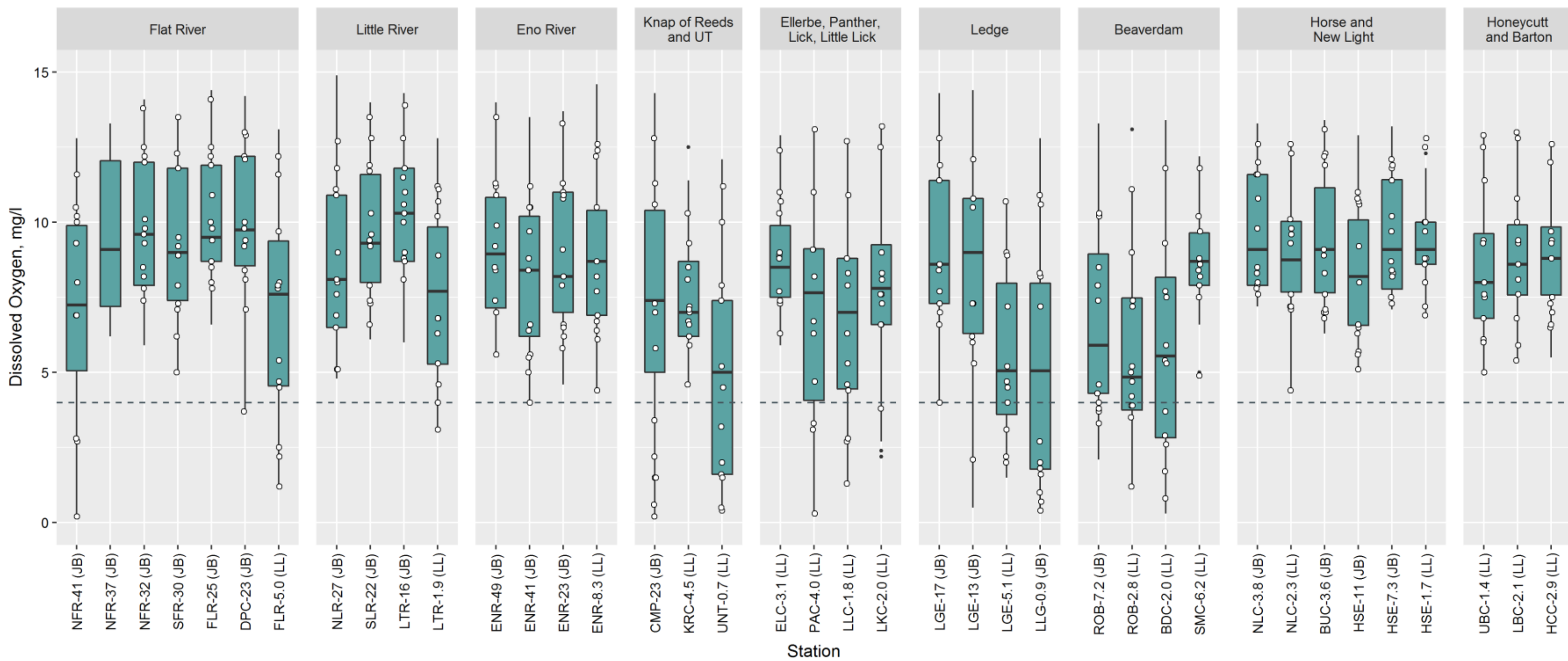


Figure 3-5. Dissolved Oxygen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

The State's instantaneous dissolved oxygen criterion of 4 mg/L is shown as a horizontal dashed line.

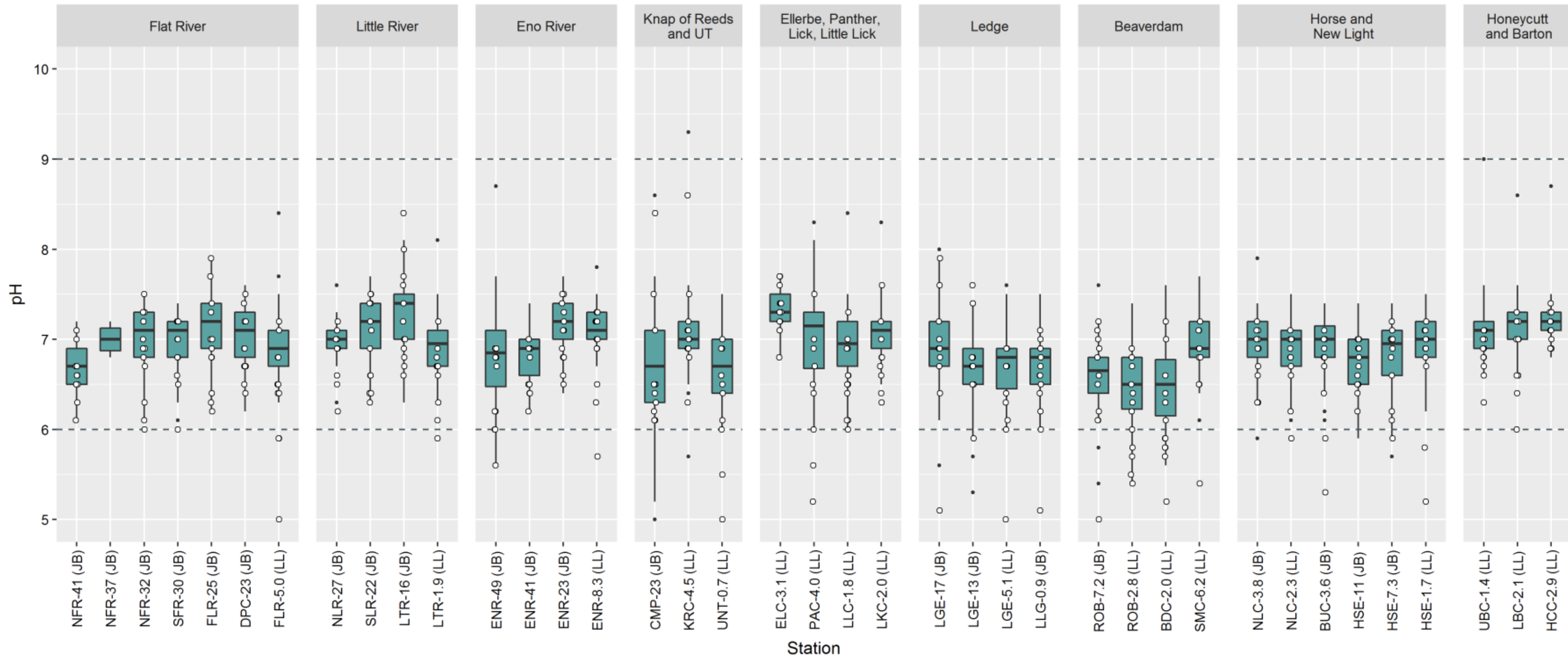


Figure 3-6. pH in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

The State's upper and lower pH criterions are shown as horizontal dashed lines at values of 9 and 6.

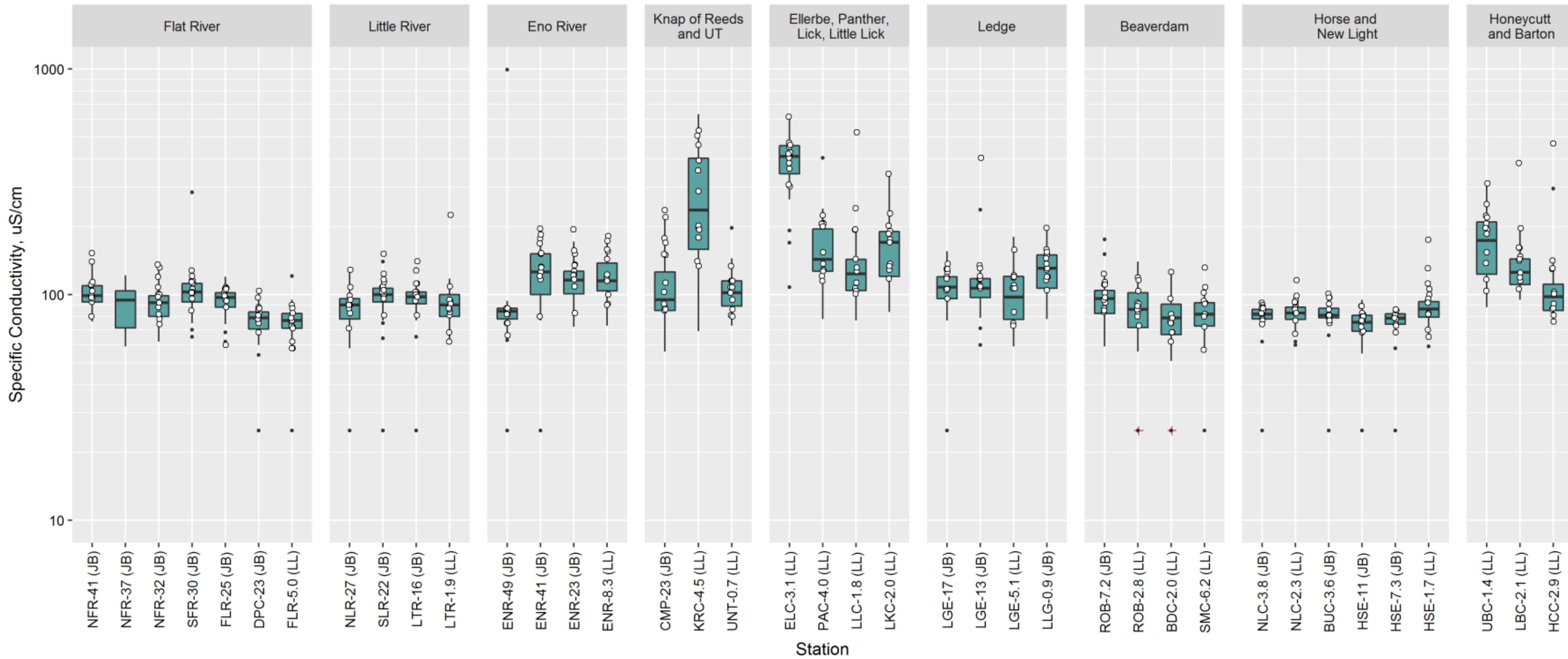


Figure 3-7. Specific Conductivity in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

- **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 WWTPs or onsite disposal systems, residential or agricultural fertilizer, and manure. Nitrogen occurs in water in organic and inorganic forms. Organic nitrogen is in living organisms (including algae) and decomposing and sequestered organic matter. Inorganic forms include ammonia, nitrate, and nitrite which are more easily used by algae than organic forms. Some forms of organic nitrogen are resistant to biological processing and are virtually unavailable as a nutrient for algae. Total nitrogen is calculated as the sum of total Kjeldahl nitrogen (TKN) and nitrate+nitrite. Total nitrogen at tributary stations is presented in Figure 3-8, nitrate+nitrite in Figure 3-9, ammonia in Figure 3-10, and organic nitrogen in Figure 3-11. Higher ranges of values for nitrate+nitrite and total nitrogen tend to occur downstream of major WWTPs and small package plants; higher values of ammonia and organic nitrogen occur downstream of these facilities and in areas dominated by very slow flowing, wetland conditions. Organic nitrogen (less available for assimilation by algae) comprises a substantial fraction of the total nitrogen observed. Ammonia (most available for algal uptake) is generally the smallest fraction of total nitrogen.
- **Phosphorus** is 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). Phosphorus is also a component of stormwater runoff, shallow groundwater, discharge from WWTPs or onsite disposal systems, fertilizers, and manure. Total phosphorus includes the ortho-phosphate fraction which is the most available form for algal production. Most values at tributary stations were less than 0.1 mg/L, with higher values downstream of major WWTPs and in areas dominated by very slow flowing, wetland conditions (Figure 3-12). The highest concentrations were observed downstream of the SGWASA WWTP (KRC-4.5) in 2015. During this period, SGWASA had been undergoing WWTP upgrades and experienced some operational disruptions that resulted in relatively high concentrations. Data collected in 2016 and 2017 did not have similarly high values.
- **Total suspended solids (TSS)** represent the amount of particulate material suspended in the water column. Most measured values were less than 10 mg/L, but there was notable variability among stations and between rainfall events within the stations (Figure 3-13). Stations draining relatively small watersheds and those located in very slow flowing areas tend to have higher concentrations of TSS. Sample collection following rain events is expected to result in samples with higher TSS associated with the increased turbidity and sediment transport.
- **Total organic carbon (TOC)** is a measurement of all organic forms of carbon in a water sample—living and non-living, particulate and dissolved. 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 treatment costs for drinking water. Figure 3-14 shows the TOC data collected in tributaries of Falls Lake. TOC values were observed between 2 and 10 mg/L at most stations, with values ranging up to 20 mg/L in areas dominated by very slow flowing conditions and wetland complexes. Despite WWTP sites generally having higher nitrogen, phosphorus, and conductivity (all of which can be indicators of the presence of a WWTP), they do not have elevated TOC concentrations. This is unsurprising given that the treatment process is designed to remove most of the organic matter through biological degradation before it is discharged into receiving waters.

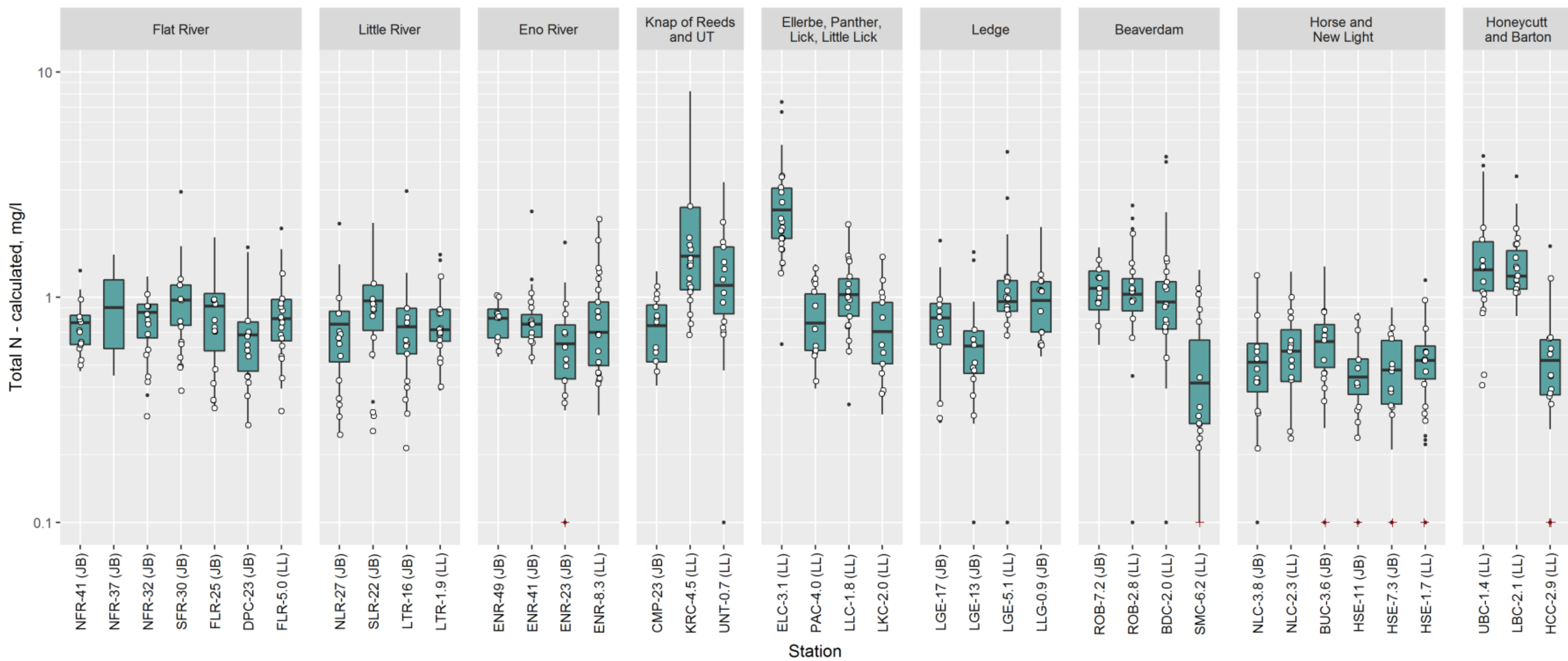


Figure 3-8. Total Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

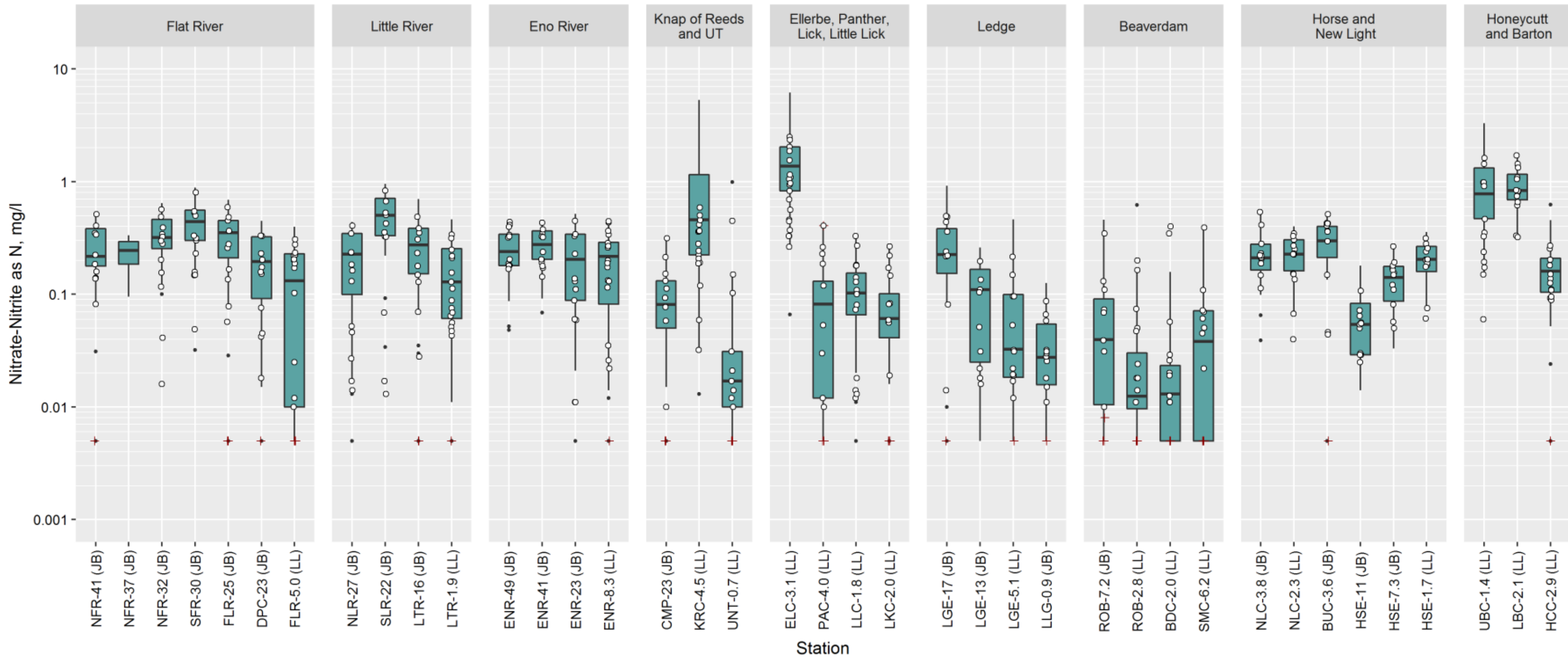


Figure 3-9. Nitrate+nitrite in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

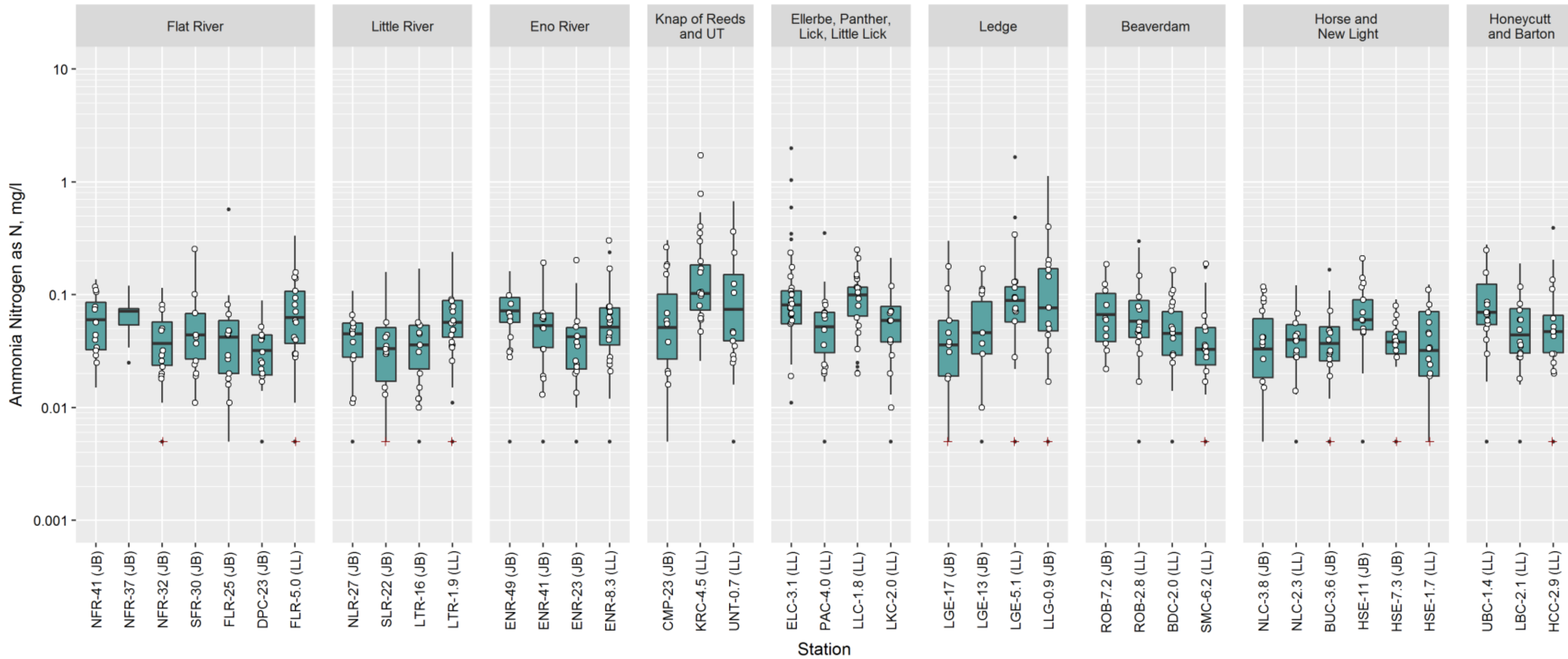


Figure 3-10. Ammonia in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

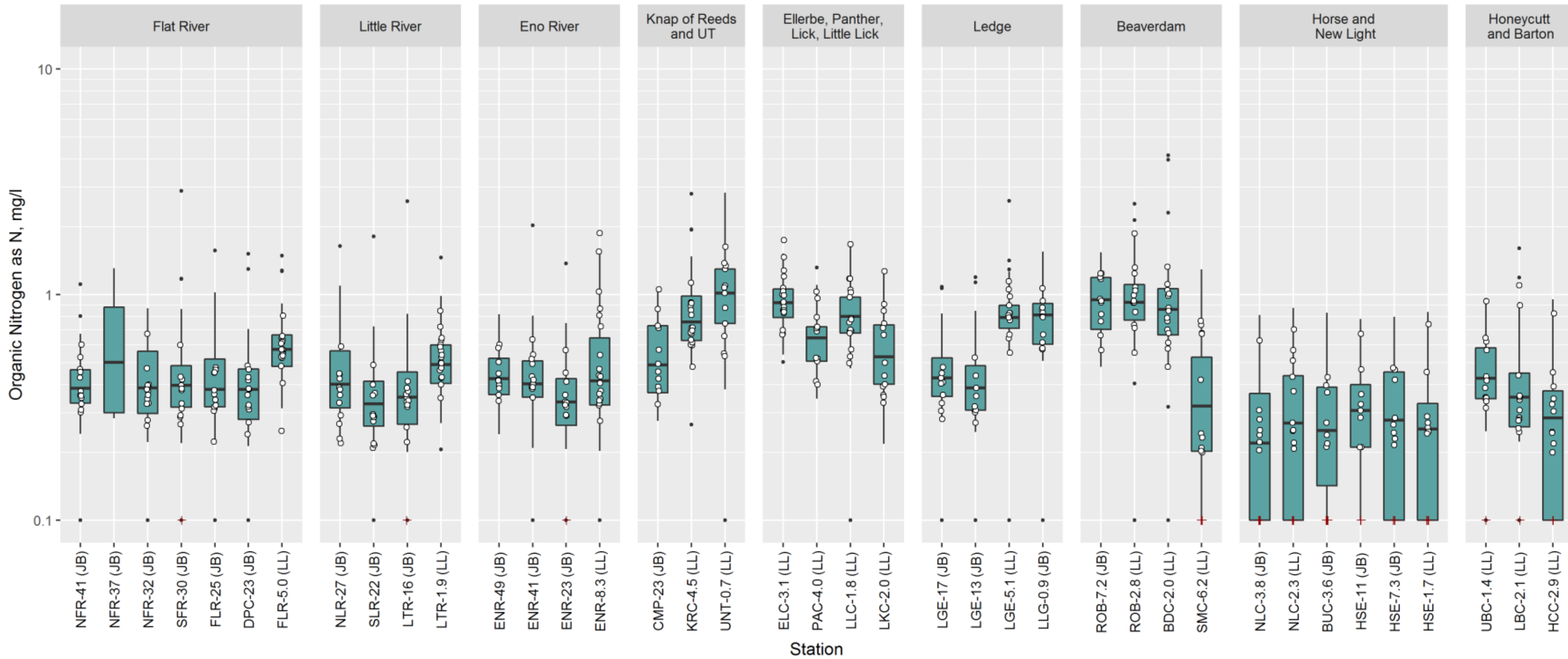


Figure 3-11. Organic Nitrogen in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

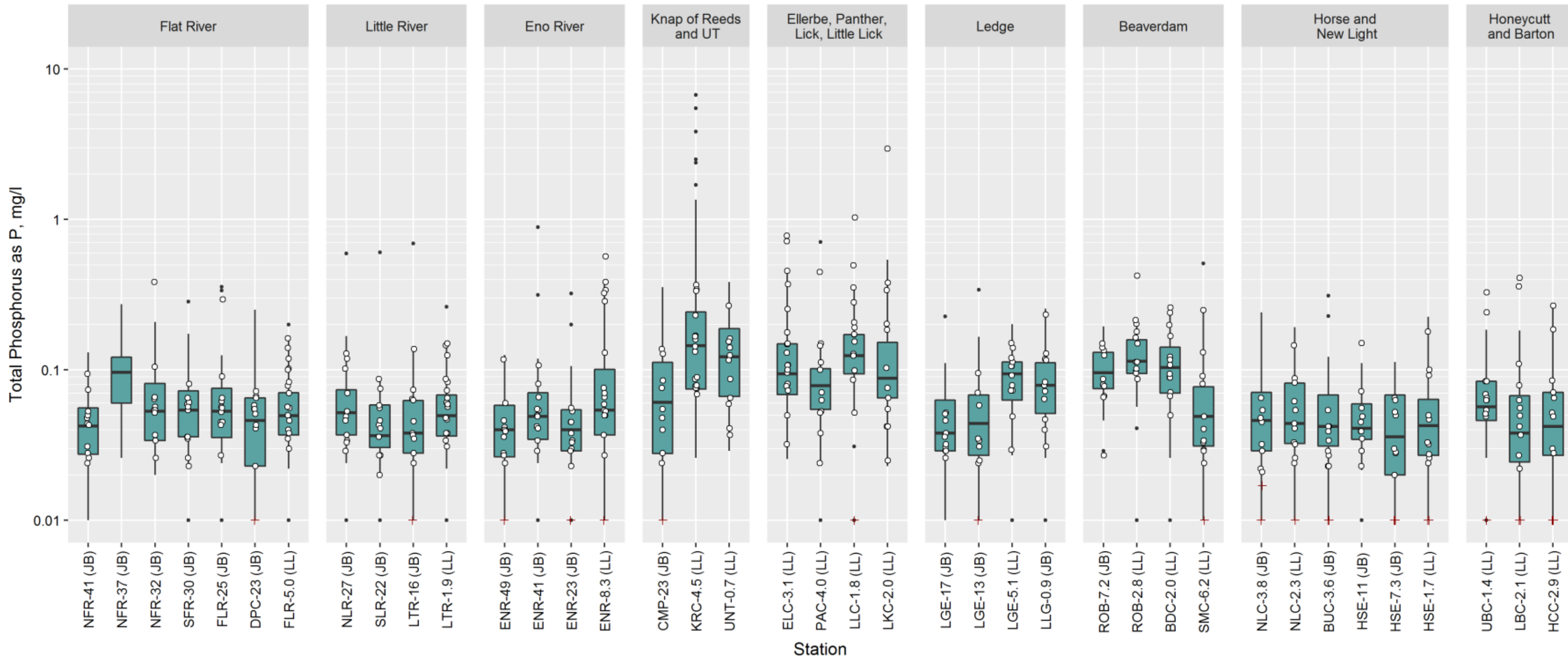


Figure 3-12. Total Phosphorus (TP) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

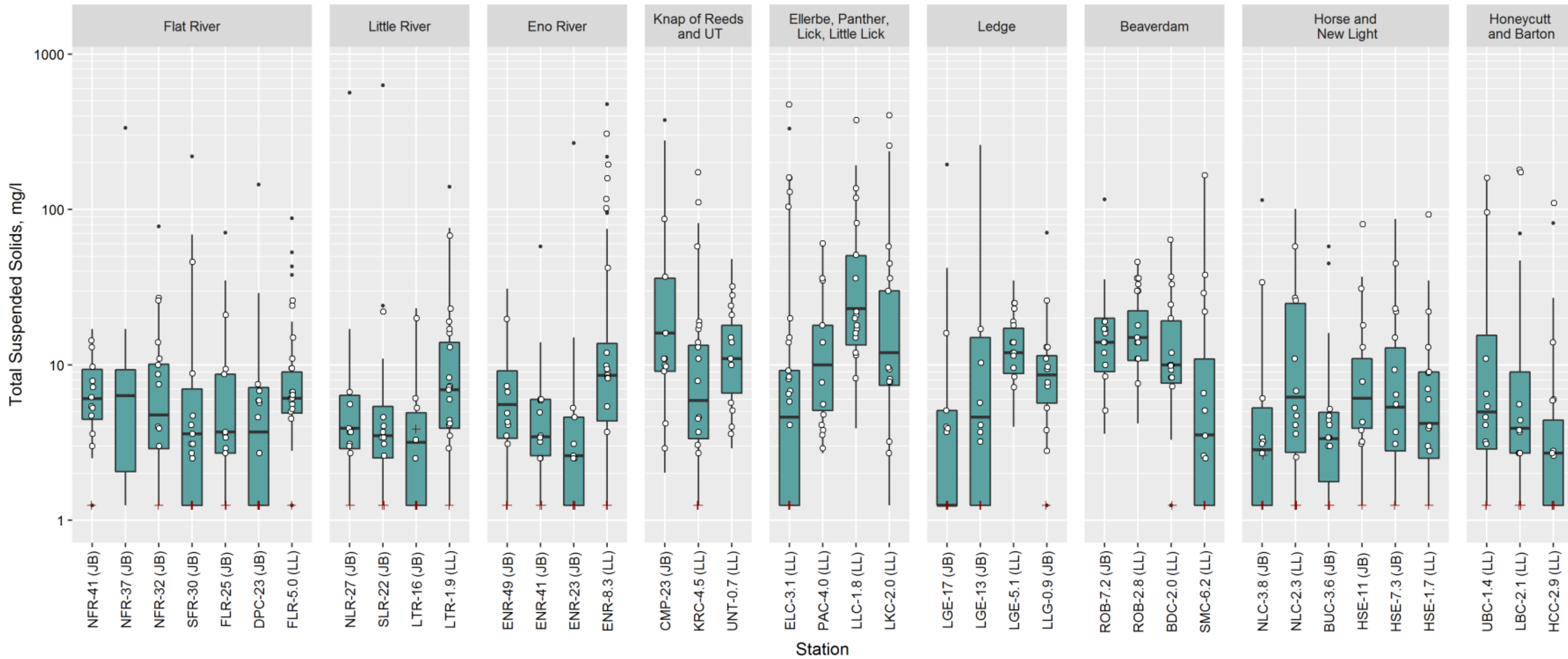


Figure 3-13. Total suspended solids (TSS) in Jurisdictional Boundary and Lake Loading Samples from August 2014 to December 2017

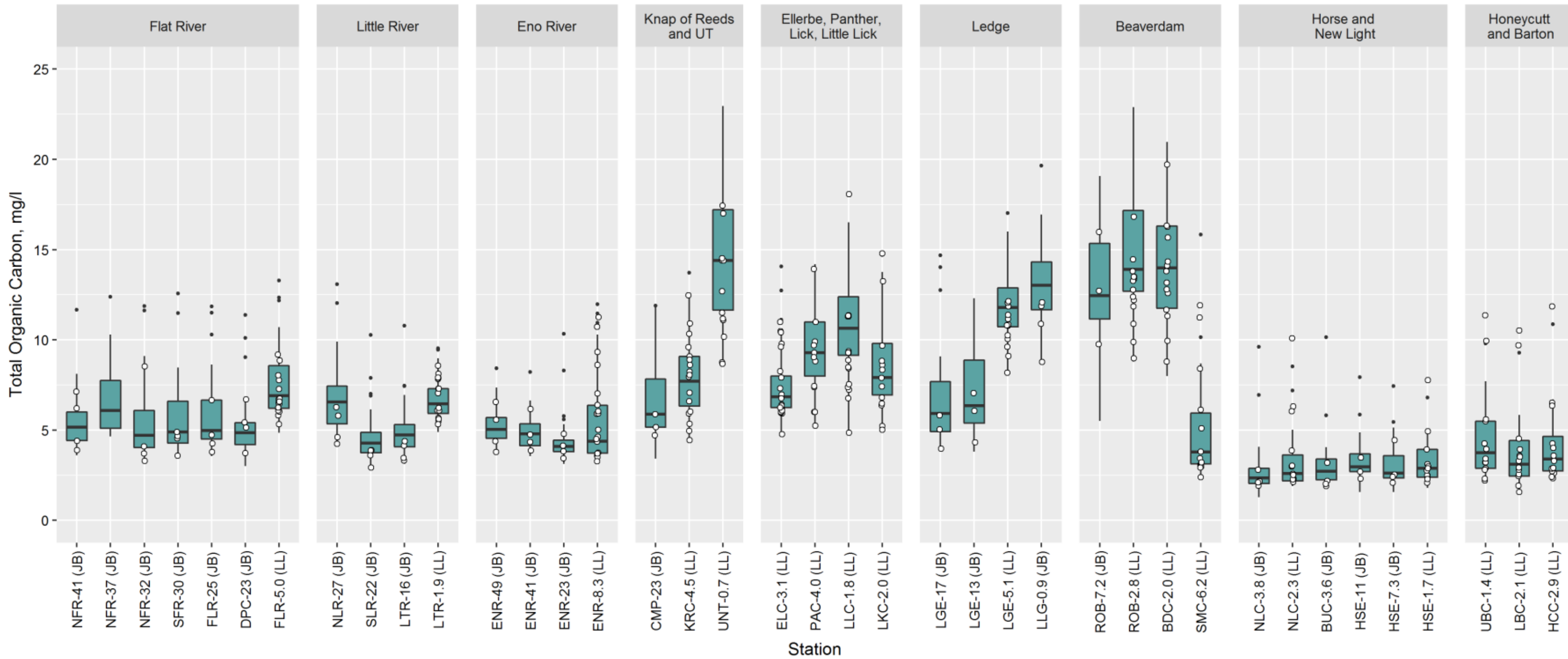


Figure 3-14. Total Organic Carbon (TOC) in Jurisdiction Boundary and Lake Loading Samples from August 2014 to December 2017

3.2.2 Lake Loading and In-Lake Water Quality Stations

The series of graphics below provides a comparative view of the data from the tributary Lake Loading stations and the in-lake DWR, CAAE and City of Durham stations between August 2014 and December 2017. Box and whisker plots represent the statistical summary of the data, with data points from 2017 superimposed to allow a visual assessment of substantial changes between 2017 and the prior years. They provide an overview of water quality for water entering the lake and within the lake itself. Box and whisker plots illustrate median and percentiles statistics. Elements of the boxes and whiskers above the reporting limit are not affected by differences in reporting limits. Thus, median values shown on the boxes can be compared across all stations.

Tributary stations are grouped on the left side of figures and in-lake stations are on the right side. Stations are presented from the top of the lake at the left toward the dam on the right. This layout facilitates visual assessment of spatial patterns among the tributaries or from upstream to downstream in the lake, and of apparent differences between tributary and in-lake concentrations. Only stations with data for each given parameter are displayed, thus there is variation in the number of stations displayed for each graph.

Lake data come from photic zone composite samples. DWR lake data consist of monthly values from the same monitoring period as the lake loading stations. City of Durham data are included for comparison, but consist of weekly measurements from April through October and only after 2015 when their QAPP had been approved by DWR. Nutrient data from CAAE are limited to values since April 2016 when CAAE began collecting photic zone composite samples as at some of their sampling sites. Chlorophyll-a data include values since August 2014 for sites at which CAAE collected photic zone composites and since April 2016 at an additional six stations.

Reporting limits are shown as horizontal lines under the bar charts when available. Reporting limits are set by individual laboratories and monitoring projects and thus may be different across the stations displayed. All results reported by the lab as below reporting limits are displayed as the reporting limit. Observations below the reporting limits are shown as a red + symbol at the reporting limit. 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 have numeric water quality criteria (dissolved oxygen, pH and chlorophyll-a). Graphs for these parameters show the state's numerical criteria.

- **Dissolved oxygen** measurements at Lake Loading stations and in-lake stations are provided in Figure 3-15. DO levels in the lake and at most Lake Loading stations are usually well above the 4 mg/L criterion. Lake Loading stations in very slow flowing areas dominated by wetlands tend to have concentrations lower than the criterion due to the combination of slow-moving water and decomposition of organic matter (which consumes oxygen). The two City of Durham stations show DO ranges slightly lower than most other lake stations, which is attributable to the fact that sampling is only conducted during the growing season when warmer temperatures mean water can hold substantially less dissolved oxygen.
- **pH.** Most pH values for in-lake and Lake Loading stations fall within the state's criteria range of 6 to 9 (Figure 3-16). Values at Lake Loading stations were generally lower than in-lake stations. 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.
- **Specific conductivity** values measured at the Lake Loading stations are generally similar to those measured at the in-lake stations, except for locations downstream of major WWTPs and package

plants (Figure 3-17). Within the lake, conductivity is somewhat lower at the downstream end than the upstream end. On Figure 3-17, note the difference in reporting limits between the tributary stations (50 μS/cm) and the DWR lake stations (14.9 μS/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.

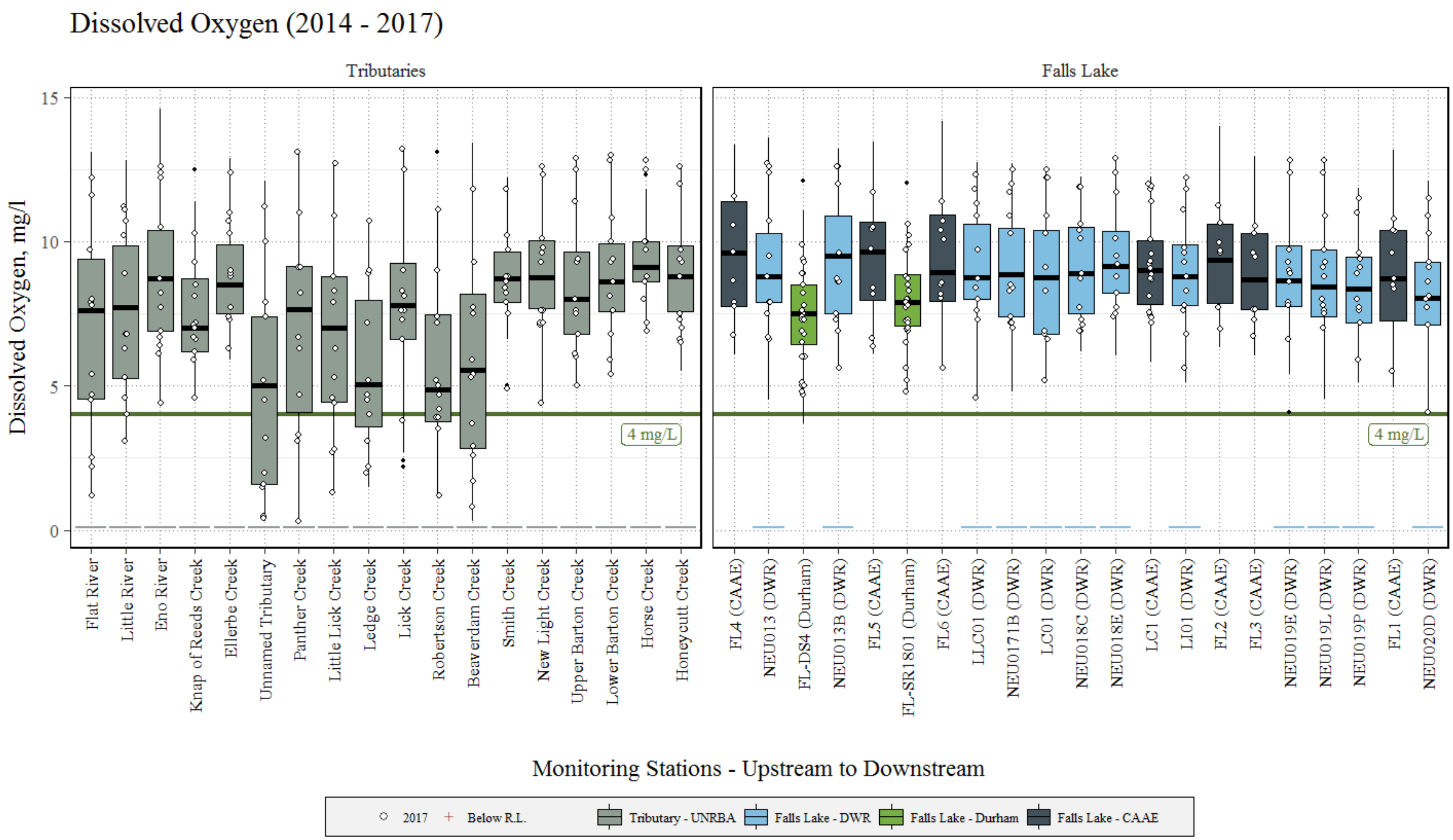


Figure 3-15. Dissolved Oxygen in Lake Loading and Lake Samples from August 2014 to December 2017

The State of North Carolina instantaneous dissolved oxygen (DO) criterion of 4 mg/L is shown as green line.

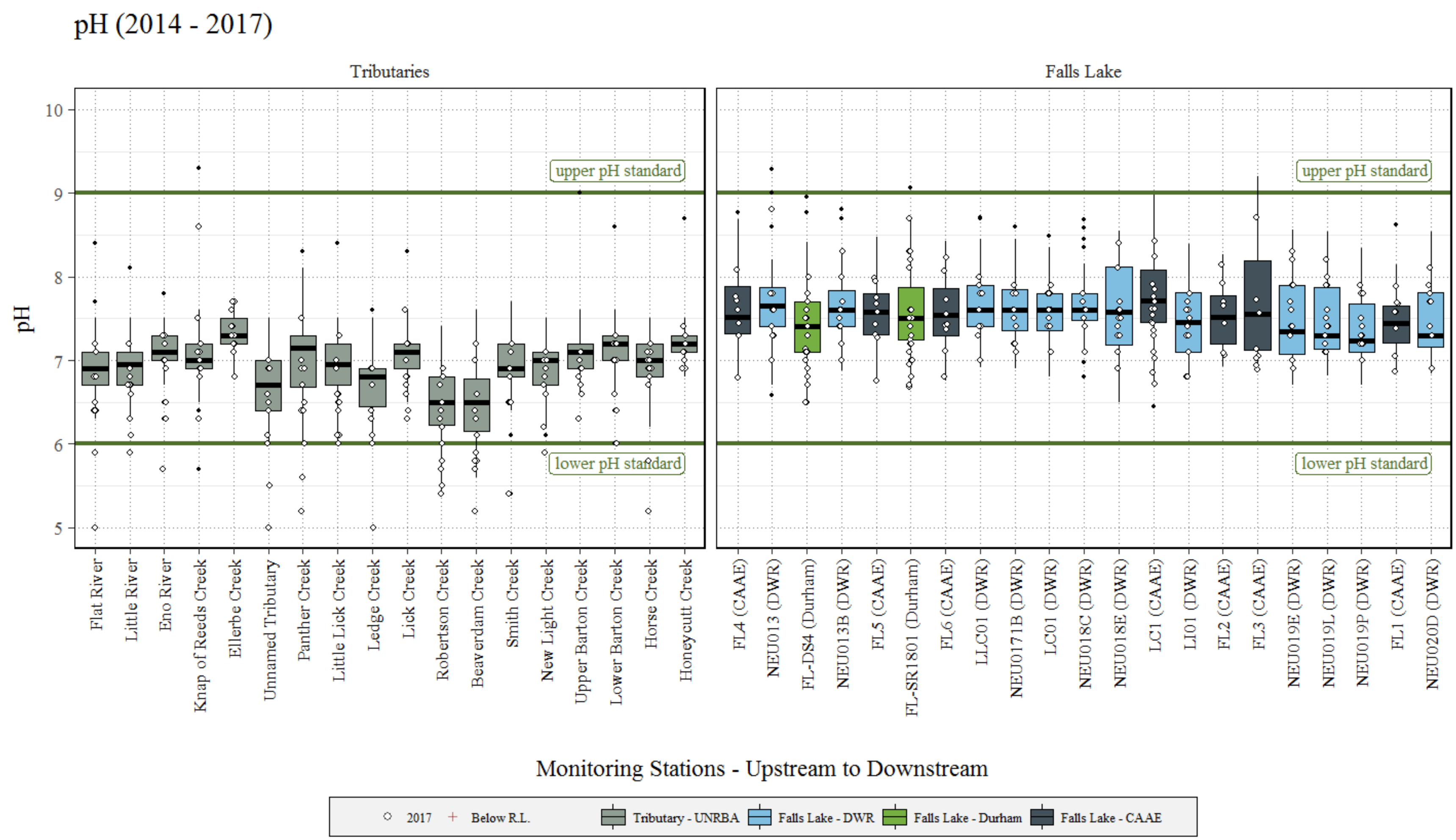


Figure 3-16. pH in Lake Loading and Lake Samples from August 2014 to December 2017

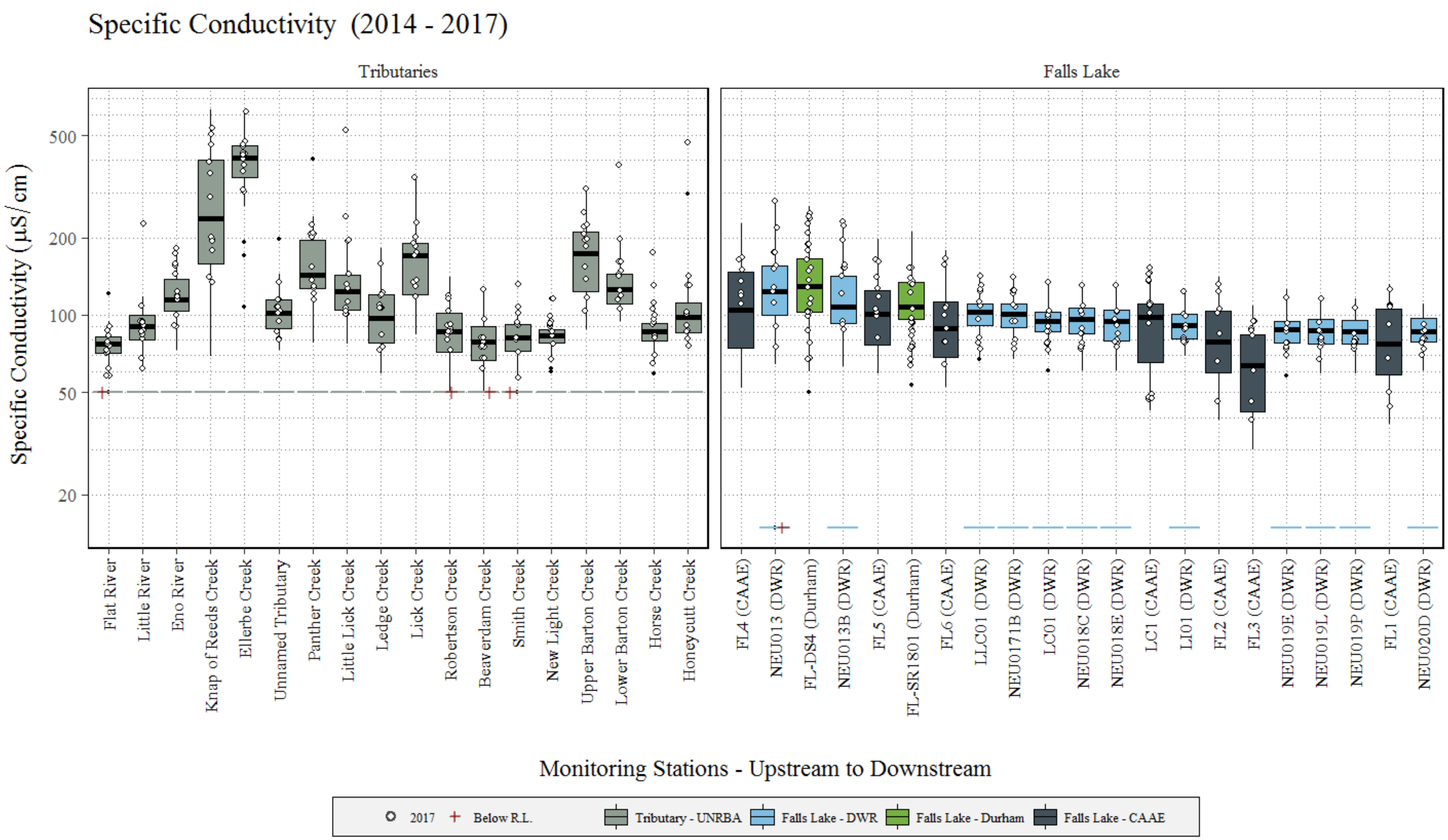


Figure 3-17. Specific Conductivity in Lake Loading and Lake Samples from August 2014 to December 2017

- **Ammonia concentrations** (Figure 3-18) 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 exceed laboratory reporting limits despite being downstream from the tributaries often with the highest concentrations of ammonia. This indicates algae are very rapidly assimilating this form of inorganic nitrogen. 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.
- **Nitrate + nitrite concentrations** (Figure 3-19) are highest at tributary stations downstream of major WWTPs and small package plants. As with ammonia, concentrations within the lake are generally lower than in the tributaries, indicating this form of inorganic nitrogen is also quickly assimilated by algae.
- **Organic nitrogen concentrations** (Figure 3-20) 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 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 WWTPs and package plants) but inorganic forms of nitrogen make up a slightly larger portion of total than within the lake. 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.
- **Total nitrogen concentrations** (Figure 3-21) in tributaries are greatest downstream of major WWTPs and package plants, and in areas often observed to have slow moving 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, and appears to correspond to the pattern seen for organic nitrogen, which is its predominant component.
- **Total Phosphorus** - Like TN, total phosphorus concentrations (Figure 3-22) at the Lake Loading tributary stations are generally higher and more variable than the in-lake stations, with the sites downstream of major WWTPs or located in very slow flowing, 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 from tributary and in-lake stations are presented in Figure 3-24. Concentrations in tributaries are generally lower than those observed in the lake, 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 (phytoplankton); rather, algae in these streams is typically found in forms attached to rocks and debris (periphyton) and therefore not collected within a chlorophyll-a water sample. When streams are slow-moving, phytoplankton may become more abundant.

Within the lake, chlorophyll-a concentrations decrease from the upstream to the downstream end. Of the 473 observations collected by DWR and CAAE (2014 to 2016) above Highway 50 within the upper portion of the lake, 109 exceeded 40 µg/L. Of these exceedances, 15 occurred in the tributary arms of the lake (including Little Lick Creek (LLC01), Lick Creek (LI01), and Ledge Creek (LC01)). In 2017 alone, 106 out of 208 observations exceeded the 40 µg/L criteria stations above Highway 50 with 12 of these exceedances occurring in the tributary arms. High chlorophyll-a concentrations were first observed in January and February before falling to more normal levels near the beginning of April. High concentrations were later observed in May and June following very large storms that occurred towards the end of April. This high flow event may have flushed nutrients and algae into the upper part of the lake and eventually, into the lower section.

Of the 334 measurements collected by DWR and CAAE (2014 to 2016) below Highway 50 and within the main channel of the reservoir, eight exceeded 40 µg/L. These eight exceedances all occurred in 2014. Of the 33 observations in tributary arms of the lake below Highway 50, only two were above 40 µg/L during these years (downstream of Lower Barton Creek (FL11C)). As with the upper segment of the lake, a higher proportion of samples exceeded the 40 µg/L criteria in 2017 than in previous years (49 out of 156) with most of these exceedances also occurring in January, February, May, and June.

In contrast with prior years, there were two distinctly elevated peaks in chlorophyll-a throughout the lake during 2017, one in February and the other in May. In both cases, levels dropped rapidly to more typical levels by the following monitoring event. There was a smaller peak September 2017, but it did not involve all stations. The specific cause of these algal blooms is not known, although one of the two larger occurrences followed a large rain event by several weeks and may have been triggered by inputs of nutrients from that event.

- **Total suspended solids** (TSS) values are shown in Figure 3-25. TSS concentrations are more variable over time within each tributary than within any lake site. This 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 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 concentrations. 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.
- **Volatile suspended solids (VSS)** (Figure 3-26) represents the fraction of TSS associated with combustible (organic) material. Monitoring of VSS began in July of 2015 in response to a review specific to a model application. 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. 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.

- **Organic Carbon** - Organic matter is a concern in water supply reservoirs because it can react with disinfectants used in water treatment to produce a wide assortment of chemical compounds generally called disinfection by-products (DBPs). Some DBPs have been recognized since the 1970s and some types are regulated by the EPA because of their potential negative health effects. However, hundreds of types of potential DBPs exist with very little known about them, their risks, or details of how they form. Given the complexity of organic molecules and the sheer variety in molecular structures, research on DBPs is relatively in its infancy.

  High concentrations of organic matter in source water can lead to higher concentrations of DBPs and therefore higher treatment costs to reduce their formation, but not all types of organic matter react the same way or yield the same byproducts. Although characterizing the reactivity of hundreds of molecules in a water sample is not possible, some simple tools measuring visible and ultraviolet absorbance of water samples at specific wavelengths can provide some insight on the organic matter character.

  Organic matter can be measured as either Total Organic Carbon (TOC) which includes particulate and dissolved forms, or Dissolved Organic Carbon (DOC). With respect to DPB formation, DOC is the primary focus. The TOC data shown in Figure 3-27 includes both particulate and dissolved fractions. Based on TOC and DOC data collected in the first two monitoring years, approximately 95 percent of the TOC was consistently in the dissolved form (DOC). Because DOC can be accurately estimated from TOC measurements, and since DOC is a relatively expensive parameter to collect, the UNRBA dropped DOC from the list of parameters collected at Lake Loading stations in FY2017 in favor of using TOC is used as a proxy. As shown in Figure 3-27, TOC concentrations at Lake Loading stations in the lower part of the watershed (mostly downstream of Beaverdam Impoundment) are generally lower and less variable than those observed at the other Lake Loading stations and within the lake. The highest concentrations are observed at Lake Loading stations dominated by wetland complexes and/or very slow flow conditions.

- **Light Absorbance** at 440 nm/Color - Humic matter, often the major organic constituent of soil, can enter lakes through runoff and stream flow with two categories of impact to the reservoir. First, humic compounds can be precursors to disinfection by-products if not removed from water before chemical disinfection. Second, they can impart a yellow to brown hue to the water, and depending on its darkness, it can reduce the amount of light available to algae for photosynthesis. Color can be measured by visually comparing filtered water samples with known Platinum-Cobalt standards (Pt-Co). Absorbance of visible light at 440 nm can also be used as an indicator of color since it specifically targets the yellow or brown material typical of humic substances. Because results from the two methods were well correlated, the UNRBA stopped using the more expensive and less precise Platinum-Cobalt method in FY2017. Figure 3-28 indicates that color is higher in tributaries that are slow-moving and most influenced by wetlands. This follows a similar pattern to the TOC concentrations, suggesting that humic substances may be a significant component of the TOC in tributaries. Color in the lake is generally lower than in the tributaries and decreases somewhat from the upper lake to the lower lake.

- **UV Absorbance** at 254 nm can be combined with measurements of DOC to measure carbon-specific UV-absorbance (SUVA) which is used as an indicator of the aromatic (ring-shaped) nature of the DOC structure. This molecular shape is also associated with the formation of DBPs. UV absorbance at 254 nm is presented in Figure 3-29. It presents a pattern similar to absorbance at 440 nm and indicates that humic matter is most prevalent in the tributaries with substantial wetland influence. Values within the lake show a slight downward trend from the upper lake to the lower lake.

- **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. Specific UV Absorbance is shown in Figure 3-30. 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 WWTPs also have lower values.

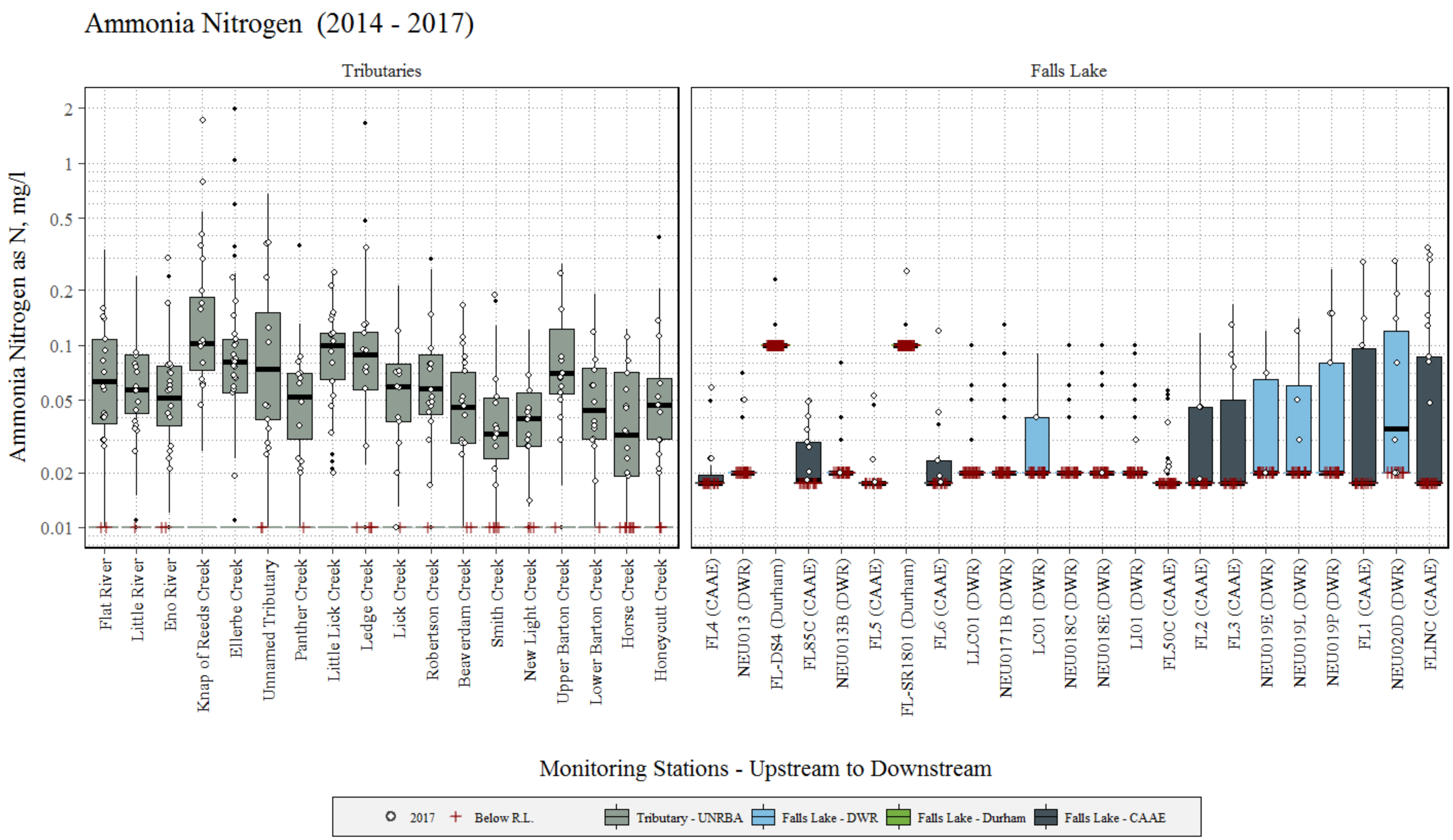


Figure 3-18. Ammonia in Lake Loading and Lake Samples from August 2014 to December 2017

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).

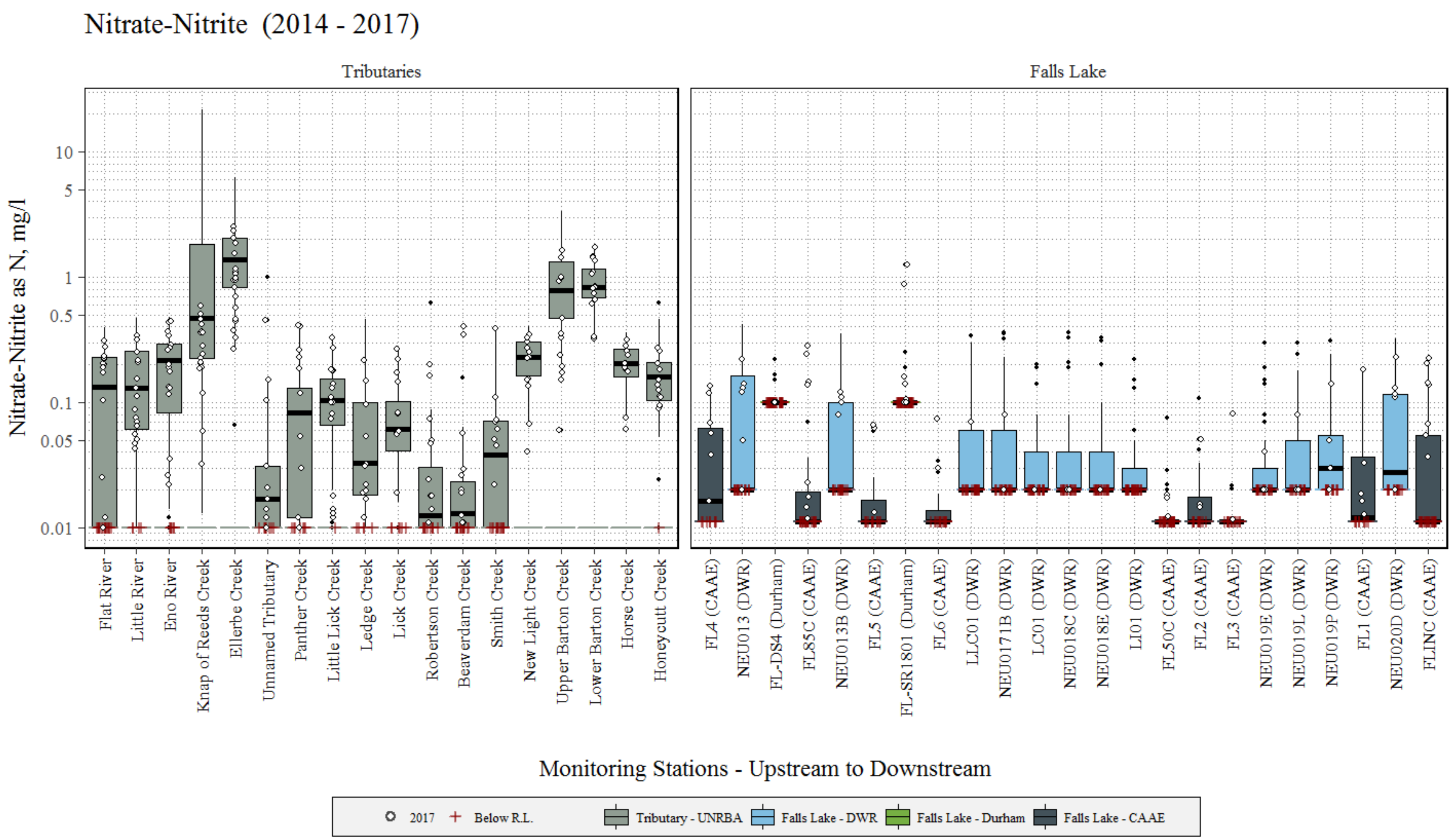


Figure 3-19. Nitrate+ Nitrite in Lake Loading and Lake Samples from August 2014 to December 2017

Different monitoring organizations have different laboratory reporting limits as seen by the distinct locations of the red symbols. Each red symbol indicates an observation below the respective laboratory reporting limit.

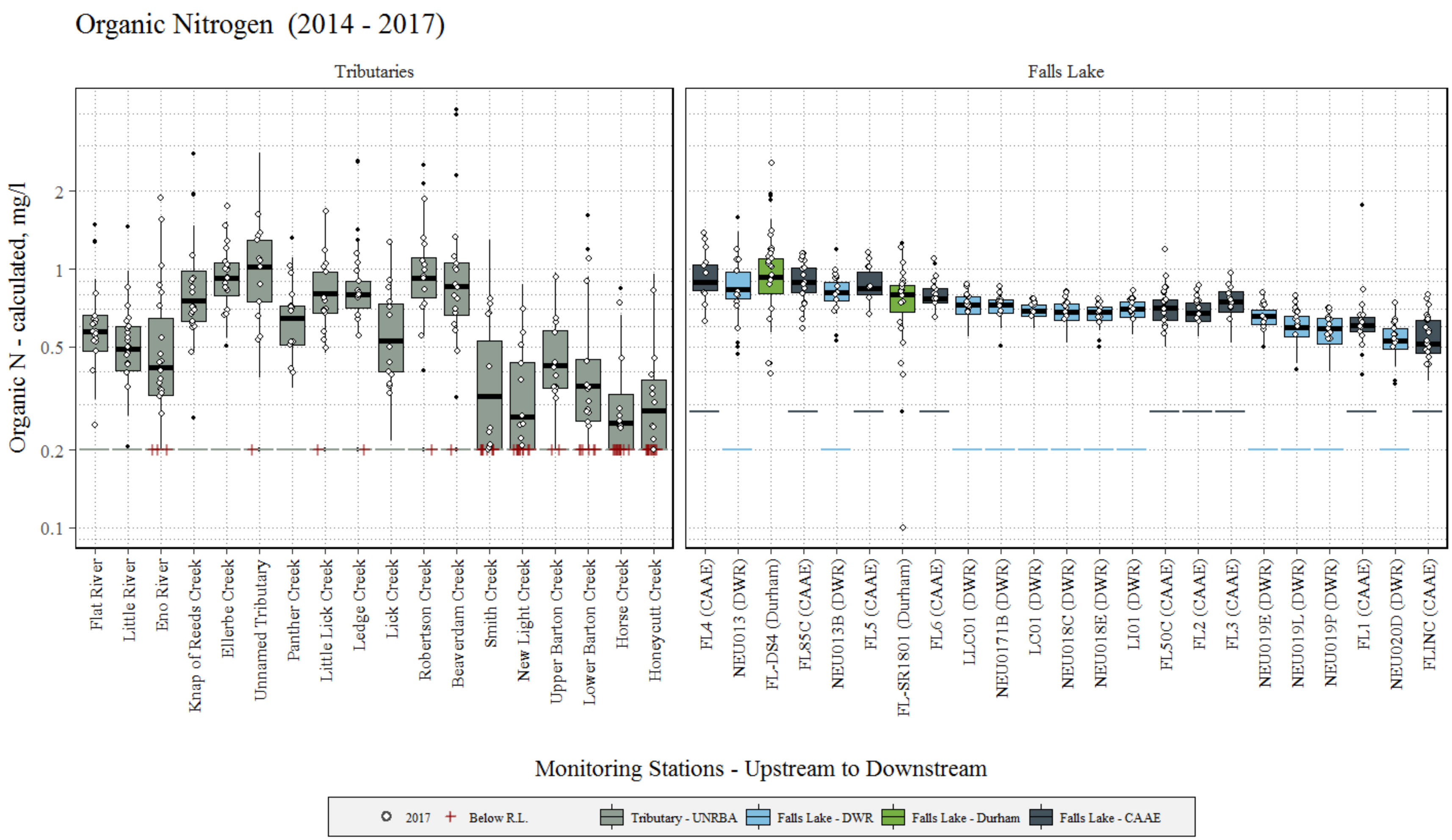


Figure 3-20. Organic Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2017

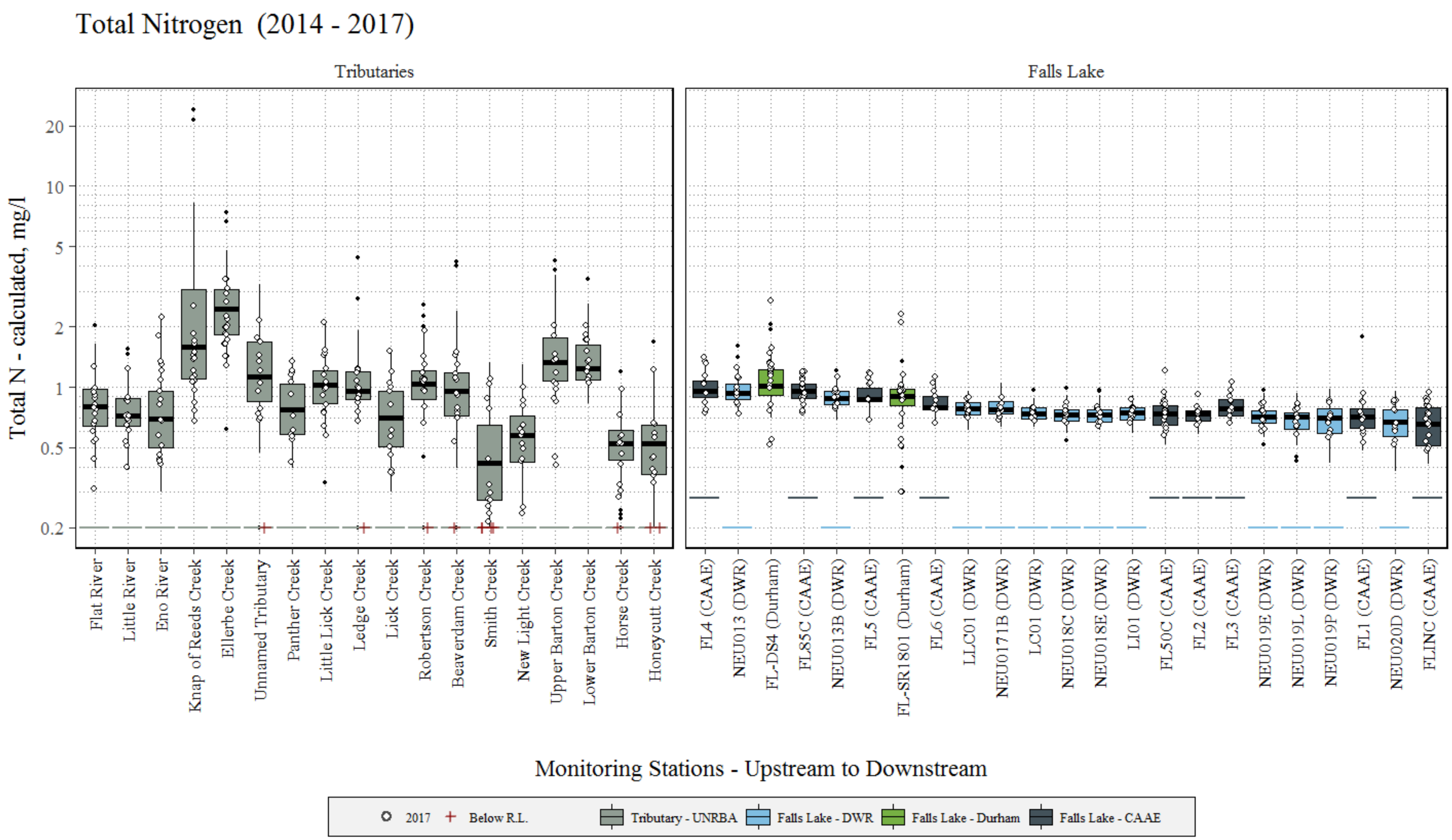


Figure 3-21. Total Nitrogen in Lake Loading and Lake Samples from August 2014 to December 2017

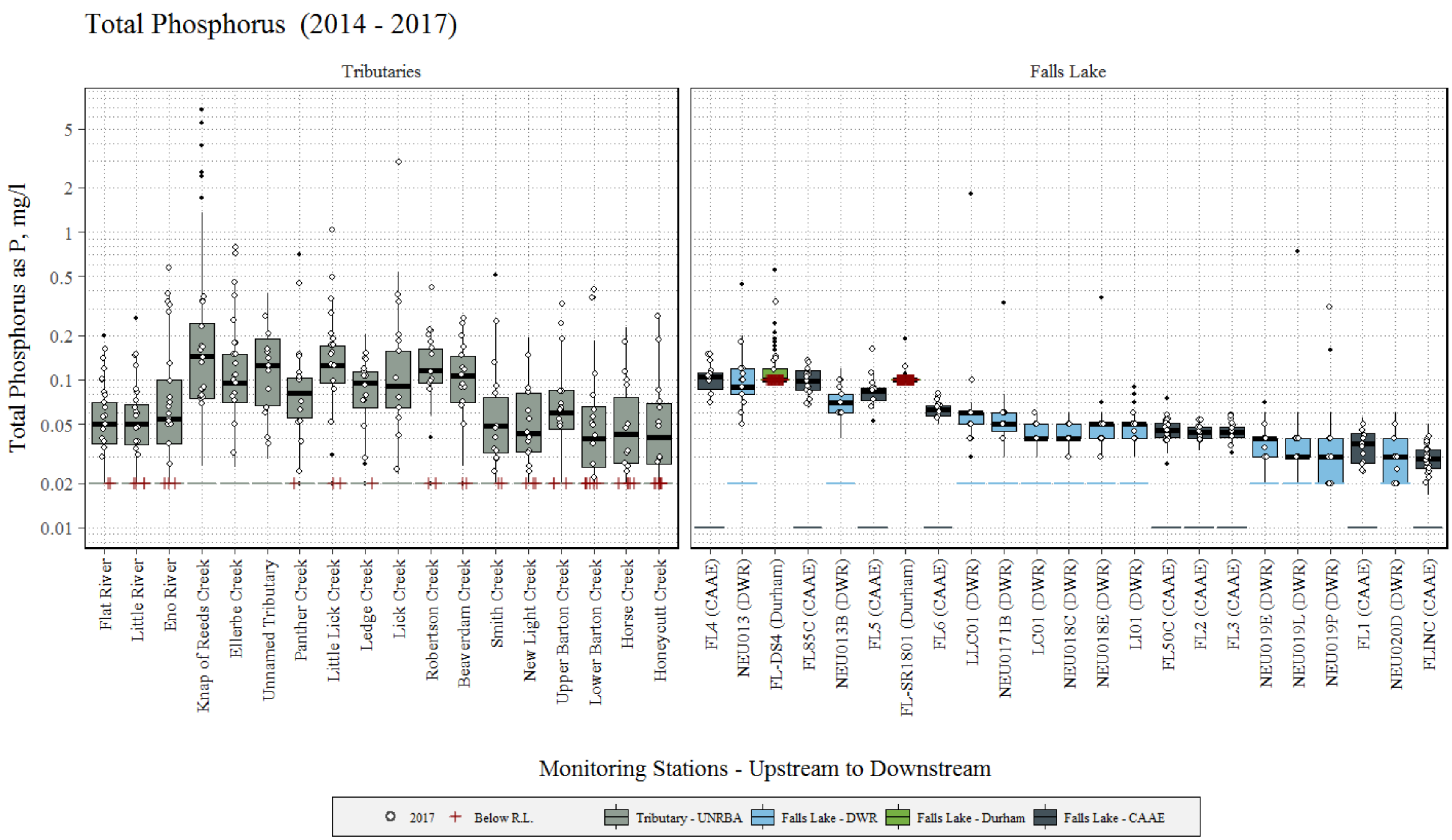


Figure 3-22. Total Phosphorus in Lake Loading and Lake Samples from August 2014 to December 2017

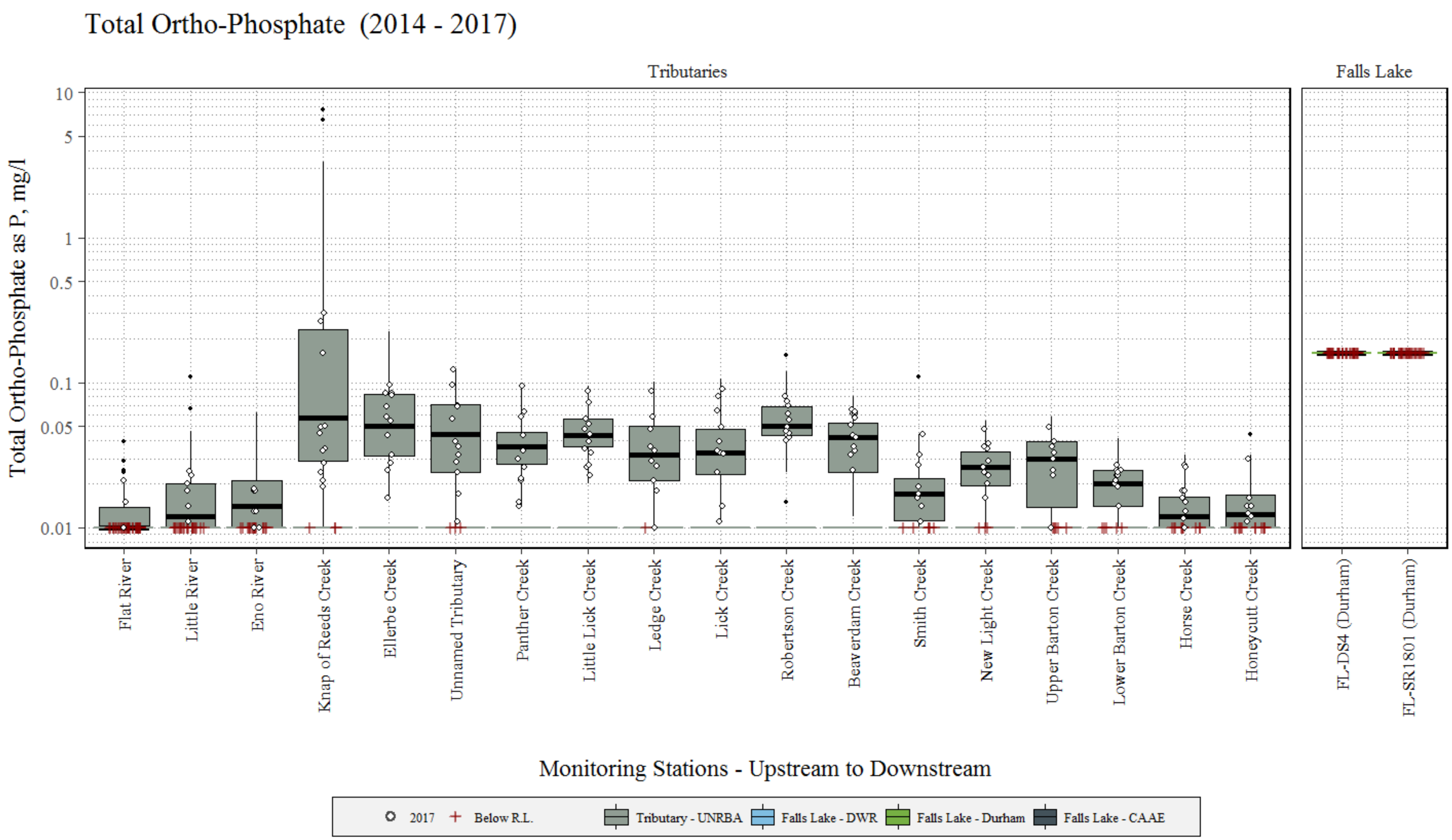


Figure 3-23. Ortho-phosphate in Lake Loading Samples from August 2014 to December 2017

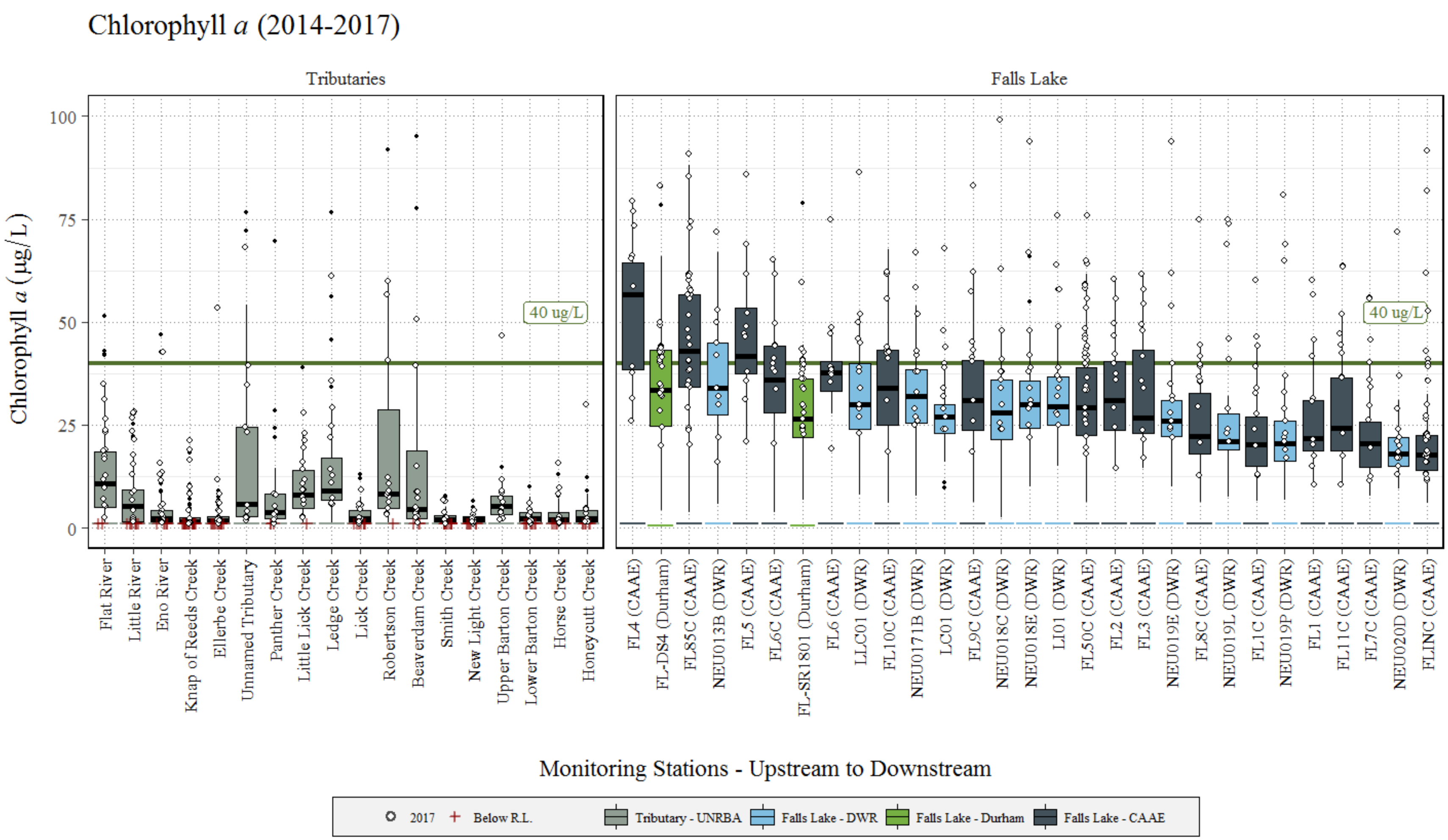


Figure 3-24. Chlorophyll-a in Lake Loading and Lake Samples from August 2014 to December 2017

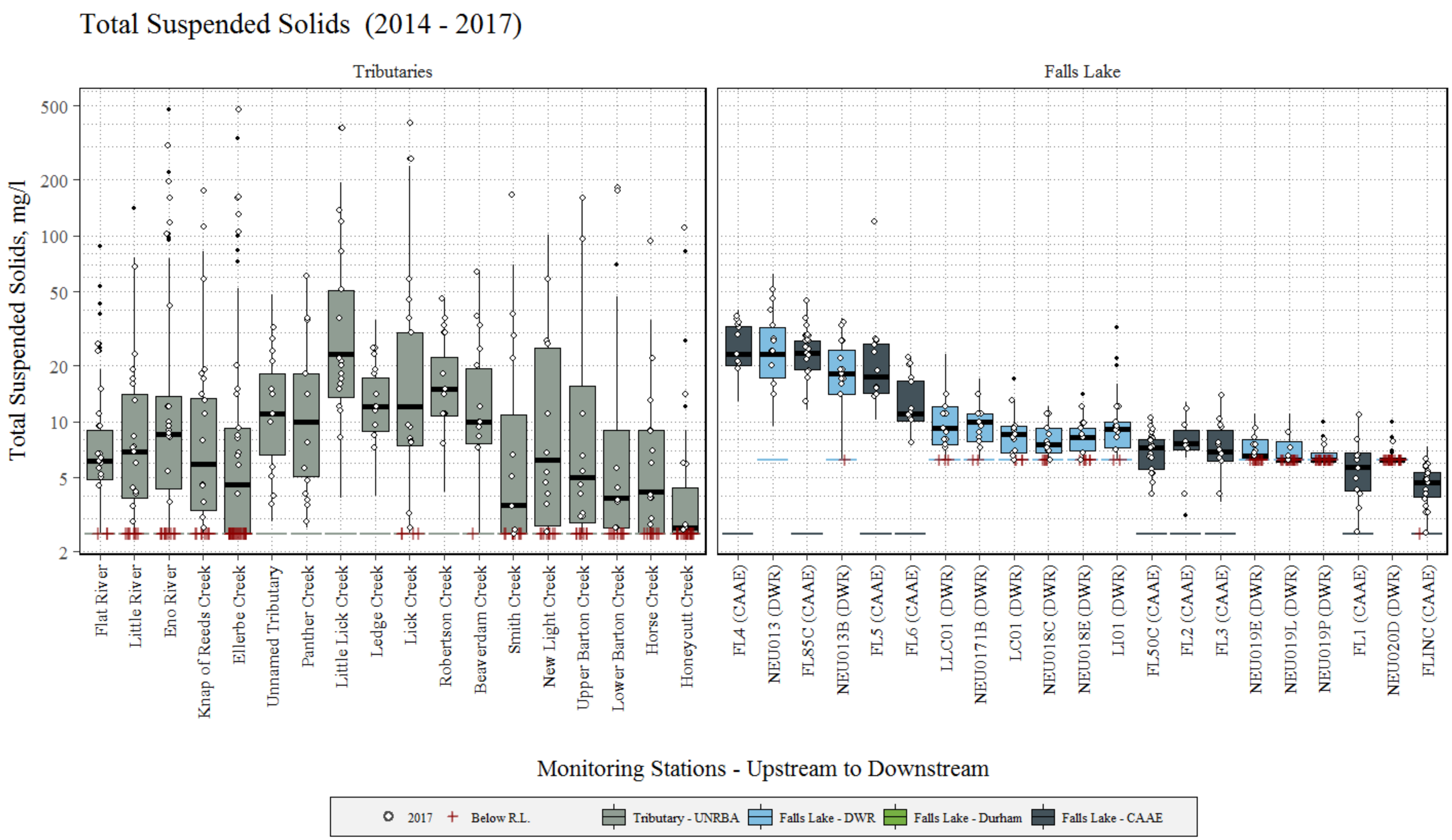


Figure 3-25. Total suspended solids (TSS) in Lake Loading and Lake Samples from August 2014 to December 2017

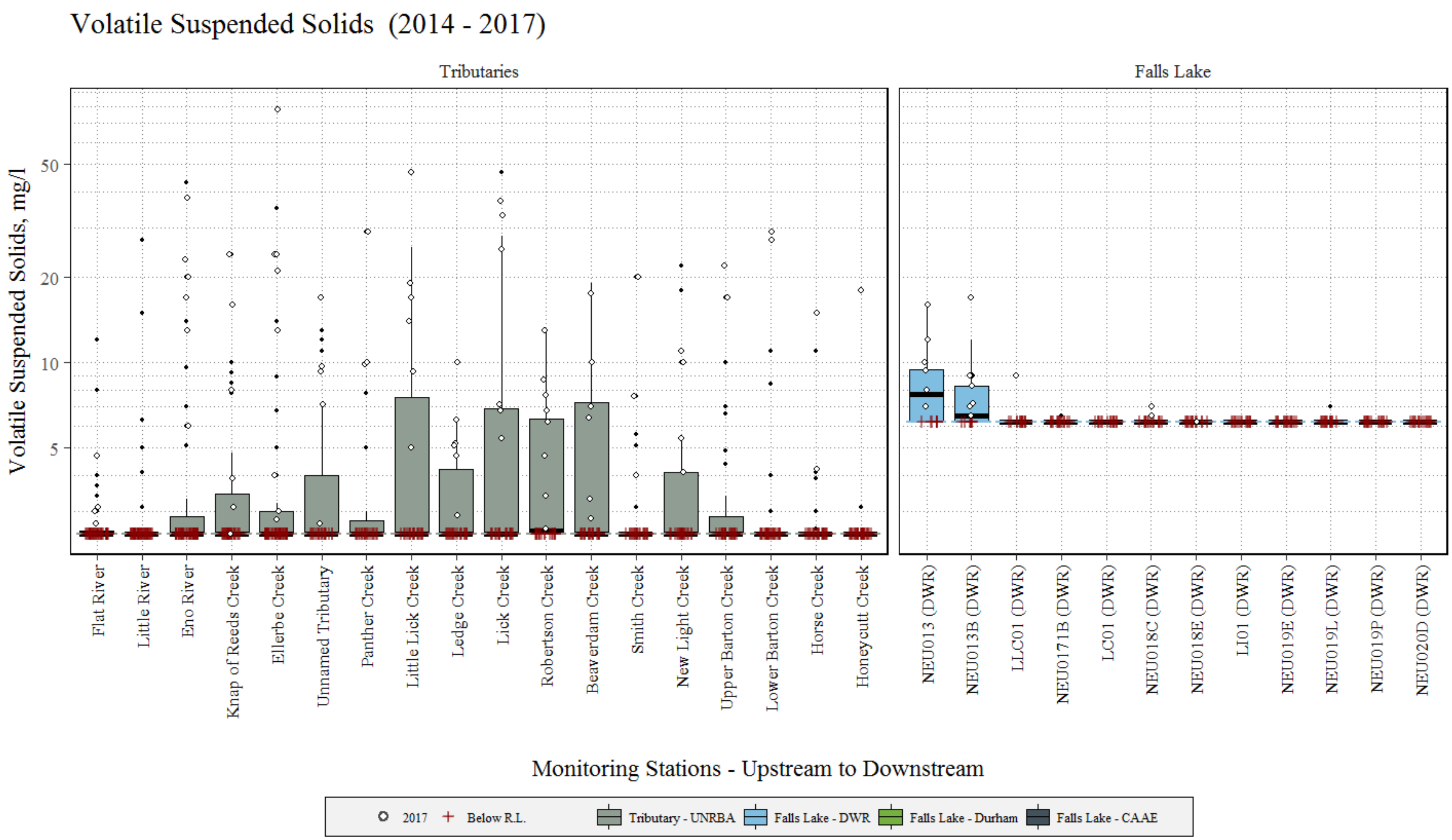


Figure 3-26. Volatile suspended solids (VSS) in Lake Loading and Lake Samples from August 2014 to December 2017

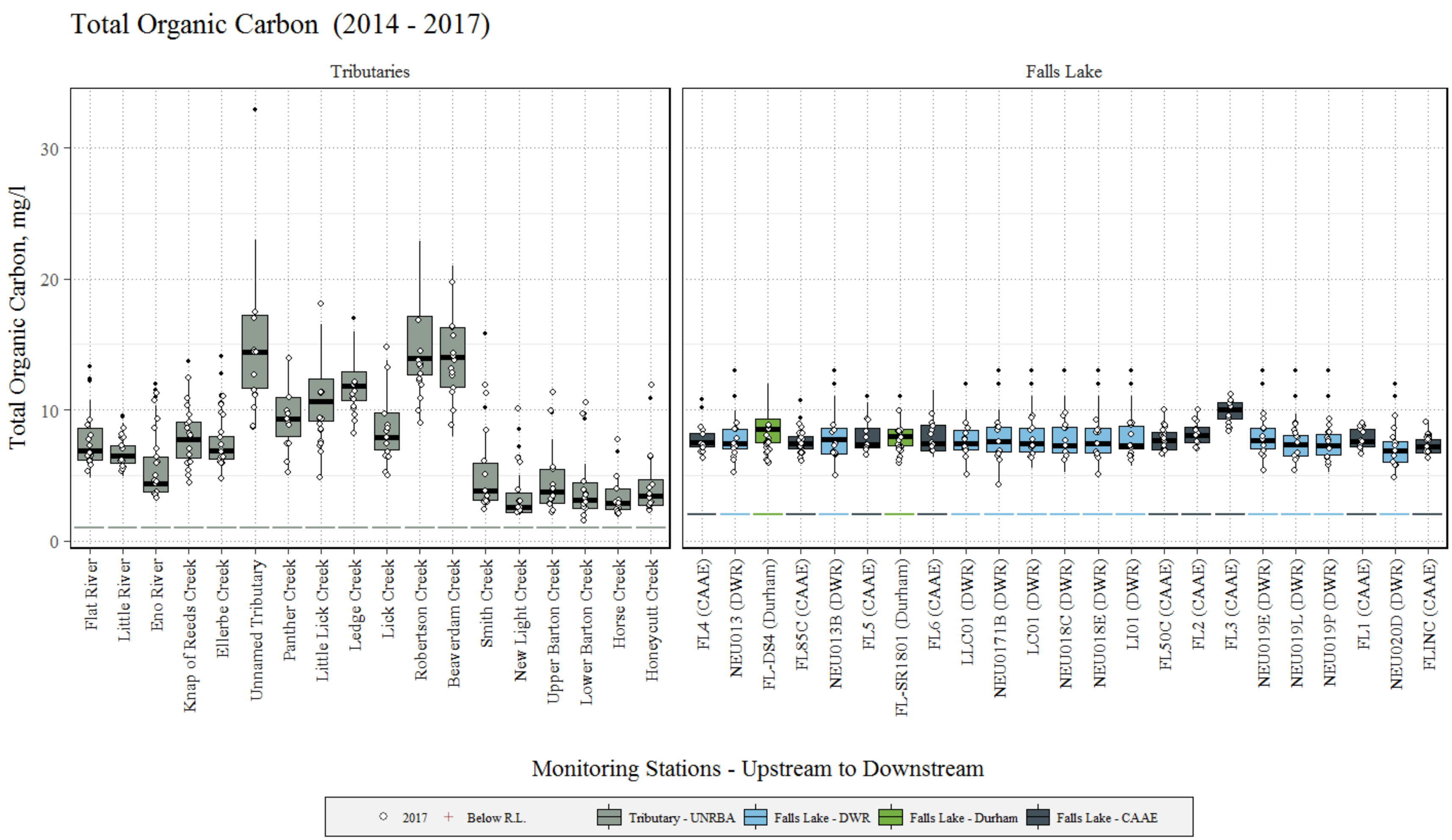


Figure 3-27. Total Organic Carbon (TOC) in Lake Loading and Lake Samples from August 2014 to December 2017

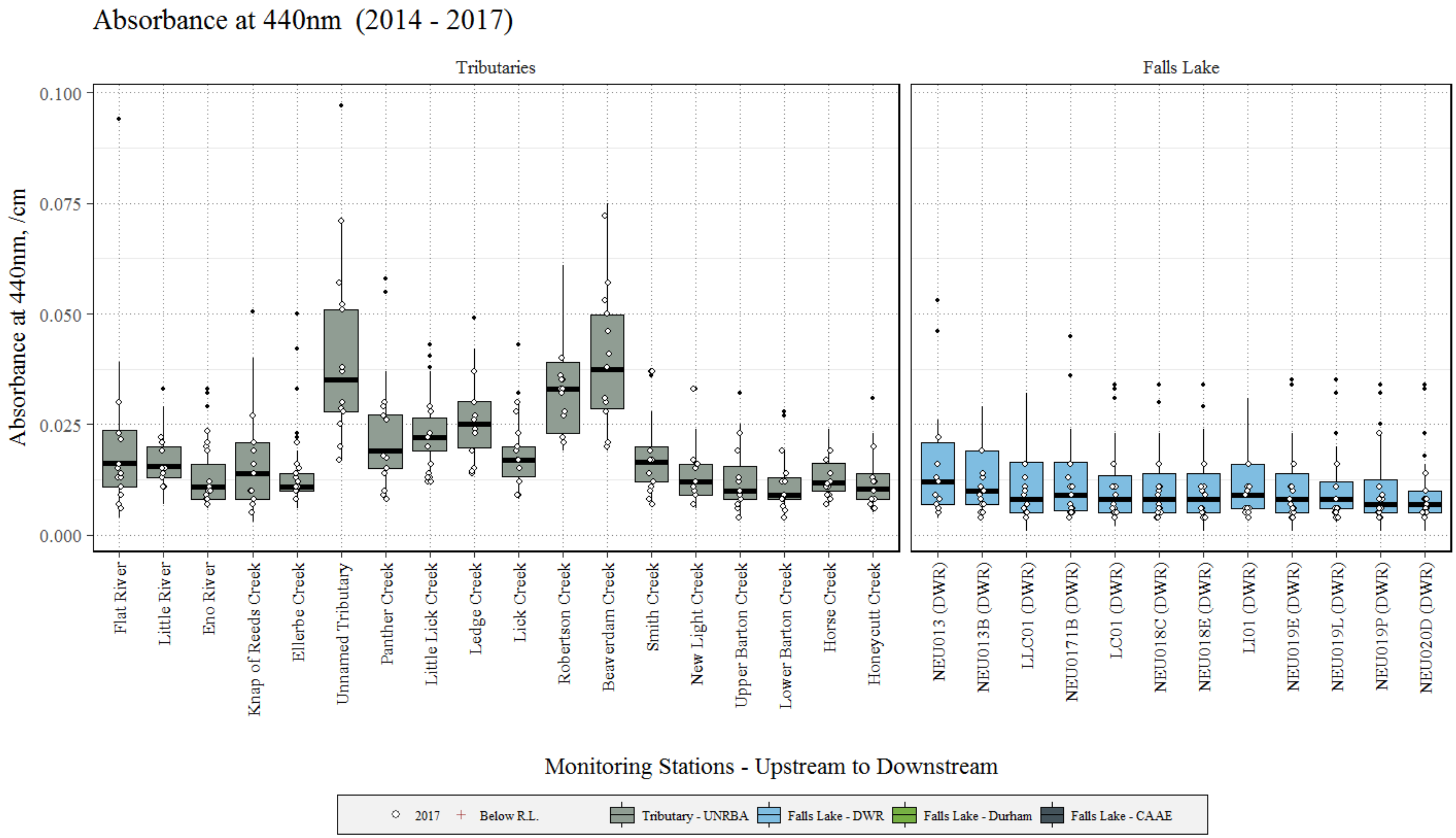


Figure 3-28. Color (absorbance at 440nm) in Lake Loading and Lake Samples from August 2014 to December 2017

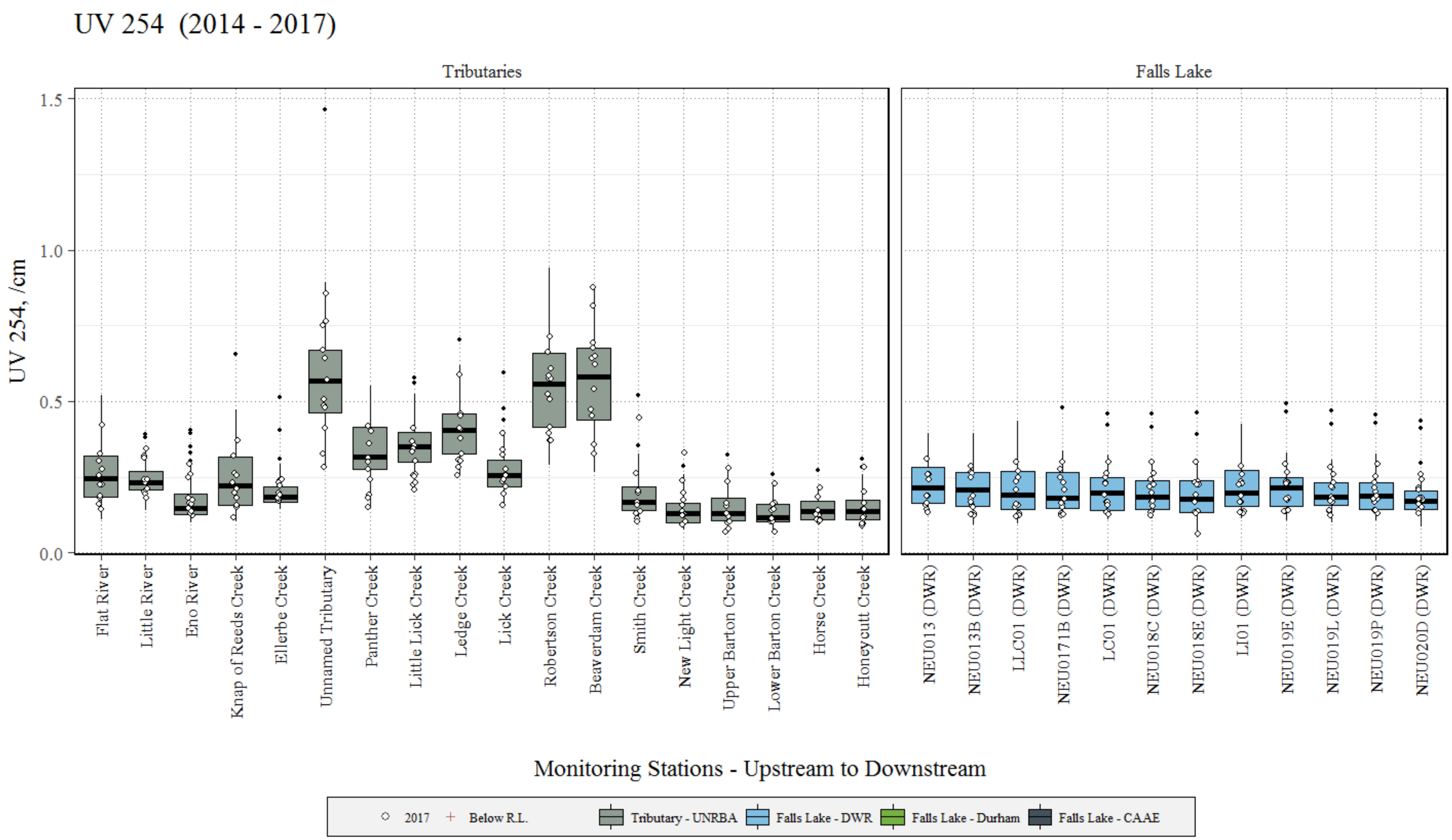


Figure 3-29. Absorbance at 254nm in Lake Loading and Lake Samples from August 2014 to December 2017

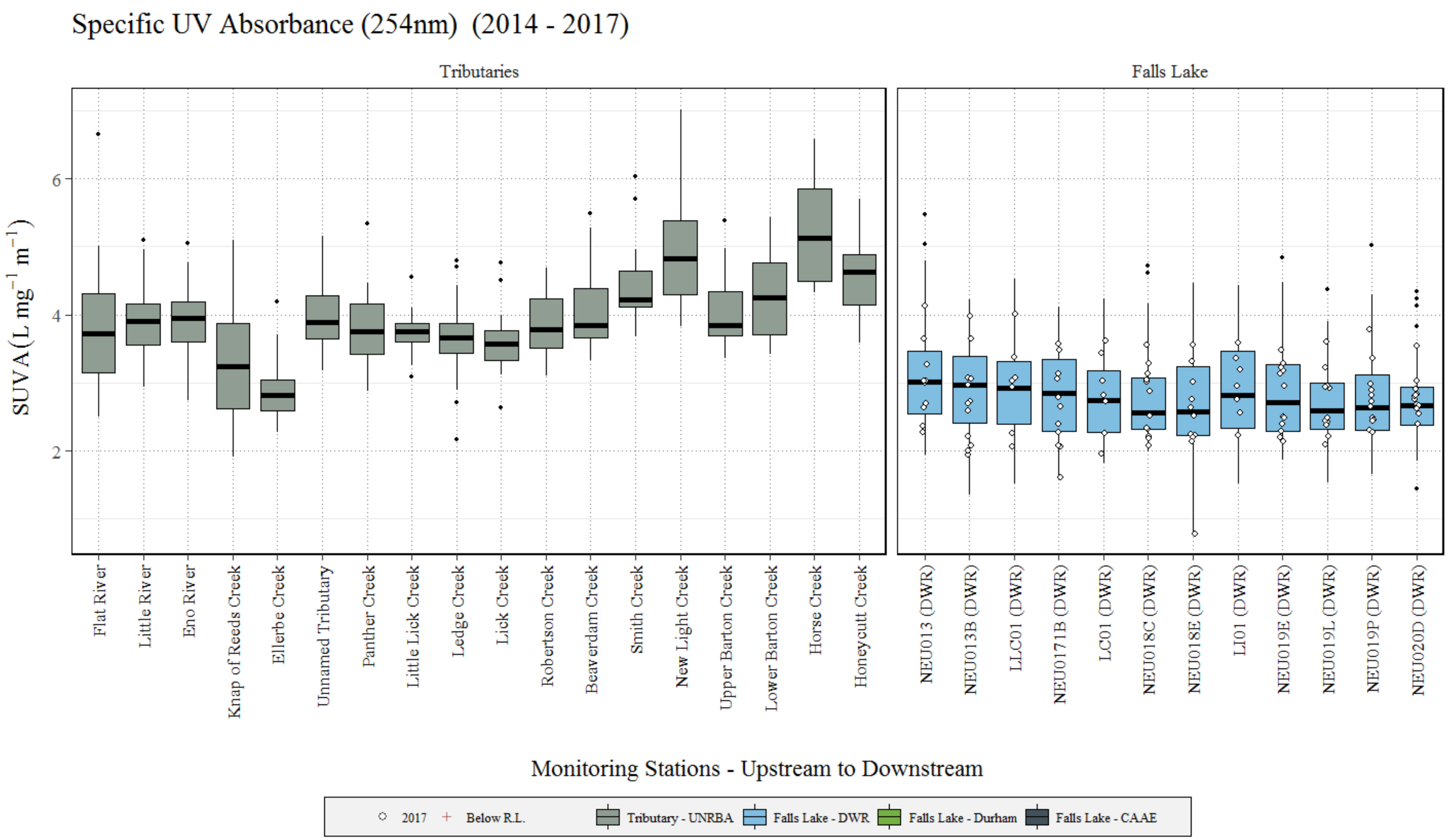


Figure 3-30. Specific UV Absorbance in Lake Loading and Lake Samples from August 2014 to December 2017

- Phytoplankton Algal Assemblage data collected by DWR. In addition to water quality measurements, DWR also conducts evaluations of phytoplankton algal assemblages from three locations in Falls Lake in order 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 to show 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 taxonomic groups at the upstream (NEU013B), midlake (NEU018E), and downstream (NEU019P) monitoring stations. The figures illustrate the substantial biovolume differences among these eight phytoplankton groups, 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 taxonomic groups with the largest estimated biovolume are Blue-green Algae, Diatoms, and Prymnesiophytes (haptophytes). Aside from chlorophyll-a concentrations present in the algae, there are no regulatory standards or formal guidance on criteria regarding algal biovolume in North Carolina. Since the EFDC and WARMF models have algorithms to simulate production of diatoms, blue-green and green algae, these data may provide value for the lake modeling efforts. Analysis of algal community structure as related to various water quality parameters may reveal relationships that could be of assistance during empirical modeling efforts. However, these determinations would need to be assessed and acted on as the UNRBA moves through the Modeling and Regulatory Support component of the Reexamination effort.

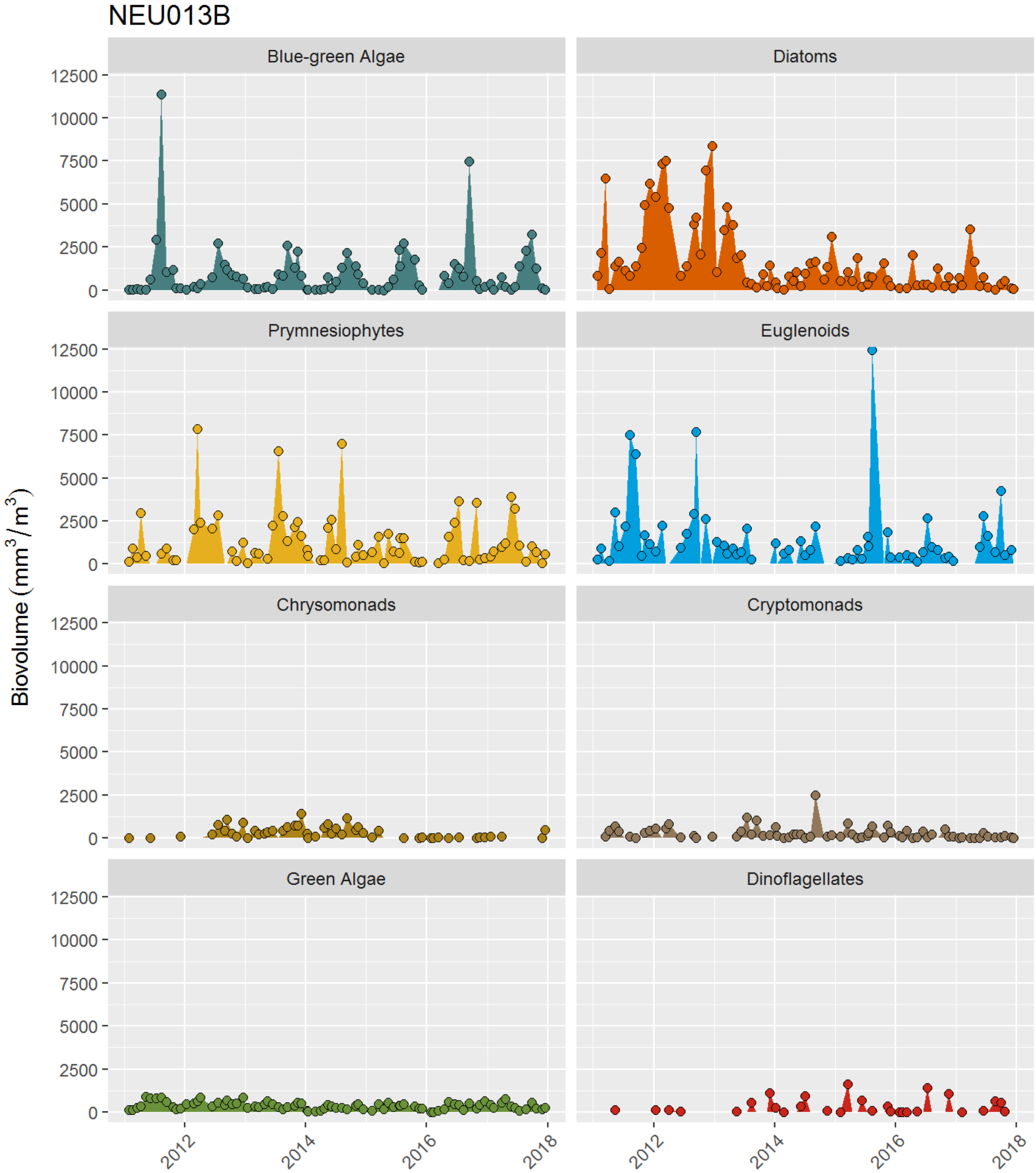


Figure 3-31. Algal Biovolumes at Station NEU013B (near Interstate 85)

Of all three monitoring stations, this site shows the clearest year-to-year patterns in algal biovolume for blue-green algae, prymnesiophytes (haptophytes), and euglenoids. Samples are collected monthly and only samples with these taxa present are shown—a data point on this figure means the taxa was present.

Figure 3-32. Algal Biovolumes at Station NEU018E (mid-lake)

Annual cycles of elevated summer and fall blue-green algae populations are apparent in this figure. The vertical scale on this figure (and across all sub-figures) is held constant across all three stations for ease of comparison.

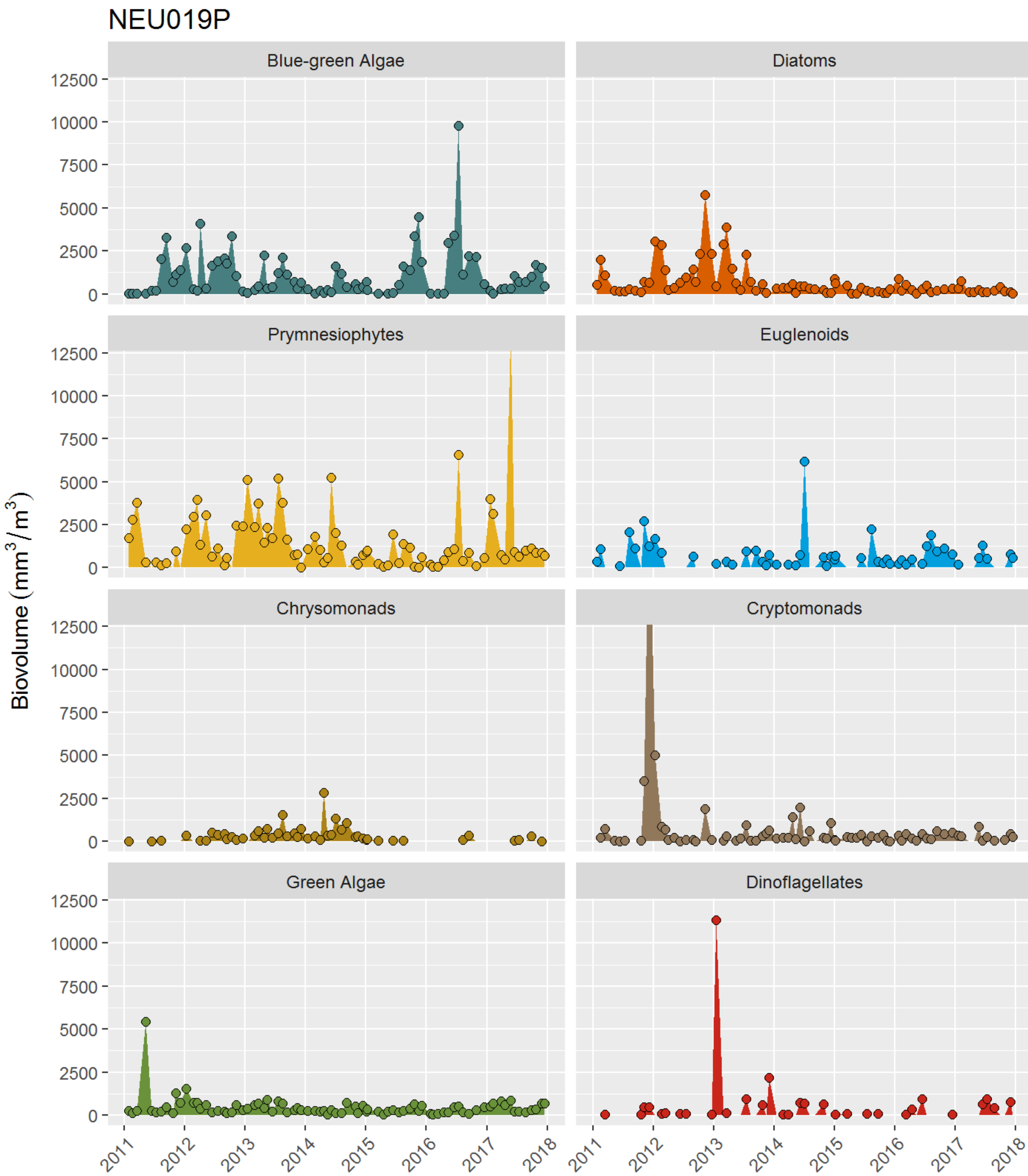


Figure 3-33. Algal Biovolumes at Station NEU019P (near Upper Barton Creek cove)

3.2.3 Tributary Loading

The figures previously presented in this report typically display results in terms of the quantified amount of a substance that occurs in one liter of water – concentrations present at the time of measurement. Concentrations, however, are not indicative of the total amount of a substance that 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 quantify the total load of each constituent (i.e., mass delivered) which depends on both concentration and the volume of water delivered by each contributing tributary to Falls Lake.

Figure 3-34 shows the relative total water volume of each tributary to Falls Lake based on the basin proration method which was previously evaluated for the UNRBA (Cardno 2014a). This proration method calculates flow for ungaged streams using drainage areas and flow measurements obtained from gaged streams in the Falls Lake watershed between August 2014 and December 2017. 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 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.

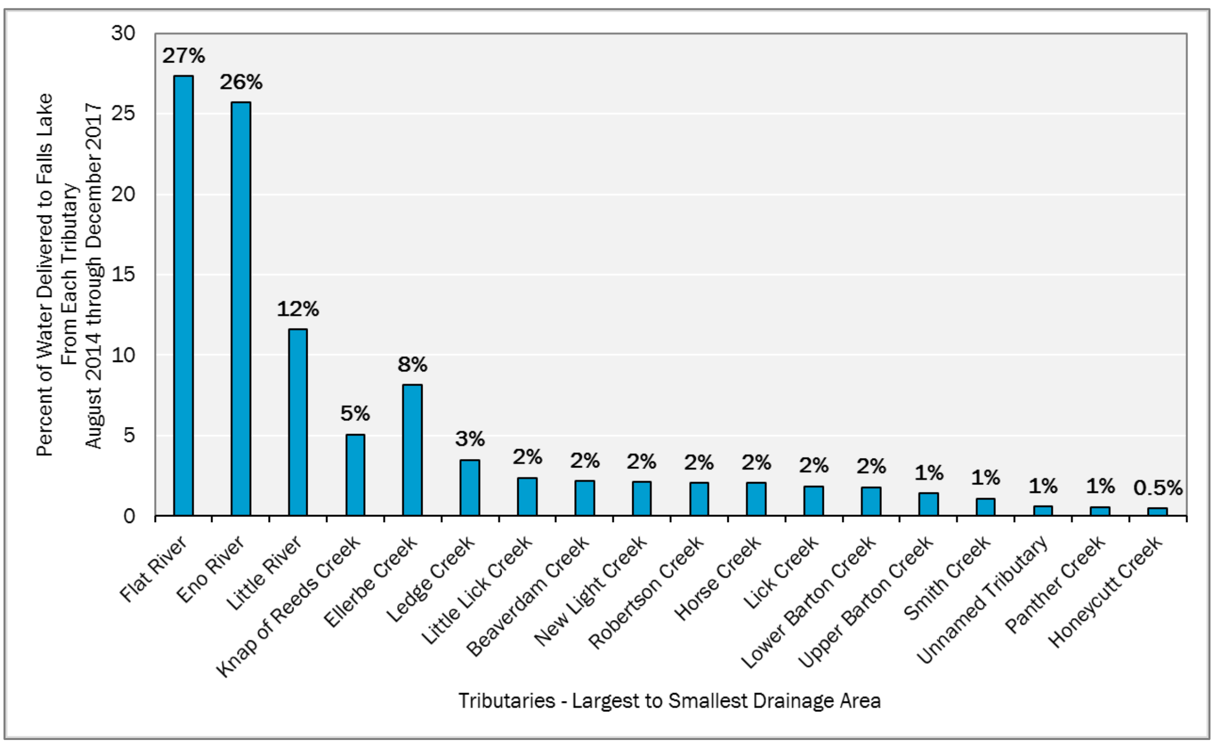


Figure 3-34. The Contribution of each Tributary to the Total Water Load to Falls Lake during the Monitoring Period of August 2014 through December 2017

The contribution is provided as an estimated 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. 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 empirical approaches involve more complicated techniques to represent relationships between concentration and flow. The UNRBA has selected the WARMF model to predict the flows and loads entering the lake.

Section 4

Extended Analysis and Discussion

This section provides an expanded discussion and analysis of the Monitoring Program and some significant topics. This discussion is intended to inform the modeling and regulatory support efforts. This discussion will be further expanded within the concluding monitoring report after the successful completion of the current water quality sampling plan which is scheduled for completion in October 2018.

4.1 Land Use Patterns

Correlation statistics were developed to look for potential relationships between land use composition and water quality measurements for stations monitored by the UNRBA in the watershed. For this analysis, 2011 National Land Cover Data was used (Figure 4-1) (the 2016 dataset has not yet been released). The analysis was done by performing Spearman's rank correlation (Spearman's r_s) between the mean water quality values for each station and the acreage of each land use type in the station's catchment area, and as well as standardizing across the catchments by using the percentage of each land use type.

Using Spearman's r_s values, the following observations were noted (correlations with land cover are listed from strongest to weakest in each statement):

- Overall, only a few moderately strong relationships were observed from this simple correlation analysis using all stations and all catchments together. That does not necessarily mean there are not relationships present at smaller temporal scales or within individual catchments.
- Where apparent relationships were noted, mean water quality concentrations were more strongly correlated with percent land use in the catchment draining to each station than actual acreage. This observation validates the approach used by the Watershed Analysis Risk Management Framework (WARMF) selected by the UNRBA to model the watershed.
- The moderate relationships (> r_s = 0.50) were:
  - Specific conductivity was positively correlated with percent Developed Land (r_s = 0.64)
  - Specific conductivity was negatively correlated with percent Forested Land (r_s = -0.56)
  - Total organic carbon was positively correlated with percent Herbaceous Land (r_s = 0.63)
  - pH was negatively correlated with percent Herbaceous Land (r_s = -0.59)
  - Total organic carbon was positively correlated with percent Wetland Cover (r_s = 0.58)
  - Total Kjeldahl nitrogen was positively correlated with percent Wetland Cover (positive correlation, r_s = 0.59)
  - Dissolved oxygen was negatively correlated with percent Wetland Cover (r_s = -0.60)
  - Chlorophyll-a was positively correlated with percent Wetland Cover (r_s = 0.50)
  - Ammonia nitrogen was positively correlated with percent Water (r_s = 0.51)

Several of these relationships have been noted in previous annual reports. For example, stations around slow-flowing wetland areas have shown higher TOC, Chl a and TKN concentrations, and commonly have lower DO levels, than other stations. It is not surprising that percent forested land was negatively correlated with TOC, since this suggests that forest areas tend to retain or sequester organic carbon.

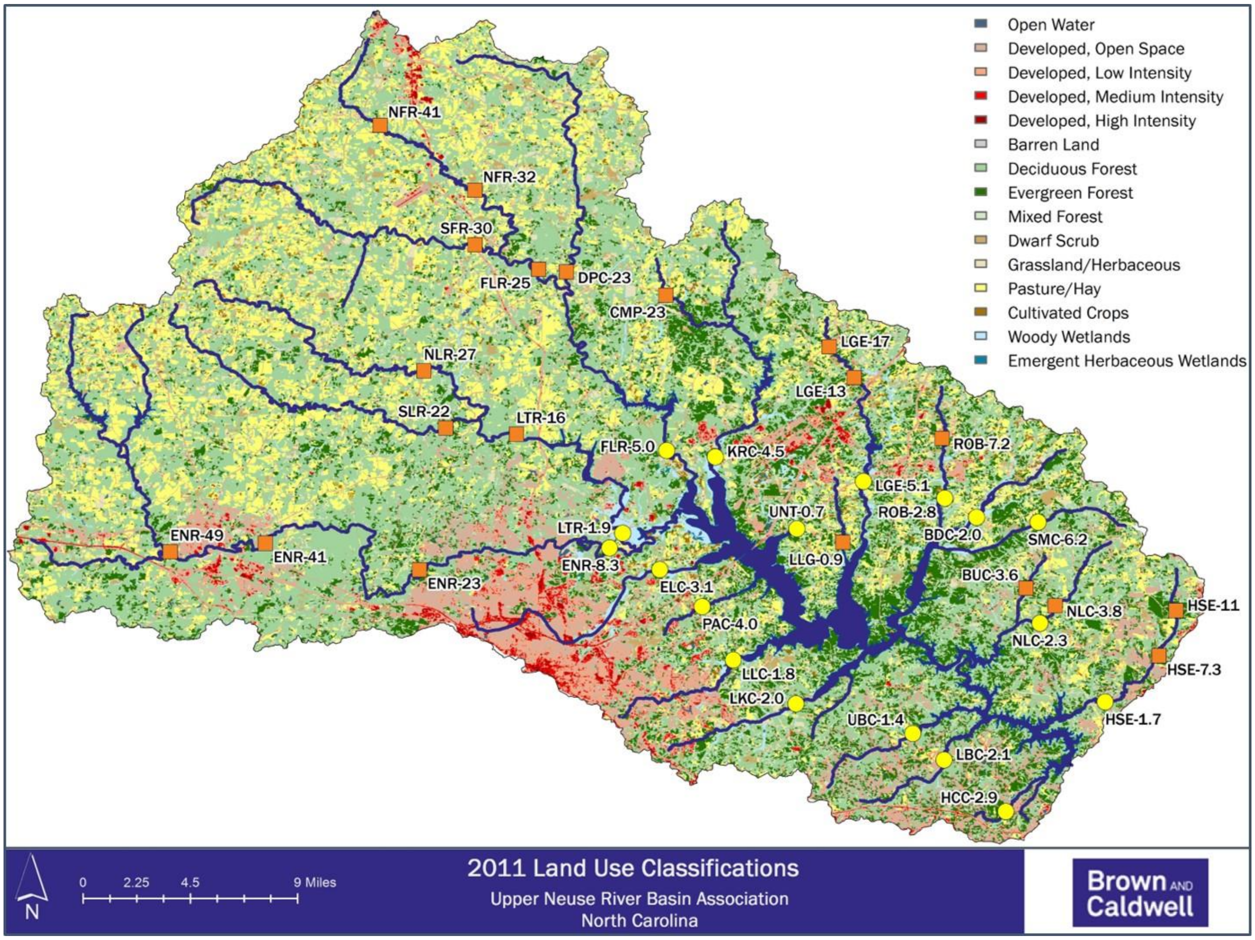


Figure 4-1. 2011 National Land Cover Data for the Falls Lake Watershed

4.2 Hydrologic Soil Group Patterns

Routine Monitoring data indicates that stations located in non-flowing, wetland dominated areas tend to have higher concentrations of total phosphorus, TOC, and chlorophyll-a and lower concentrations of dissolved oxygen. Wetlands have different hydrologic and water quality characteristics than other undisturbed land uses in a watershed, and understanding how wetlands may affect the water quality characteristics of the tributaries and the lake will be an important consideration for the re-examination strategy and nutrient management plans that are developed for the watershed. Wetlands are often located in areas with poor draining soils, and the NRCS classifies soils into hydrologic soil groups (HSG) based on their drainage characteristics. Figure 4-2 shows a map of HSGs in the watershed relative to the location of the UNRBA monitoring stations. Soils in the watershed range from those with moderately high infiltration rates (HSG B) to those with low infiltration rates (Group D). Due to the poor drainage characteristics of HSG D soils, they are often associated with the presence of wetlands. Figure 4-3 shows the distribution of water quality parameters based on the dominant HSG within each monitoring station's catchment area. For total phosphorus, ammonia, and organic nitrogen, concentrations at sites with HSG D soils tend to be somewhat higher than those with HSG B or C soils. For nitrate+nitrite, higher concentrations are observed at sites with HSG B or C soils. For TOC, concentrations tend to increase as infiltration rates decrease, with HSG D soils having the highest concentrations of TOC observed in the watershed. For chlorophyll-a, HSG B tends to have lower concentrations than many sites located on HSG C or D soils.

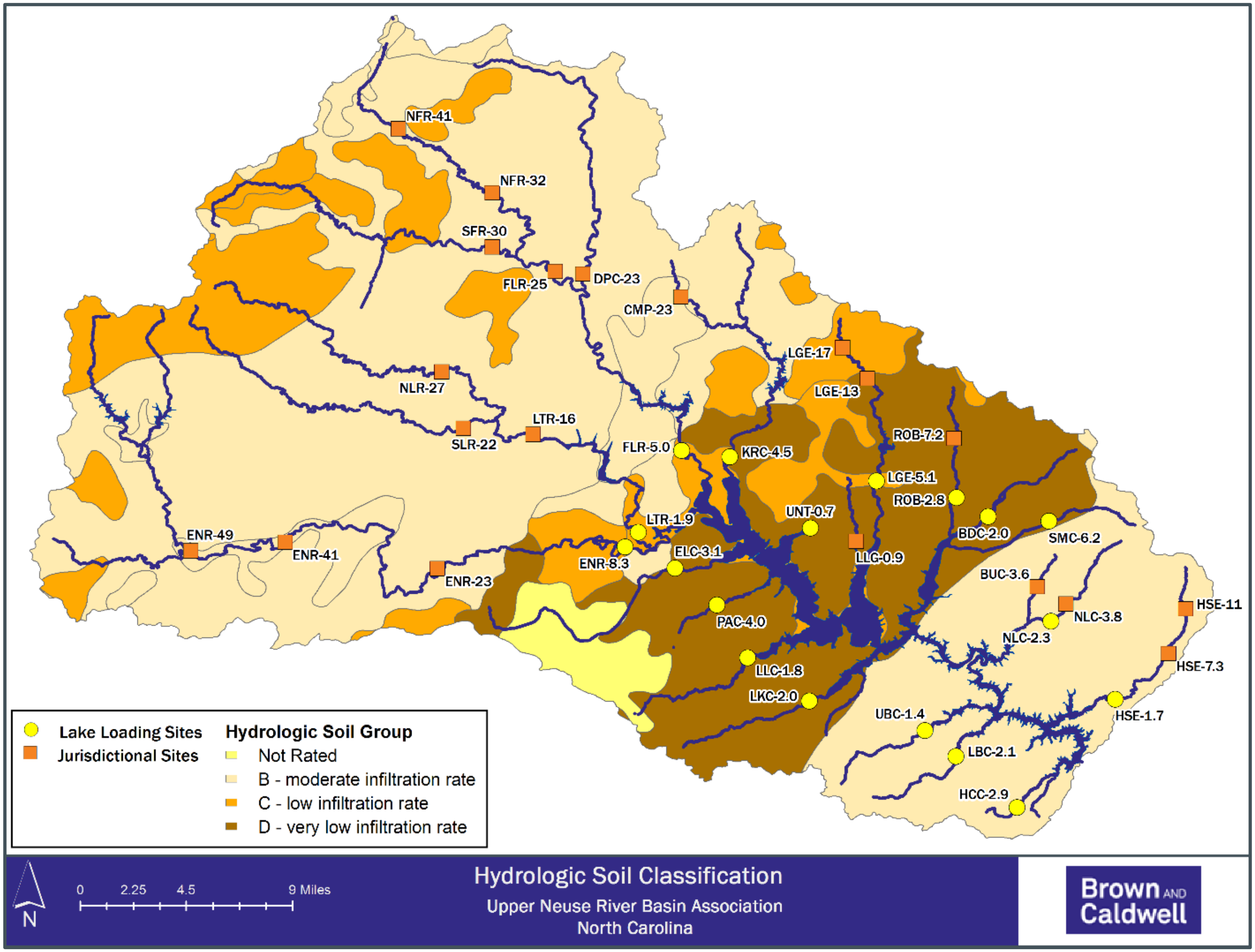


Figure 4-2. Hydrologic Soil Groups in the Falls Lake Watershed

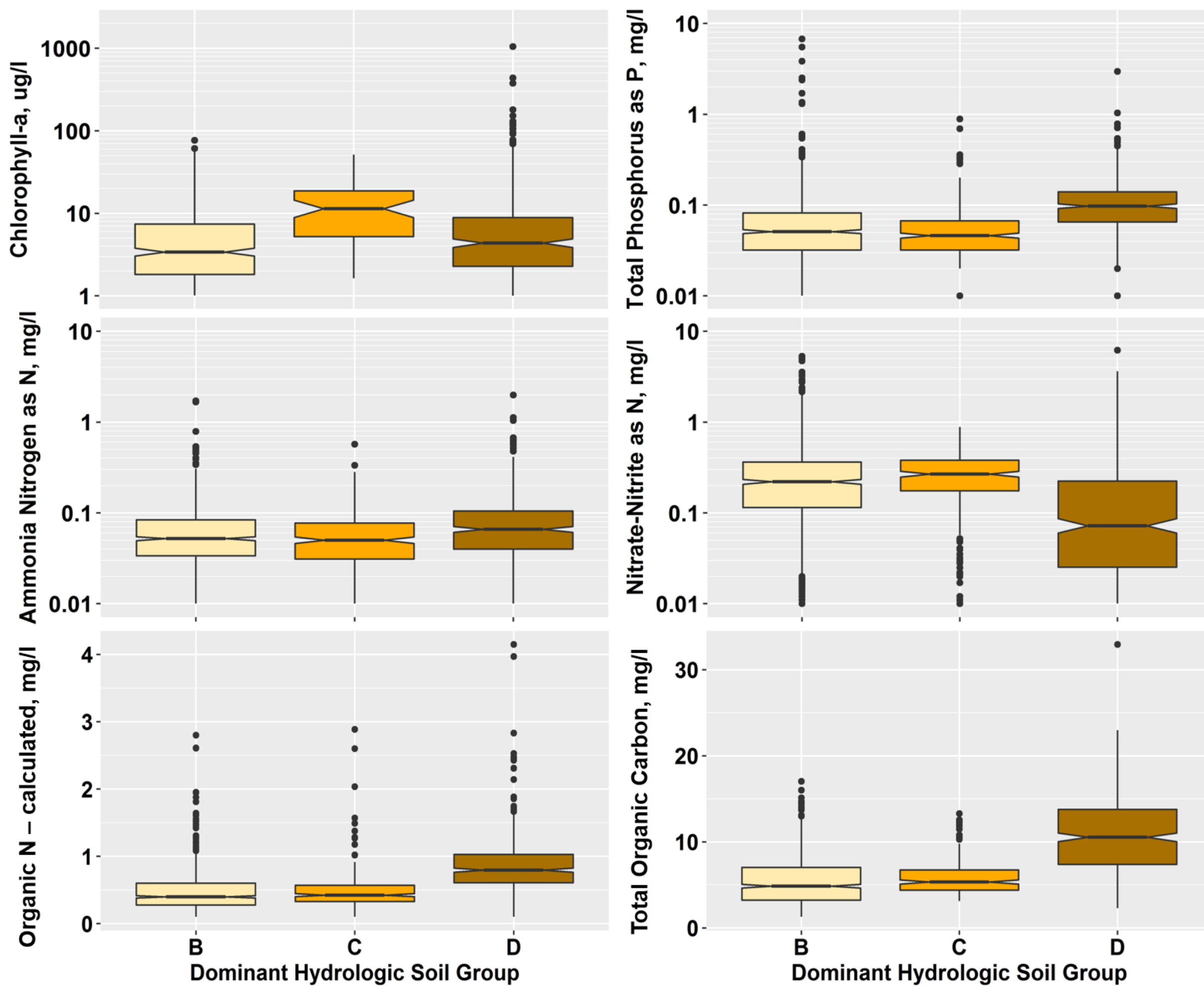


Figure 4-3. Distribution of Water Quality Parameters by Hydrologic Soil Group in the Falls Lake Watershed

Note that the Chlorophyll-a, Total Phosphorous, Ammonia, and Nitrate-Nitrite plots are shown on a logarithmic scale.

4.3 Sites Upstream and Downstream of Wastewater Treatment Plants

Stations were also categorized by the presence of an upstream WWTP as either a major facility (>1 million gallons per day) or a minor facility (i.e., a package plant) (Figure 4-4). In the Falls Lake watershed, nitrogen concentrations (ammonia, nitrate+nitrite, and organic nitrogen) collected during the monitoring period tend to be higher downstream of major WWTPs; for total phosphorus, the concentrations are similar across the three groups, which may be due to recent upgrades at the Durham and SGWASA WWTPs. TOC concentrations are fairly similar at sites with major and minor WWTPs; sites without WWTPs tend to have more variability in this parameter and the highest concentrations are observed at stations without WWTPs (these higher concentrations may be associated with non-flowing, wetland dominated areas). Chlorophyll-a concentrations tend to be lower downstream of major WWTPs, which may be due to the increased flow rates that prevent low-flow conditions and the associated higher algal densities. Chlorophyll-a concentrations at stations with higher flow are usually lower than levels measured under low/non-flowing conditions.

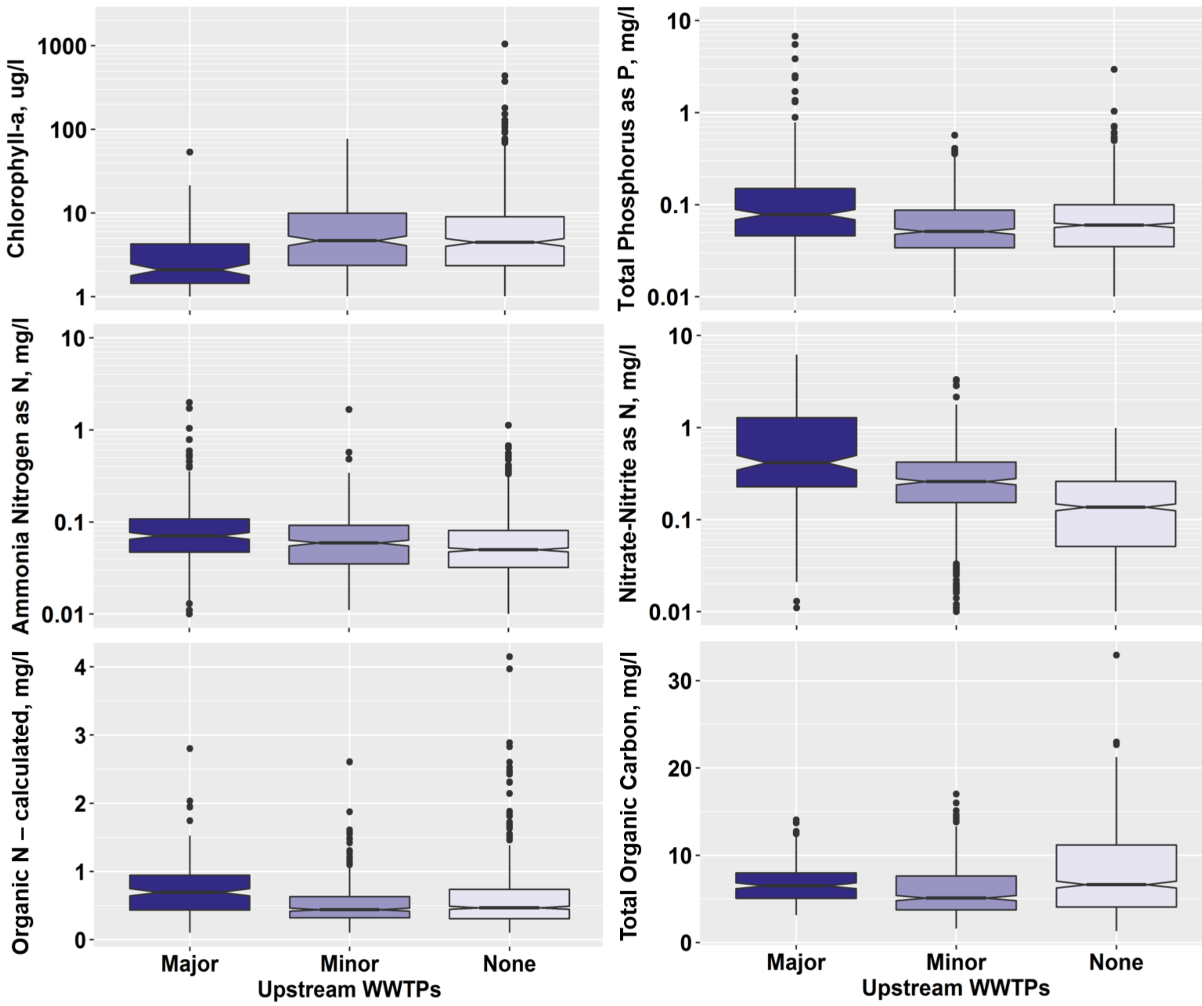


Figure 4-4. Comparison of Water Quality Parameters Relative to the Presence of a Major or Minor (Package Plant) WWTP

Note that the Chlorophyll-a, Total Phosphorous, Ammonia, and Nitrate+Nitrite plots are shown on a logarithmic scale.

4.4 Water Quality

4.4.1 Chlorophyll-a

4.4.1.1 Water Quality Criterion and Statistics

Chlorophyll-a is a central focus of concern for the Falls Lake re-examination process because it was previously identified on North Carolina's Clean Water Act Section 303(d) list of waters not attaining the state's water quality criterion of 40 µg/L (15A NCAC 02B .0211(4)). Previously, the criterion was not to be exceeded more than 10 percent of the time, with a statistical confidence of 90 percent. The EMC has recently approved changes to listing and delisting procedures for chlorophyll-a.

On March 8, 2018, the NC Environmental Management Commission approved changes to the North Carolina 2018 Clean Water Act Section 303(d) listing methodology for the designation of waters not attaining water quality standards. The 2018 303(d) methods will add more rigor to any decision to remove water bodies from an impairment status. This new assessment methodology may be of particular interest to the UNRBA since additional rigor will be required to consider waters to have attained water quality standards criteria. The 2018 assessment methodology window will include data from 2012-2016. The 2018 303(d) listing and delisting methodology is more complex than previous assessment methods because it now includes methods for both listing and delisting waters in addition to new assessment methods for small data sets of less than ten observations. The new 303(d) assessment methodology is available on the DWR website at the following location:

https://files.nc.gov/ncdeq/Water%20Quality/Planning/TMDL/303d/2018/2018%20Listing%20Methodology_ApprovedMarch2018.pdf

Table 4.1 summarizes the lake loading tributary chlorophyll-a data relative to that criterion. Of 893 chlorophyll-a values measured at the Lake Loading tributary stations from August 2014 to December 2017, 855 (96 percent) were below the 40 µg/L criterion. In 2017, 249 out of 261 (95 percent) tributary measurements were below the criterion and 12 observations exceeded 40 µg/L in seven of the monitored tributary stations, as shown in Table 4-1. Most of these elevated values occurred during times of below average streamflow.

For the Unnamed Tributary, Beaverdam, Ledge, Upper Barton, and Robertson Creeks, nine out of ten of the observed chlorophyll-a concentrations above 40 µg/L occurred during times when field-measured surface velocities were less than 0.5 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, which are characteristic of four of these tributaries. 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).

For the original lake model developed by DWR, very limited chlorophyll-a data were available for the tributaries entering the lake. DWR assumed that concentrations in the tributaries were similar to the closest in-lake station. Grab samples collected in the lake were then interpolated and used to assign daily concentrations of chlorophyll-a as time series inputs to the model. However, as reflected in Figure 3-24, chlorophyll-a levels in the tributaries are typically well below the concentrations observed at the in-lake stations—in fact, the median values for *all* Lake Loading stations are lower the median values for all reservoir stations. The highest median chlorophyll-a level at a Lake Loading station is about 10 µg/L (Flat River) which is still 8 µg/L lower than the lowest median for reservoir stations (about 18 µg/L near the dam).

Although the median tributary concentrations are well below lake values, there are a small number of tributary observations which are well above what is typically seen in the lake. These elevated chlorophyll-a concentrations have predominately been observed in smaller tributaries which are among the lowest contributors of discharge to Falls Lake and during times when even their typically low discharge was among its lowest levels. Despite the elevated concentrations, the negligible discharge results in a very small amount of chlorophyll-a being contributed to the reservoir, and therefore these high observations have a negligible effect on reservoir chlorophyll-a concentrations. Even during rain events that substantially increase streamflow, these streams are rapidly flushed of their elevated phytoplankton biomass and the runoff-generated streamflow that follows has much lower chlorophyll-a concentrations. Therefore, although a short pulse of chlorophyll-a may be delivered to the lake from these slow-flowing, wetland areas following rain events, the combination of the relatively low volume of affected stream water followed by runoff-derived, low-chlorophyll containing stormflow means that the build-up of phytoplankton during sluggish flows typically has little to no effect on reservoir chlorophyll concentrations (see Section 5.1 below, indicating high flows from storm events generally carrying less than 20 µg chlorophyll-a/L to the lake). During times of normal discharge, chlorophyll-a concentrations at these sites has typically been less than half of that observed in Falls Lake.

Table 4-1. Lake loading stations with chlorophyll-a measured above the NC state criterion between August 2014 and December 2017.

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	44	8	18
Ellerbe Creek	ELC-3.1	73	1	1
Eno River	ENR-8.3	74	2	3
Flat River	FLR-5.0	71	4	6
Ledge Creek	LGE-5.1	42	4 (	10
Panther Creek	PAC-4.0	40	1	3
Robertson Creek	ROB-2.8	44	9	20
Upper Barton Creek	UBC-1.4	38	1	3
Unnamed	UNT-0.7	41	8	20
All Lake Loading Stations		893	38	4

Like the presentation of tributary results, chlorophyll-a results within Falls Lake are summarized in Table 4-2. In-lake data from DWR, City of Durham and CAAE monitoring stations for the past four years are presented. Stations are ordered from upstream to downstream. The table provides the number of values reported for each monitored station and the number of values above the 40 µg/L criterion. In addition, annual arithmetic means and geometric means were calculated for both full years and for growing seasons. Geometric means are commonly employed when a data set is skewed or has occasional large outliers, because data extremes do not have as much effect on the geometric mean as they do on an arithmetic mean. The growing season was defined as April through October for these calculations. The City of Durham collects data only during the growing season, thus (12 month) annual averages are not possible for their two stations.

Like Figure 3-24 in the previous section, Table 4-2 indicates that the upper portion of the lake (above Hwy 50) has a greater tendency to experience chlorophyll-a values above 40 µg/L than the lower lake (below Hwy 50). This is consistent with past data and general understanding of how chlorophyll varies in the lake. This observation if important relative to the UNRBA's ongoing work on the Reexamination and its consideration of alternate regulatory approaches. The variation of chlorophyll in this area and lake arms outside of the main body of the lake continues to be an important consideration. The first three rows highlighted at the top of Table 4-2 provide a summary of the annual values for all stations in all years (2014 through 2017) by row for the entire lake, stations above Hwy 50, and stations below Hwy 50. Several observations are notable:

- Annual means for **stations above Highway 50** were about 10 µg/L higher on the average than for **stations below Hwy 50** (36 vs. 26 µg/L), while the averages of growing season means differed by 14 µg/L between the two groups (39 vs. 25 µg/L).
- None of the 32 station-year combinations below Highway 50 exceeded 40ug/L chlorophyll-a for any of the central-tendency statistics including: Annual Mean, Growing Season Mean, Annual Geometric Mean, or Growing Season Geometric Mean.
- For all station-years taken together, the difference between the average of **annual means** and **annual geometric means** was only about 2 µg/L (the highest individual difference was 7 µg/L).

The same magnitude of difference is seen between **growing season** means and **growing season geometric means.**

- **Annual geometric means** averaged about 3 µg/L lower than **annual means** for stations above Hwy 50 (33 vs. 36 µg/L), and differed by a similar margin (2 µg/L) for stations below Hwy 50. A similar pattern is seen for **growing season geometric means** relative to **growing season means**, but with even smaller differences between the averages (about 1 µg/L).

Calculating means of means can obscure variability in the underlying data. Individual station-years in Table 4-2 show differences as high as 16 µg/L between annual means and growing season means, and as high as 21 µg/L between growing season geometric means and annual geometric means.

Using geometric means to describe chlorophyll-a data from Falls Lake might not result in substantially different values from arithmetic means for large segments of the reservoir. Employing the geometric mean for environmental data (including chlorophyll-a) is widely accepted and does minimize the effect of occasional outliers on the resulting statistics. Variability among stations and between years reflects the dynamic nature of chlorophyll-a in large reservoirs. This temporal and spatial variability is a complexing factor in judging compliance with established chlorophyll criteria or the development of new numeric criteria for nutrients (including potential modification of the current chlorophyll-a criteria), as well as the interpretation of such criteria in permits and management strategies.

Table 4-2. 2014-2017 Chlorophyll-a (µg/L) summary metrics for each Falls Lake monitoring location.

	Location	Year	n	n (%) > 40 µg/L	Mean (Annual)	Mean (Growing Season)	Geometric Mean (Annual)	Geometric Mean (Growing Season)
Above Highway 50	Average of All Station-years				31	33	29	31
	Average of Station-years above Hwy 50				35	39	33	37
	Average of Station-years below Hwy 50				26	25	24	23
	CAAE - FL4	2016	9	7 (78%)	51	50	50	48
		2017	10	6 (60%)	55	66	52	64
	Durham - FL-DS4	2015	28	11 (39%)	-	39	-	35
		2016	31	5 (16%)	-	29	-	26
		2017	24	14 (58%)	-	40	-	39
	CAAE - FL85C	2015	35	20 (57%)	44	60	37	58
		2016	32	16 (50%)	40	47	33	45
		2017	28	19 (68%)	50	58	47	57
	DWR - NEU013B	2014	12	4 (33%)	36	42	33	40
		2015	12	3 (25%)	38	43	37	40
		2016	12	3 (25%)	31	43	27	42
		2017	12	6 (50%)	40	46	37	42
	CAAE - FL5	2016	9	3 (33%)	43	42	42	42
		2017	11	7 (64%)	49	58	46	56
	CAAE - FL6C	2015	12	3 (25%)	35	37	32	34
		2016	12	3 (25%)	30	39	24	38
		2017	11	6 (55%)	43	49	42	48
	Durham - FL-SR1801	2015	27	1 (4%)	-	29	-	27
		2016	31	2 (6%)	-	26	-	25
		2017	23	7 (30%)	-	38	-	36
	CAAE - FL6	2016	9	2 (22%)	35	34	34	33
		2017	11	3 (27%)	41	46	40	45
	DWR - LLC01	2014	12	4 (33%)	35	36	33	34

Table 4-2. 2014-2017 Chlorophyll-a (µg/L) summary metrics for each Falls Lake monitoring location.								
	Location	Year	n	n (%) > 40 µg/L	Mean (Annual)	Mean (Growing Season)	Geometric Mean (Annual)	Geometric Mean (Growing Season)
		2015	12	2 (17%)	31	35	30	33
		2016	12	2 (17%)	28	36	25	34
		2017	12	5 (42%)	42	49	39	47
	CAAE - FL10C	2015	12	4 (33%)	33	36	31	34
		2016	12	1 (8%)	28	32	24	32
		2017	11	9 (82%)	44	49	42	49
	DWR - NEU0171B	2014	12	3 (25%)	34	33	31	32
		2015	12	2 (17%)	33	35	32	34
		2016	12	2 (17%)	28	35	25	34
		2017	12	5 (42%)	40	45	38	44
	DWR - LC01	2014	12	1 (8%)	32	29	31	28
		2015	12	0 (0%)	25	28	24	27
		2016	12	0 (0%)	24	26	22	25
		2017	12	3 (25%)	37	40	35	39
	CAAE - FL9C	2015	12	2 (17%)	31	34	29	31
		2016	12	2 (17%)	25	26	22	26
		2017	11	8 (73%)	44	50	41	46
	DWR - NEU018C	2015	12	1 (8%)	26	31	22	29
		2016	12	0 (0%)	24	28	22	27
		2017	12	4 (33%)	42	47	38	43
	DWR - NEU018E	2014	12	3 (25%)	34	31	31	28
		2015	12	1 (8%)	27	29	25	25
		2016	12	1 (8%)	28	34	25	31
		2017	12	4 (33%)	42	46	38	42
	DWR - LI01	2014	12	2 (17%)	36	30	33	29
		2015	12	2 (17%)	29	30	28	29
		2016	12	2 (17%)	29	31	27	30
		2017	12	4 (33%)	42	42	40	40
	CAAE - FL50C	2015	35	3 (9%)	27	28	25	26
		2016	32	5 (16%)	28	29	24	28
		2017	31	17 (55%	42	43	39	41
Below Highway 50	CAAE - FL2	2016	9	0 (0%)	26	25	25	24
		2017	11	5 (45%)	40	40	37	39
	CAAE - FL3	2016	9	0 (0%)	25	24	24	23
		2017	11	6 (55%)	40	40	37	37
	DWR - NEU019E	2014	12	2 (17%)	31	25	29	24
		2015	12	0 (0%)	23	23	22	22
		2016	12	0 (0%)	24	25	23	24
		2017	12	3 (25%)	39	41	36	36
	CAAE - FL8C	2015	12	0 (0%)	21	17	20	16
		2016	12	0 (0%)	20	22	19	22
		2017	11	3 (27%)	37	34	34	33
	DWR - NEU019L	2014	12	2 (17%)	28	20	26	20
		2015	12	0 (0%)	20	18	19	17
		2016	12	0 (0%)	20	22	19	22
		2017	12	5 (42%)	39	40	35	36

Table 4-2. 2014-2017 Chlorophyll-a (µg/L) summary metrics for each Falls Lake monitoring location.

Location	Year	n	n (%) > 40 µg/L	Mean (Annual)	Mean (Growing Season)	Geometric Mean (Annual)	Geometric Mean (Growing Season)
CAAE - FL1C	2015	12	0 (0%)	20	15	18	14
	2016	12	0 (0%)	17	19	16	19
	2017	11	3 (27%)	32	30	29	28
DWR - NEU019P	2014	12	2 (17%)	28	21	24	18
	2015	12	0 (0%)	19	15	17	14
	2016	12	0 (0%)	20	21	19	21
	2017	12	3 (25%)	37	33	32	30
CAAE - FL1	2016	9	0 (0%)	20	20	20	20
	2017	11	4 (36)	32	30	28	26
CAAE - FL11C	2015	12	0 (0%)	23	23	22	22
	2016	12	2 (17%)	25	25	22	24
	2017	11	6 (55%)	40	42	35	39
CAAE - FL7C	2015	12	0 (0%)	19	15	18	14
	2016	12	0 (0%)	17	18	16	17
	2017	11	4 (36%)	33	32	30	30
DWR - NEU020D	2014	12	2 (17%)	27	18	23	17
	2015	12	0 (0%)	19	16	18	15
	2016	12	0 (0%)	18	18	17	18
	2017	12	1 (7%)	25	24	23	22
CAAE - FLINC	2015	35	0 (0%)	17	14	16	13
	2016	32	0 (0%)	16	17	16	17
	2017	31	6 (19%)	30	26	25	24

4.4.1.2 Comparison to Other Water Quality Parameters

In-lake concentrations of chlorophyll-a were also compared to other water quality parameters for the data collected from 2014 to 2017. Figure 4-5 shows a series of scatter plots that compare chlorophyll-a concentrations along the lake to six other parameters. As described previously, chlorophyll-a concentrations in the upper most part of the lake (green circles) are higher than those downstream that are closer to the dam (blue circles). Visually, the strongest relationship to chlorophyll-a is associated with organic nitrogen. This relationship is expected as nitrogen that is stored in algae is organic. A similar, but more variable relationship can be seen with total nitrogen because most is assumed in the organic form. Less of a trend can be seen with the other parameters (TOC, TP, turbidity, and specific conductivity). High or low concentrations of these four parameters are associated with the same concentrations of chlorophyll-a.

4.4.1.3 Historic Data

While the UNRBA has been collecting water quality data in Falls Lake and its watershed since August 2014, DWR has collected data as far back as 1984. To compare how chlorophyll-a levels in the lake have changed since the lake was filled, the full DWR data set was downloaded from STORET to analyze the annual and growing season arithmetic and geometric means. Data were examined for each individual year and for all years combined to evaluate spatial and temporal trends. Only stations with at least three samples collected during a season were included in the analysis. Values are plotted with respect to distance upstream of the dam - the dam is thus depicted at 0 miles. Figure 4-6 and Figure 4-7 show the arithmetic means for the growing season. For many of the historic sampling years, data were only collected during the growing season. Figure 4-6 indicates a general decrease in chlorophyll concentration and variability since the lake was created. Figure 4-7 indicates that the pattern of decreasing concentration from the upper lake to the lower lake observed in the 2014-2017 data reported in Section 3 has been the general pattern since the lake was created. Data are shown as before or after the year 2000 because there was a gap in data collection prior to this year.

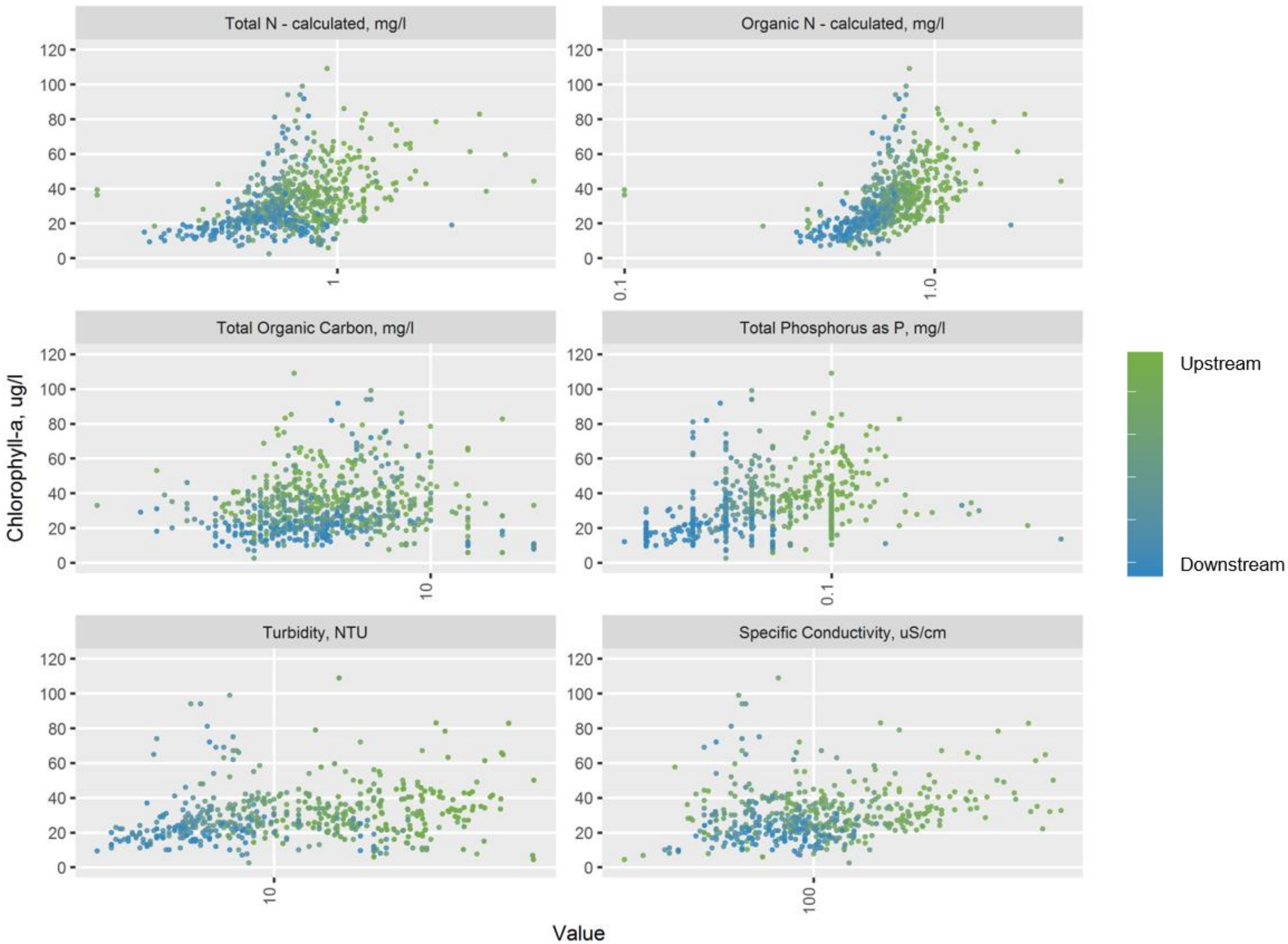
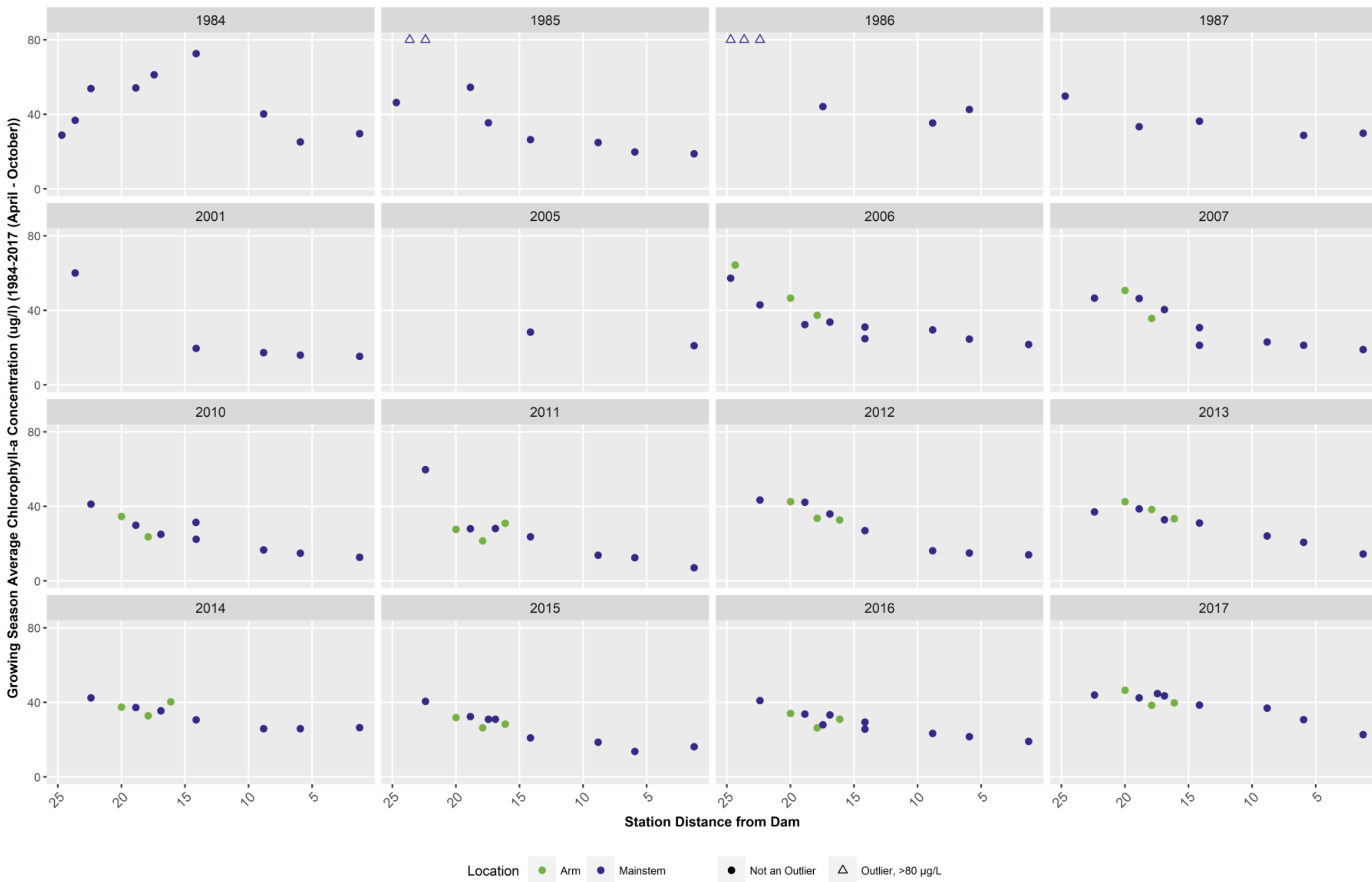
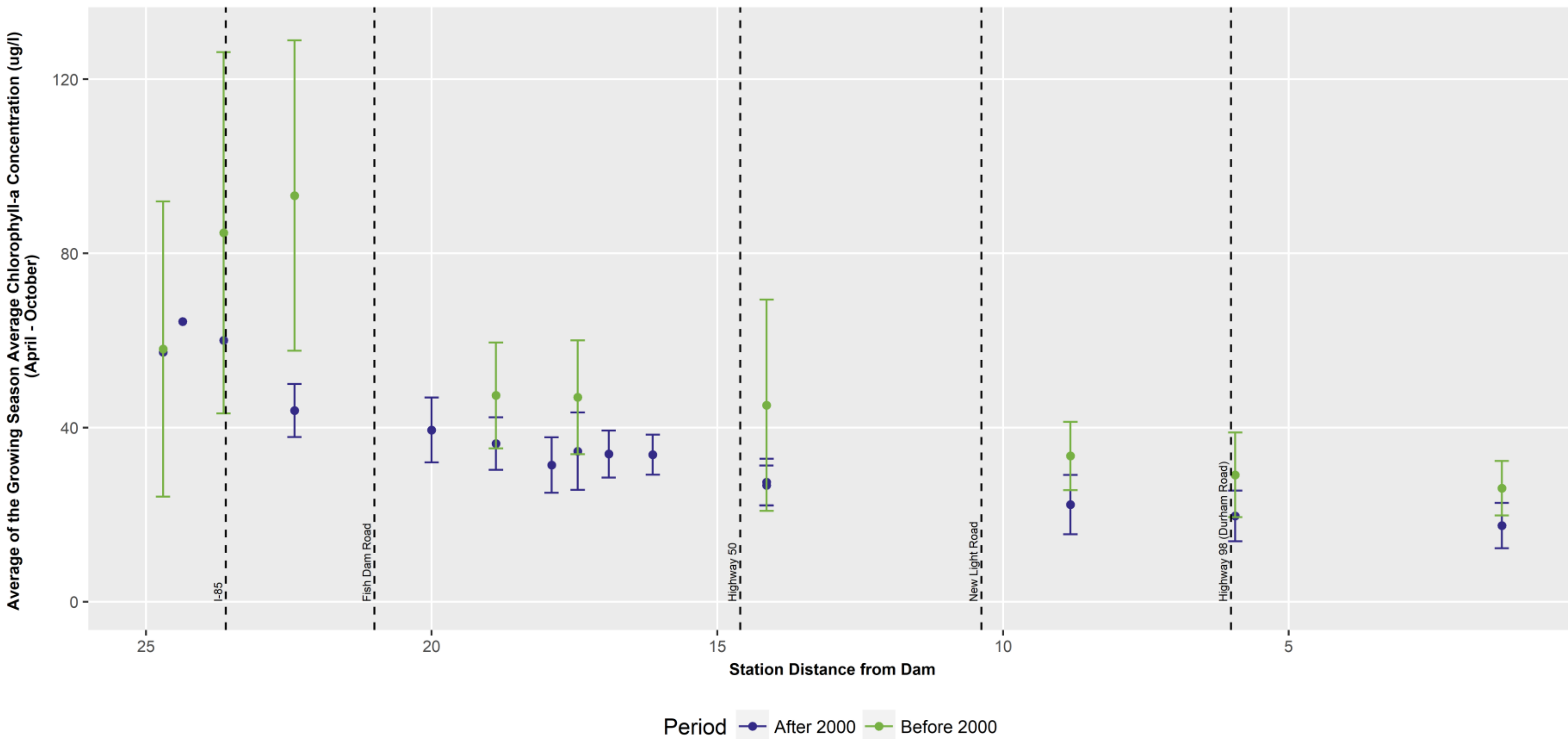


Figure 4-5. Comparison of chlorophyll-a concentrations to other lake water quality parameters (August 2014 – December 2017)



*Only Stations with at least 3 samples per season are included

Figure 4-6. Falls Lake Growing Season Arithmetic Mean Chlorophyll-a Concentrations by Year for the Historic Record (DWR Data)



*Only Stations with at least 3 samples per season are included

Figure 4-7. Falls Lake Growing Season Arithmetic Mean Chlorophyll-a Concentrations (All Years Combined) for the Historic Record (DWR Data)

4.4.2 Dissolved Oxygen Water Quality Criterion

North Carolina water quality criteria specify that DO is to be no less than 4 mg/L at any time except swamp waters, lake coves, or backwaters, and lake bottom waters may have lower values if caused by natural conditions (15A NCAC 02B .0211 (6)). Of 1,613 total DO measurements in Falls Lake tributaries, approximately 91 percent were above the criterion and 9 percent fell below 4 mg/L, as listed in Table 4-3. Stations with lower DO tend to be in areas with low slopes and very slow flows, and many are within wetland-dominated areas. "Water quality standards will not be considered violated when values outside the normal range are caused by natural conditions" (15A NCAC 02B .0205).

Table 4-3. Stations with Dissolved Oxygen Measurements below the NC State Criterion between August 2014 and December 2017

Subwatershed	Station ID	Number of DO Values Measured	DO Values Reported below 4 mg/L
Beaverdam Creek	BDC-2.0 (LL)	42	15 (36%)
Camp Creek	CMP-23 (JB)	37	9 (24%)
Deep Creek	DPC-23 (JB)	40	1 (3%)
Flat River	FLR-5.0 (LL)	62	14 (23%)
Ledge Creek	LGE-13 (JB)	29	2 (7%)
Ledge Creek	LGE-5.1 (LL)	40	11 (28%)
Lick Creek	LKC-2.0 (LL)	39	4 (10%)
Little Lick Creek	LLC-1.8 (LL)	42	8 (19%)
Little Ledge Creek	LLG-0.9 (JB)	40	18 (45%)
Little River	LTR-1.9 (LL)	64	6 (9%)
North Flat River	NFR-41 (JB)	30	6 (20%)
Panther Creek	PAC-4.0 (LL)	40	10 (25%)
Robertson Creek	ROB-7.2 (JB)	34	7 (21%)
Robertson Creek	ROB-2.8 (LL)	42	14 (33%)
Unnamed	UNT-0.7 (LL)	41	17 (41%)
All Monitored Stations		1,613	142 (9%)

4.4.3 pH Water Quality Criterion

The North Carolina water quality criteria specify that pH be between 6 and 9. Tributary station data from August 2014 through December 2017 showed approximately 97 percent compliance with the criterion, as reflected in Table 4-4. 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).

Table 4-4. Stations with pH observed below the NC state criterion between August 2014 and December 2017				
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)	42	8 (19%)	-
Buckhorn Creek	BUC-3.6 (JB)	39	3 (8%)	-
Camp Creek	CMP-23 (JB)	37	4 (11%)	-
Eno River	ENR-49 (JB)	40	3 (8%)	-
Eno River	ENR-8.3 (LL)	65	1 (2%)	-
Flat River	FLR-5.0 (LL)	62	3 (5%)	-
Horse Creek	HSE-11 (JB)	40	2 (5%)	-
Horse Creek	HSE-7.3 (JB) & HSE-5.7 (alternate)	38	3 (8%)	-
Horse Creek	HSE-1.7 (LL)	40	2 (5%)	-
Knap of Reeds Creek	KRC-4.5 (LL)	61	1 (2%)	1 (2%)
Ledge Creek	LGE-13 (JB)	29	3 (10%)	-
Ledge Creek	LGE-17 (JB)	33	2 (6%)	-
Ledge Creek	LGE-5.1 (LL)	39	1 (3%)	-
Little Ledge Creek	LLG-0.9 (JB)	40	1 (3%)	-
Little Lick Creek	LLC-1.8 (LL)	42	-	1 (2%)
Little River	LTR-1.9 (LL)	64	1 (2%)	-
New Light Creek	NLC-3.8 (JB)	41	1 (2%)	-
New Light Creek	NLC-2.3 (LL)	40	1 (3%)	-
Panther Creek	PAC-4.0 (LL)	40	2 (5%)	-
Robertson Creek	ROB-7.2 (JB)	34	3 (9%)	-
Robertson Creek	ROB-2.8 (LL)	42	4 (10%)	-
Smith Creek	SMC-6.2 (LL)	35	1 (3%)	-
Unnamed	UNT-0.7 (LL)	41	3 (7%)	-
All Monitoring Stations		1,612	53 (3%)	2 (0.1%)

4.4.4 Upstream to Downstream Trends in Lake Water Quality

Falls Reservoir is a long-drowned river system that spans over 20 miles upstream of the dam. Figure 4-8 allows for an upstream to downstream visual comparison of trends multiple parameters. For most of the parameters, the measurements decrease from upstream to downstream: chlorophyll-a, organic nitrogen, total nitrogen, total phosphorus, total suspended solids, and turbidity. Secchi depth increases from upstream to downstream as water clarity increases. These patterns indicate an improvement in water quality from the upper part of the reservoir to the downstream part near the dam and the City of Raleigh's intake. These longitudinal trends were predicted prior to the construction of the reservoir (State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources 1973, USACE 1974)). Total organic carbon concentrations are relatively consistent from upstream to downstream, with the exception of higher concentrations observed in the Beaverdam impoundment. The City of Raleigh closely monitors TOC in the lake as higher concentrations require additional treatment for drinking water.

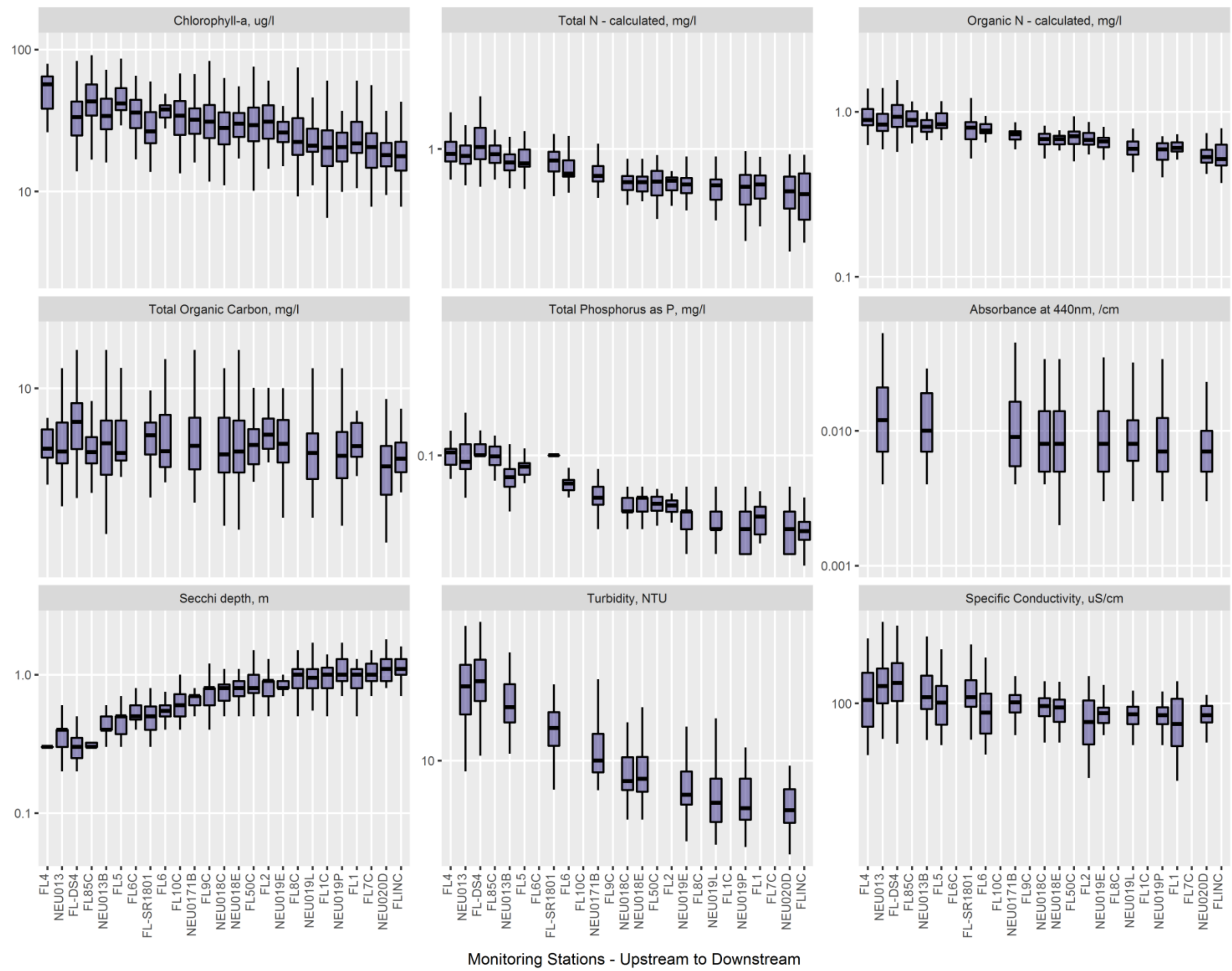


Figure 4-8. Upstream to downstream trends of key lake water quality parameters (2014-2017).

All parameters are displayed using a logarithmic scale

4.5 Reservoir Residence Time

Residence time is the average amount of time that a given parcel of water remains in a water body, and can be calculated as the volume of the water body divided by its outflow. The stage to volume relationship is known for Falls Lake, so its residence time can be calculated for any given time using USGS reservoir stage data and USGS discharge data for the Neuse River at the dam. Figure 4-9 provides time series for both residence time and lake stage during the UNRBA monitoring period. To reduce excessive noise, the lines on the figure are the 30- and 90-day moving averages for each variable (note the greater variability in the 30-day averaged lines than the 90-day lines). These increments were chosen as temporal ranges within which lake water quality might be expected to change.

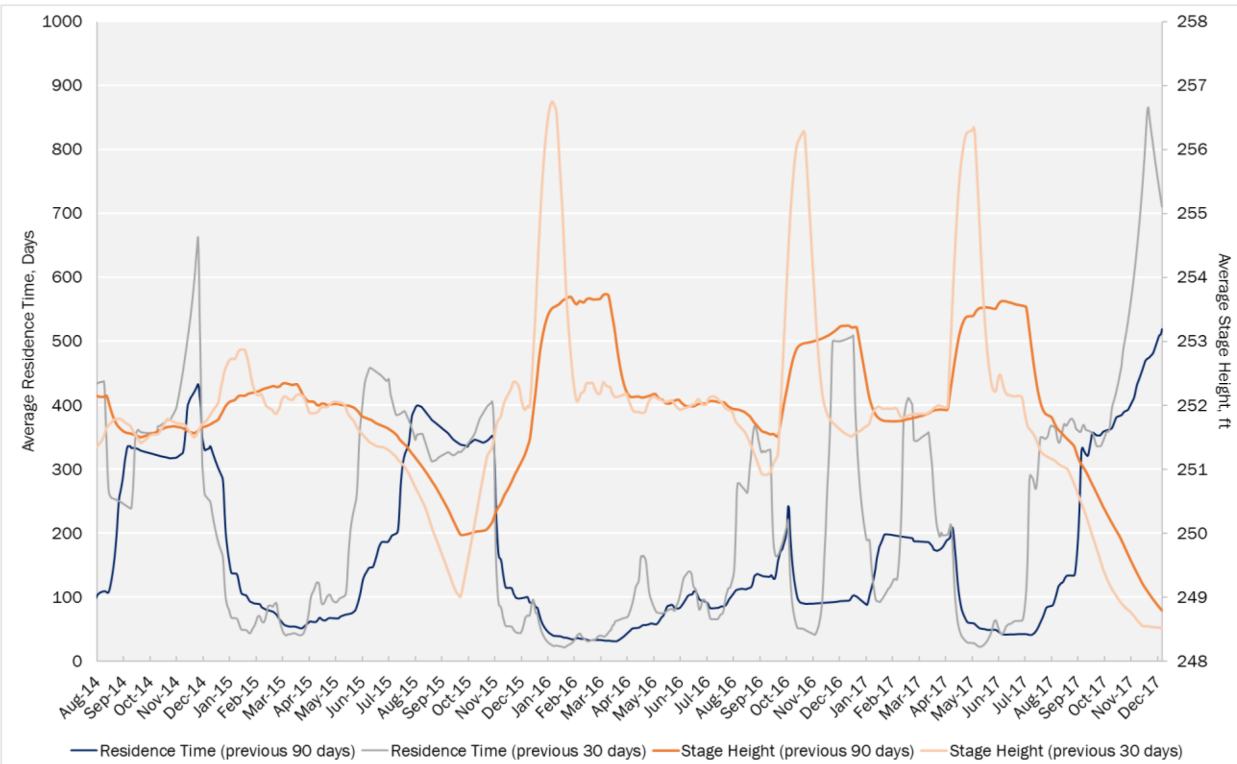


Figure 4-9. Residence time and reservoir stage, averaged over the prior 30 and 90 days, during the UNRBA monitoring period

Despite the use of moving averages that are relatively long compared to the study period (90 days is about 15 percent of the UNRBA monitoring period through 2017), frequent and dramatic changes in residence time are still apparent. This is because the lake can see rapid increases in stage in response to large rain events (e.g., multi-day rainfall or tropical storm activity), and sudden decreases in stage when the spillway at the dam is opened to allow maximum discharge to the Neuse River. As Figure 4-9 shows, residence time and stage are inversely related since the USACE controls discharge at the dam in response to rainfall patterns. Thus, when water levels in the lake are high, discharge at the dam is also high, meaning that residence time decreases. Relatively slight changes in lake stage can also be associated with substantial changes in residence time. For example, in December 2014, lake level rose gradually from about 251.5 feet to about 252.5 feet, and during that period, the 90-day average residence time dropped from about 425 days to around 50 days.

A change in residence time across an order of magnitude in a matter of days is not generally seen in natural lakes. It is a characteristic of artificial reservoirs where water levels and downstream flows are managed to prevent flooding. For Falls Lake, management of lake level and discharge is entirely controlled by the USACE according to a release schedule designed to minimize flood risk. The December 2014 discharge pattern noted above is, at least in part, because the USACE seeks to control the level in Falls Lake at 251.5 feet. During that time, area rainfall continued to raise the lake level over several weeks, so the USACE opened the spillway to hold the lake level as close to 251.5 feet as possible.

Since the USACE actively regulates reservoir discharges (and therefore residence time), some portion of the behavior of any parameter that is positively or negatively correlated with residence time is subject to a water resource management program generally outside the influence of the governmental jurisdictions around the lake or DEQ water quality standards. This fact should be considered when exploring nutrient management alternatives for the reservoir.

4.6 Nutrient Limitation

Algal growth can be influenced by a variety of physical and chemical factors. However, in many water bodies, a primary determinant of overall algal production is having a sufficient supply of nitrogen and phosphorus. Some algal species may also compete for other resources based on specific physiological needs (e.g., micronutrients or sunlight), but within the algal community as a whole, it is common to find growth to be limited by nutrients - either nitrogen or phosphorus availability, or sometimes by both.

For some water bodies, it is easy to determine whether the availability of nitrogen or phosphorus is limiting the growth of algae. Simple guidelines have been developed to indicate which nutrient is likely to be limiting. For example, a molar ratio of 30:1 for N:P could suggest that phosphorus availability is limiting, while a N:P ratio of 10:1 could suggest that nitrogen is limiting. Ratios in between 30:1 and 10:1 might indicate the possibility of “co-limitation” by N and P. These particular ratios are not directly applicable to N and P concentrations expressed in mg/L. There has been extensive limnological research on this topic, with a broad diversity of findings, and numerous exceptions to every hypothesis.

Like many reservoirs in the Southeastern U.S., Falls Lake is eutrophic, meaning it is relatively nutrient-rich and can support a relatively abundant algal community. Thus, even if N or P is shown to be “limiting,” it does not mean that algae may not be abundant. It simply means that additional increase in the phytoplankton population would be controlled by the supply of the limiting nutrient. General calculations based on the ranges of TN and TP concentrations represented in Figure 3-21 and Figure 3-22 above yield an N:P ratio (on a molar basis) on the order of 20:1 at the upper end of the lake, 35:1 in the middle section, and 50:1 at the lower end. Based on the guidelines noted above, these ratios suggest that P would limit algal growth from the dam through the middle section of the lake, but the upper end of the lake could see algae limited by both N and P.

It is important to note that measuring TN and TP in water samples is not necessarily the same as quantifying the available supply of these nutrients to algae. Much of the nutrient pool in the water column of a lake (and in water samples from the lake) is assimilated within living algae and thus not readily available to grow new algae.

Unfortunately, nutrient limitation is far more complex than the simple set of calculations and predictions above. Algal communities are complex and dynamic. A nutrient ratio that is optimal for one species group may be inhibitory to another, and some species are more efficient at using certain forms of N and P. Such nutrient preference patterns are part of the reason for shifts in the algal community of a lake both spatially and temporally (as seen in Figure 3-31 through Figure 3-33). Therefore, managing nutrients in a lake to control algal abundance (or chlorophyll-a) is not a simple cause and effect undertaking. Because N and P are naturally-occurring in the environment, implementing tight constraints on their delivery to a water body can be a very challenging prospect. These are issues that must be considered during the upcoming modeling and regulatory support efforts.

4.7 Algal Toxins

Certain species of algae are known to have the capability to produce toxins but the current scientific understanding of why and when toxins are produced or not produced is not well understood. A few of the Blue green algae species (cyanobacteria) are most commonly known for this behavior. Some blue-green strains produce cyanotoxins which include microcystin, cylindrospermopsin, saxitoxin, anatoxin-a, and beta-Methylamino-L-alanine (BMAA). Little is known about the triggers for production of toxins, and not all algae that can generate toxins actually do so (Wiltsie et al. 2017). North Carolina has not established water quality criteria for these toxins. The World Health Organization (WHO) microcystin guideline for drinking water is 1 µg/L, and the EPA draft recreational guideline is 4 µg/L.

As part of its ongoing monitoring of the water quality of Falls Lake as a water supply, the City of Raleigh measures algal toxin data at several locations in Falls Lake. Figure 4-10 shows the results of assays for microcystin, cylindrospermopsin, and anatoxin-a at six locations in the lake. For many sampling events, toxins are not detectable. Concentrations in lake arms tend to be higher than in the main channel. No samples of microcystin exceeded either the draft EPA recreational guideline nor the WHO drinking water guideline. Cylindrospermopsin was generally lower than microcystin, and anatoxin-a was sometimes higher than microcystin. Less is known about these toxins and guidelines have not yet been issued.

During the reexamination process, all water quality parameters/issues that may be raised relative to potential impairments of uses, will likely have to be addressed. This issue has been raised in other reservoirs in the state with chlorophyll standard impairments (as DWR identifies them).

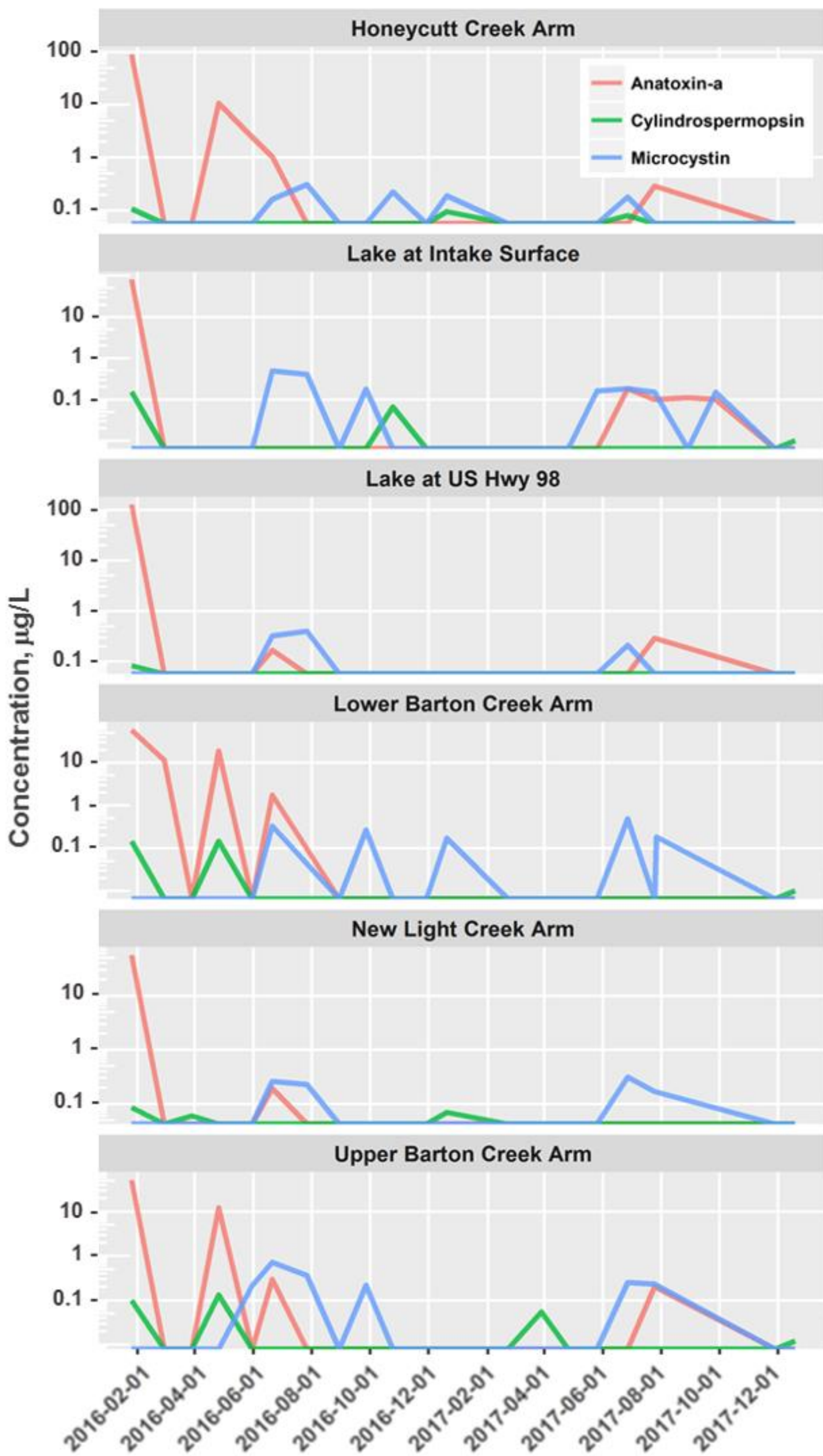


Figure 4-10. Algal Toxin Data Collected in Falls Lake

Section 5

Special Studies Results

5.1 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 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 along with Knap of Reeds Creek and Ellerbe Creek contribute nearly 80 percent of the water delivered to Falls Lake. To assess the percentage of samples collected during different flow conditions for each of the top five flow contributors to Falls Lake, loading values were calculated and distributed amongst five equal groups (quintiles) based on the range of all loading values observed during the monitoring period. The percentage of samples collected from each quintile was then calculated for all five streams (Figure 5-1).

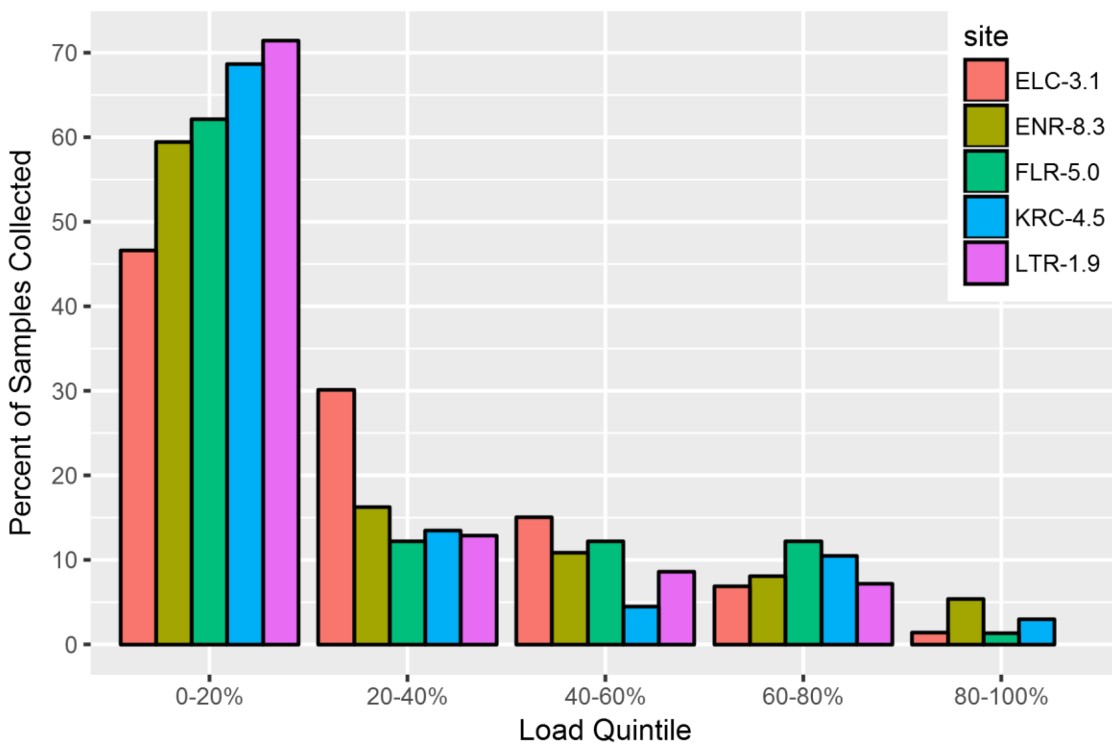


Figure 5-1. Percentage of samples collected during different loading quintiles for the five largest flow contributors to Falls Lake

Between January and December 2017, only 4 out of the 12 months had high enough flow conditions and appropriate timing (during daylight hours safe for sampling) to sampled high flow conditions. Samples were collected at a variety of lake loading sites in January, April, May, and June. 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. As part of the high flow study, over 70 measurements have been collected for volatile and total suspended solids, nutrients, TOC, and chlorophyll-a.

Differences in chlorophyll-a, total phosphorous, total organic carbon and nitrogen (ammonia, nitrate+nitrite, and organic nitrogen) concentrations for samples collected during high flow conditions (load quintiles greater than 60 percent) and for samples collected during more normal flow conditions (load quintiles less than 60 percent) are presented in Figure 5-2. With the exception of nitrate+nitrite, sample concentrations are generally higher during high flow conditions. This is the generally expected pattern, since higher flows associated with rain events would be expected to carry material from surface runoff into the streams. The pattern observed for chlorophyll-a is somewhat counterintuitive since algae would not be expected to proliferate in streams as a result of a rain event occurring just hours before. Potential explanations for this result are (1) higher flows may scour periphyton (attached algae) from the stream bed resulting in it being interpreted as phytoplanktonic algae), or (2) certain materials (e.g., humic substances) carried into the stream by the storm event may introduce interference in the fluorescent method used to quantify chlorophyll resulting in the perception of erroneously higher chlorophyll-a levels.

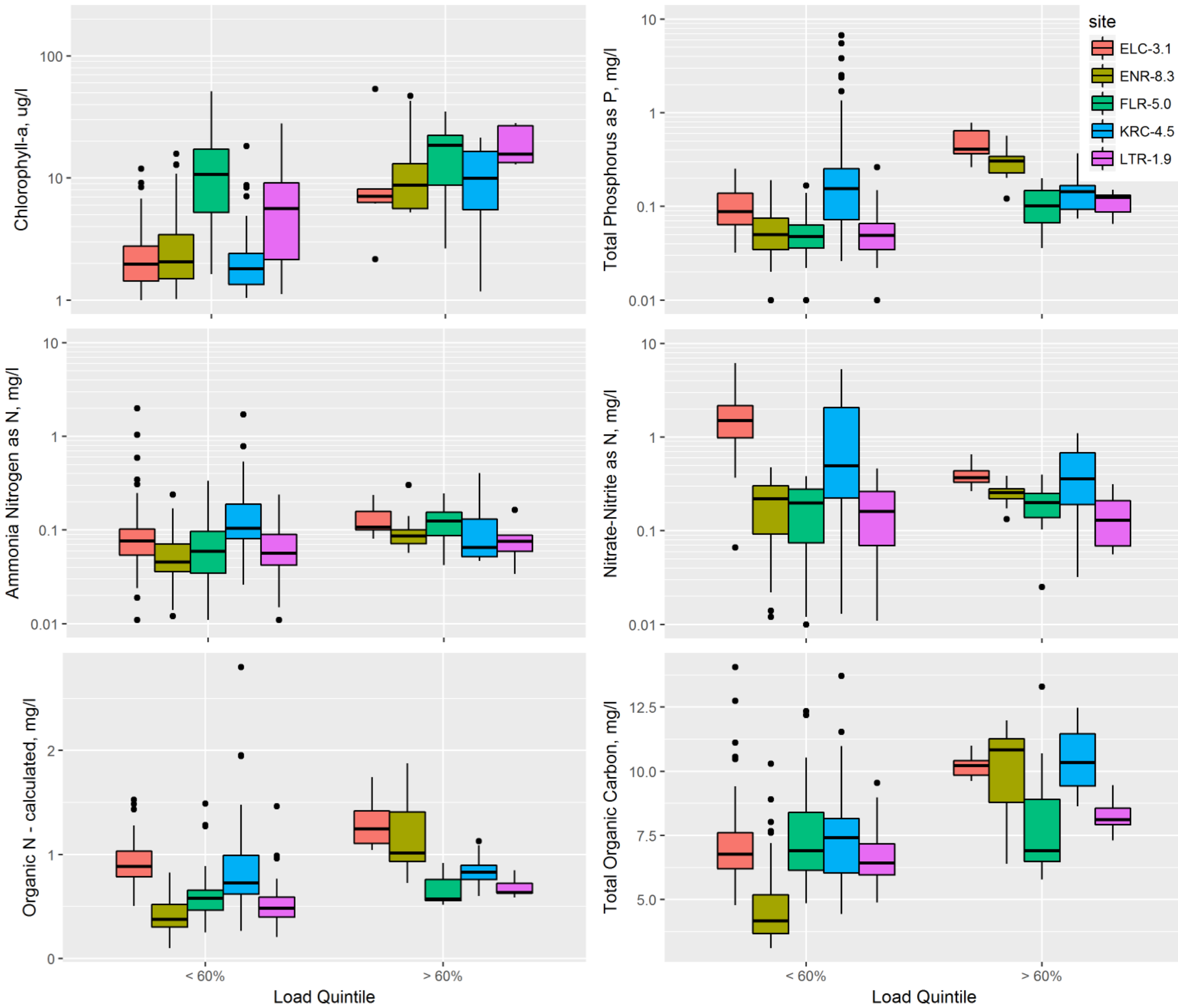


Figure 5-2. Differences in parameter concentrations for samples collected during high flow conditions and for samples collected during more normal flow conditions

High flow conditions are load quintiles greater than 60 percent. Normal flow conditions have load quintiles less than 60 percent

5.2 Lake Sediment Evaluation

In 2015, a Special Study was implemented to evaluate sediments in Falls Lake. Dr. Marc Alperin of the University of North Carolina's Marine Science Department was the Principal Investigator for that study. As of the preparation of this Annual Report, Dr. Alperin is still finalizing his report of the sediment evaluation, but the work is sufficiently complete that this summary of findings can be provided. The final report on the evaluation is anticipated prior to the end of FY2018, and will be provided to the PFC and posted to the UNRBA website at that time.

The Plan of Study developed for this evaluation summarized the purpose of the sediment evaluation:

- This Special Study will quantify the nutrient and organic carbon content of sediment samples from Falls Lake and use that data to help develop a more precise understanding of the spatial variability of sediment characteristics, bottom water, pore water, and benthic nutrient fluxes in Falls Lake. This evaluation will provide site-specific information which can be used to simulate spatial variability in benthic nutrient flux. The existing version of the Falls Lake Nutrient Response Model assumed uniform nutrient flux conditions throughout the lake and thus used a single set of model calibration factors. Information from this study will help develop a better understanding of the importance of internal nutrient loads to the waters of Falls Lake.

- A reconnaissance visit to the lake was conducted in May of 2015, with sample collection occurring on June 8 and 10, 2015. Data acquisition involved the collection of sediment cores from 24 locations in the lake. Core collection focused on the historic river channel and the adjacent “shelf” (i.e., historic river floodplain), but several cores were also obtained from historic tributaries to the river and from the “slope” between the river channel and the shelf. Coring locations were generally associated with DWR’s monthly water quality monitoring locations, and extended from the vicinity of the I-85 causeway in the upper lake to the City of Raleigh intake structure in the lower lake. Figure 5-3 is a map of the locations from which cores were obtained.

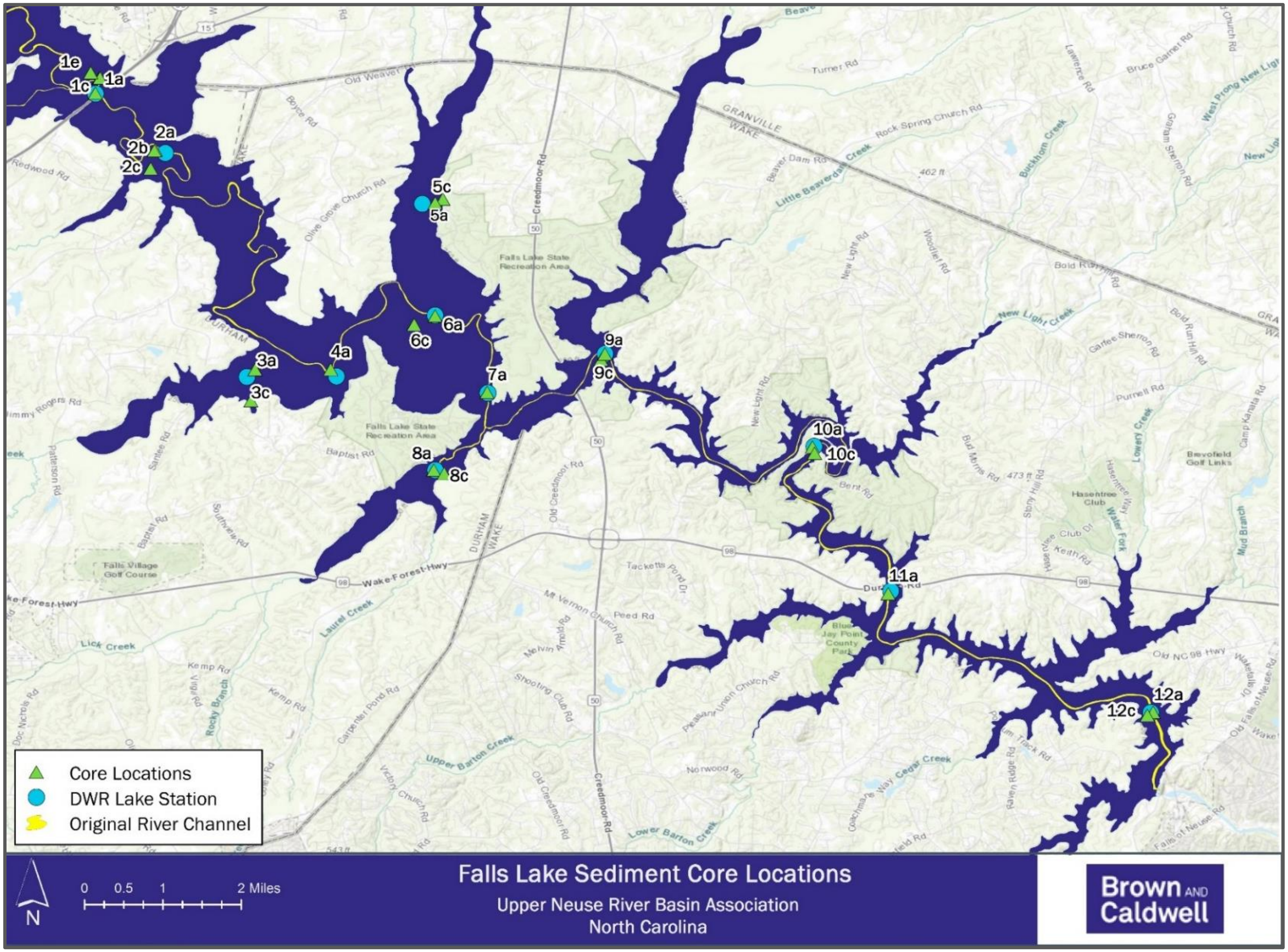


Figure 5-3. Locations of sediment core sampling in Falls Lake in June 2015

At each coring location, water quality samples were collected from ~1 m above the sediment ("overlying water") and analyzed for total dissolved phosphate (PO_4), ammonia nitrogen (NH_3) and nitrate + nitrite (NO_x). Each core was sectioned at 3-cm intervals, and those sections were sub-divided for various analyses. For each section, porosity and loss-on-ignition as an indicator of organic material were measured. A porewater sample was extracted from each section and analyzed for total phosphate and NH_3. The solid sediment material from each section was analyzed for percent organic carbon and percent total nitrogen. Phosphorus was also quantified in the solid phase of the sediment material; the majority is in mineral form and thus not available to move into the water column. Replicate cores were also taken at two locations to provide information on small-scale variability. Additional methodology details will be provided in the full report on the evaluation.

An interesting observation during collection of the cores was the variability in the thickness of the unconsolidated sediment layer (muck) among the locations. In general, the river and tributary channels had substantial sediment with cores ranging from 13 to 40 cm (the upper limit of the corer). In contrast, areas along the "shelf" typically had much less accumulated sediment, with cores ranging from less than 5 to just over 20 cm. Some shelf areas had little to no sediment, where the corer simply contacted hard clay, sand or gravel.

All data analysis was conducted under the direction of Dr. Alperin. This analysis included refinement of a mathematical model to estimate nutrient fluxes. That model and its detailed output will be provided in the full report from the Special Study.

Porosity is a measurement of the void spaces between solid particles within the sediment, and smaller particle sizes yield greater porosity. Overall, porosity ranged from about 0.50 (i.e., 50 percent void space) to about 0.9, with cores from within the river channel typically having porosity in the range of 0.8 to 0.9. In general, porosity decreased with increasing sediment depth as a result of compaction.

The decay of organic matter buried in lake sediments transforms organic nutrients into inorganic forms (e.g., NH_3 and PO_4) which may then be released back into the water column. Because decomposition is the source of nutrients, it is important to characterize the organic content within the sediment pool in conjunction with assessments of benthic nutrient flux. The organic content of each core was assessed through the determination of loss on ignition (LOI) and measurement of total organic carbon (TOC) concentration.

Loss on Ignition (LOI) is a measure of the non-mineral fraction of the sediment that is liberated when dried sediment is heated to 550°C (> 1000°F) in an oven. LOI in Falls Lake cores ranged from near 0 to about 15 percent, with cores from the lower portion of the lake having generally higher LOI values than cores from the upper lake.

Total organic carbon (TOC) in Falls Lake cores ranged from near 0 to about 4 percent, with generally the same spatial pattern seen for LOI. This is because TOC and LOI are often highly correlated, since the volatile and combustible organic substances in the sediment comprise much of what is burned off during the LOI process. For the Falls Lake cores overall, the correlation analysis of LOI and TOC yielded an r^2 of 0.72, indicating a high degree of correlation. This relationship can be of value since the cost of measuring TOC is higher than for LOI, so being able to use LOI as a surrogate can save money in future evaluations. Organic carbon was also correlated with porosity (r^2 of 0.62), indicating that organic matter is associated with the finer grained sediments.

Given the presence of decaying organic matter, nutrients can move out of the sediment through diffusion across the sediment-water interface as well as through physical activity of organisms such as burrowing worms ("bioturbation"). Diffusion is determined by the concentration gradient between the sediment pore water and the overlying water and therefore the nutrient concentrations of both were measured. NH_3 concentrations in bottom water were low at stations <5 m deep (mean = 0.014 mg/L), but increased dramatically at deeper stations, with Station 12 yielding a NH_3 concentration of 2.0 mg/L. Concentrations of NO_x in the bottom water averaged 0.0042 mg/L and were similar across all stations. PO_4 levels averaged 0.0093 mg/L and were also relatively constant among the stations.

Higher nutrient concentrations in the sediment porewater is necessary for net diffusive flux to move nutrients from the sediments to the water column. This study found conditions suitable for NH_3 movement from the sediment to the water at every location where a core was collected, with the average NH_3 porewater concentration in the upper section of the sediment being some 2.5 mg/L higher than the overlying water. The highest observed difference between the upper sediment section porewater and the overlying water was nearly 10 mg/L. NH_3 concentrations increased with depth in the sediment porewater in all 24 cores, indicating the presence of a gradient to drive a net upward flux.

Concentrations of NO_x were also higher in the upper layer of porewater than in the overlying water but NO_x did not increase with depth in the sediment profile like NH_3, because the anoxic conditions prevented the nitrification of ammonia to an oxidized form. Similarly, PO_4 in the sediment porewater was at higher concentrations than the overlying water at all sampled locations, indicating the potential for an upward flux. However, when dissolved oxygen is present at the sediment-water interface, the diffusive flux of PO_4 into the water column is generally believed to be minimal.

As noted above, a mathematical model was developed by Dr. Alperin to estimate inorganic nitrogen flux using the bottom water and pore water profiles of NH_3 and NO_x concentrations. The model applies known relationships and sediment processes and will be fully described in the final report from the Special Study, along with graphics and tables displaying all of the findings summarized here.

Nitrogen fluxes were typically dominated by NH_3, with NO_x generally making up less than 2 percent of the total flux. Estimates of NH_3 fluxes were widely variable among cores, ranging from less than 1 to 90 $mg/m^2/d$ (Figure 5-4). Although no consistent pattern is apparent along an upstream to downstream location gradient, a few patterns did emerge which can explain some of the observed spatial variation. On average, NH_3 fluxes from cores collected within the historic river channel were more than three times higher than the cores which were collected nearby, but outside of the historic channel (58 and 16 mg N / m^2 /d, respectively, $p < 1x10^{-7}$).

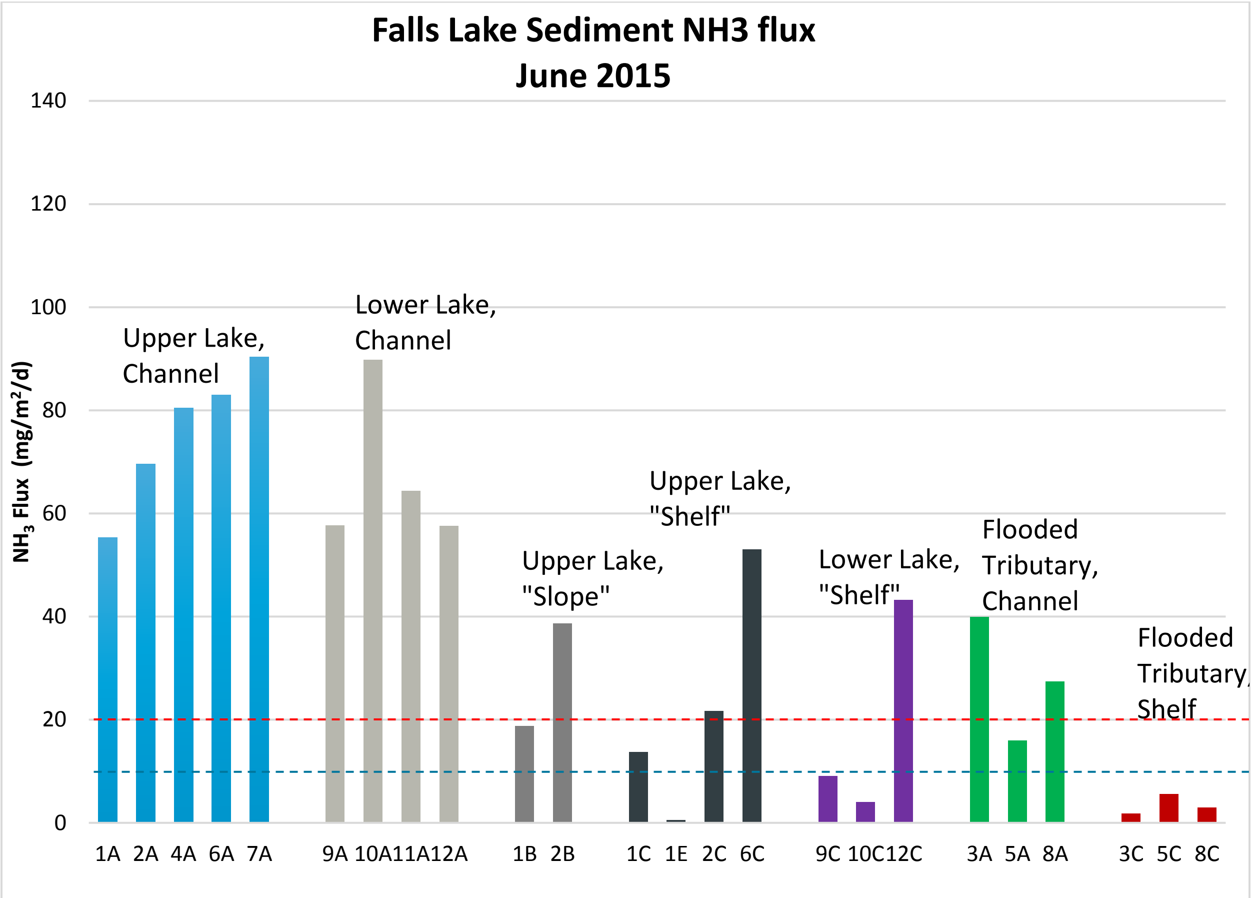


Figure 5-4. NH_3 sediment flux rates estimated using data from cores collected in Falls Lake in June 2015

The horizontal dotted lines represent the values used by DWR in its EFDC model to represent lake wide benthic nitrogen flux for 2006 (blue line, 10 mg/m²/day) and for 2005 and 2007 (red line, 20 mg/m²/day).

The average nitrogen flux based on the sediment core analysis is very similar to the two values obtained by the North Carolina Division of Water Quality (now DWR) in 2006 using sediment chambers (DWQ 2006). That study estimated an average flux of 50 mg/m²/d within the historic channel near this study's station 2A (between I-85 and Cheek Road). The DWR value is within 20 percent of the average flux estimated from all channel cores and within 30 percent of the core-based estimate from the same location. Near station 7 (upstream of Highway 50), DWQ's study estimated a flux of 10 mg/m²/d. Based on the water depth recorded for this chamber location (4.7 m), this estimate was not within the historic Neuse River channel (depth of 8.5m). Although the UNRBA survey does not include a 'shelf' core at this particular location, DWQ's value (10 mg N / m2 /d) is near this study's lake-wide average from all cores collected outside of historic channels (16 mg N /m2/d). The ranges of values observed in both studies overlap and underscore the large potential for spatial variation within the lake.

Although the flux estimates from the sediment cores are widely variable, the number of cores collected allows for a better understanding of benthic fluxes across the lake and how fluxes might vary with other measurable properties. For the full set of cores collected within Falls Lake, the best predictor of nitrogen flux was the length of the core (Figure 5-5, $r^2 = 0.71$, $p < 1 \times 10^{-7}$). Upon its completion, Dr. Alperin's work will be integrated with the results of the bathymetric and sediment mapping Special Study undertaken by the UNRBA. The synthesis of the two efforts will allow for the development of lake wide estimates of nutrient flux, with far greater resolution of location and sediment thickness than has been possible before. In addition, the modeling efforts, as well as the Final Report (to be prepared after the completion of October 2018 sampling and analysis) will examine the relative magnitude of nutrient flux from the sediments and from tributary inflows to the lake.

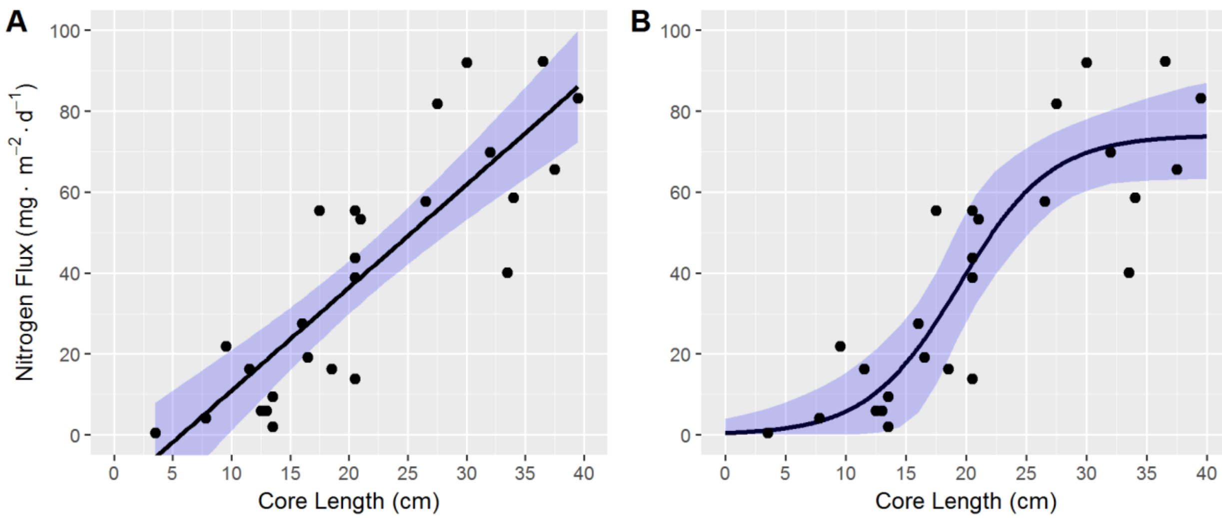


Figure 5-5. Relationships between estimated benthic nitrogen flux and length of sediment cores

*Model A is a simple linear regression (y = 2.55 * Length – 14.5) with R2adj = 0.71, RSE = 16.1 and p-value < 1 x 10-7. Model B is y = a / (1 + exp(-(b + c * Length))), with a=74.1, b=-5.09, and c=0.262, and RSE=15.0.*

5.3 Lake Bathymetry and Sediment Mapping

In FY2017, the UNRBA conducted a bathymetric survey and sediment mapping study of Falls Lake using dual-sonar frequency technology. Underwater topography (bathymetry) influences the retention and movement of water and thus partially controls the biological processing of nutrients that can affect the growth of chlorophyll-a (algae). An accurate representation of underwater topography and flow restrictions is an essential element in understanding the volume of water within each segmented portion of Falls Lake and helps to determine the amount of time water remains within each segment to grow algae. Hydrodynamic models which aim to accurately represent the movement of water and its associated constituents such as suspended sediment, chlorophyll-a, and nutrients are constructed using the most accurate measurements of the lake's morphological features as is possible to obtain. The lack of accurate lake morphology can impair a model's ability to simulate water quality conditions across a range of flow regimes. DWR collected bathymetric data at 17 transects in 2006 and used these to inform grid development for their EFDC-based Falls Lake Nutrient Response Model. However just 17 transects over the entire 20+ mile length of Falls Lake and its coves does not provide a detailed picture of Falls Lake's bathymetry. Before this UNRBA study, there were no additional data on the bathymetry of Falls Lake other than pre-reservoir USGS topographic maps.

A primary goal of this study was to significantly enhance the bathymetric data available to build a more robust hydrodynamic model for Falls Lake by collecting depth data on transects averaging every tenth of a mile throughout the reservoir. The data produced by this effort is being used by the UNRBA modeling team to refine the grid for the hydrodynamic model, provide more accurate depths for each model grid cell, and calculate average water depths and thus retention time in each segment. Although not a primary goal of the mapping effort, this survey can also provide a point of comparison with past and future surveys to estimate sedimentation rates. The USACE has shown keen interest in this data.

A second goal of this study was to provide data on the thickness of the sediment layer throughout Falls Lake. During the course of the sediment coring field work (Section 5.2), significant variability in sediment thickness was observed, with some areas of the lake having little to no accumulated sediment able to be collected in cores. Measuring the sediment thickness involved just simple equipment addition to the bathymetric survey and was intended to improve eventual estimates of benthic nutrient flux. At a minimum, mapping locations with and without sediment accumulations was intended to provide a simple way to extrapolate measured fluxes to the areas of the lake with documented sediment accumulation; more detailed information about sediment location and thickness could be more informative if it could be related to fluxes estimated from the sediment cores. The bathymetric and sediment mapping survey results are still being analyzed in conjunction with the sediment core data discussed in Section 5.2 in order to build lake wide estimates of benthic nutrient fluxes.

The field data necessary to develop the bathymetric and sediment layer maps were collected over two weeks in March and April 2017. Over four million depth sounding samples were collected throughout the lake using a boat mounted dual-frequency echosounder. Sampling transects were typically spaced between 500 and 1000 feet apart though intervals were adjusted as needed in the field according to the degree of local depth variation (Figure 5-6). Shallow, gently sloped regions required less tightly spaced transects than regions with greater degrees of change. Following the field collection effort, the four million data points were digitized by Water Cube, Inc. After removing interferences from floating debris and aquatic organisms, the data were used to identify the top-of-sediment depth (from the high-frequency acoustic signal) and the maximum penetration depth of the low-frequency acoustic signal. The difference between the depths of penetration for the two acoustic signals was interpreted as the depth of sediment accumulation.

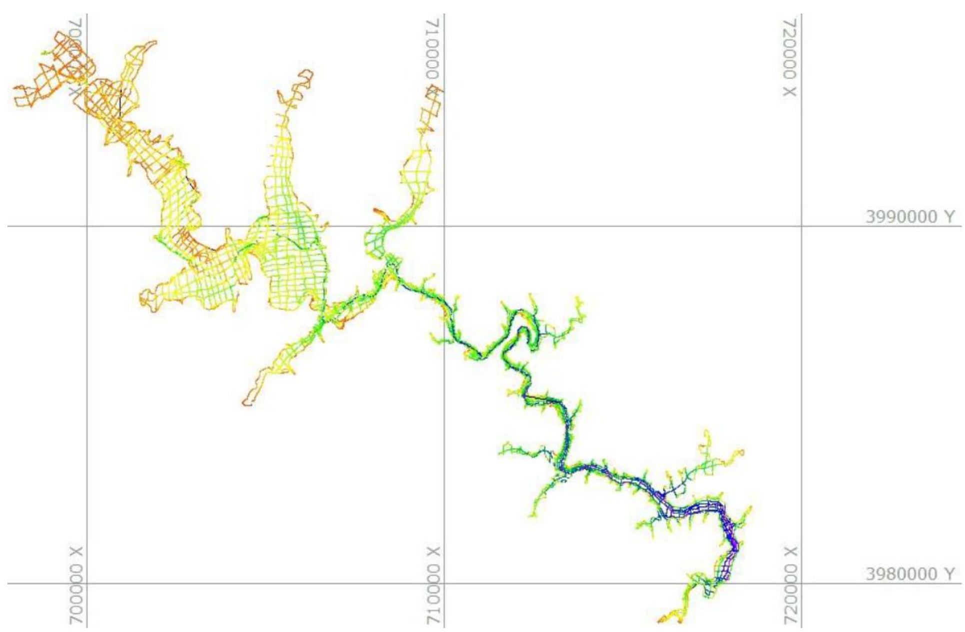


Figure 5-6. Track line locations for the bathymetric and sediment depth survey

Color is shown to provide a visual interpretation of water depth.

Relationships between water depth, surface area, and volume can be generated using the bathymetric data for the entire lake and individually for separate lake segments. Figure 5-7 compares the relationship between surface area and depth for select segments of Falls Lake. The integration of depth and surface area provides a visual representation of the volume of water in each of the segments. For instance, despite very different shapes, the volume of water in Falls Lake is almost evenly split between the upstream half (above Highway 50) and the lower half (below Highway 50). Approximately 50 percent of the total water volume in the lake is above Hwy 50, and 50 percent is below Highway 50 (with about 6 percent in the Beaverdam impoundment).

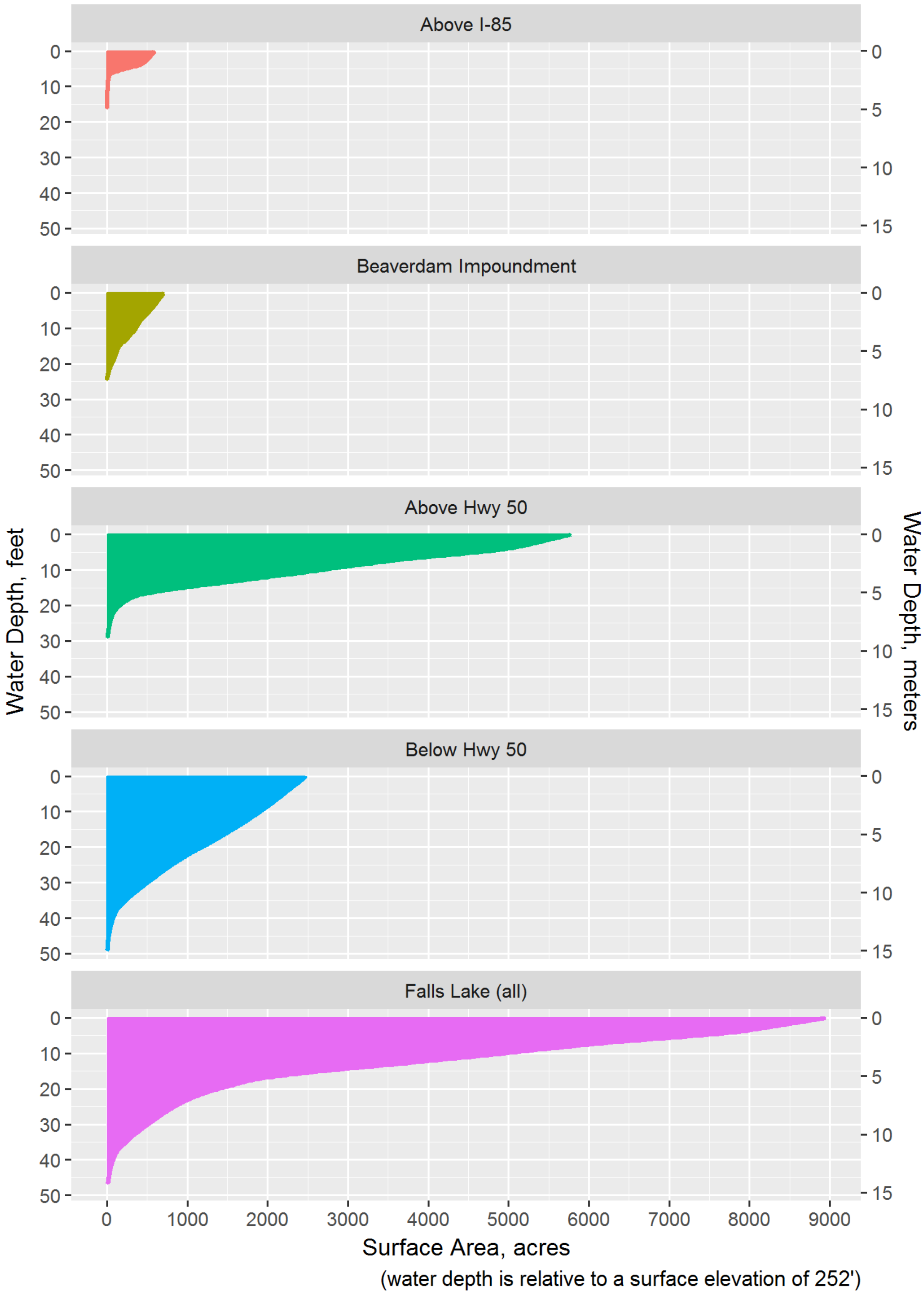


Figure 5-7. Depth-area relationships for Falls Lake (bottom figure) and selected segments of the lake

Similarly, different segments have different patterns of sedimentation (Figure5-8). Despite receiving water draining from the majority of the watershed, sediment accumulation in the upper portion of the lake is much lower than that in the lower half of the lake, largely owing to the differences in lake shape. The shallower and wider upper lake is more exposed to wind and therefore experiences more sediment resuspension, reducing the accumulation.

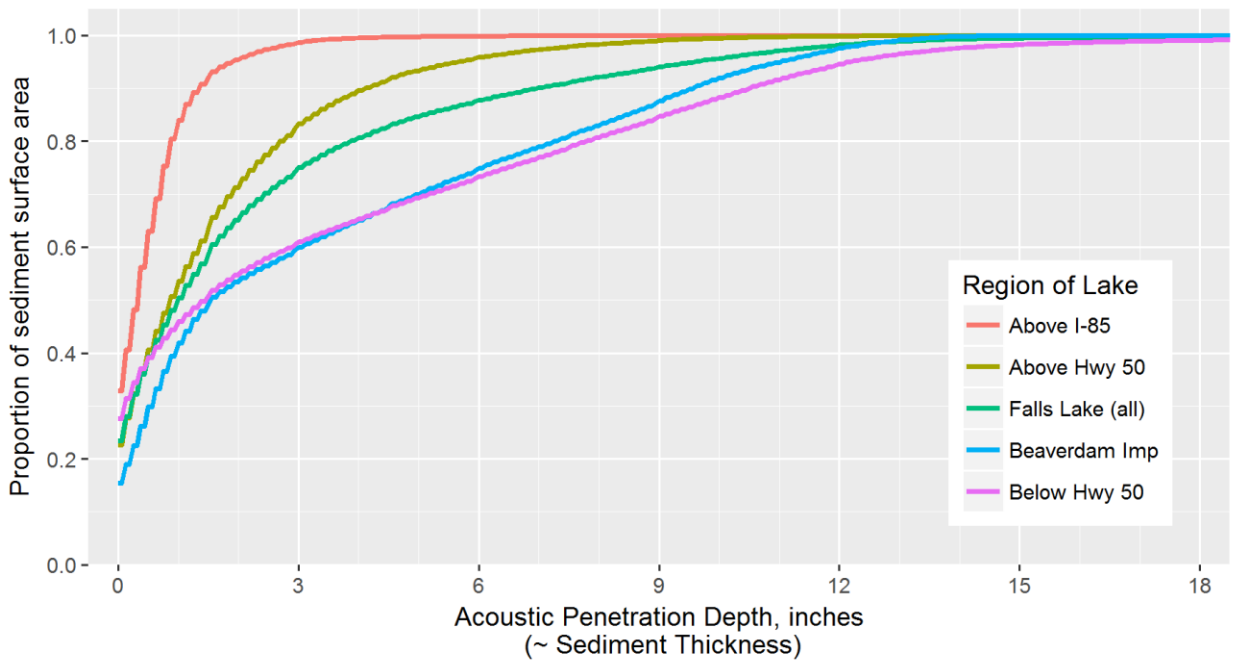


Figure 5-8. Comparisons of sediment accumulation patterns in different regions of Falls Lake

Shallower areas above Highway 50 generally have less accumulation (e.g., red and yellow lines) that the deeper, narrower areas downstream of Highway 50.

Complete gridded data sets for the sediment thickness layers and water depth were obtained through Delauney triangulation of the spatially referenced point data and are shown in Figure 5-9 and Figure 5-10, respectively.

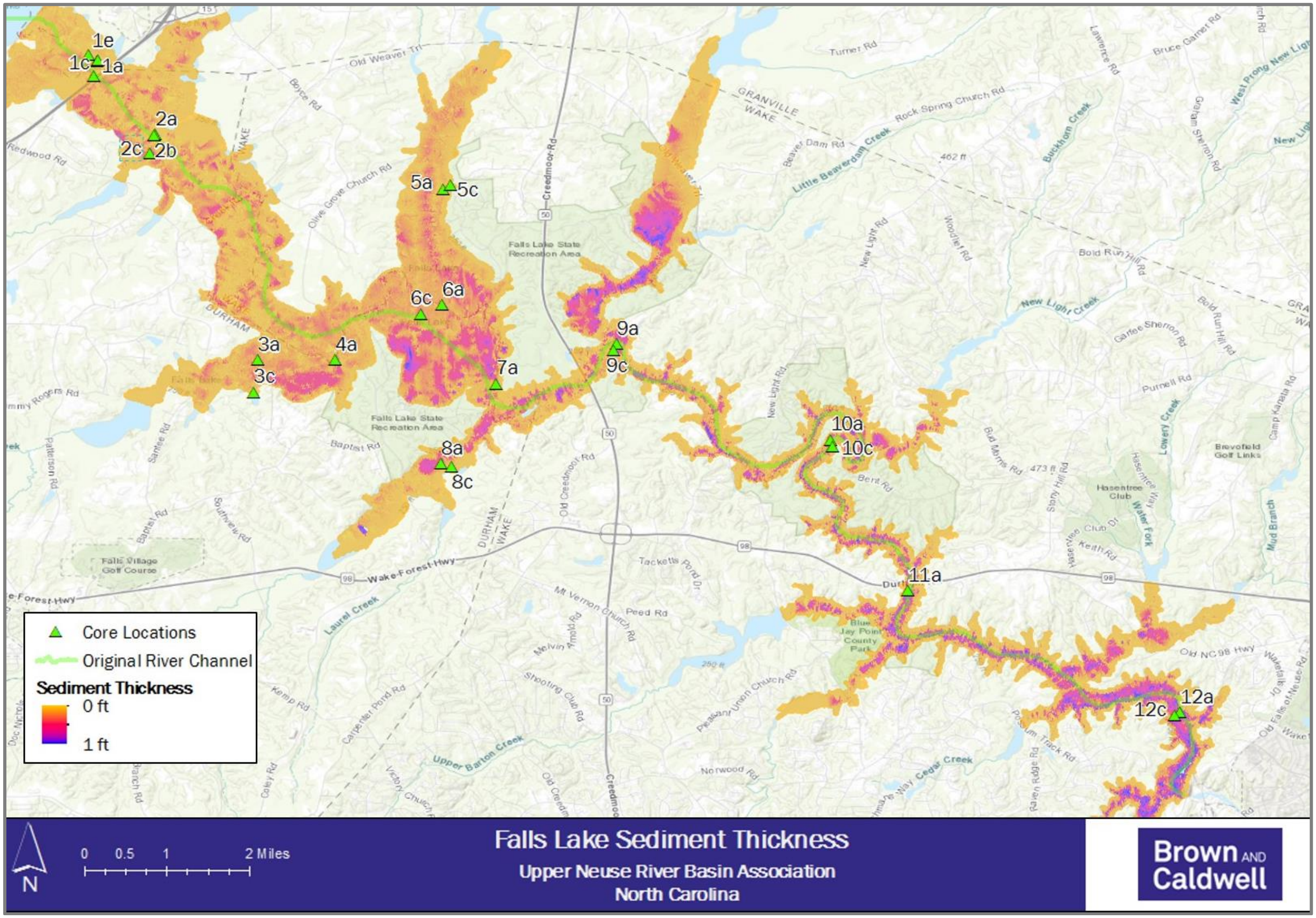


Figure 5-9. Sediment Thickness in Falls Lake

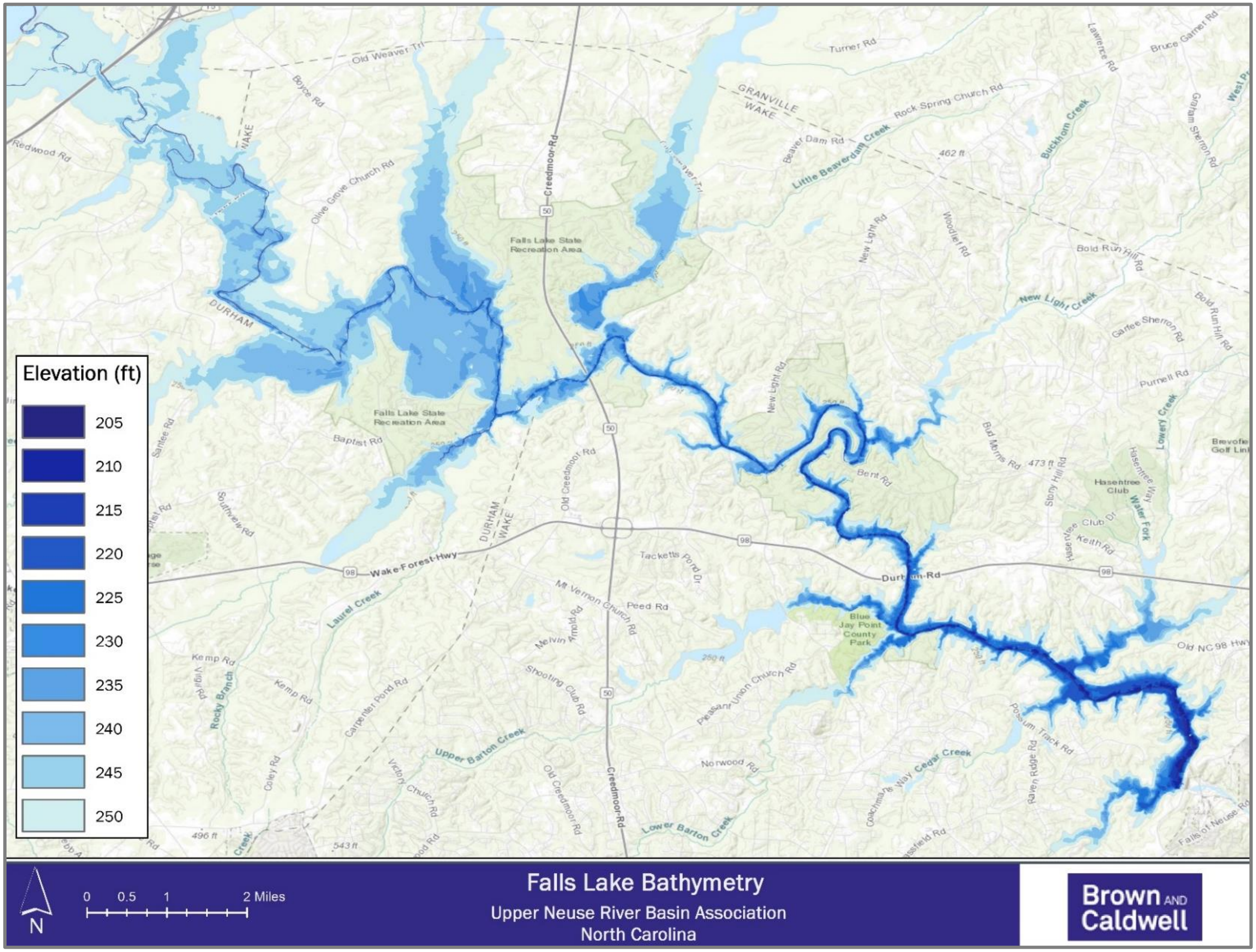


Figure 5-10. Water Depths of Falls Lake

Section 6

Quality Assurance

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

6.1 Representativeness and Completeness

6.1.1 Field Sampling

The UNRBA Routine Monitoring program was designed to collect data from representative sites in the Falls Lake basin and at regular time intervals in order to capture data during conditions representing the entire monitoring period. All efforts are made to adhere to this sampling plan; however, some samples may be understandably missed due to factors such as dry stream conditions, extreme weather, or unexpected site access limitations. Since the beginning of the UNRBA monitoring program in 2014, more than 98 percent of all planned sampling events in which the sampling location had flowing water were completed as planned, while dry stream conditions caused approximately 4 percent of planned sampling events to be skipped. In all, 94 percent of sampling events have been completed as planned (Table 6-1).

Table 6-1. Summary of planned sampling events missed because of dry streams, site inaccessibility, or weather-related concerns

	Calendar Year			
	2014	2015	2016	2017
Scheduled Sampling Events	208	516	486	456
Missed due to dry conditions	20	37	4	13
Missed due to inaccessibility	2	9	4	2
Missed due to ice or floods	0	8	1	0
Total Missed (%)	11%	10%	2%	3%

The number of sampling events planned per year varies because of the project start date, and because of changes to monitoring frequency at a sub-set of locations.

Dry streams, typically during summer and fall periods, have been the primary cause of missed samples throughout the routine monitoring program, causing approximately 4 percent of missed sampling events. Although these planned sampling events were missed, they were the direct result of a lack of water. They do not negatively affect the representativeness of the dataset. Two-thirds of the stations skipped because of dry conditions occurred in jurisdictional monitoring locations with smaller contributing drainage areas than the Lake Loading stations closer to Falls Lake.

A handful of events have been missed due to temporary limitations to accessibility such as road construction, icy and unsafe streambanks, and vegetation overgrowth. Altogether, these limitations caused approximately 1 percent of planned sampling events to be missed. Finally, icy roads from winter storms in February 2015 prevented completion of that month's sampling at eight locations and flooding in 2016 prevented access to a single location.

In 2017, a single month of sampling at each of two stations was missed due to construction activities (Smith Creek in January, and Eno River at Dimmock's Mill Road in September). The remaining 13 missed samples were all the result of dry stream conditions at some sites between July and October.

The UNRBA monitoring database includes comments that describe the reasons for missed samples.

6.1.2 Laboratory Analysis

Extensive efforts are made by the analytical laboratory to complete sample analysis attaining all necessary quality assurance requirements including all applicable sample holding times. Over the course of the monitoring program, four sets of samples needed to be analyzed outside of specified holding times because of equipment malfunctioning (Table 6-2). These results were appropriately qualified in the UNRBA database with the 'Q2' flag, indicating that the holding time was exceeded.

Table 6-2. Sample batches analyzed outside of specified sample hold times

Parameter	Samples affected
Nitrate-Nitrite	October 2015
Total Phosphorus	May-June 2016
Total Kjeldahl Nitrogen	June 2016
Ammonia Nitrogen	May 2017

6.2 Accuracy, Precision, and Measurement Uncertainty

All environmental measurements are subject to uncertainty owing to a variety of sources which may include sampling (natural heterogeneity in the ecosystem, environmental conditions), preservation and storage conditions, analytical factors (sample processing, equipment errors, purity of reagents and labware, operator error), and computational factors (selection of calibration model, result truncation and round off). When properly quantified and documented, measurement uncertainty does not imply that data are unreliable or invalid. In fact, clearly documenting the range of values that could reasonably represent each environmental measurement can improve user confidence in data and allow end users to properly evaluate how well the dataset fulfills their intended purpose.

The UNRBA quality assurance project plan specifies accuracy and precision targets based upon specific project goals as well as limits of analytical capabilities. Because these objectives were specified *a priori*, continued evaluation has been necessary to assess the degree to which these targets have been met and to which they have been achievable with samples collected outside of controlled laboratory conditions. The monitoring program was therefore designed to collect the necessary quality assurance samples to calculate and document the true accuracy and precision of the analytical methods under variable field conditions.

Accuracy can be assessed with field blank samples and laboratory control samples (LCS) of known concentrations. LCS samples are analyzed with each batch of samples to provide verification that the analytical procedure is producing accurate results. To date, there have been no cases of samples where the LCS results associated with UNRBA data were out of compliance with method criteria. Indeed, the QAPP specifies if that were to happen, the issue would need to be corrected and all samples associated with the error would be re-run. Field blank results assess whether a method can adequately distinguish samples with no analyte present from samples with analyte present. Reporting limits are intended to reduce the likelihood of 'false positives' (type I errors) in which results are recorded for water quality constituents which are not actually present. Field blank results above the reporting level may be a sign that the reporting level is set too low and increases the chances that some field samples are being recorded as having low concentrations which are not in fact present.

Table 6-3 lists all the parameters collected as part of the UNRBA monitoring program along with their associated reporting limits, the number of blank samples collected between 2014 and 2017, and the percentage of those samples with results above the nominal reporting level. It also lists the 95th percentile of all field blank results.

Table 6-3. Field blank concentrations greater than the reporting level

Parameter	N (Blanks)	N > RL	% > RL	95th Percentile Blank Concentration	Nominal Reporting Limit
Dissolved Organic Carbon, mg/L	46	-	0	< 1.0	1.0
Soluble Ortho-Phosphate as P, mg/L	290	-	0	< 0.01	0.01
Total Organic Carbon, mg/L	141	-	0	< 1.0	1.0
Total Ortho-Phosphate as P, mg/L	82	-	0	< 0.01	0.01
Volatile Suspended Residue, mg/L	60	-	0	< 2.5	2.5
Total Suspended Residue, mg/L	165	1	1	< 2.5	2.5
Chlorophyll-A, ug/L	79	1	1	< 1.0	1.0
Nitrate-Nitrite as N, mg/L	210	3	1	< 0.01	0.01
Total Kjeldahl Nitrogen as N, mg/L	208	4	2	< 0.2	0.2
Total Phosphorus as P, mg/L	203	28	14	0.04	0.02
Ammonia Nitrogen as N, mg/L	209	80	38	0.04	0.01

Total phosphorus and ammonia both have more than 5 percent of their field blank results greater than the reporting limit specified in the QAPP. The remaining parameters all have fewer than 5 percent of blanks exceeding the reporting limit. For both total phosphorus and ammonia, the blank concentration for which 95 percent of blanks were lower was 0.04 mg/L. These elevated values increase the likelihood that values reported between the RL specified in the QAPP and 0.04 mg/L may not actually have ammonia present. One means of addressing this issue would be to adjust the reporting limits to a higher level, which would eliminate the modeling team from using values falling below that. After obtaining and reviewing the final 10 months of data, a recommendation can be formulated with a specific revised reporting limit.

In addition to field blanks, field duplicates provide data necessary to quantify a large part of measurement uncertainty by pooling a number of potential sources of variation which may vary between samples collected on a single day and analyzed together. Field duplicates do not provide information on error sources arriving from day-to-day variation such as differences in instrument calibration and uncertainty among batches of reagents and standards. However, those factors do not typically form the dominant contribution to the overall uncertainty estimate for a given parameter, but they can be assessed through laboratory control samples (LCS) and matrix spike (MS) recoveries over many separate analytical runs.

Individual pairs of field duplicates are assessed for their consistency with QAPP targets through the calculation of relative percent difference(RPD).

$$RPD = \frac{|C_A - C_B|}{0.5(C_A + C_B)} \times 100$$

where C_A = measured concentration of field duplicate A

C_B = measured concentration of field duplicate B

RPD is sensitive to the mean measurement for each pair of field duplicates; when measured values are low, even small differences between the duplicates can cause RPD to be very high. Because of this sensitivity, the RPD it is not applied when measurements are less than five times the laboratory's method detection limit (5x MDL). The RPD targets for each parameter and the number of duplicate pairs with an RPD greater than those targets are shown in Table 6-4.

Table 6-4. Field duplicate precision targets and number of duplicate pairs with RPD greater than the target from August 2014 through December 2017

Parameter	RPD Target %	No. of Pairs	N > Target	% > Target
Dissolved Organic Carbon, mg/l	30	46	0	-
Total Organic Carbon, mg/l	30	137	0	-
Chlorophyll-A, ug/l	30	82	4	5
Total Ortho-Phosphate as P, mg/l	30	82	0	-
Total Phosphorus as P, mg/l	30	160	10	6
Nitrate-Nitrite as N, mg/l	30	161	1	1
Ammonia Nitrogen as N, mg/l	30	160	36	22
Total Kjeldahl Nitrogen as N, mg/l	30	161	6	4
Volatile Suspended Residue, mg/l	30	58	7	12
Total Suspended Residue, mg/l	30	160	27	17
Absorbance at 440nm, /cm	30	81	7	9
UV 254, /cm	30	80	1	1
CBOD5, mg/l	40	46	1	2

RPD values for individual duplicate pairs cannot be specifically associated with any individual measurements other than the duplicate pairs themselves. Pooled over time and repeated samples, however, these duplicate RPD measurements can be used to define the overall precision of the method and the standard deviation of the expected measurement uncertainty.

$$u_{relative} = \frac{\sum_{i=1}^{n}(RPD_i)}{n} \times \frac{1}{d_2}$$

Where the fraction to the left of the multiplication symbol is simply the average of multiple RPD measurements and d_2 is a statistical factor equal to the expected RPD for two independent normally distributed random variables with the same mean and a standard deviation equal to 1. It is often referred to as the control chart constant. For the expected range of two values from such a distribution (as in duplicate samples), d_2 is equal to 1.128.

The standard uncertainty is statistically analogous to a standard deviation of a normal distribution and provides an estimate of the precision of repeated measures for each analyte. For all parameters except ammonia, the precision estimate is less than the 30 percent target for each parameter. (Table 6-5). Applying a coverage factor, k, of 2 produces an expanded uncertainty representing a 95 percent confidence interval--the range of values that a given measurement could represent with 95 percent confidence. Except for ammonia, total phosphorus, and total suspended residue, each of the parameters has a 95 percent CI below 30 percent of the measured value. The values provided in Table 6-5 can be applied by data analysts to better understand the level of confidence associated with each data point. As an example of applying this uncertainty, with an Expanded Uncertainty of +/- 11 percent, a reported chlorophyll-a value of 40 µg/L has a 95 percent confidence that the actual chlorophyll-a in that sample fell between 35.6 µg/L and 44.4 µg/L.

Table 6-5. The uncertainty and expanded uncertainty (95% confidence interval) associated with the collection of field duplicate samples

Parameter	Measurement Range	Standard Uncertainty, u	Expanded Uncertainty, U (95% confidence level)
Chlorophyll-a, μg/l	1 - 20	9%	± 17%
	20 - 200	5%	± 11%
Dissolved Organic Carbon, mg/l	1.5 - 21	2%	± 3%
Total Organic Carbon, mg/l	1.6 - 21	2%	± 4%
Absorbance at 440nm, /cm	0.005 - 0.08	10%	± 20%
Absorbance at UV 254nm, /cm	0.07 - 0.9	4%	± 8%
Color (Apparent), CU	25 - 300	11%	± 22%
Ammonia Nitrogen as N, mg/l	0.01 - 0.06	35%	± 70%
	0.06 - 0.33	26%	± 52%
Nitrate-Nitrite as N, mg/l	0.01 - 0.2	9%	± 19%
	0.2 - 3.3	4%	± 8%
Total Kjeldahl Nitrogen as N, mg/l	0.2 - 0.8	13%	± 26%
	0.8 - 2.8	10%	± 20%
Total Ortho-Phosphate as P, mg/l	0.01 - 0.25	7%	± 15%
Total Phosphorus as P, mg/l	0.02 - 0.31	22%	± 44%
CBOD5, mg/l	2 - 11	5%	± 10%
Total Suspended Solids, mg/l	2.5 - 190	19%	± 38%
Volatile Suspended Solids, mg/l	2.5 - 26	11%	± 22%

For parameters in which the relative uncertainty was sensitive to the measurement range, separate confidence intervals have been calculated for low- and high- values.

Section 7

Recommendations

The UNRBA Monitoring Program was designed to support the UNRBA's re-examination of Stage II of the Falls Lake Nutrient Management Strategy. The Path Forward Committee (PFC) recommended, and the Board of Directors approved, the acquisition of four full years of monitoring data to support the re-examination modeling effort. That four-year (48-month) period began in August 2014 and will be complete in July 2018. The PFC further recommended extending the monitoring to the end of the 2018 growing season, so data acquisition for the modeling efforts are scheduled to continue through October 2018.

The UNRBA Monitoring Plan also provides for consideration of whether a fifth year of monitoring should be conducted because of atypical hydrologic conditions during the initial four years (as were seen during the period modeled by DWR in developing the Rules). Hydrology in the watershed and lake are summarized in Section 3.1, reflecting the inter-annual variability and characterizing what can be considered the "normal" range of conditions.

Annual precipitation patterns since the program began in August 2014 have been normal to wet. Certain months each year since 2014 have been dry relative to records from the previous 30 years and some months have been wetter. Precipitation patterns in NC are highly variable, and the timing of wet and dry periods has the potential to affect the response of algae in the lake. The prior DEQ modeling effort conducted to develop the Falls Lake Nutrient Management Strategy relied on data that included an extremely dry period. To support the DWR modeling effort, tributary data were collected on the largest five tributaries and Falls Lake (in-lake) data were collected approximately twice per month. Between the monitoring conducted previously by DWR and the data currently being collected by the UNRBA, the watershed has been monitored during a full range of hydrologic conditions.

As part of the UNRBA Modeling and Regulatory Support contract, the UNRBA requested that the modeling team review this Annual Report and weigh in on the sufficiency of the monitoring program to support modeling. Members of the watershed modeling, lake modeling, and statistical modeling team provided consistent feedback. All indicated that (1) the program through October 2018 will have sufficiently collected water quality parameters at the frequencies and locations necessary to develop and calibrate the models, and (2) a fifth year of data collection would likely yield diminishing returns in terms of new information for modeling purposes.

Thus, it is recommended to complete data collection, laboratory analysis and presentation of results for modeling support through the end of the 2018 growing season in October.

- Maintain the current monitoring program methodology through October 2018
- Data acquisition for modeling support will be considered complete as of October 2018.
- A final monitoring report for modeling use will be completed in 2019 (February-March).

By October 2018, the monitoring program will have abundantly satisfied the requirements for three years of additional data required by the Rules. The modeling team has confirmed that the data will be sufficient to support the development and calibration of the lake and watershed models.

It is necessary for the UNRBA to allocate sufficient resources for the support of the Modeling and Regulatory Support efforts. Because of these resource demands, it is necessary to consider options for altering the UNRBA monitoring program. The UNRBA has not yet determined monitoring objectives beyond October 2018. The UNRBA may determine to continue acquiring water quality monitoring data for reasons other than the re-examination modeling. The UNRBA Executive Director will be establishing an informal work group to consider the potential costs and benefits of a water quality monitoring program beyond October 2018. The work group will consider potential UNRBA issues and uses for additional monitoring that may include support of the Falls Lake Rules after the re-examination process. The monitoring work group may determine needs for examining trends in water quality, examination of relationships between water quality and future land uses changes, or perhaps, tracking improvements resulting from implementation of nutrient management strategies, and other potential beneficial uses for a monitoring program. The work group will examine specific objectives for any future monitoring that may be important for the UNRBA to consider.

It is potentially manageable for the UNRBA to continue a reduced monitoring program without jeopardizing the modeling effort and the re-examination process. Therefore, the Monitoring Service Provider will work closely with the UNRBA Executive Director, Subject Matter Experts, and the PFC to determine an appropriate monitoring strategy beyond October 2018.

Brown and Caldwell presented a set of monitoring alternatives to the PFC at its March 2018 meeting. Each option was briefly discussed in terms of its benefits and limitations, and in terms of the funding levels that could be sustained for the Modeling and Regulatory Support (MRS) efforts. These and other future monitoring options will be considered by the Executive Director with the support of the informal monitoring work group and the PFC. Following this effort, the PFC will be involved in making any monitoring recommendations beyond October 2018.

Section 8

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