# Task 2: Review Existing Data and Reports for Falls Lake and the Watershed

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## ES.1 Introduction

In 2010 the Environmental Management Commission (EMC) passed the Falls Lake Nutrient Management Strategy, requiring two stages of nutrient reductions (N.C. Rules Review Commission 2010). The Rules establish a Nutrient Management Strategy for Falls of the Neuse Reservoir aimed at attaining:

> "…the classified uses of Falls of the Neuse Reservoir set out in 15A NCAC 02B .0211 from current impaired conditions related to excess nutrient inputs; protect its classified uses as set out in 15A NCAC 02B .0216, including use as a source of water supply for drinking water; and maintain and enhance protections currently implemented by local governments in existing water supply watersheds encompassed by the watershed of Falls of the Neuse Reservoir." (15NCAC 02B .0275)

Stage I of the Nutrient Management Strategy requires "intermediate or currently achievable controls throughout the Falls watershed with the objective of reducing nitrogen and phosphorus loading, and attaining nutrient-related water quality standards in the Lower Falls Reservoir as soon as possible but no later than January 15, 2021, while also improving water quality in the Upper Falls Reservoir…" (15NCAC 02B .0275 (4) (a)).

Based on modeling and evaluation by the NC Division of Water Quality, this will require a 20 percent and 40 percent reduction in total nitrogen and total phosphorus loading, respectively, for point sources and agriculture. For development based sources, the rules require loading to be reduced to the levels of the baseline year NCDWQ established (2006). For Stage I, the rules require local jurisdictions to establish requirements to control nutrient input from new development sources as well.

Stage II requires, based on NCDWQ modeling and evaluation, additional loading reductions that will result in an overall reduction of the mass of nutrients delivered to the Lake in 2006 of 40 percent and 77 percent for total nitrogen and total phosphorus, respectively. As stated in the Rules:

> "Stage II requires implementation of additional controls in the Upper Falls Watershed beginning no later than January 15, 2021 to achieve nutrient-related water quality standards throughout Falls Reservoir by 2041 to the maximum extent technically and economically feasible…" (15NCAC 02B .0275 (4) (b))

Falls Lake, based on the North Carolina 303(d) List approved at the time this TM was prepared, is impaired for turbidity and chlorophyll *a* in the Upper Lake. The current approved 303(d) list considers portions of the Lower Lake impaired for turbidity and all of the Lower Lake is listed for chlorophyll *a*. The required nutrient reductions have been put in place with the intent of reducing eutrophication in the lake and bringing the waterbody into compliance with the chlorophyll *a* standard of 40 µg/L. The Falls Lake Rules acknowledge the uncertainty associated with the models used to develop the required nutrient load reductions and allow for re-examination of the Rule requirements for Stage II. This re-examination may include a combination of additional monitoring, evaluation, and modeling efforts to establish a scientific basis for proposing modification of the required Stage II load reductions.

In response to the Nutrient Management Strategy development, some of the local governments in the Falls Lake watershed developed and approved a set of Consensus Principles to help shape the re-examination of the Stage II rules (Local Governments in Falls Lake Watershed 2010). The group agreed that (1) any rules would need to protect Falls Lake for the purpose of water supply, (2) additional water quality monitoring would provide useful information, and (3) North Carolina should consider new information before going beyond those actions necessary to protect Falls Lake for the purpose of water supply.

Cardno ENTRIX is assisting the Upper Neuse River Basin Association (UNRBA) in determining the best approach to address the nutrient management rule requirements taking into consideration the provisions of the Consensus Principles. Key to this effort is the objective of developing a general framework for re-examination of the Stage II requirements of the Falls Lake Nutrient Management Strategy. The goal of this project is to provide the UNRBA with the information needed to 1) make informed decisions regarding the next steps to implementing the re-examination and to 2) begin the process of developing estimates of nutrient loading for regulatory and program implementation purposes. Four tasks were developed to meet this goal:

- Task 1. Develop a Framework for a Re-examination of Stage II of the Falls Nutrient Management Strategy
- Task 2. Review Existing Data and Reports to Summarize Knowledge of Falls Lake and the Falls Lake Watershed
- Task 3. Review Methods for Delivered and Jurisdictional Nutrient Loads
- Task 4. Recommend Future Monitoring and Modeling

The focus of this technical memorandum (TM) is Task 2. To support this task, Cardno ENTRIX has obtained all electronically available reports and water quality data within Falls Lake and its watershed to the best of its knowledge and as provided by organizations and agencies collecting data in the watershed. The reports include agency reports as well as studies conducted by the UNRBA and local governments. Several of the local governments also provided water quality data, reports, and presentations for the lake and its watershed. This data was combined with data from USGS and NCDWQ to create a master water quality database. Figure ES-1 shows the 157 monitoring stations sampled by organizations in the watershed. This database is summarized using statistical summaries and box plots in Section 3 of this TM. The database will also support work for Task 3 (load estimation) and Task 4 (prioritization of future monitoring and modeling studies). The Task 2 TM is the first of the reports associated with this project. The report for Task 1 will integrate information from the other supporting tasks and will be delivered to the UNRBA as one of the final products.

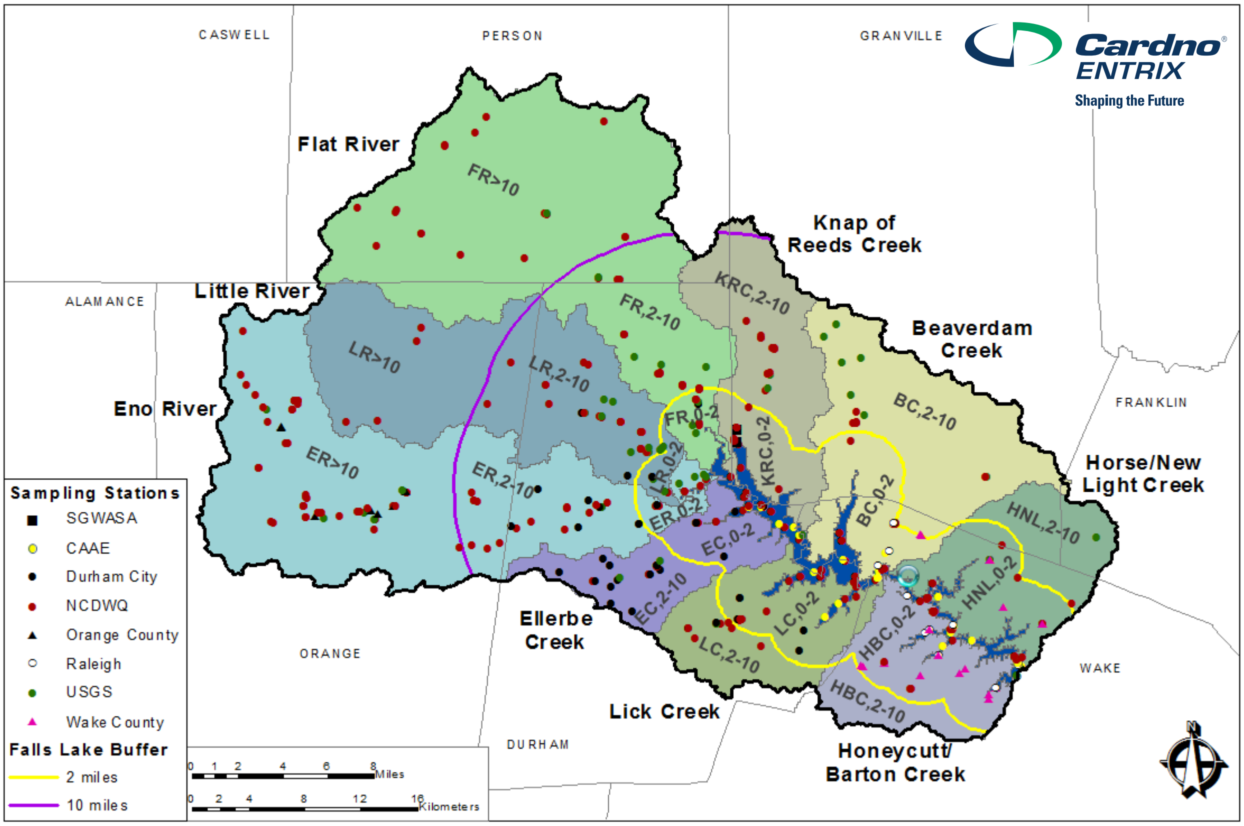



**Figure ES-1 Falls Lake Watershed Sampling Locations by Organization**

## ES.2 Objectives

The objectives of the Task 2 TM are to compile, assess, and summarize the existing data and knowledge regarding Falls Lake and its watershed to support the UNRBA in identifying strategies for re-examining Stage II of the Falls Lake Nutrient Management Strategy. The Nutrient Management Strategy was developed using modeling and analysis procedures that required a significant number of assumptions, and the work was done with a limited database. Legislative deadlines for the development of the Nutrient Management Strategy required quick agency decisions. This resulted in a regulatory program that includes a significant amount of uncertainty. The extensive work done by local governments in the watershed to develop the Consensus Principles and the member governments' decision to expand the activities of the UNRBA indicates that there is a keen interest in making sure that the Falls Lake Nutrient Management Strategy reflects a program that balances improving water quality with the resources available and considers the constraints and unique characteristics of the Lake and its watershed. The nutrient load reductions required by the Strategy, particularly for phosphorus, are higher than the relative effectiveness provided by best management practices (Nutrient Scientific Advisory Board 2012). Therefore, the financial demands of the Stage II nutrient reductions are daunting. All of these considerations are the foundation of the work being done under this project. The Task 2 TM is an important component of developing an effective and technically valid re-examination process.

The UNRBA has begun the process of re-examining the Nutrient Management Strategy. In the scope of work associated with Task 2, the UNRBA posed the following key questions with respect to the data and knowledge available in the watershed:

1. How do the past reports developed by the State and local governments compare? Do the data summaries performed for Task 2 support the findings of those reports?

2. Is the data collected by the various organizations comparable? How do the field and laboratory methods differ?
3. How does water quality in year 2006 (the baseline year for developing the Falls Lake Rules) compare to the water quality observed in other years?
4. What gaps are evident in the data sets available for Falls Lake and its watershed?

## ES.3 Summary of Approach

This TM focuses on data and studies from year 1999 to present (June 2012). The majority of the published reports and studies summarized in this TM were conducted during this time. Two historic documents preceding construction of the dam are also included. The studies are summarized in the Historic Documents section (Section 2).

For the water quality database, periods of record for stations in the watershed and lake were obtained from USGS and NCDWQ, and the local governments provided their electronically available data. This data has been compiled in a Microsoft Access database and includes 159,905 records.

To support the Task 2 objectives, the Access database was filtered to years 1999 to June 2012 for fifteen water quality parameters. There are 157 unique stations in this dataset. Summary statistics are presented in the form of tables and boxplots and show the data categorized by subwatershed, distance upstream from the lake or the dam, year, month, organization, and analysis method.

The full set of results is presented in Section 3 along with a description of how the database was structured to create these summary statistics. This executive summary includes select box plots used to illustrate the main conclusions from the data summary.

The basic information needed to interpret the box plots includes:

> Red lines on figures indicate water quality standards where applicable.

> The Box on the box plots illustrates the interquartile range (IQR). The IQR includes data from the $25^{th}$ percentile to the $75^{th}$ percentile. Comparisons of IQRs provide a visual assessment of the middle 50 percent of the data.

> The solid line across the middle of the Box represents the median (or $50^{th}$ percentile) of the data presented. The diamond represents the mean value of the data presented.

> The lines leading from the box extend to the $10^{th}$ (below) and $90^{th}$ (above) percentiles.

> Figure ES-2 illustrates the statistics displayed on the box plots.

Summary statistics and figures are provided for individual water quality parameters. Results are presented for three geographic regions: tributaries, Upper Lake, and Lower Lake including Beaverdam Impoundment. The tributary data includes only free-flowing waters. Appendix A contains the data for the impoundments within the watershed.

Within each geographic region the data is presented by distance upstream from the lake or upstream from the dam. These categories are used to illustrate spatial patterns in the data.

> For tributary samples, the distance category indicates the miles upstream from the lake. For example, the category ER, 0-2 includes samples collected in the Eno River watershed between 0 to 2 miles upstream from the lake.

> For lake samples, the distance category indicates the miles upstream from the dam. The category LowLk, 4-8 includes samples collected in the Lower Lake segment from 4 to 8 miles upstream from the dam. Beaverdam Impoundment samples are included as their own category in the Lower Lake plots.

> Additional information regarding the analysis of the data is presented in Section 3.

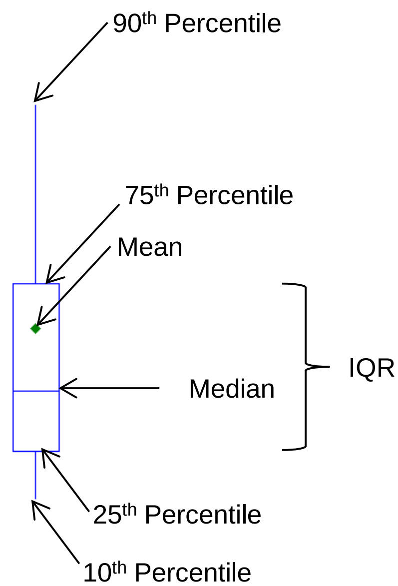



**Figure ES-2 Example Box Plot Illustrating Percentiles**

## ES.4 Summary of Findings

The Task 2 TM summarizes and combines the existing reports and studies with the current water quality data available in the watershed. The major findings associated with the objectives of this task are provided below.

### ES.4.1 Comparison of Existing Reports and Models to Data Summaries

For the most part, the existing reports and studies are consistent in their message and are supported by the data summaries presented in the Task 2 TM. In particular, several studies have demonstrated that water quality improves in the lake from the upstream end to the downstream end near the dam (NCDENR 2001, 2006, 2010, 2011b; Ecoconsultants 2009; Giorgino 2012; and Huisman 2012) and this trend was predicted by the State and USACE prior to the construction of the dam (State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources 1973, USACE 1974).

Falls Lake is listed as impaired for chlorophyll *a* due to exceedances of the ambient water quality standard (40 µg/L). Figure ES-3 presented by NCDWQ staff at the 2012 NC Lake Management Society shows the percent exceedance for chlorophyll *a* at various locations in the lake. The highest levels of chlorophyll *a* occur in the upstream segments of the lake, with stepwise improvements occurring downstream toward the dam. As described in Section 0, this longitudinal improvement in water quality was predicted in the studies that preceded construction of the dam (State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources 1973, USACE 1974). Based on the data presented in this figure (2005 to 2007), the entire portion of the Upper Lake and a portion of the Lower Lake was impaired (exceeded the standard in more than 10 percent of observations).

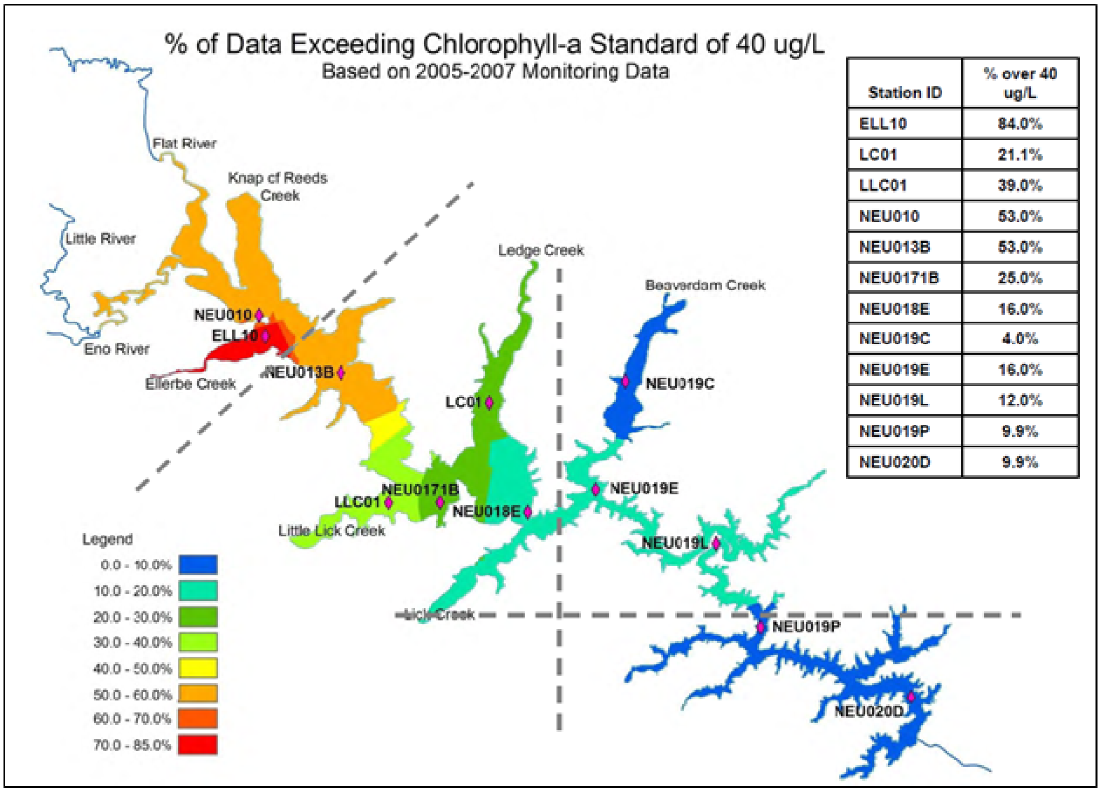



**Figure ES-3 Percent Exceedance of Chlorophyll *a* Standard by Lake Segment (from Huisman 2012)**

### *ES.4.1.1 Agency Reports*

**Historic Documents**

Two historic documents are summarized in this TM (Section 0) to provide a point of reference of current water quality trends relative to what was expected before the dam was constructed. This section of the Executive Summary provides a brief description of these reports and their predictions of water quality in Falls Lake.

In 1973, the State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources released its Special Analysis of the Falls of the Neuse Project. Predictions of water quality in the lake were an important focus of the report, and it was generally accepted that water quality in the upper end of the lake would result in algal blooms due to the shape and residence time of the waterbody. The expectation was that this area of poorer water quality would not negatively impact the drinking water supply intake at the downstream end of the lake, and that the benefits of the lake (flood protection in particular) outweighed the risks associated with eutrophic conditions in the upper most segment. It was expected that taste and odor problems at the water treatment plant would sometimes occur following fall turnover, but for the most part algal blooms would not cause problems for the facility. (Recent monitoring indicates that blooms in the lower lake sometimes occur in the spring and fall). The objectives of the Falls Lake project (flood control, water supply, water quality enhancement, and recreation) were reported to be a source of contention amongst the various stakeholder groups.

The Final Environmental Impact Statement (Revised) Falls Lake Neuse River Basin North Carolina predicted similar spatial trends in water quality (USACE 1974). The Corps predicted that the upper end of the lake would be highly eutrophic, and that recreational use in that area would likely be limited to fishing.

Both historic documents acknowledged that the uppermost section of the lake would be highly eutrophic.

### Recent Assessment Reports

Water quality impairments in the lake include turbidity in the Upper Lake, corresponding to the two most upstream segments (UppLk, 18-21 and UppLk>21), and chlorophyll *a* in the entire lake. Both segments of the lake were listed as impaired for chlorophyll *a* based on data collected by NCDWQ from 2005 to 2006. [Based on the master water quality database, approximately 13 percent of NCDWQ samples from the Lower Lake exceeded the 40 µg/L standard (5 percent in 2005 and 16 percent in 2006). CAAE and USGS also collected data during this period in the Lower Lake, and the percent exceedances based on those data are approximately 6 percent and 8 percent, respectively (when all three data sets are combined, the percent exceedance is approximately 10 percent). In 2007, approximately 8 percent of NCDWQ samples in the Lower Lake exceeded the standard. There were no NCDWQ observations of chlorophyll *a* greater than the standard in the Lower Lake in 2010 or 2011.] NCDENR reports indicate that the lake maintains other water quality standards, such as DO and pH.

Assessment of the turbidity observations in the Upper Lake confirm this trend of improving water quality from the upstream to downstream end (Figure ES-4, Table ES-1) and demonstrate that measurements in this part of the lake exceed the standard of 25 NTU in the two upper most segments. Chlorophyll *a* measurements in the Upper Lake exceed the 40 µg/L standard more than 10 percent of the time with the highest concentrations observed in the segment 18 to 21 miles upstream from the dam (Figure ES-5, Table ES-2). The high turbidity levels in the segment greater than 21 miles upstream from the dam likely impede algal growth in that segment. In the Lower Lake, none of the segments exceed the standard more than 10 percent of the time based on all samples collected from 1999 to 2012 (Figure ES-6, Table ES-3).

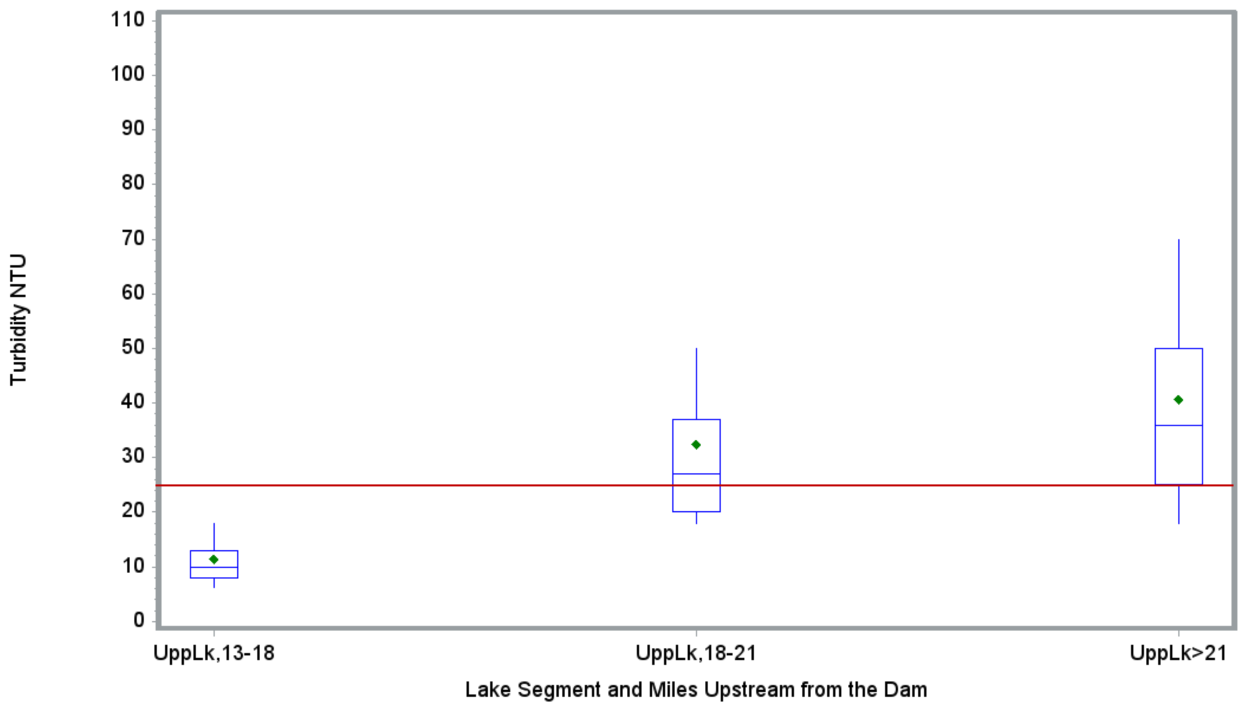



**Figure ES-4 Turbidity Upper Lake Observations Categorized by Miles Upstream from Dam**

**Table ES-1 Turbidity Upper Lake Samples Categorized by Miles Upstream from Dam (in NTU)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 290 | 3.7 | 6.2 | 7.9 | 11.4 | 10.0 | 13.0 | 18.0 | 60.0 |
| UppLk,18-21 | 83 | 10.0 | 18.0 | 20.0 | 32.4 | 27.0 | 37.0 | 50.0 | 180.0 |
| UppLk>21 | 149 | 13.0 | 18.0 | 25.0 | 40.7 | 36.0 | 50.0 | 70.0 | 170.0 |

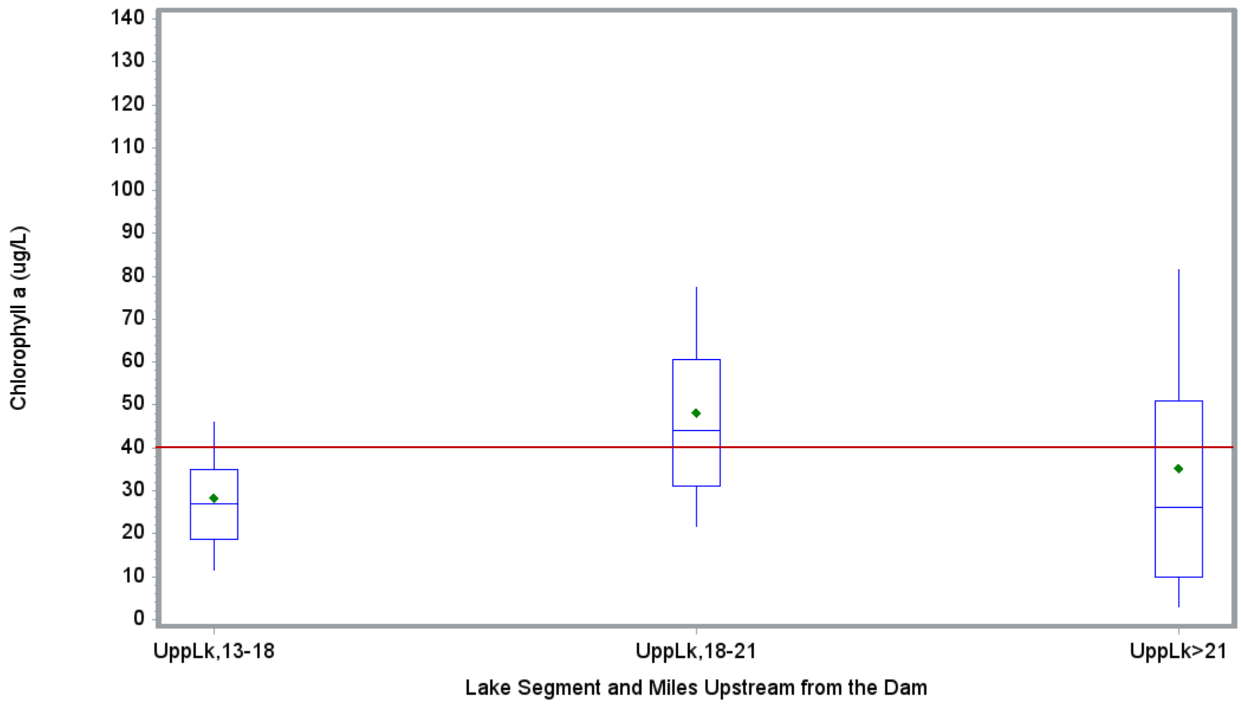



**Figure ES-5 Chlorophyll *a* Upper Lake Observations Categorized by Miles Upstream from Dam**

**Table ES-2 Chlorophyll *a* Upper Lake Samples Categorized by Miles Upstream from Dam (in µg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 433 | 0.30 | 11.60 | 18.70 | 28.30 | 27.00 | 35.00 | 46.00 | 121.00 |
| UppLk,18-21 | 160 | 3.00 | 21.70 | 31.00 | 48.26 | 44.00 | 60.50 | 77.50 | 173.00 |
| UppLk>21 | 911 | 1.00 | 3.00 | 10.00 | 35.36 | 26.00 | 51.00 | 81.60 | 230.00 |

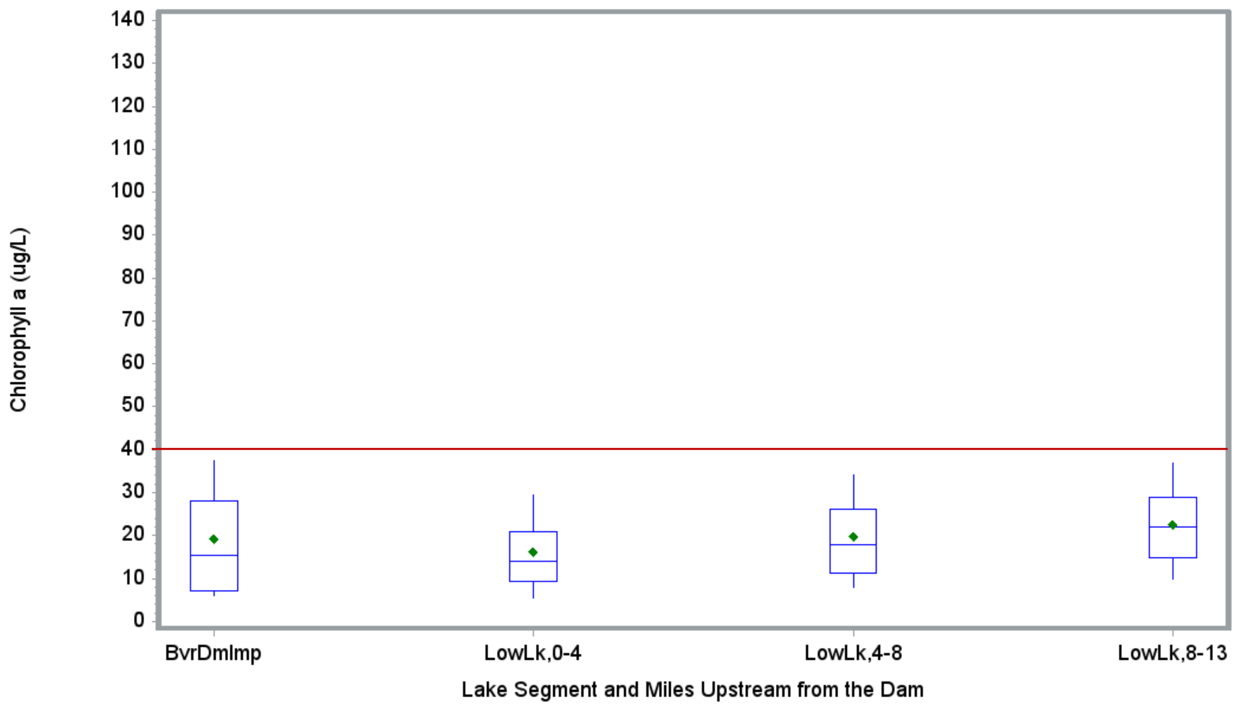



**Figure ES-6 Chlorophyll *a* Lower Lake Observations Categorized by Miles Upstream from Dam**

**Table ES-3 Chlorophyll *a* Lower Lake Samples Categorized by Miles Upstream from Dam (in µg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 120 | 3.56 | 6.00 | 7.00 | 19.19 | 15.45 | 28.15 | 37.30 | 69.70 |
| LowLk,0-4 | 617 | 1.00 | 5.40 | 9.30 | 16.32 | 14.00 | 21.00 | 29.50 | 110.00 |
| LowLk,4-8 | 434 | 2.00 | 7.80 | 11.20 | 19.67 | 17.80 | 26.00 | 34.00 | 60.80 |
| LowLk,8-13 | 353 | 3.60 | 9.90 | 14.90 | 22.46 | 21.90 | 29.00 | 36.80 | 73.00 |

#### *ES.4.1.2 NCDENR Modeling Studies*

The recent NCDENR modeling studies focusing on Falls Lake and its watershed have used a relatively small subset of the data available to develop, calibrate, and validate the models. The Falls Lake WARMF modeling used flow data from eight USGS gages and water quality data from six NCDWQ ambient monitoring stations and two USGS stations from 2004 to 2007 (NCDENR 2009b). The watershed model does not appear to account for biosolids application in the watershed or streambank erosion. The Falls Lake Nutrient Response Model was developed using data collected from 2005 to 2007 from USGS (flow and water quality data) and NCDWQ (ambient monitoring data) (NCDENR 2009a). Nutrient and TSS loads to the lake were based on concentrations observed in the tributaries; chlorophyll *a* and TOC loads, however, were based on observations collected within the lake itself. No tributary chlorophyll *a* data were available at the time the model was developed and a little number of TOC data were available for model development.

Benthic ammonia fluxes (release from the sediments) were measured at two locations and were approximately 0.01 and 0.05 g/m$^2$/d. Benthic ammonia flux is also evident in the depth plots provided for the Upper and Lower Lake samples. Figure ES-7 and Table ES-4 show higher ammonia concentrations observed in the bottom depths of the lake (shown for the Upper Lake segment). Nitrite plus nitrate and total phosphorus fluxes were insignificant, and the box plots of these parameters support the conclusion that these fluxes are negligible: surface concentrations of nitrite plus nitrate and total phosphorus are higher than those observed in the middle or bottom depths. Note that the box plots summarize all samples and locations within the lake segment (Upper versus Lower) and that localized benthic releases would not be evident at this scale. This source of nutrient loading will be addressed further in Task 3.

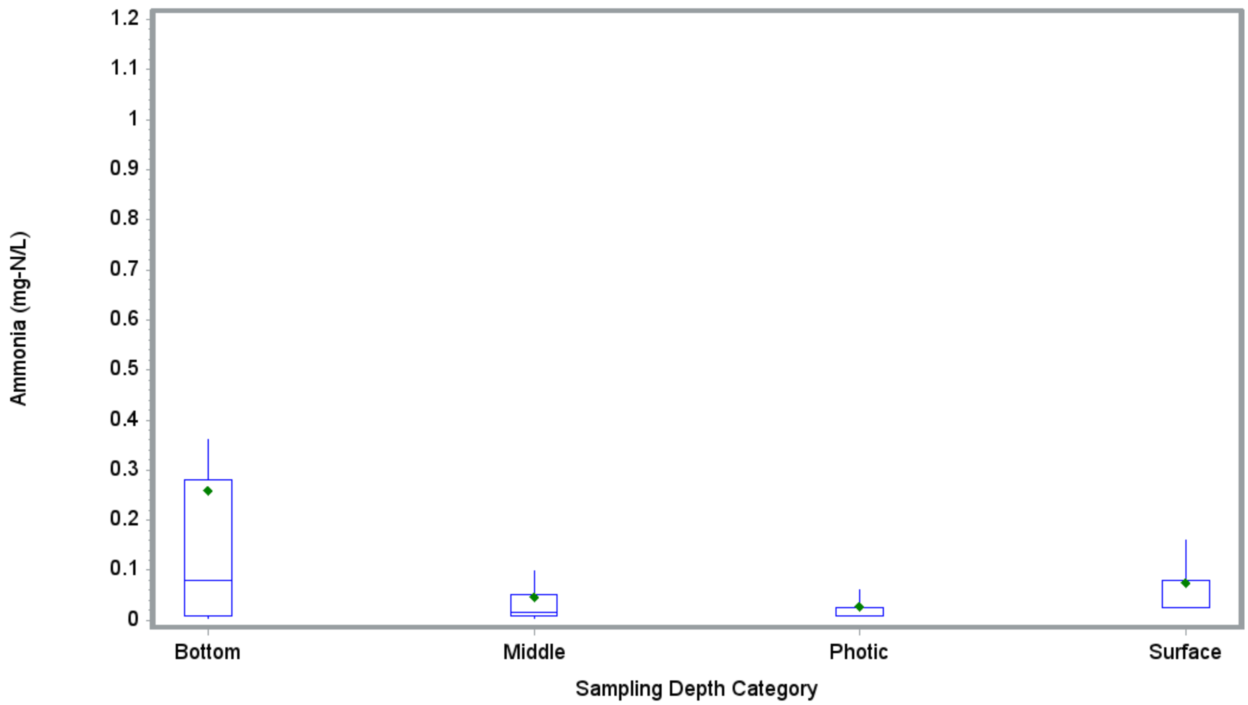



**Figure ES-7 Ammonia Upper Lake Samples Categorized by Depth Category**

**Table ES-4 Ammonia Upper Lake Samples Categorized by Depth Category (in mg-N/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 27 | 0.005 | 0.005 | 0.010 | 0.259 | 0.080 | 0.280 | 0.360 | 2.600 |
| Middle | 160 | 0.005 | 0.005 | 0.010 | 0.048 | 0.015 | 0.052 | 0.098 | 0.985 |
| Photic | 601 | 0.005 | 0.010 | 0.010 | 0.027 | 0.010 | 0.025 | 0.060 | 0.430 |
| Surface | 645 | 0.005 | 0.025 | 0.025 | 0.074 | 0.025 | 0.080 | 0.160 | 1.810 |

#### *ES.4.1.3 Independent Studies*

The local governments in the watershed have also conducted several studies to assess water quality in Falls Lake and the watershed. In 2003, the Upper Neuse River Basin Association developed the Upper Neuse Watershed Management Plan (Tetra Tech, Inc. 2003). This study concluded that while watershed loads of nitrogen and phosphorus had decreased by 50 percent and 20 percent, respectively, compared to 1989 and 1994 loads, chlorophyll *a* concentrations in the lake appeared to be increasing. Because the Task 2 data analysis focuses on years 1999 to 2012, it is not possible to make a direct comparison of the data summaries in this report to those presented in the Upper Neuse Watershed Management Plan.

For 1999 to 2012, there is little change in median total nitrogen and total phosphorus tributary concentrations from year to year. The higher concentrations for both parameters (75$^{th}$ percentiles and higher) showed an increasing trend from 2003 to 2007 followed by a decreasing trend through 2011.

Chlorophyll *a* concentrations in the lake also increased from 2003 to 2006. After 2006, concentrations have generally leveled off in the Upper Lake (Figure ES-8, Table ES-5) and declined in the Lower Lake (Figure ES-9, Table ES-6). Chlorophyll *a* measurements collected by NCDWQ from 1996 to 2001 are uncorrected for pheophytin, so data for 2001 are likely elevated due to inclusion of pheophytin in the reported value (see Section 2.2.1 for additional information).

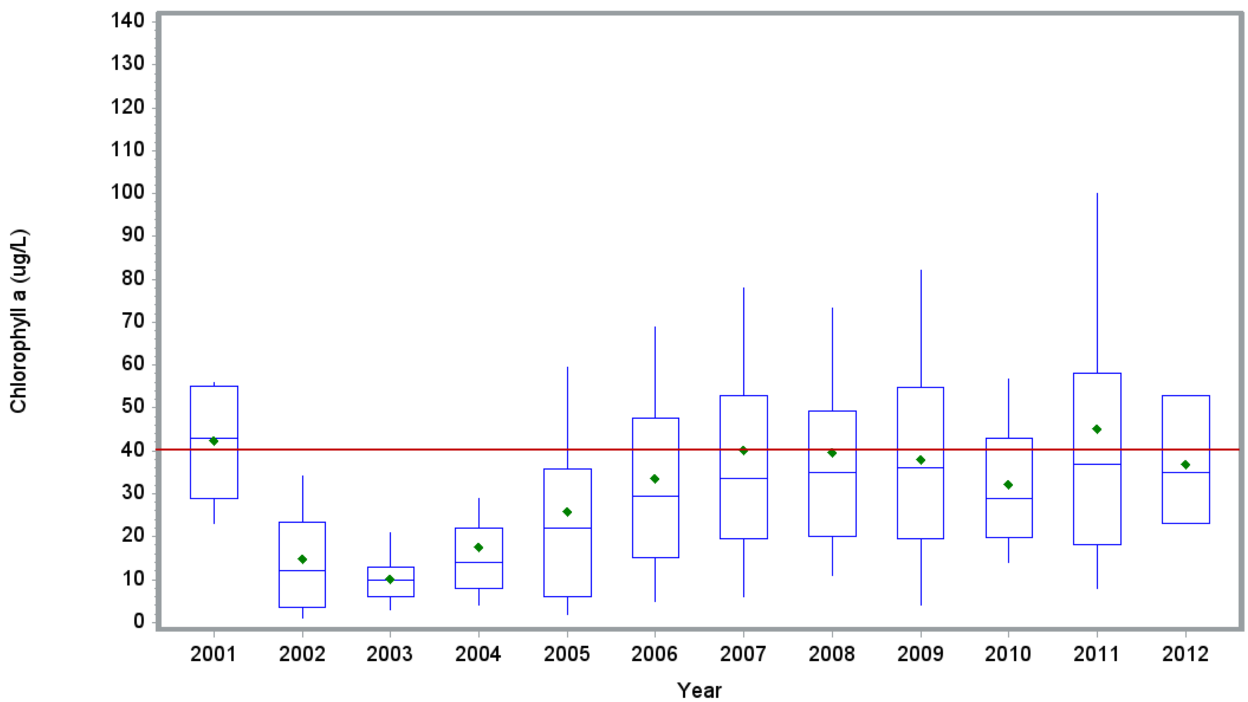



**Figure ES-8 Chlorophyll *a* Upper Lake Samples Categorized by Year**

**Table ES-5 Chlorophyll *a* Upper Lake Samples Categorized by Year (in µg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2001 | 15 | 22.00 | 23.00 | 29.00 | 42.53 | 43.00 | 55.00 | 56.00 | 79.00 |
| 2002 | 56 | 1.00 | 1.00 | 3.50 | 14.71 | 12.00 | 23.50 | 34.00 | 56.00 |
| 2003 | 59 | 1.00 | 3.00 | 6.00 | 10.25 | 10.00 | 13.00 | 21.00 | 25.00 |
| 2004 | 61 | 1.00 | 4.00 | 8.00 | 17.55 | 14.00 | 22.00 | 29.00 | 93.50 |
| 2005 | 121 | 1.00 | 2.00 | 6.00 | 25.81 | 22.00 | 35.90 | 59.60 | 126.00 |
| 2006 | 224 | 1.00 | 5.00 | 15.00 | 33.67 | 29.50 | 47.50 | 69.00 | 103.00 |
| 2007 | 208 | 1.00 | 6.00 | 19.50 | 40.17 | 33.50 | 52.90 | 78.00 | 230.00 |
| 2008 | 85 | 3.34 | 11.00 | 20.00 | 39.55 | 35.00 | 49.20 | 73.40 | 133.00 |
| 2009 | 76 | 1.50 | 4.00 | 19.50 | 38.01 | 36.00 | 54.75 | 82.00 | 135.00 |
| 2010 | 250 | 0.30 | 13.95 | 19.90 | 32.30 | 28.90 | 43.00 | 56.85 | 121.00 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2011 | 346 | 0.50 | 8.00 | 18.00 | 45.06 | 36.75 | 58.00 | 100.00 | 205.00 |
| 2012 | 3 | 23.00 | 23.00 | 23.00 | 37.00 | 35.00 | 53.00 | 53.00 | 53.00 |

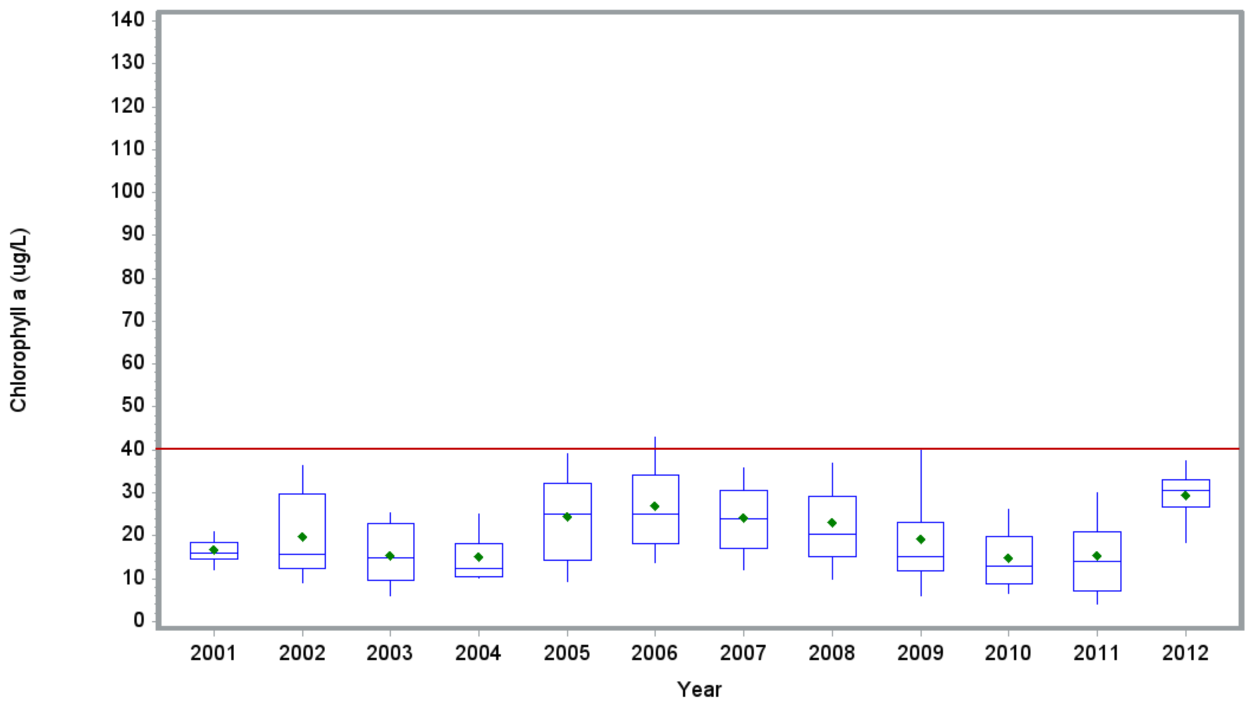



**Figure ES-9 Chlorophyll *a* Lower Lake Samples Categorized by Year**

**Table ES-6 Chlorophyll *a* Lower Lake Samples Categorized by Year**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2001 | 16 | 11.00 | 12.00 | 14.50 | 16.63 | 16.00 | 18.50 | 21.00 | 25.00 |
| 2002 | 6 | 9.10 | 9.10 | 12.30 | 19.80 | 15.70 | 29.60 | 36.40 | 36.40 |
| 2003 | 6 | 6.00 | 6.00 | 9.60 | 15.52 | 14.75 | 22.70 | 25.30 | 25.30 |
| 2004 | 10 | 10.00 | 10.10 | 10.30 | 15.02 | 12.40 | 18.10 | 25.15 | 29.00 |
| 2005 | 87 | 2.90 | 9.30 | 14.20 | 24.61 | 25.00 | 32.10 | 39.20 | 110.00 |
| 2006 | 136 | 6.00 | 13.70 | 18.00 | 27.05 | 25.00 | 34.00 | 43.00 | 60.80 |
| 2007 | 138 | 8.40 | 12.00 | 17.00 | 24.13 | 24.00 | 30.60 | 35.70 | 50.00 |
| 2008 | 163 | 4.00 | 9.90 | 15.00 | 23.09 | 20.30 | 29.20 | 36.80 | 69.70 |
| 2009 | 155 | 4.00 | 6.00 | 11.70 | 19.18 | 15.00 | 23.00 | 40.00 | 77.00 |
| 2010 | 404 | 3.50 | 6.60 | 8.90 | 14.85 | 13.00 | 19.85 | 26.00 | 41.30 |
| 2011 | 391 | 1.00 | 4.00 | 7.20 | 15.28 | 14.00 | 21.00 | 30.00 | 57.50 |
| 2012 | 12 | 18.30 | 18.30 | 26.60 | 29.37 | 30.45 | 33.10 | 37.30 | 37.30 |

The City of Raleigh has been studying water quality in Falls Lake in order to optimize and manage the E.M. Johnson Water Treatment Plant (WTP). Of particular interest is the formation of disinfection byproducts which are toxic to humans and regulated by USEPA. When lake water is treated to produce drinking water and disinfection is achieved with the use of chlorination techniques, there is a potential to produce harmful disinfection byproducts (DBP). Because DBP formation is correlated to the amount of organic material in the raw water, USEPA requires removal of organic material prior to treatment and disinfection (USEPA 2010a). The City of Raleigh monitors total organic carbon (TOC) for compliance and operational planning.

In 2006, Spirogyra Diversified Environmental Services (SDES) developed a report for the City of Raleigh that assessed the relationship between taste and odor episodes at the E.M. Johnson WTP with water quality. Analysis of seven years of data indicated that spring blooms occur annually, typically in March. The Raleigh E.M. Johnson WTP also performs annual flushing and chlorine burnout in March, which typically takes approximately four weeks to transition back into chloramines (personal communication, Kenny Waldroup, City of Raleigh, 8/8/2012). The majority of the taste and odor complaints from water users are filed in March and April each year. SDES (2006) recommended that 1) WTP operators alter the depth of the intake to avoid algal blooms in the water column and 2) treat the intake water that is stored in separate basins prior to entering the plant with chemicals such as potassium permanganate to reduce odor problems associated with these algae. Box plots and summary statistics for chlorophyll *a* in the Lower Lake by month (Figure ES-10, Table ES-7) support the findings of this report in terms of the timing of spring blooms.

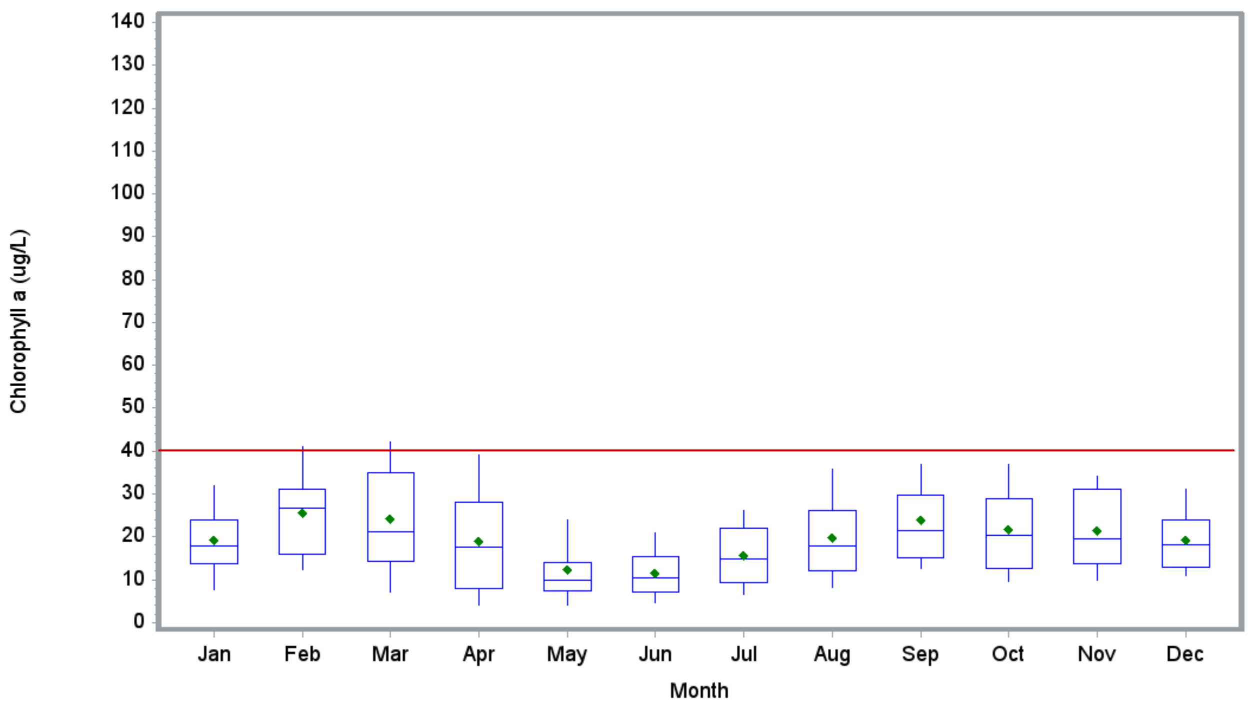



**Figure ES-10 Chlorophyll *a* Lower Lake Samples Categorized by Month**

**Table ES-7 Chlorophyll *a* Lower Lake Samples Categorized by Month**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 84 | 3.70 | 7.60 | 13.70 | 19.32 | 17.75 | 24.00 | 32.00 | 44.00 |
| Feb | 83 | 4.00 | 12.40 | 16.00 | 25.55 | 26.60 | 31.00 | 41.00 | 60.80 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Mar | 118 | 4.00 | 7.00 | 14.30 | 24.15 | 21.15 | 34.90 | 42.00 | 77.00 |
| Apr | 126 | 1.90 | 4.00 | 7.80 | 19.09 | 17.45 | 28.20 | 39.00 | 54.60 |
| May | 151 | 1.00 | 4.00 | 7.30 | 12.45 | 10.00 | 14.10 | 24.00 | 110.00 |
| Jun | 159 | 2.00 | 4.60 | 7.00 | 11.66 | 10.40 | 15.40 | 21.00 | 29.50 |
| Jul | 174 | 3.40 | 6.60 | 9.30 | 15.72 | 14.90 | 22.00 | 26.00 | 34.80 |
| Aug | 188 | 2.90 | 8.30 | 12.05 | 19.85 | 17.95 | 26.20 | 35.80 | 46.00 |
| Sep | 133 | 6.00 | 12.70 | 15.20 | 23.89 | 21.50 | 29.80 | 37.00 | 69.70 |
| Oct | 124 | 5.30 | 9.70 | 12.50 | 21.70 | 20.35 | 28.95 | 37.00 | 44.80 |
| Nov | 103 | 4.60 | 10.00 | 13.60 | 21.44 | 19.50 | 31.00 | 34.00 | 73.00 |
| Dec | 81 | 4.50 | 11.00 | 13.00 | 19.31 | 18.00 | 24.00 | 31.00 | 36.00 |

In 2009, Ecoconsultants prepared a report for the City of Raleigh summarizing the chlorophyll *a* sampling that has occurred in the reservoir from 1983 to 2009. The report summarizes water quality trends in the lake similar to the NCDENR Basinwide Assessment Reports (2001, 2006, 2010, and 2011b) with Secchi depth, nutrients, turbidity, and chlorophyll *a* improving from the upstream end of the lake downstream to the dam.

In 2009, the City of Raleigh also contracted with Hazen and Sawyer to prepare a fiscal analysis of water quality on drinking water treatment costs (Hazen and Sawyer 2009 and 2012). The report (updated in 2012) includes an analysis of TOC data collected from 1999 to spring 2012. TOC concentrations were generally highest during the 1999 to 2002 period and lowest during the 2003 to 2006 period. Concentrations increased during the 2007 to spring 2012 period, but were not as high as the 1999 to 2002 observations according to the Hazen and Sawyer (2012) report. The box plot of TOC in the Lower Lake based on the master water quality database partially confirms this assessment: concentrations fluctuate from year to year, there is an increasing trend from 2004 to 2006, stable concentrations from 2006 to 2008, and a decreasing trend from 2008 to 2010 (Figure ES-11, Table ES-8).

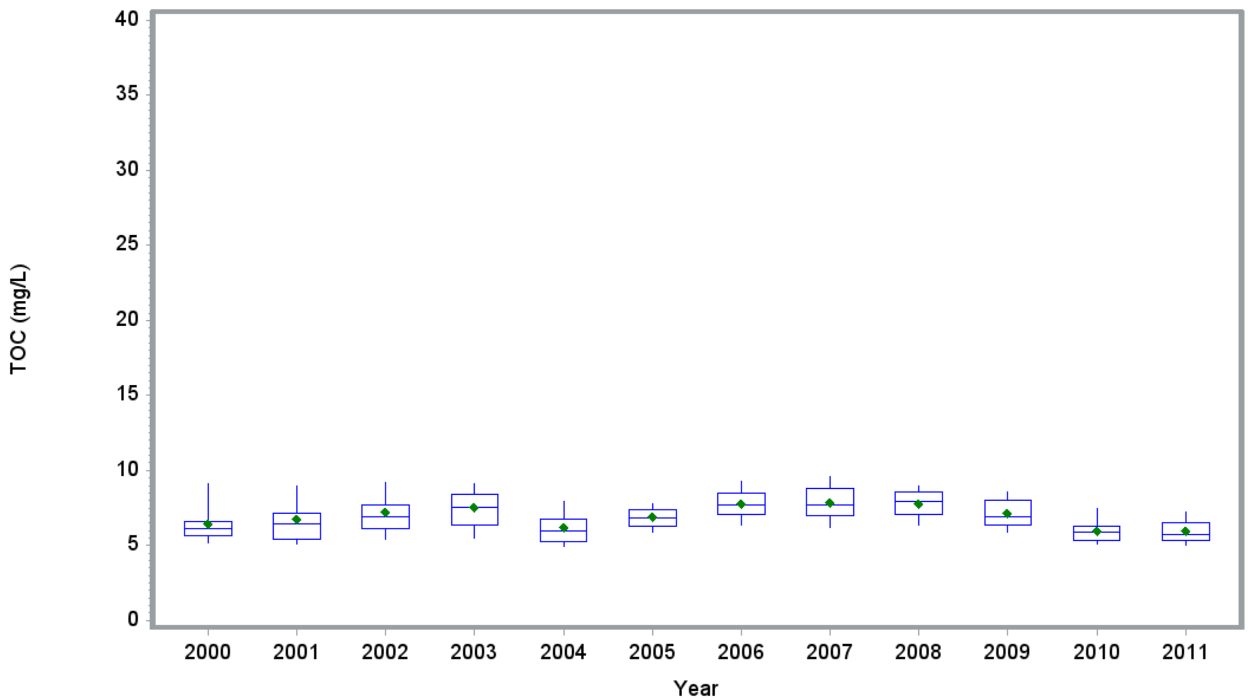



**Figure ES-11 TOC Lower Lake Samples Categorized by Year**

**Table ES-8 TOC Lower Lake Samples Categorized by Year**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 88 | 3.77 | 5.21 | 5.64 | 6.44 | 6.16 | 6.58 | 9.14 | 10.80 |
| 2001 | 88 | 4.50 | 5.10 | 5.44 | 6.72 | 6.47 | 7.15 | 8.96 | 11.80 |
| 2002 | 86 | 4.25 | 5.40 | 6.14 | 7.22 | 6.90 | 7.67 | 9.22 | 14.50 |
| 2003 | 96 | 5.01 | 5.50 | 6.40 | 7.52 | 7.55 | 8.42 | 9.12 | 13.77 |
| 2004 | 88 | 4.83 | 4.96 | 5.24 | 6.22 | 5.95 | 6.79 | 7.92 | 9.29 |
| 2005 | 81 | 5.30 | 5.90 | 6.30 | 6.90 | 6.80 | 7.40 | 7.80 | 11.00 |
| 2006 | 100 | 5.30 | 6.35 | 7.10 | 7.81 | 7.70 | 8.50 | 9.30 | 11.00 |
| 2007 | 105 | 4.59 | 6.20 | 7.00 | 7.86 | 7.70 | 8.80 | 9.59 | 11.00 |
| 2008 | 120 | 3.71 | 6.35 | 7.08 | 7.75 | 7.94 | 8.56 | 9.00 | 11.10 |
| 2009 | 94 | 5.00 | 5.90 | 6.40 | 7.15 | 6.93 | 8.00 | 8.58 | 11.30 |
| 2010 | 125 | 4.13 | 5.07 | 5.37 | 5.98 | 5.86 | 6.30 | 7.50 | 9.00 |
| 2011 | 135 | 3.03 | 4.99 | 5.37 | 5.94 | 5.70 | 6.53 | 7.20 | 8.70 |

### ES.4.2 Comparability of Data Collection Efforts by the Various Organizations

The organizations collecting data in the Falls Lake watershed provided varying levels of detail regarding how they collect and analyze data in the watershed. The differences in field and laboratory standard operating procedures (SOPs), quality assurance project plans (QAPPs), and chain of custody (COC) procedures are discussed in Section 3.1 of the report.

For the most part, the organization collecting the data did not affect the analysis results in a significant way. In the Lower Lake, the Wake County data often appeared different than data collected by other organizations, but this is mostly due to the small sampling size of the Wake County Lower Lake data set.

The City of Durham tended to observe poorer water quality than the other organizations sampling in the Upper Lake. This difference is likely due to the location of the City of Durham sampling with respect to the mouth of Ellerbe Creek, and is likely not a reflection of the differences in sampling or analysis protocols.

Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

### ES.4.3 Annual Variability

To assess annual variability, data for each parameter and geographic region are categorized by sampling year. The amount of annual variability differs by parameter and geographic region:

> For temperature there is little annual variability in the tributary or Lake segments.

> Median tributary DO was lower in years 2006 through 2011 relative to the other years. Low DO in the Upper Lake was more often observed in years 2000, 2001, 2005, 2006, and 2007. In the Lower Lake, low DO was more often observed in years 2001, 2005, 2006, 2007, 2010 and 2011.

> For TSS, median values were typically less than 10 mg/L in the tributaries. Higher values were more often observed in years 2004 and 2009. In the Upper Lake, the median TSS concentration is greater than 10 mg/L, and the highest TSS concentrations were observed in 2000. In the Lower Lake, TSS concentrations were relatively stable from year to year, but slightly higher in 2002 and 2003.

> For pH, years 2009 through 2012 have higher median pH values than the other years (2012 is a partial year) in the tributary samples, but pH is relatively consistent from year to year in the Lake samples.

> For Secchi depth, there is little variability from year to year in the Upper Lake or Lower Lake segment. Secchi depths were greater, however, in the Lower Lake in year 2001 and 2008 relative to some of the other years.

> Conductivity measurements were relatively similar from year to year in the tributary samples for years 1999 through 2005. Year 2006 began an increasing trend in conductivity measurements (sample size also increased by an order of magnitude over this period). In the Upper Lake, the highest conductivities were observed in 2002 and 2009. In the Lower Lake, median conductivities were generally constant from year to year.

> Median ortho-phosphate measurements are similar from year to year in the tributary samples; higher concentrations were more often observed in 2006, 2008, and 2011. In the Upper Lake, median concentrations are relatively stable from year to year, and year 2002 had the highest observations. In the Lower Lake samples, the ortho-phosphate measurements are relatively stable and the $90^{th}$ percentile for each year is less than 0.02 mg/L, which is at or the below the reporting limit for the majority of the ortho-phosphate samples in the database.

> Median total phosphorus measurements are similar from year to year in the tributaries, but years 2004 through 2007 have the highest observed concentrations. In the Upper Lake, median concentrations vary from year to year with the highest concentrations observed in 2002. In the Lower Lake, total phosphorus measurements are relatively stable and the $90^{th}$ percentile for each year is less than 0.06 mg/L.

> Median ammonia concentrations in the tributary samples were relatively stable from year to year. The highest ammonia concentrations were observed in 1999, 2001, 2005, and 2011. In the Upper Lake, concentrations were relatively stable, but year 2001 and 2002 had much higher concentrations than

those observed in other years. In the Lower Lake, concentrations are more variable with higher concentrations more often observed in 2001 and 2008.

> Median nitrate plus nitrite measurements in the tributary samples are similar from year to year. Higher concentrations showed an increasing trend from 2003 to 2007. In the Upper Lake, median nitrate plus nitrite concentrations were similar from year to year with the exception of 2002 which had higher median concentrations relative to the other years. The highest concentrations in the Upper Lake were also observed in 2002. In the Lower Lake, median nitrate plus nitrite concentrations were similar from year to year, except for years 2005 through 2007 when the median values and IQRs were less than the other years.

> For organic nitrogen, there is little variability from year to year in the tributary samples. In the Upper Lake and Lower Lake samples, the majority of the organic nitrogen concentrations were higher in 2008 and 2009 relative to the other years. Concentrations generally increased from 2003 to 2009, and decreased in 2010 and 2011.

> Median TN concentrations in the tributaries were similar from year to year; higher concentrations showed an increasing trend from 2002 to 2007 and a decreasing trend from 2008 to 2010. TN concentrations in the Upper Lake were highest in years 2002, 2007, 2008, and 2009. In the Lower Lake concentrations were higher in 2008, 2009, and 2010; no TN data are available for year 2002.

> Median TOC concentrations are fairly consistent from year to year in the tributary samples, but slightly higher in years 2007, 2008, 2009, and 2011. Median TOC concentrations in the Upper Lake were highest in 2008 and 2009 relative to the other eight years monitored. In the Lower Lake, median concentrations were higher in years 2003, 2006, 2007, and 2008. Years 2010 and 2011 had lower median concentrations than most of the other years.

> Chlorophyll *a* concentrations in the free flowing waterbodies in the Tributary region are limited to data collected by Orange County in the Eno River subwatershed in 2010 and 2011. The distribution of samples was similar during both of these years. Chlorophyll *a* observations in the Upper Lake were higher in 2001 than 2002 through 2004. Median concentrations from years 2003 to 2007 showed an increasing trend and leveled off from 2007 through 2012. In the Lower Lake, the highest $90^{th}$ percentile concentrations were observed in year 2006. There is a decreasing trend in the median concentrations from year 2006 to 2010.

> Data were not available to calculate the ratio of Chlorophyll *a* to TOC in the tributary samples. In the Upper Lake, the median ratio was lower in 2008, 2009, and 2010 relative to the other years. In the Lower Lake, the median ratio decreased from year 2005 to 2008 and then leveled off.

The required load reductions for the watershed as defined in the Falls Lake Rules were calculated using the baseline year 2006. For the most part, tributary water entering Falls Lake had poorer water quality in 2006 relative to the other years: tributary samples had lower DO and higher ortho-phosphate, total phosphorus, organic nitrogen, nitrate plus nitrite, and total nitrogen concentrations relative to most of the other years (concentrations of nitrate plus nitrite, total nitrogen, and total phosphorus were increasing over the period 2003 to 2007 and peaked in 2007). Figure ES-12 and Table ES-10 show tributary total phosphorus concentrations as an example of the observed water quality in 2006 relative to the other years.

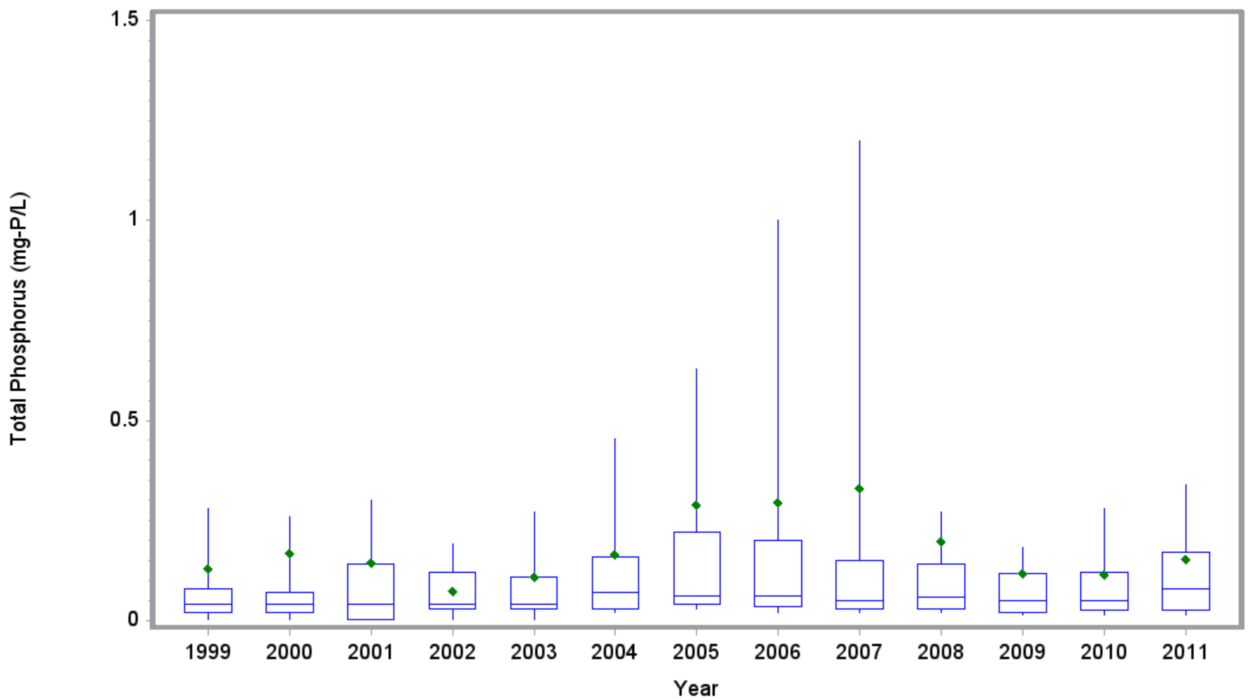



**Figure ES-12 Total Phosphorus Tributary Samples Categorized by Year**

**Table ES-10 Total Phosphorus Tributary Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 135 | 0.002 | 0.002 | 0.020 | 0.131 | 0.040 | 0.080 | 0.280 | 2.100 |
| 2000 | 138 | 0.002 | 0.002 | 0.020 | 0.167 | 0.040 | 0.070 | 0.260 | 3.900 |
| 2001 | 63 | 0.002 | 0.002 | 0.002 | 0.143 | 0.040 | 0.140 | 0.300 | 1.500 |
| 2002 | 39 | 0.002 | 0.002 | 0.030 | 0.073 | 0.040 | 0.120 | 0.190 | 0.290 |
| 2003 | 85 | 0.002 | 0.002 | 0.030 | 0.108 | 0.040 | 0.110 | 0.270 | 1.500 |
| 2004 | 90 | 0.002 | 0.020 | 0.030 | 0.166 | 0.070 | 0.160 | 0.455 | 1.500 |
| 2005 | 164 | 0.002 | 0.030 | 0.040 | 0.290 | 0.060 | 0.220 | 0.630 | 4.500 |
| 2006 | 193 | 0.002 | 0.020 | 0.036 | 0.296 | 0.060 | 0.200 | 1.000 | 3.600 |
| 2007 | 141 | 0.002 | 0.020 | 0.030 | 0.331 | 0.050 | 0.150 | 1.200 | 5.400 |
| 2008 | 226 | 0.010 | 0.020 | 0.030 | 0.197 | 0.059 | 0.140 | 0.270 | 5.400 |
| 2009 | 450 | 0.009 | 0.015 | 0.020 | 0.117 | 0.050 | 0.117 | 0.183 | 11.400 |
| 2010 | 535 | 0.006 | 0.015 | 0.025 | 0.113 | 0.050 | 0.120 | 0.280 | 1.400 |
| 2011 | 314 | 0.012 | 0.015 | 0.025 | 0.152 | 0.080 | 0.170 | 0.340 | 2.200 |

Water quality in the lake was somewhat ambiguous in 2006. Both the Upper and Lower Lake experienced a large percentage of low DO concentrations. In 2006, chlorophyll *a* in the Upper Lake was near the end of an increasing trend in concentrations that occurred from 2003 to 2007; TOC concentrations were in an increasing trend from 2005 to 2008. In the Lower Lake, year 2006 had typical TOC concentrations and the highest 90$^{th}$ percentile chlorophyll *a* concentrations observed. The total nitrogen and total phosphorus concentrations observed in the Upper and Lower Lake segments, however, were lower in 2006 compared to many of the years (Figure ES-13 and Table ES-11 show total phosphorus observations by year in the Upper Lake). Based on visible interpretation of the data, higher nutrient concentrations in both the Upper and Lower Lake segments occurred in years 2007 through 2009. Total nitrogen and total phosphorus in the Upper Lake show an increasing trend from year 2006 to 2009. Higher total nitrogen concentrations occur in the Lower Lake in 2008, 2009, and 2010; total phosphorus concentrations in the Lower Lake were relatively stable from year to year.

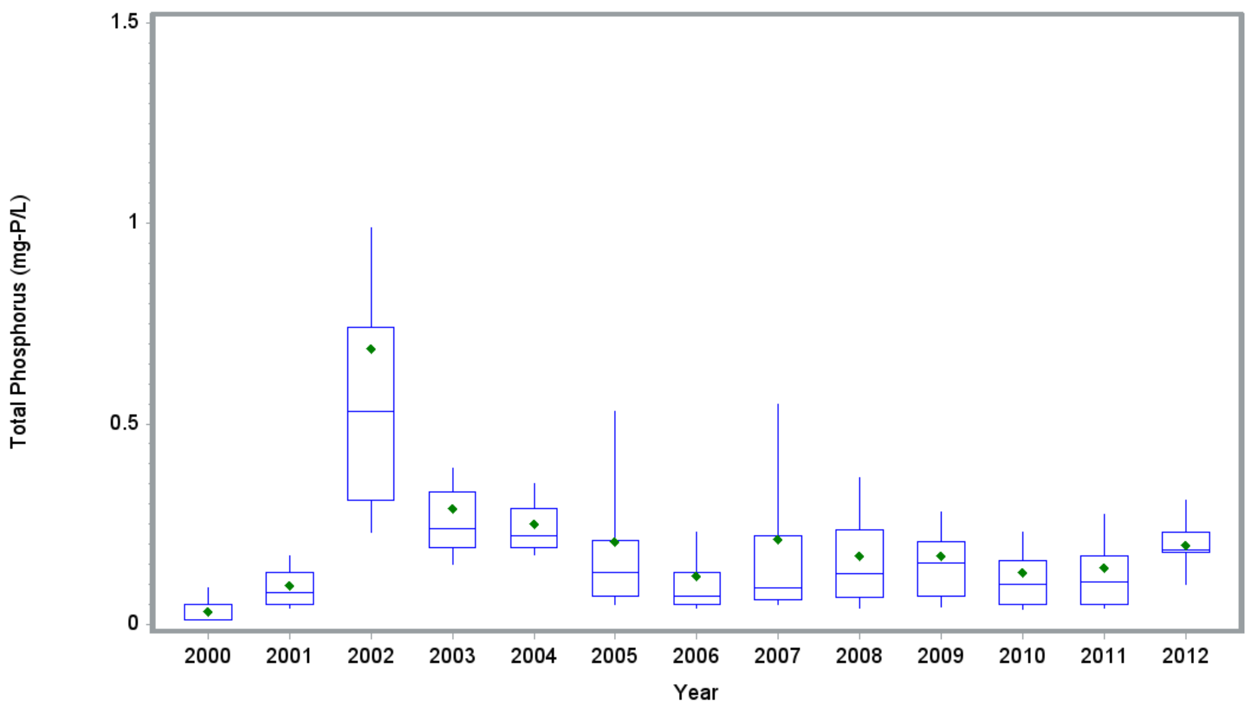



**Figure ES-13 Total Phosphorus Upper Lake Samples Categorized by Year**

**Table ES-11 Total Phosphorus Upper Lake Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 16 | 0.010 | 0.010 | 0.010 | 0.033 | 0.010 | 0.050 | 0.090 | 0.110 |
| 2001 | 35 | 0.030 | 0.040 | 0.050 | 0.096 | 0.080 | 0.130 | 0.170 | 0.240 |
| 2002 | 31 | 0.170 | 0.230 | 0.310 | 0.689 | 0.530 | 0.740 | 0.990 | 3.450 |
| 2003 | 26 | 0.120 | 0.150 | 0.190 | 0.290 | 0.240 | 0.330 | 0.390 | 1.310 |
| 2004 | 30 | 0.130 | 0.175 | 0.190 | 0.249 | 0.220 | 0.290 | 0.350 | 0.690 |
| 2005 | 139 | 0.034 | 0.050 | 0.070 | 0.208 | 0.130 | 0.210 | 0.530 | 1.820 |
| 2006 | 206 | 0.034 | 0.041 | 0.050 | 0.120 | 0.070 | 0.130 | 0.230 | 1.370 |
| 2007 | 182 | 0.020 | 0.050 | 0.060 | 0.211 | 0.090 | 0.220 | 0.550 | 1.600 |
| 2008 | 60 | 0.037 | 0.042 | 0.068 | 0.170 | 0.126 | 0.235 | 0.365 | 0.800 |
| 2009 | 68 | 0.039 | 0.044 | 0.070 | 0.172 | 0.153 | 0.205 | 0.280 | 0.980 |
| 2010 | 149 | 0.030 | 0.039 | 0.050 | 0.130 | 0.100 | 0.160 | 0.230 | 1.290 |
| 2011 | 160 | 0.025 | 0.040 | 0.050 | 0.142 | 0.105 | 0.170 | 0.275 | 1.340 |
| 2012 | 6 | 0.100 | 0.100 | 0.180 | 0.198 | 0.185 | 0.230 | 0.310 | 0.310 |

### ES.4.1 Identification of Potential Gaps in the Monitoring Data

One of the purposes of this TM is to begin identifying data needs (gaps) for estimating nutrient loads and supporting model development and to assure that they are appropriately assessed using sensitivity and uncertainty analyses. For nutrient loads, the model typically is a “rating curve” based on flow-concentration relationships or a watershed loading model that simulates runoff and associated nutrient loads. For the reservoir and watershed, the models may be process-based (e.g., the Falls Lake Nutrient Response Model and the Falls Lake Watershed Model) or empirical (e.g., USGS SPARROW).

In fundamental terms, identification of data needs is a “value of information analysis” (VOIA). A data gap exists if additional monitoring (to fill that gap) can improve knowledge (reduce uncertainty), leading to better-informed decision making at an acceptable cost. The VOIA requires a model that links management actions to desired outcomes, such as linking stormwater treatment to water quality standards compliance. Once reservoir and watershed models are selected, the model(s) can be run to determine quantitatively (using sensitivity/uncertainty analyses) what additional monitoring is most cost-effective (improves prediction at acceptable cost). Thus, the review and selection of models that will be undertaken in Task 4 will result in identification of critical data gaps.

Although the majority of the work in identifying data gaps will be addressed in Task 4, one obvious gap presents itself when comparing the existing NCDENR models to the available data. As mentioned in Section ES.4.1.2, the chlorophyll *a* and TOC loads used to develop the input files for the EFDC lake response model were based on lake concentrations, not tributary concentrations. Collection of chlorophyll *a* and TOC data in the tributaries just upstream of the lake would provide more accurate information from which to base future simulations of lake response (the relative importance of this gap may be addressed with sensitivity analyses of the existing model to this input parameter).

Several other parameters have limited data in the segments just upstream of the lake, as well as Beaverdam Impoundment. Table ES-12 summarizes the sample size for each parameter and segment. The segments near the lake with a small sample size relative to the other segments in the watershed are shaded. For each parameter, the smallest sample sizes are typically associated with the segment from 0 to 2 miles upstream from the lake and the Beaverdam Impoundment. Collection of additional data in these segments will support tributary load estimation and future lake response modeling. The downstream segments with the least amount of data include the Eno River, Horse/Barton/Cedar, Horse/New Light, Knap of Reeds, Lick Creek, Little River, the Beaverdam Creek Subwatershed, and the Beaverdam Impoundment. TOC and chlorophyll *a* data near the mouths of tributaries is lacking across the watershed.

Note that this preliminary identification of sampling needs is only based on sample size for those segments near the lake. During Task 3 when water quality concentrations are paired with flows to determine loads, additional gaps in the data may become evident (e.g., lack of sampling during particular flow regimes). Exploration of methods to determine jurisdictional loads may also reveal gaps in the data. Finally, selection of future studies will dictate the parameters, locations, and frequencies needed to support those studies. The Task 4 TM will consolidate the needs identified throughout the project and prioritize the suggested short term and long term studies for the UNRBA.

**Table ES-12 Sample Size by Subwatershed and Lake Segment**

| Subwatershed, Distance Upstream | TSS | Ammonia | NO2/NO3 | Organic Nitrogen | Ortho-Phosphorus | Total Phosphorus | Chlorophyll *a* | Total Organic Carbon |
|---|---|---|---|---|---|---|---|---|
| BC,0-2 | 18 | 19 | 15 | 15 | 17 | 15 | 0 | 0 |
| BC,2-10 | 0 | 30 | 0 | 30 | 30 | 30 | 0 | 0 |
| EC,0-2 | 153 | 225 | 453 | 222 | 40 | 444 | 0 | 11 |
| EC,2-10 | 226 | 216 | 214 | 215 | 3 | 265 | 0 | 15 |
| ER,0-2 | 58 | 69 | 115 | 68 | 4 | 118 | 0 | 5 |
| ER,2-10 | 172 | 184 | 231 | 182 | 35 | 237 | 0 | 5 |
| ER>10 | 181 | 281 | 280 | 275 | 99 | 270 | 182 | 85 |
| FR,0-2 | 113 | 201 | 214 | 199 | 95 | 248 | 0 | 1 |
| FR,2-10 | 65 | 44 | 51 | 44 | 3 | 53 | 0 | 0 |
| FR>10 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| HBC,0-2 | 78 | 78 | 76 | 76 | 76 | 76 | 0 | 0 |
| HNL,0-2 | 45 | 50 | 41 | 42 | 44 | 41 | 0 | 0 |
| KRC,0-2 | 80 | 137 | 147 | 136 | 9 | 147 | 0 | 10 |
| LC,0-2 | 31 | 36 | 36 | 36 | 5 | 36 | 0 | 5 |
| LC,2-10 | 57 | 85 | 85 | 85 | 29 | 85 | 0 | 4 |
| LR,0-2 | 0 | 3 | 0 | 3 | 3 | 3 | 0 | 0 |
| LR,2-10 | 145 | 426 | 456 | 425 | 360 | 504 | 0 | 53 |
| UppLk>21 | 146 | 947 | 1109 | 917 | 834 | 621 | 911 | 161 |
| UppLk,18-21 | 102 | 89 | 177 | 89 | 105 | 89 | 160 | 67 |
| UppLk,13-18 | 206 | 397 | 699 | 394 | 410 | 398 | 433 | 267 |
| BvrDmImp | 23 | 0 | 56 | 0 | 0 | 0 | 120 | 56 |
| LowLk,8-13 | 131 | 91 | 262 | 90 | 89 | 120 | 353 | 193 |
| LowLk,4-8 | 161 | 284 | 644 | 276 | 263 | 277 | 434 | 637 |
| LowLk,0-4 | 223 | 195 | 444 | 192 | 181 | 230 | 617 | 320 |

Note: Shaded cells only correspond to segments located near the lake boundary.

# 1 Introduction

## 1.1 Purpose and Objectives

Cardno ENTRIX is assisting the Upper Neuse River Basin Association (UNRBA) in determining the best approach to address the requirements and the Consensus Principles (Local Governments in Falls Lake Watershed 2010) regarding the re-examination of Stage II of the Falls Lake Nutrient Management Strategy (N.C. Rules Review Commission 2010). Four project tasks are designed to provide the UNRBA with the information needed to make informed decisions regarding the next steps to implement the re-examination and to develop jurisdictional loads for regulatory and program implementation purposes:

Task 1. Develop a Framework for a Re-examination of Stage II of the Falls Lake Nutrient Management Strategy

Task 2. Review Existing Data and Reports to Summarize Knowledge of Falls Lake and the Falls Lake Watershed

Task 3. Review Methods for Delivered and Jurisdictional Nutrient Loads

Task 4. Recommend Future Monitoring and Modeling

Task 2 of this project involves compilation, review, and comparison of all electronically available Falls Lake water quality and watershed data. As part of this effort, all existing reports (Section 2) and data have been compiled along with available information on field and laboratory methods and procedures (Section 3). Water quality data from 1999 to June 2012 have been compiled and organized in a Microsoft Access database which will be provided to the UNRBA. To summarize and characterize the spatial, temporal, and procedural variation in the data, the database was exported to SAS Enterprise Server to generate summary statistics and box plots of the data grouped into three geographic areas: Tributaries, Upper Lake, and Lower Lake (Section 3).

The database developed for Task 2 will support work under Tasks 3 and 4. Task 3 will combine the water quality concentration data compiled in Task 2 with flow data to estimate tributary loading to the lake. The database will also be used to support the identification of data gaps with respect to parameters, locations, and frequency which will be addressed in the planning of future monitoring studies (Task 4). Task 1 is an "umbrella" task that integrates information from the other tasks to develop a framework for re-examining the Stage II Rules.

## 1.2 Background Information

The North Carolina General Assembly's 2005 "Clean Lakes Act" (S.L. 2005-190) generated intensive data collection in water supply reservoirs across the State, including Falls Lake. Based on water quality monitoring conducted primarily in 2006, a portion of Falls Lake, from the confluence of the Eno and Flat River arms to the Interstate 85 Bridge (I-85), was included on the 2008 303(d) list as impaired for aquatic life due to violations of the turbidity and chlorophyll *a* water quality criteria. Another portion of Falls Lake, from the I-85 Bridge downstream to the dam was also determined to be impaired for aquatic life due to violation of the chlorophyll *a* water quality criteria (2008 303(d) list). The water quality criteria for chlorophyll *a* and turbidity are 40 µg/L and 50 nephelometric turbidity units (NTU), respectively. NCDWQ lists a waterbody as impaired if ten percent or more of the data (minimum of ten samples) violates the water quality criteria. The 2008 impairments were based on data collected between 2002 and 2006.

Table 1-1 summarizes the impairment listings for Falls Lake segments for the bi-annual listing cycles following the initial listing in 2008. The impairments are specified by assessment unit number, which is a unique identifier that NCDENR uses to define specific segments of a waterbody. The designated use affected by the impairments is Aquatic Life. Other designated uses of the lake include municipal drinking water supply, recreation, and flood storage. Table 1-1 only lists impairments requiring a total maximum daily load (TMDL) or other management strategy (Category 5). Once a waterbody is listed as impaired, a management strategy is required to improve water quality and remove the waterbody from the list of impaired waters. The chlorophyll *a* impairment is now classified as a Category 4 impairment due to the approval of the Falls Lake Nutrient Management Strategy in December 2010.

**Table 1-1 Falls Lake 303(d) Water Quality Impairments**

| Listing Year | Water Body | Assessment Unit Number | Cause of Impairment | Use Support Category | Use Support Rating | Category |
|---|---|---|---|---|---|---|
| 2008 | Flat River (incl. Flat R. Arm of Falls Lake) | 27-3-(9) | Low Dissolved Oxygen | Aquatic Life | Impaired | 5 |
| | Neuse River (From Source to I-85 Bridge) | 27-(1) | Turbidity; Chlorophyll a | Aquatic Life | Impaired | 5 |
| | Neuse River (From I-85 Bridge to Dam) | 27-(5.5) | Chlorophyll a | Aquatic Life | Impaired | 5 |
| 2010 | Flat River (incl. Flat R. Arm of Falls Lake) | 27-3-(9) | Low Dissolved Oxygen | Aquatic Life | Impaired | 5 |
| | Neuse River (From Source to I-85 Bridge) | 27-(1) | Turbidity; Chlorophyll a | Aquatic Life | Impaired | 5 |
| | Neuse River (From I-85 Bridge to Panther Creek) | 27-(5.5)a | Turbidity; Chlorophyll a | Aquatic Life | Impaired | 5 |
| | Neuse River (From Panther Creek to Falls Dam) | 27-(5.5)b | Chlorophyll a | Aquatic Life | Impaired | 5 |
| 2012 | Flat River (incl. Flat R. Arm of Falls Lake) | 27-3-(9) | Low Dissolved Oxygen | Aquatic Life | Impaired | 5 |
| | Neuse River (From Source to I-85 Bridge) | 27-(1) | Turbidity[1] | Aquatic Life | Impaired | 5 |
| | Neuse River (From I-85 Bridge to Panther Creek) | 27-(5.5)a | Turbidity[1] | Aquatic Life | Impaired | 5 |

The Falls Lake Rules (15A NCAC 02B .0275 Falls Water Supply Nutrient Strategy) were developed by the Division of Water Quality (DWQ), passed by the Environmental Management Commission (EMC) in November 2010, and approved by the Rules Review Commission in December 2010 (N.C. Rules Review Commission 2010). The Falls Lake Nutrient Management Strategy rules require reductions in nitrogen and phosphorus loads from significant sources throughout the Falls Lake Watershed. The two-stage (Stage I and Stage II) implementation plan requires attainment of nutrient-related water quality standards in the lower part of the lake (downstream of State Route 50) by 2021 and in the entire Falls Reservoir by 2041. If a segment of the lake achieves compliance with nutrient-related water quality standards for at least two consecutive use support assessments (approximately four years) prior to these dates, then additional load reductions are not required. Stage II of the Nutrient Management Strategy will likely require a 40 percent reduction in nitrogen loading and a 77 percent reduction in phosphorus loading relative to baseline 2006 conditions. The rules identify the parties (municipalities, counties, agriculture, and state and federal entities) responsible for implementing the nutrient reductions.

The citizens of the watershed are facing financially burdensome challenges as a result of the Falls Nutrient Strategy rules, particularly the Stage II Rules. Given the uncertainties associated with the water quality criteria with respect to attainment of designated uses (specifically chlorophyll *a*), model-based load allocations, and ecosystem response, the Falls Lake Nutrient Management Strategy rules explicitly allow for re-evaluation of the Stage II Rules. Further, uncertainty associated with the water quality targets and algal growth dynamics is documented in meeting minutes recorded in several Falls of the Neuse and High Rock Lakes Combined Technical Advisory Committee (TAC) meetings. For example, during an August 29, 2005 meeting, NCDWQ stated, “based on what NCDWQ staff has read in files from the 1970s, Water Resources Research Institute (WRRI) did not have a specific designated use that they were trying to protect by utilizing the 40 µg/L chlorophyll *a* criteria.” In addition to having no direct correlation between designated uses and the pre-established State criteria, there has been no stressor-response evaluation for this system. During the May 15, 2007 meeting, NCDWQ pointed to correlation matrices indicating that light was the limiting factor for algal growth above State Route 50. At the November 15, 2007 TAC meeting, NCDWQ mentioned that nitrogen was most commonly the limiting nutrient for algal growth while phosphorus limitation and/or co-limitation occurred less frequently; NCDWQ also speculated that the nutrient management strategy would likely require larger reductions of nitrogen than phosphorus. These statements are not consistent with the adopted Rules which require nearly twice the reduction in phosphorus relative to nitrogen.

## 1.3 Organization

This technical memorandum (TM) summarizes the monitoring efforts and studies conducted for Falls Lake and its watershed from 1999 to June 2012. In addition to summarizing the water quality data, the report also includes information regarding time period, frequency, organization, location, and field and lab methodologies. Differences in field and lab methodology between studies are identified. The TM is organized into the following sections:

> Section 2 provides a compilation of published reports and studies for the watershed.

> Section 3 describes the water quality database and provides summary statistics and box plots for fifteen parameters in three geographic regions (Tributaries, Upper Lake, Lower Lake)

> Section 4 provides a condensed version of the statistical summaries for the fifteen parameters.

> Section 5 evaluates the ability of the information provided in Sections 2, 3, and 4 to address the key issues described in the Scope of Work defined by the UNRBA.

> Section 6 lists the references documented in this report.

The report is also supported by five appendices:

> Appendix A presents the data summaries for four impoundments in the Falls Lake Watershed.

> Appendix B presents the data summaries for the Upper and Lower Lake segments of Falls Lake combined.

> Appendix C provides direct excerpts from many of the reports summarized in this TM. Much of this content is directly copied from those reports and is not paraphrased by Cardno ENTRIX. The purpose of this appendix is to provide information on Falls Lake and its watershed in a common format and in a single location.

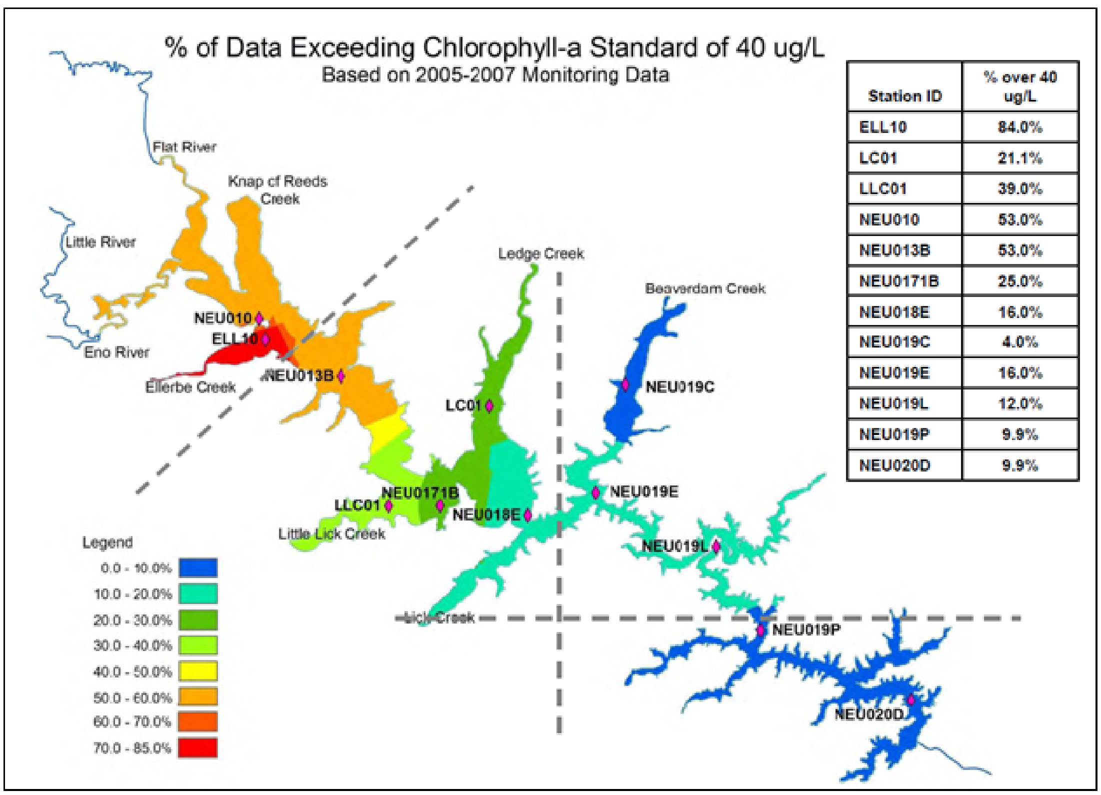
> Appendix D contains subwatershed maps showing the sampling points, waterbodies, and land uses in the watershed.

> Appendix E contains the descriptions of the laboratory analyses used to analyze the water quality parameters discussed in this TM.

# 2 Existing Reports and Studies

This section of the technical memorandum summarizes reports and studies published for the watershed from 1999 to 2012. A few historical documents are referenced to provide insight into the conditions present prior to construction of the dam, to summarize the predicted Falls Lake conditions, and to compare existing data summaries to those predictions.

A common theme among the current researchers of water quality in Falls Lake is the improvement in water quality from the upstream end of the lake near I-85 to the downstream end of the lake at the dam (NCDENR 2001, 2006, 2010, 2011b; Ecoconsultants 2009; Giorgino 2012; and Huisman 2012). Figure 2-1 presented by NCDWQ staff at the 2012 NC Lake Management Society meeting shows the percent exceedance for chlorophyll *a* at various locations in the lake. The highest levels of chlorophyll *a* occur in the upstream segments of the lake, with increasing improvement occurring downstream toward the dam. As described in Section 2.2, this longitudinal improvement in water quality was predicted in the studies that preceded construction of the dam (State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources 1973, USACE 1974).




| Station ID | % over 40 ug/L |
|---|---|
| ELL10 | 84.0% |
| LC01 | 21.1% |
| LLC01 | 39.0% |
| NEU010 | 53.0% |
| NEU013B | 53.0% |
| NEU0171B | 25.0% |
| NEU018E | 16.0% |
| NEU019C | 4.0% |
| NEU019E | 16.0% |
| NEU019L | 12.0% |
| NEU019P | 9.9% |
| NEU020D | 9.9% |

**Figure 2-1 Percent Exceedance of Chlorophyll *a* Standard by Lake Segment (from Huisman 2012)**

## 2.1 Historic Documents

Two historic documents are summarized in this section to provide a point of reference of current water quality trends relative to what was expected before the dam was constructed. The documents summarized in this section include a Special Analysis of the Falls of the Neuse Project (State of North

Carolina 1973) and the Final Environmental Impact Statement Falls Lake Neuse River Basin North Carolina (USACE 1974).

### 2.1.2 Special Analysis of the Falls of the Neuse Project

In 1973, the State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources released its Special Analysis of the Falls of the Neuse Project (Special Analysis). Predictions of water quality in the lake were an importance focus of the report, and it was generally accepted that water quality in the upper end of the lake would result in algal blooms due to the shape and residence time of the waterbody. The expectation was that this area of poorer water quality would not negatively impact the drinking water supply intake at the downstream end of the lake, and that the benefits of the lake (flood protection in particular) outweighed the risks associated with eutrophic conditions in the upper most segment. It was expected that taste and odor problems at the water treatment plant would sometimes occur following fall turnover, but for the most part algal blooms would not cause problems for the facility. The objectives of the Falls Lake project (flood control, water supply, water quality enhancement, and recreation) were reported to be a source of contention amongst the various stakeholder groups. This section of the TM summarizes several of the key points documented in this report.

According to the Special Analysis, the primary purpose for the Falls Lake project was flood control: downstream flooding caused average annual damages of approximately $1.3 million in 1972 dollars. Based on the level of historic floods that occurred in 1929 and 1964, damage projections reached up to $8.3 million dollars given the land uses present at the time. Flood damage protection following dam construction was estimated to range from 30 to 70 percent depending on downstream location.

Prior to the lake's construction, the Neuse River at this location was a source of drinking water for the City of Raleigh. With respect to drinking water supply from the lake project, the State of North Carolina predicted that due to the long narrow configuration of the lake, high expected rates of sedimentation, and location of the intake at the dam, drinking water treatment processes to control taste and odor problems associated with algae would not be necessary except during the two weeks following fall turnover (State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources 1973).

The lake was also expected to provide wildlife, aquatic resources, and recreation benefits for the area. Prior to the construction of the Dam, the lake was predicted to provide "significant benefits to the fish and wildlife resources of the basin," (State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources 1973). The State of North Carolina (1973) stated that although recreation benefits would be realized with the project, recreation was not the major purpose of the project.

As with most natural and manmade lakes, the project was expected to result in improvements to water quality in downstream waters via sedimentation and nutrient trapping. Approximately 71,000 acre-feet of storage were allocated to improve water quality and provide a minimum release of 150 cfs at least 99 percent of the time; the 7Q10 for the Neuse River at that location was approximately 30 cfs prior to construction of the dam. The study predicted that dissolved oxygen concentrations in the lake would be sufficient to support aquatic life, with the exception of the hypolimnion which would likely become anoxic during the summers. Phosphorus removal and entrapment through sedimentation processes were expected to protect the lake from highly eutrophic conditions and undesirable algae blooms. Phosphorus removal in the lake was predicted to be between 70 and 90 percent.

Prior to its impoundment, the Neuse River above the proposed dam was determined to be a poor source of water quality due to the "poor quality of the water during low flows, high sediment loads," and need to maintain minimum flows downstream. The Neuse River was determined to be moderately enriched above the proposed dam site with near full recovery just downstream. Predicted total nitrogen concentrations in the lake were estimated to remain at or below 1.5 mg/L. Algal blooms were expected to occur only in the extreme upper reaches of the lake due to the lakes long, narrow configuration and relatively low rate of flow. (Recent monitoring indicates that blooms in the lower lake sometimes occur in the spring and fall). According to the Special Analysis, the EPA predicted that Falls Lake would experience “at least some eutrophic effects” by the late 1990s and that nitrogen and phosphorus levels in the lake would be approximately 2.5 mg/L and 0.38 mg/L, respectively. Some sections of the report indicate that nitrogen would be the limiting factor for algal growth in the reservoir; other sections indicate that phosphorus would be the limiting factor. At the time of this study, it was recommended that point source discharges of nitrogen, phosphorus, and oxygen demanding waste be limited, but it was also recognized that approximately 50 percent of the pollutant loading would originate from “uncontrollable non-point sources.”

### 2.1.3 USACE Final Environmental Impact Statement

In 1974, the USACE published the Final Environmental Impact Statement (Revised) Falls Lake Neuse River Basin North Carolina, which predicted similar spatial trends in water quality compared to the Special Analysis discussed in Section 2.1.2. Prior to the construction of the dam, it was anticipated that water quality in the upper section of the lake would be less than desirable. The Final Environmental Impact Statement predicted that “abundant productivity in the upper reaches of the lake may be unpleasant to some…it is anticipated that these areas will be attractive to fishermen but not to pleasure boaters and water skiers. Therefore, it is likely that these areas will be restricted to fishing use only” (USACE 1974). The document went on to say that the effects would be associated with algae growth and vascular plant growth, and that the sight of this abundant plant growth in the upstream areas of the lake may not be pleasant to some people (USACE 1974).

## 2.2 NCDENR Reports

### 2.2.1 NCDWQ Quality Assurance Issues

In 2011 NCDENR published its Intensive Survey Unit Standard Operating Procedures Manual (NCDENR 2011c). Appendix 5 of this document describes past data quality assurance issues associated with chlorophyll *a* and nutrient data.

#### *2.2.1.2 Chlorophyll a*

The NCDWQ’s Ambient Data Explanations Document, version 2.4, Important Information for Users of North Carolina Ambient Water Quality Monitoring Data (NCDENR 2011c), noted that the State’s water quality laboratory chlorophyll *a* values from 1996 through 2001 were not corrected for pheophytin. These chlorophyll values could be expected to be slightly higher than the associated chlorophyll *a* value when corrected for pheophytin. Apparent increases in chlorophyll *a* during this time period for NCDWQ samples may be an artifact of the analytical method. Beginning in 2001 NCDWQ used new equipment and methods to calculate chlorophyll *a* that automatically compensate for pheophytin and chlorophyll *b*. Chlorophyll *a* data from NCDWQ is not available from April through August 2005 because laboratory protocols were not followed. The NCDWQ believes that chlorophyll *a* data prior to 1996 are accurate.

The Division of Water Quality initiated laboratory round robins in 2010 and 2011, using samples from Raleigh area waterbodies, to investigate differences in chlorophyll *a* measurements between laboratories. For each round robin a single water sample was divided into the same number of samples as laboratories participating in the study. Each laboratory analyzed the sample for chlorophyll *a* according to their protocols. The results of these round robins provided insight into the quality of data produced by different laboratories and the uncertainty associated with results. There was significant variability in chlorophyll *a* results between sub-samples and laboratories. The variance (standard deviation) in chlorophyll *a* measurements due to differences between labs was 4.7 µg/l in 2010 and 3.8 µg/l in 2011.

#### *2.2.1.3 Nutrients*

In early 2001 the NCDWQ laboratory reviewed its analytical methods and quality assurance procedures for a number of water quality parameters (NCDENR 2011c). Revisions to the reporting levels were made for a number of parameters including total phosphorus (TP), ammonia ($NH_3$), nitrate plus nitrite ($NO_2/NO_3$), and total Kjeldahl nitrogen (TKN). The reporting levels increased significantly for these analytes for much of 2001 (Table ES-9). New procedures and methods were implemented in July 2001 and detection limits reestablished that were similar to the old detection limits with a couple of exceptions. These changes in detection limit should not be interpreted as a doubling of the lower concentrations of these parameters.

**Table ES-9 Changes in Reporting Levels for Nutrients During 2001 (NCDENR 2011c)**

| Parameter | Pre-2001 | 3/13/2001 to 3/29/2001 | 3/30/2001 to 7/24/2001 | 7/25/2001 to present |
|---|---|---|---|---|
| $NH_3$ | 0.01 | 0.5 | 0.2 | 0.01 |
| TKN | 0.1 | 1.0 | 0.6 | 0.20 |
| $NO_2/NO_3$ | 0.01 | 0.5 | 0.15 | 0.01 |
| TP | 0.01 | 0.5 | 0.1 | 0.02 |

### 2.2.2 Basinwide Assessments

The North Carolina Department of Environment and Natural Resources (NCDENR) publishes Basinwide assessment reports for the Neuse River Basin approximately every five years. As described in each report, the Flat, Eno, and Little Rivers primarily drain lands in the Carolina Slate Belt, while Ellerbe, Ledge, Beaverdam, and Lick Creeks also drain Triassic basin soils. Geologic differences result in variations in erosion and runoff characteristics. Water quality and biological indicators are typically better in the Flat, Eno, and Little River subwatersheds compared to the Ellerbe, Ledge, Beaverdam, and Lick Creek subwatersheds, which are also impacted by urban development and point source discharges. Areas south of Falls Lake tend to be in more sandy soils. The lake itself is described as shallow and wide upstream of NC Highway 50 (Hwy 50) and more narrow and deep downstream.

For the purposes of these Basinwide assessments, water samples are collected from the photic zone and preserved in the field with concurrent measures taken for chemical and physical parameters. Samples collected in the photic zone (over twice the Secchi depth) or at bottom depths are collected using a Labline sampler. A calibrated Hydrolab is used to measure field parameters.

Algal samples are analyzed to determine the assemblage structure, density (units/ml), and biovolume ($m^3/mm^3$). These results are used to assess bloom severity based the number of filaments, colonies, or single celled taxa in a sample. NCDENR (2011a) ranks the severity and dominance of blooms as follows: “Blooms are considered mild if they are between 10,000 and 20,000 units/ml. Moderate blooms are those between 20,000 and 30,000 units/ml. Severe blooms are between 30,000 and 100,000 units/ml. Extreme blooms are those 100,000 units/ml or greater. An algal group is considered dominant when it comprises 40 percent or more of the total unit density or total biovolume. A genus is considered dominant when it comprises 30 percent or more of the total unit density or total biovolume.”

Macroinvertebrate and fish sampling are also conducted as part of the Basinwide Assessments. Macroinvertebrate scores are based on EPT Richness and the North Carolina Biotic Index. Fish scores are based on the North Carolina Index of Biotic Integrity. Scores are ranked as Excellent, Good, Good-Fair, Fair, or Poor and are used to compare biotic integrity from one assessment period to the next. In some cases, the Basinwide Assessment report offers an explanation for changing scores; in other cases scores are presented with no hypothesis provided for the change.

As summarized below, NCDENR Basinwide Assessment reports indicate that the lake is impaired for turbidity and chlorophyll *a* in the upper part of the lake, but maintains other water quality standards, such as DO and pH.

#### *2.2.2.2 NCDENR 2001 Basinwide Assessment*

The 2001 Basinwide Assessment Report Neuse River Basin (NCDENR 2001) states that 70 percent of the 23 stream sites monitored for benthic invertebrates, fish, or both ranked Good or Excellent, and Falls Lake was categorized as eutrophic based on the NCTSI score.

NCDENR sampled Falls Lake during the summer months in 1995, 1996, 1997, and 2000 (NCDENR 2001). Secchi depth was generally less than one meter with total phosphorus and turbidity greater at the upper end of the lake. DO concentrations were generally greater than the State standard of 4 mg/L with the exception of conditions observed in September following a lake turnover event. Total phosphorus concentrations appear to decrease over this assessment period while total organic nitrogen concentrations were generally consistent. Chlorophyll *a* data were dismissed for much of this period due to quality assurance issues.

Phytoplankton assemblages were assessed in June and July in 1996 and May through September (monthly) in 1997. At the upper end of the lake, seven algal blooms occurred while at the lower end of the lake three blooms occurred. In the upper lake, five of the blooms were dominated by the filamentous blue green *Oscillatoria* and the golden flagellate *Chrysochromulina*; the other two blooms also contained greens and diatoms.

The 2001 Basinwide Assessment Report Neuse River Basin (NCDENR 2001) also included a summary of a study conducted by the City of Raleigh in 1999 for the lower part of the lake, downstream of Hwy 50. This study found that water quality in the lower lake was “very good” and chlorophyll *a* concentrations were less than the water quality standard. Algal biomass often ranged from moderate to high and was dominated by nuisance blue green algae. Algal blooms were reported to occur each year since the lake was filled in 1983. According to NCDENR (2001) this study was conducted by Spirogyra Diversified Environmental Services (SDES). The City of Raleigh developed concerns about QA/QC procedures used by SDES and now uses other consultants (personal communication, Kenneth Waldroup, City of Raleigh, 8/8/2012). Cardno ENTRIX was not able to obtain this report from the City of Raleigh, but the City did provide a similar study by SDES conducted in 2006 which is discussed below in Section 2.3.2.2.

#### *2.2.2.3 NCDENR 2006 Basinwide Assessment*

The 2006 Basinwide Assessment Report Neuse River Basin (NCDENR 2006) indicated that benthic macroinvertebrate scores declined since the 2000 sampling occurred. It was suggested that drought conditions occurring in the summer of 2005 may have caused the lower scores during the spring 2006 sampling. Fish scores did not change between 2000 and 2006, except at the North Flat River site where scores decreased from Excellent to Good.

Ambient water quality monitoring occurred in 2005 at eight stations: four stations had similar water quality in 2000 and 2005, and four stations exceeded water quality standards 10 percent of the time with a 95 percent confidence level. The lake was monitored 13 times in March through September 2005 and again in March through September 2006. The 2006 monitoring was used to support development of the Falls Lake nutrient response model and the results are not discussed in the 2006 Basinwide Assessment Report which was published in April 2006.

The upper end of the lake near I-85 had percent dissolved oxygen (DO) saturation levels greater than 120 percent and high phytoplankton concentrations as well. Total Kjeldahl nitrogen concentrations ranged from 0.37 mg/L to 1.5 mg/L with the majority comprised of organic nitrogen rather than ammonia. Total phosphorus concentrations ranged from less than 0.02 mg/L to 0.23 mg/L.

Phytoplankton assemblages were collected at three stations (one at the upper, middle, and lower section of the lake) in March, July, and October of 2005. A mild bloom of the green algae *Ankistrodesmus* and cryptomonads occurred in March. In July and October, the assemblages shifted to blue greens but cyanotoxin levels remained very low in the lake. Chlorophyll *a* concentrations were measured in March and April, but an insufficient number of samples were collected to determine compliance with the State standard of 40 µg/L.

Algal growth potential tests (AGPT) were conducted at seven stations in the lake in 2005. Above I-85, AGPT indicated that nutrients were not limiting algal growth which may be due to the high turbidity levels in this area. The lake was impaired based on turbidity upstream of I-85 and supporting its designated uses downstream. Assessment was based on the average of all samples collected on a given day within an assessment unit; i.e., samples collected on the same day in the same assessment unit are treated as replicates and averaged (NCDENR 2006). Two assessment units were defined: the source of the Neuse River to the I-85 Bridge (27-(1)) and the I-85 Bridge to the dam (27-(5.5)).

#### *2.2.2.4 NCDENR 2012 Basinwide Assessment*

The 2012 Basinwide Assessment Report Neuse River Basin (NCDENR 2012) provides a comparison of 2005 and 2010 biological sampling events. For the most part, the benthic macroinvertebrate sites that were resampled (11 stations) had the same classifications (six stations) with three sites showing improvement and two stations dropping from Good-Fair to Fair or from Good to Good-Fair. Eight fish stations were resampled in 2010 with five receiving the same classification, one station improving from Good to Excellent, and two stations decreasing in ranking from either Excellent to Good or Good to Good-Fair. Several stations were not resampled in 2010 due to budget restrictions.

The water quality assessment was published in a separate report (NCDENR 2011a) which reports on data collected at eleven water quality monitoring stations in Falls Lake sampled from January 2006 to September 2010. Samples were collected intermittently until May 2010 when monthly sampling began. Secchi depths were generally less than one meter and there were no values for surface DO below the state water quality standard of 4.0 mg/L during the assessment period. Total phosphorus concentrations ranged from less than 0.02 mg/L to 0.71 mg/L and total Kjeldahl nitrogen ranged from 0.36 mg/L to 3.40 mg/L with the majority comprised of organic nitrogen as opposed to ammonia. Chlorophyll *a* exceeded the State standard 28 percent of the time.

### 2.2.3 <u>Water Quality Summaries</u>

NCDENR has also developed data summaries for water quality monitoring efforts in Falls Lake. The 2010 data summary (NCDENR 2010) based on monthly samples collected from May to December 2010 showed that mean total phosphorus concentrations were highest at the most upstream station above I-85 (0.12 mg/L at station NEU013), lower at the compliance point downstream of I-85 (0.08 mg/L at station NEU013B), with mean concentrations at other locations in the upper lake ranging from 0.04 mg/L to 0.05 mg/L and in the lower lake ranging from 0.02 mg/L to 0.03 mg/L. Mean total nitrogen concentrations were 0.99 mg/L at NEU013, to 0.85 mg/L at NEU013B, and decreased steadily to 0.57 mg/L at the most downstream station NEU020D. Chlorophyll *a* concentrations are no longer monitored above I-85 due to high turbidity (personal communication, Jason Green NCDWQ). The mean chlorophyll *a* concentrations at NEU013B and NEU020D were 36 µg/L and 12 µg/L, respectively.

The 2011 data summary for Falls Lake (NCDENR 2011b) was based on monthly samples collected during the year. Total phosphorus concentrations were highest at the most upstream station above I-85 (0.16 mg/L at station NEU013), lower at the compliance point downstream of I-85 (0.12 mg/L at station NEU013B), with mean concentrations at other locations in the upper lake ranging from 0.04 mg/L to 0.06 mg/L and in the lower lake ranging from 0.02 mg/L to 0.04 mg/L. Mean total nitrogen concentrations were 1.59 mg/L at NEU013, to 1.30 mg/L at NEU013B, and decreased steadily to 0.67 mg/L at the most downstream station NEU020D. The mean chlorophyll *a* concentrations at NEU013B and NEU020D were 53 µg/L and 11 µg/L, respectively.

### 2.2.4 Modeling Studies

NCDENR developed three models in 2009 that include hydrologic and water quality response in the Falls Lake watershed. The watershed model and lake response model were developed to determine the nutrient load allocations for the Falls Lake Rules. The hydrologic model was developed to support NCDENR's long term water supply planning and management. These models and associated reports are described briefly in this section. The purpose of this section is to allow for comparisons among the sources of data used to develop these studies relative to the full set of data available in the watershed. In general, the recent NCDENR modeling studies focusing on Falls Lake and its watershed have used a relatively small subset of the available data to develop, calibrate, and validate the models.

The results of these modeling studies in terms of load allocations and reduction strategies will be discussed further in the Task 3 memorandum.

#### *2.2.4.2 Falls Lake Watershed Analysis Risk Management Framework (WARMF) Development*

The Division of Water Quality (DWQ) published the results of the Falls Lake WARMF modeling to assess watershed loading of nitrogen and phosphorus to Falls Lake (NCDENR 2009b). The model was developed in cooperation with a Technical Advisory Committee (TAC) consisting of several members of the UNRBA, the North Carolina Department of Transportation (NCDOT), and the NCDWQ.

The model inputs were based on data collected from 2004 to 2007. Seven meteorology stations operated by the NC State Climate Office provided data for the weather inputs. The primary source for the land use data was the 2001 National Land Cover Data (NLCD) with enhancements based on City of Durham and NCDOT data. The WARMF model converts land use areas into percentages for each model catchment. For the Falls Lake watershed, the major land use types are forest (58 percent), agriculture (18 percent), urban (11 percent), shrub/grassland (6 percent), water/wetlands (5 percent), and NCDOT (2 percent). Soils data were obtained from the USDA-NRCS Soil Data Mart and soil parameters were aggregated to the model catchment using weighted averages based on percent composition. Streambank erosion does not appear to have been included in the model.

Data from eight USGS flow gages were used to develop the model along with water quality data from six NCDWQ ambient monitoring stations and two USGS stations. Prior to March 2005, NCDWQ monitored the ambient stations monthly. From March 2005 to September 2007 the frequency was increased to twice per month to support the modeling studies.

Nine reservoirs were modeled using WARMF. Hydrologic inputs and outputs were simulated, but water quality and nutrient trapping were not. Descriptions of the data sources and assumptions for simulating atmospheric deposition, onsite wastewater treatment systems, etc. will be discussed in the Task 3 TM.

#### *2.2.4.3 Falls Lake Nutrient Response Model*

In conjunction with the Falls Lake WARMF modeling, NCDWQ also developed a Falls Lake Nutrient Response Model using the Environmental Fluid Dynamics Code (EFDC) model (NCDENR 2009a). The models do not appear to be formally linked; i.e., output from the WARMF model was not used to derive inputs to the EFDC model. The Falls Lake TAC was also consulted during development of the lake response model. The EFDC model is a three dimensional hydrodynamic/water quality model capable of simulating eutrophication with multiple algal species including cyanobacteria, diatoms, and green algae.

The Falls Lake nutrient response model was developed using data collected from 2005 to 2007 from many of the same agencies used to develop the WARMF model: USGS flow and water quality data, NCDWQ ambient monitoring data, NC State Climate office meteorological data, and NADP atmospheric deposition data. For the purposes of developing the model, 2005 and 2007 were considered dry years and 2006 was considered a normal year based on total annual precipitation. It should be noted that in 2006, two very large storm events impacted the watershed (the implications of the event that occurred in June 2006, Hurricane Alberto, on the modeling of the Lake will be explored in Task 3).

Monitoring data were used to develop the model input files at a 30 second time step. TSS, nitrogen, and phosphorus inputs were generated using NCDWQ ambient monitoring data collected in tributaries to the lake. Chlorophyll *a* and TOC inputs were generated using observations collected in the lake at the closest station to the tributary being simulated. These data are reflected in the data summaries in Section 3. The EFDC modeling grid and water quality monitoring stations are shown in Figure 2-2.

DWQ measured benthic flux rates of ammonia, nitrite plus nitrate, and total phosphorus in April 2006. Ammonia fluxes were measured at two locations and were approximately 0.01 and 0.05 $g/m^2/d$. Ammonia flux is also evident in the depth plots provided for the Upper and Lower Lake samples; Figure 3-105 shows that higher ammonia concentrations were observed in the bottom depths of the Upper Lake section. Nitrite plus nitrate and total phosphorus fluxes were insignificant, and the box plots of these parameters support the conclusion that these fluxes are negligible across the lake as a whole: surface concentrations of nitrite plus nitrate and total phosphorus are higher than middle or bottom depths (Figure 3-125 and Figure 3-194, respectively). Note that the box plot analysis assesses all samples and locations within the lake segment (Upper versus Lower) and that localized benthic releases would not be evident at this scale. This source of nutrient loading will be addressed further in Task 3. NCDWQ also measured sediment oxygen demand, and the average rate observed was -1.4 $g/m^2/d$.

The results of the calibration, validation, and application of the Falls Lake nutrient response model in the development of the nutrient strategy will be assessed in Task 3.

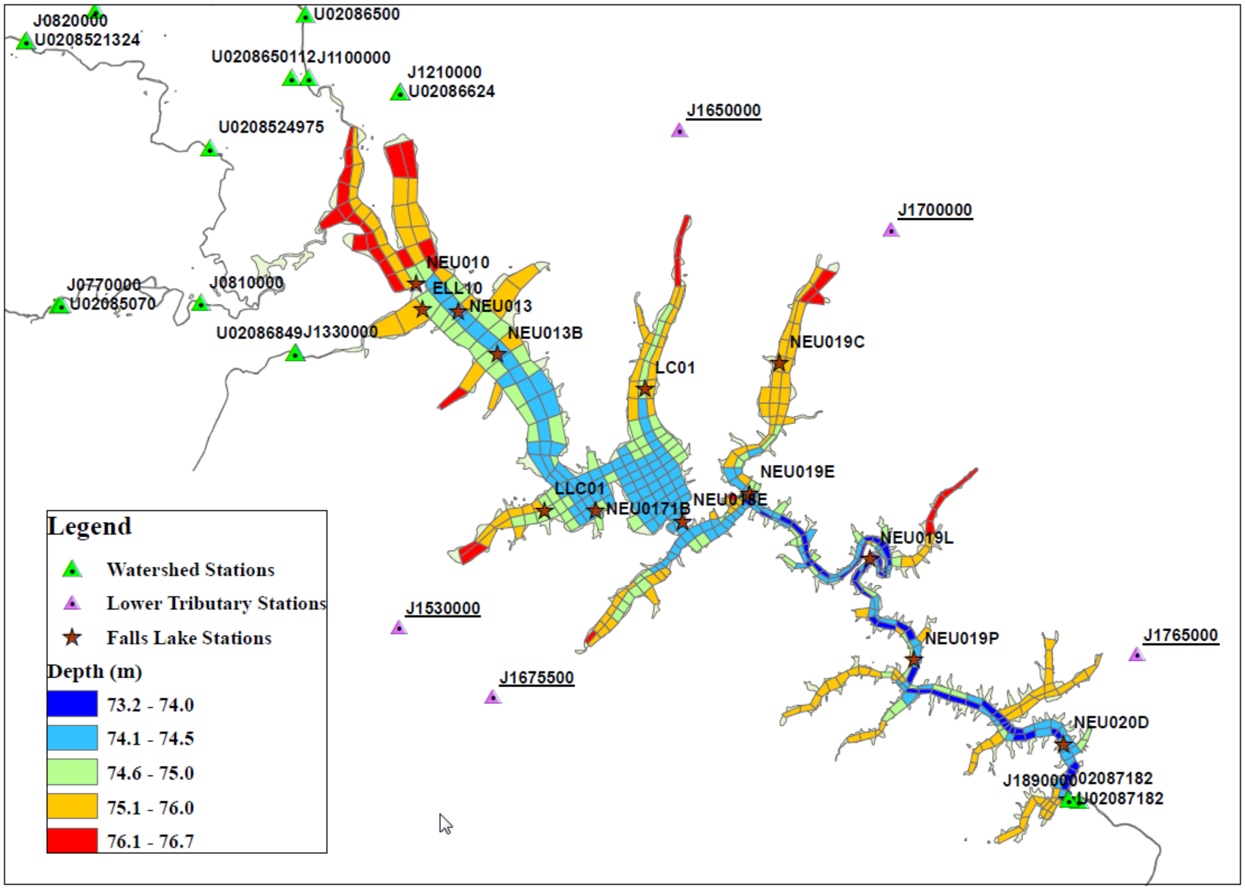



**Figure 2-2 Falls Lake EFDC Modeling Grid (from NCDENR 2009a)**

#### *2.2.4.4 Neuse River Basin Hydrologic Model*

The Division of Water Resources released the Neuse River Basin Hydrologic Model (NCDENR 2009c) which uses a mass balance approach to simulate water demand and water management scenarios. The spatial extent of the model is from the headwaters of the Eno, Flat, and Little Rivers to the mouth of the Neuse River in Craven County, and the period of record used to drive the model begins January 1, 1930 and ends April 30, 2008. Nine reservoirs, including Falls Reservoir, are accounted for in the Upper Neuse River Basin. Twenty two USGS gages were used to build the model, and nine of these are located in the Upper Neuse River Basin. The model computes “unimpaired” flows at each gage (flows that would be present without agricultural/water supply withdrawals, wastewater discharges, reservoirs, etc.) prior to running scenarios and runs on a daily time step.

## 2.3 Other Relevant Studies

Several additional studies have been conducted on Falls Lake to assess water quality and its impacts on designated uses such as drinking water. This section summarizes those reports. Several of these organizations, as well as other agencies and local governments, have provided water quality monitoring data that are discussed in Section 3.

### 2.3.1 Upper Neuse Watershed Management Plan

In 2003, the Upper Neuse River Basin Association developed the Upper Neuse Watershed Management Plan (Tetra Tech, Inc. 2003). A scoping level analysis based on data and studies conducted by USGS and NCDWQ from 1983 to 2002 led to the following conclusions:

> Total phosphorus concentrations had declined significantly from 1983 to 2002 due to improvements at wastewater treatment plants (WWTP) and the statewide ban on the use of phosphates in laundry detergent.

> Total nitrogen concentrations were generally stable at most sites from 1983 to 1995, but generally decreased at the Eno River near Hillsborough, Little River near Orange Factory, Little River Reservoir, and Lake Michie.

> Improvements at WWTPs increased DO in streams, decreased nutrient concentrations in streams, and improved toxicity testing in receiving streams.

> Watershed loads of nitrogen and phosphorus decreased by 50 percent and 20 percent, respectively, compared to 1989 to 1994 loads.

> Though nutrient loads to Falls Lake appeared to be declining, chlorophyll *a* concentrations appeared to be increasing.

### 2.3.2 <u>City of Raleigh</u>

The City of Raleigh has been studying water quality in Falls Lake to optimize and manage the E.M. Johnson Water Treatment Plant (WTP). Of particular interest is the formation of disinfection byproducts which are toxic to humans and regulated by USEPA and the NC Division of Water Resources, Public Water Supply Section. When lake water is treated to produce drinking water and disinfection is achieved with the use of chlorination techniques, there is a potential to produce harmful disinfection byproducts (DBP). Because DBP formation is correlated to the amount of organic material in the raw water, USEPA requires removal of organic material prior to treatment and disinfection (USEPA 2010a). The City of Raleigh monitors total organic carbon (TOC) for compliance and operational planning.

#### *2.3.2.2 Spirogyra Diversified Environmental Services Report on Algal Related Tastes and Odors from Falls Lake Reservoir*

In 2006, Spirogyra Diversified Environmental Services (SDES) developed a report for the City of Raleigh that assessed the relationship between taste and odor episodes at the E.M. Johnson WTP with measurements of temperature, DO, pH, specific conductance, turbidity, chlorophyll *a*, and phycocyanin. Analysis of seven years of data indicated that spring blooms occur annually, typically in March, and are often comprised of diatoms and golden algae (chrysophytes). These species require abundant amounts of silica to grow and several genera produce odorous metabolites. The Raleigh E.M. Johnson WTP also performs annual flushing and chlorine burnout in March, which typically takes approximately four weeks to transition back into chloramines (personal communication, Kenny Waldroup, City of Raleigh, 8/8/2012), and the majority of the taste and odor complaints from water users are filed in March and April each year. Analysis of seven years of data indicated that spring blooms occur annually, typically in March, and are often comprised of diatoms and golden algae (chrysophytes). These species require abundant amounts of silica to grow and several genera produce odorous metabolites. The majority of the taste and odor complaints from water users are filed in March and April each year. A linear regression indicated a relationship between chrysophytes biomass and the number of taste and odor complaints with an $r^2$ of 0.33. SDES recommended that 1) WTP operators alter the depth of the intake to avoid algal blooms in the water column and 2) treat the intake water that is stored in separate basins prior to entering the plant with chemicals such as potassium permanganate to reduce odor problems associated with these algae.

#### *2.3.2.3 Ecoconsultants Synopsis of Chlorophyll a Trends in Falls Lake*

In 2009, Ecoconsultants prepared a report for the City of Raleigh summarizing the chlorophyll *a* sampling that has occurred in the reservoir from 1983 to 2009. This analysis included chlorophyll *a* data from NCDWQ, a City of Raleigh contractor (Spirogyra Diversified, Inc.), North Carolina State Center for Applied Aquatic Ecology (CAAE), and the US Geological Survey (USGS). The assessment included data collected at four monitoring sites: the dam (or water intake), Hwy 98, Hwy 50, and I-85. According to the report, the NCDWQ, Spirogyra, and USGS samples were extracted and processed in a laboratory consistent with the approach required to assess compliance with the State standard of 40 µg/L. The CAAE performed both extracted chlorophyll *a* measurements as well as in vivo sampling measurements of the relative fluorescence units (RFU) of the lake water. This measurement is associated with the total green pigments in the water including living and recently dead plant and algal material. RFU data is typically used to optimize operations at potable water treatment plants by showing plant managers where higher plant-algal biomass or plant-algal debris are present. The USGS changed extracted chlorophyll *a* methods in July 2006 switching from the selective high-performance liquid chromatography (HPLC) to the flourometric method and reportedly advised caution when comparing results from the two methods. The CAAE collected both discrete and composite samples. Data from other sources were generally collected as composite samples over the twice the Secchi depth.

The report summarizes water quality trends in the lake similar to the NCDENR Basinwide Assessment Reports (2001, 2006, 2010, and 2011b) with Secchi depth, nutrients, turbidity, and chlorophyll *a* improving from the upstream end of the lake to the dam. The highest extracted chlorophyll *a* measurements were observed near I-85 at the upper end of the lake, which is also the compliance point for chlorophyll *a* (NEU013B). According to the report, filling of the lake in 1983 resulted in mass loading of organic material and associated nutrients. Chlorophyll *a* concentrations at I-85 continued to exceed the State standard following inundation, but the downstream stations have shown improvements in chlorophyll *a* concentrations over the past few decades. There are some excursions of the chlorophyll *a* standard downstream of I-85, and for the most part, if the criteria were exceeded at the dam, they were also exceeded at I-85 though there are a few exceptions, likely due to large precipitation events flushing the upstream waters towards the dam. Elevated chlorophyll *a* concentrations at I-85 are due to the large tributaries entering the lake just upstream of I-85; the shallow depth in this section of the lake; and the wetting and drying cycles that result in plant growth, decay, and nutrient releases.

In vivo measurements of chlorophyll *a* collected by CAAE are measured in the lake nearly instantaneously which allows for collection of a larger dataset relative to the extracted methods which are processed in a laboratory. In Falls Lake, in vivo measurements of relative fluorescence indicate lower fluorescence levels at depths less than one meter, with peaks often occurring two meters to four meters below the surface. The Ecoconsultants report states that light sufficient for algal growth is often present at depths up to four meters, and that measurements of chlorophyll *a* sampled from the water column over twice the Secchi depth may be omitting the area where primary productivity is greatest. Monitoring by CAEE indicate that high fluorescence in the deeper waters is often associated with detritus.

Both CAAE and the City of Raleigh monitor the fluorescence of chlorophyll *a* and C-Phycocyanin to monitor changes in the ratio of these values. C-Phycocyanin is the primary pigment associated with Cyanophyta (blue green algae) and shifts in the ratio of these two pigments may indicate shifts in phytoplankton species. Monitoring these ratios is used to alert WTP operators of potential taste and odor problems, algal toxins, and algal blooms. For example, in the spring of 2009, an algal bloom occurred with twice the levels of diatoms typically present in a normal spring bloom which caused decreased filter run times at the E.M. Johnson WTP. Chlorophyll *a* measurements during this time were elevated, but the C-Phycocyanin was relatively low.

#### *2.3.2.4 Fiscal Note Support for Falls Lake Source Water Quality Impacts to Drinking Water Treatment*

In 2009, the City of Raleigh prepared a fiscal analysis of water quality on drinking water treatment costs (Hazen and Sawyer 2009). This report was recently updated by Hazen and Sawyer (2012) to include more recent years of data. The reports include an analysis of TOC data collected from 1999 to spring 2012, as summarized in Table 2-1. TOC concentrations were generally highest during the 1999 to 2002 period and lowest during the 2003 to 2006 period. Concentrations increased during the 2007 to spring

2012 period, but were not as high as the 1999 to 2002 observations according to the Hazen and Sawyer (2012) report. Information presented in these reports regarding costs, chemical usage, etc. will be presented in the Task 1 memorandum.

**Table 2-1 Summary of TOC Trends at Falls Lake Intake (Hazen and Sawyer 2009 and 2012)**

| Water Quality Parameter | Time Frame | Percent of Observations Less than or Equal To | | | | Average | Maximum |
|---|---|---|---|---|---|---|---|
| | | 25% | 50% | 75% | 90% | | |
| TOC | 1999-2002 | 5.6 | 6.0 | 7.3 | 8.2 | 6.5 | 11.9 |
| TOC | 2003-2006 | 5.2 | 5.8 | 6.3 | 7.2 | 5.9 | 9.6 |
| TOC | 2007 – March 2012 | 5.5 | 6.2 | 7.0 | 7.8 | 6.4 | 10.0 |

#### *2.3.2.5 CAAE Publications and Presentations*

The North Carolina State University Center for Applied Aquatic Ecology (CAAE) studies water quality in Falls Lake and other waterbodies throughout North Carolina, with particular emphasis on measuring harmful algal blooms. CAAE utilizes both field sampling and continuous automated monitoring in Falls Lake. A selection of journal publications and public presentations on data collected from the Falls Lake watershed are summarized in this section.

Touchette et al. (2007) compared water quality data from eleven reservoirs in the Piedmont during the third year of a drought. Each reservoir was sampled monthly from June to August in 2002 (the third year of a 100-yr record drought). Summer droughts are typically associated with increased levels of cyanobacteria due to 1) increased residence times, 2) lower turbidity levels and increased light availability, and 3) warmer temperatures. Water Quality measurements for Falls Lake were collected near the Hwy 50 and Upper Barton Creek boat ramps, and summarized in a table listing the following average values: temperature 28.8°C ± 0.9, pH 7.7 ± 0.2, dissolved oxygen 6.3 mg/L ± 0.5, suspended solids 9.0 mg/L ± 3.1, total organic carbon 6 mg/L ± 0, and total nitrogen to total phosphorus ratio 25.8 ± 2.3. Chlorophyll *a* concentrations were approximately 38 µg/L ± 4. Although cyanobacteria assemblages comprised 60 percent to 95 percent of the algal species measured in the eleven reservoirs, cyanotoxin levels (microcystin) remained low in all of the reservoirs and generally ranged from 0.14 µg/L to 0.24 µg/L (the World Health Organization (WHO) recommends a microcystin limit of1 µg/L in drinking water).

Rothenberger et al. (2009) described changes in land use in the Neuse River Basin and correlated land use with water quality data throughout the entire basin from the Falls Lake watershed to the coast. Increased nutrient concentrations in the upper part of the basin were associated with the density of wastewater treatment plants, level of urban development, large precipitation events, and summer seasons. Higher nitrate concentrations were observed in the winter when water tables are higher and groundwater nitrate is flushed to surface waters. Ammonia concentrations were highest following precipitation events.

Two public presentations (Burkholder et al. 2007 and Burkholder 2010) summarize data recorded during monthly, summer sampling from 2002 to present. The following data summaries and conclusions were presented:

- Highest concentrations occur in the Upper Lake, particularly TKN, TP and suspended solids. Chlorophyll *a* concentrations were also higher in the upper lake.
- Chlorophyll *a* concentrations decreased from 2002 to 2004 and increased from 2004 to 2006. Concentrations were similar in 2002 and 2006.

> Total nitrogen to total phosphorus ratio was lowest in the upper lake and increased with distance downstream. Highest total nitrogen to total phosphorus ratio was recorded in 2002 with the lowest ratio recorded in 2006.

> Total organic carbon concentrations increased from 2002 to 2003, decreased in 2004, and then increased from 2004 to 2009 in both upper and lower lake (Figure 2-3 and Figure 2-4). [Note: it appears that concentrations presented in 2009 were similar to those observed in 2003, but because the 2010 presentation presents the data in a different format (scatter plot of data versus bar chart of mean concentrations) and does not contain the 2002 and 2003 samples, it is difficult to accurately assess trends from 2002 to 2009].

> Nitrate plus nitrite concentrations were positively related to flow at both the EM Johnson Plant intake and at Highway 50. Concentrations are generally higher in winter and spring.

> Highest suspended solids concentrations were recorded in 2002, 2003 and 2006, while lowest concentrations were recorded in 2007.

> The highest total phosphorus concentrations were recorded in 2006, and lowest concentrations were measured in 2007.

> Dissolved oxygen concentrations decline to near zero in the deeper parts of the lake during the summer months.

> Cyanobacteria comprised 75 percent to 95 percent of the phytoplankton assemblage in Falls Lake during summer monitoring.

> Microcystin levels in Falls Lake near the intake were higher in 2002 compared to 2003 and 2004. Levels remained below the WHO guideline of 1 µg/L.

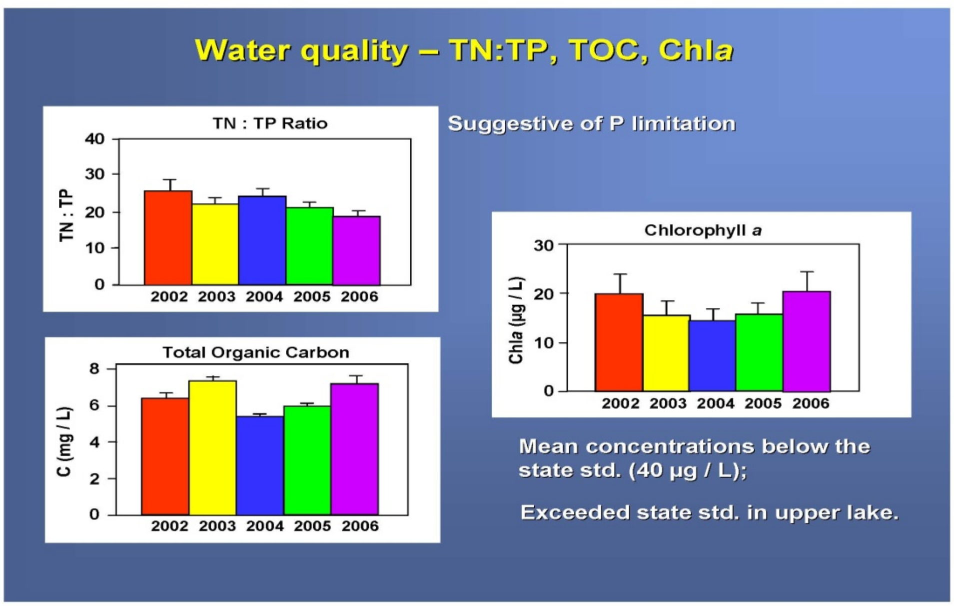



**Figure 2-3 Water Quality Figures Including TOC Presented by Burkholder (2007)**

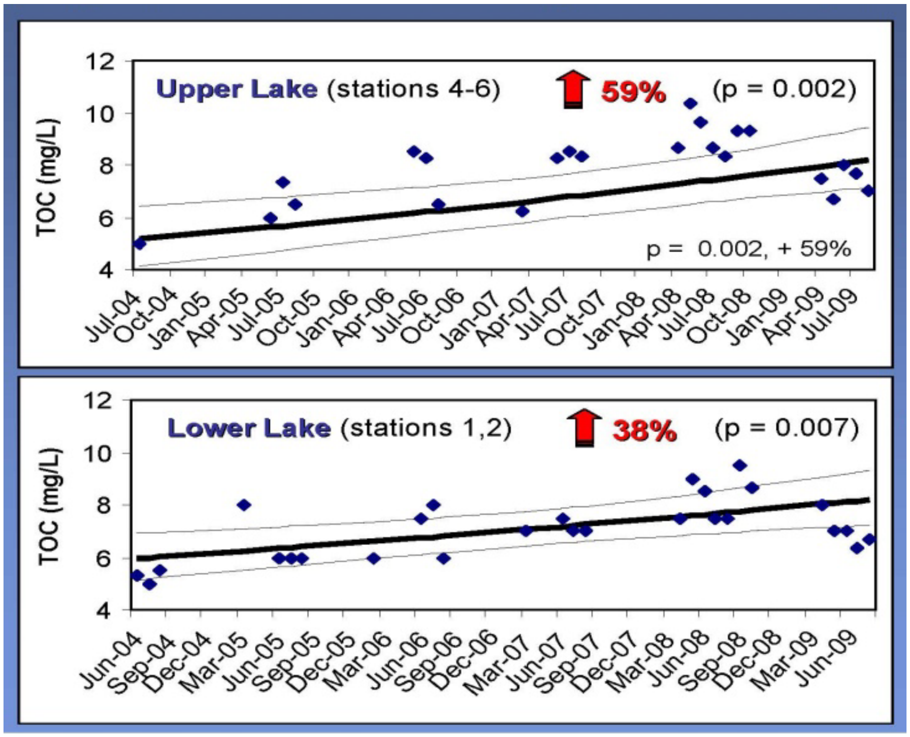



**Figure 2-4 TOC Figures Presented by Burkholder (2010)**

#### *2.3.2.6 Presentation to the North Carolina Lake Management Society*

In a presentation to the North Carolina Lake Management Society, the City of Raleigh presented a graphic showing the correlation of TOC concentration at the raw water intake to reservoir elevation. It appears from this data that increased flows to the lake may drive loading of organic material as measured by TOC (Figure 2-5). Spikes labeled on the top of the graph are referenced to periods where water surface elevation was low due to drought conditions (red circles). As water surface elevation increases following droughts, TOC increases as well.

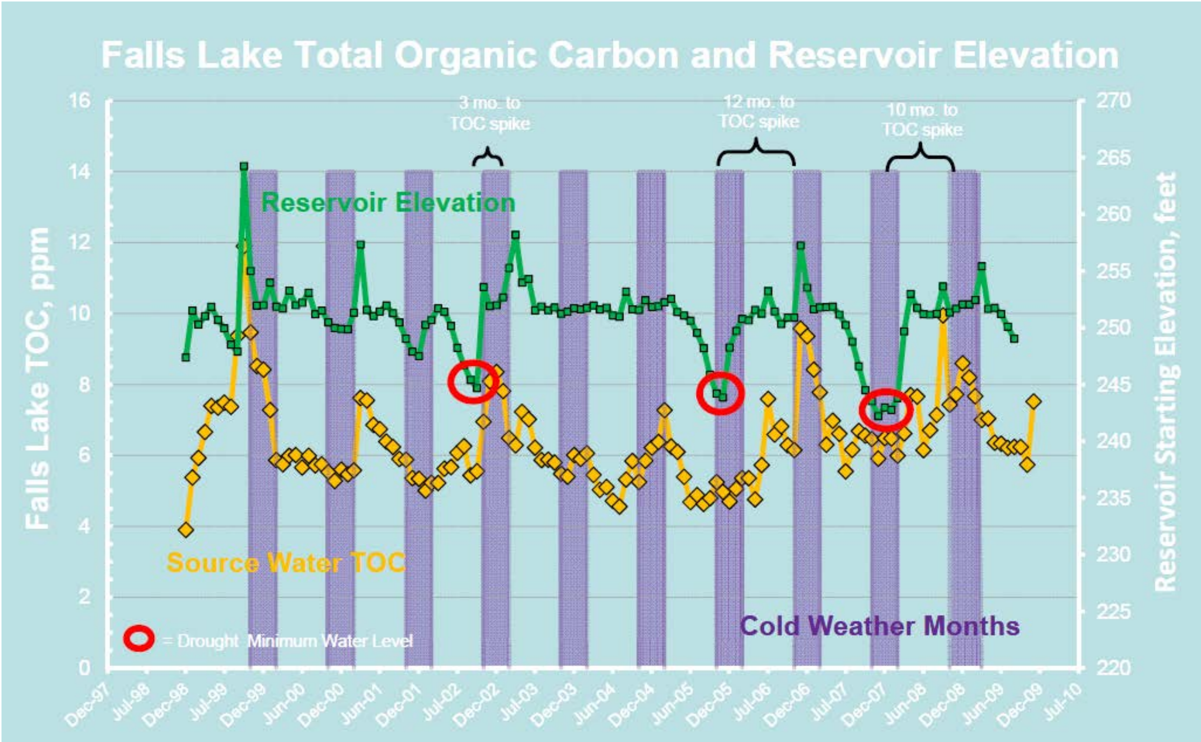



**Figure 2-5 Correlation of TOC to Reservoir Elevation (from City of Raleigh 2012)**

Net monthly flows to Falls Lake (inflow minus evaporation) were provided by the USACE (personal communication Michael Young 6, 28, 2012) and are shown in Figure 2-6 for reference. (Negative monthly flows indicate that evaporative losses were greater than tributary inflows and precipitation inputs for that month.) Increases in water surface elevation correspond to increases in net inflow to the lake.

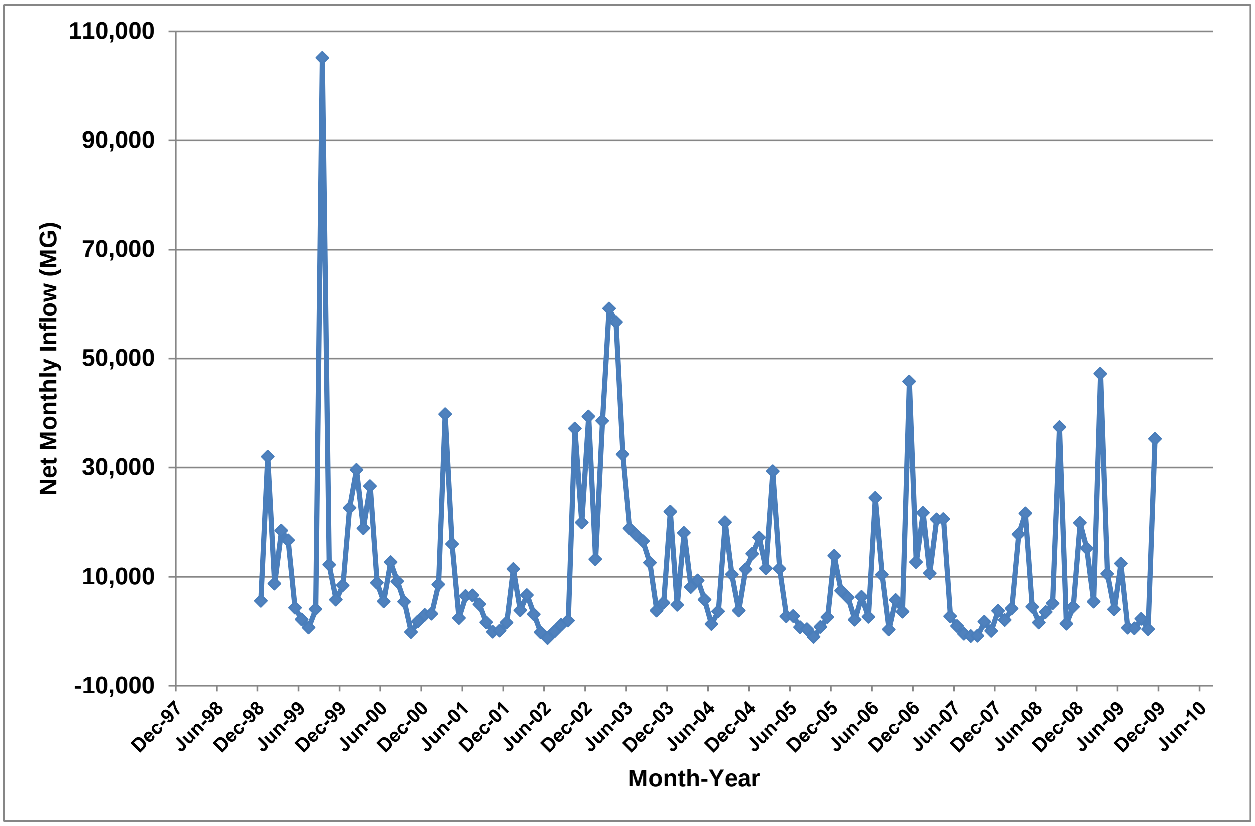



**Figure 2-6 Net Monthly Inflows to Falls Lake**

### 2.3.3 <u>City of Durham Stormwater Monitoring Program</u>

The City of Durham began quarterly monitoring of dissolved oxygen (DO), temperature, pH, turbidity, fecal coliform, nutrients, and metals in 1991; annual benthic monitoring began in 1999. Streams were monitored monthly for water quality beginning in 2004, and significant changes to the monitoring program were implemented in 2008 following a program audit. To date, the City has conducted over 2,100 illicit discharge investigations. The City has also conducted field monitoring for DO, temperature, pH and turbidity in more than 3,000 samples. It has also analyzed 3,300 stream samples for fecal coliforms, 1,700 stream samples for nutrients and selected metals, and 170 benthic samples for aquatic life support (City of Durham 2009).

The City has also conducted several special studies (City of Durham 2009) including a wet weather stormwater quality monitoring program to characterize runoff from a variety of urban land uses (1993 to 1999); an on-site wastewater treatment and disposal study to assess effluent quality from septic sand filter systems (1999/2000 and 2007/2008); a bacteria source tracking study to apportion bacterial loading from domestic animals, wildlife, and human sources in the Northeast Creek watershed (2004); and the Northeast Creek Metals Study to assess aqueous and sediment levels of zinc, copper, nickel, cadmium, and polycyclic aromatic hydrocarbons (2011).

# 3 Data Summaries for Falls Lake and the Watershed

The objectives of the Task 2 TM are to compile, assess, and summarize the existing data and knowledge regarding Falls Lake and its watershed to support the UNRBA in identifying strategies for dealing with Stage II of the Falls Lake Nutrient Strategy. The use of different laboratories and multiple analysis methods can contribute to increased data variability. Changes in a method detection limit can also influence data interpretation. An increase in a method detection limit could be interpreted as an actual increase in concentrations if data qualifications (such as a result being below the detection limit) are not considered. This section of the report describes how the water quality database was compiled and structured. Statistical summaries in the form of tables and box plots are provided for fifteen water quality parameters.

## 3.1 Sources of Data

In addition to the existing reports and summaries reviewed above, Cardno ENTRIX acquired raw data directly from the local governments, State, and Federal agencies: North Carolina Division of Water Quality (NCDWQ), the United States Geological Survey (USGS), the City of Durham (Durham_Ci), the City of Raleigh (Raleigh), Orange County (Orange_Co), Wake County (Wake_Co), the South Granville Water and Sewer Authority (SGWASA), and the North Carolina State University Center for Applied Aquatic Ecology (CAAE). Data that were publicly available and accessible online were downloaded from the USGS National Water Information System (NWIS) and the United States Environmental Protection Agency STORET data warehouse. All other data was requested and received in electronic format from the appropriate collecting entities. Data was organized and uploaded into a Microsoft Access database and formatted for easy cross-reference between datasets.

Table 3-1 shows the data collected by the eight entities for each of fifteen specific parameters (not all parameters in the database are summarized in this report). The number of samples for these parameters measured from 1999 to 2012 is over 81,000.

**Table 3-1 Number of Samples for Each Parameter by Organization**

| Parameter | CAAE | Durham _Ci | NCDWQ | Orange _Co | Raleigh | SGWASA | USGS | Wake _Co | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| Temperature | 69 | 2,133 | 6,209 | 181 | 1,229 | 1,437 | 1,002 | 160 | 12420 |
| DO | 69 | 2,135 | 6,305 | 182 | 1,104 | 1,440 | 994 | 160 | 12,389 |
| pH | 69 | 1,679 | 5,061 | 171 | 1,257 | 1,431 | 1,022 | 160 | 10,686 |
| Conductivity | 0 | 2,126 | 4,312 | 182 | 930 | 1,428 | 1,142 | 160 | 10,280 |
| TSS | 325 | 547 | 1,172 | 181 | 0 | 0 | 42 | 147 | 2,414 |
| Ammonia-N | 0 | 1,333 | 1,413 | 182 | 0 | 0 | 1,005 | 157 | 4,088 |
| NO2/NO3-N | 0 | 1,545 | 2,535 | 182 | 487 | 0 | 926 | 131 | 5,806 |
| ON-N | 0 | 1,301 | 1,397 | 182 | 0 | 0 | 997 | 135 | 4,012 |
| TN-N | 71 | 1,302 | 2,489 | 182 | 0 | 0 | 926 | 140 | 5,110 |
| Orthophosphate-P | 0 | 604 | 985 | 0 | 0 | 0 | 1,005 | 141 | 2,735 |
| TP-P | 68 | 1,251 | 1,685 | 181 | 0 | 0 | 992 | 131 | 4,308 |
| Secchi Depth | 0 | 67 | 883 | 0 | 0 | 0 | 127 | 0 | 1,077 |

| Parameter | CAAE | Durham _Ci | NCDWQ | Orange _Co | Raleigh | SGWASA | USGS | Wake _Co | Grand Total |
|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll *a* | 1,066 | 663 | 753 | 182 | 423 | 0 | 123 | 0 | 3,210 |
| TOC | 64 | 24 | 708 | 0 | 802 | 0 | 297 | 0 | 1,895 |
| CHL/TOC | 64 | 0 | 602 | 0 | 157 | 0 | 123 | 0 | 946 |
| Grand Total | 1,865 | 16,726 | 36,509 | 1,988 | 6,389 | 5,736 | 10,723 | 1,622 | 81,558 |

Along with requests for data, Cardno ENTRIX solicited information from each entity regarding field and laboratory standard operating procedures (SOPs), quality assurance project plans (QAPPs), and chain of custody (COC) procedures and any additional information relevant to the data provided. Below are detailed descriptions of the datasets received and the sampling protocols and procedures that Cardno ENTRIX was able to identify and validate.

Table 3-2 summarizes the information obtained during the data capture process regarding the SOPs, QAPPs, COCs, and laboratory QA/QC procedures used by each organization collecting temperature data. NCDWQ, USGS, the City of Raleigh, CAAE, Wake County, and the City of Durham each provided the full set of protocols. Orange County provided an SOP and COCs, but not a QAPP and there was no evidence of laboratory QA procedures on the laboratory sheets provided. SGWASA did not provide protocol information with their data submittals.

**Table 3-2 Summary of Protocols Provided by the Organizations**

| Organization | Field SOP Provided | QAPP Provided | Laboratory QA/QC Procedures | Chain of Custody Procedures In Place | Protocol Completeness |
|---|---|---|---|---|---|
| NCDWQ | Yes | Yes | Yes | Yes | Full |
| USGS | Yes | Yes | Yes | Yes | Full |
| City of Durham | Yes | Yes | Yes | Yes | Full |
| City of Raleigh | Not Applicable for Intake Monitoring | Yes | Yes | Yes | Full |
| CAAE | Yes | Yes | Yes | Yes | Full |
| SGWASA | No | No | Unknown | Unknown | None Provided |
| Orange County | Yes | No | No | Yes | Partial |
| Wake County | Yes | Yes | Yes | Yes | Full |

### 3.1.2 USGS

USGS data was obtained from the National Water Information System (NWIS) online database. Water quality data that included both field and laboratory samples were downloaded as a complete water quality dataset. Additionally, surface water discharge and all relevant sampling methodology, analytical methods, and detailed station information were downloaded.

USGS publishes its National Field Manual for the Collection of Water-Quality Data detailing protocols for the collection of field parameters and the collection and handling of water samples for laboratory analysis. The manual's nine chapters and their subsections have been written or updated individually between 1997 and 2012. These procedures are used by all local and regional USGS offices for the collection of water quality data. The USGS operates the National Water Quality Laboratory (NWQL) in Denver, Colorado, where, according to their databases, the majority of their water samples were analyzed. The NWQL publishes its Quality Management Systems manual (November 2005) specifying general quality control and quality assurance procedures for analysis and chain of custody procedures for sample acceptance. USGS data were downloaded from 1950 to November 2011, but was reduced to 1999 to November 2011 in this report summary.

### 3.1.3 NCDWQ

NCDWQ data was obtained from two sources. Data available online was downloaded from the EPA's STORET system as one dataset. NCDWQ provided additional individual datasets that included field based physical measurements and laboratory analyzed samples collected from the bottom and photic zones of Falls Lake. NCDWQ uses standard field collection procedures outlined in the Intensive Survey Unit Standard Operating Procedures Manual: Physical and Chemical Monitoring (updated November 2011) as well as field and QA/QC procedures outlined in the Ambient Monitoring System (AMS) Quality Assurance Project Plan that was approved by the US EPA in 2004. NCDWQ operates the Central Laboratory in Raleigh and processes water quality samples at this facility. The Central Laboratory follows procedures and protocols detailed in the Quality Assurance Manual for the North Carolina Division of Water Quality Laboratory Section (June 1, 2003). Central Laboratory provides sample chain of custody forms to accompany samples collected by field crews. NCDWQ data ranges from 1968 to January 2012 but was reduced to 1999 to January 2012 in this report summary. Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

### 3.1.4 City of Durham

The City of Durham conducts various monitoring programs and provided multiple datasets that include routine ambient monitoring program, benthic surveys, an isotope study in conjunction with USGS, wastewater effluent upstream and downstream monitoring, and a special nutrient loading project. The City of Durham follows procedures documented in the City of Durham, Stormwater Service, Water Quality Group Quality Assurance Project Plan (date unknown). The QAPP details sample collection and handling methods, laboratory analytical methods, QA/QC measures, and includes sample chain of custody forms. An additional study, Nutrient Loading Project, was covered by a project specific QAPP. The City of Durham analyzes samples at the South Durham Water Reclamation Facility (City Laboratory) which is a State certified laboratory. For the Nutrient Loading Project, TestAmerica Laboratories, Inc., analyzed some samples as part of a quality assurance program. City of Durham data obtained for this study ranges from January 2002 to December 2011.

### 3.1.5 City of Raleigh

The City of Raleigh provided data collected from the E.M. Johnson Water Treatment Plant. Additional algae data collected by Ecoconsultants was provided. The E.M. Johnson Water Treatment Plant follows procedures outlined in the Laboratory Quality Assurance and Quality Control Plan (June 2011). This document covers chain of custody, QA, and QC within the laboratory, however information on standard operating procedures was not provided. The E.M. Johnson Water Plant is currently certified (Expires Dec 2012) with NCDWQ. City of Raleigh data ranges from February 2000 to December 2011.

### 3.1.6 Orange County

Orange County provided data collected during a special study: Eno River Watershed Surface Quality Monitoring Project in and Around Hillsborough, North Carolina. This study followed standard operating procedures used by NCDWQ (described above). Samples were analyzed by Tritest Laboratory, Inc. in Raleigh. Chain of Custody forms and laboratory reports for these samples were provided. Orange County data ranges from April 2010 to March 2011.

### 3.1.7 Wake County

Wake County provided data collected by Wake County Environmental Services and North Carolina State University (as part of a 319 grant and separate from the NCSU-CAAE data) from July 2008 to October

2009. Wake County follows the "Integrated Approach to Watershed Management Planning and Implementation in Selected Watersheds of the Falls Lake Reservoir" Quality Assurance Project Plan (QAPP) which was approved by the NCDWQ for samples collected as part of the 319 grant. Laboratory samples are processed at the Wake County Human Service Laboratory which is currently certified by NCDWQ. Standard operating procedures for field collection and sample handling were provided.

### 3.1.8 SGWASA

SGWASA provided data collected from January 2005 to December 2011 as part of the upstream and downstream monitoring for the wastewater effluent. Information on standard operating procedures and quality assurance was not provided.

### 3.1.9 NCSU-CAAE

NCSU-CAAE (CAAE) provided data collected on behalf of the City of Raleigh in Falls Lake. The CAAE laboratory is currently certified (Expires Dec 2012) by NCDWQ. CAAE follows a Quality Assurance Project Plan (QAPP) initially approved in 2005 by NCDWQ as part of the laboratory certification, which includes yearly audits and data review. The QAPP details sample collection procedures. CAAE also provided analyte specific standard operating procedures for each laboratory method (updated in 2011) which include sample handling, processing, and quality control protocols. CAAE data were collected from June 2002 to September 2011.

## 3.2 Spatial Coverage of Monitoring Stations

The eight organizations collecting water quality in the watershed and the lake provide good spatial coverage of the drainage area. For each parameter discussed below, the stations and associated data were first grouped into three main geographical areas to ease interpretation: Tributary, Upper Lake, and Lower Lake (Figure 3-1). The Tributary data includes all stations in free flowing waters (i.e., not located in watershed impoundments, Falls Lake, or the Beaver Dam Impoundment). Data collected in watershed impoundments (e.g., Lake Michie, West Fork Eno Reservoir) are not included in the Task 2 data summaries because the sampling depths and results were very different from the free flowing tributary data, and the resulting summary statistics and box plots were difficult to interpret. These data, however, are included in the master Access database and summarized in Appendix A.

To summarize the geographical coverage of the data, 10 digit HUCs were used to define the subwatersheds. For the purposes of creating box plots, distance bins were used to group stations in the same vicinity into a subwatershed/distance category. For example, USGS station 02085000 is located on the Eno River in Hillsborough, NC. This station is categorized, along with 10 other stations, into the category ER>10 (Eno River greater than 10 miles from the lake). Stations within two miles of the lake boundary have distance category of 0-2, and stations between two and ten miles from the mouth have distance category of 2-10. Figure 3-2 shows the water quality monitoring stations in the watershed displayed by organization, subwatershed, and distance category. Individual subwatershed maps with underlying 2006 National Land Cover Data are presented in Appendix D.

Stations located in Falls Lake or the Beaverdam Impoundment were grouped into Lower Lake (LowLk-downstream of Hwy 50) or Upper Lake (UppLk – upstream of Hwy 50) categories, and the distances were assigned relative to Falls Lake Dam. Stations in the Lower Lake downstream of Hwy 50 were grouped into three categories:

> Lower Lake 0 to 4 miles upstream from the Dam (LowLk,0-4)

> Lower Lake 4 to 8 miles upstream from the Dam (LowLk,4-8)

> Lower Lake 8 to 13 miles upstream from the Dam (LowLk, 8-13).

Stations in the Upper Lake upstream of Hwy 50 were also grouped into three categories:

> Upper Lake 13 to 18 miles upstream from the Dam (UppLk,13-18)

> Upper Lake 18 to 21 miles upstream from the Dam (UppLk,18-21)

> Upper Lake upstream of Interstate 85 (UppLk>21).

Figure 3-3 shows the monitoring stations in the lake categorized by organization and lake segment. All of the stations in the Beaverdam Impoundment are located 13 to 17 miles upstream of the Falls Lake Dam. These stations are grouped with the Lower Lake data, rather than the Tributary data, and are assigned to the category BvrDmImp. Stations in the Beaverdam Creek watershed upstream of the Beaverdam Impoundment are treated as tributary stations with distances relative to the boundary of the Impoundment. These stations are assigned to BC,0-2 or BC,2-10. Note that our GIS shapefile of the lake boundary does not include the Beaverdam Impoundment, so station assignments in and around the impoundment were developed manually in the GIS environment.

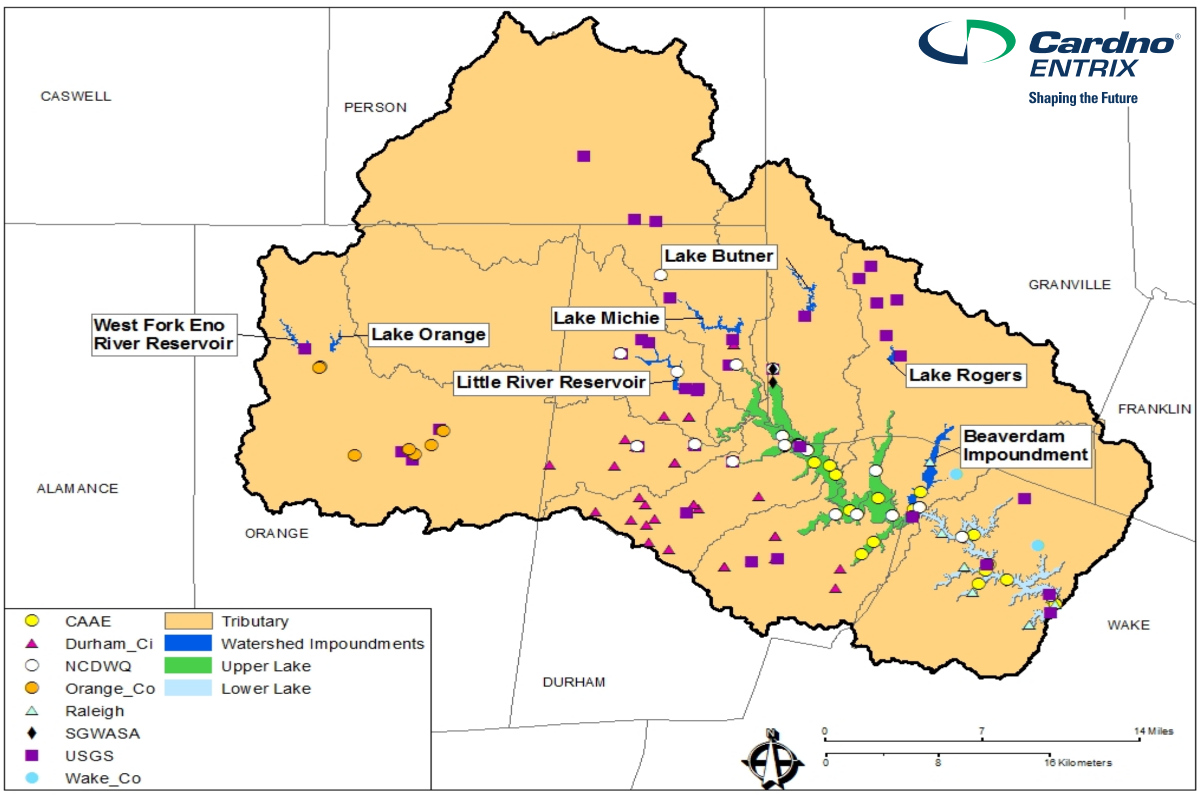



**Figure 3-1 Three Geographic Regions Used to Summarize the Water Quality Data in Falls Lake Watershed**

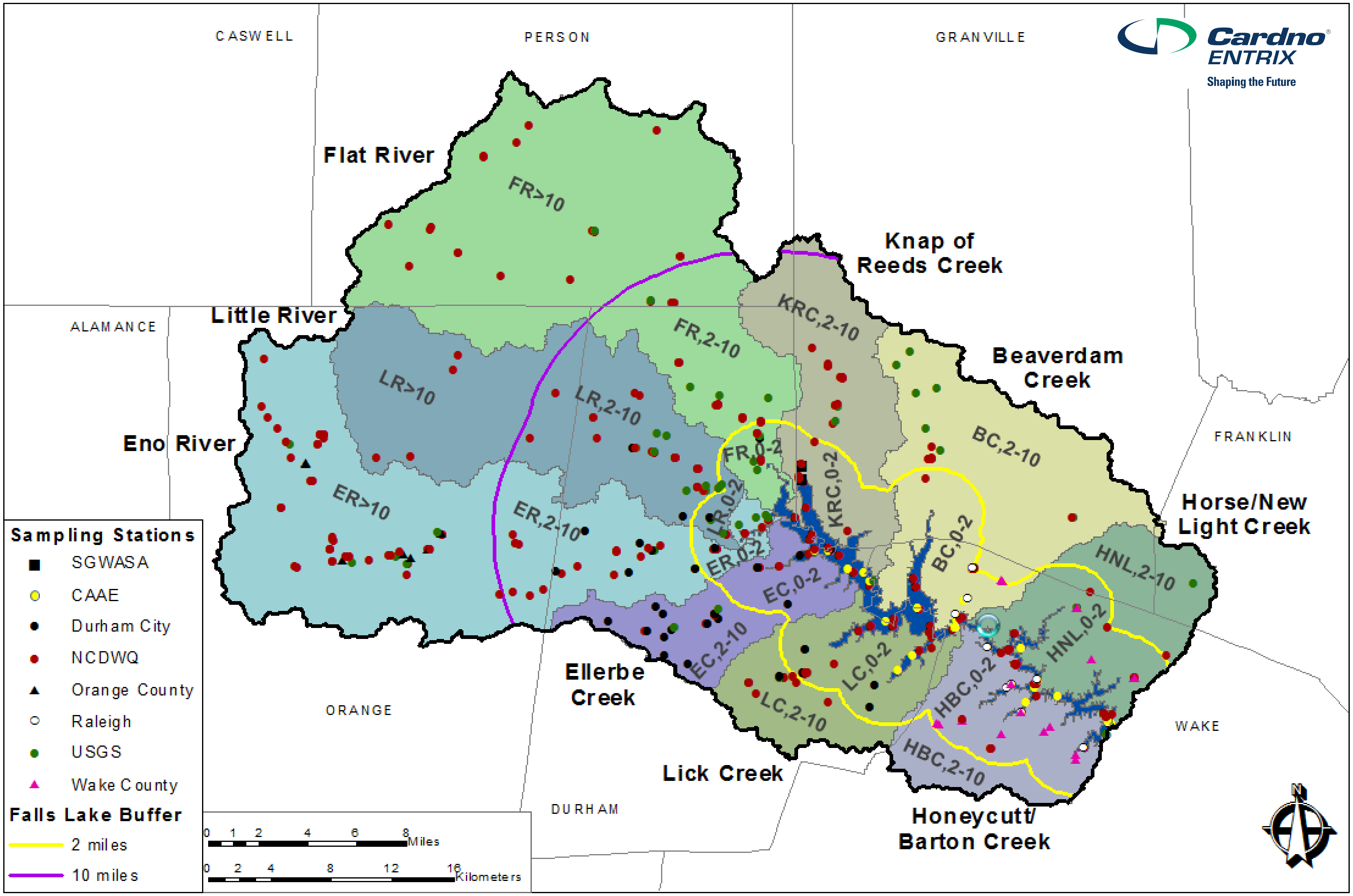



**Figure 3-2 Falls Lake Watershed Sampling Locations by Segment**

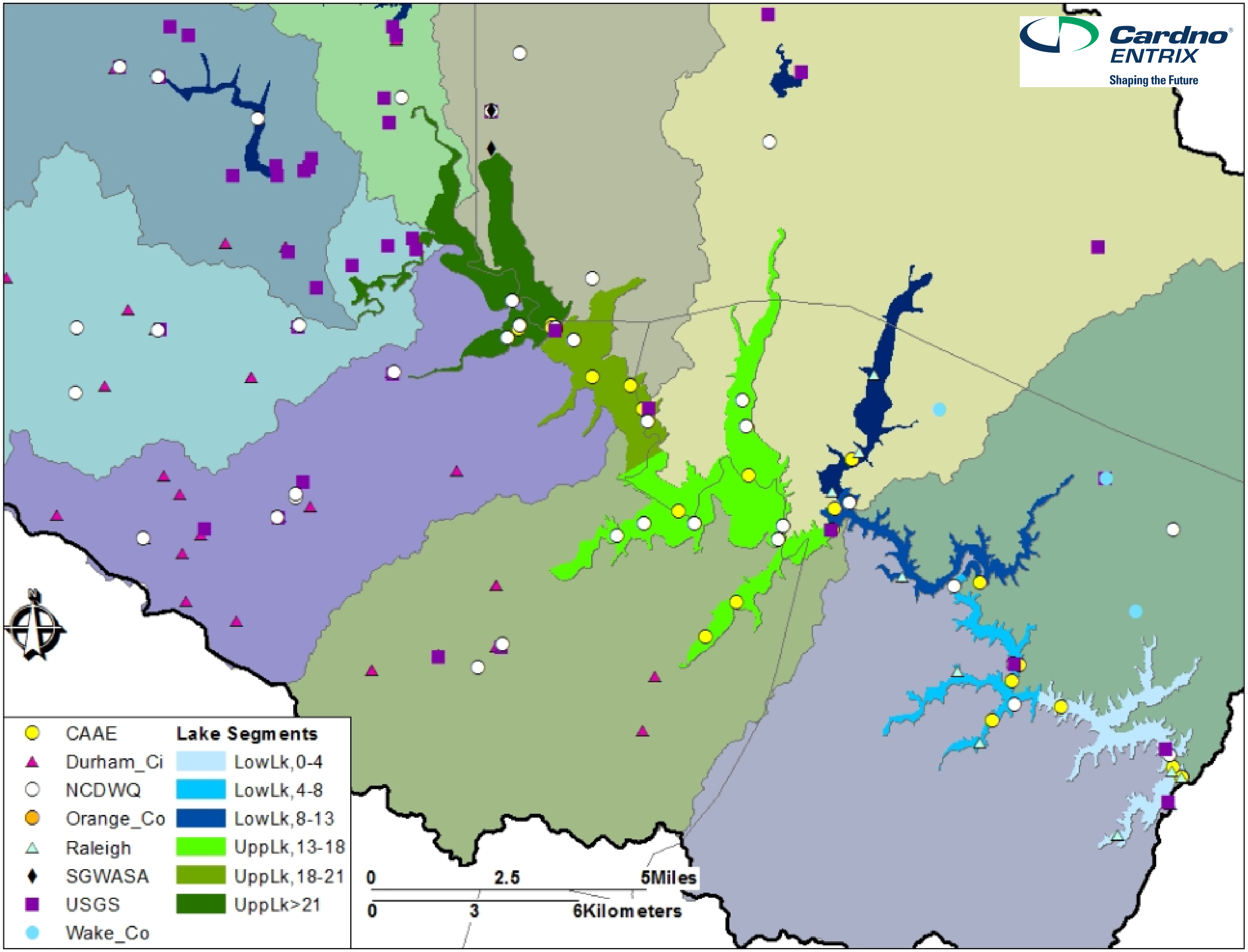



**Figure 3-3 Falls Lake Sampling Locations by Lake Segment**

Table 3-3 summarizes the number of samples collected by the organizations in each subwatershed. The abbreviations in parentheses are used in the summary tables and box plots for each parameter in Sections 3.6 thru 3.20 to describe the subwatershed. In addition to assigning each monitoring station to a subwatershed or lake segment, a GIS analysis was performed on each station to determine how many miles upstream from the mouth of the tributary, or Falls Lake Dam, each station was located. Two mile and ten mile buffers around the lake boundary were used to categorize the Tributary stations (Figure 3-2). Lake stations were categorized by the number of miles upstream from the dam (Figure 3-3).

**Table 3-3 Number of Samples Collected in Each Subwatershed by Organization**

| Sub-watershed | CAAE | Durham_Ci | NCDWQ | Orange_Co | Raleigh | SGWASA | USGS | Wake_Co | Total |
|---|---|---|---|---|---|---|---|---|---|
| Beaverdam Creek above Impoundment (BC) | 0 | 0 | 0 | 0 | 0 | 0 | 252 | 187 | 439 |
| Ellerbe Creek (EC) | 0 | 6,540 | 1,217 | 0 | 0 | 0 | 140 | | 7,897 |
| Eno River (ER) | 0 | 1,479 | 1,857 | 1,988 | 0 | 0 | 1,212 | | 6,536 |
| Flat River (FR) | 0 | 417 | 1,612 | 0 | 0 | 0 | 1,010 | | 3,039 |
| Honeycutt/ Barton/Cedar (HBC) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 869 | 869 |
| Horse/ Newlight Creek (HNL) | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 506 | 517 |
| Knap of Reeds Creek (KRC) | 0 | 0 | 1,228 | 0 | 0 | 5,736 | 104 | 0 | 7,068 |
| Lick Creek (LC) | 0 | 1,333 | 0 | 0 | 0 | 0 | 64 | 0 | 1,397 |
| Little River (LR) | 0 | 394 | 932 | 0 | 0 | 0 | 3,655 | 0 | 4,981 |
| Falls Lake Upstream of Hwy 50 (UppLk) | 385 | 6,563 | 15,681 | 0 | 0 | 0 | 2,074 | 0 | 24,703 |
| Beaverdam Creek in the Impoundment (BvrDmImp) | 67 | 0 | 0 | 0 | 692 | 0 | 0 | 0 | 759 |
| Falls Lake Downstream of Hwy 50 (LowLk) | 1,413 | 0 | 13,982 | 0 | 5,697 | 0 | 2,201 | 60 | 23,353 |
| Total | 1,865 | 16,726 | 36,509 | 1,988 | 6,389 | 5,736 | 10,723 | 1,622 | 81,558 |

## 3.3 Temporal Variations in Sampling

The data included in the master Access database and summarized in this TM spans the period 1999 to June 2012. Table 3-4 provides a general description of sampling frequency by organization based on the availability of nutrient and chlorophyll *a* data. The majority of the organizations sample monthly with occasional increases in frequency to 2 to 4 times per month.

**Table 3-4 Summary of Protocols for the Organizations**

| Organization | Predominant Sampling Frequency based on TN, TP, and chlorophyll *a* |
|---|---|
| NCDWQ | Monthly with increased frequency (2 to 3 times per month) during 2005 to 2007 |
| USGS | Monthly with occasional increases to 2 to 3 times per month |
| City of Durham | Downstream of WWTP weekly; other stations at least monthly with occasional increases to 2 to 3 times per month |
| City of Raleigh | Once or twice per month depending on station |
| CAAE | Monthly with occasional increases to 2 to 4 times per month |
| SGWASA | No applicable for these parameters |
| Orange County | Twice per month beginning in 2010 |
| Wake County | Monthly with occasional increases to 2 times per month |

The frequencies that monitoring were conducted for the Tributary, Upper Lake, and Lower Lake regions vary from year to year by parameter. Table 3-5 through Table 3-7 show the sample counts for each the three geographic regions by year. The frequency of tributary sampling has generally increased since 2005; the small sample sizes in 2012 are reflective of 2012 data capture that began in January and therefore missed a large portion of the sampling year. Chlorophyll *a* data in the free flowing waters of the Tributary region is only available in 2010 and 2011. In the Upper Lake, sampling for most parameters was highest in 2005, 2006, and 2007 with monitoring generally declining some over the past couple of years; the frequency of chlorophyll *a* sampling in 2010 and 2011 was higher than the 2005 to 2007 period. In the Lower Lake, for most parameters sampling was most intensive in 2005, 2006, and 2007, except for chlorophyll *a* and TOC which were sampled most frequently in 2010 and 2011. Increases in lake sampling from 2005 to 2007 corresponded to modeling efforts to support the Falls Lake Nutrient Management Strategy.

**Table 3-5 Number of Tributary Samples by Year**

| Parameter | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 136 | 138 | 119 | 119 | 150 | 125 | 279 | 426 | 380 | 467 | 876 | 980 | 699 | 36 |
| DO | 134 | 138 | 119 | 119 | 150 | 125 | 278 | 434 | 362 | 463 | 869 | 982 | 698 | 36 |
| pH | 138 | 138 | 119 | 119 | 146 | 125 | 279 | 426 | 372 | 465 | 889 | 975 | 701 | 36 |
| Conductivity | 66 | 64 | 56 | 54 | 73 | 41 | 154 | 280 | 273 | 397 | 851 | 965 | 687 | 36 |
| TSS | 80 | 57 | 15 | 20 | 24 | 23 | 93 | 125 | 63 | 75 | 311 | 358 | 178 | 0 |
| Ammonia-N | 125 | 107 | 61 | 43 | 80 | 84 | 126 | 135 | 105 | 159 | 362 | 458 | 240 | 0 |
| NO2/NO3-N | 133 | 138 | 71 | 43 | 85 | 90 | 142 | 179 | 131 | 209 | 395 | 508 | 291 | 0 |
| ON-N | 124 | 107 | 56 | 43 | 80 | 83 | 123 | 135 | 105 | 157 | 348 | 454 | 239 | 0 |
| TN-N | 133 | 138 | 57 | 43 | 85 | 90 | 142 | 178 | 131 | 162 | 347 | 452 | 238 | 0 |
| Ortho-phosphate-P | 54 | 54 | 45 | 43 | 60 | 43 | 44 | 40 | 30 | 128 | 143 | 111 | 58 | 0 |
| TP-P | 135 | 138 | 63 | 39 | 85 | 90 | 164 | 193 | 141 | 226 | 450 | 535 | 314 | 0 |

| Parameter | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chlorophyll *a* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 140 | 42 | 0 |
| TOC | 12 | 6 | 14 | 9 | 8 | 7 | 7 | 13 | 10 | 13 | 51 | 32 | 12 | 0 |
| Total | 1,270 | 1,223 | 795 | 701 | 1,026 | 926 | 1,831 | 2,564 | 2,103 | 2,921 | 5,892 | 6,950 | 4,397 | 144 |

**Table 3-6 Number of Upper Lake Samples by Year**

| Parameter | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 59 | 94 | 63 | 62 | 62 | 556 | 766 | 619 | 96 | 100 | 314 | 379 | 35 |
| DO | 70 | 97 | 63 | 62 | 62 | 580 | 858 | 661 | 96 | 100 | 312 | 373 | 38 |
| pH | 55 | 81 | 0 | 0 | 0 | 421 | 633 | 493 | 36 | 100 | 287 | 317 | 35 |
| Conductivity | 54 | 92 | 63 | 62 | 62 | 513 | 684 | 529 | 96 | 100 | 281 | 352 | 31 |
| TSS | 6 | 18 | 0 | 0 | 3 | 104 | 165 | 139 | 19 | 0 | 0 | 0 | 0 |
| Ammonia-N | 16 | 35 | 62 | 60 | 60 | 173 | 232 | 212 | 92 | 100 | 183 | 193 | 15 |
| NO2/NO3-N | 26 | 70 | 62 | 60 | 60 | 265 | 393 | 331 | 94 | 100 | 235 | 274 | 15 |
| ON-N | 13 | 34 | 62 | 57 | 60 | 173 | 229 | 209 | 88 | 99 | 183 | 193 | 0 |
| TN-N | 21 | 68 | 62 | 57 | 60 | 263 | 381 | 326 | 88 | 100 | 235 | 274 | 0 |
| Ortho-phosphate-P | 5 | 0 | 31 | 30 | 30 | 214 | 330 | 254 | 85 | 100 | 138 | 117 | 15 |
| TP-P | 16 | 35 | 31 | 26 | 30 | 139 | 206 | 182 | 60 | 68 | 149 | 160 | 6 |
| Secchi Depth | 13 | 18 | 0 | 0 | 0 | 99 | 163 | 134 | 12 | 12 | 94 | 114 | 0 |
| Chlorophyll *a* | 0 | 15 | 56 | 59 | 61 | 121 | 224 | 208 | 85 | 76 | 250 | 346 | 3 |
| TOC | 0 | 0 | 0 | 0 | 0 | 99 | 158 | 134 | 12 | 12 | 11 | 64 | 5 |
| CHL/TOC | 0 | 0 | 0 | 0 | 0 | 52 | 155 | 133 | 11 | 12 | 10 | 54 | 0 |
| Total | 354 | 657 | 555 | 535 | 550 | 3,772 | 5,577 | 4,564 | 970 | 1,079 | 2,682 | 3,210 | 198 |

**Table 3-7 Number of Lower Lake Samples by Year**

| Parameter | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature | 155 | 224 | 86 | 96 | 88 | 726 | 823 | 741 | 161 | 163 | 445 | 537 | 40 |
| DO | 164 | 182 | 76 | 96 | 88 | 670 | 833 | 711 | 161 | 152 | 425 | 503 | 49 |
| pH | 137 | 205 | 86 | 96 | 88 | 559 | 607 | 552 | 161 | 187 | 368 | 407 | 29 |
| Conductivity | 88 | 189 | 76 | 96 | 87 | 492 | 644 | 560 | 144 | 155 | 371 | 433 | 29 |
| TSS | 9 | 14 | 6 | 6 | 9 | 117 | 126 | 122 | 123 | 6 | 0 | 0 | 0 |
| Ammonia-N | 13 | 32 | 0 | 0 | 0 | 91 | 117 | 101 | 36 | 47 | 68 | 65 | 0 |
| NO2/NO3-N | 90 | 129 | 64 | 72 | 66 | 166 | 208 | 202 | 42 | 59 | 135 | 173 | 0 |
| ON-N | 10 | 32 | 0 | 0 | 0 | 91 | 116 | 101 | 36 | 39 | 68 | 65 | 0 |
| TN-N | 19 | 64 | 0 | 0 | 0 | 162 | 203 | 174 | 54 | 63 | 124 | 116 | 0 |
| Ortho-phosphate-P | 1 | 0 | 0 | 0 | 0 | 121 | 156 | 125 | 36 | 41 | 36 | 17 | 0 |
| TP-P | 13 | 32 | 0 | 0 | 0 | 91 | 117 | 106 | 54 | 58 | 91 | 65 | 0 |
| Secchi Depth | 11 | 16 | 0 | 0 | 0 | 81 | 100 | 81 | 12 | 12 | 44 | 54 | 0 |
| Chlorophyll *a* | 0 | 16 | 6 | 6 | 10 | 87 | 136 | 138 | 163 | 155 | 404 | 391 | 12 |
| TOC | 88 | 88 | 86 | 96 | 88 | 81 | 100 | 105 | 120 | 94 | 125 | 135 | 0 |
| CHL/TOC | 0 | 0 | 0 | 0 | 0 | 45 | 99 | 86 | 28 | 72 | 87 | 102 | 0 |
| Total | 798 | 1,223 | 486 | 564 | 524 | 3,580 | 4,385 | 3,905 | 1,331 | 1,303 | 2,791 | 3,063 | 159 |

## 3.4 Database Management and Summary Approach

In order to analyze the data submitted by the eight organizations, each raw data file was imported to Microsoft Access and reformatted so that all data has consistent parameter names, parameter units, column headings, date formats, etc. A single “flat file” was created such that the attributes for each dataset were consistent. This Task 2 memorandum includes assessment of the differences in results by organization, analysis method, and method for dealing with data that are reported below detection limits. This memorandum also includes a component of the Task 1 scope of work (assessment of the temporal and spatial variability in key water quality parameters) to streamline the data processing, reporting, and review.

### 3.4.1 Limits

The following sections detail each of the fifteen parameters that are analyzed in this Task 2 memorandum. Each section includes a description of the analysis methods, the period of record, and the detection, reporting, and practical quantification limits specified in the raw data files. Brief descriptions of analysis methods are provided in the main body of the memorandum, and detailed descriptions of the analysis methodologies are provided in Appendix E. There are four types of limits summarized in the tables (USEPA 2010b):

> Detection Limit (DL) is defined as minimum concentration of an analyte that can be measured and reported with a 99% confidence that the concentration is greater than zero. The detection limit can be described as a method detection limit (MDL) or an instrument detection limit (IDL).

> Reporting Limit (RL) is the minimum value below which data are documented as not detected. Analyte concentrations between detection limits and reporting limits are reported as estimates.

> Practical Quantification Limit - The practical quantitation limit (PQL) is the lowest concentration that can be reliably measured within the specified limits of precision and accuracy for a given analytical method. PQL values are typically 3 to 5 times greater than MDL values.

> Range of Limit Specified with Results – In the tables below, this column presents the range of values for a specific dataset (parameter, organization, analysis method) where the qualifier was "<" and a numeric value was provided.

The four types of limits were used to define the Limit for each record in the database based on the following rules:

> If a qualified value was provided in the raw data file, then the qualified value was assumed the Limit for that record (e.g., <3 has a Limit of 3)

> If only the qualifier was provided in the raw data file (<), the following hierarchy was applied:

- if a PQL was listed in the raw data file, then Limit = PQL
- if a DL was listed in the raw data file, then Limit = DL
- if a RL was listed in the raw data file, then Limit = RL

Table 3-8 lists the number of samples less than the limit for each parameter and geographic region. The highest percentages of samples that are less than the limit occur in the Tributary and Upper Lake samples for ammonia and orthophosphate as well as chlorophyll *a* samples in the Tributary region. Specific limits for each parameter and organization are provided in the data summary sections below.

**Table 3-8 Number of Samples Less Than Detection Limit by Geographic Region**

| Parameter | Tributary Samples Number Less than Detection / Total Number of Samples (percent less than detection) | Upper Lake Number Less than Detection / Total Number of Samples (percent less than detection) | Lower Lake Number Less than Detection / Total Number of Samples (percent less than detection) | All Samples Number Less than Detection / Total Number of Samples (percent less than detection) |
|---|---|---|---|---|
| Temperature | Not applicable | Not applicable | Not applicable | Not applicable |
| DO | Not applicable | Not applicable | Not applicable | Not applicable |
| pH | Not applicable | Not applicable | Not applicable | Not applicable |
| Conductivity | Not applicable | Not applicable | Not applicable | Not applicable |
| TSS | 218 / 1,422 (15.3%) | 1 / 454 (0.2%) | 35 / 538 (6.5%) | 254 / 2,414 (10.5%) |
| Ammonia-N | 692 / 2,085 (33.2%) | 524 / 1,433 (36.6%) | 35 / 570 (6.1%) | 1251 / 4,088 (30.6%) |
| NO2/NO3-N | 211 / 2,415 (8.7%) | 298 / 1985 (15%) | 0 / 1,406 (0%) | 509 / 5,806 (8.8%) |
| ON-N | 15 / 2,054 (0.7%) | 0 / 1,400 (0%) | 0 / 558 (0%) | 15 / 4,012 (0.4%) |
| TN-N | 0 / 2,196 (0%) | 0 / 1,935 (0%) | 0 / 979 (0%) | 0 / 5,110 (0%) |
| Orthophosphate-P | 226 / 853 (26.5%) | 361 / 1,349 (26.8%) | 73 / 533 (13.7%) | 660 / 2,735 (24.1%) |
| TP-P | 453 / 2,573 (17.6%) | 0 / 1,108 (0%) | 0 / 627 (0%) | 453 / 4,308 (10.5%) |
| Secchi Depth | Not applicable | Not applicable | Not applicable | Not applicable |
| Chlorophyll *a* | 67 / 182 (36.8%) | 13 / 1,504 (0.9%) | 0 / 1,524 (0%) | 80 / 3,210 (2.5%) |
| TOC | 0 / 194 (0%) | 0 / 495 (0%) | 0 / 1,206 (0%) | 0 / 1,895 (0%) |
| CHL/TOC | Not applicable | Not applicable | Not applicable | Not applicable |

### 3.4.2 Methods for Dealing with Less Than Detection Limit Data

Records identified as "less than" imply that the actual value is between zero and the Limit. For the purposes of performing the analyses summarized in this memorandum, once the Limit was determined for each record qualified as less than, the result for that record was assumed equal to half the Limit as described by Gilbert (1987). Other approaches that may be explored during future studies include distributional methods and robust methods (Helsel and Hirsch 2002, USEPA 2006).

For comparative purposes, where there is data reported as below the detection limit, the database calculates results assuming the value is zero, that the value is equal to half of the Limit, and that the value is equal to the Limit. Thus, each record in the database that was reported as below the detection limit includes values in separate columns for three detection methods: Zero, Half Limit, and Limit. All of the summary statistic tables and most of the box plots presented in this memorandum use the Half Limit method.

A final boxplot is provided in some sections, where there is a significant amount of the data reported as below the detection limit, that compares the distribution of results if those records qualified as "less than" were set to zero, half of the Limit, or the Limit. For the most part, the distribution of results were similar for these three calculation methods, which means the detection limits for each parameter are likely sufficiently low so that the method used to assign values to below detection limit data does not significantly affect the overall results. For those datasets where limits were not applicable (e.g., temperature, DO, pH), there is no comparison of results with the zero, half of the Limit, or Limit assumptions.

### 3.4.3 Geographic Regions

The summary statistics and figures for each parameter are subdivided into three geographic regions: Tributaries (free flowing waters only), Upper Lake, and Lower Lake including Beaverdam Impoundment. Breaking the data into the three regions allows for more spatial information to be displayed, and supports the assessment of the relationships between water quality in the tributaries, Upper Lake, and Lower Lake segments. Data collected in watershed impoundments are presented separately in Appendix A. Summary statistics and box plots for the lake data combined (Upper and Lower) are presented in Appendix B.

### 3.4.4 Summary Statistics and Figure Layout

Summary tables include sample counts, various percentiles, minimum, means, medians, and maximum values. To improve the visual interpretation of the box plots, only data within the $10^{th}$ to $90^{th}$ percentiles are shown (when the minimum to maximum values are included, the whiskers on the plots are so long that the resulting boxes are difficult to discern on the figures). The $10^{th}$ and $90^{th}$ percentiles also correspond to compliance with water quality standards. For example, if a $90^{th}$ percentile value is less than a not to exceed standard, such as chlorophyll *a*, compliance is met; if a $10^{th}$ percentile value is greater than a not to drop below standard, such as DO, then compliance is met. At least ten samples must be available for this compliance assessment to be valid. The median is equivalent to the $50^{th}$ percentile where half of the measurements are less than and half are greater than that value. The mean is equivalent to the average value and is more affected by data points near the minimum and maximum values than the median. The mean is represented on the box plots as a star, and the median by a line within the box. The box itself illustrates the interquartile range (IQR) and extends from the $25^{th}$ to $75^{th}$ percentile of the data. The line at the bottom of each box extends from the $10^{th}$ percentile value to the $25^{th}$ percentile value where the box begins. The line at the top of the box extends from the 75th percentile value to the 90th percentile value. Figure 3-5 includes an illustration of the $10^{th}$, $25^{th}$, mean, median, $75^{th}$ and $90^{th}$ percentile values that are displayed on the plots in this TM.

Scales for the vertical axes were adjusted to accommodate the highest 90th percentile value for the Tributary, Upper Lake, or Lower Lake samples for a given parameter. Scales were maintained for each figure in the parameter section to maintain relativity across sections.

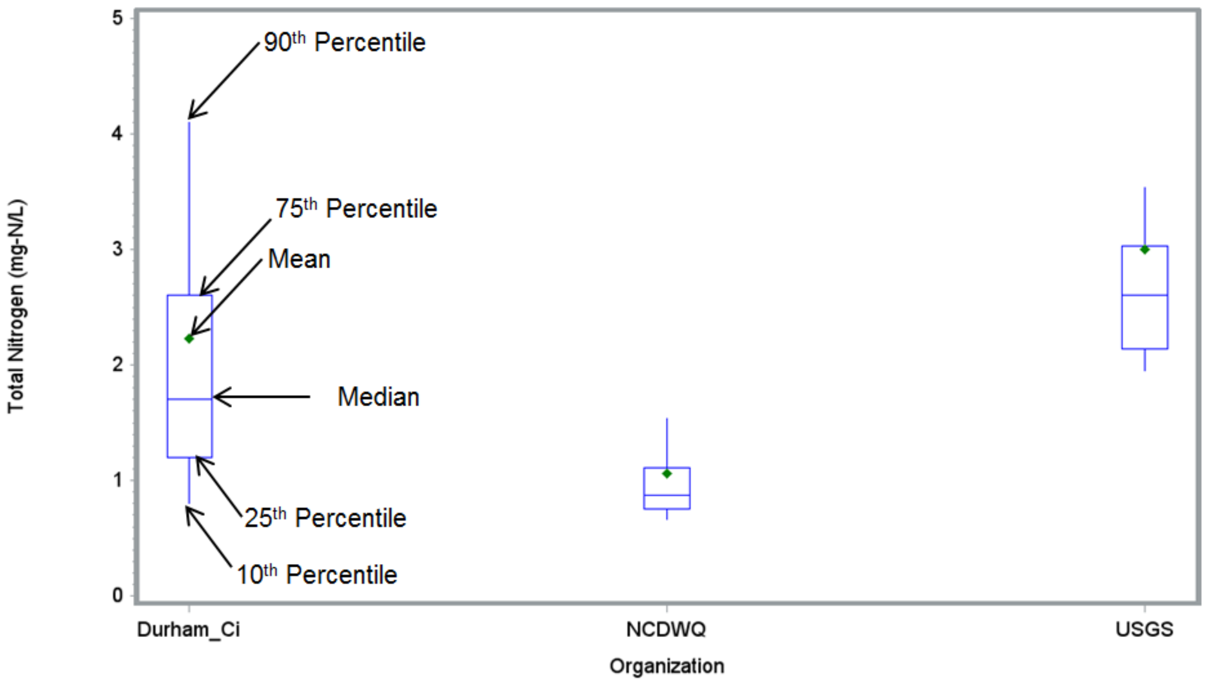



**Figure 3-4 Example Box Plot Illustrating Percentiles**

## 3.5 Net Inflows to the Lake

Much of the variability for water quality in the tributaries and the lake are evident in the temporal comparisons of year and month. Although inflows to the lake will be a focus of Task 3 (determination of tributary loading to the lake) the net daily flows provided by the USACE were converted to annual net inflow (Figure 3-5) and average monthly inflow (Figure 3-6) for comparison to the box plots for year and month in the following sections. The USACE did not provide data on inflow and evaporation separately, so these plots show net inflow (inflow minus evaporation). Flows used to develop the loadings to the lake for Task 3 will rely on USGS data and reflect direct flows to the lake.

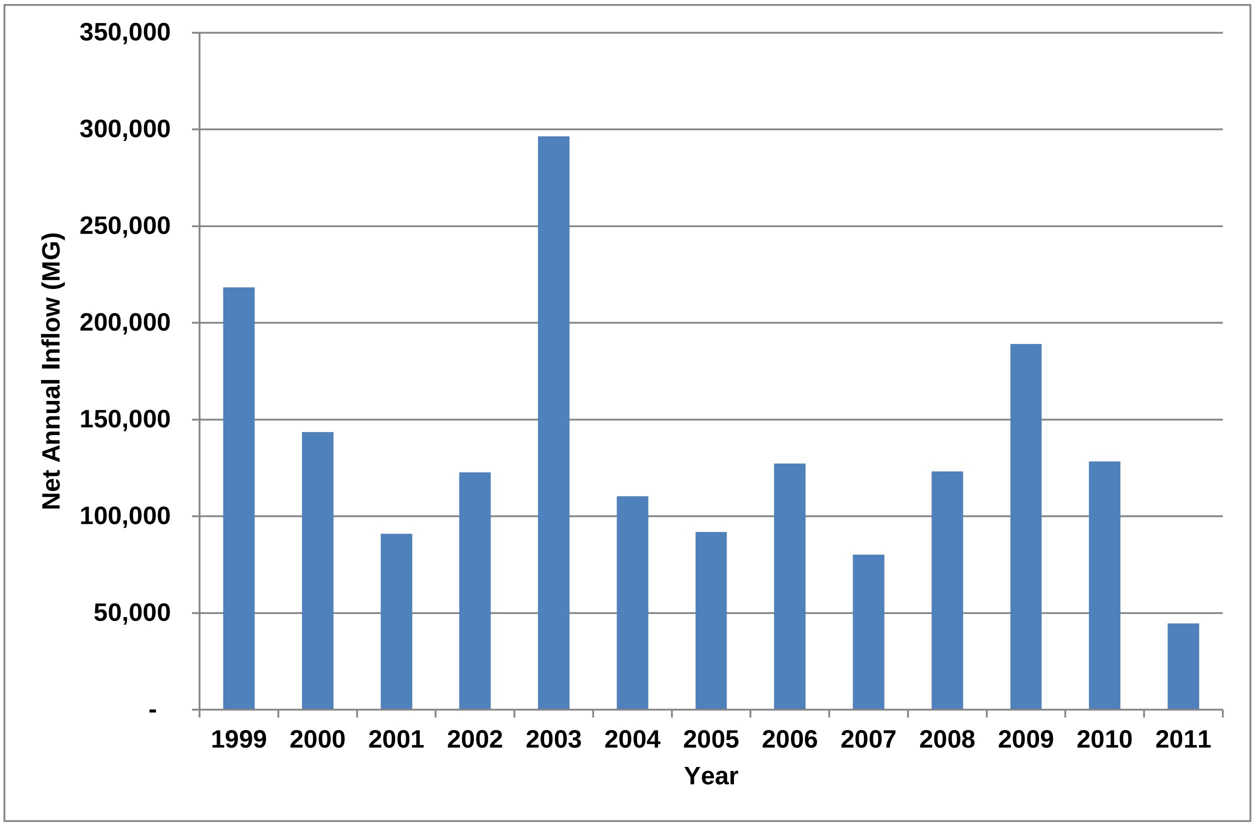



**Figure 3-5 Net Annual Inflows to Falls Lake (1999 to 2011)**

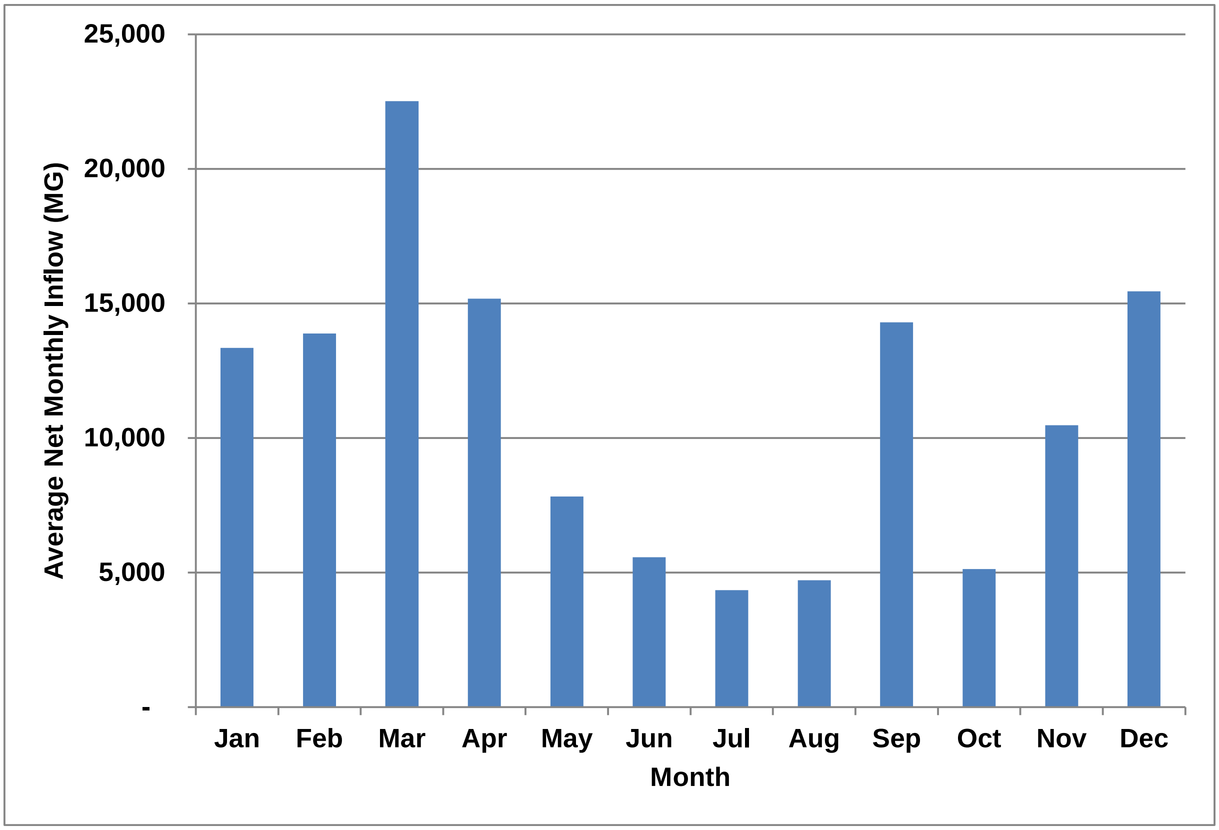



**Figure 3-6 Average Monthly Net Inflows to Falls Lake (January 1999 to June 2012)**

## 3.6 Temperature

Each of the eight participating organizations measured temperature as part of the water quality sampling effort. Temperature data was collected in-situ. For those organizations that provided information on methodology, the following methods were used:

> Temperature using thermometer or thermistor (EPA 170.1)

> Standard method using thermometer, thermophone or thermistor (SM 2550)

> Temperature using portable instrument (YSI 550A)

> Temperature using methods described in the NCDENR SOP (NCDENR 2011c) which specifies using either a Hydrolab or YSI meter (WQS_SOP)

Appendix E provides detailed descriptions of these methods.

Table 3-9 describes the organizations and analysis methods used to measure temperature and includes the number of samples, date range, and limits. The majority of the temperature data has been collected by NCDWQ using method EPA_170.1. The limits for temperature are listed as not applicable (NA) because ambient conditions would not exceed the limits of the equipment used. Temperature is presented in Celsius and to two decimal places based on reported data.

**Table 3-9 Summary of Analysis Methods for the Temperature Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit | Reporting Limit | Practical Quanti-fication Limit | Range of Limit Specified with Results |
|---|---|---|---|---|---|---|---|---|
| CAAE | Not Provided | 07/24/2007 | 12/17/2010 | 69 | NA | NA | NA | NA |
| Durham_Ci | Not Provided | 04/01/2002 | 04/30/2012 | 1,236 | NA | NA | NA | NA |
| Durham_Ci | YSI_550A | 01/10/2005 | 12/07/2011 | 897 | NA | NA | NA | NA |
| NCDWQ | EPA_170.1 | 06/07/2000 | 01/10/2012 | 5,152 | NA | NA | NA | NA |
| NCDWQ | WQS_SOP | 01/11/1999 | 04/06/2011 | 1,057 | NA | NA | NA | NA |
| Orange_Co | EPA_170.1 | 04/09/2010 | 03/25/2011 | 181 | NA | NA | NA | NA |
| Raleigh | Not Provided | 01/13/2009 | 03/05/2012 | 122 | NA | NA | NA | NA |
| Raleigh | SM_2550 | 02/07/2000 | 12/30/2011 | 1,107 | NA | NA | NA | NA |
| SGWASA | Not Provided | 01/04/2005 | 12/27/2011 | 1,437 | NA | NA | NA | NA |
| USGS | Not Provided | 01/15/1999 | 11/04/2011 | 1,002 | NA | NA | NA | NA |
| Wake_Co | Not Provided | 07/29/2008 | 10/28/2009 | 160 | NA | NA | NA | NA |

NA: Limits not applicable for temperature in ambient conditions.

### 3.6.2 Tributary Samples

Six organizations collected temperature data in the tributaries of Falls Lake from 1999 to present. Highest mean and median temperatures were recorded by SGWASA and lowest mean temperatures were recorded by Orange County. All monitored tributaries returned similar mean temperatures with highest mean and median temperatures recorded in Knap of Reeds Creek and lowest mean and median temperatures recorded in Beaverdam Creek and Lick Creek. Summary statistics and box plots are provided below.

***Temperature in Tributary Samples by Subwatershed and Distance from the Lake***

> Temperature was recorded in nine catchments, Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.

> The highest mean and median temperatures were recorded in Flat River (> than 10 miles from the mouth); however, only one sample was collected from this location. The second highest mean and median temperatures were recorded in Knap of Reeds Creek 0 to 2 miles from the mouth; this location included a much larger number of samples.

> The lowest mean temperature was recorded in Beaverdam Creek 2 to 10 miles from the dam followed by Lick Creek 0 to 2 miles.

> For Lick Creek mean temperature recorded 2 to 10 miles from the dam was greater than mean temperature recorded 0 to 2 miles from the mouth. For the remaining catchments where multiple

segments were sampled, the mean temperature recorded 2 to 10 miles from the mouth was less than the mean temperature recorded 0 to 2 miles from the dam.

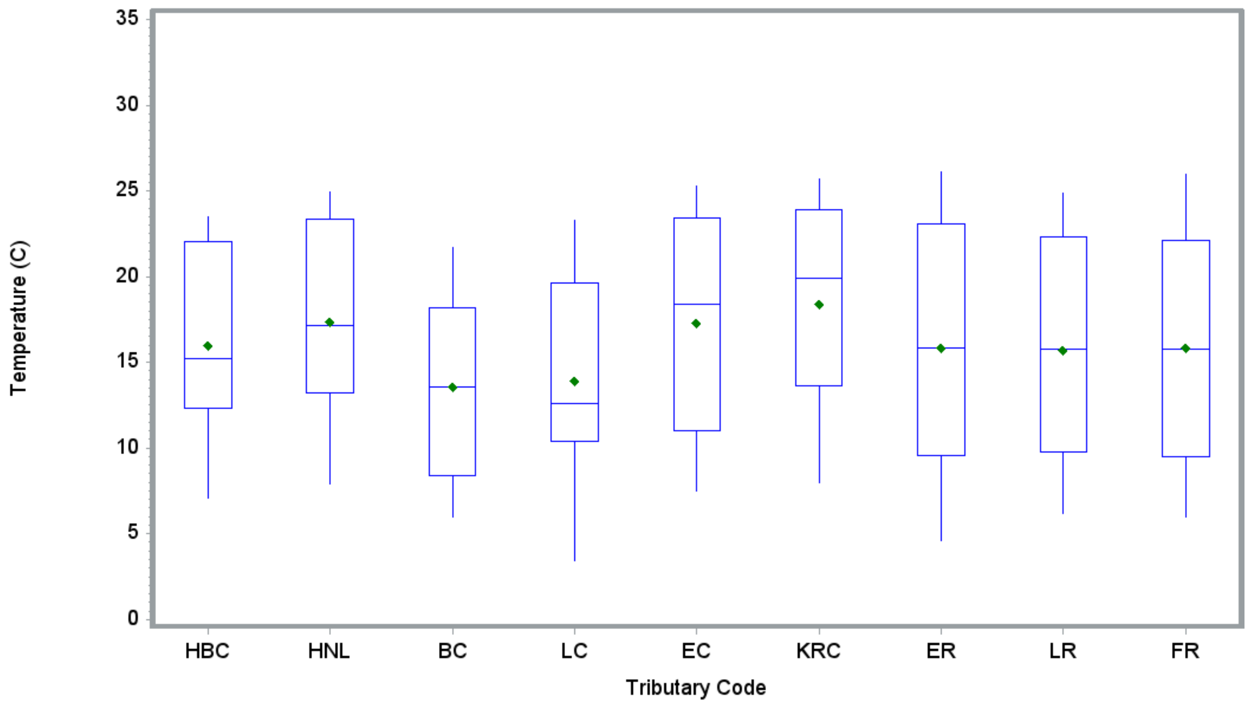



**Figure 3-7 Temperature Tributary Samples Categorized by Subwatershed**

**Table 3-10 Temperature Tributary Samples Categorized by Subwatershed (in Celsius)**

| Sub Watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 83 | 3.88 | 7.06 | 12.29 | 16.01 | 15.20 | 22.03 | 23.50 | 24.85 |
| HNL | 52 | 4.20 | 7.89 | 13.20 | 17.37 | 17.16 | 23.34 | 24.93 | 27.40 |
| BC | 48 | 3.54 | 6.00 | 8.40 | 13.56 | 13.55 | 18.20 | 21.70 | 23.80 |
| LC | 165 | 0.20 | 3.40 | 10.40 | 13.89 | 12.60 | 19.60 | 23.30 | 26.50 |
| EC | 1224 | 0.70 | 7.50 | 11.00 | 17.29 | 18.40 | 23.40 | 25.30 | 65.10[1] |
| KRC | 1608 | 0.70 | 8.00 | 13.60 | 18.41 | 19.90 | 23.90 | 25.70 | 29.70 |
| ER | 762 | 0.10 | 4.60 | 9.60 | 15.85 | 15.85 | 23.10 | 26.10 | 29.70 |
| LR | 555 | 0.40 | 6.20 | 9.80 | 15.73 | 15.80 | 22.30 | 24.90 | 32.70 |
| FR | 433 | 0.20 | 6.00 | 9.50 | 15.83 | 15.80 | 22.10 | 26.00 | 31.90 |

[1] This value was reported as 65.1 degrees C in the raw data file. The value is likely a data entry error.

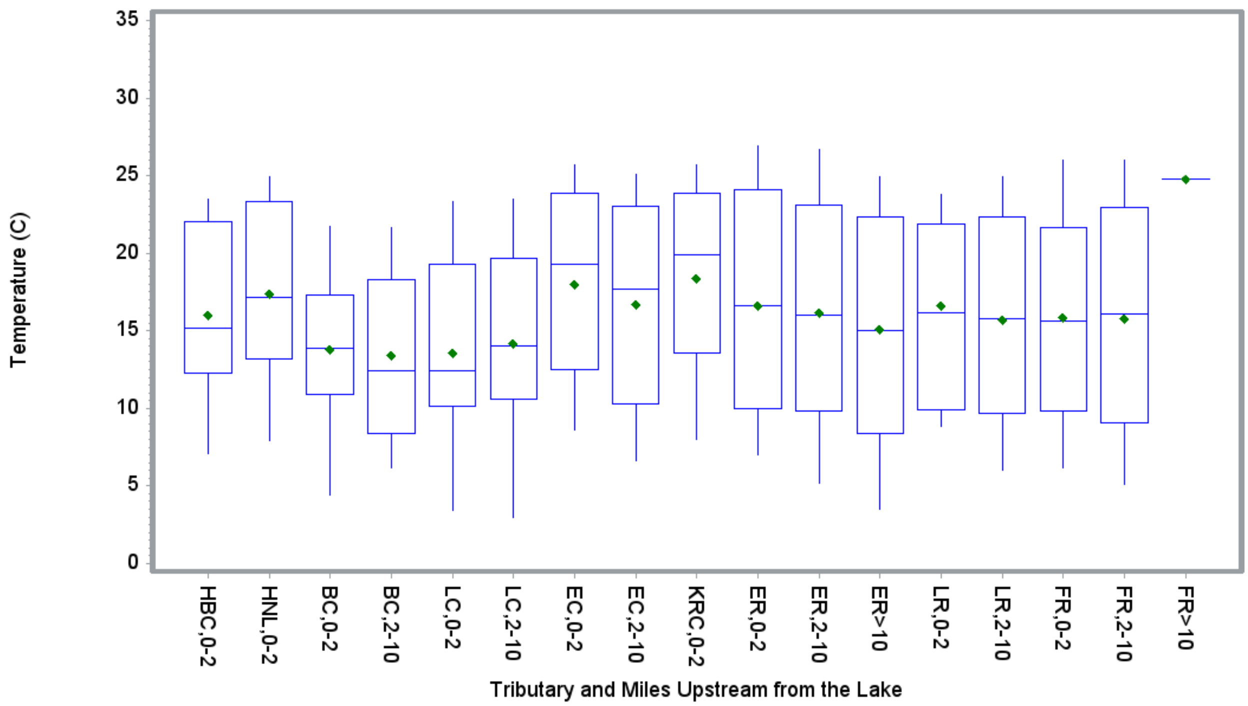



**Figure 3-8 Temperature Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-11 Temperature Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in Celsius)**

| Subwatershed, Miles from Lake | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 83 | 3.88 | 7.06 | 12.29 | 16.01 | 15.20 | 22.03 | 23.50 | 24.85 |
| HNL,0-2 | 52 | 4.20 | 7.89 | 13.20 | 17.37 | 17.16 | 23.34 | 24.93 | 27.40 |
| BC,0-2 | 18 | 3.54 | 4.43 | 10.87 | 13.81 | 13.85 | 17.30 | 21.70 | 22.40 |
| BC,2-10 | 30 | 4.60 | 6.15 | 8.40 | 13.41 | 12.45 | 18.30 | 21.65 | 23.80 |
| LC,0-2 | 76 | 0.20 | 3.40 | 10.15 | 13.57 | 12.45 | 19.30 | 23.30 | 26.50 |
| LC,2-10 | 89 | 0.20 | 3.00 | 10.60 | 14.16 | 14.00 | 19.70 | 23.50 | 26.30 |
| EC,0-2 | 559 | 0.70 | 8.60 | 12.50 | 18.01 | 19.30 | 23.90 | 25.70 | 28.40 |
| EC,2-10 | 665 | 0.80 | 6.60 | 10.30 | 16.69 | 17.70 | 23.00 | 25.10 | 65.10[1] |
| KRC,0-2 | 1608 | 0.70 | 8.00 | 13.60 | 18.41 | 19.90 | 23.90 | 25.70 | 29.70 |
| ER,0-2 | 151 | 2.30 | 7.00 | 10.00 | 16.62 | 16.60 | 24.10 | 26.90 | 29.20 |
| ER,2-10 | 326 | 0.60 | 5.20 | 9.80 | 16.16 | 16.00 | 23.10 | 26.70 | 29.70 |
| ER>10 | 285 | 0.10 | 3.50 | 8.40 | 15.09 | 15.00 | 22.30 | 24.90 | 29.20 |
| LR,0-2 | 18 | 7.90 | 8.80 | 9.90 | 16.64 | 16.15 | 21.90 | 23.80 | 26.90 |
| LR,2-10 | 537 | 0.40 | 6.00 | 9.70 | 15.70 | 15.80 | 22.30 | 24.90 | 32.70 |
| FR,0-2 | 276 | 2.50 | 6.20 | 9.85 | 15.83 | 15.60 | 21.65 | 26.00 | 31.90 |
| FR,2-10 | 156 | 0.20 | 5.10 | 9.10 | 15.78 | 16.05 | 22.95 | 26.00 | 28.00 |
| FR>10 | 1 | 24.80 | 24.80 | 24.80 | 24.80 | 24.80 | 24.80 | 24.80 | 24.80 |

[1] This value was reported as 65.1 degrees C in the raw data file. The value is likely a data entry error.

***Temperature in Tributary Samples Categorized by Depth***

> Temperature was only recorded at the surface level for all tributaries.

***Temperature in Tributary Samples Categorized by Year***

> By year, highest mean temperatures were recorded in 2007 and 2006.

> The lowest mean and median temperatures were recorded in 2012; however this is a partial dataset, and only represents he first part of the year.  The second lowest mean and median temperatures were recorded in 2005.

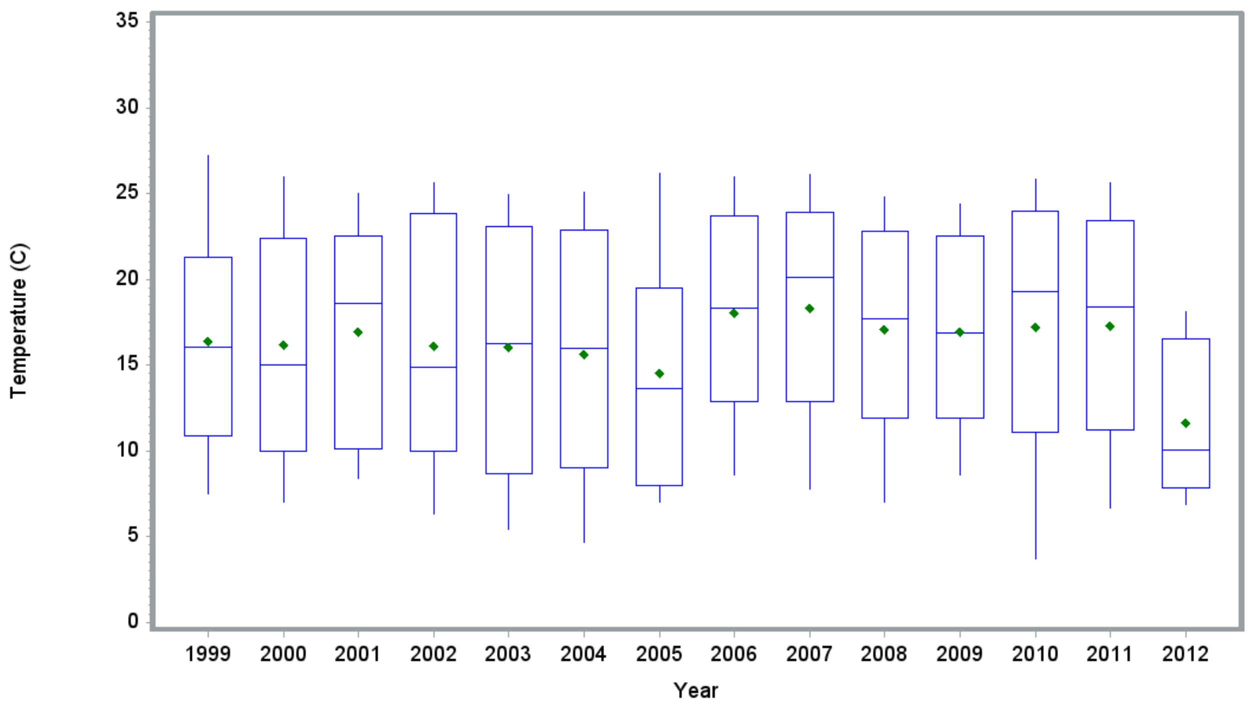



**Figure 3-9 Temperature Tributary Samples Categorized by Year**

**Table 3-12 Temperature Tributary Samples Categorized by Year (in Celsius)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 136 | 2.60 | 7.50 | 10.90 | 16.39 | 16.05 | 21.25 | 27.20 | 29.50 |
| 2000 | 138 | 2.90 | 7.00 | 10.00 | 16.18 | 15.00 | 22.40 | 26.00 | 28.00 |
| 2001 | 119 | 6.00 | 8.40 | 10.10 | 16.92 | 18.60 | 22.50 | 25.00 | 29.00 |
| 2002 | 119 | 4.30 | 6.30 | 10.00 | 16.12 | 14.90 | 23.80 | 25.60 | 31.90 |
| 2003 | 150 | 3.20 | 5.45 | 8.70 | 16.05 | 16.25 | 23.10 | 24.95 | 27.90 |
| 2004 | 125 | 0.80 | 4.70 | 9.00 | 15.61 | 16.00 | 22.90 | 25.10 | 28.60 |
| 2005 | 279 | 3.00 | 7.00 | 8.00 | 14.50 | 13.60 | 19.50 | 26.20 | 29.50 |
| 2006 | 426 | 5.10 | 8.60 | 12.90 | 18.03 | 18.30 | 23.70 | 26.00 | 30.30 |
| 2007 | 380 | 1.30 | 7.75 | 12.85 | 18.29 | 20.10 | 23.90 | 26.10 | 29.70 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2008 | 467 | 1.80 | 7.03 | 11.90 | 17.05 | 17.68 | 22.80 | 24.80 | 27.60 |
| 2009 | 876 | 0.70 | 8.60 | 11.90 | 16.95 | 16.85 | 22.50 | 24.40 | 28.60 |
| 2010 | 980 | 0.20 | 3.70 | 11.10 | 17.21 | 19.30 | 24.00 | 25.80 | 65.10[1] |
| 2011 | 699 | 0.10 | 6.70 | 11.20 | 17.28 | 18.40 | 23.40 | 25.60 | 32.70 |
| 2012 | 36 | 5.90 | 6.90 | 7.85 | 11.64 | 10.05 | 16.55 | 18.10 | 19.60 |

[1] This value was reported as 65.1 degrees C in the raw data file. The value is likely a data entry error.

***Temperature in Tributary Samples Categorized by Month***

> By month, the highest mean and median temperatures were recorded in August and July.

> The lowest mean temperatures were recorded in January, February and December.

> The bell shaped curve of the monthly box plots reflects seasonality in mean temperature.

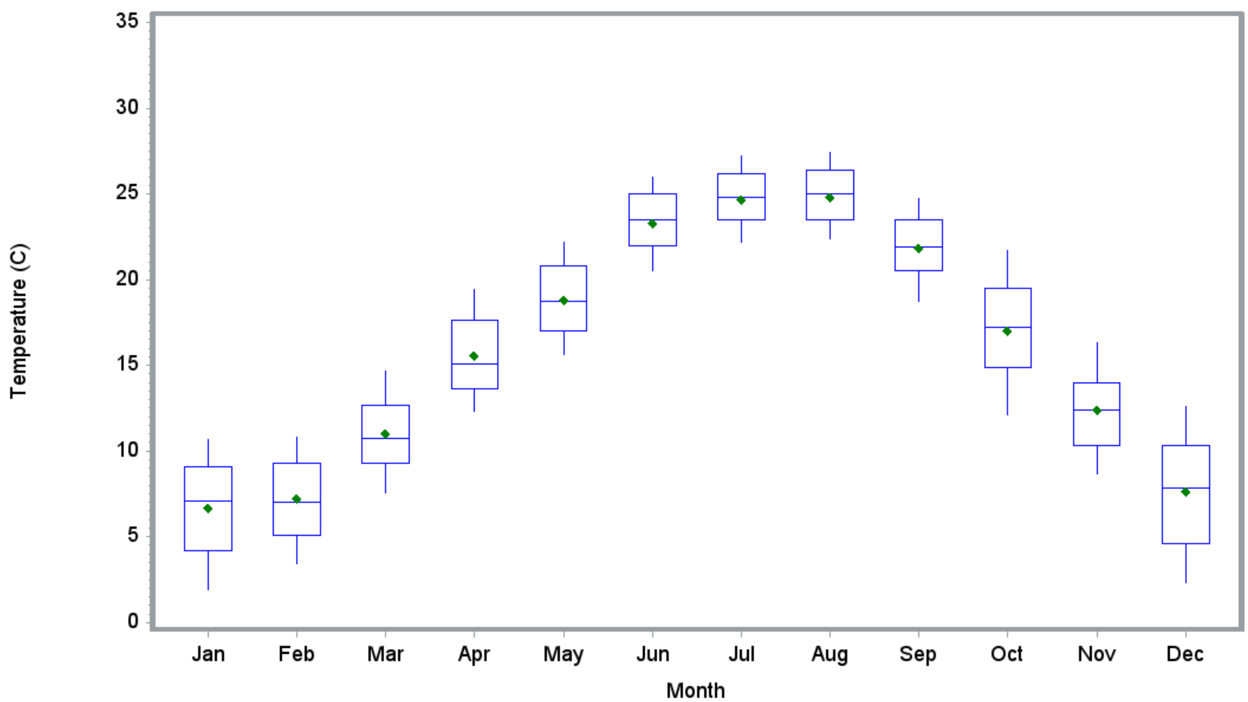



**Figure 3-10 Temperature Tributary Samples Categorized by Month**

**Table 3-13 Temperature Tributary Samples Categorized by Month (in Celsius)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 336 | 0.10 | 1.90 | 4.20 | 6.70 | 7.10 | 9.05 | 10.70 | 16.50 |
| Feb | 331 | 1.40 | 3.40 | 5.10 | 7.22 | 7.00 | 9.30 | 10.80 | 18.00 |
| Mar | 336 | 1.30 | 7.60 | 9.30 | 10.99 | 10.75 | 12.70 | 14.70 | 18.80 |
| Apr | 463 | 7.00 | 12.30 | 13.60 | 15.55 | 15.10 | 17.60 | 19.40 | 22.20 |
| May | 428 | 7.00 | 15.60 | 17.00 | 18.77 | 18.75 | 20.80 | 22.20 | 25.50 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jun | 515 | 7.00 | 20.50 | 22.00 | 23.27 | 23.50 | 25.00 | 26.00 | 28.90 |
| Jul | 495 | 7.00 | 22.20 | 23.50 | 24.64 | 24.80 | 26.20 | 27.20 | 65.10[1] |
| Aug | 468 | 7.00 | 22.40 | 23.50 | 24.77 | 25.00 | 26.40 | 27.40 | 31.90 |
| Sep | 459 | 7.00 | 18.70 | 20.50 | 21.83 | 21.90 | 23.50 | 24.70 | 27.90 |
| Oct | 464 | 7.00 | 12.10 | 14.85 | 17.02 | 17.20 | 19.50 | 21.70 | 25.60 |
| Nov | 317 | 6.40 | 8.70 | 10.30 | 12.38 | 12.40 | 14.00 | 16.30 | 20.50 |
| Dec | 318 | 0.50 | 2.30 | 4.60 | 7.64 | 7.85 | 10.30 | 12.60 | 18.40 |

[1] This value was reported as 65.1 degrees C in the raw data file. The value is likely a data entry error.

***Temperature in Tributary Samples Categorized by Sampling Organization***

> Highest mean and median temperatures were recorded by SGWASA.

> Lowest mean and median temperatures were recorded by Orange County.

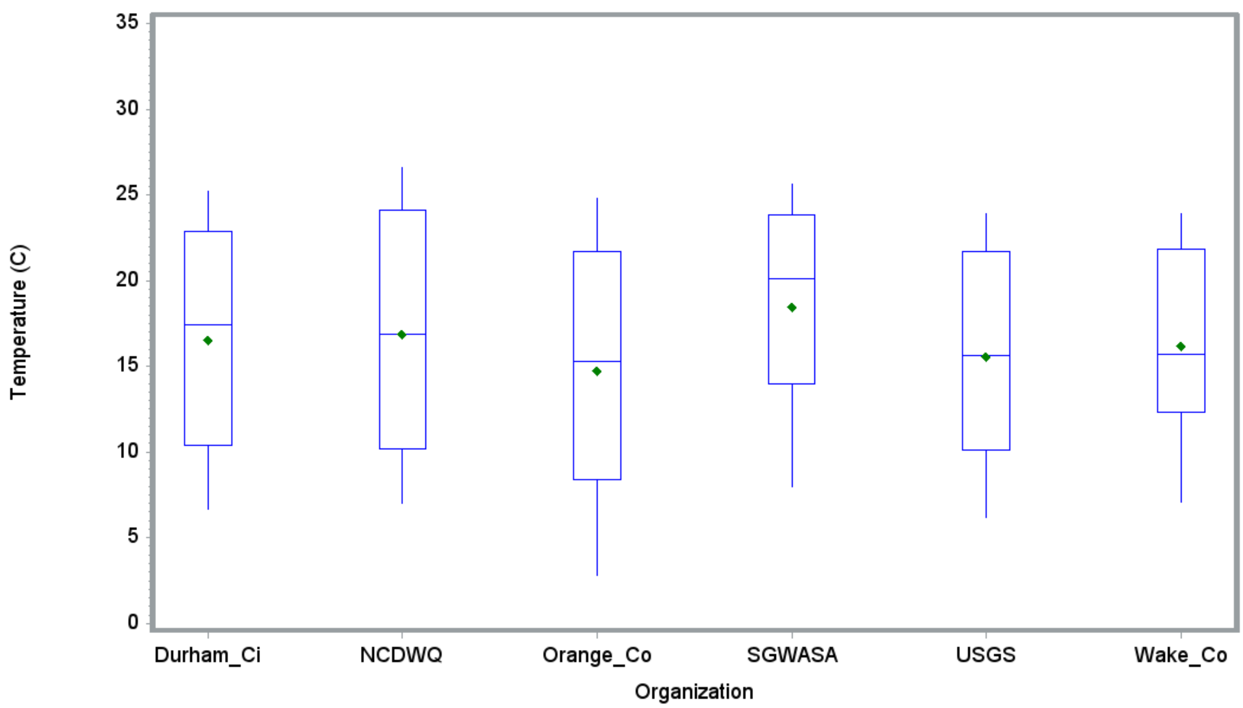



**Figure 3-11 Temperature Tributary Samples Categorized by Sampling Organization**

**Table 3-14 Temperature Tributary Samples Categorized by Sampling Organization (in Celsius)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 1479 | 0.20 | 6.70 | 10.40 | 16.51 | 17.40 | 22.90 | 25.20 | 65.1[1] |
| NCDWQ | 1057 | 0.80 | 7.00 | 10.20 | 16.84 | 16.90 | 24.10 | 26.60 | 31.90 |
| Orange_Co | 181 | 0.10 | 2.80 | 8.40 | 14.74 | 15.30 | 21.70 | 24.80 | 29.20 |
| SGWASA | 1437 | 0.70 | 8.00 | 14.00 | 18.47 | 20.10 | 23.80 | 25.60 | 29.70 |

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| USGS | 624 | 0.40 | 6.20 | 10.15 | 15.58 | 15.60 | 21.70 | 23.90 | 32.70 |
| Wake_Co | 152 | 3.54 | 7.06 | 12.34 | 16.16 | 15.67 | 21.84 | 23.87 | 27.40 |

[1] This value was reported as 65.1 degrees C in the raw data file. The value is likely a data entry error.

***Temperature in Tributary Samples Categorized by Method***

> The four analysis method categories returned similar mean temperature recordings, with the unknown category returning the highest mean temperatures and EPA 170.1 returning the lowest mean temperatures.

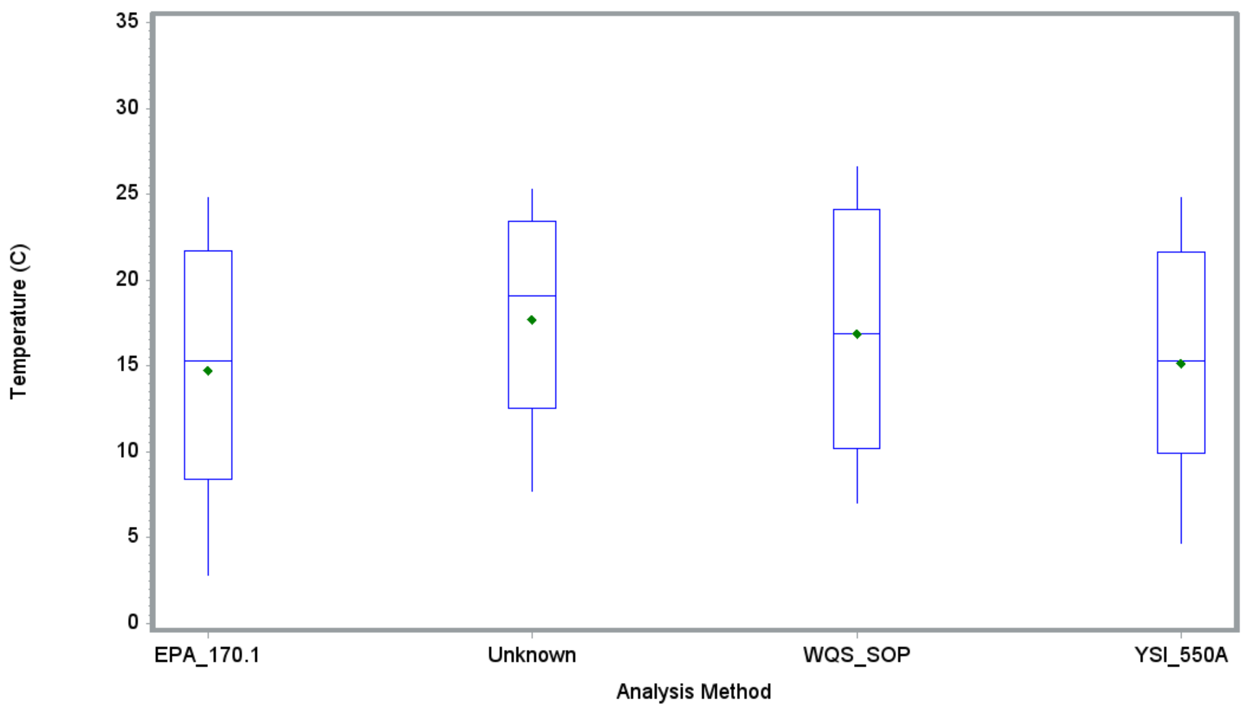



**Figure 3-12 Temperature Tributary Samples Categorized by Analysis Method**

**Table 3-15 Temperature Tributary Samples Categorized by Analysis Method**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_170.1 | 181 | 0.10 | 2.80 | 8.40 | 14.74 | 15.30 | 21.70 | 24.80 | 29.20 |
| Unknown | 2795 | 0.40 | 7.70 | 12.50 | 17.72 | 19.10 | 23.40 | 25.30 | 65.1[1] |
| WQS_SOP | 1057 | 0.80 | 7.00 | 10.20 | 16.84 | 16.90 | 24.10 | 26.60 | 31.90 |
| YSI_550A | 897 | 0.20 | 4.70 | 9.90 | 15.18 | 15.30 | 21.60 | 24.80 | 30.30 |

[1] This value was reported as 65.1 degrees C in the raw data file. The value is likely a data entry error.

### 3.6.3 Upper Lake Samples

Three organizations collected temperature data in Upper Falls Lake from 2000 to present. Highest mean and median temperatures were recorded by the City of Durham and lowest mean and median temperatures were collected by the USGS. All monitored sections of upper Falls Lake returned similar mean temperatures with highest mean temperatures recorded > than 21 miles from the dam and lowest mean temperatures recorded 18 to 21 miles from the dam. Highest mean temperatures were recorded in 2001. Summary statistics and box plots are provided below.

***Temperature Upper Lake Samples Categorized by Miles Upstream from Dam***

> The mean temperature at all three locations was similar, with highest mean temperature recorded > 21 miles from the dam and lowest mean temperature recorded 18 to 21 miles from the dam.

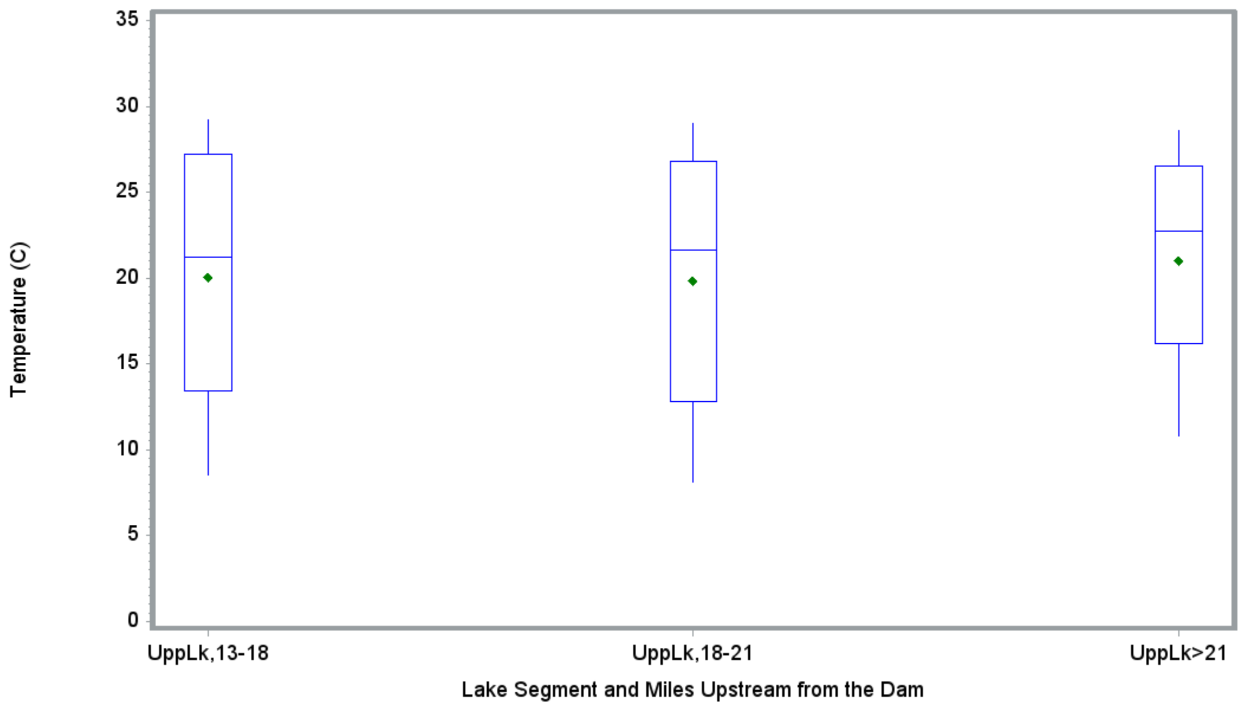



**Figure 3-13 Temperature Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-16 Temperature Upper Lake Samples Categorized by Miles Upstream from Dam (in Celsius)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 1496 | 2.20 | 8.50 | 13.45 | 20.02 | 21.20 | 27.20 | 29.20 | 32.80 |
| UppLk,18-21 | 333 | 2.60 | 8.10 | 12.80 | 19.82 | 21.60 | 26.80 | 29.00 | 31.20 |
| UppLk>21 | 1376 | 0.88 | 10.80 | 16.15 | 21.02 | 22.70 | 26.50 | 28.60 | 32.50 |

***Temperature Upper Lake Samples Categorized by Depth***

> By depth, highest mean temperatures were recorded at the surface level, with similar but slightly lower readings at the mid-level category.

> Lowest mean temperatures were recorded at the bottom level. The range of temperatures recorded at the bottom level was also significantly less than the other two depth zones; however, the sample size for this category was also significantly less (n=12).

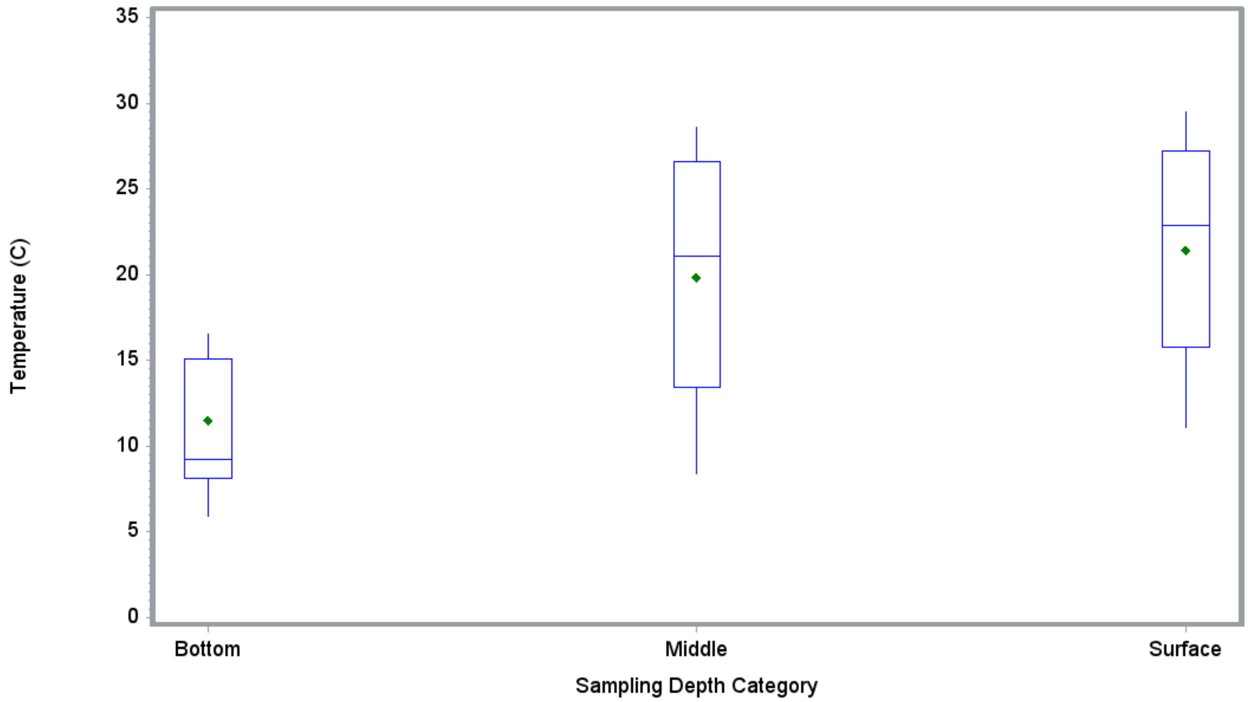



**Figure 3-14 Temperature Upper Lake Samples Categorized by Depth Category (surface, photic, bottom)**

**Table 3-17 Temperature Upper Lake Samples Categorized by Depth Category (surface, photic, bottom) (in Celsius)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 12 | 5.50 | 5.90 | 8.15 | 11.48 | 9.20 | 15.10 | 16.50 | 24.50 |
| Middle | 1913 | 2.20 | 8.40 | 13.40 | 19.81 | 21.10 | 26.60 | 28.60 | 31.60 |
| Surface | 1280 | 0.88 | 11.05 | 15.80 | 21.43 | 22.90 | 27.20 | 29.50 | 32.80 |

***Temperature Upper Lake Samples Categorized by Year***

- By full year, highest mean temperatures were recorded in 2001, followed by 2000.
- The lowest mean and median temperatures were recorded in 2012, likely because this dataset represents only the first part of 2012. The second lowest mean and median temperatures were recorded in 2006.

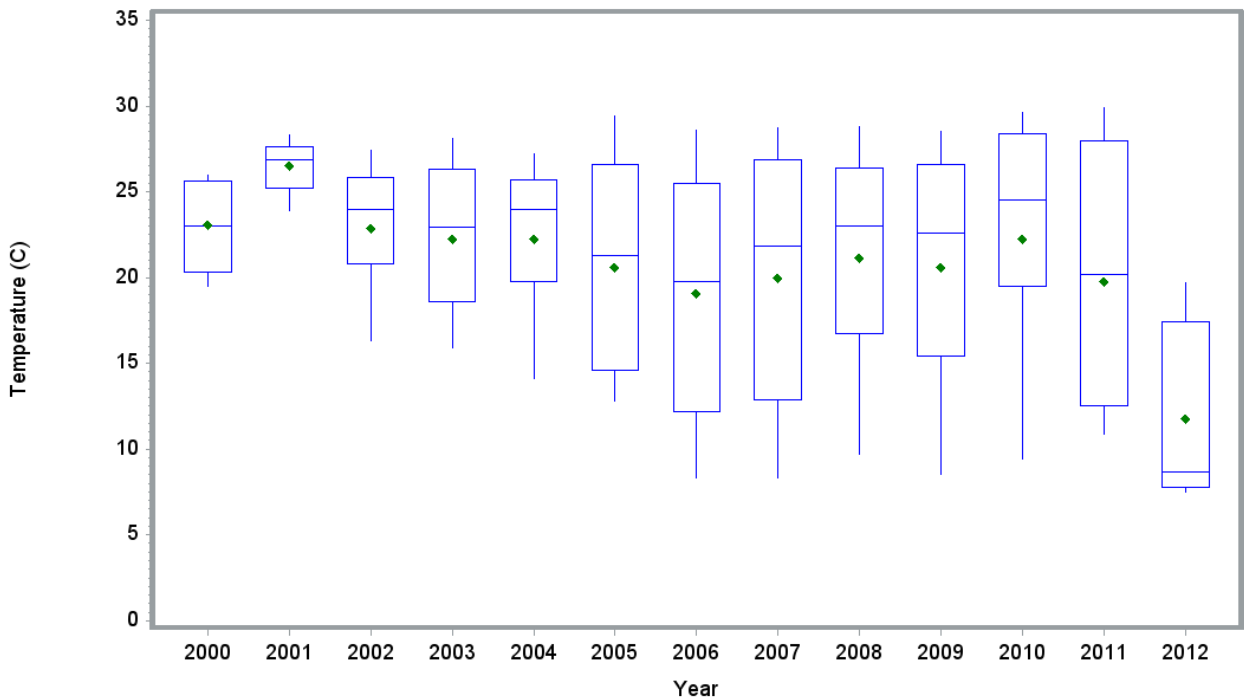



**Figure 3-15 Temperature Upper Lake Samples Categorized by Year**

**Table 3-18 Temperature Upper Lake Samples Categorized by Year (in Celsius)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 59 | 18.90 | 19.50 | 20.30 | 23.04 | 23.00 | 25.60 | 26.00 | 26.60 |
| 2001 | 94 | 20.70 | 23.90 | 25.20 | 26.52 | 26.85 | 27.60 | 28.30 | 30.50 |
| 2002 | 63 | 13.50 | 16.30 | 20.80 | 22.85 | 24.00 | 25.80 | 27.40 | 29.60 |
| 2003 | 62 | 11.90 | 15.90 | 18.60 | 22.27 | 22.95 | 26.30 | 28.10 | 29.00 |
| 2004 | 62 | 5.10 | 14.10 | 19.80 | 22.24 | 24.00 | 25.70 | 27.20 | 31.40 |
| 2005 | 556 | 5.10 | 12.80 | 14.60 | 20.58 | 21.30 | 26.60 | 29.40 | 32.30 |
| 2006 | 766 | 5.30 | 8.30 | 12.20 | 19.11 | 19.80 | 25.50 | 28.60 | 32.80 |
| 2007 | 619 | 4.70 | 8.30 | 12.90 | 19.96 | 21.80 | 26.90 | 28.70 | 32.70 |
| 2008 | 96 | 5.50 | 9.70 | 16.75 | 21.18 | 23.00 | 26.35 | 28.80 | 30.80 |
| 2009 | 100 | 3.70 | 8.50 | 15.40 | 20.62 | 22.60 | 26.60 | 28.50 | 30.30 |
| 2010 | 314 | 0.88 | 9.40 | 19.50 | 22.25 | 24.55 | 28.40 | 29.60 | 32.00 |
| 2011 | 379 | 3.80 | 10.90 | 12.50 | 19.78 | 20.20 | 28.00 | 29.90 | 31.60 |
| 2012 | 35 | 7.30 | 7.50 | 7.80 | 11.78 | 8.70 | 17.40 | 19.70 | 21.40 |

***Temperature Upper Lake Samples Categorized by Month***

> By month, the highest mean and median temperatures were recorded in August and July and lowest mean and median temperatures were recorded in January, December and February.

> The bell shaped curve of the monthly box plots reflects seasonality in mean temperature.

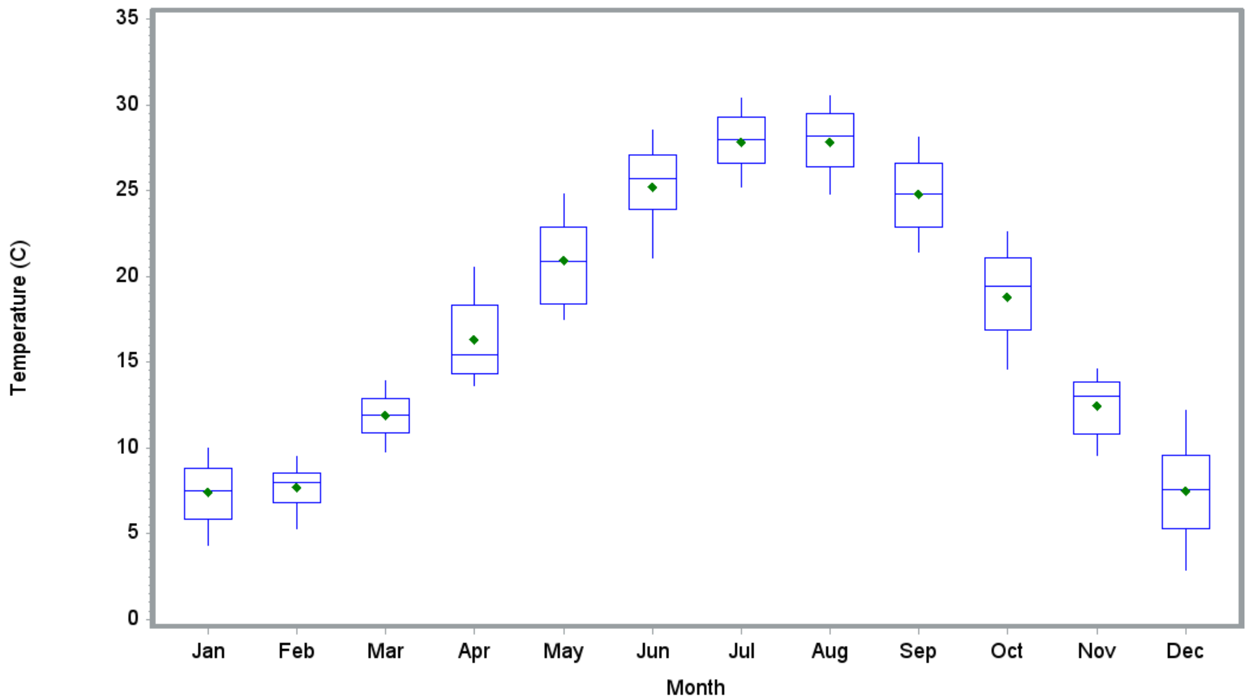



**Figure 3-16 Temperature Upper Lake Samples Categorized by Month**

**Table 3-19 Temperature Upper Lake Samples Categorized by Month (in Celsius)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 124 | 3.80 | 4.30 | 5.85 | 7.40 | 7.50 | 8.80 | 10.00 | 11.30 |
| Feb | 125 | 3.70 | 5.30 | 6.80 | 7.68 | 8.00 | 8.50 | 9.50 | 12.90 |
| Mar | 204 | 8.80 | 9.80 | 10.85 | 11.92 | 11.90 | 12.85 | 13.90 | 17.70 |
| Apr | 336 | 0.88 | 13.60 | 14.30 | 16.32 | 15.40 | 18.35 | 20.50 | 24.20 |
| May | 323 | 5.50 | 17.50 | 18.40 | 20.94 | 20.90 | 22.90 | 24.80 | 29.90 |
| Jun | 395 | 5.10 | 21.10 | 23.90 | 25.19 | 25.70 | 27.10 | 28.50 | 30.90 |
| Jul | 382 | 17.60 | 25.20 | 26.60 | 27.81 | 28.00 | 29.30 | 30.40 | 32.40 |
| Aug | 463 | 18.00 | 24.80 | 26.40 | 27.85 | 28.20 | 29.50 | 30.50 | 32.80 |
| Sep | 308 | 18.90 | 21.40 | 22.90 | 24.81 | 24.80 | 26.60 | 28.10 | 31.50 |
| Oct | 255 | 10.10 | 14.60 | 16.90 | 18.80 | 19.40 | 21.10 | 22.60 | 24.80 |
| Nov | 168 | 8.90 | 9.60 | 10.80 | 12.48 | 13.00 | 13.85 | 14.60 | 16.30 |
| Dec | 122 | 1.60 | 2.90 | 5.30 | 7.53 | 7.60 | 9.60 | 12.20 | 13.60 |

***Temperature Upper Lake Samples Categorized by Sampling Organization***

> Mean temperatures recorded by each organization were similar.

> Highest mean and median temperatures were recorded by the City of Durham and lowest mean and median temperatures were collected by the USGS.

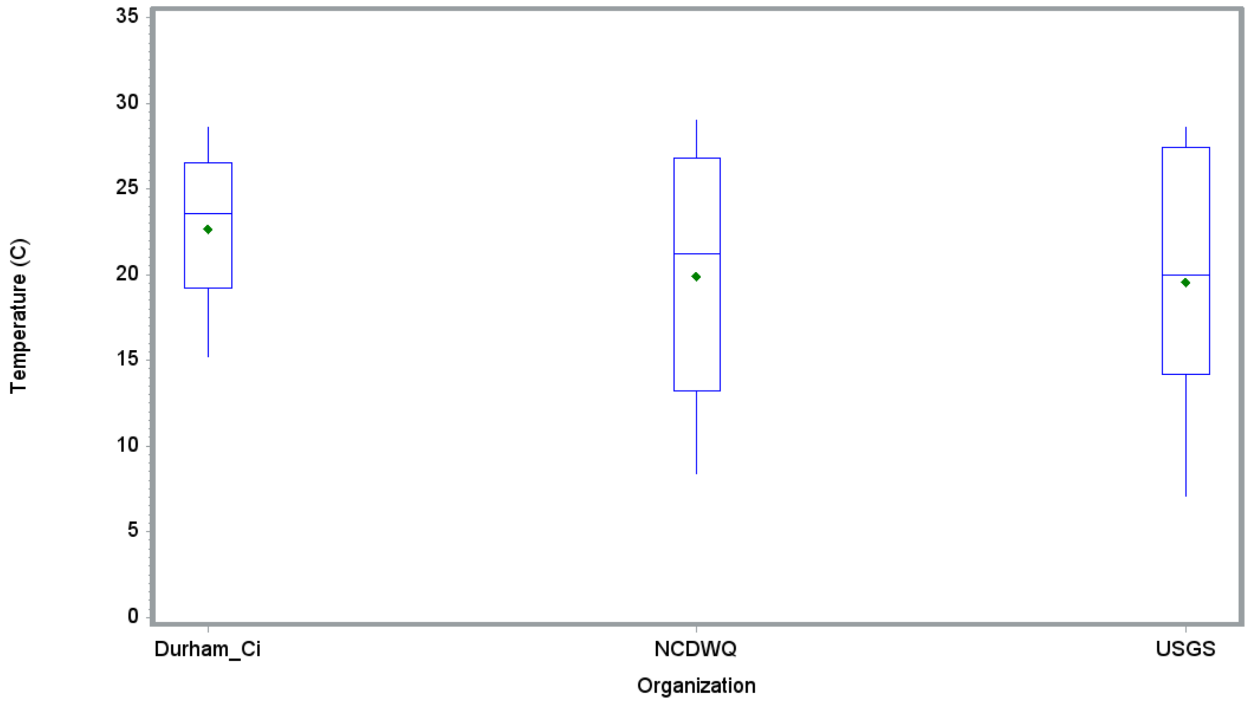



**Figure 3-17 Temperature Upper Lake Samples Categorized by Sampling Organization**

**Table 3-20 Temperature Upper Lake Samples Categorized by Sampling Organization (in Celsius)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 654 | 0.88 | 15.20 | 19.20 | 22.66 | 23.55 | 26.50 | 28.60 | 31.90 |
| NCDWQ | 2368 | 1.60 | 8.40 | 13.20 | 19.88 | 21.20 | 26.80 | 29.00 | 32.80 |
| USGS | 183 | 3.70 | 7.10 | 14.20 | 19.56 | 20.00 | 27.40 | 28.60 | 31.00 |

***Temperature Upper Lake Samples Categorized by Method***

> Of the two analysis method categories, the unknown category returned higher mean and median temperatures than the EPA 170.1 category.

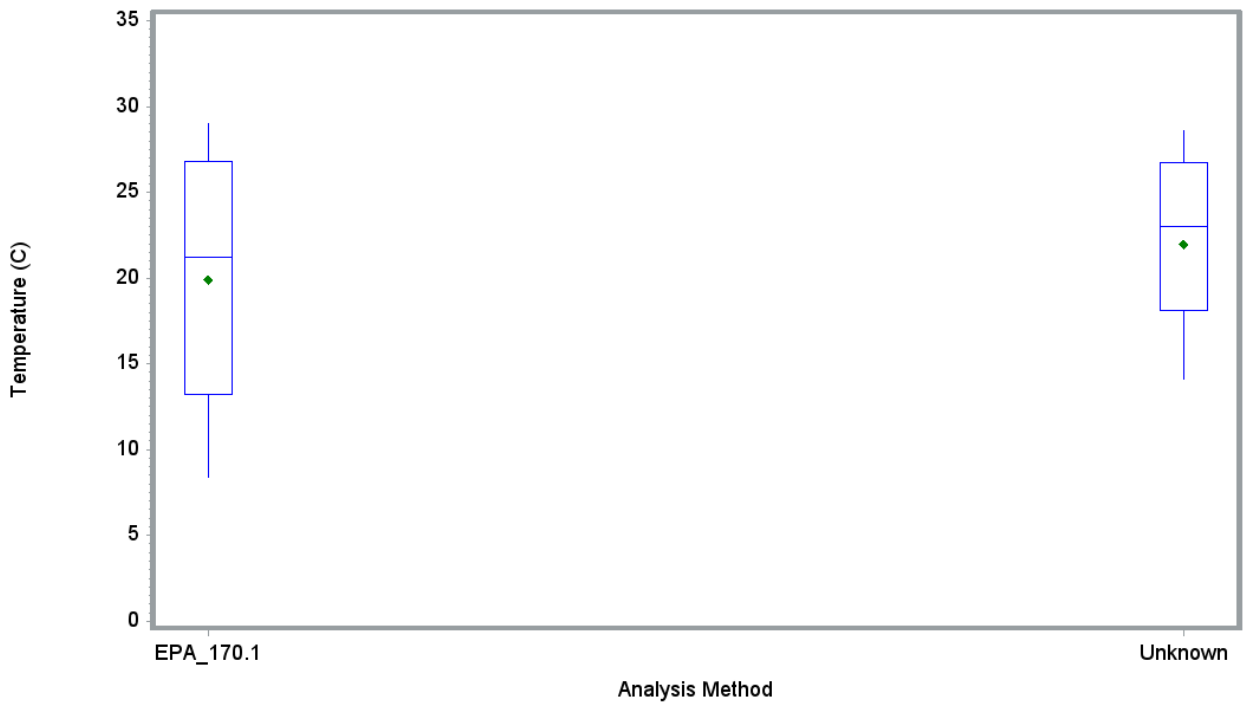



**Figure 3-18 Temperature Upper Lake Samples Categorized by Analysis Method**

**Table 3-21 Temperature Upper Lake Samples Categorized by Analysis Method (in Celsius)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_170.1 | 2368 | 1.60 | 8.40 | 13.20 | 19.88 | 21.20 | 26.80 | 29.00 | 32.80 |
| Unknown | 837 | 0.88 | 14.10 | 18.10 | 21.98 | 23.00 | 26.70 | 28.60 | 31.90 |

### 3.6.4 Lower Lake Samples

Five organizations collected temperature data in Lower Falls Lake from 2000 to present. Highest mean and median temperatures were recorded by the City of Raleigh and NCSU-CAAE and lowest mean and median temperature were recorded by Wake County (this dataset also represents the smallest sample size). Mean and median temperatures at lake sections were similar, with highest mean and median temperatures recorded in Lower Lake 8 to 13 miles from the dam and lowest mean and median temperature recorded in Beaverdam Impoundment. Summary statistics and box plots are provided below.

***Temperature Lower Lake Samples Categorized Lake Segment and Miles Upstream from Dam***

> Mean and median temperatures at all locations were similar, with highest mean and median temperatures recorded in Lower Lake 8 to 13 miles from the dam and lowest mean and median temperature recorded in Beaverdam Impoundment.

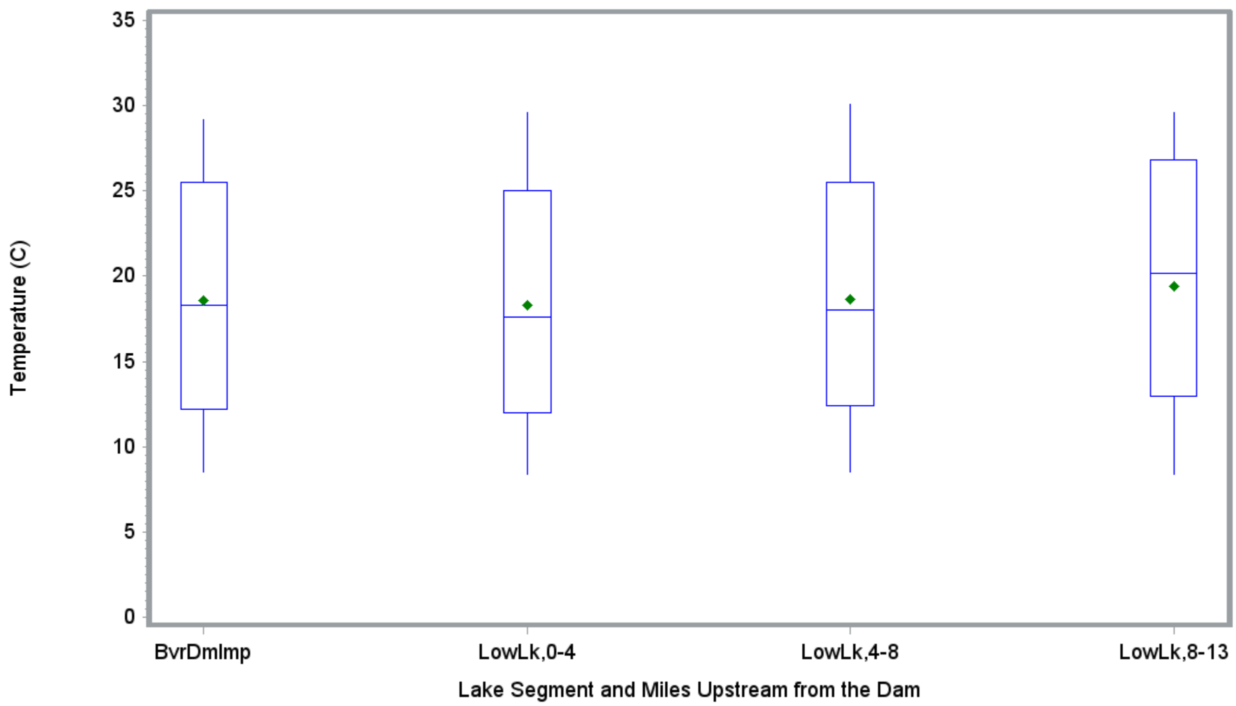



**Figure 3-19 Temperature Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-22 Temperature Lower Lake Samples Categorized by Miles Upstream from Dam (in Celsius)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 123 | 2.80 | 8.00 | 12.00 | 18.42 | 17.90 | 26.30 | 30.00 | 31.80 |
| LowLk,0-4 | 1276 | 2.50 | 8.80 | 13.20 | 18.96 | 18.60 | 25.30 | 29.10 | 33.80 |
| LowLk,4-8 | 2271 | 2.40 | 9.30 | 13.80 | 19.43 | 19.30 | 25.90 | 29.30 | 36.00 |
| LowLk,8-13 | 615 | 2.50 | 8.80 | 13.90 | 20.23 | 21.30 | 27.20 | 29.60 | 32.80 |

***Temperature Lower Lake Samples Categorized by Depth***

> By depth, highest mean and median temperatures were recorded at the surface level.

> Lowest mean and median temperatures, and the smallest range of temperatures, were recorded at the bottom level; however the sample size for this category was less than the other two categories.

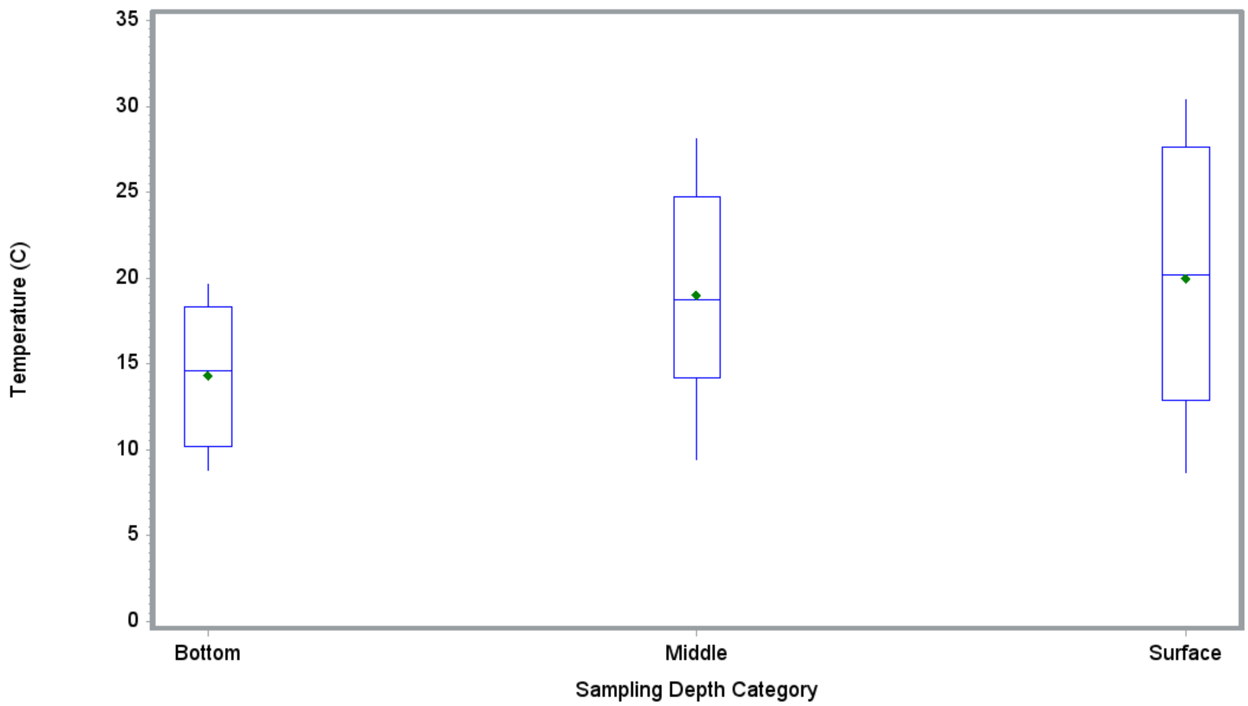



**Figure 3-20 Temperature Lower Lake Samples Categorized by Depth**

**Table 3-23 Temperature Lower Lake Samples Categorized by Depth (in Celsius)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 43 | 4.70 | 8.80 | 10.20 | 14.34 | 14.60 | 18.30 | 19.60 | 23.90 |
| Middle | 2327 | 3.80 | 9.40 | 14.20 | 19.00 | 18.70 | 24.70 | 28.10 | 31.50 |
| Surface | 1915 | 2.40 | 8.70 | 12.90 | 19.95 | 20.20 | 27.60 | 30.40 | 36.00 |

***Temperature Lower Lake Samples Categorized by Year***

> Mean temperatures across all years were fairly similar, except for 2012, which is a partial dataset and represents only a portion of the year.

> By year, highest mean temperatures were recorded in 2001 and 2010.

> The lowest mean temperature was recorded in 2012, likely because this dataset represents only the first part of 2012. The second lowest mean temperatures were recorded in 2011 and 2008.

> Similar variability in measurements was recorded for all years (except for 2012)

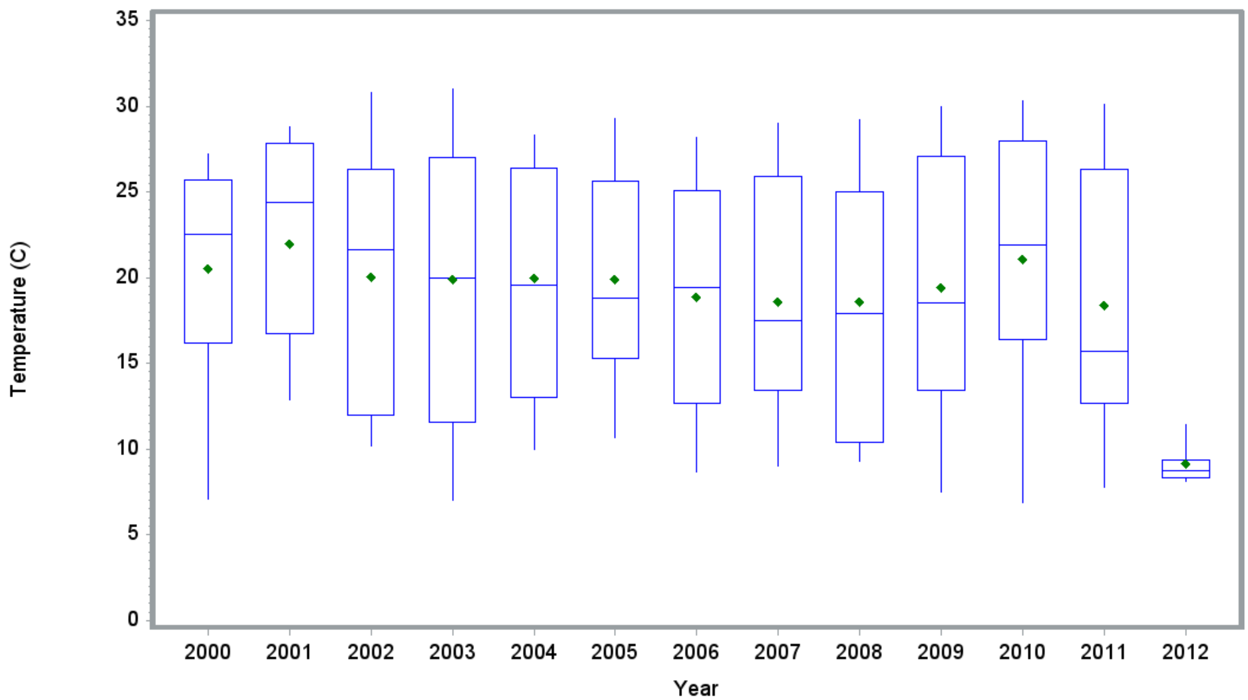



**Figure 3-21 Temperature Lower Lake Samples Categorized by Year**

**Table 3-24 Temperature Lower Lake Samples Categorized by Year (in Celsius)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 155 | 4.10 | 7.10 | 16.20 | 20.54 | 22.50 | 25.70 | 27.20 | 30.20 |
| 2001 | 224 | 3.00 | 12.90 | 16.70 | 21.97 | 24.40 | 27.80 | 28.80 | 31.00 |
| 2002 | 86 | 7.30 | 10.20 | 12.00 | 20.01 | 21.65 | 26.30 | 30.80 | 32.50 |
| 2003 | 96 | 2.50 | 7.00 | 11.55 | 19.88 | 20.00 | 27.00 | 31.00 | 36.00 |
| 2004 | 88 | 7.00 | 10.00 | 13.00 | 20.00 | 19.55 | 26.35 | 28.30 | 32.00 |
| 2005 | 726 | 7.00 | 10.70 | 15.30 | 19.88 | 18.80 | 25.60 | 29.30 | 32.80 |
| 2006 | 823 | 6.70 | 8.70 | 12.70 | 18.88 | 19.40 | 25.10 | 28.20 | 31.70 |
| 2007 | 741 | 4.70 | 9.00 | 13.40 | 18.60 | 17.50 | 25.90 | 29.00 | 32.70 |
| 2008 | 161 | 6.10 | 9.30 | 10.40 | 18.58 | 17.90 | 25.00 | 29.20 | 31.40 |
| 2009 | 163 | 5.60 | 7.50 | 13.40 | 19.39 | 18.50 | 27.10 | 30.00 | 31.30 |
| 2010 | 445 | 2.40 | 6.90 | 16.40 | 21.09 | 21.90 | 28.00 | 30.30 | 32.80 |
| 2011 | 537 | 4.00 | 7.80 | 12.70 | 18.38 | 15.70 | 26.30 | 30.10 | 33.80 |
| 2012 | 40 | 8.00 | 8.10 | 8.30 | 9.14 | 8.71 | 9.35 | 11.43 | 11.88 |

***Temperature Lower Lake Samples Categorized by Month***

> By month, the highest mean and median temperatures were recorded in August and July and lowest mean temperatures were recorded in January, February, and December.

> The bell shaped curve of the monthly box plots reflects seasonality in mean temperature.

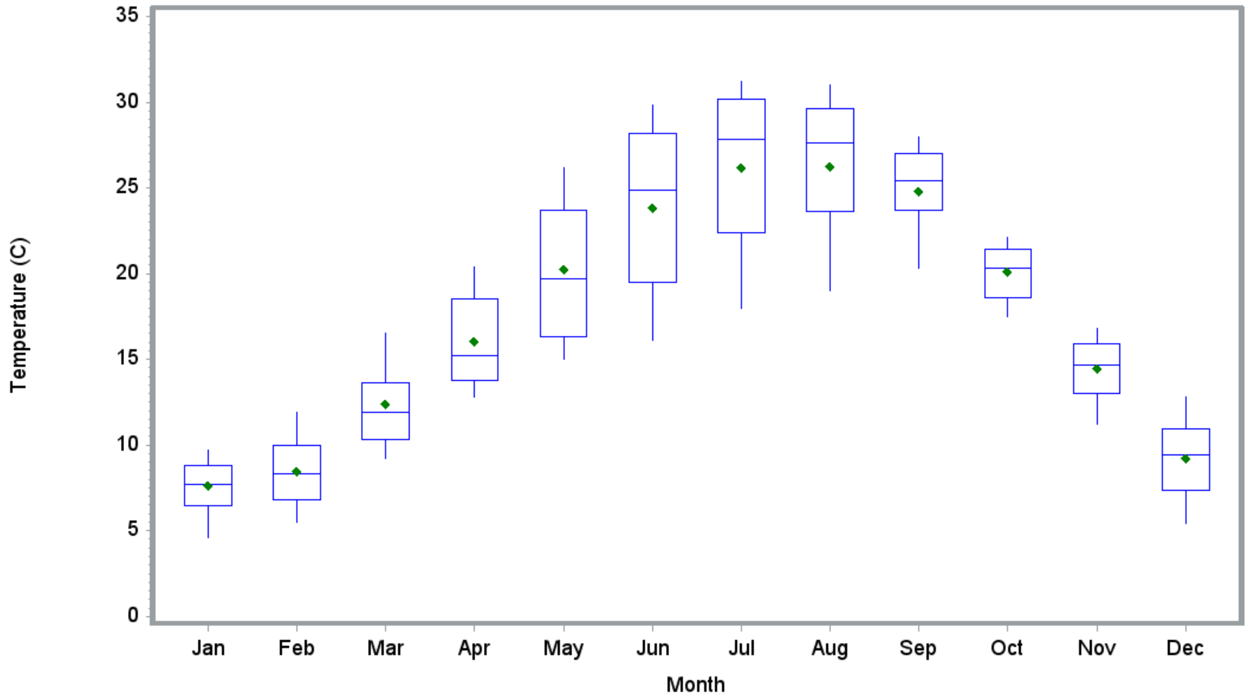



**Figure 3-22 Temperature Lower Lake Samples Categorized by Month**

**Table 3-25 Temperature Lower Lake Samples Categorized by Month (in Celsius)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 208 | 2.50 | 4.60 | 6.45 | 7.65 | 7.70 | 8.80 | 9.70 | 14.20 |
| Feb | 229 | 4.70 | 5.50 | 6.80 | 8.43 | 8.30 | 10.00 | 11.90 | 15.10 |
| Mar | 343 | 6.30 | 9.20 | 10.30 | 12.37 | 11.90 | 13.60 | 16.50 | 25.50 |
| Apr | 384 | 9.90 | 12.80 | 13.80 | 16.05 | 15.20 | 18.55 | 20.40 | 25.00 |
| May | 419 | 12.80 | 15.00 | 16.30 | 20.26 | 19.70 | 23.70 | 26.20 | 31.90 |
| Jun | 470 | 12.10 | 16.10 | 19.50 | 23.81 | 24.85 | 28.20 | 29.80 | 32.80 |
| Jul | 506 | 14.40 | 18.00 | 22.40 | 26.18 | 27.85 | 30.20 | 31.20 | 36.00 |
| Aug | 588 | 11.70 | 19.00 | 23.60 | 26.22 | 27.60 | 29.60 | 31.00 | 32.70 |
| Sep | 380 | 15.00 | 20.35 | 23.70 | 24.78 | 25.40 | 27.00 | 28.00 | 30.20 |
| Oct | 269 | 14.10 | 17.50 | 18.60 | 20.10 | 20.30 | 21.40 | 22.10 | 26.90 |
| Nov | 273 | 9.20 | 11.20 | 13.00 | 14.44 | 14.70 | 15.90 | 16.80 | 22.00 |
| Dec | 216 | 2.40 | 5.40 | 7.35 | 9.21 | 9.40 | 10.95 | 12.80 | 14.90 |

### *Temperature Lower Lake Samples Categorized by Sampling Organization*

> Highest mean and median temperatures were recorded by City of Raleigh and CAAE and lowest mean and median temperature recorded by Wake County (this dataset also represents the smallest sampling size).

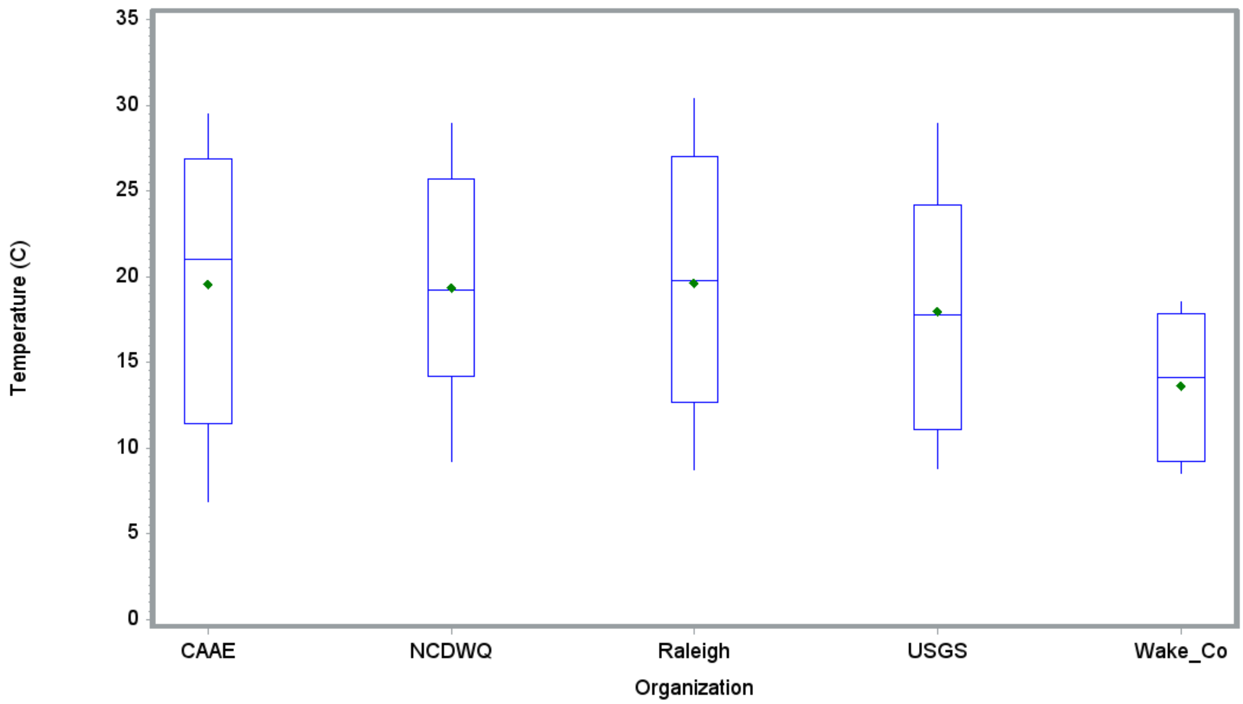



**Figure 3-23 Temperature Lower Lake Samples Categorized by Sampling Organization**

**Table 3-26 Temperature Lower Lake Samples Categorized by Sampling Organization (in Celsius)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 69 | 3.60 | 6.90 | 11.40 | 19.59 | 21.00 | 26.90 | 29.50 | 32.20 |
| NCDWQ | 2784 | 3.80 | 9.20 | 14.20 | 19.37 | 19.20 | 25.70 | 28.90 | 32.80 |
| Raleigh | 1229 | 2.40 | 8.71 | 12.70 | 19.63 | 19.80 | 27.00 | 30.40 | 36.00 |
| USGS | 195 | 5.20 | 8.80 | 11.10 | 18.01 | 17.80 | 24.20 | 28.90 | 31.70 |
| Wake_Co | 8 | 8.50 | 8.50 | 9.20 | 13.66 | 14.10 | 17.85 | 18.50 | 18.50 |

***Temperature Lower Lake Samples Categorized by Method***

> Of the three analysis method categories, SM 2250 returned the highest mean and median temperature.

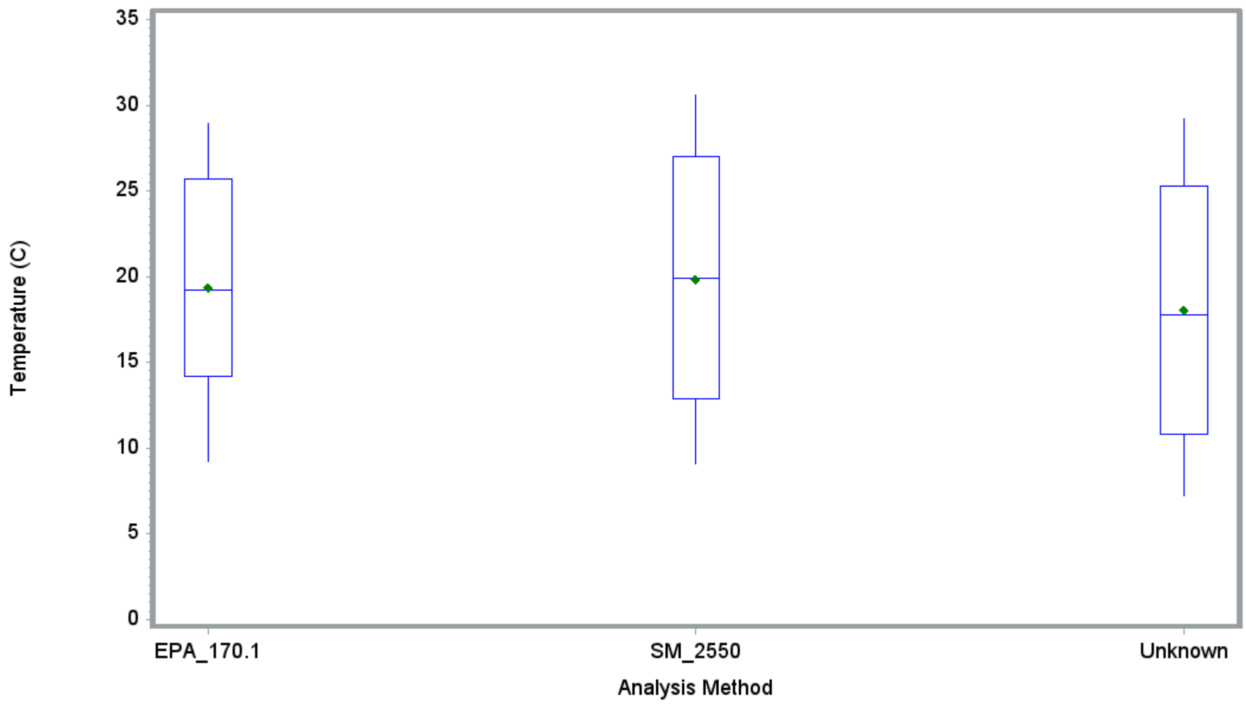



**Figure 3-24 Temperature Lower Lake Samples Categorized by Method**

**Table 3-27 Temperature Lower Lake Samples Categorized by Method (in Celsius)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_170.1 | 2784 | 3.80 | 9.20 | 14.20 | 19.37 | 19.20 | 25.70 | 28.90 | 32.80 |
| SM_2550 | 1107 | 2.40 | 9.10 | 12.90 | 19.87 | 19.90 | 27.00 | 30.60 | 36.00 |
| Unknown | 394 | 3.60 | 7.20 | 10.80 | 18.02 | 17.75 | 25.30 | 29.20 | 32.20 |

## 3.7 Dissolved Oxygen (DO)

Each of the eight participating organizations measured dissolved oxygen as part of their water quality sampling efforts. Dissolved oxygen data was collected in-situ. For those organizations that provided method, the following were used:

> DO by membrane electrode (EPA 360.1)

> Standard method using membrane electrode (SM 4500G)

> DO using portable electrode (YSI 550A)

> Standard test method for dissolved oxygen in water (ASTM D888-05)

> DO using methods described in the NCDENR SOP (NCDENR 2011c) which specifies using either a Hydrolab or YSI meter (WQS_SOP)

Appendix E provides detailed descriptions of these methods.

Table 3-28 describes the organizations and analysis methods used to measure DO and includes the number of samples, date range, and limits. Several organizations did not report the method used to measure DO for some, or all of, the datasets they provided. In these cases, the analysis method is listed as Not Provided. The majority of the DO data has been collected by NCDWQ using method EPA_360.1. The limits for DO are listed as not applicable (NA) because ambient conditions would not exceed the limits of the equipment used. DO is presented as mg/L and to two decimal places based on reported data.

**Table 3-28 Summary of Analysis Methods for the DO Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit | Reporting Limit | Practical Quanti-fication Limit | Range of Limit Specified with Results |
|---|---|---|---|---|---|---|---|---|
| CAAE | Not Provided | 07/24/2007 | 12/17/2010 | 69 | NA | NA | NA | NA |
| Durham_Ci | YSI_550A | 04/01/2002 | 04/30/2012 | 2,135 | NA | NA | NA | NA |
| NCDWQ | EPA_360.1 | 06/07/2000 | 01/10/2012 | 5,269 | NA | NA | NA | NA |
| NCDWQ | WQS_SOP | 01/11/1999 | 04/06/2011 | 1,036 | NA | NA | NA | NA |
| Orange_Co | SM_4500G | 04/09/2010 | 03/25/2011 | 182 | NA | NA | NA | NA |
| Raleigh | Not Provided | 01/13/2009 | 03/05/2012 | 118 | NA | NA | NA | NA |
| Raleigh | SM_4500G | 02/07/2000 | 12/30/2011 | 986 | NA | NA | NA | NA |
| SGWASA | Not Provided | 01/04/2005 | 12/27/2011 | 1,440 | NA | NA | NA | NA |
| USGS | ASTM_D888-05 | 01/15/1999 | 11/04/2011 | 1994 | NA | NA | NA | NA |
| Wake_Co | Not Provided | 07/29/2008 | 10/28/2009 | 160 | NA | NA | NA | NA |

NA: Limits not applicable for DO in ambient conditions.

### 3.7.2 Tributary Samples

Six organizations measured dissolved oxygen concentrations in Falls Lake tributaries from 1999 to present. Highest mean DO concentrations were recorded by Wake County. Lowest mean DO concentrations were recorded by SGWASA. Highest concentrations were recorded in Horse/New Light Creek and lowest concentrations recorded in the Knap of Reeds Creek. Highest mean concentrations were recorded in 2004 and the lowest mean concentrations were recorded in 2007. Box plot summaries are provided below.

***Dissolved Oxygen Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

- Dissolved oxygen was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.
- Highest mean concentrations were measured in Horse/New Light Creek, Little River and Honeycutt/Barton Creek overall.
- Higher concentrations were recorded in the 0 to 2 mile sections of Horse/New Light Creek and Beaverdam Creek.
- Lowest mean and median concentrations were measured in Knap of Reeds Creek.
- Greatest variability was recorded in Beaverdam Creek.

> By distance upstream, concentrations were higher in the 2 to 10 mile sections of Little River, Flat River and Eno River compared with the 0 to 2 mile sections.

> For Lick Creek and Beaverdam Creek, lower concentrations were measured in the 2 to 10 mile section compared with the 0 to 2 mile sections.

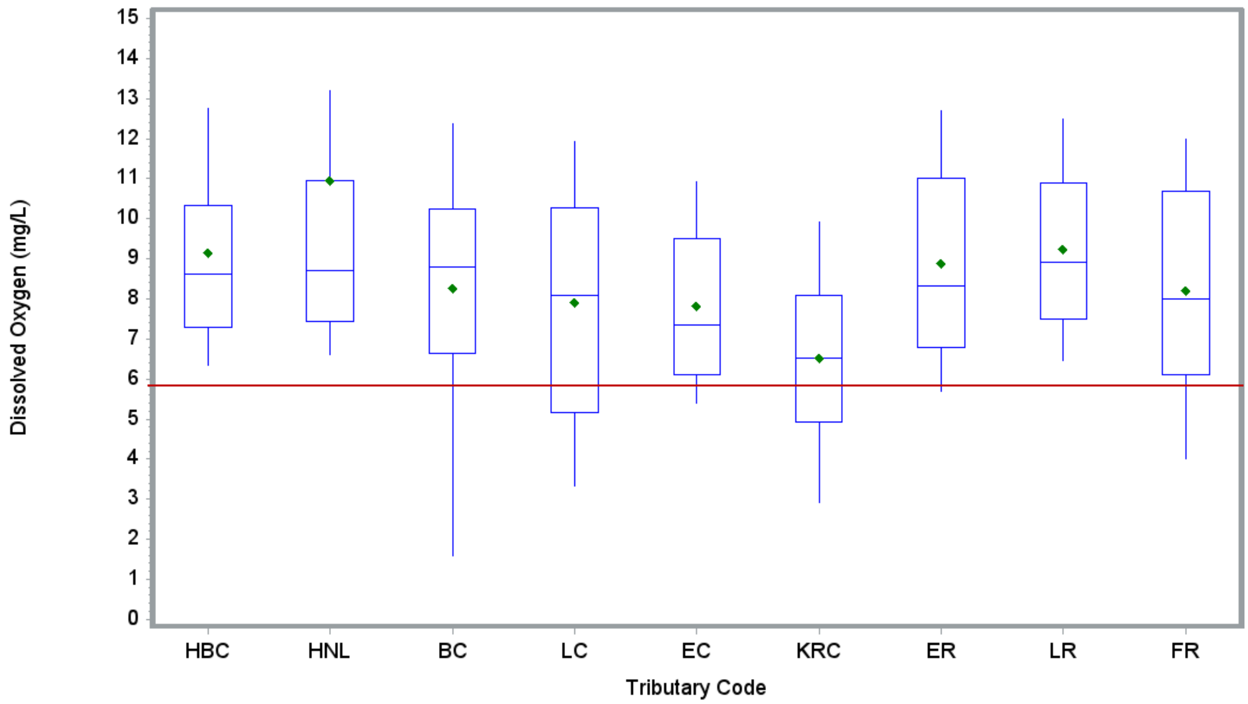



**Figure 3-25 DO Tributary Samples Categorized by Subwatershed**

**Table 3-29 DO Tributary Samples Categorized by Subwatershed (in mg/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 83 | 4.94 | 6.34 | 7.30 | 9.16 | 8.63 | 10.33 | 12.75 | 17.31 |
| HNL | 52 | 2.80 | 6.60 | 7.43 | 10.94 | 8.72 | 10.95 | 13.21 | 98.00[1] |
| BC | 48 | 0.30 | 1.60 | 6.65 | 8.26 | 8.80 | 10.24 | 12.38 | 16.37 |
| LC | 165 | 1.36 | 3.32 | 5.15 | 7.92 | 8.10 | 10.26 | 11.94 | 14.88 |
| EC | 1222 | 0.12 | 5.40 | 6.10 | 7.83 | 7.35 | 9.51 | 10.92 | 16.00 |
| KRC | 1608 | 0.29 | 2.93 | 4.94 | 6.54 | 6.52 | 8.09 | 9.91 | 15.30 |
| ER | 756 | 1.38 | 5.70 | 6.80 | 8.87 | 8.33 | 11.00 | 12.70 | 18.10 |
| LR | 547 | 1.92 | 6.47 | 7.50 | 9.23 | 8.90 | 10.90 | 12.50 | 17.80 |
| FR | 426 | 0.40 | 4.00 | 6.10 | 8.21 | 8.00 | 10.70 | 12.00 | 18.10 |

[1] This value was reported as 98.0 mg/L in the raw data file. The value is likely a data entry error.

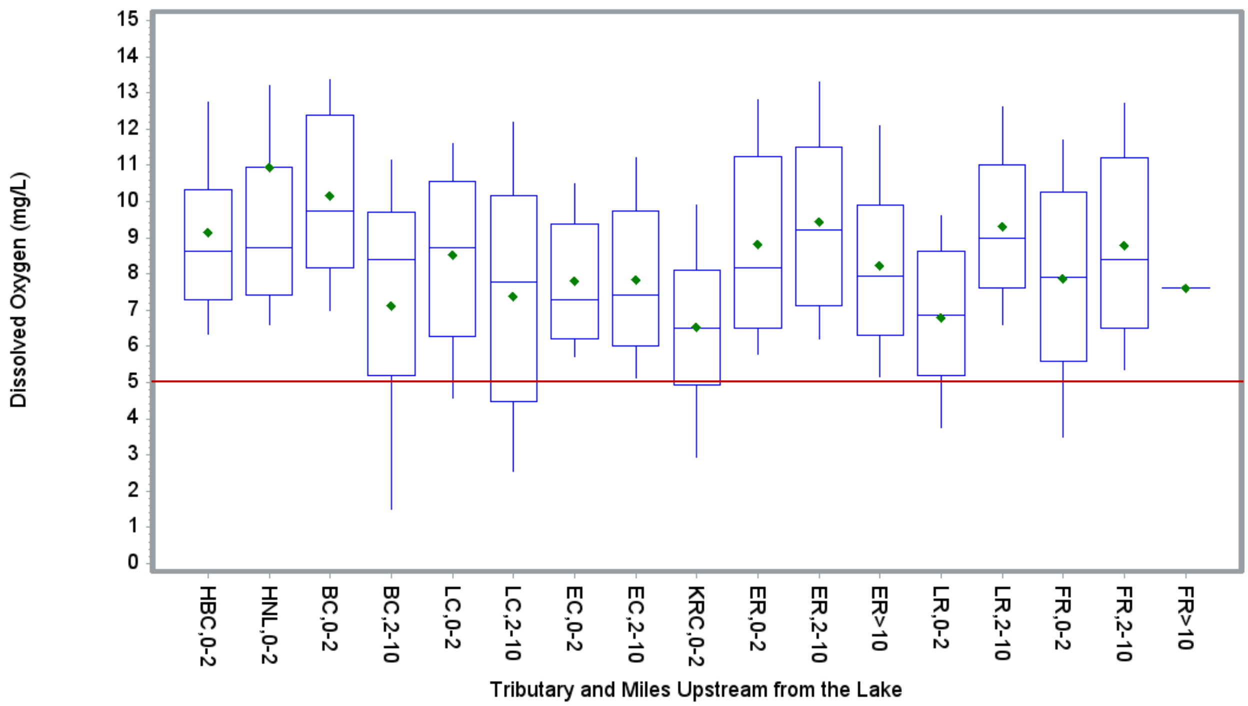



**Figure 3-26 DO Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-30 DO Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in mg/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 83 | 4.94 | 6.34 | 7.30 | 9.16 | 8.63 | 10.33 | 12.75 | 17.31 |
| HNL,0-2 | 52 | 2.80 | 6.60 | 7.43 | 10.94 | 8.72 | 10.95 | 13.21 | 98.00[1] |
| BC,0-2 | 18 | 5.85 | 7.00 | 8.16 | 10.16 | 9.75 | 12.38 | 13.35 | 16.37 |
| BC,2-10 | 30 | 0.30 | 1.50 | 5.20 | 7.13 | 8.40 | 9.70 | 11.15 | 11.70 |
| LC,0-2 | 76 | 1.40 | 4.57 | 6.27 | 8.54 | 8.72 | 10.57 | 11.59 | 14.88 |
| LC,2-10 | 89 | 1.36 | 2.55 | 4.49 | 7.38 | 7.77 | 10.15 | 12.18 | 14.74 |
| EC,0-2 | 556 | 1.07 | 5.70 | 6.20 | 7.80 | 7.30 | 9.39 | 10.50 | 16.00 |
| EC,2-10 | 666 | 0.12 | 5.13 | 6.00 | 7.85 | 7.40 | 9.74 | 11.21 | 15.67 |
| KRC,0-2 | 1608 | 0.29 | 2.93 | 4.94 | 6.54 | 6.52 | 8.09 | 9.91 | 15.30 |
| ER,0-2 | 149 | 3.60 | 5.78 | 6.50 | 8.83 | 8.16 | 11.24 | 12.80 | 17.50 |
| ER,2-10 | 323 | 1.38 | 6.20 | 7.13 | 9.45 | 9.20 | 11.49 | 13.30 | 18.10 |
| ER>10 | 284 | 3.41 | 5.15 | 6.30 | 8.23 | 7.96 | 9.91 | 12.10 | 14.93 |
| LR,0-2 | 18 | 3.77 | 3.77 | 5.20 | 6.79 | 6.85 | 8.64 | 9.62 | 9.62 |
| LR,2-10 | 529 | 1.92 | 6.60 | 7.60 | 9.31 | 9.00 | 11.00 | 12.60 | 17.80 |
| FR,0-2 | 272 | 0.40 | 3.50 | 5.59 | 7.88 | 7.90 | 10.25 | 11.70 | 16.30 |
| FR,2-10 | 153 | 3.20 | 5.35 | 6.50 | 8.80 | 8.40 | 11.20 | 12.70 | 18.10 |

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| FR>10 | 1 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 | 7.60 |

[1] This value was reported as 98.0 mg/L in the raw data file. The value is likely a data entry error.

### *Dissolved Oxygen Tributary Categorized by Year*

> By year, highest mean concentrations were recorded in 2004 and 2003.

> The lowest mean concentrations were recorded in 2007, 2006 and 2011.

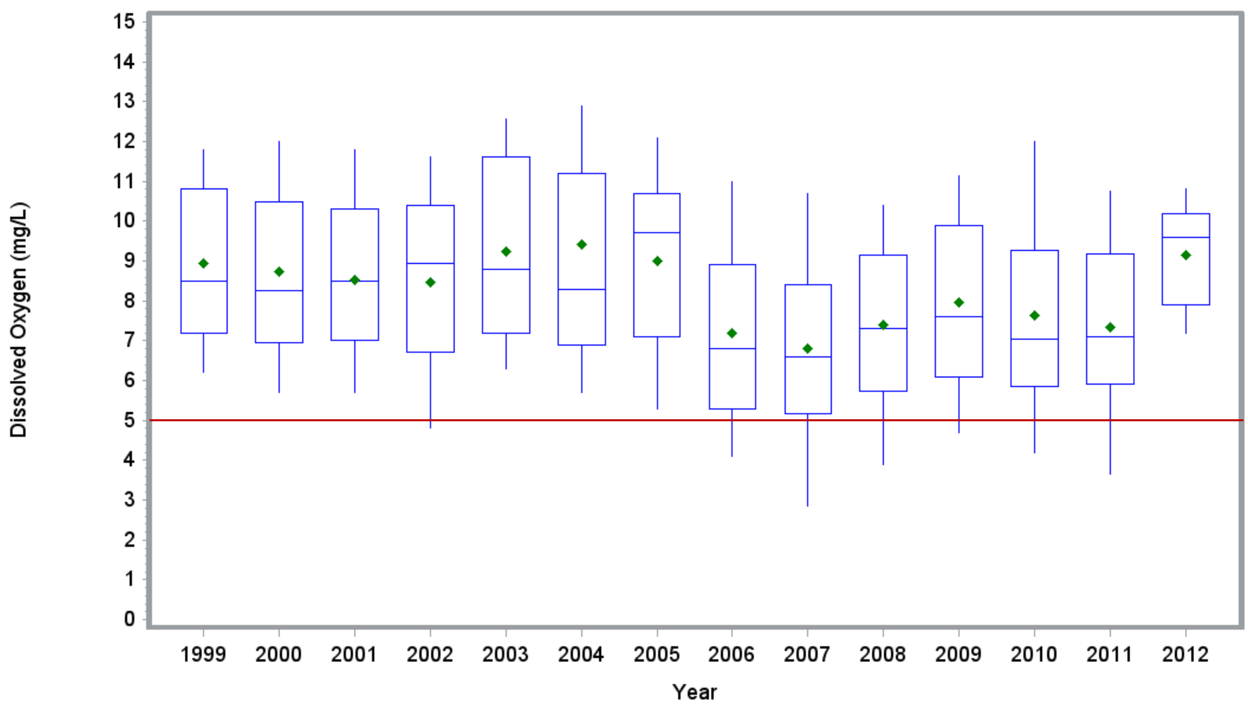



**Figure 3-27 DO Tributary Samples Categorized by Year**

**Table 3-31 DO Tributary Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 134 | 4.90 | 6.20 | 7.20 | 8.92 | 8.50 | 10.80 | 11.80 | 14.30 |
| 2000 | 138 | 2.50 | 5.70 | 7.00 | 8.74 | 8.30 | 10.50 | 12.00 | 15.90 |
| 2001 | 119 | 2.00 | 5.70 | 7.00 | 8.52 | 8.50 | 10.30 | 11.80 | 13.10 |
| 2002 | 119 | 1.50 | 4.50 | 6.60 | 8.43 | 8.90 | 10.40 | 11.60 | 13.30 |
| 2003 | 150 | 1.30 | 6.30 | 7.20 | 9.24 | 8.80 | 11.60 | 12.55 | 15.00 |
| 2004 | 125 | 2.80 | 5.70 | 7.00 | 9.43 | 8.70 | 11.60 | 14.20 | 18.10 |
| 2005 | 278 | 0.30 | 5.30 | 7.10 | 9.00 | 9.70 | 10.70 | 12.20 | 16.10 |
| 2006 | 434 | 1.16 | 4.10 | 5.29 | 7.20 | 6.80 | 8.90 | 11.00 | 14.70 |
| 2007 | 362 | 0.29 | 2.84 | 5.16 | 6.80 | 6.61 | 8.41 | 10.70 | 14.80 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2008 | 463 | 0.69 | 3.94 | 5.77 | 7.39 | 7.36 | 9.20 | 10.50 | 17.31 |
| 2009 | 869 | 0.16 | 4.70 | 6.10 | 7.96 | 7.60 | 9.90 | 11.20 | 98.00[1] |
| 2010 | 982 | 0.12 | 4.21 | 5.87 | 7.63 | 7.09 | 9.30 | 12.07 | 16.82 |
| 2011 | 698 | 0.42 | 3.67 | 5.90 | 7.35 | 7.10 | 9.20 | 10.78 | 15.33 |
| 2012 | 36 | 6.30 | 7.20 | 7.90 | 9.14 | 9.60 | 10.20 | 10.80 | 11.20 |

[1] This value was reported as 98.0 mg/L in the raw data file. The value is likely a data entry error.

***Dissolved Oxygen Tributary Samples Categorized by Month***

> By month, the highest mean and median concentrations were measured in the colder months, December to March

> The lowest mean and median concentrations were measured in the warmer months, May to October.

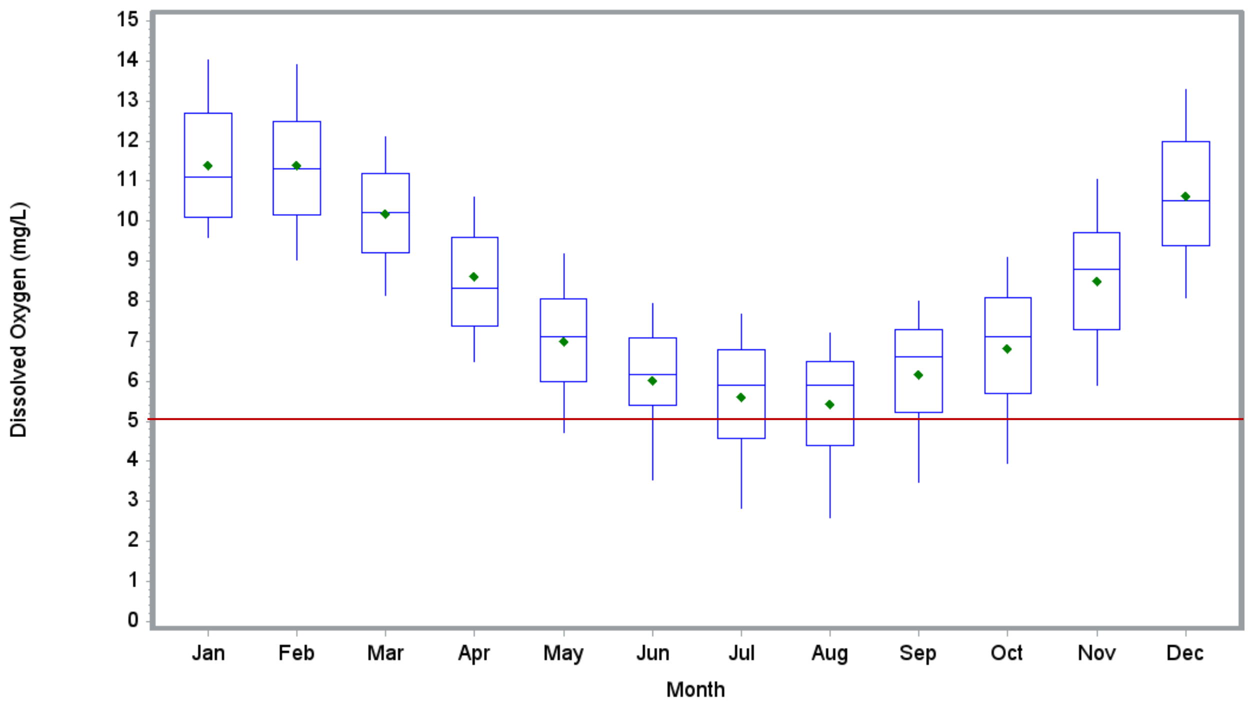



**Figure 3-28 DO Tributary Samples Categorized by Month**

**Table 3-32 DO Tributary Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 330 | 7.13 | 9.58 | 10.10 | 11.40 | 11.10 | 12.70 | 14.02 | 15.91 |
| Feb | 332 | 5.13 | 9.04 | 10.15 | 11.40 | 11.30 | 12.50 | 13.91 | 18.10 |
| Mar | 335 | 2.71 | 8.16 | 9.20 | 10.18 | 10.20 | 11.18 | 12.10 | 15.33 |
| Apr | 461 | 1.60 | 6.50 | 7.38 | 8.61 | 8.31 | 9.60 | 10.60 | 98.00[1] |
| May | 425 | 0.12 | 4.73 | 6.00 | 7.00 | 7.10 | 8.06 | 9.18 | 12.70 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jun | 513 | 0.69 | 3.54 | 5.39 | 6.01 | 6.17 | 7.07 | 7.95 | 12.70 |
| Jul | 488 | 0.29 | 2.82 | 4.59 | 5.61 | 5.90 | 6.80 | 7.67 | 12.70 |
| Aug | 457 | 0.16 | 2.58 | 4.40 | 5.44 | 5.90 | 6.50 | 7.20 | 12.70 |
| Sep | 460 | 0.30 | 3.48 | 5.21 | 6.16 | 6.60 | 7.30 | 8.01 | 12.70 |
| Oct | 464 | 0.80 | 3.94 | 5.71 | 6.83 | 7.10 | 8.10 | 9.10 | 12.70 |
| Nov | 316 | 0.40 | 5.90 | 7.30 | 8.50 | 8.80 | 9.70 | 11.05 | 13.08 |
| Dec | 326 | 2.10 | 8.10 | 9.40 | 10.62 | 10.50 | 12.00 | 13.30 | 17.31 |

[1] This value was reported as 98.0 mg/L in the raw data file. The value is likely a data entry error.

### *Dissolved Oxygen Tributary Samples Categorized by Sampling Organization*

> By sampling organization, the highest mean and median concentrations were recorded by Wake County and lowest mean and median concentrations were recorded by SGWASA.

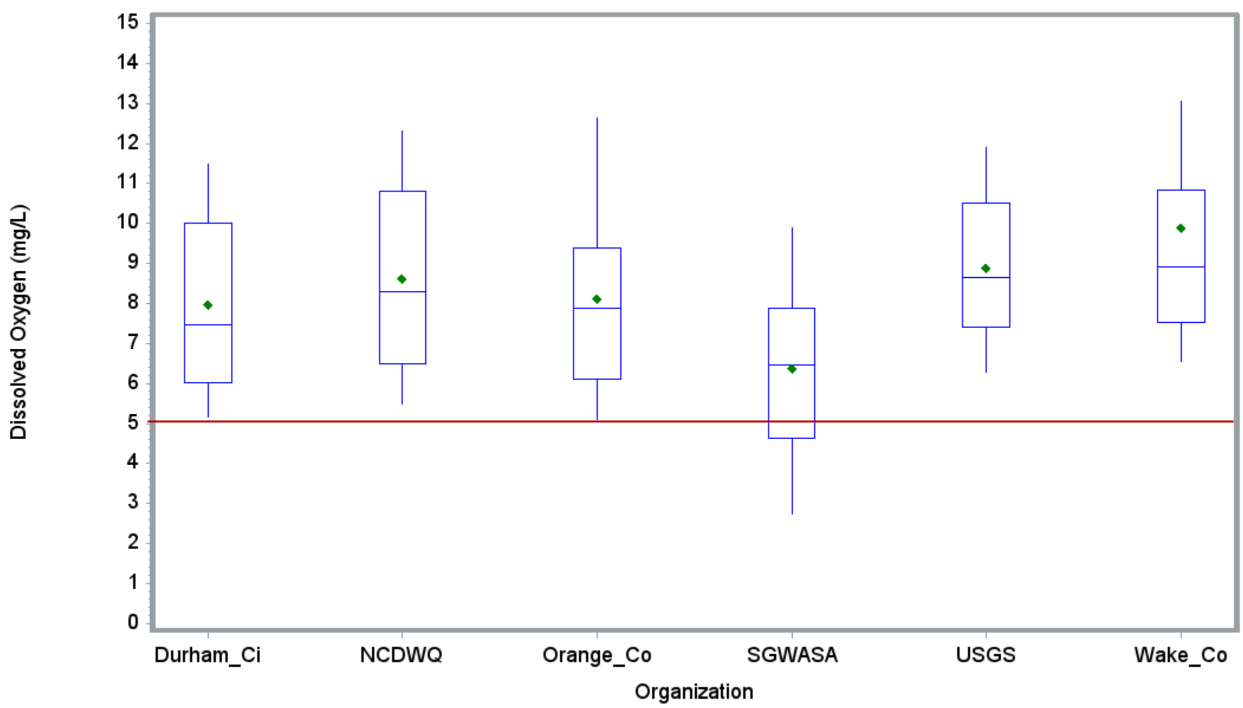



**Figure 3-29 DO Tributary Samples Categorized by Sampling Organization**

**Table 3-33 DO Tributary Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 1481 | 0.12 | 5.15 | 6.01 | 7.97 | 7.47 | 10.00 | 11.49 | 16.82 |
| NCDWQ | 1036 | 0.40 | 5.50 | 6.50 | 8.63 | 8.30 | 10.80 | 12.30 | 18.10 |
| Orange_Co | 182 | 3.41 | 5.09 | 6.11 | 8.12 | 7.88 | 9.38 | 12.64 | 14.93 |
| SGWASA | 1440 | 0.29 | 2.76 | 4.62 | 6.37 | 6.45 | 7.88 | 9.89 | 14.50 |

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| USGS | 616 | 0.30 | 6.30 | 7.40 | 8.88 | 8.65 | 10.50 | 11.90 | 15.00 |
| Wake_Co | 152 | 2.80 | 6.56 | 7.52 | 9.90 | 8.92 | 10.85 | 13.05 | 98.00[1] |

[1] This value was reported as 98.0 mg/L in the raw data file. The value is likely a data entry error.

### *Dissolved Oxygen Tributary Samples Categorized by Method*

> Four known and one unknown method were used to determine dissolved oxygen.

> Highest concentrations were measured using ASTM D888-05 method and the lowest concentrations were measured using the unknown method.

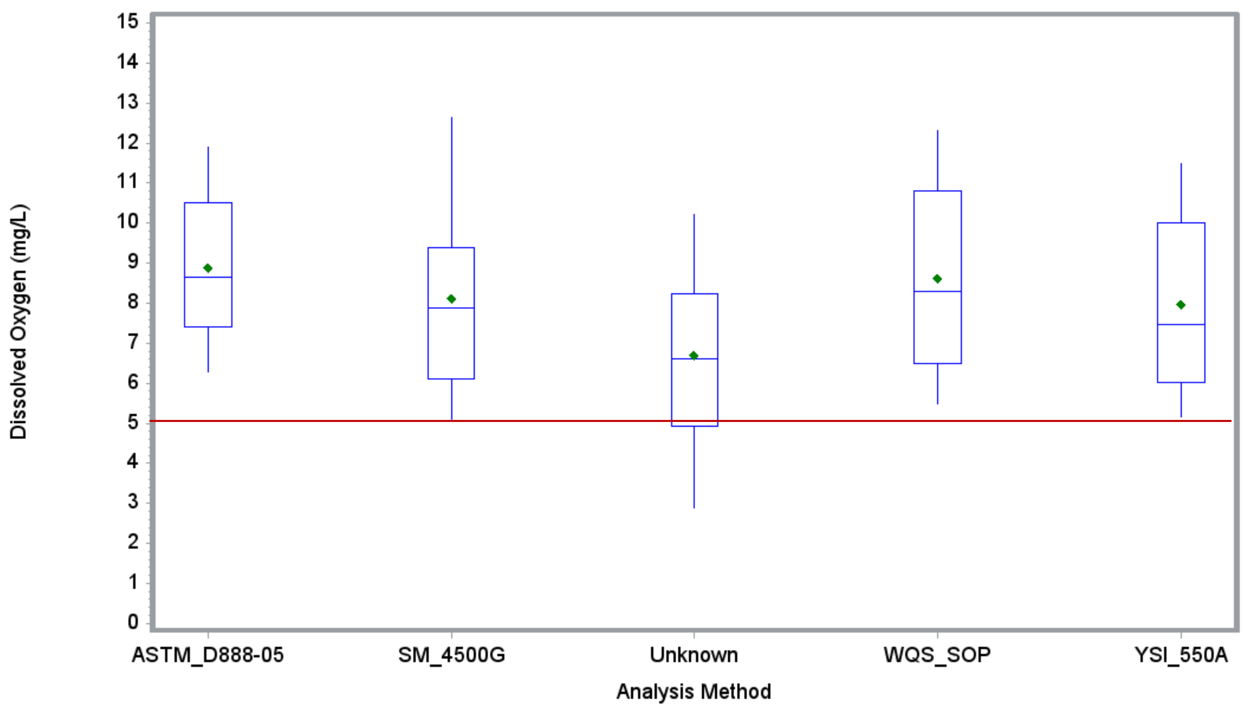



**Figure 3-30 DO Tributary Samples Categorized by Analysis Method**

**Table 3-34 DO Tributary Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| ASTM_D888-05 | 616 | 0.30 | 6.30 | 7.40 | 8.88 | 8.65 | 10.50 | 11.90 | 15.00 |
| SM_4500G | 182 | 3.41 | 5.09 | 6.11 | 8.12 | 7.88 | 9.38 | 12.64 | 14.93 |
| Unknown | 1592 | 0.29 | 2.89 | 4.92 | 6.70 | 6.61 | 8.25 | 10.20 | 98.00[1] |
| WQS_SOP | 1036 | 0.40 | 5.50 | 6.50 | 8.63 | 8.30 | 10.80 | 12.30 | 18.10 |
| YSI_550A | 1481 | 0.12 | 5.15 | 6.01 | 7.97 | 7.47 | 10.00 | 11.49 | 16.82 |

[1] This value was reported as 98.0 mg/L in the raw data file. The value is likely a data entry error.

### 3.7.3 Upper Lake Samples

Three organizations measured dissolved oxygen concentrations in upper Falls Lake from 1999 to present. Highest concentrations were recorded by NCDWQ while lowest concentrations were recorded by City of Durham. Highest mean concentrations were measured in the 13 to 18 mile section upstream of the dam and in the surface layer. Lowest mean concentrations were recorded in the > 21 mile section as well as the bottom depth layer. Highest mean concentrations were recorded in 2012, while lowest mean concentrations were recorded in 2001. Box plot summaries are provided below.

***Dissolved Oxygen Samples Categorized by Lake Segment and Miles Upstream from Dam***

Mean and median concentrations were similar by segment, with highest concentrations in the 8 to 13 mile section and lowest concentrations measured in the > 21 mile section.

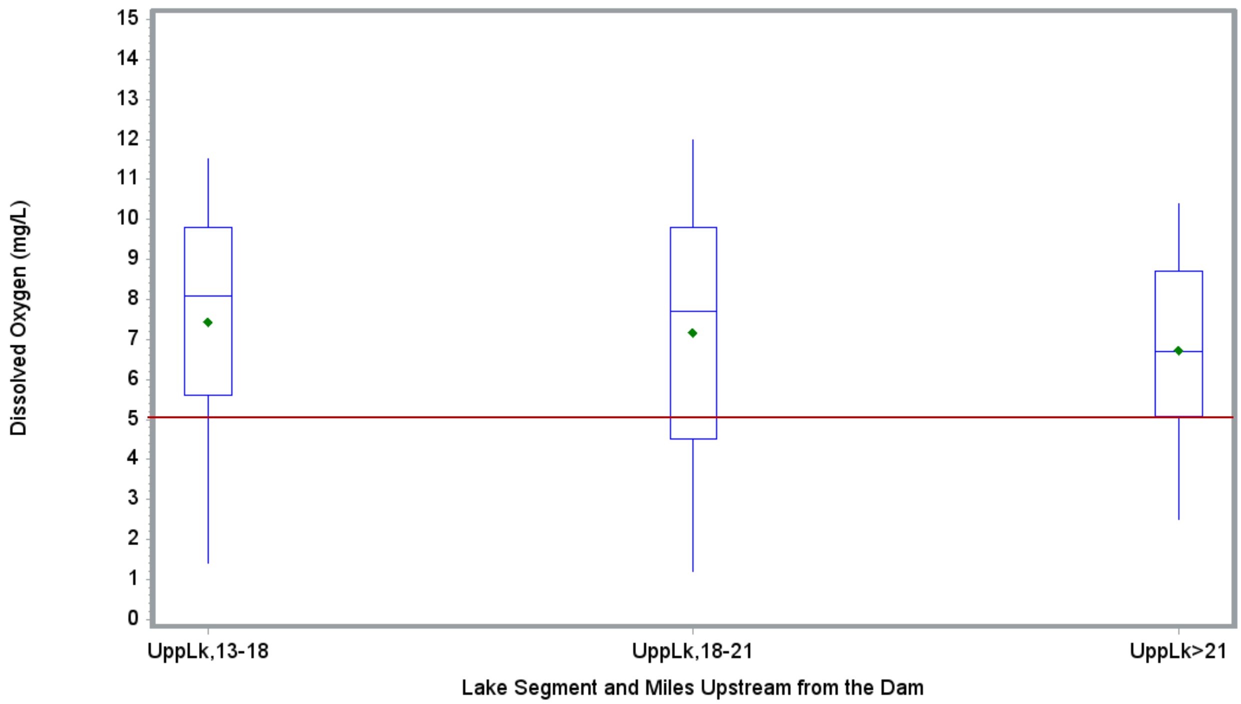



**Figure 3-31 DO Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-35 DO Upper Lake Samples Categorized by Miles Upstream from Dam (in mg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 1596 | 0.10 | 1.40 | 5.60 | 7.45 | 8.10 | 9.80 | 11.50 | 14.10 |
| UppLk,18-21 | 364 | 0.20 | 1.20 | 4.50 | 7.17 | 7.70 | 9.80 | 12.00 | 14.60 |
| UppLk>21 | 1412 | 0.10 | 2.50 | 5.07 | 6.72 | 6.70 | 8.70 | 10.40 | 16.40 |

***Dissolved Oxygen Upper Lake Samples Categorized by Depth***

> By depth, highest mean and median concentrations were measured in the surface layer.

> Lowest mean concentrations were measured in the bottom layer, however there was a small samples size (n=12).

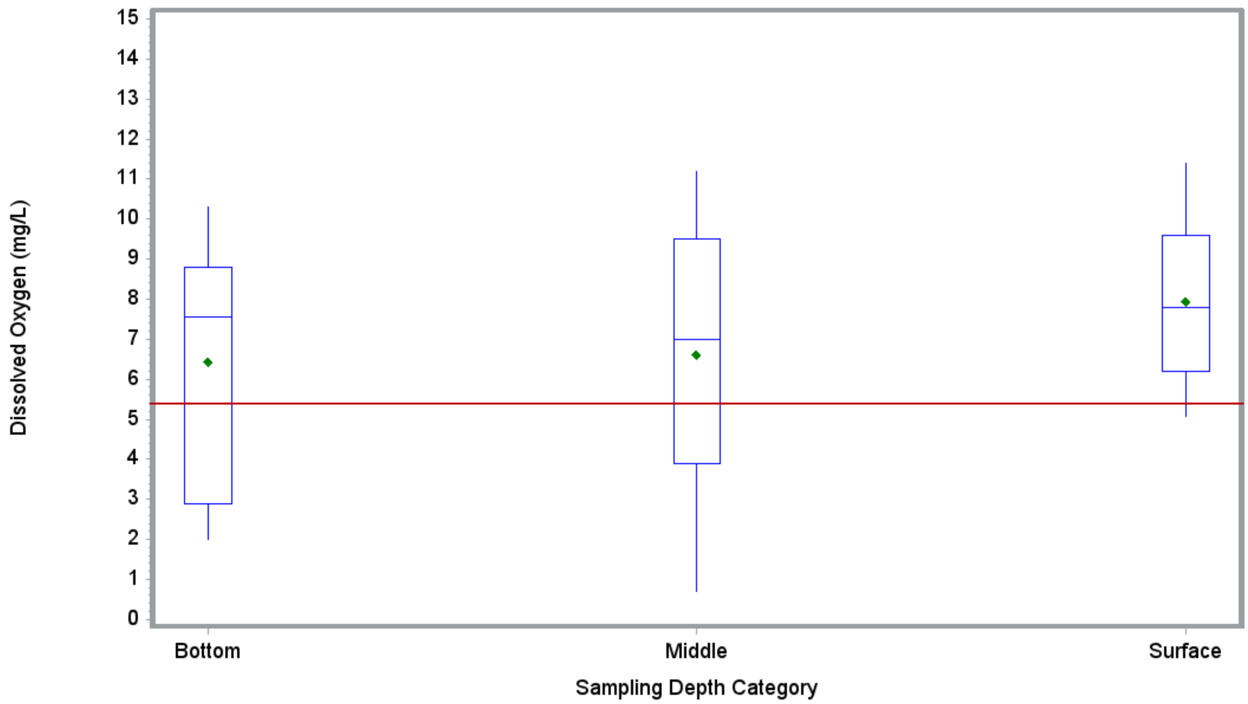



**Figure 3-32 DO Upper Lake Samples Categorized by Depth Category (surface, photic, bottom)**

**Table 3-36 DO Upper Lake Samples Categorized by Depth Category (surface, photic, bottom) (in mg/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 12 | 0.20 | 2.00 | 2.90 | 6.43 | 7.55 | 8.80 | 10.30 | 11.50 |
| Middle | 2077 | 0.10 | 0.70 | 3.90 | 6.60 | 7.00 | 9.50 | 11.20 | 16.20 |
| Surface | 1283 | 0.10 | 5.07 | 6.20 | 7.95 | 7.80 | 9.60 | 11.40 | 16.40 |

### *Dissolved Oxygen Upper Lake Categorized by Year*

> Highest mean and median concentrations were recorded in 2012, however, this dataset only represents the first part of the year.

> The full year with the highest mean and median concentrations was 2011.

> The lowest annual mean was recorded in 2001 and the lowest annual median concentration in 2008.

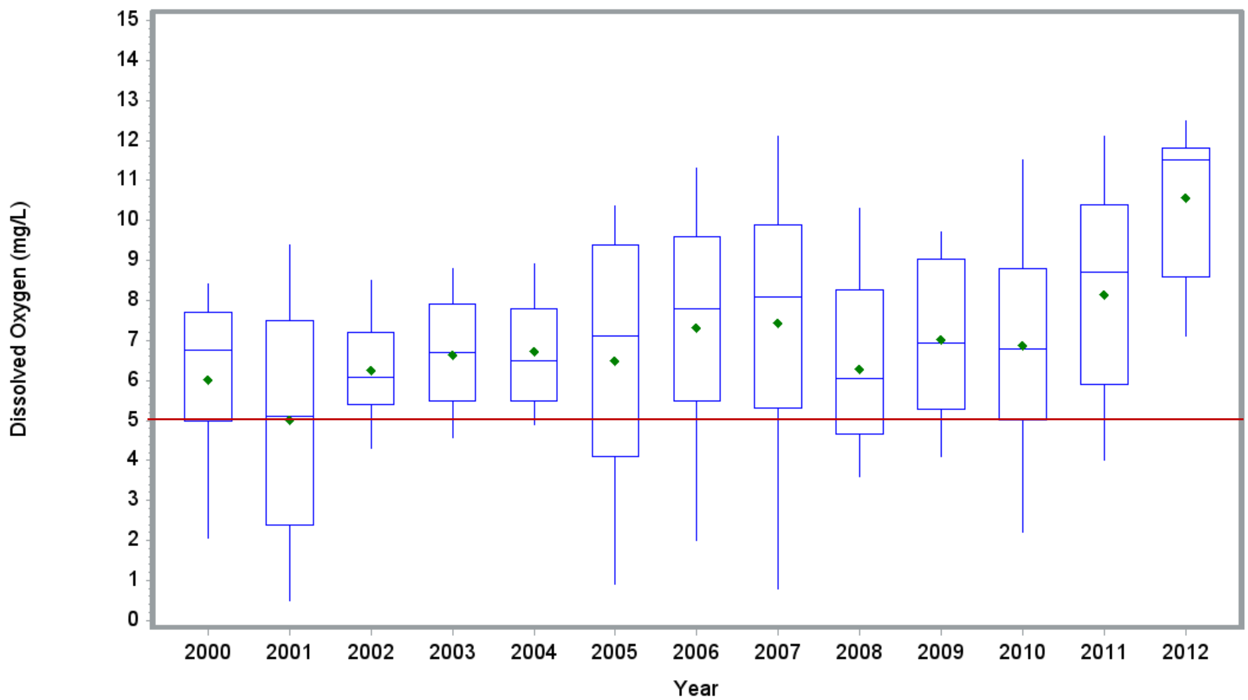



**Figure 3-33 DO Upper Lake Samples Categorized by Year**

**Table 3-37 DO Upper Lake Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 70 | 0.30 | 2.05 | 5.00 | 6.03 | 6.75 | 7.70 | 8.40 | 9.30 |
| 2001 | 97 | 0.20 | 0.50 | 2.40 | 5.01 | 5.10 | 7.50 | 9.40 | 10.70 |
| 2002 | 63 | 0.10 | 4.30 | 5.40 | 6.25 | 6.08 | 7.20 | 8.50 | 12.54 |
| 2003 | 62 | 3.50 | 4.58 | 5.50 | 6.64 | 6.70 | 7.90 | 8.80 | 9.60 |
| 2004 | 62 | 3.20 | 4.90 | 5.50 | 6.72 | 6.50 | 7.80 | 8.90 | 11.60 |
| 2005 | 580 | 0.10 | 0.90 | 4.10 | 6.49 | 7.10 | 9.40 | 10.35 | 12.70 |
| 2006 | 858 | 0.10 | 2.00 | 5.50 | 7.32 | 7.80 | 9.60 | 11.30 | 16.40 |
| 2007 | 661 | 0.10 | 0.80 | 5.30 | 7.44 | 8.10 | 9.90 | 12.10 | 14.60 |
| 2008 | 96 | 0.10 | 3.60 | 4.65 | 6.30 | 6.05 | 8.25 | 10.30 | 11.90 |
| 2009 | 100 | 0.10 | 4.09 | 5.29 | 7.02 | 6.93 | 9.05 | 9.70 | 12.60 |
| 2010 | 312 | 0.10 | 2.20 | 5.01 | 6.89 | 6.80 | 8.80 | 11.50 | 14.60 |
| 2011 | 373 | 0.10 | 4.00 | 5.90 | 8.14 | 8.70 | 10.40 | 12.10 | 13.60 |
| 2012 | 38 | 6.10 | 7.12 | 8.60 | 10.58 | 11.50 | 11.80 | 12.50 | 13.50 |

### *Dissolved Oxygen Upper Lake Samples Categorized by Month*

- By month, the highest mean and median concentrations were measured in the colder months, November to April.
- The lowest mean and median concentrations were measured in the warmer months, May to October.

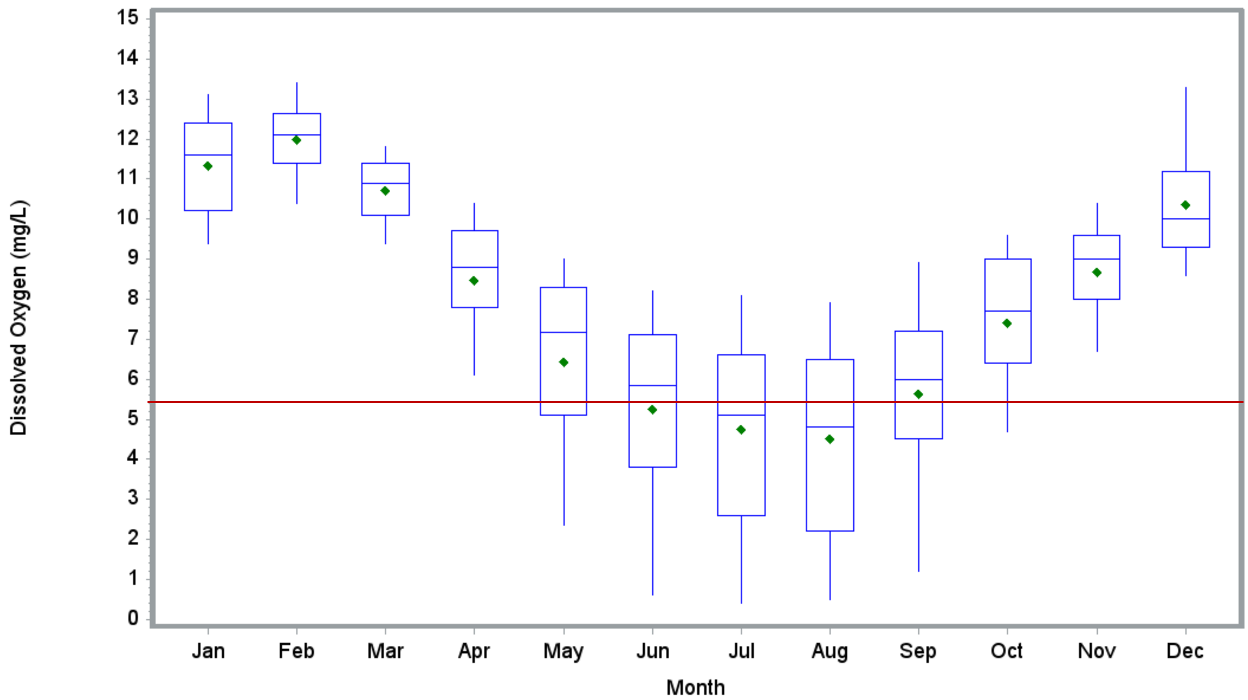



**Figure 3-34 DO Upper Lake Samples Categorized by Month**

**Table 3-38 DO Upper Lake Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 146 | 2.50 | 9.40 | 10.20 | 11.35 | 11.60 | 12.40 | 13.10 | 14.40 |
| Feb | 152 | 5.50 | 10.40 | 11.40 | 11.99 | 12.10 | 12.65 | 13.40 | 16.40 |
| Mar | 222 | 5.10 | 9.40 | 10.10 | 10.72 | 10.90 | 11.40 | 11.80 | 14.80 |
| Apr | 357 | 0.50 | 6.10 | 7.80 | 8.46 | 8.80 | 9.70 | 10.40 | 13.58 |
| May | 350 | 0.30 | 2.35 | 5.10 | 6.43 | 7.17 | 8.30 | 9.00 | 10.63 |
| Jun | 392 | 0.10 | 0.60 | 3.80 | 5.24 | 5.85 | 7.10 | 8.20 | 12.60 |
| Jul | 374 | 0.10 | 0.40 | 2.60 | 4.76 | 5.10 | 6.60 | 8.10 | 13.40 |
| Aug | 441 | 0.10 | 0.50 | 2.20 | 4.51 | 4.80 | 6.50 | 7.90 | 10.40 |
| Sep | 325 | 0.10 | 1.20 | 4.50 | 5.64 | 6.00 | 7.20 | 8.90 | 13.00 |
| Oct | 277 | 0.50 | 4.70 | 6.40 | 7.39 | 7.70 | 9.00 | 9.60 | 11.80 |
| Nov | 197 | 0.60 | 6.70 | 8.00 | 8.67 | 9.00 | 9.60 | 10.40 | 11.77 |
| Dec | 139 | 5.00 | 8.60 | 9.30 | 10.37 | 10.00 | 11.20 | 13.30 | 14.60 |

***Dissolved Oxygen Upper Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean concentrations were recorded by NCDWQ and lowest mean concentrations were recorded by City of Durham.

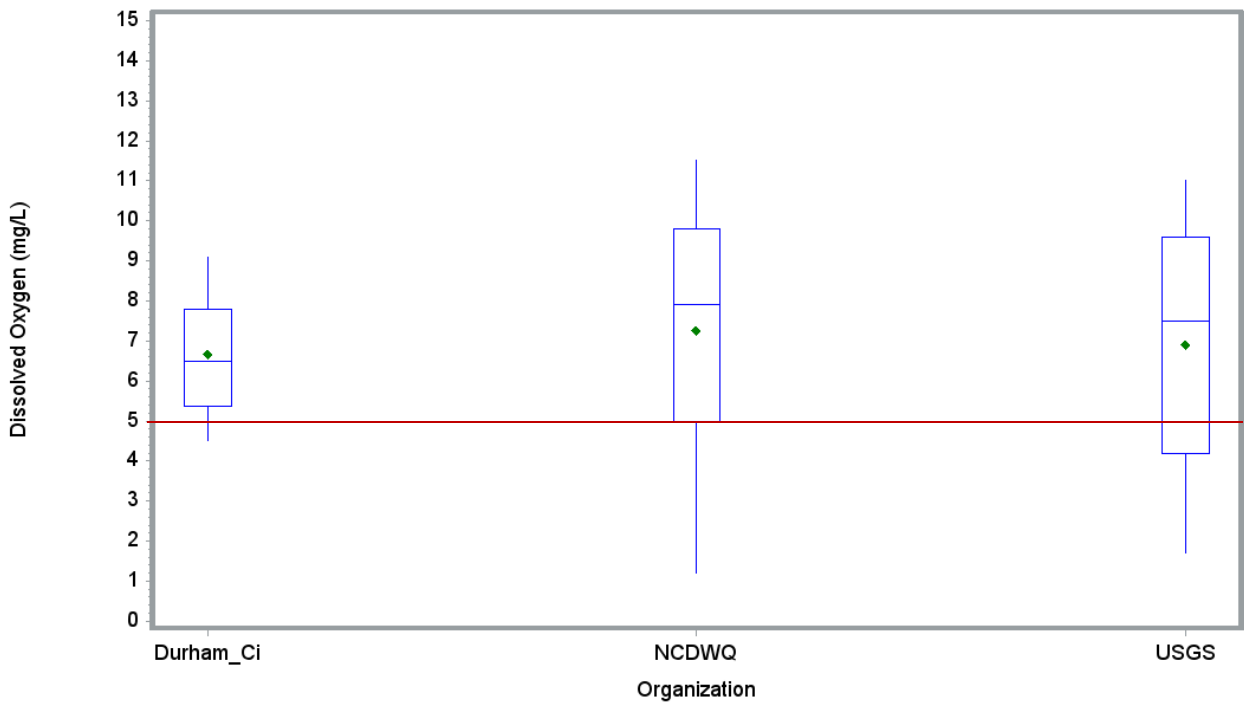



**Figure 3-35 DO Upper Lake Samples Categorized by Sampling Organization**

**Table 3-39 DO Upper Lake Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 654 | 0.10 | 4.50 | 5.37 | 6.66 | 6.50 | 7.80 | 9.10 | 14.10 |
| NCDWQ | 2535 | 0.10 | 1.20 | 5.00 | 7.25 | 7.90 | 9.80 | 11.50 | 16.40 |
| USGS | 183 | 0.10 | 1.70 | 4.20 | 6.89 | 7.50 | 9.60 | 11.00 | 12.60 |

### *Dissolved Oxygen Upper Lake Samples Categorized by Method*

> By method, the highest mean concentrations were recorded by EPA 360.1 method and lowest mean concentrations were recorded by YSI 550A method.

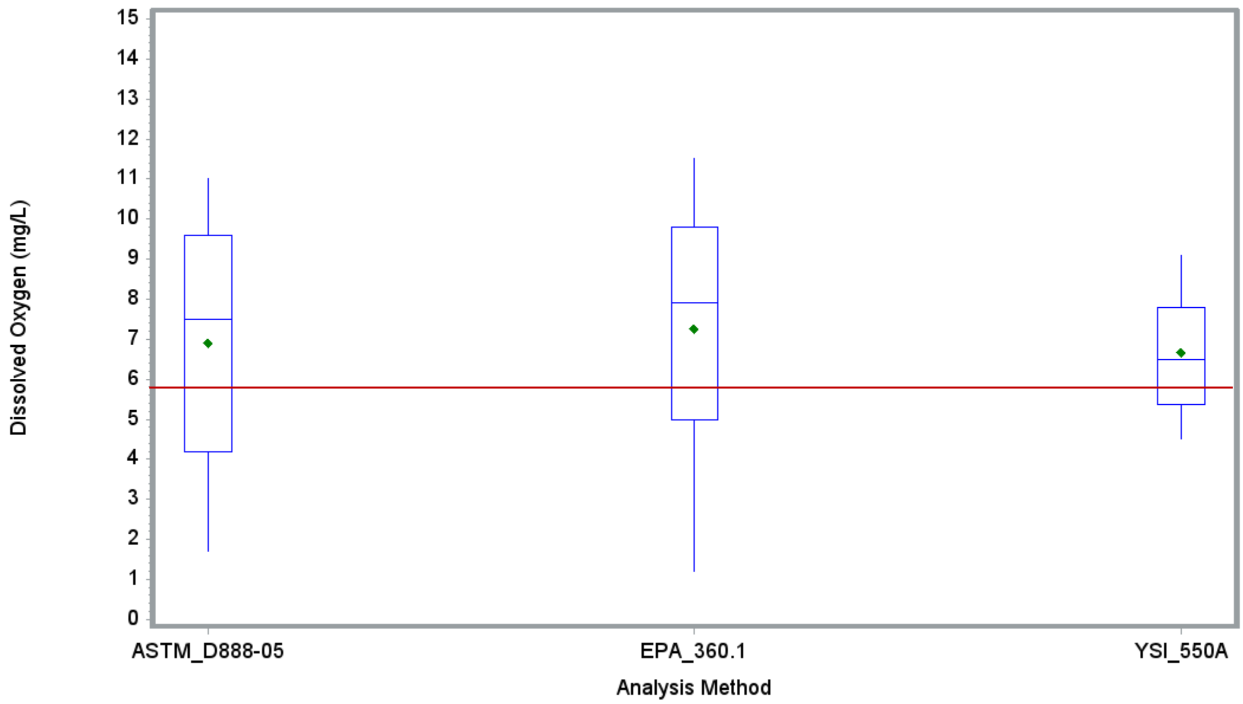



**Figure 3-36 DO Upper Lake Samples Categorized by Analysis Method**

**Table 3-40 DO Upper Lake Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| ASTM_D888-05 | 183 | 0.10 | 1.70 | 4.20 | 6.89 | 7.50 | 9.60 | 11.00 | 12.60 |
| EPA_360.1 | 2535 | 0.10 | 1.20 | 5.00 | 7.25 | 7.90 | 9.80 | 11.50 | 16.40 |
| YSI_550A | 654 | 0.10 | 4.50 | 5.37 | 6.66 | 6.50 | 7.80 | 9.10 | 14.10 |

### 3.7.4 Lower Lake Samples

Five organizations measured dissolved oxygen concentrations in lower Falls Lake from 2000 to present. Highest mean and median concentrations were recorded by Wake County, while lowest concentrations were recorded by USGS. Highest concentrations were recorded in the surface layer and in the 8 to 13 mile section. Highest mean concentrations were recorded in 2012, while the lowest mean concentrations were recorded in 2004. Box plot summaries are provided below.

***Dissolved Oxygen Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean and median concentrations were measured in the 8 to 13 mile section and lowest concentrations were measured in the 4 to 8 mile section.

> Concentrations measured in Beaverdam Impoundment were the least variable.

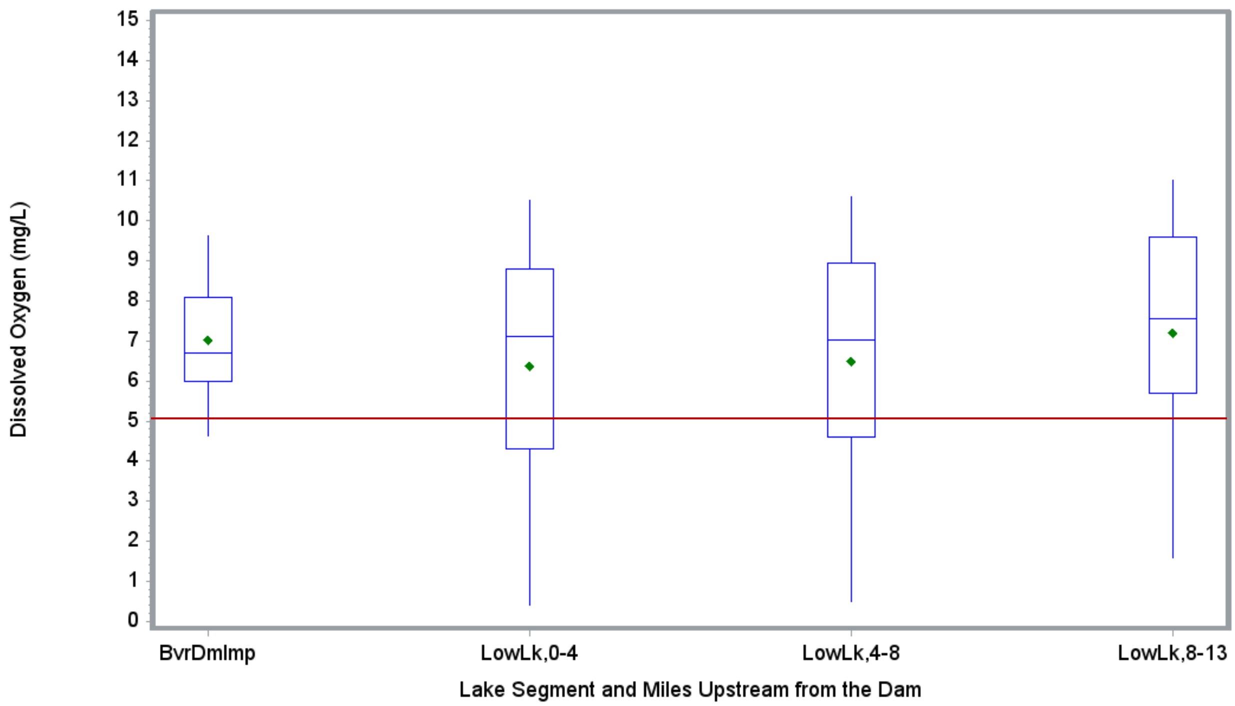



**Figure 3-37 DO Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-41 DO Lower Lake Samples Categorized by Miles Upstream from Dam (in mg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 107 | 1.90 | 4.63 | 5.99 | 7.02 | 6.69 | 8.09 | 9.63 | 11.92 |
| LowLk,0-4 | 1196 | 0.10 | 0.40 | 4.30 | 6.38 | 7.10 | 8.79 | 10.50 | 12.90 |
| LowLk,4-8 | 2151 | 0.10 | 0.50 | 4.60 | 6.49 | 7.03 | 8.95 | 10.60 | 13.30 |
| LowLk,8-13 | 656 | 0.20 | 1.60 | 5.70 | 7.19 | 7.55 | 9.59 | 11.02 | 13.00 |

***Dissolved Oxygen Lower Lake Samples Categorized by Depth***

> By depth, highest mean and median concentrations were measured in the surface layer

> Lowest mean and median concentrations measured in the bottom layers.

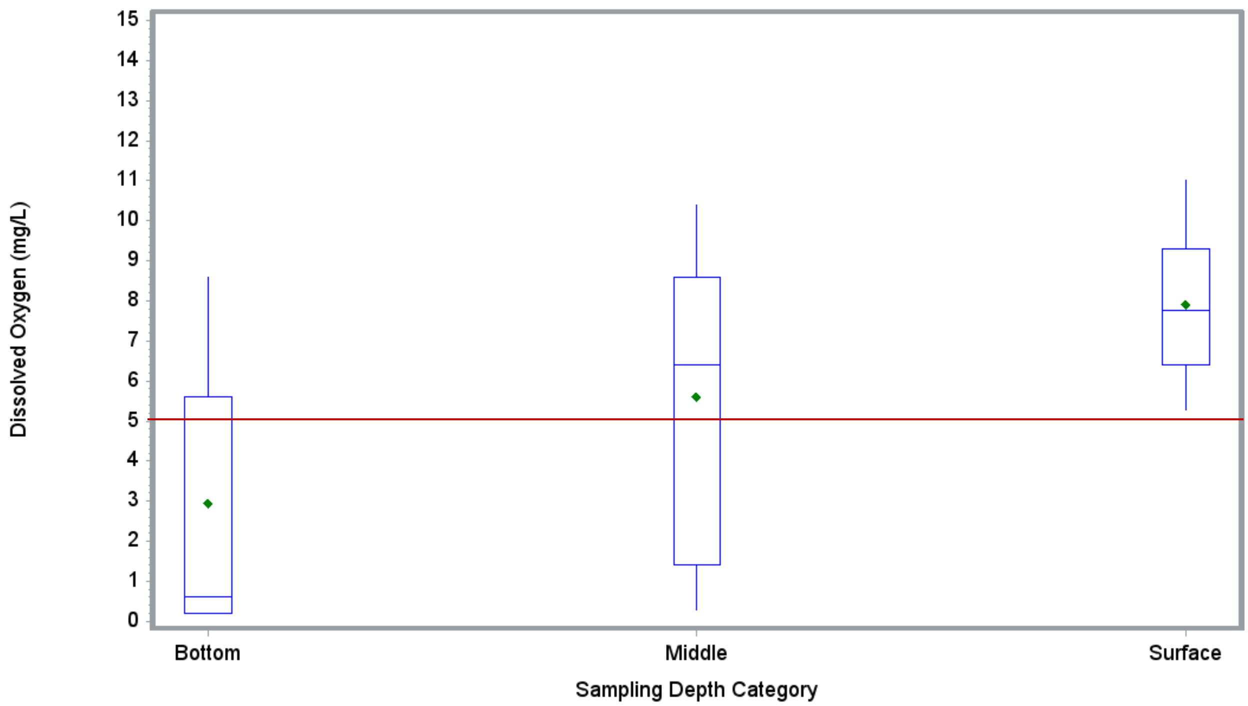



**Figure 3-38 DO Lower Lake Samples Categorized by Depth Category (surface, photic, bottom)**

**Table 3-42 DO Lower Lake Samples Categorized by Depth Category (surface, photic, bottom) (in mg/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 43 | 0.10 | 0.20 | 0.20 | 2.94 | 0.60 | 5.60 | 8.60 | 12.00 |
| Middle | 2264 | 0.10 | 0.30 | 1.40 | 5.61 | 6.40 | 8.60 | 10.40 | 13.10 |
| Surface | 1803 | 1.56 | 5.29 | 6.40 | 7.90 | 7.76 | 9.30 | 11.00 | 13.30 |

***Dissolved Oxygen Lower Lake Categorized by Year***

> Highest mean and median concentrations for a full year of data were recorded in 2008.The lowest mean and median DO concentrations were in 2004.

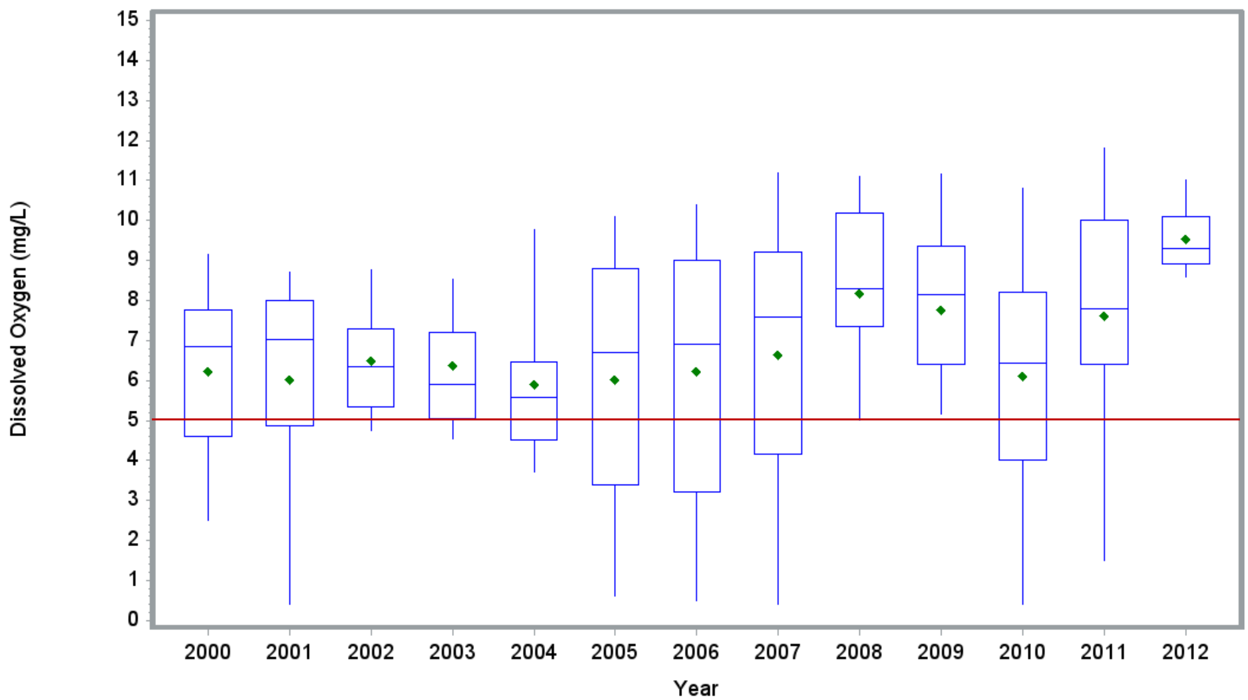



**Figure 3-39 DO Lower Lake Samples Categorized by Year**

**Table 3-43 DO Lower Lake Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 164 | 0.10 | 2.50 | 4.60 | 6.21 | 6.86 | 7.76 | 9.16 | 10.60 |
| 2001 | 182 | 0.20 | 0.40 | 4.86 | 6.01 | 7.03 | 8.00 | 8.70 | 10.60 |
| 2002 | 76 | 3.39 | 4.76 | 5.35 | 6.49 | 6.35 | 7.30 | 8.77 | 11.10 |
| 2003 | 96 | 3.36 | 4.54 | 5.04 | 6.37 | 5.91 | 7.22 | 8.53 | 11.20 |
| 2004 | 88 | 3.13 | 3.73 | 4.50 | 5.90 | 5.57 | 6.46 | 9.76 | 11.30 |
| 2005 | 670 | 0.10 | 0.60 | 3.38 | 6.01 | 6.70 | 8.80 | 10.10 | 12.70 |
| 2006 | 833 | 0.10 | 0.50 | 3.20 | 6.22 | 6.90 | 9.00 | 10.40 | 12.70 |
| 2007 | 711 | 0.10 | 0.40 | 4.16 | 6.64 | 7.60 | 9.20 | 11.20 | 13.00 |
| 2008 | 161 | 0.10 | 5.01 | 7.34 | 8.18 | 8.30 | 10.17 | 11.10 | 13.30 |
| 2009 | 152 | 0.10 | 5.15 | 6.41 | 7.76 | 8.14 | 9.36 | 11.16 | 12.50 |
| 2010 | 425 | 0.10 | 0.40 | 4.02 | 6.10 | 6.43 | 8.20 | 10.80 | 12.10 |
| 2011 | 503 | 0.10 | 1.50 | 6.40 | 7.63 | 7.80 | 10.00 | 11.80 | 13.20 |
| 2012 | 49 | 7.90 | 8.60 | 8.90 | 9.54 | 9.30 | 10.10 | 11.00 | 11.42 |

### *Dissolved Oxygen Lower Lake Samples Categorized by Month*

> By month, the highest mean and median concentrations were measured in the colder months, November to April.

> The lowest mean and median concentrations were measured in the warmer months, May to October.

> Data variability was greater from May to September than in other months.

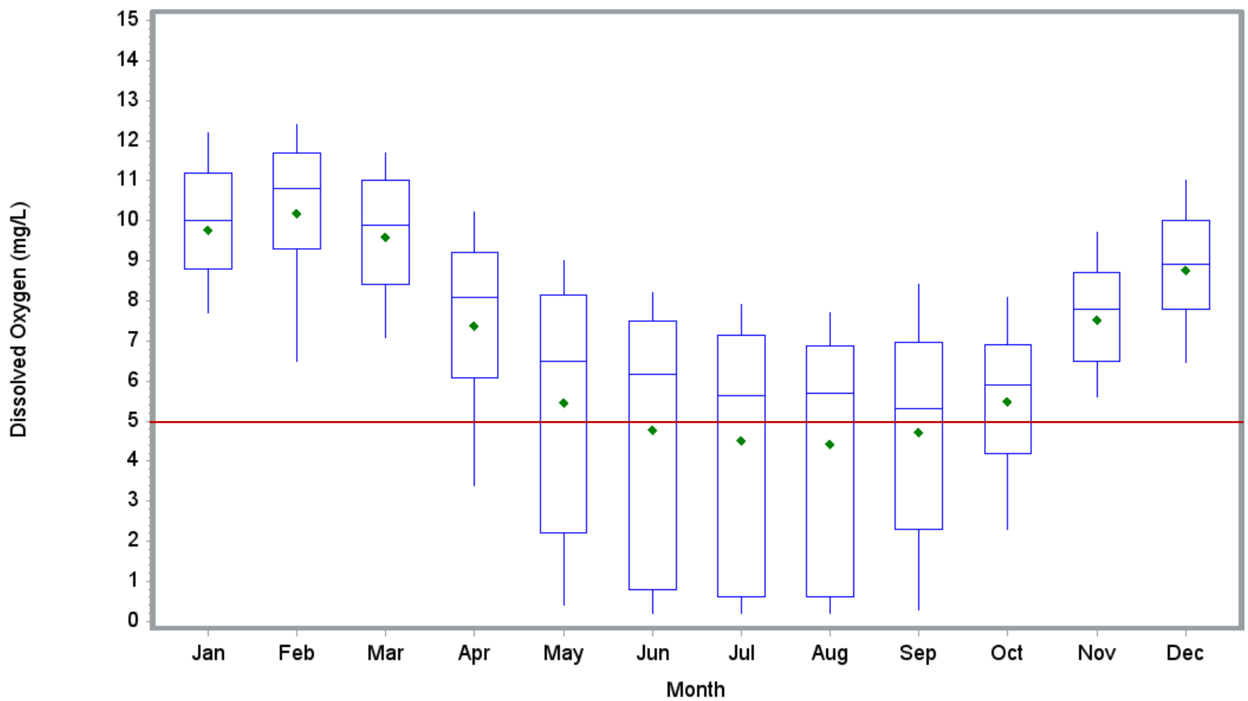



**Figure 3-40 DO Lower Lake Samples Categorized by Month**

**Table 3-44 DO Lower Lake Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 244 | 0.50 | 7.70 | 8.80 | 9.78 | 10.00 | 11.20 | 12.20 | 13.30 |
| Feb | 247 | 0.50 | 6.49 | 9.30 | 10.18 | 10.80 | 11.70 | 12.40 | 13.20 |
| Mar | 379 | 0.50 | 7.08 | 8.40 | 9.60 | 9.90 | 11.00 | 11.70 | 12.70 |
| Apr | 395 | 0.40 | 3.40 | 6.07 | 7.37 | 8.08 | 9.20 | 10.20 | 11.49 |
| May | 401 | 0.10 | 0.40 | 2.20 | 5.46 | 6.50 | 8.16 | 9.00 | 10.30 |
| Jun | 416 | 0.10 | 0.20 | 0.80 | 4.77 | 6.16 | 7.50 | 8.20 | 10.30 |
| Jul | 411 | 0.10 | 0.20 | 0.60 | 4.52 | 5.65 | 7.15 | 7.90 | 9.22 |
| Aug | 436 | 0.10 | 0.20 | 0.60 | 4.43 | 5.70 | 6.88 | 7.70 | 10.14 |
| Sep | 338 | 0.10 | 0.30 | 2.30 | 4.73 | 5.31 | 6.96 | 8.40 | 10.11 |
| Oct | 302 | 0.10 | 2.30 | 4.20 | 5.50 | 5.90 | 6.90 | 8.10 | 10.00 |
| Nov | 291 | 0.50 | 5.60 | 6.50 | 7.54 | 7.80 | 8.70 | 9.70 | 11.50 |
| Dec | 250 | 0.70 | 6.46 | 7.80 | 8.76 | 8.90 | 10.00 | 11.00 | 12.10 |

***Dissolved Oxygen Lower Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded by Wake County (small sample size, n=8) and CAAE.

> Lowest mean and median concentrations were recorded by USGS.

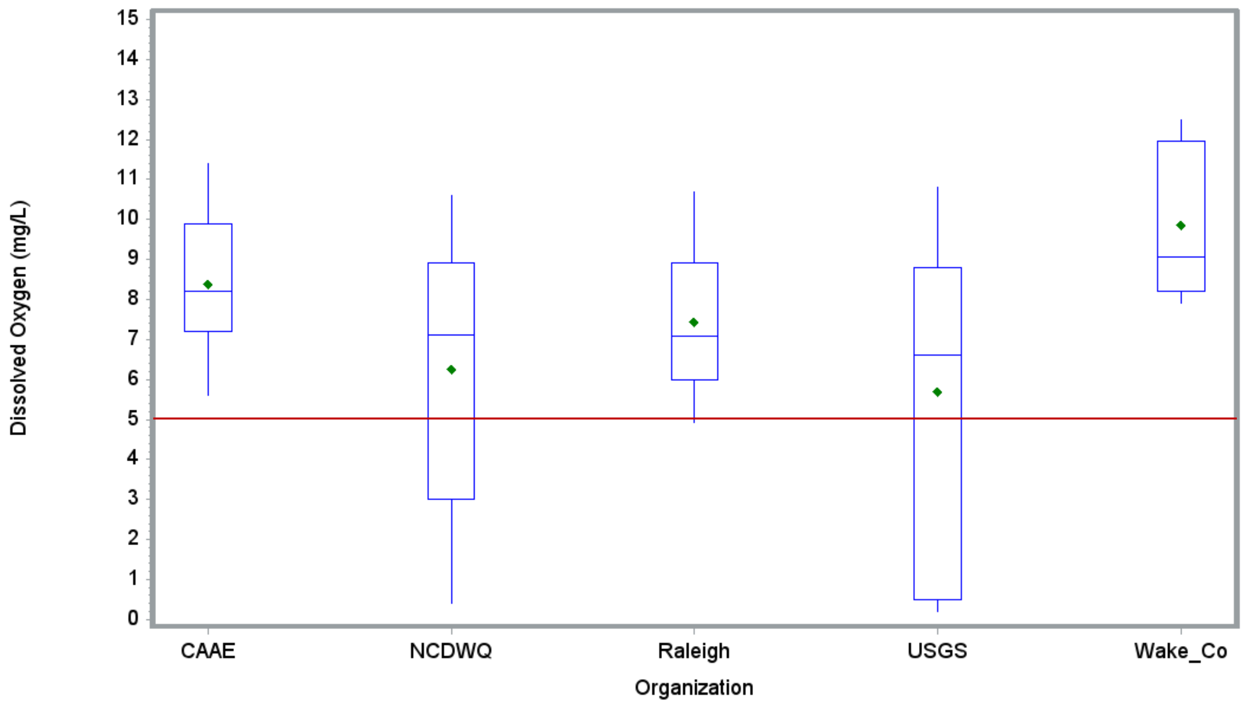



**Figure 3-41 DO Lower Lake Samples Categorized by Sampling Organization**

**Table 3-45 DO Lower Lake Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 69 | 3.53 | 5.62 | 7.19 | 8.39 | 8.21 | 9.88 | 11.41 | 12.40 |
| NCDWQ | 2734 | 0.10 | 0.40 | 3.00 | 6.25 | 7.10 | 8.90 | 10.60 | 13.20 |
| Raleigh | 1104 | 1.56 | 4.93 | 6.00 | 7.43 | 7.07 | 8.90 | 10.70 | 13.30 |
| USGS | 195 | 0.10 | 0.20 | 0.50 | 5.71 | 6.60 | 8.80 | 10.80 | 11.70 |
| Wake_Co | 8 | 7.90 | 7.90 | 8.20 | 9.85 | 9.05 | 11.95 | 12.50 | 12.50 |

### *Dissolved Oxygen Lower Lake Samples Categorized by Method*

> Three known methods and one unknown method were used to determine DO in the lower lake.

> Highest mean concentrations were measured using the unknown method, while lowest concentrations measured using the ASTM D888-87 method.

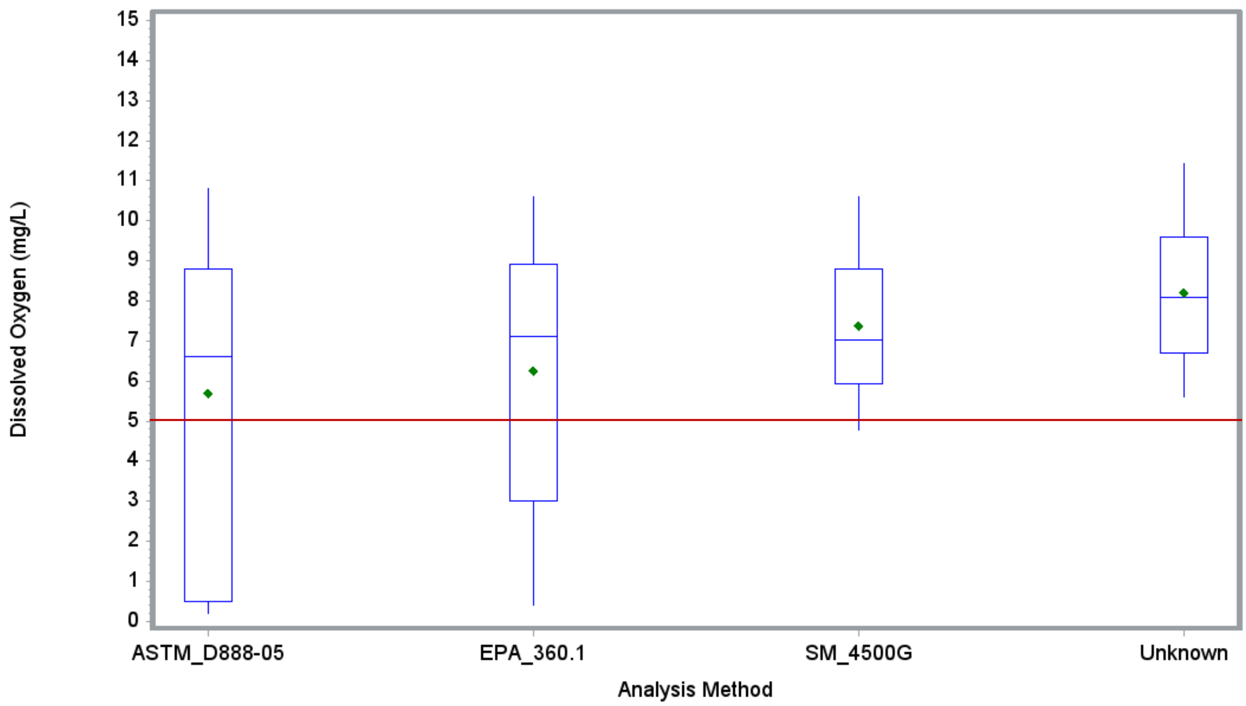



**Figure 3-42 DO Lower Lake Samples Categorized by Analysis Method**

**Table 3-46 DO Lower Lake Samples Categorized by Analysis Method**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| ASTM_D888-05 | 195 | 0.10 | 0.20 | 0.50 | 5.71 | 6.60 | 8.80 | 10.80 | 11.70 |
| EPA_360.1 | 2734 | 0.10 | 0.40 | 3.00 | 6.25 | 7.10 | 8.90 | 10.60 | 13.20 |
| SM_4500G | 986 | 1.56 | 4.79 | 5.94 | 7.37 | 7.03 | 8.81 | 10.60 | 13.30 |
| Unknown | 195 | 3.53 | 5.60 | 6.69 | 8.20 | 8.09 | 9.60 | 11.42 | 12.50 |

## 3.8 pH

Each of the eight participating organizations measured pH as part of their water quality sampling effort. pH data was collected in-situ. For those organizations that provided method, the following were used:

> pH in water by electronic method (EPA 150.1)

> Standard method dissolved pH Electronic (SM 4500HB)

> pH, electrometric using glass electrode (USGS I-2587-85)

> pH using portable instrument (Oakton WP pH)

> pH using methods described in the NCDENR SOP (NCDENR 2011c) which specifies using an Accumet AP Series handheld pH meter (WQS_SOP)

Appendix E provides detailed descriptions of these methods.

Table 3-47 describes the organizations and analysis methods used to measure pH and includes the number of samples, date range, and limits. Several organizations did not report the method used to measure pH for some, or all of, the data they provided. In these cases, the analysis method is listed as Not Provided. The majority of the pH data was collected by NCDWQ using method EPA_150.1. The limits for pH are listed as not applicable (NA) because ambient conditions would not exceed the limits of the equipment used.  pH is presented to two decimal places based on reported data.

**Table 3-47 Summary of Analysis Methods for the pH Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit | Reporting Limit | Practical Quanti-fication Limit | Range of Limit Specified with Results |
|---|---|---|---|---|---|---|---|---|
| CAAE | SM_4500HB | 07/24/2007 | 12/17/2010 | 69 | NA | NA | NA | NA |
| Durham_Ci | Not Provided | 10/28/2008 | 04/30/2012 | 917 | NA | NA | NA | NA |
| Durham_Ci | Oakton_ WP_pH | 01/10/2005 | 12/07/2011 | 780 | NA | NA | NA | NA |
| NCDWQ | EPA_150.1 | 06/07/2000 | 01/10/2012 | 4,012 | NA | NA | NA | NA |
| NCDWQ | WQS_SOP | 01/11/1999 | 04/06/2011 | 1,049 | NA | NA | NA | NA |
| Orange_Co | SM_16_423 | 04/09/2010 | 03/25/2011 | 171 | NA | NA | NA | NA |
| Raleigh | Not Provided | 01/13/2009 | 03/05/2012 | 150 | NA | NA | NA | NA |
| Raleigh | SM_4500HB | 02/07/2000 | 12/30/2011 | 1,107 | NA | NA | NA | NA |
| SGWASA | Not Provided | 01/04/2005 | 12/27/2011 | 1,431 | NA | NA | NA | NA |
| USGS | USGS_I-2587-85 | 01/15/1999 | 11/04/2011 | 1,022 | NA | NA | NA | NA |
| Wake_Co | Not Provided | 07/29/2008 | 10/28/2009 | 160 | NA | NA | NA | NA |

NA: Limits not applicable for pH in ambient conditions.

### 3.8.2 Tributary Samples

Six organizations collected pH data in the tributaries of Falls Lake from 1999 to present.  Mean pH values recorded by each organization were fairly similar.  Highest mean and median pH values were recorded by the City of Durham and lowest mean and median pH values were recorded by USGS.  All monitored tributaries returned similar mean and median pH values with highest mean and median pH recorded in Lick Creek and lowest mean pH recorded in Beaverdam Creek.  Summary statistics and box plots are provided below.

***pH Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Nine catchments were sampled for pH: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.

> For all tributaries, the highest mean and median pH values were recorded in Lick Creek and the lowest mean pH value was recorded in Beaverdam Creek.

> By location from the mouth, the highest mean and median pH values were recorded in Lick Creek 0 to 2 miles from the dam and the lowest mean and median pH values were recorded in Beaverdam Creek 2 to 10 miles from the mouth.

> For Beaverdam Creek, Lick Creek and Little River mean pH recorded 2 to 10 miles from the dam was slightly less than mean pH recorded 0 to 2 miles from the dam.  For Ellerbe Creek, Eno River, and Flat River mean pH recorded 2 to 10 miles from the dam was slightly greater than mean pH recorded 0 to 2 miles from the dam.

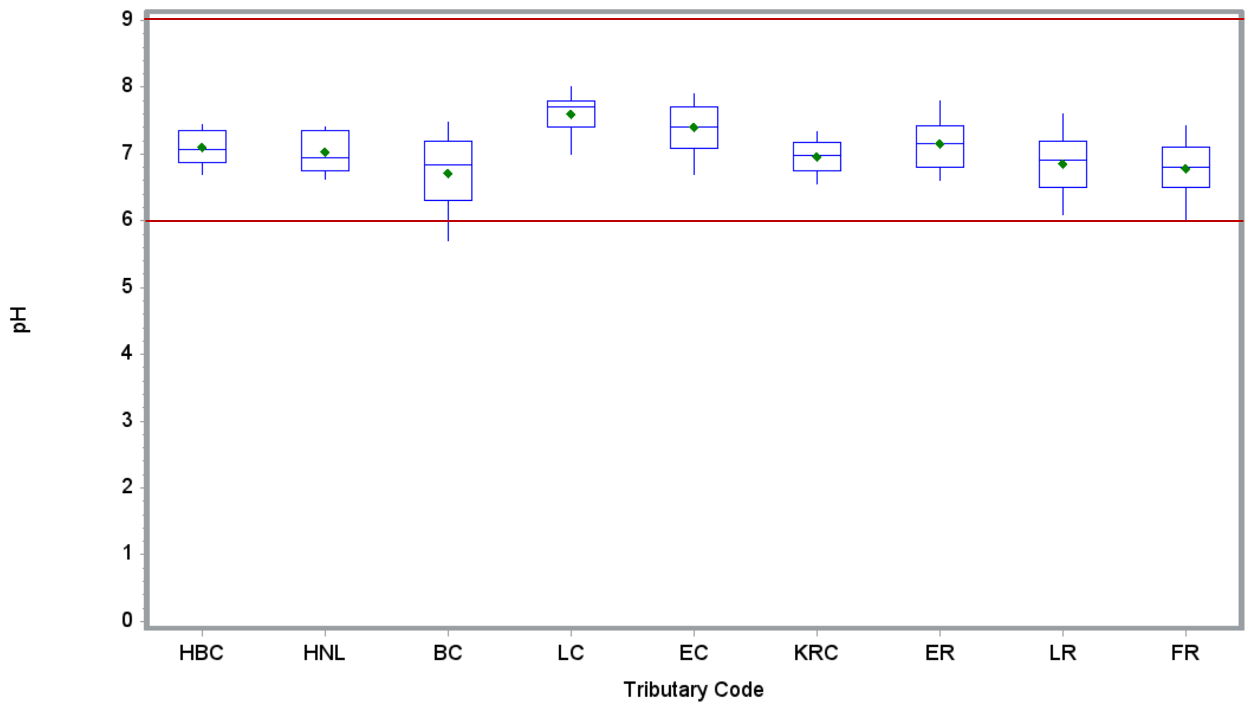



**Figure 3-43 pH Tributary Samples Categorized by Subwatershed**

**Table 3-48 pH Tributary Samples Categorized by Subwatershed**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 83 | 6.25 | 6.70 | 6.88 | 7.10 | 7.07 | 7.36 | 7.44 | 8.37 |
| HNL | 52 | 6.48 | 6.62 | 6.76 | 7.03 | 6.94 | 7.35 | 7.40 | 8.30 |
| BC | 48 | 5.40 | 5.70 | 6.30 | 6.71 | 6.84 | 7.20 | 7.48 | 7.63 |
| LC | 165 | 6.10 | 7.00 | 7.40 | 7.60 | 7.70 | 7.80 | 8.00 | 8.54 |
| EC | 1227 | 5.60 | 6.70 | 7.09 | 7.41 | 7.40 | 7.70 | 7.90 | 72.00[1] |
| KRC | 1601 | 4.50 | 6.55 | 6.74 | 6.95 | 6.98 | 7.18 | 7.33 | 10.70 |
| ER | 748 | 5.60 | 6.60 | 6.80 | 7.15 | 7.17 | 7.43 | 7.80 | 8.70 |
| LR | 574 | 5.30 | 6.10 | 6.50 | 6.86 | 6.90 | 7.20 | 7.60 | 8.30 |
| FR | 430 | 4.60 | 6.00 | 6.50 | 6.78 | 6.80 | 7.10 | 7.42 | 8.30 |

[1] This value was reported as 72.00 in the raw data file. The value is likely a data entry error.

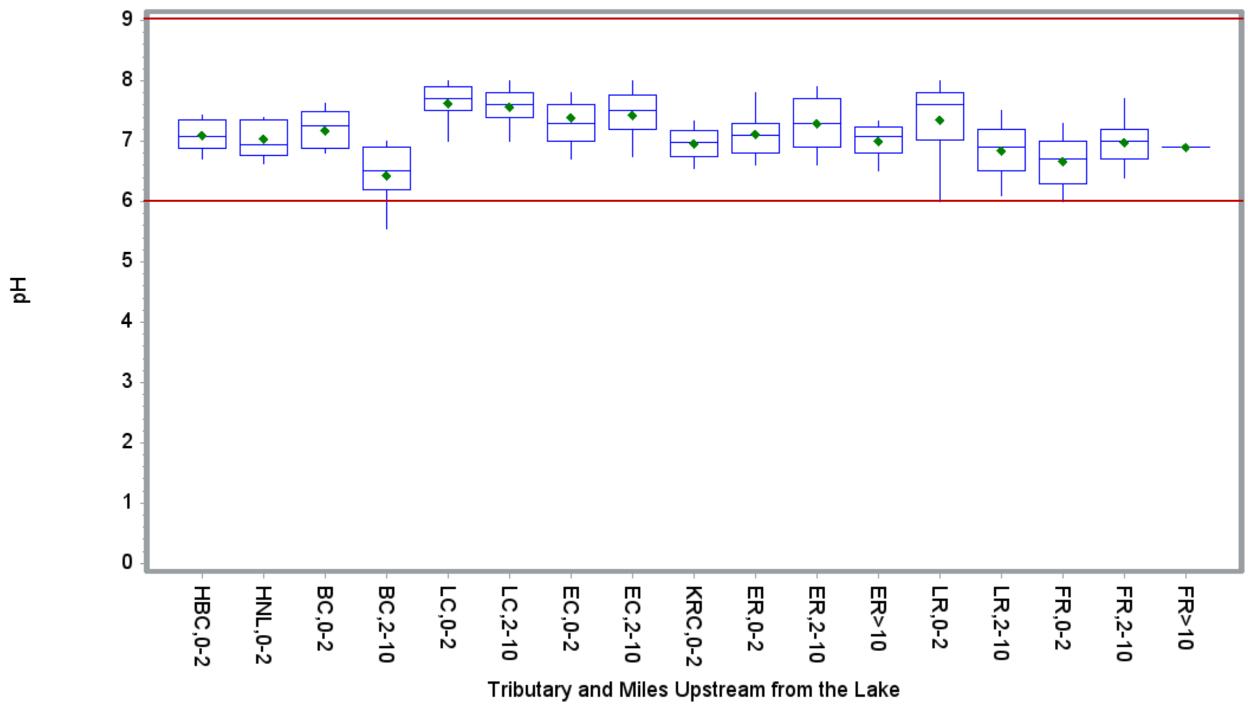



**Figure 3-44 pH Tributary Samples Categorized by Subwatershed and Distance from Lake**

**Table 3-49 pH Tributary Samples Categorized by Subwatershed and Distance from Lake**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 83 | 6.25 | 6.70 | 6.88 | 7.10 | 7.07 | 7.36 | 7.44 | 8.37 |
| HNL,0-2 | 52 | 6.48 | 6.62 | 6.76 | 7.03 | 6.94 | 7.35 | 7.40 | 8.30 |
| BC,0-2 | 18 | 6.46 | 6.80 | 6.89 | 7.17 | 7.25 | 7.48 | 7.63 | 7.63 |
| BC,2-10 | 30 | 5.40 | 5.55 | 6.20 | 6.44 | 6.50 | 6.90 | 7.00 | 7.30 |
| LC,0-2 | 76 | 6.40 | 7.00 | 7.52 | 7.62 | 7.70 | 7.90 | 8.00 | 8.20 |
| LC,2-10 | 89 | 6.10 | 7.00 | 7.40 | 7.58 | 7.60 | 7.80 | 8.00 | 8.54 |
| EC,0-2 | 561 | 5.70 | 6.70 | 6.99 | 7.39 | 7.30 | 7.60 | 7.80 | 72.00[1] |
| EC,2-10 | 666 | 5.60 | 6.74 | 7.20 | 7.43 | 7.50 | 7.77 | 8.00 | 8.72 |
| KRC,0-2 | 1601 | 4.50 | 6.55 | 6.74 | 6.95 | 6.98 | 7.18 | 7.33 | 10.70 |
| ER,0-2 | 152 | 5.90 | 6.60 | 6.80 | 7.12 | 7.10 | 7.30 | 7.80 | 8.20 |
| ER,2-10 | 325 | 5.70 | 6.60 | 6.90 | 7.30 | 7.30 | 7.70 | 7.90 | 8.70 |
| ER>10 | 271 | 5.60 | 6.50 | 6.80 | 6.99 | 7.07 | 7.24 | 7.34 | 7.79 |
| LR,0-2 | 18 | 5.80 | 6.00 | 7.01 | 7.36 | 7.60 | 7.80 | 8.00 | 8.10 |
| LR,2-10 | 556 | 5.30 | 6.10 | 6.50 | 6.85 | 6.90 | 7.20 | 7.50 | 8.30 |
| FR,0-2 | 275 | 4.60 | 6.00 | 6.30 | 6.67 | 6.70 | 7.00 | 7.30 | 8.30 |
| FR,2-10 | 154 | 6.00 | 6.40 | 6.70 | 6.99 | 7.00 | 7.20 | 7.70 | 8.20 |
| FR>10 | 1 | 6.90 | 6.90 | 6.90 | 6.90 | 6.90 | 6.90 | 6.90 | 6.90 |

[1] This value was reported as 72.00 in the raw data file. The value is likely a data entry error.

***pH in Tributary Samples Categorized by Depth***

> Only the surface level was sampled for pH in all tributaries.

***pH in Tributary Samples Categorized by Year***

> Mean pH values recorded from 1999 to 2008 were lower than mean pH values recorded from 2009 to present.

> By year, highest mean pH values were recorded in 2012 and lowest mean pH values were recorded in 2003.

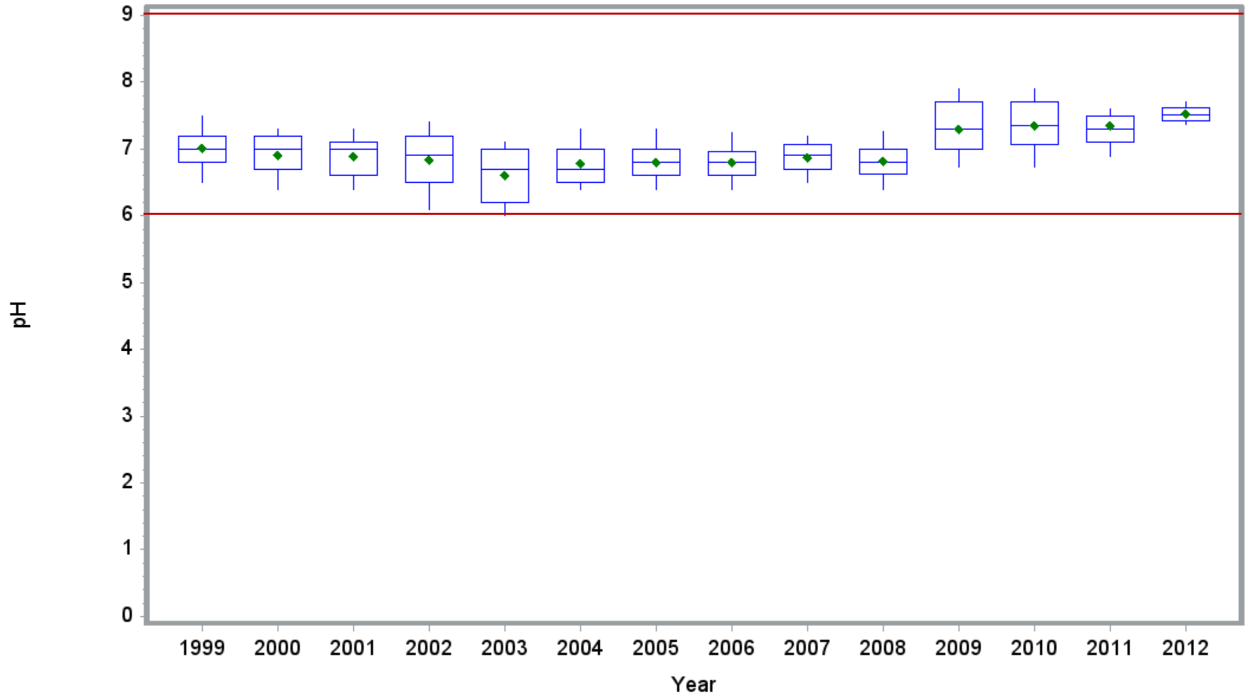



**Figure 3-45 pH Tributary Samples Categorized by Year**

**Table 3-50 pH Tributary Samples Categorized by Year**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 138 | 5.90 | 6.50 | 6.80 | 7.01 | 7.00 | 7.20 | 7.50 | 8.20 |
| 2000 | 138 | 5.40 | 6.40 | 6.70 | 6.91 | 7.00 | 7.20 | 7.30 | 7.80 |
| 2001 | 119 | 6.00 | 6.40 | 6.60 | 6.90 | 7.00 | 7.10 | 7.30 | 8.00 |
| 2002 | 119 | 5.30 | 6.10 | 6.50 | 6.84 | 6.90 | 7.20 | 7.40 | 7.70 |
| 2003 | 146 | 5.50 | 6.00 | 6.20 | 6.61 | 6.70 | 7.00 | 7.10 | 7.60 |
| 2004 | 125 | 6.00 | 6.40 | 6.50 | 6.78 | 6.70 | 7.00 | 7.30 | 8.50 |
| 2005 | 279 | 5.50 | 6.40 | 6.60 | 6.81 | 6.80 | 7.00 | 7.30 | 7.90 |
| 2006 | 426 | 5.70 | 6.40 | 6.60 | 6.80 | 6.80 | 6.96 | 7.25 | 8.00 |
| 2007 | 372 | 5.40 | 6.50 | 6.70 | 6.87 | 6.90 | 7.06 | 7.19 | 8.70 |
| 2008 | 465 | 4.50 | 6.40 | 6.62 | 6.81 | 6.80 | 7.00 | 7.27 | 10.70 |
| 2009 | 889 | 5.60 | 6.73 | 7.00 | 7.31 | 7.30 | 7.70 | 7.90 | 8.60 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | 975 | 4.60 | 6.73 | 7.07 | 7.35 | 7.35 | 7.70 | 7.90 | 8.72 |
| 2011 | 701 | 5.30 | 6.89 | 7.10 | 7.34 | 7.30 | 7.50 | 7.60 | 72.00[1] |
| 2012 | 36 | 6.90 | 7.37 | 7.43 | 7.52 | 7.51 | 7.62 | 7.70 | 8.05 |

[1] This value was reported as 72.00 in the raw data file. The value is likely a data entry error.

### *pH in Tributary Samples Categorized by Month*

> There was very little variation in mean and median pH between all months sampled.

> The highest mean pH was recorded in August and the lowest mean pH was recorded in June.

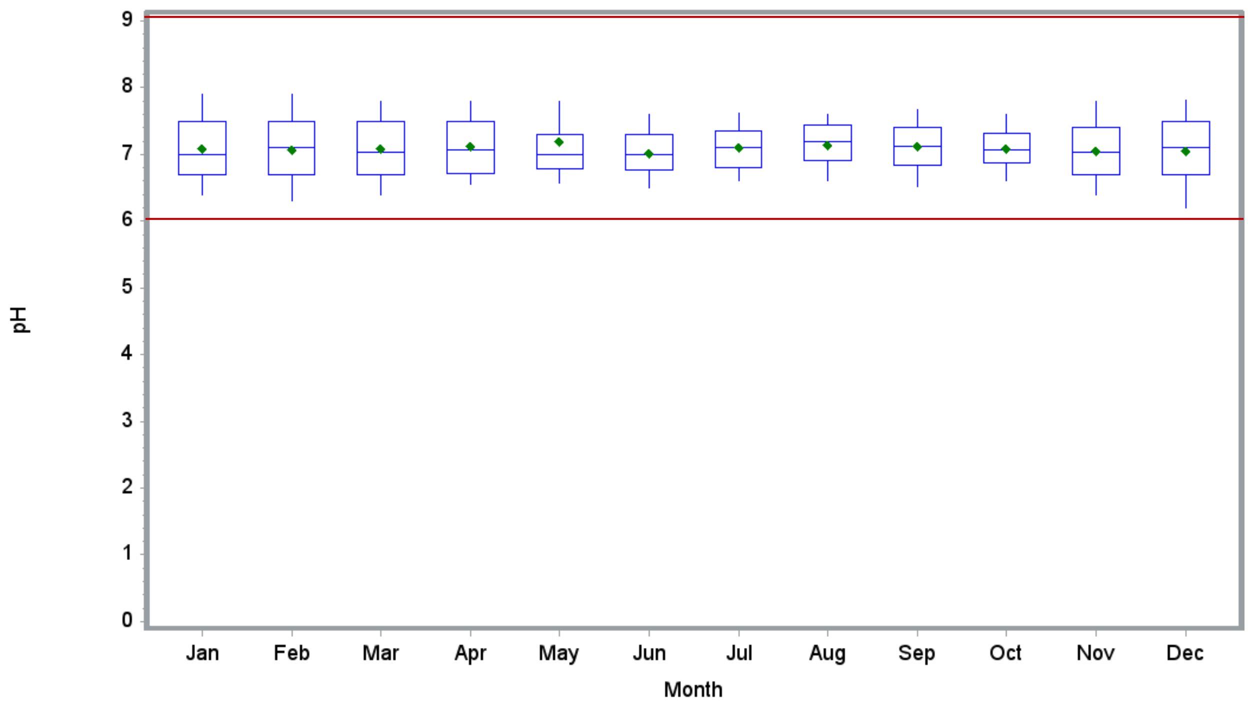



**Figure 3-46 pH Tributary Samples Categorized by Month**

**Table 3-51 pH Tributary Samples Categorized by Month**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 338 | 5.50 | 6.40 | 6.70 | 7.08 | 7.00 | 7.50 | 7.90 | 8.72 |
| Feb | 335 | 5.30 | 6.30 | 6.70 | 7.08 | 7.10 | 7.50 | 7.90 | 10.70 |
| Mar | 337 | 5.50 | 6.40 | 6.70 | 7.08 | 7.03 | 7.50 | 7.80 | 8.42 |
| Apr | 462 | 5.40 | 6.55 | 6.72 | 7.12 | 7.07 | 7.50 | 7.80 | 8.50 |
| May | 427 | 5.50 | 6.57 | 6.78 | 7.20 | 7.00 | 7.30 | 7.80 | 72.00[1] |
| Jun | 513 | 5.90 | 6.50 | 6.77 | 7.02 | 7.00 | 7.30 | 7.60 | 8.60 |
| Jul | 498 | 5.60 | 6.60 | 6.80 | 7.10 | 7.10 | 7.35 | 7.62 | 8.50 |
| Aug | 463 | 5.80 | 6.60 | 6.90 | 7.15 | 7.20 | 7.44 | 7.60 | 8.00 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Sep | 462 | 5.30 | 6.52 | 6.83 | 7.12 | 7.12 | 7.40 | 7.67 | 8.10 |
| Oct | 465 | 5.60 | 6.60 | 6.87 | 7.08 | 7.07 | 7.32 | 7.60 | 8.70 |
| Nov | 318 | 5.30 | 6.40 | 6.70 | 7.04 | 7.03 | 7.40 | 7.80 | 8.20 |
| Dec | 338 | 5.50 | 6.40 | 6.70 | 7.08 | 7.00 | 7.50 | 7.90 | 8.70 |

[1] This value was reported as 72.00 in the raw data file. The value is likely a data entry error.

### *pH in Tributary Samples Categorized by Sampling Organization*

> Highest mean and median pH values were recorded by the City of Durham.

> Lowest mean and median pH values were recorded by USGS.

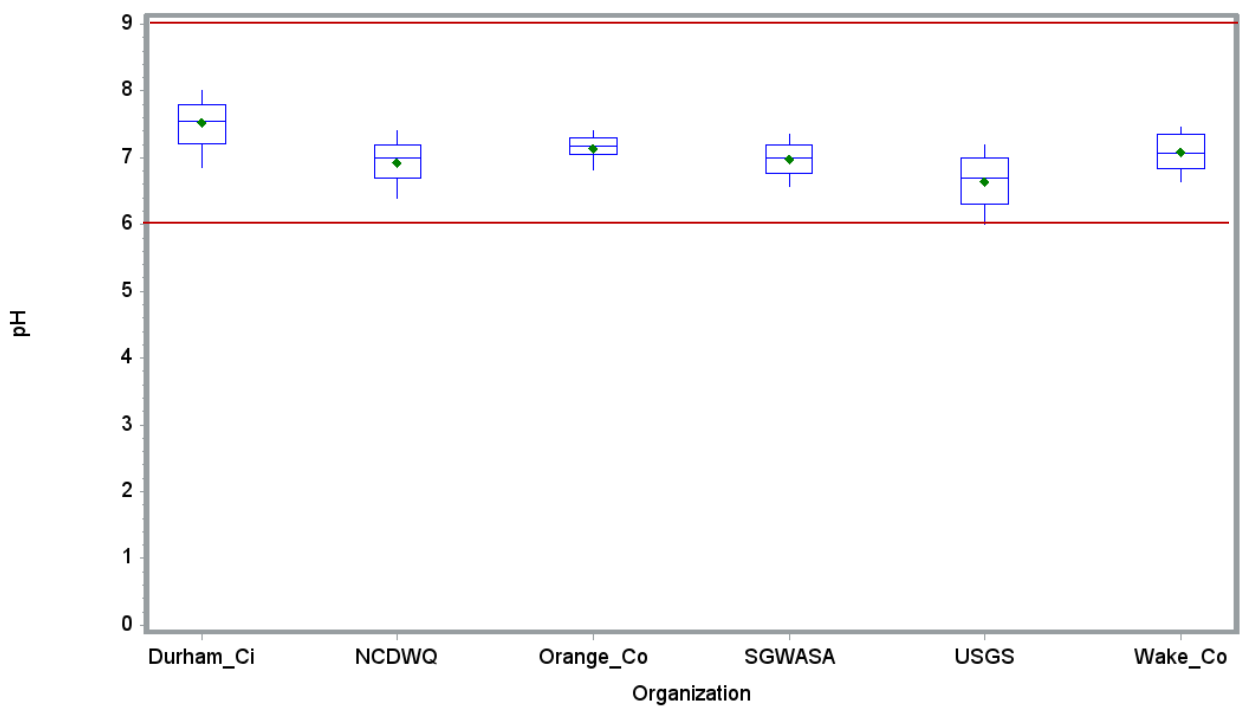



**Figure 3-47 pH Tributary Samples Categorized by Sampling Organization**

**Table 3-52 pH Tributary Samples Categorized by Sampling Organization**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 1481 | 5.60 | 6.85 | 7.21 | 7.52 | 7.55 | 7.80 | 8.00 | 72.00[1] |
| NCDWQ | 1049 | 5.70 | 6.40 | 6.70 | 6.93 | 7.00 | 7.20 | 7.40 | 8.70 |
| Orange_Co | 171 | 6.12 | 6.82 | 7.05 | 7.14 | 7.18 | 7.30 | 7.40 | 7.79 |
| SGWASA | 1431 | 4.50 | 6.58 | 6.76 | 6.97 | 6.99 | 7.19 | 7.35 | 10.70 |
| USGS | 644 | 644 | 4.60 | 6.00 | 6.30 | 6.64 | 6.70 | 7.00 | 7.20 |
| Wake_Co | 152 | 6.25 | 6.64 | 6.84 | 7.09 | 7.07 | 7.35 | 7.45 | 8.37 |

[1] This value was reported as 72.00 in the raw data file. The value is likely a data entry error.

***pH in Tributary Samples Categorized by Method***

> Of the five analysis methods categories, the Oakton WP method returned the highest mean and median pH values and USGS I-2587-85 category returned the lowest mean and median pH values.

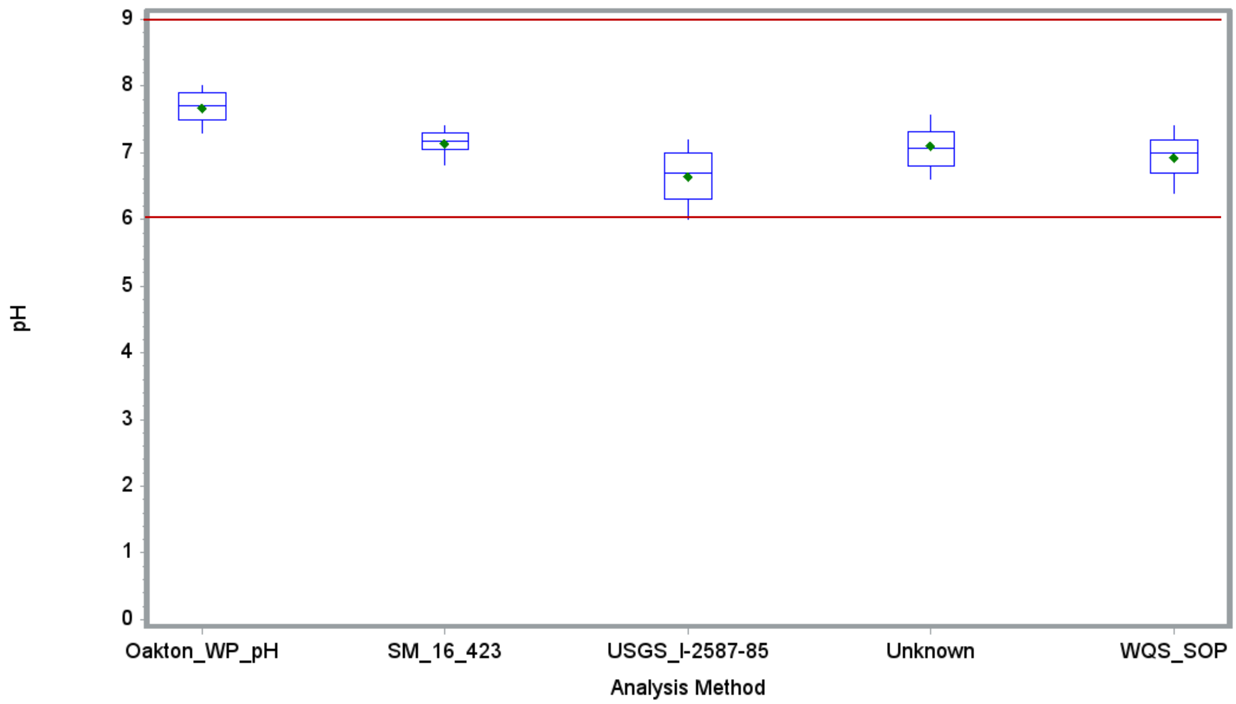



**Figure 3-48 pH Tributary Samples Categorized by Analysis Method**

**Table 3-53 pH Tributary Samples Categorized by Analysis Method**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Oakton_WP_pH | 780 | 5.90 | 7.30 | 7.50 | 7.67 | 7.70 | 7.90 | 8.00 | 8.70 |
| SM_16_423 | 171 | 6.12 | 6.82 | 7.05 | 7.14 | 7.18 | 7.30 | 7.40 | 7.79 |
| USGS_I-2587-85 | 644 | 4.60 | 6.00 | 6.30 | 6.64 | 6.70 | 7.00 | 7.20 | 8.00 |
| Unknown | 2284 | 4.50 | 6.60 | 6.80 | 7.09 | 7.06 | 7.31 | 7.56 | 72.00[1] |
| WQS_SOP | 1049 | 5.70 | 6.40 | 6.70 | 6.93 | 7.00 | 7.20 | 7.40 | 8.70 |

[1] This value was reported as 72.00 in the raw data file. The value is likely a data entry error.

### 3.8.3 Upper Lake Samples

Three organizations collected pH data in Upper Falls Lake from 2000 to present. Highest mean and median pH values were recorded by the City of Durham and lowest mean and median pH values were collected by the USGS. All monitored sections of Upper Lake returned very similar mean pH values. Highest pH measurements were recorded in 2012 and lowest measurements were recorded in 2000. Summary statistics and box plots are provided below.

***pH Upper Lake Samples Categorized by Miles Upstream from Dam***

> The mean pH at all three locations was very similar, with slightly higher mean pH values recorded 13 to 18 miles from the dam and slightly lower mean pH values recorded > 21 miles from the dam.

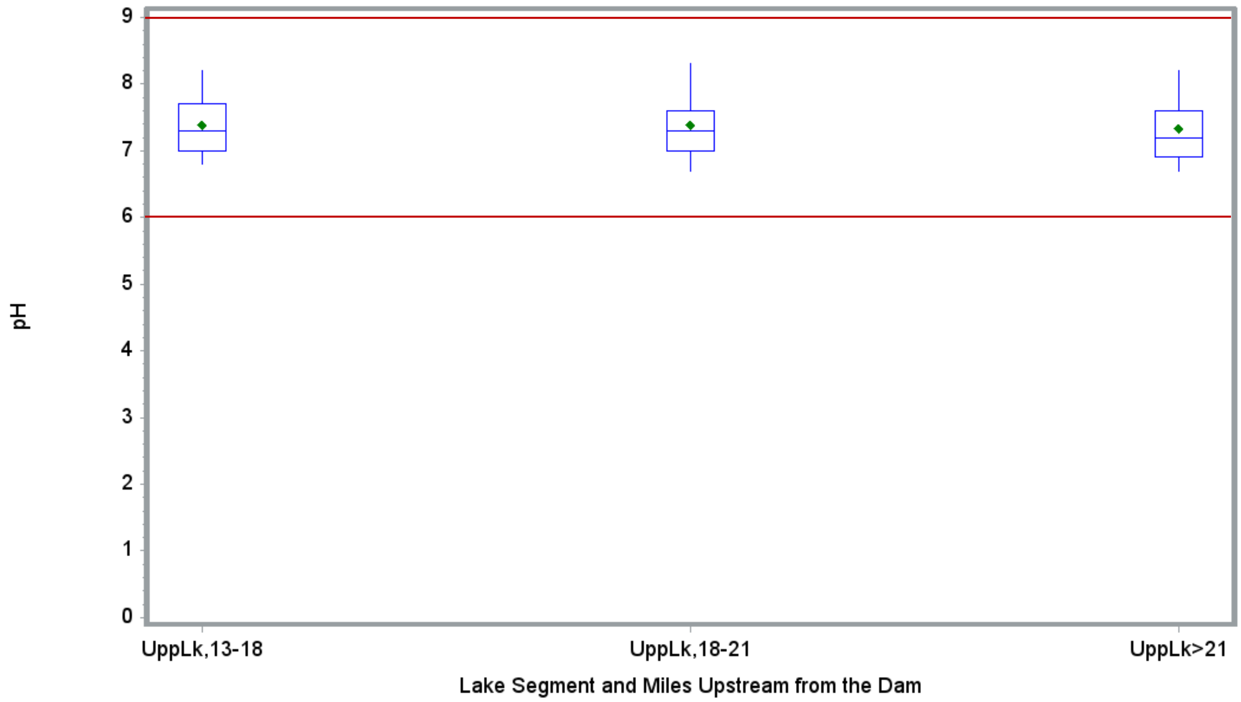



**Figure 3-49 pH Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-54 pH Upper Lake Samples Categorized by Miles Upstream from Dam**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 1319 | 6.00 | 6.80 | 7.00 | 7.39 | 7.30 | 7.70 | 8.20 | 9.10 |
| UppLk,18-21 | 312 | 6.10 | 6.70 | 7.00 | 7.38 | 7.30 | 7.60 | 8.30 | 10.00 |
| UppLk>21 | 827 | 5.80 | 6.70 | 6.90 | 7.33 | 7.20 | 7.60 | 8.20 | 9.50 |

***pH Upper Lake Samples Categorized by Depth***

- Highest mean and median pH values were recorded at the surface level.
- Lowest mean and median pH values were recorded at the bottom level (also the category with the smallest range of pH values), although the sample size for this category was significantly less than for the other two categories (n=12).

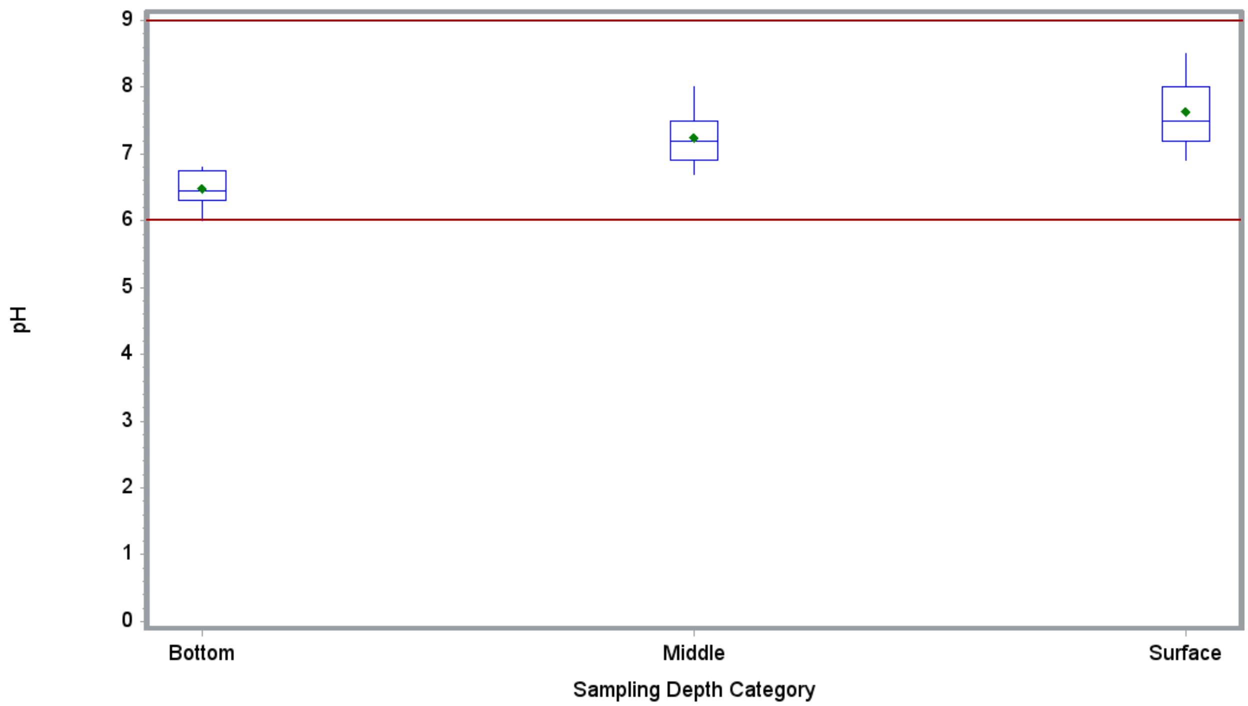



**Figure 3-50 pH Upper Lake Samples Categorized by Depth Category (surface, photic, bottom)**

**Table 3-55 pH Upper Lake Samples Categorized by Depth Category (surface, photic, bottom)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 12 | 5.80 | 6.00 | 6.30 | 6.49 | 6.45 | 6.75 | 6.80 | 7.40 |
| Middle | 1615 | 6.00 | 6.70 | 6.90 | 7.24 | 7.20 | 7.50 | 8.00 | 10.00 |
| Surface | 831 | 6.10 | 6.90 | 7.20 | 7.63 | 7.50 | 8.00 | 8.50 | 10.00 |

***pH Upper Lake Samples Categorized by Year***

> Sampling of pH has been recorded in all years from 2000 to 2012 except for years 2002-2004.

> By year, highest mean and median pH values were recorded in 2012 and 2011.

> Lowest mean pH value was recorded in 2000.

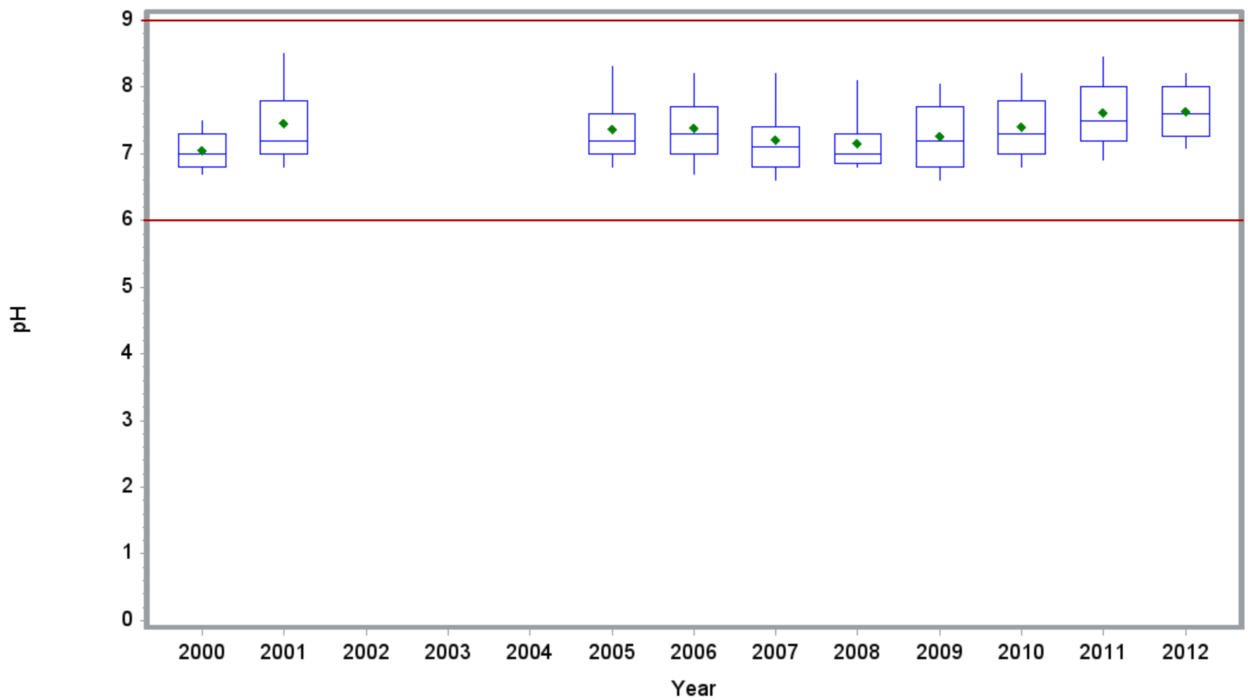



**Figure 3-51 pH Upper Lake Samples Categorized by Year**

**Table 3-56 pH Upper Lake Samples Categorized by Year**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 55 | 6.40 | 6.70 | 6.80 | 7.05 | 7.00 | 7.30 | 7.50 | 7.60 |
| 2001 | 81 | 6.70 | 6.80 | 7.00 | 7.46 | 7.20 | 7.80 | 8.50 | 8.90 |
| 2005 | 421 | 6.20 | 6.80 | 7.00 | 7.36 | 7.20 | 7.60 | 8.30 | 9.00 |
| 2006 | 633 | 6.00 | 6.70 | 7.00 | 7.39 | 7.30 | 7.70 | 8.20 | 9.50 |
| 2007 | 493 | 5.80 | 6.60 | 6.80 | 7.21 | 7.10 | 7.40 | 8.20 | 9.20 |
| 2008 | 36 | 6.70 | 6.80 | 6.85 | 7.16 | 7.00 | 7.30 | 8.10 | 8.20 |
| 2009 | 100 | 6.10 | 6.60 | 6.80 | 7.27 | 7.20 | 7.70 | 8.05 | 8.80 |
| 2010 | 287 | 6.10 | 6.80 | 7.00 | 7.41 | 7.30 | 7.80 | 8.20 | 8.90 |
| 2011 | 317 | 6.20 | 6.90 | 7.20 | 7.61 | 7.50 | 8.00 | 8.45 | 10.00 |
| 2012 | 35 | 6.30 | 7.08 | 7.26 | 7.63 | 7.60 | 8.00 | 8.20 | 8.30 |

### *pH Upper Lake Samples Categorized by Month*

> Highest mean and median pH values were recorded in February and lowest mean and median pH values were recorded in December.

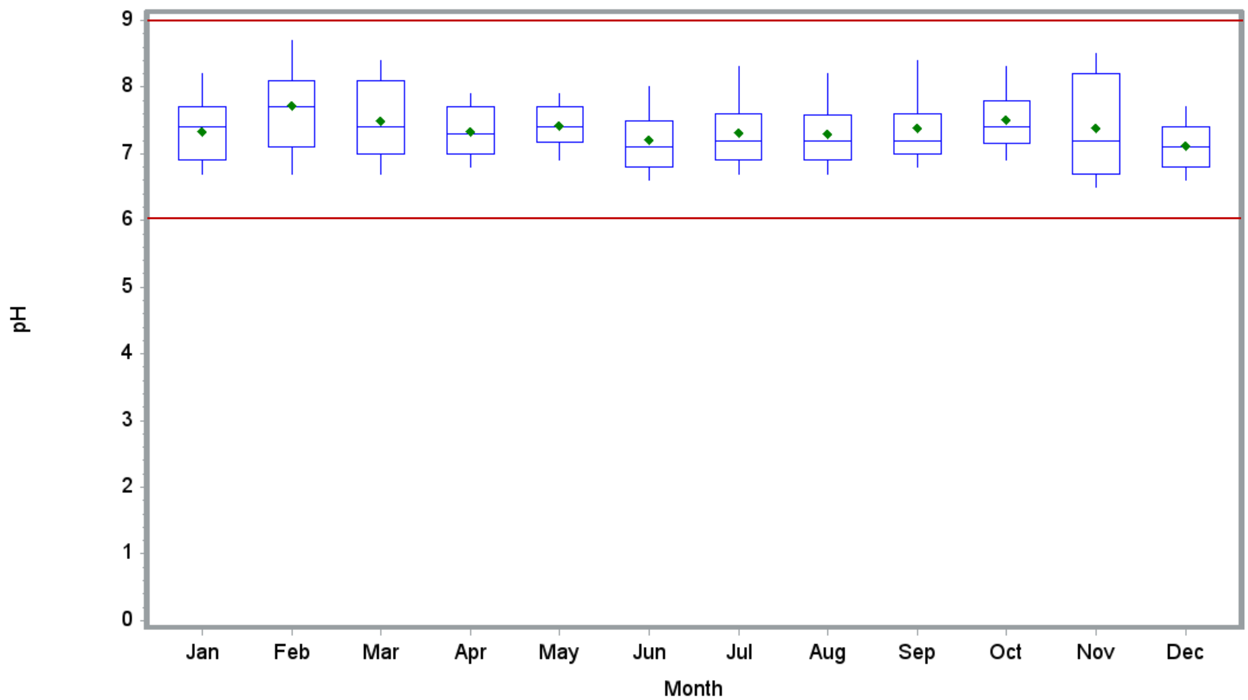



**Figure 3-52 pH Upper Lake Samples Categorized by Month**

**Table 3-57 pH Upper Lake Samples Categorized by Month**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 115 | 6.40 | 6.70 | 6.90 | 7.34 | 7.40 | 7.70 | 8.20 | 8.60 |
| Feb | 134 | 6.10 | 6.70 | 7.10 | 7.72 | 7.70 | 8.10 | 8.70 | 10.00 |
| Mar | 183 | 6.20 | 6.70 | 7.00 | 7.50 | 7.40 | 8.10 | 8.40 | 9.30 |
| Apr | 234 | 5.80 | 6.80 | 7.00 | 7.33 | 7.30 | 7.70 | 7.90 | 8.60 |
| May | 235 | 6.30 | 6.90 | 7.18 | 7.42 | 7.40 | 7.70 | 7.90 | 8.80 |
| Jun | 294 | 6.20 | 6.60 | 6.80 | 7.22 | 7.10 | 7.50 | 8.00 | 9.21 |
| Jul | 264 | 6.00 | 6.70 | 6.90 | 7.32 | 7.20 | 7.60 | 8.30 | 9.23 |
| Aug | 333 | 6.20 | 6.70 | 6.90 | 7.30 | 7.19 | 7.59 | 8.20 | 8.80 |
| Sep | 225 | 6.40 | 6.80 | 7.00 | 7.39 | 7.20 | 7.60 | 8.40 | 9.10 |
| Oct | 196 | 6.50 | 6.90 | 7.15 | 7.51 | 7.40 | 7.80 | 8.30 | 8.82 |
| Nov | 139 | 6.00 | 6.50 | 6.70 | 7.39 | 7.20 | 8.20 | 8.50 | 9.00 |
| Dec | 106 | 6.30 | 6.60 | 6.80 | 7.12 | 7.10 | 7.40 | 7.70 | 8.60 |

### *pH Upper Lake Samples Categorized by Sampling Organization*

> Highest mean and median pH values were recorded by the City of Durham and lowest mean and median pH values were collected by the USGS.

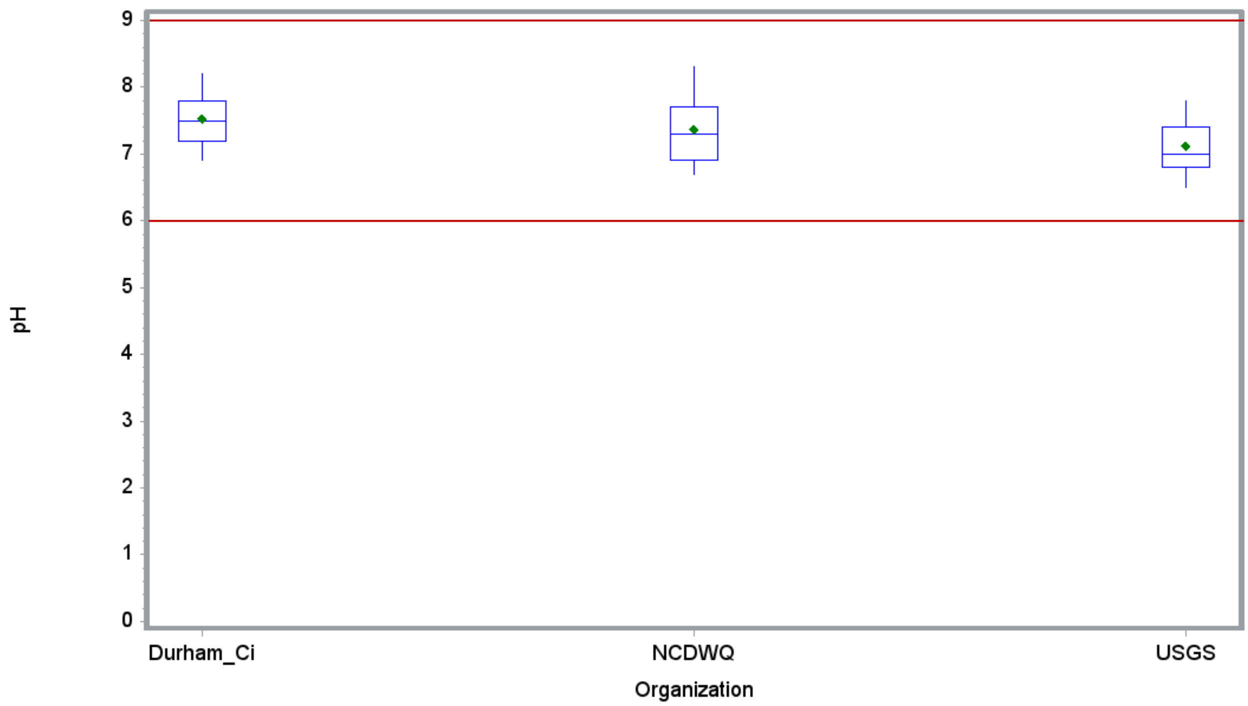



**Figure 3-53 pH Upper Lake Samples Categorized by Sampling Organization**

**Table 3-58 pH Upper Lake Samples Categorized by Sampling Organization**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 216 | 6.20 | 6.90 | 7.19 | 7.53 | 7.49 | 7.80 | 8.20 | 9.23 |
| NCDWQ | 2059 | 6.00 | 6.70 | 6.90 | 7.38 | 7.30 | 7.70 | 8.30 | 10.00 |
| USGS | 183 | 5.80 | 6.50 | 6.80 | 7.11 | 7.00 | 7.40 | 7.80 | 8.80 |

### *pH Upper Lake Samples Categorized by Method*

> The three analysis method categories returned similar mean and median pH recordings, with the unknown analysis method category returning highest mean and median values and the USGS I-2587-85 method returning the lowest mean and median pH values.

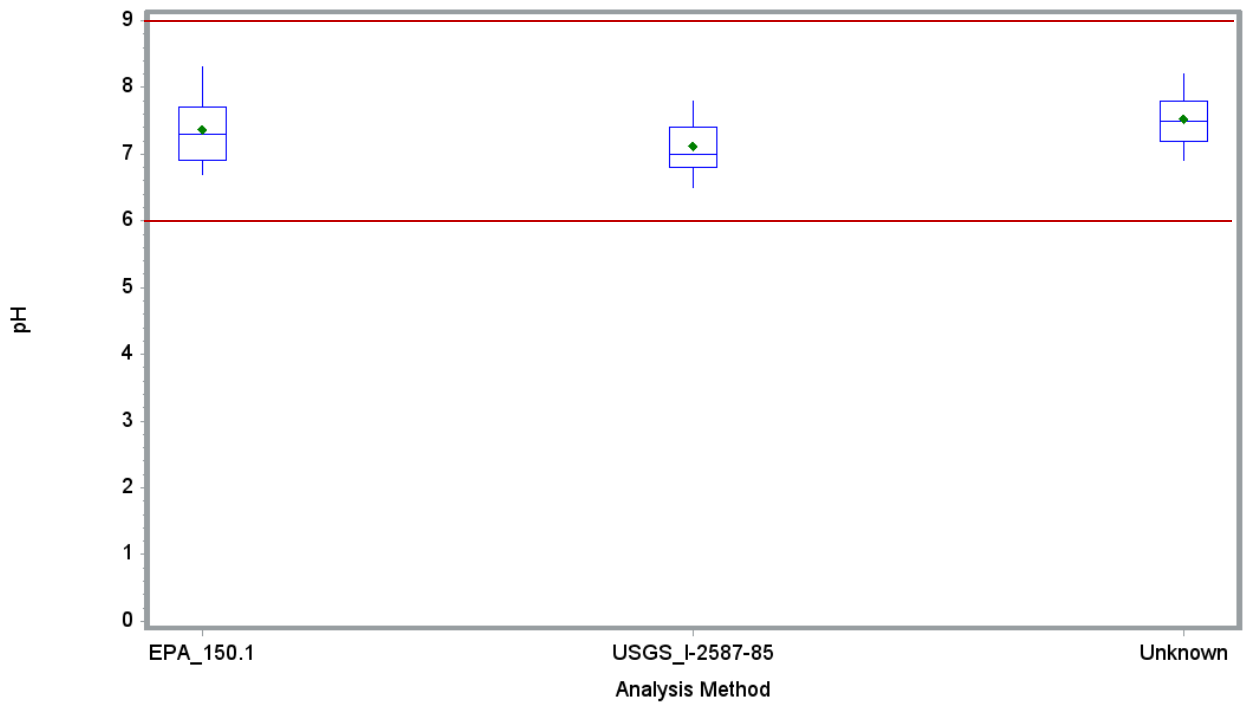



**Figure 3-54 pH Upper Lake Samples Categorized by Analysis Method**

**Table 3-59 pH Upper Lake Samples Categorized by Analysis Method**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_150.1 | 2059 | 6.00 | 6.70 | 6.90 | 7.38 | 7.30 | 7.70 | 8.30 | 10.00 |
| USGS_I-2587-85 | 183 | 5.80 | 6.50 | 6.80 | 7.11 | 7.00 | 7.40 | 7.80 | 8.80 |
| Unknown | 216 | 6.20 | 6.90 | 7.19 | 7.53 | 7.49 | 7.80 | 8.20 | 9.23 |

### 3.8.4 Lower Lake Samples

Five organizations collected pH data in Lower Falls Lake from 2000 to present. Highest mean and median pH values recorded by the Wake County and NCSU-CAAE and lowest mean and median pH recorded by USGS. Within the monitored sections of lower lake, highest mean and median pH values were recorded 8 to 13 miles from the dam and lowest mean and median pH values were recorded 4 to 8 miles from the dam. Mean pH values recorded in Beaverdam Impoundment exceeded mean pH values at all locations in Lower Lake. Summary statistics and box plots are provided below.

***pH Lower Lake Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Mean and median pH values recorded in Beaverdam Impoundment slightly exceeded mean pH values in the lower lake sections.

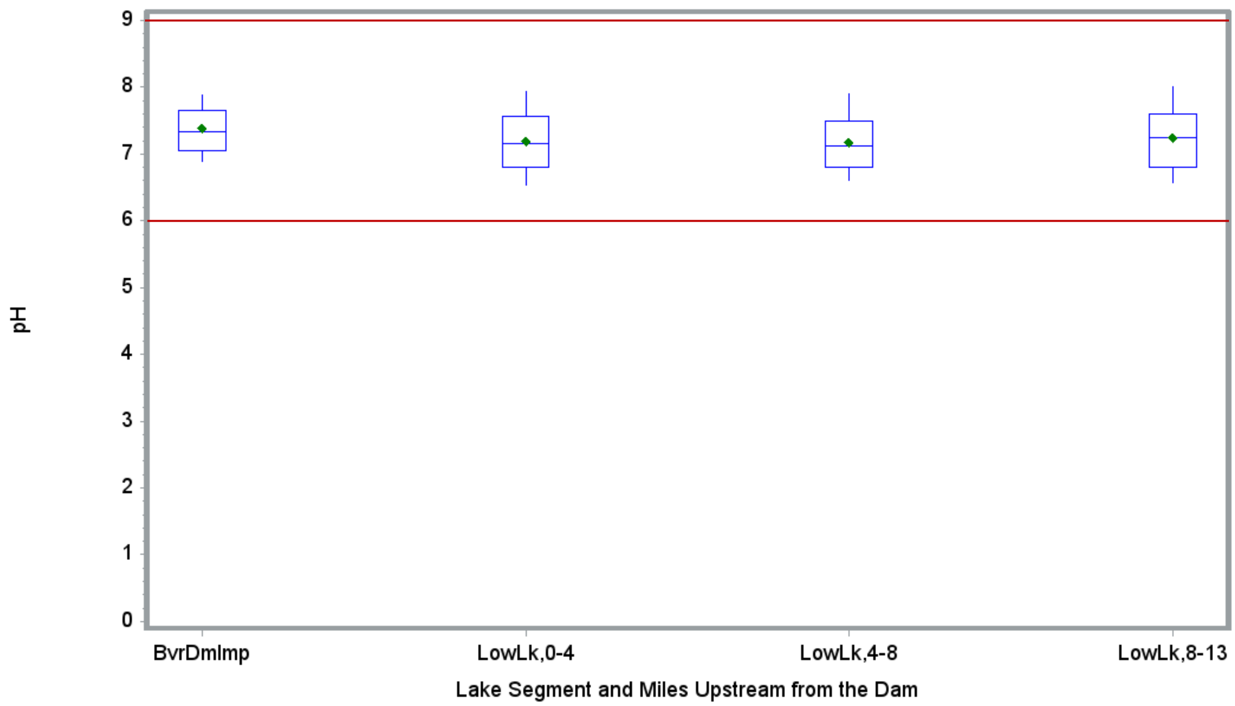



**Figure 3-55 pH Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-60 pH Lower Lake Samples Categorized by Miles Upstream from Dam**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 151 | 6.51 | 6.89 | 7.05 | 7.38 | 7.34 | 7.66 | 7.88 | 9.04 |
| LowLk,0-4 | 1030 | 5.69 | 6.55 | 6.80 | 7.20 | 7.15 | 7.57 | 7.94 | 9.51 |
| LowLk,4-8 | 1751 | 3.69 | 6.60 | 6.80 | 7.17 | 7.12 | 7.50 | 7.90 | 9.85 |
| LowLk,8-13 | 550 | 5.65 | 6.58 | 6.80 | 7.24 | 7.25 | 7.60 | 8.00 | 9.00 |

***pH Lower Lake Samples Categorized by Depth***

> By depth, highest mean and median pH values were recorded at the surface layer.

> Lowest mean and median pH values were recorded at the bottom layer.

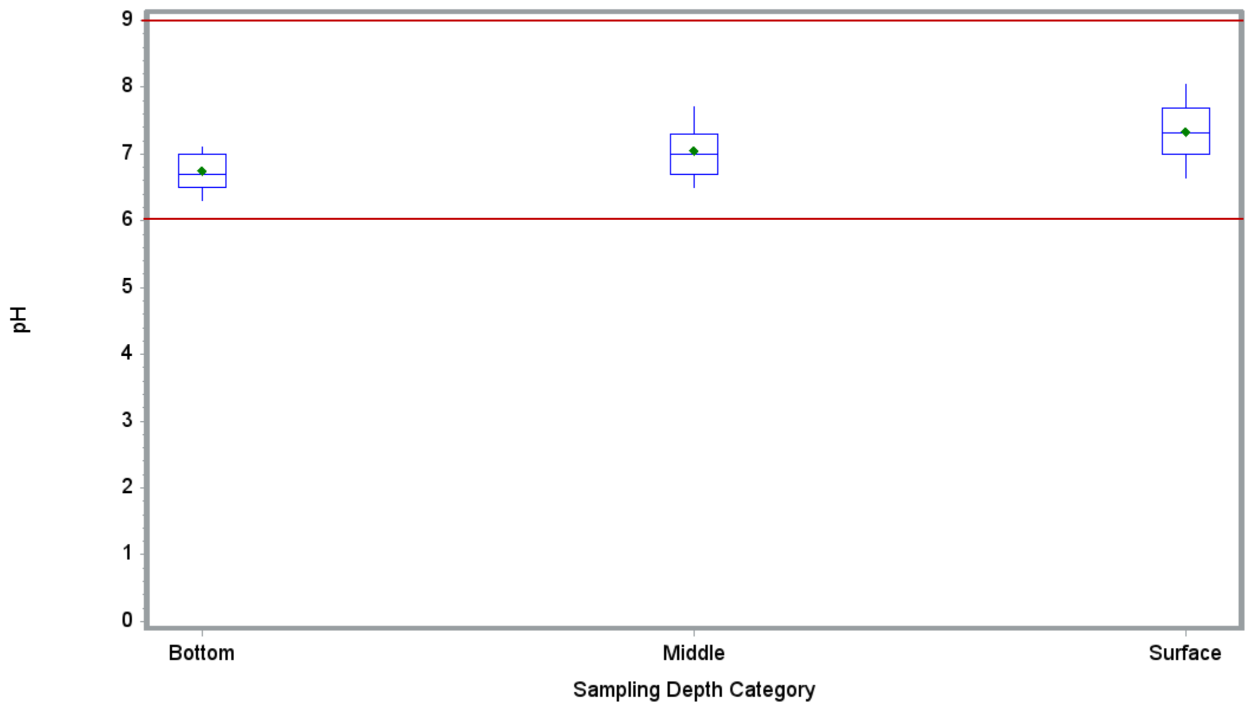



**Figure 3-56 pH Lower Lake Samples Categorized by Depth Category (surface, photic, bottom)**

**Table 3-61 pH Lower Lake Samples Categorized by Depth Category (surface, photic, bottom)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 43 | 5.90 | 6.30 | 6.50 | 6.75 | 6.70 | 7.00 | 7.10 | 7.90 |
| Middle | 1546 | 5.90 | 6.50 | 6.70 | 7.04 | 7.00 | 7.30 | 7.70 | 8.50 |
| Surface | 1893 | 3.69 | 6.65 | 7.00 | 7.34 | 7.31 | 7.69 | 8.05 | 9.85 |

### *pH Lower Lake Samples Categorized by Year*

> By year, highest mean pH values were recorded in 2012 (also smallest sampling size and incomplete sampling year) and 2004

> Lowest mean pH values were recorded in 2008.

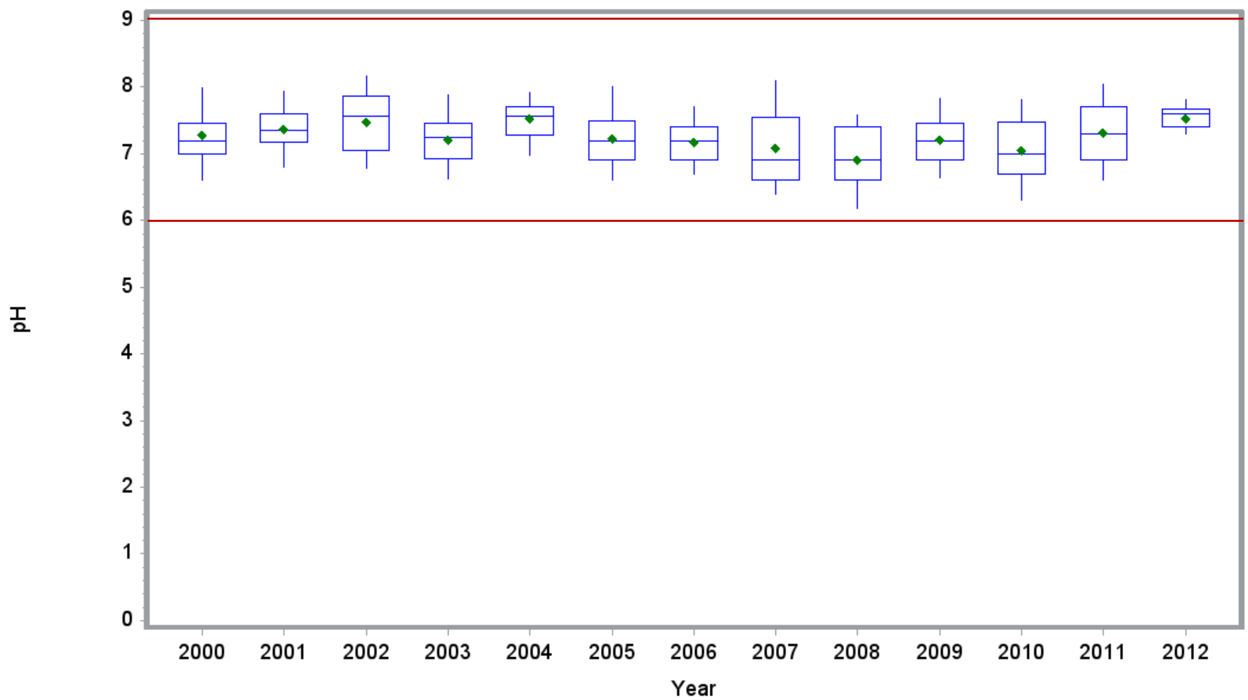



**Figure 3-57 pH Lower Lake Samples Categorized by Year**

**Table 3-62 pH Lower Lake Samples Categorized by Year**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 137 | 6.50 | 6.60 | 6.99 | 7.27 | 7.19 | 7.45 | 7.99 | 9.00 |
| 2001 | 205 | 5.69 | 6.80 | 7.17 | 7.37 | 7.35 | 7.60 | 7.93 | 8.30 |
| 2002 | 86 | 6.51 | 6.79 | 7.05 | 7.47 | 7.56 | 7.86 | 8.16 | 8.28 |
| 2003 | 96 | 6.05 | 6.63 | 6.92 | 7.20 | 7.25 | 7.47 | 7.88 | 8.06 |
| 2004 | 88 | 6.68 | 6.98 | 7.28 | 7.53 | 7.57 | 7.71 | 7.92 | 9.85 |
| 2005 | 559 | 6.20 | 6.60 | 6.90 | 7.23 | 7.19 | 7.50 | 8.00 | 8.50 |
| 2006 | 607 | 5.90 | 6.70 | 6.90 | 7.18 | 7.19 | 7.40 | 7.70 | 8.40 |
| 2007 | 552 | 5.90 | 6.40 | 6.60 | 7.08 | 6.90 | 7.54 | 8.10 | 9.51 |
| 2008 | 161 | 3.69 | 6.19 | 6.60 | 6.91 | 6.90 | 7.40 | 7.58 | 8.37 |
| 2009 | 187 | 6.20 | 6.65 | 6.90 | 7.20 | 7.20 | 7.45 | 7.83 | 8.72 |
| 2010 | 368 | 5.63 | 6.31 | 6.69 | 7.05 | 7.00 | 7.48 | 7.81 | 9.04 |
| 2011 | 407 | 5.87 | 6.60 | 6.90 | 7.31 | 7.30 | 7.70 | 8.05 | 8.76 |
| 2012 | 29 | 7.00 | 7.30 | 7.40 | 7.53 | 7.60 | 7.67 | 7.81 | 7.90 |

***pH Lower Lake Samples Categorized by Month***

> There was very little variation in mean pH by sampling month.

> The highest mean pH value was recorded in May and lowest mean pH value was recorded in January.

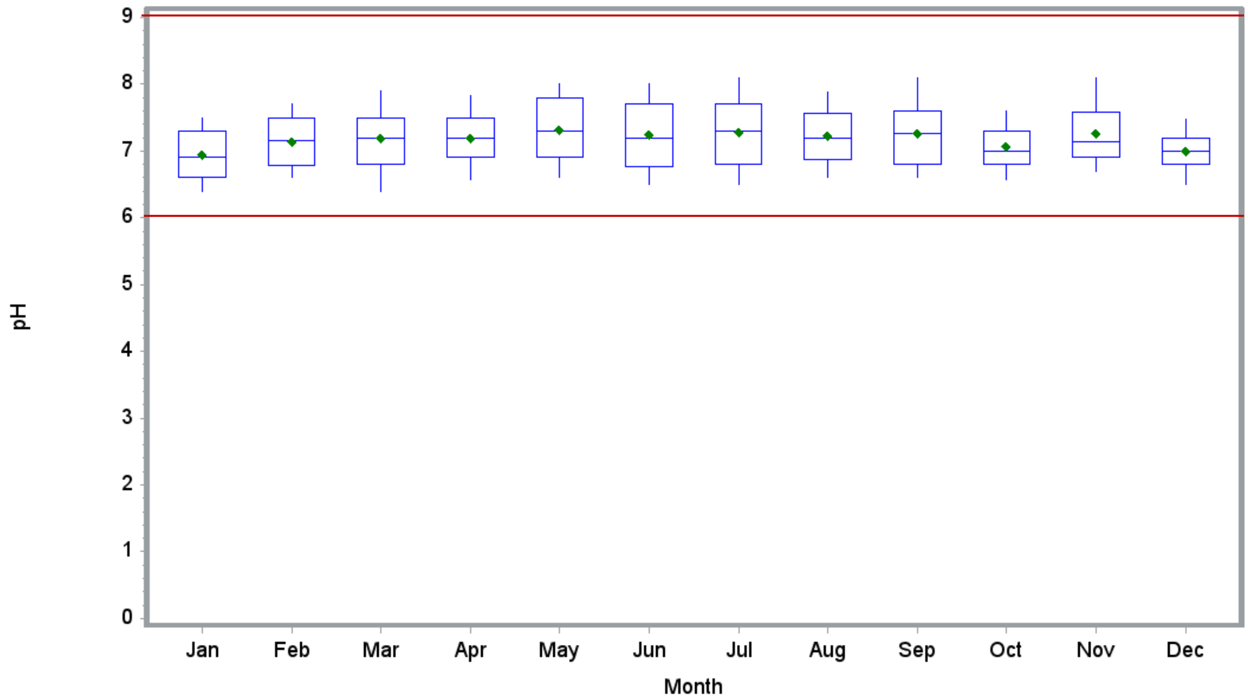



**Figure 3-58 pH Lower Lake Samples Categorized by Month**

**Table 3-63 pH Lower Lake Samples Categorized by Month**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 180 | 5.65 | 6.40 | 6.60 | 6.94 | 6.90 | 7.30 | 7.50 | 7.90 |
| Feb | 204 | 6.20 | 6.60 | 6.79 | 7.15 | 7.17 | 7.50 | 7.70 | 9.51 |
| Mar | 305 | 5.83 | 6.40 | 6.80 | 7.19 | 7.20 | 7.50 | 7.90 | 9.13 |
| Apr | 318 | 5.90 | 6.58 | 6.90 | 7.19 | 7.20 | 7.50 | 7.83 | 8.66 |
| May | 338 | 6.05 | 6.60 | 6.90 | 7.32 | 7.30 | 7.80 | 8.00 | 8.49 |
| Jun | 376 | 6.10 | 6.50 | 6.76 | 7.24 | 7.20 | 7.70 | 8.00 | 8.82 |
| Jul | 365 | 5.69 | 6.50 | 6.80 | 7.28 | 7.30 | 7.70 | 8.10 | 8.72 |
| Aug | 432 | 5.97 | 6.60 | 6.87 | 7.22 | 7.20 | 7.57 | 7.89 | 9.04 |
| Sep | 285 | 5.83 | 6.60 | 6.80 | 7.27 | 7.26 | 7.60 | 8.10 | 8.79 |
| Oct | 248 | 3.69 | 6.58 | 6.80 | 7.07 | 7.00 | 7.30 | 7.60 | 9.00 |
| Nov | 229 | 6.00 | 6.70 | 6.90 | 7.26 | 7.13 | 7.58 | 8.10 | 8.40 |
| Dec | 202 | 5.79 | 6.50 | 6.80 | 7.00 | 7.00 | 7.20 | 7.47 | 9.85 |

### *pH Lower Lake Samples Categorized by Sampling Organization*

> Mean and median pH recorded by each organization were similar, with highest mean and median pH values recorded by the Wake County and NCSU-CAAE and lowest mean and median pH recorded by USGS.

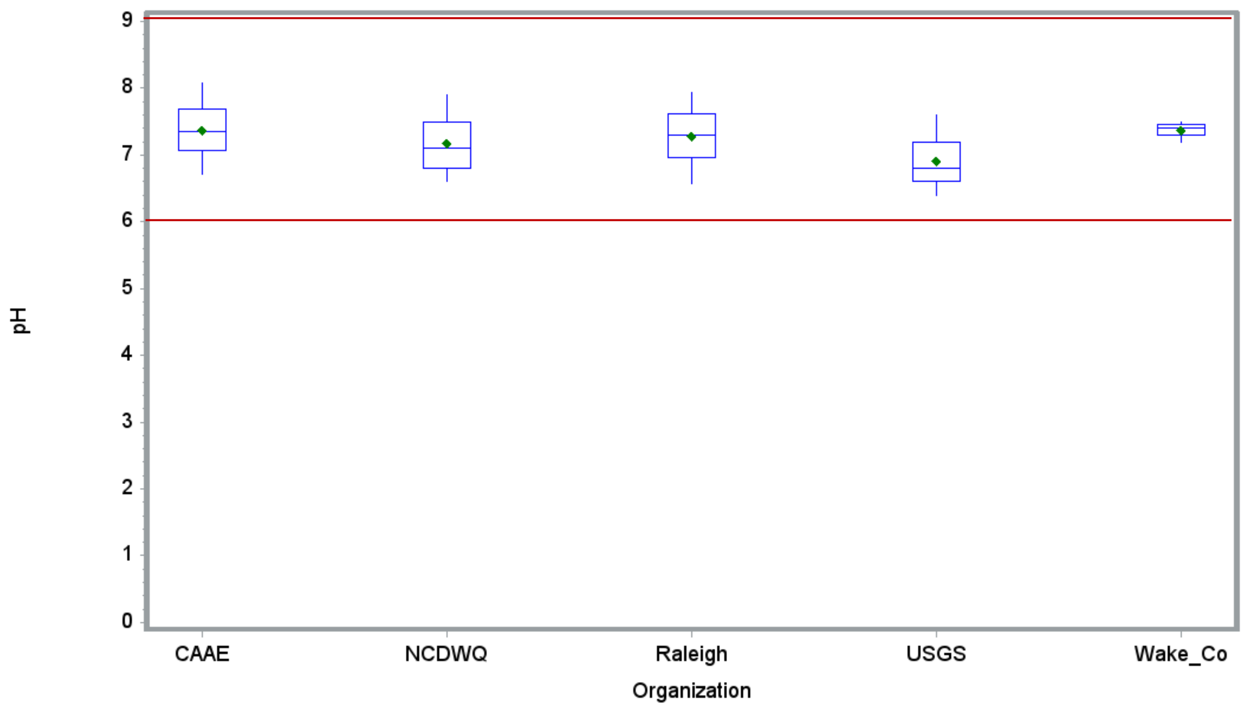



**Figure 3-59 pH Lower Lake Samples Categorized by Sampling Organization**

**Table 3-64 pH Lower Lake Samples Categorized by Sampling Organization**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 69 | 6.45 | 6.72 | 7.07 | 7.37 | 7.36 | 7.69 | 8.07 | 8.72 |
| NCDWQ | 1953 | 6.00 | 6.60 | 6.80 | 7.17 | 7.10 | 7.50 | 7.90 | 8.50 |
| Raleigh | 1257 | 3.69 | 6.58 | 6.96 | 7.28 | 7.29 | 7.61 | 7.94 | 9.85 |
| USGS | 195 | 5.90 | 6.40 | 6.60 | 6.91 | 6.80 | 7.20 | 7.60 | 8.30 |
| Wake_Co | 8 | 7.20 | 7.20 | 7.30 | 7.38 | 7.40 | 7.45 | 7.50 | 7.50 |

### *pH Lower Lake Samples Categorized by Method*

> By method, the unknown category returned the highest mean and median pH values and the USGS I-2587-85 category returned the lowest mean and median pH values.

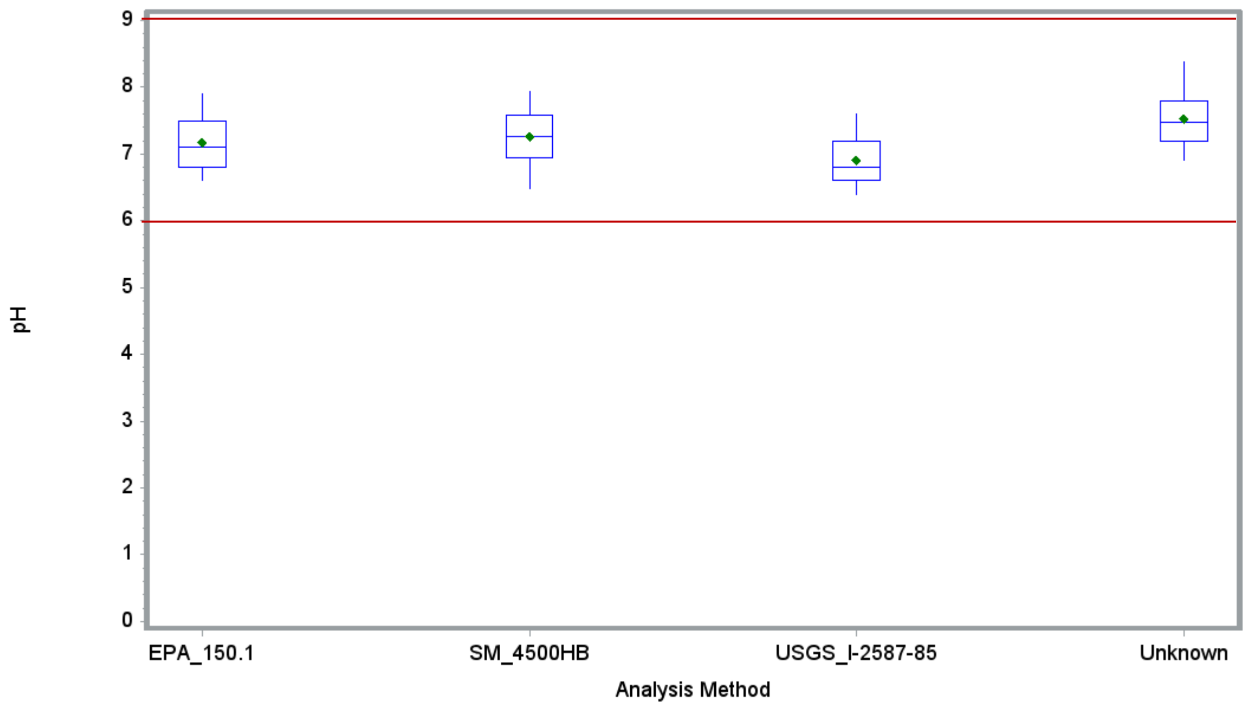



**Figure 3-60 pH Lower Lake Samples Categorized by Analysis Method**

**Table 3-65 pH Lower Lake Samples Categorized by Analysis Method**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_150.1 | 1953 | 6.00 | 6.60 | 6.80 | 7.17 | 7.10 | 7.50 | 7.90 | 8.50 |
| SM_4500HB | 1176 | 3.69 | 6.49 | 6.95 | 7.25 | 7.26 | 7.59 | 7.93 | 9.85 |
| USGS_I-2587-85 | 195 | 5.90 | 6.40 | 6.60 | 6.91 | 6.80 | 7.20 | 7.60 | 8.30 |
| Unknown | 158 | 6.60 | 6.90 | 7.20 | 7.52 | 7.47 | 7.80 | 8.38 | 9.04 |

## 3.9 Conductivity

Seven organizations measured conductivity as part of their water quality sampling effort. Conductivity data was collected in-situ or in the laboratory.

For those organizations that provided method, the following were used:

> Specific conductance, *u*mhos at 25° C using conductivity meter (EPA 120.1)

> Standard method conductivity (SM 2510B)

> Specific conductance, electrometric, Wheatstone bridge (USGS I-2781-85)

> Conductivity using portable instrument (Oakton ECTestr, TDSTestr)

Appendix E provides detailed descriptions of these methods.

Table 3-66 describes the organizations and analysis methods used to measure conductivity and includes the number of samples, date range, and limits. Several organizations did not report the method used to measure conductivity for some, or all of, the data they provided. In these cases, the analysis method is listed as “Not Provided”. The majority of the conductivity data has been collected by NCDWQ using method EPA_120.1. The various limits for conductivity are listed as not applicable (NA) because ambient conditions would not exceed the limits of the equipment used. Conductivity is presented to one decimal place based on reported data.

**Table 3-66 Summary of Analysis Methods for the Conductivity Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit | Reporting Limit | Practical Quanti-fication Limit | Range of Limit Specified with Results |
|---|---|---|---|---|---|---|---|---|
| Durham_Ci | Not Provided | 04/01/2002 | 04/30/2012 | 1,236 | NA | NA | NA | NA |
| Durham_Ci | Various[1] | 01/10/2005 | 12/07/2011 | 890 | NA | NA | NA | NA |
| NCDWQ | EPA_120.1 | 06/07/2000 | 01/10/2012 | 4,312 | NA | NA | NA | NA |
| Orange_Co | EPA 120.1 | 04/09/2010 | 03/25/2011 | 182 | NA | NA | NA | NA |
| Raleigh | Not Provided | 01/13/2009 | 03/05/2012 | 142 | NA | NA | NA | NA |
| Raleigh | SM_2510B | 02/07/2000 | 12/30/2011 | 788 | NA | NA | NA | NA |
| SGWASA | Not Provided | 01/04/2005 | 12/27/2011 | 1,428 | NA | NA | NA | NA |
| USGS | I-2781-85 | 02/19/1999 | 09/30/2010 | 114 | NA | NA | NA | NA |
| USGS | Not Provided | 01/15/1999 | 11/04/2011 | 1,028 | NA | NA | NA | NA |
| Wake_Co | Not Provided | 07/29/2008 | 10/28/2009 | 160 | NA | NA | NA | NA |

[1] Conductivity measured by either the Oakton ECTestr or the TDSTestr. Methods were not unique to the organization/dataset.

### 3.9.2 Tributary Samples

Five organizations collected conductivity data in the tributaries of Falls Lake from 1999 to present. Highest mean and median conductivity were recorded by the City of Durham and SGWASA. Lowest mean and median conductivity were recorded by Orange County and USGS. By location, mean and median conductivity levels recorded in the Ellerbe Creek catchment exceeded those recorded in all other catchments. Lowest mean and median conductivity levels were recorded in the Flat River and Horse/New Light Creek catchments. Highest conductivity measurements were recorded in 2012, 2011 and 2007. Summary statistics and box plots are provided below.

***Conductivity Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Conductivity was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.

> By location, highest mean and median conductivity levels were recorded in Ellerbe Creek and Knap of Reeds Creek overall.

> By section, highest mean conductivity levels were measured in the 0 to 2 mile segments of Ellerbe Creek and Knap of Reeds Creek and the 2 to 10 mile segments of Ellerbe Creek and Lick Creek.

> Lowest mean and median conductivity levels were recorded in the Flat River and Horse/New Light Creek catchments overall.

- By section, lowest conductivity was measured in the 0 to 2 mile and 2 to 10 mile segments Flat River and the 0 to 2 mile segment of Horse/New Light Creek.
- Variability in measurements increased with higher conductivity levels.

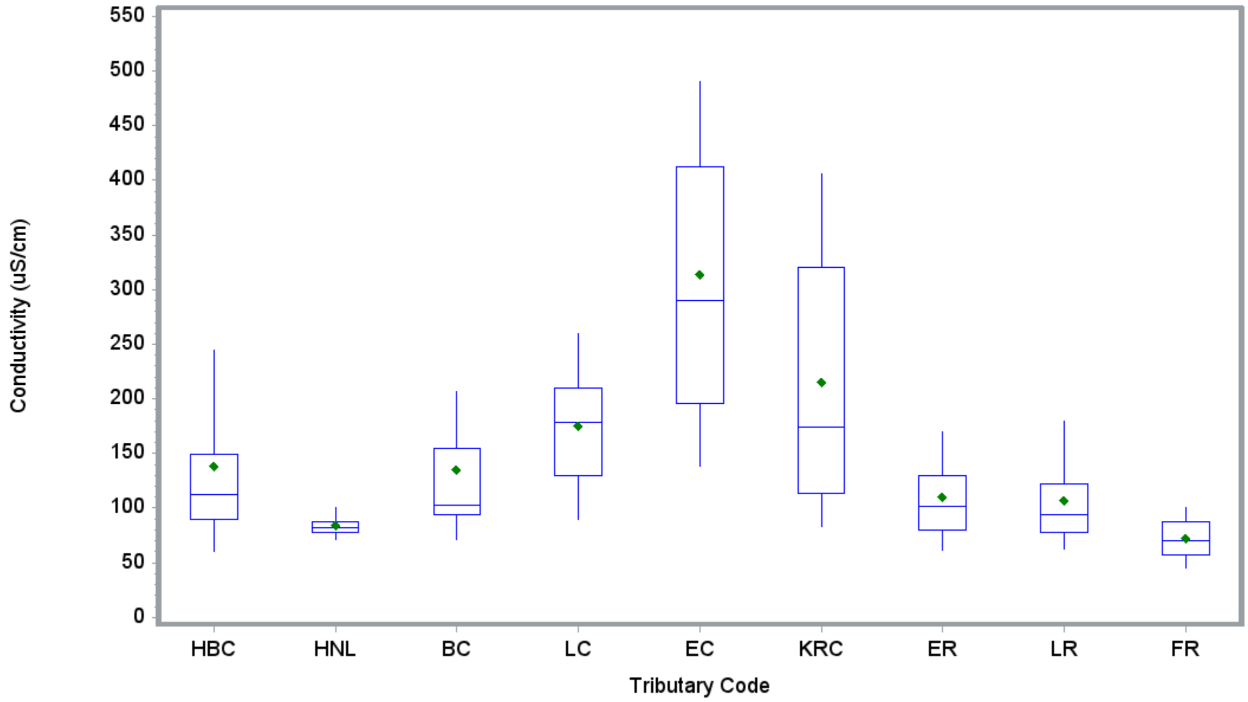



**Figure 3-61 Conductivity Tributary Samples Categorized by Subwatershed**

**Table 3-67 Conductivity Tributary Samples Categorized by Subwatershed (in µS/cm)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 83 | 29.5 | 60.0 | 90.0 | 138.3 | 112.0 | 149.0 | 245.0 | 503.0 |
| HNL | 53 | 60.0 | 71.0 | 78.0 | 83.9 | 82.0 | 88.0 | 100.0 | 100.0 |
| BC | 60 | 57.0 | 71.0 | 93.5 | 134.9 | 102.5 | 155.0 | 207.0 | 417.0 |
| LC | 166 | 40.0 | 90.0 | 130.0 | 174.8 | 178.6 | 210.0 | 260.0 | 410.0 |
| EC | 1066 | 53.0 | 138.0 | 196.0 | 313.4 | 290.0 | 412.0 | 490.0 | 1780.0 |
| KRC | 1439 | 19.8 | 82.8 | 113.0 | 215.3 | 173.8 | 320.2 | 406.4 | 1118.8 |
| ER | 513 | 1.2 | 62.0 | 80.0 | 110.0 | 102.0 | 130.0 | 170.0 | 400.0 |
| LR | 468 | 8.2 | 63.0 | 78.0 | 107.4 | 94.1 | 122.5 | 180.0 | 255.0 |
| FR | 149 | 25.0 | 45.0 | 57.0 | 71.9 | 70.0 | 88.0 | 100.0 | 140.0 |

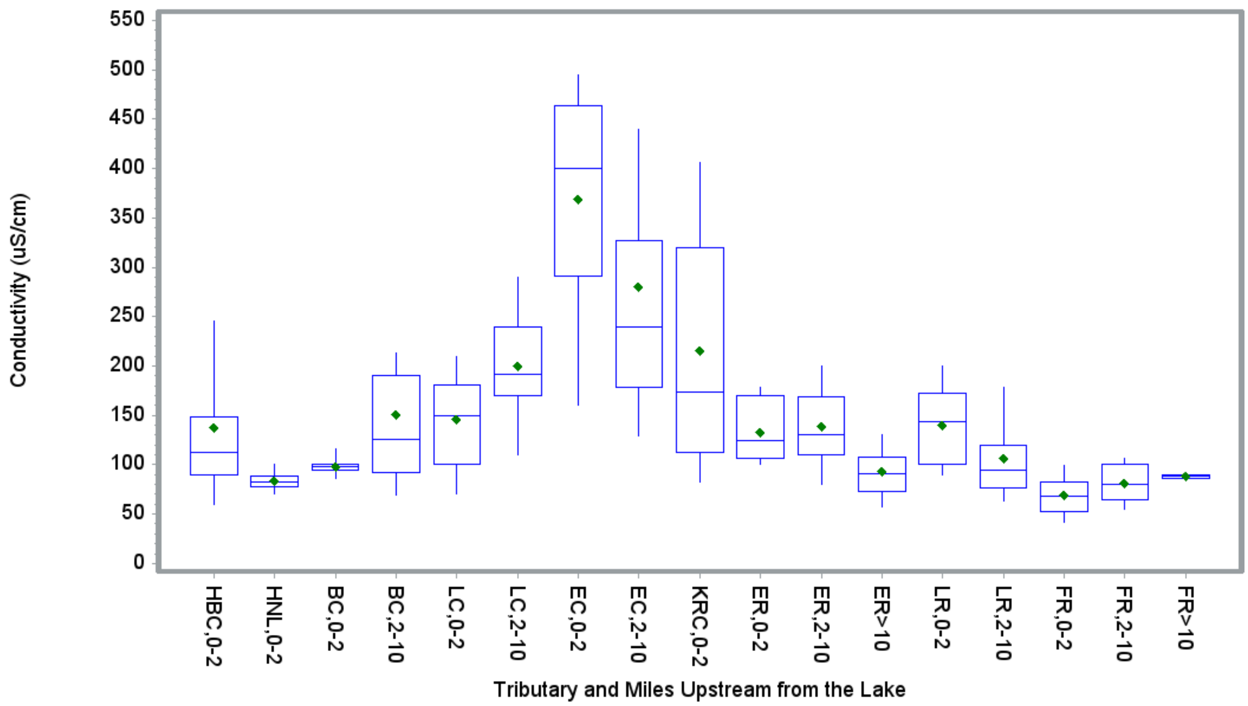



**Figure 3-62 Conductivity Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-68 Conductivity Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in µS/cm)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 83 | 29.5 | 60.0 | 90.0 | 138.3 | 112.0 | 149.0 | 245.0 | 503.0 |
| HNL,0-2 | 53 | 60.0 | 71.0 | 78.0 | 83.9 | 82.0 | 88.0 | 100.0 | 100.0 |
| BC,0-2 | 18 | 65.0 | 86.0 | 94.0 | 98.1 | 98.5 | 101.0 | 116.0 | 118.0 |
| BC,2-10 | 42 | 57.0 | 69.0 | 92.0 | 150.6 | 126.0 | 190.0 | 213.0 | 417.0 |
| LC,0-2 | 77 | 40.0 | 70.0 | 100.0 | 145.9 | 150.0 | 181.0 | 210.0 | 380.0 |
| LC,2-10 | 89 | 80.0 | 110.0 | 170.0 | 199.8 | 192.1 | 240.0 | 290.0 | 410.0 |
| EC,0-2 | 400 | 53.0 | 160.0 | 290.5 | 368.9 | 400.0 | 463.5 | 495.0 | 1150.0 |
| EC,2-10 | 666 | 61.0 | 129.7 | 179.0 | 280.0 | 240.0 | 327.0 | 439.7 | 1780.0 |
| KRC,0-2 | 1439 | 19.8 | 82.8 | 113.0 | 215.3 | 173.8 | 320.2 | 406.4 | 1118.8 |
| ER,0-2 | 31 | 70.0 | 100.0 | 106.0 | 132.3 | 124.0 | 170.0 | 178.0 | 208.0 |
| ER,2-10 | 160 | 2.6 | 80.0 | 110.0 | 139.4 | 130.0 | 168.6 | 200.0 | 400.0 |
| ER>10 | 322 | 1.2 | 57.2 | 72.5 | 93.2 | 90.4 | 108.0 | 130.9 | 253.1 |
| LR,0-2 | 18 | 87.0 | 90.0 | 100.0 | 139.8 | 144.0 | 172.0 | 200.0 | 200.0 |
| LR,2-10 | 450 | 8.2 | 63.0 | 77.0 | 106.1 | 94.0 | 120.0 | 178.5 | 255.0 |
| FR,0-2 | 117 | 25.0 | 42.0 | 53.0 | 69.2 | 68.0 | 82.0 | 99.0 | 140.0 |
| FR,2-10 | 30 | 47.0 | 55.0 | 65.0 | 81.0 | 80.0 | 100.0 | 107.0 | 110.0 |

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| FR>10 | 2 | 86.0 | 86.0 | 86.0 | 88.0 | 88.0 | 90.0 | 90.0 | 90.0 |

***Conductivity in Tributary Samples Categorized by Depth***

> Only surface level conductivity samples were collected in the tributaries.

***Conductivity in Tributary Samples Categorized by Year***

> By year, highest mean and median conductivity were recorded in 2012; however the 2012 dataset is a partial dataset, and only represents a small portion of the year. The next highest mean and median conductivity levels were recorded in 2011 and 2007.

> The lowest mean and median conductivity were recorded in 2003, followed by 1999.

> Conductivity concentrations appear to be increasing over time, however significantly more samples have been collected since 2006 than in earlier years.

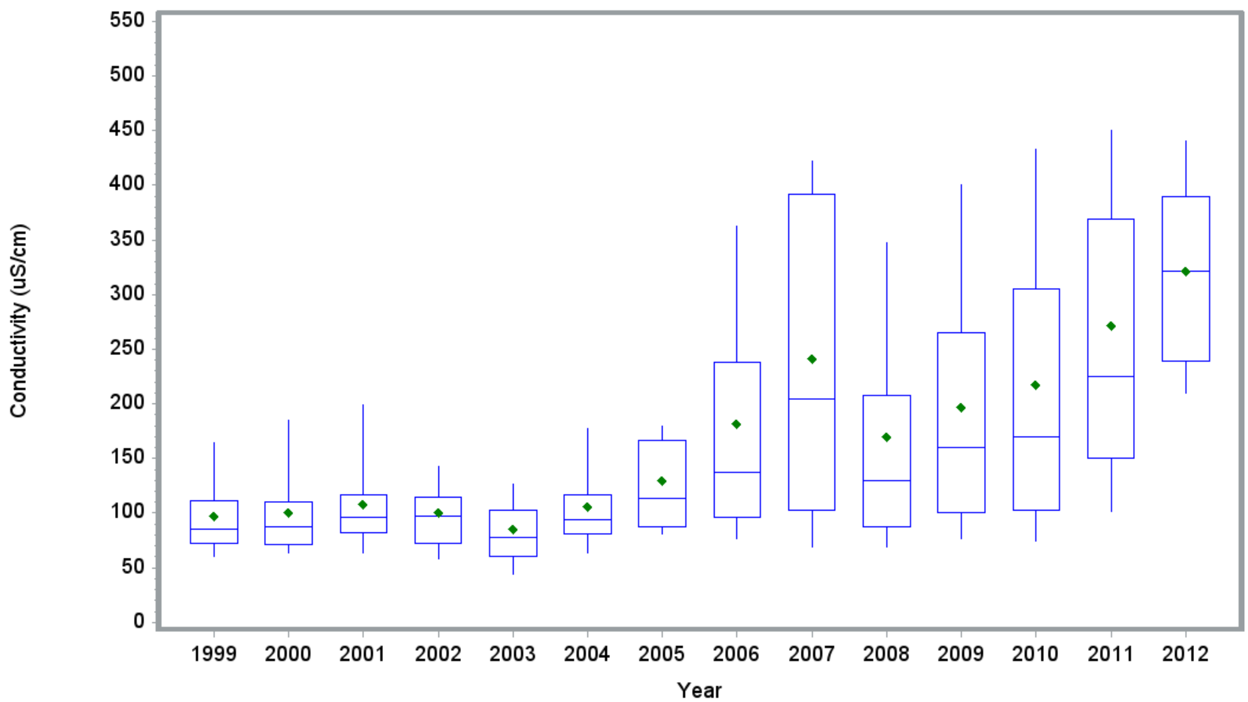



**Figure 3-63 Conductivity Tributary Samples Categorized by Year**

**Table 3-69 Conductivity Tributary Samples Categorized by Year (in µS/cm)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 66 | 30.0 | 60.0 | 72.0 | 97.7 | 85.5 | 111.0 | 164.0 | 227.0 |
| 2000 | 64 | 39.0 | 64.0 | 71.0 | 100.5 | 87.5 | 110.5 | 185.0 | 248.0 |
| 2001 | 56 | 42.0 | 64.0 | 82.5 | 108.6 | 96.0 | 117.0 | 199.0 | 228.0 |
| 2002 | 54 | 40.0 | 58.0 | 72.0 | 100.0 | 97.5 | 115.0 | 143.0 | 221.0 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2003 | 73 | 25.0 | 44.0 | 60.0 | 85.4 | 78.0 | 103.0 | 127.0 | 242.0 |
| 2004 | 41 | 49.0 | 64.0 | 81.0 | 106.0 | 94.0 | 117.0 | 177.0 | 244.0 |
| 2005 | 154 | 59.0 | 81.0 | 87.0 | 129.8 | 113.0 | 167.0 | 180.0 | 417.0 |
| 2006 | 280 | 40.0 | 76.7 | 96.0 | 181.5 | 137.5 | 238.0 | 362.3 | 500.9 |
| 2007 | 273 | 40.0 | 68.7 | 103.0 | 240.8 | 204.5 | 391.9 | 422.4 | 488.0 |
| 2008 | 397 | 31.0 | 69.0 | 88.0 | 169.6 | 130.0 | 208.0 | 347.6 | 1118.8 |
| 2009 | 851 | 8.2 | 77.0 | 100.0 | 196.7 | 160.0 | 265.0 | 400.0 | 660.0 |
| 2010 | 965 | 2.6 | 75.0 | 103.1 | 217.3 | 170.0 | 305.0 | 433.0 | 1104.0 |
| 2011 | 687 | 1.2 | 101.6 | 150.3 | 271.9 | 225.0 | 369.4 | 450.8 | 1780.0 |
| 2012 | 36 | 171.0 | 210.0 | 239.0 | 321.5 | 321.0 | 390.0 | 441.0 | 507.0 |

***Conductivity in Tributary Samples Categorized by Month***

> By month, the highest mean conductivity measurements were recorded in August, followed by September and January.

> The lowest mean conductivity was recorded in April and March.

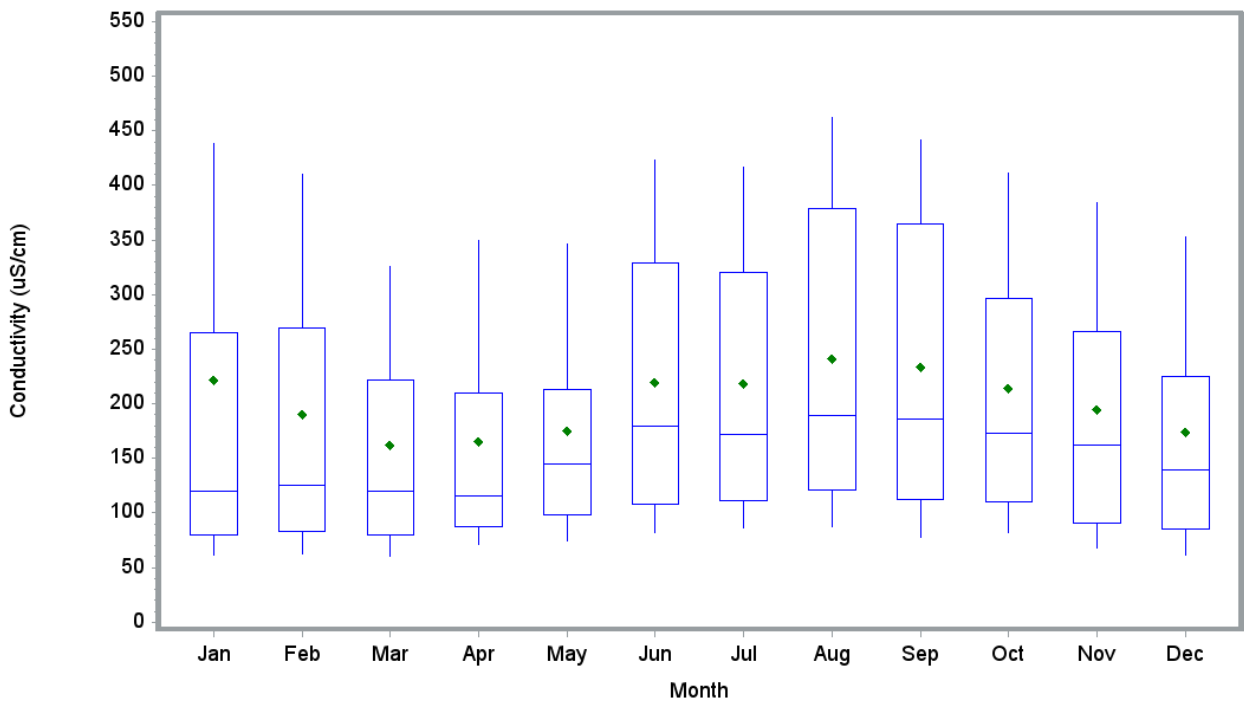



**Figure 3-64 Conductivity Tributary Samples Categorized by Month**

**Table 3-70 Conductivity Tributary Samples Categorized by Month (in µS/cm)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 241 | 1.2 | 61.0 | 80.0 | 222.1 | 120.0 | 265.5 | 438.0 | 1780.0 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Feb | 266 | 8.2 | 62.9 | 83.0 | 190.8 | 124.9 | 269.5 | 410.0 | 856.0 |
| Mar | 268 | 25.0 | 60.0 | 80.0 | 162.4 | 120.0 | 221.4 | 325.7 | 750.0 |
| Apr | 368 | 39.0 | 71.4 | 87.4 | 165.7 | 115.3 | 210.0 | 350.0 | 786.0 |
| May | 343 | 19.8 | 74.0 | 98.0 | 174.7 | 145.2 | 212.7 | 346.7 | 630.0 |
| Jun | 433 | 50.0 | 82.5 | 108.0 | 219.8 | 180.0 | 329.0 | 423.0 | 653.0 |
| Jul | 400 | 28.2 | 86.2 | 111.7 | 218.7 | 172.4 | 320.1 | 416.7 | 1118.8 |
| Aug | 396 | 29.5 | 87.0 | 121.2 | 241.8 | 189.8 | 378.4 | 462.0 | 620.0 |
| Sep | 403 | 30.0 | 77.7 | 112.8 | 234.2 | 186.0 | 365.0 | 441.6 | 660.0 |
| Oct | 372 | 40.0 | 82.0 | 110.0 | 214.1 | 173.4 | 296.5 | 410.9 | 750.0 |
| Nov | 240 | 12.0 | 68.5 | 90.6 | 194.4 | 161.9 | 266.0 | 384.3 | 640.0 |
| Dec | 267 | 2.6 | 61.0 | 85.0 | 174.1 | 140.0 | 224.8 | 353.0 | 1104.0 |

***Conductivity in Tributary Samples Categorized by Sampling Organization***

> Highest mean and median conductivity and variability were recorded by the City of Durham and SGWASA.

> Lowest mean and median conductivity were recorded by Orange County and USGS.

> Variability increases with higher sample number and higher conductivity measurements.

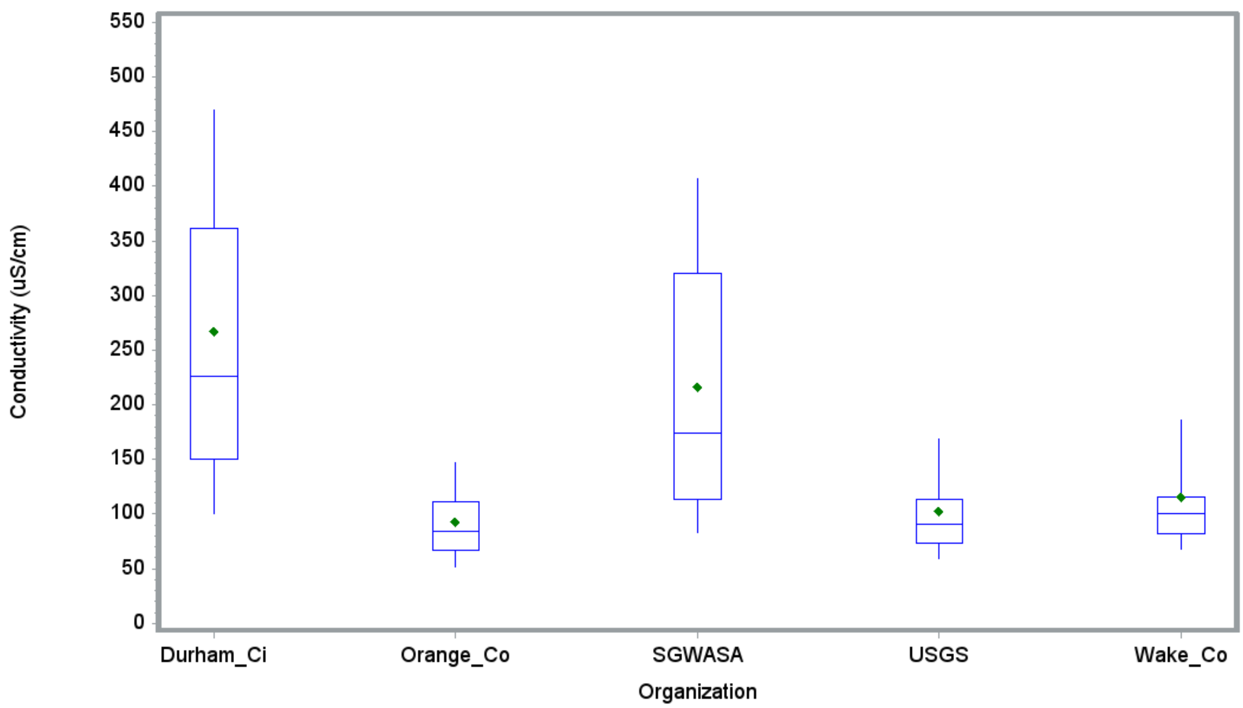


**Figure 3-65 Conductivity Tributary Samples Categorized by Sampling Organization**

**Table 3-71 Conductivity Tributary Samples Categorized by Sampling Organization (in μS/cm)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 1472 | 2.6 | 100.0 | 150.0 | 267.1 | 226.0 | 361.2 | 470.0 | 1780.0 |
| Orange_Co | 182 | 1.2 | 52.2 | 67.3 | 93.0 | 84.0 | 111.4 | 147.0 | 253.1 |
| SGWASA | 1428 | 19.8 | 82.9 | 114.0 | 216.0 | 174.3 | 320.6 | 407.0 | 1118.8 |
| USGS | 763 | 763 | 12.0 | 59.0 | 73.0 | 102.5 | 91.0 | 113.0 | 169.0 |
| Wake_Co | 152 | 29.5 | 68.0 | 82.0 | 115.5 | 100.0 | 116.0 | 186.0 | 503.0 |

### *Conductivity in Tributary Samples Categorized by Method*

Of the four method categories, highest mean and median conductivity was reported for the "Various" method category (indicating multiple methods were reported for records in the data set) and lowest mean conductivity was reported for the EPA 120.1 method.

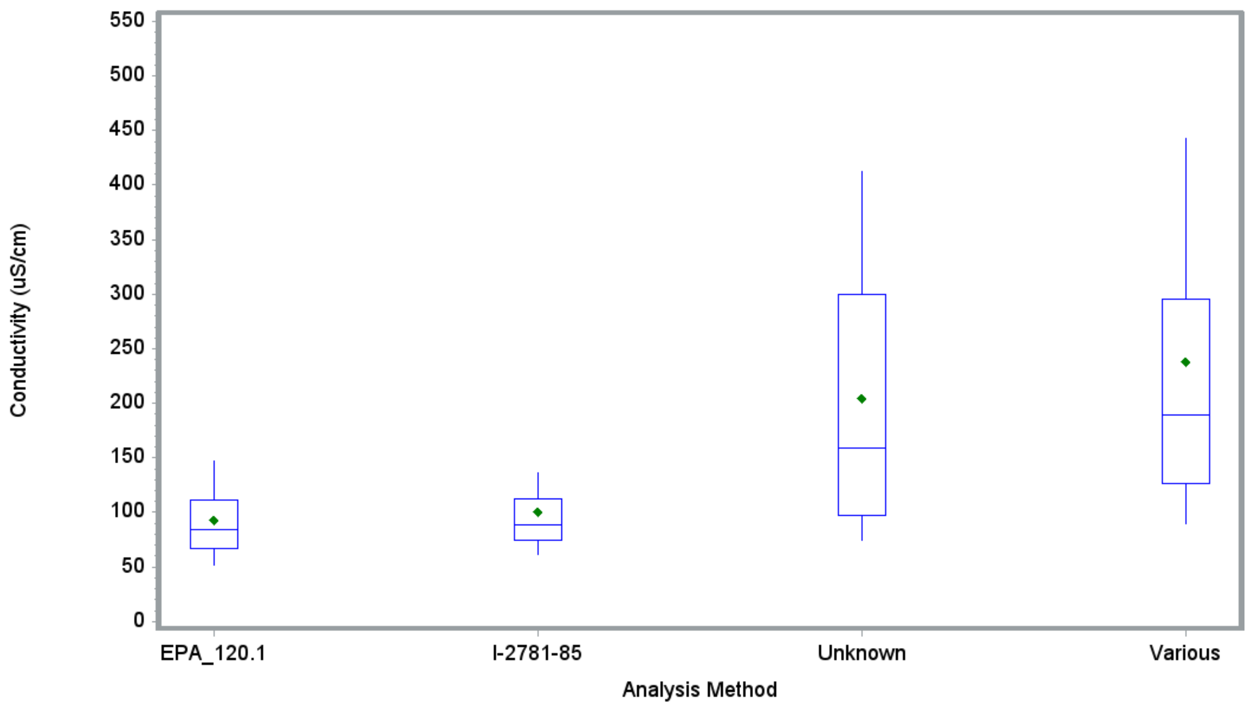



**Figure 3-66 Conductivity Tributary Samples Categorized by Analysis Method**

**Table 3-72 Conductivity Tributary Samples Categorized by Analysis Method (in μS/cm)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_120.1 | 182 | 1.2 | 52.2 | 67.3 | 93.0 | 84.0 | 111.4 | 147.0 | 253.1 |
| I-2781-85 | 113 | 42.0 | 62.0 | 75.0 | 100.7 | 89.0 | 112.0 | 136.0 | 417.0 |
| Unknown | 2812 | 12.0 | 74.1 | 97.0 | 204.3 | 159.3 | 300.1 | 412.7 | 1118.8 |
| Various | 890 | 2.6 | 90.0 | 126.3 | 237.5 | 189.7 | 295.0 | 442.8 | 1780.0 |

### 3.9.3 Upper Lake Samples

Three organizations collected conductivity data in Upper Falls Lake from 2000 to present. During this time period, highest mean conductivity was recorded in 2002 and lowest mean conductivity was recorded 2001. By organization, highest mean conductivity was recorded by the City of Durham. By location, the highest mean conductivity was recorded > 21 miles from the dam and lowest mean conductivity was recorded 13 to 18 miles from the dam. Summary statistics and box plots are provided below.

***Conductivity Upper Lake Samples Categorized by Catchment ID***

> Conductivity was recorded in only one catchment, Upper Lake.

***Conductivity Upper Lake Samples Categorized by Miles Upstream from Dam***

> By location, highest mean and median conductivity were recorded greater than 21 miles from the dam and lowest mean and median conductivity were recorded 13 to 18 miles from the dam.

> Conductivity concentrations tend to increase as distance from the dam increases.

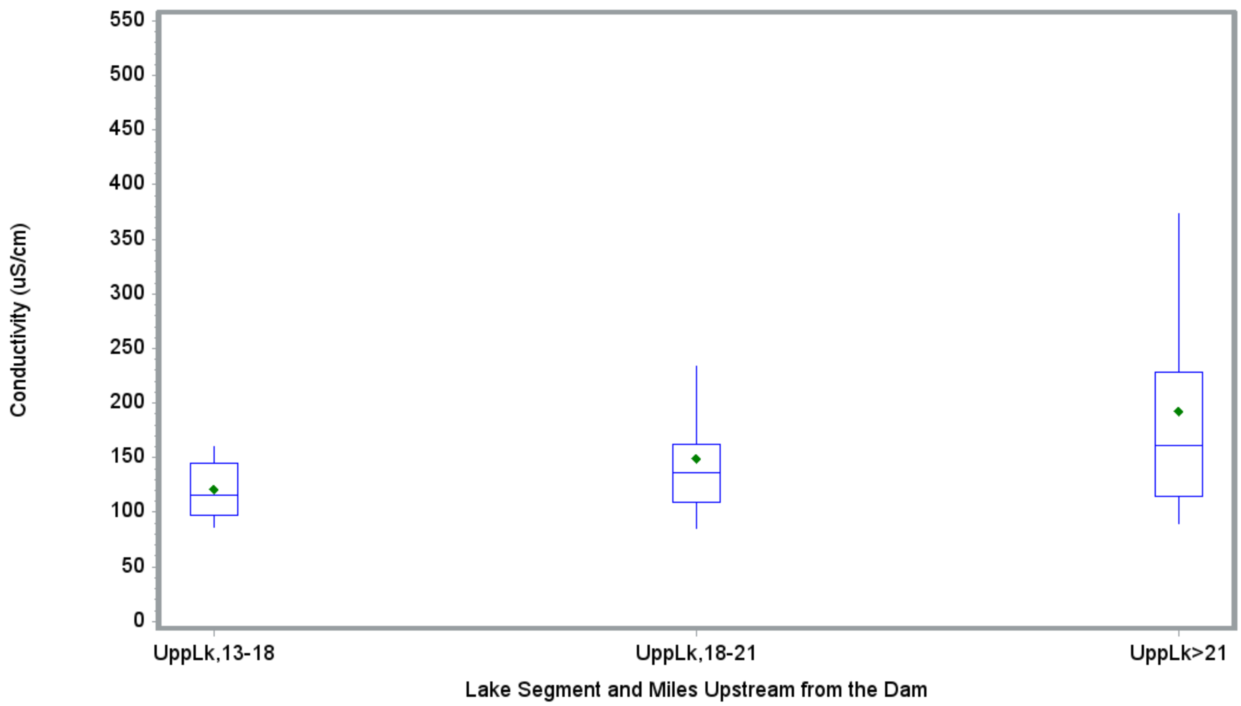



**Figure 3-67 Conductivity Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-73 Conductivity Upper Lake Samples Categorized by Miles Upstream from Dam (in µS/cm)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 1258 | 43.0 | 86.0 | 97.0 | 121.6 | 116.0 | 145.0 | 160.0 | 285.0 |
| UppLk,18-21 | 326 | 60.0 | 85.0 | 109.0 | 149.0 | 136.0 | 162.0 | 234.0 | 438.0 |
| UppLk>21 | 1335 | 40.0 | 90.0 | 115.0 | 192.8 | 161.0 | 228.0 | 373.0 | 910.0 |

### *Conductivity Upper Lake Samples Categorized by Depth*

> By depth, highest mean and median conductivity were recorded at the surface layer.

> Lowest mean conductivity was recorded in the bottom layer; however the sample size for this category was significantly less than for the other two categories.

> Greatest variability in the data was recorded for the surface layer.

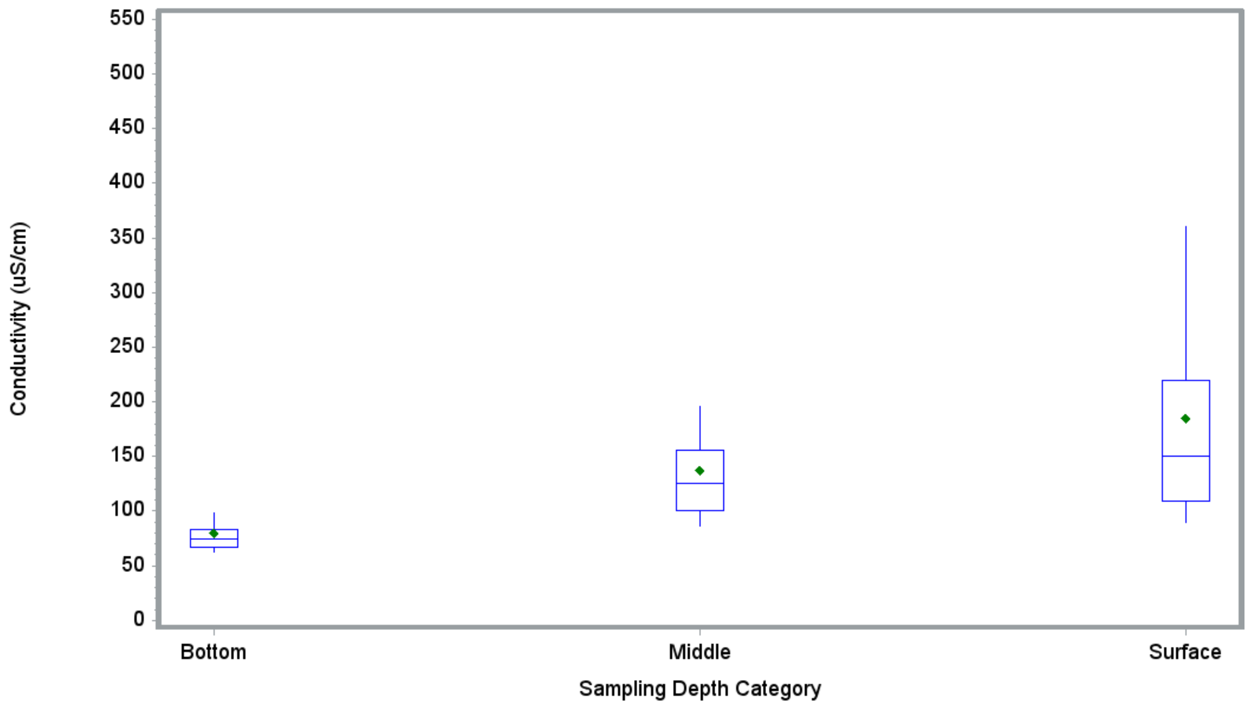



**Figure 3-68 Conductivity Upper Lake Samples Categorized by Depth Category (surface, photic, bottom)**

**Table 3-74 Conductivity Upper Lake Samples Categorized by Depth Category (surface, photic, bottom) (in µS/cm)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 12 | 53.0 | 63.0 | 66.5 | 80.3 | 74.5 | 83.5 | 98.0 | 155.0 |
| Middle | 1664 | 43.0 | 86.0 | 100.0 | 137.0 | 125.0 | 156.0 | 196.0 | 446.0 |
| Surface | 1243 | 40.0 | 90.0 | 109.0 | 185.1 | 150.0 | 220.0 | 365.0 | 910.0 |

### *Conductivity Upper Lake Samples Categorized by Year*

> By year, highest mean conductivity was recorded in 2002, followed by 2004 and 2009.

> The lowest mean conductivity was recorded in 2001, followed by 2000.

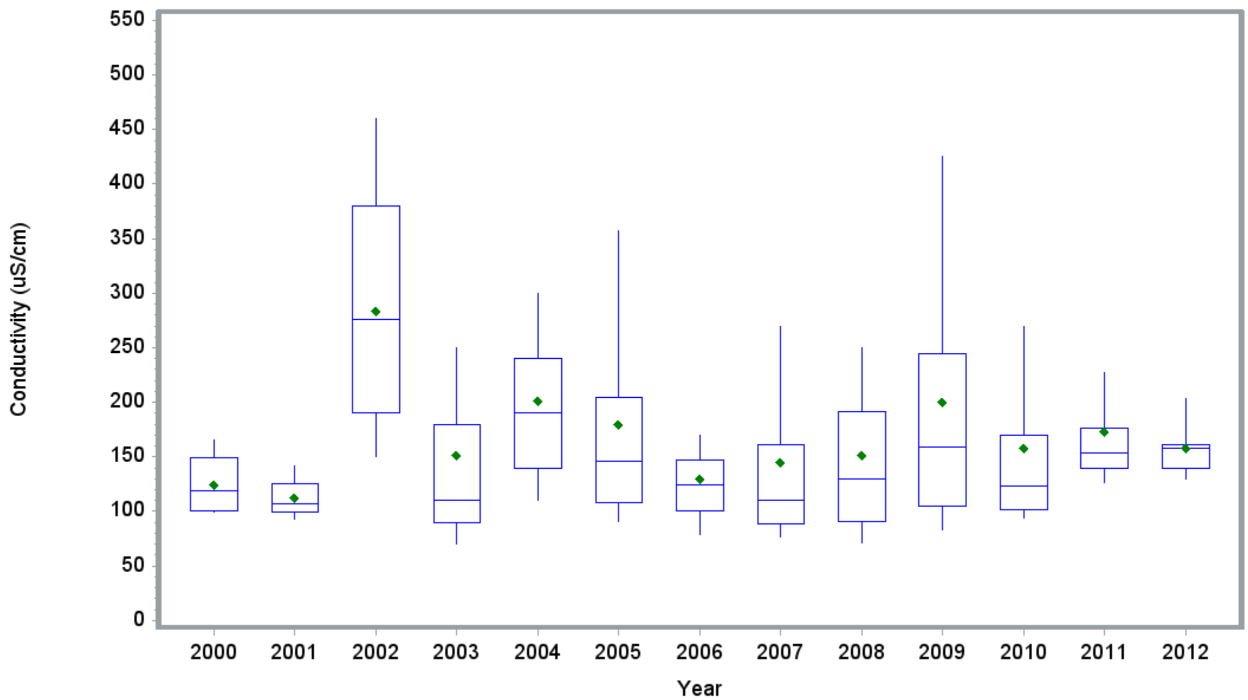



**Figure 3-69 Conductivity Upper Lake Samples Categorized by Year**

**Table 3-75 Conductivity Upper Lake Samples Categorized by Year (in µS/cm)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 54 | 85.0 | 99.0 | 101.0 | 124.2 | 119.0 | 149.0 | 165.0 | 179.0 |
| 2001 | 92 | 72.0 | 93.0 | 99.5 | 112.8 | 106.5 | 125.0 | 142.0 | 174.0 |
| 2002 | 63 | 64.0 | 150.0 | 190.0 | 283.7 | 276.0 | 380.0 | 460.0 | 503.0 |
| 2003 | 62 | 40.0 | 70.0 | 90.0 | 151.5 | 110.0 | 180.0 | 250.0 | 630.0 |
| 2004 | 62 | 70.0 | 110.0 | 140.0 | 201.3 | 190.0 | 240.0 | 300.0 | 910.0 |
| 2005 | 513 | 67.0 | 91.0 | 108.0 | 179.5 | 146.0 | 204.0 | 357.0 | 540.0 |
| 2006 | 684 | 43.0 | 79.0 | 100.0 | 129.5 | 124.0 | 147.0 | 170.0 | 466.0 |
| 2007 | 529 | 59.0 | 77.0 | 89.0 | 144.8 | 110.0 | 161.0 | 270.0 | 500.0 |
| 2008 | 96 | 58.0 | 71.0 | 91.0 | 151.4 | 130.0 | 191.0 | 250.0 | 470.0 |
| 2009 | 100 | 60.0 | 83.0 | 105.0 | 200.6 | 159.5 | 245.0 | 425.0 | 540.0 |
| 2010 | 281 | 66.0 | 94.0 | 102.0 | 157.7 | 123.0 | 170.0 | 270.0 | 560.0 |
| 2011 | 352 | 100.0 | 126.0 | 140.0 | 173.4 | 154.0 | 176.0 | 227.0 | 485.0 |
| 2012 | 31 | 102.0 | 130.0 | 140.0 | 158.4 | 158.0 | 161.0 | 203.0 | 219.0 |

***Conductivity Upper Lake Samples Categorized by Month***

> By month, the highest mean conductivity was recorded in October, followed by September.

> The lowest mean conductivity was recorded in March, followed by February.

> Greatest variability was recorded from July to November.

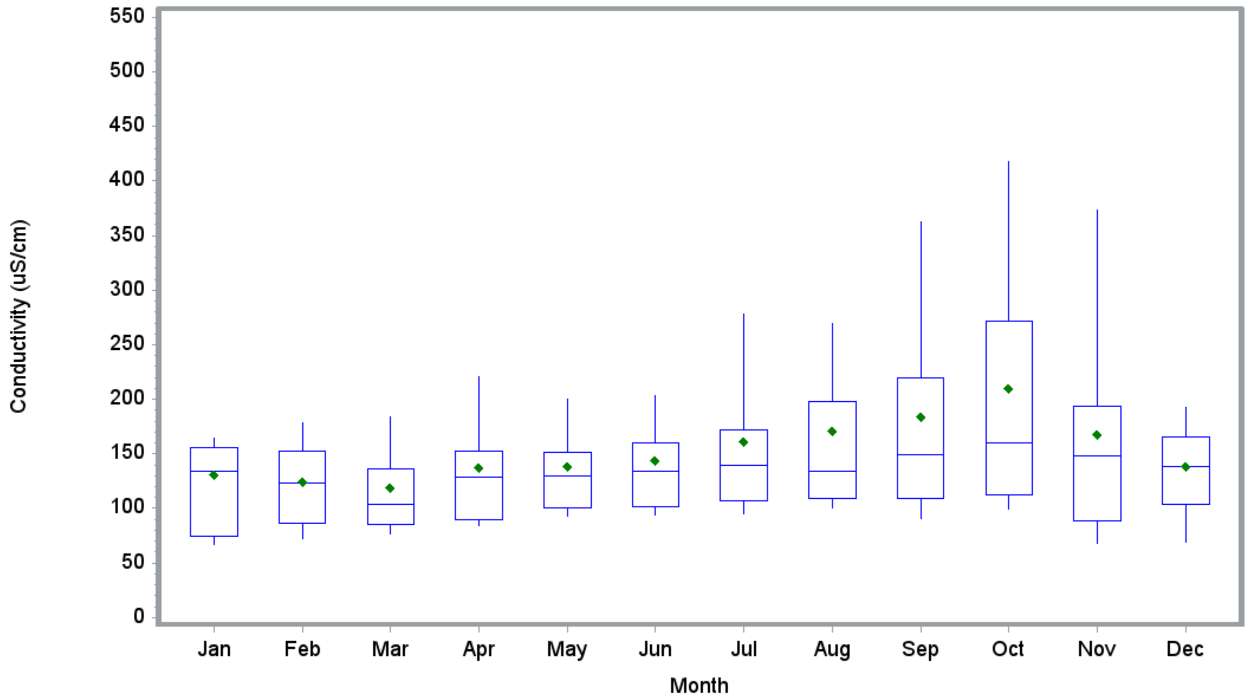



**Figure 3-70 Conductivity Upper Lake Samples Categorized by Month**

**Table 3-76 Conductivity Upper Lake Samples Categorized by Month (in µS/cm)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 106 | 59.0 | 67.0 | 75.0 | 131.1 | 134.0 | 156.0 | 164.0 | 328.0 |
| Feb | 108 | 66.0 | 72.0 | 86.0 | 123.9 | 123.0 | 153.0 | 179.0 | 228.0 |
| Mar | 156 | 67.0 | 77.0 | 85.5 | 118.9 | 104.0 | 136.5 | 184.0 | 290.0 |
| Apr | 290 | 40.0 | 84.0 | 90.0 | 137.3 | 128.5 | 152.0 | 221.0 | 460.0 |
| May | 288 | 60.0 | 93.0 | 100.0 | 138.5 | 130.0 | 151.0 | 200.0 | 400.0 |
| Jun | 351 | 50.0 | 94.0 | 102.0 | 144.3 | 134.0 | 160.0 | 203.0 | 480.0 |
| Jul | 348 | 60.0 | 95.0 | 107.5 | 160.9 | 139.0 | 171.5 | 278.0 | 560.0 |
| Aug | 441 | 70.0 | 101.0 | 109.0 | 171.0 | 134.0 | 198.0 | 270.0 | 910.0 |
| Sep | 300 | 46.0 | 91.0 | 109.5 | 184.0 | 149.0 | 220.0 | 362.5 | 540.0 |
| Oct | 252 | 64.0 | 99.0 | 112.5 | 209.7 | 160.5 | 272.0 | 418.0 | 540.0 |
| Nov | 165 | 43.0 | 68.0 | 89.0 | 167.1 | 148.0 | 194.0 | 373.0 | 510.0 |
| Dec | 114 | 60.0 | 69.0 | 104.0 | 137.9 | 138.5 | 165.0 | 193.0 | 334.0 |

***Conductivity Upper Lake Samples Categorized by Sampling Organization***

> Three organizations recorded conductivity in Upper Lake.

> Highest mean conductivity was recorded by the City of Durham and lowest mean conductivity w recorded by NCDWQ and USGS.

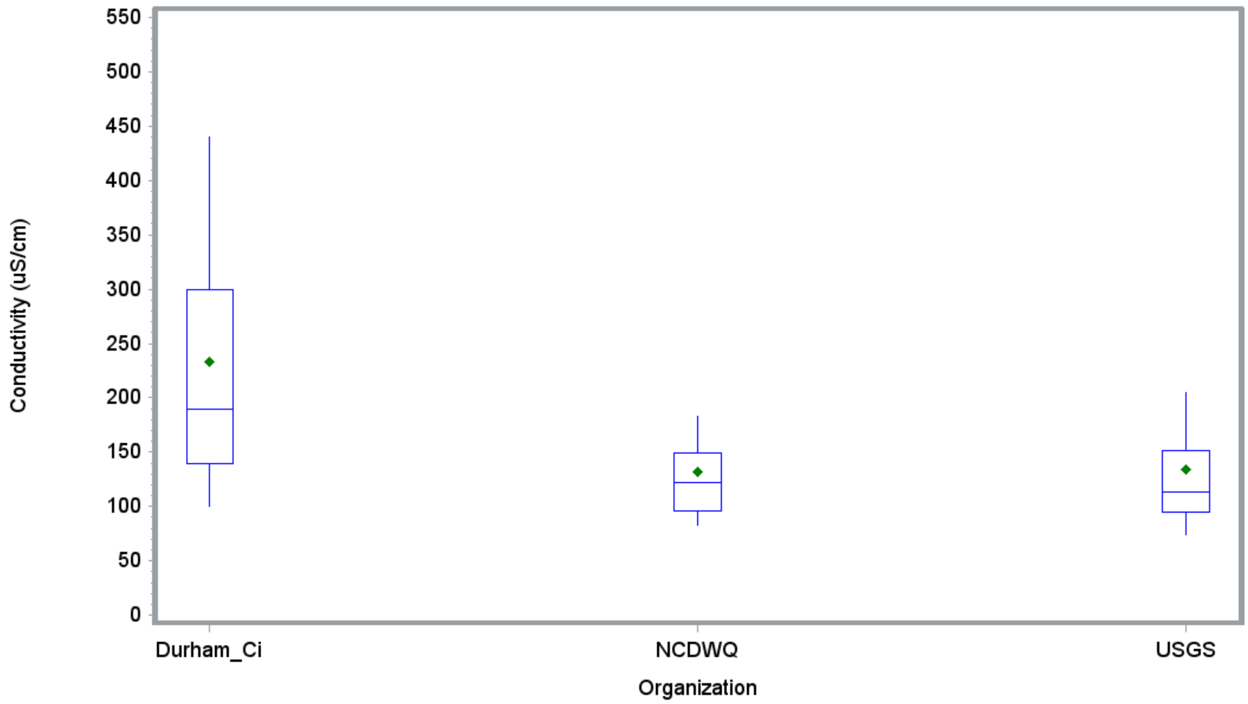



**Figure 3-71 Conductivity Upper Lake Samples Categorized by Sampling Organization**

**Table 3-77 Conductivity Upper Lake Samples Categorized by Sampling Organization (in µS/cm)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 654 | 40.0 | 100.0 | 140.0 | 233.2 | 195.0 | 300.0 | 450.0 | 910.0 |
| NCDWQ | 2082 | 43.0 | 86.0 | 100.0 | 135.2 | 125.0 | 154.0 | 190.0 | 492.0 |
| USGS | 183 | 60.0 | 74.0 | 94.0 | 136.1 | 116.0 | 155.0 | 208.0 | 452.0 |

### *Conductivity Upper Lake Samples Categorized by Method*

> One known and one unknown analysis method were used in upper Falls Lake.

> Mean and median conductivity using EPA 120.1 method were less than the mean and median conductivity of the unknown analysis method category.

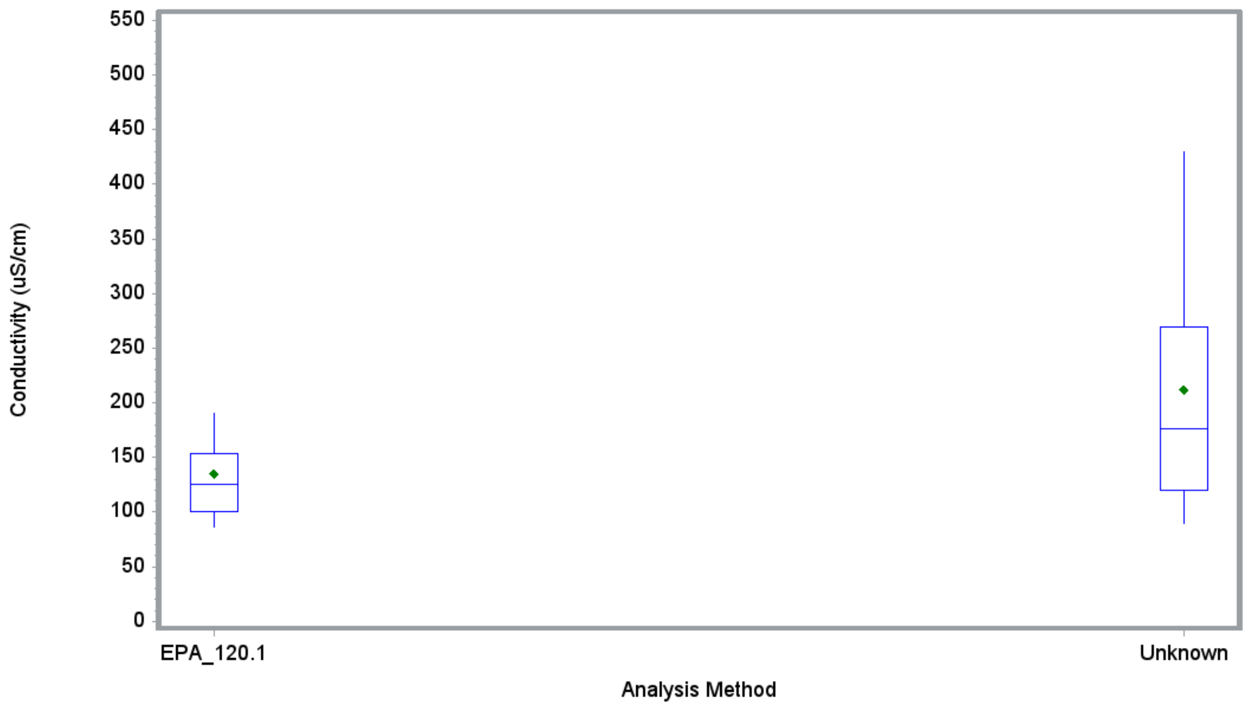



**Figure 3-72 Conductivity Upper Lake Samples Categorized by Analysis Method**

**Table 3-78 Conductivity Upper Lake Samples Categorized by Analysis Method (in µS/cm)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_120.1 | 2082 | 43.0 | 86.0 | 100.0 | 135.2 | 125.0 | 154.0 | 190.0 | 492.0 |
| Unknown | 837 | 40.0 | 90.0 | 120.0 | 212.0 | 176.0 | 270.0 | 430.0 | 910.0 |

### 3.9.4 Lower Lake Samples

Four organizations collected conductivity data in Lower Falls Lake from 2000 to present. Mean and median conductivity measurements were similar for all sampling organizations. By catchment, mean and median conductivity measurements were higher in the lower lake segments than in Beaverdam Impoundment. Highest mean and median measurements were recorded in 2011 and 2012 and lowest levels were measured in 2003. Summary statistics and box plots are provided below.

***Conductivity Lower Lake Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Conductivity levels recorded in all location categories were similar.

> Higher mean conductivity was recorded in the lower lake sections compared with Beaverdam Creek; however, the sampling size for lake segments was significantly greater than the sampling size within the Beaverdam Impoundment.

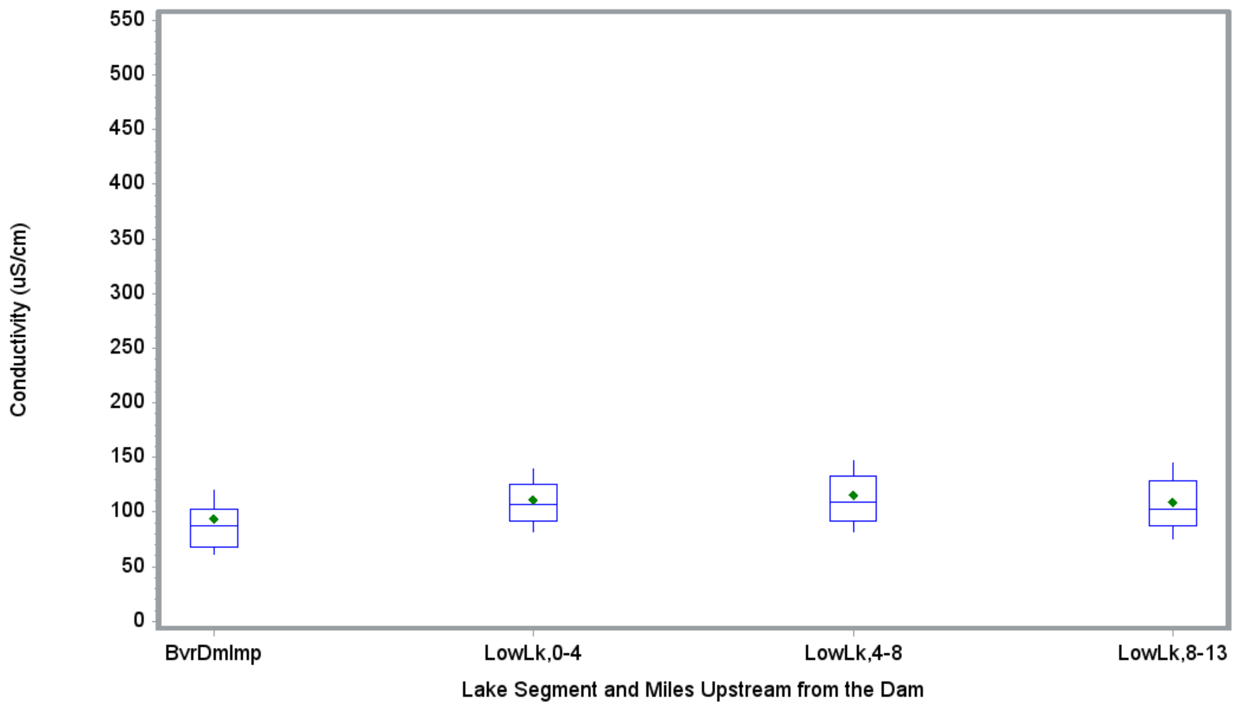



**Figure 3-73 Conductivity Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-79 Conductivity Lower Lake Samples Categorized by Miles Upstream from Dam (in µS/cm)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 123 | 34.3 | 61.6 | 68.0 | 93.7 | 87.2 | 103.0 | 120.0 | 916.0 |
| LowLk,0-4 | 941 | 55.9 | 82.0 | 92.0 | 111.1 | 107.0 | 125.0 | 140.0 | 363.0 |
| LowLk,4-8 | 1760 | 54.0 | 82.0 | 92.0 | 115.7 | 109.0 | 133.0 | 147.0 | 1387.0 |
| LowLk,8-13 | 540 | 52.0 | 76.0 | 88.0 | 108.7 | 103.0 | 129.0 | 145.0 | 280.0 |

***Conductivity Lower Lake Samples Categorized by Depth***

> By depth, highest mean and median conductivity were recorded at the bottom level; however the sample size for this category was significantly less than for the other two categories.

> Mean and median conductivity levels at the middle and surface levels were very similar (note overlap in the IQR), with slightly lower mean and median conductivity recorded at the mid-level sampling depth.

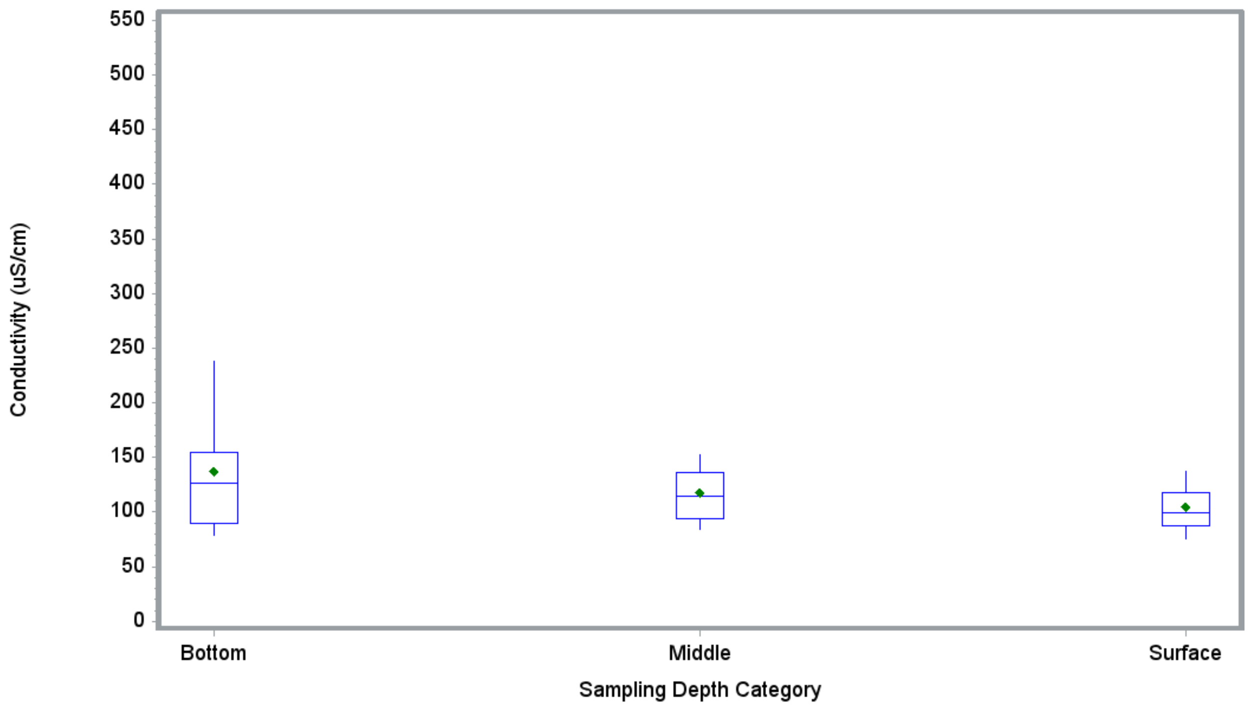



**Figure 3-74 Conductivity Lower Lake Samples Categorized by Depth Category (surface, photic, bottom)**

**Table 3-80 Conductivity Lower Lake Samples Categorized by Depth Category (surface, photic, bottom) (in µS/cm)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 43 | 55.0 | 79.0 | 90.0 | 136.9 | 126.0 | 155.0 | 238.0 | 363.0 |
| Middle | 1897 | 52.0 | 84.0 | 94.0 | 117.4 | 115.0 | 136.0 | 152.0 | 463.0 |
| Surface | 1424 | 34.3 | 75.1 | 87.0 | 105.2 | 99.1 | 118.0 | 137.0 | 1387.0 |

***Conductivity Lower Lake Samples Categorized by Year***

> By year, highest mean and median conductivity were recorded in 2011, followed by 2012; however the 2012 dataset is a partial dataset, and only represents a small portion of the year.

> The lowest mean conductivity was recorded in 2003, followed by 2000 and 2001.

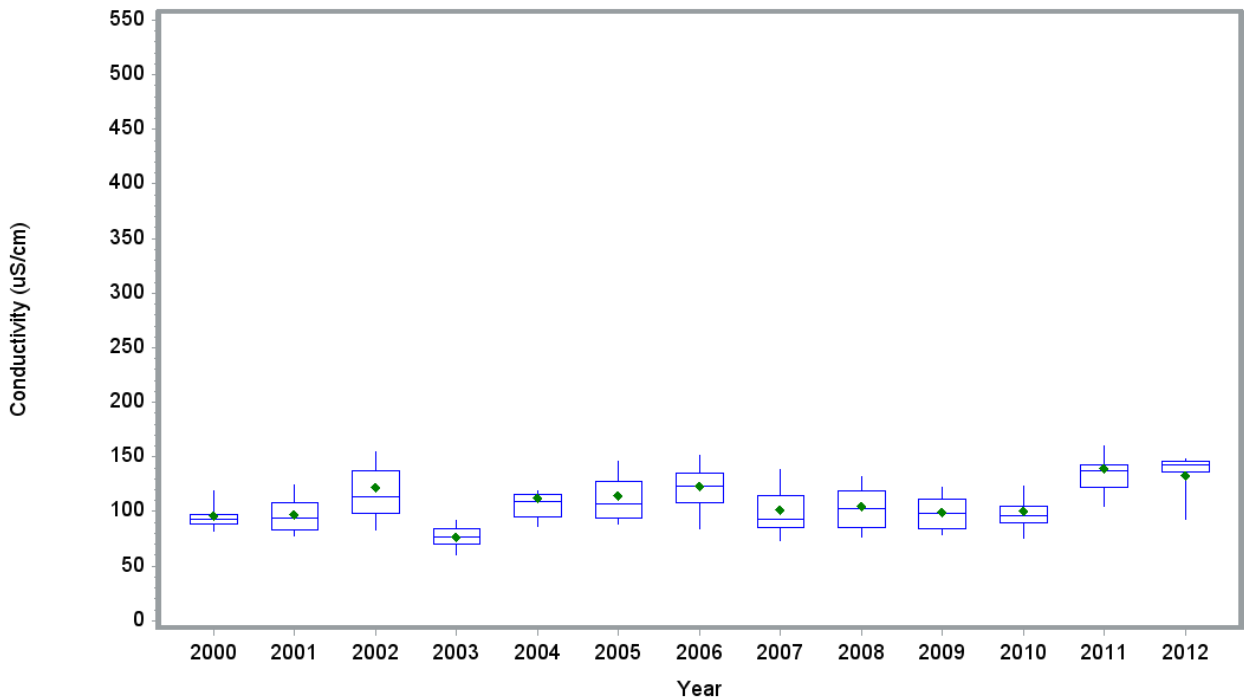



**Figure 3-75 Conductivity Lower Lake Samples Categorized by Year**

**Table 3-81 Conductivity Lower Lake Samples Categorized by Year (in µS/cm)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 88 | 46.2 | 82.0 | 88.5 | 96.4 | 93.3 | 97.5 | 119.0 | 169.0 |
| 2001 | 189 | 54.4 | 78.0 | 83.0 | 97.1 | 94.3 | 108.0 | 124.0 | 145.0 |
| 2002 | 76 | 60.9 | 83.3 | 97.9 | 122.3 | 113.0 | 137.5 | 155.0 | 315.0 |
| 2003 | 96 | 51.8 | 60.3 | 70.6 | 76.9 | 76.3 | 83.9 | 92.0 | 103.9 |
| 2004 | 87 | 34.3 | 86.8 | 94.7 | 112.4 | 108.9 | 115.3 | 118.6 | 916.0 |
| 2005 | 492 | 75.0 | 89.0 | 94.0 | 114.6 | 107.0 | 128.0 | 146.0 | 363.0 |
| 2006 | 644 | 54.0 | 84.0 | 108.0 | 123.7 | 123.0 | 135.0 | 151.0 | 463.0 |
| 2007 | 560 | 52.0 | 73.0 | 85.0 | 101.6 | 93.0 | 115.0 | 138.5 | 349.0 |
| 2008 | 144 | 68.0 | 77.0 | 85.0 | 104.3 | 103.0 | 118.5 | 132.0 | 165.0 |
| 2009 | 155 | 62.7 | 78.3 | 84.0 | 99.5 | 98.3 | 111.0 | 122.0 | 200.0 |
| 2010 | 371 | 64.0 | 76.0 | 90.0 | 100.2 | 96.0 | 105.0 | 123.0 | 282.0 |
| 2011 | 433 | 68.0 | 105.0 | 122.0 | 140.0 | 137.0 | 143.0 | 160.0 | 1387.0 |
| 2012 | 29 | 87.0 | 93.0 | 136.0 | 132.9 | 143.0 | 146.0 | 148.0 | 153.0 |

### *Conductivity Lower Lake Samples Categorized by Month*

> By month, the highest mean conductivity was recorded in September and August.

> The lowest mean conductivity was recorded in March and February.

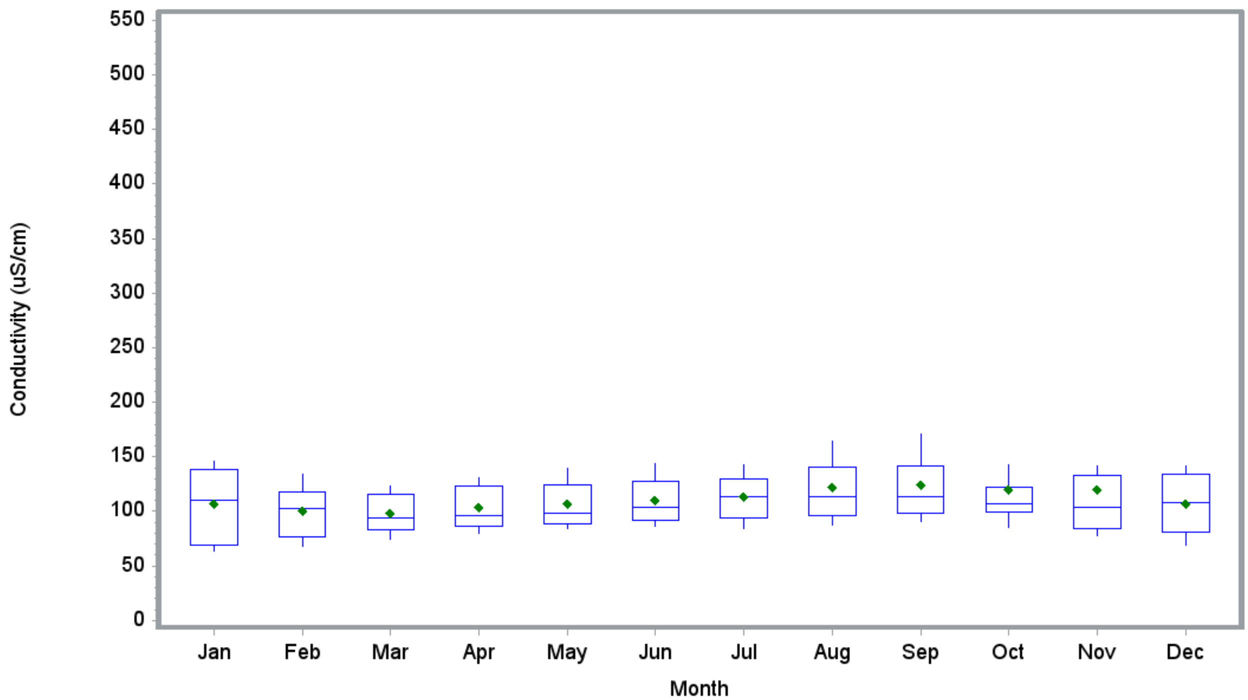



**Figure 3-76 Conductivity Lower Lake Samples Categorized by Month**

**Table 3-82 Conductivity Lower Lake Samples Categorized by Month (in µS/cm)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 155 | 52.0 | 64.0 | 69.0 | 107.1 | 110.0 | 138.0 | 146.0 | 165.0 |
| Feb | 152 | 46.2 | 68.0 | 77.0 | 100.1 | 103.0 | 118.1 | 134.0 | 150.0 |
| Mar | 228 | 50.7 | 75.0 | 83.0 | 97.8 | 94.1 | 116.0 | 123.0 | 142.0 |
| Apr | 267 | 54.4 | 79.8 | 86.0 | 103.5 | 96.3 | 123.0 | 131.0 | 200.0 |
| May | 324 | 51.8 | 84.0 | 89.0 | 107.2 | 98.3 | 124.1 | 139.0 | 363.0 |
| Jun | 404 | 54.0 | 86.0 | 92.0 | 110.6 | 103.5 | 128.0 | 144.0 | 195.0 |
| Jul | 407 | 56.4 | 83.9 | 94.0 | 113.8 | 113.0 | 130.0 | 143.0 | 206.0 |
| Aug | 492 | 34.3 | 88.0 | 96.0 | 122.2 | 113.5 | 141.0 | 164.0 | 349.0 |
| Sep | 311 | 56.0 | 91.0 | 98.0 | 123.9 | 114.0 | 142.0 | 171.0 | 298.0 |
| Oct | 219 | 55.9 | 85.0 | 99.0 | 119.5 | 107.0 | 122.0 | 143.0 | 916.0 |
| Nov | 210 | 55.0 | 78.0 | 84.0 | 120.4 | 104.0 | 133.0 | 142.0 | 1387.0 |
| Dec | 195 | 57.0 | 69.0 | 81.0 | 106.6 | 108.0 | 134.0 | 142.0 | 160.0 |

***Conductivity Lower Lake Samples Categorized by Sampling Organization***

> Highest mean and median measurements were recorded by Wake County, however there was a small sample size (n=8).

> Mean measurements recorded by NCDWQ, City of Raleigh and USGS were similar.

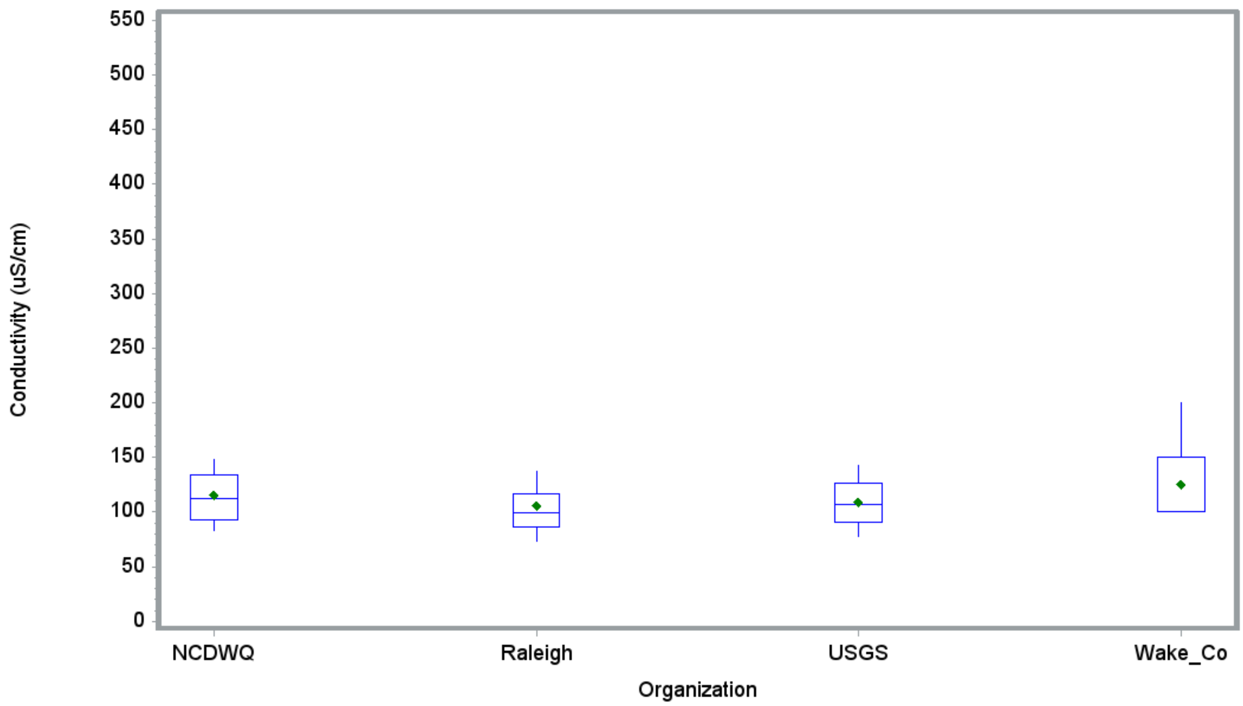



**Figure 3-77 Conductivity Lower Lake Samples Categorized by Sampling Organization**

**Table 3-83 Conductivity Lower Lake Samples Categorized by Sampling Organization (in µS/cm)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| NCDWQ | 2230 | 52.0 | 83.0 | 93.0 | 115.6 | 112.0 | 134.0 | 148.0 | 463.0 |
| Raleigh | 930 | 34.3 | 73.7 | 86.3 | 105.6 | 99.0 | 116.3 | 137.0 | 1387.0 |
| USGS | 196 | 69.0 | 78.0 | 90.5 | 109.3 | 107.0 | 127.0 | 143.0 | 188.0 |
| Wake_Co | 8 | 100.0 | 100.0 | 100.0 | 125.0 | 100.0 | 150.0 | 200.0 | 200.0 |

### *Conductivity Lower Lake Samples Categorized by Method*

> The three known and one unknown analysis method returned similar mean and median conductivity recordings.

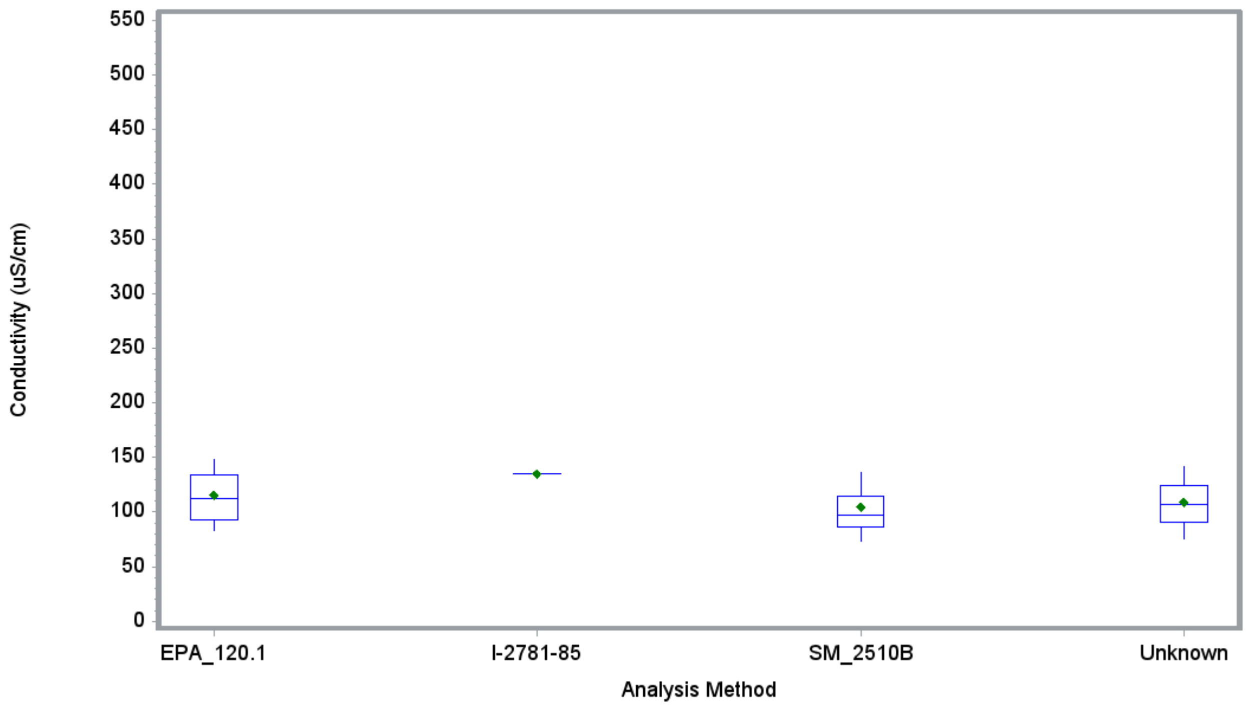



**Figure 3-78 Conductivity Lower Lake Samples Categorized by Analysis Method**

**Table 3-84 Conductivity Lower Lake Samples Categorized by Analysis Method (in µS/cm)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_120.1 | 2230 | 2230 | 52.0 | 83.0 | 93.0 | 115.6 | 112.0 | 134.0 | 148.0 |
| I-2781-85 | 1 | 1 | 135.0 | 135.0 | 135.0 | 135.0 | 135.0 | 135.0 | 135.0 |
| SM_2510B | 788 | 788 | 34.3 | 73.9 | 86.0 | 105.3 | 97.3 | 115.0 | 136.1 |
| Unknown | 345 | 345 | 67.0 | 76.0 | 91.0 | 108.7 | 107.0 | 124.0 | 142.0 |

## 3.10 Total Suspended Sediment (TSS)

Five organizations measured total suspended sediment (TSS) as part of their water quality sampling effort. TSS was measured in the laboratory. For those organizations that provided information on methodology, the following methods were used:

> Total Suspended Solids Dried at 103-105 Deg C (APHA2540D/SM 2540D)

> Suspended solids, dried at 105C, by weight (USGS I-3765-85)

> Residue, Filterable (Gravimetric, Dried at 180 Deg C) (EPA 160.1)

> Residue, Non-Filterable (Gravimetric, Dried at 103-105 Deg C) (EPA 160.2)

> Total Suspended Solids Dried at 103-105 C (CAAE 300)

Appendix E provides detailed descriptions of these methods.

Table 3-85 describes the organizations and analysis methods used to measure TSS and includes the number of samples, date range, and limits. The majority of the TSS data have been collected by NCDWQ using method SM_2540D. TSS is presented as mg/L and to two decimal places based on reported data

**Table 3-85 Summary of Analysis Methods for the TSS Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg/L) | Reporting Limit (mg/L) | Practical Quanti-fication Limit (mg/L) | Range of Limit Specified with Results (mg/L) |
|---|---|---|---|---|---|---|---|---|
| CAAE | CAAE_300 | 06/20/2002 | 11/26/2008 | 325 | Not Provided | Not Provided | Not Provided | Not Provided |
| Durham_Ci | EPA_160.2 | 01/10/2005 | 12/07/2011 | 528 | Not Provided | Not Provided | Not Provided | 1 to 5 |
| Durham_Ci | SM_2540D | 07/23/2009 | 12/20/2011 | 19 | Not Provided | Not Provided | Not Provided | 2.5 |
| NCDWQ | APHA_2540-D | 06/04/2007 | 04/06/2011 | 39 | Not Provided | Not Provided | Not Provided | 6.2 to 142 |
| NCDWQ | EPA_160.1 | 01/11/1999 | 02/26/2001 | 143 | Not Provided | Not Provided | Not Provided | 1 to 150 |
| NCDWQ | EPA_160.2 | 05/22/2001 | 05/18/2007 | 329 | Not Provided | Not Provided | Not Provided | 2.5 to 275 |
| NCDWQ | SM_2540D | 06/07/2000 | 09/20/2007 | 661 | Not Provided | Not Provided | Not Provided | 2.5 to 12 |
| Orange_Co | SM_2540D | 04/09/2010 | 03/25/2011 | 181 | Not Provided | Not Provided | 2.5 | 2.5 to 2.9 |
| USGS | USGS_I-3765-85 | 05/05/2009 | 04/22/2010 | 42 | Not Provided | Not Provided | Not Provided | 15 to 30 |
| Wake_Co | Not Provided | 07/29/2008 | 10/14/2009 | 147 | Not Provided | Not Provided | Not Provided | 0.05 to 0.1 |

### 3.10.2 Tributary Samples

Five organizations collected total suspended sediment (TSS) data in the tributaries of Falls Lake from 1999 to 2011. Highest mean and median TSS values were recorded by the USGS and lowest mean and median TSS values were recorded by Wake County and Orange County. By location, highest mean TSS measurements were recorded in the Little River and Lick Creek catchments. Lowest mean TSS measurements were recorded in Beaverdam Creek. Highest mean measurements were recorded in 2004 and 2009. Summary statistics and box plots are provided below.

***Total Suspended Sediment Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

TSS was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.

- Between all location sampling categories, the highest mean TSS was recorded 2 to 10 miles from the mouth in the Little River catchment and the lowest mean TSS was recorded 0 to 2 miles from the mouth in the Beaverdam Creek catchment.
- For Ellerbe Creek, Eno River, and Lick Creek mean TSS was higher 0 to 2 miles from the mouth and lower in the 2 to 10 mile category. For Flat River, mean TSS was lower 0 to 2 miles from the mouth and higher in the 2 to 10 mile category.

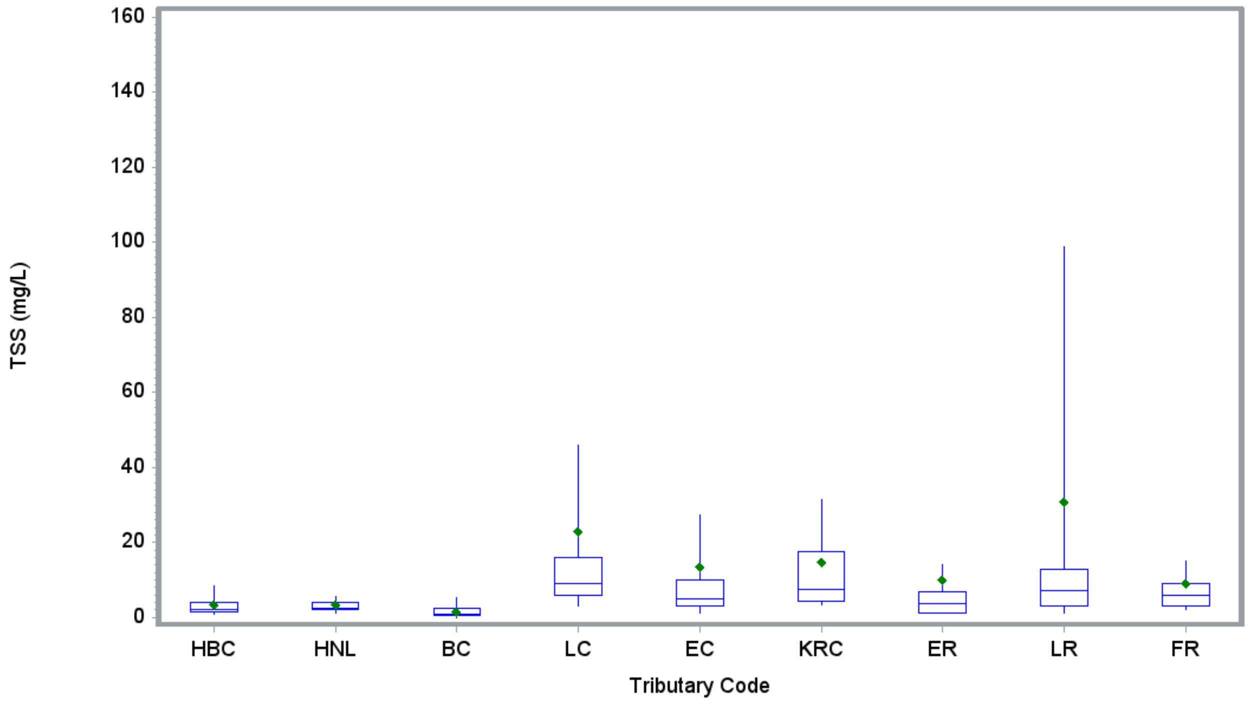



**Figure 3-79 TSS Tributary Samples Categorized by Subwatershed**

**Table 3-86 TSS Tributary Samples Categorized by Subwatershed (in mg/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 78 | 0.40 | 1.00 | 1.40 | 3.36 | 2.00 | 4.00 | 8.40 | 20.00 |
| HNL | 45 | 0.80 | 1.30 | 2.00 | 3.49 | 2.50 | 4.00 | 5.60 | 19.10 |
| BC | 18 | 0.03 | 0.05 | 0.50 | 1.64 | 1.00 | 2.30 | 5.20 | 5.40 |
| LC | 88 | 1.25 | 3.00 | 6.00 | 22.98 | 9.00 | 16.00 | 46.00 | 335.00 |
| EC | 379 | 0.50 | 1.25 | 3.00 | 13.41 | 5.00 | 10.00 | 27.20 | 309.00 |
| KRC | 80 | 1.00 | 3.50 | 4.20 | 14.86 | 7.65 | 17.50 | 31.50 | 120.00 |
| ER | 411 | 1.00 | 1.25 | 1.30 | 10.09 | 3.80 | 7.00 | 14.00 | 382.00 |
| LR | 145 | 1.00 | 1.25 | 3.00 | 30.68 | 7.20 | 13.00 | 99.00 | 510.00 |
| FR | 178 | 1.00 | 2.00 | 3.20 | 9.12 | 6.00 | 9.00 | 15.00 | 220.00 |

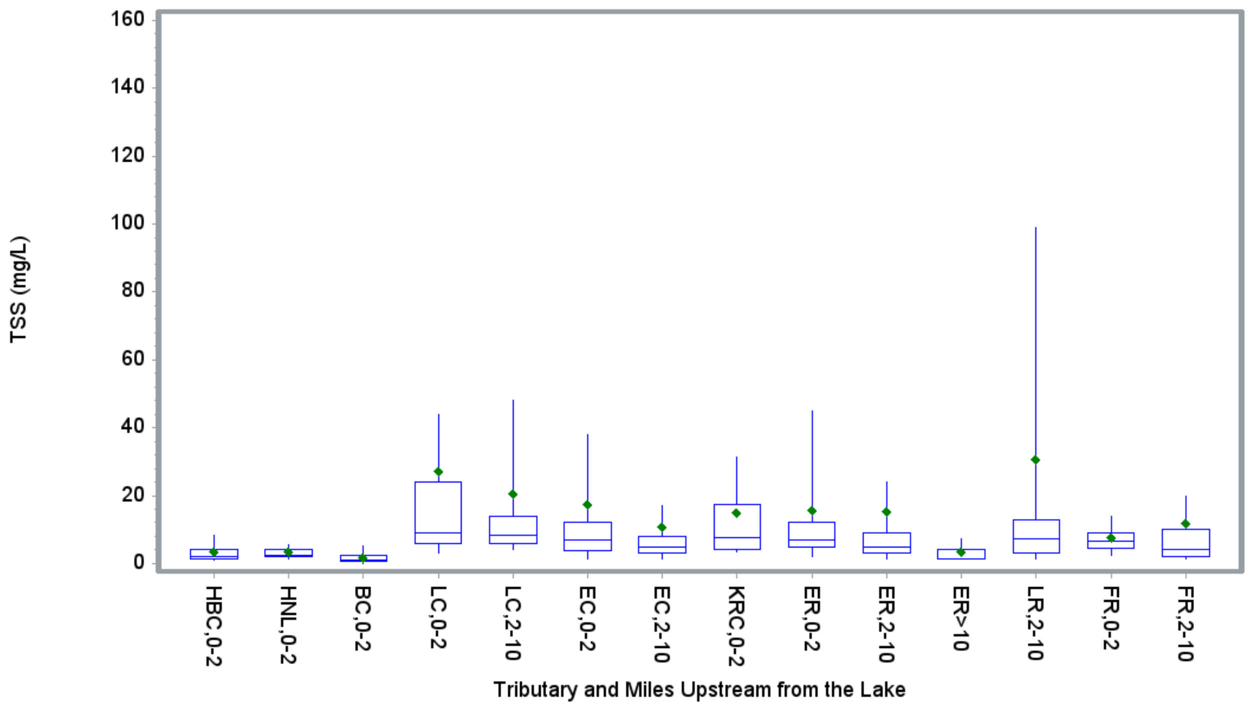



**Figure 3-80 TSS Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-87 TSS Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in mg/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 78 | 78 | 0.40 | 1.00 | 1.40 | 3.36 | 2.00 | 4.00 | 8.40 |
| HNL,0-2 | 45 | 45 | 0.80 | 1.30 | 2.00 | 3.49 | 2.50 | 4.00 | 5.60 |
| BC,0-2 | 18 | 18 | 0.03 | 0.05 | 0.50 | 1.64 | 1.00 | 2.30 | 5.20 |
| LC,0-2 | 31 | 31 | 1.25 | 3.00 | 6.00 | 27.18 | 9.00 | 24.00 | 44.00 |
| LC,2-10 | 57 | 57 | 3.00 | 4.00 | 6.00 | 20.69 | 8.30 | 14.00 | 48.00 |
| EC,0-2 | 153 | 153 | 1.00 | 1.25 | 3.80 | 17.27 | 6.80 | 12.00 | 38.00 |
| EC,2-10 | 226 | 226 | 0.50 | 1.25 | 3.00 | 10.79 | 5.00 | 8.00 | 17.00 |
| KRC,0-2 | 80 | 80 | 1.00 | 3.50 | 4.20 | 14.86 | 7.65 | 17.50 | 31.50 |
| ER,0-2 | 58 | 58 | 1.00 | 2.00 | 5.00 | 15.47 | 7.00 | 12.00 | 45.00 |
| ER,2-10 | 172 | 172 | 1.00 | 1.25 | 3.00 | 15.41 | 4.80 | 9.00 | 24.00 |
| ER>10 | 181 | 181 | 1.25 | 1.25 | 1.25 | 3.31 | 1.45 | 4.00 | 7.40 |
| LR,2-10 | 145 | 145 | 1.00 | 1.25 | 3.00 | 30.68 | 7.20 | 13.00 | 99.00 |
| FR,0-2 | 113 | 113 | 1.00 | 2.50 | 4.50 | 7.49 | 6.50 | 9.00 | 14.00 |
| FR,2-10 | 65 | 65 | 1.00 | 1.25 | 2.00 | 11.94 | 4.00 | 10.00 | 20.00 |

### *Total Suspended Sediment in Tributary Samples Categorized by Depth*

> Only surface level depths were recorded in the tributaries.

### *Total Suspended Sediment in Tributary Samples Categorized by Year*

> By year, highest mean TSS was recorded in 2004, followed by 2009 and the lowest mean TSS was recorded in 2008, followed by 2003.

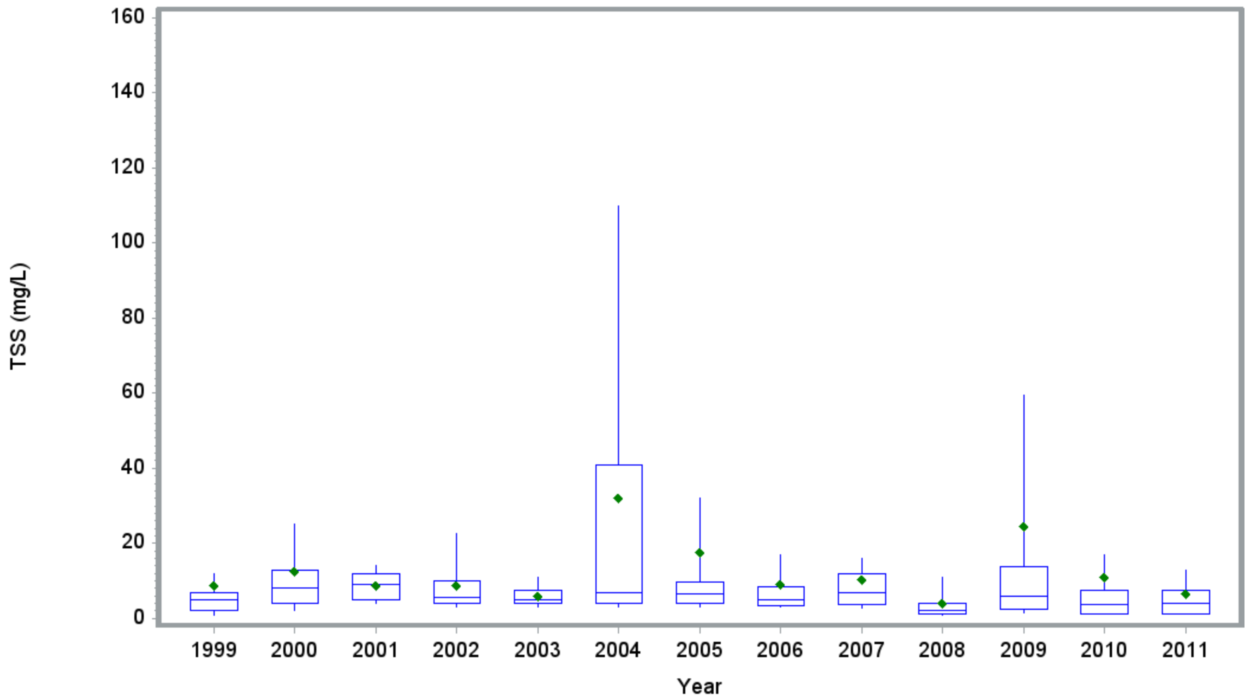



**Figure 3-81 TSS Tributary Samples Categorized by Year**

**Table 3-88 TSS Tributary Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 80 | 1.00 | 1.00 | 2.00 | 8.74 | 5.00 | 7.00 | 12.00 | 150.00 |
| 2000 | 57 | 1.00 | 2.00 | 4.00 | 12.40 | 8.00 | 13.00 | 25.00 | 66.00 |
| 2001 | 15 | 4.00 | 4.00 | 5.00 | 8.87 | 9.00 | 12.00 | 14.00 | 14.00 |
| 2002 | 20 | 2.50 | 3.00 | 4.00 | 8.68 | 5.50 | 10.00 | 22.50 | 34.00 |
| 2003 | 24 | 2.50 | 3.00 | 4.00 | 6.02 | 5.00 | 7.50 | 11.00 | 13.00 |
| 2004 | 23 | 3.00 | 3.00 | 4.00 | 32.22 | 7.00 | 41.00 | 110.00 | 220.00 |
| 2005 | 93 | 2.50 | 3.00 | 4.00 | 17.71 | 6.50 | 9.70 | 32.00 | 275.00 |
| 2006 | 125 | 1.00 | 3.00 | 3.50 | 9.02 | 5.00 | 8.50 | 17.00 | 92.00 |
| 2007 | 63 | 1.00 | 2.80 | 3.80 | 10.41 | 7.00 | 12.00 | 16.00 | 142.00 |
| 2008 | 75 | 0.50 | 0.80 | 1.20 | 4.08 | 2.00 | 4.00 | 11.00 | 22.00 |
| 2009 | 311 | 0.03 | 1.60 | 2.60 | 24.37 | 6.00 | 13.80 | 59.60 | 510.00 |
| 2010 | 358 | 1.25 | 1.25 | 1.30 | 10.81 | 3.70 | 7.40 | 17.00 | 326.00 |
| 2011 | 178 | 1.25 | 1.25 | 1.30 | 6.62 | 4.00 | 7.60 | 13.00 | 147.00 |

### *Total Suspended Sediment in Tributary Samples Categorized by Month*

- By month, the highest mean TSS was recorded in December and November.
- By month, the highest median TSS was recorded in June followed by March.
- The lowest mean TSS was recorded in September, followed by May.

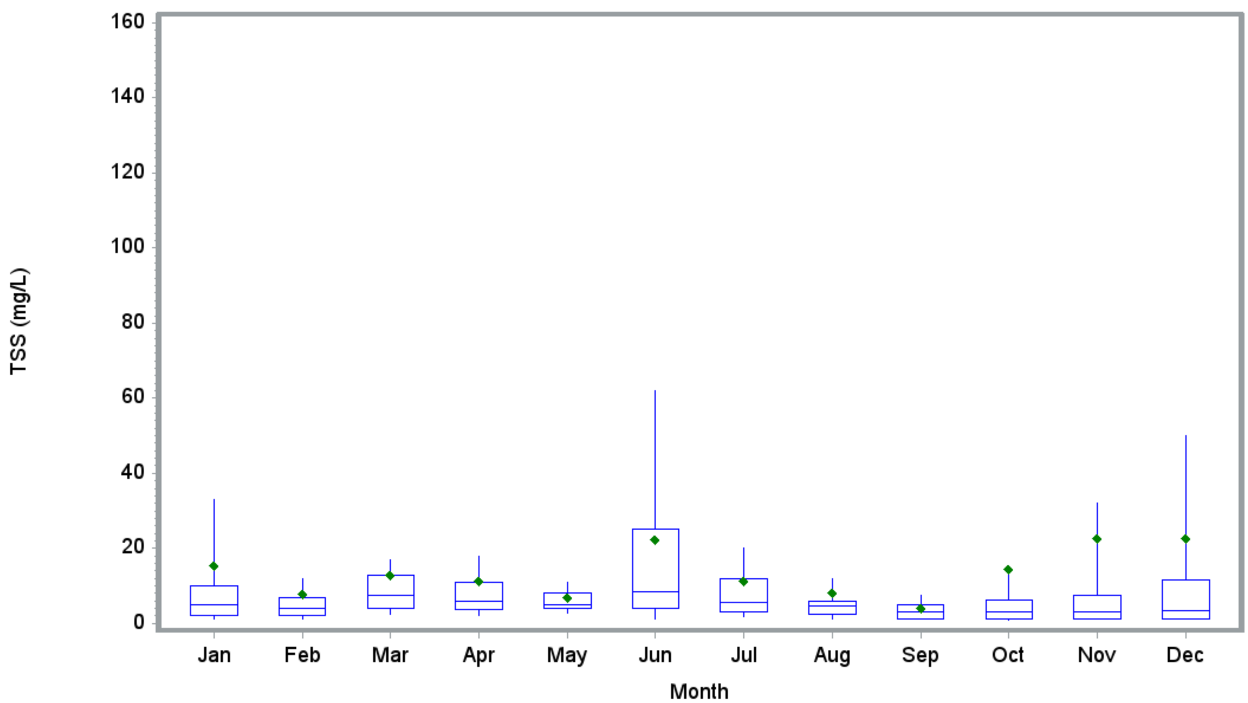



**Figure 3-82 TSS Tributary Samples Categorized by Month**

**Table 3-89 TSS Tributary Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 116 | 0.50 | 1.25 | 2.00 | 15.46 | 5.00 | 10.15 | 33.00 | 204.00 |
| Feb | 117 | 0.50 | 1.25 | 2.00 | 7.70 | 4.00 | 7.00 | 12.00 | 144.00 |
| Mar | 116 | 1.00 | 2.60 | 4.00 | 12.75 | 7.35 | 12.70 | 17.00 | 272.00 |
| Apr | 148 | 0.03 | 2.00 | 3.65 | 11.14 | 6.00 | 11.00 | 18.00 | 220.00 |
| May | 122 | 0.50 | 2.80 | 4.00 | 6.94 | 5.05 | 8.00 | 11.00 | 65.00 |
| Jun | 118 | 1.00 | 1.25 | 4.00 | 22.32 | 8.50 | 25.00 | 62.00 | 199.00 |
| Jul | 131 | 1.00 | 1.70 | 3.00 | 11.16 | 5.50 | 12.00 | 20.00 | 169.00 |
| Aug | 117 | 0.80 | 1.25 | 2.50 | 8.14 | 4.60 | 6.00 | 12.00 | 142.00 |
| Sep | 91 | 0.50 | 1.25 | 1.25 | 4.06 | 3.20 | 5.00 | 7.50 | 31.00 |
| Oct | 117 | 0.40 | 1.00 | 1.30 | 14.33 | 3.20 | 6.20 | 15.00 | 326.00 |
| Nov | 125 | 0.50 | 1.25 | 1.30 | 22.69 | 3.20 | 7.50 | 32.00 | 510.00 |
| Dec | 104 | 0.50 | 1.25 | 1.25 | 22.70 | 3.50 | 11.50 | 50.00 | 335.00 |

### *Total Suspended Sediment in Tributary Samples Categorized by Sampling Organization*

> Highest mean and median TSS values were recorded by the USGS.

> Lowest mean and median TSS values were recorded by Wake County and Orange County.

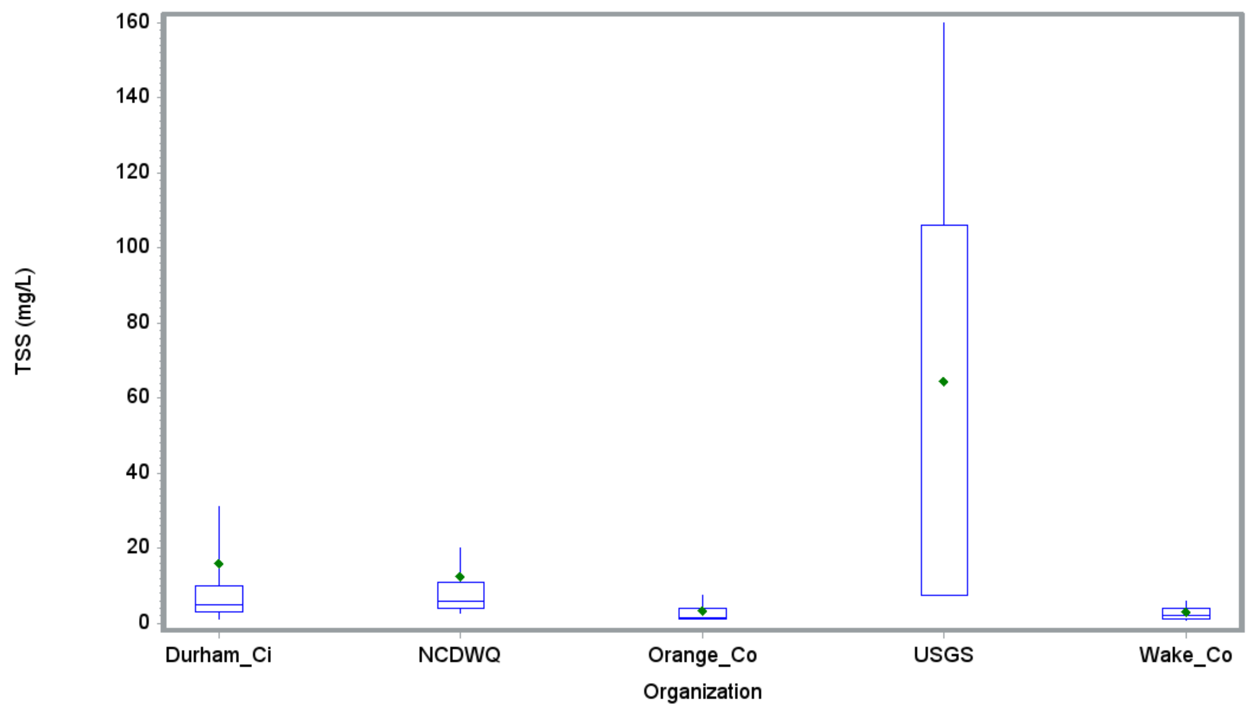



**Figure 3-83 TSS Tributary Samples Categorized by Sampling Organization**

**Table 3-90 TSS Tributary Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 547 | 0.50 | 1.25 | 3.00 | 16.03 | 5.00 | 10.00 | 31.00 | 442.00 |
| NCDWQ | 511 | 1.00 | 2.80 | 4.00 | 12.60 | 6.00 | 11.00 | 20.00 | 275.00 |
| Orange_Co | 181 | 1.25 | 1.25 | 1.25 | 3.31 | 1.45 | 4.00 | 7.40 | 16.20 |
| USGS | 42 | 7.50 | 7.50 | 7.50 | 64.38 | 7.50 | 106.00 | 160.00 | 510.00 |
| Wake_Co | 141 | 0.03 | 0.90 | 1.30 | 3.18 | 2.00 | 4.00 | 6.00 | 20.00 |

### *Total Suspended Sediment in Tributary Samples Categorized by Method*

> Five known analysis method categories and one unknown category were used to measure TSS.

> The USGS I-3765 method returned the highest mean TSS values.

> The unknown and SM 2540D categories returned the lowest mean and median TSS values.

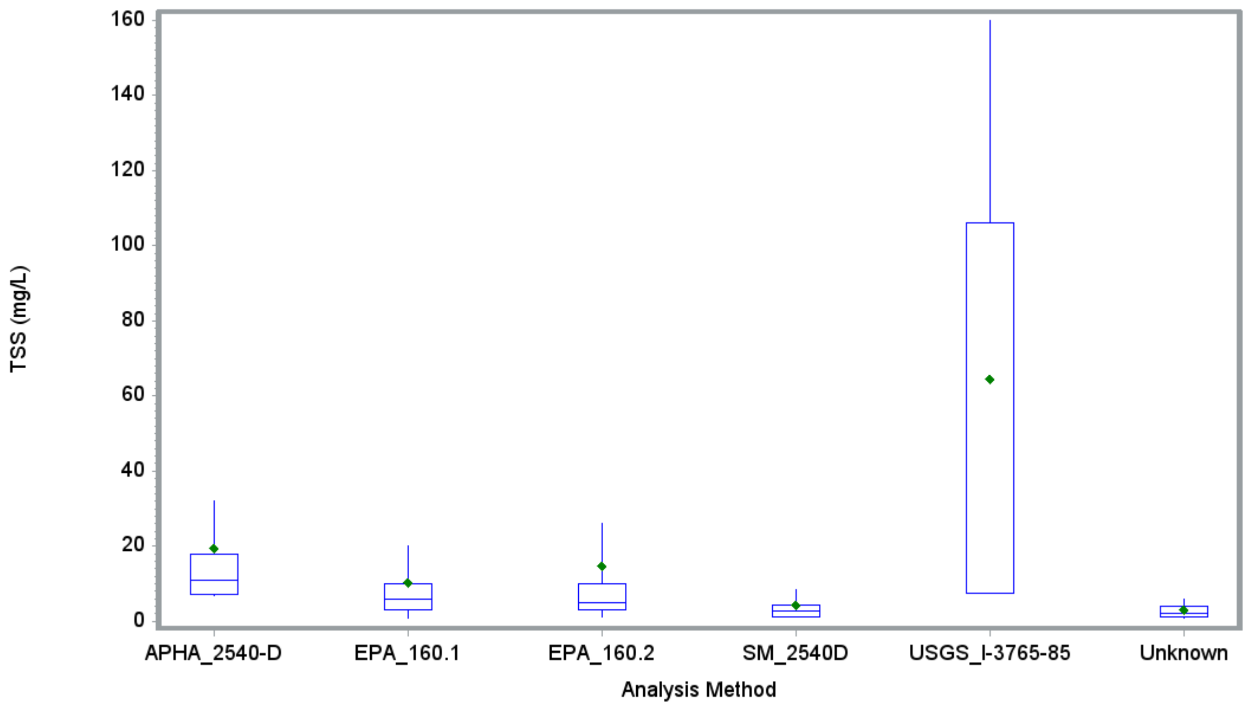



**Figure 3-84 TSS Tributary Samples Categorized by Analysis Method**

**Table 3-91 TSS Tributary Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| APHA_2540-D | 39 | 6.20 | 6.80 | 7.30 | 19.36 | 11.00 | 18.00 | 32.00 | 142.00 |
| EPA_160.1 | 143 | 1.00 | 1.00 | 3.00 | 10.26 | 6.00 | 10.00 | 20.00 | 150.00 |
| EPA_160.2 | 857 | 0.50 | 1.25 | 3.00 | 14.87 | 5.00 | 10.00 | 26.00 | 442.00 |
| SM_2540D | 200 | 1.25 | 1.25 | 1.30 | 4.20 | 2.70 | 4.40 | 8.55 | 59.60 |
| USGS_I-3765-85 | 42 | 7.50 | 7.50 | 7.50 | 64.38 | 7.50 | 106.00 | 160.00 | 510.00 |
| Unknown | 141 | 0.03 | 0.90 | 1.30 | 3.18 | 2.00 | 4.00 | 6.00 | 20.00 |

### 3.10.3 Upper Lake Samples

Two organizations collected Total Suspended Sediment (TSS) data in Upper Falls Lake from 2000 to 2008. NCSU-CAAE recorded higher mean and median TSS values than NCDWQ. By location, the highest mean and median TSS values were recorded > 21 miles from the dam and lowest mean and median TSS values were recorded 13 to 18 miles from the dam. Summary statistics and box plots are provided below.

***Total Suspended Sediment Upper Lake Samples Categorized by Lake Segment and Miles Upstream from Dam***

> By location, the highest mean and median TSS values were recorded > 21 miles from the dam and lowest mean and median TSS values were recorded 13 to 18 miles from the dam.

> Higher mean TSS values are observed with increasing distance from the dam.

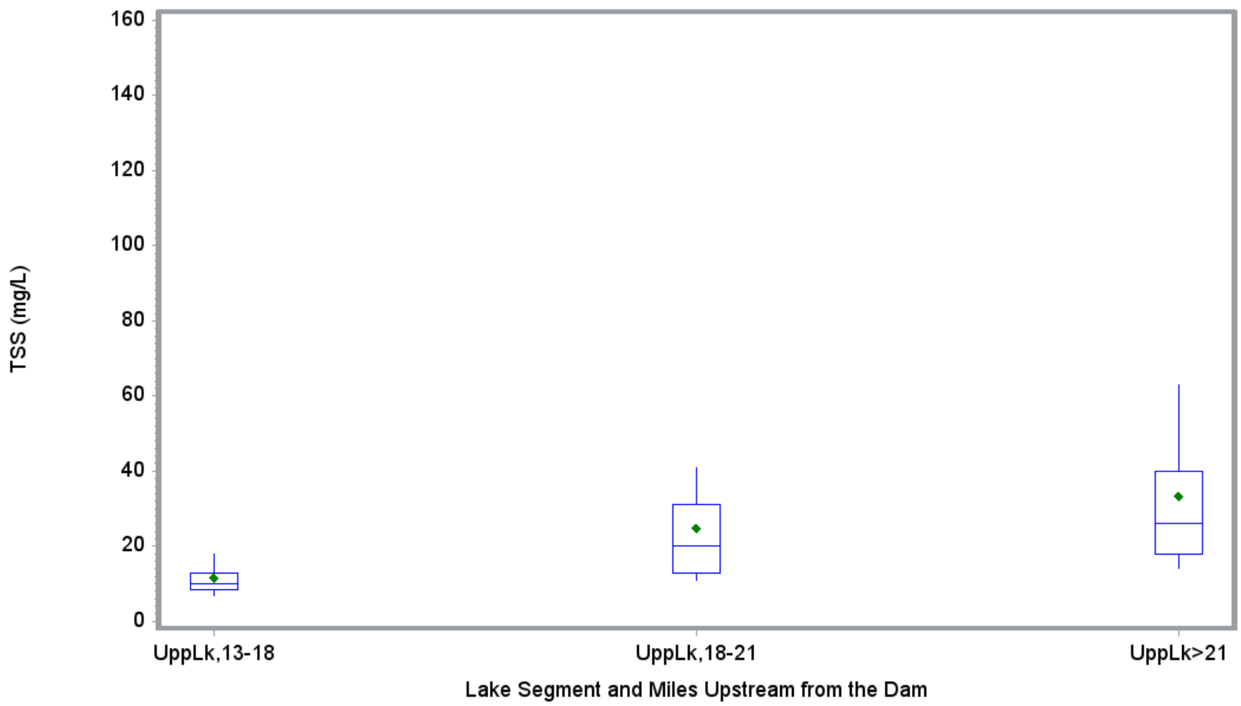



**Figure 3-85 TSS Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-92 TSS Upper Lake Samples Categorized by Miles Upstream from Dam (in mg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 206 | 1.65 | 7.00 | 8.50 | 11.72 | 10.00 | 13.00 | 18.00 | 44.00 |
| UppLk,18-21 | 102 | 5.00 | 11.00 | 13.00 | 24.93 | 20.00 | 31.00 | 41.00 | 197.00 |
| UppLk>21 | 146 | 4.00 | 14.00 | 18.00 | 33.22 | 26.00 | 40.00 | 63.00 | 147.00 |

### *Total Suspended Sediment Upper Lake Samples Categorized by Depth*

> Two sampling depth categories were recorded for TSS. The surface level returned higher mean and median TSS values than composite samples taken of the photic zone.

> From minimum to maximum, the range of TSS values recorded at the surface level was less than the range of values recorded in the photic zone; however, the sample size at the surface level was considerably less than the sample size in the photic zone.


**Figure 3-86 TSS Upper Lake Samples Categorized by Depth Category**

**Table 3-93 TSS Upper Lake Samples Categorized by Depth Category (in mg/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Photic | 398 | 1.65 | 8.00 | 10.00 | 20.81 | 14.00 | 24.00 | 40.00 | 197.00 |
| Surface | 56 | 4.00 | 11.00 | 13.00 | 27.21 | 21.00 | 36.00 | 45.00 | 94.00 |

### *Total Suspended Sediment Upper Lake Samples Categorized by Year*

> TSS values were recorded for all years from 2000 to 2008 except for 2002 and 2003.

> By year, highest mean TSS value was recorded in 2000, followed by 2005.

> The lowest mean TSS value was recorded in 2006, followed by 2001.

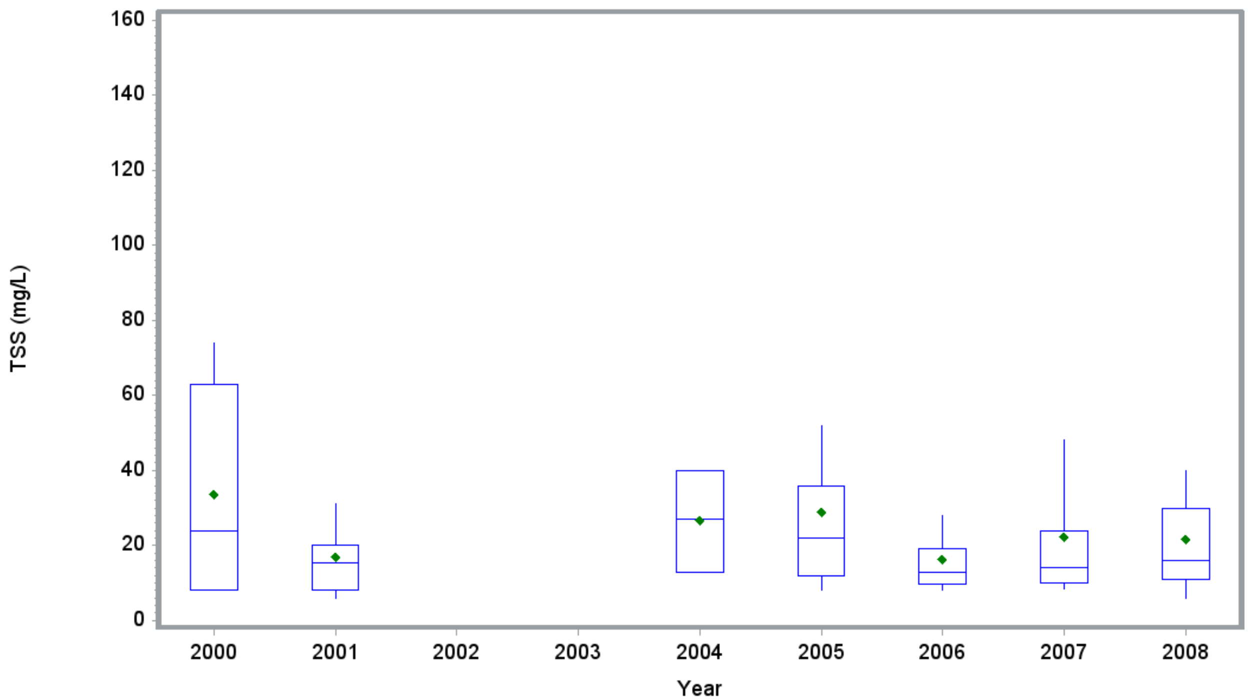



**Figure 3-87 TSS Upper Lake Samples Categorized by Year**

**Table 3-94 TSS Upper Lake Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 6 | 8.00 | 8.00 | 8.00 | 33.50 | 24.00 | 63.00 | 74.00 | 74.00 |
| 2001 | 18 | 1.65 | 6.00 | 8.00 | 16.81 | 15.50 | 20.00 | 31.00 | 54.00 |
| 2004 | 3 | 13.00 | 13.00 | 13.00 | 26.67 | 27.00 | 40.00 | 40.00 | 40.00 |
| 2005 | 104 | 4.00 | 8.20 | 12.00 | 28.80 | 22.00 | 36.00 | 52.00 | 197.00 |
| 2006 | 165 | 5.00 | 8.00 | 9.80 | 16.37 | 13.00 | 19.00 | 28.00 | 92.00 |
| 2007 | 139 | 6.50 | 8.50 | 10.00 | 22.44 | 14.00 | 24.00 | 48.00 | 147.00 |
| 2008 | 19 | 4.00 | 6.00 | 11.00 | 21.53 | 16.00 | 30.00 | 40.00 | 78.00 |

### *Total Suspended Sediment Upper Lake Samples Categorized by Month*

> By month, the highest mean TSS was recorded in December, followed by September.

> The lowest mean TSS was recorded in February, followed by May.

> Median values were similar for all months.

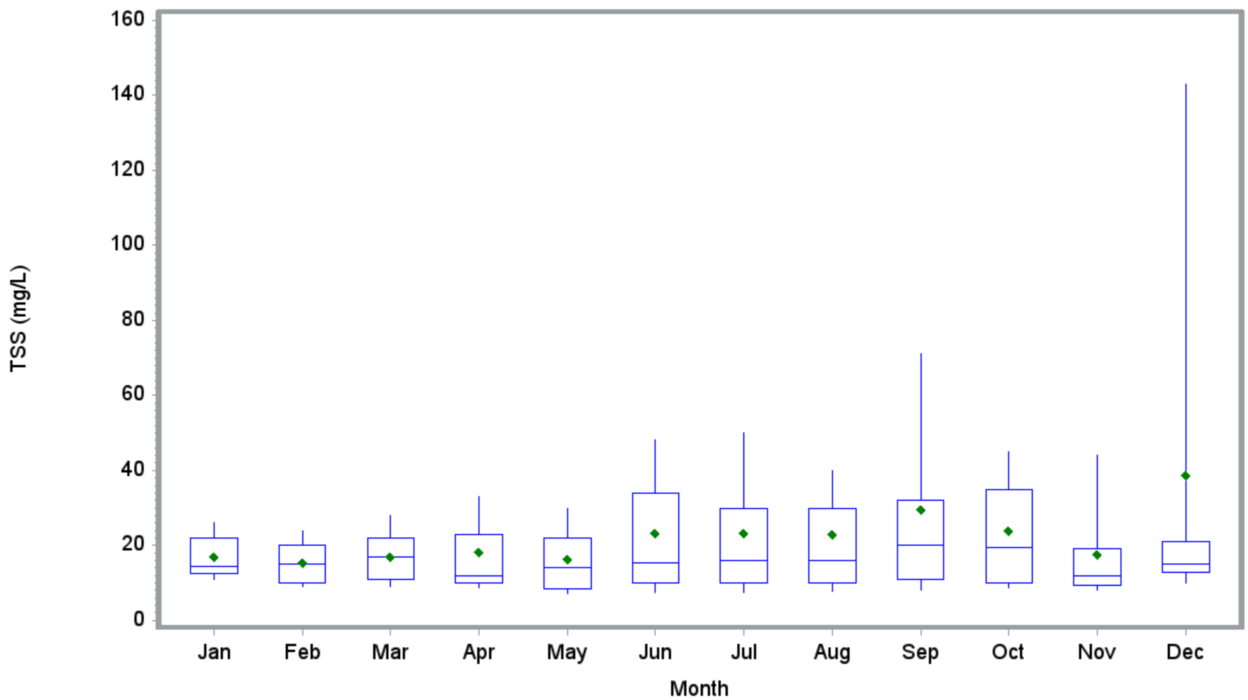



**Figure 3-88 TSS Upper Lake Samples Categorized by Month**

**Table 3-95 TSS Upper Lake Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 24 | 10.00 | 11.00 | 12.50 | 16.88 | 14.50 | 22.00 | 26.00 | 28.00 |
| Feb | 27 | 7.50 | 9.00 | 10.00 | 15.31 | 15.00 | 20.00 | 24.00 | 25.00 |
| Mar | 41 | 6.80 | 9.00 | 11.00 | 16.81 | 17.00 | 22.00 | 28.00 | 30.00 |
| Apr | 41 | 4.00 | 8.80 | 10.00 | 18.24 | 12.00 | 23.00 | 33.00 | 78.00 |
| May | 38 | 6.00 | 7.20 | 8.50 | 16.30 | 14.00 | 22.00 | 30.00 | 40.00 |
| Jun | 54 | 6.00 | 7.50 | 10.00 | 23.28 | 15.50 | 34.00 | 48.00 | 74.00 |
| Jul | 63 | 6.00 | 7.50 | 10.00 | 23.13 | 16.00 | 30.00 | 50.00 | 92.00 |
| Aug | 62 | 1.65 | 7.80 | 10.00 | 23.05 | 16.00 | 30.00 | 40.00 | 94.00 |
| Sep | 37 | 7.80 | 8.00 | 11.00 | 29.52 | 20.00 | 32.00 | 71.00 | 147.00 |
| Oct | 26 | 7.20 | 8.80 | 10.00 | 23.76 | 19.50 | 35.00 | 45.00 | 54.00 |
| Nov | 24 | 5.00 | 8.00 | 9.40 | 17.56 | 12.00 | 19.00 | 44.00 | 54.00 |
| Dec | 17 | 9.80 | 10.00 | 13.00 | 38.69 | 15.00 | 21.00 | 143.00 | 197.00 |

***Total Suspended Sediment Upper Lake Samples Categorized by Sampling Organization***

> Two organizations recorded TSS in Upper Lake.

> CAAE recorded higher mean and median TSS values than NCDWQ.


**Figure 3-89 TSS Upper Lake Samples Categorized by Sampling Organization**

**Table 3-96 TSS Upper Lake Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 56 | 4.00 | 11.00 | 13.00 | 27.21 | 21.00 | 36.00 | 45.00 | 94.00 |
| NCDWQ | 398 | 1.65 | 8.00 | 10.00 | 20.81 | 14.00 | 24.00 | 40.00 | 197.00 |

***Total Suspended Sediment Upper Lake Samples Categorized by Method***

- Only one known analysis method was used in Upper Lake, SM 2540D.
- Mean and median TSS using the known method was less than the mean and median TSS of the unknown analysis method category.

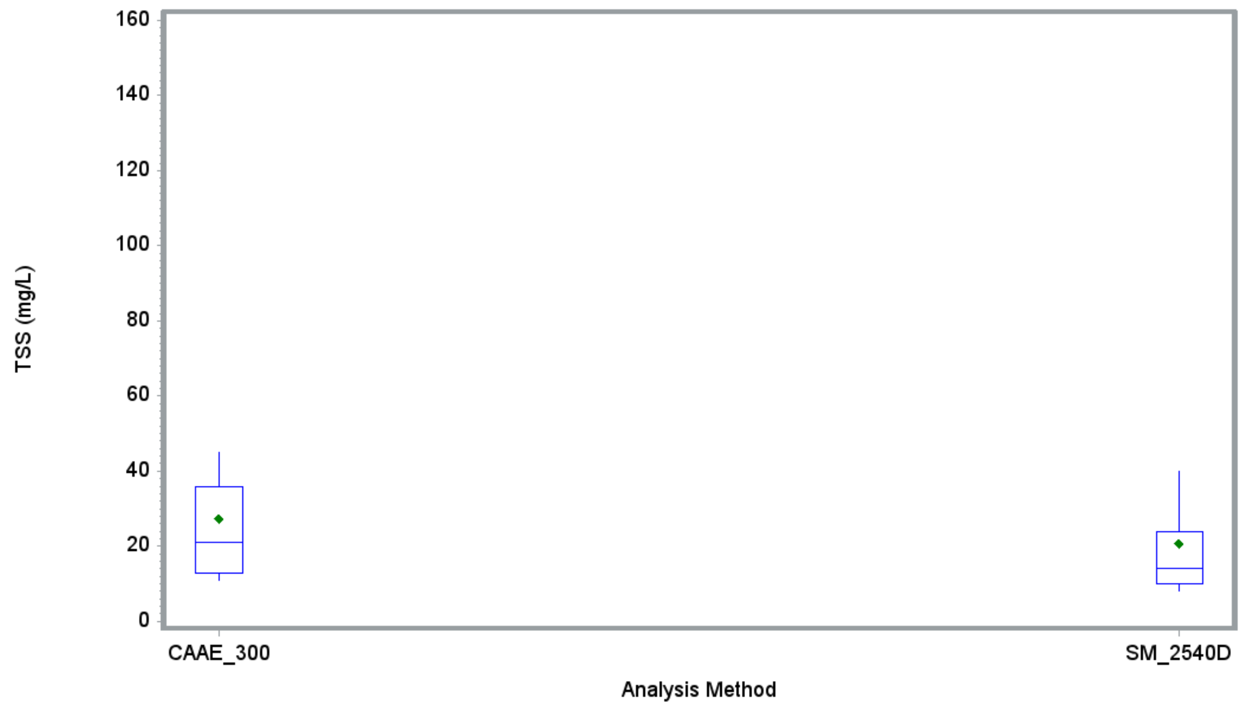



**Figure 3-90 TSS Upper Lake Samples Categorized by Analysis Method**

**Table 3-97 TSS Upper Lake Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE_300 | 56 | 4.00 | 11.00 | 13.00 | 27.21 | 21.00 | 36.00 | 45.00 | 94.00 |
| SM_2540D | 398 | 1.65 | 8.00 | 10.00 | 20.81 | 14.00 | 24.00 | 40.00 | 197.00 |

### 3.10.4 <u>Lower Lake Samples</u>

Three organizations collected Total Suspended Sediment (TSS) data in Lower Falls Lake from 2000 to 2009. Highest mean and median TSS values were recorded 8 to 13 miles from the dam in the Lower Lake catchment and lowest mean and median TSS values were recorded 0 to 4 miles from the dam in the Lower Lake catchment. Summary statistics and box plots are provided below.

***Total Suspended Sediment Lower Lake Samples Categorized by Lake Segment and Miles Upstream from Dam***

> In the lower lake catchment, highest mean and median TSS values were recorded 8 to 13 miles from the dam and lowest mean and median TSS values were recorded 0 to 4 miles from the dam.

> Mean TSS levels collected within Beaverdam Impoundment were only slightly higher than TSS levels collected in Lower Lake 0 to 4 miles from the dam.

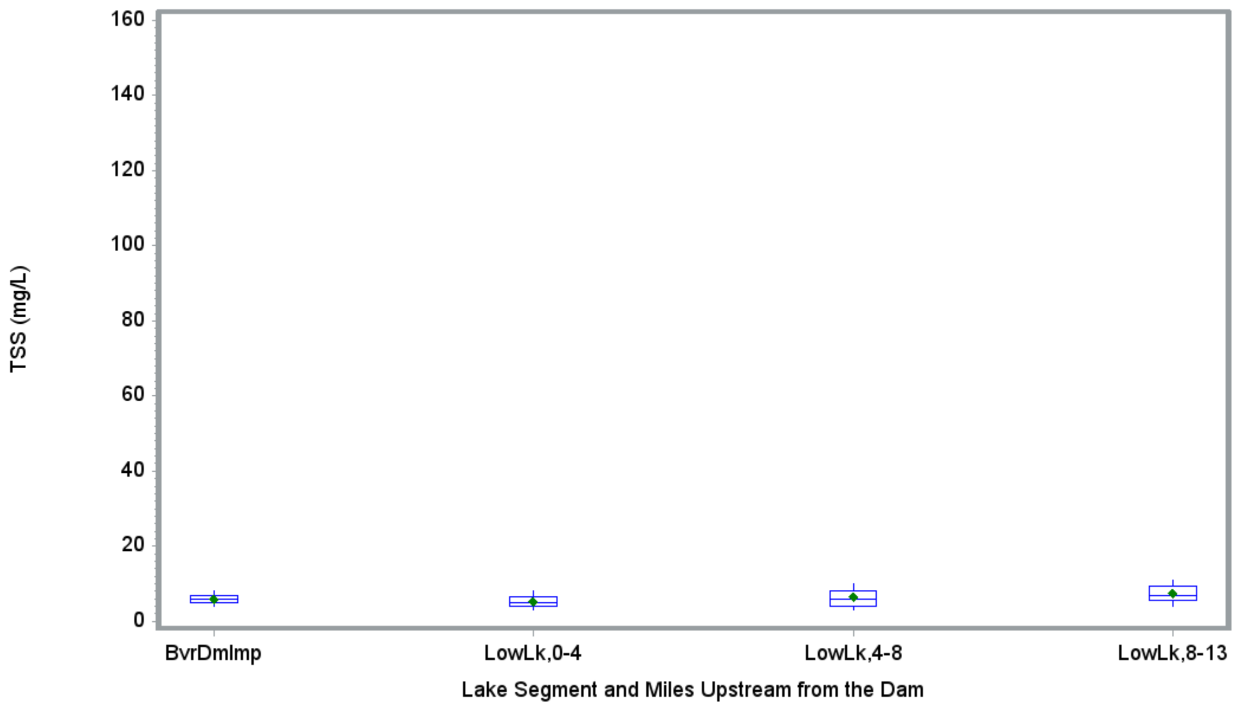



**Figure 3-91 TSS Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-98 TSS Lower Lake Samples Categorized by Miles Upstream from Dam (in mg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 23 | 4.00 | 4.00 | 5.00 | 5.96 | 6.00 | 7.00 | 8.00 | 9.00 |
| LowLk,0-4 | 223 | 0.90 | 3.00 | 4.00 | 5.41 | 5.00 | 6.50 | 8.00 | 48.00 |
| LowLk,4-8 | 161 | 1.25 | 3.10 | 4.00 | 6.62 | 6.00 | 8.20 | 10.00 | 46.00 |
| LowLk,8-13 | 131 | 1.25 | 4.00 | 5.50 | 7.63 | 7.00 | 9.50 | 11.00 | 17.00 |

***Total Suspended Sediment Lower Lake Samples Categorized by Depth***

> Between the surface level and within the photic zone, mean TSS levels were similar with only slightly higher mean TSS values recorded at the surface level.

> The other depth categories are measured by meter, with highest mean TSS values occurring at the 4 to 8 meter depth and lowest mean TSS values occurring at the 0 to 1 meter depth.

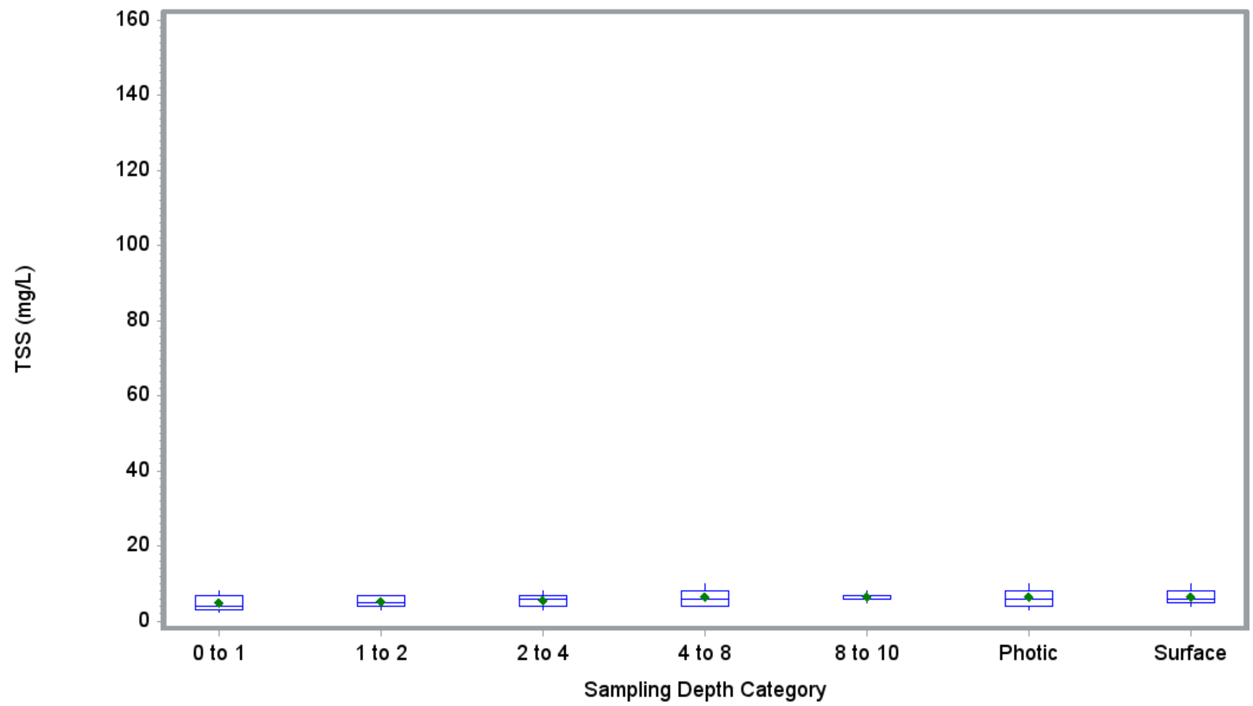



**Figure 3-92 TSS Lower Lake Samples Categorized by Depth Category**

**Table 3-99 TSS Lower Lake Samples Categorized by Depth Category (in mg/L)**

| Sampling Depth (m) | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 0 to 1 | 10 | 2.00 | 2.50 | 3.00 | 4.90 | 4.00 | 7.00 | 8.00 | 9.00 |
| 1 to 2 | 54 | 2.00 | 3.00 | 4.00 | 5.28 | 5.00 | 7.00 | 7.00 | 11.00 |
| 2 to 4 | 61 | 2.00 | 3.00 | 4.00 | 5.57 | 6.00 | 7.00 | 8.00 | 12.00 |
| 4 to 8 | 63 | 3.00 | 4.00 | 4.00 | 6.63 | 6.00 | 8.00 | 10.00 | 17.00 |
| 8 to 10 | 5 | 5.00 | 5.00 | 6.00 | 6.40 | 6.00 | 7.00 | 8.00 | 8.00 |
| Photic | 263 | 1.25 | 3.10 | 4.00 | 6.61 | 6.00 | 8.20 | 10.00 | 48.00 |
| Surface | 82 | 0.90 | 4.00 | 5.00 | 6.66 | 6.00 | 8.00 | 10.00 | 24.00 |

### *Total Suspended Sediment Lower Lake Samples Categorized by Year*

- TSS samples were collected from 2000 to 2009.
- By year, highest mean and median TSS values were recorded in 2002, followed by 2003; and the lowest mean and median TSS values were recorded in 2009, followed by 2000.

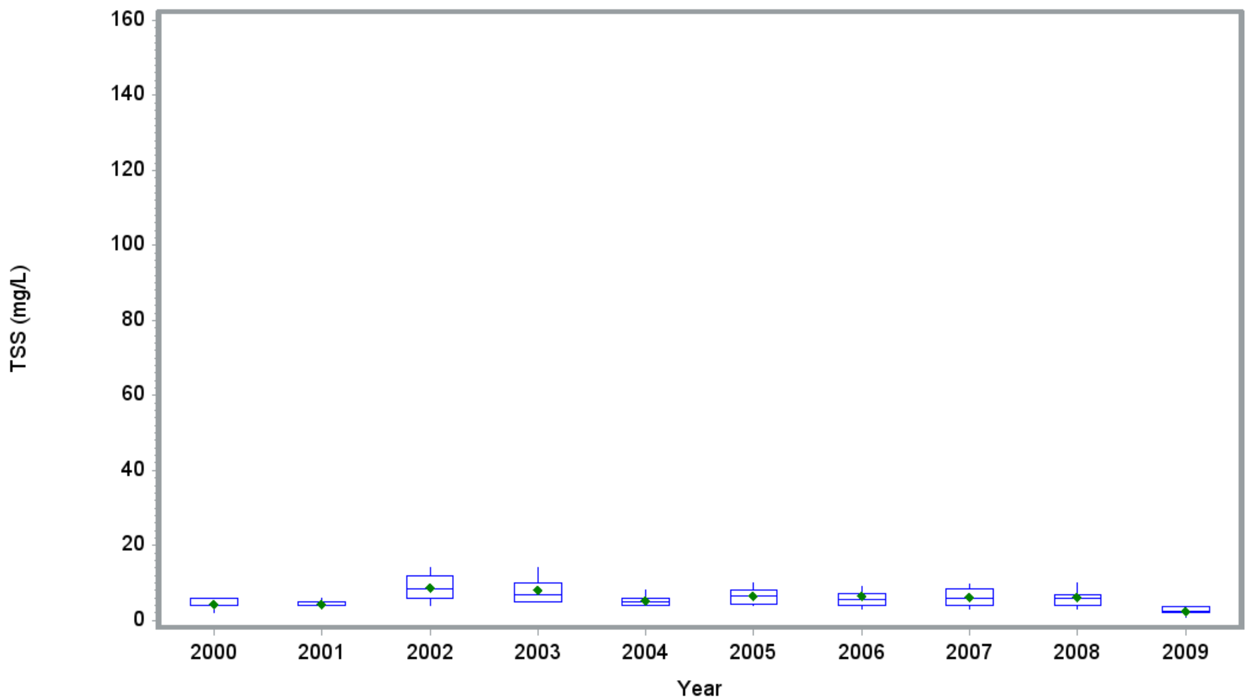



**Figure 3-93 TSS Lower Lake Samples Categorized by Year**

**Table 3-100 TSS Lower Lake Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 9 | 2.00 | 2.00 | 4.00 | 4.33 | 4.00 | 6.00 | 6.00 | 6.00 |
| 2001 | 14 | 1.65 | 3.00 | 4.00 | 4.48 | 4.00 | 5.00 | 6.00 | 10.00 |
| 2002 | 6 | 4.00 | 4.00 | 6.00 | 8.83 | 8.50 | 12.00 | 14.00 | 14.00 |
| 2003 | 6 | 5.00 | 5.00 | 5.00 | 8.00 | 7.00 | 10.00 | 14.00 | 14.00 |
| 2004 | 9 | 4.00 | 4.00 | 4.00 | 5.44 | 5.00 | 6.00 | 8.00 | 8.00 |
| 2005 | 117 | 1.25 | 4.00 | 4.50 | 6.66 | 6.50 | 8.20 | 10.00 | 17.00 |
| 2006 | 126 | 1.25 | 3.20 | 4.00 | 6.64 | 5.65 | 7.20 | 9.00 | 48.00 |
| 2007 | 122 | 3.00 | 3.10 | 4.00 | 6.33 | 6.00 | 8.50 | 9.80 | 14.00 |
| 2008 | 123 | 2.00 | 3.00 | 4.00 | 6.13 | 6.00 | 7.00 | 10.00 | 17.00 |
| 2009 | 6 | 0.90 | 0.90 | 2.00 | 2.55 | 2.55 | 3.60 | 3.70 | 3.70 |

***Total Suspended Sediment Lower Lake Samples Categorized by Month***

> By month, the highest mean TSS was recorded in October, followed by December.

> The lowest mean TSS was recorded in July, followed by September.

> There is a general trend towards higher measurements in the winter months.

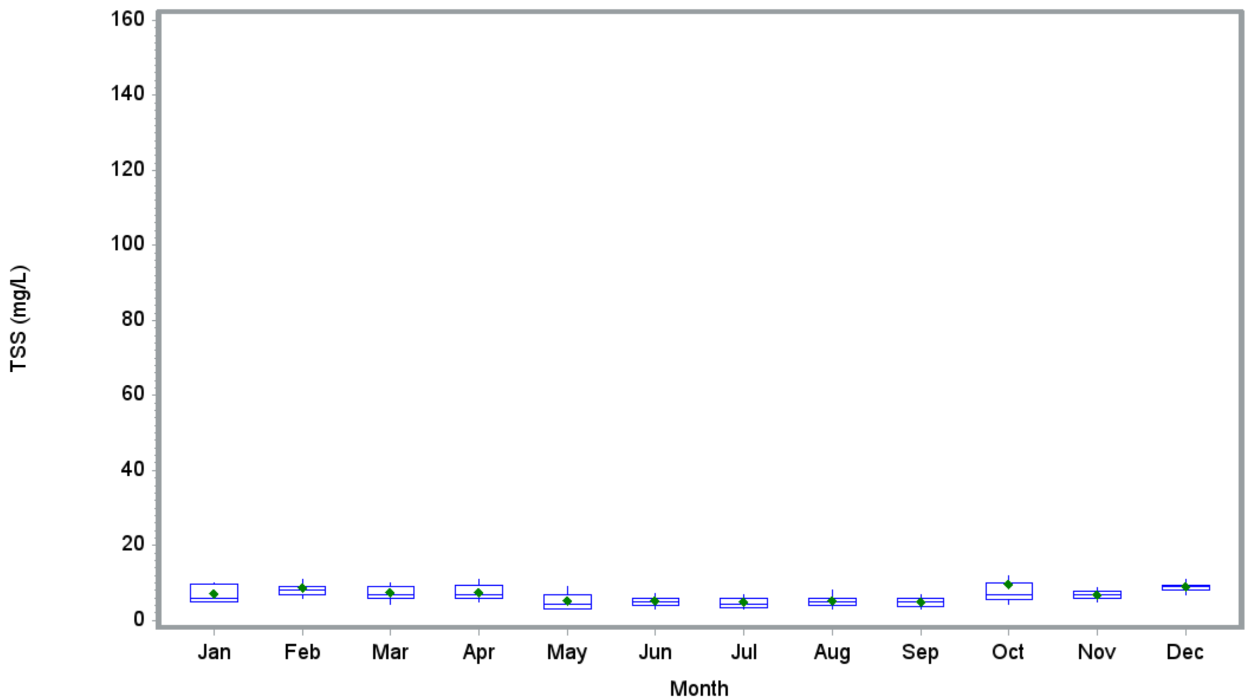



**Figure 3-94 TSS Lower Lake Samples Categorized by Month**

**Table 3-101 TSS Lower Lake Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 26 | 2.80 | 5.00 | 5.00 | 7.13 | 6.00 | 9.80 | 10.00 | 11.00 |
| Feb | 28 | 6.00 | 6.00 | 7.00 | 8.77 | 8.10 | 9.00 | 11.00 | 24.00 |
| Mar | 42 | 2.00 | 4.50 | 6.00 | 7.53 | 7.00 | 9.00 | 10.00 | 17.00 |
| Apr | 50 | 0.90 | 5.00 | 6.00 | 7.61 | 7.00 | 9.50 | 11.00 | 15.00 |
| May | 42 | 1.25 | 3.00 | 3.10 | 5.22 | 4.50 | 7.00 | 9.00 | 13.00 |
| Jun | 66 | 1.25 | 3.10 | 4.00 | 5.34 | 5.00 | 6.00 | 7.20 | 17.00 |
| Jul | 74 | 2.00 | 3.00 | 3.50 | 4.90 | 4.50 | 6.00 | 7.00 | 17.00 |
| Aug | 75 | 1.65 | 3.00 | 4.00 | 5.25 | 5.00 | 6.00 | 8.00 | 14.00 |
| Sep | 52 | 2.00 | 3.00 | 3.75 | 5.07 | 5.00 | 6.00 | 7.00 | 14.00 |
| Oct | 32 | 4.00 | 4.20 | 5.50 | 9.78 | 6.75 | 10.00 | 12.00 | 48.00 |
| Nov | 36 | 4.00 | 5.00 | 6.00 | 6.72 | 6.75 | 7.75 | 8.80 | 10.00 |
| Dec | 15 | 7.00 | 7.00 | 8.20 | 8.99 | 9.20 | 9.50 | 11.00 | 11.00 |

***Total Suspended Sediment Lower Lake Samples Categorized by Sampling Organization***

> Highest mean TSS values were recorded by NCDWQ and lowest mean TSS values were recorded by Wake County.

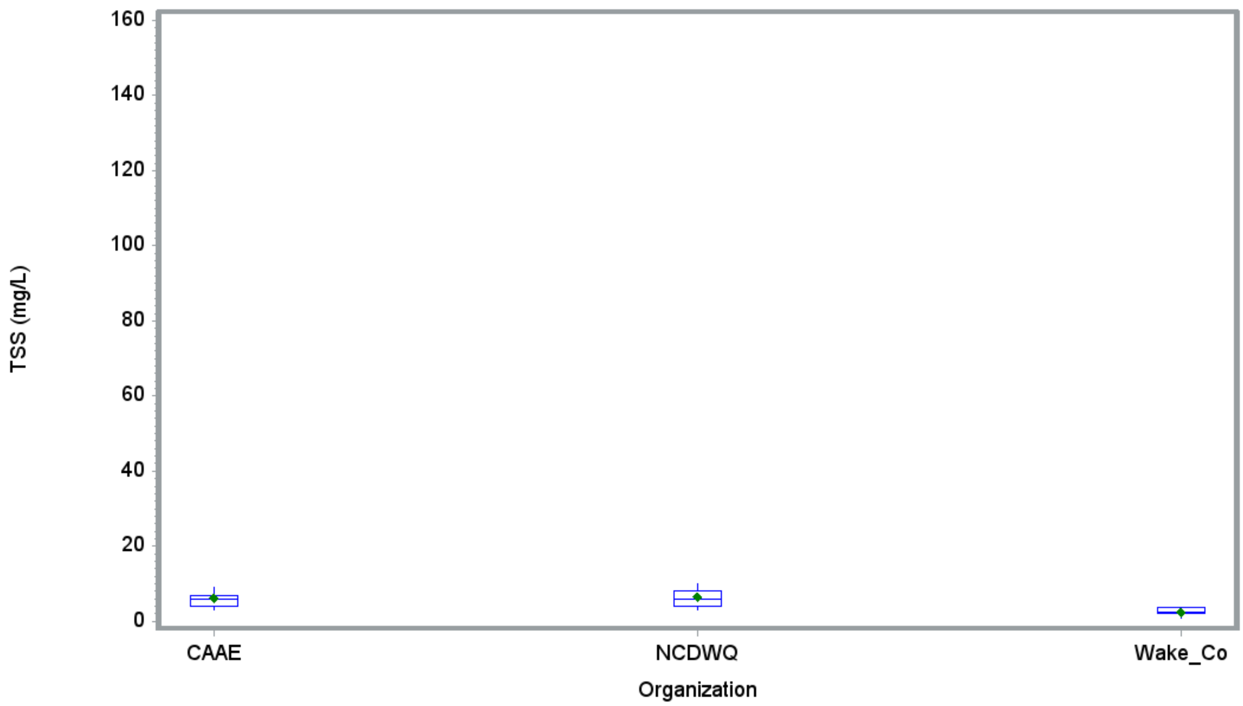



**Figure 3-95 TSS Lower Lake Samples Categorized by Sampling Organization**

**Table 3-102 TSS Lower Lake Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 269 | 2.00 | 3.00 | 4.00 | 6.15 | 6.00 | 7.00 | 9.00 | 24.00 |
| NCDWQ | 263 | 1.25 | 3.10 | 4.00 | 6.61 | 6.00 | 8.20 | 10.00 | 48.00 |
| Wake_Co | 6 | 0.90 | 0.90 | 2.00 | 2.55 | 2.55 | 3.60 | 3.70 | 3.70 |

***Total Suspended Sediment Lower Lake Samples Categorized by Method***

> Both known methods, SM 2540D and CAAE 300 returned similar results, with the mean for SM 2540D being slightly higher. There was a small sample size (n=6) for the unknown method.

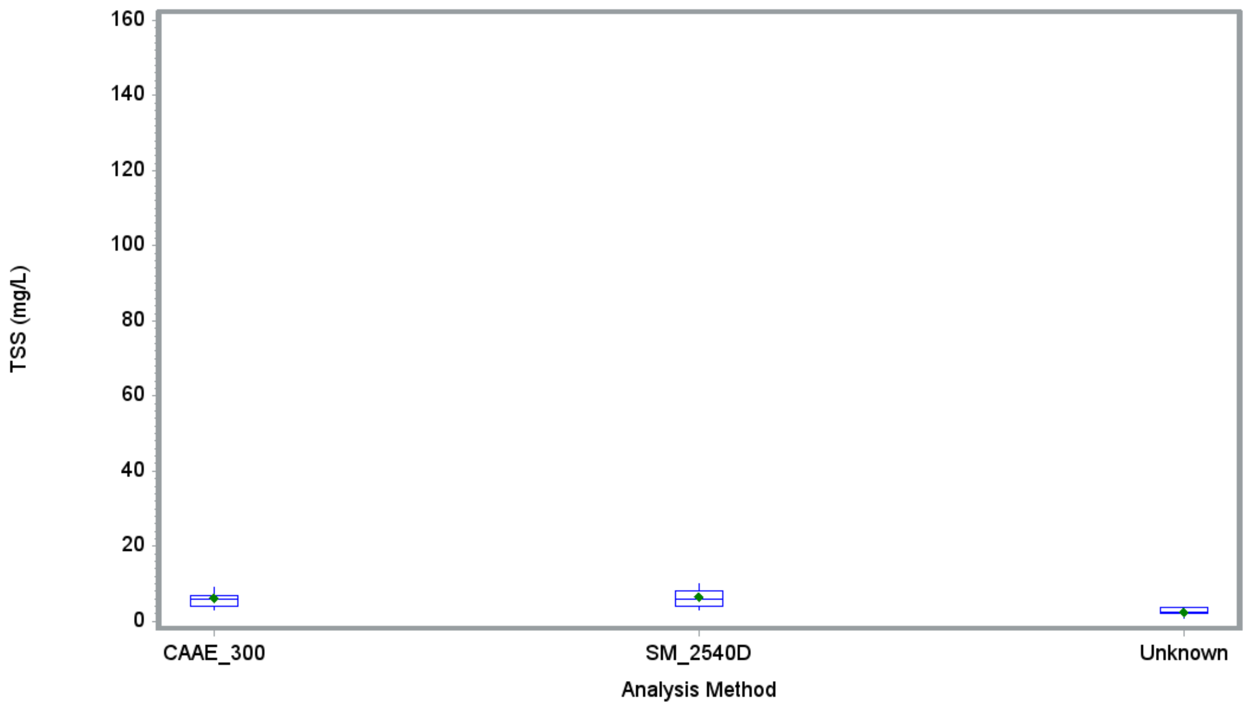



**Figure 3-96 TSS Lower Lake Samples Categorized by Analysis Method**

**Table 3-103 TSS Lower Lake Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE_300 | 269 | 2.00 | 3.00 | 4.00 | 6.15 | 6.00 | 7.00 | 9.00 | 24.00 |
| SM_2540D | 263 | 1.25 | 3.10 | 4.00 | 6.61 | 6.00 | 8.20 | 10.00 | 48.00 |
| Unknown | 6 | 0.90 | 0.90 | 2.00 | 2.55 | 2.55 | 3.60 | 3.70 | 3.70 |

## 3.11 Ammonia

Five organizations measured ammonia concentrations as part of the water quality sampling effort. Ammonia was measured in the laboratory. All concentrations were converted to elemental nitrogen for this analysis (mg-N/L). For those organizations that provided method, the following were used:

- Determination of ammonia nitrogen by semi-automated colorimetry (EPA 350.1)
- Nitrogen, ammonia, potentiometric, ion selective electrode (EPA 350.3)
- Standard method ammonia, ammonia-selective electrode method using known addition (SM 4500$NH_3$-E)
- Nutrients, filtered water, salicylate-hypochlorite, colorimetric (USGS I-2522-90)
- Nutrients, low level, filtered water, salicylate-hypochlorite, colorimetric (USGS I-2525-89)
- Nutrients in filtered water, colorimetric, by discrete analyzer (USGS 48)

Appendix E provides detailed descriptions of these methods.

Table 3-104 describes the organizations and analysis methods used to measure ammonia and includes the number of samples, date range, and limits. The majority of the ammonia data has been collected by

USGS using method USGS_I-2522-90, USGS_I-2525-89, or USGS 48. Ammonia is presented in mg-N/L and to three decimal places based on reported data.

**Table 3-104 Summary of Analysis Methods for the Ammonia Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg-N/L) | Reporting Limit (mg-N/L) | Practical Quanti-fication Limit (mg-N/L) | Range of Limit Specified with Results (mg-N/L) |
|---|---|---|---|---|---|---|---|---|
| Durham_Ci | EPA_350.3 | 04/01/2002 | 04/23/2012 | 1331 | Not Provided | 0.05 | 0.05 | 0.05 |
| NCDWQ[1] | EPA_350.1 | 01/11/1999 | 12/06/2011 | 1,413 | 0.01 | 0.005 | Not Provided | 0.01 to 1.3 |
| Orange_Co | EPA_350.1 | 04/09/2010 | 03/25/2011 | 182 | Not Provided | Not Provided | 0.02 | 0.02 |
| USGS | Various[2] | 01/15/1999 | 10/14/2011 | 1,005 | Not Provided | Not Provided | Not Provided | 0.002 to 0.04 |
| Wake_Co | Not Provided | 07/29/2008 | 10/14/2009 | 157 | Not Provided | Not Provided | 0.007 | 0.04 to 0.08 |

[1]Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

[2]Ammonia analyzed by method USGS_I-2522-90, USGS_I-2525-89, or USGS 48. Methods were not unique to the organization/dataset. Box plot by analysis method displays "Various" for this data to omit long category names.

### 3.11.2 Tributary Samples

Five organizations collected ammonia data in the Falls Lake tributaries from 1999 to 2011. The highest mean concentrations were recorded in Ellerbe Creek and Lick Creek. Lowest mean concentrations were recorded in Honeycutt/Barton Creek and Horse/New Light Creek. Highest mean and median concentrations were recorded by City of Durham and NCDWQ and lowest mean and median concentrations were recorded by Orange County. Highest mean concentrations were recorded in 2011 and 2001, while lowest mean concentrations were recorded in 2002 and 2003.

***Ammonia Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

- Ammonia was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River and Horse/New Light Creek, and Honeycutt/Barton Creek.
- Highest mean and median concentrations were measured in Ellerbe Creek and Lick Creek.
- By section, highest mean concentrations were recorded in Ellerbe Creek 0 to 2 miles, Lick Creek 2 to 10 miles, and Beaverdam Creek 2 to 10 miles from mouth.
- Lowest mean concentrations were measured in Honeycutt/Barton Creek and Horse/New Light Creek, while lowest median concentrations were recorded Little River.
- By section, lowest mean concentrations were recorded in the Flat River > 10 mile, Beaverdam Creek 0 to 2 mile, and Eno River > 10 mile sections, however, there was only one sample for the Flat River section.
- Median concentrations were highest in the Lick Creek 2 to 10 miles and Ellerbe Creek 0 to 2 miles sections.

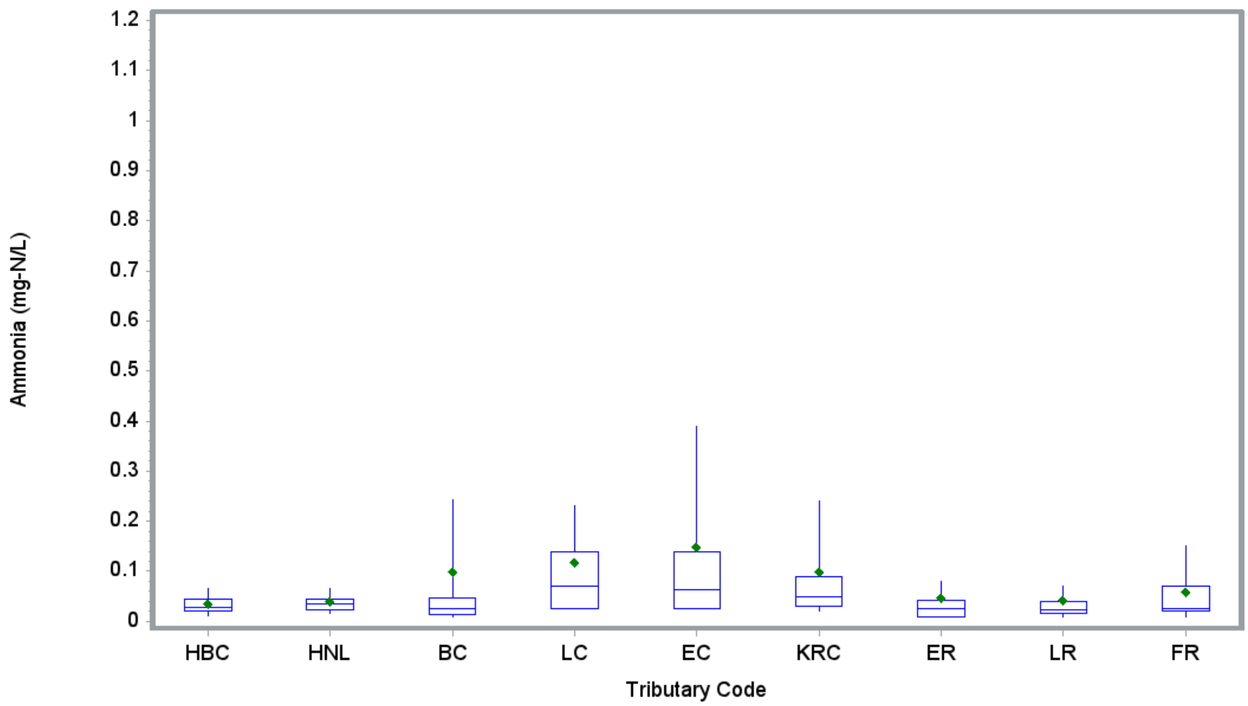



**Figure 3-97 Ammonia Tributary Samples Categorized by Subwatershed**

**Table 3-105 Ammonia Tributary Samples Categorized by Subwatershed (in mg-N/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 78 | 0.005 | 0.012 | 0.021 | 0.036 | 0.029 | 0.044 | 0.066 | 0.206 |
| HNL | 50 | 0.003 | 0.017 | 0.023 | 0.039 | 0.035 | 0.044 | 0.066 | 0.233 |
| BC | 49 | 0.007 | 0.010 | 0.013 | 0.098 | 0.026 | 0.047 | 0.242 | 1.130 |
| LC | 121 | 0.010 | 0.025 | 0.025 | 0.117 | 0.070 | 0.140 | 0.230 | 0.920 |
| EC | 441 | 0.005 | 0.025 | 0.025 | 0.150 | 0.064 | 0.140 | 0.390 | 1.940 |
| KRC | 137 | 0.020 | 0.020 | 0.030 | 0.099 | 0.050 | 0.090 | 0.240 | 0.920 |
| ER | 534 | 0.001 | 0.010 | 0.010 | 0.046 | 0.025 | 0.041 | 0.080 | 1.020 |
| LR | 429 | 0.005 | 0.010 | 0.016 | 0.043 | 0.022 | 0.040 | 0.070 | 1.950 |
| FR | 246 | 0.002 | 0.010 | 0.020 | 0.057 | 0.025 | 0.070 | 0.150 | 0.730 |

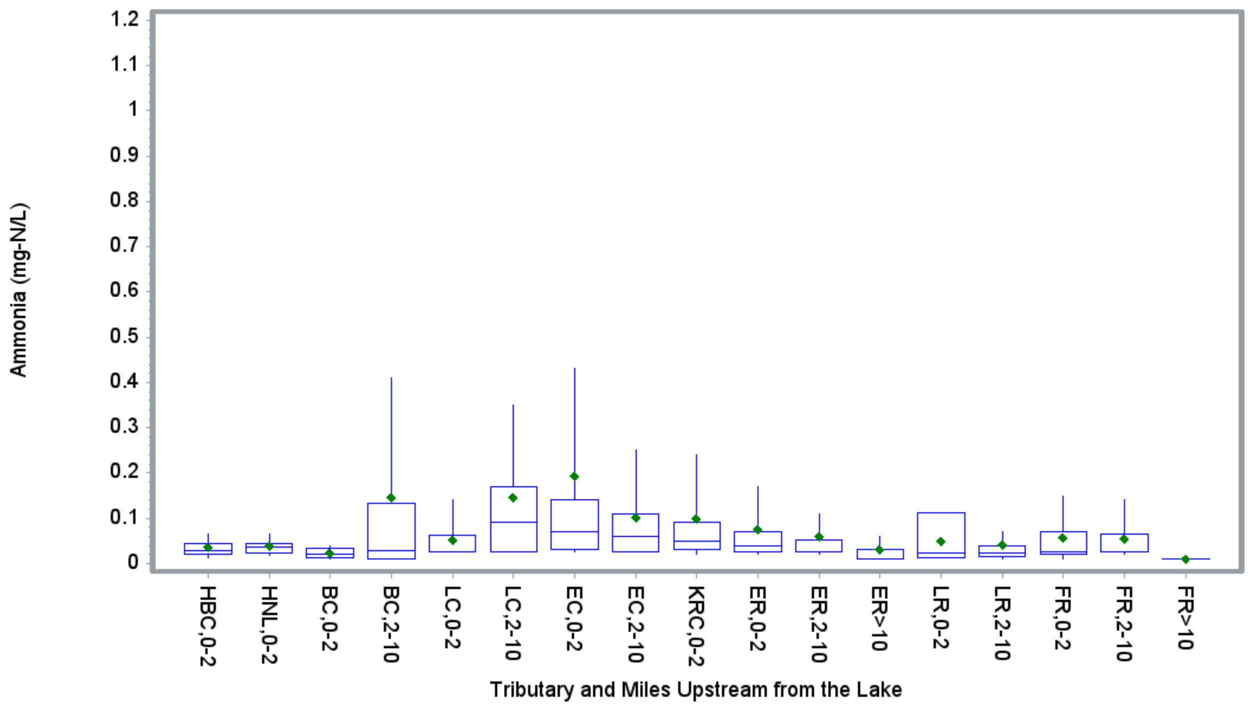



**Figure 3-98 Ammonia Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-106 Ammonia Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in mg-N/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 78 | 0.005 | 0.012 | 0.021 | 0.036 | 0.029 | 0.044 | 0.066 | 0.206 |
| HNL,0-2 | 50 | 0.003 | 0.017 | 0.023 | 0.039 | 0.035 | 0.044 | 0.066 | 0.233 |
| BC,0-2 | 19 | 0.008 | 0.011 | 0.014 | 0.024 | 0.020 | 0.033 | 0.039 | 0.039 |
| BC,2-10 | 30 | 0.007 | 0.010 | 0.010 | 0.145 | 0.030 | 0.134 | 0.410 | 1.130 |
| LC,0-2 | 36 | 0.010 | 0.025 | 0.025 | 0.051 | 0.025 | 0.062 | 0.140 | 0.190 |
| LC,2-10 | 85 | 0.013 | 0.025 | 0.025 | 0.145 | 0.090 | 0.170 | 0.350 | 0.920 |
| EC,0-2 | 225 | 0.010 | 0.025 | 0.030 | 0.194 | 0.070 | 0.150 | 0.500 | 1.940 |
| EC,2-10 | 216 | 0.005 | 0.025 | 0.025 | 0.103 | 0.060 | 0.115 | 0.260 | 1.290 |
| KRC,0-2 | 137 | 0.020 | 0.020 | 0.030 | 0.099 | 0.050 | 0.090 | 0.240 | 0.920 |
| ER,0-2 | 69 | 0.004 | 0.020 | 0.025 | 0.075 | 0.040 | 0.070 | 0.170 | 1.000 |
| ER,2-10 | 184 | 0.010 | 0.020 | 0.025 | 0.059 | 0.025 | 0.052 | 0.110 | 0.460 |
| ER>10 | 281 | 0.001 | 0.010 | 0.010 | 0.031 | 0.010 | 0.030 | 0.060 | 1.020 |
| LR,0-2 | 3 | 0.012 | 0.012 | 0.012 | 0.049 | 0.023 | 0.111 | 0.111 | 0.111 |
| LR,2-10 | 426 | 0.005 | 0.010 | 0.016 | 0.043 | 0.022 | 0.040 | 0.070 | 1.950 |
| FR,0-2 | 201 | 0.002 | 0.010 | 0.020 | 0.058 | 0.025 | 0.070 | 0.150 | 0.730 |
| FR,2-10 | 44 | 0.010 | 0.020 | 0.025 | 0.056 | 0.025 | 0.065 | 0.140 | 0.320 |
| FR>10 | 1 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 | 0.010 |

### *Ammonia Tributary Samples Categorized by Depth*

> All samples were collected in the surface layer.

### *Ammonia Tributary Samples Categorized by Year*

> By year, highest mean concentrations were recorded in 2011, 2001 and 2005.

> The lowest mean concentrations were recorded in 2002 and 2008.

> Median concentrations were similar for all years, with highest concentrations recorded in 1999 and lowest concentrations recorded in 2002 and 2003.

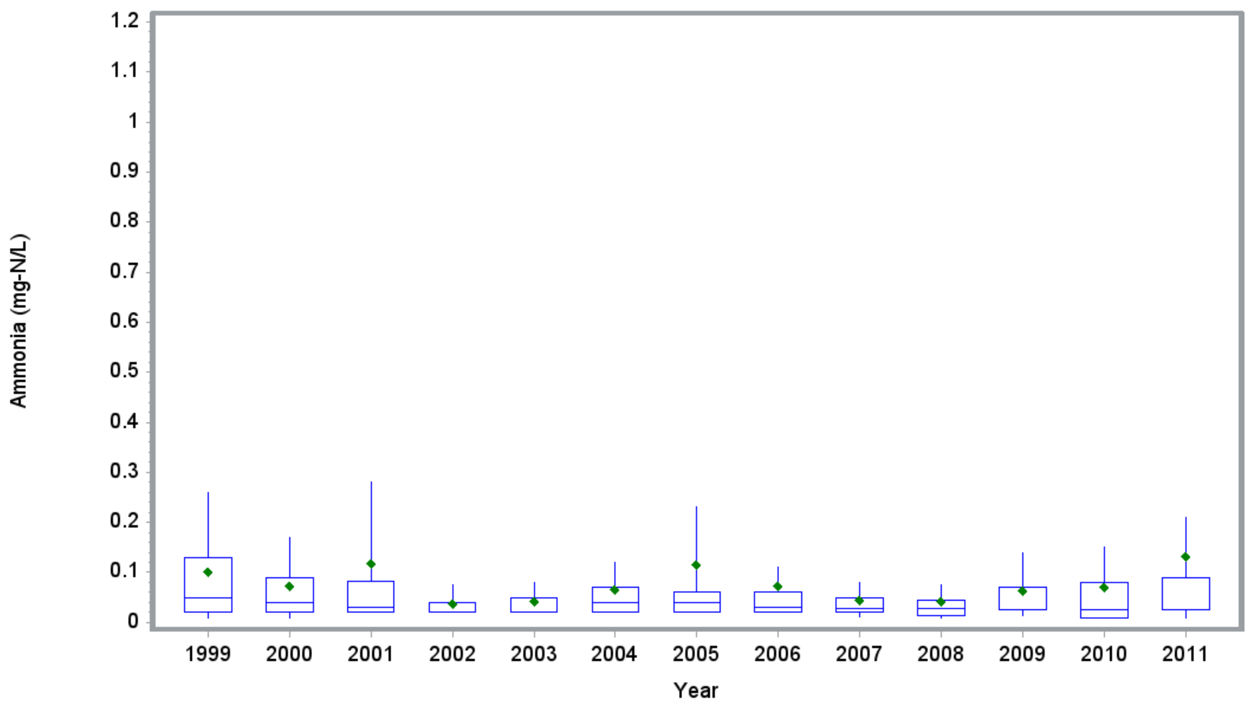



**Figure 3-99 Ammonia Tributary Samples Categorized by Year**

**Table 3-107 Ammonia Tributary Samples Categorized by Year (in mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 125 | 0.002 | 0.010 | 0.021 | 0.102 | 0.050 | 0.130 | 0.260 | 0.920 |
| 2000 | 107 | 0.001 | 0.010 | 0.020 | 0.072 | 0.040 | 0.090 | 0.170 | 0.650 |
| 2001 | 61 | 0.002 | 0.020 | 0.020 | 0.117 | 0.030 | 0.082 | 0.280 | 1.000 |
| 2002 | 43 | 0.012 | 0.020 | 0.020 | 0.037 | 0.021 | 0.040 | 0.074 | 0.152 |
| 2003 | 80 | 0.008 | 0.020 | 0.020 | 0.042 | 0.021 | 0.050 | 0.080 | 0.200 |
| 2004 | 84 | 0.009 | 0.020 | 0.020 | 0.065 | 0.040 | 0.070 | 0.120 | 0.470 |
| 2005 | 126 | 0.007 | 0.020 | 0.020 | 0.115 | 0.040 | 0.070 | 0.300 | 1.950 |
| 2006 | 135 | 0.009 | 0.020 | 0.020 | 0.073 | 0.030 | 0.060 | 0.113 | 1.300 |
| 2007 | 105 | 0.010 | 0.011 | 0.020 | 0.044 | 0.028 | 0.050 | 0.080 | 0.740 |
| 2008 | 159 | 0.003 | 0.010 | 0.013 | 0.041 | 0.028 | 0.045 | 0.074 | 0.450 |
| 2009 | 362 | 0.009 | 0.014 | 0.025 | 0.063 | 0.026 | 0.070 | 0.140 | 0.760 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | 458 | 0.005 | 0.010 | 0.010 | 0.071 | 0.025 | 0.080 | 0.150 | 1.020 |
| 2011 | 240 | 0.005 | 0.010 | 0.025 | 0.132 | 0.025 | 0.105 | 0.300 | 1.940 |

***Ammonia Tributary Samples Categorized by Month***

> By month, the highest mean and median concentrations were recorded in January, May, and June.

> The lowest mean concentrations were recorded in February.

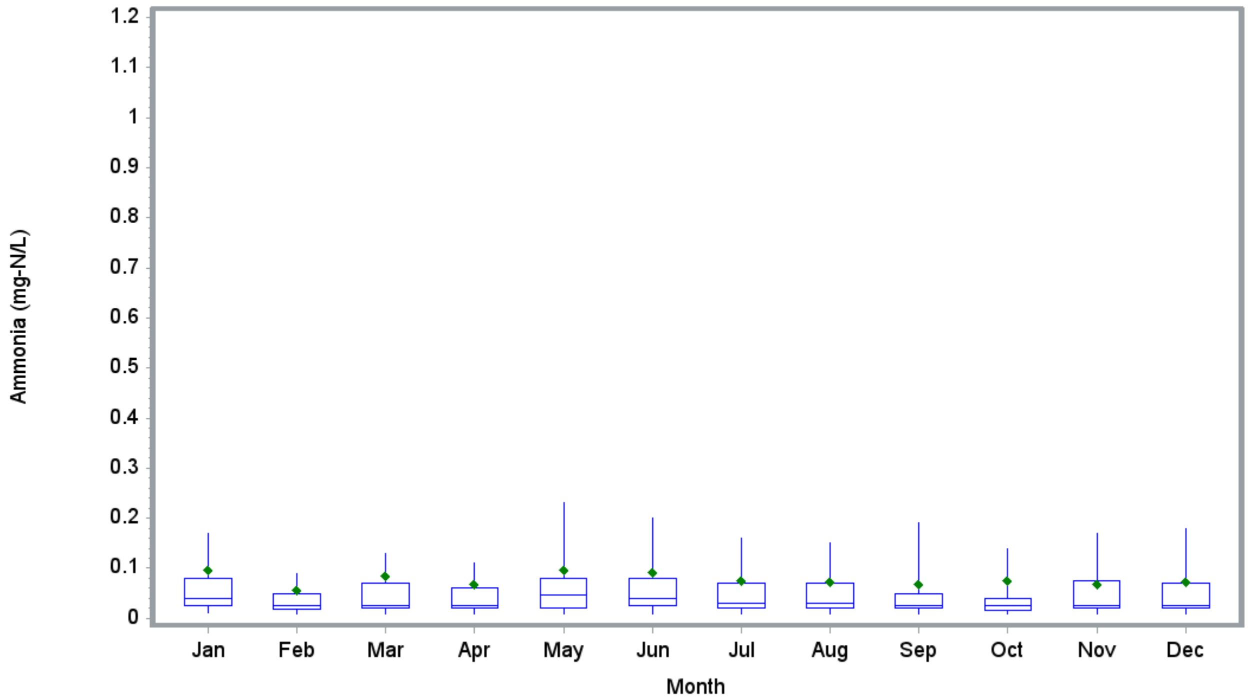



**Figure 3-100 Ammonia Tributary Samples Categorized by Month**

**Table 3-108 Ammonia Tributary Samples Categorized by Month (in mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 155 | 0.010 | 0.012 | 0.025 | 0.097 | 0.040 | 0.090 | 0.180 | 1.500 |
| Feb | 176 | 0.003 | 0.010 | 0.019 | 0.057 | 0.025 | 0.050 | 0.100 | 1.300 |
| Mar | 167 | 0.005 | 0.010 | 0.020 | 0.084 | 0.027 | 0.070 | 0.134 | 1.720 |
| Apr | 193 | 0.002 | 0.010 | 0.020 | 0.068 | 0.025 | 0.060 | 0.110 | 1.940 |
| May | 169 | 0.005 | 0.010 | 0.020 | 0.096 | 0.050 | 0.080 | 0.230 | 1.290 |
| Jun | 200 | 0.009 | 0.010 | 0.025 | 0.092 | 0.040 | 0.080 | 0.200 | 1.950 |
| Jul | 189 | 0.005 | 0.010 | 0.020 | 0.075 | 0.030 | 0.070 | 0.160 | 0.870 |
| Aug | 169 | 0.009 | 0.010 | 0.020 | 0.073 | 0.031 | 0.070 | 0.150 | 1.700 |
| Sep | 169 | 0.005 | 0.010 | 0.020 | 0.069 | 0.025 | 0.050 | 0.190 | 1.130 |
| Oct | 166 | 0.001 | 0.010 | 0.015 | 0.074 | 0.025 | 0.050 | 0.180 | 1.300 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Nov | 150 | 0.002 | 0.010 | 0.020 | 0.069 | 0.025 | 0.074 | 0.169 | 0.670 |
| Dec | 182 | 0.005 | 0.010 | 0.020 | 0.072 | 0.025 | 0.070 | 0.180 | 0.820 |

***Ammonia Tributary Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean concentrations were recorded by NCDWQ and City of Durham.

> Lowest mean and median concentrations were recorded by Orange County.

> For the most part, the data categorized by organization is similar.  The Orange County dataset appears to have lower ammonia concentrations relative to the other organizations which is likely due to sampling location.

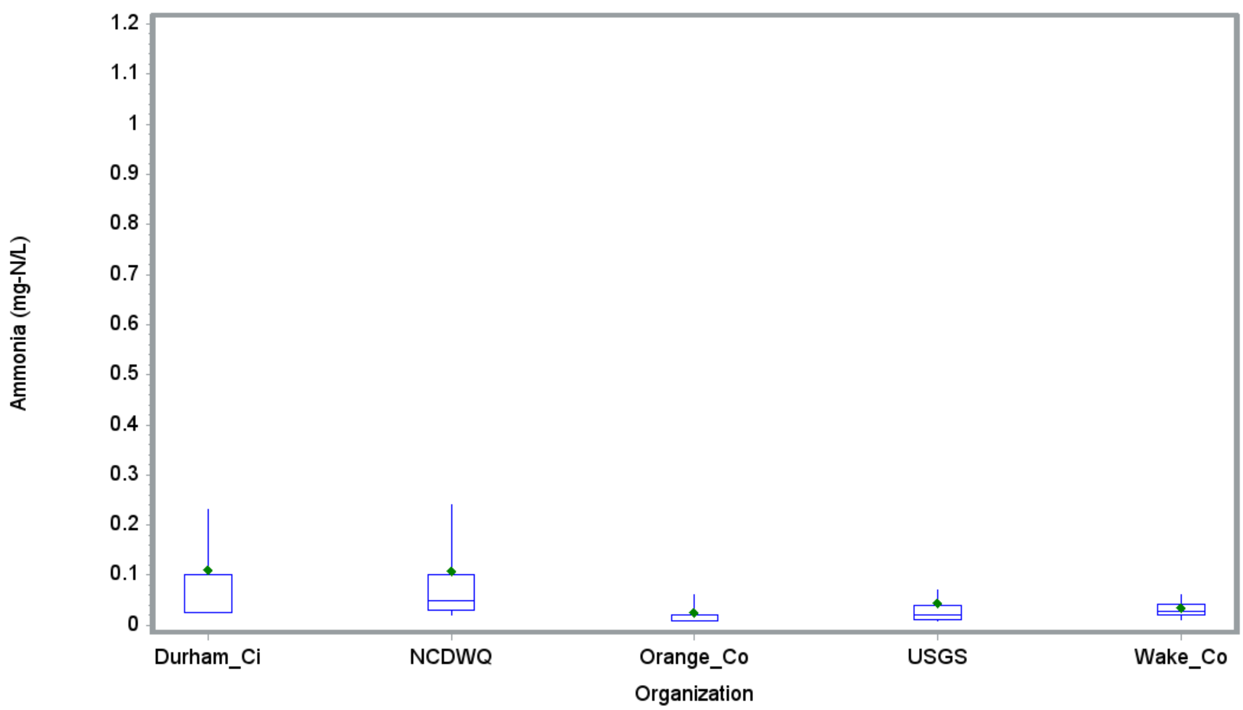



**Figure 3-101  Ammonia Tributary Samples Categorized by Sampling Organization**

**Table 3-109  Ammonia Tributary Samples Categorized by Sampling Organization (in mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 630 | 0.013 | 0.025 | 0.025 | 0.110 | 0.025 | 0.100 | 0.255 | 1.940 |
| NCDWQ | 499 | 0.010 | 0.020 | 0.030 | 0.107 | 0.050 | 0.100 | 0.260 | 1.300 |
| Orange_Co | 182 | 0.010 | 0.010 | 0.010 | 0.026 | 0.010 | 0.020 | 0.060 | 0.260 |
| USGS | 628 | 0.001 | 0.010 | 0.012 | 0.045 | 0.020 | 0.040 | 0.073 | 1.950 |
| Wake_Co | 146 | 0.003 | 0.012 | 0.020 | 0.035 | 0.029 | 0.042 | 0.061 | 0.233 |

### *Ammonia Tributary Samples Categorized by Method*

- By method, the highest mean concentrations were recorded using EPA 350.1 and EPA 350.3 methods.
- Lowest mean concentrations were recorded using unknown and various methods.

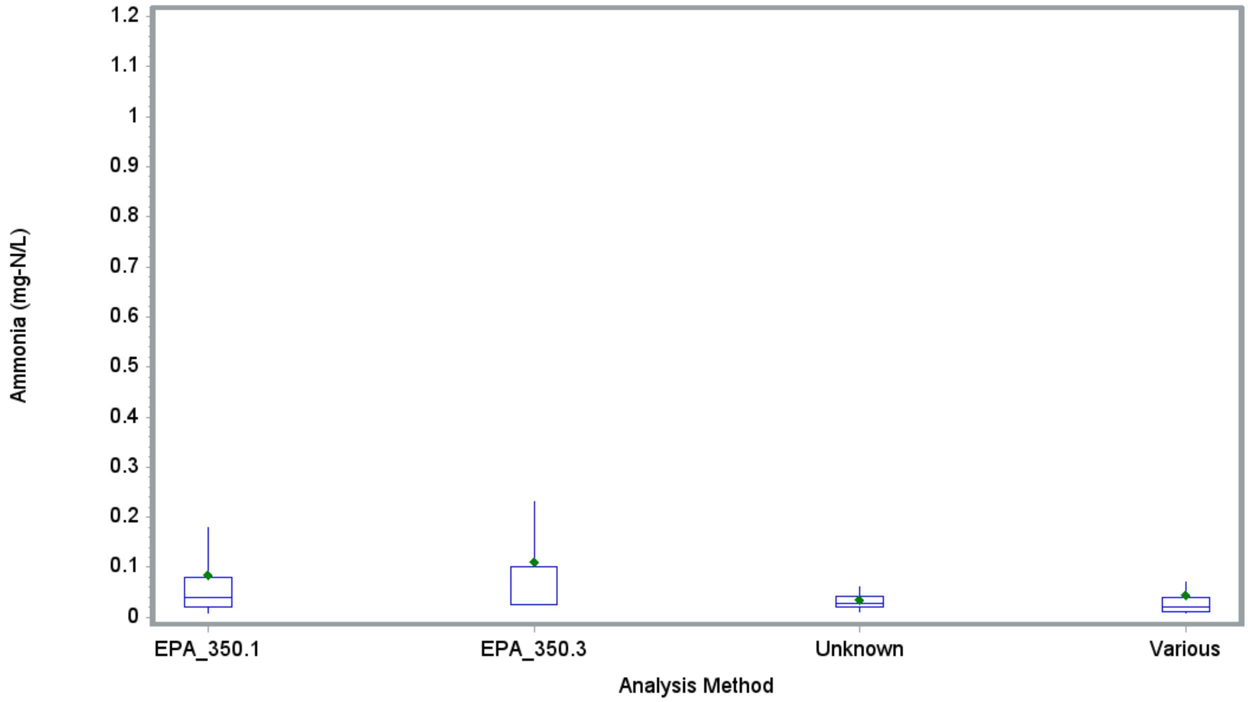



**Figure 3-102 Ammonia Tributary Samples Categorized by Analysis Method**

**Table 3-110 Ammonia Tributary Samples Categorized by Analysis Method (in mg-N/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_350.1 | 681 | 0.010 | 0.010 | 0.020 | 0.086 | 0.040 | 0.080 | 0.180 | 1.300 |
| EPA_350.3 | 630 | 0.013 | 0.025 | 0.025 | 0.110 | 0.025 | 0.100 | 0.255 | 1.940 |
| Unknown | 146 | 0.003 | 0.012 | 0.020 | 0.035 | 0.029 | 0.042 | 0.061 | 0.233 |
| Various | 626 | 0.001 | 0.010 | 0.012 | 0.045 | 0.020 | 0.040 | 0.073 | 1.950 |

### *Ammonia Comparing Different Methods for Handling Data Reported as Below the Detection Limit*

- There is little difference in the distribution of results when using full detection limit, half detection limit, or zero to represent below detection limit values.

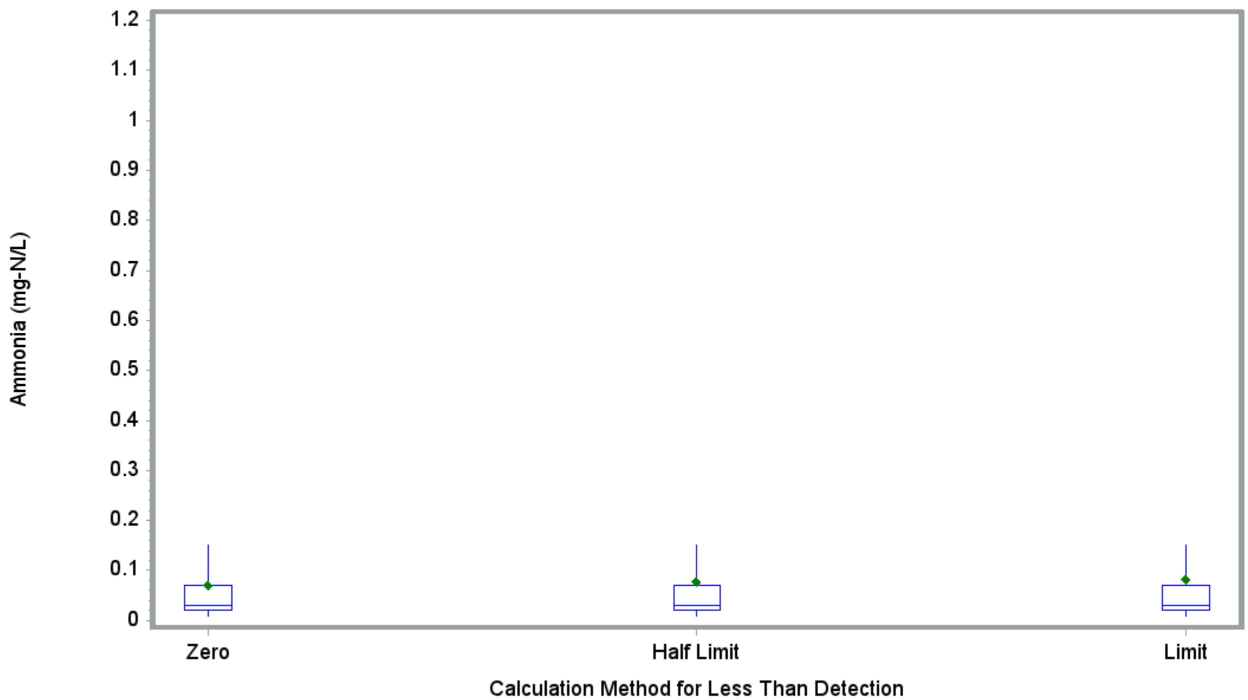



**Figure 3-103 Ammonia Tributary Samples Categorized by Limit Calculation**

### 3.11.3 Upper Lake Samples

Three organizations measured total ammonia concentrations in upper Falls Lake from 2000 to 2012. Highest mean and median concentrations were recorded by City of Durham and lowest mean concentration was recorded by NCDWQ. Highest mean concentrations were recorded in the > 21 mile section upstream of the dam and in the bottom depth zone. Highest mean concentrations were recorded in 2002 and 2001, while the lowest mean concentrations were recorded in 2010 and 2000. Box plot summaries are provided below.

***Total Ammonia Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Mean and median concentrations were highest in the > 21 mile section.

> Mean and median concentrations were similar in the 13 to 18 and 18 to 21 mile sections.

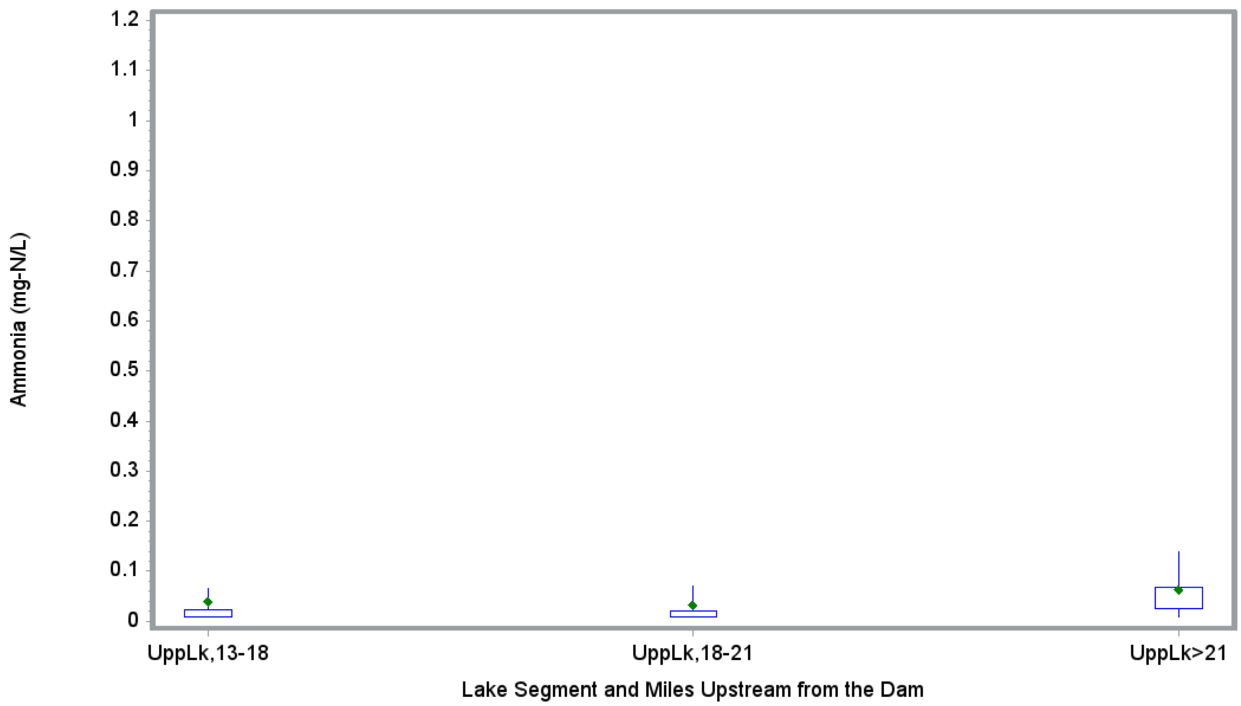



**Figure 3-104 Ammonia Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-111 Ammonia Upper Lake Samples Categorized by Miles Upstream from Dam (in mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 397 | 0.005 | 0.010 | 0.010 | 0.040 | 0.010 | 0.022 | 0.065 | 2.600 |
| UppLk,18-21 | 89 | 0.005 | 0.010 | 0.010 | 0.032 | 0.010 | 0.020 | 0.070 | 0.360 |
| UppLk>21 | 947 | 0.005 | 0.010 | 0.025 | 0.063 | 0.025 | 0.067 | 0.140 | 1.810 |

### *Total Ammonia Upper Lake Samples Categorized by Depth*

> By depth, highest mean and median concentrations were measured at the bottom layer and lowest concentrations measured in the photic zone.

> The greatest variability of measurements was from the bottom layer, however there was a low sample size (n=27) relative to the other two categories.

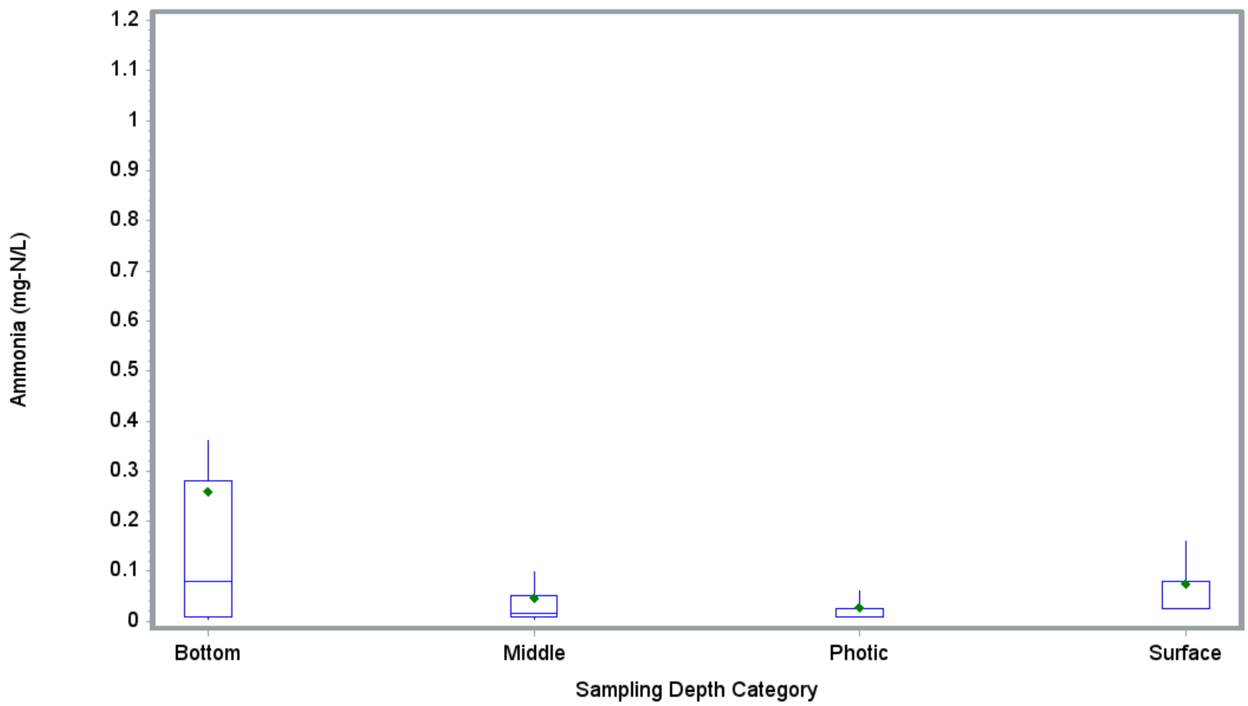



**Figure 3-105 Ammonia Upper Lake Samples Categorized by Depth Category**

**Table 3-112 Ammonia Upper Lake Samples Categorized by Depth Category (in mg-N/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 27 | 0.005 | 0.005 | 0.010 | 0.259 | 0.080 | 0.280 | 0.360 | 2.600 |
| Middle | 160 | 0.005 | 0.005 | 0.010 | 0.048 | 0.015 | 0.052 | 0.098 | 0.985 |
| Photic | 601 | 0.005 | 0.010 | 0.010 | 0.027 | 0.010 | 0.025 | 0.060 | 0.430 |
| Surface | 645 | 0.005 | 0.025 | 0.025 | 0.074 | 0.025 | 0.080 | 0.160 | 1.810 |

***Total Ammonia Upper Lake Categorized by Year***

> By year, highest mean concentration was recorded in 2002 and 2001.

> Median concentrations were relatively similar across all years except for 2001.

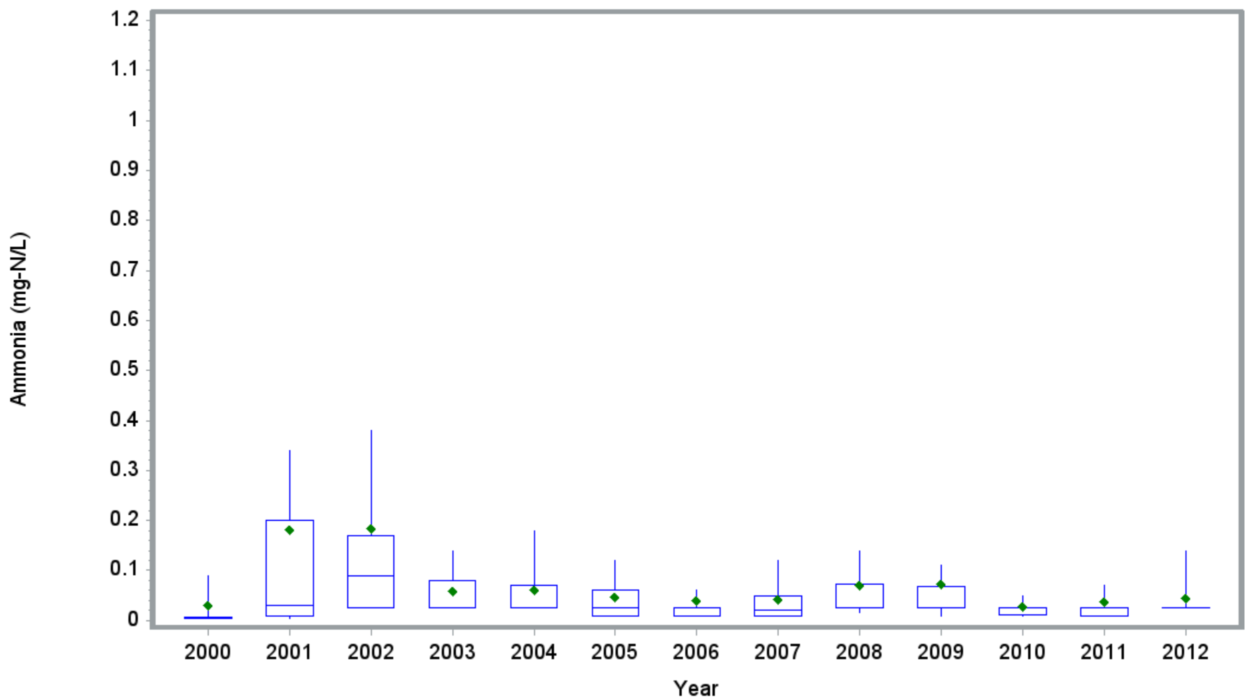



**Figure 3-106 Ammonia Upper Lake Samples Categorized by Year**

**Table 3-113 Ammonia Upper Lake Samples Categorized by Year (in mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 16 | 0.005 | 0.005 | 0.005 | 0.030 | 0.005 | 0.008 | 0.090 | 0.260 |
| 2001 | 35 | 0.005 | 0.005 | 0.010 | 0.182 | 0.030 | 0.210 | 0.340 | 2.600 |
| 2002 | 62 | 0.025 | 0.025 | 0.025 | 0.183 | 0.095 | 0.180 | 0.510 | 1.810 |
| 2003 | 60 | 0.025 | 0.025 | 0.025 | 0.059 | 0.025 | 0.080 | 0.140 | 0.490 |
| 2004 | 60 | 0.025 | 0.025 | 0.025 | 0.061 | 0.025 | 0.070 | 0.180 | 0.310 |
| 2005 | 173 | 0.005 | 0.010 | 0.010 | 0.047 | 0.025 | 0.060 | 0.120 | 0.540 |
| 2006 | 232 | 0.006 | 0.010 | 0.010 | 0.039 | 0.010 | 0.025 | 0.070 | 1.370 |
| 2007 | 212 | 0.010 | 0.010 | 0.010 | 0.043 | 0.020 | 0.050 | 0.120 | 0.340 |
| 2008 | 92 | 0.010 | 0.015 | 0.025 | 0.071 | 0.025 | 0.077 | 0.140 | 1.300 |
| 2009 | 100 | 0.010 | 0.010 | 0.025 | 0.074 | 0.025 | 0.068 | 0.115 | 1.440 |
| 2010 | 183 | 0.005 | 0.010 | 0.011 | 0.029 | 0.025 | 0.025 | 0.050 | 0.230 |
| 2011 | 193 | 0.005 | 0.010 | 0.010 | 0.037 | 0.025 | 0.025 | 0.070 | 0.985 |
| 2012 | 15 | 0.020 | 0.025 | 0.025 | 0.044 | 0.025 | 0.025 | 0.140 | 0.190 |

### *Total Ammonia Upper Lake Samples Categorized by Month*

> By month, the highest mean concentrations were measured in August, October, and November.

> The lowest mean concentrations were measured March, February and January.

> Median concentrations were similar between all months with the highest concentration recorded in December.

> The lowest variability in measurements were recorded in February, March and April.

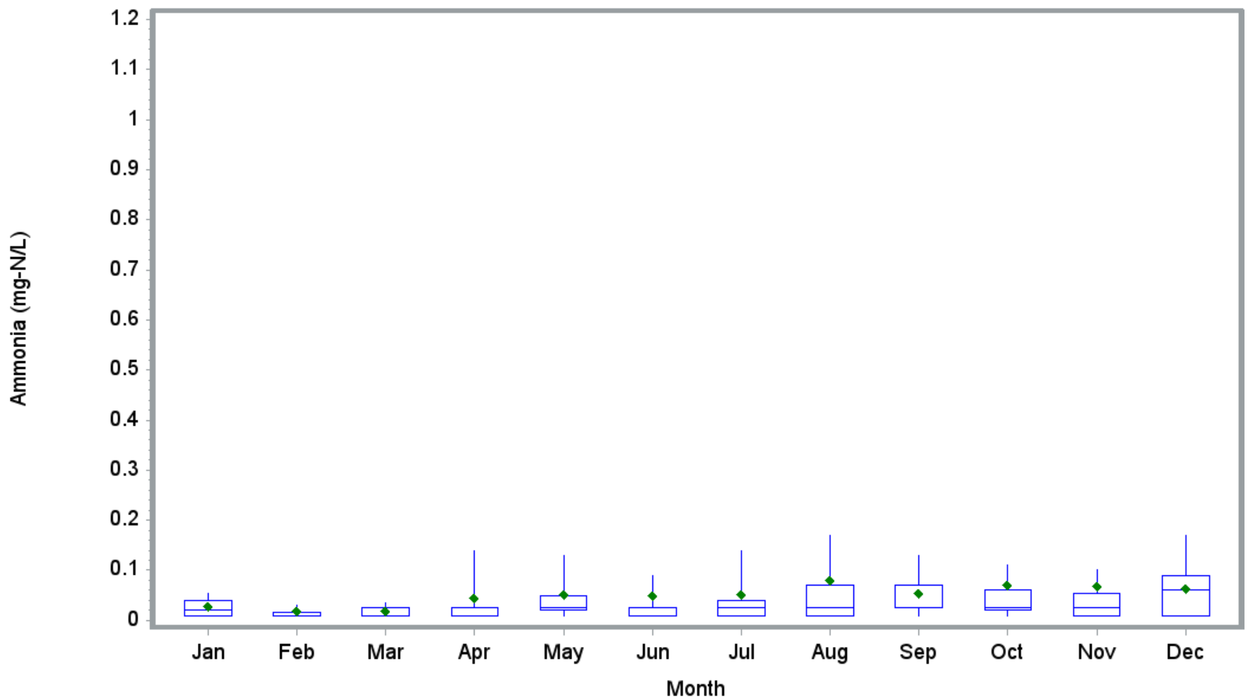



**Figure 3-107 Ammonia Upper Lake Samples Categorized by Month**

**Table 3-114 Ammonia Upper Lake Samples Categorized by Month (in mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 30 | 0.010 | 0.010 | 0.010 | 0.028 | 0.020 | 0.040 | 0.055 | 0.080 |
| Feb | 48 | 0.010 | 0.010 | 0.010 | 0.020 | 0.010 | 0.016 | 0.030 | 0.286 |
| Mar | 57 | 0.005 | 0.010 | 0.010 | 0.017 | 0.010 | 0.025 | 0.035 | 0.070 |
| Apr | 186 | 0.005 | 0.010 | 0.010 | 0.044 | 0.025 | 0.025 | 0.140 | 0.410 |
| May | 137 | 0.010 | 0.010 | 0.020 | 0.051 | 0.025 | 0.050 | 0.130 | 0.820 |
| Jun | 183 | 0.005 | 0.010 | 0.010 | 0.049 | 0.025 | 0.025 | 0.090 | 1.300 |
| Jul | 167 | 0.005 | 0.010 | 0.010 | 0.052 | 0.025 | 0.040 | 0.140 | 0.600 |
| Aug | 211 | 0.005 | 0.010 | 0.010 | 0.079 | 0.025 | 0.070 | 0.170 | 2.600 |
| Sep | 149 | 0.005 | 0.010 | 0.025 | 0.055 | 0.025 | 0.070 | 0.130 | 0.310 |
| Oct | 162 | 0.005 | 0.010 | 0.020 | 0.069 | 0.025 | 0.060 | 0.110 | 1.810 |
| Nov | 56 | 0.010 | 0.010 | 0.010 | 0.068 | 0.025 | 0.055 | 0.100 | 1.440 |
| Dec | 47 | 0.010 | 0.010 | 0.010 | 0.064 | 0.060 | 0.090 | 0.170 | 0.220 |

***Total Ammonia Upper Lake Samples Categorized by Sampling Organization***

> By sampling organization, City of Durham recorded the highest mean and median concentrations.

> Lowest mean and median measurements were recorded by NCDWQ.

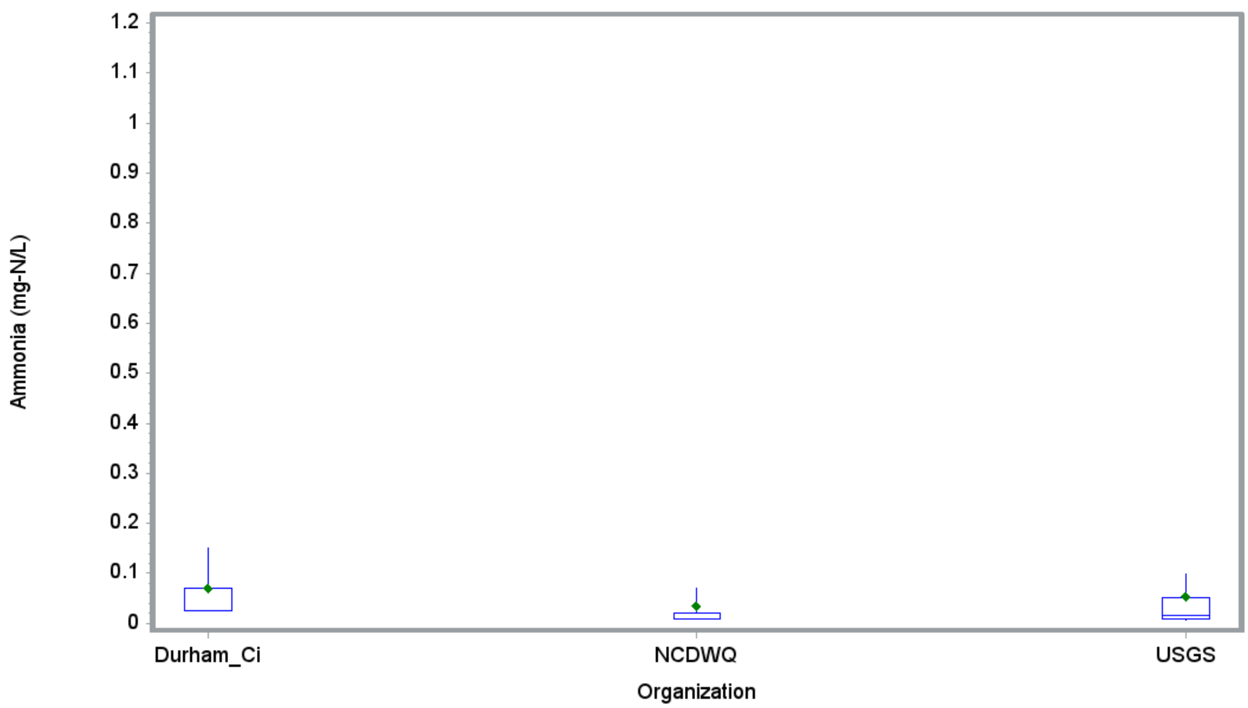



**Figure 3-108 Ammonia Upper Lake Samples Categorized by Sampling Organization**

**Table 3-115 Ammonia Upper Lake Samples Categorized by Sampling Organization (in mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 701 | 0.020 | 0.025 | 0.025 | 0.071 | 0.025 | 0.070 | 0.150 | 1.810 |
| NCDWQ | 549 | 0.005 | 0.010 | 0.010 | 0.035 | 0.010 | 0.020 | 0.070 | 2.600 |
| USGS | 183 | 0.005 | 0.006 | 0.010 | 0.054 | 0.015 | 0.051 | 0.099 | 1.300 |

***Total Ammonia Upper Lake Samples Categorized by Method***

> By method, highest mean and median concentrations were recorded using EPA 350.3 method.

> The EPA 350.1 method returned the lowest mean and median concentrations.

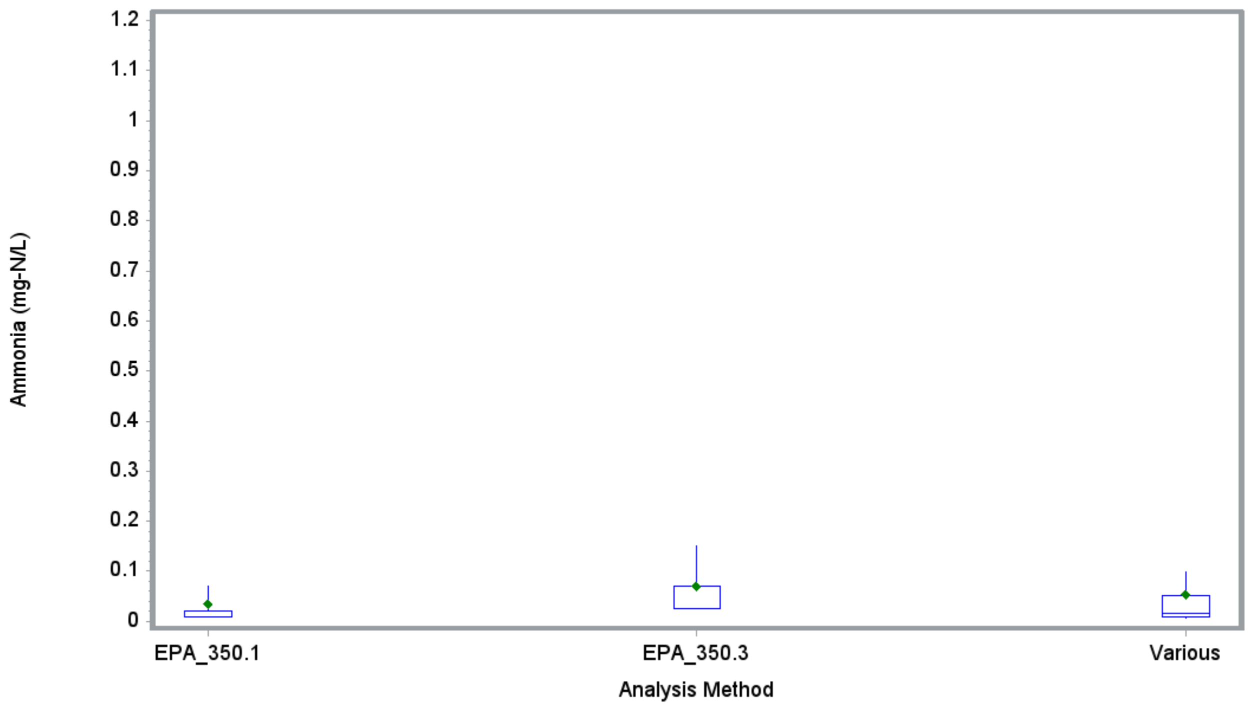



**Figure 3-109 Ammonia Upper Lake Samples Categorized by Analysis Method**

**Table 3-116 Ammonia Upper Lake Samples Categorized by Analysis Method (in mg-N/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_350.1 | 549 | 0.005 | 0.010 | 0.010 | 0.035 | 0.010 | 0.020 | 0.070 | 2.600 |
| EPA_350.03 | 701 | 0.020 | 0.025 | 0.025 | 0.071 | 0.025 | 0.070 | 0.150 | 1.810 |
| Various | 183 | 0.005 | 0.006 | 0.010 | 0.054 | 0.015 | 0.051 | 0.099 | 1.300 |

***Total Ammonia Comparing Different Methods for Handling Data Reported as Below the Detection Limit***

> There is little difference in the overall distribution of results when using full detection limit, half detection limit, or zero to represent below detection limit values.

> Using the full detection limits results in higher mean concentration.

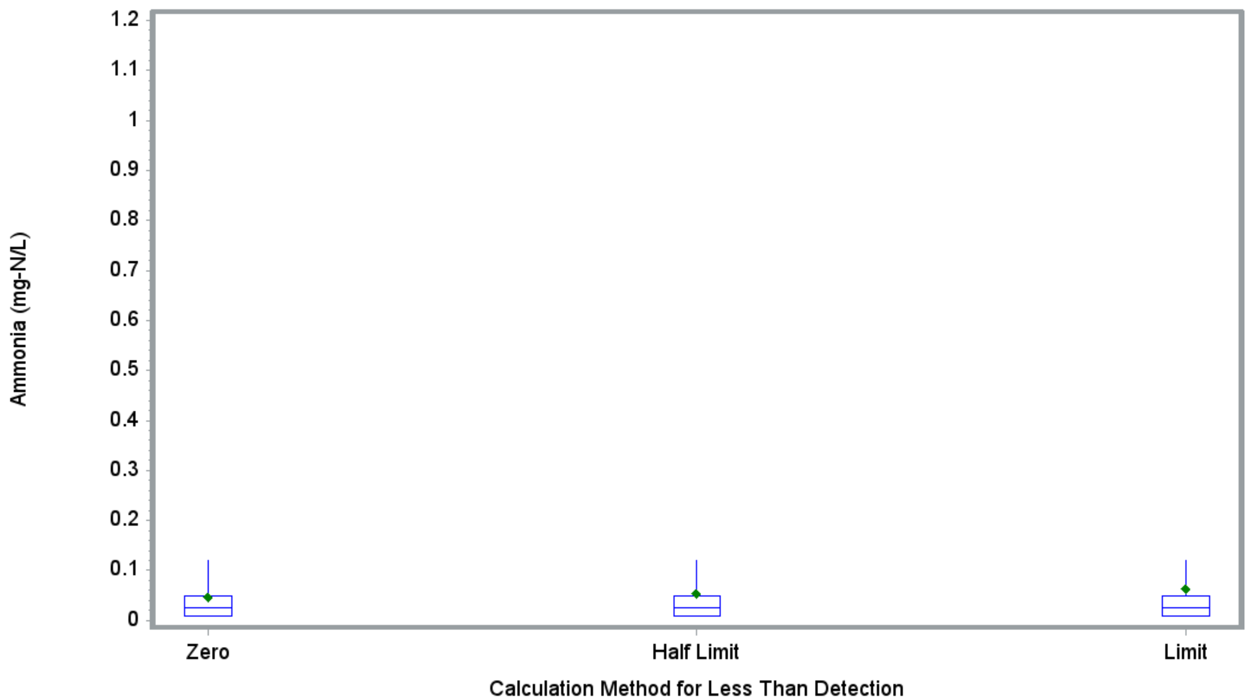



**Figure 3-110 Ammonia Upper Lake Samples Categorized by Limit Calculation**

### 3.11.4 Lower Lake Samples

Three organizations measured ammonia concentrations in lower Falls Lake from 2000, 2001 and from 2005 to 2011. The highest mean ammonia concentrations were measured by USGS and lowest mean concentrations were recorded by Wake County. Highest mean and median concentrations were recorded in the 0 to 4 mile section of the lower lake and lowest mean concentrations were recorded in the 8 to 13 mile section. Highest concentrations were measured in the bottom layer. Highest mean concentrations were recorded in 2001 and 2008, while the lowest concentrations were recorded in 2011. Box plot summaries are provided below.

***Ammonia Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean and median concentrations were measured 0 to 4 mile and 4 to 8 mile sections upstream of the dam.

> Lowest mean concentrations and lowest variability were measured 8 to 13 miles upstream of the dam. This section is also reflected by the smallest sampling size.

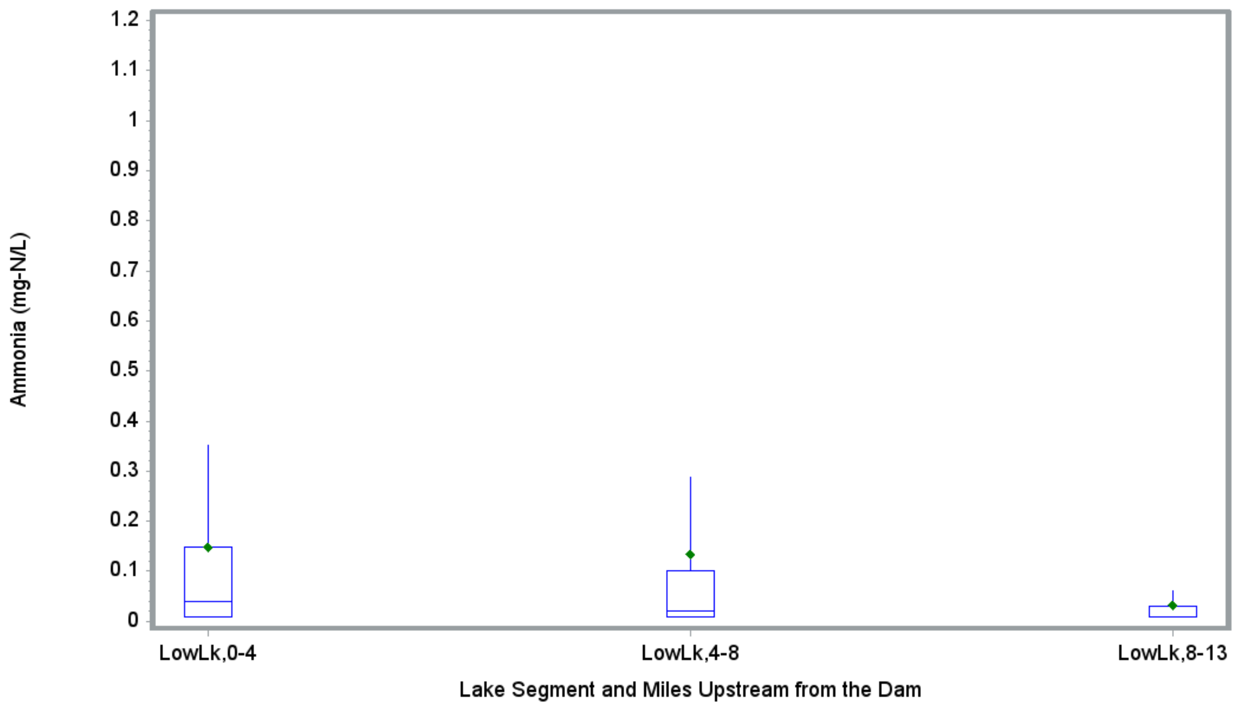



**Figure 3-111 Ammonia Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-117 Ammonia Lower Lake Samples Categorized by Miles Upstream from Dam (in mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LowLk,0-4 | 195 | 0.005 | 0.010 | 0.010 | 0.148 | 0.040 | 0.148 | 0.351 | 2.630 |
| LowLk,4-8 | 284 | 0.005 | 0.010 | 0.010 | 0.133 | 0.020 | 0.100 | 0.287 | 2.060 |
| LowLk,8-13 | 91 | 0.005 | 0.010 | 0.010 | 0.033 | 0.010 | 0.030 | 0.060 | 0.400 |

### *Ammonia Lower Lake Samples Categorized by Depth*

> By depth, highest mean and median concentrations were measured in the bottom layer, followed by the middle depth category.

> Measurements in the photic zone and surface layer were similar.

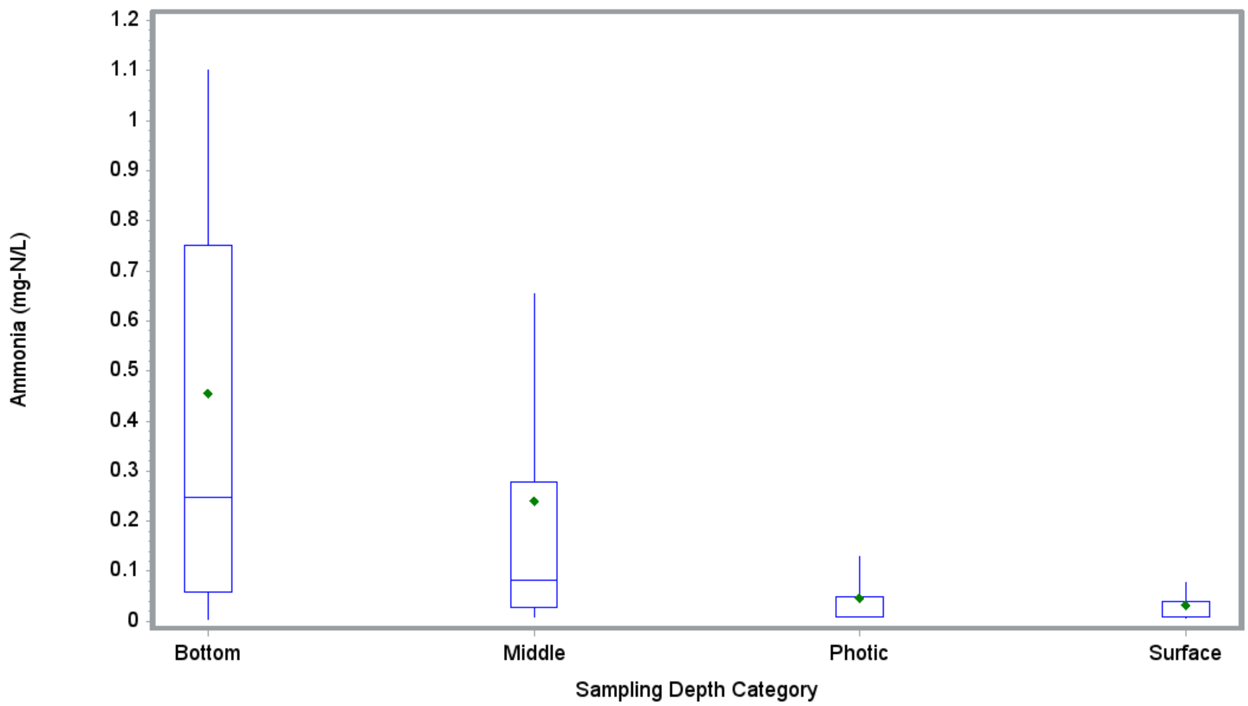



**Figure 3-112 Ammonia Lower Lake Samples Categorized by Depth Category**

**Table 3-118 Ammonia Lower Lake Samples Categorized by Depth Category (in mg-N/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 35 | 0.005 | 0.005 | 0.058 | 0.457 | 0.248 | 0.750 | 1.100 | 2.630 |
| Middle | 153 | 0.005 | 0.010 | 0.029 | 0.239 | 0.083 | 0.279 | 0.654 | 2.060 |
| Photic | 346 | 0.005 | 0.010 | 0.010 | 0.046 | 0.010 | 0.050 | 0.130 | 0.940 |
| Surface | 36 | 0.005 | 0.006 | 0.009 | 0.032 | 0.010 | 0.039 | 0.078 | 0.242 |

***Ammonia Lower Lake Categorized by Year***

> By year, highest mean and median concentrations were recorded in 2001 followed by 2008.

> The lowest mean concentrations were recorded in 2005

> 2005, 2006, and 2007had the lowest median values.

> Greatest variability was recorded in 2001.

> No measurements were recorded in 2002, 2003, and 2004.

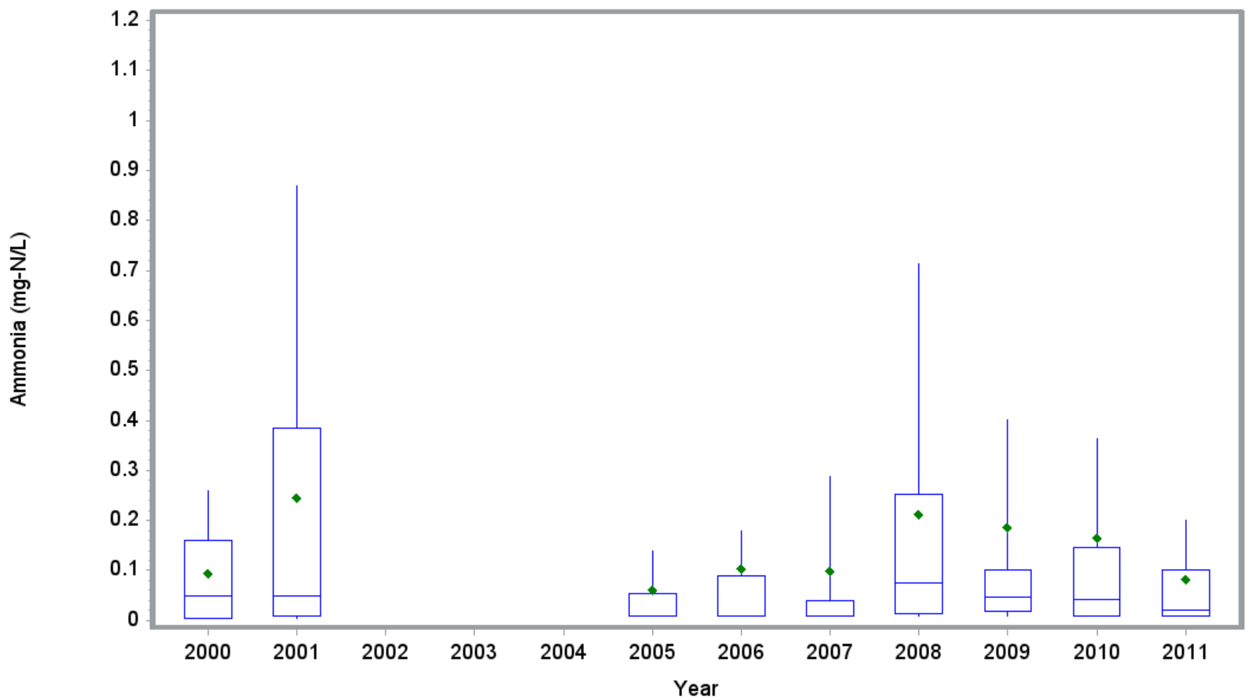



**Figure 3-113 Ammonia Lower Lake Samples Categorized by Year**

**Table 3-119 Ammonia Lower Lake Samples Categorized by Year (in mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 13 | 0.005 | 0.005 | 0.005 | 0.093 | 0.050 | 0.160 | 0.260 | 0.360 |
| 2001 | 32 | 0.005 | 0.005 | 0.010 | 0.246 | 0.050 | 0.385 | 0.870 | 1.300 |
| 2005 | 91 | 0.005 | 0.010 | 0.010 | 0.061 | 0.010 | 0.053 | 0.140 | 1.250 |
| 2006 | 117 | 0.006 | 0.010 | 0.010 | 0.104 | 0.010 | 0.090 | 0.180 | 2.630 |
| 2007 | 101 | 0.010 | 0.010 | 0.010 | 0.099 | 0.010 | 0.040 | 0.287 | 2.060 |
| 2008 | 36 | 0.010 | 0.010 | 0.015 | 0.212 | 0.076 | 0.253 | 0.714 | 1.660 |
| 2009 | 47 | 0.010 | 0.010 | 0.019 | 0.185 | 0.046 | 0.100 | 0.402 | 1.740 |
| 2010 | 68 | 0.010 | 0.010 | 0.010 | 0.166 | 0.042 | 0.145 | 0.363 | 1.820 |
| 2011 | 65 | 0.005 | 0.010 | 0.010 | 0.081 | 0.020 | 0.100 | 0.200 | 0.803 |

### *Ammonia Lower Lake Samples Categorized by Month*

- By month, the highest mean concentrations were measured in October and August.
- The lowest mean concentrations were measured in May and March.

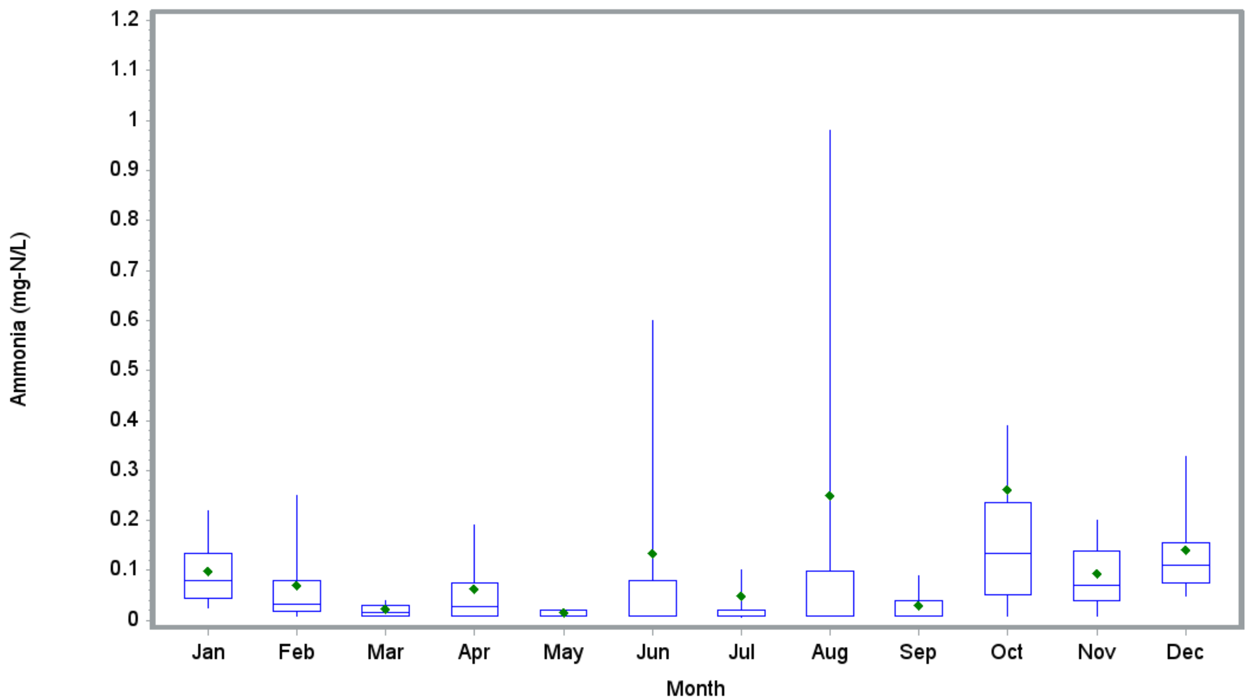



**Figure 3-114 Ammonia Lower Lake Samples Categorized by Month**

**Table 3-120 Ammonia Lower Lake Samples Categorized by Month (in mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 20 | 0.010 | 0.025 | 0.045 | 0.100 | 0.080 | 0.135 | 0.220 | 0.300 |
| Feb | 38 | 0.010 | 0.010 | 0.018 | 0.070 | 0.033 | 0.080 | 0.250 | 0.297 |
| Mar | 40 | 0.010 | 0.010 | 0.010 | 0.022 | 0.016 | 0.030 | 0.039 | 0.075 |
| Apr | 69 | 0.007 | 0.010 | 0.010 | 0.062 | 0.029 | 0.076 | 0.191 | 0.409 |
| May | 32 | 0.010 | 0.010 | 0.010 | 0.016 | 0.010 | 0.020 | 0.020 | 0.080 |
| Jun | 66 | 0.005 | 0.010 | 0.010 | 0.134 | 0.010 | 0.081 | 0.599 | 1.180 |
| Jul | 54 | 0.005 | 0.006 | 0.010 | 0.049 | 0.010 | 0.020 | 0.100 | 0.560 |
| Aug | 91 | 0.005 | 0.008 | 0.010 | 0.250 | 0.010 | 0.099 | 0.980 | 1.740 |
| Sep | 32 | 0.005 | 0.010 | 0.010 | 0.031 | 0.010 | 0.040 | 0.090 | 0.160 |
| Oct | 60 | 0.007 | 0.010 | 0.052 | 0.262 | 0.134 | 0.235 | 0.391 | 2.630 |
| Nov | 24 | 0.010 | 0.010 | 0.040 | 0.093 | 0.070 | 0.140 | 0.200 | 0.300 |
| Dec | 44 | 0.010 | 0.050 | 0.074 | 0.142 | 0.110 | 0.155 | 0.328 | 0.379 |

### *Ammonia Lower Lake Samples Categorized by Sampling Organization*

- By sampling organization, the highest mean concentrations were recorded by USGS.
- Lowest concentrations were recorded by Wake County, however the sample size was small (n=11) relative to the other two categories.

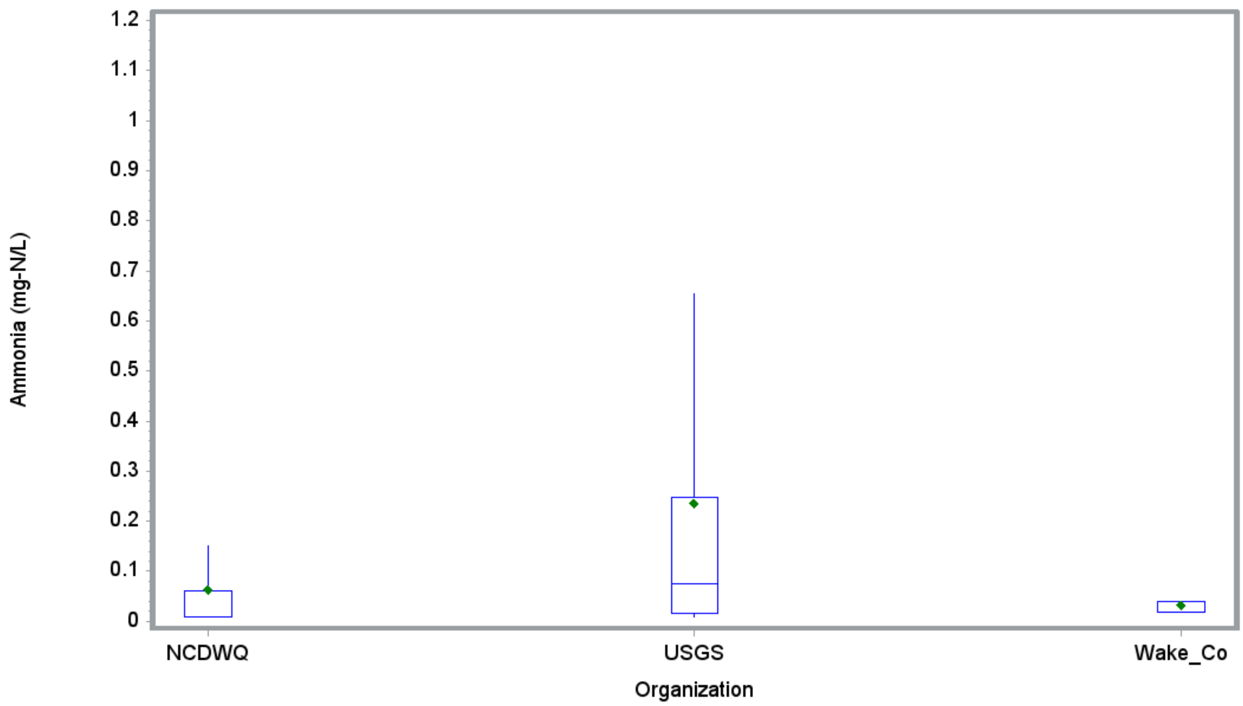



**Figure 3-115 Ammonia Lower Lake Samples Categorized by Sampling Organization**

**Table 3-121 Ammonia Lower Lake Samples Categorized by Sampling Organization (in mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| NCDWQ | 365 | 0.005 | 0.010 | 0.010 | 0.064 | 0.010 | 0.060 | 0.150 | 1.300 |
| USGS | 194 | 0.005 | 0.010 | 0.017 | 0.237 | 0.076 | 0.248 | 0.654 | 2.630 |
| Wake_Co | 11 | 0.019 | 0.019 | 0.019 | 0.034 | 0.039 | 0.039 | 0.039 | 0.078 |

***Ammonia Lower Lake Samples Categorized by Method***

> By method, highest mean concentration was recorded using 'Various' methods.

> The lowest mean concentrations were recorded using an unknown method, however there was a small sample size (n=11) for this category, relative to the other two categories.

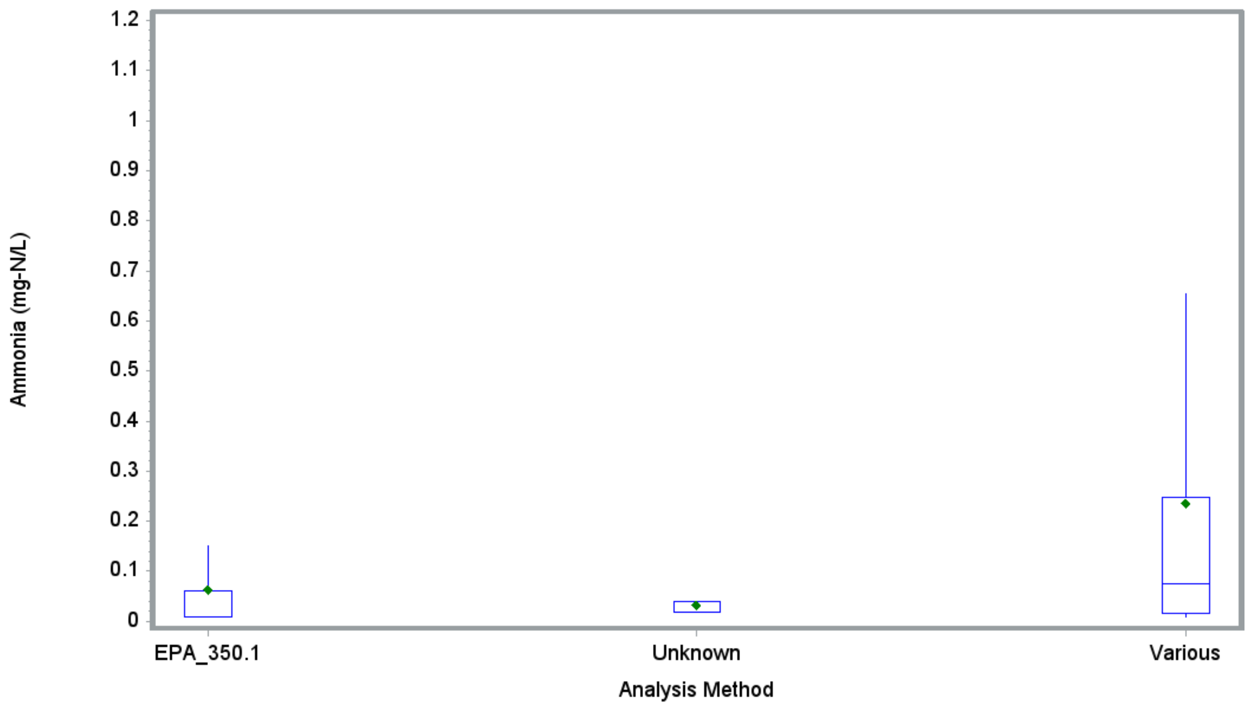



**Figure 3-116 Ammonia Lower Lake Samples Categorized by Analysis Method**

**Table 3-122 Ammonia Lower Lake Samples Categorized by Analysis Method (in mg-N/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_350.1 | 365 | 0.005 | 0.010 | 0.010 | 0.064 | 0.010 | 0.060 | 0.150 | 1.300 |
| Unknown | 11 | 0.019 | 0.019 | 0.019 | 0.034 | 0.039 | 0.039 | 0.039 | 0.078 |
| Various | 194 | 0.005 | 0.010 | 0.017 | 0.237 | 0.076 | 0.248 | 0.654 | 2.630 |

***Ammonia Comparing Different Methods for Handling Data Reported as Below the Detection Limit***

> There is little difference in the overall distribution of results when using full detection limit, half detection limit, or zero to represent below detection limit values.

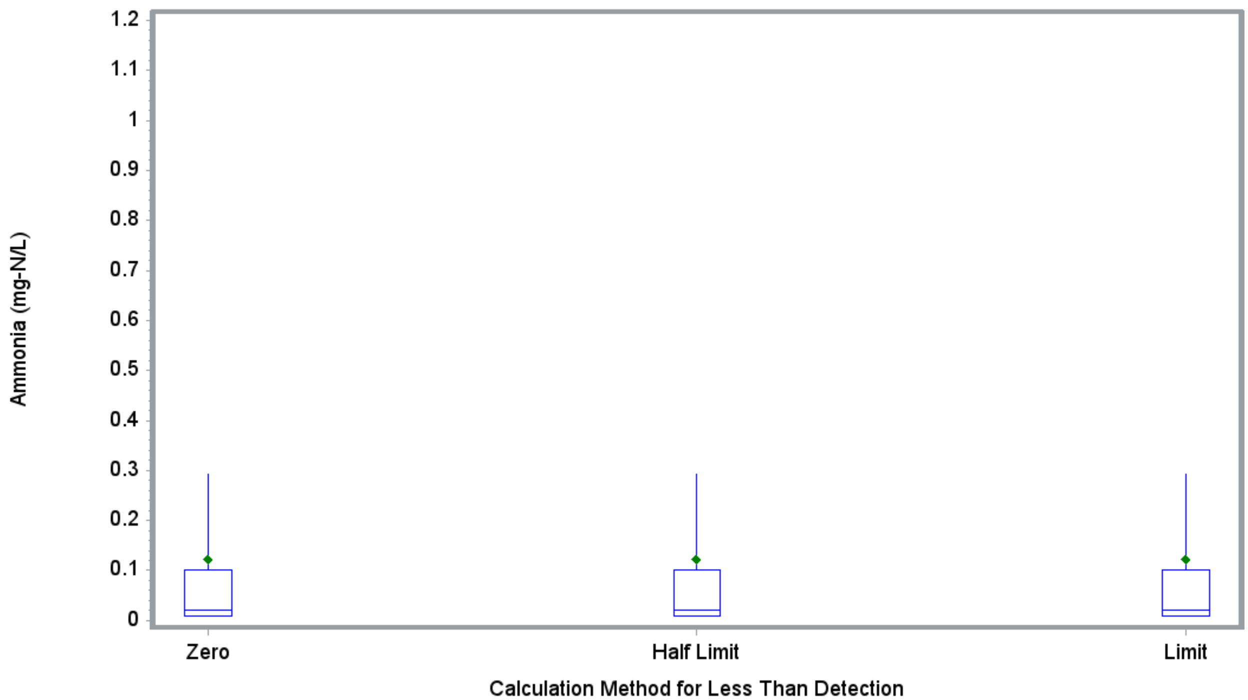



**Figure 3-117 Ammonia Upper Lake Samples Categorized by Limit Calculation**

## 3.12 Nitrate Plus Nitrite (NO2/NO3)

Six organizations measured nitrate and nitrite concentrations (either individually or as a single analysis) as part of the water quality sampling effort. NCDWQ, USGS, City of Durham, Orange County, and Wake County analyzed nitrate plus nitrite together. USGS and City of Raleigh reported nitrate and nitrite results separately (USGS also reported nitrate plus nitrite analyzed together where the individual results were separate. These samples are not included in the database, to prevent inserting duplicate results). Cardno ENTRIX combined the individual nitrate and nitrite results (after converting to elemental nitrogen if necessary) to calculate nitrate plus nitrite. Nitrate plus nitrite, nitrate, and nitrite were measured in the laboratory. All concentrations were converted to elemental nitrogen for this analysis (mg-N/L).

For those organizations that provided method, the following methods were used to analyze nitrate plus nitrite (summation of individual nitrite plus nitrate has an analysis method of Calculated):

> Determination of inorganic anions by ion chromatography (EPA 300.0)

> Determination of nitrate-nitrite by semi-automated colorimetry (EPA 351.2)

> Nitrogen, nitrate-nitrite, colorimetric, automated, cadmium reduction (EPA 353.2)

> Nitrate plus nitrite (Calculated)

Appendix E provides detailed descriptions of these methods.

Table 3-123 describes the organizations and analysis methods used to measure nitrate plus nitrite and includes the number of samples, date range, and limits. The majority of the nitrate plus nitrite data has been collected by the City of Durham and NCDWQ. Nitrate plus nitrite is presented in mg-N/L and to three decimal places based on reported data.

**Table 3-123 Summary of Analysis Methods for the Nitrite Plus Nitrate Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg-N/L) | Reporting Limit (mg-N/L) | Practical Quanti-fication Limit (mg-N/L) | Range of Limit Specified with Results (mg-N/L) |
|---|---|---|---|---|---|---|---|---|
| Durham_Ci | EPA_300.0 | 04/01/2002 | 04/30/2012 | 1,443 | Not Provided | 0.1 | 0.1 | 0.1 to 0.3 |
| Durham_Ci | EPA_353.2 | 01/26/2010 | 12/20/2011 | 102 | 0.01 | 0.05 | Not Provided | 0.015 to 0.1 |
| NCDWQ[1] | Calculated | 06/07/2000 | 12/06/2011 | 865 | Not Provided | Not Provided | Not Provided | NA |
| NCDWQ[1] | EPA_351.2 | 06/07/2000 | 08/27/2001 | 39 | 0.2 | 0.04 | Not Provided | 0 |
| NCDWQ[1] | EPA_353.2 | 01/11/1999 | 12/06/2011 | 1,631 | 0.01 | 0.004 | Not Provided | 0.01 to 26 |
| Orange_Co | EPA_353.2 | 04/09/2010 | 03/25/2011 | 182 | Not Provided | Not Provided | 0.02 | 0.02 |
| Raleigh | Calculated | 02/07/2000 | 12/30/2011 | 487 | Not Provided | Not Provided | Not Provided | 0 |
| USGS | Calculated | 01/15/1999 | 09/07/2011 | 926 | Not Provided | Not Provided | Not Provided | 0 |
| Wake_Co | Not Provided | 07/29/2008 | 10/14/2009 | 131 | Not Provided | Not Provided | 0.0056 | 0.0056 |

[1]Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

### 3.12.2 <u>Tributary Samples</u>

Five organizations collected nitrate and nitrite data in the Falls Lake tributaries from 1999 to 2011. Highest mean and median concentrations were recorded by NCDWQ and lowest mean concentrations were recorded by USGS. The highest mean and median concentrations were recorded in Knap of Reeds Creek and Ellerbe Creek. Lowest mean and median concentrations were recorded in Beaverdam Creek and Lick Creek. Highest mean concentrations were recorded in 2008 and 2007, while lowest concentrations were recorded in 2002 and 2010. See Table 1 for additional summary statistics. Box plot summaries are provided below.

***Nitrate plus Nitrite Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Nitrate plus nitrite was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River and Horse/New Light Creek, and Honeycutt/Barton Creek.

> Highest mean and median concentrations were measured in Knap of Reeds Creek (0 to 2 miles upstream of mouth) and Ellerbe Creek (0 to 2 miles upstream) and Honeycutt/Barton Creek (0 to 2 miles upstream) in decreasing order.

> Lowest mean and median concentrations were measured in Beaverdam Creek (0 to 2 miles) and Lick Creek (0 to 2 miles and 2 to 10 miles).

> For Ellerbe Creek, mean concentrations at the 0 to 2 mile category are greater than mean concentrations in the 2 to 10 mile segment. For Flat River and Lick Creek, mean concentrations at the 0 to 2 mile category are less than mean concentrations at the 2 to 10 mile segment.

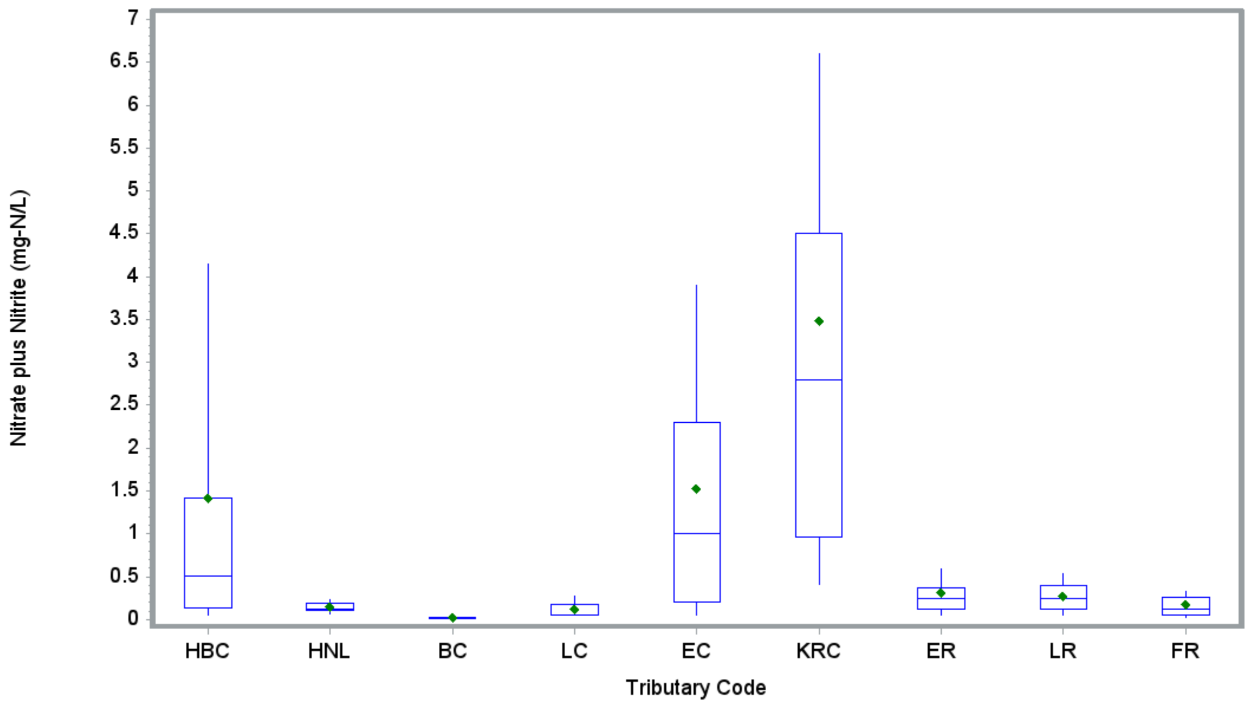



**Figure 3-118 Nitrate plus Nitrite Tributary Samples Categorized by Subwatershed**

**Table 3-124 Nitrate plus Nitrite Tributary Samples Categorized by Subwatershed (mg-N/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 76 | 0.022 | 0.050 | 0.136 | 1.416 | 0.505 | 1.412 | 4.150 | 13.062 |
| HNL | 41 | 0.025 | 0.072 | 0.105 | 0.142 | 0.125 | 0.194 | 0.226 | 0.275 |
| BC | 15 | 0.003 | 0.004 | 0.007 | 0.026 | 0.013 | 0.020 | 0.065 | 0.176 |
| LC | 121 | 0.008 | 0.050 | 0.050 | 0.120 | 0.050 | 0.170 | 0.275 | 0.600 |
| EC | 667 | 0.010 | 0.050 | 0.200 | 1.527 | 1.000 | 2.300 | 3.900 | 8.300 |
| KRC | 147 | 0.100 | 0.415 | 0.960 | 3.479 | 2.800 | 4.500 | 6.600 | 26.000 |
| ER | 626 | 0.010 | 0.050 | 0.120 | 0.320 | 0.250 | 0.370 | 0.590 | 3.430 |
| LR | 456 | 0.009 | 0.050 | 0.120 | 0.279 | 0.248 | 0.390 | 0.530 | 1.872 |
| FR | 266 | 0.007 | 0.030 | 0.056 | 0.171 | 0.120 | 0.255 | 0.330 | 2.700 |

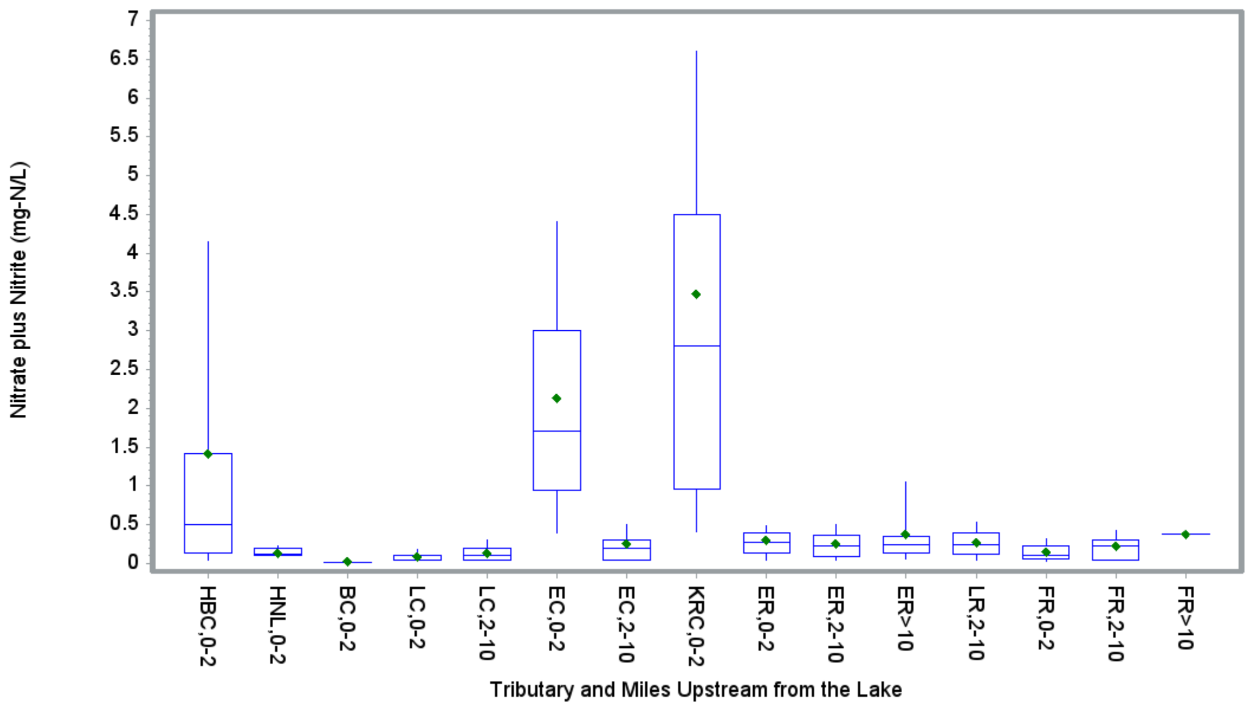



**Figure 3-119 Nitrate plus Nitrite Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-125 Nitrate plus Nitrite Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (mg-N/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 76 | 0.022 | 0.050 | 0.136 | 1.416 | 0.505 | 1.412 | 4.150 | 13.062 |
| HNL,0-2 | 41 | 0.025 | 0.072 | 0.105 | 0.142 | 0.125 | 0.194 | 0.226 | 0.275 |
| BC,0-2 | 15 | 0.003 | 0.004 | 0.007 | 0.026 | 0.013 | 0.020 | 0.065 | 0.176 |
| LC,0-2 | 36 | 0.050 | 0.050 | 0.050 | 0.086 | 0.050 | 0.100 | 0.183 | 0.400 |
| LC,2-10 | 85 | 0.008 | 0.050 | 0.050 | 0.134 | 0.100 | 0.200 | 0.300 | 0.600 |
| EC,0-2 | 453 | 0.010 | 0.400 | 0.940 | 2.129 | 1.700 | 3.000 | 4.400 | 8.300 |
| EC,2-10 | 214 | 0.050 | 0.050 | 0.050 | 0.251 | 0.200 | 0.300 | 0.500 | 2.300 |
| KRC,0-2 | 147 | 0.100 | 0.415 | 0.960 | 3.479 | 2.800 | 4.500 | 6.600 | 26.000 |
| ER,0-2 | 115 | 0.010 | 0.050 | 0.140 | 0.299 | 0.280 | 0.400 | 0.490 | 2.500 |
| ER,2-10 | 231 | 0.014 | 0.050 | 0.090 | 0.251 | 0.230 | 0.360 | 0.500 | 1.300 |
| ER>10 | 280 | 0.010 | 0.059 | 0.136 | 0.386 | 0.240 | 0.352 | 1.045 | 3.430 |
| LR,2-10 | 456 | 0.009 | 0.050 | 0.120 | 0.279 | 0.248 | 0.390 | 0.530 | 1.872 |
| FR,0-2 | 214 | 0.007 | 0.030 | 0.056 | 0.156 | 0.100 | 0.230 | 0.320 | 2.700 |
| FR,2-10 | 51 | 0.020 | 0.050 | 0.050 | 0.228 | 0.220 | 0.310 | 0.420 | 0.600 |
| FR>10 | 1 | 0.375 | 0.375 | 0.375 | 0.375 | 0.375 | 0.375 | 0.375 | 0.375 |

***Nitrate plus Nitrite Tributary Samples Categorized by Depth***

> All samples were collected in the surface layer.

***Nitrate plus Nitrite Tributary Samples Categorized by Year***

> By year, highest mean concentrations were recorded in 2008, 2007, 2011 and 2006 (in decreasing order).

> The lowest mean concentrations were recorded in 2002, 2010 and 2003 (in increasing order).Median concentrations were relatively similar for all years.

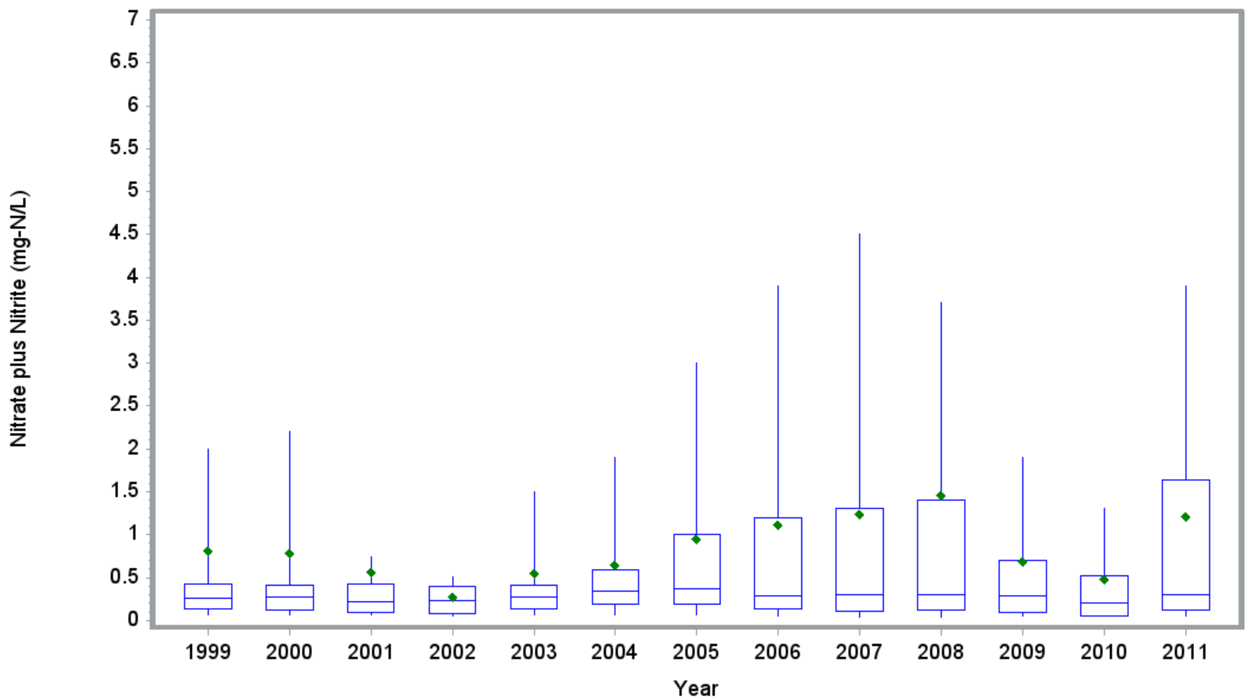



**Figure 3-120 Nitrate plus Nitrite Tributary Samples Categorized by Year**

**Table 3-126 Nitrate plus Nitrite Tributary Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 133 | 0.007 | 0.060 | 0.140 | 0.807 | 0.261 | 0.430 | 2.000 | 9.900 |
| 2000 | 138 | 0.030 | 0.060 | 0.119 | 0.781 | 0.270 | 0.410 | 2.200 | 15.000 |
| 2001 | 71 | 0.010 | 0.062 | 0.100 | 0.563 | 0.213 | 0.420 | 0.739 | 6.000 |
| 2002 | 43 | 0.055 | 0.058 | 0.074 | 0.269 | 0.238 | 0.403 | 0.508 | 0.759 |
| 2003 | 85 | 0.020 | 0.068 | 0.131 | 0.543 | 0.271 | 0.410 | 1.500 | 4.700 |
| 2004 | 90 | 0.038 | 0.073 | 0.190 | 0.650 | 0.335 | 0.593 | 1.900 | 4.300 |
| 2005 | 142 | 0.020 | 0.068 | 0.190 | 0.942 | 0.375 | 1.000 | 3.000 | 6.400 |
| 2006 | 179 | 0.020 | 0.050 | 0.132 | 1.113 | 0.291 | 1.200 | 3.900 | 9.400 |
| 2007 | 131 | 0.018 | 0.040 | 0.110 | 1.235 | 0.304 | 1.300 | 4.500 | 6.500 |
| 2008 | 209 | 0.004 | 0.032 | 0.123 | 1.453 | 0.301 | 1.400 | 3.700 | 26.000 |
| 2009 | 395 | 0.003 | 0.050 | 0.100 | 0.683 | 0.290 | 0.702 | 1.900 | 8.300 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | 508 | 0.008 | 0.050 | 0.050 | 0.475 | 0.200 | 0.525 | 1.300 | 5.200 |
| 2011 | 291 | 0.009 | 0.050 | 0.120 | 1.204 | 0.300 | 1.640 | 3.900 | 7.600 |

***Nitrate plus Nitrite Tributary Samples Categorized by Month***

> By month, the highest mean concentrations were recorded in July and August.

> The lowest mean concentrations were recorded in December, March and April (in increasing order).

> Median concentrations were relatively similar for all months with October the lowest and January the highest.

> Higher concentrations are more often observed in the summer months.

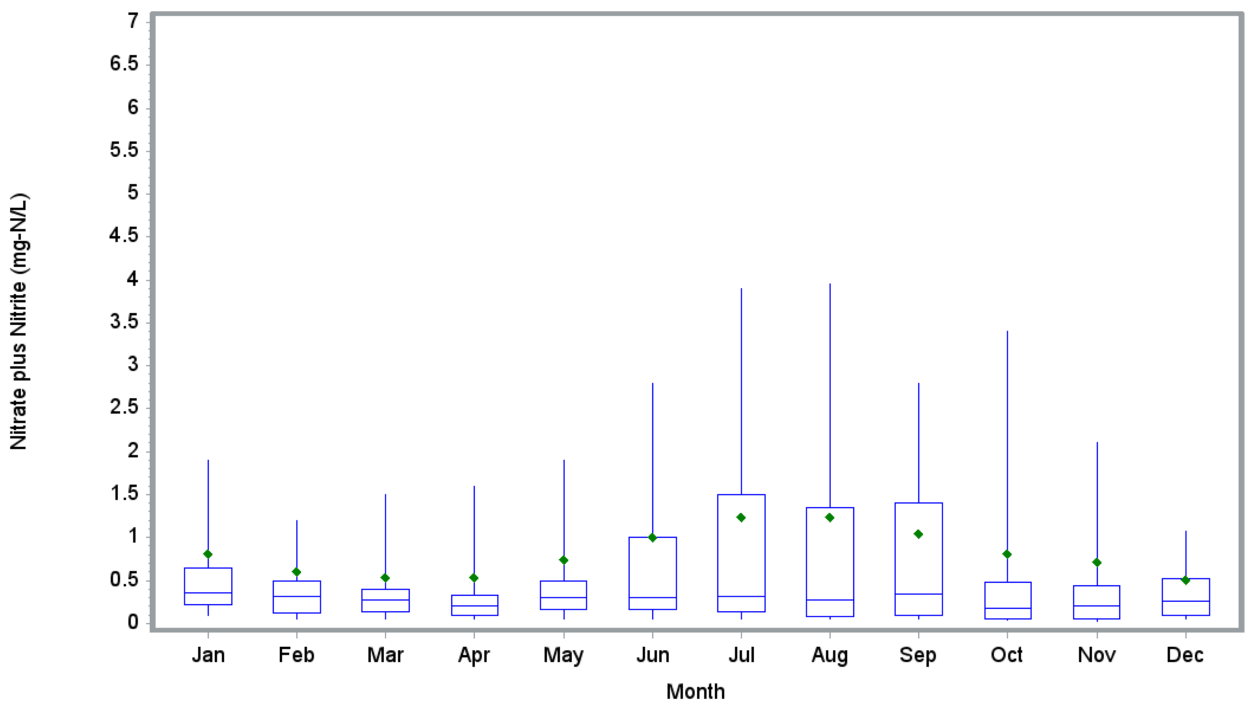



**Figure 3-121 Nitrate plus Nitrite Tributary Samples Categorized by Month**

**Table 3-127 Nitrate plus Nitrite Tributary Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 179 | 0.007 | 0.100 | 0.220 | 0.808 | 0.350 | 0.640 | 1.900 | 7.600 |
| Feb | 187 | 0.003 | 0.050 | 0.123 | 0.605 | 0.320 | 0.490 | 1.196 | 8.300 |
| Mar | 178 | 0.008 | 0.050 | 0.130 | 0.536 | 0.270 | 0.400 | 1.500 | 5.100 |
| Apr | 202 | 0.004 | 0.050 | 0.090 | 0.536 | 0.200 | 0.330 | 1.600 | 5.200 |
| May | 188 | 0.008 | 0.055 | 0.160 | 0.745 | 0.300 | 0.500 | 1.900 | 16.000 |
| Jun | 260 | 0.01 | 0.050 | 0.165 | 1.009 | 0.297 | 1.000 | 2.800 | 26.000 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jul | 243 | 0.010 | 0.050 | 0.140 | 1.239 | 0.320 | 1.500 | 3.900 | 19.000 |
| Aug | 220 | 0.010 | 0.050 | 0.079 | 1.240 | 0.277 | 1.350 | 3.950 | 20.000 |
| Sep | 221 | 0.010 | 0.050 | 0.099 | 1.044 | 0.341 | 1.400 | 2.800 | 15.000 |
| Oct | 186 | 0.009 | 0.044 | 0.053 | 0.812 | 0.175 | 0.480 | 3.400 | 10.000 |
| Nov | 164 | 0.007 | 0.028 | 0.050 | 0.717 | 0.200 | 0.438 | 2.100 | 7.400 |
| Dec | 187 | 0.004 | 0.050 | 0.100 | 0.505 | 0.260 | 0.521 | 1.070 | 4.900 |

### *Nitrate plus Nitrite Tributary Samples Categorized by Sampling Organization*

> By sampling organization, the highest mean concentrations were recorded by NCDWQ.

> Lowest mean concentrations were recorded by USGS and Orange County.

> Median concentrations were relatively similar for all organizations with Wake County the lowest.

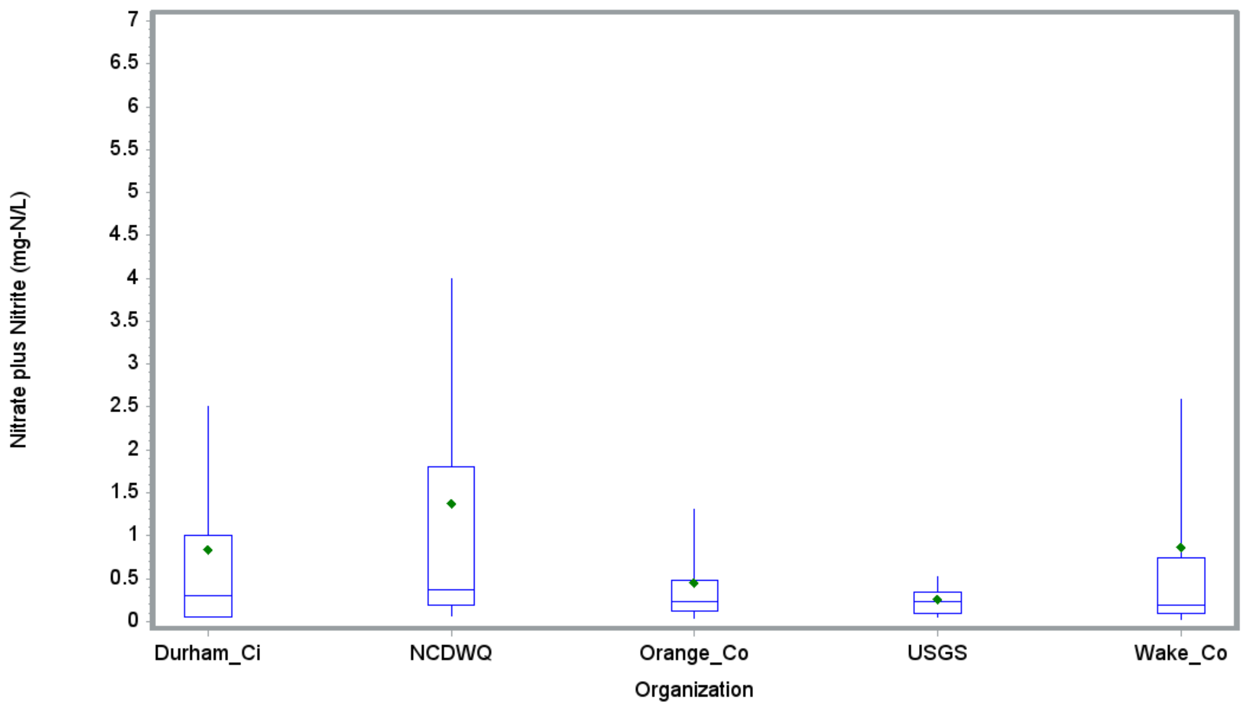



**Figure 3-122 Nitrate plus Nitrite Tributary Samples Categorized by Sampling Organization**

**Table 3-128 Nitrate plus Nitrite Tributary Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 836 | 0.008 | 0.050 | 0.050 | 0.842 | 0.300 | 1.000 | 2.500 | 7.600 |
| NCDWQ | 717 | 0.010 | 0.070 | 0.190 | 1.377 | 0.370 | 1.800 | 4.000 | 26.000 |
| Orange_Co | 182 | 0.010 | 0.040 | 0.120 | 0.453 | 0.230 | 0.480 | 1.300 | 3.430 |
| USGS | 549 | 0.007 | 0.057 | 0.098 | 0.263 | 0.229 | 0.347 | 0.521 | 1.872 |

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Wake_Co | 131 | 0.003 | 0.025 | 0.089 | 0.867 | 0.188 | 0.740 | 2.591 | 13.062 |

***Nitrate plus Nitrite Tributary Samples Categorized by Method***

> By method, the highest mean and median concentrations were recorded using EPA 353.2 method and the lowest mean concentrations were calculated.

> The greatest variability was seen in EPA 353.2 and the unknown method, while the least variability was seen in the calculated method.

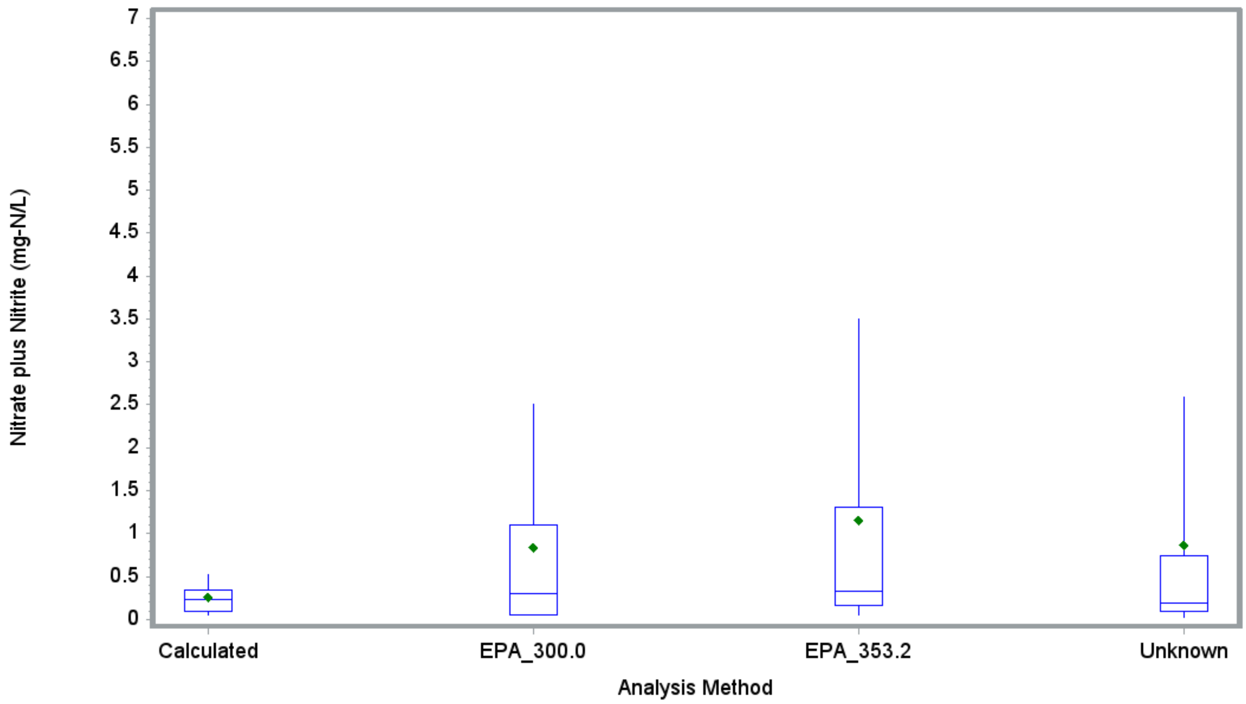



**Figure 3-123 Nitrate plus Nitrite Tributary Samples Categorized by Analysis Method**

**Table 3-129 Nitrate plus Nitrite Tributary Samples Categorized by Analysis Method (mg-N/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Calculated | 549 | 0.007 | 0.057 | 0.098 | 0.263 | 0.229 | 0.347 | 0.521 | 1.872 |
| EPA_300.0 | 734 | 0.050 | 0.050 | 0.050 | 0.841 | 0.300 | 1.100 | 2.500 | 7.500 |
| EPA_353.2 | 1001 | 0.008 | 0.050 | 0.160 | 1.155 | 0.330 | 1.300 | 3.500 | 26.000 |
| Unknown | 131 | 0.003 | 0.025 | 0.089 | 0.867 | 0.188 | 0.740 | 2.591 | 13.062 |

### 3.12.3 Upper Lake Samples

Three organizations measured nitrate and nitrite concentrations in upper Falls Lake from 2000 to present. The highest mean and median nitrate plus nitrite concentrations were measured by City of Durham, while lowest mean and median concentrations were measured by NCDWQ. Highest concentrations were recorded in the > 21 mile section of the lower lake and lowest concentrations were recorded in the 13 to 18 miles section. Highest mean and median concentrations were recorded in 2002 and lowest mean and median concentrations were recorded in 2000. Box plot summaries are provided below.

### *Nitrate plus Nitrite Samples Categorized by Lake Segment and Miles Upstream from Dam*

> By lake segment, highest mean concentrations were measured in the > 21 mile section upstream of the dam.

> Lowest mean concentrations were measured in the 13 to 18 mile section.

> Median concentrations were equal for the 13 to 18 and 18 to 21 mile sections.

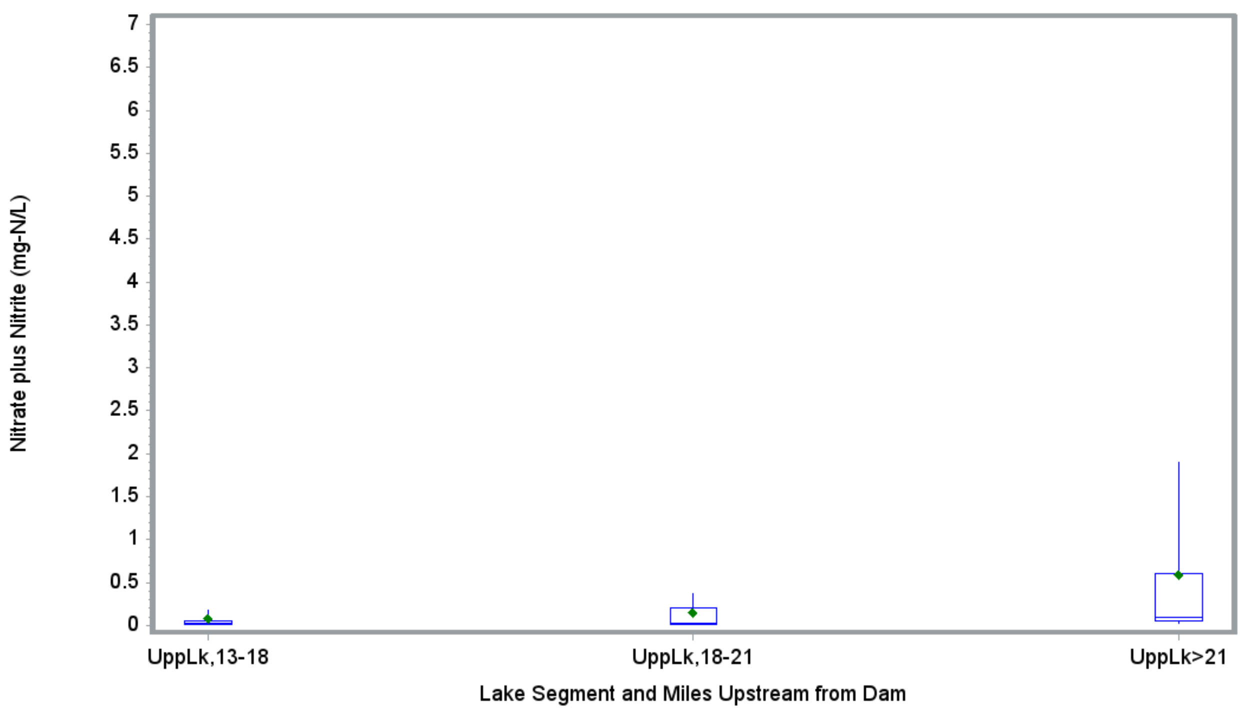



**Figure 3-124 Nitrate plus Nitrite Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-130 Nitrate plus Nitrite Upper Lake Samples Categorized by Miles Upstream from Dam (mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 699 | 0.005 | 0.010 | 0.010 | 0.084 | 0.020 | 0.054 | 0.180 | 2.605 |
| UppLk,18-21 | 177 | 0.005 | 0.010 | 0.010 | 0.151 | 0.020 | 0.200 | 0.370 | 1.670 |
| UppLk>21 | 1109 | 0.005 | 0.020 | 0.050 | 0.596 | 0.100 | 0.600 | 1.900 | 7.100 |

### *Nitrate plus Nitrite Lower Lake Samples Categorized by Depth*

> By depth, highest mean and median concentrations were measured in the surface layer.

> Lowest mean and median concentrations were recorded in the photic layer.

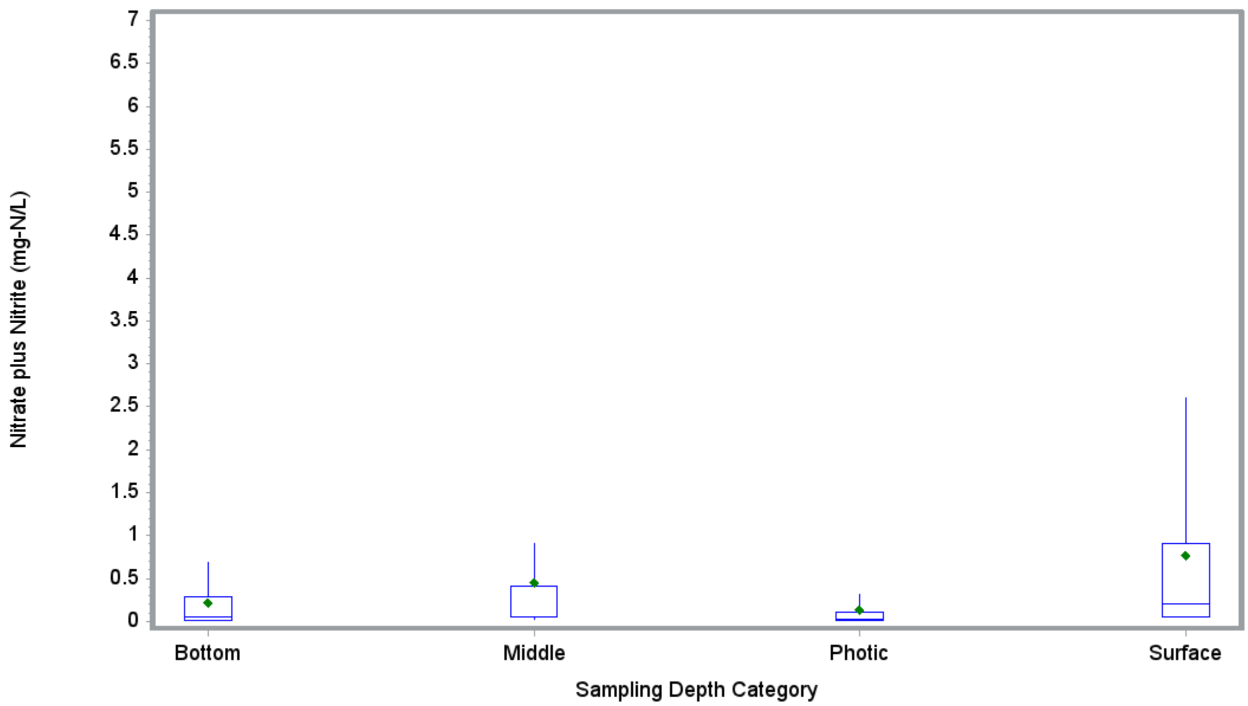



**Figure 3-125 Nitrate plus Nitrite Upper Lake Samples Categorized by Depth Category**

**Table 3-131 Nitrate plus Nitrite Upper Lake Samples Categorized by Depth Category (mg-N/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 47 | 0.005 | 0.005 | 0.005 | 0.216 | 0.055 | 0.285 | 0.690 | 2.605 |
| Middle | 153 | 0.026 | 0.029 | 0.047 | 0.445 | 0.054 | 0.415 | 0.900 | 5.371 |
| Photic | 1126 | 0.005 | 0.010 | 0.010 | 0.140 | 0.020 | 0.110 | 0.320 | 5.270 |
| Surface | 659 | 0.041 | 0.050 | 0.050 | 0.774 | 0.200 | 0.900 | 2.600 | 7.100 |

### *Nitrate plus Nitrite Upper Lake Categorized by Year*

> By year, highest mean and median concentrations were recorded in 2002.

> The lowest mean and median concentrations were recorded in 2000.

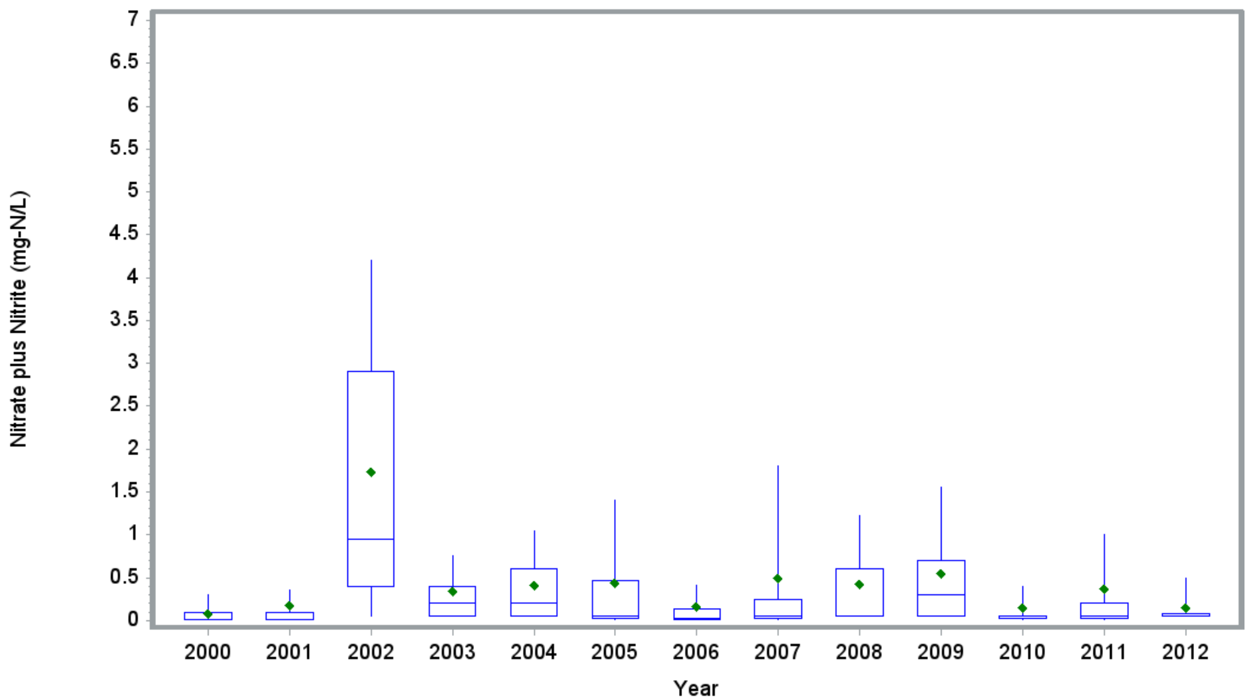



**Figure 3-126 Nitrate plus Nitrite Upper Lake Samples Categorized by Year**

**Table 3-132 Nitrate plus Nitrite Upper Lake Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 26 | 0.005 | 0.005 | 0.005 | 0.083 | 0.005 | 0.100 | 0.295 | 0.390 |
| 2001 | 70 | 0.005 | 0.005 | 0.005 | 0.169 | 0.013 | 0.100 | 0.355 | 2.605 |
| 2002 | 62 | 0.050 | 0.050 | 0.400 | 1.736 | 0.950 | 2.900 | 4.200 | 7.100 |
| 2003 | 60 | 0.050 | 0.050 | 0.050 | 0.339 | 0.200 | 0.400 | 0.750 | 2.400 |
| 2004 | 60 | 0.050 | 0.050 | 0.050 | 0.407 | 0.200 | 0.600 | 1.050 | 2.500 |
| 2005 | 265 | 0.010 | 0.010 | 0.020 | 0.433 | 0.050 | 0.470 | 1.400 | 5.371 |
| 2006 | 393 | 0.010 | 0.010 | 0.010 | 0.169 | 0.030 | 0.130 | 0.410 | 5.100 |
| 2007 | 331 | 0.010 | 0.010 | 0.020 | 0.499 | 0.052 | 0.240 | 1.800 | 5.270 |
| 2008 | 94 | 0.041 | 0.050 | 0.050 | 0.422 | 0.054 | 0.606 | 1.221 | 3.000 |
| 2009 | 100 | 0.045 | 0.050 | 0.050 | 0.544 | 0.300 | 0.700 | 1.550 | 3.300 |
| 2010 | 235 | 0.010 | 0.010 | 0.020 | 0.154 | 0.050 | 0.054 | 0.400 | 3.800 |
| 2011 | 274 | 0.010 | 0.010 | 0.020 | 0.369 | 0.050 | 0.200 | 1.000 | 6.000 |
| 2012 | 15 | 0.050 | 0.050 | 0.050 | 0.142 | 0.050 | 0.080 | 0.500 | 0.700 |

### *Nitrate plus Nitrite Lower Lake Samples Categorized by Month*

> By month, the highest mean concentrations were measured in October followed by September and November (in decreasing order).

> The lowest mean concentrations were measured in March, May, and June (in increasing order).

> Higher concentrations are observed more frequently in the fall months.

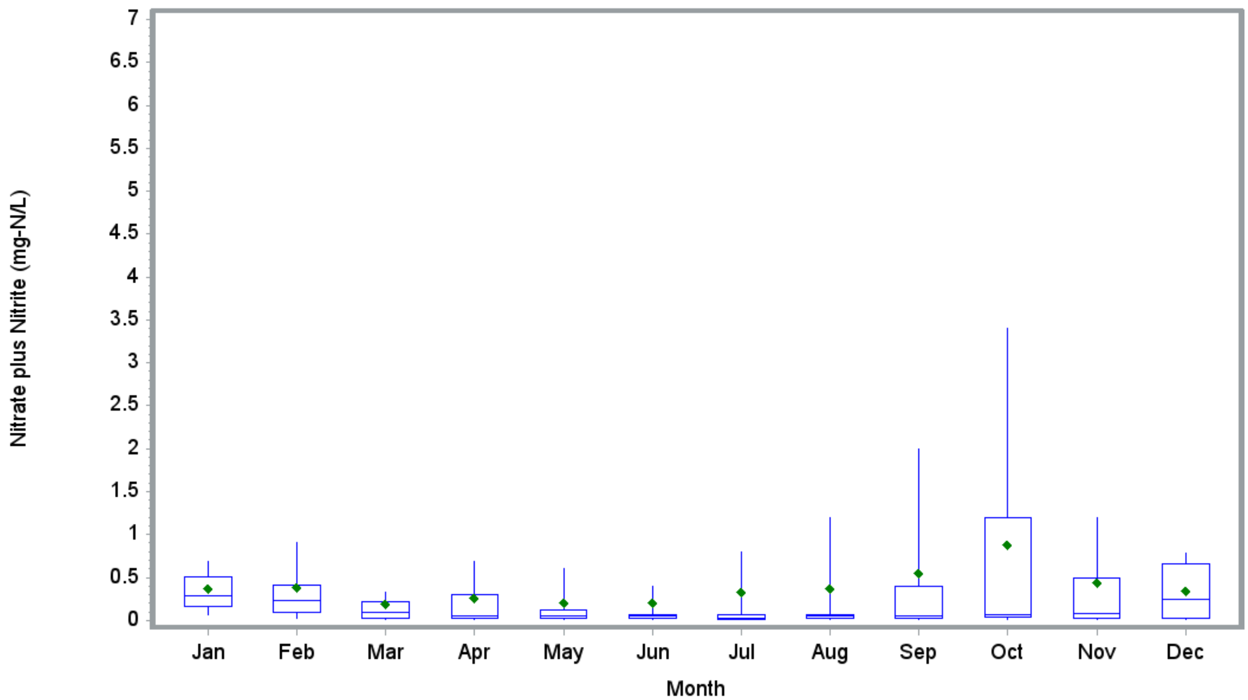



**Figure 3-127 Nitrate plus Nitrite Upper Lake Samples Categorized by Month**

**Table 3-133 Nitrate plus Nitrite Upper Lake Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 60 | 0.020 | 0.065 | 0.160 | 0.363 | 0.285 | 0.505 | 0.685 | 1.210 |
| Feb | 81 | 0.010 | 0.030 | 0.100 | 0.378 | 0.230 | 0.410 | 0.900 | 1.980 |
| Mar | 101 | 0.010 | 0.010 | 0.020 | 0.184 | 0.100 | 0.220 | 0.330 | 2.400 |
| Apr | 232 | 0.010 | 0.010 | 0.020 | 0.256 | 0.050 | 0.300 | 0.687 | 2.900 |
| May | 193 | 0.010 | 0.010 | 0.020 | 0.199 | 0.050 | 0.120 | 0.600 | 3.400 |
| Jun | 239 | 0.005 | 0.010 | 0.020 | 0.199 | 0.050 | 0.070 | 0.400 | 7.100 |
| Jul | 233 | 0.005 | 0.010 | 0.010 | 0.333 | 0.030 | 0.070 | 0.800 | 6.300 |
| Aug | 282 | 0.005 | 0.010 | 0.020 | 0.370 | 0.050 | 0.070 | 1.200 | 6.000 |
| Sep | 197 | 0.005 | 0.010 | 0.020 | 0.545 | 0.050 | 0.400 | 2.000 | 5.270 |
| Oct | 196 | 0.010 | 0.010 | 0.036 | 0.886 | 0.067 | 1.200 | 3.400 | 5.371 |
| Nov | 93 | 0.010 | 0.010 | 0.020 | 0.440 | 0.080 | 0.500 | 1.200 | 4.500 |
| Dec | 78 | 0.010 | 0.010 | 0.027 | 0.336 | 0.245 | 0.660 | 0.780 | 0.950 |

***Nitrate plus Nitrite Lower Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded City of Durham, while lowest mean and median concentrations were recorded by NCDWQ.

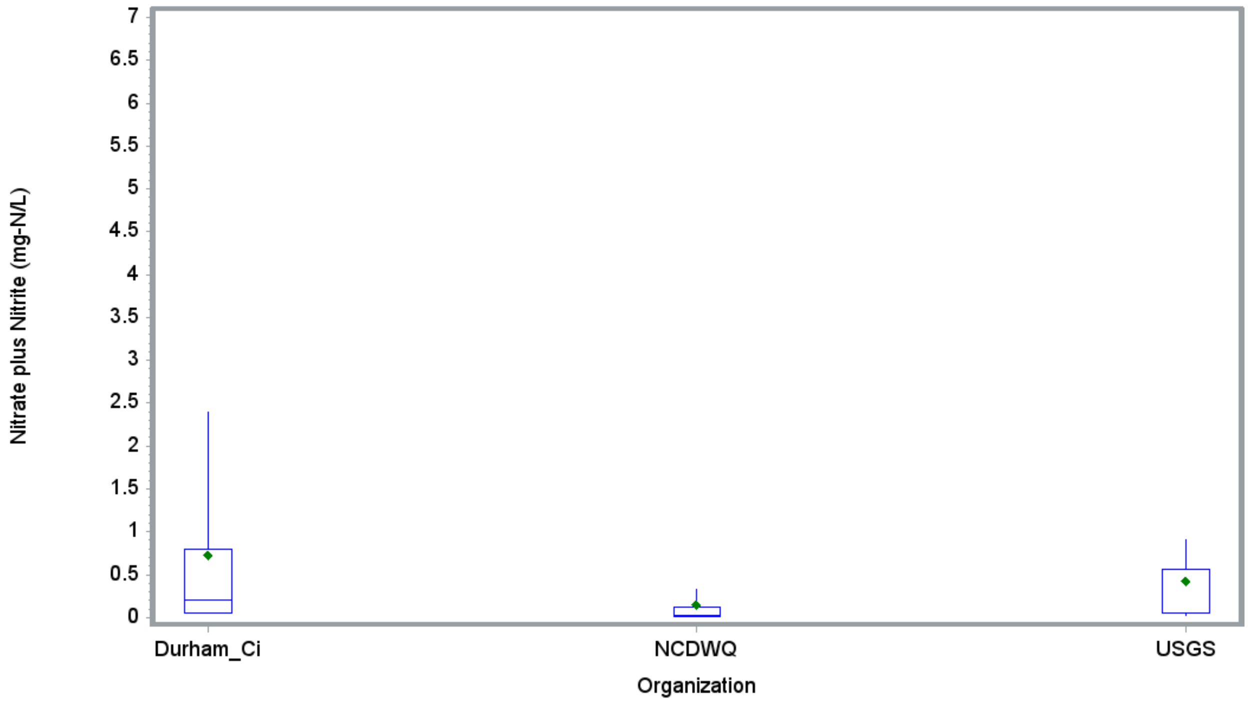



**Figure 3-128 Nitrate plus Nitrite Upper Lake Samples Categorized by Sampling Organization**

**Table 3-134 Nitrate plus Nitrite Upper Lake Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 709 | 0.050 | 0.050 | 0.050 | 0.723 | 0.200 | 0.800 | 2.400 | 7.100 |
| NCDWQ | 1093 | 0.005 | 0.010 | 0.010 | 0.143 | 0.020 | 0.120 | 0.330 | 5.270 |
| USGS | 183 | 0.026 | 0.029 | 0.048 | 0.419 | 0.054 | 0.556 | 0.900 | 5.371 |

### *Nitrate plus Nitrite Lower Lake Samples Categorized by Method*

> By method, highest and median mean concentrations were measured using EPA 300.0 and lowest mean and median concentrations were measured using EPA 353.2 method.

> Greatest variability is seen with EPA 300.0 method (also represented by the greatest sample size) and least variability is seen with EPA 353.2 method.

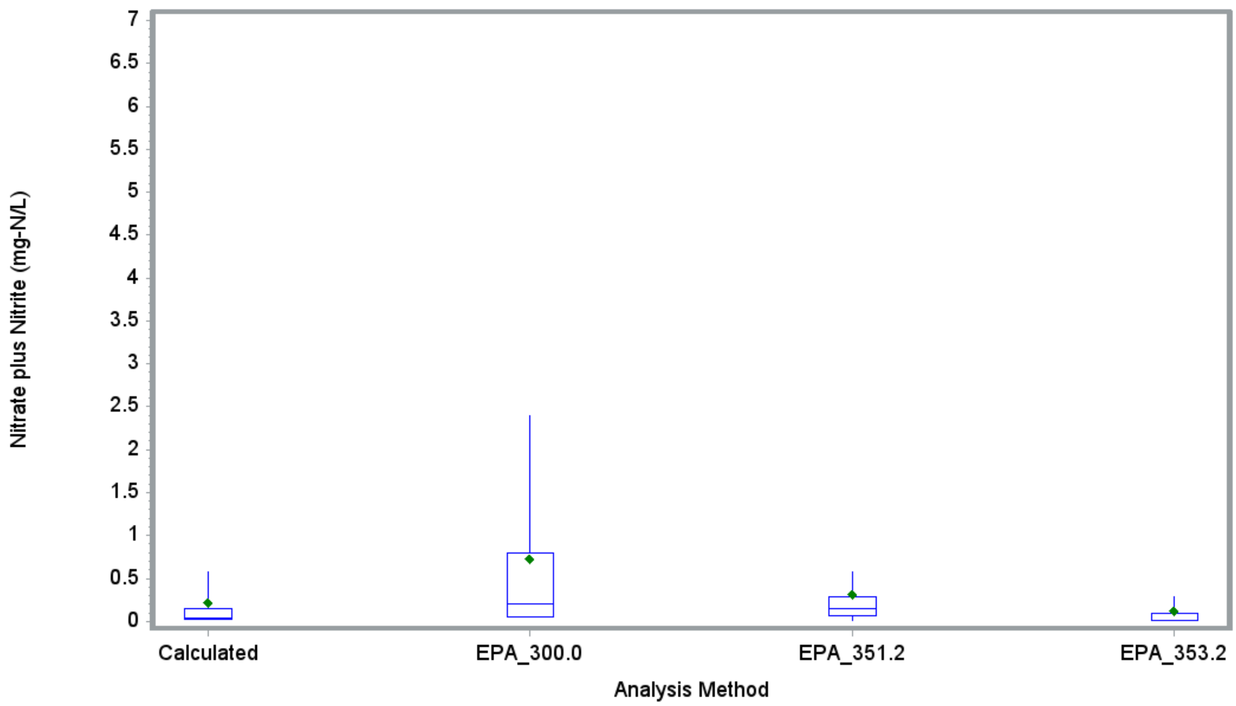



**Figure 3-129 Nitrate plus Nitrite Upper Lake Samples Categorized by Analysis Method**

**Table 3-135 Nitrate plus Nitrite Upper Lake Samples Categorized by Analysis Method (mg-N/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Calculated | 706 | 0.010 | 0.020 | 0.020 | 0.224 | 0.044 | 0.155 | 0.576 | 5.371 |
| EPA_300.0 | 709 | 0.050 | 0.050 | 0.050 | 0.723 | 0.200 | 0.800 | 2.400 | 7.100 |
| EPA_351.2 | 20 | 0.010 | 0.010 | 0.070 | 0.309 | 0.155 | 0.285 | 0.575 | 2.605 |
| EPA_353.2 | 550 | 0.005 | 0.010 | 0.010 | 0.125 | 0.010 | 0.100 | 0.285 | 5.200 |

### 3.12.4 Lower Lake Samples

Three organizations measured nitrate and nitrite concentrations in lower Falls Lake from 2000 to present. The highest mean and median nitrate plus nitrite concentrations were measured by City of Raleigh, while lowest mean and median concentrations were measured by NCDWQ. Highest concentrations were recorded in the 4 to 8 mile section of the lower lake and lowest concentrations were recorded in the 8 to 13 mile section. Highest mean concentrations were recorded in 2002 and lowest concentrations were recorded in 2005. Box plot summaries are provided below.

***Nitrate plus Nitrite Lower Lake Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Nitrate plus nitrite was recorded in two catchments, Lower Lake and Beaverdam Impoundment.

> Higher mean concentrations were recorded in the Lower Lake catchment; however, the sampling size for this category was significantly greater than the sampling size within the Beaverdam Impoundment.

> By lake segment, highest mean concentrations were measured in the 4 to 8 and 0 to 4 mile sections upstream of the dam.

> Lowest mean concentrations were measured 8 to 13 mile section and Beaverdam Impoundment.

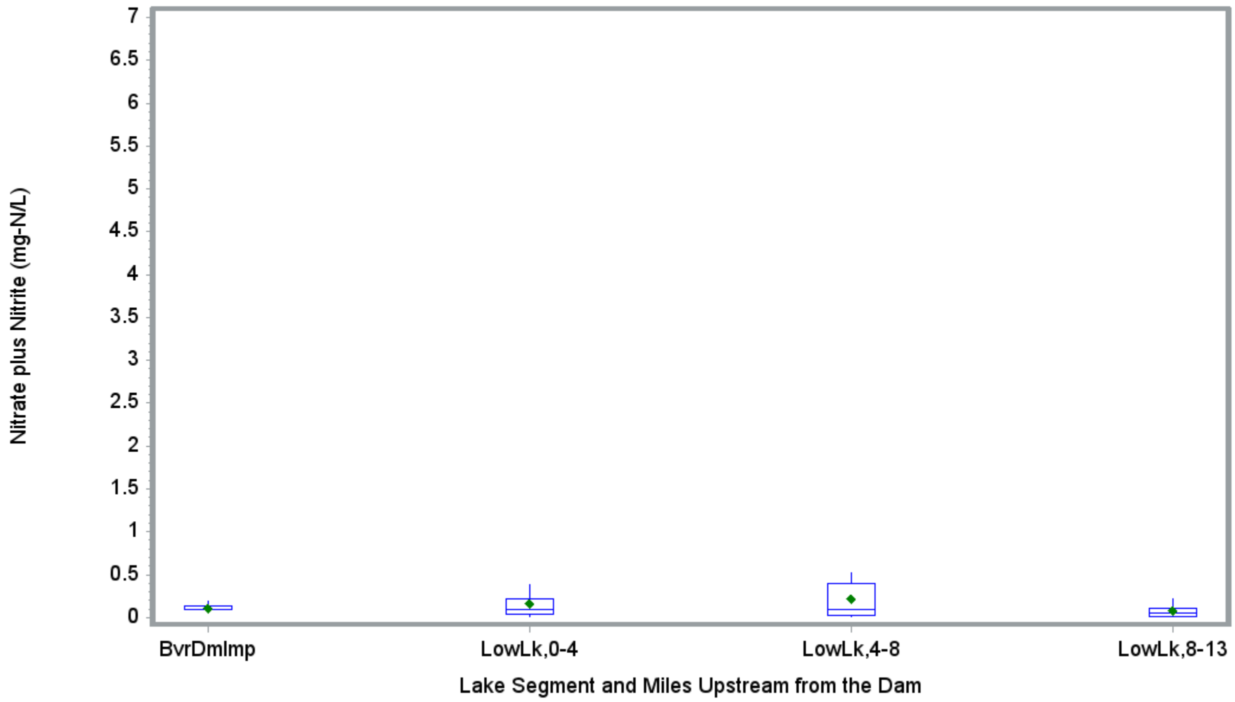



**Figure 3-130 Nitrate plus Nitrite Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-136 Nitrate plus Nitrite Lower Lake Samples Categorized by Miles Upstream from Dam (mg-N/L)**

| Lake Segment | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 56 | 0.050 | 0.050 | 0.100 | 0.113 | 0.100 | 0.135 | 0.195 | 0.220 |
| LowLk,0-4 | 444 | 0.005 | 0.010 | 0.040 | 0.166 | 0.100 | 0.220 | 0.385 | 1.555 |
| LowLk,4-8 | 644 | 0.005 | 0.010 | 0.020 | 0.213 | 0.095 | 0.400 | 0.520 | 2.120 |
| LowLk,8-13 | 262 | 0.005 | 0.010 | 0.010 | 0.085 | 0.050 | 0.110 | 0.220 | 0.535 |

### *Nitrate plus Nitrite Lower Lake Samples Categorized by Depth*

- By depth, highest mean and median concentrations were measured in the surface layer.
- Lowest mean and median concentrations were recorded in the photic layer.

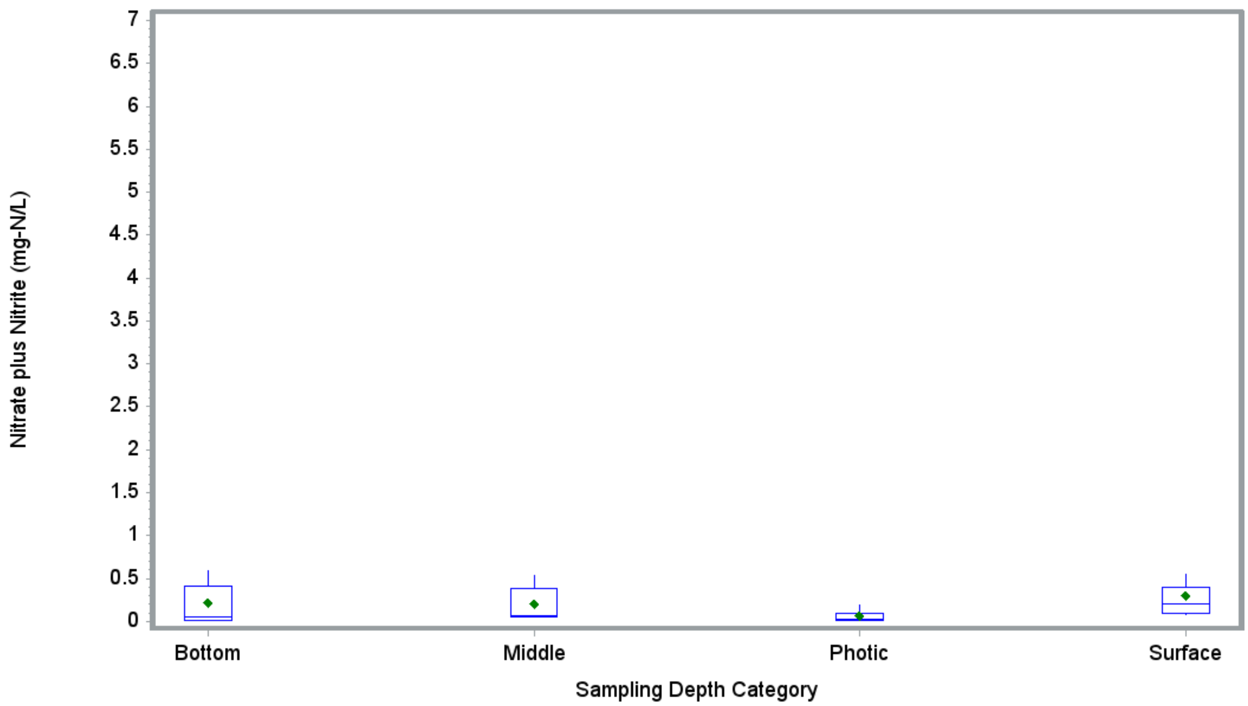



**Figure 3-131 Nitrate plus Nitrite Lower Lake Samples Categorized by Depth Category**

**Table 3-137 Nitrate plus Nitrite Lower Lake Samples Categorized by Depth Category (mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 54 | 0.005 | 0.005 | 0.005 | 0.224 | 0.051 | 0.410 | 0.592 | 1.305 |
| Middle | 150 | 0.017 | 0.048 | 0.052 | 0.209 | 0.060 | 0.378 | 0.537 | 0.843 |
| Photic | 687 | 0.005 | 0.010 | 0.010 | 0.064 | 0.020 | 0.090 | 0.190 | 0.950 |
| Surface | 515 | 0.027 | 0.080 | 0.100 | 0.296 | 0.210 | 0.400 | 0.555 | 2.120 |

### *Nitrate plus Nitrite Lower Lake Categorized by Year*

- By year, highest mean and median concentrations were recorded in 2002 and 2003.
- The lowest mean concentrations were recorded in 2005 and 2007

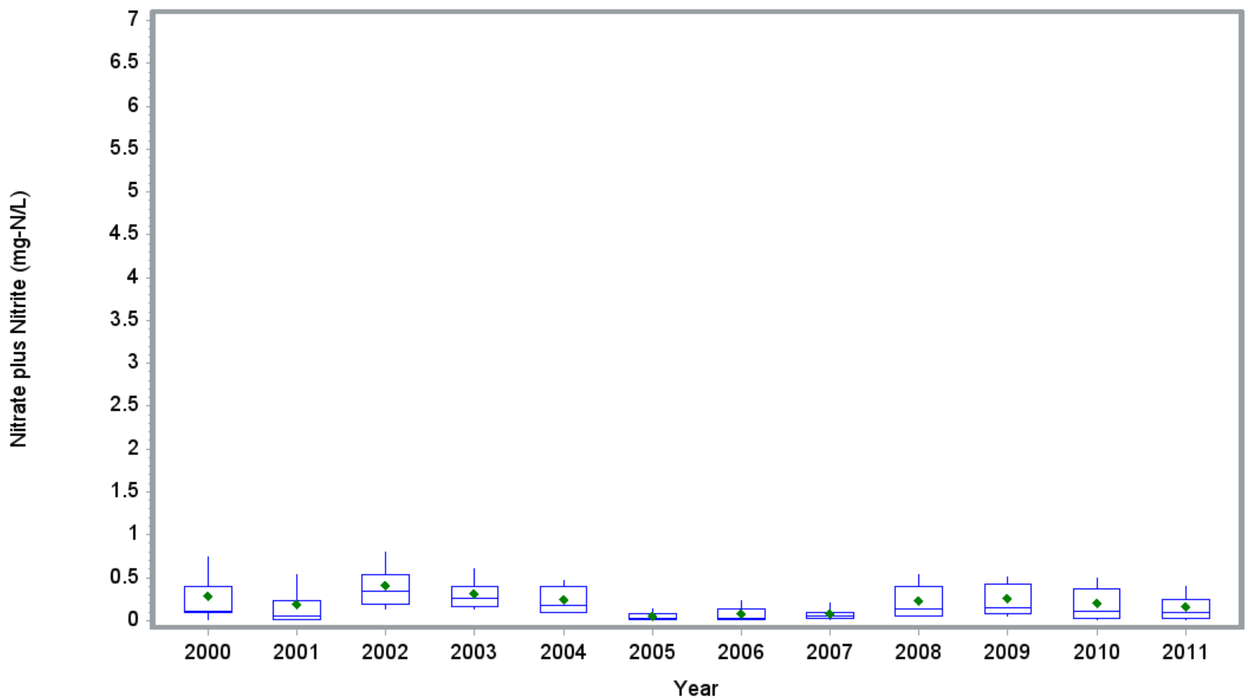



**Figure 3-132 Nitrate plus Nitrite Lower Lake Samples Categorized by Year**

**Table 3-138 Nitrate plus Nitrite Lower Lake Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 90 | 0.005 | 0.005 | 0.100 | 0.284 | 0.105 | 0.400 | 0.745 | 1.760 |
| 2001 | 129 | 0.005 | 0.005 | 0.010 | 0.188 | 0.050 | 0.235 | 0.540 | 2.120 |
| 2002 | 64 | 0.100 | 0.130 | 0.185 | 0.414 | 0.335 | 0.538 | 0.800 | 1.340 |
| 2003 | 72 | 0.075 | 0.130 | 0.160 | 0.316 | 0.260 | 0.400 | 0.600 | 0.940 |
| 2004 | 66 | 0.100 | 0.100 | 0.100 | 0.249 | 0.175 | 0.400 | 0.460 | 0.880 |
| 2005 | 166 | 0.010 | 0.010 | 0.010 | 0.056 | 0.020 | 0.080 | 0.130 | 0.400 |
| 2006 | 208 | 0.010 | 0.010 | 0.010 | 0.086 | 0.020 | 0.139 | 0.230 | 0.950 |
| 2007 | 202 | 0.010 | 0.010 | 0.020 | 0.081 | 0.048 | 0.100 | 0.200 | 0.400 |
| 2008 | 42 | 0.039 | 0.049 | 0.052 | 0.225 | 0.129 | 0.400 | 0.532 | 0.532 |
| 2009 | 59 | 0.050 | 0.052 | 0.077 | 0.253 | 0.150 | 0.425 | 0.510 | 0.549 |
| 2010 | 135 | 0.010 | 0.010 | 0.020 | 0.199 | 0.110 | 0.370 | 0.499 | 0.843 |
| 2011 | 173 | 0.010 | 0.010 | 0.020 | 0.167 | 0.100 | 0.250 | 0.400 | 1.680 |

***Nitrate plus Nitrite Lower Lake Samples Categorized by Month***

- By month, the highest mean concentrations were measured in January, February and December while highest median concentrations were measured in February and January.
- The lowest median concentrations were measured in June, July, and September in increasing order.

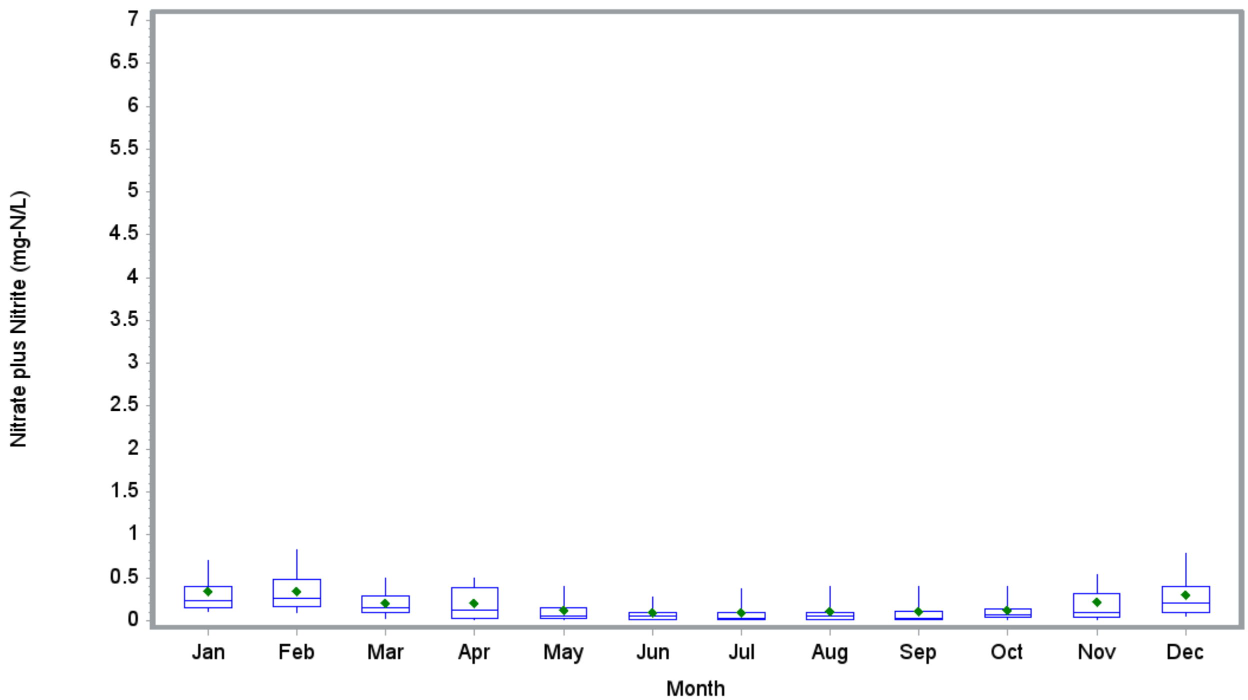



**Figure 3-133 Nitrate plus Nitrite Lower Lake Samples Categorized by Month**

**Table 3-139 Nitrate plus Nitrite Lower Lake Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 70 | 0.040 | 0.105 | 0.150 | 0.340 | 0.230 | 0.390 | 0.700 | 2.120 |
| Feb | 94 | 0.010 | 0.100 | 0.160 | 0.348 | 0.265 | 0.480 | 0.824 | 1.120 |
| Mar | 109 | 0.010 | 0.030 | 0.090 | 0.203 | 0.150 | 0.280 | 0.500 | 0.860 |
| Apr | 122 | 0.010 | 0.010 | 0.020 | 0.198 | 0.120 | 0.378 | 0.499 | 0.760 |
| Jay | 111 | 0.010 | 0.010 | 0.020 | 0.124 | 0.050 | 0.150 | 0.400 | 0.540 |
| Jun | 141 | 0.005 | 0.010 | 0.010 | 0.087 | 0.048 | 0.100 | 0.270 | 0.520 |
| Jul | 143 | 0.005 | 0.005 | 0.010 | 0.088 | 0.020 | 0.100 | 0.375 | 0.565 |
| Aug | 184 | 0.005 | 0.010 | 0.010 | 0.107 | 0.048 | 0.096 | 0.400 | 1.305 |
| Sep | 104 | 0.005 | 0.010 | 0.010 | 0.102 | 0.020 | 0.105 | 0.400 | 0.520 |
| Oct | 126 | 0.010 | 0.010 | 0.039 | 0.121 | 0.062 | 0.140 | 0.400 | 0.620 |
| Nov | 101 | 0.010 | 0.010 | 0.040 | 0.219 | 0.100 | 0.320 | 0.535 | 1.555 |
| Dec | 101 | 0.010 | 0.050 | 0.095 | 0.300 | 0.210 | 0.400 | 0.780 | 1.760 |

***Nitrate plus Nitrite Lower Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded City of Raleigh and USGS.

> Lowest mean and median concentrations were recorded by NCDWQ.

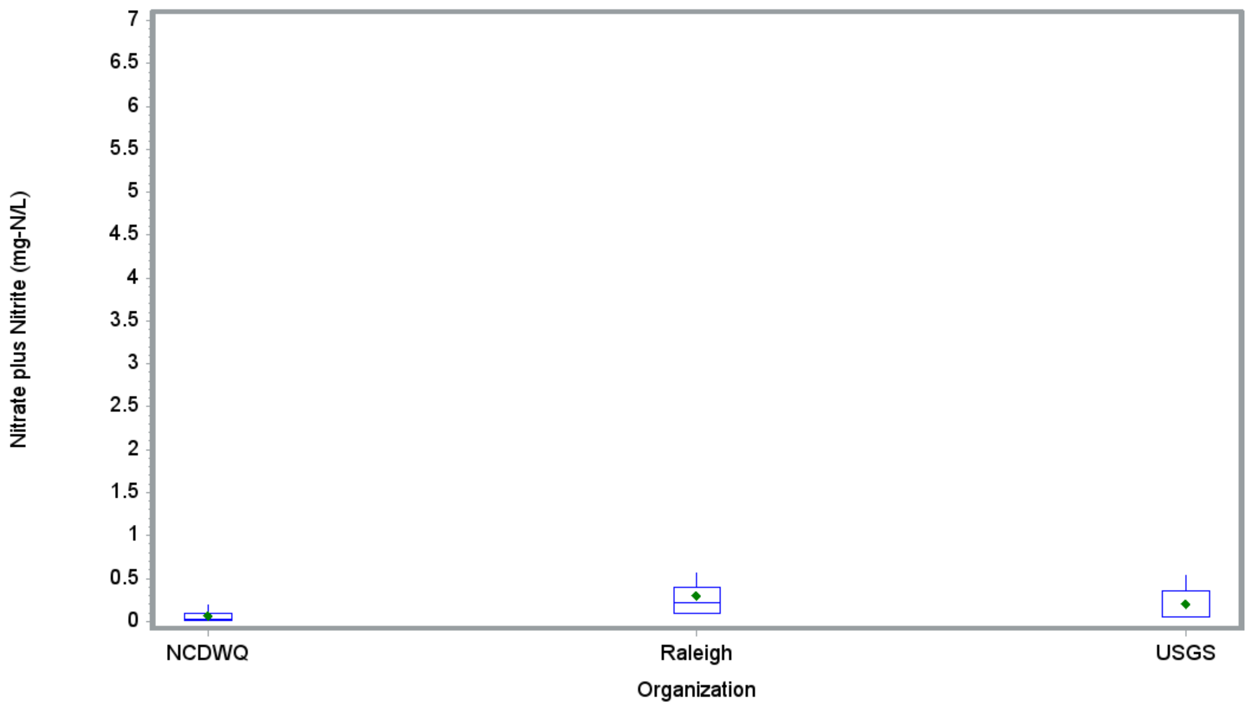



**Figure 3-134 Nitrate plus Nitrite Lower Lake Samples Categorized by Sampling Organization**

**Table 3-140 Nitrate plus Nitrite Lower Lake Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| NCDWQ | 725 | 0.005 | 0.010 | 0.010 | 0.071 | 0.020 | 0.090 | 0.190 | 1.305 |
| Raleigh | 487 | 0.050 | 0.100 | 0.100 | 0.306 | 0.220 | 0.400 | 0.560 | 2.120 |
| USGS | 194 | 0.017 | 0.046 | 0.050 | 0.200 | 0.054 | 0.356 | 0.532 | 0.843 |

### *Nitrate plus Nitrite Lower Lake Samples Categorized by Method*

> By method, mean concentrations using the EPA 351.2 method were the highest.

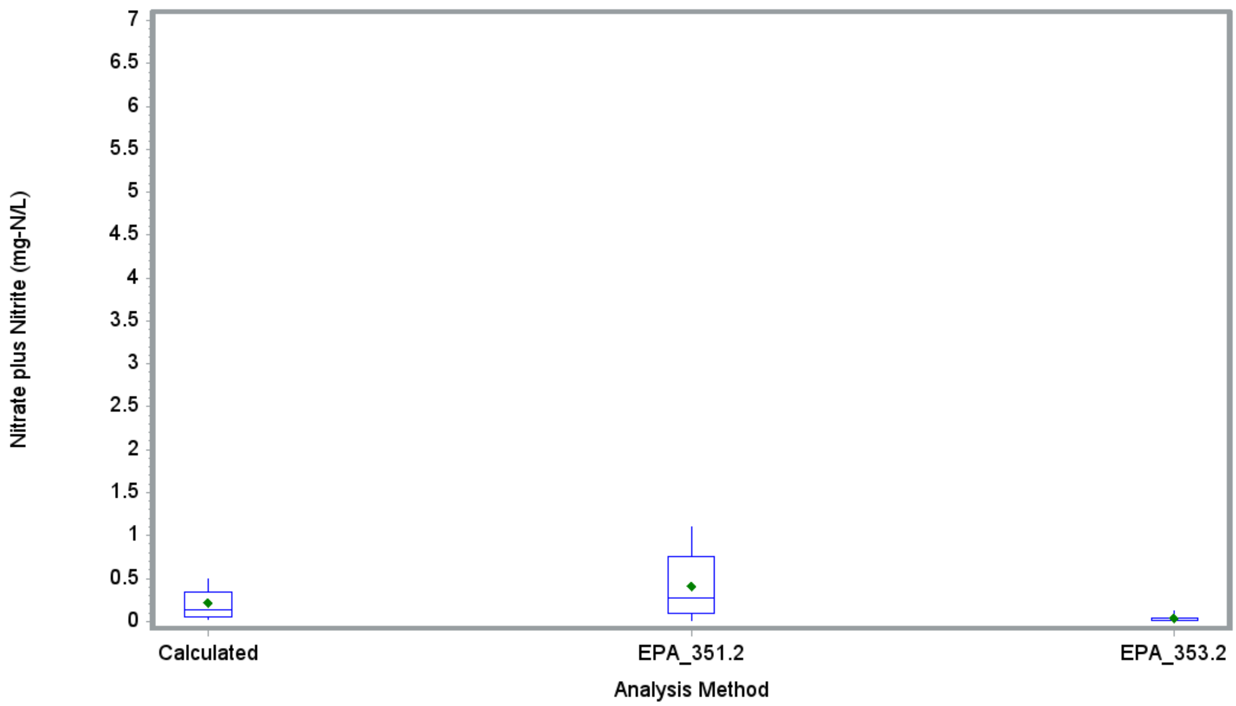



**Figure 3-135 Nitrate plus Nitrite Lower Lake Samples Categorized by Analysis Method**

**Table 3-141 Nitrate plus Nitrite Lower Lake Samples Categorized by Analysis Method (mg-N/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Calculated | 1023 | 0.010 | 0.020 | 0.050 | 0.213 | 0.130 | 0.340 | 0.499 | 2.120 |
| EPA_351.2 | 19 | 0.010 | 0.010 | 0.100 | 0.414 | 0.275 | 0.755 | 1.105 | 1.305 |
| EPA_353.2 | 364 | 0.005 | 0.005 | 0.010 | 0.038 | 0.010 | 0.040 | 0.120 | 0.290 |

## 3.13 Organic Nitrogen

Organic nitrogen was calculated from samples where both ammonia and total Kjeldahl nitrogen (TKN) were analyzed. Cardno ENTRIX determined organic nitrogen concentrations using the calculation ON=TKN - Ammonia. If reported ammonia or TKN results were less than reporting limits, then a value of one-half the limit was assumed in the calculation. Five organizations reported ammonia and TKN concentrations: NCWDQ, USGS, City of Durham, Orange County and Wake County. Ammonia and total Kjeldahl nitrogen were measured in the laboratory. For those organizations that provided TKN methods, the following methods were used:

> Determination of total Kjeldahl nitrogen by semi-automated colorimetry (EPA 351.2)

> Nitrogen, Kjeldahl, total, potentiometric, ion selective electrode (EPA 351.4)

> Ammonia plus organic nitrogen, unfiltered water, acidified, Kjeldahl digestion, continuous flow colorimetry (USGS I-4515-91)

Appendix E provides detailed descriptions of these methods. Ammonia analysis methods were described in the prior ammonia section. The analysis methods summarized in Table 3-142 for organic nitrogen are all calculated. The majority of the organic nitrogen data is calculated from data reported by USGS. Each of the limits is listed as not applicable (NA) because these values are calculated. Organic nitrogen is presented in mg-N/L and to three decimal places based on reported data.

**Table 3-142 Summary of Analysis Methods for the Organic Nitrogen Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg-N/L) | Reporting Limit (mg-N/L) | Practical Quanti-fication Limit (mg-N/L) | Range of Limit Specified with Results (mg-N/L) |
|---|---|---|---|---|---|---|---|---|
| Durham_Ci | Calculated | 04/01/2002 | 12/20/2011 | 1301 | NA | NA | NA | NA |
| NCDWQ[1] | Calculated | 01/11/1999 | 12/06/2011 | 1,397 | NA | NA | NA | NA |
| Orange_Co | Calculated | 04/09/2010 | 03/25/2011 | 182 | NA | NA | NA | NA |
| USGS | Calculated | 01/15/1999 | 10/14/2011 | 997 | NA | NA | NA | NA |
| Wake_Co | Calculated | 07/29/2008 | 10/14/2009 | 135 | NA | NA | NA | NA |

[1]Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

### 3.13.2 Tributary Samples

Five organizations measured organic nitrogen concentrations in Falls Lake tributaries from 1999 to 2011. Mean concentrations were comparable for four of the organizations with the fifth (Wake County) having lower concentrations. Highest concentrations were recorded in Knap of Reeds Creek 2-10 miles from the lake and lowest concentrations recorded in Horse/New Light Creek. Highest mean concentrations were recorded in 2006 and 2011 and the lowest mean concentrations were recorded in 2000 and 1999. Box plot summaries are provided below.

***Organic Nitrogen Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Organic nitrogen was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.

> Highest mean and median concentrations were measured in the Ellerbe Creek and Knap of Reeds Creek 0 to 2 mile segments.

> Lowest mean and median concentrations were measured in Horse/New Light Creek, in the 0 to 2 mile segment.

> By distance upstream of the mouth, concentrations were higher in the 2 to 10 mile section of Beaverdam Creek than in the 0 to 2 mile section.

> For Ellerbe Creek, lower concentrations were measured in the 2 to 10 mile section than in the 0 to 2 mile section.

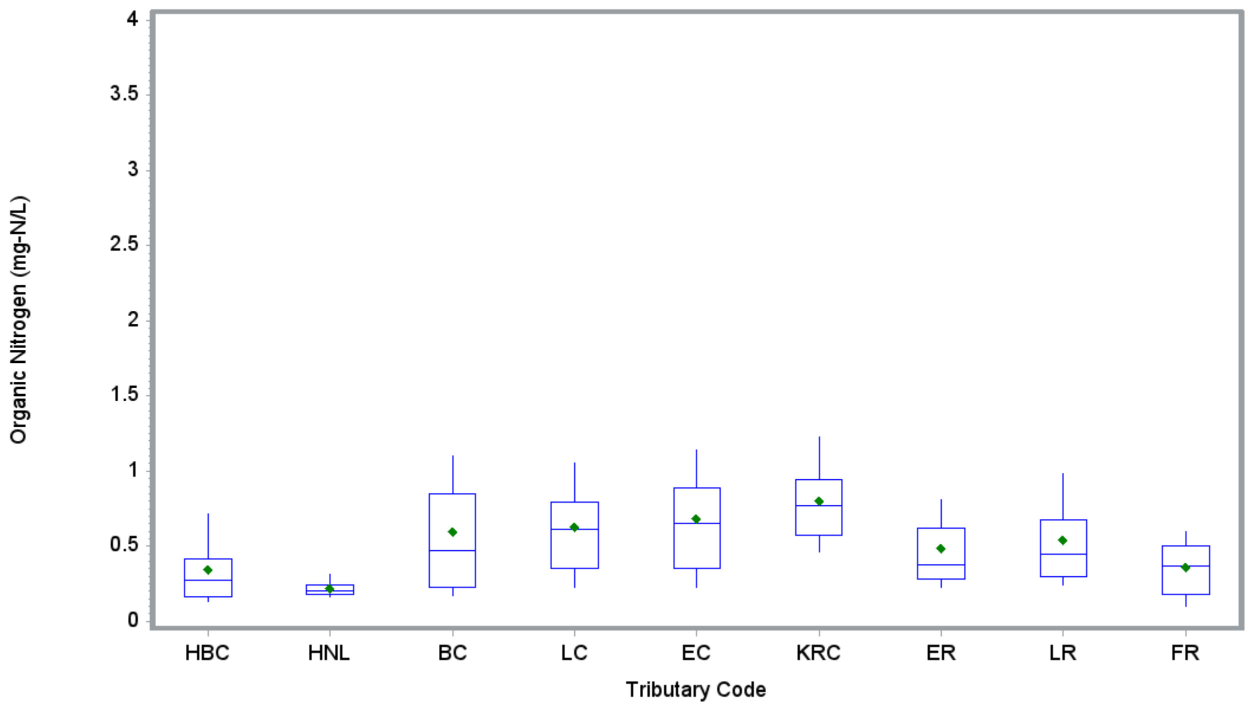



**Figure 3-136 Organic Nitrogen Tributary Samples Categorized by Subwatershed**

**Table 3-143 Organic Nitrogen Tributary Samples Categorized by Subwatershed (mg-N/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 76 | 0.058 | 0.129 | 0.167 | 0.348 | 0.276 | 0.419 | 0.718 | 1.261 |
| HNL | 42 | 0.011 | 0.167 | 0.180 | 0.218 | 0.203 | 0.241 | 0.316 | 0.520 |
| BC | 45 | 0.143 | 0.174 | 0.227 | 0.593 | 0.470 | 0.850 | 1.100 | 1.450 |
| LC | 121 | 0.000 | 0.230 | 0.350 | 0.628 | 0.610 | 0.790 | 1.050 | 1.860 |
| EC | 437 | 0.000 | 0.230 | 0.350 | 0.686 | 0.650 | 0.890 | 1.140 | 4.350 |
| KRC | 136 | 0.100 | 0.460 | 0.575 | 0.806 | 0.770 | 0.940 | 1.230 | 3.630 |
| ER | 525 | 0.000 | 0.230 | 0.280 | 0.484 | 0.380 | 0.620 | 0.810 | 3.807 |
| LR | 428 | 0.000 | 0.240 | 0.299 | 0.542 | 0.445 | 0.679 | 0.980 | 2.550 |
| FR | 244 | 0.000 | 0.100 | 0.180 | 0.364 | 0.365 | 0.500 | 0.600 | 1.640 |

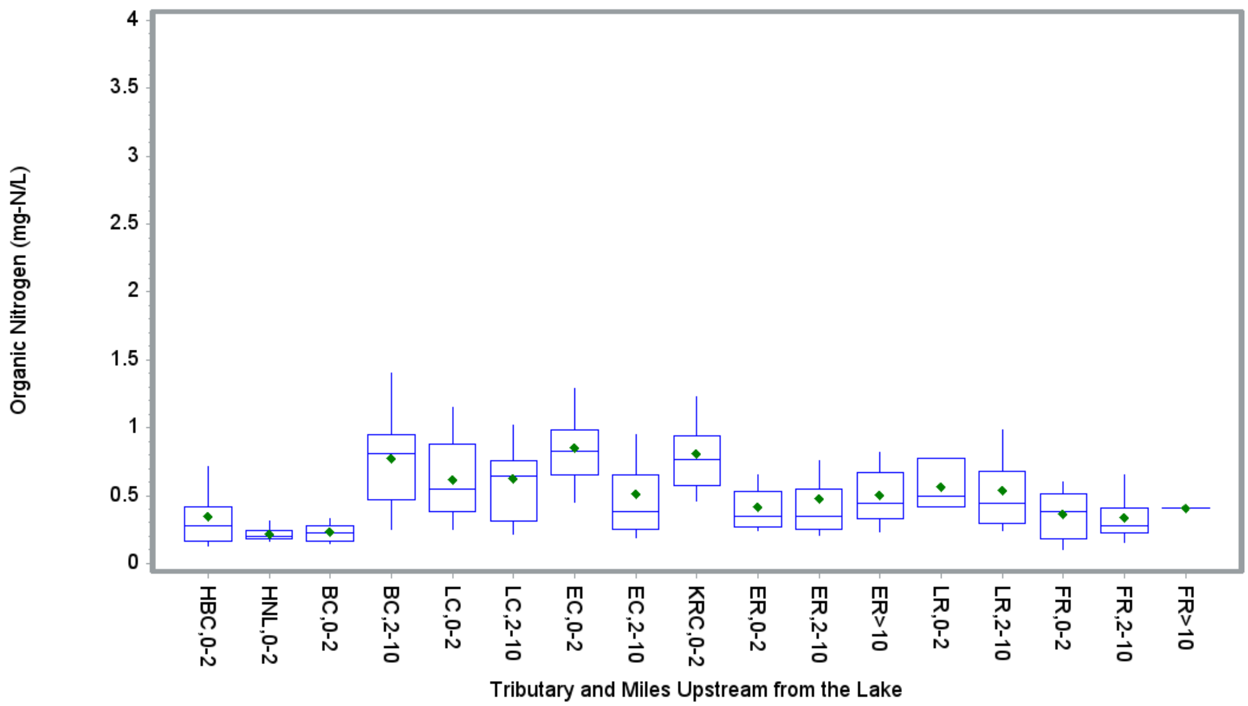



**Figure 3-137 Organic Nitrogen Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-144 Organic Nitrogen Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (mg-N/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 76 | 0.058 | 0.129 | 0.167 | 0.348 | 0.276 | 0.419 | 0.718 | 1.261 |
| HNL,0-2 | 42 | 0.011 | 0.167 | 0.180 | 0.218 | 0.203 | 0.241 | 0.316 | 0.520 |
| BC,0-2 | 15 | 0.143 | 0.151 | 0.167 | 0.230 | 0.223 | 0.281 | 0.327 | 0.438 |
| BC,2-10 | 30 | 0.175 | 0.255 | 0.470 | 0.775 | 0.810 | 0.950 | 1.400 | 1.450 |
| LC,0-2 | 36 | 0.000 | 0.250 | 0.385 | 0.621 | 0.550 | 0.884 | 1.150 | 1.750 |
| LC,2-10 | 85 | 0.000 | 0.220 | 0.317 | 0.630 | 0.640 | 0.760 | 1.020 | 1.860 |
| EC,0-2 | 222 | 0.000 | 0.450 | 0.650 | 0.852 | 0.830 | 0.980 | 1.285 | 2.520 |
| EC,2-10 | 215 | 0.000 | 0.190 | 0.250 | 0.515 | 0.380 | 0.650 | 0.950 | 4.350 |
| KRC,0-2 | 136 | 0.100 | 0.460 | 0.575 | 0.806 | 0.770 | 0.940 | 1.230 | 3.630 |
| ER,0-2 | 68 | 0.000 | 0.240 | 0.273 | 0.417 | 0.346 | 0.530 | 0.650 | 1.290 |
| ER,2-10 | 182 | 0.000 | 0.210 | 0.250 | 0.474 | 0.350 | 0.550 | 0.760 | 3.807 |
| ER>10 | 275 | 0.110 | 0.230 | 0.327 | 0.507 | 0.440 | 0.670 | 0.820 | 1.690 |
| LR,0-2 | 3 | 0.419 | 0.419 | 0.419 | 0.565 | 0.498 | 0.777 | 0.777 | 0.777 |
| LR,2-10 | 425 | 0.000 | 0.240 | 0.298 | 0.542 | 0.440 | 0.678 | 0.980 | 2.550 |
| FR,0-2 | 199 | 0.000 | 0.100 | 0.180 | 0.369 | 0.380 | 0.510 | 0.600 | 1.640 |
| FR,2-10 | 44 | 0.000 | 0.160 | 0.225 | 0.342 | 0.280 | 0.410 | 0.650 | 0.950 |

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| FR>10 | 1 | 0.410 | 0.410 | 0.410 | 0.410 | 0.410 | 0.410 | 0.410 | 0.410 |

***Organic Nitrogen Tributary Samples Categorized by Depth***

> All samples were collected in the surface layer.

***Organic Nitrogen Tributary Categorized by Year***

> The highest mean concentrations were observed in 2006 and 2011.

> The lowest mean concentrations were recorded in 2000 and 1999

> Median concentrations were comparable for all years.

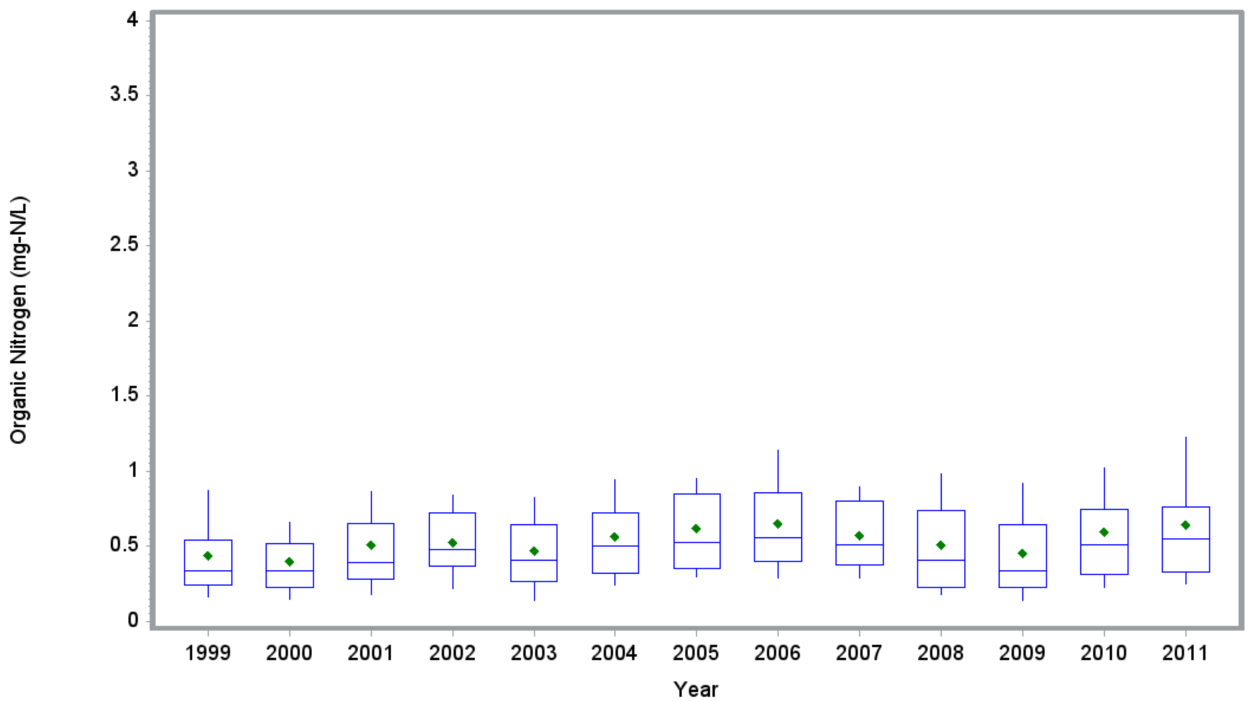



**Figure 3-138 Organic Nitrogen Tributary Samples Categorized by Year**

**Table 3-145 Organic Nitrogen Tributary Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 124 | 0.040 | 0.160 | 0.240 | 0.442 | 0.340 | 0.540 | 0.870 | 1.640 |
| 2000 | 107 | 0.080 | 0.150 | 0.230 | 0.399 | 0.340 | 0.520 | 0.660 | 1.380 |
| 2001 | 56 | 0.030 | 0.180 | 0.280 | 0.509 | 0.395 | 0.650 | 0.866 | 3.630 |
| 2002 | 43 | 0.120 | 0.220 | 0.370 | 0.527 | 0.480 | 0.720 | 0.839 | 1.076 |
| 2003 | 80 | 0.090 | 0.140 | 0.264 | 0.471 | 0.410 | 0.645 | 0.825 | 1.334 |
| 2004 | 83 | 0.040 | 0.240 | 0.320 | 0.565 | 0.500 | 0.720 | 0.940 | 2.200 |
| 2005 | 123 | 0.080 | 0.300 | 0.350 | 0.621 | 0.530 | 0.850 | 0.950 | 2.550 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2006 | 135 | 0.000 | 0.290 | 0.400 | 0.655 | 0.560 | 0.860 | 1.140 | 1.643 |
| 2007 | 105 | 0.079 | 0.287 | 0.380 | 0.572 | 0.510 | 0.801 | 0.900 | 1.511 |
| 2008 | 157 | 0.100 | 0.180 | 0.230 | 0.508 | 0.410 | 0.740 | 0.980 | 1.689 |
| 2009 | 348 | 0.000 | 0.144 | 0.230 | 0.454 | 0.335 | 0.645 | 0.917 | 2.520 |
| 2010 | 454 | 0.040 | 0.230 | 0.317 | 0.599 | 0.510 | 0.750 | 1.020 | 4.350 |
| 2011 | 239 | 0.000 | 0.250 | 0.330 | 0.646 | 0.550 | 0.760 | 1.230 | 3.807 |

### *Organic Nitrogen Tributary Samples Categorized by Month*

> Highest mean concentrations were measured in June and January.
> The lowest mean and median concentrations were measured in February.
> Mean and median concentrations are comparable for all months.

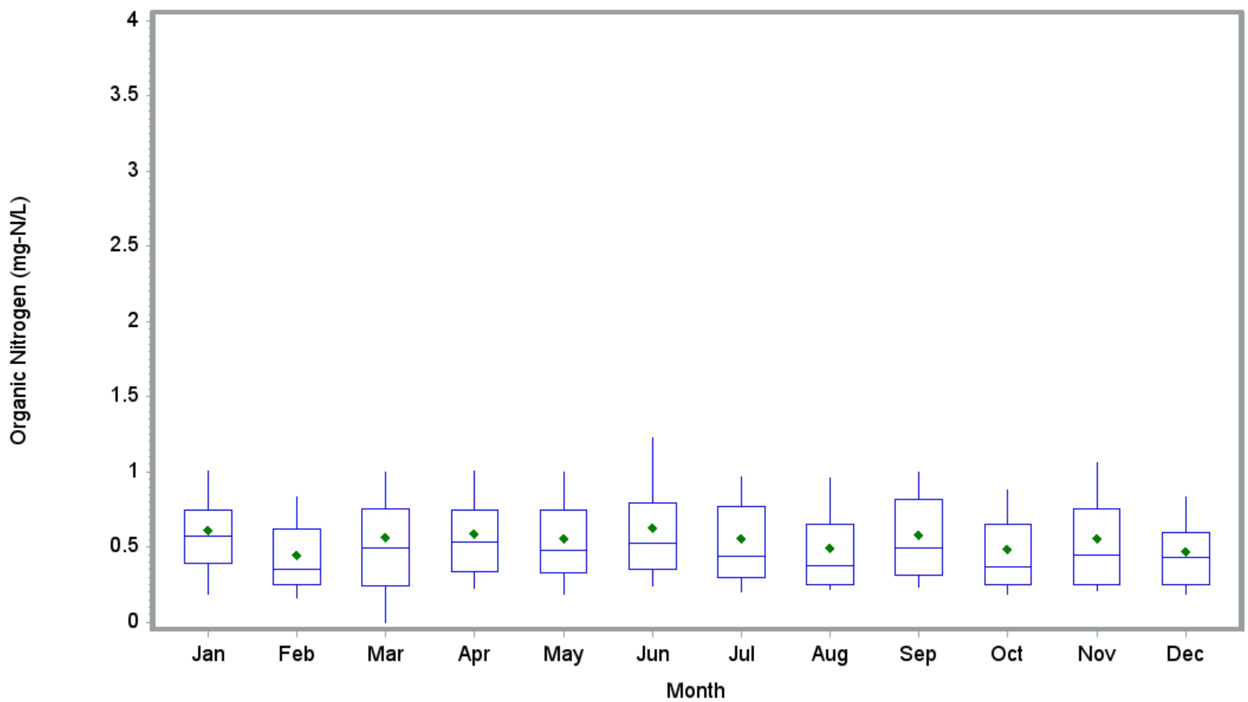



**Figure 3-139 Organic Nitrogen Tributary Samples Categorized by Month**

**Table 3-146 Organic Nitrogen Tributary Samples Categorized by Month**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 154 | 0.079 | 0.190 | 0.390 | 0.610 | 0.570 | 0.750 | 1.010 | 2.390 |
| Feb | 175 | 0.000 | 0.160 | 0.250 | 0.451 | 0.350 | 0.620 | 0.830 | 2.420 |
| Mar | 162 | 0.000 | 0.000 | 0.245 | 0.563 | 0.498 | 0.755 | 1.000 | 4.350 |
| Apr | 184 | 0.080 | 0.230 | 0.336 | 0.593 | 0.535 | 0.750 | 1.010 | 3.350 |
| May | 169 | 0.000 | 0.190 | 0.328 | 0.560 | 0.480 | 0.750 | 1.000 | 2.163 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jun | 193 | 0.000 | 0.242 | 0.350 | 0.628 | 0.530 | 0.790 | 1.230 | 2.550 |
| Jul | 188 | 0.058 | 0.200 | 0.300 | 0.555 | 0.440 | 0.770 | 0.970 | 3.630 |
| Aug | 167 | 0.000 | 0.220 | 0.250 | 0.494 | 0.376 | 0.650 | 0.960 | 1.671 |
| Sep | 167 | 0.040 | 0.236 | 0.310 | 0.583 | 0.498 | 0.820 | 0.998 | 1.689 |
| Oct | 166 | 0.040 | 0.190 | 0.250 | 0.489 | 0.365 | 0.650 | 0.880 | 3.110 |
| Nov | 148 | 0.050 | 0.210 | 0.250 | 0.557 | 0.450 | 0.755 | 1.060 | 2.990 |
| Dec | 181 | 0.040 | 0.185 | 0.250 | 0.474 | 0.435 | 0.600 | 0.830 | 2.250 |

***Organic Nitrogen Tributary Samples Categorized by Sampling Organization***

> By sampling organization, the mean and median concentrations recorded by Durham City, NCDWQ, Orange County, and USGS were similar.

> Lowest mean and median concentrations were recorded by Wake County.

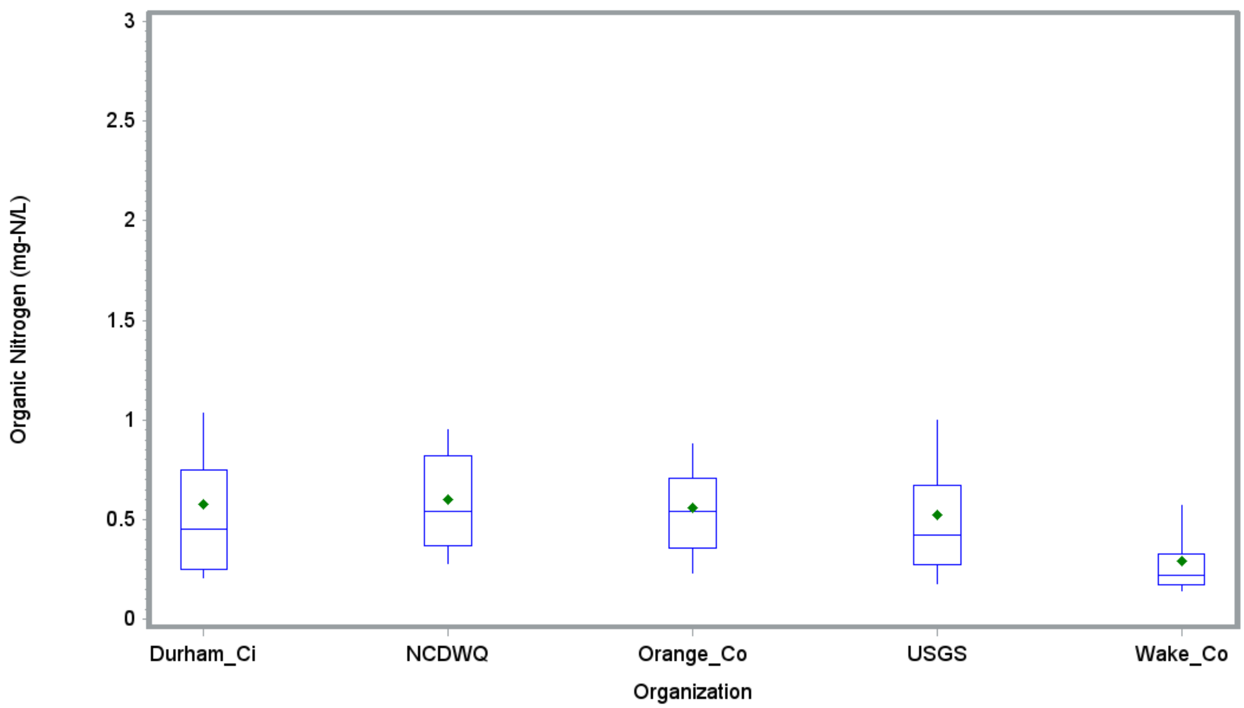



**Figure 3-140 Organic Nitrogen Tributary Samples Categorized by Sampling Organization**

**Table 3-147 Organic Nitrogen Tributary Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 626 | 0.000 | 0.210 | 0.250 | 0.579 | 0.450 | 0.750 | 1.050 | 4.350 |
| NCDWQ | 494 | 0.030 | 0.280 | 0.370 | 0.601 | 0.540 | 0.820 | 0.960 | 3.630 |
| Orange_Co | 182 | 0.220 | 0.230 | 0.360 | 0.557 | 0.540 | 0.710 | 0.880 | 1.690 |

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| USGS | 620 | 0.040 | 0.180 | 0.277 | 0.522 | 0.420 | 0.674 | 1.000 | 2.550 |
| Wake_Co | 132 | 0.011 | 0.143 | 0.175 | 0.292 | 0.222 | 0.327 | 0.570 | 1.261 |

***Organic Nitrogen Tributary Samples Categorized by Method***

> Only the calculated method was used to determine organic nitrogen.

### 3.13.3 Upper Lake Samples

Three organizations measured organic nitrogen concentrations in upper Falls Lake from 2000 to present. Highest concentrations were recorded by USGS while lowest concentrations were recorded by City of Durham and NCDWQ. Lowest mean concentrations were recorded in the 13 to 18 mile section. Highest mean concentrations were recorded in 2009 and 2008, while lowest mean concentrations were recorded in 2000. Box plot summaries are provided below.

***Organic Nitrogen Samples Categorized by Lake Segment and Miles Upstream from Dam***

> The mean and median concentrations were similar in the > 21 mile and 13 to 18 mile segments, while mean concentrations were lowed in the 18 to 21 mile segment

> The lowest variability in concentrations was measured in the 18 to 21 mile section.

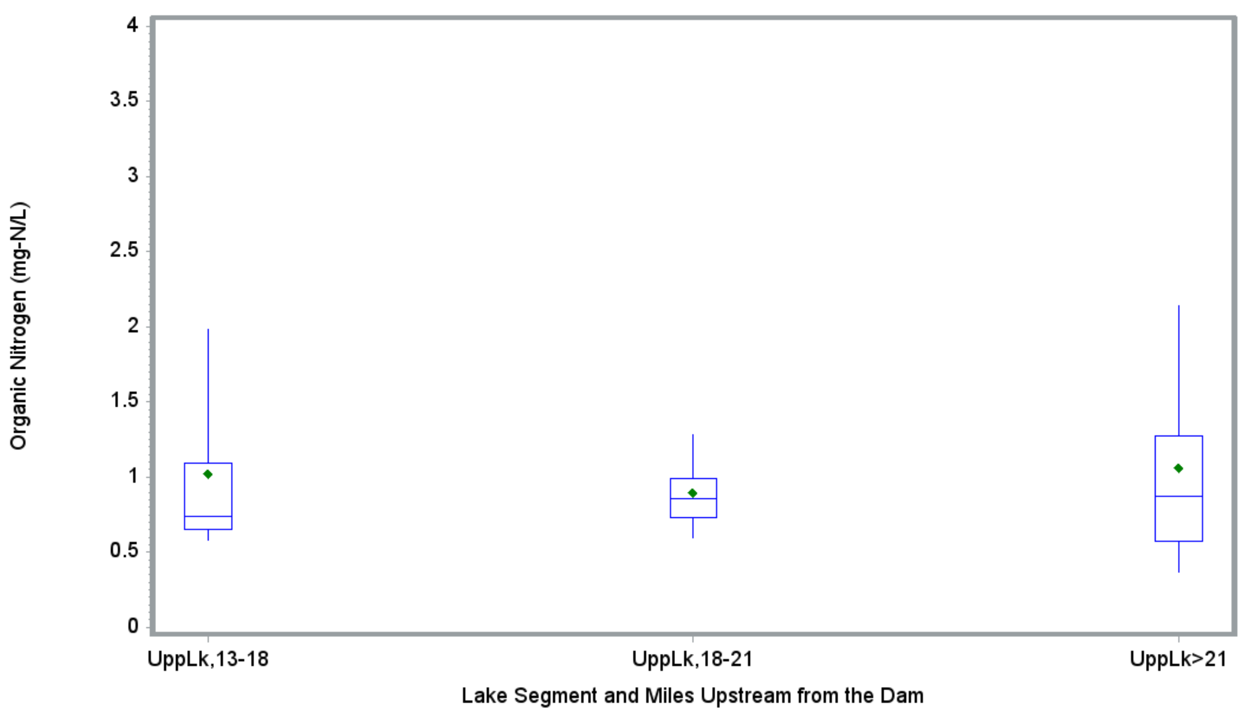



**Figure 3-141 Organic Nitrogen Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-148 Organic Nitrogen Upper Lake Samples Categorized by Miles Upstream from Dam (mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 394 | 0.000 | 0.580 | 0.650 | 1.022 | 0.740 | 1.090 | 1.981 | 2.910 |
| UppLk,18-21 | 89 | 0.000 | 0.600 | 0.730 | 0.894 | 0.860 | 0.990 | 1.280 | 2.090 |
| UppLk>21 | 917 | 0.000 | 0.370 | 0.575 | 1.062 | 0.875 | 1.275 | 2.138 | 5.237 |

### *Organic Nitrogen Tributary Samples Categorized by Depth*

> Highest mean concentrations were recorded in the middle depth layer while lowest mean concentrations were in the surface layer.

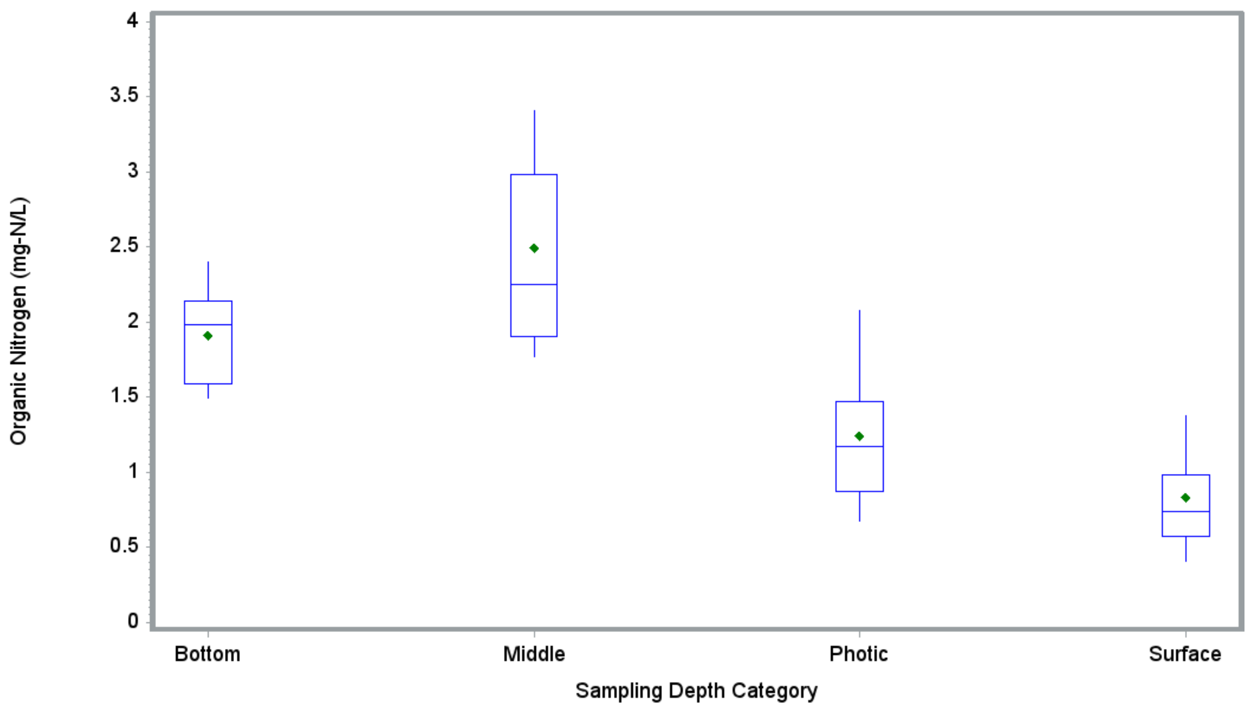



**Figure 3-142 Organic Nitrogen Upper Lake Samples Categorized by Depth**

**Table 3-149 Organic Nitrogen Upper Lake Samples Categorized by Depth**

| Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 7 | 1.494 | 1.494 | 1.586 | 1.912 | 1.981 | 2.138 | 2.397 | 2.397 |
| Middle | 153 | 1.014 | 1.767 | 1.906 | 2.496 | 2.252 | 2.981 | 3.408 | 5.237 |
| Photic | 67 | 0.125 | 0.675 | 0.875 | 1.241 | 1.175 | 1.475 | 2.075 | 2.475 |
| Surface | 1173 | 0.000 | 0.410 | 0.575 | 0.833 | 0.740 | 0.980 | 1.375 | 4.110 |

***Organic Nitrogen Tributary Categorized by Year***

> The highest concentrations were recorded in 2009 and 2008.

> The lowest mean and median concentrations were observed in 2000.

> There is a general trend of increasing concentrations from 2000 to 2011.

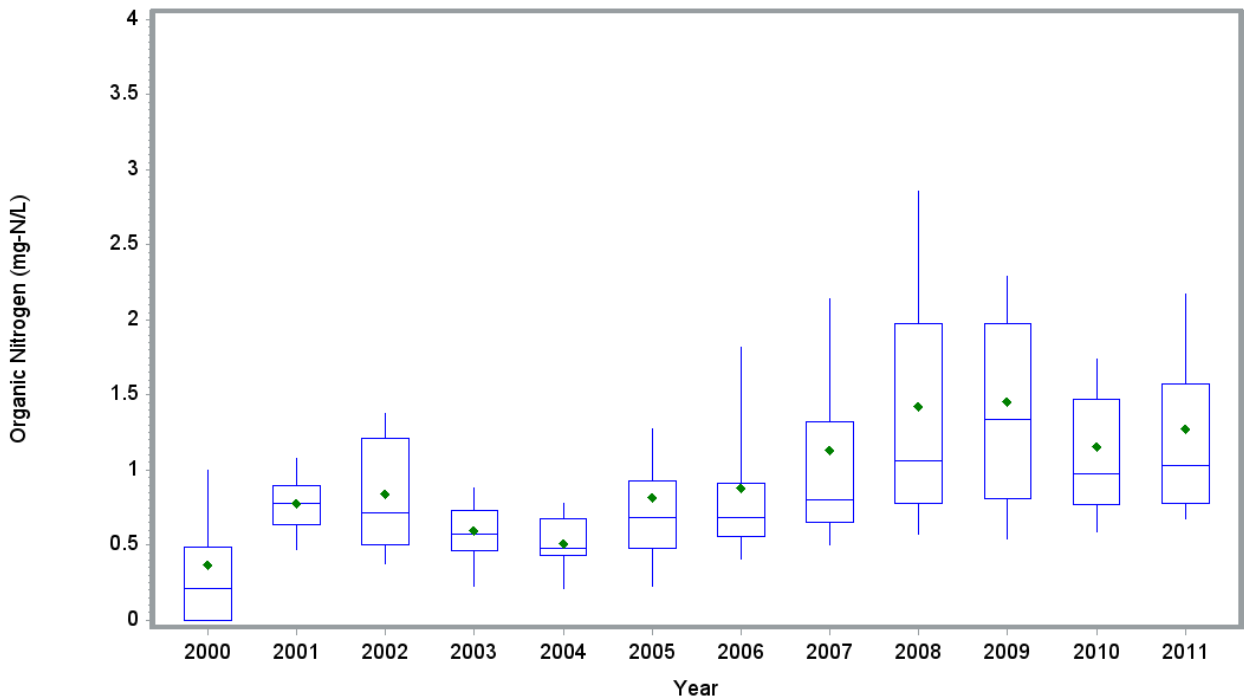



**Figure 3-143 Organic Nitrogen Upper Lake Samples Categorized by Year**

**Table 3-150 Organic Nitrogen Upper Lake Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 13 | 0.000 | 0.000 | 0.000 | 0.366 | 0.210 | 0.490 | 0.995 | 1.640 |
| 2001 | 34 | 0.400 | 0.470 | 0.640 | 0.778 | 0.775 | 0.900 | 1.080 | 1.410 |
| 2002 | 62 | 0.030 | 0.380 | 0.500 | 0.841 | 0.715 | 1.210 | 1.380 | 1.875 |
| 2003 | 57 | 0.160 | 0.225 | 0.460 | 0.595 | 0.575 | 0.730 | 0.880 | 2.160 |
| 2004 | 60 | 0.010 | 0.213 | 0.430 | 0.509 | 0.475 | 0.675 | 0.775 | 0.975 |
| 2005 | 173 | 0.150 | 0.225 | 0.475 | 0.821 | 0.680 | 0.930 | 1.275 | 3.911 |
| 2006 | 229 | 0.225 | 0.410 | 0.560 | 0.884 | 0.680 | 0.910 | 1.820 | 3.324 |
| 2007 | 209 | 0.110 | 0.500 | 0.650 | 1.132 | 0.800 | 1.320 | 2.138 | 5.237 |
| 2008 | 88 | 0.475 | 0.575 | 0.775 | 1.426 | 1.063 | 1.973 | 2.856 | 3.408 |
| 2009 | 99 | 0.125 | 0.540 | 0.810 | 1.454 | 1.340 | 1.977 | 2.288 | 3.580 |
| 2010 | 183 | 0.125 | 0.590 | 0.770 | 1.160 | 0.975 | 1.475 | 1.740 | 3.159 |
| 2011 | 193 | 0.125 | 0.675 | 0.775 | 1.272 | 1.030 | 1.575 | 2.175 | 4.370 |

### *Organic Nitrogen Tributary Samples Categorized by Month*

> The highest monthly mean and median concentrations were in August and October. The lowest mean and median concentrations were in January.

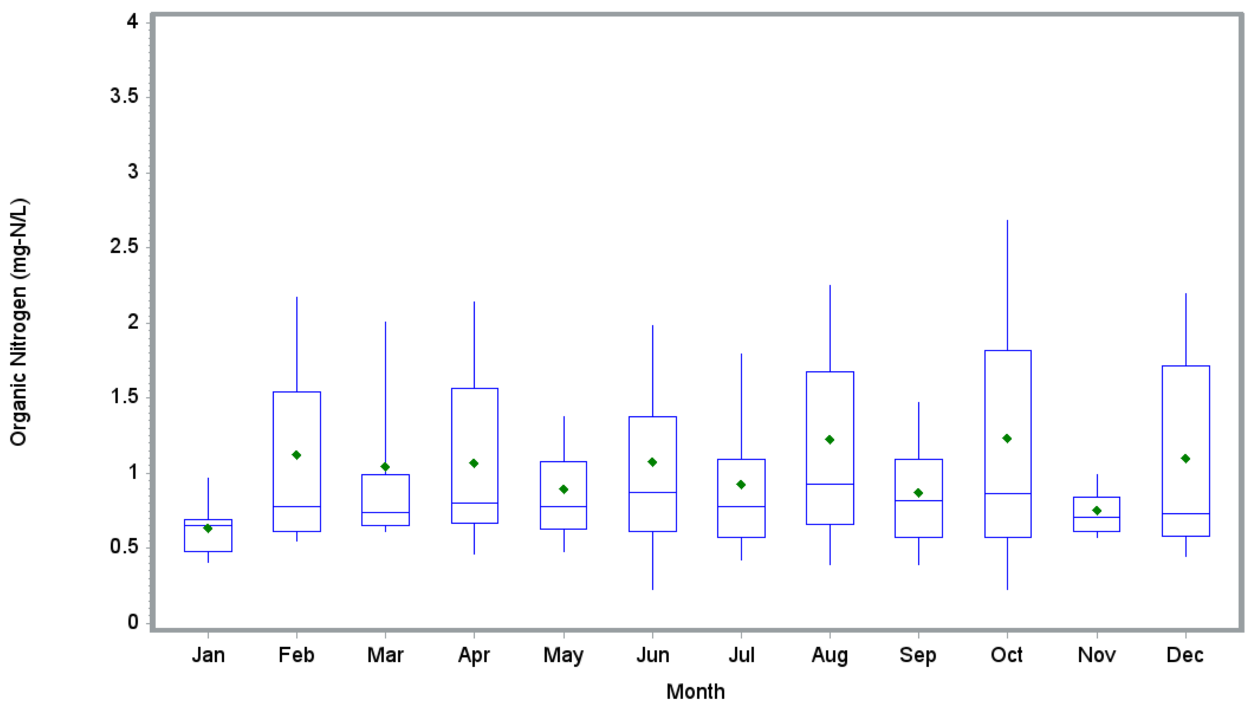



**Figure 3-144 Organic Nitrogen Upper Lake Samples Categorized by Month**

**Table 3-151 Organic Nitrogen Upper Lake Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 29 | 0.360 | 0.410 | 0.480 | 0.638 | 0.650 | 0.690 | 0.970 | 0.980 |
| Feb | 48 | 0.400 | 0.550 | 0.610 | 1.127 | 0.780 | 1.540 | 2.170 | 2.856 |
| Mar | 57 | 0.475 | 0.610 | 0.650 | 1.045 | 0.740 | 0.990 | 2.005 | 4.370 |
| Apr | 166 | 0.110 | 0.460 | 0.670 | 1.072 | 0.800 | 1.566 | 2.138 | 2.983 |
| May | 135 | 0.180 | 0.475 | 0.630 | 0.897 | 0.775 | 1.075 | 1.375 | 4.110 |
| Jun | 175 | 0.120 | 0.225 | 0.610 | 1.081 | 0.875 | 1.375 | 1.982 | 3.170 |
| Jul | 166 | 0.040 | 0.420 | 0.575 | 0.928 | 0.775 | 1.090 | 1.795 | 2.975 |
| Aug | 211 | 0.000 | 0.390 | 0.660 | 1.230 | 0.930 | 1.675 | 2.252 | 5.237 |
| Sep | 149 | 0.000 | 0.390 | 0.575 | 0.869 | 0.820 | 1.090 | 1.475 | 2.340 |
| Oct | 162 | 0.030 | 0.230 | 0.575 | 1.232 | 0.863 | 1.820 | 2.684 | 4.197 |
| Nov | 55 | 0.470 | 0.575 | 0.610 | 0.752 | 0.710 | 0.840 | 0.990 | 1.275 |
| Dec | 47 | 0.400 | 0.450 | 0.580 | 1.102 | 0.730 | 1.718 | 2.194 | 2.318 |

### *Organic Nitrogen Tributary Samples Categorized by Sampling Organization*

> By sampling organization, the highest mean and median concentrations were recorded by USGS and the lowest mean and median concentrations were recorded by NCDWQ and City of Durham.

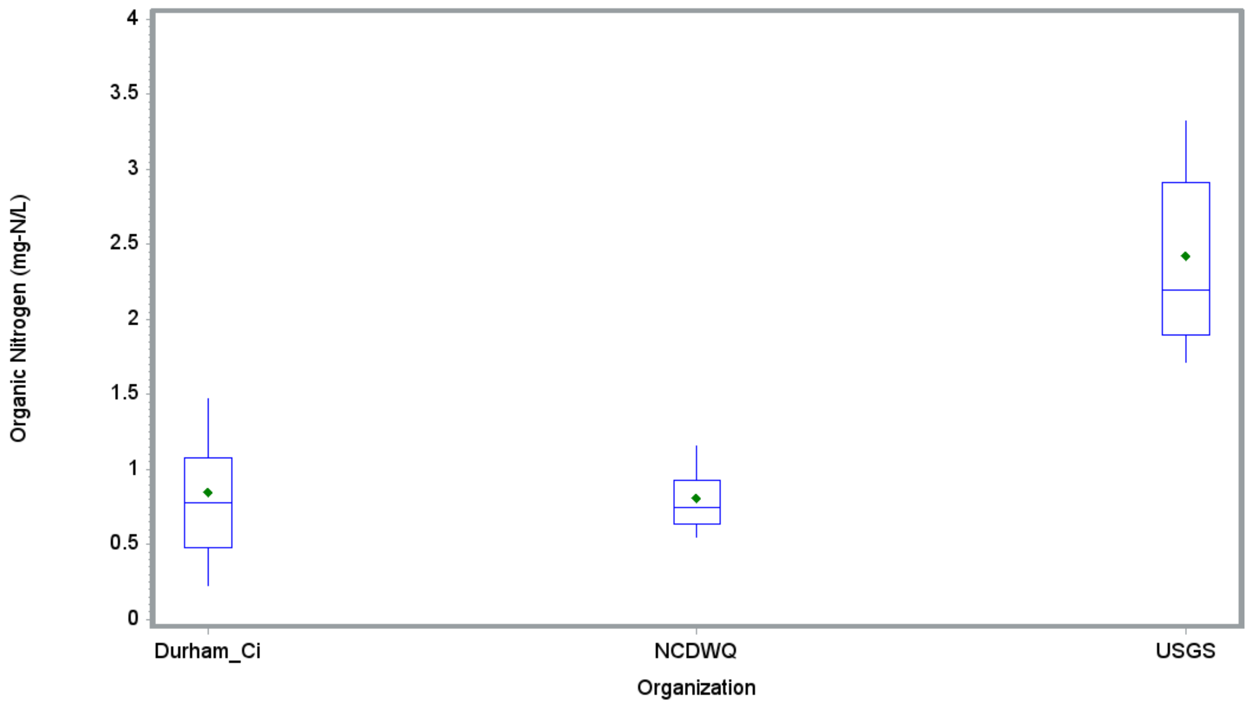



**Figure 3-145 Organic Nitrogen Upper Lake Samples Categorized by Sampling Organization**

**Table 3-152 Organic Nitrogen Upper Lake Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 675 | 0.010 | 0.225 | 0.475 | 0.847 | 0.775 | 1.075 | 1.475 | 4.110 |
| NCDWQ | 542 | 0.000 | 0.550 | 0.640 | 0.812 | 0.745 | 0.930 | 1.160 | 3.390 |
| USGS | 183 | 1.014 | 1.718 | 1.897 | 2.427 | 2.194 | 2.910 | 3.324 | 5.237 |

### *Organic Nitrogen Tributary Samples Categorized by Method*

> Only the calculated method was used to determine organic nitrogen.

## 3.13.4 Lower Lake Samples

Three organizations measured organic nitrogen concentrations in lower Falls Lake from 2000 to present. Highest mean and median concentrations were recorded by USGS, while lowest concentrations were recorded by Wake County. Highest concentrations were recorded in the 0 to 4 mile and 4 to 8 mile segments. Highest mean concentrations were recorded in 2008, while the lowest mean concentrations were recorded in 2000. Box plot summaries are provided below.

### *Organic Nitrogen Samples Categorized by Lake Segment and Miles Upstream from Dam*

> Organic nitrogen was calculated in three lower lake sections, but not in Beaverdam Impoundment.

> Median and mean values were similar for the 0 to 4 and 4 to 8 mile segments.

> Lowest mean concentrations were in the 8 to 13 mile segments.

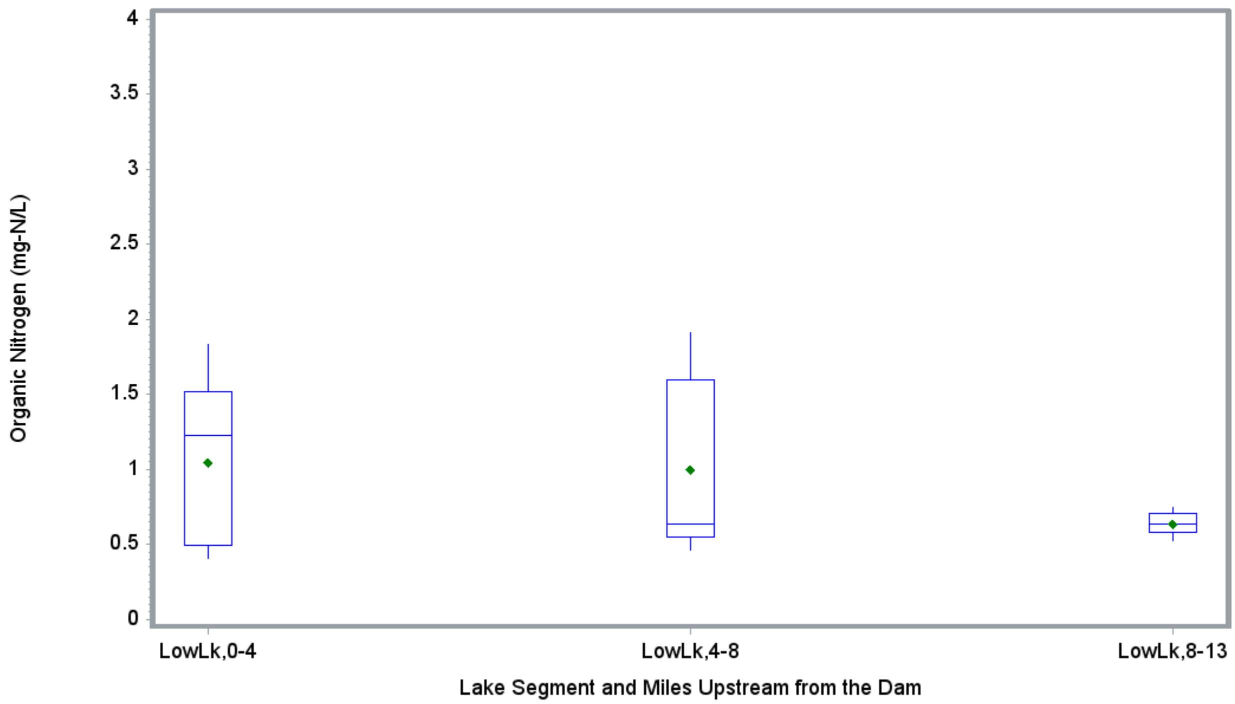



**Figure 3-146 Organic Nitrogen Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-153 Organic Nitrogen Lower Lake Samples Categorized by Miles Upstream from Dam (mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LowLk,0-4 | 192 | 0.011 | 0.410 | 0.495 | 1.045 | 1.226 | 1.521 | 1.831 | 2.614 |
| LowLk,4-8 | 276 | 0.000 | 0.460 | 0.550 | 1.002 | 0.640 | 1.599 | 1.913 | 2.806 |
| LowLk,8-13 | 90 | 0.230 | 0.530 | 0.580 | 0.639 | 0.640 | 0.710 | 0.750 | 0.920 |

### *Organic Nitrogen Lower Lake Samples Categorized by Depth*

> Mean concentrations were similar for bottom and middle depth layers, and lowest in the surface depth layer.

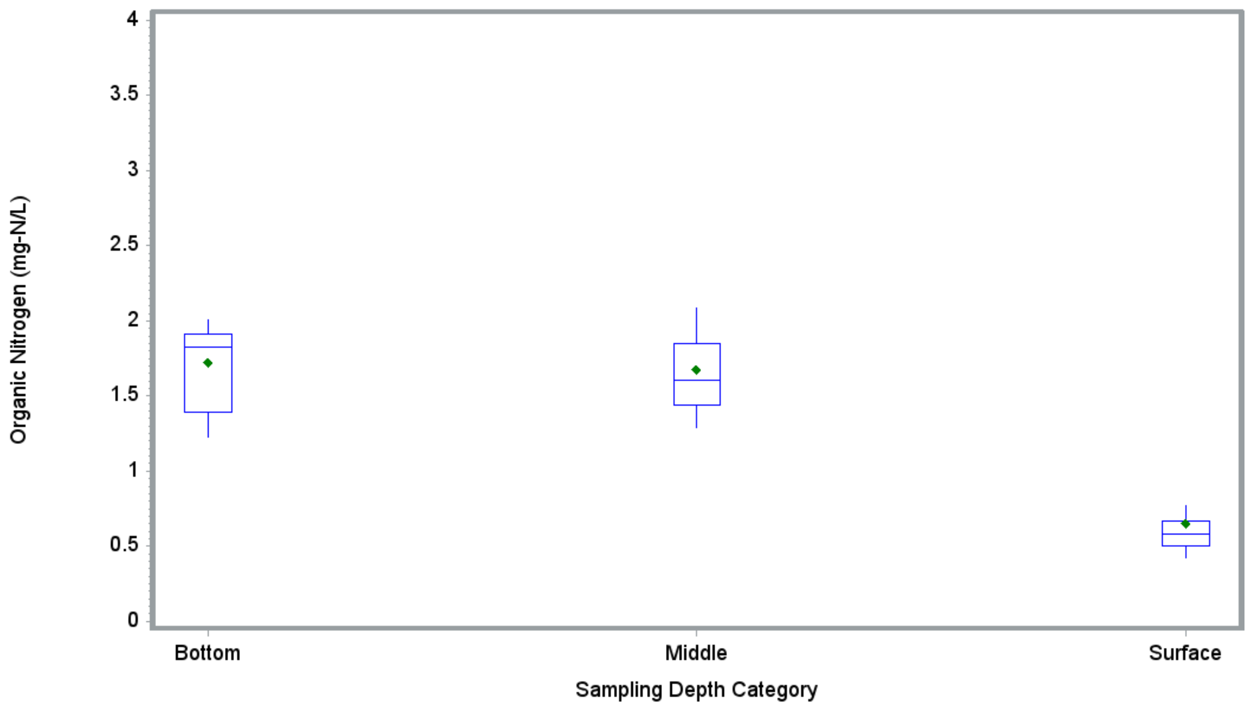



**Figure 3-147 Organic Nitrogen Lower Lake Samples Categorized by Depth**

**Table 3-154 Organic Nitrogen Lower Lake Samples Categorized by Depth (mg-N/L)**

| Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 16 | 1.216 | 1.230 | 1.397 | 1.724 | 1.822 | 1.913 | 2.004 | 2.614 |
| Middle | 150 | 1.216 | 1.291 | 1.442 | 1.680 | 1.609 | 1.853 | 2.084 | 2.806 |
| Surface | 392 | 0.000 | 0.420 | 0.500 | 0.651 | 0.580 | 0.670 | 0.770 | 2.682 |

***Organic Nitrogen Lower Lake Categorized by Year***

> Organic nitrogen was calculated in nine years: 2000, 2001 and 2005 through 2011.

> The highest mean and median concentrations were recorded in 2008 and 2009.

> The lowest mean and median concentrations were observed in 2000.

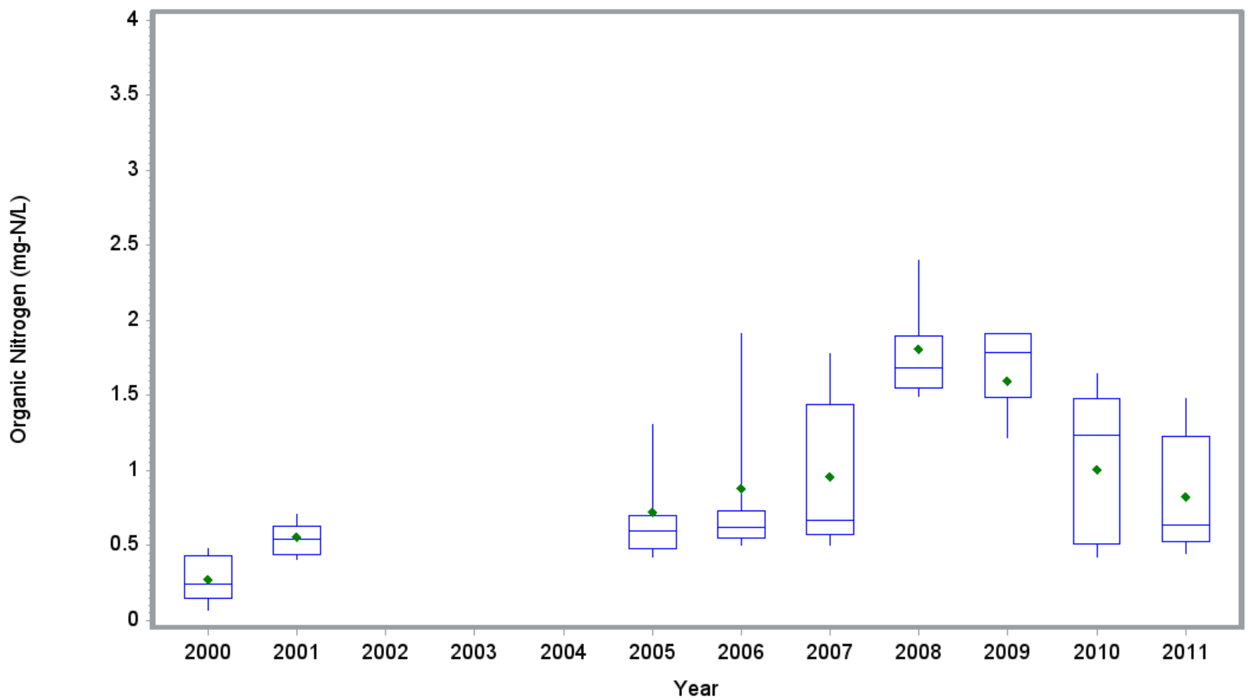



**Figure 3-148 Organic Nitrogen Lower Lake Samples Categorized by Year**

**Table 3-155 Organic Nitrogen Lower Lake Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 10 | 0.000 | 0.070 | 0.150 | 0.271 | 0.240 | 0.430 | 0.483 | 0.495 |
| 2001 | 32 | 0.250 | 0.410 | 0.440 | 0.557 | 0.545 | 0.628 | 0.710 | 1.150 |
| 2005 | 91 | 0.360 | 0.420 | 0.480 | 0.724 | 0.600 | 0.700 | 1.305 | 2.272 |
| 2006 | 116 | 0.390 | 0.500 | 0.550 | 0.882 | 0.620 | 0.730 | 1.910 | 2.614 |
| 2007 | 101 | 0.370 | 0.500 | 0.570 | 0.956 | 0.670 | 1.442 | 1.782 | 2.682 |
| 2008 | 36 | 1.311 | 1.496 | 1.553 | 1.809 | 1.682 | 1.899 | 2.402 | 2.806 |
| 2009 | 39 | 0.011 | 1.216 | 1.488 | 1.596 | 1.786 | 1.912 | 1.913 | 2.004 |
| 2010 | 68 | 0.360 | 0.420 | 0.510 | 1.008 | 1.235 | 1.476 | 1.641 | 1.809 |
| 2011 | 65 | 0.370 | 0.450 | 0.530 | 0.824 | 0.640 | 1.230 | 1.478 | 1.840 |

### *Organic Nitrogen Lower Lake Samples Categorized by Month*

> The highest mean concentrations were observed in October, followed by December and April in decreasing order.

> The lowest mean concentrations were measured in September and May in increasing order.

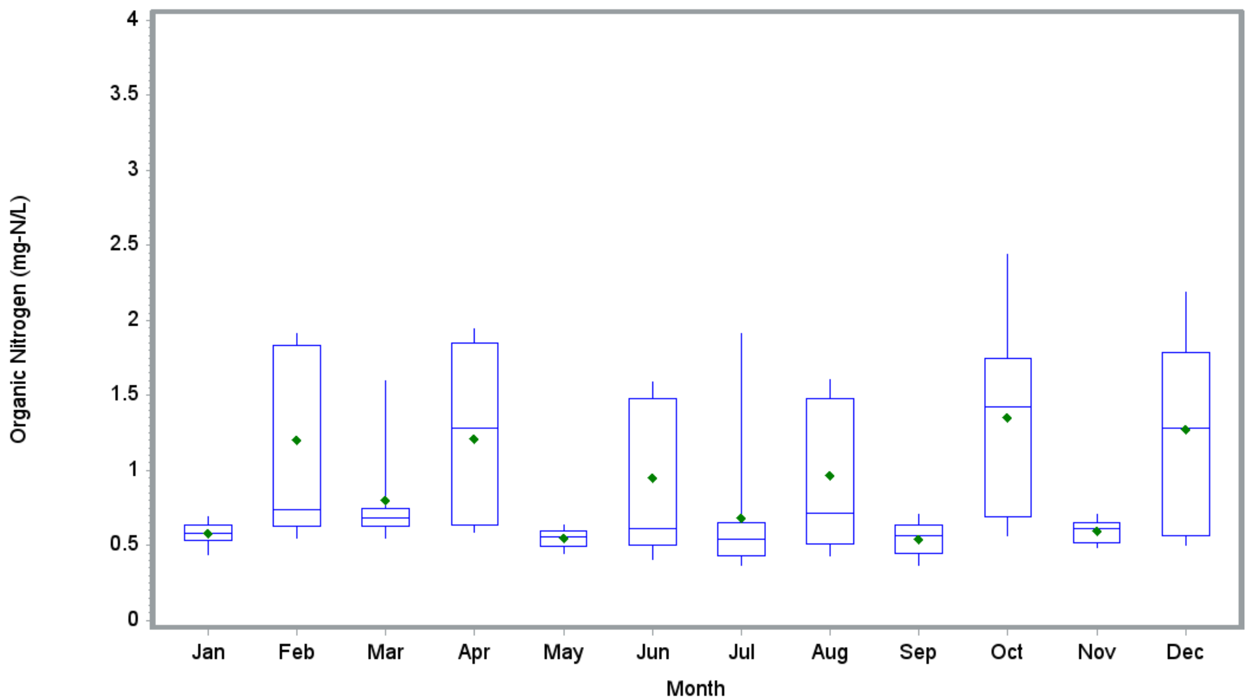



**Figure 3-149 Organic Nitrogen Lower Lake Samples Categorized by Month**

**Table 3-156 Organic Nitrogen Lower Lake Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 20 | 0.390 | 0.440 | 0.535 | 0.580 | 0.585 | 0.635 | 0.690 | 0.720 |
| Feb | 26 | 0.430 | 0.450 | 0.580 | 0.903 | 0.665 | 0.750 | 1.912 | 2.402 |
| Mar | 32 | 0.011 | 0.550 | 0.620 | 0.689 | 0.670 | 0.720 | 0.770 | 1.840 |
| Apr | 41 | 0.011 | 0.550 | 0.610 | 0.926 | 0.670 | 1.279 | 1.861 | 2.097 |
| May | 32 | 0.410 | 0.450 | 0.495 | 0.547 | 0.555 | 0.600 | 0.640 | 0.690 |
| Jun | 44 | 0.140 | 0.380 | 0.455 | 0.710 | 0.545 | 0.670 | 1.496 | 1.912 |
| Jul | 50 | 0.250 | 0.370 | 0.420 | 0.583 | 0.540 | 0.615 | 0.725 | 2.071 |
| Aug | 64 | 0.240 | 0.420 | 0.470 | 0.749 | 0.560 | 0.810 | 1.488 | 1.865 |
| Sep | 32 | 0.000 | 0.370 | 0.445 | 0.542 | 0.565 | 0.640 | 0.710 | 0.830 |
| Oct | 36 | 0.440 | 0.510 | 0.605 | 1.040 | 0.720 | 1.450 | 1.809 | 2.682 |
| Nov | 24 | 0.420 | 0.490 | 0.515 | 0.595 | 0.615 | 0.655 | 0.710 | 0.770 |
| Dec | 28 | 0.440 | 0.480 | 0.525 | 0.935 | 0.615 | 1.425 | 1.858 | 2.806 |

***Organic Nitrogen Lower Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded by USGS.

> Lowest mean and median concentrations were recorded by Wake County, however only three samples were available.

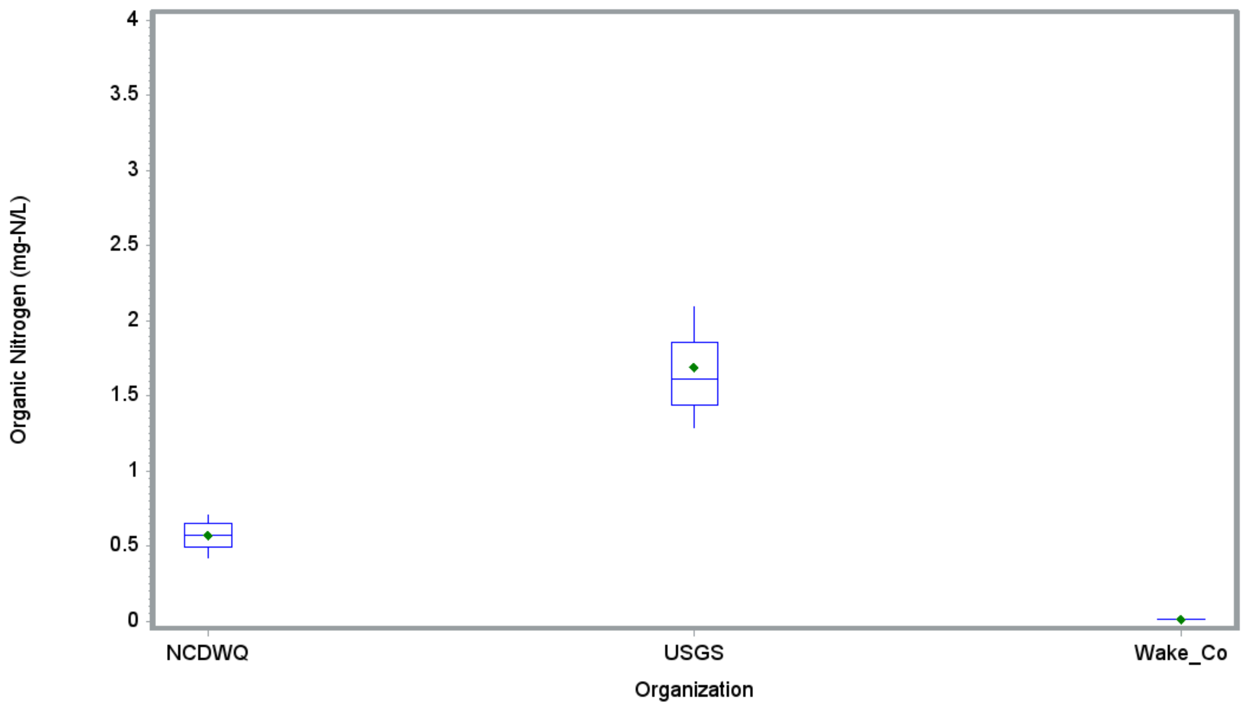



**Figure 3-150 Organic Nitrogen Lower Lake Samples Categorized by Sampling Organization**

**Table 3-157 Organic Nitrogen Lower Lake Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| NCDWQ | 361 | 0.000 | 0.420 | 0.495 | 0.571 | 0.570 | 0.650 | 0.710 | 1.280 |
| USGS | 194 | 1.216 | 1.291 | 1.442 | 1.693 | 1.617 | 1.861 | 2.097 | 2.806 |
| Wake_Co | 3 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 | 0.011 |

***Organic Nitrogen Lower Lake Samples Categorized by Method***

> The only method used to determine organic nitrogen is calculated.

## 3.14 Total Nitrogen (TN)

Six organizations either report total nitrogen (TN) concentrations or provide the results for the nitrogen species needed to calculate TN. For five of the organizations (USGS, NCDWQ, City of Durham, Orange County, and Wake county) total nitrogen values in the database were calculated as
TN = Ammonia + Organic Nitrogen + NO2/NO3.

If nitrogen species were reported as less than the limits, then a value of one-half the limit was assumed in the calculation. Analytical methods for determining ammonia, organic nitrogen, and nitrate plus nitrite are described in previous sections. Because CAAE only provided total nitrogen values, and not the nitrogen species used to calculate TN, these samples were retained and analyzed as reported in the database.

Table 3-158 describes the organizations with sufficient nitrogen species to calculate total nitrogen. The analysis methods are calculated for each organization. The count and date ranges are included, but each limit is listed as not applicable (NA) because these values were calculated. The majority of the total nitrogen values are based on data collected by NCDWQ. Total nitrogen is presented in mg-N/L and to three decimal places based on reported data.

**Table 3-158 Summary of Analysis Methods for the Total Nitrogen Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg-N/L) | Reporting Limit (mg-N/L) | Practical Quanti-fication Limit (mg-N/L) | Range of Limit Specified with Results (mg-N/L) |
|---|---|---|---|---|---|---|---|---|
| CAAE | Calculated | 07/24/2007 | 12/17/2010 | 71 | NA | NA | NA | NA |
| Durham_Ci | Calculated | 04/01/2002 | 04/02/2012 | 1,302 | NA | NA | NA | NA |
| NCDWQ[1] | Calculated | 01/11/1999 | 12/06/2011 | 2,489 | NA | NA | NA | NA |
| Orange_Co | Calculated | 04/09/2010 | 03/25/2011 | 182 | NA | NA | NA | NA |
| USGS | Calculated | 01/15/1999 | 09/07/2011 | 926 | NA | NA | NA | NA |
| Wake_Co | Calculated | 07/29/2008 | 10/14/2009 | 140 | NA | NA | NA | NA |

[1]Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

### 3.14.2 Tributary Samples

Five organizations measured total nitrogen concentrations in Falls Lake tributaries from 1999 to 2011. Highest mean concentrations were recorded by NCDWQ. Lowest mean concentrations were recorded by USGS. Highest concentrations were recorded in Knap of Reeds Creek and lowest concentrations recorded in the Beaverdam Creek and Horse/New Light. Highest mean concentrations were recorded from 2006 to 2008. Lowest mean concentrations were recorded in 2002. Box plot summaries are provided below.

***Total Nitrogen Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Total nitrogen was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.

> Highest mean and median concentrations were measured in Knap of Reeds Creek and Ellerbe Creek overall. In these Ellerbe Creek, concentrations were highest in the section 0 to 2 miles upstream of tributary mouth.

> Lowest mean and median concentrations were measured in Beaverdam Creek and Horse/New Light Creek overall, and in the 0 to 2 mile sections of those catchments.

> Greatest variability was recorded in Knap of Reeds Creek, Honeycutt/Barton Creek, and Ellerbe Creek, while the least variability was measured in Beaverdam Creek and Horse/New Light Creek.

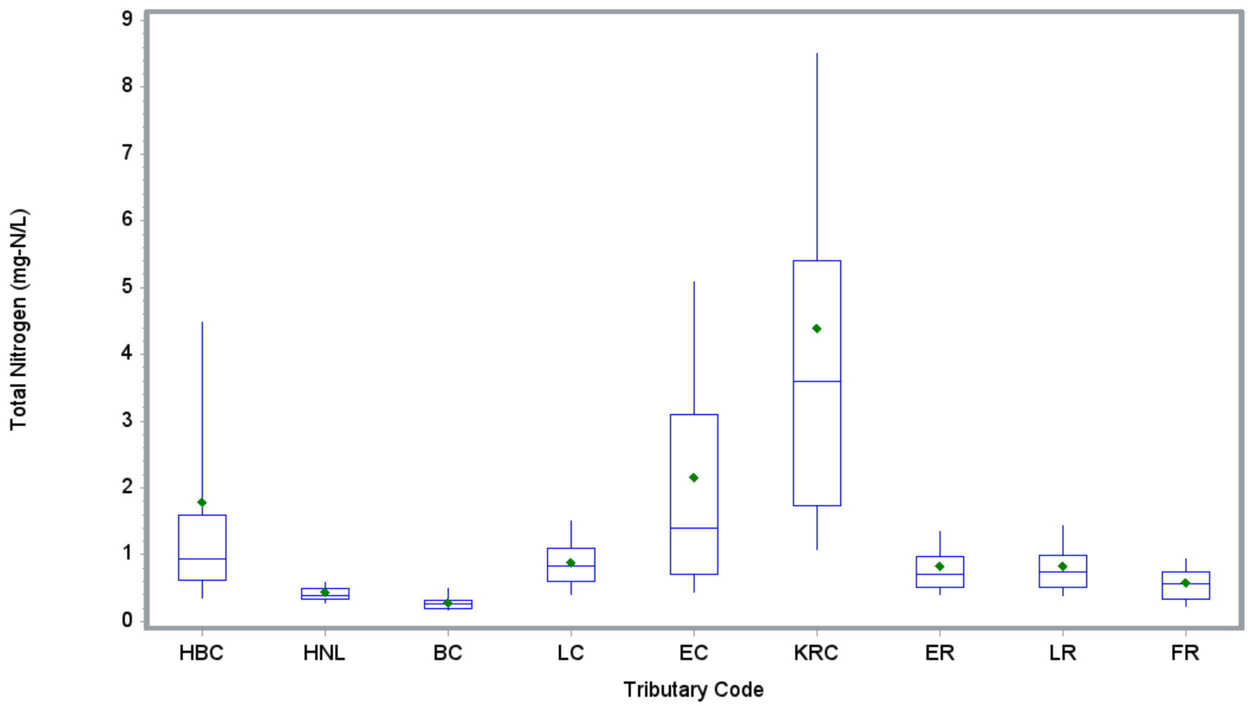



**Figure 3-151 Total Nitrogen Tributary Samples Categorized by Subwatershed**

**Table 3-159 Total Nitrogen Tributary Samples Categorized by Subwatershed (mg-N/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 77 | 0.152 | 0.354 | 0.620 | 1.783 | 0.934 | 1.598 | 4.478 | 13.631 |
| HNL | 45 | 0.212 | 0.278 | 0.336 | 0.439 | 0.384 | 0.497 | 0.584 | 1.700 |
| BC | 16 | 0.174 | 0.174 | 0.197 | 0.280 | 0.260 | 0.319 | 0.485 | 0.535 |
| LC | 121 | 0.130 | 0.400 | 0.600 | 0.891 | 0.828 | 1.100 | 1.500 | 2.620 |
| EC | 455 | 0.130 | 0.440 | 0.700 | 2.153 | 1.400 | 3.100 | 5.090 | 9.400 |
| KRC | 145 | 0.410 | 1.080 | 1.740 | 4.400 | 3.600 | 5.410 | 8.500 | 27.500 |
| ER | 619 | 0.231 | 0.400 | 0.510 | 0.825 | 0.700 | 0.970 | 1.343 | 4.300 |
| LR | 455 | 0.189 | 0.382 | 0.513 | 0.833 | 0.738 | 0.997 | 1.426 | 5.232 |
| FR | 263 | 262 | 0.108 | 0.227 | 0.341 | 0.581 | 0.560 | 0.743 | 3.200 |

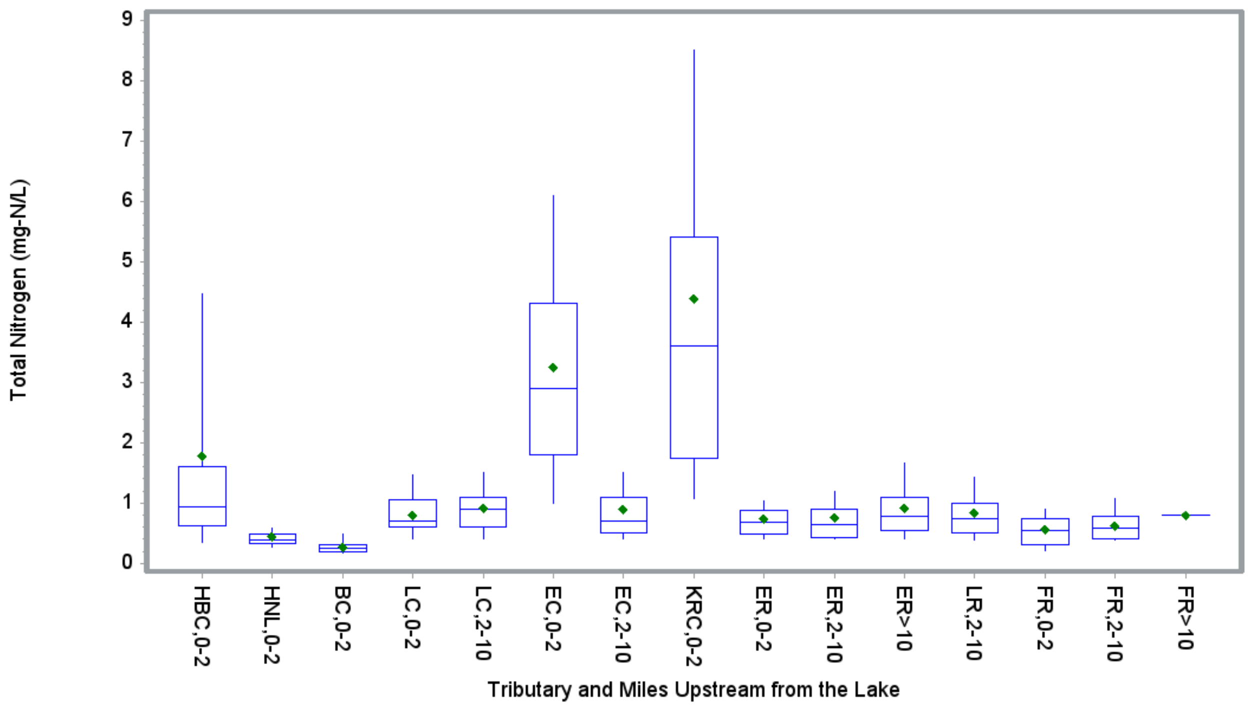



**Figure 3-152 Total Nitrogen Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-160 Total Nitrogen Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (mg-N/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 77 | 0.152 | 0.354 | 0.620 | 1.783 | 0.934 | 1.598 | 4.478 | 13.631 |
| HNL,0-2 | 45 | 0.212 | 0.278 | 0.336 | 0.439 | 0.384 | 0.497 | 0.584 | 1.700 |
| BC,0-2 | 16 | 0.174 | 0.174 | 0.197 | 0.280 | 0.260 | 0.319 | 0.485 | 0.535 |
| LC,0-2 | 36 | 0.130 | 0.400 | 0.600 | 0.806 | 0.700 | 1.050 | 1.475 | 1.900 |
| LC,2-10 | 85 | 0.230 | 0.400 | 0.600 | 0.927 | 0.900 | 1.100 | 1.500 | 2.620 |
| EC,0-2 | 242 | 0.130 | 1.000 | 1.800 | 3.262 | 2.900 | 4.310 | 6.100 | 9.400 |
| EC,2-10 | 213 | 0.300 | 0.400 | 0.500 | 0.893 | 0.700 | 1.100 | 1.500 | 5.800 |
| KRC,0-2 | 145 | 0.410 | 1.080 | 1.740 | 4.400 | 3.600 | 5.410 | 8.500 | 27.500 |
| ER,0-2 | 113 | 0.300 | 0.400 | 0.490 | 0.735 | 0.680 | 0.880 | 1.040 | 4.300 |
| ER,2-10 | 226 | 0.249 | 0.400 | 0.430 | 0.754 | 0.650 | 0.900 | 1.200 | 4.110 |
| ER>10 | 280 | 0.231 | 0.413 | 0.550 | 0.919 | 0.780 | 1.090 | 1.665 | 4.250 |
| LR,2-10 | 455 | 0.189 | 0.382 | 0.513 | 0.833 | 0.738 | 0.997 | 1.426 | 5.232 |
| FR,0-2 | 211 | 0.108 | 0.208 | 0.308 | 0.568 | 0.550 | 0.740 | 0.900 | 3.200 |
| FR,2-10 | 50 | 0.230 | 0.380 | 0.400 | 0.634 | 0.581 | 0.790 | 1.070 | 1.300 |
| FR>10 | 1 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |

### *Total Nitrogen Tributary Samples Categorized by Depth*

> All samples were collected in the surface layer.

### *Total Nitrogen Tributary Categorized by Year*

> By year, highest mean concentrations were recorded in 2008, 2007 and 2006 (in increasing order).

> The lowest mean concentrations were recorded in 2002, 2009, and 2010 (in decreasing order).

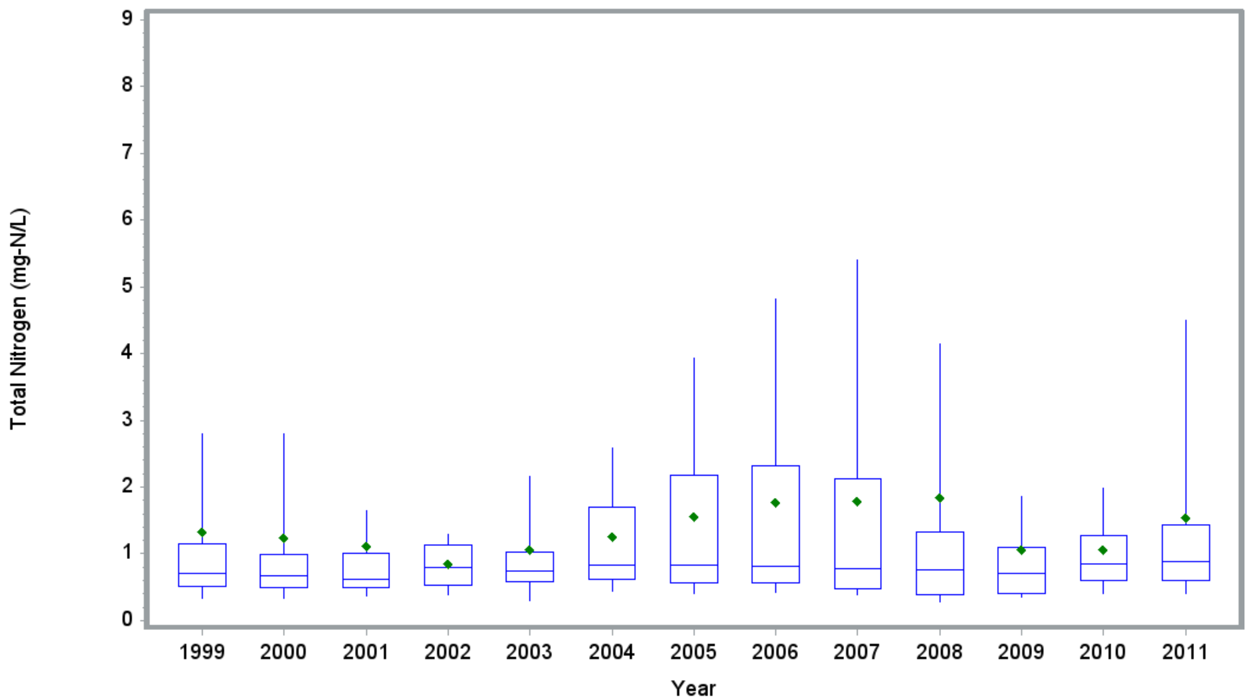



**Figure 3-153 Total Nitrogen Tributary Samples Categorized by Year**

**Table 3-161 Total Nitrogen Tributary Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 133 | 0.117 | 0.340 | 0.510 | 1.329 | 0.706 | 1.150 | 2.800 | 11.400 |
| 2000 | 138 | 0.180 | 0.333 | 0.490 | 1.243 | 0.675 | 0.996 | 2.800 | 16.400 |
| 2001 | 57 | 0.248 | 0.362 | 0.486 | 1.115 | 0.609 | 1.013 | 1.649 | 10.500 |
| 2002 | 43 | 0.234 | 0.380 | 0.535 | 0.842 | 0.794 | 1.123 | 1.298 | 1.859 |
| 2003 | 85 | 0.185 | 0.300 | 0.575 | 1.062 | 0.736 | 1.030 | 2.160 | 5.630 |
| 2004 | 90 | 0.160 | 0.434 | 0.615 | 1.254 | 0.823 | 1.693 | 2.582 | 5.190 |
| 2005 | 142 | 0.188 | 0.400 | 0.560 | 1.552 | 0.835 | 2.170 | 3.930 | 7.500 |
| 2006 | 177 | 0.210 | 0.420 | 0.560 | 1.774 | 0.810 | 2.320 | 4.810 | 10.400 |
| 2007 | 131 | 0.152 | 0.392 | 0.480 | 1.781 | 0.769 | 2.129 | 5.410 | 7.600 |
| 2008 | 162 | 0.138 | 0.277 | 0.387 | 1.842 | 0.751 | 1.331 | 4.149 | 27.500 |
| 2009 | 347 | 0.118 | 0.351 | 0.400 | 1.054 | 0.700 | 1.100 | 1.850 | 9.400 |
| 2010 | 452 | 0.108 | 0.400 | 0.595 | 1.059 | 0.850 | 1.265 | 1.980 | 7.300 |
| 2011 | 238 | 0.125 | 0.400 | 0.600 | 1.544 | 0.875 | 1.426 | 4.500 | 9.200 |

### *Total Nitrogen Tributary Samples Categorized by Month*

- By month, the highest mean concentrations were measured in from June through August.
- The lowest mean concentration was measured in December and February.

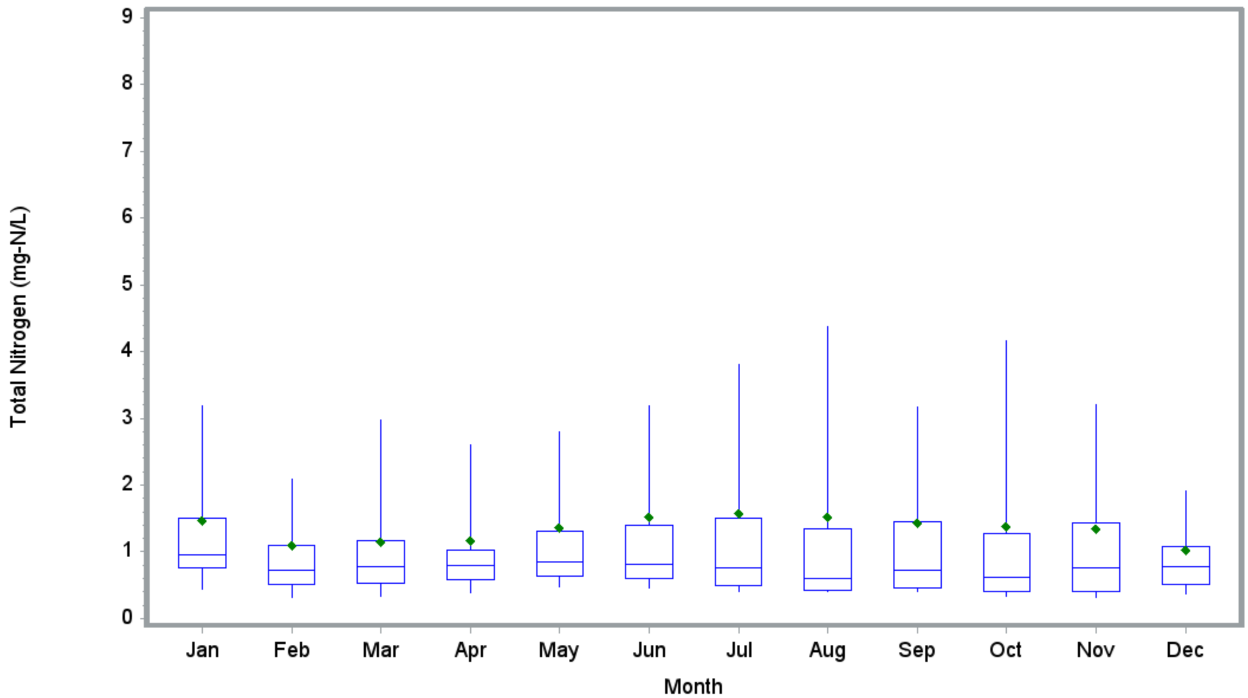



**Figure 3-154 Total Nitrogen Tributary Samples Categorized by Month**

**Table 3-162 Total Nitrogen Tributary Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 177 | 0.152 | 0.443 | 0.750 | 1.475 | 0.960 | 1.500 | 3.180 | 9.200 |
| Feb | 187 | 0.125 | 0.323 | 0.510 | 1.098 | 0.718 | 1.100 | 2.095 | 9.400 |
| Mar | 178 | 0.130 | 0.330 | 0.520 | 1.149 | 0.780 | 1.160 | 2.970 | 6.300 |
| Apr | 205 | 0.118 | 0.380 | 0.580 | 1.167 | 0.788 | 1.030 | 2.600 | 6.300 |
| May | 181 | 0.198 | 0.471 | 0.632 | 1.354 | 0.854 | 1.300 | 2.800 | 17.200 |
| Jun | 207 | 0.230 | 0.450 | 0.600 | 1.522 | 0.816 | 1.400 | 3.190 | 27.500 |
| Jul | 193 | 0.287 | 0.400 | 0.500 | 1.569 | 0.753 | 1.500 | 3.800 | 20.000 |
| Aug | 168 | 0.212 | 0.400 | 0.420 | 1.524 | 0.600 | 1.335 | 4.380 | 21.400 |
| Sep | 166 | 0.227 | 0.400 | 0.450 | 1.434 | 0.720 | 1.458 | 3.170 | 16.400 |
| Oct | 185 | 0.152 | 0.330 | 0.400 | 1.372 | 0.610 | 1.280 | 4.170 | 11.700 |
| Nov | 162 | 0.109 | 0.318 | 0.410 | 1.343 | 0.758 | 1.434 | 3.200 | 8.900 |
| Dec | 186 | 0.108 | 0.362 | 0.510 | 1.023 | 0.780 | 1.080 | 1.910 | 5.800 |

***Total Nitrogen Tributary Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean concentrations were recorded by NCDWQ and lowest mean concentrations were recorded by USGS and Orange County.

> Median concentrations were similar for all organizations.

> Greatest variability was seen in measurements by NCDWQ.

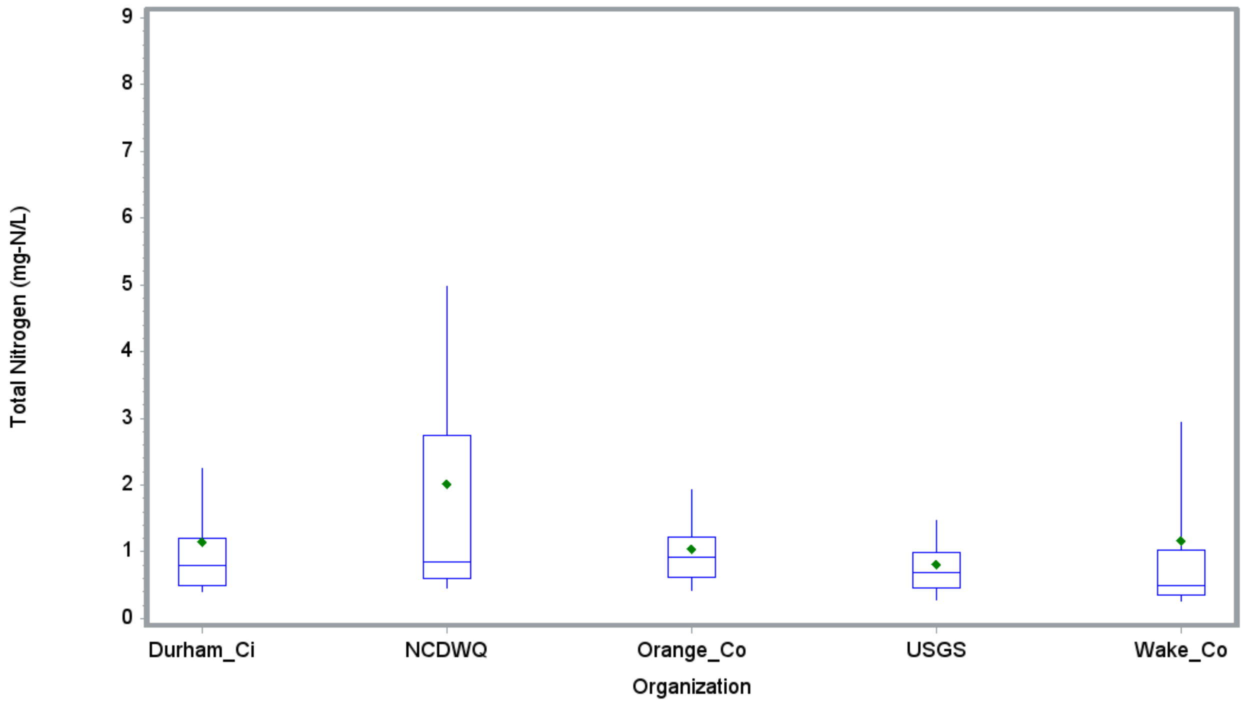



**Figure 3-155 Total Nitrogen Tributary Samples Categorized by Sampling Organization**

**Table 3-163 Total Nitrogen Tributary Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 625 | 0.130 | 0.400 | 0.500 | 1.156 | 0.800 | 1.200 | 2.250 | 9.200 |
| NCDWQ | 702 | 0.230 | 0.450 | 0.590 | 2.011 | 0.850 | 2.740 | 4.970 | 27.500 |
| Orange_Co | 182 | 0.270 | 0.430 | 0.620 | 1.044 | 0.920 | 1.220 | 1.930 | 4.250 |
| USGS | 549 | 0.108 | 0.273 | 0.458 | 0.809 | 0.684 | 0.986 | 1.474 | 5.232 |
| Wake_Co | 137 | 0.152 | 0.254 | 0.346 | 1.174 | 0.500 | 1.016 | 2.940 | 13.631 |

***Total Nitrogen Tributary Samples Categorized by Method***

> Only the calculated method was used to determine total nitrogen.

### 3.14.3 Upper Lake Samples

Data were available from three organizations from which to calculate total nitrogen concentrations in upper Falls Lake from 2000 to 2011. Highest mean and median concentrations were recorded by USGS, while lowest mean and median concentrations were recorded by NCDWQ. Highest mean concentrations were recorded in the > 21 mile section upstream of the dam and in the middle layer. Lowest concentrations were measured in the 13 to 18 miles section and in the photic zone. Highest mean concentrations were recorded in 2002, while the lowest mean concentrations were recorded in 2000. Box plot summaries are provided below.

***Total Nitrogen Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean and median concentrations were measured > 21 miles upstream of the dam.

> Lowest mean and median concentrations were measured in the segment closest to the dam (13 to 18 miles upstream of the dam).

> Greatest variability was observed in the > 21 mile section.

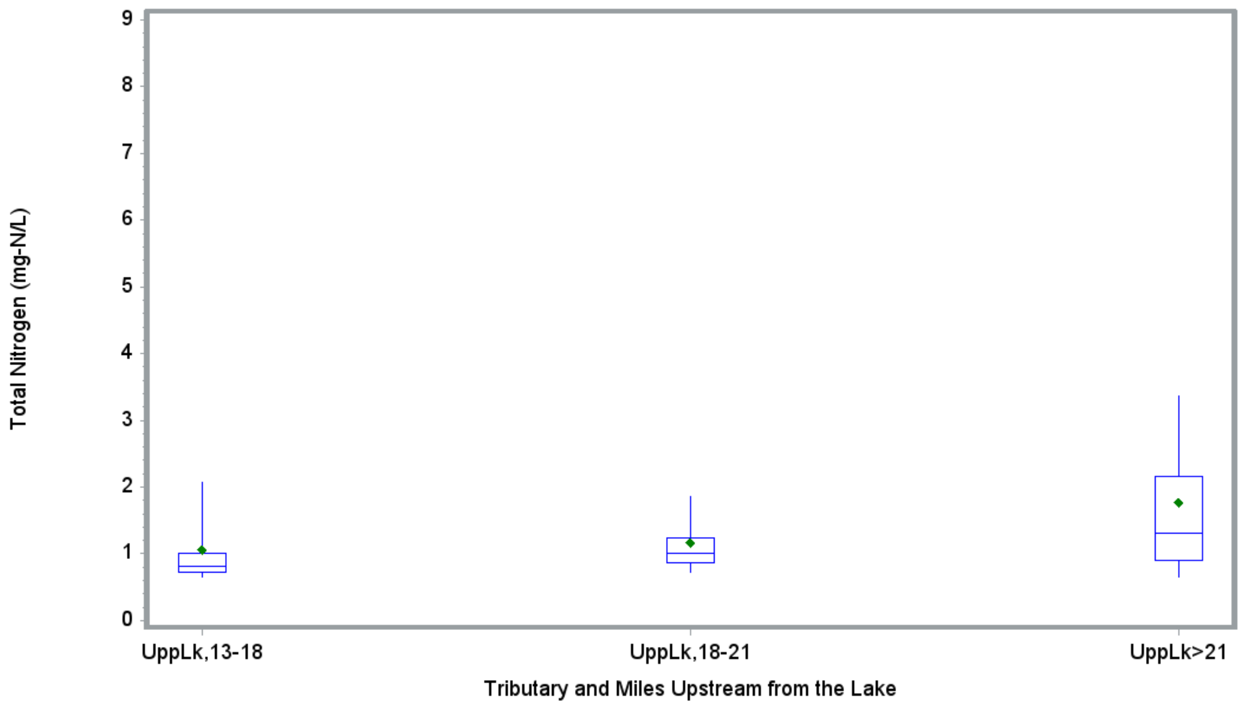



**Figure 3-156 Total Nitrogen Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-164 Total Nitrogen Upper Lake Samples Categorized by Miles Upstream from Dam (mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 690 | 0.405 | 0.645 | 0.720 | 1.051 | 0.810 | 1.000 | 2.072 | 6.010 |
| UppLk,18-21 | 173 | 0.620 | 0.730 | 0.860 | 1.170 | 1.000 | 1.230 | 1.850 | 4.270 |
| UppLk>21 | 1067 | 0.200 | 0.650 | 0.900 | 1.762 | 1.310 | 2.150 | 3.360 | 11.870 |

***Total Nitrogen Upper Lake Samples Categorized by Depth***

> By depth, highest mean concentrations were measured at the middle layer and lowest concentrations measured in photic zone

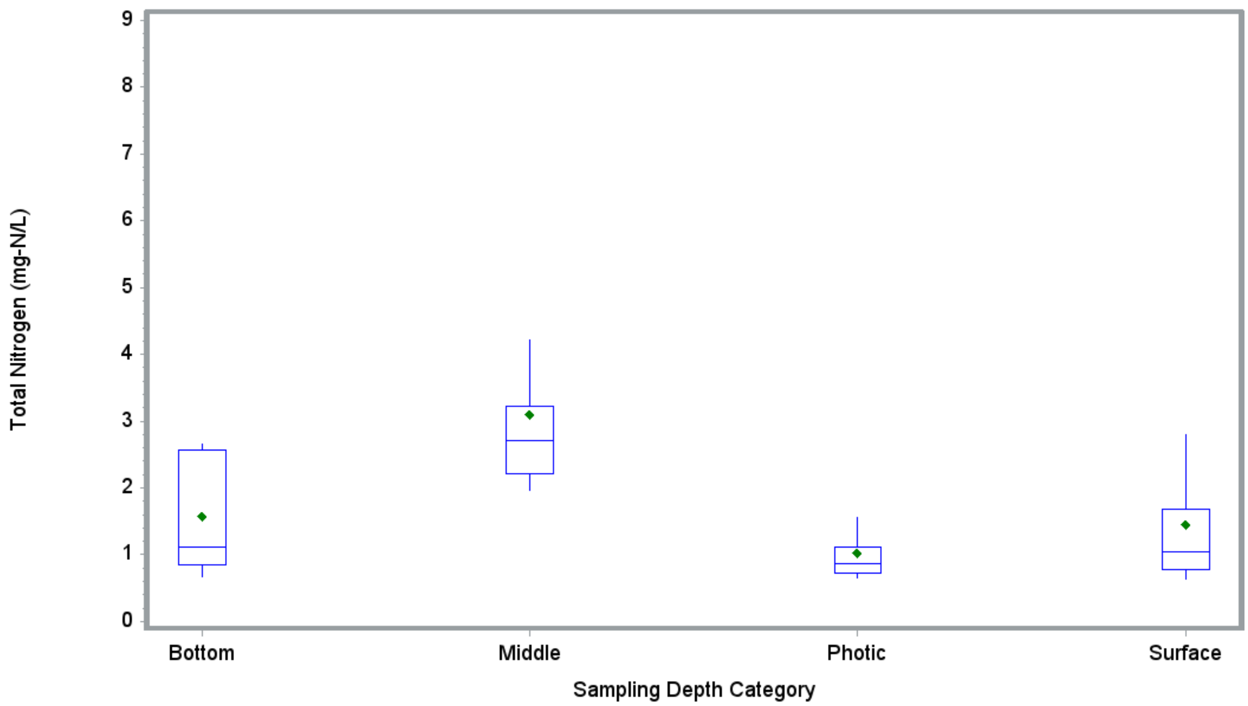



**Figure 3-157 Total Nitrogen Upper Lake Samples Categorized by Depth Category**

**Table 3-165 Total Nitrogen Upper Lake Samples Categorized by Depth Category (mg-N/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 23 | 0.435 | 0.665 | 0.845 | 1.579 | 1.120 | 2.558 | 2.662 | 3.442 |
| Middle | 153 | 1.787 | 1.961 | 2.204 | 3.102 | 2.704 | 3.227 | 4.210 | 9.571 |
| Photic | 585 | 0.200 | 0.650 | 0.730 | 1.022 | 0.860 | 1.110 | 1.550 | 6.600 |
| Surface | 1169 | 0.300 | 0.640 | 0.780 | 1.454 | 1.040 | 1.680 | 2.800 | 11.870 |

***Total Nitrogen Upper Lake Categorized by Year***

> The highest mean and median concentrations were recorded in 2002, 2009, and 2008.

> The lowest mean and median concentrations were recorded in 2000, 2004 and 2006.

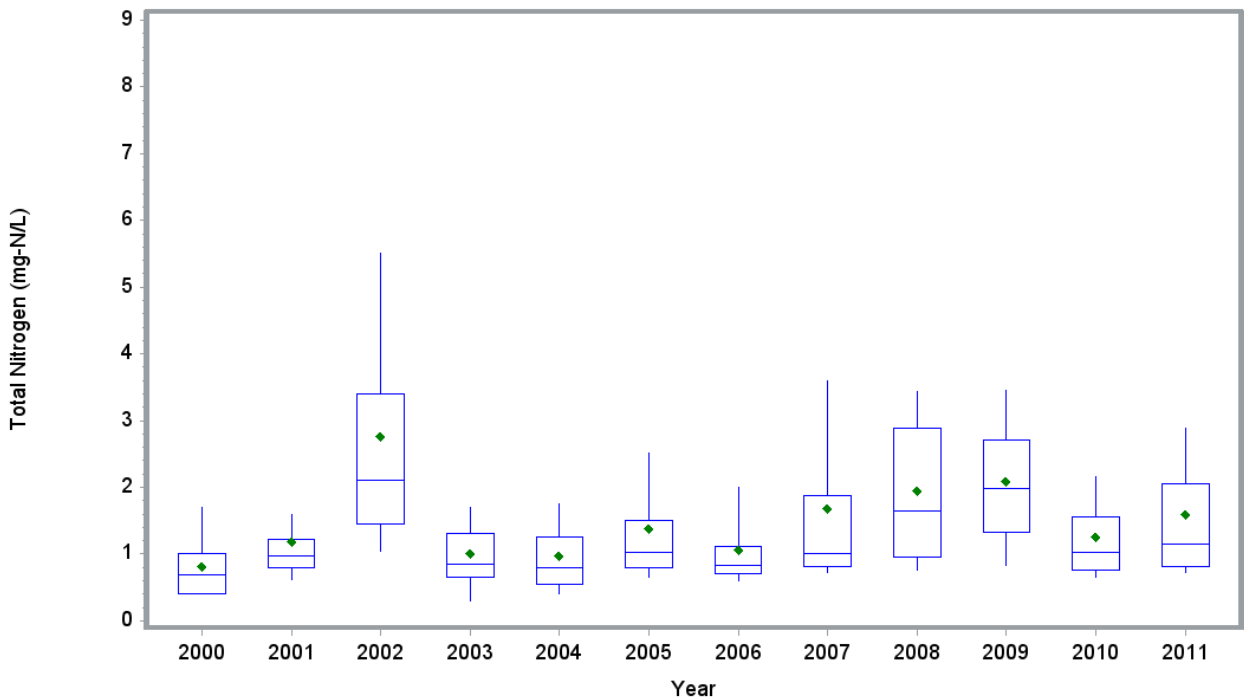



**Figure 3-158 Total Nitrogen Upper Lake Samples Categorized by Year**

**Table 3-166 Total Nitrogen Upper Lake Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 16 | 0.305 | 0.400 | 0.410 | 0.808 | 0.680 | 1.010 | 1.705 | 1.770 |
| 2001 | 68 | 0.425 | 0.625 | 0.785 | 1.179 | 0.972 | 1.215 | 1.600 | 6.010 |
| 2002 | 62 | 0.750 | 1.050 | 1.450 | 2.760 | 2.100 | 3.400 | 5.500 | 8.500 |
| 2003 | 57 | 0.300 | 0.300 | 0.650 | 1.001 | 0.850 | 1.300 | 1.700 | 3.200 |
| 2004 | 60 | 0.300 | 0.400 | 0.550 | 0.977 | 0.800 | 1.250 | 1.750 | 2.750 |
| 2005 | 263 | 0.300 | 0.650 | 0.800 | 1.384 | 1.030 | 1.510 | 2.514 | 9.571 |
| 2006 | 381 | 0.300 | 0.600 | 0.710 | 1.063 | 0.830 | 1.110 | 2.000 | 5.800 |
| 2007 | 326 | 0.300 | 0.720 | 0.810 | 1.685 | 1.005 | 1.870 | 3.590 | 11.870 |
| 2008 | 88 | 0.550 | 0.750 | 0.950 | 1.942 | 1.650 | 2.885 | 3.442 | 4.141 |
| 2009 | 100 | 0.550 | 0.825 | 1.325 | 2.093 | 1.975 | 2.716 | 3.447 | 4.389 |
| 2010 | 235 | 0.200 | 0.650 | 0.750 | 1.248 | 1.030 | 1.550 | 2.150 | 4.800 |
| 2011 | 274 | 0.350 | 0.730 | 0.820 | 1.593 | 1.145 | 2.050 | 2.887 | 7.000 |

***Total Nitrogen Upper Lake Samples Categorized by Month***

> By month, the highest mean concentrations were measured in October, September (in decreasing order) and highest median concentration was recorded in October.

> The lowest mean concentrations were measured in May, March and January.

> Greatest variability was recorded from August and October.

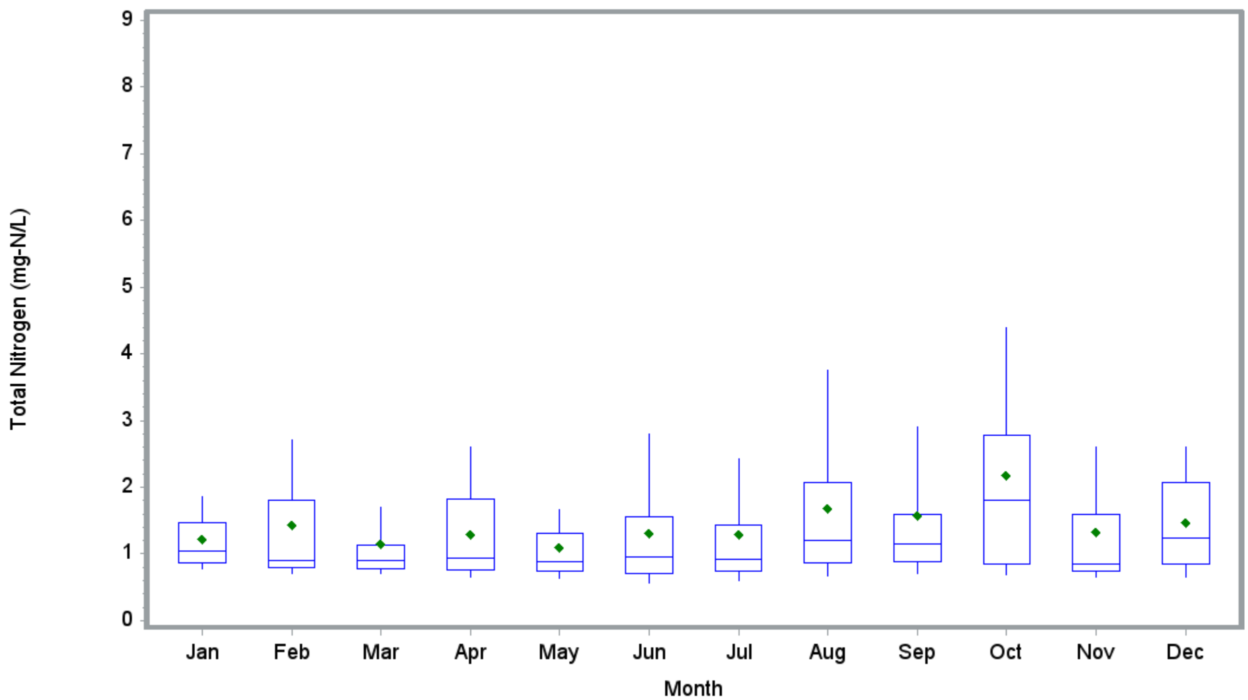



**Figure 3-159 Total Nitrogen Upper Lake Samples Categorized by Month**

**Table 3-167 Total Nitrogen Upper Lake Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 54 | 0.630 | 0.770 | 0.870 | 1.219 | 1.040 | 1.470 | 1.850 | 3.360 |
| Feb | 82 | 0.620 | 0.700 | 0.790 | 1.424 | 0.895 | 1.810 | 2.716 | 4.210 |
| Mar | 100 | 0.570 | 0.705 | 0.780 | 1.156 | 0.905 | 1.130 | 1.700 | 5.834 |
| Apr | 212 | 0.200 | 0.650 | 0.750 | 1.296 | 0.930 | 1.828 | 2.605 | 3.200 |
| May | 188 | 0.300 | 0.630 | 0.735 | 1.102 | 0.885 | 1.300 | 1.670 | 6.400 |
| Jun | 225 | 0.300 | 0.560 | 0.700 | 1.306 | 0.950 | 1.550 | 2.800 | 8.500 |
| Jul | 233 | 0.300 | 0.600 | 0.740 | 1.296 | 0.920 | 1.430 | 2.424 | 7.100 |
| Aug | 278 | 0.300 | 0.675 | 0.860 | 1.685 | 1.210 | 2.072 | 3.745 | 9.420 |
| Sep | 195 | 0.300 | 0.700 | 0.880 | 1.570 | 1.140 | 1.600 | 2.900 | 11.870 |
| Oct | 194 | 0.300 | 0.690 | 0.850 | 2.182 | 1.800 | 2.774 | 4.389 | 9.571 |
| Nov | 92 | 0.590 | 0.650 | 0.735 | 1.325 | 0.850 | 1.590 | 2.600 | 5.200 |
| Dec | 77 | 0.540 | 0.650 | 0.850 | 1.459 | 1.230 | 2.072 | 2.605 | 2.996 |

***Total Nitrogen Upper Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded by USGS, lowest mean and median concentrations were recorded by NCDWQ.

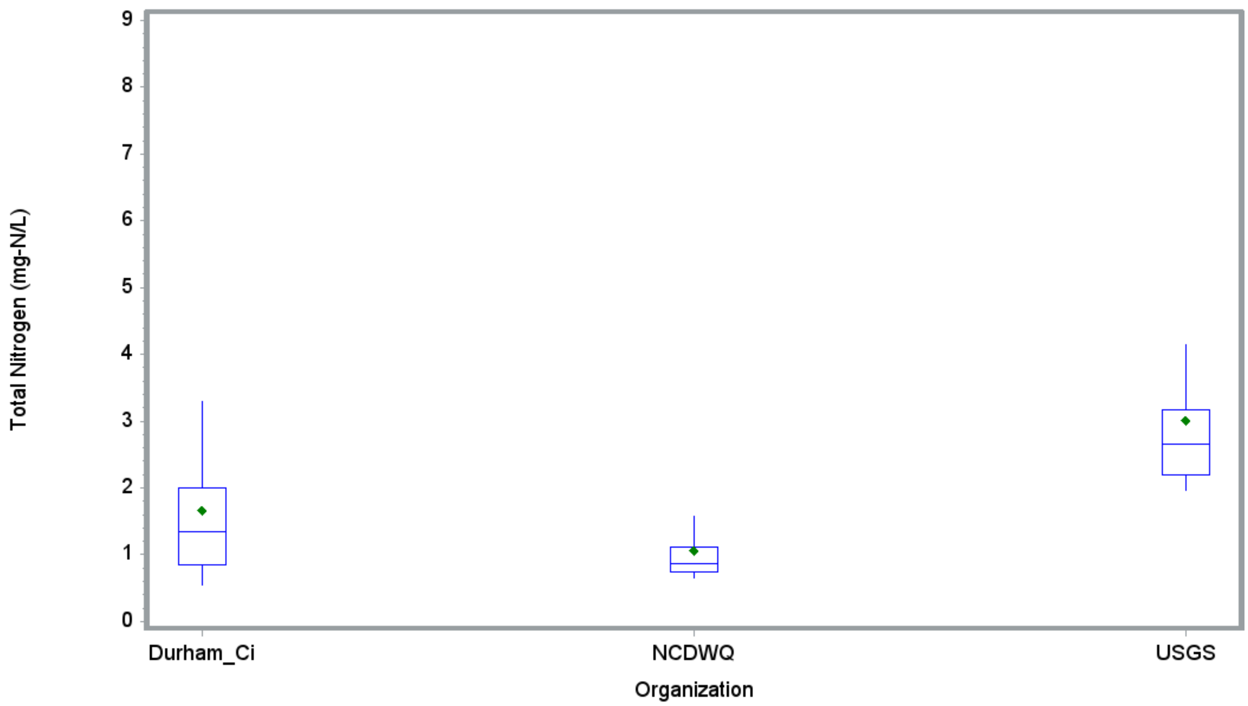



**Figure 3-160 Total Nitrogen Upper Lake Samples Categorized by Sampling Organization**

**Table 3-168 Total Nitrogen Upper Lake Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 676 | 0.200 | 0.550 | 0.850 | 1.656 | 1.350 | 2.000 | 3.300 | 8.500 |
| NCDWQ | 1071 | 0.305 | 0.660 | 0.740 | 1.062 | 0.870 | 1.110 | 1.570 | 11.870 |
| USGS | 183 | 1.787 | 1.961 | 2.192 | 3.011 | 2.662 | 3.174 | 4.141 | 9.571 |

***Total Nitrogen Upper Lake Samples Categorized by Method***

> Only the calculated method was used to determine total nitrogen.

### 3.14.4 Lower Lake Samples

Four organizations measured total nitrogen concentrations in lower Falls Lake from 2000 to 2011. Highest mean and median concentrations were recorded by USGS, while lowest mean and median concentrations were recorded by NCDWQ. Mean concentrations were lowest in the 8 to 13 mile segment. Highest concentrations were recorded in the middle and bottom layers. Highest mean and median concentrations were recorded in 2008 and 2009, while the lowest mean and median concentrations were recorded in 2000. Box plot summaries are provided below.

***Total Nitrogen Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Mean and median concentrations were lowest in the 8 to 13 mile segment.

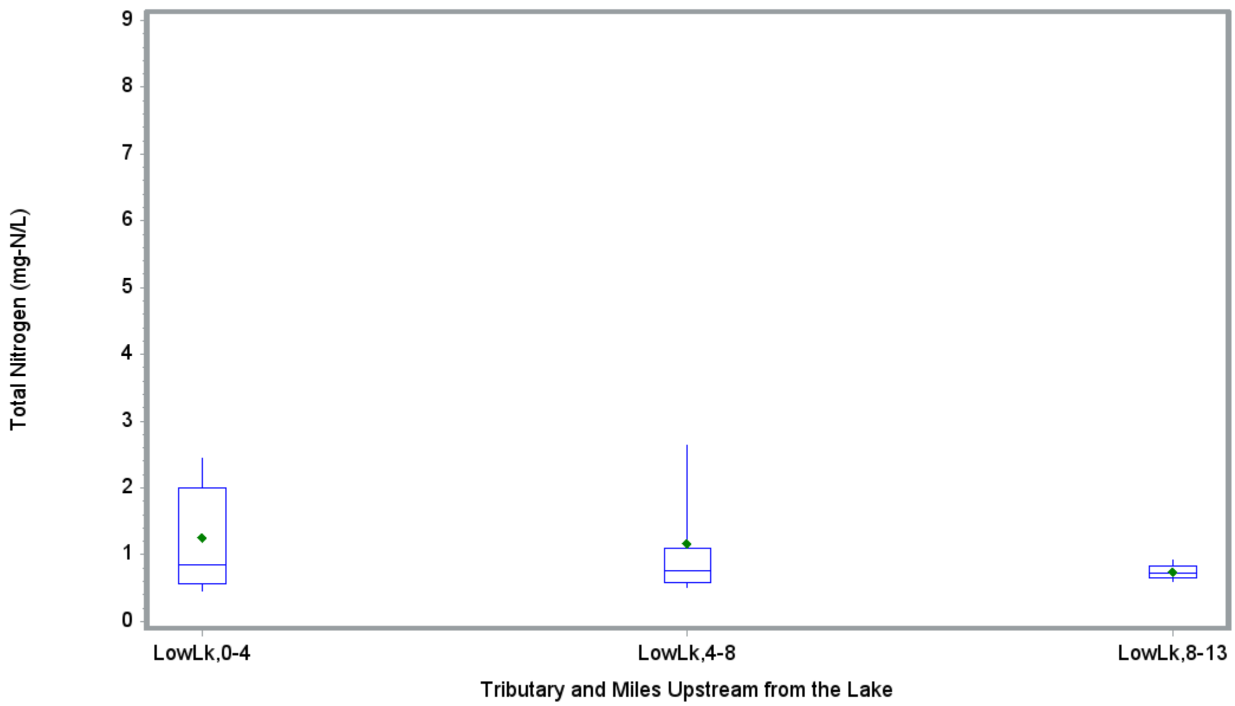



**Figure 3-161 Total Nitrogen Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-169 Total Nitrogen Lower Lake Samples Categorized by Miles Upstream from Dam (mg-N/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LowLk,0-4 | 314 | 0.205 | 0.450 | 0.560 | 1.251 | 0.840 | 2.003 | 2.438 | 5.664 |
| LowLk,4-8 | 453 | 0.375 | 0.510 | 0.580 | 1.172 | 0.750 | 1.100 | 2.638 | 5.040 |
| LowLk,8-13 | 211 | 0.405 | 0.590 | 0.650 | 0.747 | 0.730 | 0.830 | 0.923 | 1.510 |

***Total Nitrogen Lower Lake Samples Categorized by Depth***

> By depth, highest mean and median concentrations were measured in the middle and bottom layers.

.

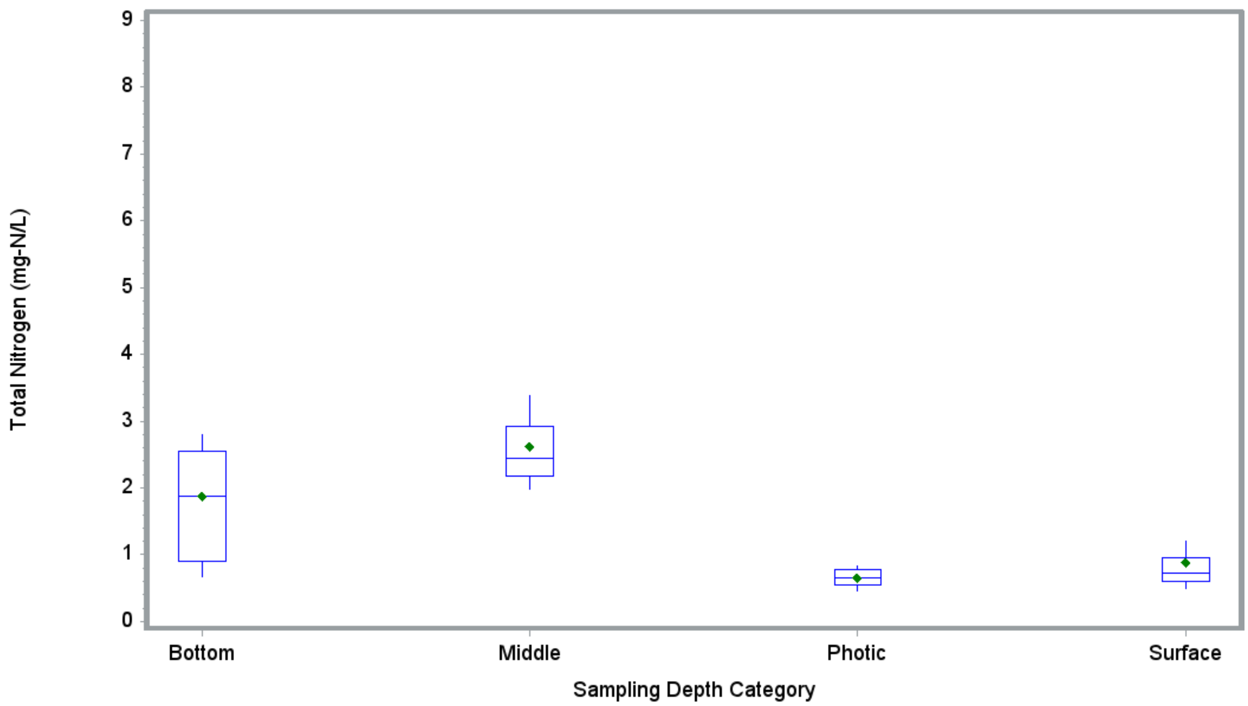



**Figure 3-162 Total Nitrogen Lower Lake Samples Categorized by Depth Category**

**Table 3-170 Total Nitrogen Lower Lake Samples Categorized by Depth Category (mg-N/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 32 | 0.425 | 0.675 | 0.905 | 1.872 | 1.882 | 2.547 | 2.802 | 5.664 |
| Middle | 150 | 1.408 | 1.990 | 2.172 | 2.611 | 2.438 | 2.922 | 3.382 | 5.664 |
| Photic | 334 | 0.205 | 0.460 | 0.550 | 0.660 | 0.660 | 0.780 | 0.830 | 1.610 |
| Surface | 462 | 0.205 | 0.500 | 0.590 | 0.886 | 0.730 | 0.945 | 1.200 | 5.664 |

### *Total Nitrogen Lower Lake Categorized by Year*

> By year, total nitrogen was calculated over nine years, 2000, 2001 and from 2005 through 2011.

> The mean and median concentrations were higher in 2008 and 2009 than for other years.

> The lowest mean and median concentrations were recorded in 2000.

> Mean and median concentrations were similar all years except 2000, 2008, and 2009.

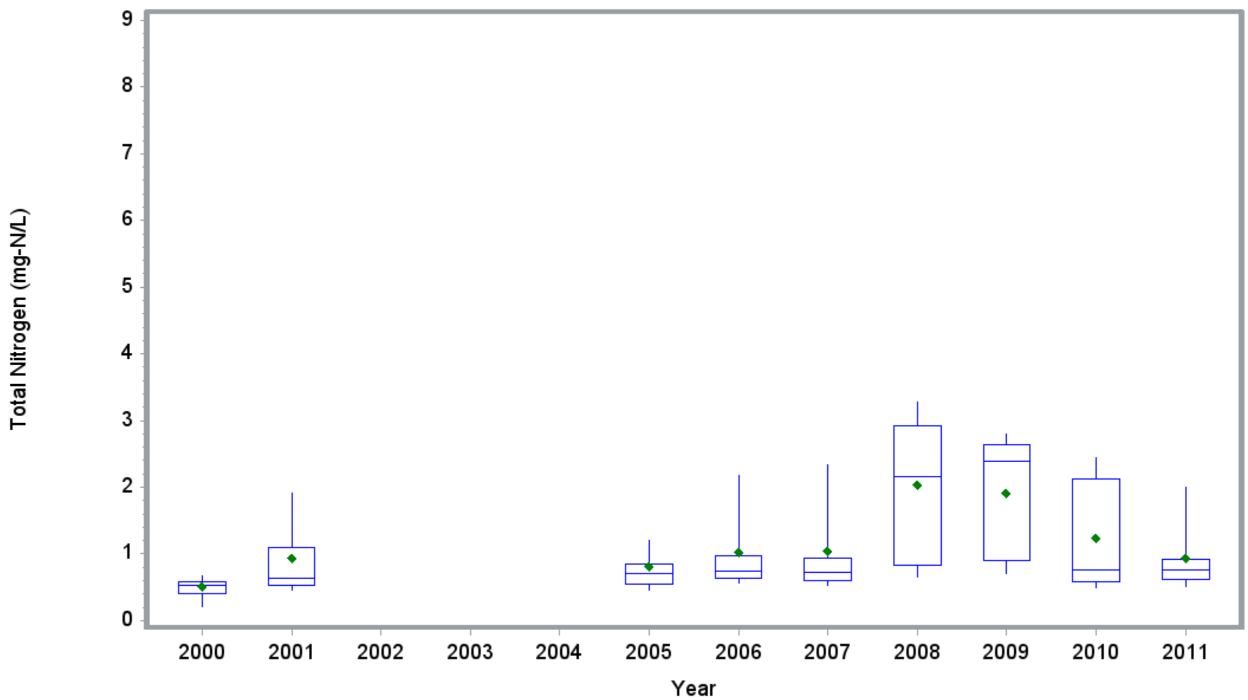



**Figure 3-163 Total Nitrogen Lower Lake Samples Categorized by Year**

**Table 3-171 Total Nitrogen Lower Lake Samples Categorized by Year (mg-N/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 18 | 0.205 | 0.205 | 0.405 | 0.509 | 0.520 | 0.580 | 0.670 | 0.970 |
| 2001 | 64 | 0.375 | 0.450 | 0.532 | 0.934 | 0.637 | 1.098 | 1.905 | 3.210 |
| 2005 | 162 | 0.380 | 0.450 | 0.550 | 0.807 | 0.710 | 0.850 | 1.200 | 2.750 |
| 2006 | 203 | 0.410 | 0.570 | 0.640 | 1.024 | 0.740 | 0.970 | 2.174 | 5.664 |
| 2007 | 174 | 0.390 | 0.520 | 0.590 | 1.045 | 0.725 | 0.930 | 2.332 | 5.040 |
| 2008 | 54 | 0.444 | 0.650 | 0.821 | 2.027 | 2.154 | 2.922 | 3.279 | 3.522 |
| 2009 | 63 | 0.515 | 0.700 | 0.900 | 1.911 | 2.386 | 2.629 | 2.802 | 3.752 |
| 2010 | 124 | 0.380 | 0.490 | 0.588 | 1.235 | 0.765 | 2.119 | 2.438 | 4.262 |
| 2011 | 116 | 0.450 | 0.510 | 0.620 | 0.941 | 0.765 | 0.920 | 2.004 | 2.517 |

### *Total Nitrogen Lower Lake Samples Categorized by Month*

- By month, the highest mean concentrations were measured in October, December and February in decreasing order.
- The lowest mean concentrations were measured in May, September and July in increasing order.
- Median concentrations for all months were similar, but tended to be lower from May to September.
- There is a general trend for higher median concentrations in winter months and lower concentrations in summer months.

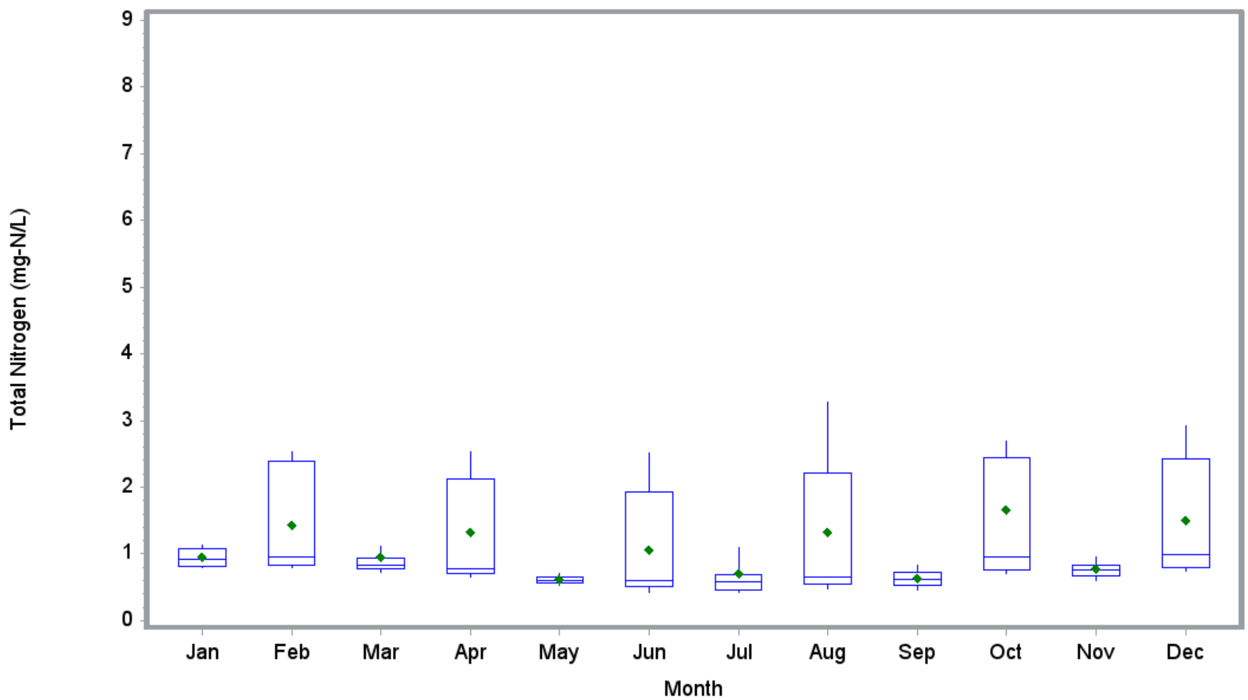



**Figure 3-164 Total Nitrogen Lower Lake Samples Categorized by Month**

**Table 3-172 Total Nitrogen Lower Lake Samples Categorized by Month (mg-N/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 42 | 0.740 | 0.800 | 0.820 | 0.955 | 0.922 | 1.070 | 1.130 | 1.250 |
| Feb | 63 | 0.510 | 0.790 | 0.823 | 1.429 | 0.945 | 2.386 | 2.533 | 3.522 |
| Mar | 67 | 0.490 | 0.720 | 0.770 | 0.956 | 0.830 | 0.930 | 1.111 | 2.361 |
| Apr | 99 | 0.590 | 0.650 | 0.700 | 1.323 | 0.782 | 2.119 | 2.535 | 2.870 |
| May | 70 | 0.480 | 0.525 | 0.560 | 0.609 | 0.605 | 0.660 | 0.706 | 0.840 |
| Jun | 100 | 0.205 | 0.430 | 0.514 | 1.056 | 0.590 | 1.929 | 2.517 | 2.922 |
| Jul | 108 | 0.375 | 0.430 | 0.463 | 0.698 | 0.585 | 0.695 | 1.090 | 2.174 |
| Aug | 144 | 0.380 | 0.478 | 0.550 | 1.317 | 0.660 | 2.207 | 3.279 | 3.752 |
| Sep | 67 | 0.390 | 0.460 | 0.520 | 0.628 | 0.620 | 0.730 | 0.830 | 0.900 |
| Oct | 92 | 0.560 | 0.700 | 0.765 | 1.666 | 0.950 | 2.438 | 2.687 | 5.664 |
| Nov | 57 | 0.540 | 0.590 | 0.670 | 0.772 | 0.760 | 0.830 | 0.960 | 1.370 |
| Dec | 69 | 0.650 | 0.740 | 0.800 | 1.503 | 0.990 | 2.419 | 2.922 | 3.195 |

### *Total Nitrogen Lower Lake Samples Categorized by Sampling Organization*

> By sampling organization, the highest mean and median concentrations were recorded by USGS, lowest mean and median concentrations were recorded by NCDWQ and NCSU-CAAE.

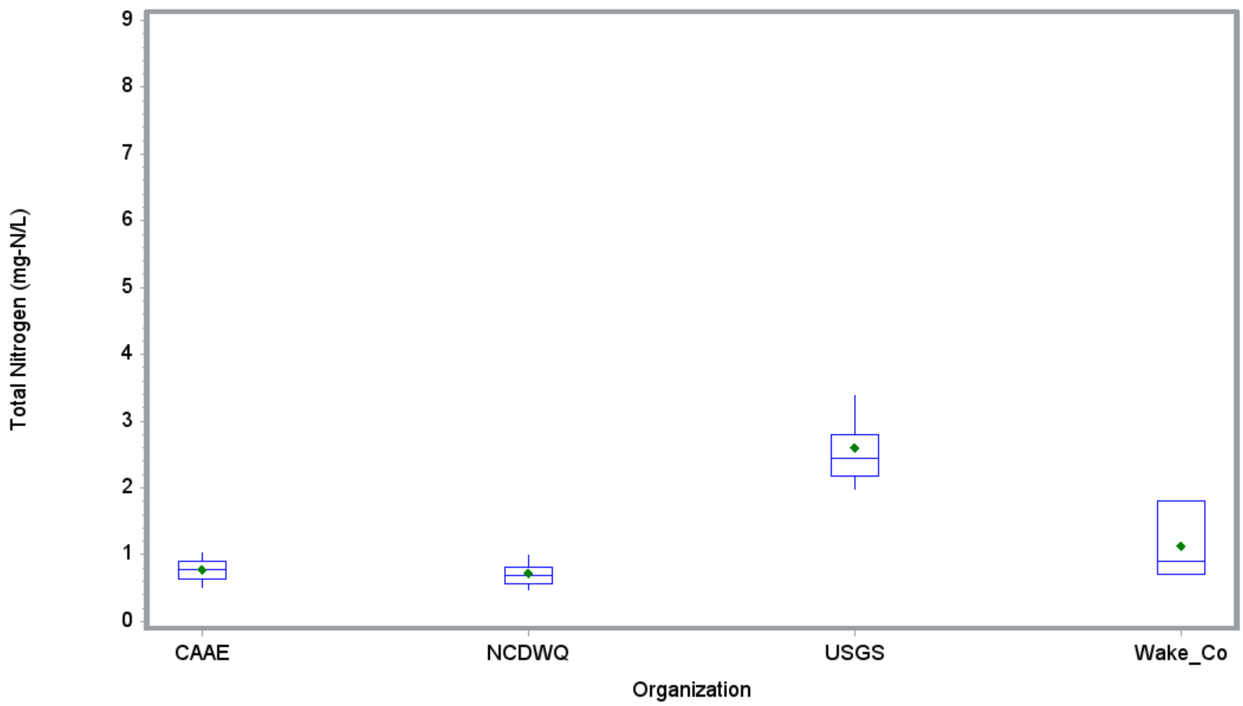



**Figure 3-165 Total Nitrogen Lower Lake Samples Categorized by Sampling Organization**

**Table 3-173 Total Nitrogen Lower Lake Samples Categorized by Sampling Organization (mg-N/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 71 | 0.444 | 0.515 | 0.636 | 0.770 | 0.782 | 0.900 | 1.017 | 1.111 |
| NCDWQ | 710 | 0.205 | 0.480 | 0.570 | 0.731 | 0.690 | 0.820 | 0.980 | 3.250 |
| USGS | 194 | 1.408 | 1.987 | 2.172 | 2.601 | 2.438 | 2.802 | 3.382 | 5.664 |
| Wake_Co | 3 | 0.700 | 0.700 | 0.700 | 1.133 | 0.900 | 1.800 | 1.800 | 1.800 |

***Total Nitrogen Lower Lake Samples Categorized by Method***

> Only the method used to determine total nitrogen was a calculation.

## 3.15 Ortho-Phosphate

Four organizations measured ortho-phosphate as part of the water quality sampling effort. Ortho-phosphate was measured in the laboratory.

For those organizations that provided method, the following were used:

> Phosphorus, all forms, colorimetric, automated, ascorbic acid (EPA 365.1)

> Phosphorus, orthophosphate, colorimetry, phosphomolybdate, automated-segmented flow (USGS I-2601-90)

> Phosphorus, orthophosphate, low ionic-strength water, colorimetry, phosphomolybdate, automated-segmented flow (USGS I-2606-89)

Appendix E provides detailed descriptions of these methods.

Table 3-174 describes the organizations and analysis methods used to measure ortho-phosphate and includes the number of samples, date range, and limits. The majority of the ortho-phosphate data has been collected by USGS using method USGS_I-2601-90 or USGS_I-2602-85. Ortho-phosphate is presented in mg/L and to four decimal places based on reported data.

**Table 3-174 Summary of Analysis Methods for the Ortho-Phosphate Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg-P/L) | Reporting Limit (mg-P/L) | Practical Quanti-fication Limit (mg-P/L) | Range of Limit Specified with Results (mg-P/L) |
|---|---|---|---|---|---|---|---|---|
| Durham_Ci | Not Provided | 04/01/2002 | 04/30/2012 | 515 | Not Provided | Not Provided | 0.05 | 0.0163 to 0.05 |
| Durham_Ci | EPA_365.1 | 01/26/2010 | 06/02/2011 | 89 | 0.016 | 0.05 | Not Provided | 0.00522 to 0.0163 |
| NCDWQ | EPA_365.1 | 08/23/2000 | 09/20/2007 | 985 | 0.01 | 0.02 | Not Provided | 0.02 |
| USGS | Various[1] | 01/15/1999 | 10/14/2011 | 1,005 | Not Provided | Not Provided | Not Provided | 0.001 to 0.18 |
| Wake_Co | Not Provided | 07/29/2008 | 10/14/2009 | 141 | Not Provided | Not Provided | 0.006 | 0.02 |

[1] Ortho-phosphate analyzed by method USGS_I-2601-90 or USGS_I-2602-85. Methods were not unique to the organization/dataset. Box plot by analysis method displays "Various" for this data to omit long category names.

### 3.15.2 Tributary Samples

Three organizations collected orthophosphate-P data in the Falls Lake tributaries from 1999 to 2011. The highest mean and median concentrations were recorded in Knap of Reeds Creek and the lowest concentrations were recorded in Eno River. Highest mean and median concentrations were recorded in 2011 and the lowest concentrations were recorded in 2000. See Table 1 for additional summary statistics. Box plot summaries are provided below.

***Orthophosphate-P Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Orthophosphate-P concentrations were recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Honeycutt/Barton Creek and Horse/New Light Creek

> Highest mean concentrations were measured in Knap of Reeds Creek followed by Ellerbe Creek. Orthophosphate-P levels were highest in the 0 to 2 mile segment upstream of the tributary mouth for those two subwatersheds. Lowest mean concentrations were measured in Eno River, Flat River and Horse/New Light Creek overall, with Eno River > 10 mile and Flat River 2 to 10 mile segments having the lowest recorded mean concentrations.

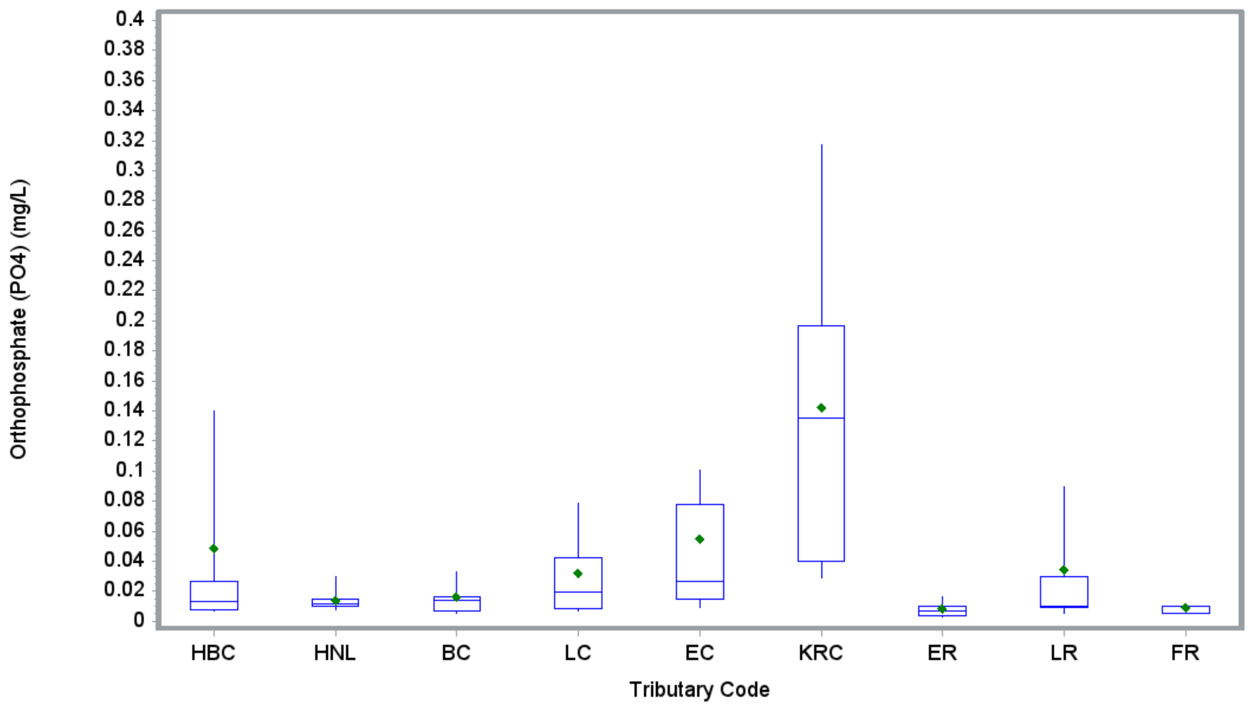



**Figure 3-166 Ortho-Phosphate Tributary Samples Categorized by Subwatershed**

**Table 3-175 Ortho-Phosphate Tributary Samples Categorized by Subwatershed (in mg-P/L))**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 76 | 0.0040 | 0.0070 | 0.0080 | 0.0483 | 0.0135 | 0.0265 | 0.1400 | 0.5400 |
| HNL | 44 | 0.0050 | 0.0080 | 0.0100 | 0.0142 | 0.0120 | 0.0150 | 0.0300 | 0.0350 |
| BC | 47 | 0.0030 | 0.0050 | 0.0070 | 0.0163 | 0.0140 | 0.0160 | 0.0330 | 0.0930 |
| LC | 34 | 0.0059 | 0.0068 | 0.0082 | 0.0323 | 0.0197 | 0.0424 | 0.0782 | 0.1337 |
| EC | 43 | 0.0052 | 0.0095 | 0.0147 | 0.0554 | 0.0270 | 0.0780 | 0.1010 | 0.4238 |
| KRC | 9 | 0.0290 | 0.0290 | 0.0400 | 0.1424 | 0.1350 | 0.1970 | 0.3170 | 0.3170 |
| ER | 138 | 0.0005 | 0.0030 | 0.0040 | 0.0086 | 0.0070 | 0.0100 | 0.0163 | 0.0540 |
| LR | 363 | 0.0010 | 0.0050 | 0.0090 | 0.0345 | 0.0100 | 0.0300 | 0.0900 | 0.4500 |
| FR | 99 | 0.0005 | 0.0050 | 0.0050 | 0.0091 | 0.0100 | 0.0100 | 0.0100 | 0.0900 |

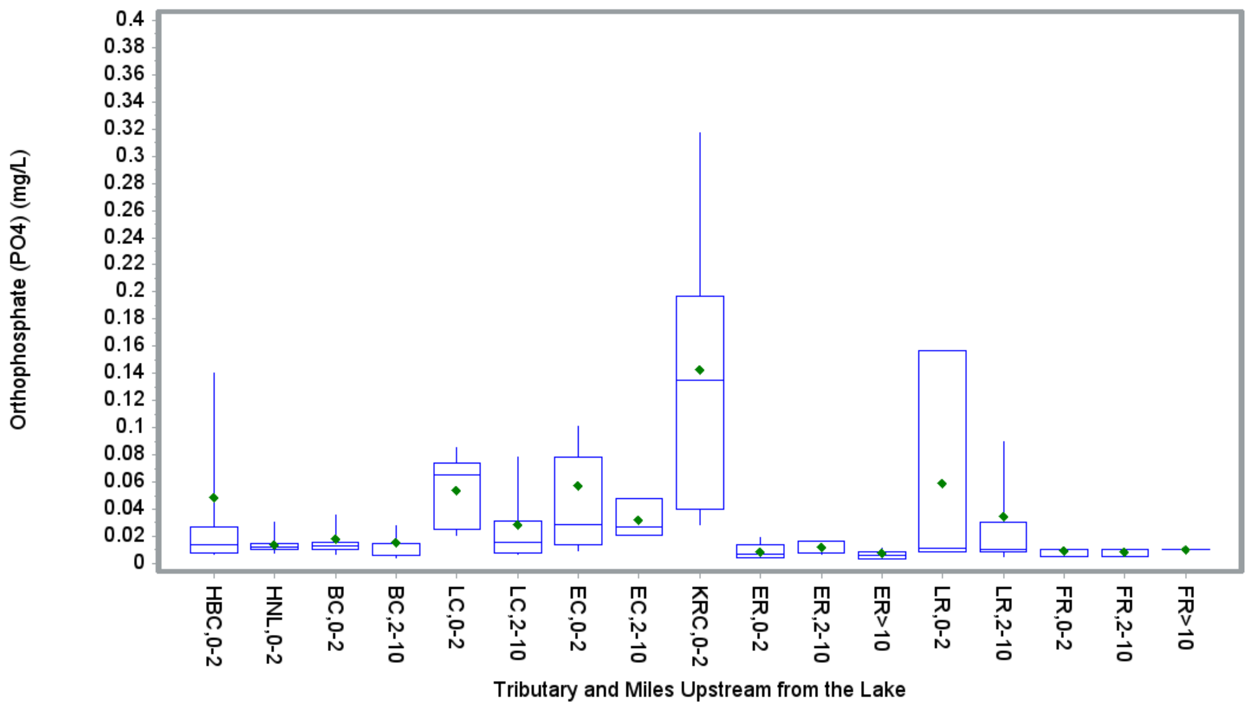



**Figure 3-167 Ortho-Phosphate Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-176 Ortho-Phosphate Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in mg-P /L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 76 | 0.0040 | 0.0070 | 0.0080 | 0.0483 | 0.0135 | 0.0265 | 0.1400 | 0.5400 |
| HNL,0-2 | 44 | 0.0050 | 0.0080 | 0.0100 | 0.0142 | 0.0120 | 0.0150 | 0.0300 | 0.0350 |
| BC,0-2 | 17 | 0.0050 | 0.0070 | 0.0100 | 0.0183 | 0.0130 | 0.0160 | 0.0360 | 0.0660 |
| BC,2-10 | 30 | 0.0030 | 0.0045 | 0.0060 | 0.0152 | 0.0145 | 0.0150 | 0.0275 | 0.0930 |
| LC,0-2 | 5 | 0.0210 | 0.0210 | 0.0250 | 0.0540 | 0.0650 | 0.0740 | 0.0850 | 0.0850 |
| LC,2-10 | 29 | 0.0059 | 0.0065 | 0.0082 | 0.0285 | 0.0160 | 0.0316 | 0.0782 | 0.1337 |
| EC,0-2 | 40 | 0.0052 | 0.0091 | 0.0139 | 0.0571 | 0.0286 | 0.0781 | 0.1010 | 0.4238 |
| EC,2-10 | 3 | 0.0210 | 0.0210 | 0.0210 | 0.0320 | 0.0270 | 0.0480 | 0.0480 | 0.0480 |
| KRC,0-2 | 9 | 0.0290 | 0.0290 | 0.0400 | 0.1424 | 0.1350 | 0.1970 | 0.3170 | 0.3170 |
| ER,0-2 | 4 | 0.0040 | 0.0040 | 0.0040 | 0.0090 | 0.0065 | 0.0140 | 0.0190 | 0.0190 |
| ER,2-10 | 35 | 0.0026 | 0.0068 | 0.0082 | 0.0122 | 0.0082 | 0.0163 | 0.0163 | 0.0330 |
| ER>10 | 99 | 0.0005 | 0.0030 | 0.0035 | 0.0073 | 0.0060 | 0.0090 | 0.0110 | 0.0540 |
| LR,0-2 | 3 | 0.0090 | 0.0090 | 0.0090 | 0.0590 | 0.0110 | 0.1570 | 0.1570 | 0.1570 |
| LR,2-10 | 360 | 0.0010 | 0.0050 | 0.0090 | 0.0343 | 0.0100 | 0.0300 | 0.0900 | 0.4500 |
| FR,0-2 | 95 | 0.0005 | 0.0050 | 0.0050 | 0.0092 | 0.0100 | 0.0100 | 0.0100 | 0.0900 |
| FR,2-10 | 3 | 0.0050 | 0.0050 | 0.0050 | 0.0083 | 0.0100 | 0.0100 | 0.0100 | 0.0100 |

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| FR>10 | 1 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 |

***Orthophosphate-P Tributary Samples Categorized by Depth***

> All samples were collected in the surface layer.

***Orthophosphate-P Tributary Samples Categorized by Year***

> By year, highest mean concentrations were recorded in 2011and 2006.

> The lowest mean concentrations were recorded in 2000 and 2007.

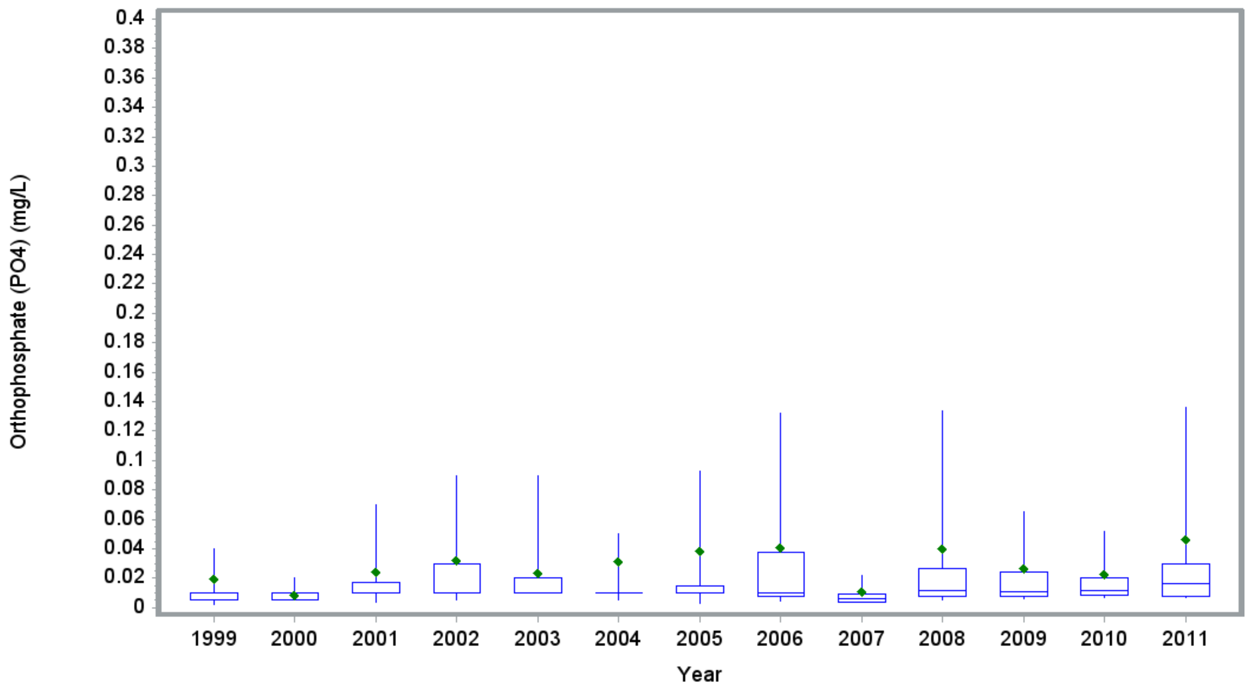



**Figure 3-168 Ortho-Phosphate Tributary Samples Categorized by Year**

**Table 3-177 Ortho-Phosphate Tributary Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 54 | 0.0005 | 0.0020 | 0.0050 | 0.0197 | 0.0050 | 0.0100 | 0.0400 | 0.1800 |
| 2000 | 54 | 0.0005 | 0.0050 | 0.0050 | 0.0087 | 0.0050 | 0.0100 | 0.0200 | 0.0600 |
| 2001 | 45 | 0.0035 | 0.0040 | 0.0100 | 0.0242 | 0.0100 | 0.0170 | 0.0700 | 0.2100 |
| 2002 | 43 | 0.0035 | 0.0050 | 0.0100 | 0.0322 | 0.0100 | 0.0300 | 0.0900 | 0.2300 |
| 2003 | 60 | 0.0030 | 0.0100 | 0.0100 | 0.0234 | 0.0100 | 0.0200 | 0.0900 | 0.1200 |
| 2004 | 43 | 0.0030 | 0.0050 | 0.0100 | 0.0317 | 0.0100 | 0.0100 | 0.0500 | 0.4300 |
| 2005 | 44 | 0.0030 | 0.0030 | 0.0100 | 0.0383 | 0.0100 | 0.0150 | 0.0930 | 0.4500 |
| 2006 | 40 | 0.0030 | 0.0045 | 0.0075 | 0.0409 | 0.0100 | 0.0380 | 0.1325 | 0.3170 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2007 | 30 | 0.0030 | 0.0040 | 0.0040 | 0.0106 | 0.0060 | 0.0090 | 0.0220 | 0.0780 |
| 2008 | 128 | 0.0030 | 0.0050 | 0.0075 | 0.0397 | 0.0120 | 0.0270 | 0.1340 | 0.5400 |
| 2009 | 143 | 0.0040 | 0.0060 | 0.0080 | 0.0265 | 0.0110 | 0.0240 | 0.0650 | 0.2340 |
| 2010 | 111 | 0.0026 | 0.0070 | 0.0082 | 0.0223 | 0.0120 | 0.0200 | 0.0522 | 0.1970 |
| 2011 | 58 | 0.0052 | 0.0068 | 0.0080 | 0.0462 | 0.0163 | 0.0300 | 0.1360 | 0.4238 |

### *Orthophosphate-P Tributary Samples Categorized by Month*

> By month, the highest mean concentrations were recorded in November followed by August and September.

> The lowest mean concentrations were recorded in April and March

> Median concentrations were similar for all months.

> The greatest variability in measurements was recorded in November.

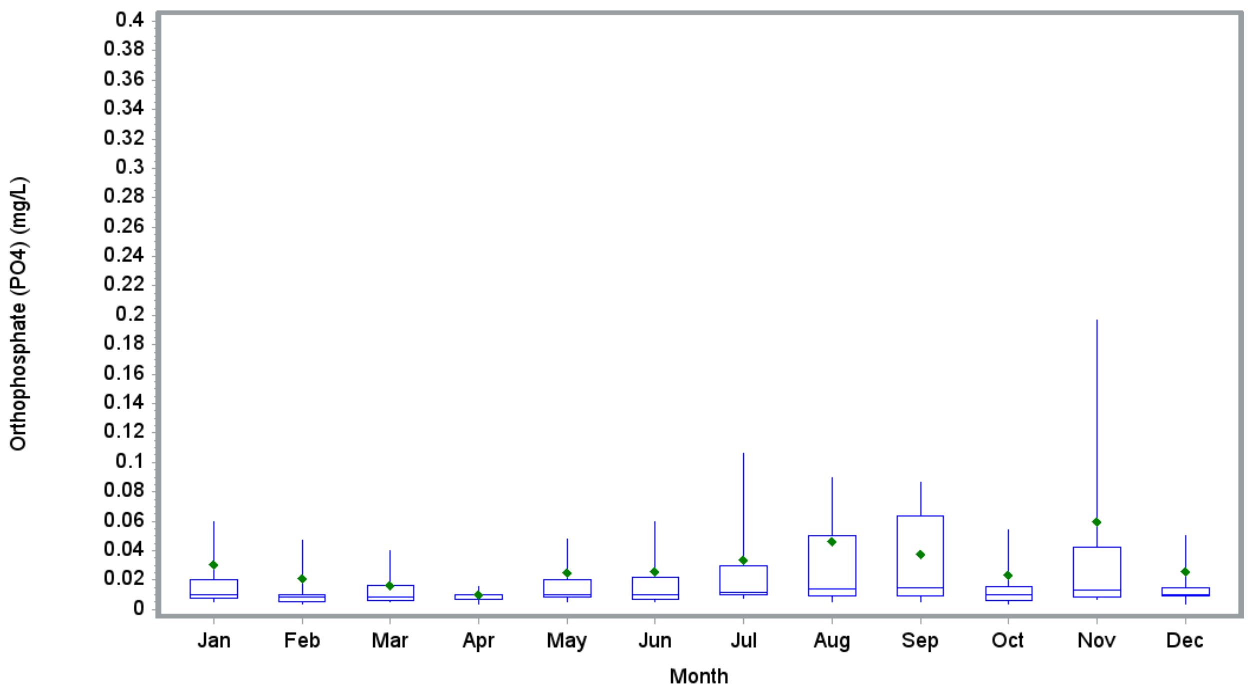



**Figure 3-169 Ortho-Phosphate Tributary Samples Categorized by Month**

**Table 3-178 Ortho-Phosphate Tributary Samples Categorized by Month (in mg-P/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 53 | 0.0030 | 0.0050 | 0.0080 | 0.0304 | 0.0100 | 0.0200 | 0.0600 | 0.3170 |
| Feb | 85 | 0.0020 | 0.0040 | 0.0050 | 0.0211 | 0.0082 | 0.0100 | 0.0470 | 0.4238 |
| Mar | 71 | 0.0030 | 0.0050 | 0.0060 | 0.0161 | 0.0082 | 0.0163 | 0.0400 | 0.1350 |
| Apr | 80 | 0.0026 | 0.0040 | 0.0067 | 0.0102 | 0.0100 | 0.0100 | 0.0157 | 0.0370 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| May | 69 | 0.0050 | 0.0050 | 0.0082 | 0.0250 | 0.0100 | 0.0200 | 0.0480 | 0.2670 |
| Jun | 77 | 0.0030 | 0.0050 | 0.0070 | 0.0259 | 0.0100 | 0.0222 | 0.0600 | 0.1850 |
| Jul | 64 | 0.0050 | 0.0080 | 0.0100 | 0.0341 | 0.0120 | 0.0295 | 0.1060 | 0.3030 |
| Aug | 72 | 0.0010 | 0.0050 | 0.0090 | 0.0467 | 0.0140 | 0.0505 | 0.0900 | 0.4300 |
| Sep | 80 | 0.0005 | 0.0050 | 0.0095 | 0.0378 | 0.0150 | 0.0635 | 0.0865 | 0.2180 |
| Oct | 72 | 0.0030 | 0.0040 | 0.0065 | 0.0236 | 0.0100 | 0.0155 | 0.0540 | 0.3100 |
| Nov | 52 | 0.0005 | 0.0070 | 0.0084 | 0.0594 | 0.0130 | 0.0420 | 0.1970 | 0.5400 |
| Dec | 78 | 0.0005 | 0.0040 | 0.0090 | 0.0257 | 0.0100 | 0.0150 | 0.0500 | 0.2700 |

### *Orthophosphate-P Tributary Samples Categorized by Sampling Organization*

> By sampling organization, Wake County recorded higher mean concentrations.

> Median concentrations were similar for all organizations.

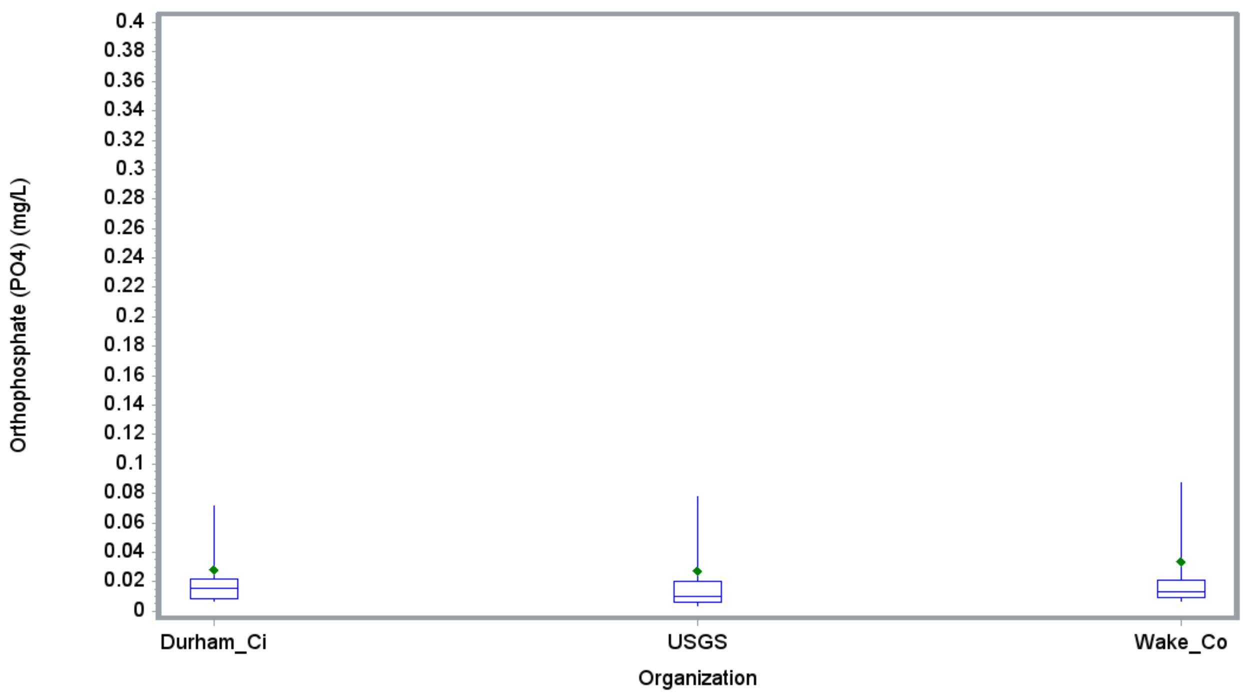



**Figure 3-170 Ortho-Phosphate Tributary Samples Categorized by Sampling Organization**

**Table 3-179 Ortho-Phosphate Tributary Samples Categorized by Sampling Organization (in mg-P/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 89 | 0.0026 | 0.0068 | 0.0082 | 0.0278 | 0.0153 | 0.0222 | 0.0717 | 0.4238 |
| USGS | 628 | 0.0005 | 0.0040 | 0.0060 | 0.0277 | 0.0100 | 0.0200 | 0.0780 | 0.4500 |
| Wake_Co | 136 | 0.0040 | 0.0070 | 0.0090 | 0.0338 | 0.0130 | 0.0210 | 0.0870 | 0.5400 |

### *Orthophosphate-P Tributary Samples Categorized by Method*

> By method, the highest mean concentrations were recorded using an unknown method, while EPA 365.1 and the "Various" methods returned similar mean concentrations.

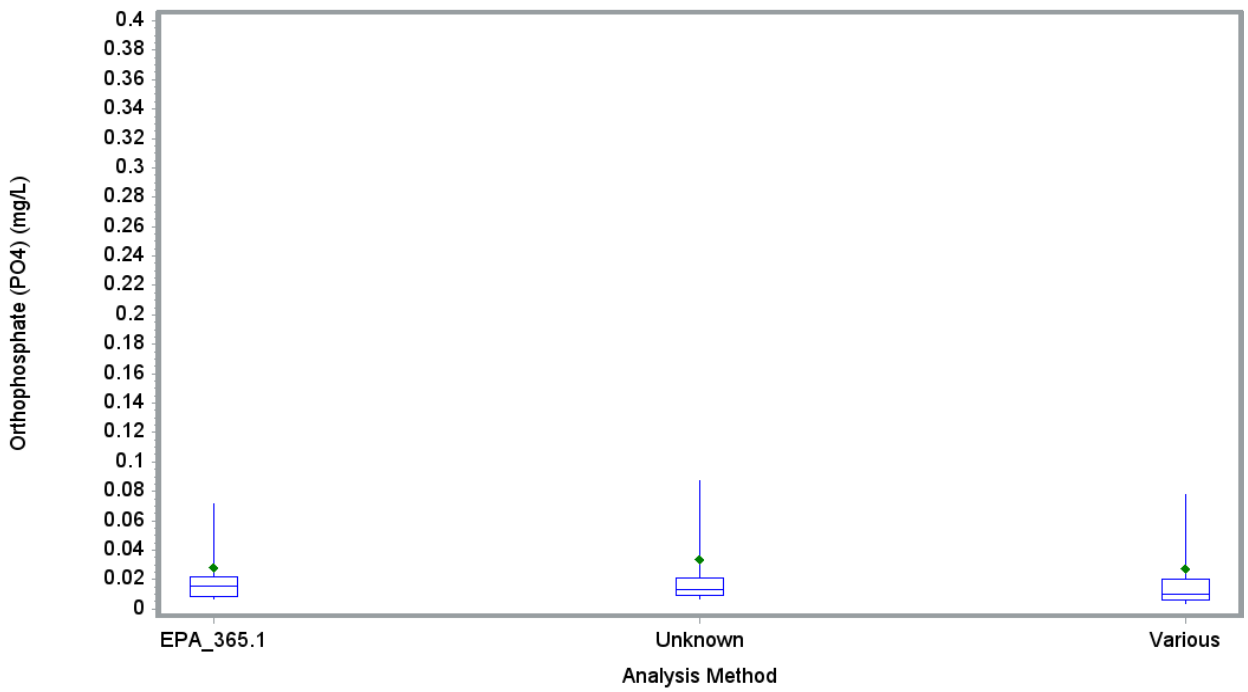



**Figure 3-171 Ortho-Phosphate Tributary Samples Categorized by Analysis Method**

**Table 3-180 Ortho-Phosphate Tributary Samples Categorized by Analysis Method (in mg-P/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_365.1 | 89 | 0.0026 | 0.0068 | 0.0082 | 0.0278 | 0.0153 | 0.0222 | 0.0717 | 0.4238 |
| Unknown | 136 | 0.0040 | 0.0070 | 0.0090 | 0.0338 | 0.0130 | 0.0210 | 0.0870 | 0.5400 |
| Various | 628 | 0.0005 | 0.0040 | 0.0060 | 0.0277 | 0.0100 | 0.0200 | 0.0780 | 0.4500 |

### *Orthophosphate-P Comparing Different Methods for Handling Data Reported as Below the Detection Limit*

> There is little difference in the median values when using full detection limit, half detection limit, or zero values to estimate values for below detection limit data.

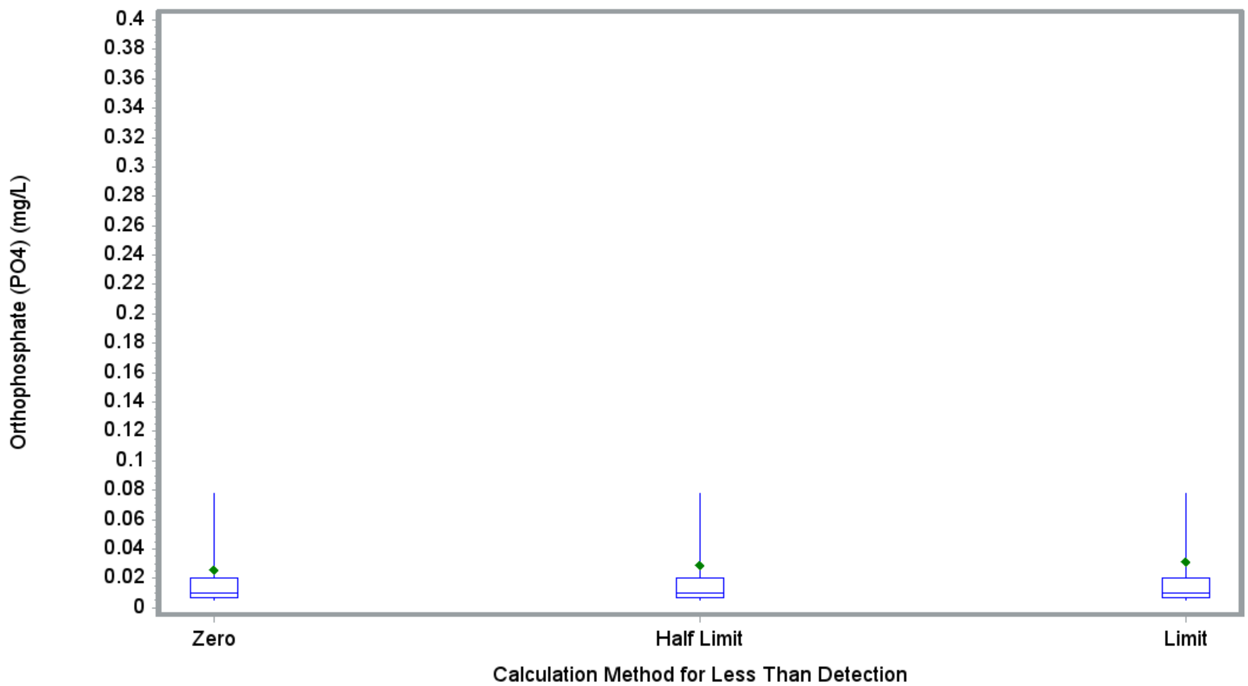



**Figure 3-172 Ortho-Phosphate Tributary Samples Categorized by Limit Calculation**

### 3.15.3 <u>Upper Lake Samples</u>

Three organizations measured orthophosphate concentrations in upper Falls Lake from 2000 to present. The highest mean orthophosphate concentrations were measured by City of Durham. Lowest mean concentrations were measured by USGS. Highest mean concentrations were recorded in > 21 miles section of the upper lake and in the surface layer. Highest mean concentrations were recorded in 2002 and lowest mean concentrations were recorded in 2000. Box plot summaries are provided below.

***Orthophosphate-P Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean concentrations were measured > 21 miles upstream of the dam.

> Lowest mean concentration were recorded 13 to 18 miles from the dam.

> Median concentrations were identical for all three lake segments.

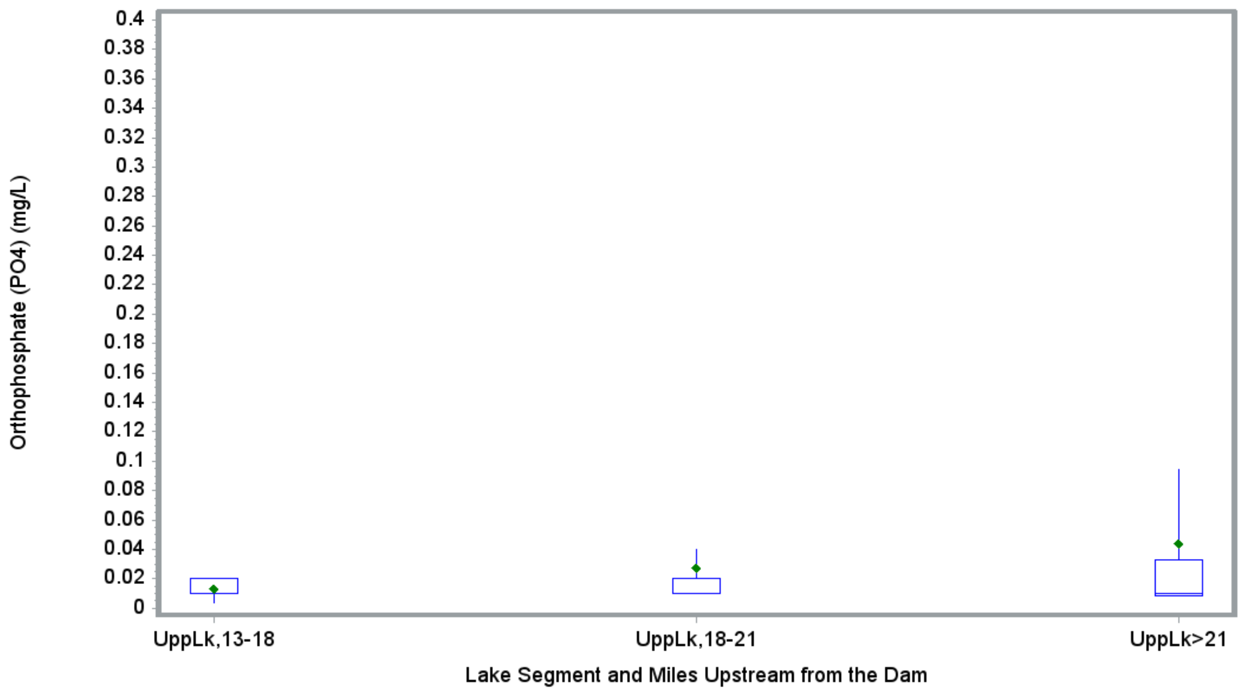



**Figure 3-173 Ortho-Phosphate Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-181 Ortho-Phosphate Upper Lake Samples Categorized by Miles Upstream from Dam (in mg-P/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 410 | 0.0020 | 0.0040 | 0.0100 | 0.0136 | 0.0100 | 0.0200 | 0.0200 | 0.3000 |
| UppLk,18-21 | 105 | 0.0100 | 0.0100 | 0.0100 | 0.0276 | 0.0100 | 0.0200 | 0.0400 | 0.3400 |
| UppLk>21 | 834 | 0.0020 | 0.0082 | 0.0082 | 0.0436 | 0.0100 | 0.0326 | 0.0945 | 0.9682 |

### *Orthophosphate-P Upper Lake Samples Categorized by Depth*

> By depth, highest mean concentrations were measured in the surface layer.

> Lowest mean concentrations were measured in the bottom layer, however there was a small sample size (n=7)

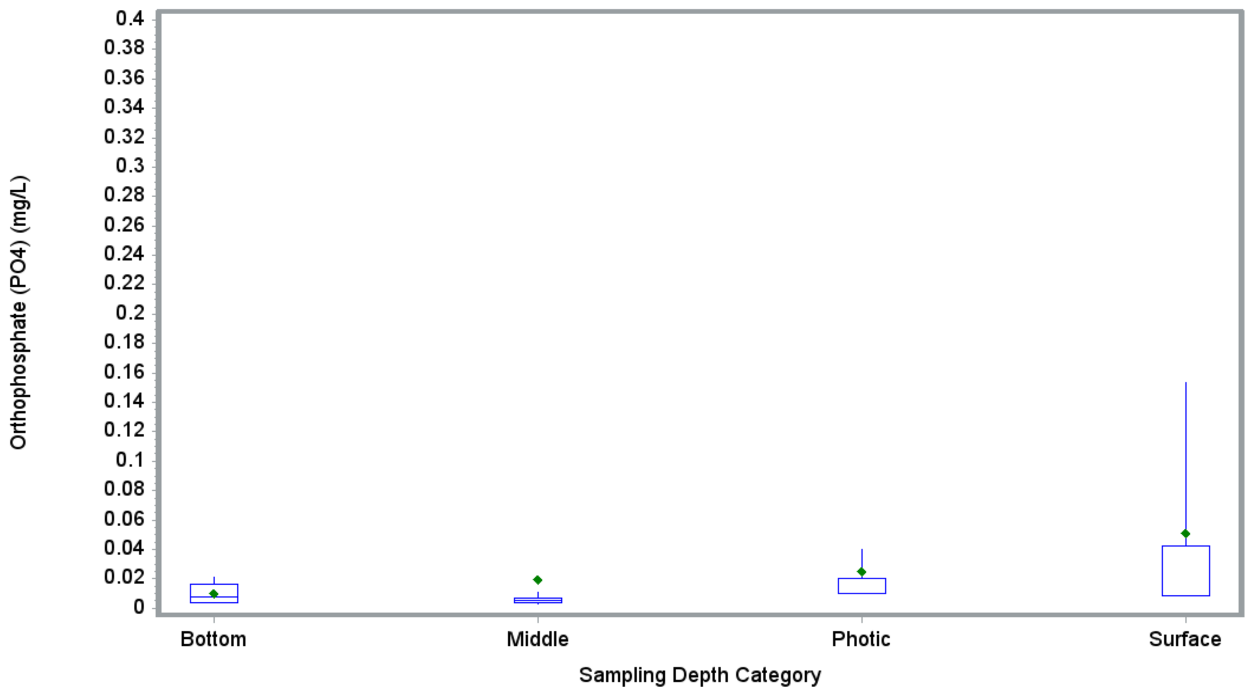



**Figure 3-174 Ortho-Phosphate Upper Lake Samples Categorized by Depth Category**

**Table 3-182 Ortho-Phosphate Upper Lake Samples Categorized by Depth Category (in mg-P/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 7 | 0.0040 | 0.0040 | 0.0040 | 0.0100 | 0.0080 | 0.0160 | 0.0210 | 0.0210 |
| Middle | 160 | 0.0020 | 0.0030 | 0.0040 | 0.0196 | 0.0055 | 0.0070 | 0.0110 | 0.4170 |
| Photic | 724 | 0.0082 | 0.0100 | 0.0100 | 0.0252 | 0.0100 | 0.0200 | 0.0400 | 0.9300 |
| Surface | 458 | 0.0030 | 0.0082 | 0.0082 | 0.0510 | 0.0082 | 0.0424 | 0.1532 | 0.9682 |

### *Orthophosphate-P Upper Lake Categorized by Year*

- Orthophosphate was measured for all years from 2000 to 2012 except for 2001.
- The highest mean and median concentrations were recorded in 2002.
- The lowest mean concentrations were recorded in 2000, however 2000 was represented by a small sample size (n=5) relative to the other sampling years.

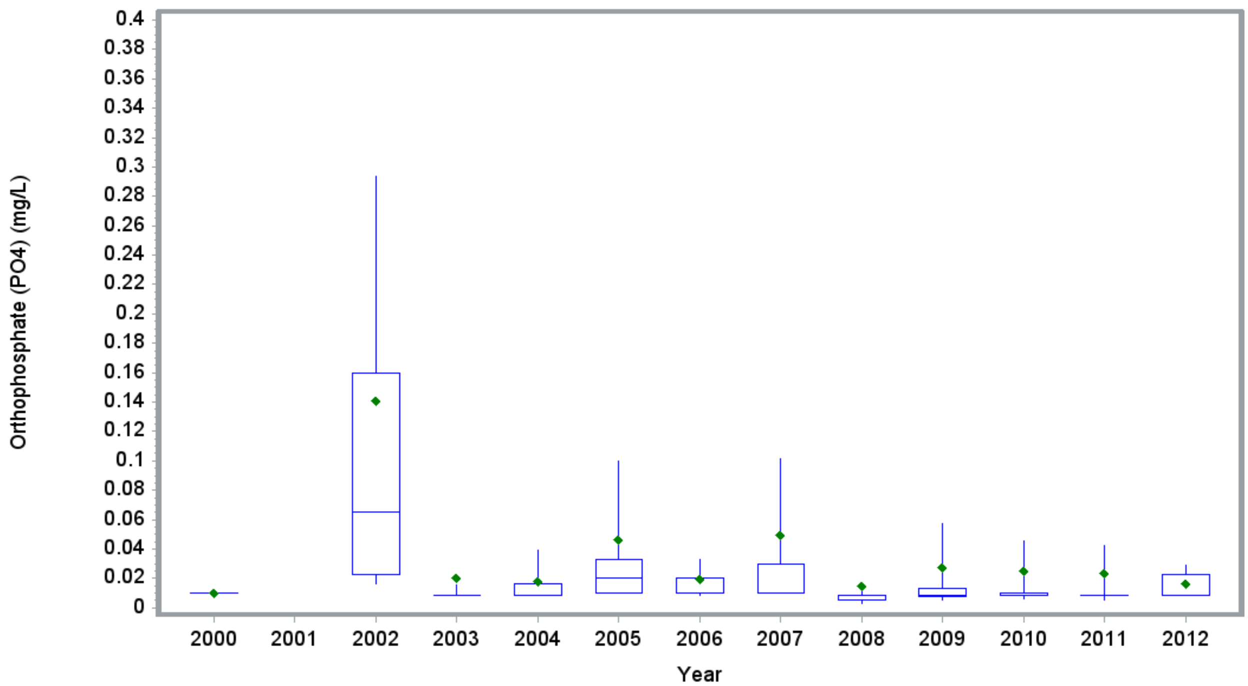



**Figure 3-175 Ortho-Phosphate Upper Lake Samples Categorized by Year**

**Table 3-183 Ortho-Phosphate Upper Lake Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 5 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 |
| 2002 | 31 | 0.0082 | 0.0163 | 0.0228 | 0.1411 | 0.0652 | 0.1597 | 0.2934 | 0.9682 |
| 2003 | 30 | 0.0082 | 0.0082 | 0.0082 | 0.0200 | 0.0082 | 0.0082 | 0.0155 | 0.3064 |
| 2004 | 30 | 0.0082 | 0.0082 | 0.0082 | 0.0176 | 0.0082 | 0.0163 | 0.0391 | 0.1402 |
| 2005 | 214 | 0.0030 | 0.0100 | 0.0100 | 0.0465 | 0.0200 | 0.0326 | 0.1000 | 0.7889 |
| 2006 | 330 | 0.0030 | 0.0082 | 0.0100 | 0.0193 | 0.0100 | 0.0200 | 0.0326 | 0.3521 |
| 2007 | 254 | 0.0030 | 0.0100 | 0.0100 | 0.0492 | 0.0100 | 0.0300 | 0.1011 | 0.9300 |
| 2008 | 85 | 0.0030 | 0.0030 | 0.0050 | 0.0152 | 0.0082 | 0.0082 | 0.0163 | 0.3130 |
| 2009 | 100 | 0.0040 | 0.0050 | 0.0081 | 0.0273 | 0.0082 | 0.0130 | 0.0571 | 0.3619 |
| 2010 | 138 | 0.0040 | 0.0060 | 0.0082 | 0.0249 | 0.0082 | 0.0100 | 0.0456 | 0.4205 |
| 2011 | 117 | 0.0020 | 0.0050 | 0.0082 | 0.0235 | 0.0082 | 0.0082 | 0.0424 | 0.4531 |
| 2012 | 15 | 0.0082 | 0.0082 | 0.0082 | 0.0163 | 0.0082 | 0.0228 | 0.0293 | 0.0489 |

### *Orthophosphate-P Upper Lake Samples Categorized by Month*

- By month, the highest mean concentrations were measured in October, July and September (in decreasing order).
- The lowest mean concentrations were measured in April, February and March.
- Median concentrations were similar for all months.

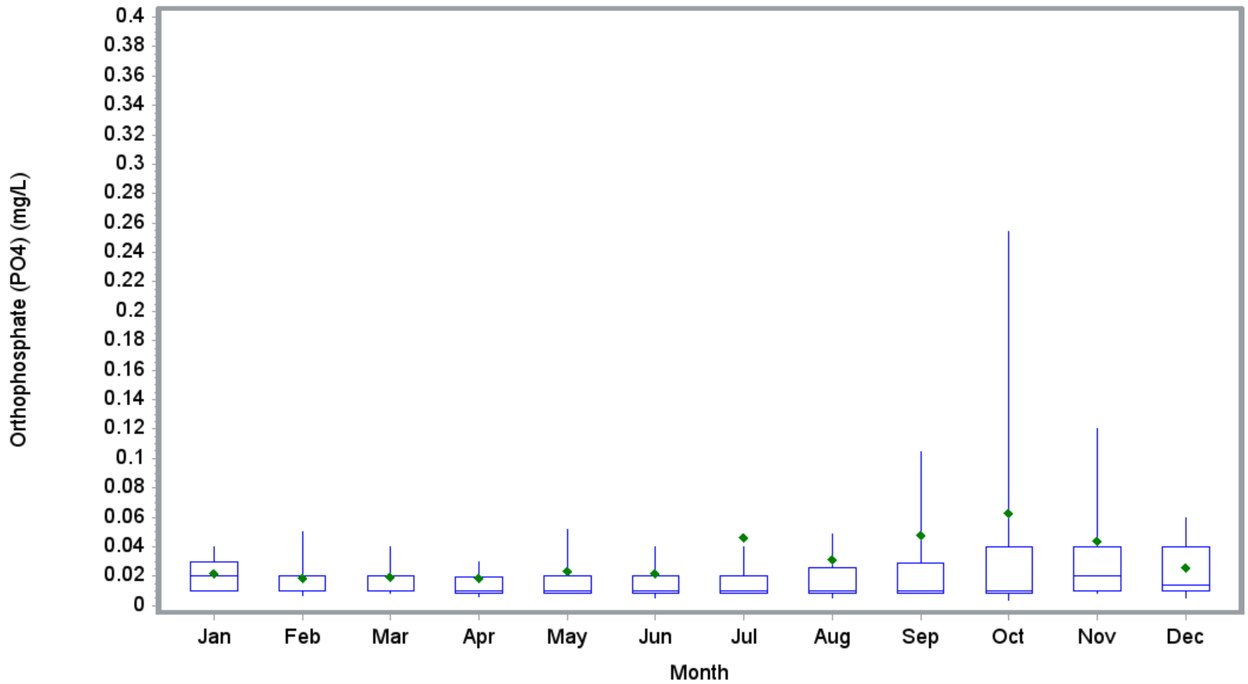



**Figure 3-176 Ortho-Phosphate Upper Lake Samples Categorized by Month**

**Table 3-184 Ortho-Phosphate Upper Lake Samples Categorized by Month (in mg-P/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 43 | 0.0100 | 0.0100 | 0.0100 | 0.0216 | 0.0200 | 0.0300 | 0.0400 | 0.0500 |
| Feb | 65 | 0.0030 | 0.0070 | 0.0100 | 0.0190 | 0.0100 | 0.0200 | 0.0500 | 0.0800 |
| Mar | 83 | 0.0020 | 0.0082 | 0.0100 | 0.0192 | 0.0200 | 0.0200 | 0.0400 | 0.0800 |
| Apr | 168 | 0.0020 | 0.0060 | 0.0082 | 0.0188 | 0.0100 | 0.0196 | 0.0300 | 0.3130 |
| May | 127 | 0.0082 | 0.0082 | 0.0082 | 0.0238 | 0.0100 | 0.0200 | 0.0522 | 0.2184 |
| Jun | 163 | 0.0030 | 0.0050 | 0.0082 | 0.0217 | 0.0100 | 0.0200 | 0.0400 | 0.3716 |
| Jul | 135 | 0.0030 | 0.0082 | 0.0082 | 0.0465 | 0.0100 | 0.0200 | 0.0400 | 0.9682 |
| Aug | 175 | 0.0030 | 0.0050 | 0.0082 | 0.0316 | 0.0100 | 0.0261 | 0.0489 | 0.4531 |
| Sep | 127 | 0.0082 | 0.0082 | 0.0082 | 0.0476 | 0.0100 | 0.0293 | 0.1043 | 0.9300 |
| Oct | 150 | 0.0030 | 0.0040 | 0.0082 | 0.0629 | 0.0100 | 0.0400 | 0.2539 | 0.6846 |
| Nov | 64 | 0.0082 | 0.0082 | 0.0100 | 0.0440 | 0.0200 | 0.0400 | 0.1200 | 0.3400 |
| Dec | 49 | 0.0030 | 0.0050 | 0.0100 | 0.0257 | 0.0140 | 0.0400 | 0.0600 | 0.1100 |

***Orthophosphate-P Upper Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean concentrations were recorded by City of Durham.

> Lowest mean and median concentrations were recorded by USGS.

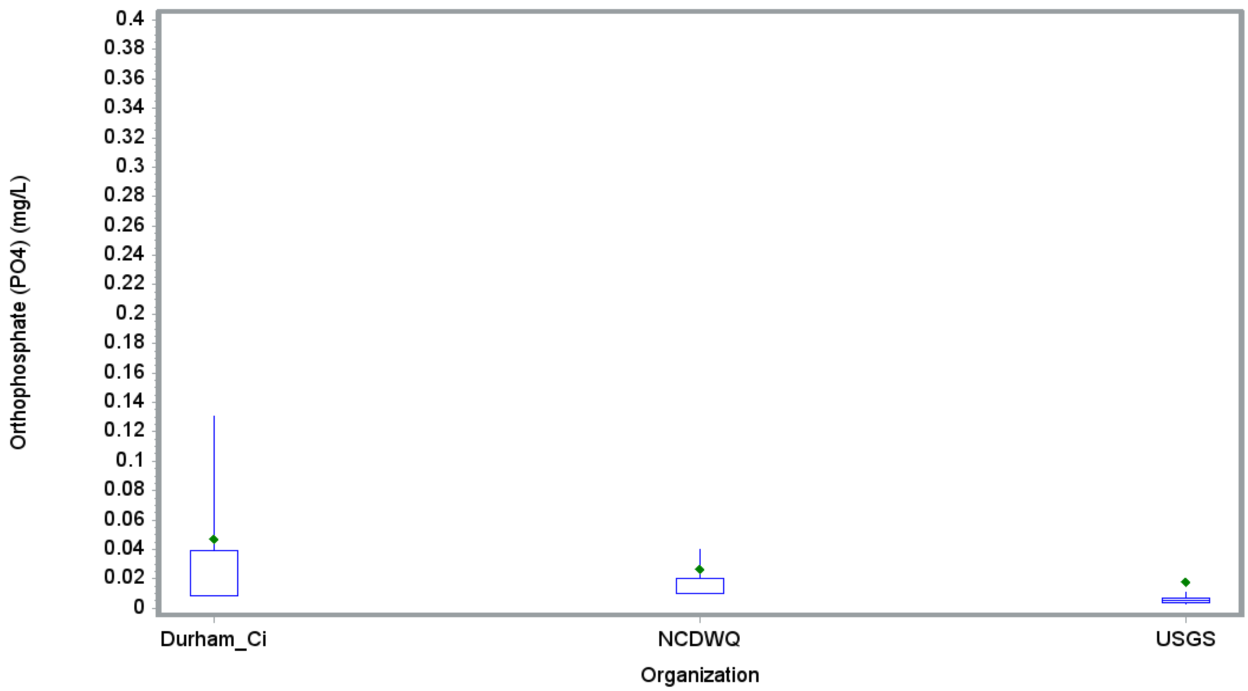



**Figure 3-177 Ortho-Phosphate Upper Lake Samples Categorized by Sampling Organization**

**Table 3-185 Ortho-Phosphate Upper Lake Samples Categorized by Sampling Organization (in mg-P/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 515 | 0.0065 | 0.0082 | 0.0082 | 0.0470 | 0.0082 | 0.0391 | 0.1304 | 0.9682 |
| NCDWQ | 651 | 0.0100 | 0.0100 | 0.0100 | 0.0266 | 0.0100 | 0.0200 | 0.0400 | 0.9300 |
| USGS | 183 | 0.0020 | 0.0030 | 0.0040 | 0.0182 | 0.0050 | 0.0070 | 0.0110 | 0.4170 |

***Orthophosphate-P Upper Lake Samples Categorized by Method***

> By method, the highest mean concentrations were recorded using the unknown method.

> The lowest mean concentrations were recorded using the ‘Various’ methods.

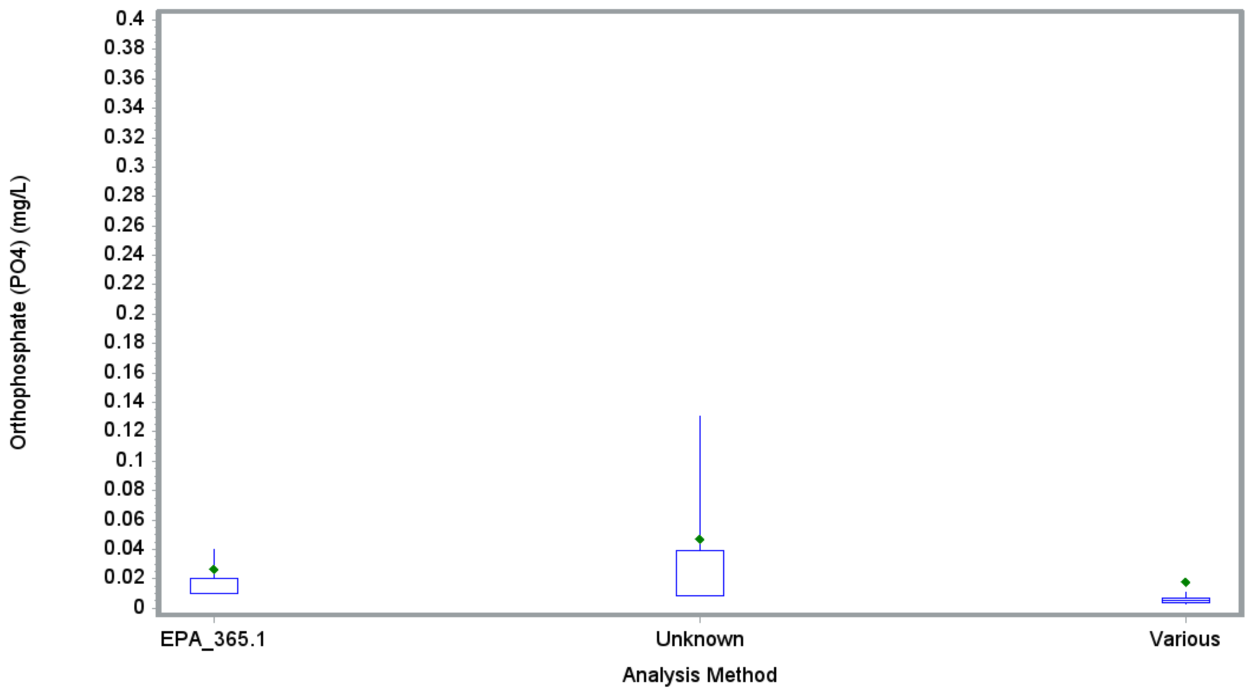



**Figure 3-178 Ortho-Phosphate Upper Lake Samples Categorized by Analysis Method**

**Table 3-186 Ortho-Phosphate Upper Lake Samples Categorized by Analysis Method (in mg-P/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_365.1 | 651 | 0.0100 | 0.0100 | 0.0100 | 0.0266 | 0.0100 | 0.0200 | 0.0400 | 0.9300 |
| Unknown | 515 | 0.0065 | 0.0082 | 0.0082 | 0.0470 | 0.0082 | 0.0391 | 0.1304 | 0.9682 |
| Various | 183 | 0.0020 | 0.0030 | 0.0040 | 0.0182 | 0.0050 | 0.0070 | 0.0110 | 0.4170 |

***Orthophosphate-P Comparing Different Methods for Handling Data Reported as Below the Detection Limit***

> There is little difference in the median when using full detection limit, half detection limit, or zero values to estimate values for below detection limit data.

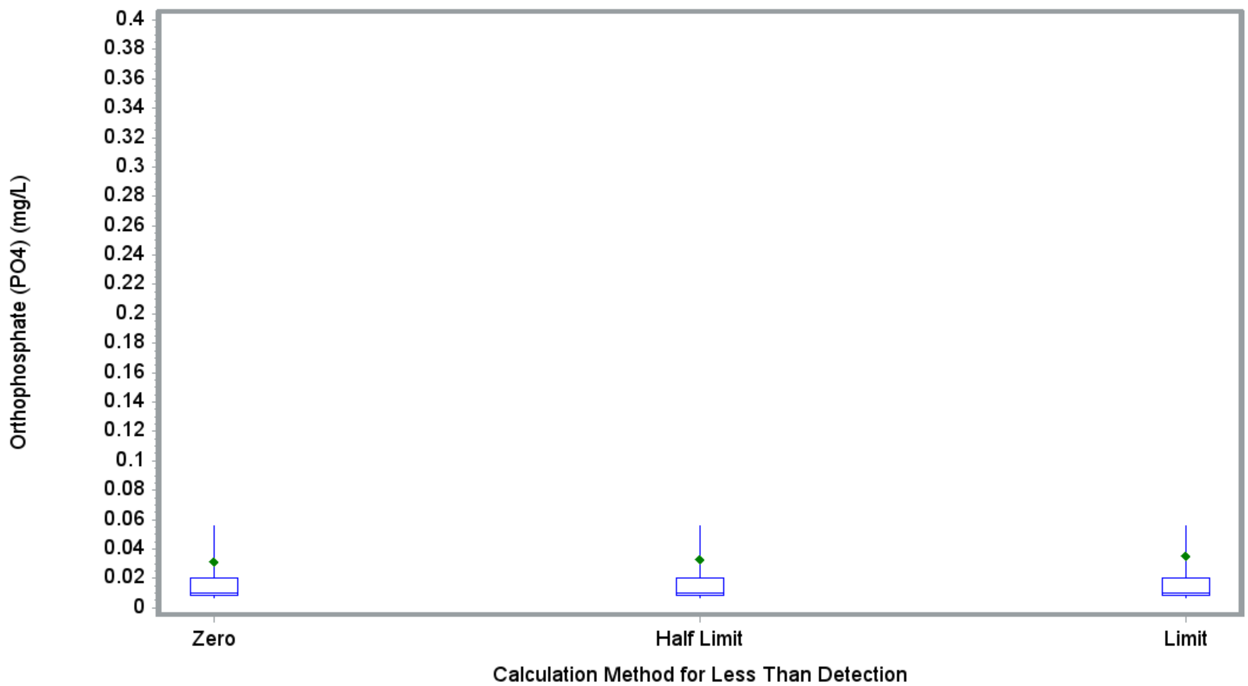



**Figure 3-179 Ortho-Phosphate Upper Lake Samples Categorized by Limit Calculation**

### 3.15.4 Lower Lake Samples

Three organizations measured orthophosphate-P concentrations in lower Falls Lake from 2000 to 2011. The highest mean orthophosphate-P concentrations were measured by Wake County and lowest mean concentrations were measured by USGS. Measurements were similar across lake segment, however highest mean concentrations were recorded 8 to 13 miles from the dam, and lowest mean concentrations were recorded 0 to 4 miles from the dam. Highest mean concentrations were recorded in the photic zone. Highest mean concentrations were recorded in 2006 while the lowest mean concentrations were recorded in 2008. Box plot summaries are provided below. Y-axes scales are adjusted to the same scale as the tributary samples to provide relative comparisons across the geographic regions. This results in small boxes, and it is sometimes difficult to visually assess the differences among the categories. Inspection of the tables that are also included aids in this assessment.

***Orthophosphate-P Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean concentrations were measured 8 to 13 miles upstream of the dam.

> Lowest mean concentrations were measured 0 to 4 miles upstream of the dam.

> Median concentrations were similar for all lake segments.

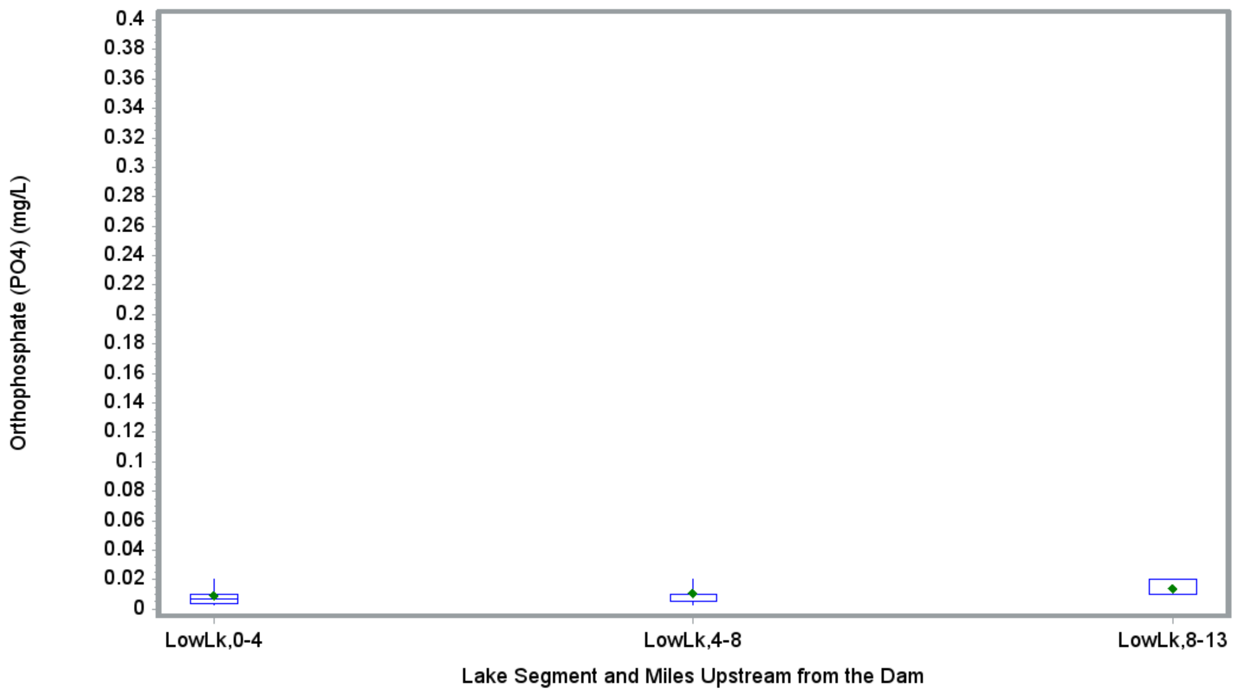



**Figure 3-180 Ortho-Phosphate Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-187 Ortho-Phosphate Lower Lake Samples Categorized by Miles Upstream from Dam (in mg-P/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LowLk,0-4 | 181 | 0.0020 | 0.0030 | 0.0040 | 0.0090 | 0.0070 | 0.0100 | 0.0200 | 0.1700 |
| LowLk,4-8 | 263 | 0.0030 | 0.0030 | 0.0050 | 0.0110 | 0.0100 | 0.0100 | 0.0200 | 0.1000 |
| LowLk,8-13 | 89 | 0.0100 | 0.0100 | 0.0100 | 0.0144 | 0.0100 | 0.0200 | 0.0200 | 0.0400 |

### *Orthophosphate-P Lower Lake Samples Categorized by Depth*

> By depth, highest mean and median concentrations were measured in the photic zone with lowest measurements recorded in the middle layer.

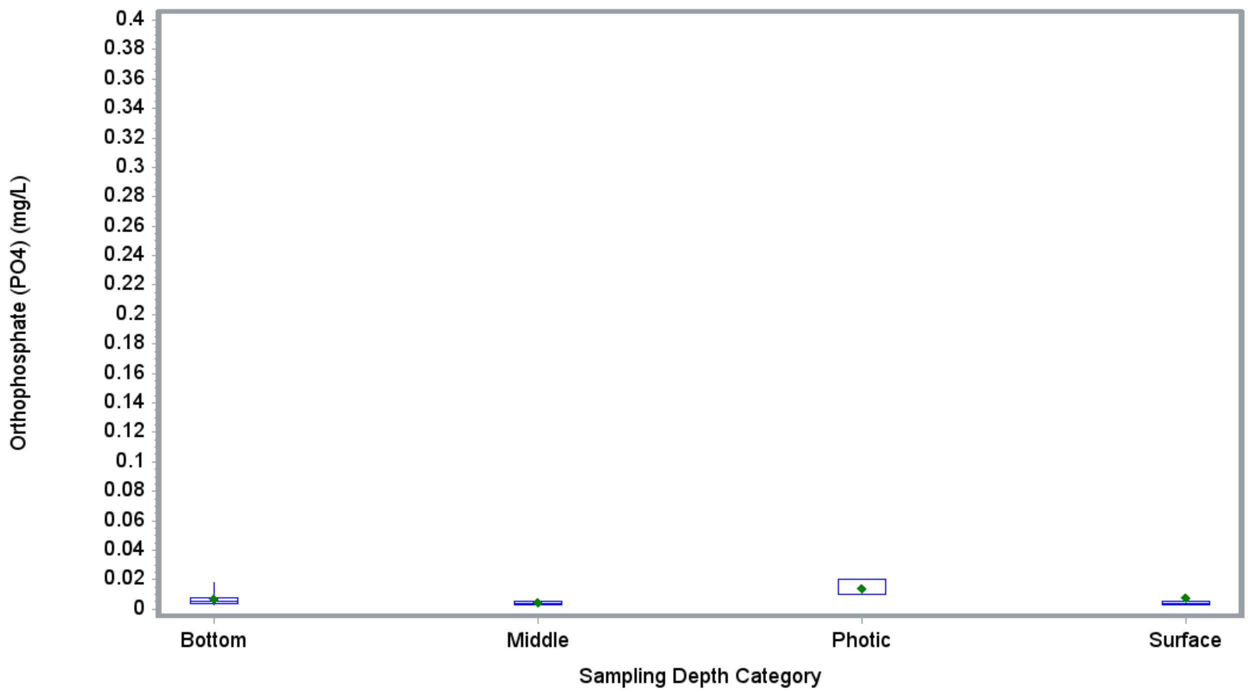



**Figure 3-181 Ortho-Phosphate Lower Lake Samples Categorized by Depth Category**

**Table 3-188 Ortho-Phosphate Lower Lake Samples Categorized by Depth Category (in mg-P/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 16 | 0.0030 | 0.0030 | 0.0035 | 0.0073 | 0.0050 | 0.0080 | 0.0180 | 0.0180 |
| Middle | 153 | 0.0020 | 0.0030 | 0.0030 | 0.0047 | 0.0040 | 0.0050 | 0.0070 | 0.0310 |
| Photic | 334 | 0.0100 | 0.0100 | 0.0100 | 0.0142 | 0.0100 | 0.0200 | 0.0200 | 0.1700 |
| Surface | 30 | 0.0030 | 0.0030 | 0.0030 | 0.0078 | 0.0040 | 0.0050 | 0.0100 | 0.1000 |

***Orthophosphate-P Lower Lake Categorized by Year***

- Orthophosphate was recorded in 2000 and from 2005 through 2011.
- By year, highest mean concentrations were recorded from 2005 through 2007.
- The lowest mean concentrations were recorded in 2008, 2011, and 2010 in increasing order.
- The lowest median concentration was in 2008.

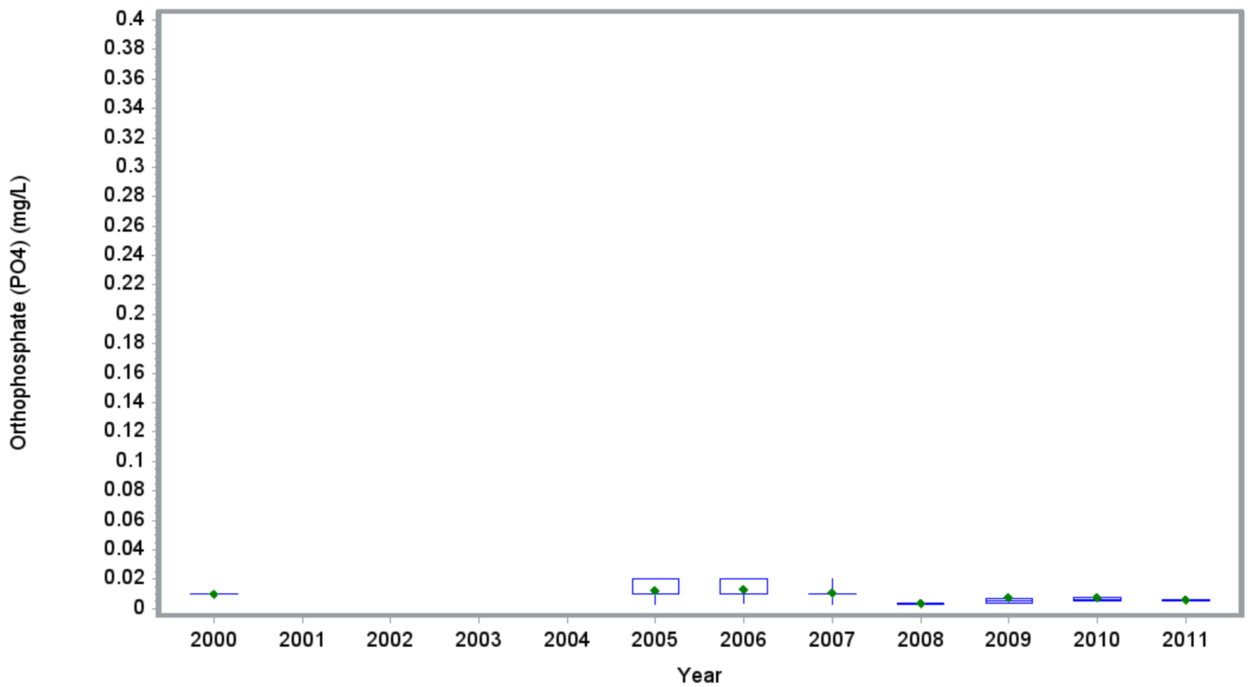



**Figure 3-182 Ortho-Phosphate Lower Lake Samples Categorized by Year**

**Table 3-189 Ortho-Phosphate Lower Lake Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 1 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 | 0.0100 |
| 2005 | 121 | 0.0030 | 0.0030 | 0.0100 | 0.0125 | 0.0100 | 0.0200 | 0.0200 | 0.0300 |
| 2006 | 156 | 0.0030 | 0.0040 | 0.0100 | 0.0133 | 0.0100 | 0.0200 | 0.0200 | 0.1700 |
| 2007 | 125 | 0.0030 | 0.0030 | 0.0100 | 0.0110 | 0.0100 | 0.0100 | 0.0200 | 0.0400 |
| 2008 | 36 | 0.0030 | 0.0030 | 0.0030 | 0.0036 | 0.0030 | 0.0040 | 0.0040 | 0.0080 |
| 2009 | 41 | 0.0040 | 0.0040 | 0.0040 | 0.0081 | 0.0050 | 0.0070 | 0.0100 | 0.1000 |
| 2010 | 36 | 0.0020 | 0.0050 | 0.0050 | 0.0073 | 0.0060 | 0.0080 | 0.0100 | 0.0310 |
| 2011 | 17 | 0.0040 | 0.0040 | 0.0050 | 0.0061 | 0.0050 | 0.0060 | 0.0080 | 0.0180 |

### *Orthophosphate-P Lower Lake Samples Categorized by Month*

> By month, there was little variability between mean and median concentrations.

> The highest mean concentrations were measured in January and March.

> The lowest mean concentrations were measured in October, and August in increasing order.

> Median values were similar for all months.

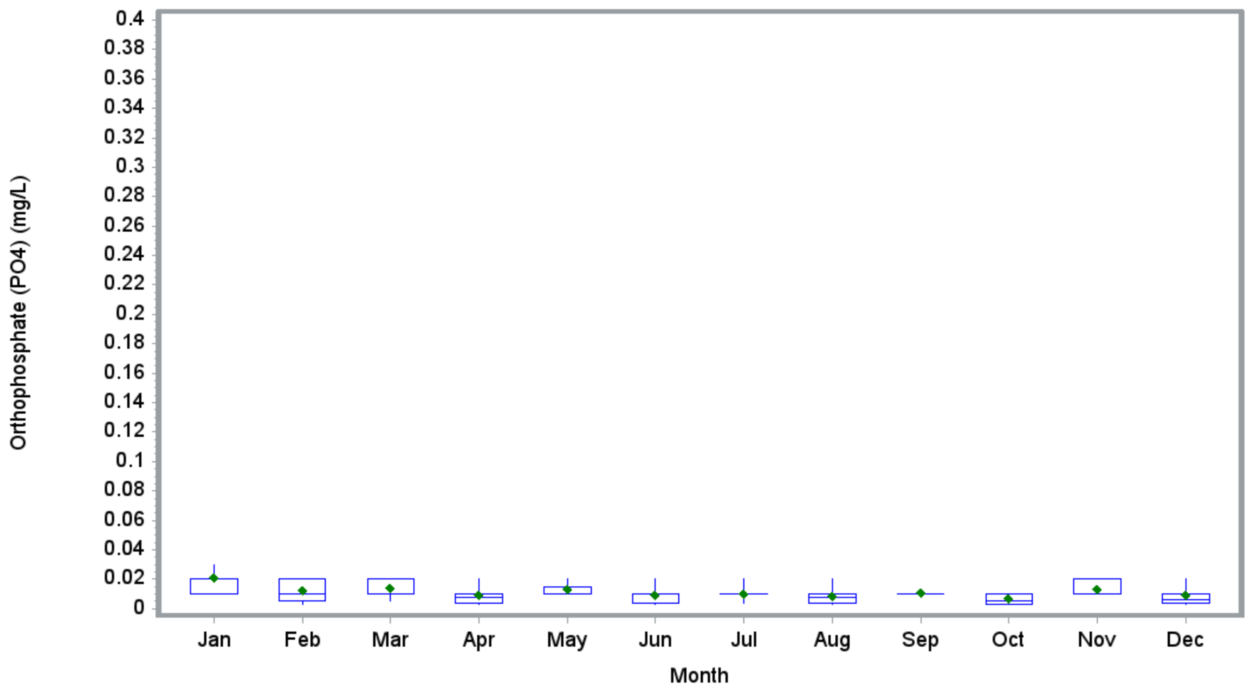



**Figure 3-183 Ortho-Phosphate Lower Lake Samples Categorized by Month**

**Table 3-190 Ortho-Phosphate Lower Lake Samples Categorized by Month (in mg-P/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 27 | 0.0100 | 0.0100 | 0.0100 | 0.0211 | 0.0100 | 0.0200 | 0.0300 | 0.1700 |
| Feb | 46 | 0.0030 | 0.0030 | 0.0050 | 0.0122 | 0.0100 | 0.0200 | 0.0200 | 0.0400 |
| Mar | 51 | 0.0050 | 0.0050 | 0.0100 | 0.0143 | 0.0100 | 0.0200 | 0.0200 | 0.0400 |
| Apr | 67 | 0.0030 | 0.0030 | 0.0040 | 0.0096 | 0.0080 | 0.0100 | 0.0200 | 0.1000 |
| May | 32 | 0.0100 | 0.0100 | 0.0100 | 0.0131 | 0.0100 | 0.0150 | 0.0200 | 0.0300 |
| Jun | 59 | 0.0030 | 0.0030 | 0.0040 | 0.0091 | 0.0100 | 0.0100 | 0.0200 | 0.0200 |
| Jul | 35 | 0.0030 | 0.0040 | 0.0100 | 0.0103 | 0.0100 | 0.0100 | 0.0200 | 0.0200 |
| Aug | 73 | 0.0030 | 0.0030 | 0.0040 | 0.0088 | 0.0080 | 0.0100 | 0.0200 | 0.0310 |
| Sep | 23 | 0.0100 | 0.0100 | 0.0100 | 0.0109 | 0.0100 | 0.0100 | 0.0100 | 0.0200 |
| Oct | 57 | 0.0020 | 0.0030 | 0.0030 | 0.0071 | 0.0050 | 0.0100 | 0.0100 | 0.0200 |
| Nov | 22 | 0.0100 | 0.0100 | 0.0100 | 0.0132 | 0.0100 | 0.0200 | 0.0200 | 0.0300 |
| Dec | 41 | 0.0030 | 0.0030 | 0.0040 | 0.0096 | 0.0060 | 0.0100 | 0.0200 | 0.0400 |

***Orthophosphate-P Lower Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean concentrations were recorded by Wake County, however this category was represented by a small sample size (n=5) relative to the other categories.

> Lowest concentrations were recorded by USGS.

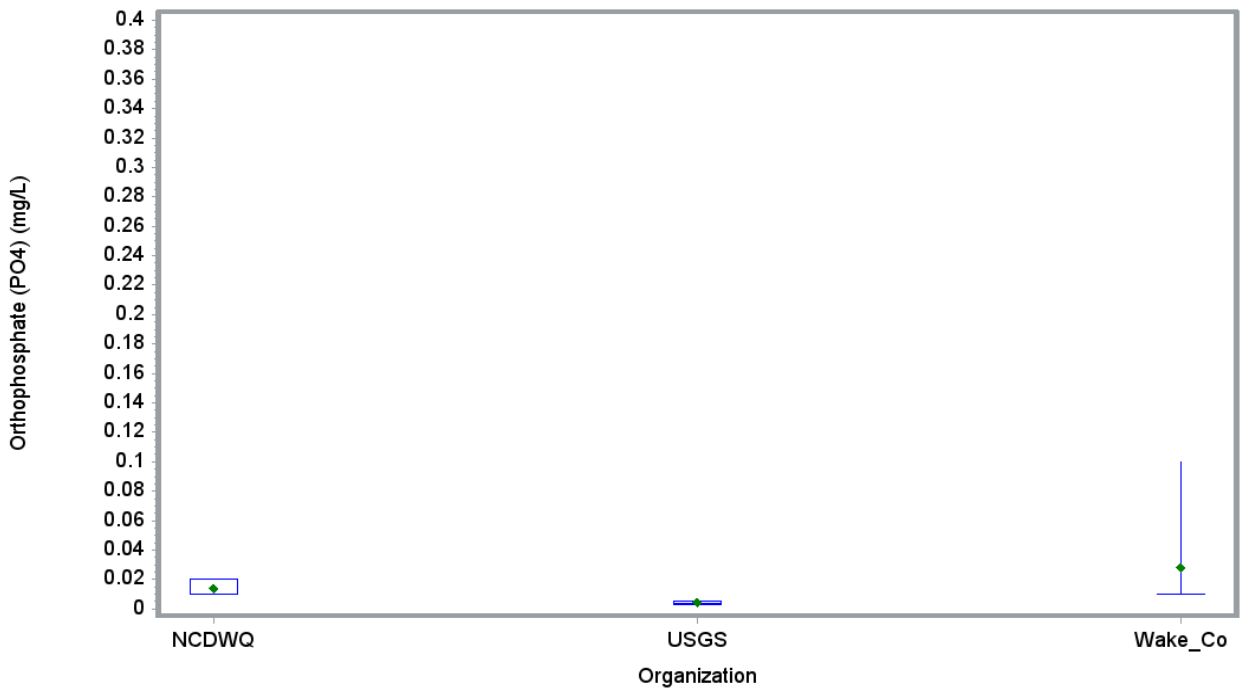



**Figure 3-184 Ortho-Phosphate Lower Lake Samples Categorized by Sampling Organization**

**Table 3-191 Ortho-Phosphate Lower Lake Samples Categorized by Sampling Organization (in mg-P/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| NCDWQ | 334 | 0.0100 | 0.0100 | 0.0100 | 0.0142 | 0.0100 | 0.0200 | 0.0200 | 0.1700 |
| USGS | 194 | 0.0020 | 0.0030 | 0.0030 | 0.0048 | 0.0040 | 0.0050 | 0.0070 | 0.0310 |
| Wake_Co | 5 | 0.0100 | 0.0100 | 0.0100 | 0.0280 | 0.0100 | 0.0100 | 0.1000 | 0.1000 |

### *Orthophosphate-P Lower Lake Samples Categorized by Method*

> By method, the highest mean concentrations were recorded using the unknown method, however this category was represented by a small sample size (n=5) compared to the other categories.

> The lowest mean and median concentrations were recorded using the ’Various’ methods.

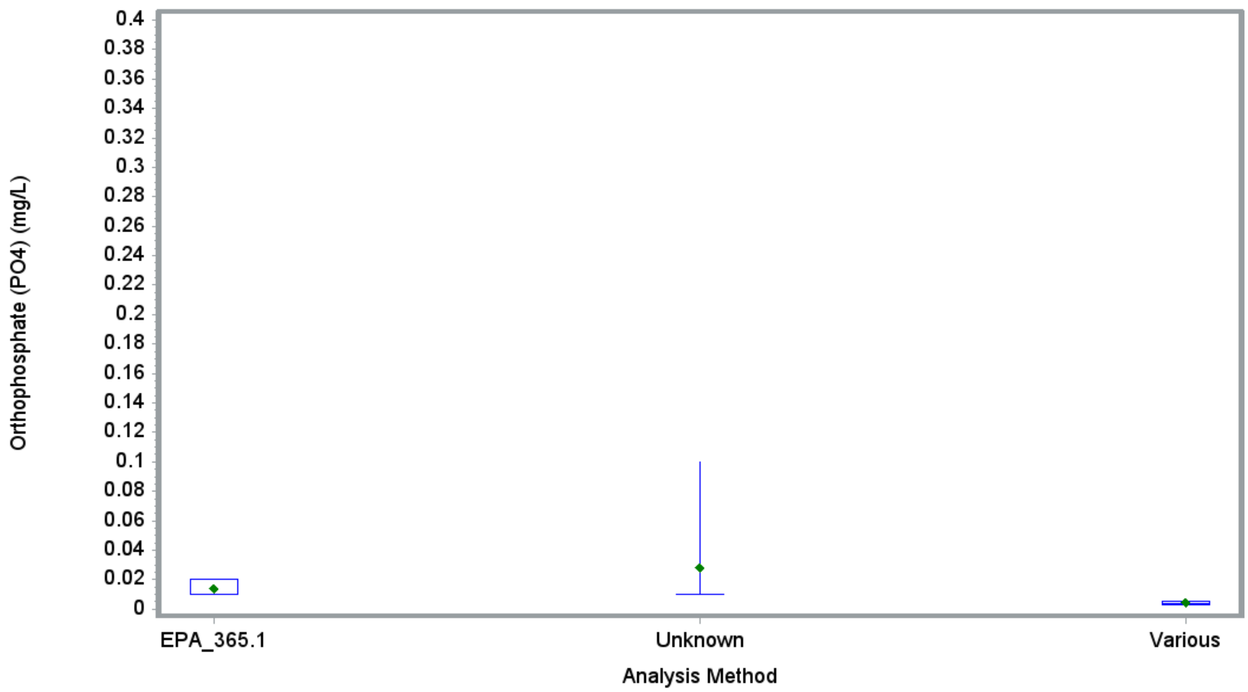



**Figure 3-185 Ortho-Phosphate Lower Lake Samples Categorized by Analysis Method**

**Table 3-192 Ortho-Phosphate Lower Lake Samples Categorized by Analysis Method (in mg-P/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_365.1 | 334 | 0.0100 | 0.0100 | 0.0100 | 0.0142 | 0.0100 | 0.0200 | 0.0200 | 0.1700 |
| Unknown | 5 | 0.0100 | 0.0100 | 0.0100 | 0.0280 | 0.0100 | 0.0100 | 0.1000 | 0.1000 |
| Various | 194 | 0.0020 | 0.0030 | 0.0030 | 0.0048 | 0.0040 | 0.0050 | 0.0070 | 0.0310 |

***Orthophosphate-P Comparing Different Methods for Handling Data Reported as Below the Detection Limit***

> There is little difference in the median when using full detection limit, half detection limit, or zero values to estimate values for below detection limit data.

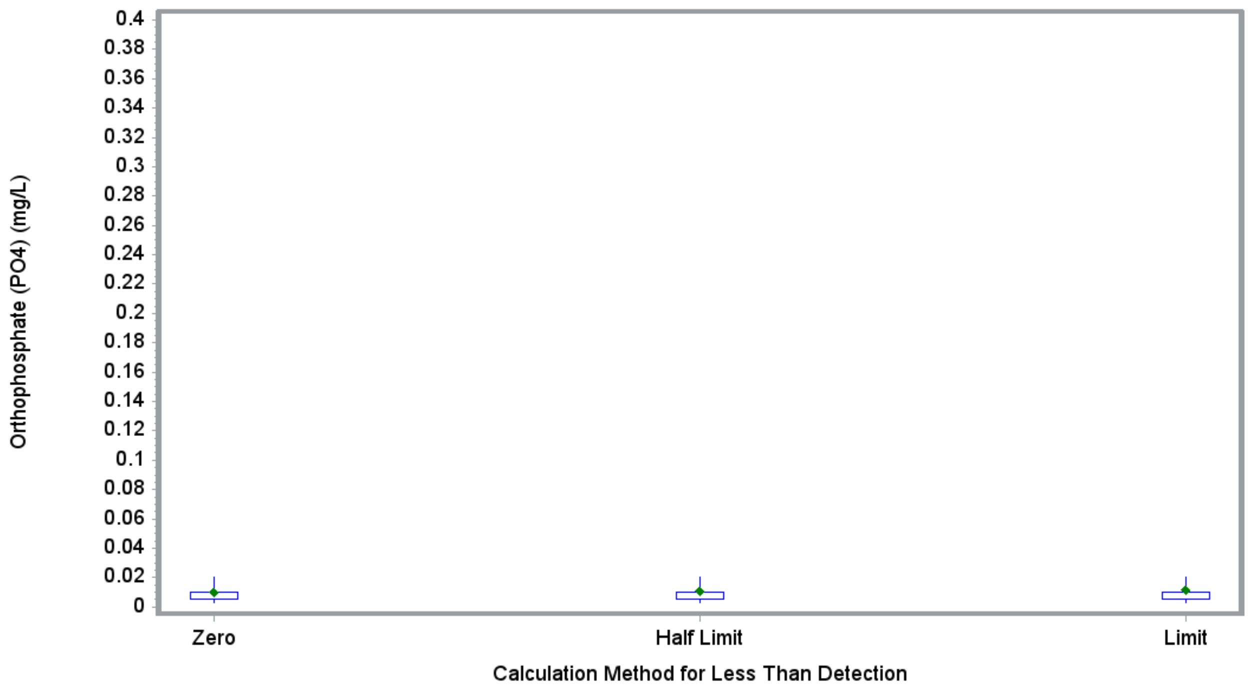



**Figure 3-186 Ortho-Phosphate Lower Lake Samples Categorized by Limit Calculation**

## 3.16 Total Phosphorus

Six organizations measured total phosphorus as part of the water quality sampling effort. Total phosphorus was analyzed in the laboratory. For those organizations that provided analysis method, the following were used:

> Phosphorus, all forms, colorimetric, automated, ascorbic acid (EPA 365.1)

> Phosphorus, all forms, colorimetric, ascorbic acid, two reagent (EPA 365.3)

> Phosphorus, total, colorimetric, automated, block digester (EPA 365.4)

> Total phosphorus in unfiltered water by microkjeldahl digestion, and ASF dialysis and colorimetry (USGS I-4610-91)

> Nutrients, unfiltered water, acidified, alkaline-persulfate digestion, continuous flow colorimetry (USGS I-4650-03)

> Total phosphorous in seawater and fresh water (CAAE 310)

Appendix E provides detailed descriptions of these methods.

Table 3-193 describes the organizations and analysis methods used to measure total phosphorus, and includes the number of samples, date range, and limits. The majority of the total phosphorus data have been collected by NCDWQ using method EPA_365.1, the City of Durham using EPA_365.3, and USGS using multiple methods. Total phosphorus is presented in mg-P/L and to three decimal places based on reported data.

**Table 3-193 Summary of Analysis Methods for the Total Phosphorus Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg-P/L) | Reporting Limit (mg-P/L) | Practical Quanti-fication Limit (mg-P/L) | Range of Limit Specified with Results (mg-P/L) |
|---|---|---|---|---|---|---|---|---|
| CAAE | CAAE_310 | 07/24/2007 | 12/17/2010 | 68 | Not Provided | Not Provided | Not Provided | Not Provided |
| Durham_Ci | EPA_365.3 | 04/01/2002 | 04/19/2012 | 1,251 | Not Provided | 0.05 | 0.05 | 0.03 to 0.06 |
| NCDWQ[1] | EPA_365.1 | 01/11/1999 | 12/06/2011 | 1,685 | 0.02 | 0.01 | Not Provided | 0.01 to 5.4 |
| Orange_Co | EPA_365.4 | 04/09/2010 | 03/25/2011 | 181 | Not Provided | Not Provided | 0.05 | 0.05 |
| USGS | Various | 01/15/1999 | 10/14/2011 | 992 | Not Provided | 0.004 | Not Provided | 0.004 |
| Wake_Co | Not Provided | 07/29/2008 | 10/14/2009 | 131 | Not Provided | Not Provided | 0.01 | 0.01 |

[1]Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

### 3.16.2 Tributary Samples

Five organizations measured total phosphorus concentrations in Falls Lake tributaries from 1999 to 2011. Highest mean concentrations were recorded by NCDWQ. Lowest mean and median concentrations were recorded by Orange County. Highest mean and median concentrations were recorded in Knap of Reeds Creek and lowest mean concentrations were recorded in Horse/New Light Creek and Flat River. Highest mean concentrations were recorded from 2005 to 2007. Lowest mean concentrations were recorded in 2002. Box plot summaries are provided below.

***Total Phosphorus Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Total phosphorus was recorded in nine catchments: Beaverdam Creek, Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, Little River, Horse/New Light Creek and Honeycutt/Barton Creek.

> Highest median and median concentrations were recorded in Knap of Reeds Creek and these samples were collected in the 0 to 2 mile segment upstream of the mouth.

> Lowest mean concentrations were recorded in Horse/New Light Creek (0 to 2 miles from the mouth).

> Beaverdam Creek and Lick Creek had higher concentrations in the 2 to 10 mile segments compared with the 0 to 2 mile segments.

> Littler River and Ellerbe Creek had lower concentrations in the 2 to 10 mile segments compared with the 0 to 2 mile segments.

> Mean concentrations were similar for all sections of Flat River and Eno River.

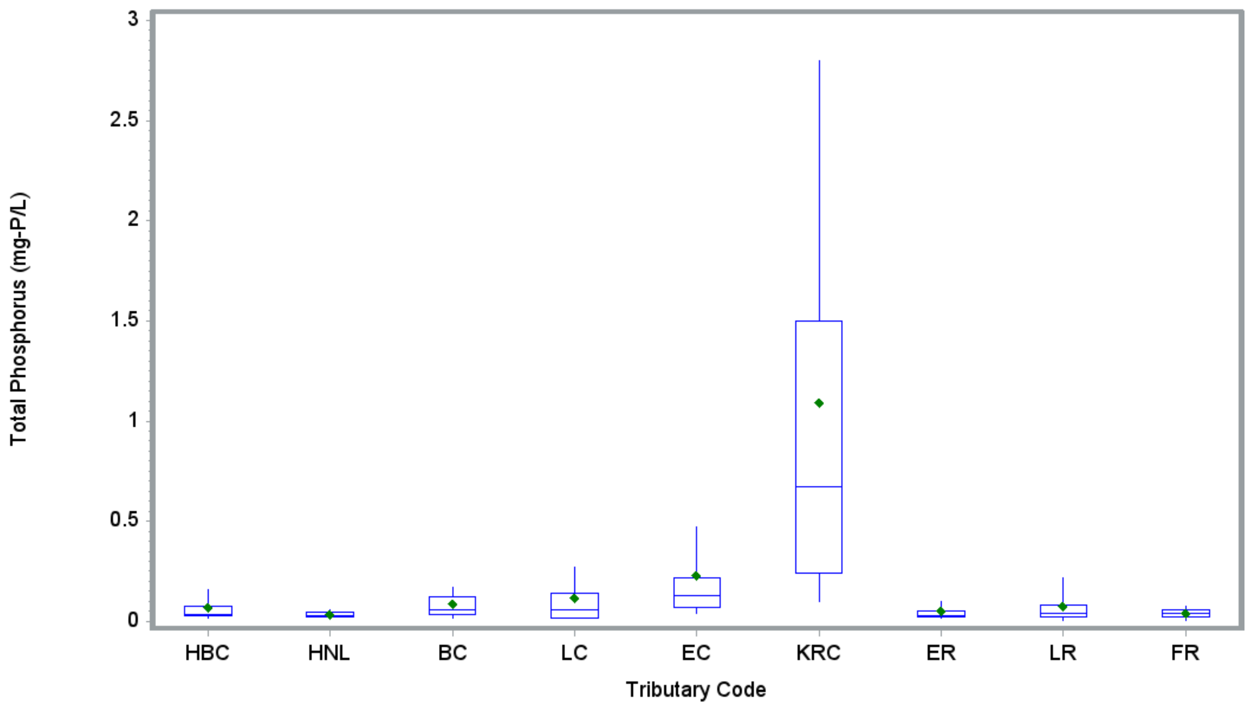



**Figure 3-187 Total Phosphorus Tributary Samples Categorized by Subwatershed**

**Table 3-194 Total Phosphorus Tributary Samples Categorized by Subwatershed (in mg-P/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC | 76 | 0.009 | 0.019 | 0.027 | 0.071 | 0.036 | 0.075 | 0.159 | 0.537 |
| HNL | 41 | 0.013 | 0.019 | 0.024 | 0.036 | 0.029 | 0.044 | 0.055 | 0.122 |
| BC | 45 | 0.010 | 0.018 | 0.034 | 0.088 | 0.060 | 0.120 | 0.170 | 0.430 |
| LC | 121 | 0.015 | 0.015 | 0.015 | 0.120 | 0.060 | 0.140 | 0.271 | 1.400 |
| EC | 709 | 0.015 | 0.040 | 0.070 | 0.231 | 0.130 | 0.220 | 0.470 | 11.400 |
| KRC | 147 | 0.020 | 0.100 | 0.240 | 1.089 | 0.670 | 1.500 | 2.800 | 5.400 |
| ER | 625 | 0.002 | 0.015 | 0.025 | 0.051 | 0.030 | 0.050 | 0.100 | 2.200 |
| LR | 507 | 0.002 | 0.002 | 0.023 | 0.078 | 0.040 | 0.080 | 0.215 | 0.665 |
| FR | 302 | 0.002 | 0.002 | 0.020 | 0.043 | 0.040 | 0.060 | 0.075 | 0.270 |

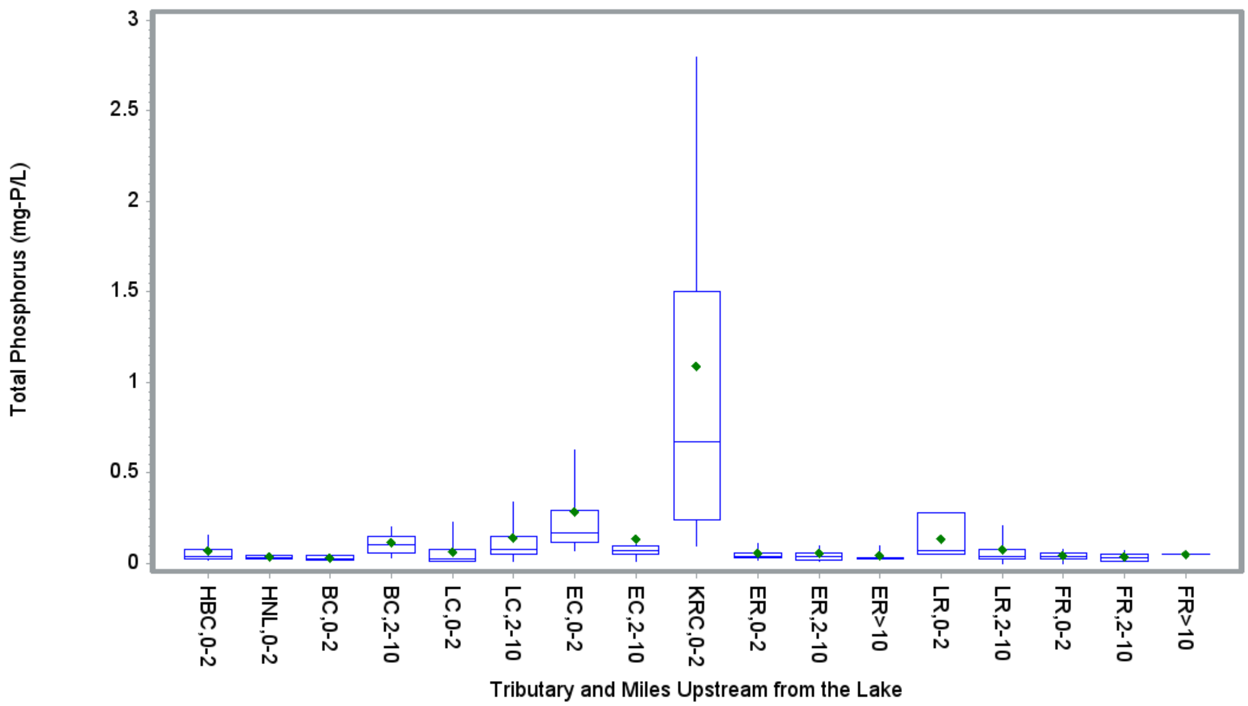



**Figure 3-188 Total Phosphorus Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-195 Total Phosphorus Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in mg-P/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| HBC,0-2 | 76 | 0.009 | 0.019 | 0.027 | 0.071 | 0.036 | 0.075 | 0.159 | 0.537 |
| HNL,0-2 | 41 | 0.013 | 0.019 | 0.024 | 0.036 | 0.029 | 0.044 | 0.055 | 0.122 |
| BC,0-2 | 15 | 0.013 | 0.013 | 0.018 | 0.034 | 0.028 | 0.045 | 0.054 | 0.086 |
| BC,2-10 | 30 | 0.010 | 0.030 | 0.055 | 0.115 | 0.105 | 0.150 | 0.200 | 0.430 |
| LC,0-2 | 36 | 0.015 | 0.015 | 0.015 | 0.066 | 0.028 | 0.080 | 0.230 | 0.271 |
| LC,2-10 | 85 | 0.015 | 0.015 | 0.050 | 0.143 | 0.078 | 0.150 | 0.340 | 1.400 |
| EC,0-2 | 444 | 0.015 | 0.070 | 0.120 | 0.289 | 0.170 | 0.295 | 0.630 | 4.500 |
| EC,2-10 | 265 | 0.015 | 0.015 | 0.050 | 0.134 | 0.070 | 0.100 | 0.150 | 11.400 |
| KRC,0-2 | 147 | 0.020 | 0.100 | 0.240 | 1.089 | 0.670 | 1.500 | 2.800 | 5.400 |
| ER,0-2 | 118 | 0.010 | 0.020 | 0.030 | 0.058 | 0.040 | 0.060 | 0.110 | 0.610 |
| ER,2-10 | 237 | 0.010 | 0.015 | 0.020 | 0.057 | 0.039 | 0.056 | 0.100 | 2.200 |
| ER>10 | 270 | 0.002 | 0.021 | 0.025 | 0.042 | 0.025 | 0.030 | 0.095 | 0.340 |
| LR,0-2 | 3 | 0.054 | 0.054 | 0.054 | 0.136 | 0.073 | 0.281 | 0.281 | 0.281 |
| LR,2-10 | 504 | 0.002 | 0.002 | 0.023 | 0.078 | 0.040 | 0.080 | 0.210 | 0.665 |
| FR,0-2 | 248 | 0.002 | 0.002 | 0.023 | 0.044 | 0.040 | 0.060 | 0.080 | 0.233 |
| FR,2-10 | 53 | 0.010 | 0.015 | 0.015 | 0.038 | 0.029 | 0.050 | 0.070 | 0.270 |

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| FR>10 | 1 | 0.054 | 0.054 | 0.054 | 0.054 | 0.054 | 0.054 | 0.054 | 0.054 |

***Total Phosphorus Tributary Samples Categorized by Depth***

> All samples were collected in the surface layer.

***Total Phosphorus Tributary Categorized by Year***

> The highest mean concentrations were recorded in 2007, 2006 and 2005 (in decreasing order).

> The lowest mean concentrations were recorded in 2002 and 2003.

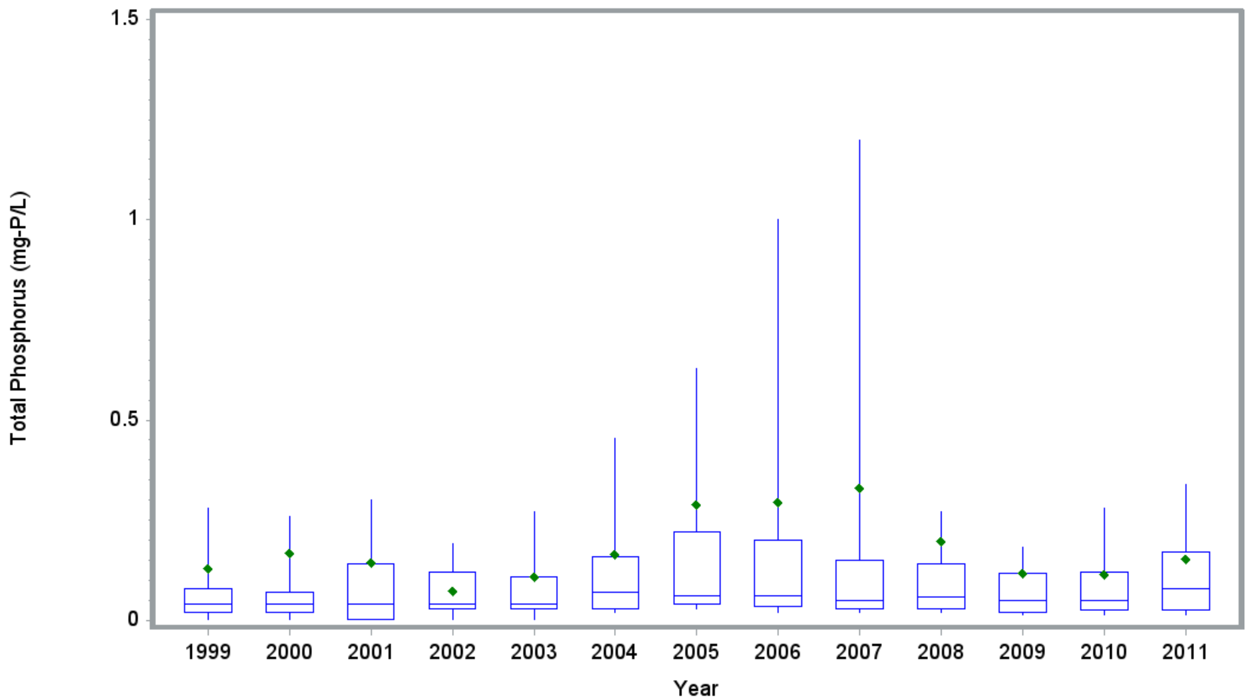



**Figure 3-189 Total Phosphorus Tributary Samples Categorized by Year**

**Table 3-196 Total Phosphorus Tributary Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 135 | 0.002 | 0.002 | 0.020 | 0.131 | 0.040 | 0.080 | 0.280 | 2.100 |
| 2000 | 138 | 0.002 | 0.002 | 0.020 | 0.167 | 0.040 | 0.070 | 0.260 | 3.900 |
| 2001 | 63 | 0.002 | 0.002 | 0.002 | 0.143 | 0.040 | 0.140 | 0.300 | 1.500 |
| 2002 | 39 | 0.002 | 0.002 | 0.030 | 0.073 | 0.040 | 0.120 | 0.190 | 0.290 |
| 2003 | 85 | 0.002 | 0.002 | 0.030 | 0.108 | 0.040 | 0.110 | 0.270 | 1.500 |
| 2004 | 90 | 0.002 | 0.020 | 0.030 | 0.166 | 0.070 | 0.160 | 0.455 | 1.500 |
| 2005 | 164 | 0.002 | 0.030 | 0.040 | 0.290 | 0.060 | 0.220 | 0.630 | 4.500 |
| 2006 | 193 | 0.002 | 0.020 | 0.036 | 0.296 | 0.060 | 0.200 | 1.000 | 3.600 |

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2007 | 141 | 0.002 | 0.020 | 0.030 | 0.331 | 0.050 | 0.150 | 1.200 | 5.400 |
| 2008 | 226 | 0.010 | 0.020 | 0.030 | 0.197 | 0.059 | 0.140 | 0.270 | 5.400 |
| 2009 | 450 | 0.009 | 0.015 | 0.020 | 0.117 | 0.050 | 0.117 | 0.183 | 11.400 |
| 2010 | 535 | 0.006 | 0.015 | 0.025 | 0.113 | 0.050 | 0.120 | 0.280 | 1.400 |
| 2011 | 314 | 0.012 | 0.015 | 0.025 | 0.152 | 0.080 | 0.170 | 0.340 | 2.200 |

### *Total Phosphorus Tributary Samples Categorized by Month*

> By month, the highest mean and median concentrations were measured in June through September.

> The lowest mean concentrations were measured in April and December (in increasing order).

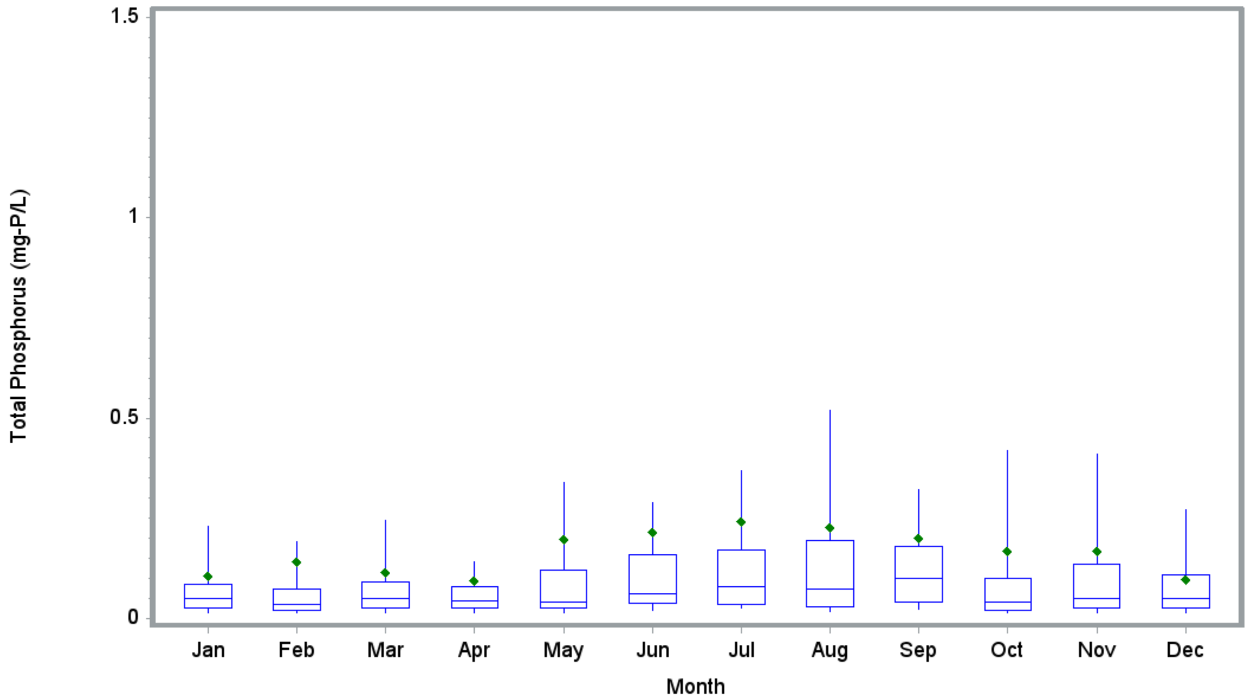



**Figure 3-190 Total Phosphorus Tributary Samples Categorized by Month**

**Table 3-197 Total Phosphorus Tributary Samples Categorized by Month (in mg-P/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 184 | 0.002 | 0.015 | 0.025 | 0.105 | 0.050 | 0.085 | 0.230 | 1.300 |
| Feb | 200 | 0.002 | 0.015 | 0.020 | 0.143 | 0.036 | 0.074 | 0.190 | 200 |
| Mar | 190 | 0.002 | 0.015 | 0.025 | 0.115 | 0.050 | 0.090 | 0.245 | 190 |
| Apr | 218 | 0.002 | 0.015 | 0.025 | 0.095 | 0.045 | 0.080 | 0.140 | 218 |
| May | 188 | 0.002 | 0.015 | 0.025 | 0.197 | 0.040 | 0.120 | 0.340 | 188 |
| Jun | 264 | 0.002 | 0.020 | 0.039 | 0.215 | 0.061 | 0.160 | 0.290 | 264 |
| Jul | 263 | 0.002 | 0.025 | 0.034 | 0.240 | 0.080 | 0.170 | 0.370 | 263 |

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Aug | 236 | 0.002 | 0.018 | 0.030 | 0.225 | 0.073 | 0.195 | 0.520 | 236 |
| Sep | 244 | 0.002 | 0.024 | 0.040 | 0.202 | 0.100 | 0.180 | 0.320 | 244 |
| Oct | 205 | 0.002 | 0.015 | 0.020 | 0.167 | 0.040 | 0.100 | 0.420 | 205 |
| Nov | 180 | 0.002 | 0.015 | 0.025 | 0.167 | 0.050 | 0.135 | 0.409 | 180 |
| Dec | 201 | 0.002 | 0.015 | 0.025 | 0.098 | 0.050 | 0.110 | 0.270 | 201 |

***Total Phosphorus Tributary Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean concentrations were recorded by NCDWQ and highest median concentrations were recorded by City of Durham.

> The lowest mean and median concentrations were recorded by Orange County.

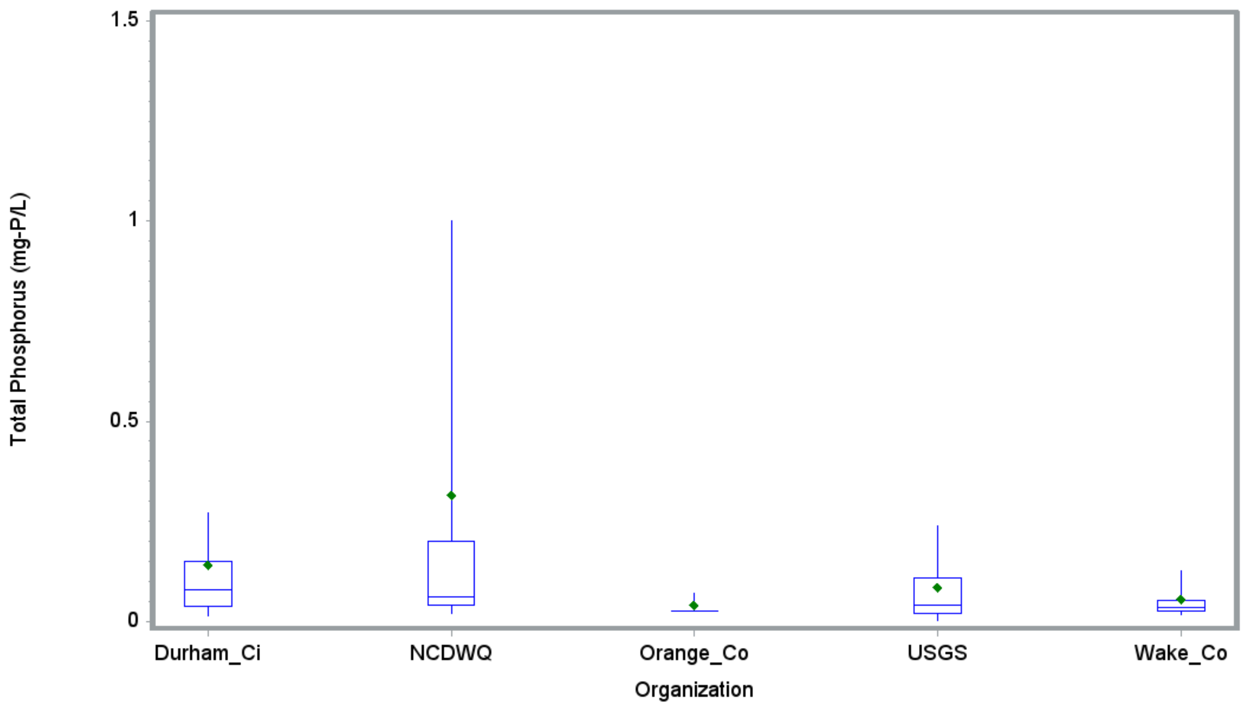



**Figure 3-191 Total Phosphorus Tributary Samples Categorized by Sampling Organization**

**Table 3-198 Total Phosphorus Tributary Samples Categorized by Sampling Organization (in mg-P/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 877 | 0.015 | 0.015 | 0.039 | 0.142 | 0.080 | 0.150 | 0.270 | 11.400 |
| NCDWQ | 769 | 0.010 | 0.020 | 0.040 | 0.315 | 0.060 | 0.200 | 1.000 | 5.400 |
| Orange_Co | 181 | 0.025 | 0.025 | 0.025 | 0.042 | 0.025 | 0.025 | 0.070 | 0.340 |
| USGS | 615 | 0.002 | 0.002 | 0.020 | 0.086 | 0.040 | 0.110 | 0.239 | 0.665 |
| Wake_Co | 131 | 0.009 | 0.018 | 0.025 | 0.055 | 0.034 | 0.054 | 0.125 | 0.537 |

***Total Phosphorus Tributary Samples Categorized by Method***

> The highest mean concentrations were measured using the EPA 365.1 method and highest median concentrations were recorded using the EPA 365.3 method.

> The lowest mean and median concentrations were measured using the EPA 365.4 method.

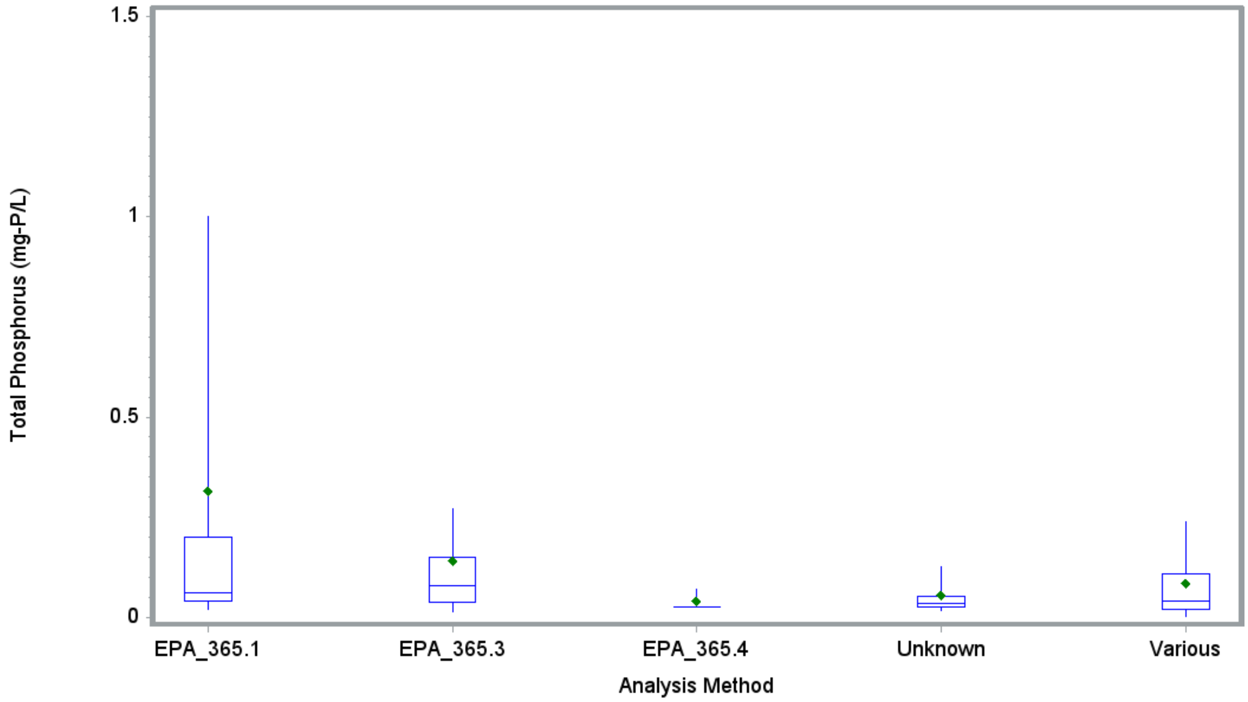



**Figure 3-192 Total Phosphorus Tributary Samples Categorized by Analysis Method**

**Table 3-199 Total Phosphorus Tributary Samples Categorized by Analysis Method (in mg-P/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_365.1 | 769 | 0.010 | 0.020 | 0.040 | 0.315 | 0.060 | 0.200 | 1.000 | 5.400 |
| EPA_365.3 | 877 | 0.015 | 0.015 | 0.039 | 0.142 | 0.080 | 0.150 | 0.270 | 11.400 |
| EPA_365.4 | 181 | 0.025 | 0.025 | 0.025 | 0.042 | 0.025 | 0.025 | 0.070 | 0.340 |
| Unknown | 131 | 0.009 | 0.018 | 0.025 | 0.055 | 0.034 | 0.054 | 0.125 | 0.537 |
| Various | 615 | 0.002 | 0.002 | 0.020 | 0.086 | 0.040 | 0.110 | 0.239 | 0.665 |

### 3.16.3 Upper Lake Samples

Three organizations measured total phosphorus concentrations in upper Falls Lake from 2000 to present. Highest mean and median concentrations were recorded by City of Durham, and lowest mean concentrations were recorded by NCDWQ and USGS. Highest mean and median concentrations were recorded in the > 21 mile section upstream of the dam and lowest mean and median concentrations were measured in the 13 to 18 miles section. Highest mean concentrations were recorded in 2002, while the lowest mean concentrations were recorded in 2000 and 2001. Box plot summaries are provided below.

***Total Phosphorus Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean and median concentrations were measured > 21 miles upstream of the dam.

> Lowest mean and median concentrations were measured 13 to 18 miles upstream of the dam.

> From minimum to maximum statistical categories, the trend was increasing concentration with increasing distance from the dam.

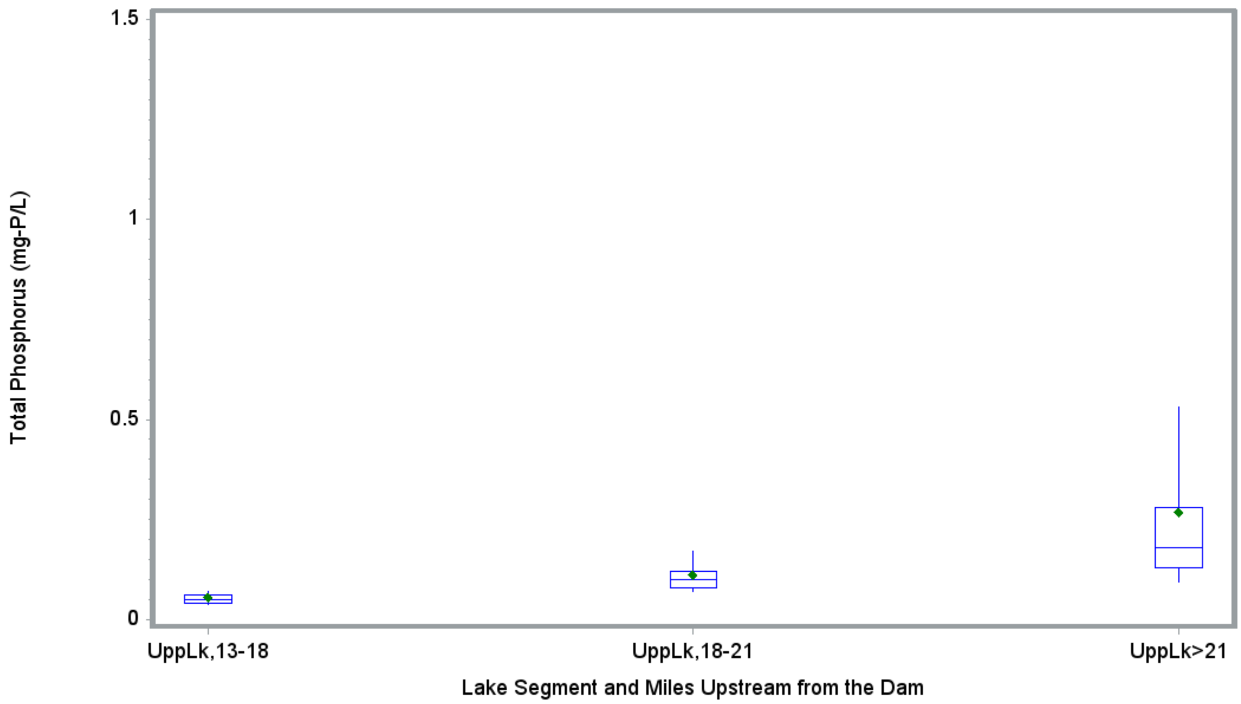



**Figure 3-193 Total Phosphorus Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-200 Total Phosphorus Upper Lake Samples Categorized by Miles Upstream from Dam (in mg-P/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 398 | 0.010 | 0.039 | 0.040 | 0.054 | 0.050 | 0.060 | 0.070 | 0.190 |
| UppLk,18-21 | 89 | 0.010 | 0.070 | 0.080 | 0.113 | 0.100 | 0.120 | 0.170 | 0.560 |
| UppLk>21 | 621 | 0.010 | 0.093 | 0.130 | 0.267 | 0.180 | 0.280 | 0.530 | 3.450 |

***Total Phosphorus Upper Lake Samples Categorized by Depth***

> By depth, highest mean and median concentrations were measured in the surface layer.

> Mean and median concentrations were similar for the remaining layers.

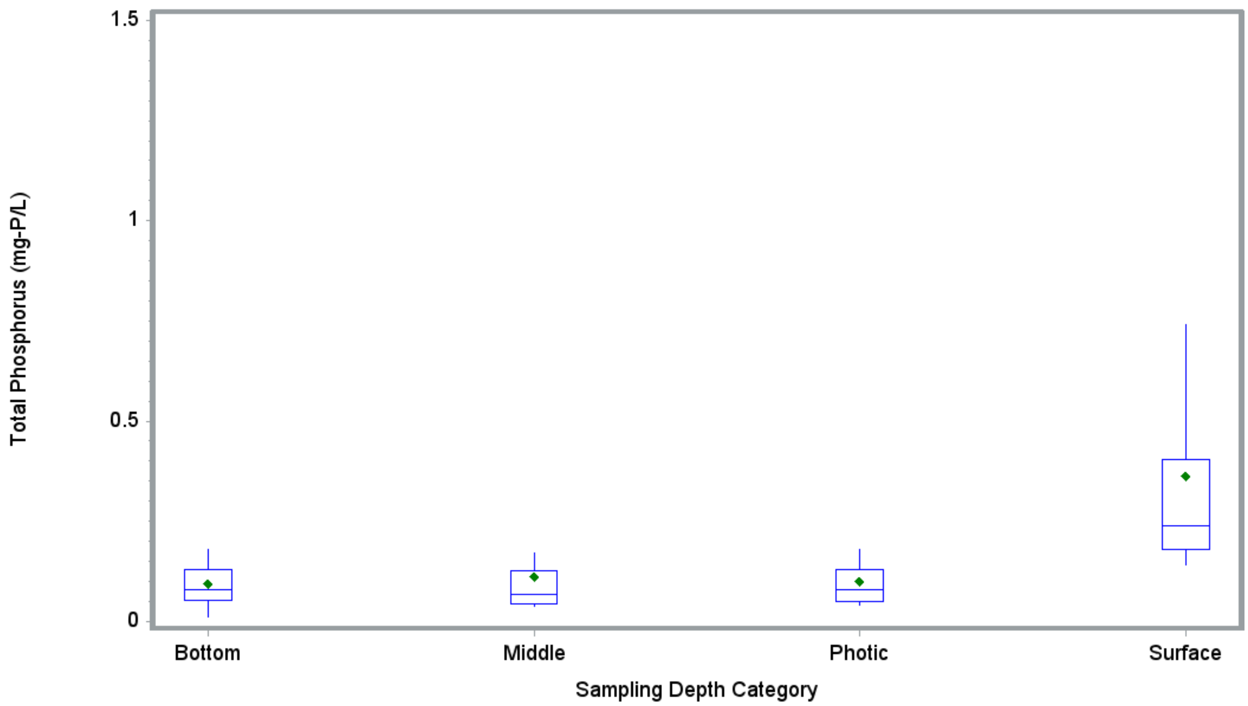



**Figure 3-194 Total Phosphorus Upper Lake Samples Categorized by Depth Category**

**Table 3-201 Total Phosphorus Upper Lake Samples Categorized by Depth Category (in mg-P/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 27 | 0.010 | 0.010 | 0.054 | 0.093 | 0.080 | 0.130 | 0.180 | 0.240 |
| Middle | 160 | 0.025 | 0.038 | 0.043 | 0.110 | 0.068 | 0.127 | 0.170 | 0.790 |
| Photic | 601 | 0.010 | 0.040 | 0.050 | 0.101 | 0.080 | 0.130 | 0.180 | 1.200 |
| Surface | 320 | 0.034 | 0.140 | 0.180 | 0.364 | 0.240 | 0.405 | 0.740 | 3.450 |

### *Total Phosphorus Upper Lake Categorized by Year*

> By year, highest mean and median concentrations were recorded in 2002, followed by 2003 and 2004 in decreasing order.

> The lowest mean and median concentrations were recorded in 2000, followed by 2001, and 2006 in increasing order.

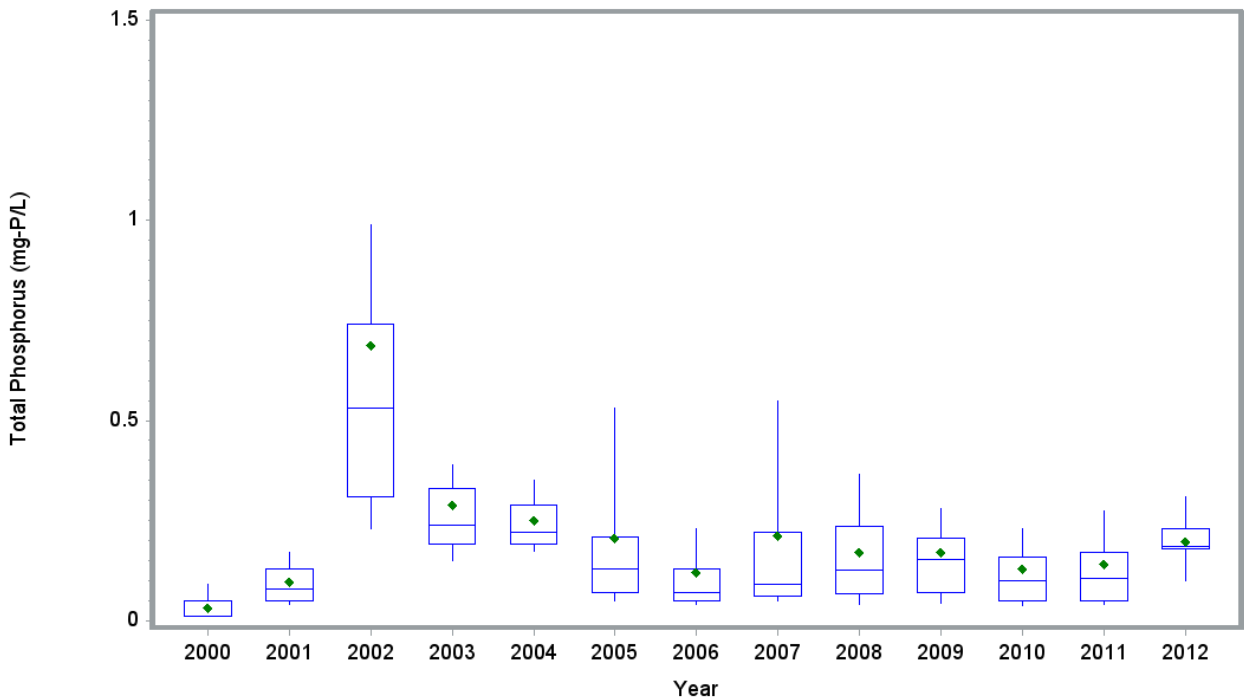



**Figure 3-195 Total Phosphorus Upper Lake Samples Categorized by Year**

**Table 3-202 Total Phosphorus Upper Lake Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 16 | 0.010 | 0.010 | 0.010 | 0.033 | 0.010 | 0.050 | 0.090 | 0.110 |
| 2001 | 35 | 0.030 | 0.040 | 0.050 | 0.096 | 0.080 | 0.130 | 0.170 | 0.240 |
| 2002 | 31 | 0.170 | 0.230 | 0.310 | 0.689 | 0.530 | 0.740 | 0.990 | 3.450 |
| 2003 | 26 | 0.120 | 0.150 | 0.190 | 0.290 | 0.240 | 0.330 | 0.390 | 1.310 |
| 2004 | 30 | 0.130 | 0.175 | 0.190 | 0.249 | 0.220 | 0.290 | 0.350 | 0.690 |
| 2005 | 139 | 0.034 | 0.050 | 0.070 | 0.208 | 0.130 | 0.210 | 0.530 | 1.820 |
| 2006 | 206 | 0.034 | 0.041 | 0.050 | 0.120 | 0.070 | 0.130 | 0.230 | 1.370 |
| 2007 | 182 | 0.020 | 0.050 | 0.060 | 0.211 | 0.090 | 0.220 | 0.550 | 1.600 |
| 2008 | 60 | 0.037 | 0.042 | 0.068 | 0.170 | 0.126 | 0.235 | 0.365 | 0.800 |
| 2009 | 68 | 0.039 | 0.044 | 0.070 | 0.172 | 0.153 | 0.205 | 0.280 | 0.980 |
| 2010 | 149 | 0.030 | 0.039 | 0.050 | 0.130 | 0.100 | 0.160 | 0.230 | 1.290 |
| 2011 | 160 | 0.025 | 0.040 | 0.050 | 0.142 | 0.105 | 0.170 | 0.275 | 1.340 |
| 2012 | 6 | 0.100 | 0.100 | 0.180 | 0.198 | 0.185 | 0.230 | 0.310 | 0.310 |

### *Total Phosphorus Upper Lake Samples Categorized by Month*

> By month, the highest mean concentrations were measured in October, July and September (in decreasing order) while highest median concentrations were measures in September and October.

> The lowest mean and median concentrations were from December to March.

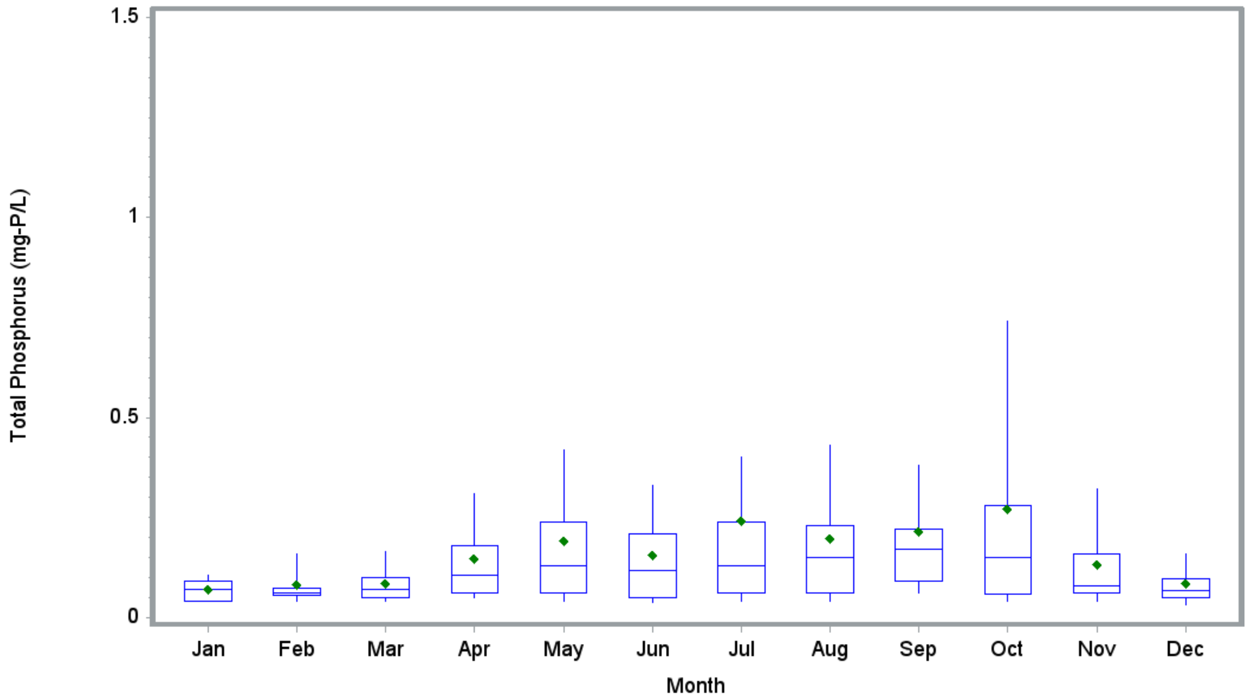



**Figure 3-196 Total Phosphorus Upper Lake Samples Categorized by Month**

**Table 3-203 Total Phosphorus Upper Lake Samples Categorized by Month (in mg-P/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 30 | 0.020 | 0.040 | 0.040 | 0.071 | 0.070 | 0.090 | 0.105 | 0.160 |
| Feb | 49 | 0.040 | 0.040 | 0.055 | 0.081 | 0.060 | 0.072 | 0.160 | 0.360 |
| Mar | 54 | 0.040 | 0.040 | 0.050 | 0.085 | 0.070 | 0.100 | 0.166 | 0.240 |
| Apr | 133 | 0.035 | 0.050 | 0.062 | 0.146 | 0.105 | 0.180 | 0.310 | 0.710 |
| May | 98 | 0.030 | 0.040 | 0.060 | 0.192 | 0.130 | 0.240 | 0.420 | 0.940 |
| Jun | 136 | 0.010 | 0.038 | 0.050 | 0.156 | 0.118 | 0.210 | 0.330 | 1.120 |
| Jul | 124 | 0.030 | 0.040 | 0.060 | 0.242 | 0.130 | 0.240 | 0.400 | 3.450 |
| Aug | 166 | 0.010 | 0.040 | 0.060 | 0.196 | 0.150 | 0.230 | 0.430 | 1.340 |
| Sep | 103 | 0.010 | 0.060 | 0.090 | 0.214 | 0.170 | 0.220 | 0.380 | 1.310 |
| Oct | 119 | 0.034 | 0.041 | 0.059 | 0.271 | 0.150 | 0.280 | 0.740 | 2.680 |
| Nov | 49 | 0.040 | 0.040 | 0.060 | 0.132 | 0.080 | 0.160 | 0.320 | 0.560 |
| Dec | 47 | 0.030 | 0.033 | 0.050 | 0.084 | 0.066 | 0.097 | 0.160 | 0.300 |

***Total Phosphorus Upper Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded by City of Durham, lowest mean and median concentrations were recorded by NCDWQ and USGS.

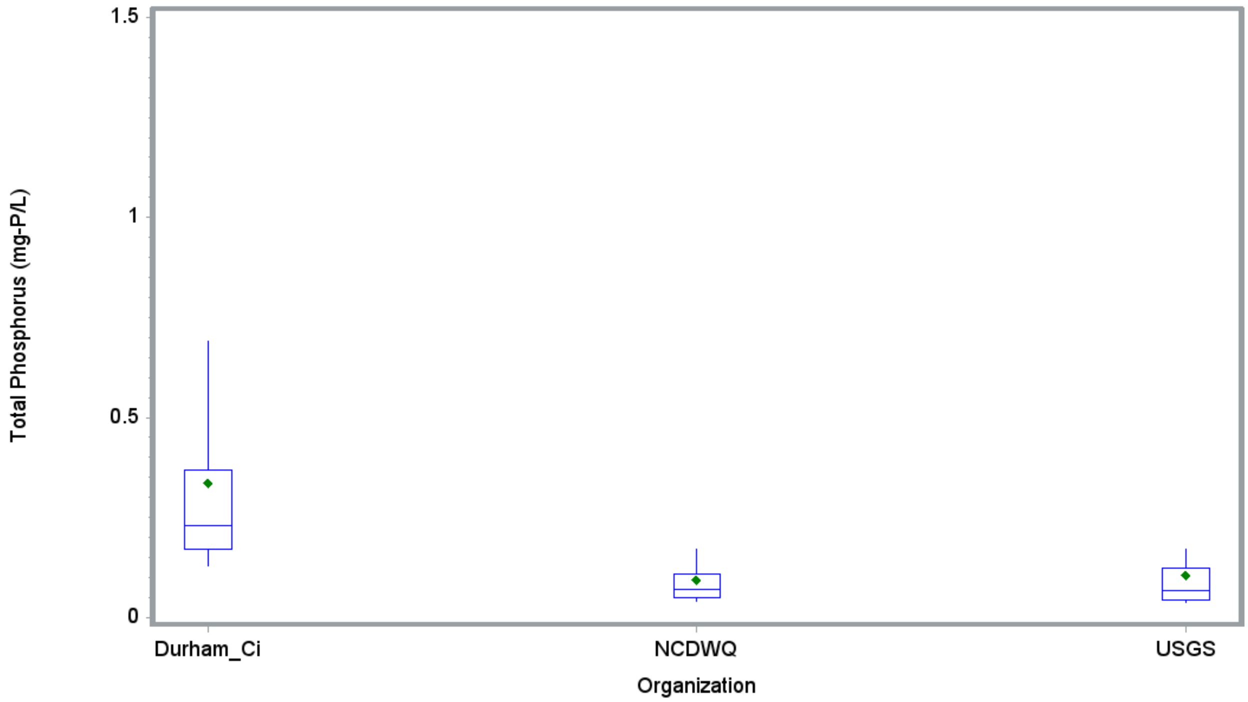



**Figure 3-197 Total Phosphorus Upper Lake Samples Categorized by Sampling Organization**

**Table 3-204 Total Phosphorus Upper Lake Samples Categorized by Sampling Organization (in mg-P/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 374 | 0.040 | 0.130 | 0.170 | 0.336 | 0.230 | 0.370 | 0.690 | 3.450 |
| NCDWQ | 551 | 0.010 | 0.040 | 0.050 | 0.094 | 0.070 | 0.110 | 0.170 | 1.200 |
| USGS | 183 | 0.025 | 0.038 | 0.043 | 0.107 | 0.068 | 0.124 | 0.170 | 0.790 |

***Total Phosphorus Upper Lake Samples Categorized by Method***

> By method, the highest mean and median concentrations were recorded using EPA 365.3 method.

> The lowest mean and median concentrations were recorded using EPA 365.1 and various methods.

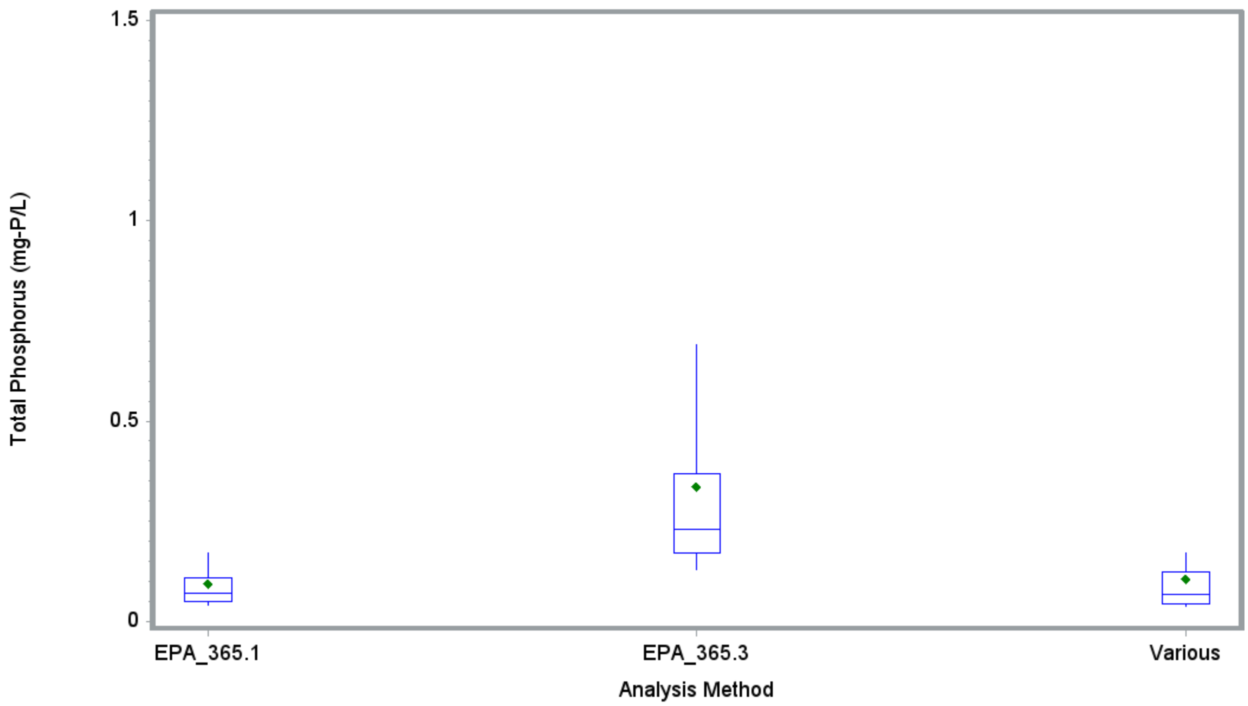



**Figure 3-198 Total Phosphorus Upper Lake Samples Categorized by Analysis Method**

**Table 3-205 Total Phosphorus Upper Lake Samples Categorized by Analysis Method (in mg-P/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_365.1 | 551 | 0.010 | 0.040 | 0.050 | 0.094 | 0.070 | 0.110 | 0.170 | 1.200 |
| EPA_365.3 | 374 | 0.040 | 0.130 | 0.170 | 0.336 | 0.230 | 0.370 | 0.690 | 3.450 |
| Various | 183 | 0.025 | 0.038 | 0.043 | 0.107 | 0.068 | 0.124 | 0.170 | 0.790 |

### 3.16.4 Lower Lake Samples

Three organizations measured total phosphorus concentrations in lower Falls Lake from 2000 to 2011. Measurements were similar by organization, depth zone and by lake segment. Highest mean concentrations were recorded in 2005 and 2009, while the lowest mean concentrations were recorded in 2000 and 2011. Box plot summaries are provided below.

***Total Phosphorus Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Total phosphorus concentrations were similar for all lake segments; however, the highest mean and median concentrations were measured in the most upstream portion of the lower lake (8 to 13 miles upstream of the dam).

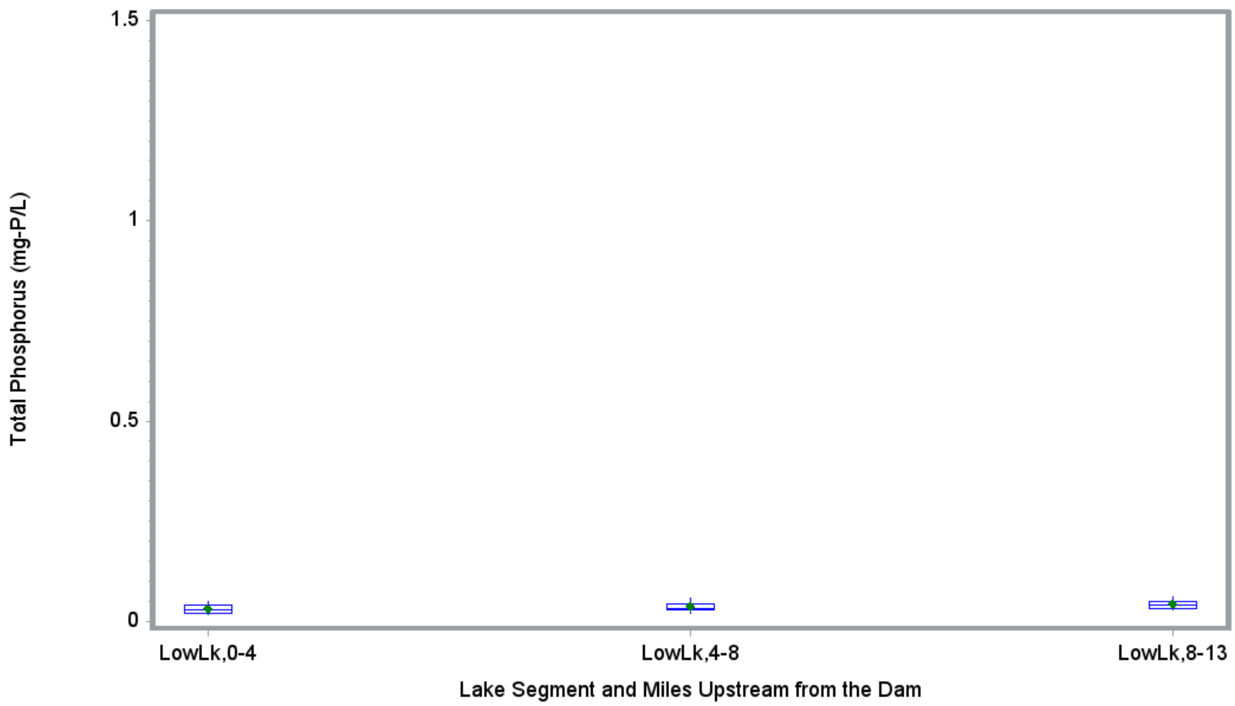



**Figure 3-199 Total Phosphorus Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-206 Total Phosphorus Lower Lake Samples Categorized by Miles Upstream from Dam (in mg-P/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LowLk,0-4 | 230 | 0.005 | 0.017 | 0.020 | 0.031 | 0.028 | 0.040 | 0.050 | 0.141 |
| LowLk,4-8 | 277 | 0.005 | 0.020 | 0.030 | 0.037 | 0.031 | 0.044 | 0.059 | 0.090 |
| LowLk,8-13 | 120 | 0.010 | 0.030 | 0.031 | 0.043 | 0.040 | 0.050 | 0.060 | 0.080 |

***Total Phosphorus Lower Lake Samples Categorized by Depth***

> Mean and median concentrations were similar for the three depth zones, with slightly lower concentrations at the bottom level.

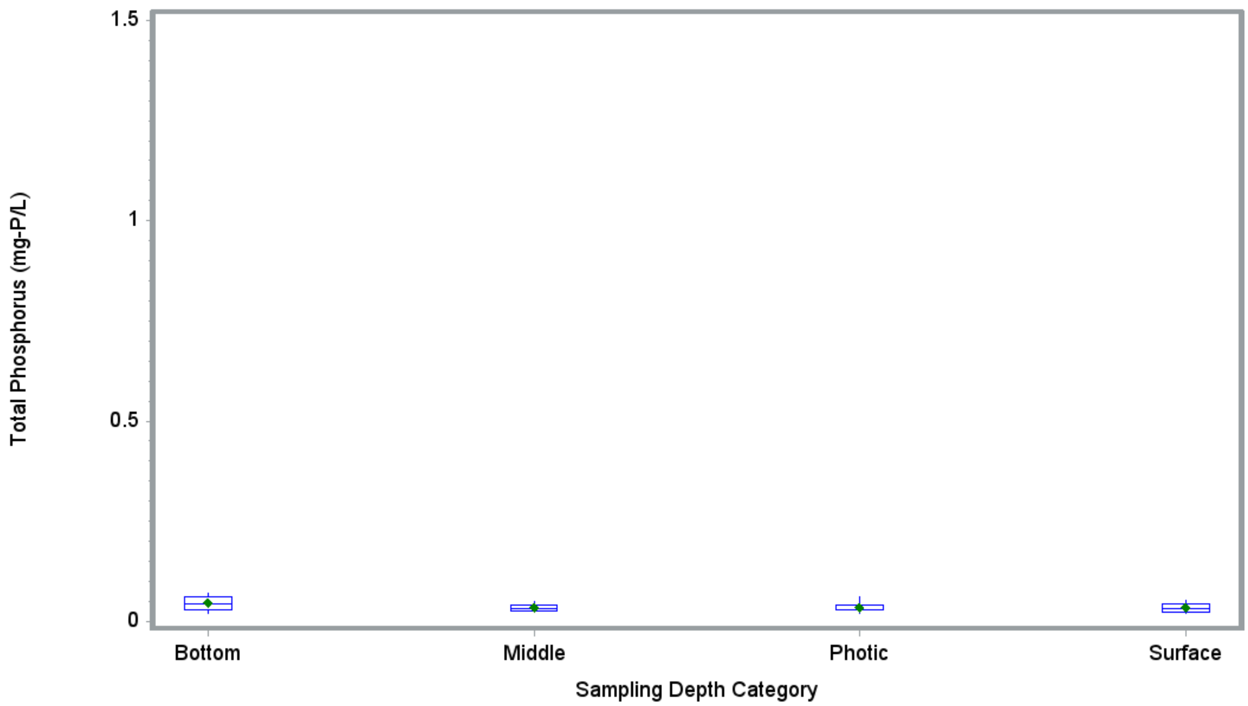



**Figure 3-200 Total Phosphorus Lower Lake Samples Categorized by Depth Category**

**Table 3-207 Total Phosphorus Lower Lake Samples Categorized by Depth Category (in mg-P/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Bottom | 35 | 0.010 | 0.020 | 0.030 | 0.047 | 0.044 | 0.060 | 0.070 | 0.141 |
| Middle | 153 | 0.014 | 0.022 | 0.026 | 0.034 | 0.032 | 0.041 | 0.050 | 0.074 |
| Photic | 346 | 0.005 | 0.020 | 0.030 | 0.035 | 0.030 | 0.040 | 0.060 | 0.080 |
| Surface | 93 | 0.012 | 0.020 | 0.023 | 0.035 | 0.031 | 0.044 | 0.054 | 0.075 |

***Total Phosphorus Lower Lake Categorized by Year***

> Total phosphorus was recorded in 2000, 2001 and from 2005 to 2011.

> The mean and median concentrations for all years were relatively similar with 2000 having the lowest mean and median concentration.

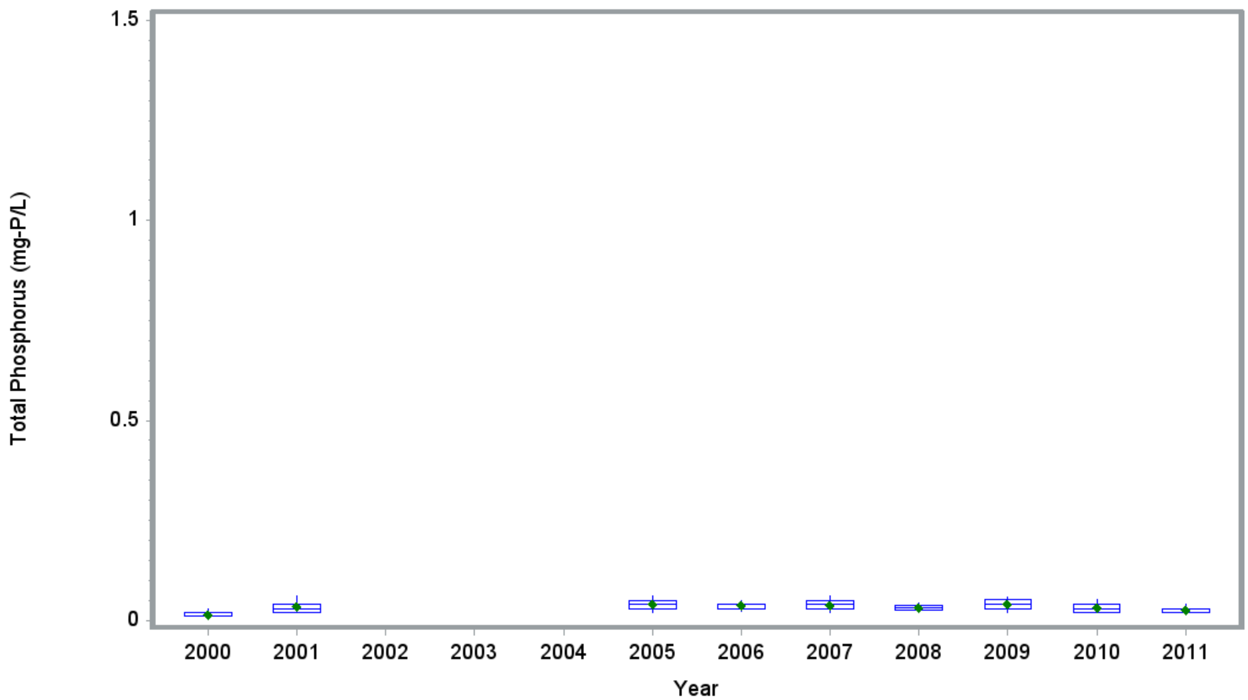



**Figure 3-201 Total Phosphorus Lower Lake Samples Categorized by Year**

**Table 3-208 Total Phosphorus Lower Lake Samples Categorized by Year (in mg-P/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 13 | 0.005 | 0.005 | 0.010 | 0.015 | 0.010 | 0.020 | 0.030 | 0.030 |
| 2001 | 32 | 0.010 | 0.020 | 0.020 | 0.035 | 0.030 | 0.040 | 0.060 | 0.090 |
| 2005 | 91 | 0.010 | 0.020 | 0.030 | 0.041 | 0.040 | 0.050 | 0.060 | 0.080 |
| 2006 | 117 | 0.020 | 0.024 | 0.030 | 0.038 | 0.040 | 0.040 | 0.050 | 0.141 |
| 2007 | 106 | 0.010 | 0.020 | 0.028 | 0.038 | 0.040 | 0.050 | 0.060 | 0.080 |
| 2008 | 54 | 0.012 | 0.020 | 0.026 | 0.032 | 0.032 | 0.039 | 0.045 | 0.047 |
| 2009 | 58 | 0.016 | 0.021 | 0.028 | 0.041 | 0.042 | 0.053 | 0.059 | 0.076 |
| 2010 | 91 | 0.010 | 0.020 | 0.021 | 0.033 | 0.030 | 0.042 | 0.052 | 0.075 |
| 2011 | 65 | 0.010 | 0.019 | 0.020 | 0.027 | 0.030 | 0.030 | 0.040 | 0.050 |

***Total Phosphorus Lower Lake Samples Categorized by Month***

> By month, the highest mean and median concentrations were measured in February and March.

> The mean and median results were relatively similar between months.

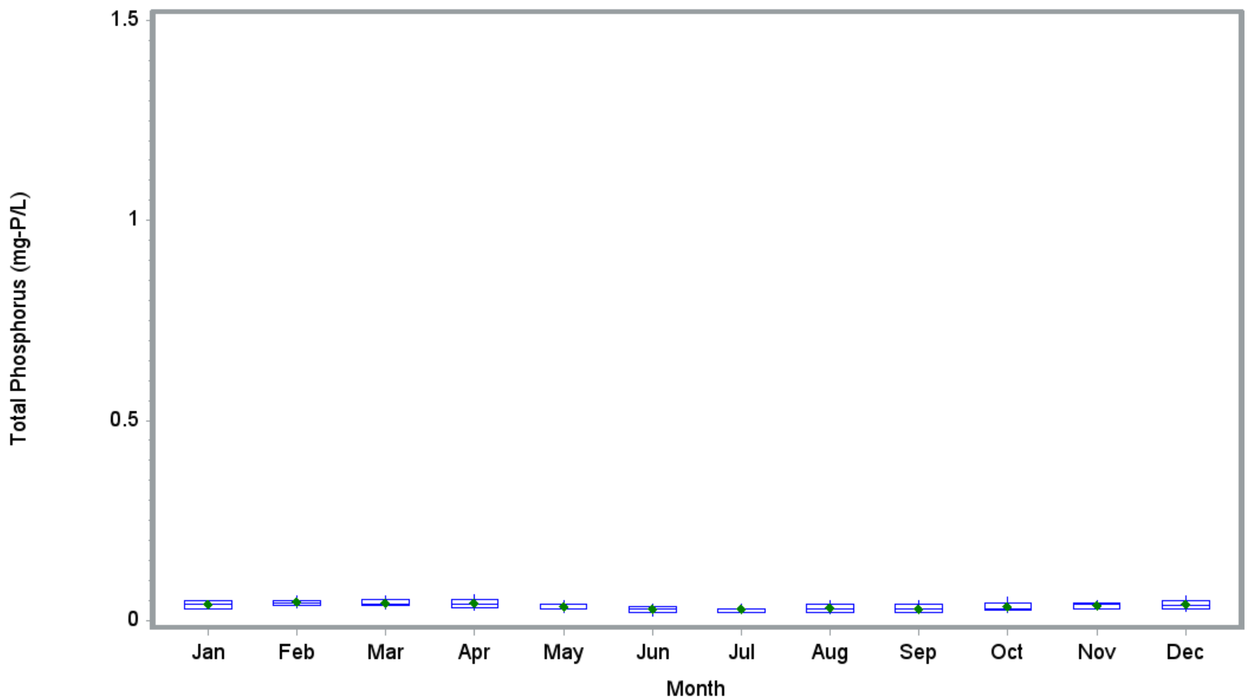



**Figure 3-202 Total Phosphorus Lower Lake Samples Categorized by Month**

**Table 3-209 Total Phosphorus Lower Lake Samples Categorized by Month (in mg-P/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 23 | 0.030 | 0.030 | 0.030 | 0.041 | 0.040 | 0.050 | 0.050 | 0.060 |
| Feb | 43 | 0.030 | 0.033 | 0.039 | 0.046 | 0.045 | 0.051 | 0.060 | 0.070 |
| Mar | 38 | 0.020 | 0.030 | 0.038 | 0.045 | 0.041 | 0.053 | 0.060 | 0.080 |
| Apr | 69 | 0.020 | 0.026 | 0.031 | 0.043 | 0.040 | 0.053 | 0.065 | 0.080 |
| May | 38 | 0.020 | 0.020 | 0.030 | 0.034 | 0.030 | 0.040 | 0.050 | 0.060 |
| Jun | 72 | 0.005 | 0.010 | 0.020 | 0.029 | 0.030 | 0.035 | 0.040 | 0.076 |
| Jul | 61 | 0.010 | 0.016 | 0.020 | 0.028 | 0.030 | 0.030 | 0.042 | 0.060 |
| Aug | 98 | 0.010 | 0.016 | 0.020 | 0.032 | 0.030 | 0.040 | 0.050 | 0.090 |
| Sep | 39 | 0.010 | 0.017 | 0.020 | 0.029 | 0.030 | 0.040 | 0.050 | 0.060 |
| Oct | 67 | 0.020 | 0.020 | 0.025 | 0.036 | 0.030 | 0.044 | 0.059 | 0.141 |
| Nov | 31 | 0.020 | 0.028 | 0.030 | 0.038 | 0.040 | 0.044 | 0.050 | 0.051 |
| Dec | 48 | 0.020 | 0.024 | 0.030 | 0.040 | 0.038 | 0.050 | 0.060 | 0.080 |

***Total Phosphorus Lower Lake Samples Categorized by Sampling Organization***

> The mean and median results were relatively similar between organizations.

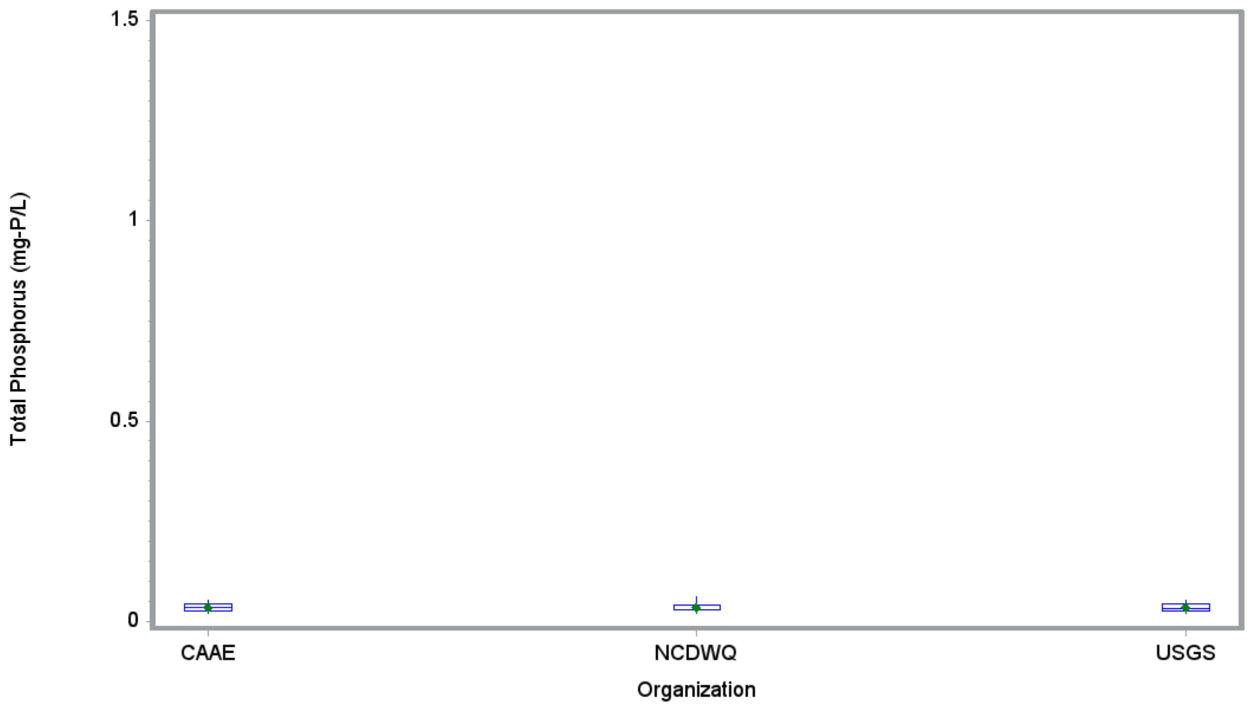



**Figure 3-203 Total Phosphorus Lower Lake Samples Categorized by Sampling Organization**

**Table 3-210 Total Phosphorus Lower Lake Samples Categorized by Sampling Organization (in mg-P/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 68 | 0.012 | 0.020 | 0.025 | 0.036 | 0.034 | 0.045 | 0.054 | 0.075 |
| NCDWQ | 365 | 0.005 | 0.020 | 0.030 | 0.036 | 0.030 | 0.040 | 0.060 | 0.090 |
| USGS | 194 | 0.014 | 0.021 | 0.026 | 0.036 | 0.032 | 0.044 | 0.053 | 0.141 |

***Total Phosphorus Lower Lake Samples Categorized by Method***

> Mean and median concentrations were similar for all methods.

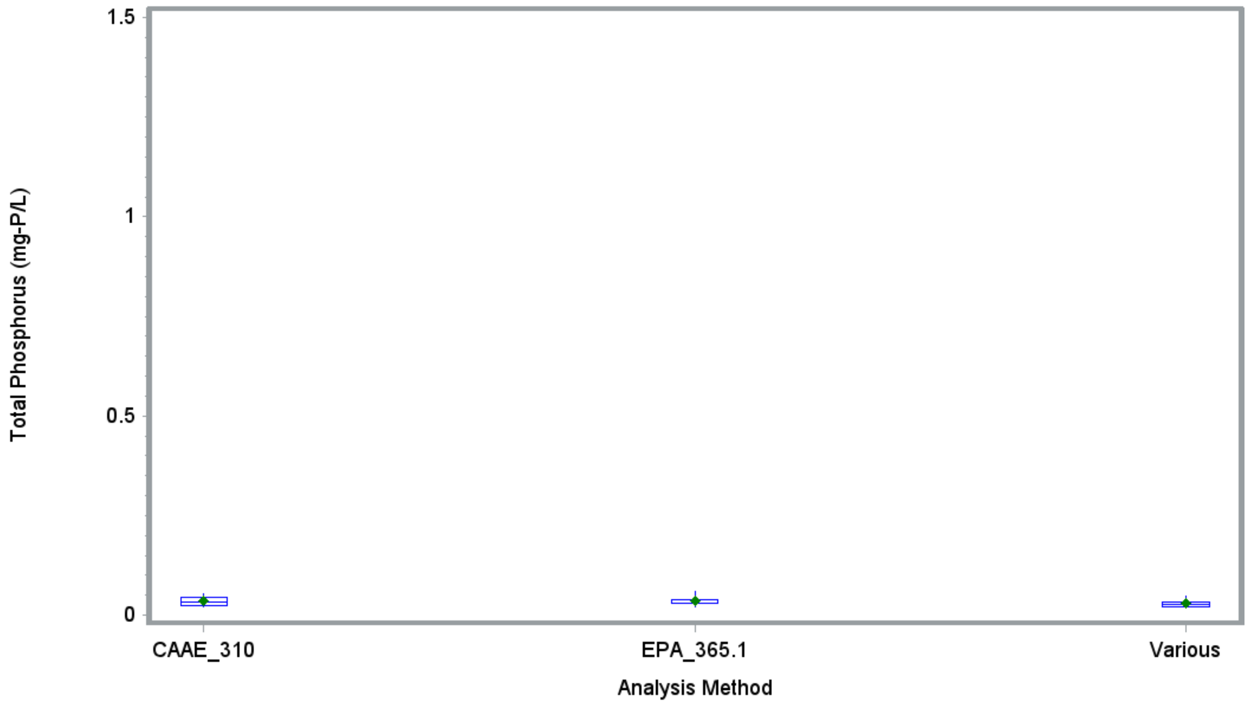



**Figure 3-204 Total Phosphorus Lower Lake Samples Categorized by Analysis Method**

**Table 3-211 Total Phosphorus Lower Lake Samples Categorized by Analysis Method (in mg-P/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE_310 | 68 | 0.012 | 0.020 | 0.025 | 0.036 | 0.034 | 0.045 | 0.054 | 0.075 |
| EPA_365.1 | 365 | 0.005 | 0.020 | 0.030 | 0.036 | 0.030 | 0.040 | 0.060 | 0.090 |
| Various | 194 | 0.014 | 0.021 | 0.026 | 0.036 | 0.032 | 0.044 | 0.053 | 0.141 |

## 3.17 Secchi Depth

Secchi depth measures of the clarity of the water by lowering a white and black disk from the surface toward the bottom and recording the distance when the disk is no longer visible. Secchi depth is higher in clear waters and lower in waters that are turbid or have high color. The turbidity that affects Secchi depth may be due to suspended sediment, algae, and other floating organisms. Three organizations measured Secchi depth in Falls Lake as part of their water quality sampling effort. Secchi depth was converted to meters for this analysis.

For those organizations that provided method, the following were used:

> Secchi depth using methods described in the NCDENR SOP (NCDENR 2011c) (WQS_SOP)

Appendix E provides detailed descriptions of these methods. Table 3-212 describes the organizations and analysis methods used to measure Secchi depth and includes the number of samples, date range, and limits. Several organizations did not report the method used to measure Secchi depth for some, or all of, the data categories they provided. In these cases, the analysis method is listed as “Not Provided.” The majority of the Secchi depth data has been collected by NCDWQ using an unspecified method; the seven NCDWQ records that specified using methods described in WQS_SOP were obtained from the

STORET database rather than from NCDWQ directly. The limits for Secchi depth are listed as not applicable (NA) because this is a visual assessment test. Secchi depth is presented in meters and to two decimal places based on reported data.

**Table 3-212 Summary of Analysis Methods for the Secchi depth Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (m) | Reporting Limit (m) | Practical Quantification Limit (m) | Range of Limit Specified with Results (m) |
|---|---|---|---|---|---|---|---|---|
| Durham_Ci | Unknown | 03/08/2010 | 11/14/2011 | 67 | NA | NA | NA | NA |
| NCDWQ | Unknown | 06/07/2000 | 12/06/2011 | 876 | NA | NA | NA | NA |
| NCDWQ | WQS_SOP | 05/13/2002 | 05/13/2002 | 7 | NA | NA | NA | NA |
| USGS | Unknown | 04/23/1999 | 10/20/2011 | 127 | NA | NA | NA | NA |

### 3.17.2 Tributary Samples

Secchi depth data are not presented for the free-flowing tributary monitoring stations. Data collected in watershed impoundments is presented in Appendix A.

### 3.17.3 Upper Lake Samples

Three organizations measured Secchi disk depth in upper Falls Lake from 2000 to 2011. Deepest measurements were recorded by USGS and NCDWQ. Shallowest measurements were recorded in the > 21 mile section. Depth measurements were similar for all years. Box plot summaries are provided below.

***Secchi Depth Categorized by Lake Segment and Miles Upstream from Dam***

> Secchi depth measurements increase (improve) from the upstream to downstream segments of the Upper Lake.

> The deepest mean and median measurements and greatest variability were recorded in the 13 to 18 mile section.

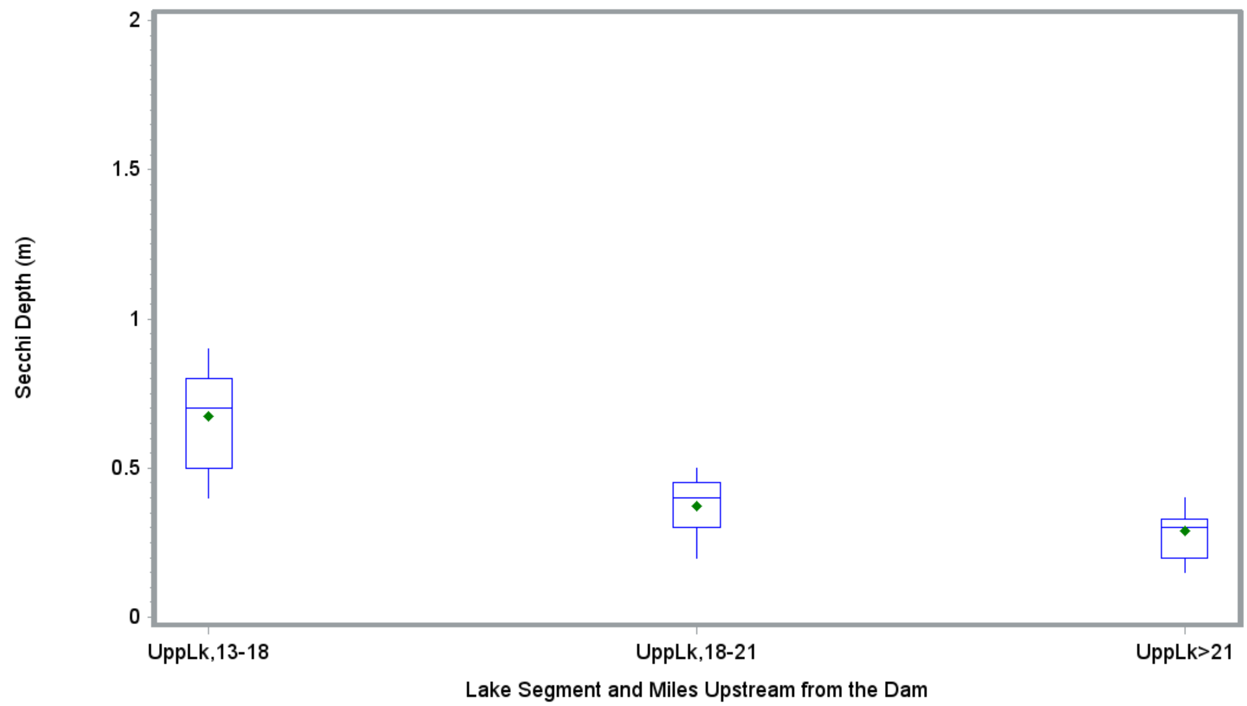



**Figure 3-205 Secchi Depth Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-213 Secchi Depth Upper Lake Samples Categorized by Miles Upstream from Dam (in m)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 325 | 0.20 | 0.40 | 0.50 | 0.67 | 0.70 | 0.80 | 0.90 | 1.40 |
| UppLk,18-21 | 85 | 0.10 | 0.20 | 0.30 | 0.37 | 0.40 | 0.45 | 0.50 | 0.80 |
| UppLk>21 | 249 | 0.09 | 0.15 | 0.20 | 0.29 | 0.30 | 0.33 | 0.40 | 0.80 |

***Secchi Depth Upper Lake Categorized by Year***

> Secchi depth was recorded in 2000, 2001 and 2005 through 2011.

> Mean and median values were similar for all years.

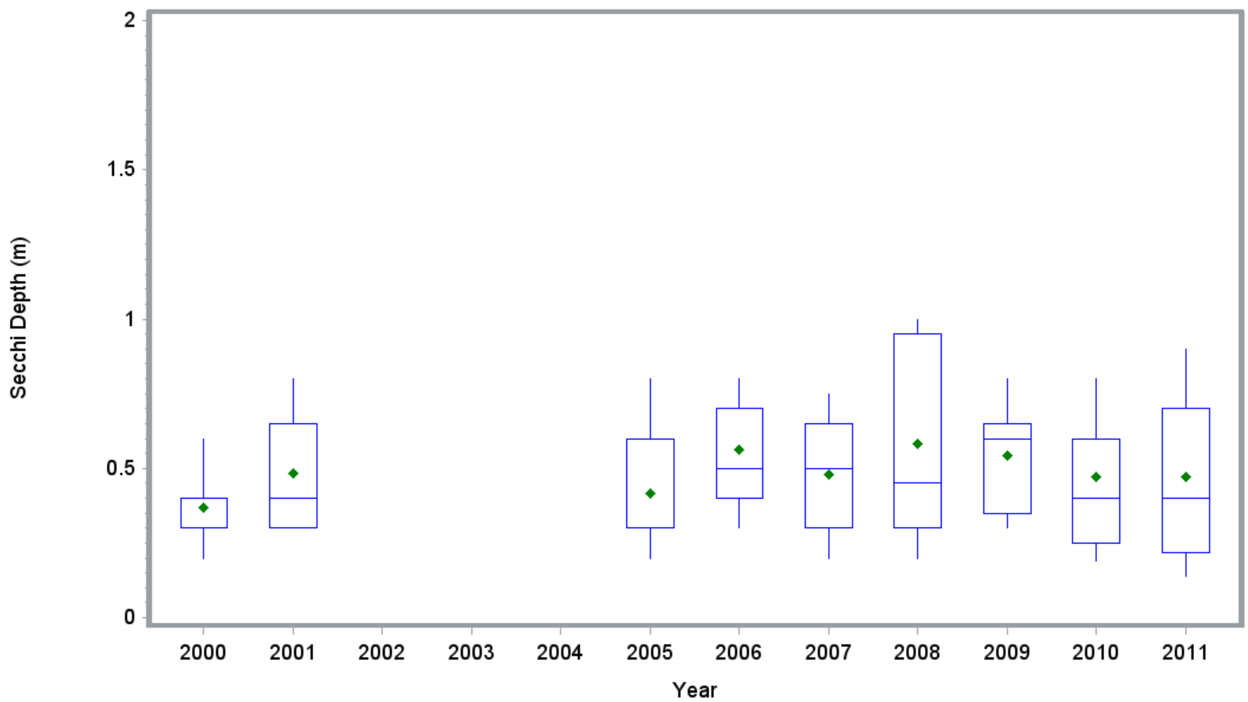



**Figure 3-206 Secchi Depth Upper Lake Samples Categorized by Year**

**Table 3-214 Secchi Depth Upper Lake Samples Categorized by Year (in m)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 13 | 0.20 | 0.20 | 0.30 | 0.37 | 0.30 | 0.40 | 0.60 | 0.70 |
| 2001 | 18 | 0.20 | 0.30 | 0.30 | 0.48 | 0.40 | 0.65 | 0.80 | 0.90 |
| 2005 | 99 | 0.10 | 0.20 | 0.30 | 0.42 | 0.30 | 0.60 | 0.80 | 1.10 |
| 2006 | 163 | 0.20 | 0.30 | 0.40 | 0.56 | 0.50 | 0.70 | 0.80 | 1.30 |
| 2007 | 134 | 0.10 | 0.20 | 0.30 | 0.48 | 0.50 | 0.65 | 0.75 | 1.20 |
| 2008 | 12 | 0.10 | 0.20 | 0.30 | 0.58 | 0.45 | 0.95 | 1.00 | 1.30 |
| 2009 | 12 | 0.20 | 0.30 | 0.35 | 0.54 | 0.60 | 0.65 | 0.80 | 0.90 |
| 2010 | 94 | 0.12 | 0.19 | 0.25 | 0.47 | 0.40 | 0.60 | 0.80 | 1.10 |
| 2011 | 114 | 0.09 | 0.14 | 0.22 | 0.47 | 0.40 | 0.70 | 0.90 | 1.40 |

***Secchi Depth Upper Lake Samples Categorized by Month***

> Mean and median depths and variability were similar for all months.

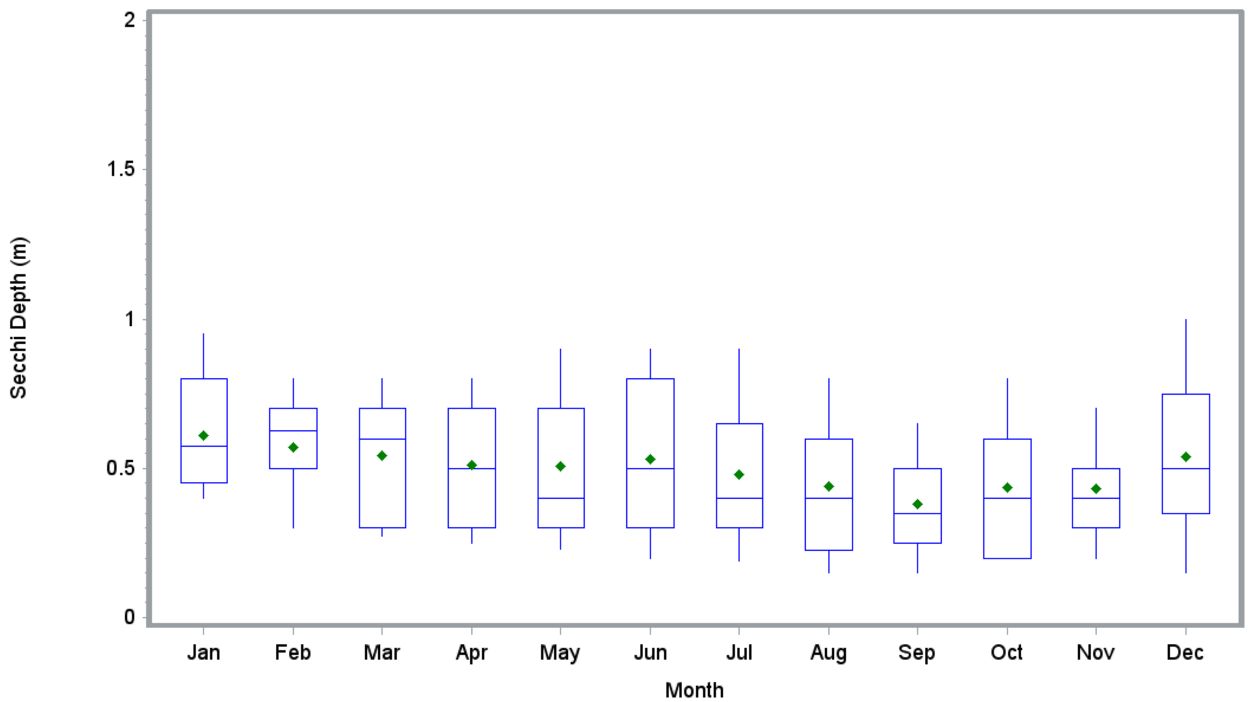



**Figure 3-207 Secchi Depth Upper Lake Samples Categorized by Month**

**Table 3-215 Secchi Depth Upper Lake Samples Categorized by Month (in m)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 30 | 0.30 | 0.40 | 0.45 | 0.61 | 0.58 | 0.80 | 0.95 | 1.10 |
| Feb | 38 | 0.10 | 0.30 | 0.50 | 0.57 | 0.63 | 0.70 | 0.80 | 0.85 |
| Mar | 47 | 0.15 | 0.28 | 0.30 | 0.54 | 0.60 | 0.70 | 0.80 | 0.90 |
| Apr | 65 | 0.20 | 0.25 | 0.30 | 0.51 | 0.50 | 0.70 | 0.80 | 1.30 |
| May | 60 | 0.13 | 0.23 | 0.30 | 0.51 | 0.40 | 0.70 | 0.90 | 1.40 |
| Jun | 73 | 0.17 | 0.20 | 0.30 | 0.53 | 0.50 | 0.80 | 0.90 | 1.30 |
| Jul | 69 | 0.10 | 0.19 | 0.30 | 0.48 | 0.40 | 0.65 | 0.90 | 1.00 |
| Aug | 88 | 0.09 | 0.15 | 0.23 | 0.44 | 0.40 | 0.60 | 0.80 | 1.20 |
| Sep | 58 | 0.12 | 0.15 | 0.25 | 0.38 | 0.35 | 0.50 | 0.65 | 0.80 |
| Oct | 53 | 0.12 | 0.20 | 0.20 | 0.43 | 0.40 | 0.60 | 0.80 | 1.00 |
| Nov | 42 | 0.10 | 0.20 | 0.30 | 0.43 | 0.40 | 0.50 | 0.70 | 0.90 |
| Dec | 36 | 0.10 | 0.15 | 0.35 | 0.54 | 0.50 | 0.75 | 1.00 | 1.10 |

### *Secchi Depth Upper Lake Samples Categorized by Sampling Organization*

> By sampling organization, the deepest measurements were recorded by USGS and the lowest by the City of Durham.

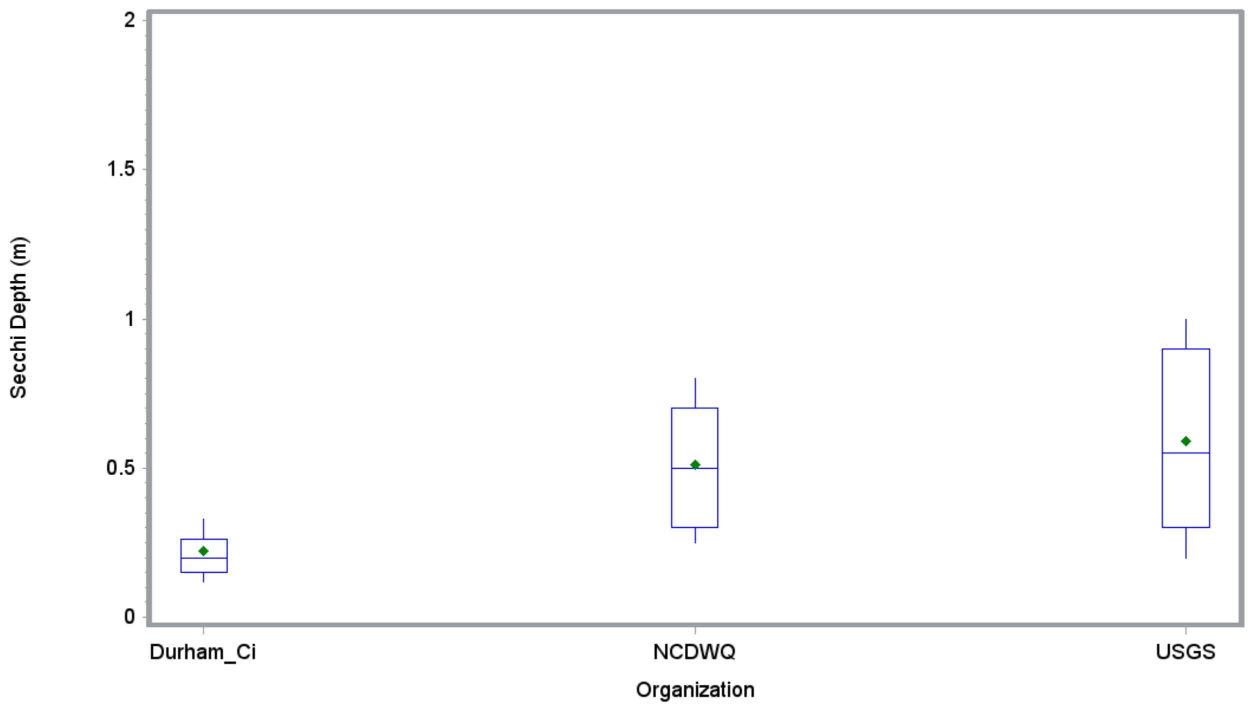



**Figure 3-208 Secchi Depth Upper Lake Samples Categorized by Sampling Organization**

**Table 3-216 Secchi Depth Upper Lake Samples Categorized by Sampling Organization (in m)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 67 | 0.09 | 0.12 | 0.15 | 0.22 | 0.20 | 0.26 | 0.33 | 0.80 |
| NCDWQ | 530 | 0.10 | 0.25 | 0.30 | 0.51 | 0.50 | 0.70 | 0.80 | 1.40 |
| USGS | 62 | 0.10 | 0.20 | 0.30 | 0.59 | 0.55 | 0.90 | 1.00 | 1.30 |

***Secchi Depth Upper Lake Samples Categorized by Method***

> Information regarding measurement of Secchi depth was not provided for the sampling in the Upper Lake.

### 3.17.4 Lower Lake Samples

Two organizations measured Secchi disk depth in lower Falls Lake from 2000 to 2011. Secchi measurements were similar for both USGS and NCDWQ. Shallowest measurements were recorded in the 8 to 13 mile section. Measurements were deepest in 2001. Box plot summaries are provided below.

***Secchi Depth Categorized by Lake Segment and Miles Upstream from Dam***

> Deepest mean and median measurements and slightly greater variability were recorded in the 0 to 4 mile segment.

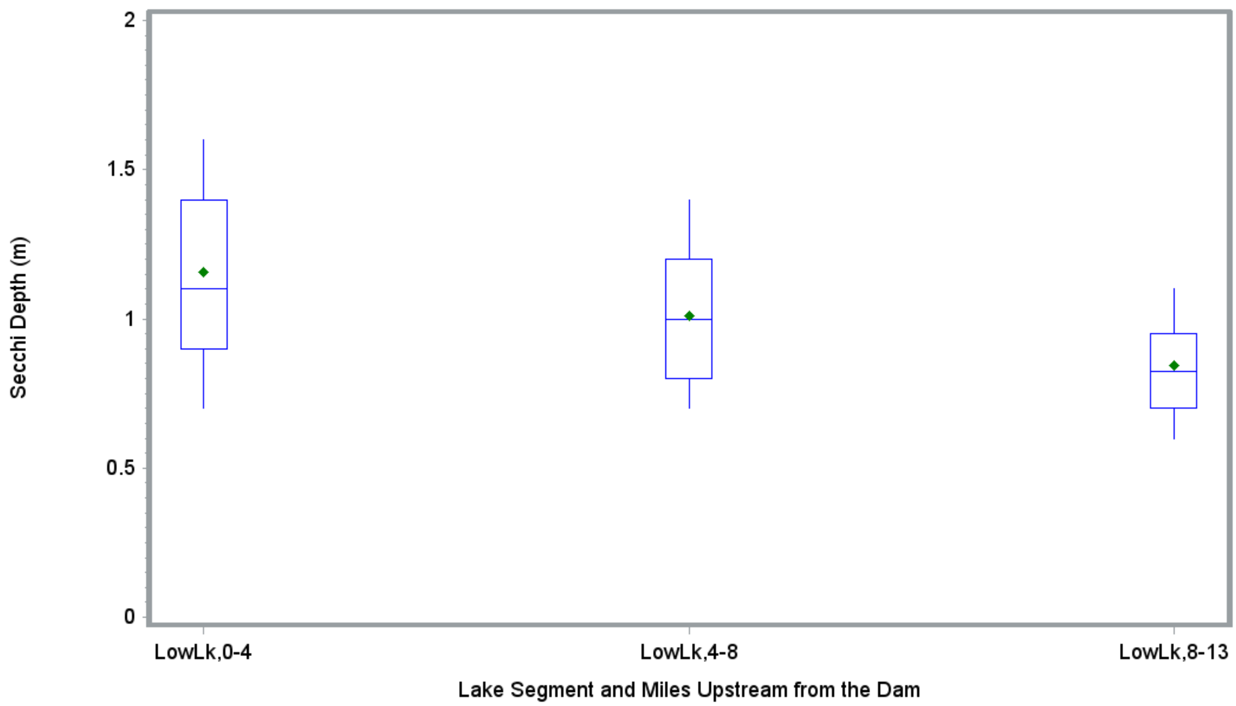



**Figure 3-209 Secchi Depth Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-217 Secchi Depth Lower Lake Samples Categorized by Miles Upstream from Dam (in m)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LowLk,0-4 | 120 | 0.60 | 0.70 | 0.90 | 1.16 | 1.10 | 1.40 | 1.60 | 2.20 |
| LowLk,4-8 | 205 | 0.50 | 0.70 | 0.80 | 1.01 | 1.00 | 1.20 | 1.40 | 1.70 |
| LowLk,8-13 | 86 | 0.50 | 0.60 | 0.70 | 0.84 | 0.83 | 0.95 | 1.10 | 1.40 |

***Secchi Depth Lower Lake Categorized by Year***

- Secchi depth was recorded in 2000, 2001 and 2005 through 2011.
- Mean and median Secchi depth was greatest in 2001.
- Mean and median values were similar for all years, except for 2001 and 2008, which had slightly deeper Secchi depths.

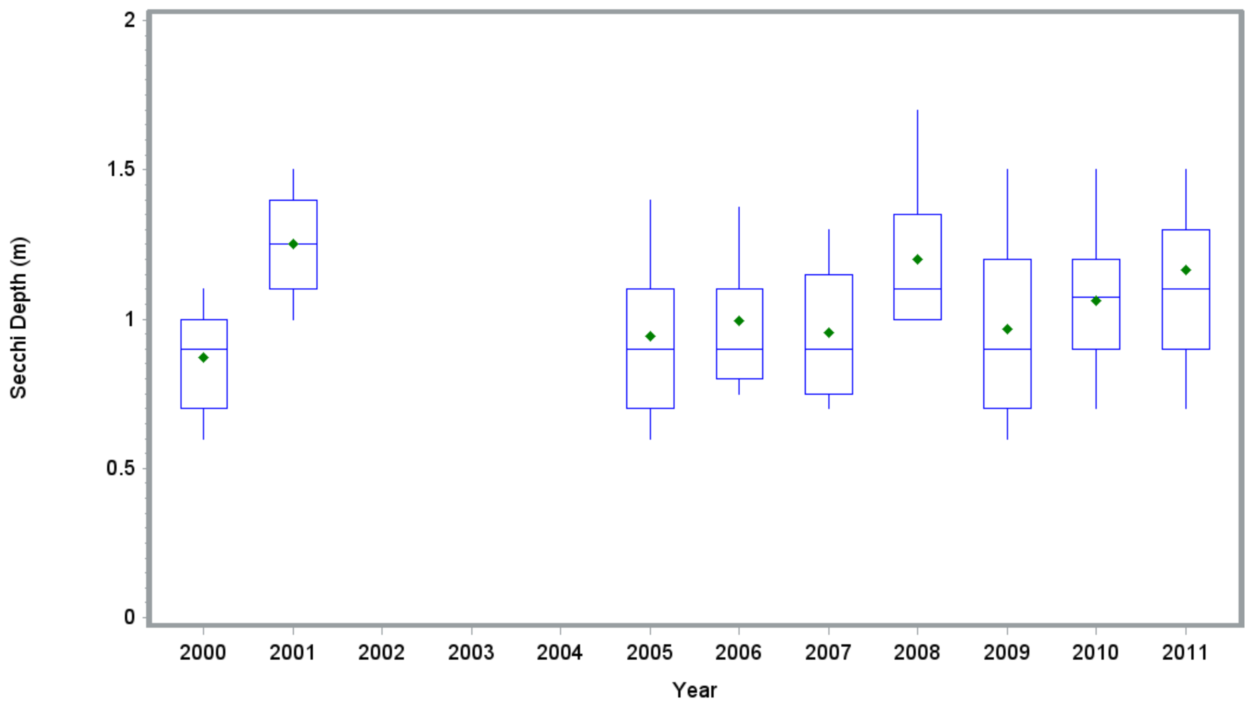



**Figure 3-210 Secchi Depth Lower Lake Samples Categorized by Year**

**Table 3-218 Secchi Depth Lower Lake Samples Categorized by Year (in m)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 11 | 0.60 | 0.60 | 0.70 | 0.87 | 0.90 | 1.00 | 1.10 | 1.20 |
| 2001 | 16 | 0.95 | 1.00 | 1.10 | 1.25 | 1.25 | 1.40 | 1.50 | 1.70 |
| 2005 | 81 | 0.50 | 0.60 | 0.70 | 0.94 | 0.90 | 1.10 | 1.40 | 1.90 |
| 2006 | 100 | 0.65 | 0.75 | 0.80 | 0.99 | 0.90 | 1.10 | 1.38 | 1.60 |
| 2007 | 81 | 0.50 | 0.70 | 0.75 | 0.96 | 0.90 | 1.15 | 1.30 | 1.60 |
| 2008 | 12 | 0.80 | 1.00 | 1.00 | 1.20 | 1.10 | 1.35 | 1.70 | 1.70 |
| 2009 | 12 | 0.50 | 0.60 | 0.70 | 0.97 | 0.90 | 1.20 | 1.50 | 1.50 |
| 2010 | 44 | 0.55 | 0.70 | 0.90 | 1.06 | 1.08 | 1.20 | 1.50 | 1.70 |
| 2011 | 54 | 0.50 | 0.70 | 0.90 | 1.16 | 1.10 | 1.30 | 1.60 | 2.20 |

### *Secchi Depth Lower Lake Samples Categorized by Month*

> By month, a seasonal pattern was apparent with deeper mean and median measurements recorded in the warmer months, May to August.

> The highest mean and median Secchi depths were in July.

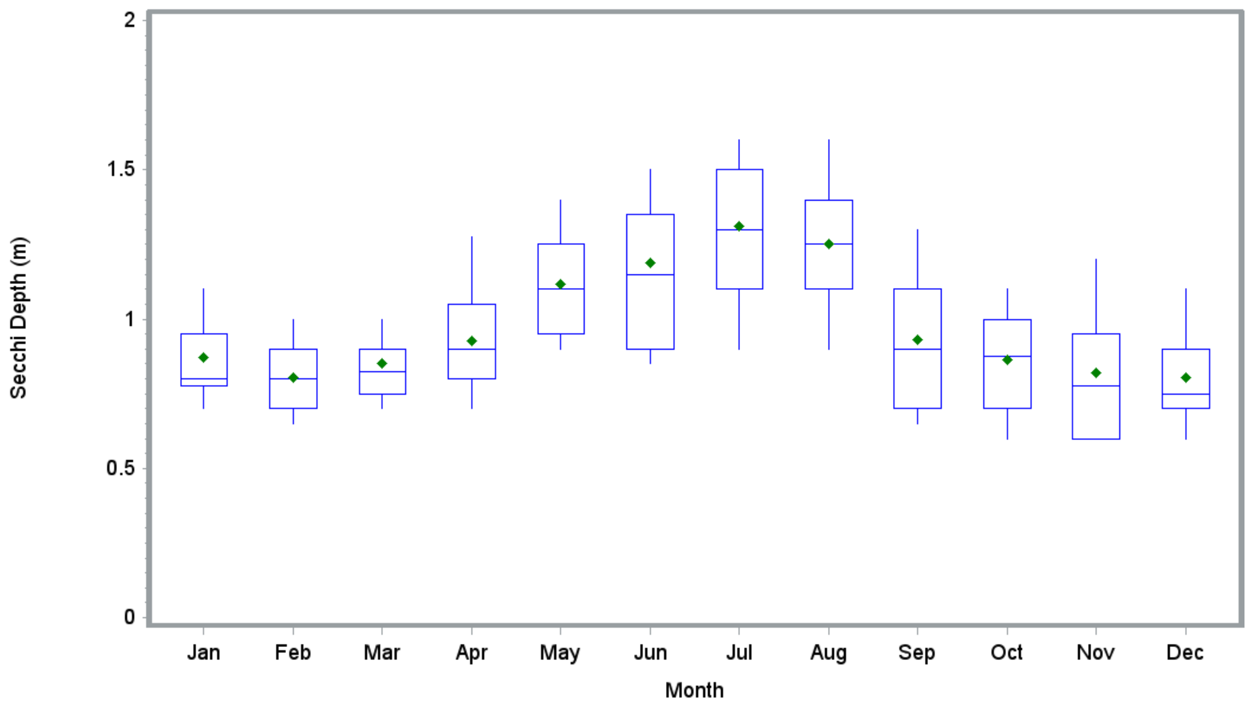



**Figure 3-211 Secchi Depth Lower Lake Samples Categorized by Month**

**Table 3-219 Secchi Depth Lower Lake Samples Categorized by Month (in m)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 20 | 0.70 | 0.70 | 0.78 | 0.87 | 0.80 | 0.95 | 1.10 | 1.30 |
| Feb | 26 | 0.60 | 0.65 | 0.70 | 0.81 | 0.80 | 0.90 | 1.00 | 1.30 |
| Mar | 30 | 0.60 | 0.70 | 0.75 | 0.85 | 0.83 | 0.90 | 1.00 | 1.20 |
| Apr | 40 | 0.50 | 0.70 | 0.80 | 0.93 | 0.90 | 1.05 | 1.28 | 1.40 |
| May | 32 | 0.65 | 0.90 | 0.95 | 1.12 | 1.10 | 1.25 | 1.40 | 1.80 |
| Jun | 44 | 0.60 | 0.85 | 0.95 | 1.19 | 1.15 | 1.38 | 1.60 | 2.20 |
| Jul | 42 | 0.90 | 0.90 | 1.10 | 1.31 | 1.30 | 1.50 | 1.60 | 2.00 |
| Aug | 57 | 0.70 | 0.90 | 1.10 | 1.25 | 1.25 | 1.40 | 1.60 | 1.80 |
| Sep | 32 | 0.50 | 0.65 | 0.70 | 0.93 | 0.90 | 1.10 | 1.30 | 1.50 |
| Oct | 36 | 0.50 | 0.60 | 0.70 | 0.86 | 0.88 | 1.00 | 1.10 | 1.20 |
| Nov | 24 | 0.55 | 0.60 | 0.60 | 0.82 | 0.78 | 0.95 | 1.20 | 1.30 |
| Dec | 28 | 0.55 | 0.60 | 0.70 | 0.80 | 0.75 | 0.90 | 1.10 | 1.10 |

***Secchi Depth Lower Lake Samples Categorized by Sampling Organization***

> By sampling organization, the measurements were similar for USGS and NCDWQ.


**Figure 3-212 Secchi Depth Lower Lake Samples Categorized by Sampling Organization**

**Table 3-220 Secchi Depth Lower Lake Samples Categorized by Sampling Organization (in m)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| NCDWQ | 346 | 0.50 | 0.70 | 0.80 | 1.00 | 0.90 | 1.20 | 1.40 | 2.00 |
| USGS | 65 | 0.50 | 0.70 | 0.90 | 1.13 | 1.10 | 1.30 | 1.55 | 2.20 |

***Secchi Depth Lower Lake Samples Categorized by Method***

> Information regarding measurement of Secchi depth was not provided for the sampling in the Lower Lake.

## 3.18 Chlorophyll *a* (µg/L)

Chlorophyll *a* is a measure of the amount of green pigment associated with floating plant and algal growth in the water column. Six organizations measured chlorophyll *a* as part of the water quality sampling effort. The chlorophyll *a* data presented in this report were measured in the laboratory. CAAE collects in situ chlorophyll *a* data as well, but that data is not presented in this memorandum because 1) methods for measuring in situ chlorophyll *a* reflect live and dead algae in the water as well as other sources of organic material and 2) in situ chlorophyll *a* measurements are not comparable to the State standard of 40 µg/L,.

For those organizations that provided method, the following were used:

> In vitro determination of chlorophyll *a* and pheophytin-*a* in marine and freshwater algae by fluorescence (EPA 445.0)

> Standard method, spectrophotometric determination of chlorophyll (SM 10200H)

> Chlorophyll in phytoplankton by high performance liquid chromatography (USGS B-6530-85)

> In vitro determination of chlorophyll *a* in marine and freshwater phytoplankton by fluorescence (CAAE 370)

Appendix E provides detailed descriptions of these methods. Table 3-221 describes the organizations and the analysis methods used to measure chlorophyll *a*, and includes the number of samples, date range, and limits. The majority of the chlorophyll *a* data were collected by CAAE. Chlorophyll *a* is reported in µg/L and presented to one decimal place based on reported data.

**Table 3-221 Summary of Analysis Methods for the Chlorophyll *a* Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (µg/L) | Reporting Limit (µg/L) | Practical Quantification Limit (µg/L) | Range of Limit Specified with Results (µg/L) |
|---|---|---|---|---|---|---|---|---|
| CAAE | CAAE_370 | 06/20/2002 | 09/29/2011 | 1066 | Not Provided | Not Provided | Not Provided | 0.6 to 2.6 |
| Durham_Ci | Unknown | 04/01/2002 | 04/02/2012 | 663 | Not Provided | Not Provided | Not Provided | 2 |
| NCDWQ | EPA_445.0 | 07/11/2001 | 12/06/2011 | 753 | Not Provided | Not Provided | Not Provided | 44[1] |
| Orange_Co | SM_10200H | 04/09/2010 | 03/25/2011 | 182 | Not Provided | Not Provided | Not Provided | 2 |
| Raleigh | EPA_445.0 | 05/27/2009 | 12/30/2011 | 269 | Not Provided | Not Provided | Not Provided | None listed |
| Raleigh | Unknown | 01/13/2009 | 03/05/2012 | 154 | Not Provided | Not Provided | Not Provided | None listed |
| USGS | Various | 04/23/1999 | 08/23/2011 | 123 | Not Provided | Not Provided | 0.1 | 0.1 |

[1] One NCDWQ chlorophyll *a* sample was reported as <44 µg/L.

### 3.18.2 Tributary Samples

One organization, Orange County, measured chlorophyll *a* concentrations in Falls Lake tributaries in 2010 and 2011. Higher mean concentrations were recorded in 2010 and in the months of May and March. Box plot summaries are provided below.

***Chlorophyll a Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> The Eno River > 10 mile segment was the only part of a subwatershed to be sampled.

> None of the values exceeded the water quality standard.

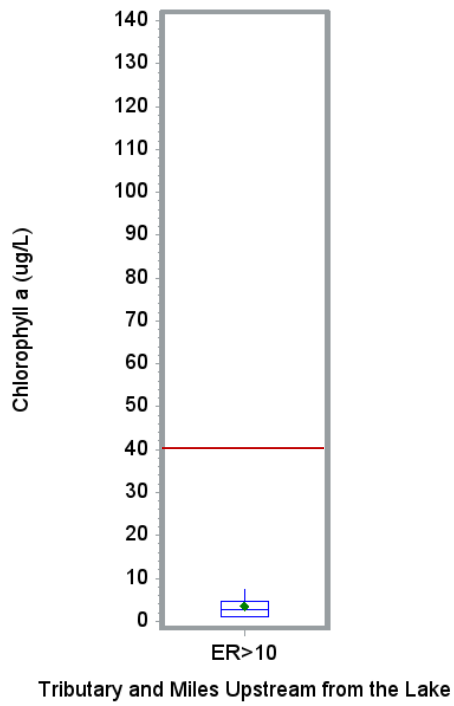



**Figure 3-213 Chlorophyll *a* Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake**

**Table 3-222 Chlorophyll *a* Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake (in µg/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| ER>10 | 182 | 1.0 | 1.0 | 1.0 | 3.62 | 2.7 | 4.7 | 7.3 | 20.0 |

### *Chlorophyll a Tributary Samples Categorized by Depth*

> All samples were collected in the surface layer.

### *Chlorophyll a Tributary Categorized by Year*

> Chlorophyll *a* concentrations were higher in 2010.

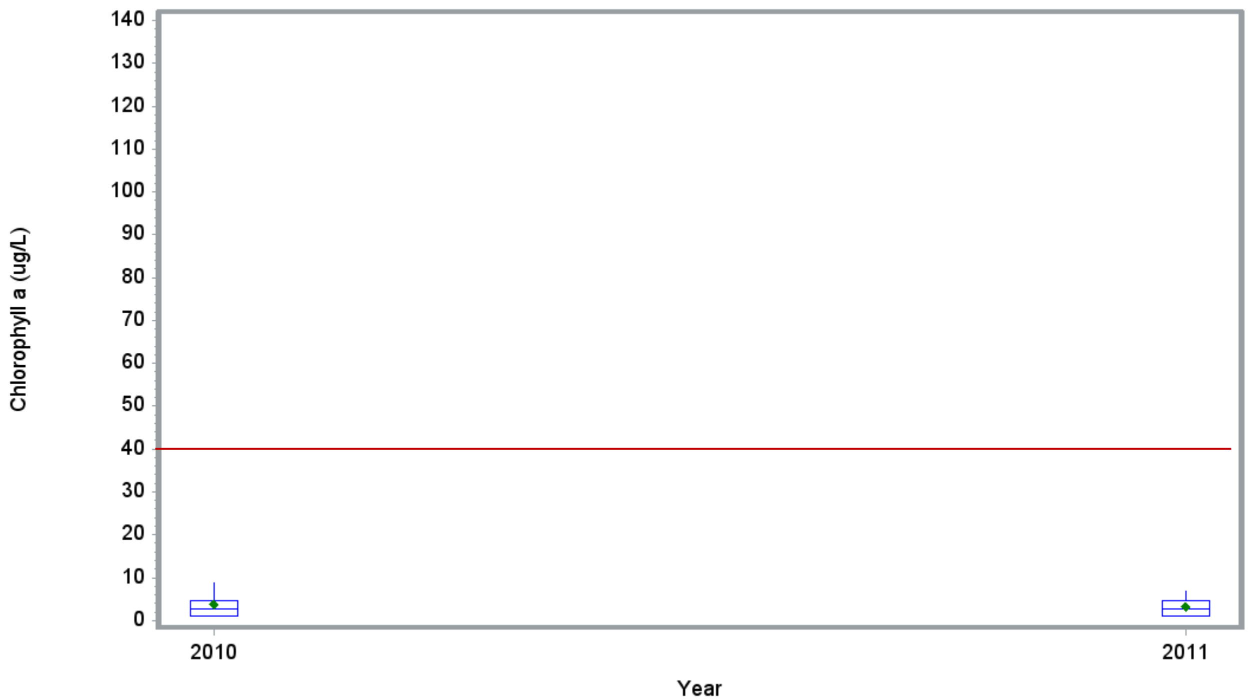



**Figure 3-214 Chlorophyll *a* Tributary Samples Categorized by Year**

**Table 3-223 Chlorophyll *a* Tributary Samples Categorized by Year (in µg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2010 | 140 | 1.0 | 1.0 | 1.0 | 3.71 | 2.7 | 4.7 | 8.7 | 20.0 |
| 2011 | 42 | 1.0 | 1.0 | 1.0 | 3.30 | 2.7 | 4.7 | 6.7 | 10.0 |

### *Chlorophyll a Tributary Samples Categorized by Month*

> The highest mean and median concentrations were recorded in May and March.

> The lowest mean concentrations were recorded in October.

> Greatest variability was recorded in May and September.

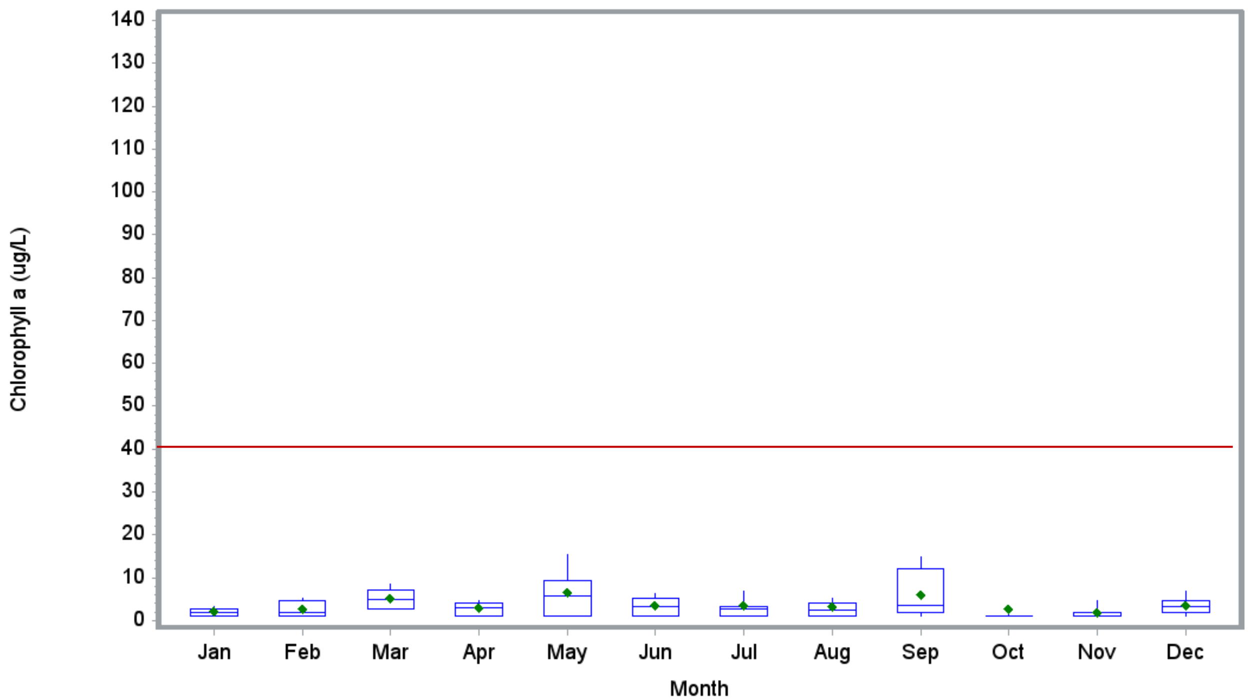



**Figure 3-215 Chlorophyll *a* Tributary Samples Categorized by Month**

**Table 3-224 Chlorophyll *a* Tributary Samples Categorized by Month (in µg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 14 | 1.0 | 1.0 | 1.0 | 2.04 | 2.0 | 2.7 | 3.3 | 4.0 |
| Feb | 14 | 1.0 | 1.0 | 1.0 | 2.69 | 1.9 | 4.7 | 5.3 | 5.3 |
| Mar | 14 | 2.0 | 2.7 | 2.7 | 5.16 | 5.0 | 7.0 | 8.4 | 10.0 |
| Apr | 14 | 1.0 | 1.0 | 1.0 | 2.85 | 3.0 | 4.0 | 4.6 | 8.7 |
| May | 14 | 1.0 | 1.0 | 1.0 | 6.69 | 5.9 | 9.3 | 15.4 | 16.7 |
| Jun | 14 | 1.0 | 1.0 | 1.0 | 3.41 | 3.4 | 5.3 | 6.3 | 6.7 |
| Jul | 21 | 1.0 | 1.0 | 1.0 | 3.57 | 2.7 | 3.3 | 6.7 | 16.0 |
| Aug | 14 | 1.0 | 1.0 | 1.0 | 3.19 | 2.4 | 4.0 | 5.3 | 11.3 |
| Sep | 14 | 1.0 | 1.0 | 2.0 | 6.00 | 3.7 | 12.0 | 14.7 | 18.0 |
| Oct | 14 | 1.0 | 1.0 | 1.0 | 2.59 | 1.0 | 1.0 | 3.3 | 20.0 |
| Nov | 14 | 1.0 | 1.0 | 1.0 | 1.81 | 1.0 | 2.0 | 4.7 | 5.3 |
| Dec | 21 | 1.0 | 1.0 | 2.0 | 3.49 | 3.3 | 4.7 | 6.7 | 7.3 |

***Chlorophyll a Tributary Samples Categorized by Sampling Organization***

> All samples were collected by Orange County.

***Chlorophyll a Tributary Samples Categorized by Method***

> All samples were collected using the SM 10200H method.

### 3.18.3 Upper Lake Samples

Four organizations measured chlorophyll *a* concentrations in upper Falls Lake from 2001 to present. Highest concentrations were recorded by NCSU-CAAE and NCDWQ. Highest mean concentrations were measured in the 18 to 21 mile section upstream of the dam and in the 1 to 2 meter and 2 to 4 meter depth layers. Lowest mean concentrations were recorded in the 13 to 18 mile section as well as the surface layer. Box plot summaries are provided below.

***Chlorophyll a Samples Categorized by Lake Segment and Miles Upstream from Dam***

> The highest mean and median concentrations were measured in the 18 to 21 mile section.

> The lowest mean and median concentrations were measured in the 13 to 18 mile section.

> The 75th percentile values for the > 21 mile and the 18 to 21 mile segments exceeded the water quality standard.

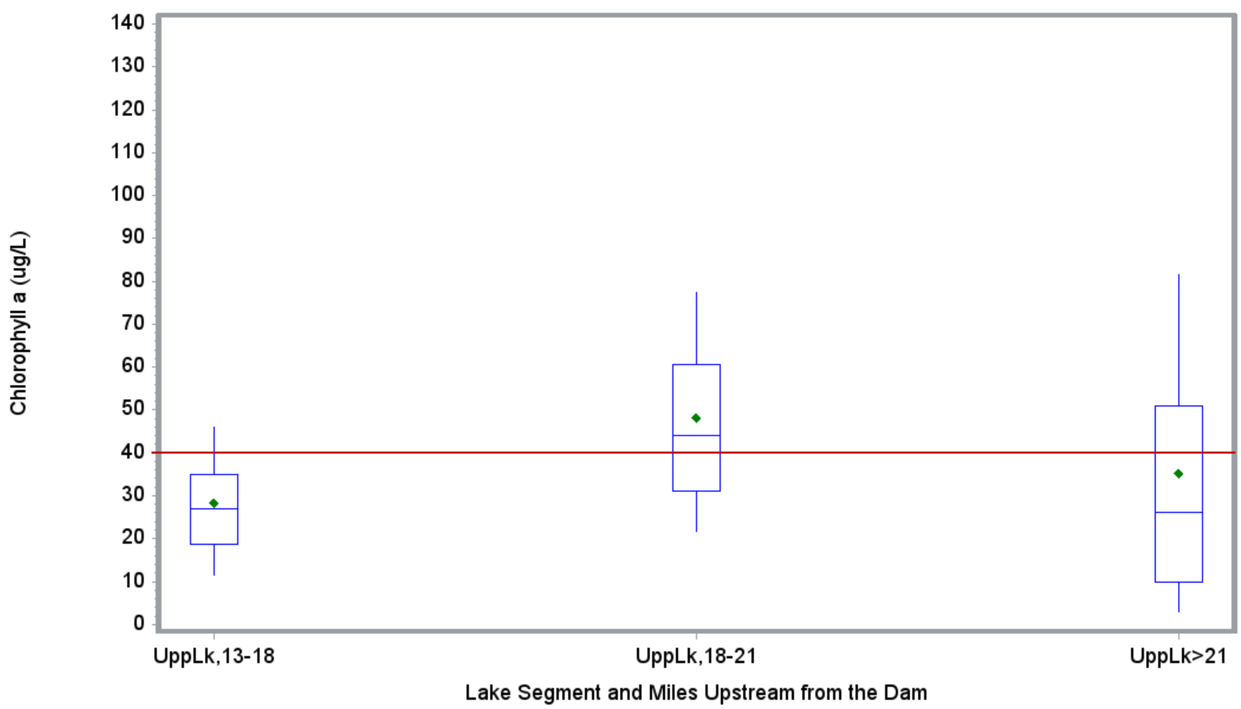



**Figure 3-216 Chlorophyll *a* Upper Lake Samples Categorized by Lake Segment and Miles Upstream from the Dam**

**Table 3-225 Chlorophyll *a* Upper Lake Samples Categorized by Lake Segment and Miles Upstream from the Dam (in µg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 433 | 0.3 | 11.6 | 18.7 | 28.30 | 27.0 | 35.0 | 46.0 | 121.0 |
| UppLk,18-21 | 160 | 3.0 | 21.7 | 31.0 | 48.26 | 44.0 | 60.5 | 77.5 | 173.0 |

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk>21 | 911 | 1.0 | 3.0 | 10.0 | 35.36 | 26.0 | 51.0 | 81.6 | 230.0 |

### *Chlorophyll a Upper Lake Samples Categorized by Depth*

> Different data sets reported sampling depth differently: either numerically, or by "surface" or photic zone.

> The highest mean and median concentrations were measured in the 1 to 2 meter and 2 to 4 meter depth layers.

> The median values for 1 to 2 meter and 2 to 4 meter depth layers exceeded the water quality standard, while the 75$^{th}$ percentile for the other categories was at or exceeding the standard.

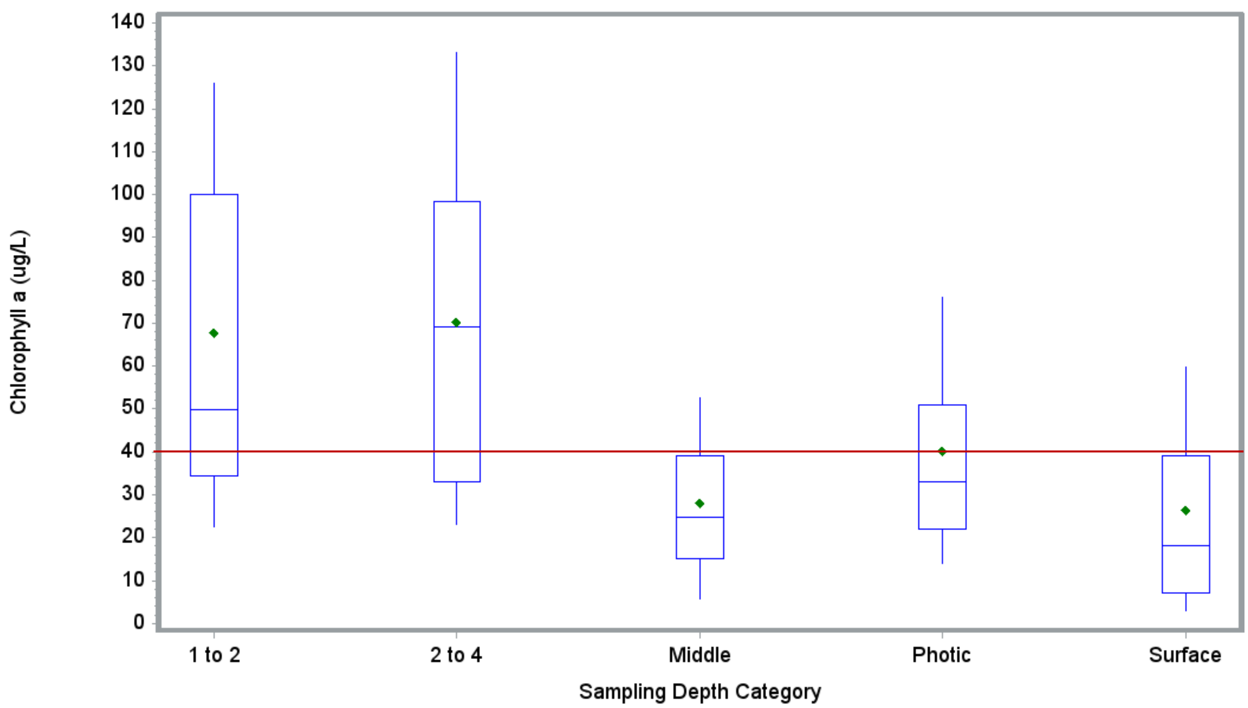



**Figure 3-217 Chlorophyll *a* Upper Lake Samples Categorized by Depth**

**Table 3-226 Chlorophyll *a* Upper Lake Samples Categorized by Depth (in µg/L)**

| Sampling Depth (m) | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1 to 2 | 18 | 19.9 | 22.6 | 34.4 | 67.76 | 49.8 | 100.0 | 126.0 | 153.0 |
| 2 to 4 | 34 | 15.1 | 23.0 | 32.9 | 70.13 | 69.3 | 98.4 | 133.0 | 135.0 |
| Middle | 44 | 1.5 | 5.8 | 15.1 | 28.02 | 24.9 | 39.1 | 52.5 | 75.6 |
| Photic | 736 | 0.3 | 14.0 | 22.0 | 40.28 | 33.0 | 50.9 | 76.0 | 230.0 |
| Surface | 672 | 1.0 | 3.0 | 7.0 | 26.34 | 18.0 | 39.1 | 59.8 | 135.0 |

### *Chlorophyll a Upper Lake Samples Categorized by Year*

- Highest mean and median concentrations were recorded in 2011 and 2001.
- The lowest mean and median concentrations were recorded in 2003 and 2002.
- The 75th percentile values exceeded the water quality standard in 8 out of 12 years of data collection.

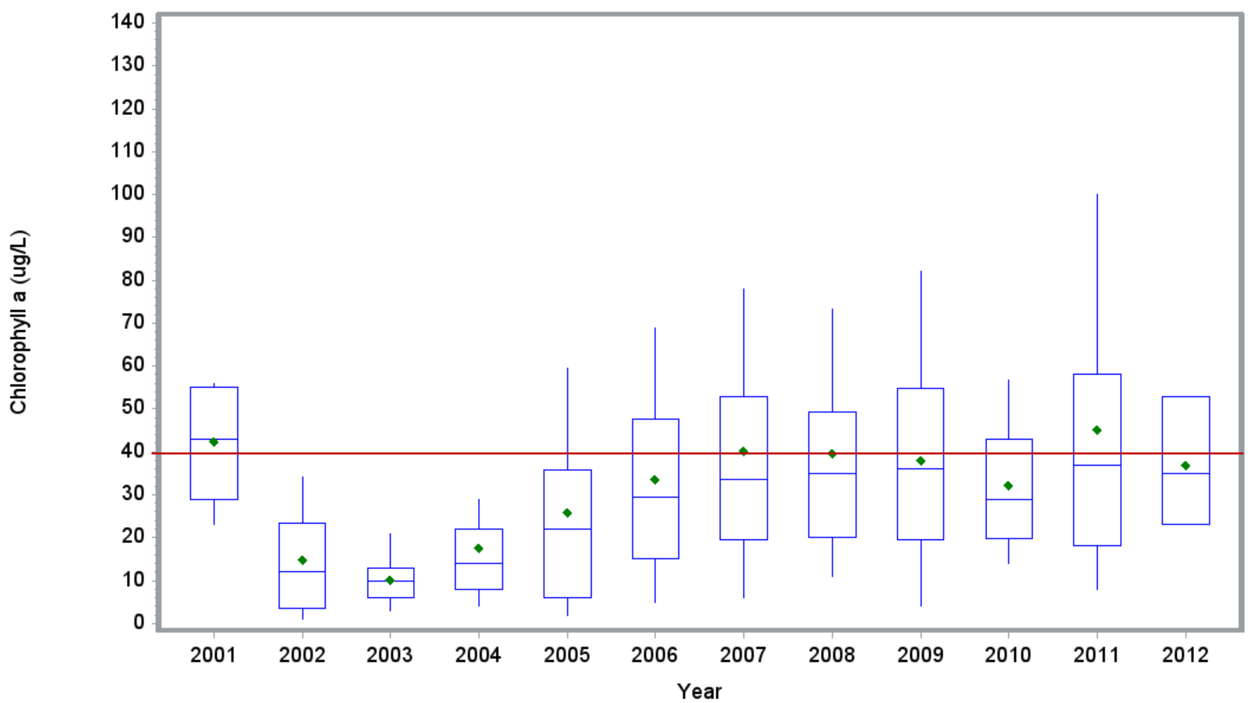



**Figure 3-218 Chlorophyll *a* Upper Lake Samples Categorized by Year**

**Table 3-227 Chlorophyll *a* Upper Lake Samples Categorized by Year (in µg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2001 | 15 | 22.0 | 23.0 | 29.0 | 42.53 | 43.0 | 55.0 | 56.0 | 79.0 |
| 2002 | 56 | 1.0 | 1.0 | 3.5 | 14.71 | 12.0 | 23.5 | 34.0 | 56.0 |
| 2003 | 59 | 1.0 | 3.0 | 6.0 | 10.25 | 10.0 | 13.0 | 21.0 | 25.0 |
| 2004 | 61 | 1.0 | 4.0 | 8.0 | 17.55 | 14.0 | 22.0 | 29.0 | 93.5 |
| 2005 | 121 | 1.0 | 2.0 | 6.0 | 25.81 | 22.0 | 35.9 | 59.6 | 126.0 |
| 2006 | 224 | 1.0 | 5.0 | 15.0 | 33.67 | 29.5 | 47.5 | 69.0 | 103.0 |
| 2007 | 208 | 1.0 | 6.0 | 19.5 | 40.17 | 33.5 | 52.9 | 78.0 | 230.0 |
| 2008 | 85 | 3.3 | 11.0 | 20.0 | 39.55 | 35.0 | 49.2 | 73.4 | 133.0 |
| 2009 | 76 | 1.5 | 4.0 | 19.5 | 38.01 | 36.0 | 54.8 | 82.0 | 135.0 |
| 2010 | 250 | 0.3 | 14.0 | 19.9 | 32.30 | 28.9 | 43.0 | 56.9 | 121.0 |
| 2011 | 346 | 0.5 | 8.0 | 18.0 | 45.06 | 36.8 | 58.0 | 100.0 | 205.0 |
| 2012 | 3 | 23.0 | 23.0 | 23.0 | 37.00 | 35.0 | 53.0 | 53.0 | 53.0 |

### *Chlorophyll a Upper Lake Samples Categorized by Month*

> The highest mean and median concentrations were measured in August.

> The lowest mean and median concentrations were measured in December.

> The 90th percentile values exceeded the water quality standard for all months except December.

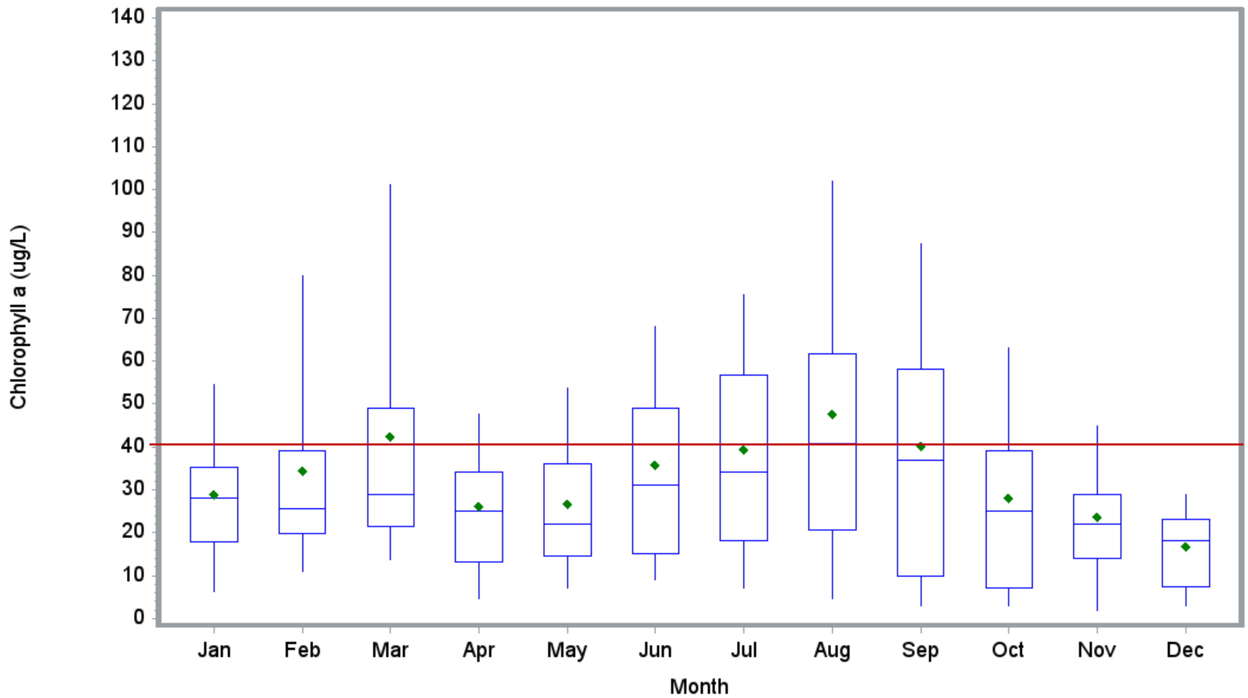



**Figure 3-219 Chlorophyll *a* Upper Lake Samples Categorized by Month**

**Table 3-228 Chlorophyll *a* Upper Lake Samples Categorized by Month (in µg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 43 | 1.5 | 6.3 | 17.8 | 29.0 | 28.0 | 35.3 | 54.5 | 82.0 |
| Feb | 46 | 2.8 | 11.0 | 19.9 | 34.32 | 25.5 | 39.0 | 80.0 | 103.0 |
| Mar | 76 | 0.5 | 13.6 | 21.5 | 42.28 | 29.0 | 49.0 | 101.0 | 138.0 |
| Apr | 170 | 0.8 | 4.5 | 13.2 | 26.01 | 25.2 | 34.0 | 47.5 | 110.0 |
| May | 169 | 0.6 | 7.0 | 14.5 | 26.64 | 22.0 | 36.0 | 53.6 | 110.0 |
| Jun | 190 | 1.0 | 9.0 | 15.0 | 35.86 | 31.0 | 49.0 | 68.0 | 160.0 |
| Jul | 193 | 1.0 | 7.0 | 18.0 | 39.37 | 34.2 | 56.7 | 75.5 | 180.0 |
| Aug | 214 | 1.0 | 4.6 | 20.6 | 47.63 | 40.7 | 61.7 | 102.0 | 230.0 |
| Sep | 163 | 1.0 | 3.0 | 10.0 | 40.29 | 37.0 | 58.0 | 87.3 | 173.0 |
| Oct | 145 | 1.0 | 3.0 | 7.0 | 27.98 | 25.0 | 39.0 | 63.0 | 113.0 |
| Nov | 59 | 0.3 | 2.0 | 14.0 | 23.56 | 22.0 | 29.0 | 45.0 | 77.0 |
| Dec | 36 | 1.5 | 3.0 | 7.5 | 16.78 | 18.0 | 23.0 | 29.0 | 41.0 |

### *Chlorophyll a Upper Lake Samples Categorized by Sampling Organization*

> By sampling organization, the highest mean and median concentrations were recorded by NCSU-CAAE and NCDWQ.

> Lowest mean concentrations were recorded by City of Durham and USGS.

> The mean concentrations recorded by NCSU-CAAE and NCDWQ exceeded water quality standards.

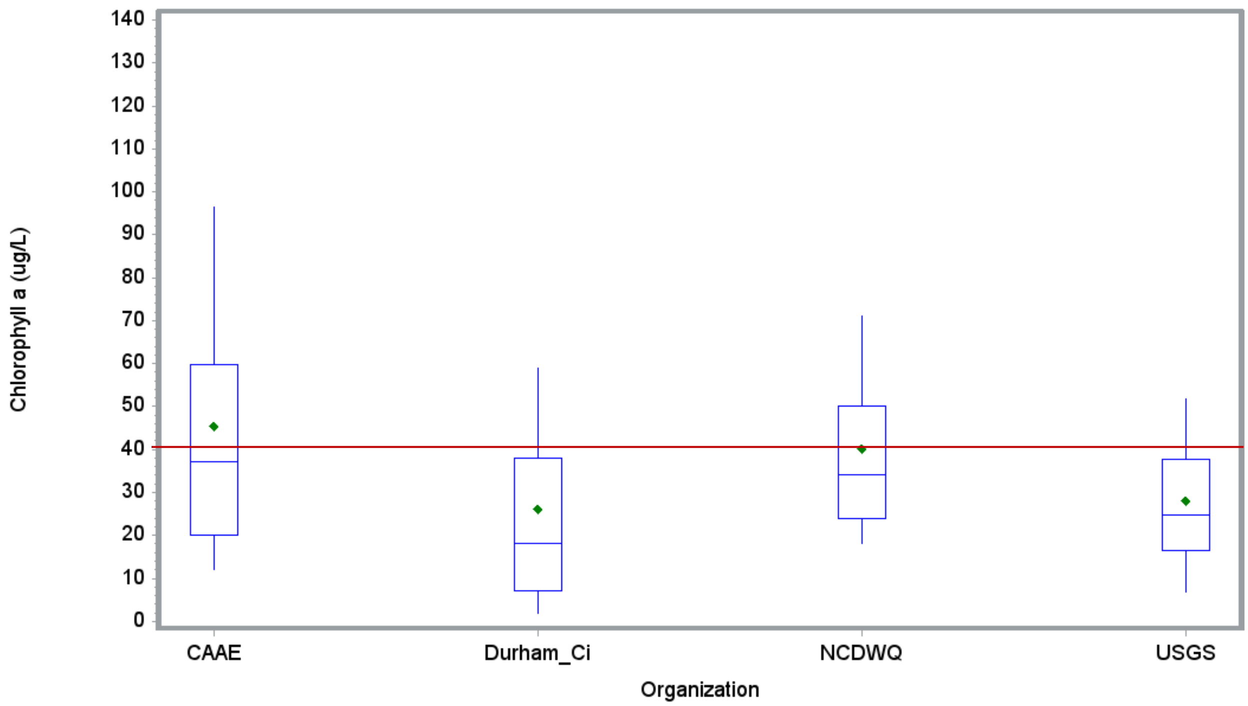



**Figure 3-220 Chlorophyll *a* Upper Lake Samples Categorized by Organization**

**Table 3-229 Chlorophyll *a* Upper Lake Samples Categorized by Organization (in µg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 329 | 0.3 | 12.1 | 20.0 | 45.39 | 37.2 | 59.8 | 96.4 | 205.0 |
| Durham_Ci | 663 | 1.0 | 2.0 | 7.0 | 26.24 | 18.0 | 38.0 | 59.0 | 140.0 |
| NCDWQ | 452 | 3.0 | 18.0 | 24.0 | 40.22 | 34.0 | 50.0 | 71.0 | 230.0 |
| USGS | 60 | 1.5 | 6.9 | 16.5 | 27.93 | 24.9 | 37.7 | 51.7 | 75.6 |

### *Chlorophyll a Upper Lake Samples Categorized by Method*

> .Highest mean and median concentrations were measured using CAAE 370 and EPA 445.0 methods and the lowest concentrations were measured using ‘Various’ and unknown methods.

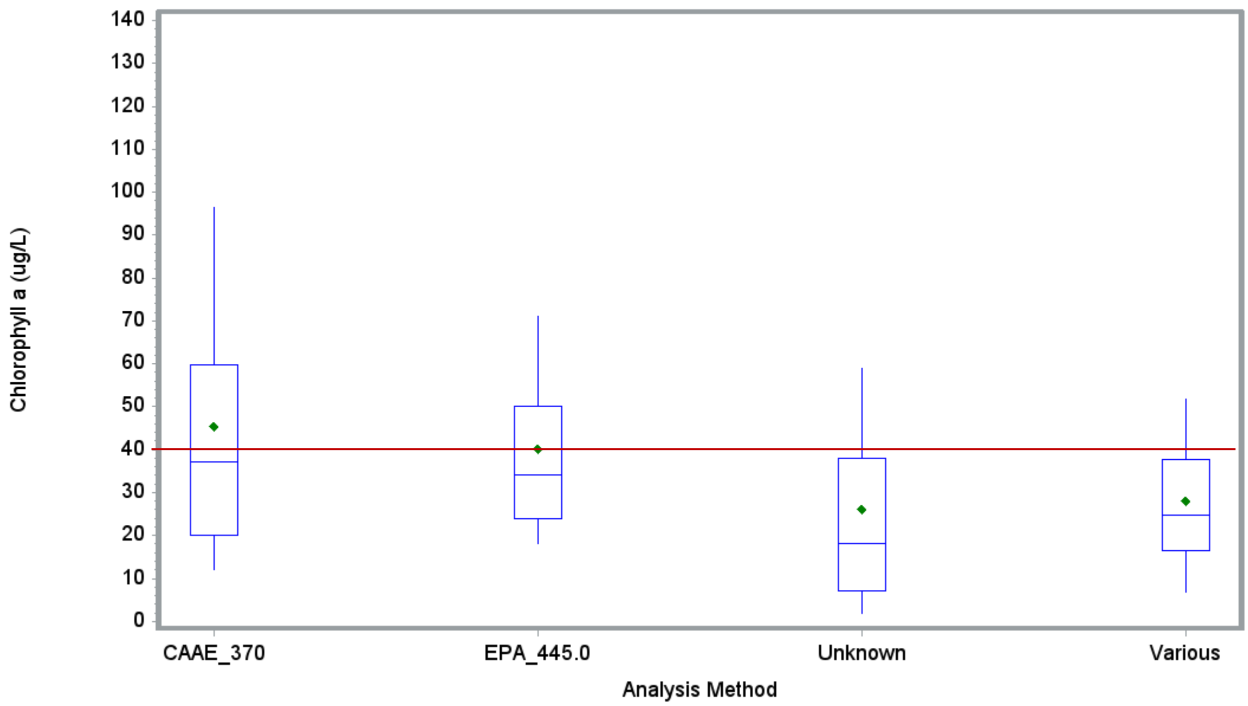



**Figure 3-221 Chlorophyll *a* Upper Lake Samples Categorized by Analysis Method**

**Table 3-230 Chlorophyll *a* Upper Lake Samples Categorized by Analysis Method (in µg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE_370 | 329 | 0.3 | 12.1 | 20.0 | 45.39 | 37.2 | 59.8 | 96.4 | 205.0 |
| EPA_445.0 | 452 | 3.0 | 18.0 | 24.0 | 40.22 | 34.0 | 50.0 | 71.0 | 230.0 |
| Unknown | 663 | 1.0 | 2.0 | 7.0 | 26.2 | 18.0 | 38.0 | 59.0 | 140.0 |
| Various | 60 | 1.5 | 6.9 | 16.5 | 27.9 | 24.9 | 37.7 | 51.7 | 75.6 |

### 3.18.4 Lower Lake Samples

Four organizations measured chlorophyll *a* concentrations in lower Falls Lake from 2001 to present. Highest mean and median concentrations were recorded by NCDWQ. Lowest mean concentrations were measured in the 0 to 4 mile section upstream of the dam and in the 8 to 10 meter depth layers. Highest mean concentrations were recorded in 2012 and from 2005 to 2008. Box plot summaries are provided below.

***Chlorophyll a Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Mean and median concentrations were similar by segment, with highest concentrations in the 8 to 13 segment.

> The 90$^{th}$ percentile values are less than the water quality standard in all segments.

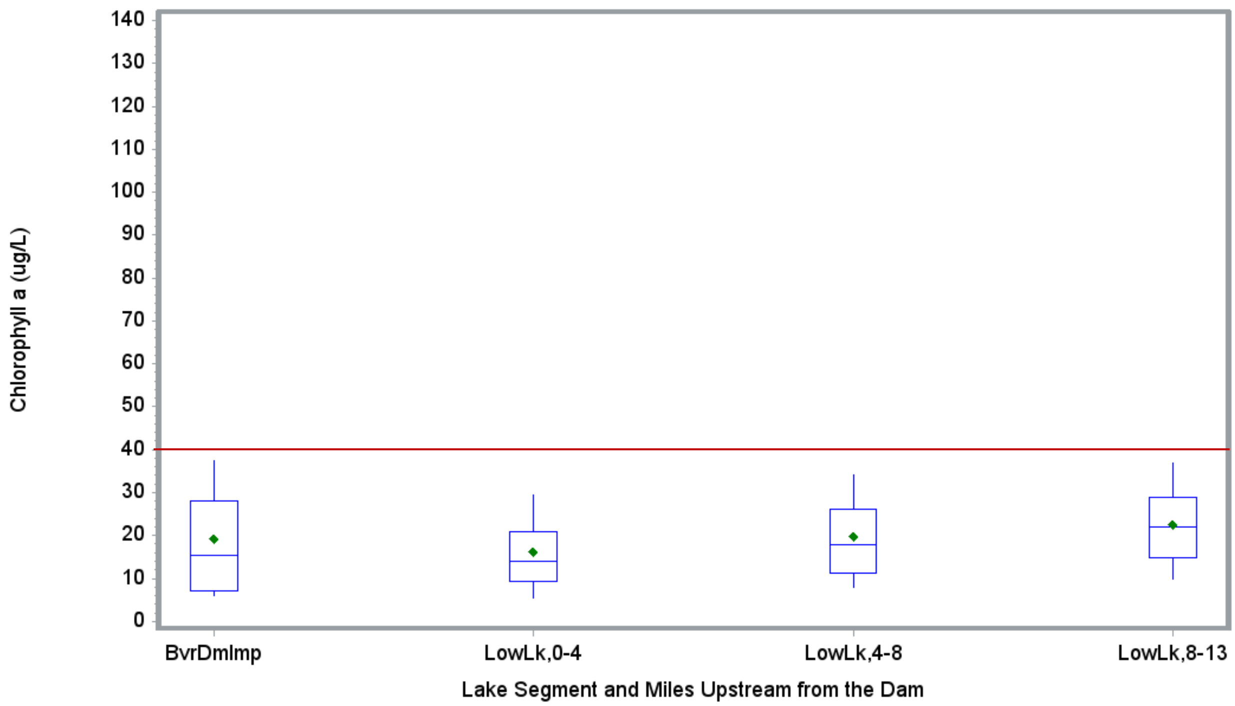



**Figure 3-222 Chlorophyll *a* Lower Lake Samples Categorized by Lake Segment and Miles Upstream from the Dam**

**Table 3-231 Chlorophyll *a* Lower Lake Samples Categorized by Lake Segment and Miles Upstream from the Dam (in µg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 120 | 3.6 | 6.0 | 7.0 | 19.19 | 15.5 | 28.2 | 37.3 | 69.7 |
| LowLk,0-4 | 617 | 1.0 | 5.4 | 9.3 | 16.32 | 14.0 | 21.0 | 29.5 | 110.0 |
| LowLk,4-8 | 434 | 2.0 | 7.8 | 11.2 | 19.67 | 17.8 | 26.0 | 34.0 | 60.8 |
| LowLk,8-13 | 353 | 3.6 | 9.9 | 14.9 | 22.46 | 21.9 | 29.0 | 36.8 | 73.0 |

### *Chlorophyll a Lower Lake Samples Categorized by Depth*

- By depth, lowest mean and median concentrations were measured in the 8 to 10 meter depth layer, however there was small sample size (n=5).
- Concentrations in the surface layer, photic zone, and shallower depth layers were similar.
- The 90$^{th}$ percentile values were below the water quality standard.

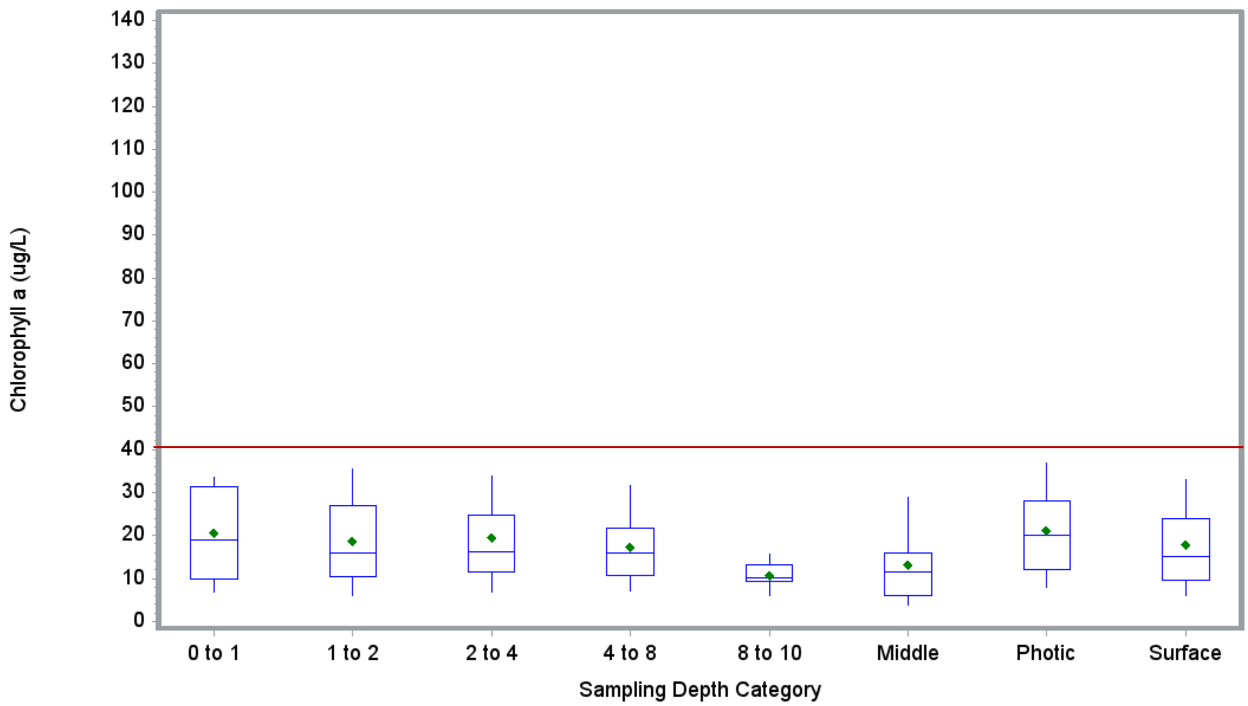



**Figure 3-223 Chlorophyll *a* Lower Lake Samples Categorized by Depth**

**Table 3-232 Chlorophyll *a* Lower Lake Samples Categorized by Depth (in µg/L)**

| Sampling Depth (m) | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 0 to 1 | 10 | 6.6 | 6.9 | 10.0 | 20.5 | 19.1 | 31.4 | 33.7 | 35.2 |
| 1 to 2 | 135 | 2.7 | 6.1 | 10.4 | 18.69 | 16.0 | 26.9 | 35.4 | 53.4 |
| 2 to 4 | 141 | 2.7 | 6.8 | 11.5 | 19.39 | 16.2 | 24.8 | 33.9 | 110.0 |
| 4 to 8 | 139 | 3.3 | 7.1 | 10.8 | 17.42 | 15.9 | 21.8 | 31.7 | 46.7 |
| 8 to 10 | 5 | 6.0 | 6.0 | 9.3 | 10.82 | 10.1 | 13.1 | 15.6 | 15.6 |
| Middle | 39 | 1.9 | 3.8 | 6.1 | 13.27 | 11.6 | 15.8 | 29.0 | 43.2 |
| Photic | 447 | 2.6 | 7.9 | 12.0 | 21.29 | 20.0 | 28.0 | 37.0 | 58.0 |
| Surface | 608 | 1.0 | 6.0 | 9.7 | 17.87 | 15.0 | 24.0 | 33.1 | 77.0 |

### *Chlorophyll a Lower Lake Categorized by Year*

- Chlorophyll *a* was measured from 2001 to 2012.
- The highest mean and median concentrations were recorded in 2012 and 2006, however, the 2012 dataset only represents the first part of the year and has a small sample size (n=12).
- The lowest mean concentrations were recorded in 2010 and 2004.
- The 90$^{th}$ percentile values were at or above the water quality standard for 2 of the 12 years of available data.

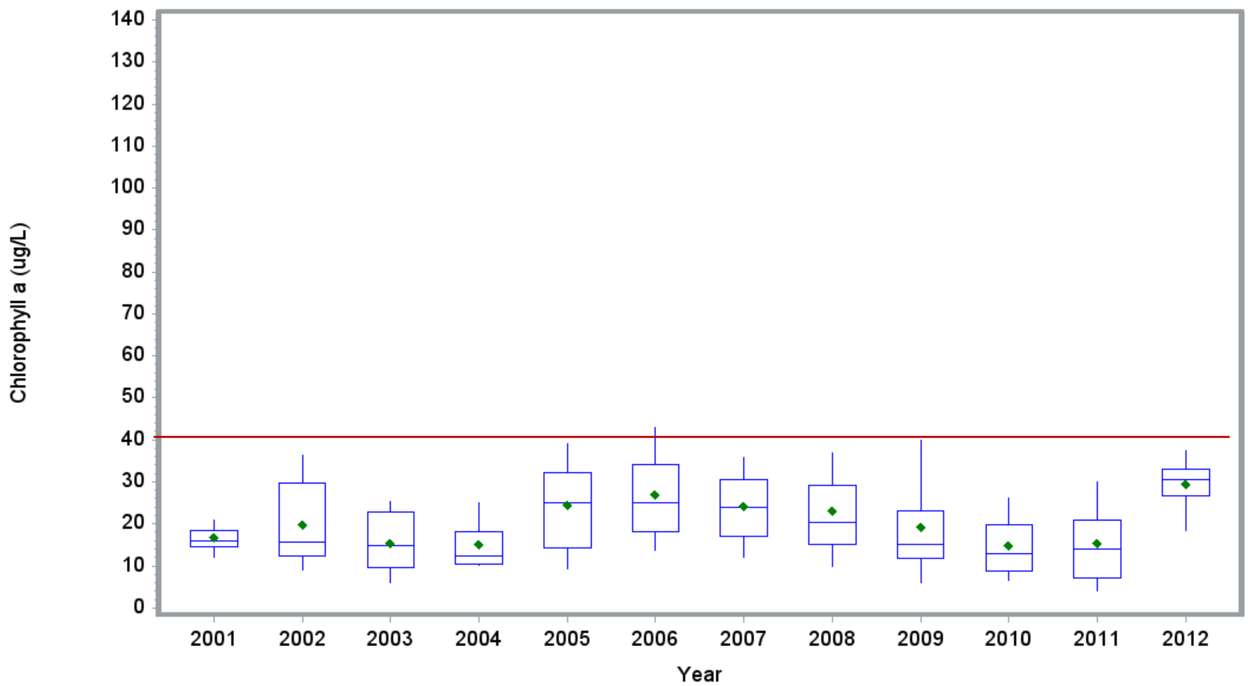



**Figure 3-224 Chlorophyll *a* Lower Lake Samples Categorized by Year**

**Table 3-233 Chlorophyll *a* Lower Lake Samples Categorized by Year (in µg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2001 | 16 | 11.0 | 12.0 | 14.5 | 16.63 | 16.0 | 18.5 | 21.0 | 25.0 |
| 2002 | 6 | 9.1 | 9.1 | 12.3 | 19.80 | 15.7 | 29.6 | 36.4 | 36.4 |
| 2003 | 6 | 6.0 | 6.0 | 9.6 | 15.52 | 14.8 | 22.7 | 25.3 | 25.3 |
| 2004 | 10 | 10.0 | 10.1 | 10.3 | 15.02 | 12.4 | 18.1 | 25.2 | 29.0 |
| 2005 | 87 | 2.9 | 9.3 | 14.2 | 24.61 | 25.0 | 32.1 | 39.2 | 110.0 |
| 2006 | 136 | 6.0 | 13.7 | 18.0 | 27.05 | 25.0 | 34.0 | 43.0 | 60.8 |
| 2007 | 138 | 8.4 | 12.0 | 17.0 | 24.13 | 24.0 | 30.6 | 35.7 | 50.0 |
| 2008 | 163 | 4.0 | 9.9 | 15.0 | 23.09 | 20.3 | 29.2 | 36.8 | 69.7 |
| 2009 | 155 | 4.0 | 6.0 | 11.7 | 19.18 | 15.0 | 23.0 | 40.0 | 77.0 |
| 2010 | 404 | 3.5 | 6.6 | 8.9 | 14.85 | 13.0 | 19.9 | 26.0 | 41.3 |
| 2011 | 391 | 1.0 | 4.0 | 7.2 | 15.28 | 14.0 | 21.0 | 30.0 | 57.5 |
| 2012 | 12 | 18.3 | 18.3 | 26.6 | 29.37 | 30.5 | 33.1 | 37.3 | 37.3 |

### *Chlorophyll a Lower Lake Samples Categorized by Month*

> By month, the highest mean and median concentrations were measured in February and March. The lowest mean and median concentrations were measured in May and June.

> The 90th percentile values for February and March were the only data to exceed the water quality standard.

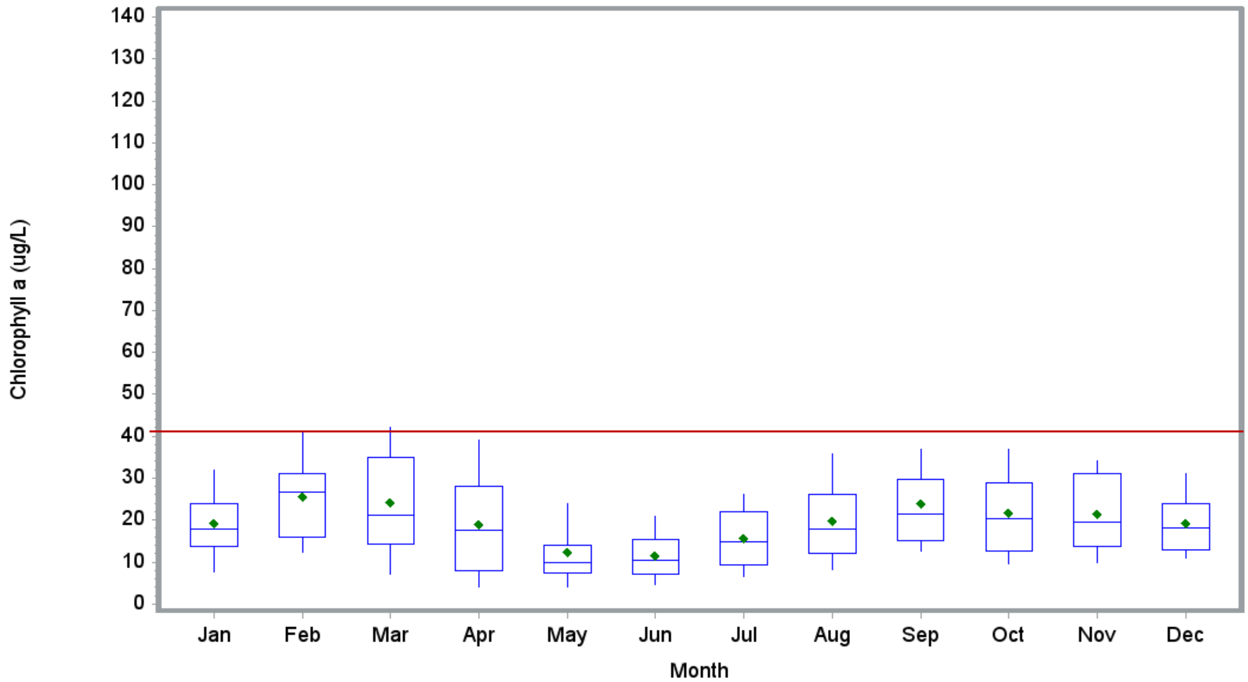



**Figure 3-225 Chlorophyll *a* Lower Lake Samples Categorized by Month**

**Table 3-234 Chlorophyll *a* Lower Lake Samples Categorized by Month (in µg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 84 | 3.7 | 7.6 | 13.7 | 19.32 | 17.8 | 24.0 | 32.0 | 44.0 |
| Feb | 83 | 4.0 | 12.4 | 16.0 | 25.55 | 26.6 | 31.0 | 41.0 | 60.8 |
| Mar | 118 | 4.0 | 7.0 | 14.3 | 24.15 | 21.2 | 34.9 | 42.0 | 77.0 |
| Apr | 126 | 1.9 | 4.0 | 7.8 | 19.09 | 17.5 | 28.2 | 39.0 | 54.6 |
| May | 151 | 1.0 | 4.0 | 7.3 | 12.45 | 10.0 | 14.1 | 24.0 | 110.0 |
| Jun | 159 | 2.0 | 4.6 | 7.0 | 11.66 | 10.4 | 15.4 | 21.0 | 29.5 |
| Jul | 174 | 3.4 | 6.6 | 9.3 | 15.72 | 14.9 | 22.0 | 26.0 | 34.8 |
| Aug | 188 | 2.9 | 8.3 | 12.1 | 19.85 | 18.0 | 26.2 | 35.8 | 46.0 |
| Sep | 133 | 6.0 | 12.7 | 15.2 | 23.89 | 21.5 | 29.8 | 37.0 | 69.7 |
| Oct | 124 | 5.3 | 9.7 | 12.5 | 21.70 | 20.4 | 29.0 | 37.0 | 44.8 |
| Nov | 103 | 4.6 | 10.0 | 13.6 | 21.44 | 19.5 | 31.0 | 34.0 | 73.0 |
| Dec | 81 | 4.5 | 11.0 | 13.0 | 19.31 | 18.0 | 24.0 | 31.0 | 36.0 |

***Chlorophyll a Lower Lake Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded by NCDWQ.

> Lowest mean concentrations were recorded by City of Raleigh and USGS.

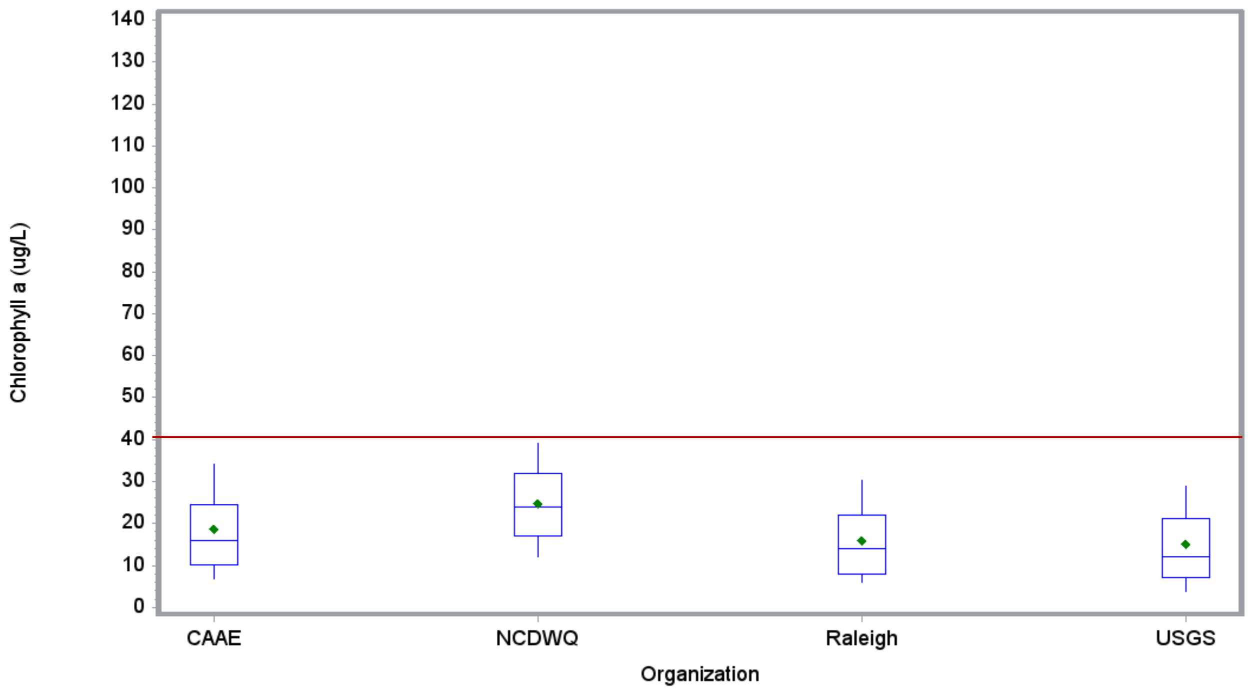



**Figure 3-226 Chlorophyll *a* Lower Lake Samples Categorized by Organization**

**Table 3-235 Chlorophyll *a* Lower Lake Samples Categorized by Organization (in µg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 737 | 2.6 | 6.7 | 10.2 | 18.69 | 16.0 | 24.6 | 34.0 | 110.0 |
| NCDWQ | 301 | 3.4 | 12.0 | 17.0 | 24.63 | 24.0 | 32.0 | 39.0 | 58.0 |
| Raleigh | 423 | 1.0 | 6.0 | 8.0 | 15.84 | 14.0 | 22.0 | 30.2 | 46.0 |
| USGS | 63 | 1.9 | 3.9 | 7.2 | 15.1 | 12.1 | 21.3 | 29.0 | 44.7 |

### *Chlorophyll a Lower Lake Samples Categorized by Method*

- > Concentrations were similar by using the four methods.
- > Highest mean and median concentrations were measured using EPA 445.0 method and the lowest concentrations were measured using unknown methods.

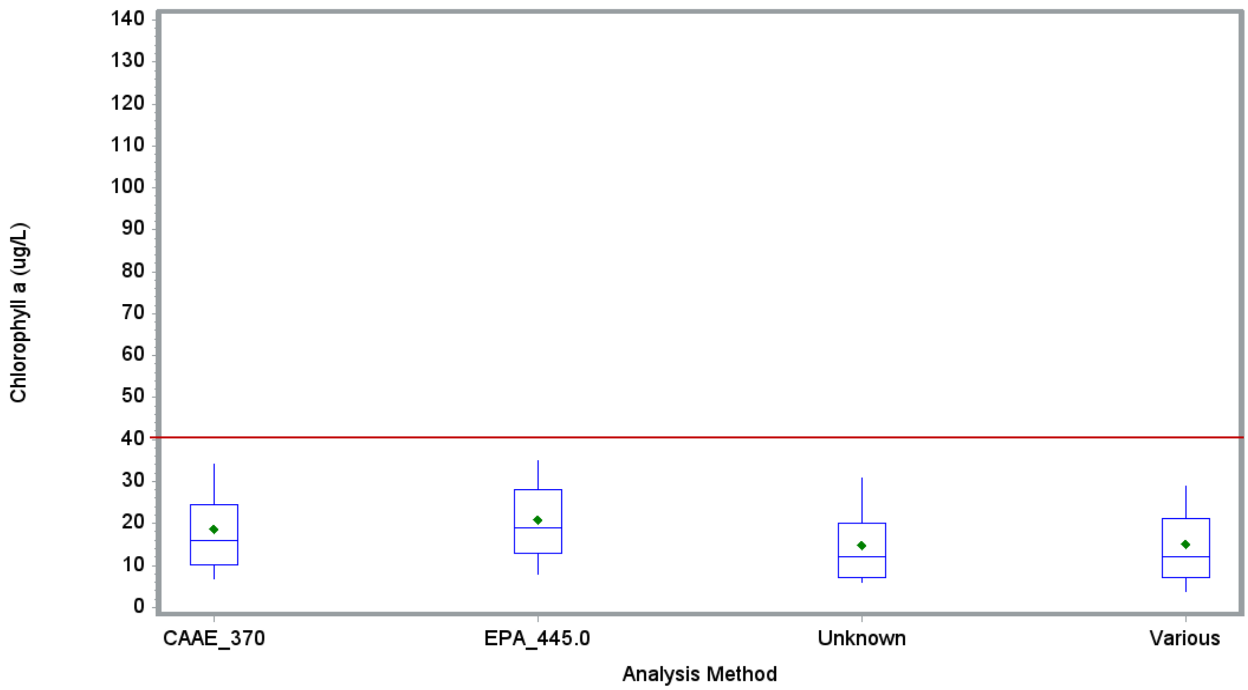



**Figure 3-227 Chlorophyll *a* Lower Lake Samples Categorized by Analysis Method**

**Table 3-236 Chlorophyll *a* Lower Lake Samples Categorized by Analysis Method (in µg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE_370 | 737 | 2.6 | 6.7 | 10.2 | 18.69 | 16.0 | 24.6 | 34.0 | 110.0 |
| EPA_445.0 | 570 | 1.0 | 8.0 | 13.0 | 20.78 | 19.0 | 28.0 | 35.0 | 58.0 |
| Unknown | 154 | 3.6 | 6.0 | 7.0 | 14.74 | 12.0 | 20.2 | 30.7 | 45.7 |
| Various | 63 | 1.9 | 3.9 | 7.2 | 15.1 | 12.1 | 21.3 | 29.0 | 44.7 |

## 3.19 Total Organic Carbon (TOC)

Four organizations measured total organic carbon (TOC) as part of the water quality sampling effort. TOC was measured in the laboratory. For those organizations that provided method, the following were used:

- Organic carbon, total, combustion or oxidation (EPA 415.1)
- Standard method TOC, combustion infrared method (SM18_5310_B)
- Standard method TOC, persulfate-ultraviolet or heated-persulfate oxidation method (SM 5310C)
- Carbon, organic, total, wet oxidation (USGS O-3100-83)
- Total organic carbon, high temperature combustion method (CAAE 390)

Appendix E provides detailed descriptions of these methods.

Table 3-237 describes the organizations and the analysis methods used to measure TOC and includes the number of samples, date range, and limits. The majority of the TOC data has been collected by the City of Raleigh using method SM_5310C. TOC is presented in mg/L and to two decimal places based on reported data.

**Table 3-237 Summary of Analysis Methods for the TOC Samples**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (mg/L) | Reporting Limit (mg/L) | Practical Quantification Limit (mg/L) | Range of Limit Specified with Results (mg/L)[1] |
|---|---|---|---|---|---|---|---|---|
| CAAE | CAAE_390 | 07/24/2007 | 12/17/2010 | 64 | Not Provided | Not Provided | Not Provided | NA |
| Durham_Ci | SM_5310C | 07/23/2009 | 12/20/2011 | 19 | Not Provided | 0.5 | Not Provided | NA |
| Durham_Ci | Unknown | 04/02/2012 | 04/30/2012 | 5 | Not Provided | Not Provided | Not Provided | NA |
| NCDWQ | EPA_415.1 | 02/26/2001 | 02/26/2001 | 5 | Not Provided | 0.1244 | Not Provided | NA |
| NCDWQ | SM18_5310_B | 03/15/2005 | 12/06/2011 | 703 | Not Provided | 0.1244 | Not Provided | NA |
| Raleigh | SM_5310C | 02/07/2000 | 12/30/2011 | 802 | 0.08 | 0.5 | 0.5 | NA |
| USGS | USGS_O-3100-83 | 02/19/1999 | 10/25/2011 | 297 | Not Provided | Not Provided | Not Provided | NA |

[1] None of the organizations reported TOC values with a “<” qualifier.

### 3.19.2 Tributary Samples

Three organizations measured total organic carbon (TOC) concentrations in Falls Lake tributaries from 1999 to 2011. Highest mean and median concentrations were recorded by USGS and lowest mean and median concentrations were recorded by NCDWQ. Highest and median concentrations were recorded in Knap of Reeds Creek and lowest mean concentrations were recorded in the Flat River and Eno River. Overall, sampling size is small (n=194). Box plot summaries are provided below.

***TOC Tributary Samples Categorized by Subwatershed and Miles Upstream from the Lake***

> Total organic carbon was recorded in six catchments: Ellerbe Creek, Eno River, Flat River, Knap of Reeds Creek, Lick Creek, and Little River.

> Highest mean and median concentrations were measured in Knap of Reeds Creek overall

> By section, highest mean concentrations were measured in the 0 to 2 mile segments of Ellerbe Creek, Knap of Reeds Creek, and Lick Creek.

> Lowest mean and median concentrations were measured in Eno River and Flat River overall.

> By segment, lowest mean and median concentrations were measured in the 2 to 10 mile segment of Ellerbe Creek and the 0 to 2 mile segment of Eno River.

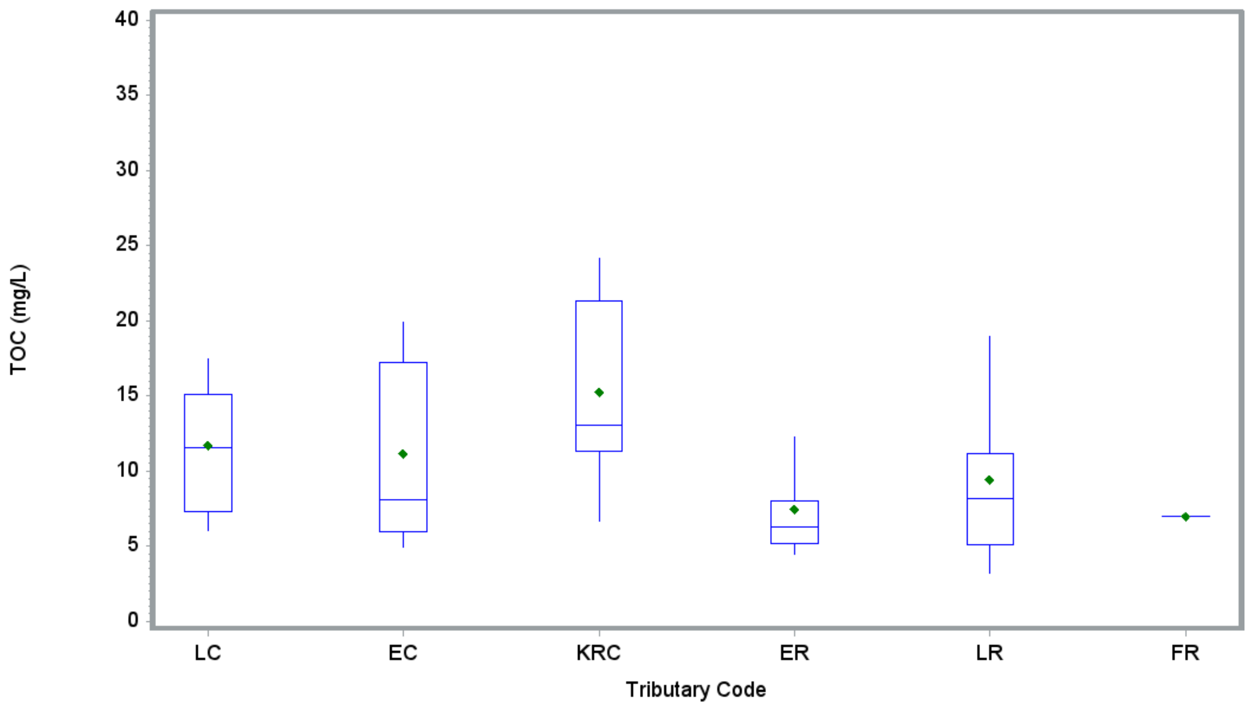



**Figure 3-228 TOC Tributary Samples Categorized by Subwatershed**

**Table 3-238 TOC Tributary Samples Categorized by Subwatershed (in mg/L)**

| Sub-watershed | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LC | 9 | 6.07 | 6.07 | 7.27 | 11.70 | 11.60 | 15.10 | 17.50 | 17.50 |
| EC | 26 | 4.13 | 4.97 | 5.96 | 11.17 | 8.11 | 17.20 | 19.90 | 33.40 |
| KRC | 10 | 6.00 | 6.70 | 11.30 | 15.23 | 13.05 | 21.30 | 24.15 | 26.90 |
| ER | 95 | 3.20 | 4.50 | 5.20 | 7.44 | 6.30 | 8.00 | 12.30 | 26.60 |
| LR | 53 | 2.70 | 3.20 | 5.10 | 9.44 | 8.20 | 11.20 | 19.00 | 27.90 |
| FR | 1 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |

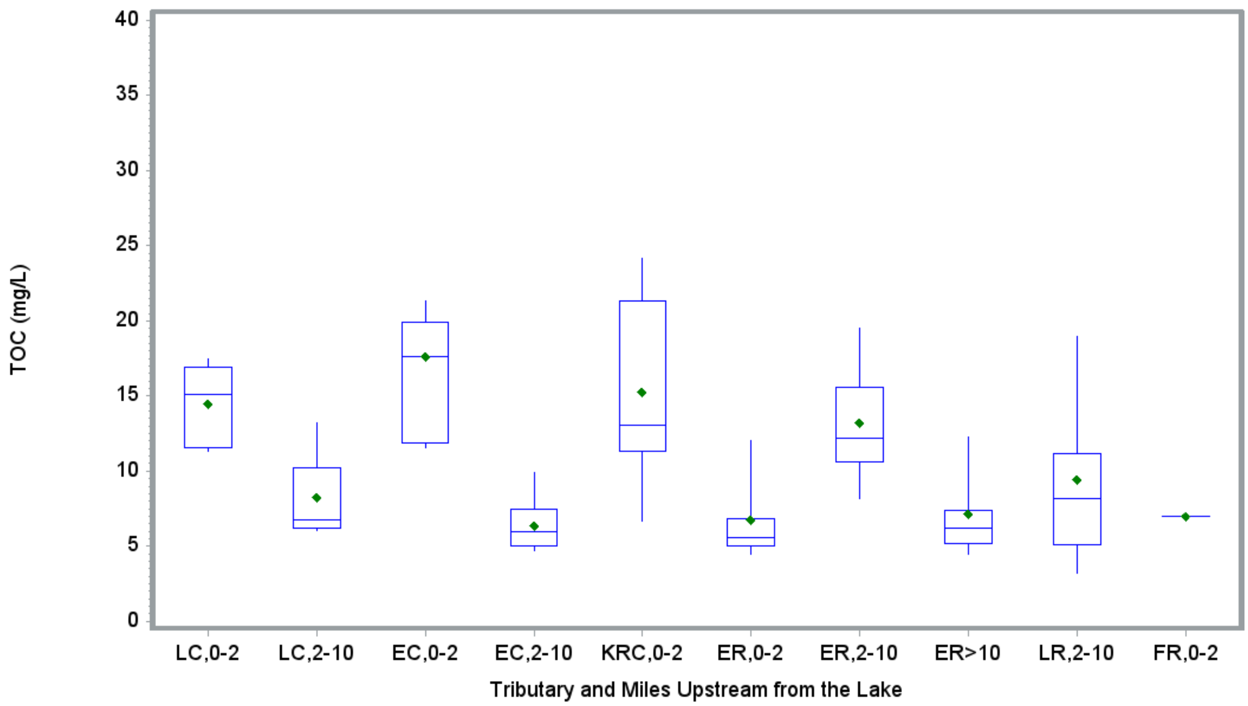



**Figure 3-229 TOC Tributary Samples Categorized by Miles Upstream from Mouth of Tributary**

**Table 3-239 TOC Tributary Samples Categorized by Miles Upstream from Mouth of Tributary (in mg/L)**

| Sub-watershed and Distance Upstream | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LC,0-2 | 5 | 11.30 | 11.30 | 11.60 | 14.48 | 15.10 | 16.90 | 17.50 | 17.50 |
| LC,2-10 | 4 | 6.07 | 6.07 | 6.20 | 8.22 | 6.80 | 10.24 | 13.20 | 13.20 |
| EC,0-2 | 11 | 8.00 | 11.60 | 11.90 | 17.66 | 17.60 | 19.90 | 21.30 | 33.40 |
| EC,2-10 | 15 | 4.13 | 4.74 | 4.99 | 6.40 | 5.97 | 7.48 | 9.93 | 10.46 |
| KRC,0-2 | 10 | 6.00 | 6.70 | 11.30 | 15.23 | 13.05 | 21.30 | 24.15 | 26.90 |
| ER,0-2 | 5 | 4.50 | 4.50 | 5.00 | 6.78 | 5.60 | 6.80 | 12.00 | 12.00 |
| ER,2-10 | 5 | 8.20 | 8.20 | 10.60 | 13.22 | 12.20 | 15.60 | 19.50 | 19.50 |
| ER>10 | 85 | 3.20 | 4.50 | 5.20 | 7.13 | 6.20 | 7.40 | 12.30 | 26.60 |
| LR,2-10 | 53 | 2.70 | 3.20 | 5.10 | 9.44 | 8.20 | 11.20 | 19.00 | 27.90 |
| FR,0-2 | 1 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |

### *TOC Tributary Samples Categorized by Depth*

> All samples were collected in the surface layer.

### *TOC Tributary Categorized by Year*

> The highest mean concentrations were recorded in 2011 and 2008.

> The lowest mean concentrations were recorded in 2000 and 2010.

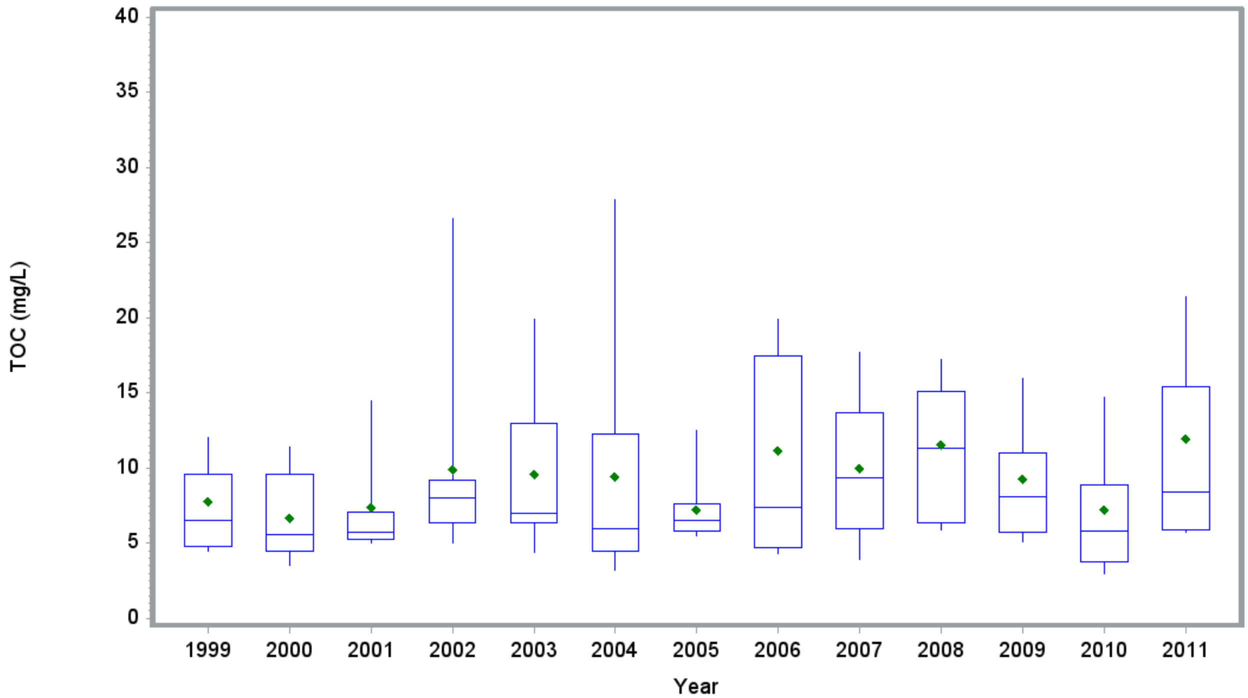



**Figure 3-230 TOC Tributary Samples Categorized by Year**

**Table 3-240 TOC Tributary Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 1999 | 12 | 3.40 | 4.50 | 4.75 | 7.77 | 6.55 | 9.60 | 12.00 | 19.00 |
| 2000 | 6 | 3.50 | 3.50 | 4.50 | 6.68 | 5.55 | 9.60 | 11.40 | 11.40 |
| 2001 | 14 | 4.90 | 5.00 | 5.30 | 7.36 | 5.75 | 7.10 | 14.50 | 17.40 |
| 2002 | 9 | 5.00 | 5.00 | 6.40 | 9.92 | 8.00 | 9.20 | 26.60 | 26.60 |
| 2003 | 8 | 4.40 | 4.40 | 6.35 | 9.61 | 7.00 | 12.95 | 19.90 | 19.90 |
| 2004 | 7 | 3.20 | 3.20 | 4.50 | 9.43 | 6.00 | 12.30 | 27.90 | 27.90 |
| 2005 | 7 | 5.50 | 5.50 | 5.80 | 7.24 | 6.50 | 7.60 | 12.50 | 12.50 |
| 2006 | 13 | 4.10 | 4.30 | 4.70 | 11.15 | 7.40 | 17.50 | 19.90 | 26.90 |
| 2007 | 10 | 3.60 | 3.90 | 6.00 | 10.01 | 9.35 | 13.70 | 17.70 | 21.30 |
| 2008 | 13 | 5.20 | 5.90 | 6.40 | 11.53 | 11.30 | 15.10 | 17.20 | 26.80 |
| 2009 | 51 | 4.50 | 5.10 | 5.70 | 9.29 | 8.10 | 11.00 | 16.00 | 24.00 |
| 2010 | 32 | 2.70 | 3.00 | 3.77 | 7.20 | 5.83 | 8.85 | 14.70 | 20.20 |
| 2011 | 12 | 5.22 | 5.70 | 5.90 | 11.93 | 8.39 | 15.45 | 21.40 | 33.40 |

***TOC Tributary Samples Categorized by Month***

> By month, the highest mean concentrations were measured in May, September, and November, in decreasing order. Spikes in TOC during warm weather may cause compliance issues with the Safe Drinking Water Act.

> The lowest mean concentrations were measured in February and April.
> Variability differed greatly by month, with highest variability measured in May.

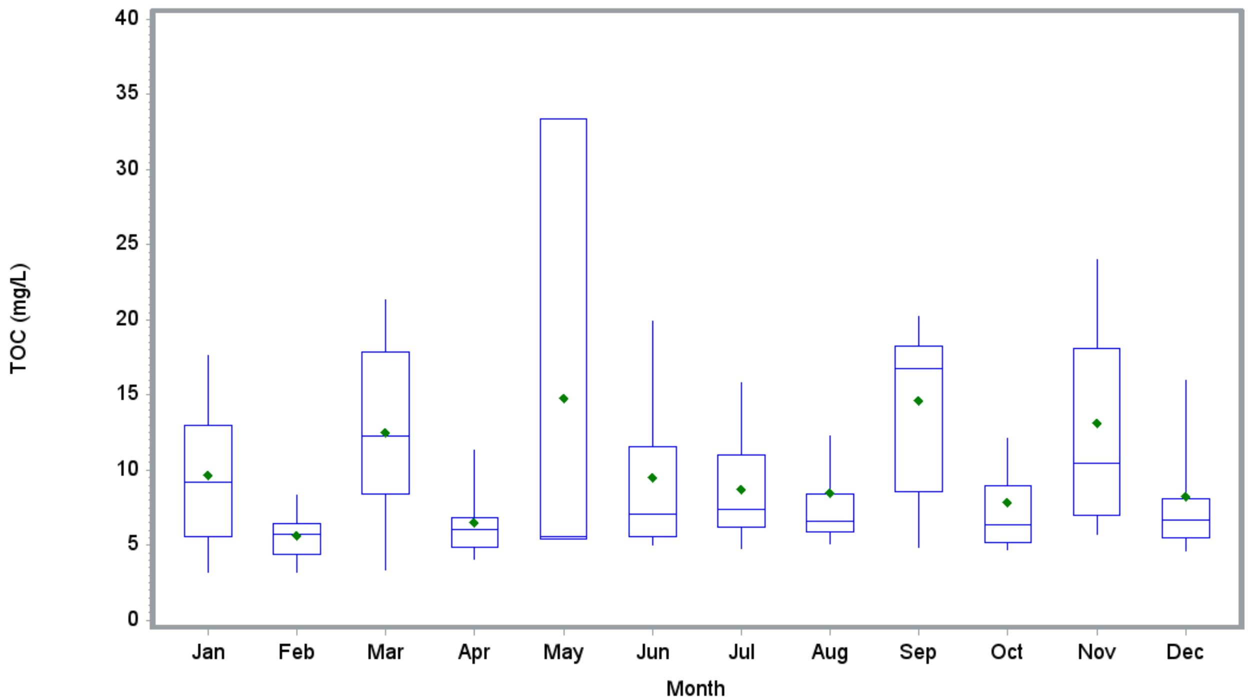



**Figure 3-231 TOC Tributary Samples Categorized by Month**

**Table 3-241 TOC Tributary Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 16 | 2.90 | 3.20 | 5.55 | 9.64 | 9.20 | 13.00 | 17.60 | 19.50 |
| Feb | 24 | 2.70 | 3.20 | 4.40 | 5.68 | 5.75 | 6.45 | 8.30 | 11.30 |
| Mar | 16 | 2.70 | 3.40 | 8.40 | 12.48 | 12.30 | 17.85 | 21.30 | 21.40 |
| Apr | 22 | 3.00 | 4.10 | 4.90 | 6.51 | 6.02 | 6.80 | 11.30 | 14.10 |
| May | 3 | 5.40 | 5.40 | 5.40 | 14.80 | 5.60 | 33.40 | 33.40 | 33.40 |
| Jun | 23 | 4.20 | 5.00 | 5.60 | 9.53 | 7.10 | 11.60 | 19.90 | 26.90 |
| Jul | 10 | 4.60 | 4.75 | 6.24 | 8.76 | 7.39 | 11.00 | 15.80 | 18.70 |
| Aug | 19 | 4.90 | 5.10 | 5.90 | 8.53 | 6.60 | 8.40 | 12.30 | 27.90 |
| Sep | 12 | 4.50 | 4.90 | 8.55 | 14.65 | 16.75 | 18.25 | 20.20 | 26.80 |
| Oct | 23 | 3.50 | 4.70 | 5.20 | 7.85 | 6.40 | 9.00 | 12.10 | 26.60 |
| Nov | 9 | 5.70 | 5.70 | 7.00 | 13.12 | 10.46 | 18.10 | 24.00 | 24.00 |
| Dec | 17 | 4.4 | 4.6 | 5.5 | 8.25 | 6.70 | 8.10 | 16.0 | 20.4 |

***TOC Tributary Samples Categorized by Sampling Organization***

> By sampling organization, the highest mean and median concentrations were recorded by USGS and lowest mean and median concentrations were recorded by NCWDQ.

> Greatest variability was seen in measurements by USGS.

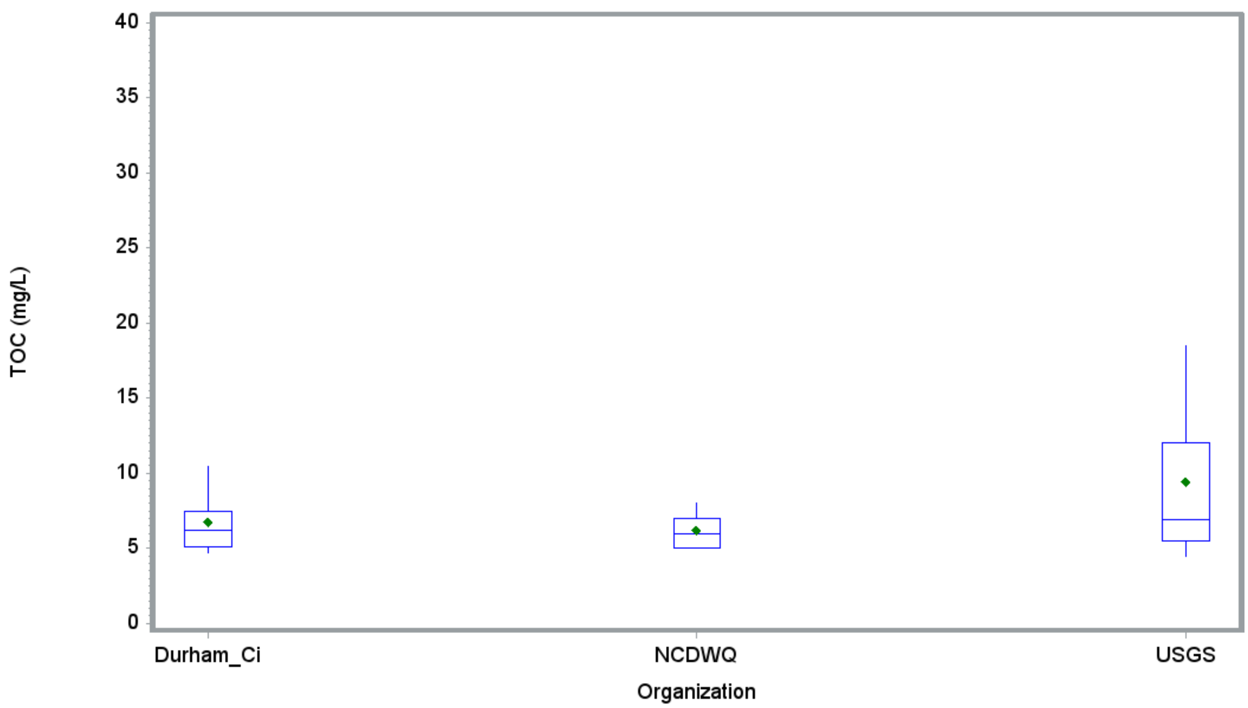



**Figure 3-232 TOC Tributary Samples Categorized by Sampling Organization**

**Table 3-242 TOC Tributary Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 19 | 4.13 | 4.74 | 5.13 | 6.78 | 6.24 | 7.48 | 10.46 | 13.20 |
| NCDWQ | 5 | 5.00 | 5.00 | 5.00 | 6.20 | 6.00 | 7.00 | 8.00 | 8.00 |
| USGS | 170 | 2.70 | 4.50 | 5.50 | 9.42 | 6.95 | 12.00 | 18.50 | 33.40 |

***TOC Tributary Samples Categorized by Method***

> By method, the highest mean and median concentrations were recorded by USGS O-3100 method and lowest mean and median concentrations were recorded by EPA 415.1 method.

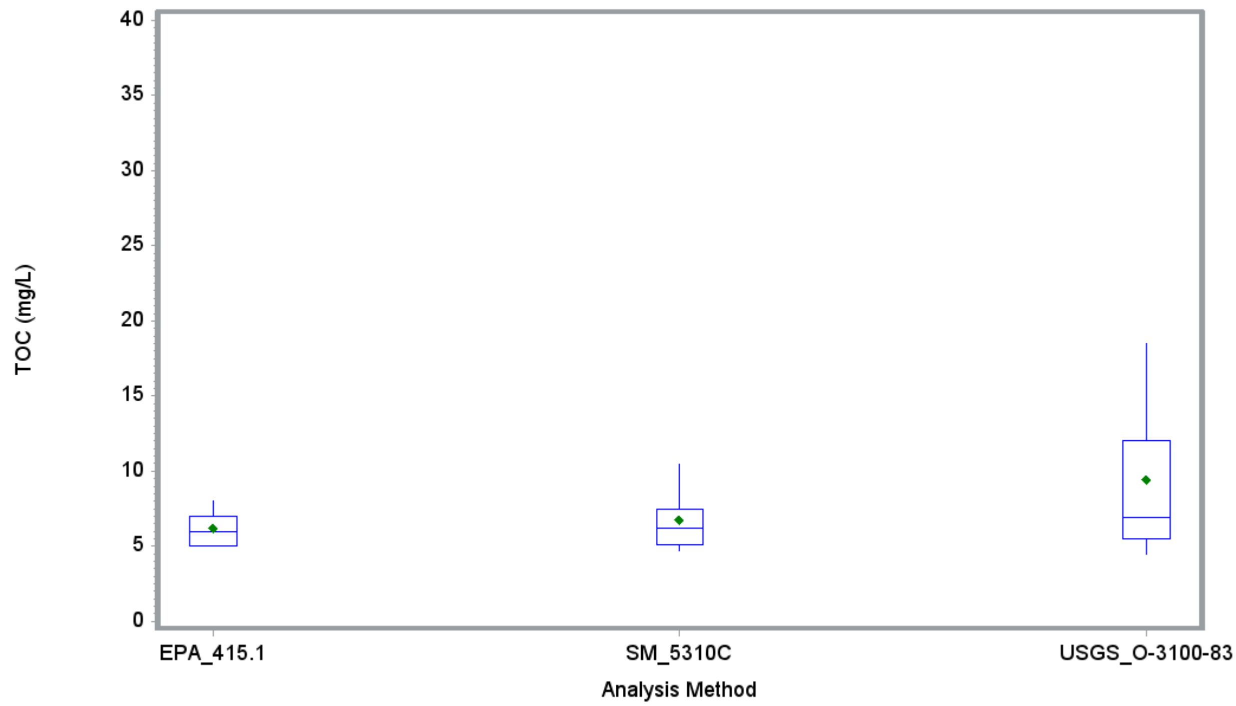



**Figure 3-233 TOC Tributary Samples Categorized by Analysis Method**

**Table 3-243 TOC Tributary Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| EPA_415.1 | 5 | 5.00 | 5.00 | 5.00 | 6.20 | 6.00 | 7.00 | 8.00 | 8.00 |
| SM_5310C | 19 | 4.13 | 4.74 | 5.13 | 6.78 | 6.24 | 7.48 | 10.46 | 13.20 |
| USGS_O-3100-83 | 170 | 2.70 | 4.50 | 5.50 | 9.42 | 6.95 | 12.00 | 18.50 | 33.40 |

### 3.19.3 Upper Lake Samples

Three organizations measured total organic carbon concentrations in upper Falls Lake from 2005 to present. Highest mean concentrations were measured in the > 21 mile section upstream of the dam and in the surface layer. Highest mean concentrations were recorded in 2008, while lowest mean concentrations were recorded in 2005. Box plot summaries are provided below.

***Total Organic Carbon Samples Categorized by Lake Segment and Miles Upstream from Dam***

> Mean and median concentrations were similar by segment, with highest concentrations in the > 21 mile section and lowest concentrations in the 13 to 18 mile section.

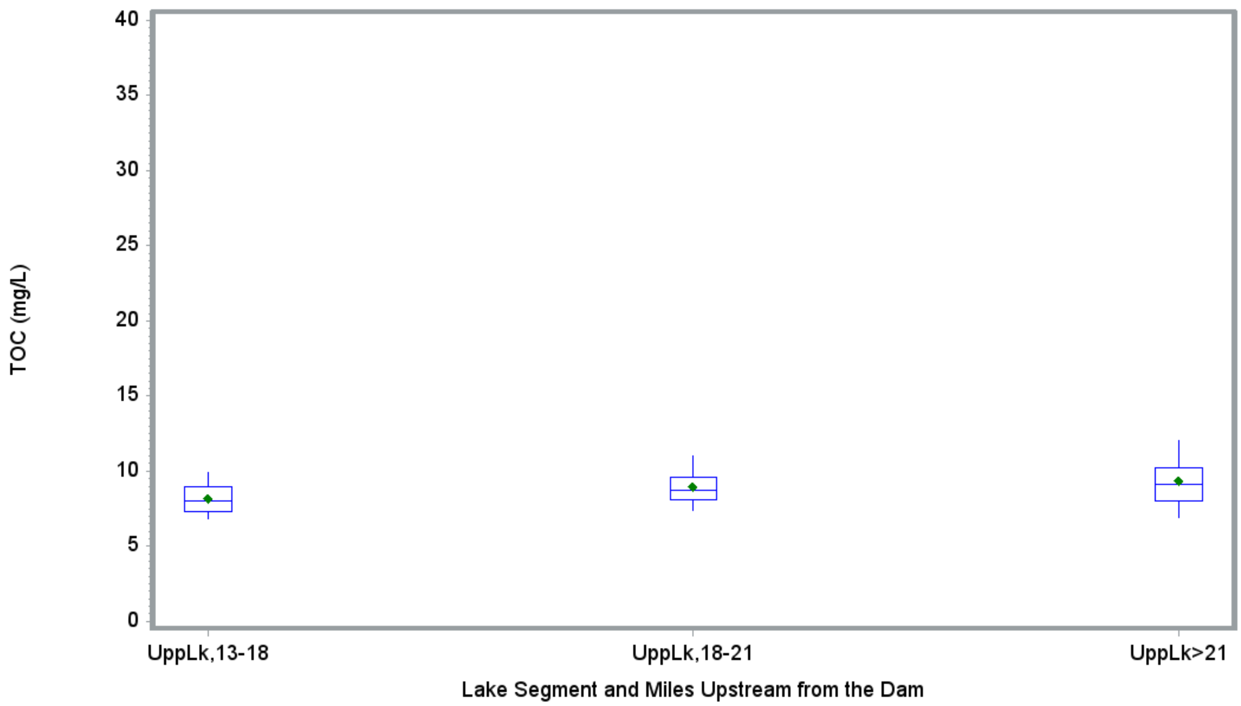



**Figure 3-234 TOC Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-244 TOC Upper Lake Samples Categorized by Miles Upstream from Dam (in mg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 267 | 5.10 | 6.80 | 7.30 | 8.15 | 8.00 | 9.00 | 9.90 | 11.90 |
| UppLk,18-21 | 67 | 6.70 | 7.40 | 8.10 | 8.95 | 8.70 | 9.60 | 11.00 | 13.00 |
| UppLk>21 | 161 | 5.40 | 6.90 | 8.00 | 9.36 | 9.16 | 10.20 | 12.00 | 16.00 |

***Total Organic Carbon Tributary Samples Categorized by Depth***

> By depth, highest mean and median concentrations were measured in the middle layer.


**Figure 3-235 TOC Upper Lake Samples Categorized by Depth Category**

**Table 3-245 TOC Upper Lake Samples Categorized by Depth Category (in mg/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Middle | 30 | 6.80 | 8.90 | 10.10 | 11.31 | 11.60 | 12.20 | 14.00 | 15.30 |
| Photic | 433 | 5.10 | 6.80 | 7.40 | 8.40 | 8.20 | 9.20 | 10.00 | 16.00 |
| Surface | 32 | 6.80 | 8.20 | 8.70 | 9.54 | 9.50 | 10.50 | 11.00 | 11.90 |

***Total Organic Carbon Tributary Categorized by Year***

> TOC was recorded in the upper lake from 2005 to the present.

> Highest mean and median concentrations were recorded in 2008 followed by 2009.

> The lowest mean and median concentrations were recorded in 2005.

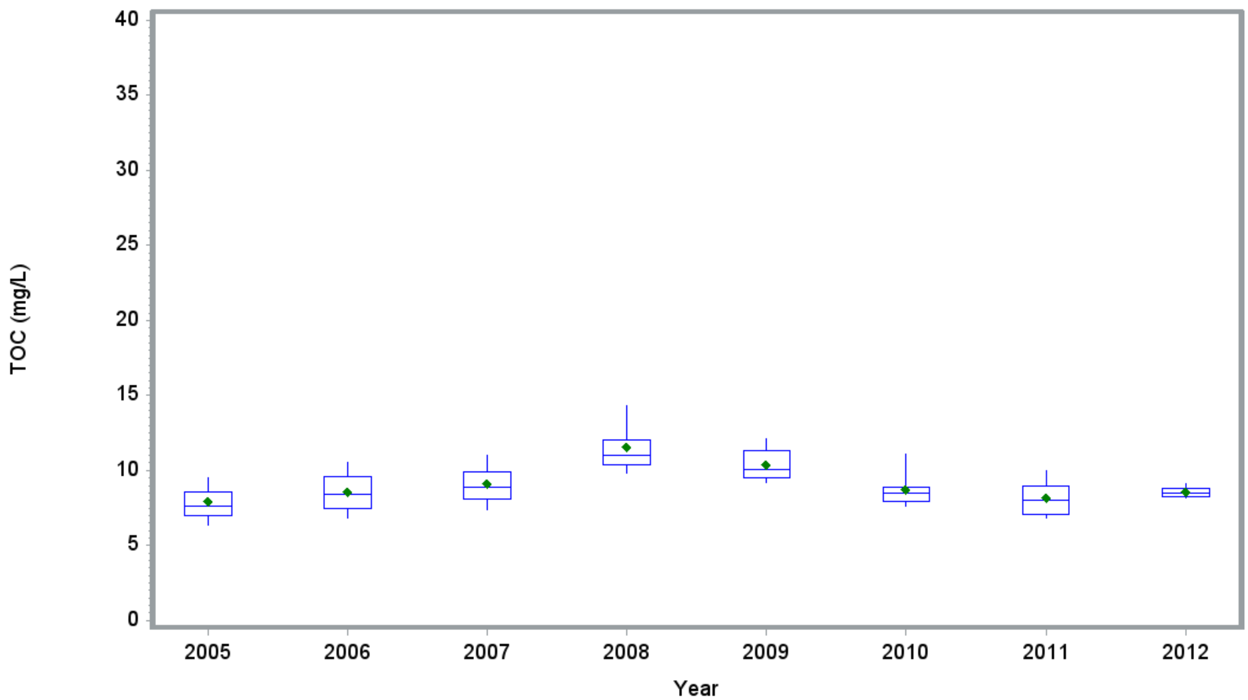



**Figure 3-236 TOC Upper Lake Samples Categorized by Year**

**Table 3-246 TOC Upper Lake Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2005 | 99 | 5.30 | 6.40 | 7.00 | 7.90 | 7.60 | 8.60 | 9.50 | 14.00 |
| 2006 | 158 | 5.10 | 6.80 | 7.50 | 8.57 | 8.40 | 9.60 | 10.50 | 13.40 |
| 2007 | 134 | 6.20 | 7.40 | 8.10 | 9.11 | 8.90 | 9.90 | 11.00 | 16.00 |
| 2008 | 12 | 9.80 | 9.80 | 10.40 | 11.54 | 11.00 | 12.05 | 14.30 | 15.30 |
| 2009 | 12 | 7.50 | 9.20 | 9.50 | 10.40 | 10.10 | 11.30 | 12.10 | 13.70 |
| 2010 | 11 | 6.80 | 7.60 | 7.90 | 8.76 | 8.50 | 8.90 | 11.10 | 11.70 |
| 2011 | 64 | 5.80 | 6.80 | 7.10 | 8.16 | 8.00 | 9.00 | 10.00 | 12.00 |
| 2012 | 5 | 8.20 | 8.20 | 8.26 | 8.58 | 8.49 | 8.81 | 9.16 | 9.16 |

### *Total Organic Carbon Tributary Samples Categorized by Month*

- August had the highest mean value and December the highest median value. Spikes in TOC during warm weather may cause compliance issues with the Safe Drinking Water Act.
- Mean and median concentrations were relatively similar for all months.
- The significant overlap between IQRs suggests that the months have similar TOC distributions.

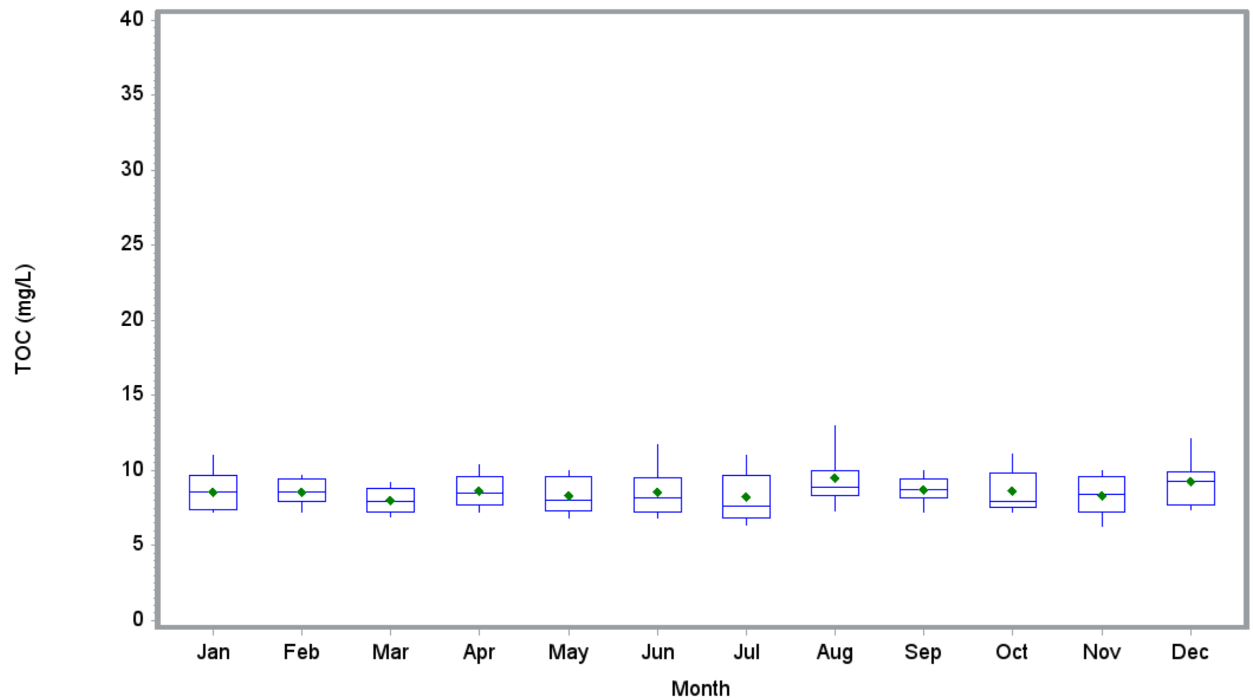



**Figure 3-237 TOC Upper Lake Samples Categorized by Month**

**Table 3-247 TOC Upper Lake Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 24 | 5.50 | 7.20 | 7.40 | 8.61 | 8.55 | 9.65 | 11.00 | 12.00 |
| Feb | 33 | 5.80 | 7.20 | 7.90 | 8.58 | 8.60 | 9.40 | 9.70 | 11.80 |
| Mar | 39 | 5.80 | 6.90 | 7.20 | 8.03 | 7.90 | 8.80 | 9.20 | 11.60 |
| Apr | 62 | 5.10 | 7.20 | 7.70 | 8.65 | 8.50 | 9.60 | 10.40 | 11.80 |
| May | 45 | 5.90 | 6.80 | 7.30 | 8.31 | 8.00 | 9.60 | 10.00 | 11.00 |
| Jun | 55 | 6.50 | 6.80 | 7.20 | 8.61 | 8.20 | 9.50 | 11.70 | 13.00 |
| Jul | 43 | 5.30 | 6.40 | 6.80 | 8.27 | 7.60 | 9.70 | 11.00 | 14.00 |
| Aug | 57 | 6.20 | 7.30 | 8.30 | 9.53 | 8.90 | 10.00 | 13.00 | 16.00 |
| Sep | 40 | 6.90 | 7.25 | 8.15 | 8.75 | 8.75 | 9.45 | 10.00 | 11.00 |
| Oct | 36 | 5.40 | 7.20 | 7.55 | 8.62 | 7.90 | 9.80 | 11.10 | 14.30 |
| Nov | 31 | 5.80 | 6.30 | 7.20 | 8.35 | 8.40 | 9.60 | 10.00 | 11.00 |
| Dec | 30 | 6.20 | 7.40 | 7.70 | 9.28 | 9.25 | 9.90 | 12.15 | 14.00 |

### *Total Organic Carbon Tributary Samples Categorized by Sampling Organization*

> By sampling organization, the highest mean concentrations were recorded by USGS and lowest mean concentrations were recorded by NCDWQ and City of Durham.

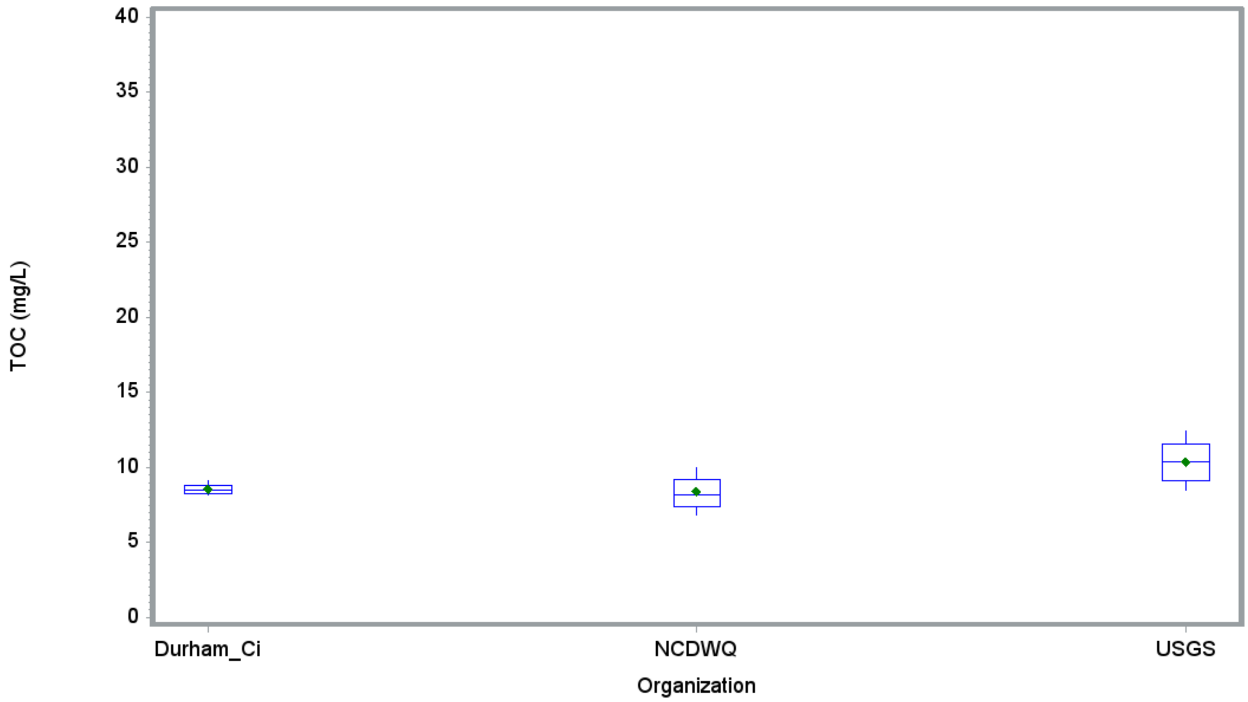



**Figure 3-238 TOC Upper Lake Samples Categorized by Sampling Organization**

**Table 3-248 TOC Upper Lake Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Durham_Ci | 5 | 8.20 | 8.20 | 8.26 | 8.58 | 8.49 | 8.81 | 9.16 | 9.16 |
| NCDWQ | 428 | 5.10 | 6.80 | 7.40 | 8.40 | 8.20 | 9.20 | 10.00 | 16.00 |
| USGS | 62 | 6.80 | 8.50 | 9.10 | 10.40 | 10.40 | 11.60 | 12.40 | 15.30 |

### *Total Organic Carbon Tributary Samples Categorized by Method*

> By method, the highest mean concentrations were recorded by USGS 0-3100-83 and lowest mean concentrations were recorded by SM 5310C and the unknown method.

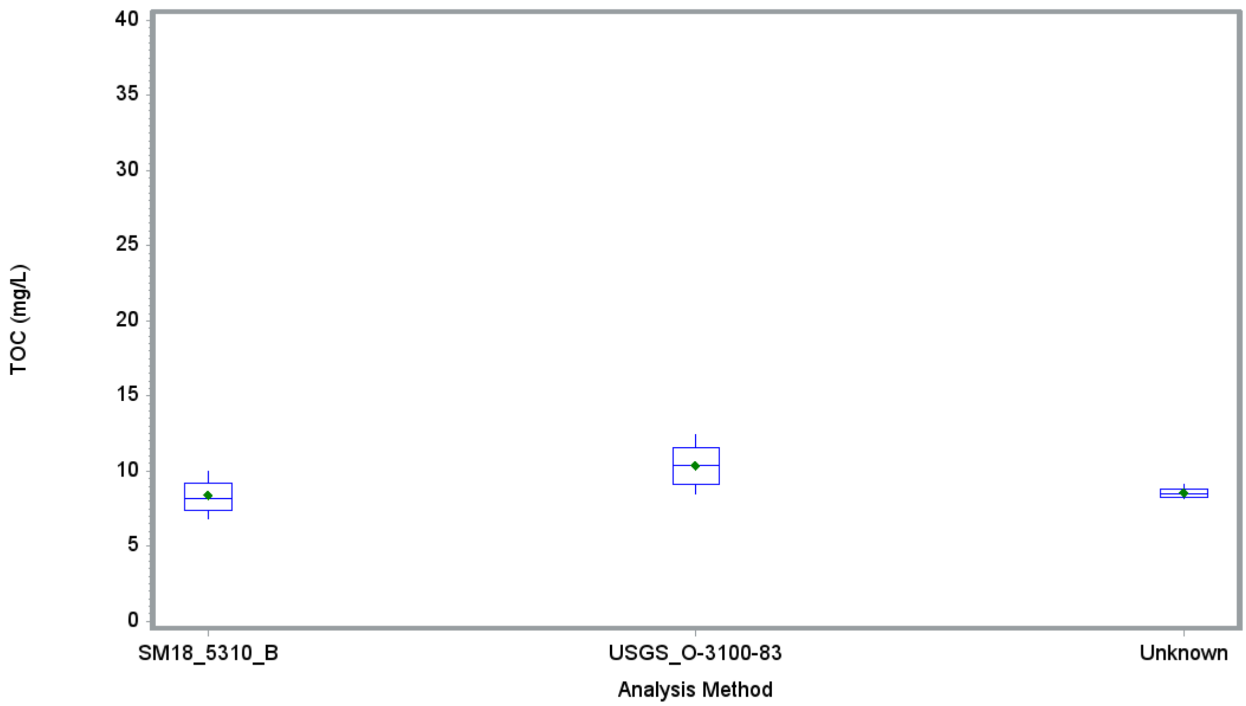



**Figure 3-239 TOC Upper Lake Samples Categorized by Analysis Method**

**Table 3-249 TOC Upper Lake Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| SM18_5310_B | 428 | 5.10 | 6.80 | 7.40 | 8.40 | 8.20 | 9.20 | 10.00 | 16.00 |
| USGS_O-3100-83 | 62 | 6.80 | 8.50 | 9.10 | 10.40 | 10.40 | 11.60 | 12.40 | 15.30 |
| Unknown | 5 | 8.20 | 8.20 | 8.26 | 8.58 | 8.49 | 8.81 | 9.16 | 9.16 |

### 3.19.4 Lower Lake Samples

Four organizations measured total organic carbon concentrations in lower Falls Lake from 2000 to 2012. Highest mean and median concentrations were recorded by USGS, while lowest concentrations were recorded by City of Raleigh. Highest concentrations were recorded in the photic zone. Highest mean concentrations were recorded in 2007 and 2006, while the lowest mean concentrations were recorded in 2010 and 2011. Box plot summaries are provided below.

***Total Organic Carbon Samples Categorized by Lake Segment and Miles Upstream from Dam***

- Highest mean and median concentrations were measured in Beaverdam Impoundment.
- Mean and median concentrations decreased from upstream to downstream within the Lower Lake.

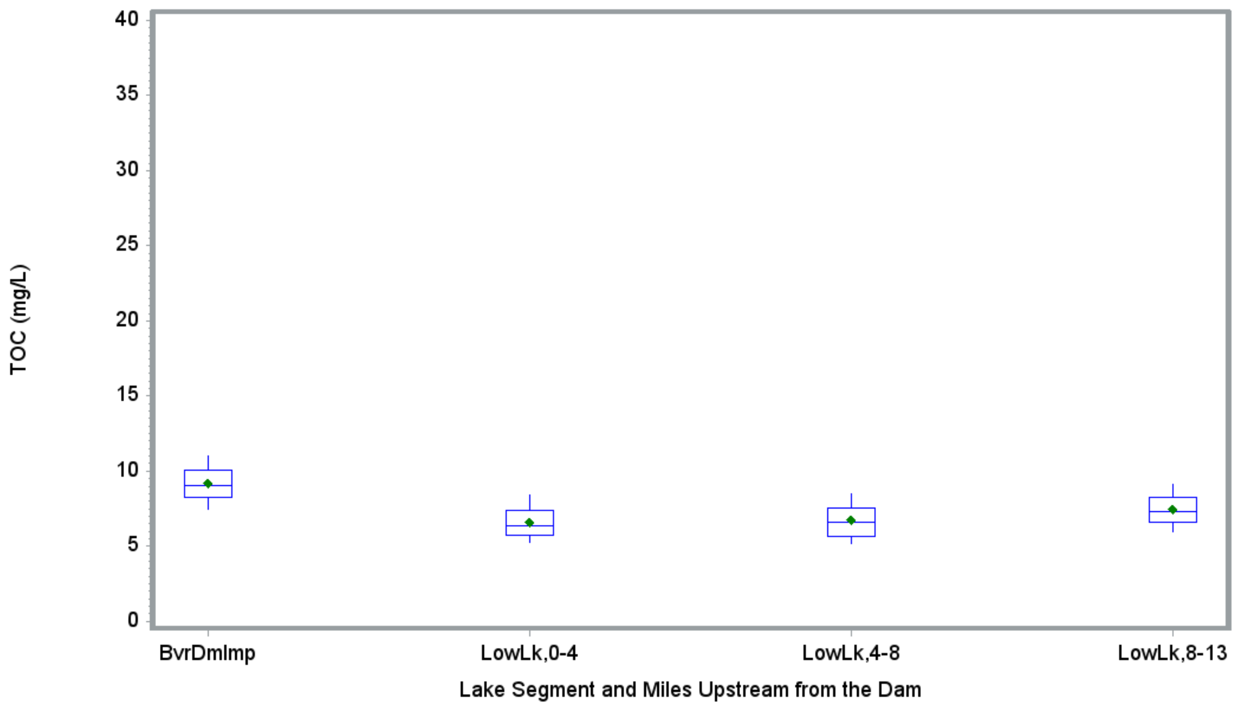



**Figure 3-240 TOC Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-250 TOC Lower Lake Samples Categorized by Miles Upstream from Dam (in mg/L)**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| BvrDmImp | 56 | 5.50 | 7.44 | 8.27 | 9.23 | 9.05 | 10.10 | 11.00 | 14.50 |
| LowLk,0-4 | 320 | 4.02 | 5.24 | 5.71 | 6.64 | 6.36 | 7.41 | 8.40 | 13.10 |
| LowLk,4-8 | 637 | 3.03 | 5.21 | 5.68 | 6.72 | 6.58 | 7.55 | 8.50 | 11.40 |
| LowLk,8-13 | 193 | 4.83 | 6.00 | 6.62 | 7.47 | 7.30 | 8.24 | 9.12 | 11.00 |

### *Total Organic Carbon Lower Lake Samples Categorized by Depth*

> By depth, highest mean and median concentrations were measured in the photic zone

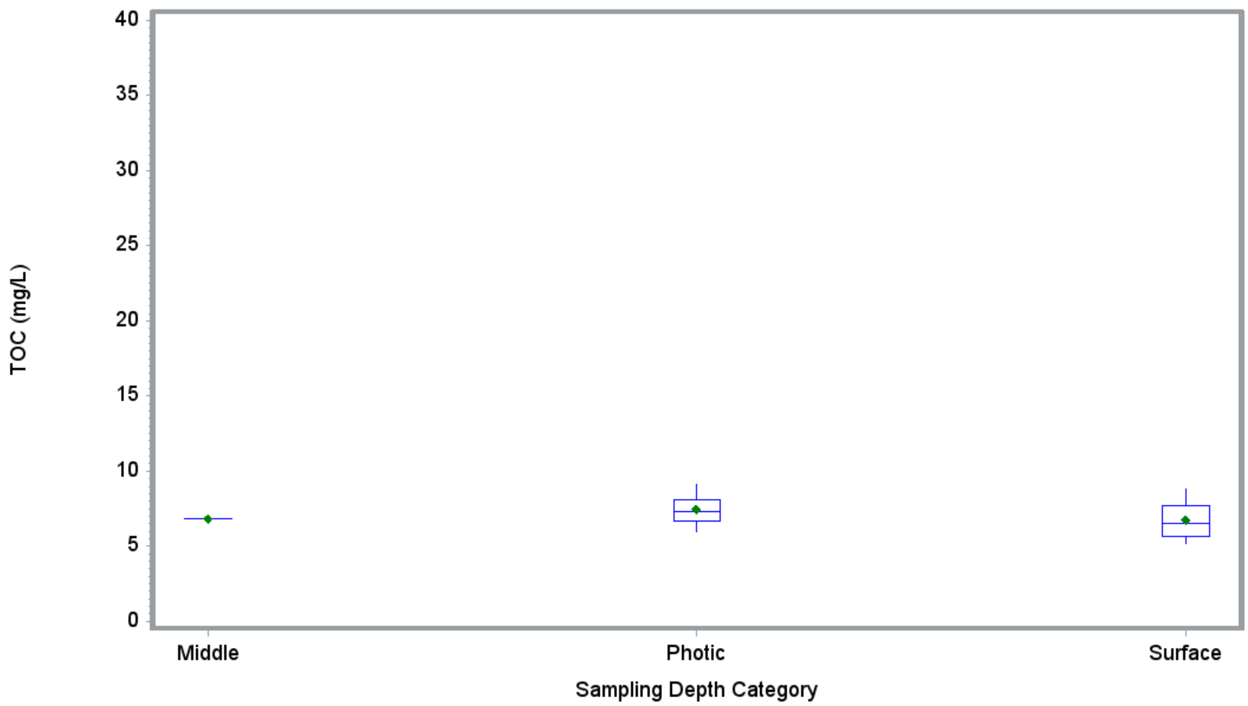



**Figure 3-241 TOC Lower Lake Samples Categorized by Depth Category**

**Table 3-251 TOC Lower Lake Samples Categorized by Depth Category (in mg/L)**

| Sampling Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Middle | 1 | 6.80 | 6.80 | 6.80 | 6.80 | 6.80 | 6.80 | 6.80 | 6.80 |
| Photic | 275 | 5.10 | 6.00 | 6.70 | 7.44 | 7.30 | 8.10 | 9.10 | 11.00 |
| Surface | 930 | 3.03 | 5.21 | 5.67 | 6.79 | 6.53 | 7.69 | 8.81 | 14.50 |

***Total Organic Carbon Lower Lake Categorized by Year***

> Highest mean concentrations were recorded 2007 and 2006. The highest median concentration was in 2008.

> The lowest mean and median values were observed in 2010 and 2011.

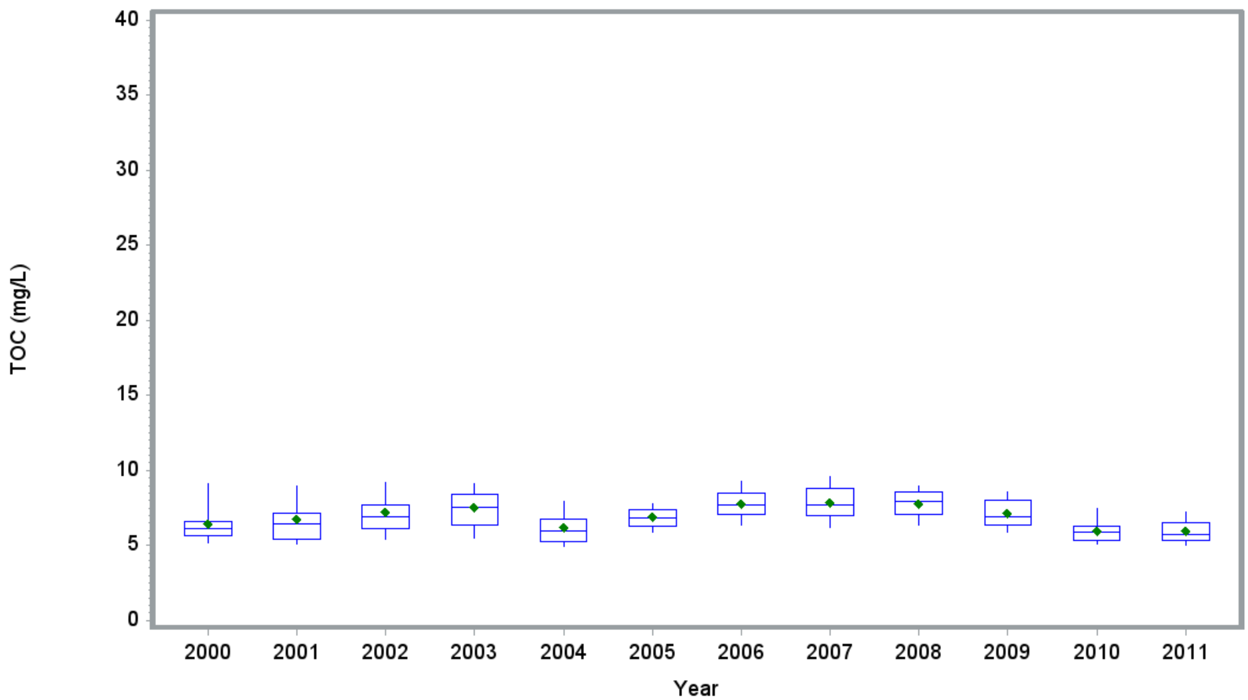



**Figure 3-242 TOC Lower Lake Samples Categorized by Year**

**Table 3-252 TOC Lower Lake Samples Categorized by Year (in mg/L)**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | 88 | 3.77 | 5.21 | 5.64 | 6.44 | 6.16 | 6.58 | 9.14 | 10.80 |
| 2001 | 88 | 4.50 | 5.10 | 5.44 | 6.72 | 6.47 | 7.15 | 8.96 | 11.80 |
| 2002 | 86 | 4.25 | 5.40 | 6.14 | 7.22 | 6.90 | 7.67 | 9.22 | 14.50 |
| 2003 | 96 | 5.01 | 5.50 | 6.40 | 7.52 | 7.55 | 8.42 | 9.12 | 13.77 |
| 2004 | 88 | 4.83 | 4.96 | 5.24 | 6.22 | 5.95 | 6.79 | 7.92 | 9.29 |
| 2005 | 81 | 5.30 | 5.90 | 6.30 | 6.90 | 6.80 | 7.40 | 7.80 | 11.00 |
| 2006 | 100 | 5.30 | 6.35 | 7.10 | 7.81 | 7.70 | 8.50 | 9.30 | 11.00 |
| 2007 | 105 | 4.59 | 6.20 | 7.00 | 7.86 | 7.70 | 8.80 | 9.59 | 11.00 |
| 2008 | 120 | 3.71 | 6.35 | 7.08 | 7.75 | 7.94 | 8.56 | 9.00 | 11.10 |
| 2009 | 94 | 5.00 | 5.90 | 6.40 | 7.15 | 6.93 | 8.00 | 8.58 | 11.30 |
| 2010 | 125 | 4.13 | 5.07 | 5.37 | 5.98 | 5.86 | 6.30 | 7.50 | 9.00 |
| 2011 | 135 | 3.03 | 4.99 | 5.37 | 5.94 | 5.70 | 6.53 | 7.20 | 8.70 |

***Total Organic Carbon Lower Lake Samples Categorized by Month***

> Mean and median concentrations were similar for all months.

> Highest mean concentrations were measured in April and May.

> The lowest mean concentrations were measured in November and March.

> The significant overlap between IQRs suggests that the months have similar data distributions.

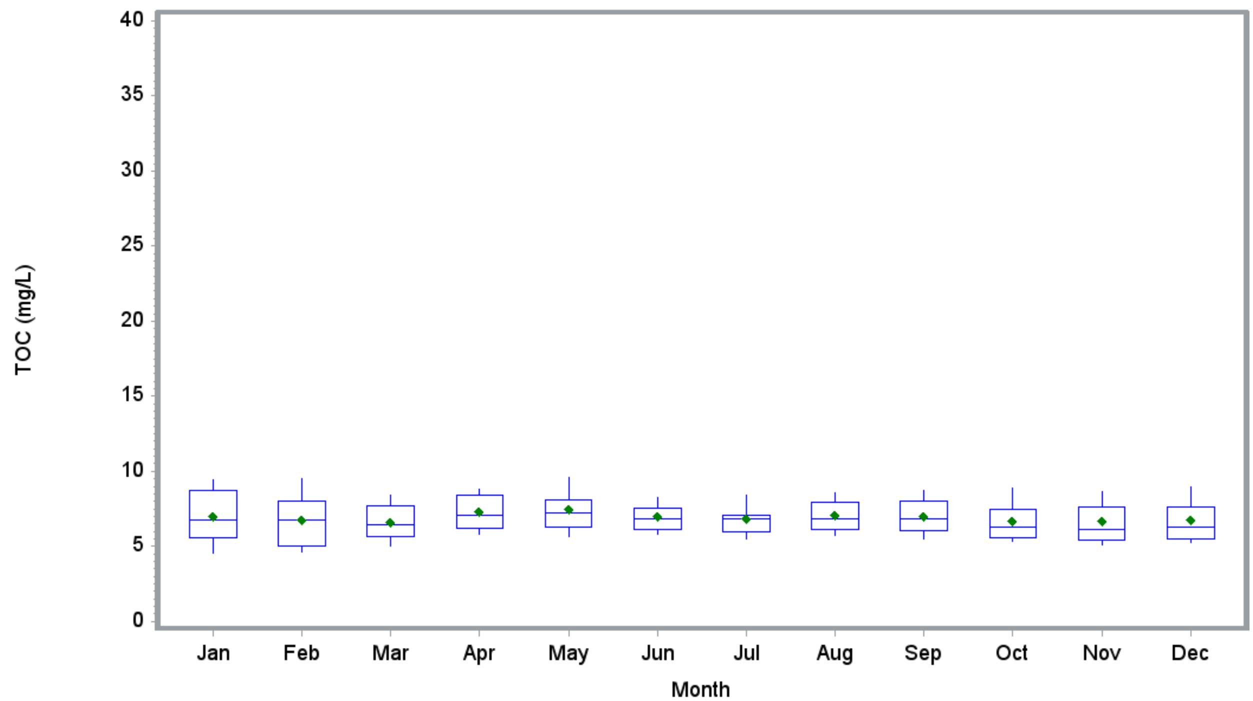



**Figure 3-243 TOC Lower Lake Samples Categorized by Month**

**Table 3-253 TOC Lower Lake Samples Categorized by Month (in mg/L)**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 77 | 3.03 | 4.59 | 5.55 | 6.99 | 6.75 | 8.70 | 9.40 | 11.00 |
| Feb | 80 | 4.16 | 4.67 | 5.06 | 6.73 | 6.74 | 8.00 | 9.50 | 13.10 |
| Mar | 96 | 3.77 | 5.06 | 5.69 | 6.63 | 6.44 | 7.70 | 8.40 | 10.20 |
| Apr | 103 | 5.09 | 5.82 | 6.22 | 7.34 | 7.10 | 8.38 | 8.80 | 13.77 |
| May | 107 | 5.25 | 5.65 | 6.31 | 7.44 | 7.20 | 8.10 | 9.60 | 12.50 |
| Jun | 118 | 4.95 | 5.84 | 6.12 | 6.96 | 6.83 | 7.55 | 8.22 | 11.60 |
| Jul | 90 | 4.94 | 5.51 | 6.00 | 6.83 | 6.80 | 7.10 | 8.45 | 10.60 |
| Aug | 122 | 5.10 | 5.74 | 6.11 | 7.04 | 6.87 | 7.94 | 8.60 | 11.00 |
| Sep | 101 | 5.00 | 5.46 | 6.07 | 7.02 | 6.80 | 8.00 | 8.70 | 10.80 |
| Oct | 107 | 5.00 | 5.37 | 5.56 | 6.71 | 6.30 | 7.50 | 8.90 | 11.10 |
| Nov | 92 | 4.79 | 5.09 | 5.43 | 6.67 | 6.14 | 7.62 | 8.67 | 14.50 |
| Dec | 113 | 4.13 | 5.27 | 5.49 | 6.75 | 6.32 | 7.61 | 9.00 | 11.30 |

### *Total Organic Carbon Lower Lake Samples Categorized by Sampling Organization*

> By sampling organization, the highest mean and median concentrations were recorded by USGS, lowest mean and median concentrations were recorded by City of Raleigh.

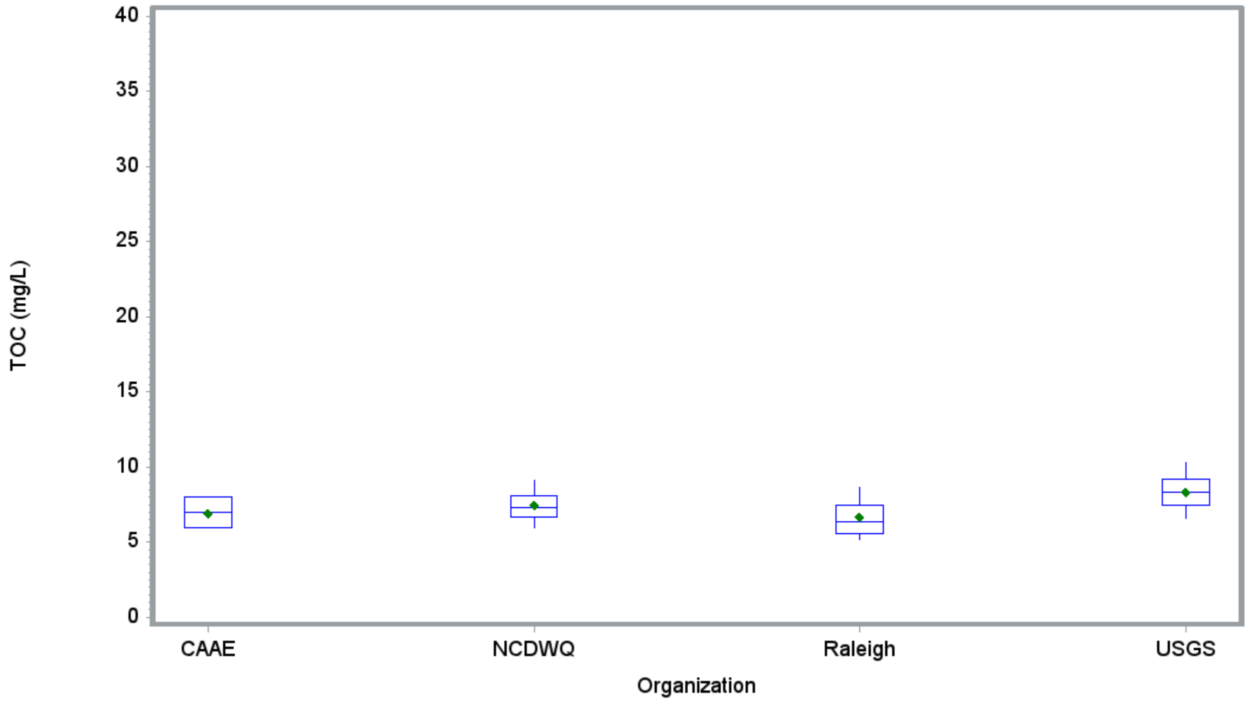



**Figure 3-244 TOC Lower Lake Samples Categorized by Sampling Organization**

**Table 3-254 TOC Lower Lake Samples Categorized by Sampling Organization (in mg/L)**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 64 | 5.00 | 6.00 | 6.00 | 6.94 | 7.00 | 8.00 | 8.00 | 9.00 |
| NCDWQ | 275 | 5.10 | 6.00 | 6.70 | 7.44 | 7.30 | 8.10 | 9.10 | 11.00 |
| Raleigh | 802 | 3.03 | 5.18 | 5.59 | 6.65 | 6.35 | 7.44 | 8.65 | 14.50 |
| USGS | 65 | 6.00 | 6.60 | 7.50 | 8.37 | 8.30 | 9.20 | 10.30 | 11.30 |

### *Total Organic Carbon Lower Lake Samples Categorized by Method*

> Four known methods were used to determine TOC in the lower lake.

> Highest concentrations were measured using USGS O-3100 method and lowest concentrations were recorded using SM 5310C

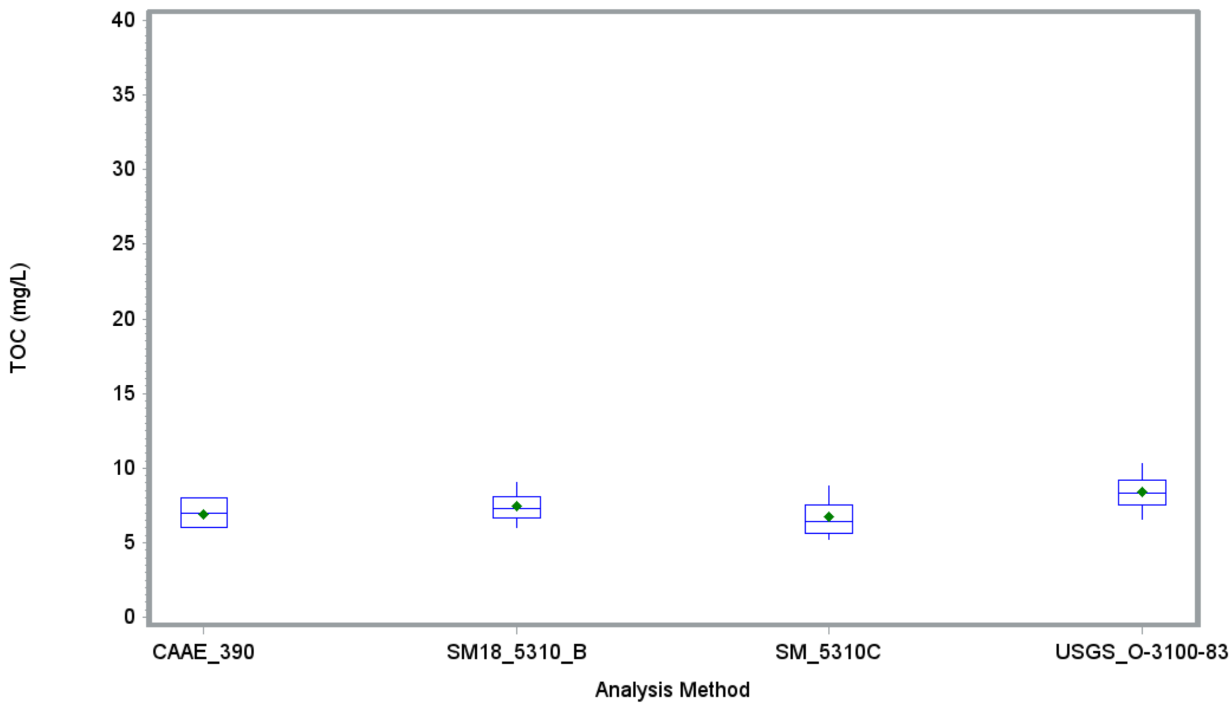



**Figure 3-245 TOC Lower Lake Samples Categorized by Analysis Method**

**Table 3-255 TOC Lower Lake Samples Categorized by Analysis Method (in mg/L)**

| Analysis Method | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE_390 | 64 | 5.00 | 6.00 | 6.00 | 6.94 | 7.00 | 8.00 | 8.00 | 9.00 |
| SM18_5310_B | 275 | 5.10 | 6.00 | 6.70 | 7.44 | 7.30 | 8.10 | 9.10 | 11.00 |
| SM_5310C | 802 | 3.03 | 5.18 | 5.59 | 6.65 | 6.35 | 7.44 | 8.65 | 14.50 |
| USGS_O-3100-83 | 65 | 6.00 | 6.60 | 7.50 | 8.37 | 8.30 | 9.20 | 10.30 | 11.30 |

## 3.20 Ratio of Chlorophyll *a* to TOC

Drinking water supply reservoirs are closely monitored for both chlorophyll *a* and TOC due to the impacts of these compounds on drinking water treatment costs and quality. Identifying the sources of the TOC assists in managing those levels, and it is helpful to know if TOC is originating from the lake via plant and algal growth or from the watershed. Though answering these questions with certainty is outside of the scope of work for this project, Cardno ENTRIX performed a simple calculation of the ratio of chlorophyll *a* (µg/L) to TOC (mg/L) to provide an assessment of how this ratio changes relative to other water quality parameters as well as by month, year, etc. Note that the resulting units of this ratio are µg/mg, and the volumetric component of each parameter cancels out. This calculation was only performed on those samples where both chlorophyll *a* and TOC measurements were available. Four organizations collected samples with both constituents as summarized in Table 3-256, and the majority of records are based on NCDWQ data. The limits for each data set are listed as NA because this ratio is a calculation. The ratio is presented to two decimal places.

**Table 3-256 Summary of the Ratio of Chlorophyll *a* to TOC Calculations**

| Organization | Analysis Method | Date Start | Date End | Number of Samples Using Analysis Method | Detection Limit (µg/mg) | Reporting Limit (µg/mg) | Practical Quantifi-cation Limit (µg/mg) | Range of Limit Specified with Results (µg/mg) |
|---|---|---|---|---|---|---|---|---|
| CAAE | Calculated | 07/24/2007 | 12/17/2010 | 64 | NA | NA | NA | NA |
| NCDWQ | Calculated | 03/15/2005 | 12/06/2011 | 602 | NA | NA | NA | NA |
| Raleigh | Calculated | 05/27/2009 | 12/30/2011 | 157 | NA | NA | NA | NA |
| USGS | Calculated | 04/23/1999 | 08/23/2011 | 123 | NA | NA | NA | NA |

### 3.20.2 Tributary Samples

No samples of both chlorophyll *a* and TOC were available to calculate ratios for the tributaries.

### 3.20.3 Upper Lake Samples

Two organizations collected both chlorophyll *a* and total organic carbon data in upper Falls Lake from 2005 to 2011. The highest mean and median ratios were recorded by NCDWQ and the lowest mean and median ratios were recorded by USGS. Highest mean and median ratios were recorded in 2007, while lowest mean and median ratios were recorded in 2010 and 2008. Box plot summaries are provided below.

***Chlorophyll a to Total Organic Carbon ratio Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean ratio was measured in the > 21 mile section while lowest ratio was measured in the 13 to 18 mile section.

> The median ratio was highest in the 18 to 21 mile section of the Lower Lake.

> The significant overlap between IQRs indicates that the data categories are similar in distribution.

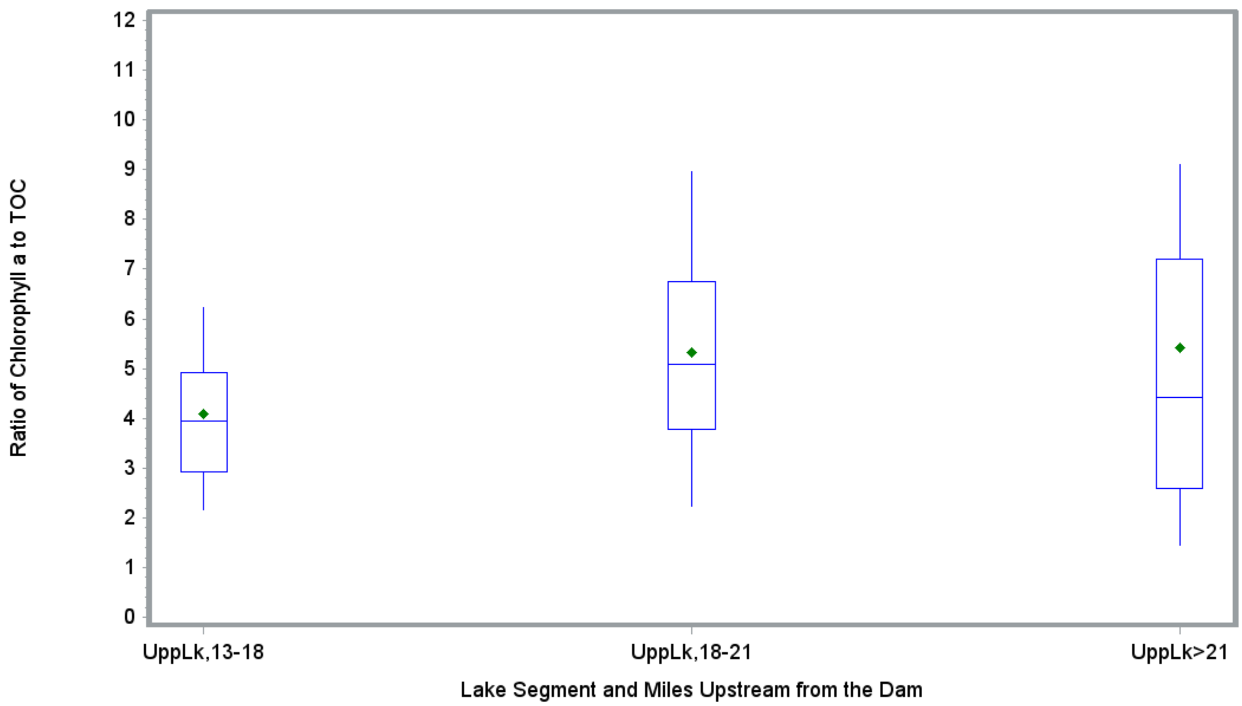



**Figure 3-246 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-257 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Miles Upstream from Dam**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| UppLk,13-18 | 245 | 0.59 | 2.15 | 2.93 | 4.08 | 3.96 | 4.93 | 6.22 | 10.24 |
| UppLk,18-21 | 57 | 0.39 | 2.24 | 3.78 | 5.32 | 5.09 | 6.75 | 8.97 | 11.34 |
| UppLk>21 | 125 | 0.14 | 1.44 | 2.70 | 5.42 | 4.55 | 7.60 | 10.00 | 18.39 |

***Chlorophyll a to Total Organic Carbon ratio Tributary Samples Categorized by Depth***

> Higher mean and median ratios were recorded in the surface layer.


**Figure 3-247 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Depth**

**Table 3-258 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Depth**

| Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Middle | 37 | 0.14 | 0.59 | 1.93 | 2.71 | 2.47 | 3.69 | 4.69 | 7.49 |
| Surface | 390 | 0.39 | 2.15 | 3.15 | 4.82 | 4.32 | 6.11 | 7.95 | 18.39 |

### *Chlorophyll a to Total Organic Carbon ratio Tributary Samples Categorized by Year*

> Chlorophyll *a* to total organic carbon was calculated from 2005 to 2011.

> By year, highest mean and median ratios were recorded in 2007, 2006 and 2011 in decreasing order.

> The lowest mean and median ratios were recorded in 2010, 2008 and 2009 in increasing order.

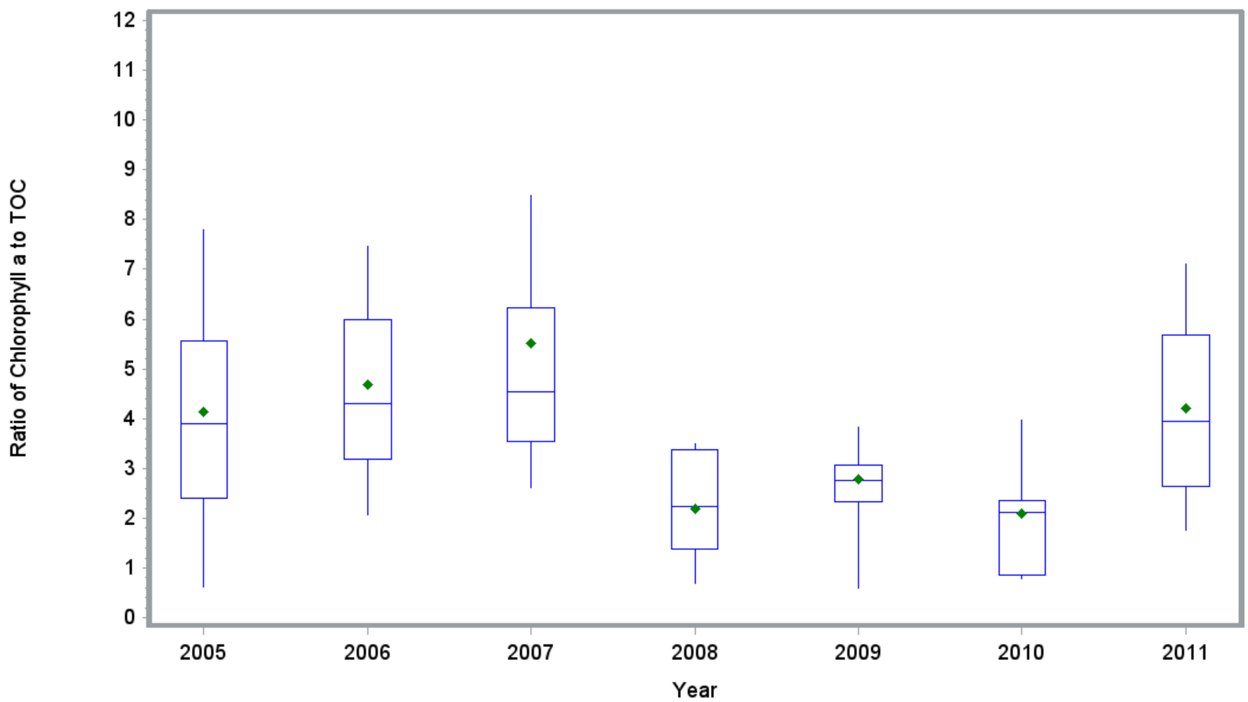



**Figure 3-248 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Year**

**Table 3-259 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Year**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2005 | 52 | 0.39 | 0.62 | 2.39 | 4.13 | 3.89 | 5.56 | 7.79 | 10.76 |
| 2006 | 155 | 0.91 | 2.08 | 3.18 | 4.68 | 4.30 | 6.00 | 7.45 | 11.90 |
| 2007 | 133 | 2.05 | 2.72 | 3.63 | 5.52 | 4.61 | 6.63 | 8.82 | 18.39 |
| 2008 | 11 | 0.43 | 0.69 | 1.39 | 2.19 | 2.24 | 3.37 | 3.50 | 3.69 |
| 2009 | 12 | 0.14 | 0.59 | 2.32 | 2.79 | 2.77 | 3.07 | 3.83 | 7.28 |
| 2010 | 10 | 0.71 | 0.78 | 0.87 | 2.10 | 2.12 | 2.36 | 3.96 | 5.56 |
| 2011 | 54 | 0.38 | 1.76 | 2.65 | 4.20 | 3.94 | 5.69 | 7.10 | 9.24 |

### *Chlorophyll a to Total Organic Carbon ratio Tributary Samples Categorized by Month*

> By month, the highest and median mean ratios were recorded in September, July and August in decreasing order.

> The lowest mean ratios were recorded in December, November and January in increasing order.

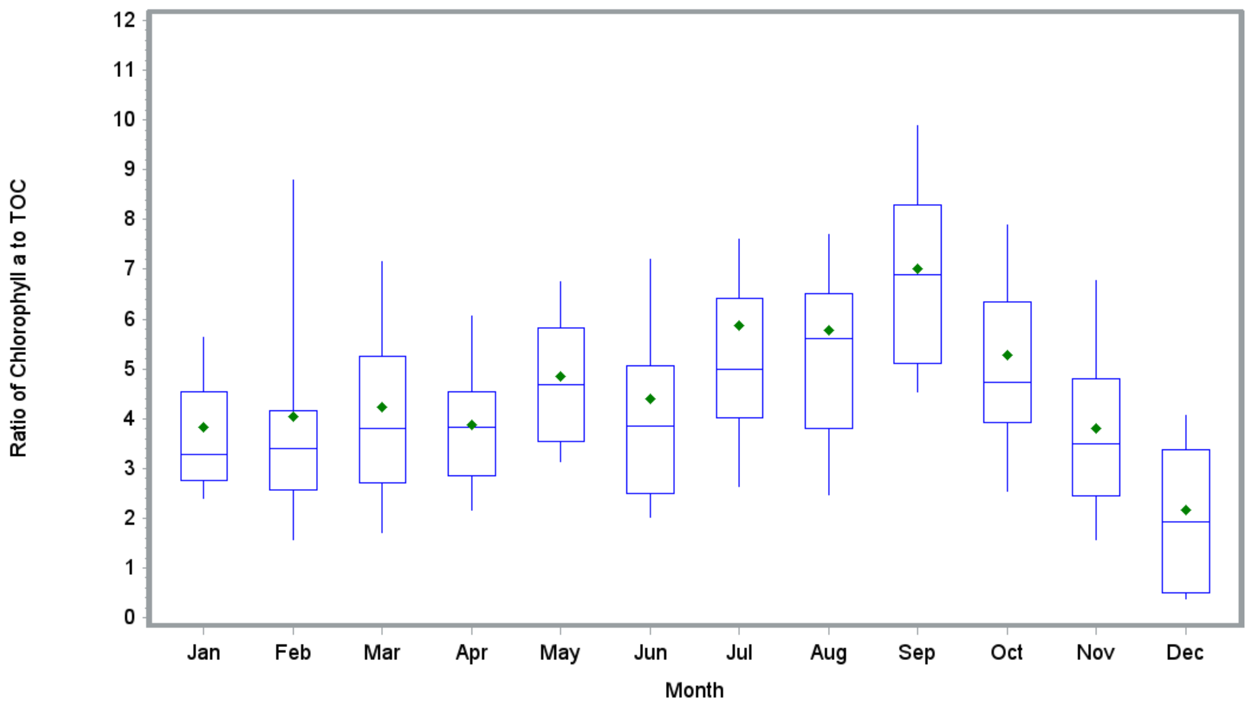



**Figure 3-249 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Month**

**Table 3-260 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Month**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 24 | 1.27 | 2.40 | 2.76 | 3.83 | 3.27 | 4.53 | 5.63 | 8.97 |
| Feb | 32 | 0.69 | 1.57 | 2.57 | 4.05 | 3.40 | 4.16 | 8.79 | 10.73 |
| Mar | 38 | 0.38 | 1.72 | 2.72 | 4.24 | 3.81 | 5.26 | 7.16 | 10.00 |
| Apr | 55 | 0.71 | 2.16 | 2.86 | 3.87 | 3.83 | 4.53 | 6.07 | 7.79 |
| May | 34 | 1.76 | 3.14 | 3.54 | 4.84 | 4.69 | 5.83 | 6.75 | 10.00 |
| Jun | 44 | 1.16 | 2.03 | 2.72 | 4.41 | 3.90 | 5.13 | 7.38 | 18.39 |
| Jul | 30 | 2.08 | 2.90 | 4.18 | 5.86 | 5.47 | 6.71 | 9.81 | 14.43 |
| Aug | 46 | 1.20 | 2.48 | 3.83 | 5.77 | 5.69 | 6.63 | 9.20 | 17.50 |
| Sep | 34 | 2.20 | 4.53 | 5.12 | 7.01 | 6.90 | 8.51 | 10.00 | 15.92 |
| Oct | 33 | 1.55 | 2.53 | 3.92 | 5.28 | 4.72 | 6.35 | 7.89 | 11.90 |
| Nov | 30 | 0.91 | 1.58 | 2.44 | 3.80 | 3.50 | 4.79 | 6.78 | 8.65 |
| Dec | 27 | 0.14 | 0.39 | 0.50 | 2.18 | 1.92 | 3.38 | 4.05 | 9.24 |

***Chlorophyll a to Total Organic Carbon ratio Upper Lake Samples Categorized by Sampling Organization***

> Highest mean and median ratios were measured by NCDWQ and lowest mean and median ratios were measured by USGS.


**Figure 3-250 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Sampling Organization**

**Table 3-261 Ratio of Chlorophyll *a* to TOC Upper Lake Samples Categorized by Sampling Organization**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| NCDWQ | 367 | 0.39 | 2.24 | 3.29 | 4.97 | 4.41 | 6.17 | 8.29 | 18.39 |
| USGS | 60 | 0.14 | 0.78 | 1.91 | 2.63 | 2.42 | 3.36 | 4.14 | 7.49 |

***Chlorophyll a to Total Organic Carbon ratio Tributary Samples Categorized by Method***

> Chlorophyll *a* to Total Organic Carbon ratio was calculated.

### 3.20.4 Lower Lake Samples

Four organizations collected both chlorophyll *a* and total organic carbon data in lower Falls Lake from 2005 to present. The highest mean and median ratios were recorded by NCDWQ and NCSU-CAAE and the lowest mean and median ratios were recorded by USGS. Highest mean median ratios were recorded in 2005, while lowest mean ratio was recorded in 2008. Box plot summaries are provided below.

***Chlorophyll a to Total Organic Carbon ratio Categorized by Lake Segment and Miles Upstream from Dam***

> Highest mean and median ratios were measured in the 8 to 13 mile section while lowest mean and median ratios were measured in the 0 to 4 mile section.

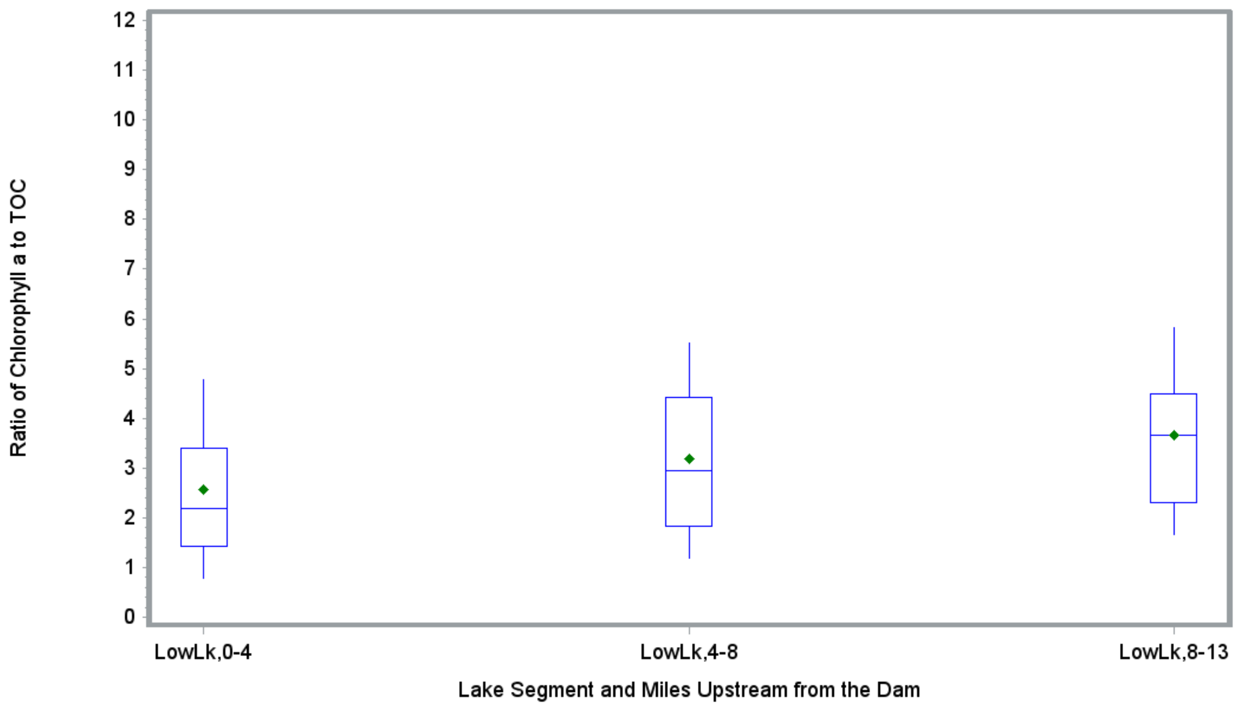



**Figure 3-251 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Miles Upstream from Dam**

**Table 3-262 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Miles Upstream from Dam**

| Lake Segment and Miles from Dam | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| LowLk,0-4 | 174 | 0.17 | 0.79 | 1.43 | 2.56 | 2.20 | 3.40 | 4.78 | 9.63 |
| LowLk,4-8 | 230 | 0.33 | 1.19 | 1.83 | 3.19 | 2.94 | 4.42 | 5.52 | 8.03 |
| LowLk,8-13 | 115 | 0.60 | 1.67 | 2.32 | 3.66 | 3.67 | 4.50 | 5.94 | 12.17 |

***Chlorophyll a to Total Organic Carbon ratio Lower Lake Samples Categorized by Depth***

> Higher mean and median ratios were recorded in the surface layer.


**Figure 3-252 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Depth**

**Table 3-263 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Depth**

| Depth | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Middle | 35 | 0.29 | 0.53 | 0.88 | 1.64 | 1.41 | 2.29 | 2.82 | 4.80 |
| Surface | 484 | 0.17 | 1.17 | 1.84 | 3.19 | 2.92 | 4.29 | 5.51 | 12.17 |

### *Chlorophyll a to Total Organic Carbon ratio Lower Lake Samples Categorized by Year*

> Chlorophyll *a* to Total Organic Carbon ratios were calculated from 2005 to 2011.

> By year, highest mean and median ratios were recorded in 2005 and 2006.

> The lowest mean and median ratios were recorded in 2008 and 2010.

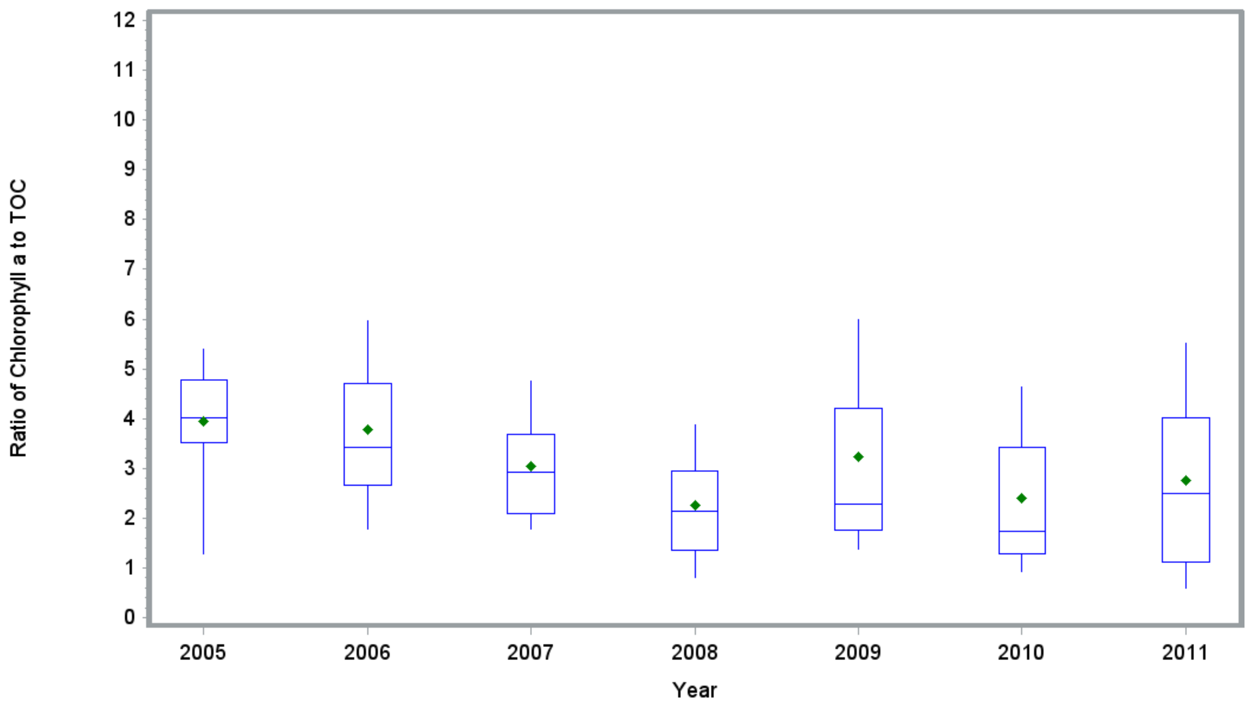



**Figure 3-253 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Year**

**Table 3-264 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Year**

| Year | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| 2005 | 45 | 0.37 | 1.30 | 3.51 | 3.96 | 4.03 | 4.78 | 5.41 | 6.45 |
| 2006 | 99 | 0.95 | 1.78 | 2.67 | 3.78 | 3.43 | 4.71 | 5.97 | 8.03 |
| 2007 | 86 | 1.12 | 1.79 | 2.11 | 3.04 | 2.91 | 3.68 | 4.76 | 6.80 |
| 2008 | 28 | 0.57 | 0.82 | 1.35 | 2.27 | 2.13 | 2.94 | 3.88 | 4.80 |
| 2009 | 72 | 0.40 | 1.38 | 1.78 | 3.23 | 2.29 | 4.21 | 6.50 | 12.17 |
| 2010 | 87 | 0.50 | 0.92 | 1.28 | 2.41 | 1.75 | 3.43 | 4.63 | 6.74 |
| 2011 | 102 | 0.17 | 0.59 | 1.11 | 2.76 | 2.50 | 4.03 | 5.51 | 8.21 |

### *Chlorophyll a to Total Organic Carbon ratio Lower Lake Samples Categorized by Month*

> By month, the highest mean and median ratios were recorded in March, November and September.

> The lowest mean ratios were recorded in June, May and July in increasing order.

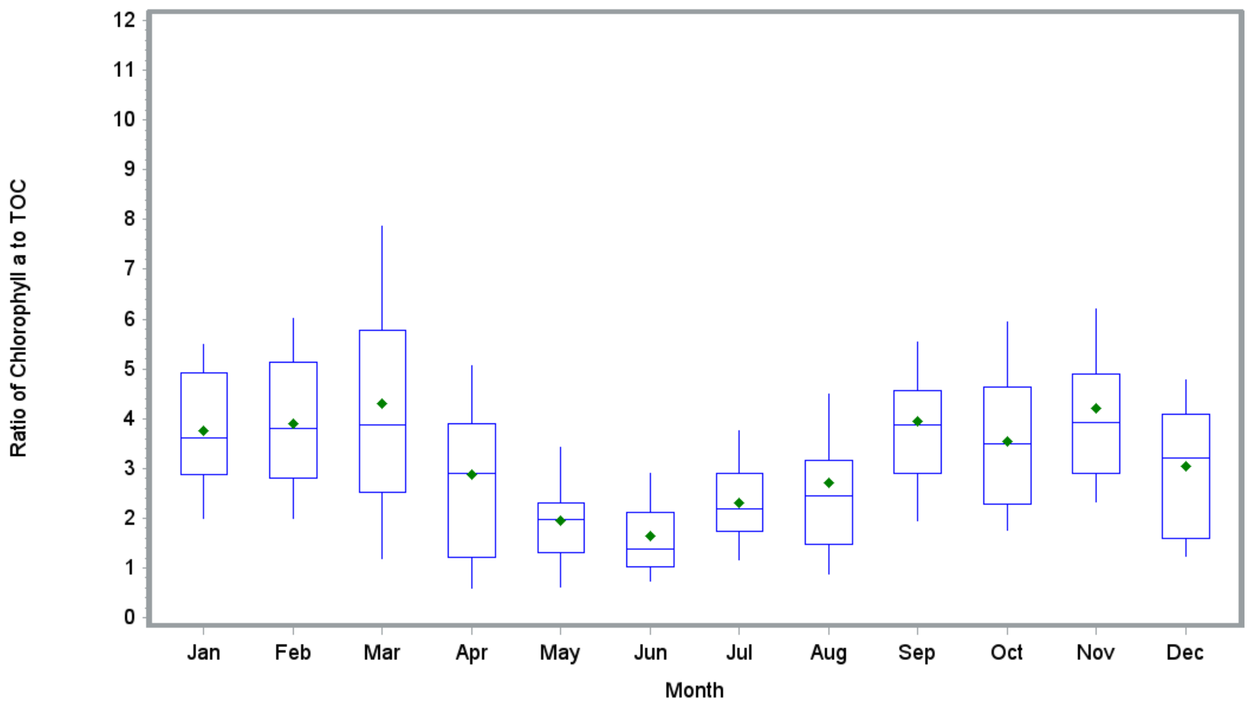



**Figure 3-254 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Month**

**Table 3-265 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Month**

| Month | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 26 | 1.73 | 1.99 | 2.89 | 3.76 | 3.61 | 4.92 | 5.48 | 6.97 |
| Feb | 33 | 0.71 | 2.00 | 2.82 | 3.90 | 3.80 | 5.13 | 6.01 | 7.40 |
| Mar | 35 | 1.01 | 1.20 | 2.51 | 4.29 | 3.88 | 5.78 | 7.87 | 9.63 |
| Apr | 55 | 0.29 | 0.59 | 1.22 | 2.87 | 2.90 | 3.90 | 5.07 | 7.29 |
| May | 42 | 0.17 | 0.62 | 1.31 | 1.96 | 1.97 | 2.32 | 3.43 | 4.72 |
| Jun | 53 | 0.29 | 0.75 | 1.03 | 1.63 | 1.38 | 2.12 | 2.90 | 3.92 |
| Jul | 42 | 0.57 | 1.17 | 1.73 | 2.31 | 2.20 | 2.91 | 3.76 | 4.36 |
| Aug | 55 | 0.37 | 0.88 | 1.47 | 2.70 | 2.45 | 3.16 | 4.48 | 8.21 |
| Sep | 41 | 1.49 | 1.94 | 2.91 | 3.94 | 3.89 | 4.57 | 5.54 | 7.83 |
| Oct | 56 | 1.30 | 1.76 | 2.28 | 3.55 | 3.49 | 4.63 | 5.94 | 6.74 |
| Nov | 38 | 1.00 | 2.33 | 2.91 | 4.21 | 3.94 | 5.00 | 6.29 | 12.17 |
| Dec | 43 | 0.40 | 1.24 | 1.60 | 3.04 | 3.20 | 4.09 | 4.78 | 5.71 |

### *Chlorophyll a to Total Organic Carbon ratio Lower Lake Samples Categorized by Sampling Organization*

> Highest mean and median ratios were measured by NCDWQ and NCSU-CAAE and lowest ratios were measured by USGS.

> Minimal overlap between boxes indicates greater statistical difference between NCDWQ and USGS data categories.

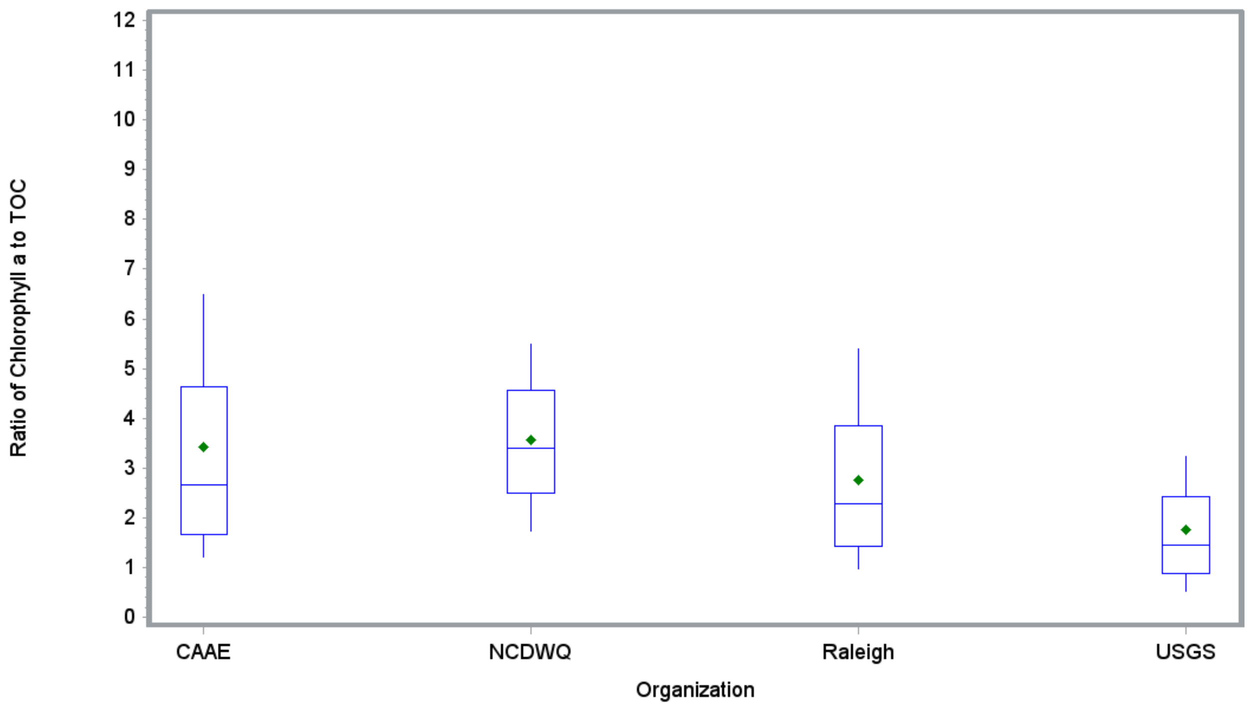



**Figure 3-255 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Sampling Organization**

**Table 3-266 Ratio of Chlorophyll *a* to TOC Lower Lake Samples Categorized by Sampling Organization**

| Organization | Count | Minimum | 10th | 25th | Mean | Median | 75th | 90th | Maximum |
|---|---|---|---|---|---|---|---|---|---|
| CAAE | 64 | 0.57 | 1.22 | 1.67 | 3.42 | 2.75 | 4.65 | 6.80 | 12.17 |
| NCDWQ | 235 | 0.59 | 1.74 | 2.50 | 3.56 | 3.41 | 4.56 | 5.48 | 8.21 |
| Raleigh | 157 | 0.17 | 0.98 | 1.44 | 2.76 | 2.29 | 3.85 | 5.41 | 6.97 |
| USGS | 63 | 0.29 | 0.52 | 0.88 | 1.76 | 1.44 | 2.43 | 3.24 | 5.32 |

***Chlorophyll a to Total Organic Carbon ratio Lower Lake Samples Categorized by Method***

> Chlorophyll *a* to Total Organic Carbon ratio was calculated.

# 4 Summary

The section briefly summarizes the lessons learned from the graphical analysis of individual water quality parameters. The summary focuses on the spatial and temporal relationships among the measured data for each parameter. Box and whisker plots display the empirical distribution of the parameters for specific metrics such as space (e.g., distance from the lake for a particular Subwatershed), time (e.g., months), organization, and analysis method. Visual interpretation of these plots is used as the basis for evaluating differences among categories. The relative distributions of the metrics are visually examined using the box and whisker plots, and the discussion focuses on the overlap of IQRs. When the IQRs do not overlap significantly, then the relative difference in metrics (e.g., difference among analysis methods, or differences in months) is considered notable. In some cases, the means and medians are used explicitly to determine patterns and differences (as compared to differences in overlap of IQRs).

## 4.1 Temperature

**Spatial -** There is little spatial difference at the Subwatershed scale for the tributary temperature data. Median and mean temperature in the Upper Lake segment greater than 21 miles from the dam is slightly higher than the other lake segments; there is a decreasing trend in the medians in the downstream direction.

**Depth** – All of the tributary data were collected in the surface layer. In the Upper Lake and Lower Lake segments, median temperatures in the surface are higher than the middle, and the lowest temperatures were observed in the bottom.

**Year** – There is little annual variability in the tributary data for temperature. In the Upper Lake segment, temperatures recorded in 2001 are different (higher IQR) than the other years because temperatures were only measured during the summer months that year. Temperatures are fairly consistent in the Lower lake segment from year to year. Both lake segments appear to have a lower distribution of temperatures in 2012, but 2012 is a partial year with measurements from January to April included in the lake dataset.

**Month** – As expected, temperature varies seasonally in the tributary and Lake data, with warmer temperatures observed in the summer months and cooler temperatures observed in the winter months.

**Organization** – Temperature data in the tributaries do not differ significantly by organization. In the Upper Lake, the median and mean temperatures in the City of Durham data are higher than the NCDWQ and USGS data. In the Lower Lake segment, the Wake County temperature data have a lower IQR than the other four organizations, but this data set has a small sample size (n=8) relative to the other data sources and the samples were collected in the spring and fall.

**Analysis Method** – There is little difference among the temperature data when analysis methods are compared for the tributary and Lake data, and the majority of the distributions overlap.

## 4.2 DO

**Spatial** – DO concentrations in the Lake segments are similar, including Beaverdam Impoundment. In the tributary data, aggregation to the Subwatershed scale shows little difference in median concentrations, except for Knap of Reeds Creek which is lower. In the Upper Lake, median DO is slightly lower in the segment greater than 21 upstream from the dam relative to the other segments. Lower DO concentrations are more often observed in the segments between 13 and 21 miles upstream from the dam. In the Lower Lake, median concentrations are stable throughout the lake.

**Depth** - All of the tributary data were collected in the surface layer. In the Upper Lake and Lower Lake, the lowest DO observations were recorded in the middle and bottom depths.

**Year** – Median DO is generally lower in years 2006 through 2011 in the tributary samples. In the Upper Lake, median DO was lowest in 2008 and highest in 2006, 2007, and 2011. In the Lower Lake, median DO increases from year 2004 through 2009. The differences in the length of the boxes for years 2005, 2006, and 2007 in the Lower Lake segment is due to the larger sample size relative to the other years.

**Month** – DO is lower in the warmer summer months and higher in the cooler months in the tributary and Lake data. Low DO occurs more frequently in the Lower Lake data in June through August relative to the Upper Lake data.

**Organization** – Median DO is similar for each organization for the tributary data, except for SGWASA which has a lower median value than the other organizations. In the Upper Lake, the City of Durham recorded lower median DO. In the Lower Lake, the organizations tend to observe similar DO concentrations, though the distribution of the Wake County data is higher than the other organizations. The Wake County data has a small sample size (n=8) relative to the other data sources and the samples were collected in the spring and fall. NCDWQ and USGS observe low DO more frequently because these organizations collect the majority of the DO data in the middle and bottom depths.

**Analysis Method** – Median DOs are similar with overlapping IQRs for the tributary and Lake data with respect to analysis method. In the lake samples, ASTM_D888-05 and EPA_360.1 appear to measure low DO more frequently, which may be a function of their application in the field.

## 4.3 pH

**Spatial** –At the Subwatershed scale, Lick Creek has higher median pH values than seven of the eight other Subwatersheds. Beaverdam Creek 2 to 10 miles has lower medians than the other segments in the watershed. In the Upper Lake and Lower Lake, there is little difference in pH from one segment to the next, including Beaverdam Impoundment.

**Depth** - All of the tributary data were collected in the surface layer. There is an increasing trend in the distribution of pH measurements in the bottom, middle, and surface layers in the Upper and Lower Lake segments.

**Year** – Median pH in years 2009 through 2012 appears higher than the other years (2012 is a partial year) in the tributary data. Median pH fluctuates from year to year in the Lake data.

**Month** – There is little monthly or seasonal variability in pH in the tributary or Lake data.

**Organization** – The City of Durham observed higher median pH values in the tributary data relative to the other organizations. In the Upper Lake and Lower Lake data, the USGS median measurements are lower than the other organizations.

**Analysis Method** – In the tributary data, pH measurements with the Oakton_WP_pH are higher than the other three methods. In the Upper Lake and Lower Lake data, USGS_I-2587-85 has a lower median value than the other datasets.

## 4.4 Conductivity

**Spatial** – Conductivity varies greatly by Subwatershed in the tributary data. Ellerbe Creek and Knap of Reeds Creek have the highest conductivity measurements with the highest observations in the 0 to 2 miles from the lake segments. In the Upper Lake, the segments have similar conductivities, but those in the Upper Lake more than 21 miles upstream from the dam are more variable with higher concentrations observed. In the Lower Lake data, there is little difference in median conductivities among the segments, including Beaverdam Impoundment.

**Depth** - All of the tributary data were collected in the surface layer. In the Upper Lake samples, conductivity is lowest at the bottom and increases toward the surface. In the Lower Lake, higher conductivities are more prevalent at the bottom.

**Year** – Conductivity measurements in the tributary data increase after year 2005, as does the range of observations. Conductivity in the Upper and Lower Lake fluctuates from year to year. In the Upper Lake, 2002 and 2009 have higher conductivities than 8 of the other years. Slight differences from year to year are apparent in the Lower Lake data, but for the most part the IQRs overlap.

**Month** – There is little monthly or seasonal variability in the median conductivities in the tributary or Lake data. Higher conductivities were recorded in the tributaries in the summer and in the Upper Lake in late summer and fall.

**Organization** – The City of Durham and SGWASA generally observed higher conductivity values than the other organizations in the tributary data. The City of Durham also observed higher conductivities in the Upper Lake. There is little variability by Organization in the Lower Lake data.

**Analysis Method** – There is little difference in the median conductivities for the tributary and Lake data with respect to analysis method.

## 4.5 Total Suspended Sediment (TSS)

**Spatial** – Median TSS values are fairly similar at the Subwatershed scale, though higher concentrations are most often observed in the Little River subwatershed. In the Upper Lake, the segment that is 13 to 18 miles upstream from the dam has lower TSS values relative to the segments located further upstream. In the Lower Lake data, the segments have similar TSS values.

**Depth** - All of the tributary data were collected in the surface layer. Median TSS is higher in the surface samples relative to the photic zone samples in the Upper Lake. There is little difference in TSS values by depth in the Lower Lake segments.

**Year** – Median TSS is fairly similar from year to year in the tributary data with the highest concentrations observed in years 2004 and 2009. In the Lake, the median TSS from year to year is similar in the both the Upper and Lower Lake segments. The highest TSS observations in the Upper Lake occurred in 2001.

**Month** – There is little monthly or seasonal variability in the median TSS for the tributary or Lake data. Higher concentrations in the Tributary data were observed in June and December.

**Organization** – There is little variation due to sampling organization in the tributary or Lake data with the exception of USGS tributary samples, which are higher than the other data.

**Analysis Method** – There is little variation in median TSS due to analysis method in the tributary or Lake data with the exception of the Tributary data analyzed by method USGS_I-3765-85 which are higher than the other data.

## 4.6 Ammonia

**Spatial** – Median ammonia values are fairly similar at the Subwatershed scale, though higher concentrations are more often observed in Ellerbe Creek. There is little difference between the lake segments in the Upper and Lower Lake data, though higher ammonia concentrations tend to occur in the most downstream segments closest to the dam.

**Depth** - All of the tributary data were collected in the surface layer. In the Lake segments, observations in the surface and photic zone are similar. Higher ammonia concentrations are consistently observed in the bottom depths for the both the Upper and Lower Lake segments.

**Year** – Median ammonia in the Tributary, Upper Lake, and Lower Lake regions are fairly consistent from year to year. 2001 and 2002 had the highest observations of ammonia in the Upper Lake and Lower Lake.

**Month** – There is little monthly or seasonal variability in the median ammonia concentrations in the tributary data. In the Upper Lake segment, the monthly and seasonal variability is small with the exception of the lower concentrations observed January through March. In the Lower Lake, concentrations in June, August, and October tend to be higher than the other months.

**Organization** – There is little difference in the tributary data for the various organizations, though the City of Durham and NCDWQ observed the majority of the higher measurements. In the Upper Lake segments, there is little difference in data collected by organization. In the Lower Lake, USGS recorded the highest concentrations

**Analysis Method** – There is little difference among the analysis methods for the tributary, Upper Lake, and Lower Lake data, though ‘Various’ methods associated with the USGS data recorded higher concentrations in the Lower Lake.

**Less than Detection Method** – The assumption regarding how to deal with less than detection (zero, half of the limit, or limit), do not alter the results of the analysis significantly for the tributary, Upper Lake, and Lower Lake data.

## 4.7 Nitrate plus Nitrite (NO2/NO3)

**Spatial** – The Ellerbe Creek, Honeycutt/Barton/Cedar, and Knap of Reeds from 0 to 2 miles from the Lake tend to have higher NO2/NO3 concentrations relative to the other tributary segments. There is little difference among the lake segments, though higher concentrations tend to occur in the Upper Lake segment more than 21 miles upstream from the dam (upstream of I-85).

**Depth -** All of the tributary data were collected in the surface layer. The majority of NO2/NO3 data in the both the Upper and Lower Lake data have been collected in the surface and photic zones. The highest observations occur in the surface data in in the Upper Lake.

**Year** – For the most part, annual variability in the median concentrations in the tributary and Lake segments is small. The highest NO2/NO3 concentrations observed in the tributaries occurred in 2005 through 2008 and in 2011. 2002 in the Upper Lake segments had higher concentrations overall relative to the other years and there is generally more variability in the Upper Lake data from one year to the next. Median concentrations were fairly consistent from one year to the next in the Lower Lake data, except for 2005 through 2007 which had lower distributions than the other years.

**Month** – The tributary and Lake segments have similar median concentrations from month to month. Higher concentrations tend to occur in the summer in the tributaries and during the fall in the Upper Lake. Median concentrations are relatively constant in the Lower Lake with slightly higher measurements in the winter months.

**Organization** – There is little difference among the median concentrations for the organizations for the tributary and Lake data. The City of Durham tends to observe higher concentrations in the Upper Lake compared to NCDWQ and USGS.

**Analysis Method** – There is little difference among the median concentrations for the analysis methods for the tributary and Lower Lake data. EPA_300.0 and EPA_353.2 tend to have higher values than the other methods.

## 4.8 Organic Nitrogen

**Spatial** – The highest distribution of organic nitrogen concentrations are observed in the Beaverdam Creek from 2 to 10 miles upstream of the lake and the Knap of Reeds Creek and Ellerbe Creek segments 0 to 2 miles from the lake. The lowest concentrations occur in Beaverdam Creek and Horse/Newlight from 0 to 2 miles upstream of the lake, and these segments have non-overlapping IQRs compared to several of the other segments. The distributions in the lake segments are relatively similar though the segments from 8 to 13 and 18 to 21 miles upstream from the dam have lower observations (these segments also have smaller sample sizes than the other segments). Higher concentrations are observed most often from 0 to 8 miles upstream from the dam.

**Depth** – All of the tributary data were collected in the surface layer. Concentrations in the middle and bottom layers of the Upper and Lower Lake were greater than the surface and photic layers. There is little overlap between the surface IQRs relative to the other depths.

**Year** – There is little variability from year to year in the tributary data for median organic nitrogen; the highest concentrations were observed in 2006 and 2011. In the Upper Lake and Lower Lake data, organic nitrogen was lower in 2000 relative to the other years and higher in 2008 and 2009 (in the Lower Lake the IQRs for 2008 and 2009 did not overlap with the other years).

**Month** – There is little monthly or seasonal variation in the median organic nitrogen concentrations for the tributaries. Concentrations vary from month to month in the Upper and Lower Lake.

**Organization** – In the tributaries, median organic nitrogen concentrations did not vary significantly among most of the organizations, but they were lower for Wake County. In the Lake segments, USGS tended to have higher organic nitrogen values than the other organizations and the USGS IQR does not overlap with the others. Wake County values in the Lower Lake were less than both USGS and NCDWQ but the sample size was small (n=3).

**Analysis Method** – Organic nitrogen is calculated, not directly measured.

## 4.9 Total Nitrogen (TN)

**Spatial** – The distribution of total nitrogen values in Ellerbe Creek and Knap of Reeds Creek from 0 to 2 miles from the lake are higher than the other tributary segments (IQRs do not overlap with other segments). The lowest TN observations were recorded in Beaverdam Creek 0 to 2 miles and Horse/Newlight 0 to 2 miles from the Lake. In the Upper Lake, the distribution of total nitrogen concentrations decreases from the upstream to the downstream segment. Concentrations in the middle section of the lake (near Hwy 50) tend to be lowest with increases occurring in the Lower Lake segments closer to the dam. Spatial TN patterns track closely to those observed for organic nitrogen.

**Depth -** All of the tributary data were collected in the surface layer. The highest concentrations are observed in the middle and bottom layers in the Upper and Lower Lake.

**Year** – Median TN concentrations in the tributaries were similar from year to year; the highest TN concentrations were observed in 2005 through 2008. The distributions of TN concentrations in the Upper Lake were highest in years 2002, 2008, and 2009. Patterns were similar in the Lower Lake, though no TN data are available for year 2002.

**Month** – There is little monthly or seasonal variation in the tributary data. Concentrations vary from month to month in the Upper and Lower Lake.

**Organization** – The five organizations measuring nitrogen tend to have similar results for TN in the tributaries, though most of the higher values were reported by NCDWQ. In the Upper Lake, NCDWQ tended to observe lower TN concentrations compared to the City of Durham and USGS. In the Lower

Lake, USGS observed higher concentrations than CAAE, NCDWQ, and Wake County. In both segments of the Lake, the IQRs for USGS are higher and do not overlap with the other organizations.

**Analysis Method** – Total nitrogen is calculated, not directly measured.

## 4.10 Ortho-Phosphate

**Spatial** – Ellerbe Creek, Lick Creek, Little River, and Knap of Reeds Creek from 0 to 2 miles from the lake have higher ortho-phosphate distributions relative to the other tributary segments. There is little variation in the Lake segments, though the highest concentrations are observed in the Upper Lake greater than 21 miles from the dam.

**Depth** - All of the tributary data were collected in the surface layer. There is little difference between the median ortho-phosphate values in the Lake by depth, but higher concentrations were more often observed in the surface for the Upper Lake samples and in the photic zone for Lower Lake samples.

**Year** – There is little annual variability in the tributary median ortho-phosphate concentrations. Years 2008, 2008, and 2011 had higher concentrations in the tributaries than the other years. Year 2002 had higher concentrations in the Upper Lake relative to the other years. There was little annual variability in the Lower Lake, though no data are available for years 2001 through 2004.

**Month** – There is little monthly or seasonal variability in the median ortho-phosphate concentrations in the tributary or Lake data. The highest concentrations were observed in the tributaries in November and in the Upper Lake in October.

**Organization** – There is little variability between the sampling organizations for the median ortho-phosphate concentrations in the tributary and Lake data, although the City of Durham observed higher concentrations than NCDWQ and USGS in the Upper Lake.

**Analysis Method** – There is little variability between the analysis methods in the tributary and Lake data.

**Less than Detection Method** – The assumption regarding how to deal with less than detection (zero, half of the limit, or limit), do not alter the results of the analysis significantly for the tributary, Upper Lake, and Lower Lake data.

## 4.11 Total Phosphorus (TP)

**Spatial** – The Knap of Reeds Subwatershed from 0 to 2 miles from the Lake had higher TP concentrations than each of the other Subwatersheds, followed by Ellerbe Creek. Total phosphorus concentrations are highest in the Upper Lake 21 miles upstream from the dam and decrease downstream of the I-85 bridge. Concentrations remain fairly stable from 0 to 18 miles upstream from the dam, and the $90^{th}$ percentile concentrations do not exceed 0.07 mg/L.

**Depth** - All of the tributary data were collected in the surface layer. In the Upper Lake, the highest TP concentrations were observed in the surface data, and the surface IQR did not overlap with the bottom, middle, and photic zone data which had similar distributions. In the Lower Lake, the distributions of total phosphorus for each depth category were similar.

**Year** – There is little annual variability in the median total phosphorus concentrations for the tributary and Lower Lake TP data, but the highest tributary values were observed in 2004 through 2007. In the Upper Lake, the distribution of concentrations were highest in 2002 (there are no corresponding Lower Lake measurements in 2002). For years with similar sample size in the Upper Lake, there is little difference in median TP concentrations.

**Month** – There is little monthly or seasonal variability in the median total phosphorus concentrations for the tributary or Lake data. The highest $90^{th}$ percentile concentrations in the Upper Lake were observed in October.

**Organization** – Median total phosphorus concentrations for the tributary data are generally the same for each organization; NCDWQ measured the highest total phosphorus concentrations. The City of Durham measured higher TP concentrations (IQR did not overlap) compared to the NCDWQ or USGS data in the Upper Lake. There was no significant difference among the organizations collecting TP data in the Lower Lake.

**Analysis Method** – There is little variability among the median total phosphorus concentrations based on analysis methods for the tributary and Lower Lake data. In the tributary data, higher concentrations were more often observed with method EPA_365.1. For the Upper Lake data, results for EPA_365.3 tended to be higher than the other methods.

## 4.12 Secchi Depth

Secchi depth data are not presented for the free-flowing tributary monitoring stations. Data collected in watershed impoundments is presented in Appendix A. This section summarizes Secchi depth data in the Upper Lake and Lower Lake only.

**Spatial** – Secchi depth tends to increase in the downstream direction with the Upper Lake greater than 21 miles upstream from the dam having the lowest Secchi depths and the Lower Lake near the Dam having the highest observed Secchi depths.

**Depth** – A depth analysis is not applicable for Secchi depth.

**Year** – There is little variability in median Secchi depth from year to year in the Upper Lake or Lower Lake segments. Secchi depths were greater, however, in the Upper Lake in 2008 and in the Lower Lake in 2001 and 2008.

**Month** – In the Upper Lake, there is little monthly or seasonal variation in median Secchi depth. In the Lower Lake, median Secchi depths are generally higher in the summer months (May through August) relative to the other months.

**Organization** – The City of Durham tends to observe lower Secchi depths (non-overlapping IQR) in the Upper Lake relative to the NCDWQ and USGS observations. There is little difference in the distributions of Secchi depth by organization in the Lower Lake.

**Analysis Method** –Secchi depth is recorded in the field.

## 4.13 Chlorophyll *a*

**Spatial** – In the tributary region, chlorophyll *a* was only measured in the Eno River subwatershed more than 10 miles from the Lake. In the Upper Lake, the highest chlorophyll *a* observations were recorded in the segment more than 21 miles upstream from the dam, but median concentrations were higher in the segment from 18 to 21 miles upstream from the dam. In the Lower Lake, there is very little difference among the distributions in the segments (including Beaverdam Impoundment) though concentrations increase in the upstream direction, and the distributions are similar to those observed in Upper Lake 13 to 18 miles upstream from the Dam.

**Depth** - All of the tributary data were collected in the surface layer. In the Upper Lake, concentrations observed from 1 m to 4 m tend to be higher than those categorized as surface, photic, or bottom. In the Lower Lake, little variation is evident among depth categories, but concentrations tend to be lower in the 8 to 10 meter category.

**Year** – Median chlorophyll *a* in the tributary data is consistent for the two sampling years: 2010 and 2011. Chlorophyll *a* observations in the Upper Lake were higher in 2001 than 2002 through 2004 (no overlap). There was an increasing trend in the chlorophyll *a* distributions from year 2003 to 2007 in the Upper Lake; years 2007 through 2012 are fairly similar. In the Lower Lake, there is a decreasing trend in the distributions from 2006 to 2010; the highest $90^{th}$ percentile concentrations were observed in 2006.

**Month** – There is little monthly or seasonal variability among the median chlorophyll *a* in the tributary data, although September and May tended to have the higher observations. In the Upper Lake, higher concentrations are consistently observed in the spring and summer months. In the Lower Laker, the highest 90$^{th}$ percentile concentrations are observed in February through April and the lowest are observed in May through July.

**Organization** – In the tributary region, chlorophyll *a* was only measured by Orange County. There is little difference in median chlorophyll *a* concentrations among the organizations in the Upper Lake; however, CAAE observed higher chlorophyll *a* concentrations compared to the other organizations. In the Lower Lake, NCDWQ observed higher concentrations relative to the other groups.

**Analysis Method** – There is little difference in median chlorophyll *a* concentrations between the analysis methods used to measure chlorophyll *a* concentrations in the tributaries or Lake segments (none of these samples include the in situ method for chlorophyll *a*).

## 4.14 Total Organic Carbon (TOC)

**Spatial** – TOC distributions for the tributary data generally fall into two categories with IQRs either above or below the 10 mg/L to 11 mg/L range. The segments with lower TOC distributions are the Eno River 0-2, Eno River>10, Flat River 0-2, Ellerbe Creek 2-10, and Lick Creek 2-10. The segments with higher TOC distributions include Ellerbe Creek 0-2, Eno River 2-10, Knap of Reeds Creek 0-2, and Lick Creek 0-2. There is little variability in the TOC distributions in the Upper Lake or Lower Lake segments. The Beaverdam Impoundment, however, has a higher distribution of TOC than each of the other Lake segments except for Upper Lake greater than 21 miles upstream from the dam, which has a similar distribution to the Beaverdam Impoundment.

**Depth -** All of the tributary data were collected in the surface layer. In the Upper Lake, the median TOC concentrations in the middle layer are greater than those assessed over the photic zone. In the Lower Lake, there is little difference in median TOC between the sampling depths.

**Year** – Median TOC concentrations are fairly consistent from year to year in the tributary data. TOC distributions in the Upper Lake were highest in 2008 and 2009 relative to the other six years monitored. In the Lower Lake, concentrations are fairly consistent from 2000 to 2011 with slight fluctuations up or down during this period.

**Month** – For the tributary data, median TOC concentrations were fairly consistent except for those observed in January, March, September, and November which were higher. There is little monthly or seasonal variation in the distribution of TOC in the Upper or Lower Lake.

**Organization** – There is little difference between the median TOC concentrations measured by the various organizations in the tributaries. In the Lake segments, USGS measured higher TOC concentrations than the other organizations.

**Analysis Method** – There is little difference between the median TOC concentrations measured by the various analysis methods in the tributaries or Lake segments though USGS_O-3100-83 measured higher TOC concentrations in the Upper Lake and Lower Lake.

## 4.15 Ratio of Chlorophyll *a* to TOC

**Spatial** –No ratios were calculated for the tributaries. In the Lake segments, a decreasing trend in the Chlorophyll *a* to TOC ratio is evident from the upstream to downstream end.

**Depth** –Ratios calculated in the surface layer are higher than the middle layer for both Lake segments.

**Year** –In the Upper Lake, this ratio was lower in 2008, 2009, and 2010 relative to the other years. In the Lower Lake, the median ratio decreased from 2005 to 2008 and then remained relatively constant.

**Month** –For the most part, the distributions increase over the summer months and decrease in the winter months in the Upper Lake. For the Lower Lake, ratios are generally lower in late spring/early summer.

**Organization** –In the lake segments, CAAE and NCDWQ data resulted in higher ratios than USGS or City of Raleigh.

**Analysis Method** – Chlorophyll *a* to total organic carbon ratio was calculated.

**Table 4-1 Conclusions**

The objectives of the Task 2 TM are to compile, assess, and summarize the existing data and knowledge regarding Falls Lake and its watershed to support the UNRBA in identifying strategies for re-examining Stage II of the Falls Lake Nutrient Management Strategy. The Nutrient Management Strategy was developed using modeling and analysis procedures that required a significant number of assumptions, and the work was done with a limited database. Legislative deadlines for the development of the Nutrient Management Strategy required quick agency decisions. This resulted in a regulatory program that includes a significant amount of uncertainty. The extensive work done by local governments in the watershed to develop the Consensus Principles and the member governments' decision to expand the activities of the UNRBA indicates that there is a keen interest in making sure that the Falls Lake Nutrient Management Strategy reflects a program that balances improving water quality with the resources available and considers the constraints and unique characteristics of the Lake and its watershed. The nutrient load reductions required by the Strategy, particularly for phosphorus, are higher than the relative effectiveness provided by best management practices (Nutrient Scientific Advisory Board 2012). Therefore, the financial demands of the Stage II nutrient reductions are daunting. All of these considerations are the foundation of the work being done under this project.

The UNRBA is beginning the process to reexamine the Nutrient Management Strategy. The UNRBA has posed the following key questions with respect to the data and knowledge available in the watershed:

> How do the past reports developed by the State and local governments compare? Do the data summaries performed for Task 2 support the findings of those reports? (Section 5.1)

> Is the data collected by the various organizations comparable? How do the field and laboratory methods differ? (Section 5.2)

> How does water quality in year 2006 (the baseline year for developing the Falls Lake Rules) compare to the water quality observed in the other years? (Section 5.3)

> What gaps are evident in the data sets available for Falls Lake and its watershed? (Section 5.4)

## 4.16 Comparison of Existing Reports and Models to Data Summaries

For the most part, the existing reports and studies are consistent in their message and are supported by the data summaries presented in the Task 2 TM. In particular, several studies have demonstrated that water quality improves in the lake from the upstream end to the downstream end near the dam (NCDENR 2001, 2006, 2010, 2011b; Ecoconsultants 2009; Giorgino 2012; and Huisman 2012) and this trend was predicted by the State and USACE prior to the construction of the dam (State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources 1973, USACE 1974).

### 4.16.1 <u>Agency Reports</u>

#### *4.16.1.2 Historic Documents*

Two historic documents are summarized in this TM to provide a point of reference of current water quality trends relative to what was expected before the dam was constructed.

In 1973, the State of North Carolina Department of Natural and Economic Resources Office of Water and Air Resources released its Special Analysis of the Falls of the Neuse Project (Special Analysis). Predictions of water quality in the lake were an importance focus of the report, and it was generally accepted that water quality in the upper end of the lake would result in algal blooms due to the shape and residence time of the waterbody. The expectation was that this area of poorer water quality would not negatively impact the drinking water supply intake at the downstream end of the lake, and that the benefits of the lake (flood protection in particular) outweighed the risks associated with eutrophic conditions in the upper most segment. It was expected that taste and odor problems at the water treatment plant would sometimes occur following fall turnover, but for the most part algal blooms would not cause problems for the facility. (Recent monitoring indicates that blooms in the lower lake sometimes occur in the spring and fall). The objectives of the Falls Lake project (flood control, water supply, water quality enhancement, and recreation) were reported to be a source of contention amongst the various stakeholder groups.

The Final Environmental Impact Statement (Revised) Falls Lake Neuse River Basin North Carolina predicted similar spatial trends in water quality (USACE 1974). The Corps predicted that the upper end of the lake would be highly eutrophic, and that recreational use in that area would likely be limited to fishing.

Both historic documents anticipated that the uppermost section of the lake would be highly eutrophic. The data summaries and recent reports presented in this TM confirm that the upper part of the lake has higher nutrient and chlorophyll *a* concentrations than the lower part of the lake.

#### *4.16.1.3 Recent Assessment Reports*

Water quality impairments in the lake include turbidity in the Upper Lake, corresponding to the two most upstream segments (UppLk, 18-21 and UppLk>21), and chlorophyll *a* in the entire lake. Both segments of the lake were listed as impaired for chlorophyll *a* based on data collected by NCDWQ from 2005 to 2006. [Based on the master water quality database, approximately 13 percent of NCDWQ samples from the Lower Lake exceeded the 40 µg/L standard (5 percent in 2005 and 16 percent in 2006). CAAE and USGS also collected data during this period in the Lower Lake, and the percent exceedances based on those data are approximately 6 percent and 8 percent, respectively (when all three data sets are combined, the percent exceedance is approximately 10 percent). In 2007, approximately 8 percent of NCDWQ samples in the Lower Lake exceeded the standard. There were no NCDWQ observations of chlorophyll *a* greater than the standard in the Lower Lake in 2010 or 2011.] NCDENR reports indicate that the lake maintains other water quality standards, such as DO and pH.

Assessment of the turbidity observations in the Upper Lake confirm this trend of improving water quality from the upstream to downstream end (Figure 5-1) and demonstrate that measurements in this part of the lake exceed the standard of 25 NTU in the two upper most segments. Chlorophyll *a* measurements in the Upper Lake exceed the 40 µg/L standard more than 10 percent of the time with the highest median concentrations observed in the segment 18 to 21 miles upstream from the dam (Figure 5-2). The high turbidity levels in the segment greater than 21 miles upstream from the dam impede algal growth in that segment. In the lower lake, the only segment that exceeds the standard more than 10 percent of the time based on all samples collected from 1999 to 2012 is the Beaverdam Impoundment segment (Figure 5-3).

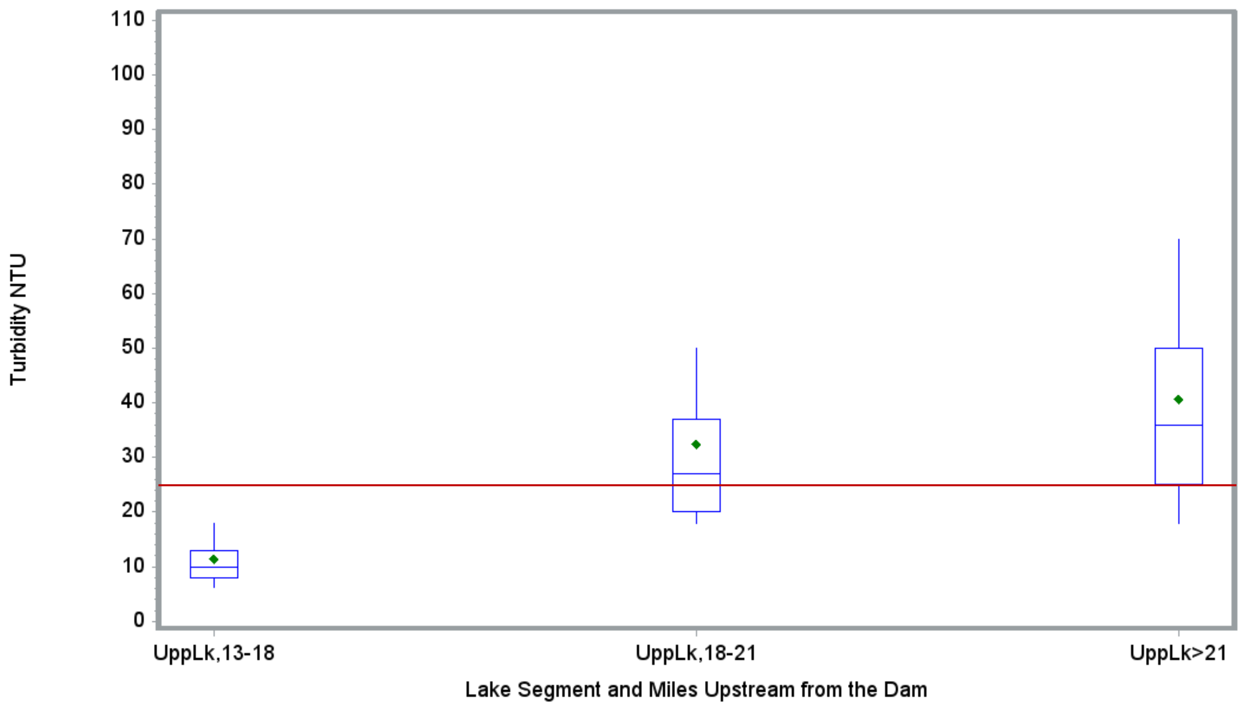



**Figure 4-1 Turbidity Upper Lake Observations Categorized by Miles Upstream from Dam**

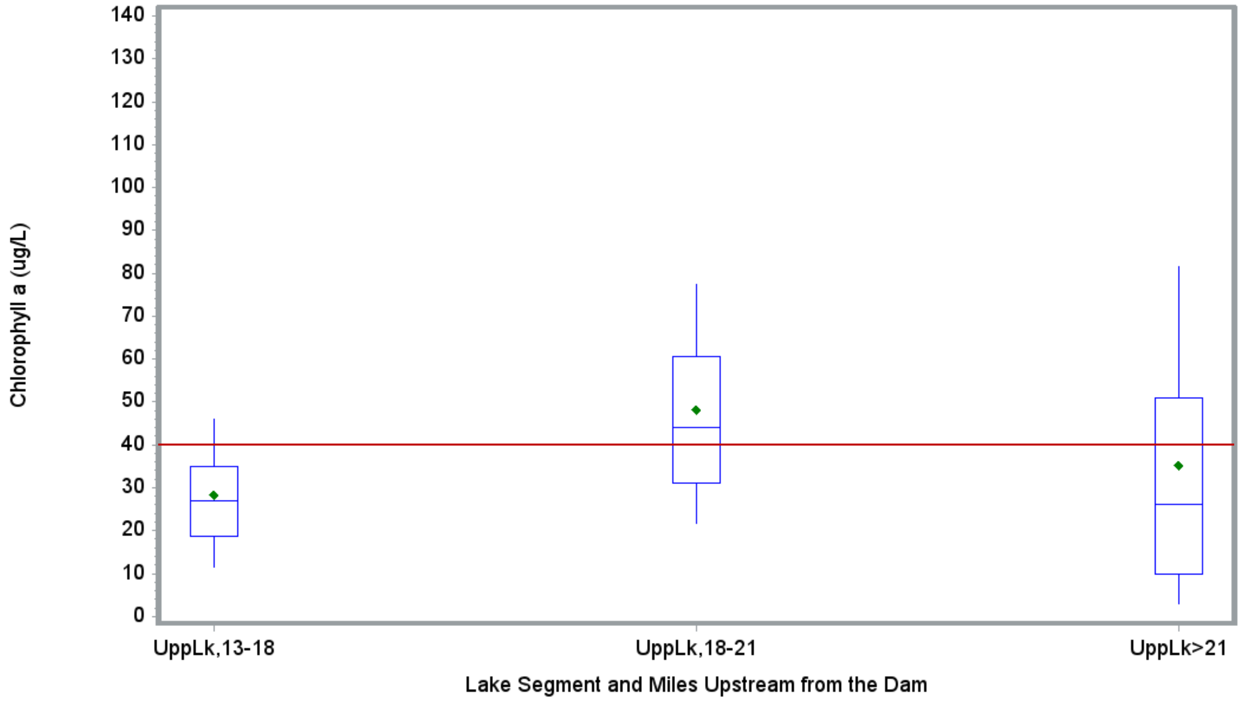



**Figure 4-2 Chlorophyll *a* Upper Lake Observations Categorized by Miles Upstream from Dam**

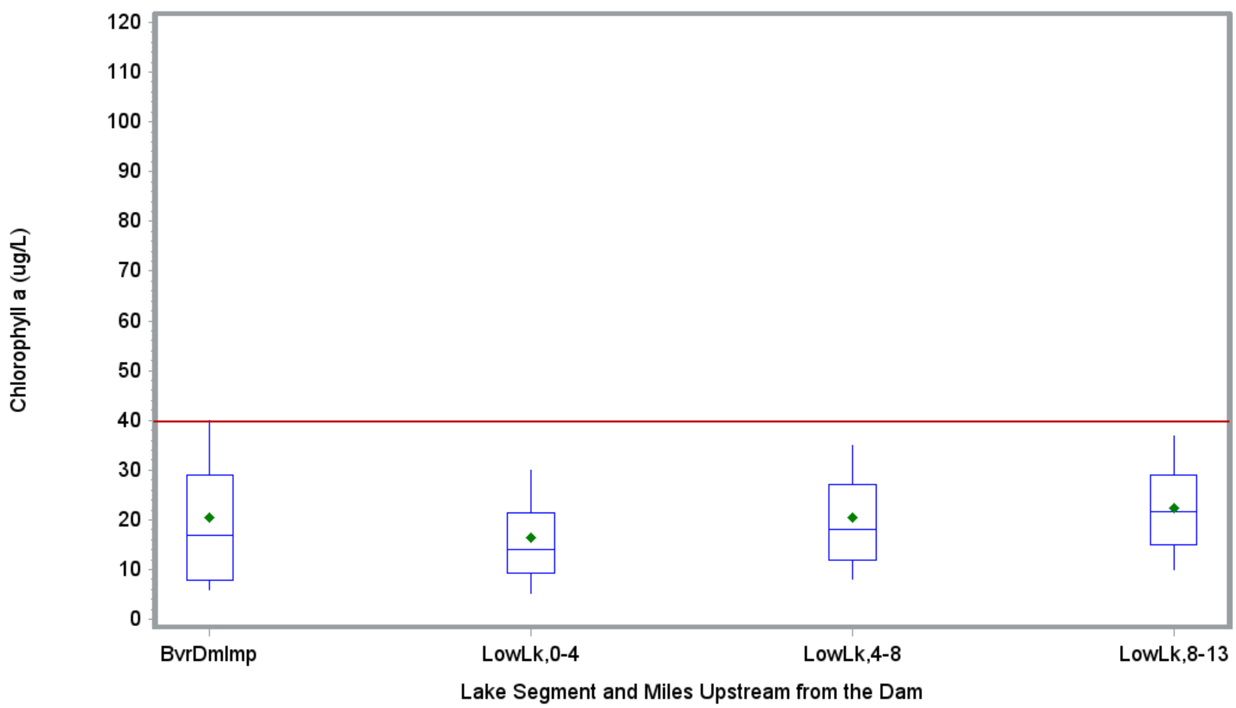



**Figure 4-3 Chlorophyll *a* Lower Lake Observations Categorized by Miles Upstream from Dam**

#### *4.16.1.4 NCDENR Modeling Studies*

The recent NCDENR modeling studies focusing on Falls Lake and its watershed have used a relatively small subset of the data available to develop, calibrate, and validate the models. The Falls Lake WARMF modeling used flow data from eight USGS gages and water quality data from six NCDWQ ambient monitoring stations and two USGS stations from 2004 to 2007. The watershed model does not appear to account for biosolids application in the watershed or streambank erosion. The Falls Lake Nutrient Response Model was developed using data collected from 2005 to 2007 from USGS (flow and water quality data) and NCDWQ (ambient monitoring data). Nutrient and TSS loads to the lake were based on concentrations observed in the tributaries; chlorophyll *a* and TOC loads, however, were based on observations collected within the lake itself. No tributary chlorophyll *a* data were available at the time the model was developed and a little number of TOC data were available for model development.

Ammonia fluxes were measured at two locations and were approximately 0.01 and 0.05 $g/m^2/d$. Ammonia flux is also evident in the depth plots provided for the Upper and Lower Lake samples; Figure 5-4 shows that higher ammonia concentrations were observed in the bottom depths of the Upper Lake section. Nitrite plus nitrate and total phosphorus fluxes were insignificant, and the box plots of these parameters support the conclusion that these fluxes are negligible: surface concentrations of nitrite plus nitrate and total phosphorus are higher than middle or bottom depths. Note that the box plot analysis assesses all samples and locations within the lake segment (Upper versus Lower) and that localized benthic releases would not be evident at this scale. This source of nutrient loading will be addressed further in Task 3.

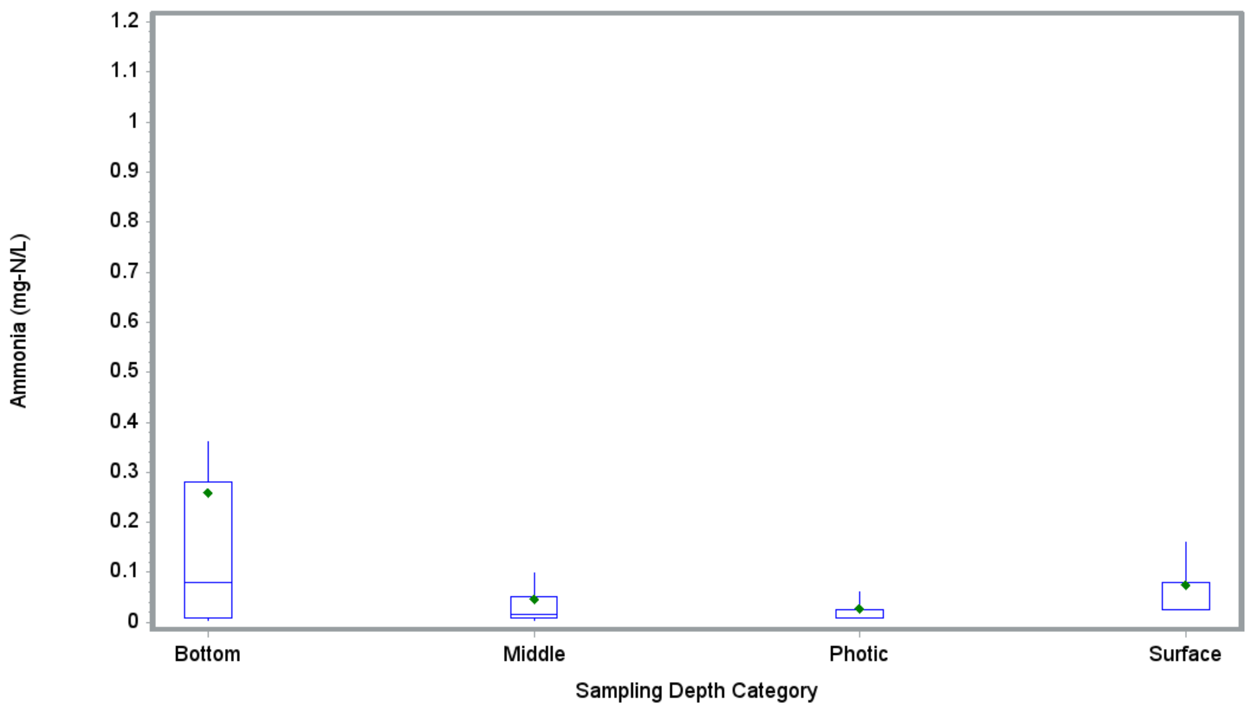



**Figure 4-4 Ammonia Upper Lake Samples Categorized by Depth Category**

### 4.16.2 Independent Studies

The local governments in the watershed have also conducted several studies to assess water quality in Falls Lake and the watershed. In 2003, the Upper Neuse River Basin Association developed the Upper Neuse Watershed Management Plan (Tetra Tech, Inc. 2003). This study concluded that while watershed loads of nitrogen and phosphorus had decreased by 50 percent and 20 percent, respectively, compared to 1989 to 1994 loads, chlorophyll *a* concentrations in the lake appeared to be increasing. Because the Task 2 data analysis focuses on years 1999 to 2012, it is not possible to make a direct correlation using the data summaries in this report.

For 1999 to 2012, there is little change in median total nitrogen and total phosphorus tributary concentrations from year to year. The higher concentrations for both parameters showed an increasing trend from the early to middle 2000's followed by a decreasing trend through 2011. Chlorophyll *a* concentrations in the lake also increased over from 2002 to 2006. After 2006, concentrations have leveled off in the Upper Lake (Figure 5-5) and declined in the lower lake over the period 2007 to 2011 (Figure 5-6).

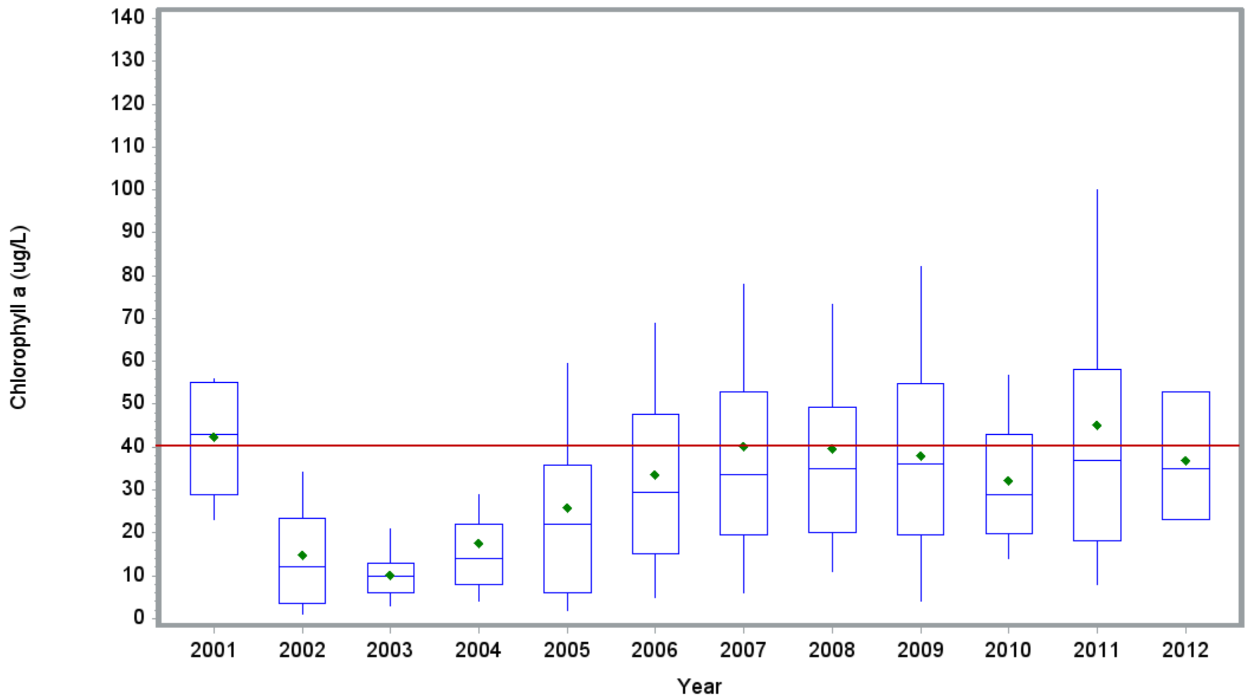



**Figure 4-5 Chlorophyll *a* Upper Lake Samples Categorized by Year**

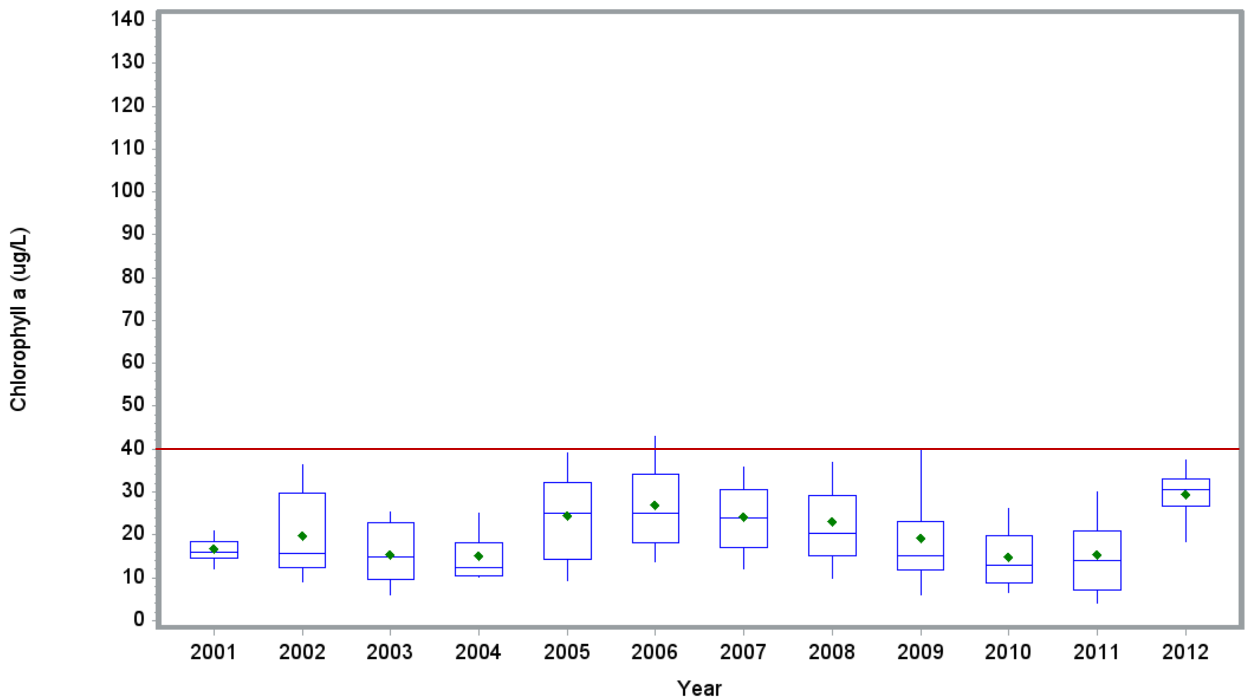



**Figure 4-6 Chlorophyll *a* Lower Lake Samples Categorized by Year**

The City of Raleigh has been studying water quality in Falls Lake to optimize and manage the E.M. Johnson Water Treatment Plant (WTP). Of particular interest is the formation of disinfection byproducts which are toxic to humans and regulated by USEPA. When lake water is treated to produce drinking water and disinfection is achieved with the use of chlorination techniques, there is a potential to produce harmful disinfection byproducts (DBP). Because DBP formation is correlated to the amount of organic material in the raw water, USEPA requires removal of organic material prior to treatment and disinfection (USEPA 2010a). The City of Raleigh monitors total organic carbon (TOC) for compliance and operational planning.

In 2006, Spirogyra Diversified Environmental Services (SDES) developed a report for the City of Raleigh that assessed the relationship between taste and odor episodes at the E.M. Johnson WTP with water quality. Analysis of seven years of data indicated that spring blooms occur annually, typically in March. The Raleigh E.M. Johnson WTP also performs annual flushing and chlorine burnout in March, which typically takes approximately four weeks to transition back into chloramines (personal communication, Kenny Waldroup, City of Raleigh, 8/8/2012). The majority of the taste and odor complaints from water users are filed in March and April each year. SDES recommended that 1) WTP operators alter the depth of the intake to avoid algal blooms in the water column and 2) treat the intake water that is stored in separate basins prior to entering the plant with chemicals such as potassium permanganate to reduce odor problems associated with these algae. Box plots and summary statistics for chlorophyll *a* in the Lower Lake by month (Figure 5-7) support the findings of this report.

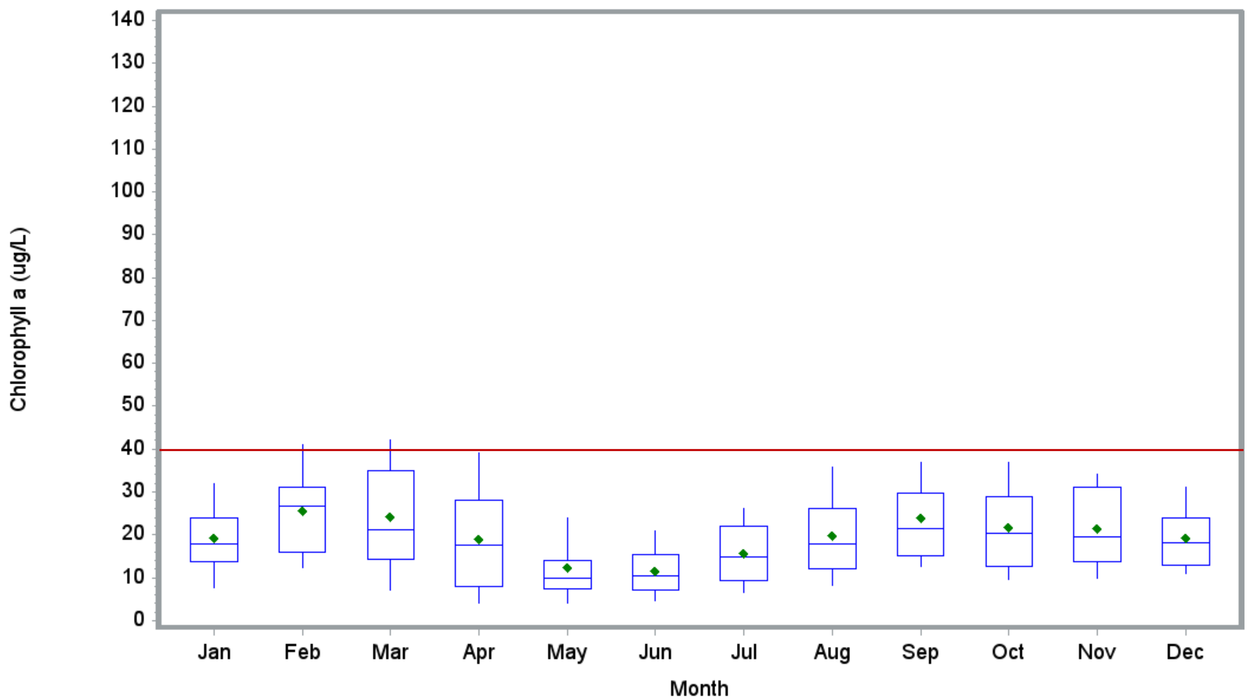



**Figure 4-7 Chlorophyll *a* Lower Lake Samples Categorized by Month**

In 2009, Ecoconsultants prepared a report for the City of Raleigh summarizing the chlorophyll *a* sampling that has occurred in the reservoir from 1983 to 2009. The report summarizes water quality trends in the lake similar to the NCDENR Basinwide Assessment Reports (2001, 2006, 2010, and 2011b) with Secchi depth, nutrients, turbidity, and chlorophyll *a* improving from the upstream end of the lake to the dam.

In 2009, the City of Raleigh also contracted with Hazen and Sawyer to prepare a fiscal analysis of water quality on drinking water treatment costs (Hazen and Sawyer 2009 and 2012). The report (updated in 2012) includes an analysis of TOC data collected from 1999 to spring 2012. TOC concentrations were generally highest during the 1999 to 2002 period and lowest during the 2003 to 2006 period. Concentrations increased during the 2007 to spring 2012 period, but were not as high as the 1999 to 2002 observations according to the Hazen and Sawyer (2012) report. The box plot of TOC in the Lower Lake based on the master water quality database partially confirms this assessment: concentrations fluctuate from year to year, there is an increasing trend from 2004 to 2006, stable concentrations from 2006 to 2008, and a decreasing trend from 2008 to 2010 (Figure 5-8).

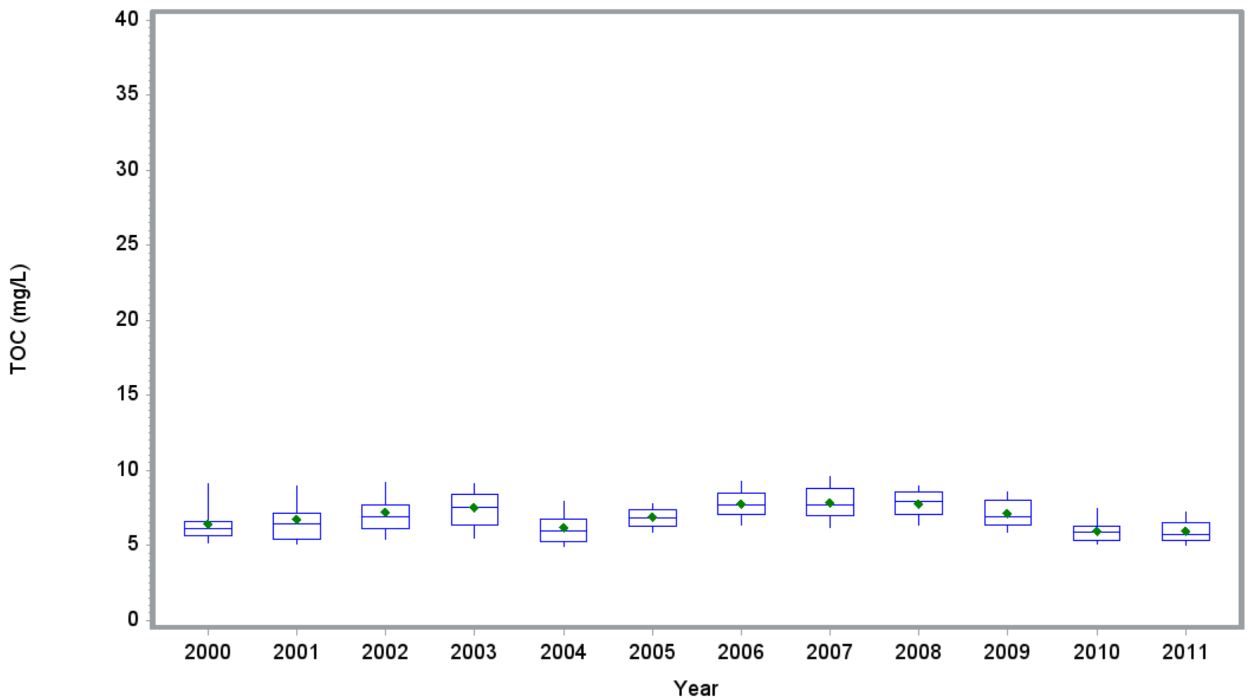



**Figure 4-8 TOC Lower Lake Samples Categorized by Year**

## 4.17 Comparability of Data Collection Efforts by the Various Organizations

The organizations collecting data in the Falls Lake watershed provided varying levels of detail regarding how they collect and analyze data in the watershed. The differences in field and laboratory standard operating procedures (SOPs), quality assurance project plans (QAPPs), and chain of custody (COC) procedures are discussed in Section 3.1 of the report.

For the most part, the organization collecting the data did not affect the analysis results in a significant way. In the Lower Lake, the Wake County data often appeared different than data collected by other organizations, but this is mostly due to the small sampling size of the Wake County Lower Lake data set.

The City of Durham tended to observe poorer water quality than the other organizations sampling in the Upper Lake. This difference is likely due to the location of the City of Durham sampling with respect to the mouth of Ellerbe Creek, and is likely not a reflection of the differences in sampling or analysis protocols.

Quality assurance issues identified by NCDWQ regarding their nutrient and chlorophyll *a* data are described in Section 2.2.1.

## 4.18 Assessment of Annual Variability

To assess annual variability, data for each parameter and geographic region are categorized by sampling year. The amount of annual variability differs by parameter and geographic region:

> For temperature there is little annual variability in the tributary or Lake segments.

> Median tributary DO was lower in years 2006 through 2011 relative to the other years. Low DO in the Upper Lake was more often observed in years 2000, 2001, 2005, 2006, and 2007. In the Lower Lake, low DO was more often observed in years 2001, 2005, 2006, 2007, 2010, and 2011.

> For TSS, median values were typically less than 10 mg/L in the tributaries. Higher values were more often observed in years 2004 and 2009. In the Upper Lake, the highest TSS concentrations were observed in 2000. In the Lower Lake, TSS concentrations were relatively stable from year to year.

> For pH, years 2009 through 2012 have higher median pH values than the other years (2012 is a partial year) in the tributary samples, but pH is relatively consistent from year to year in the Lake samples.

> For Secchi depth, there is little variability from year to year in the Upper Lake or Lower Lake segment. Secchi depths were higher in 2008 in both Lake segments.

> Conductivity measurements were relatively similar from year to year in the tributary samples for years 1999 through 2004. Year 2005 began an increasing trend in conductivity measurements (sample size also increased by an order of magnitude over this period). In the Upper Lake, the highest conductivities were observed in 2002 and 2009. In the Lower Lake, median conductivities were generally constant from year to year.

> Median ortho-phosphate measurements are similar from year to year in the tributary samples; higher concentrations were more often observed in 2006, 2008, and 2011. In the Upper Lake, median concentrations are relatively stable from year to year except for year 2002 which had the highest observations. In the Lower Lake samples, the ortho-phosphate measurements are relatively stable and the $90^{th}$ percentile for each year is less than 0.02 mg/L.

> Median total phosphorus measurements are similar from year to year in the tributaries, but years 2004 through 2007 have the highest observed concentrations. In the Upper Lake, median concentrations vary from year to year with the highest concentrations observed in 2002. In the Lower Lake, total phosphorus measurements are relatively stable and the $90^{th}$ percentile for each year is less than 0.06 mg/L.

> Median ammonia concentrations in the tributary samples were relative stable from year to year. The highest ammonia concentrations were observed in 2005, 2006, and 2011. In the Upper Lake, concentrations were relatively stable, but year 2001 and 2002 had much higher concentrations than those observed in other years. In the Lower Lake, there was much variability in the higher concentrations, with higher concentrations more often observed in 2001 and 2008.

> Median nitrate plus nitrite measurements in the tributary samples are similar from year to year. Higher concentrations were more often observed in years 2005 through 2008 and 2011. In the Upper Lake, median nitrate plus nitrite concentrations fluctuated from year to year, and the highest concentrations were observed in 2002 and 2007. In the Lower Lake, median nitrate plus nitrite concentrations were similar from year to year, except for years 2005 through 2007 when the median values and IQRs were less than the other years.

> For organic nitrogen, there is little variability from year to year in the tributary samples. In the Upper Lake and Lower Lake samples, the majority of the organic nitrogen concentrations were higher in 2008 and 2009 relative to the other years.

> Median TN concentrations in the tributaries were similar from year to year; higher concentrations showed an increasing trend from 2002 to 2007 and a decreasing trend from 2008 to 2010. TN concentrations in the Upper Lake were highest in 2002 and had an increasing trend from 2006 to 2009. In the Lower Lake concentrations were highest in 2008 through 2011.

> Median TOC concentrations are fairly consistent from year to year in the tributary samples, but are higher in years 2007 and 2008. Median TOC concentrations in the Upper Lake were highest in 2008 and 2009 relative to the other years monitored. In the Lower Lake, median concentrations were higher in years 2006, 2007, and 2008. Years 2010 and 2011 had lower median concentrations than most of the other years.

> Median chlorophyll *a* in the tributary samples is consistent for both years with monitoring data (2010 and 2011). Chlorophyll *a* observations in the Upper Lake were higher in 2001 than 2002 through 2004 (no overlap of the IQRs). Median concentrations from years 2003 to 2009 showed an increasing trend. In the Lower Lake, the highest 90th percentile concentrations were observed in year 2006, with years 2005 through 2009 having the highest maximum observations. There is a decreasing trend in the medians from year 2006 to 2010.

> In the Upper Lake, the media ratio of Chlorophyll *a* to TOC was lower in 2008, 2009, and 2010 relative to the other years. In the Lower Lake, the median ratio decreased from year 2005 to 2008 and then leveled off.

The required load reductions for the watershed as defined in the Falls Lake Rules were calculated using the baseline year 2006. For the most part, tributary water entering Falls Lake had poorer water quality in 2006 relative to the other years: tributary samples had lower DO and higher ortho-phosphate, total phosphorus, nitrate plus nitrite, and total nitrogen concentrations relative to most of the other years. Figure 5-9 shows tributary total phosphorus concentrations as an example of the differences observed in 2006 tributary samples.

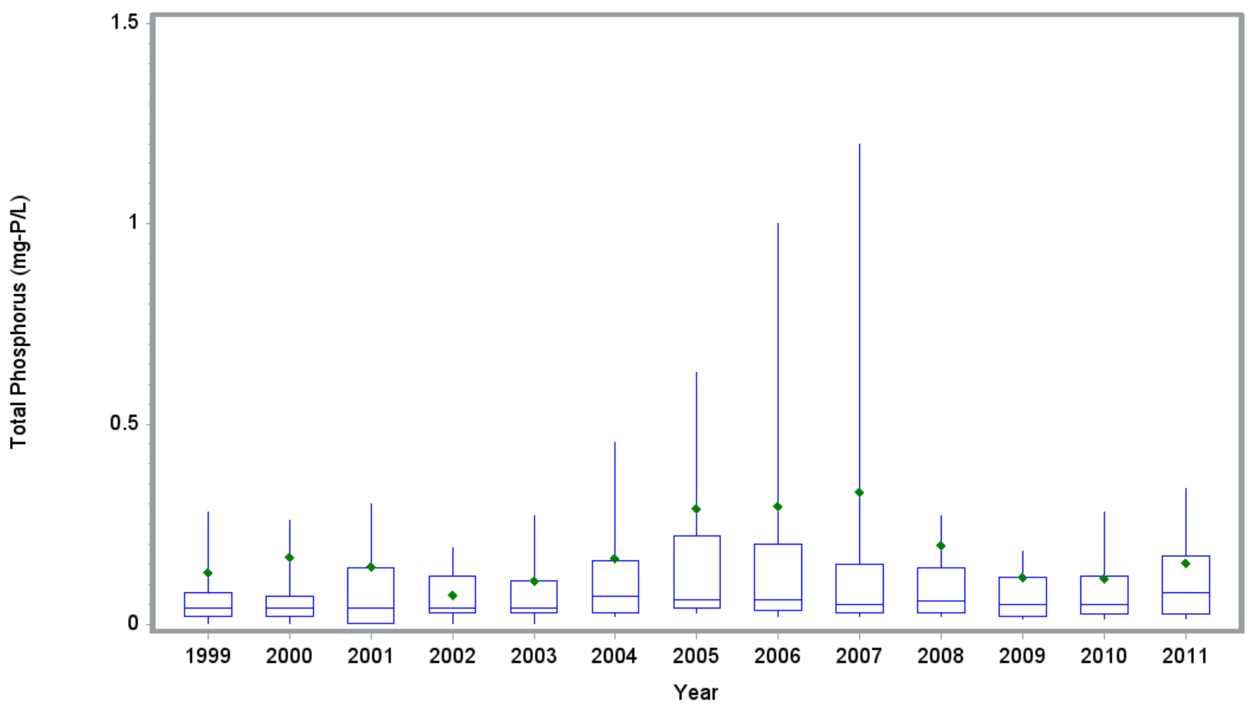



**Figure 4-9 Total Phosphorus Tributary Samples Categorized by Year**

Water quality in the lake was somewhat ambiguous in 2006. Both the Upper and Lower Lake experienced a large percentage of low DO concentrations. In 2006, chlorophyll *a* in the Upper Lake was in the middle of an increasing trend in concentrations that occurred from 2003 to 2007; TOC concentrations were in an increasing trend from 2005 to 2008. In the Lower Lake, year 2006 had typical TOC concentrations and the highest 90th percentile chlorophyll *a* concentrations observed. The total nitrogen and total phosphorus concentrations observed in the Upper and Lower Lake segments, however, were lower in 2006 compared to many of the years (Figure 5-10 shows total phosphorus observations by year in the Upper Lake). Based on visible interpretation of the data, higher nutrient concentrations in both the Upper and Lower Lake segments occurred in years 2007 through 2010. Total nitrogen and total phosphorus in the Upper Lake show an increasing trend from year 2006 to 2009. Higher total nitrogen concentrations occur in the Lower Lake in 2008, 2009, and 2010; total phosphorus concentrations were relatively stable from year to year.

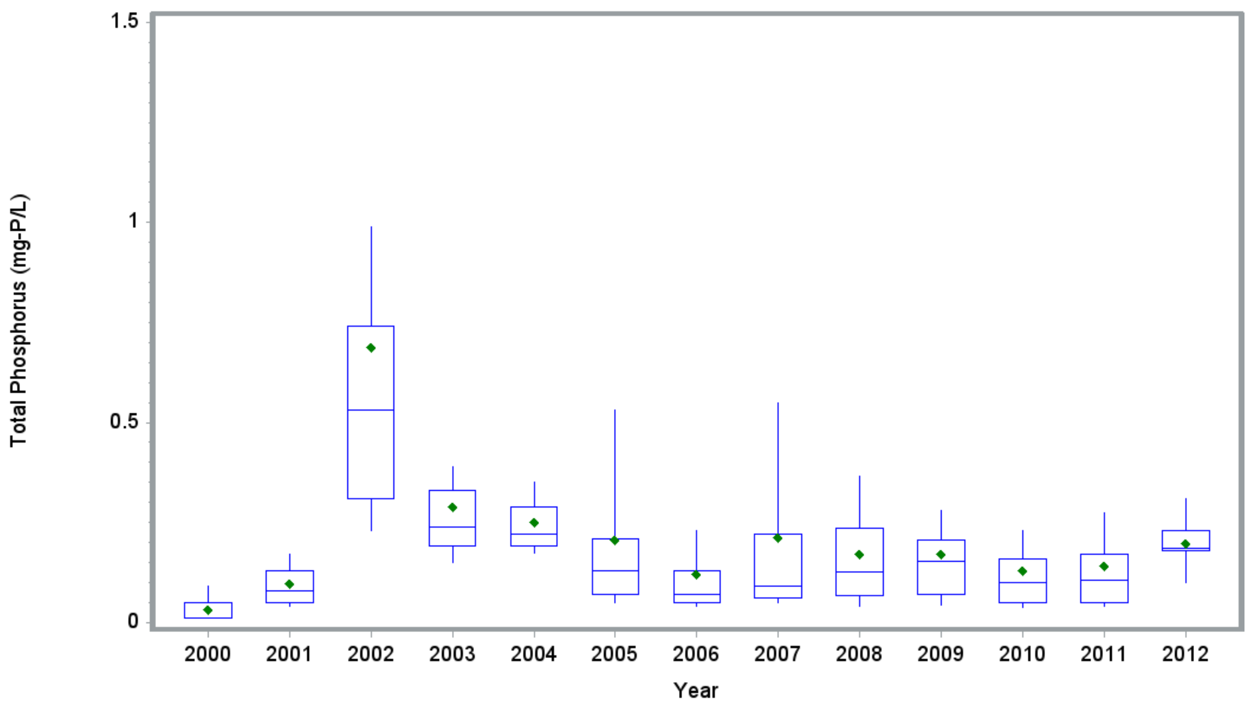



**Figure 4-10 Total Phosphorus Upper Lake Samples Categorized by Year**

## 4.19 Identification of Potential Gaps in the Monitoring Data

Data needs (gaps) to estimate nutrient loads and to support models are appropriately assessed using sensitivity and uncertainty analyses with the models to be applied. For nutrient loads, the model typically is a “rating curve” based on flow-concentration relations or a watershed loading model that simulates runoff and associated nutrient loads. For the reservoir and watershed, the models may be process-based (e.g., the Falls Lake Nutrient Response Model and the Falls Lake Watershed Model) or empirical (e.g., USGS SPARROW).

In fundamental terms, identification of data needs is a “value of information analysis” (VOIA). A data gap exists if additional monitoring (to fill that gap) can improve knowledge (reduce uncertainty), leading to better-informed decision making at an acceptable cost. The VOIA requires a model that links management actions to desired outcomes, such as linking stormwater treatment to water quality standards compliance. Once reservoir and watershed models are selected, the model(s) can be run to determine quantitatively (using sensitivity/uncertainty analyses) what additional monitoring is most cost-effective (improves prediction at acceptable cost). Thus, the review and selection of models that will be undertaken in Task 4 will result in identification of critical data gaps.

Although the majority of the work in identifying data gaps will be addressed in Task 4, one obvious gap presents itself when comparing the existing NCDENR models to the available data. As mentioned in Section 5.1.1.4, the chlorophyll *a* and TOC loads used to develop the input files for the EFDC lake response model were based on lake concentrations, not tributary concentrations. Collection of chlorophyll *a* and TOC data in the tributaries just upstream of the lake would provide more accurate information from which to base simulations of lake response (the relative importance of this gap can be addressed with sensitivity analyses of the existing model to this input parameter).

Several other parameters have limited data in the segments just upstream of the lake, as well as Beaverdam Impoundment. Table 5-1 summarizes the sample size for each parameter and segment. The segments near the lake with a small sample size relative to the other segments in the watershed are shaded. For each parameter, the smallest sample sizes are typically associated with the segment from 0 to 2 miles upstream from the lake and the Beaverdam Impoundment. Collection of additional data in these segments will support tributary load estimation and future lake response modeling. The downstream segments with the least amount of data include the Eno River, Horse/Barton/Cedar, Horse/Newlight, Knap of Reeds, Lick Creek, Little River, the Beaverdam Creek Subwatershed, and the Beaverdam Impoundment. TOC and chlorophyll *a* data near the mouths of tributaries is lacking across the watershed.

Note that this preliminary identification of sampling needs is only based on sample size for those segments near the lake. During Task 3 when water quality concentrations are paired with flows to determine loads, additional gaps in the data may become evident (e.g., lack of sampling during particular flow regimes). Exploration of methods to determine jurisdictional loads may also reveal gaps in the data. Finally, selection of future studies will dictate the parameters, locations, and frequencies needed to support those studies. The Task 4 TM will consolidate the needs identified throughout the project and prioritize the short term and long term studies for the UNRBA.

**Table 4-2 Sample Size by Subwatershed and Lake Segment**

| Sub-watershed and Distance Upstream | TSS | Ammonia | NO2/ NO3 | Organic Nitrogen | Ortho-Phosphorus | Total Phosphorus | Chlorophyll *a* | Total Organic Carbon |
|---|---|---|---|---|---|---|---|---|
| BC,0-2 | 18 | 19 | 15 | 15 | 17 | 15 | 0 | 0 |
| BC,2-10 | 0 | 30 | 0 | 30 | 30 | 30 | 0 | 0 |
| EC,0-2 | 153 | 225 | 453 | 222 | 40 | 444 | 0 | 11 |
| EC,2-10 | 216 | 225 | 214 | 215 | 3 | 265 | 0 | 27 |
| ER,0-2 | 58 | 69 | 115 | 68 | 4 | 118 | 0 | 5 |
| ER,2-10 | 172 | 184 | 231 | 182 | 35 | 237 | 0 | 5 |
| ER>10 | 181 | 289 | 280 | 275 | 99 | 270 | 182 | 85 |
| FR,0-2 | 113 | 201 | 214 | 199 | 95 | 248 | 0 | 1 |
| FR,2-10 | 65 | 44 | 51 | 44 | 3 | 53 | 0 | 0 |
| FR>10 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| HBC,0-2 | 78 | 78 | 76 | 76 | 76 | 76 | 0 | 0 |
| HNL,0-2 | 45 | 50 | 41 | 42 | 44 | 41 | 0 | 0 |
| KRC,0-2 | 80 | 137 | 147 | 136 | 9 | 147 | 0 | 10 |
| LC,0-2 | 31 | 36 | 36 | 36 | 5 | 36 | 0 | 5 |
| LC,2-10 | 57 | 85 | 85 | 85 | 29 | 85 | 0 | 8 |
| LR,0-2 | 0 | 3 | 0 | 3 | 3 | 3 | 0 | 0 |
| LR,2-10 | 145 | 426 | 456 | 424 | 360 | 504 | 0 | 53 |
| UppLk>21 | 146 | 397 | 1109 | 917 | 834 | 621 | 911 | 161 |
| UppLk,18-21 | 102 | 89 | 177 | 89 | 105 | 89 | 160 | 67 |
| UppLk,13-18 | 206 | 947 | 699 | 394 | 410 | 398 | 433 | 267 |
| BvrDmImp | 23 | 0 | 56 | 0 | 0 | 0 | 120 | 56 |

| Sub-watershed and Distance Upstream | TSS | Ammonia | NO2/NO3 | Organic Nitrogen | Ortho-Phosphorus | Total Phosphorus | Chlorophyll *a* | Total Organic Carbon |
|---|---|---|---|---|---|---|---|---|
| LowLk,8-13 | 131 | 195 | 262 | 90 | 89 | 120 | 353 | 193 |
| LowLk,4-8 | 161 | 284 | 644 | 276 | 263 | 277 | 434 | 637 |
| LowLk,0-4 | 223 | 91 | 444 | 192 | 181 | 230 | 617 | 320 |

Note: Shaded cells only correspond to segments located near the lake boundary.

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