Smith Mountain Lake

Water Quality Monitoring Program

2013 Report

Prepared by

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Moneta, Virginia

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Advanced Monitors

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Tony and Alice DeCesare, Glade Hill
Paul Gascoyne, Goodview
Richard and Janet Hill, Huddleston
Larry Iceman, Wirtz
Daphne Jamison, Wirtz
Don and Sandy Kelso, Moneta
Jim and Kathy LeCleir, Glade Hill
Dick Leroy, Hardy
Rusty MacMullan, Moneta
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Earl Mattox, Union Hall
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Mike and Gail McCord, Moneta
Herb and Marilyn Mocksfield, Moneta
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Carol and Gary Noesner, Moneta
Jerry and Karen Over, Moneta
Ken Ralph, Union Hall
Gale and Bill Taylor, Union Hall

1. EXECUTIVE SUMMARY

The Smith Mountain Lake Volunteer Water Quality Monitoring Program was initiated in 1987 and has functioned each year since. The Smith Mountain Lake Association and scientists from Ferrum College cooperatively administer the program. The mission of the program is to monitor water quality in Smith Mountain Lake and to encourage active participation of the lake community in protecting this resource.

The 2013 monitoring season began in mid-May with a training and organizational meeting. The volunteer monitors measured water clarity and collected water samples every other week until mid-August. Student interns from Ferrum College traveled around the lake every other week to pick up the samples for analysis at the Ferrum College Water Quality Lab. During this trip, the interns also collected grab samples from 21 tributaries that were analyzed for total phosphorus. Also on a bi-weekly schedule, Ferrum College personnel collected additional lake samples for bacterial analysis. Twice during the season, samples were collected from tributaries (20 in May and 22 in August) for bacterial source tracking.

The trophic status (an indication of the degree of aging a lake has sustained) of Smith Mountain Lake is monitored by measuring three parameters: total phosphorus as an indicator of nutrient enrichment, chlorophyll-*a* as an indicator of algal biomass, and Secchi depth as an indicator of water clarity. According to the Virginia Department of Environmental Quality, enumerating the bacterial species chosen as indicator organisms assesses bacterial water quality. In 2013, *E. coli* was enumerated to assess the bacterial populations in Smith Mountain Lake.

Depth profile monitoring has continued to provide interesting insights about the dynamics of Smith Mountain Lake. At five locations in the main channels of the lake, measurements of dissolved oxygen, temperature, pH and conductivity are taken as a function of depth. These profiles are measured six times during the summer.

In 2013, plankton tow samples were taken during the summer for two types of sample sites. Horizontal plankton tow samples were collected and analyzed six times at bacterial sampling sites, and vertical plankton tow samples were collected and analyzed five times at depth profile monitoring sites. Algae were identified and grouped by algal divisions.

1.1 Conclusions – Trophic Status

In 2013, water quality improved from the upper channels to the dam, as usual, but there is a lack of consistency among the three trophic parameters. The average total phosphorus concentration in the lake increased by 44.0 percent. This is a rather large increase, but the average total phosphorus concentration of 23.9 ppb is slightly lower than the ten-year average. This increase is most likely due to the low total phosphorus concentrations observed last year. However, average chlorophyll-*a* concentration increased by 77.3 percent and is the highest value recorded in the past ten years. Average Secchi depth increased slightly, by 9.5 percent, indicating improved water clarity.

In 2013 the average combined TSI was below 50 (46.0), indicating that, on average, the lake is in the early stages of eutrophic conditions. However, the TSI did increase slightly from the 2012 value of 46.5. Similar to 2012, all three trophic status indicators are consistent with beginning stages of eutrophication. While all parts of the lake further than 17 miles from the dam are eutrophic, the condition has moved a mile down-channel since 2012 when it was all stations further than 18 miles from the dam.

1.2 Conclusions – Algae in Smith Mountain Lake

In 2013 the overall dominant algal population groups found in Smith Mountain Lake changed from 2012 when diatoms and blue-green algae outnumbered green algae. Results of algal counts in 2013 reverted back to the dominant algal group of diatoms and a slightly higher number of green algae. Typically higher levels of blue-greens are seen later in the season but this trend did not appear this year. Later in the summer, the blue-green levels dropped off. This may be due to early higher water temperatures and a milder winter. This is the second year this trend was seen and will continue to be monitored in future years to see if it continues. As is expected, headwaters and marina sites had higher algal populations due to higher nutrient input. The highest algal populations were recorded at the sites most distant from the Dam.

1.3 Conclusions – Dissolved Oxygen, Temperature, pH and Conductivity Lake Depth Profiles

The depleted oxygen at lower depths (hypolimnion), especially in the more nutrient rich upper channels, is of concern because low dissolved oxygen is appearing earlier in the summer. The temperature profiles indicate that the thermocline is moving lower in the water column. Continued study of thermal stratification, using depth profiling, and of algal dynamics will provide the scientific data necessary to effectively manage Smith Mountain Lake as it ages.

1.4 Conclusions – Escherichia coli Measurements and Bacterial Source Tracking

Bacterial populations, specifically *Escherichia coli,* were higher in 2013 than in 2012. Every bacterial sample week had one or two sites that had *E. coli* values that exceeded the Virginia Health Department standards except the last sample week (August 6). Results were the highest at two of the headwaters sites since 1995. All samples from the twenty-two tributary sites analyzed for bacterial source analysis still indicate some of the bacteria are still coming from human sources. The human and livestock contributions to bacterial isolates from the tributaries indicated an increase in percentage of bacterial isolates.

2. INTRODUCTION

The Smith Mountain Lake Water Quality Monitoring Program (SMLWQMP), now in its twenty-seventh year, is a water quality program designed to monitor the water quality and the trophic status of Smith Mountain Lake, a large (25,000 acre) pump-storage reservoir located in southwestern Virginia. Scientists from Ferrum College and designated members of the Smith Mountain Lake Association (SMLA) jointly manage the project. This report describes the 2013 monitoring season.

The sampling season for the monitoring program runs roughly from Memorial Day to Labor Day. On a biweekly schedule, volunteer monitors measure water clarity at both basic and advanced monitoring stations and collect samples at the advanced monitoring stations. The monitoring network includes "trend stations" on the main channels and "watchdog stations" in coves off the main channels. In 2013, there were 83 stations in the monitoring network: 55 advanced stations and an additional 28 basic stations, with all but one of the basic stations located in coves (see Methods, page 6 for a description of the different station types). The samples are picked up at the homes of monitors by Ferrum College interns and then analyzed for total phosphorus, total nitrogen and chlorophyll-*a* concentrations in the Water Quality Laboratory at Ferrum College. Sample collection began the week of May 26 through June 1 and the first sample bottles and filters were picked up on Tuesday, June 4. The last week of sample collection was August 4 to August 10, and the samples and filters were picked up on August 13.

There are twenty-two tributary samples now collected during the weeks that samples are picked up from monitors' homes to assess tributary inputs of nutrients to the lake. Site T21a, in the upper Roanoke channel just below the confluence of Back Creek (34 miles from the dam), is considered the headwaters station for the Roanoke channel. (See Methods, page 6, for an explanation of the numbering system). Sample site T3 is the headwaters station designated for the Blackwater channel; it is located at the SR834 Bridge near Riverside Exxon. Both headwaters stations are considered to be tributary stations, although there is minimal velocity at either site during base flow conditions. All other tributary stations are on flowing tributaries near their confluence with the lake, except for three sites from below the dam (which impact the lake through pumpback) and the upper Gills Creek site. This site, T0, is several miles from the lake

and a volunteer monitor collects the samples. This site is important because Gills Creek has been a water quality concern for many years.

Since 1998 bacterial samples have been collected at 14 sites on six occasions each summer. In 2004 the method used in the bacterial analyses was changed to measure the *Escherichia coli* (*E. coli*) populations instead of fecal coliform populations. This change reflects the revision in the Virginia Department of Environmental Quality's bacterial standard, which uses *E. coli* as the indicator organism rather than fecal coliform. Ferrum College technicians collected bacterial samples every other week in 2013, for a total of six samples at each station.

DO profiles and Plankton tows

Additionally, bacterial source tracking or Antibiotic Resistance Analysis (ARA), is conducted twice during the sampling season. These samples were taken at the tributary sites at the beginning of the summer (May, 22 sites) and toward the end of the summer (August, 22 sites)

Ferrum College scientists Carolyn Thomas, Delia Heck, Bob Pohlad, and Maria Puccio along with Larry Iceman, the SMLA Volunteer Monitoring Coordinator, carried out the 2013 training session in May. They were assisted by the student technicians Caitlin Deaton, Courtney Epps, Megan Gerald, Megan Maeang, and Calista Warden, and lab coordinator Carol Love. The program included a review of the previous year's findings and plans for the upcoming season. Experienced monitors reviewed their sample site locations and sample site identification numbers, received new supplies (sample bottles and filters), and had their monitoring equipment checked, if needed. The program co-directors worked with new volunteer monitors to assign sample station locations and sample station identification numbers, practiced the sampling procedures, and issued sampling equipment and supplies.

Newsletters were written and published by the program co-directors and student technicians during the summer, reporting on activities of the program. Announcements were included in the newsletters in addition to advice and tips on sample collection. Four newsletters were published in 2013. In October, the annual end-of-the-season meeting and social event was held at Bay Roc Marina in Hardy, Virginia. At this meeting the preliminary report of results was presented and the fourth newsletter was given out.

Significant support for the program in 2013 came from the Appalachian Power Company with additional support from the Smith Mountain Lake Association and the Virginia Department of Environmental Quality (DEQ). The Western Virginia Water Authority of Roanoke, Virginia has also provided financial support for the water quality program on Smith Mountain Lake. Funding also came from Bedford County, Franklin County, and Pittsylvania County through the Tri-County Lake Administrative Committee (TLAC). This year's monitoring results, data analyses, and comparisons with the other twenty-six years of data are discussed in the full report.

Monitoring results from 1990 to 2012 can be found in the project's annual reports for those years. These results can be found at wqp.ferrum.edu.

3. METHODS

Detailed descriptions of the methods of sample collection, preservation and analyses, and quality control/quality assurance procedures can be found in the Procedures Manual 2013: Ferrum College Water Quality Lab (Heck, et al), Virginia Environmental Endowment Report (Johnson and Thomas, 1990), and in the *Training Manual for Smith Mountain Lake Volunteer Monitoring Program* (Thomas and Johnson, 2002). The water quality parameters measured include water clarity (turbidity), measured as Secchi disk depth; total phosphorus, measured spectrophotometrically (λ =880 nm) after persulfate digestion using the ascorbic acid method (QuikChem Method 10-115-01-1-F); total nitrogen analysis measured spectrophotometrically (λ =520 nm) after persulfate digestion (QuikChem Method 10-107-04-4-B) and chlorophyll-*a*, determined using the acetone extraction method and measured fluorometrically. The specifics of each method are outlined in the appropriate section below. Additionally, quality control and quality assurance procedures evaluate laboratory procedures and are described later in this report.

Sampling station codes contain information on the location of the site. The sample station codes are based on:

(1) The section of the lake in which the station is located ("C" for Craddock Creek, "B" for Blackwater, “M” for main basin, “R” for Roanoke, and “G” for Gills Creek).

(2) The approximate number of miles to the Smith Mountain Lake Dam (*i.e.*, 23 miles from the dam would have a "23" in the station code).

(3) Designation of the sampling station as a cove, main channel, or tributary (cove sampling station codes start with "C", tributary sampling station codes begin with “T”, channel sampling station codes have no letter designation and begin with the letter of the channel as given in (1) above).

(4) Basic monitoring station codes begin with an "S" (for Secchi depth).

(5) A lowercase letter following a tributary station number indicates a change to the original sampling location for that tributary, usually made for safety reasons.

An example of a sampling station code would be "CB14" which would indicate a cove station off the Blackwater channel 14 miles from Smith Mountain Lake Dam.

Channel sampling stations are located approximately every two miles on the Roanoke and Blackwater channels to monitor the movement of the silt and nutrient laden waters moving toward the main basin of the lake. These sites begin at the dam and extend two miles beyond the Hardy Ford Bridge on the Roanoke channel and to the SR834 Bridge in Franklin County on the Blackwater channel. The cove sampling stations are also important for trend analysis and help us fulfill the role of "watchdogs". In the "watchdog" mode, we monitor as much of the lake as possible for signs of localized deterioration of water quality, which may be due to site-specific problems such as malfunctioning septic systems. To evaluate tributary loading of nutrients, interns collect grab samples (to fill a bottle with water) every other week at 21 tributary stations on their rounds to pick up lake water samples. A volunteer monitor collects one additional tributary sample (T0) in upper Gills Creek.

Maps generated using a Geographic Information System (GIS) are used to represent the Smith Mountain Lake samples. In addition, a preliminary report including maps and initial results is produced for the citizen monitors and the Smith Mountain Lake community prior to this final report.

The use of GIS in water quality monitoring is not new. Several states, including California and Idaho, as well as the EPA, are using GIS to collect, store and analyze water quality data (Kerney, Viers, et al, 1998; ESRI, 2007). The 1972 Clean Water Act biennial reporting requirements include guidelines for GIS frameworks (EPA, 2005). Currently the objectives for the Smith Mountain Lake maps include highlighting “hot spots,” or areas of concern, to citizens and demonstrating the variation of the nutrient characteristics across the lake. Summer averages for bacteria, chlorophyll-*a*, total phosphorus, Secchi depth, and combined trophic status index (TSI-C) at each of the sampling locations are used in the maps.

The symbols, colors and scales are chosen very purposefully. Although the maps in this report are produced in grayscale, colored maps are used in all public discussions of the data obtained as part of this program, including the preliminary report. In the bacteria map (see Figure 7.6), a color gradient of green to yellow to red is used to reflect the danger associated with higher levels of bacteria counts. The scale for this map follows guidelines established by the Virginia Department of Environmental Quality for levels of bacteria that constitute a health hazard.

Chlorophyll-*a* levels (see Figure 4.3) are represented with a green color gradient ranging from a light green for excellent levels to dark green for the highest levels. This reflects criteria established by Reckhow and Chapra (1983). The total phosphorus levels map (see Figure 4.3) has a color ramp from yellow to green to blue representing low levels to highest levels, also based upon Reckhow and Chapra. The water clarity map (see Figure 4.3) reports the Secchi depth readings from the various sampling locations. It has a color gradient that uses brown to symbolize the murkiness of the water where Secchi disk readings were low and blues to indicate clearer water and higher Secchi disk readings. The TSI-C map (see Figure 8.6) uses intervals established by Carlson to relate trophic state index to the level of eutrophication in freshwater lakes (1996).

The maps in the report convey at a glance the variation in nutrient characteristics in Smith Mountain Lake. The pattern of improving water quality closer to Smith Mountain Lake Dam is readily apparent as exhibited by all nutrients measured. The maps serve as an effective vehicle for conveying very complex and crucial information to concerned citizens and public organizations.

4. TROPHIC STATUS MONITORING

4.1 Introduction

Trophic status monitoring on Smith Mountain Lake has consisted of three components for this program: total phosphorus, chlorophyll-*a*, and Secchi depth. Total phosphorus concentration is an indication of the level of nutrient enrichment in the lake. Chlorophyll-*a* is closely correlated with the number of green algae cells present in the water, so chlorophyll-*a* concentration is a good measure of the amount of algae present in the lake. Secchi depth is a reliable and longstanding method of measuring water clarity. Secchi depth depends on the amount of sediment and algae in the lake water. In 2013 total nitrogen concentration, another nutrient that enriches aquatic systems, was measured as a trophic parameter, but not reported here.

Phosphorus and nitrogen are plant nutrients that stimulate the growth of algae. Phosphate, the form of phosphorus most immediately available to algae, is the limiting nutrient in Smith Mountain Lake. As a result, monitoring of total phosphorus (TP) concentrations in Smith Mountain Lake can provide early warning of increased nutrient enrichment and the possibility of algal blooms. Chlorophyll-*a* is the component of plant cells that enables photosynthesis and is largely responsible for the green color of many plants and algae. Its concentration is a direct measure of the concentration of the number of algae cells in a sample of water. This can provide current information on the presence or absence of algal blooms. Secchi depth water clarity measurements show the combined effects of sediment from runoff and algal activity in lake water.

4.2 Methods

Detailed descriptions of the methods of sample collection, preservation, analyses, and quality control/quality assurance procedures can be found in the VEE Report (Johnson and Thomas, 1990), in the *Training Manual for Smith Mountain Lake Volunteer Monitoring Program* (Thomas and Johnson, 2002), and in the *Ferrum College Water Quality Procedures Manual* (Johnson, Thomas, Love, Powell, Heck, and Puccio, 2013). The methods used are adapted from *Standard Methods*, 1999, and audited annually by the Virginia Department of Environmental Quality. Channel sampling stations are located approximately every two miles on the Roanoke River and Blackwater River channels on Smith Mountain Lake to monitor the movement of silt

and nutrient-laden waters moving toward the main basin of the lake. These sites begin at the dam and extend two miles beyond the Hardy Ford Bridge on the Roanoke River channel and to the SR834 Bridge in Franklin County on the Blackwater River channel. Cove sampling stations are also monitored to provide additional information for trend analysis. This results in a total of 56 sites for total phosphorus and chlorophyll-*a* samples and a total of 82 sites for Secchi depth measurements. Samples are also collected from 22 tributary stations and analyzed for total phosphorus to provide information about inputs to Smith Mountain Lake. Maps of the lake sampling stations and tributary sampling stations are provided in the Appendix of this report (Figures A.1 and A.2).

At the sites below the dam (T9, T10, and T11), student technicians grab samples from bridges in the same manner as the other tributary samples. The difference is that these samples are collected below the dam and are not tributaries flowing directly into the lake. Because of the pump-back system, some water from these sites does enter the lake. Station T9 is on the Roanoke River just below the dam at the AEP Visitor Center, Station T10 is on the Pigg River near its confluence with the Roanoke River, and Station T11 is on the Roanoke River after its confluence with the Pigg River at the headwaters of Leesville Lake.

In the spring of 2012, a Lachat QuikChem 8500 Series 2 Flow Injection Analyzer (FIA) with an automated sampler was purchased. This was used for the analysis of total phosphorus (TP), which has been monitored in the past, and total nitrogen (TN), which was reintroduced in 2012. The FIA can analyze both parameters simultaneously. One of the biggest advantages of the FIA is that the coloring reagents used to detect TP and TN are mixed in real time, during the course of the measurement. Thus, there is no worry that the color will fade during the course of an analysis. The other advantage is that the instrument uses less reagent than the previous method, reducing analysis cost and time.

The samples are analyzed for TP and TN using the QuikChem methods 10-115-01-4-B and 10-107-04-4-B, respectively. This procedure requires two digestion steps. First, the sample is digested in a basic persulfate solution in an autoclave, and then the sample is digested in an acidic solution of sulfuric acid and persulfate ion in an autoclave. In the previous method, only the acidic digestion was performed. The acidic digestion converts the various forms of

phosphorus into the phosphate ion. The additional basic persulfate digestion is required to convert the various forms of nitrogen into the nitrate ion.

The concentration of orthophosphate ion is determined using the FIA. The orthophosphate ion reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a complex. This complex is reduced with ascorbic acid to form a blue complex, which absorbs light at 880 nm. The absorbance measured by the FIA is proportional to the concentration of TP in the sample. This detection method is similar to the previous method; however, the reagents are mixed in real-time automatically by the FIA.

Nitrate in the digested sample is reduced to nitrite by passage of the sample through a copperized cadmium column. The nitrite thus produced is then mixed with sulfanilamide and NED (N-(1-naphthyl)ethylenediamine dihydrochloride) to produce a red solution, which absorbs light at 520 nm. The absorbance measured by the FIA is proportional to the concentration of TN in the sample. Again, these reagents are mixed in real-time by the FIA so that there is no worry that the red color of the solution will fade during the course of an analysis.

The two TN procedures are still being refined. Ultrapure type 1water is being used to make up the digestion reagents and recrystallized potassium persulfate is used for both the acidic and basic digestion solutions. This appears to be reducing the background nitrogen levels, therefore the observed and recorded values are more accurate and reflective of the total nitrogen concentration in Smith Mountain Lake.

4.3 Results

The trophic status parameters for Smith Mountain Lake and its tributaries for the past ten years are presented in Table 4.1. The parenthetical values indicate the relative change in percent in the parameter from each previous year. Figure 4.1 shows the comparison of the six sampling periods with the average value of each trophic status parameter monitored in 2013.

Table 4.1. Average trophic parameter values and relative annual change for Smith Mountain Lake and its tributaries

Year	Smith Mountain Lake Average Total Phosphorus (ppb)	Tributaries Average Total Phosphorus (ppb)	Smith Mountain Lake Average Chlorophyll-*a* (ppb)	Smith Mountain Lake Average Secchi Depth (m)
2013	23.9 (+44.0%)	69.6 (+62.2%)	13.3 (+77.3%)	2.2 (+9.5%)
2012	16.6 (–35.9%)	42.9 (–44.6%)	7.5 (+59.6%)	2.0 (–13.0%)
2011	25.9 (+2.4%)	77.4 (–8.0%)	4.7 (+14.6%)	2.1 (–8.7%)
2010	25.3 (–10.3%)	84.1 (+1.2%)	4.1 (–4.9%)	2.3 (+4.3%)
2009	27.9 (–5.1%)	83.1 (+8.6%)	4.4 (+120%)	2.2 (–12%)
2008	29.4 (+36.1%)	76.5 (+14.0%)	2.0 (–56%)	2.5 (+8.7%)
2007	21.6 (–33.5%)	67.1 (–14.0%)	4.5 (–40%)	2.3 (+9.5%)
2006	32.5 (+12.4%)	76.8 (–19.4%)	7.5 (+21.0%)	2.1 (±0%)
2005	28.9 (+8%)	95.3 (+8%)	6.2 (+68%)	2.1 (–5%)
2004	26.7 (–51%)	87.9 (–0.2%)	3.7 (–57%)	2.2 (+16%)
Average	***25.9***	***76.1***	***5.8***	***2.2***

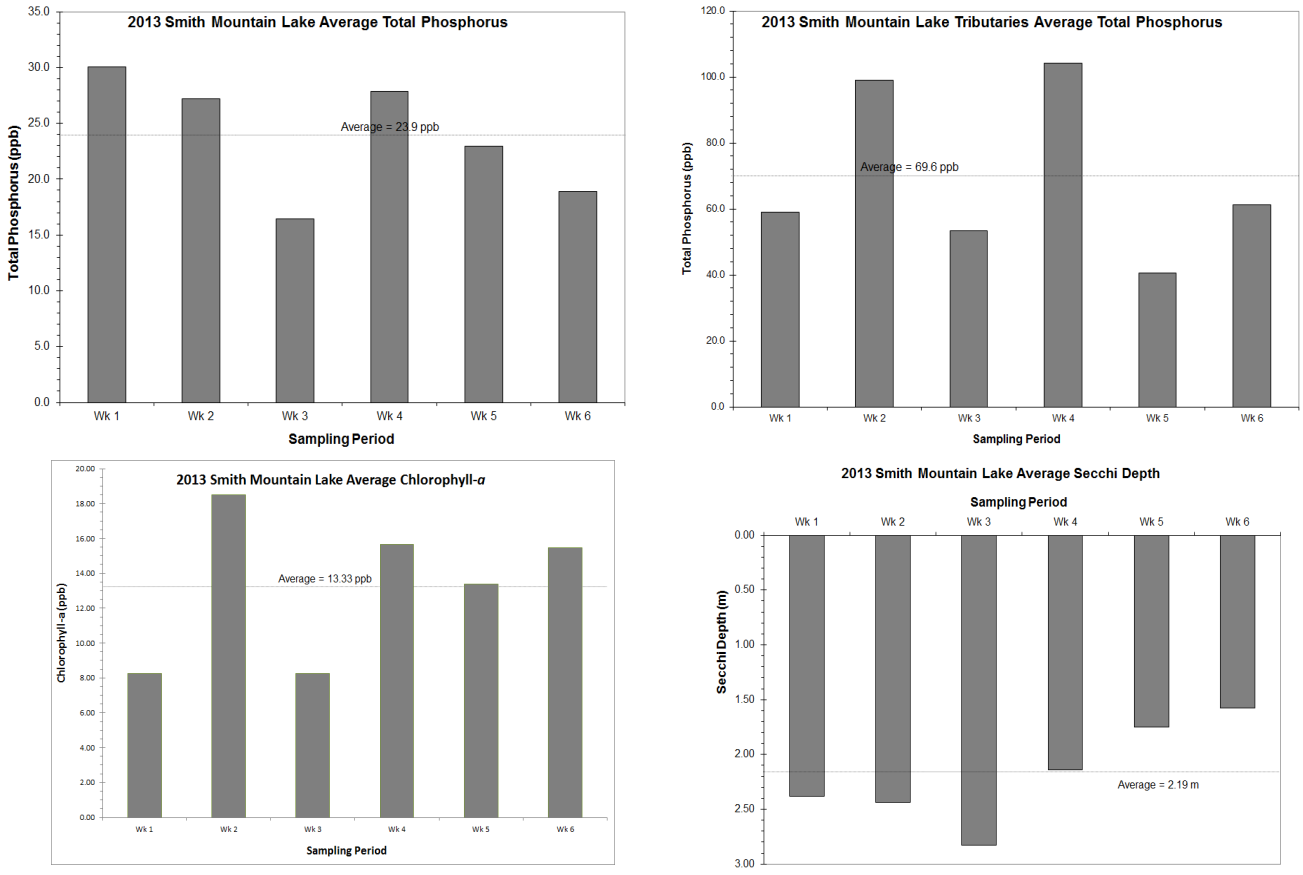


Figure 4.1. Trophic status parameters (total phosphorus, chlorophyll-*a*, and Secchi depth) for Smith Mountain Lake for each sampling period in 2013

The complete results for total phosphorus concentration for the 2013 sampling season on Smith Mountain Lake are included in the Appendix of this report (Tables A.3 and A.4). The average total phosphorus concentration for lake sampling sites over all five sampling periods was 23.9 ppb. The highest average lake concentration was observed in week 1 (30.1 ppb) and the lowest average concentration was observed in week 3 (16.4 ppb). The average total phosphorus concentration for tributary sampling sites over all six sampling periods was 69.6 ppb. The highest average tributary concentration was observed in week 4 (104.2 ppb) and the lowest average concentration was observed in week 5 (40.6 ppb).

The complete results for chlorophyll-*a* concentration for the 2013 sampling season on Smith Mountain Lake are included in the Appendix of this report (Table A.5). The average chlorophyll-*a* concentration for lake sampling sites over all six sampling periods was 13.3 ppb. The highest average lake concentration was observed in week 2 (18.5 ppb) and the lowest average concentration was observed in week 1 (8.2 ppb).

The complete results for Secchi depth for the 2013 sampling season on Smith Mountain Lake are included in the Appendix of this report (Table A.6). The average Secchi depth over all six sampling periods was 2.2 m. The deepest average Secchi depth was observed in week 3 (2.8 m) and the shallowest average Secchi depth was observed in week 6 (1.6 m).

The average total phosphorus concentration for 2013 was significantly higher for the lake and for the tributaries than in 2012, but was lower than those seen in 2011 and lower than the ten-year average. Chlorophyll-*a* concentration increased significantly in 2013 and was much higher than the average seen in 2012 and the ten-year average. Secchi depth increased slightly (see Table 4.2).

Table 4.2. 2013 average trophic status parameters and relative change from 2012 for Smith Mountain Lake and its tributaries

Year	Smith Mountain Lake Average Total Phosphorus (ppb)	Tributaries Average Total Phosphorus (ppb)	Smith Mountain Lake Average Chlorophyll-*a* (ppb)	Smith Mountain Lake Average Secchi Depth (m)
2013	23.9 (+44.0%)	69.6 (+61.9%)	13.3 (+77.3%)	2.2 (+4.8%)

The parameters were averaged by station over the six sampling periods and the average values were then plotted as a function of distance to the dam. The results are displayed in Figure 4.2.

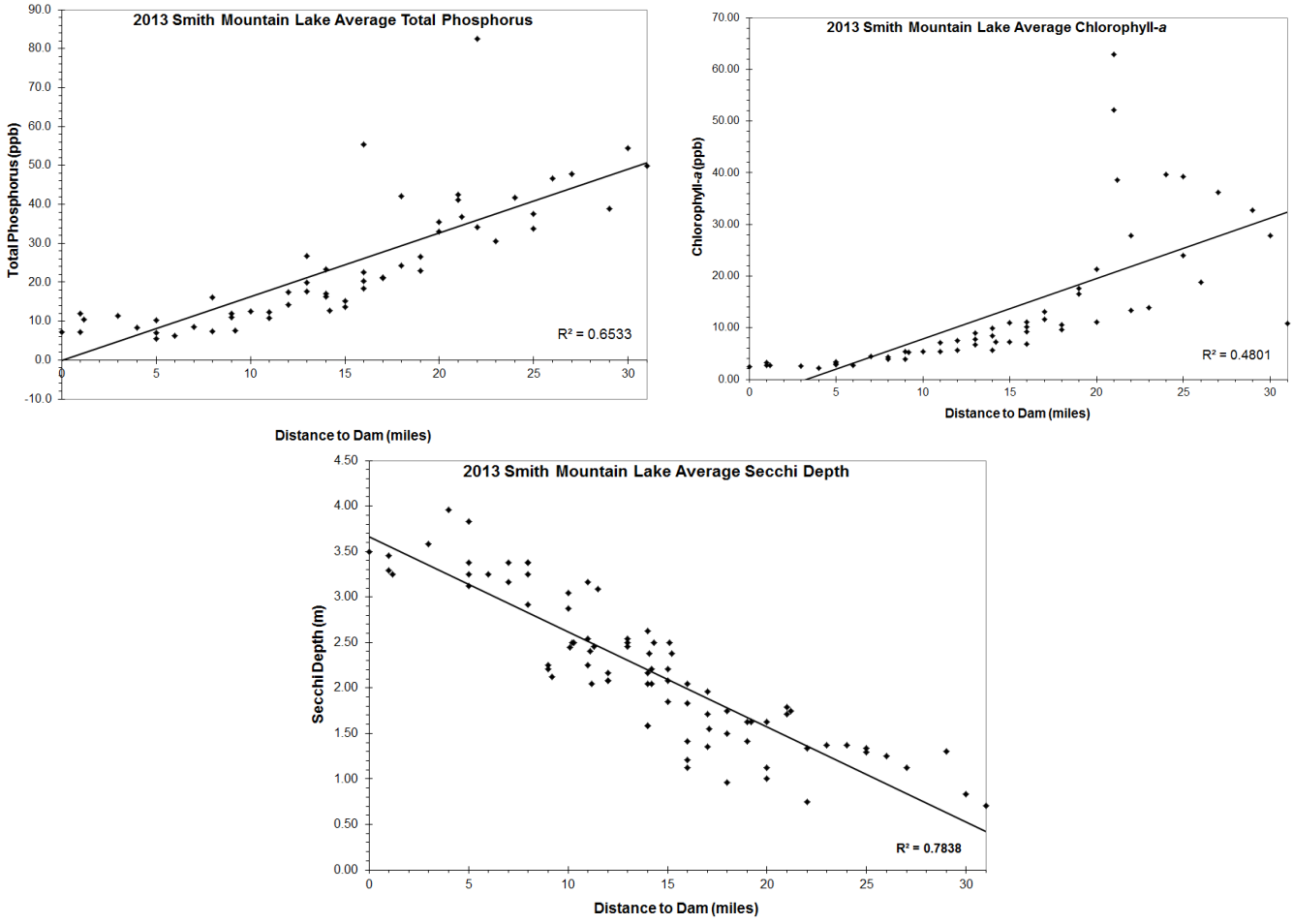


Figure 4.2. Variation of trophic status parameters with distance to the dam for Smith Mountain Lake in 2013

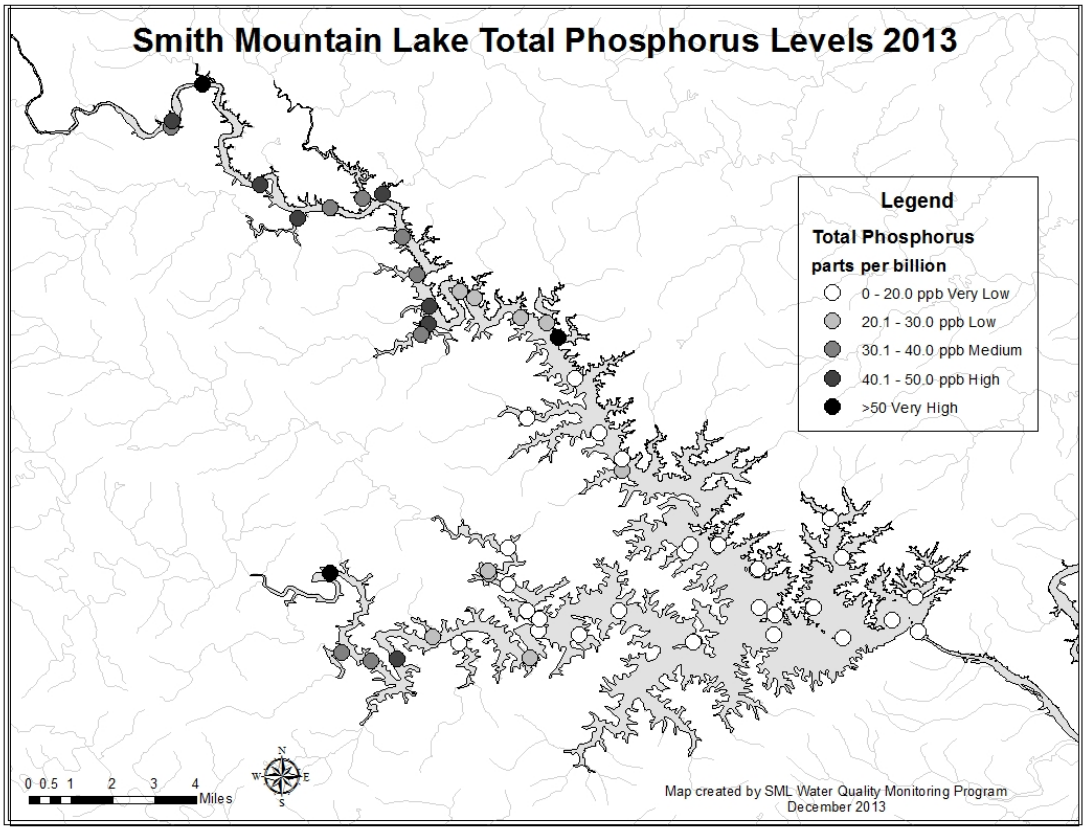
4.4 Discussion

Total phosphorus concentration and chlorophyll-*a* concentration both show a significant trend (R^2 = 0.6533 and 0.4801, respectively) where concentration increases directly as distance to the dam increases. For total phosphorus, sample sites that differ from the general trend seem to fall into two general categories. One category consists of sites near the dam with higher total phosphorus levels than those predicted by the general trend. This difference can likely be attributed to pump-back of water from the Pigg River, although development near the dam may

also have contributed to the observed increase in concentration. The second category consists of sample sites distant from the dam that exhibit higher total phosphorus levels than those predicted by the general trend. In general, these are sample sites with high sediment loads, and it is likely that the observed increase in concentration is due to phosphorus that is closely associated with those sediments. The most noticeable outliers are site CR16 which is 16 miles from the dam and had an average total phosphorus concentration of 55.3 ppb, and CR 22 which is 22 miles from the dam and had an average total phosphorus concentration of 82.5 ppb.

Chlorophyll-*a* levels show a weaker trend with distance to the dam than total phosphorus concentrations. As has been observed in prior years, there appears to be a baseline level of algal activity from the dam until approximately 15 miles from the dam, followed by a significant increase with several high outliers at about 25 miles from the dam. The most notable outliers are CR21 with an average chlorophyll-a concentration of 52.15 ppb, and R21 with an average chlorophyll-a concentration of 62.89 ppb, both of which are 21 miles from the dam. We will continue to monitor these sites to determine the source of this water quality degradation.

Secchi depth shows a significant inverse correlation with distance to the dam (Secchi depth decreases as distance to the dam increases, $R^2 = 0.7838$). This is consistent with the general observation that water is clearer in the main basin of the lake than it is in the channels that extend away from the dam. This decrease in clarity is due to a combination of increased sediment load and increased algal activity. There were high outliers nearer to and further from the dam with stronger correlation at intermediate distances from the dam.


Smith Mountain Lake Total Phosphorus Levels 2013
Legend
Total Phosphorus
parts per billion
0 - 20.0 ppb Very Low
20.1 - 30.0 ppb Low
30.1 - 40.0 ppb Medium
40.1 - 50.0 ppb High
>50 Very High
0 0.5 1 2 3 4
Miles
N
W
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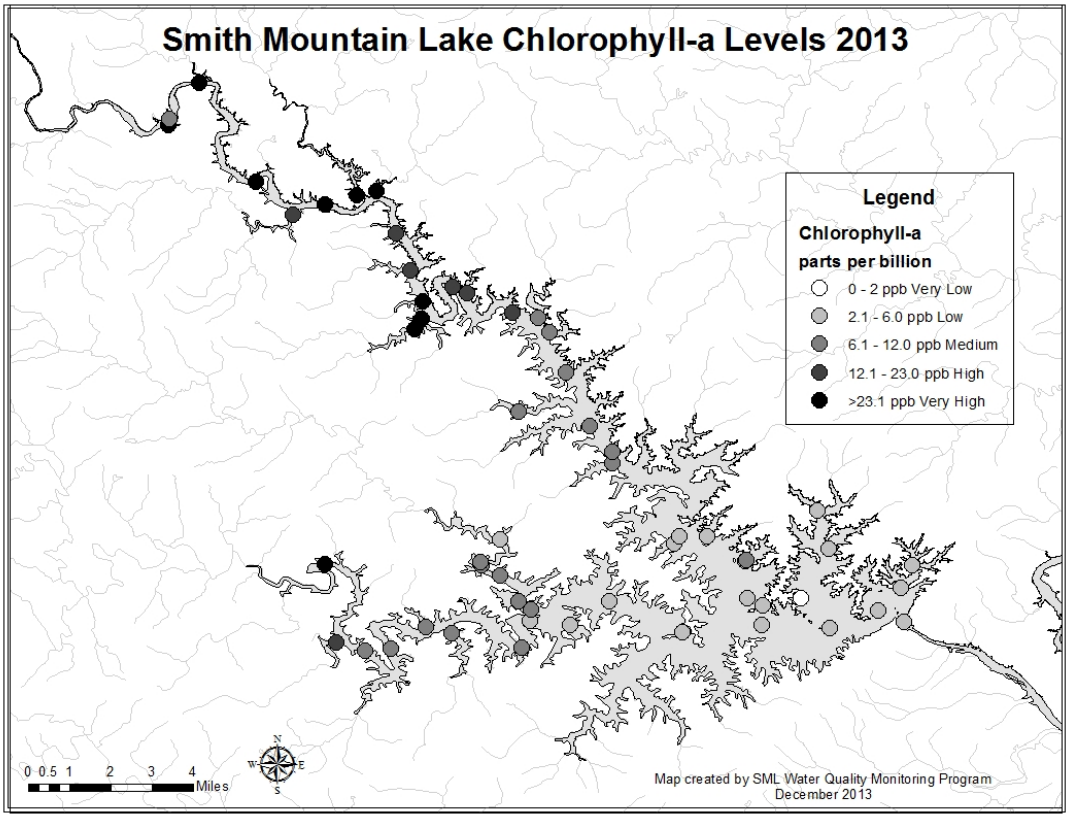
S
Map created by SML Water Quality Monitoring Program
December 2013


Smith Mountain Lake Chlorophyll-a Levels 2013
Legend
Chlorophyll-a
parts per billion
0 - 2 ppb Very Low
2.1 - 6.0 ppb Low
6.1 - 12.0 ppb Medium
12.1 - 23.0 ppb High
>23.1 ppb Very High
0 0.5 1 2 3 4
Miles
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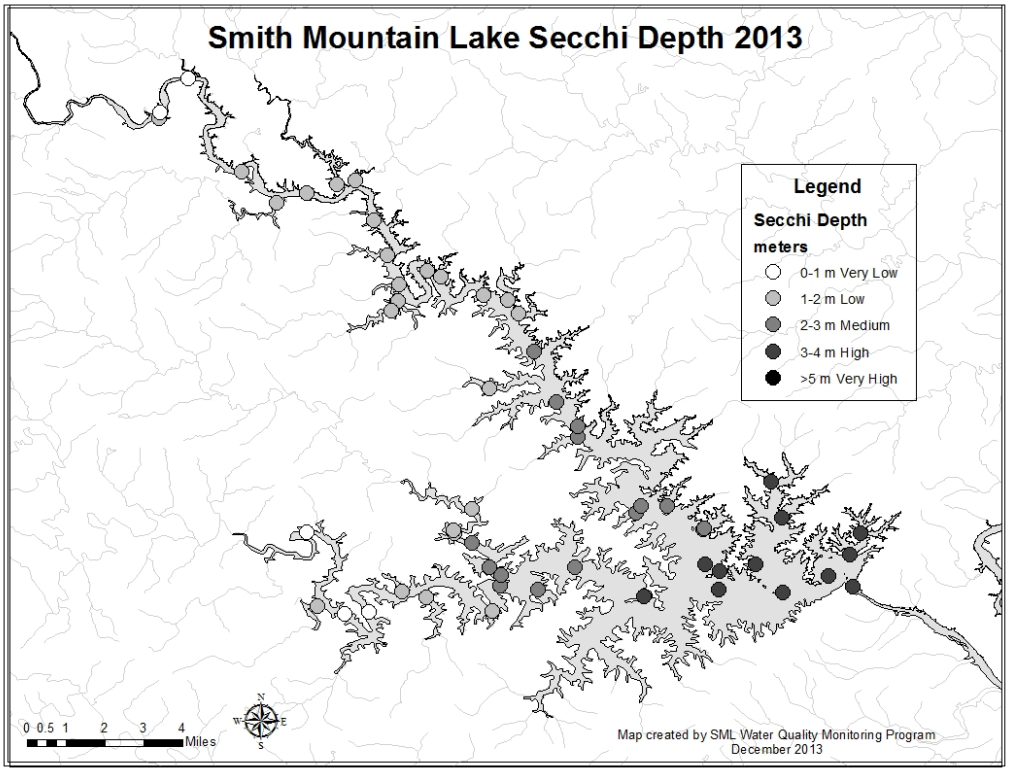
Map created by SML Water Quality Monitoring Program
December 2013



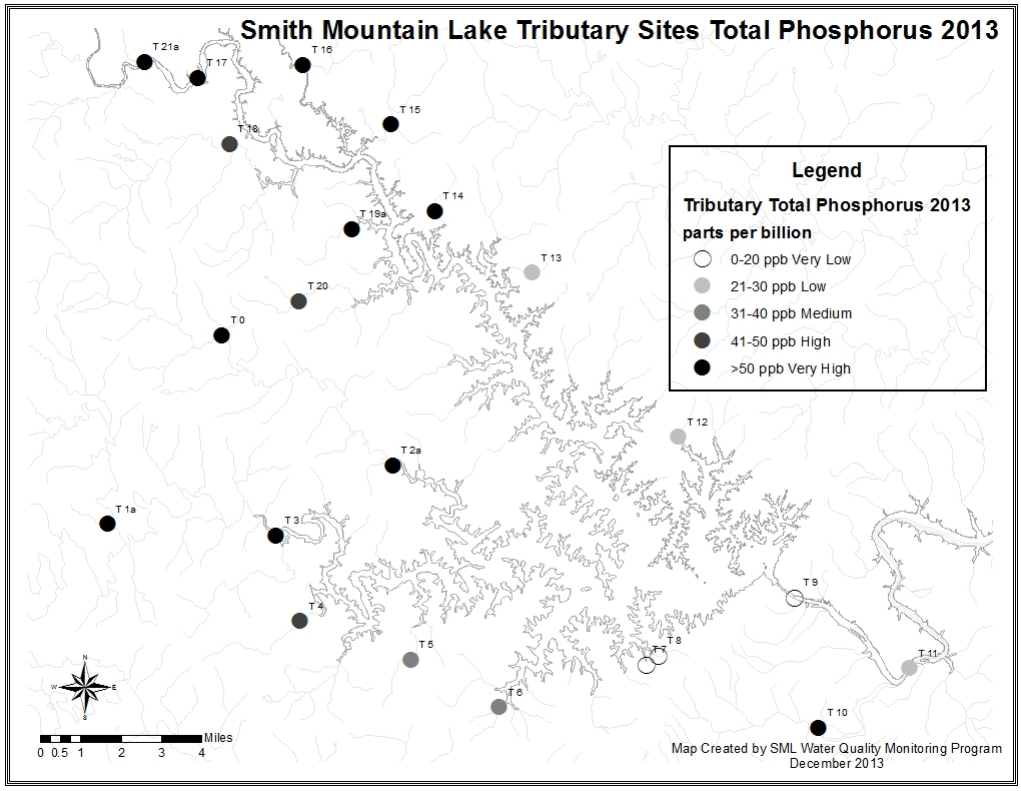


Figure 4.3. Maps showing variation in trophic status parameters across Smith Mountain Lake for 2013

Table 4.3 is a 10-year compilation of total phosphorus data for Smith Mountain Lake, its tributaries, and the three sites collected below the dam.

Table 4.3. 10-year comparison of average total phosphorus concentrations for lake and tributaries with tributary sites collected below the dam for Smith Mountain Lake

Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	***Avg***
Average Lake Total Phosphorus (ppb)	26.7	28.9	32.5	21.4	29.4	28.2	25.3	25.9	16.6	23.9	***25.9***
Average Tributary Total Phosphorus (ppb)	90.5	95.3	76.8	67.6	76.5	65.8	84.1	77.4	43.0	69.6	***74.7***
T9 (Roanoke River below dam)	17.8	19.0	14.0	14.0	18.1	14.4	8.7	15.5	7.8	10.5	***14.0***
T10 (Pigg River at Route 605)	76.6	158.9	64.5	50.8	74.2	59.5	51.9	74.9	47.2	66.0	***72.5***
T11 (Roanoke River at Route 608)	53.8	45.1	25.7	46.9	27.8	23.5	17.8	22.7	18.5	29.0	***31.1***
Annual Average (T9, T10, T11)	***49.4***	***74.3***	***34.7***	***37.2***	***40.0***	***38.6***	***39.0***	***40.4***	***24.5***	***35.2***	***41.3***

In 2013, the average total phosphorus concentration in the below-dam sites was higher than in 2012, although it was lower than the ten-year average. There was also an increase in lake total phosphorus concentrations, although this too was lower than the ten-year average. The average for the below-dam sites continues to be higher than the overall average for Smith Mountain Lake.

4.5 Conclusions

In general, water quality improves significantly as the water moves from the upper channels toward the dam. This is consistent with observations that have been made since the second year of the monitoring project. Eroded soil is carried to the lake by silt-laden streams, but sedimentation begins in the quiescent lake water. Phosphorus, primarily in the form of phosphate ions, strongly associates with the soil particles and settles out during the sedimentation process. Concentrations of total phosphorus and chlorophyll-*a* and Secchi depth all correlate significantly with distance from the dam.

In 2013, water quality improved from the upper channels to the dam, as usual. The average total phosphorus concentration in the lake and tributaries increased significantly; although the average total phosphorus concentration was slightly lower than the ten-year average. This large increase is most likely due to the very low total phosphorus concentrations observed last year, which were significantly lower than the ten-year average. Chlorophyll-a increased again this year by 77.3

percent. The average chlorophyll-a concentration of 13.3 ppb is the highest average concentration observed in over ten years. The average Secchi depth increased slightly by 9.5 percent, indicating slightly improved water clarity. The influence of total nitrogen on the trophic status of the lake is still be determined. Continued monitoring of this nutrient in future studies of the lake will be important.

5. ALGAE IN SMITH MOUNTAIN LAKE

5.1 Introduction

The Smith Mountain Lake algae sampling program began in 2007. Prior to this time the only measure of productivity, an indication of algae in the lake, came from the measurement of chlorophyll-*a*. The diversity of algal species became of interest because of the potential presence of blue-green species. Typically blue-green algae are indicators of pollutants in water. Diatoms typically are present in clean water, as are green algae, but green algae can also indicate high nutrients.

Many blue-green algae produce toxins that can be harmful to fish species and potentially harmful to humans. They also have the potential to impart a taste to drinking water. The production of toxins such as microcystin and their presence in the water can be tested. Initial testing procedures for these toxins were conducted this year with indications of the presence of microcystin. Future testing could lead to a better understanding of potential toxins in the lake.

5.2 Methods

Plankton tow samples are used to measure the populations of diatoms, green algae and blue green algae. Horizontal plankton tows were done six times at the sites used for bacterial samples (on bacterial sampling dates) and vertical tows were done six times at the sites used for dissolved oxygen profiling (on dissolved oxygen profiling dates) using a standard plankton tow net (12" ring, 63 micron mesh). Sample tow lengths were a maximum of ten meters. The tow sample was preserved by adding 1 ml of Lugol's solution to the 100 ml sample. The phytoplankton counting method procedure follows the field method outlined in Standard Methods for Water and Wastewater Analysis (APHA, 1999). Using fifty random Whipple Disk grid fields across a 1 mL Sedgwick Rafter counting cell, the algae were identified, counted and recorded.

5.3 Results

Algae collected in the plankton tows were identified and grouped by major algal groups: diatoms, green algae and blue green algae. Figures 5.1, 5.2, and 5.3 demonstrate the differences in abundance of algal groups from each sample site type (headwaters, marinas, and non-marinas) for each sample date for the horizontal tows and Figure 5.4 shows the differences for the vertical

tows. Site descriptions are listed in Section 7.2 of this report. Figure 5.5 shows the averages of algae type for each sample site type. Figure 5.6 shows the average of algae types for each sample period across the entire lake for both 2012 and 2013. Figure 5.7 shows the relative populations of the different algal groups averaged over all sites and all sample dates for both 2012 and 2013. Figure 5.8 shows the algal totals by group for all lake sample sites their relative distance from the dam, and the trend lines associated with the algal groups for both 2012 and 2013. Figure 5.9 shows the overall abundance of algal groups over all sample sites for both last year and this year as well.

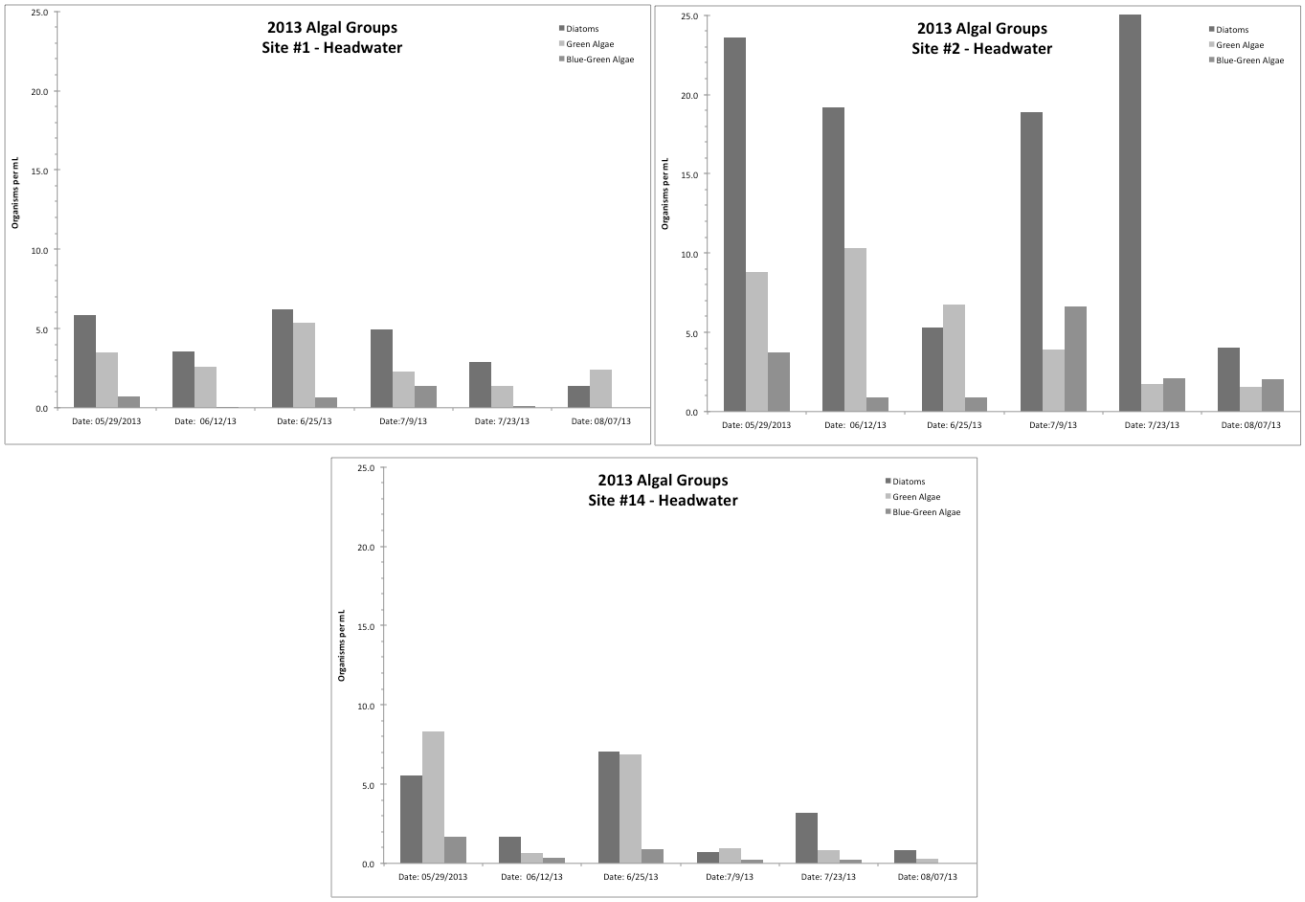


Figure 5.1. Algal groups versus week sampled on Smith Mountain Lake in 2013 from headwaters sites (Sites 1, 2, and 14)

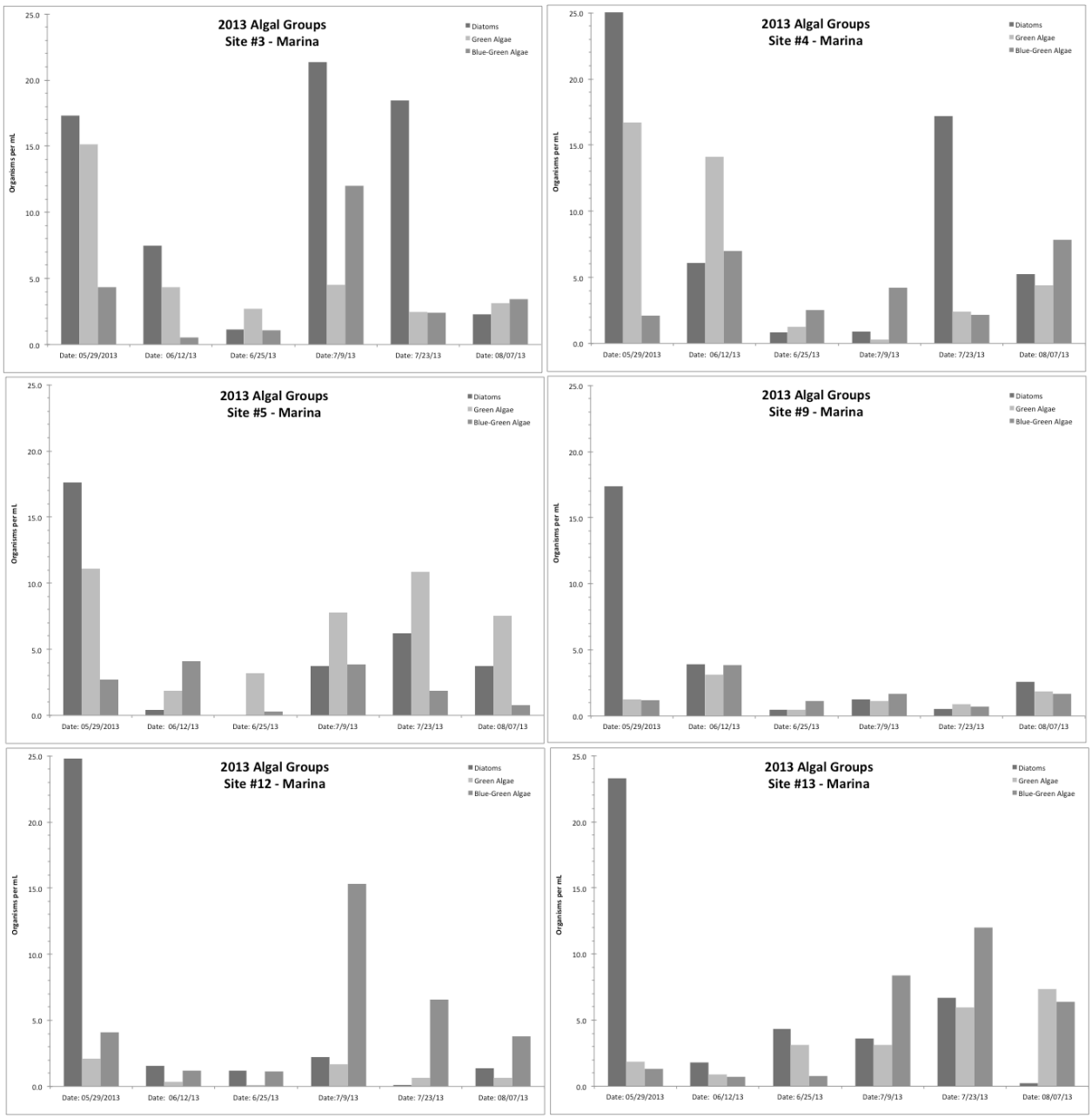


Figure 5.2. Algal groups versus week sampled on Smith Mountain Lake in 2013 from marina sites (Sites 3, 4, 5, 9, 12, and 13)

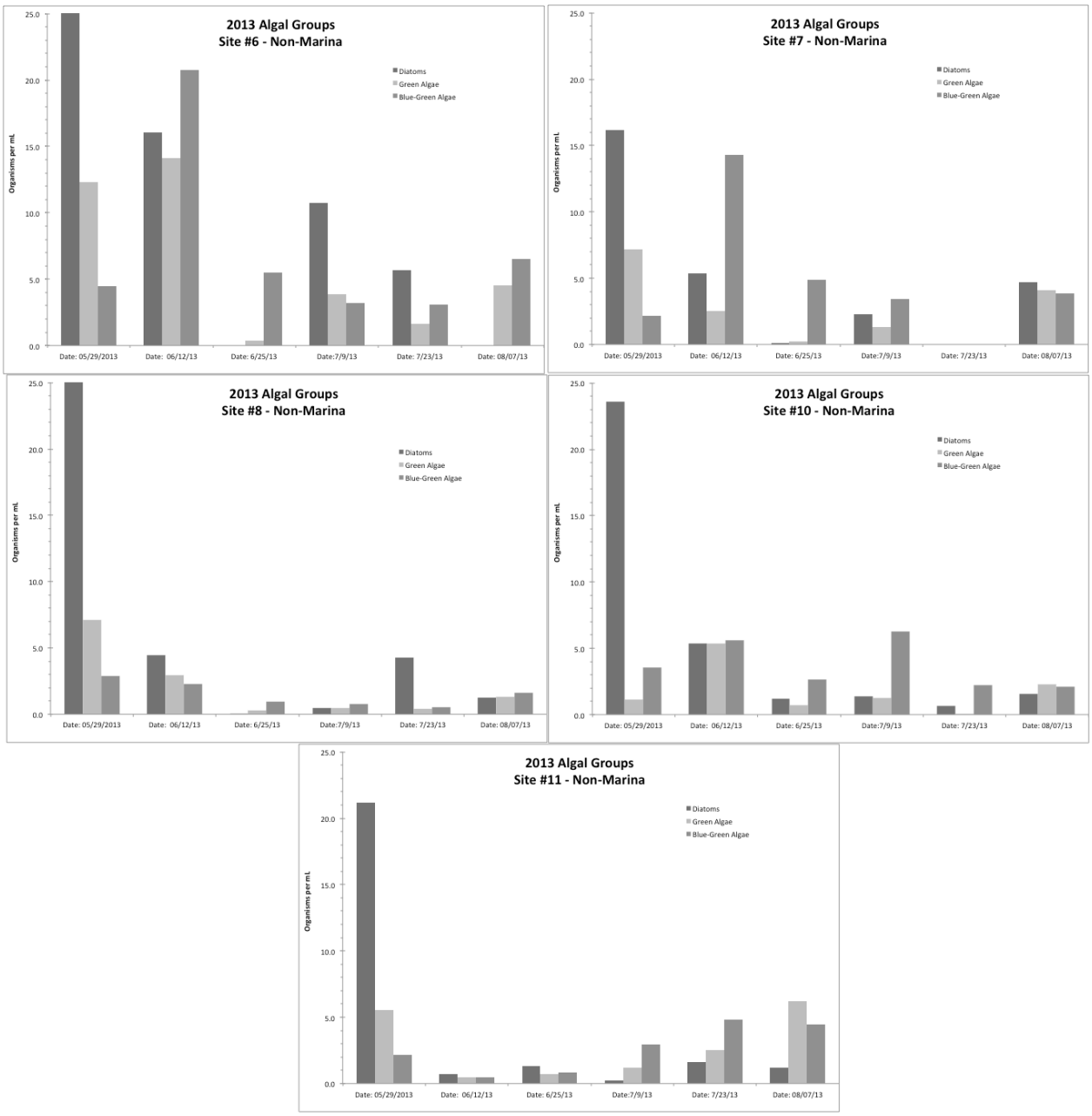


Figure 5.3. Algal groups versus week sampled on Smith Mountain Lake in 2013 from non-marina sites (Sites 6, 7, 8, 10, and 11)

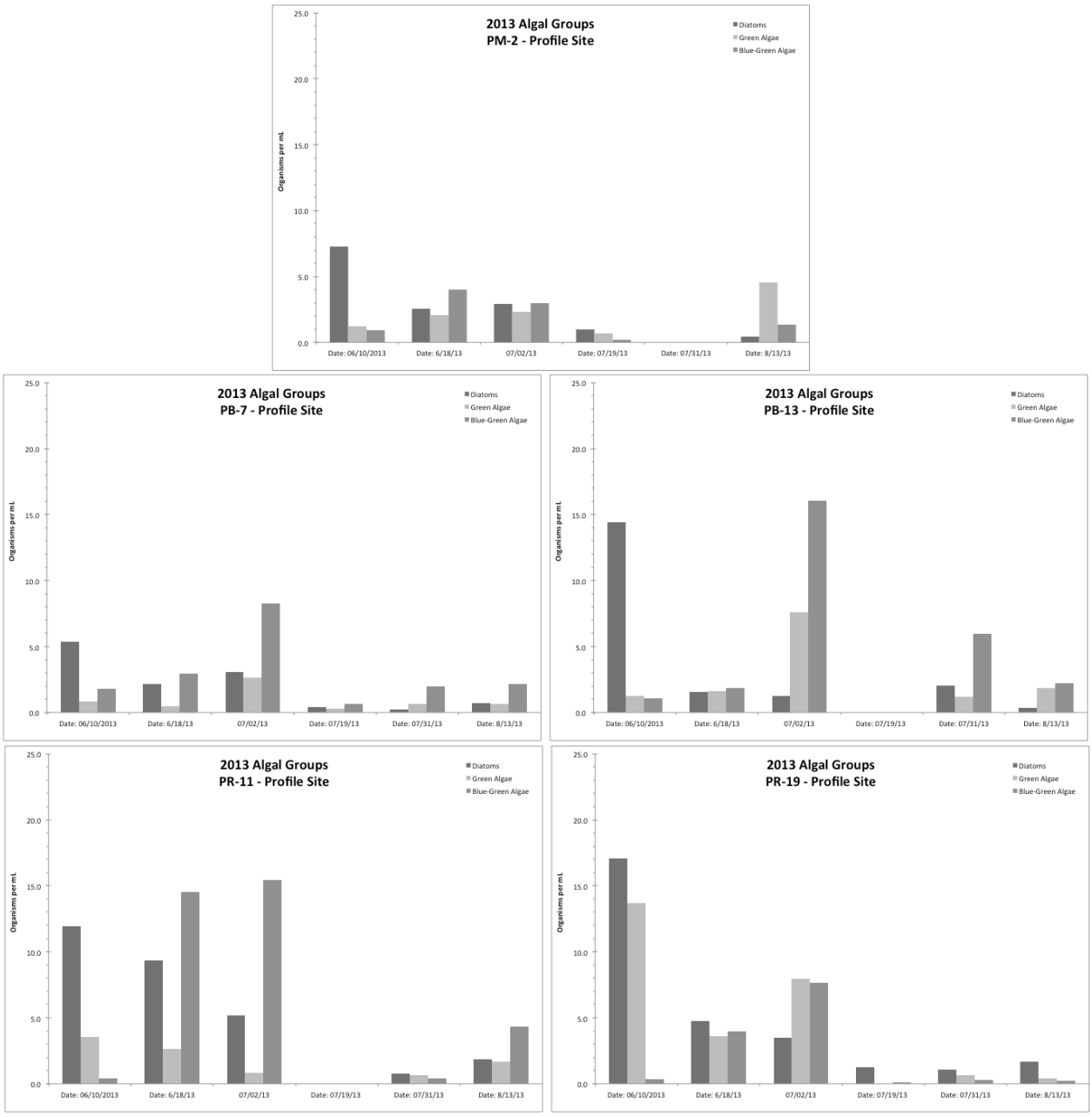


Figure 5.4. Algal groups versus week sampled on Smith Mountain Lake in 2013 from profile sites (Sites PM-2, PB-7, PB-13, PR-11, and PR-19)

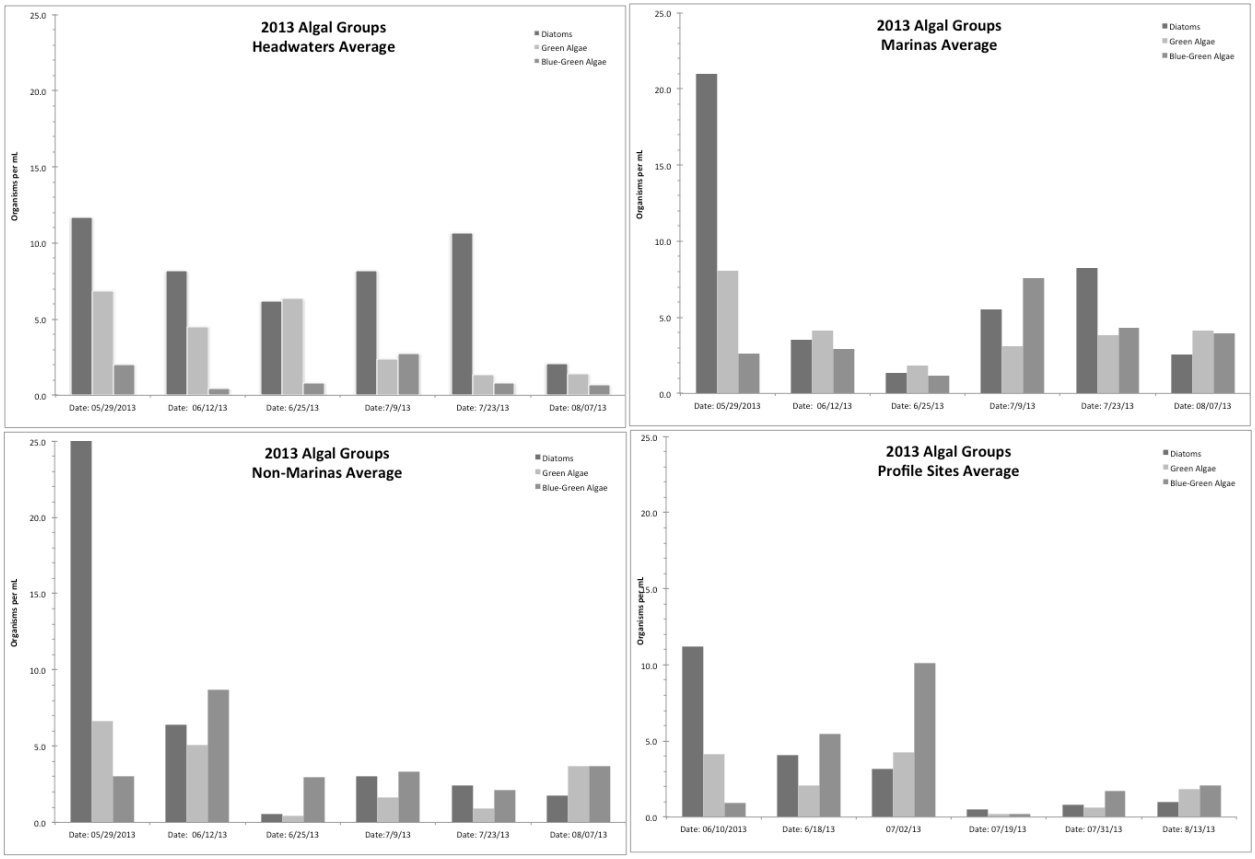


Figure 5.5. Average concentrations of algal groups versus week sampled on Smith Mountain Lake in 2013 by site type

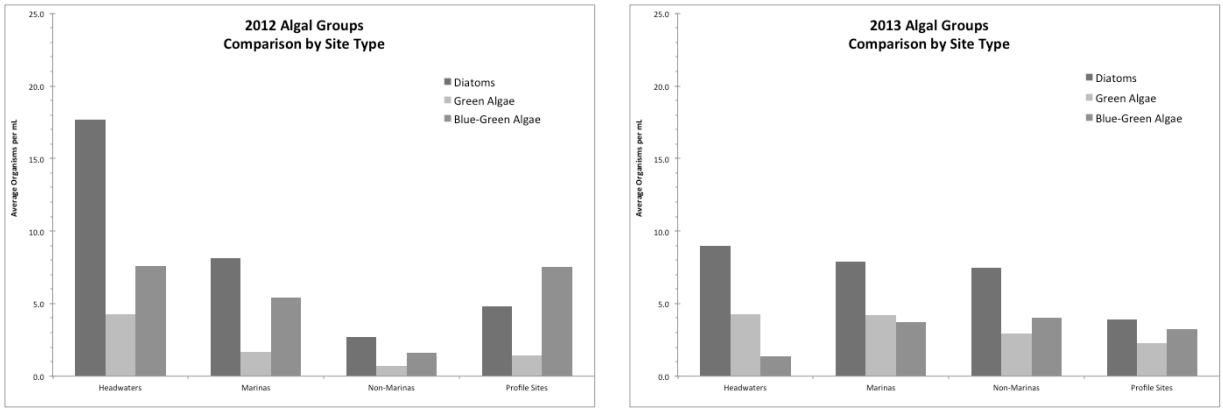


Figure 5.6. A comparison of algal groups' abundance sampled on Smith Mountain Lake in 2012 and 2013 by site type

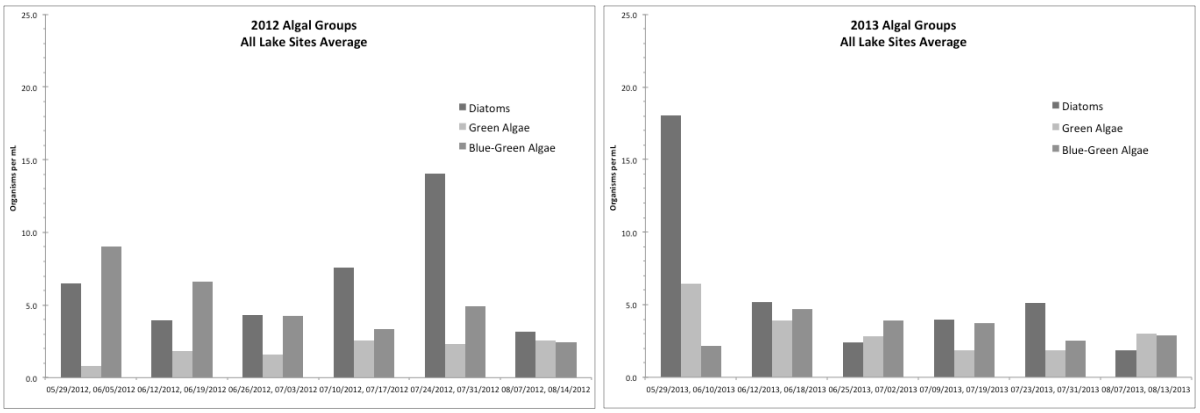


Figure 5.7. A comparison of algal groups versus week sampled on Smith Mountain Lake in 2012 and 2013 from all lake sites

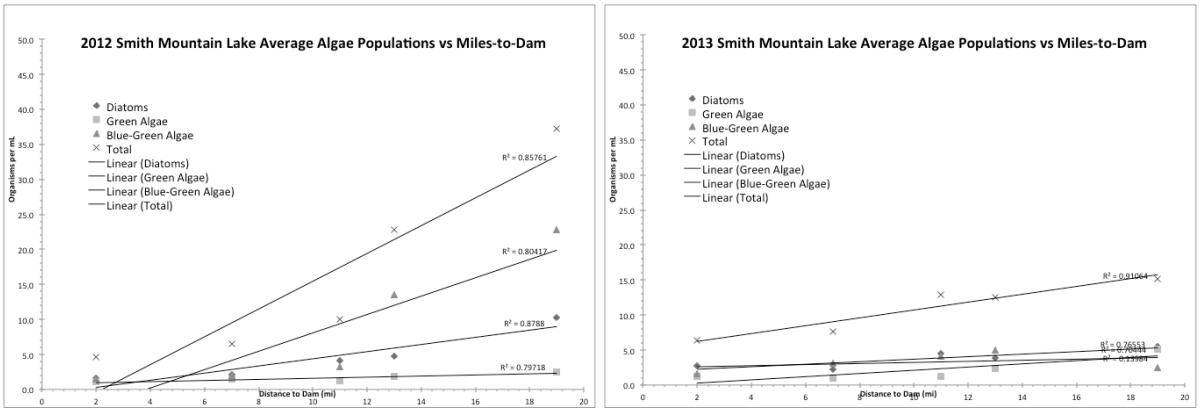


Figure 5.8. A comparison of algal groups versus miles to the dam sampled in 2012 and 2013 on Smith Mountain Lake from the five profile sites sampled (vertical tows)

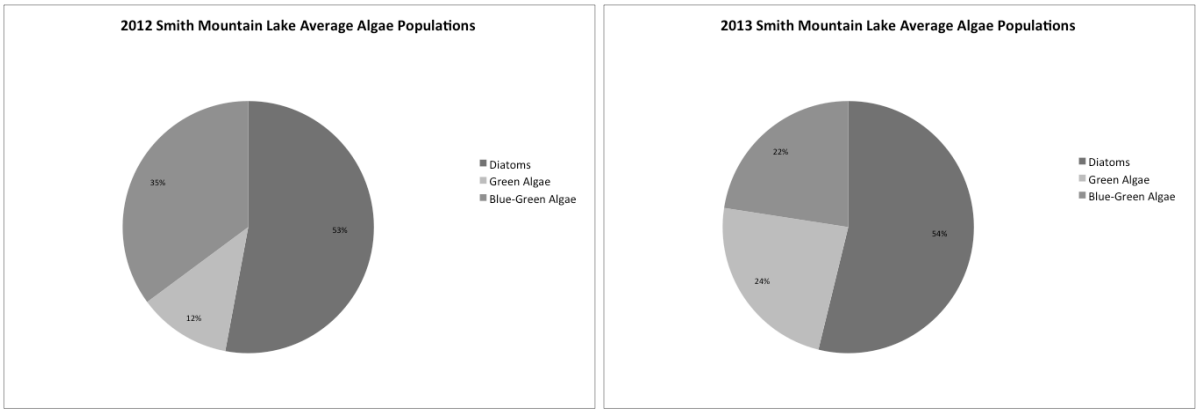


Figure 5.9. Algal groups' abundance sampled on Smith Mountain Lake in 2012 and 2013 from all sample sites sampled

5.4 Discussion

A significant shift in the dominant alga population types was observed in 2012 from previous years. Diatoms and blue-green algae outnumbered green algae as indicated in the overall summaries diagram (Figure 5.9). As can be seen in Figure 5.9, results of algal counts in 2013 reverted back to a dominance of diatoms and a slightly higher number of green algae. The blue-green algae were back to levels seen in previous years. The actual differences between site types were variable, however, with no consistent trend. No strong correlation can be found between algae diversity, abundance and any of the other parameters such as Secchi depth, phosphorus and chlorophyll-*a* as might be expected, but future correlations may occur with climate change and temperature increases.

In Figure 5.1 it is apparent that headwater sites again varied significantly in algal levels in 2013. Site 2 at Beaverdam Creek had significantly higher levels of diatoms and slightly higher levels of blue-green algae than the other sites even though the diatoms were still dominant at that site as the year before. The same variation is true of the marina sites as can be seen in Figure 5.2. Indian Point Marina (site 3), Pelican Point Marina (site 12), and Gills Creek Marina (site 13) all had high numbers of blue-green algae during week 4 of sampling. It is interesting to note that phosphorus was also higher in week 4. Other marina sites had lower levels of all alga types except for the first sampling site with higher diatom levels. Non-marina sites showed lower levels of algae except for Fairway Bay (site 6) and The Smith Mountain Lake State Park (site 7) (Figure 5.3). There were peaks of blue-greens and diatoms during the earlier parts of the summer. An unusual trend this year occurred in the vertical tows of the profile sites. As can be seen in Figure 5.4, higher levels of blue-green algae were found during weeks 2 and 3 especially at Palmer's Trailer Park Cove (site 11). Typically we have found higher levels of blue-greens later in the season but this trend did not appear this year. Later in the summer, the blue-green levels dropped off. This may be due to early higher water temperatures and a milder winter. This is the second year this trend was seen and will continue to be monitored in future years to see if it continues.

It is also interesting to note that the blue-green species composition was similar to 2012. The highest number of species from these sample sites was *Phormidium* (which can be potentially toxic in high concentrations) and *Anabaena* (which can potentially be toxic in high

concentrations). *Aphanocapsa,* a microcystin producing blue-green was also found as a dominate species this year. *Microcystis*, a producer of higher levels of toxins, was also present but not at a high level. A microcystin toxin assay procedure was tested this year to determine if we could measure the levels of toxin produced by these algae in lake samples. The addition of this test in future years would allow us to determine if the blue-green algae present are producing microcystin toxins at harmful levels in the lake at any time during the year sample period. The test could also be used for samples taken from coves that have algal blooms which are reported by residents. The Envirologix® QualiTube™ Kit for Microcystin testing was used and microcystin was found in a few samples taken. Samples taken in the Beaverdam area in July showed microcystin at level more than 3.0 ppb. Other sites such as Ponderosa Campground (site 14) and Palmer's Trailer Park Cove (site 11) showed no toxins in water samples. Hoehn and Long, (1999) point out the value of this testing to determine toxin levels in water systems. Brylinsky (2012) recently did a comparative review of current procedures for microcystin testing in water systems. New procedures by both Envirologix® and ABRAXIS® show promise for both laboratory and field-testing with strips and meters that allow rapid assessment. These techniques are being used in many states. One example of this is Bigham et al (2009) in their survey of Florida lakes.

Results summarized in Figure 5.5 seems to indicate that the headwater sites have higher algae amounts early in the summer while the marina sites had higher levels of algae later in the summer. Run-off carried down through the lake might contribute to this also activity at he marinas might also be a factor later in the season.

One additional change from previous years is the type of algae in relation to the distance from the dam (Figure 5.8). While there is still an increase in total algae further upstream from the dam, the dominant species type shifted back to previous year trends. Blue-green algae were no higher than greens or diatoms. This is more similar to the patterns in 2009-2011. Comparing 2012 and 2013 in Figure 5.8 shows there were also fewer overall counts of algae even though there is still a slight increase in algae away from the dam.

5.5 Conclusions

In 2013 the overall dominant algal population group found in Smith Mountain Lake was the diatom group (Figure 5.9). These algae are indicators of a clean lake. Green and blue-green algae comprised 24 percent and 22 percent of the total algal population.

We must continue to monitor these parameters and compare the algal populations to the corresponding total phosphorus and chlorophyll-*a* levels in order to continue to keep Smith Mountain Lake water quality high and prevent future algal blooms. It is possible that warming trends in the climate, along with earlier spring and longer lasting summer temperatures, may intensify the increasing algal populations resulting in unwanted algal blooms and deterioration of water quality.

6. DISSOLVED OXYGEN (DO) PROFILES

6.1 Introduction

Dissolved oxygen levels are critically important to aquatic systems and useful for evaluating the health and trophic status of a lake. During warmer seasons, thermal stratification takes place when solar energy has increased the temperature of surface waters (called the *epilimnion*) that causes a transition zone of rapidly changing temperature (known as the *thermocline*) down to the lower-temperature bottom waters (called the *hypolimnion*). This thermal stratification is stable because water density decreases with increasing temperature, so stratification produces a physical barrier that prevents mixing of the epilimnion and hypolimnion until the surface water cools again in the fall. Algal production occurs where light is sufficient in the "photic zone" of the epilimnion, consuming carbon dioxide and producing oxygen. When algal cells die, they sink and the resulting organic matter leads to oxygen depletion in the lower layer of the lake as bacterial decomposition consumes oxygen. With nutrient enrichment, photosynthesis and oxygen production increase near the surface while decomposition and oxygen consumption increase below the thermocline. This increases the difference in dissolved oxygen between epilimnion and hypolimnion and significantly affects the biota and nutrient dynamics. This effect stresses cool water fish populations as oxygen levels become insufficient at depths where the water remains sufficiently cool. Depth profiles of temperature and oxygen increase the sensitivity of trophic state analysis and give early indications of nutrient enrichment and stress on cool water fish.

6.2 Methods

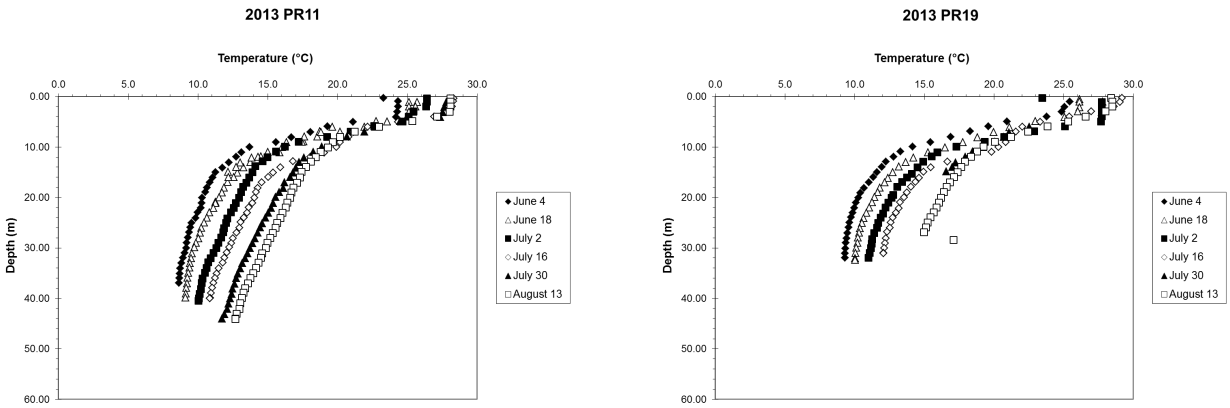
Depth profiles were obtained using an In-Situ Troll 9500 Profiler™ (which includes a multi-sensor probe with 200 feet of cable) and Rugged Reader™ handheld PC. The parameters measured through a single profiling event are depth, temperature, dissolved oxygen concentration (DO), pH, and conductivity. Sampling occurred at five sites on Smith Mountain Lake on six days in 2013: June 4, June 18, July 2, July 16, July 30, and August 13. The five sample sites were selected to represent the major sections of Smith Mountain Lake; PM-2 is in the main channel two miles from the dam, PB-7 and PB-13 are in the Blackwater River channel seven and thirteen miles from the dam and PR-11

and PR-19 are in the Roanoke River channel eleven and nineteen miles from the dam (See Figure A.3 in the Appendix). For each depth profile, parameter readings were logged at the surface (~ 0.250 m) and then at each meter until the probe casing touched the bottom of the lake. Because the cable and sensor probe do not necessarily drop straight to the bottom of the lake, a pressure sensor provides accurate depth readings for each measurement and this is used to determine when to record ("log") data from the probe sensors using the Rugged Reader™. The probe sensor for temperature was calibrated at the beginning of the sampling season, and sensors for dissolved oxygen concentration, pH, and conductivity were calibrated less than 24 hours before each sampling event and then checked against standards less than 24 hours after each sampling event.

6.3 Results

The depth profile results are included in the following three figures: temperature (Figure 6.1), dissolved oxygen (Figure 6.2), and conductivity (Figure 6.3). Each parameter starts on a new page for ease of comparison between profile data and discussion of results.

Depth profiling normally includes pH but, based on quality control results and a review of the profile data, the pH sensor was determined to have malfunctioned several times during the sampling season and the pH data is not being reported for 2013. Steps are being taken to find the cause of the malfunction and help assure that pH profile data will be reliable in future seasons.



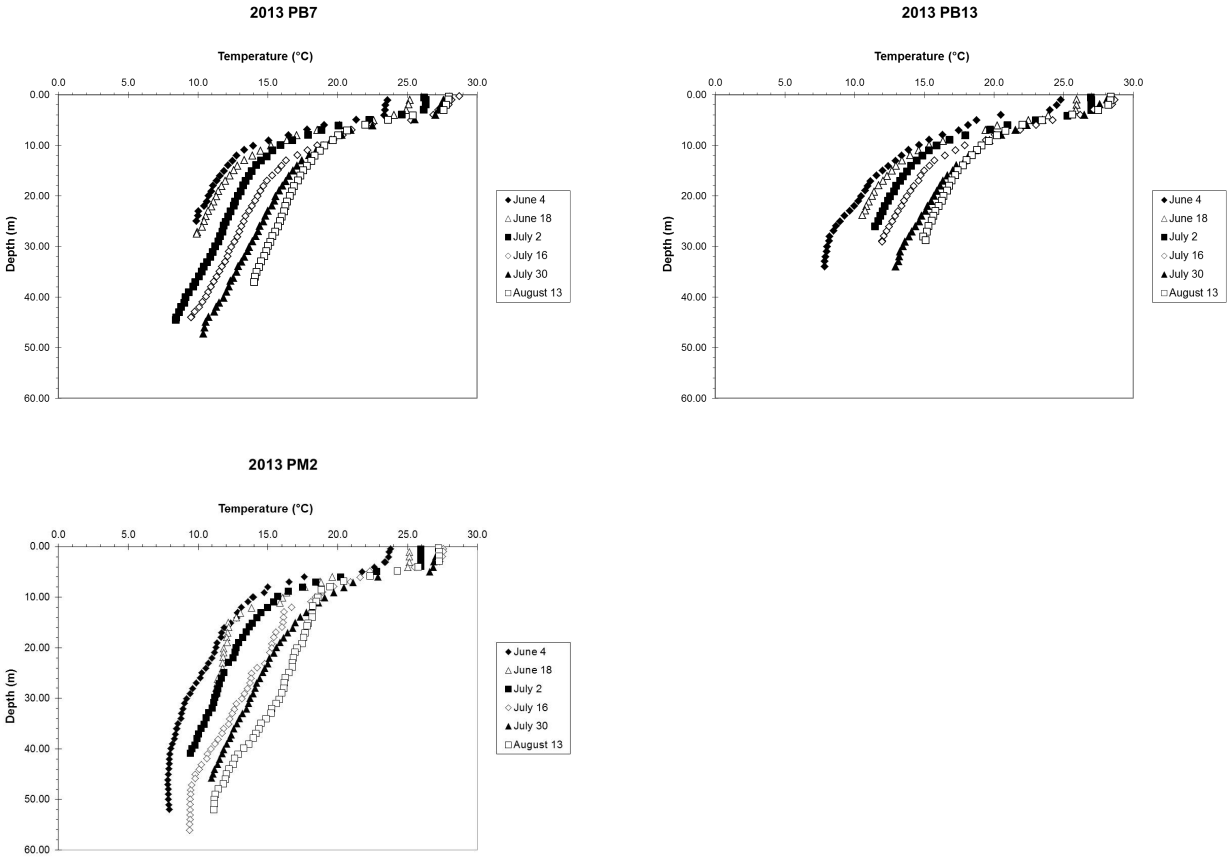


Figure 6.1. Temperature depth profiles for Smith Mountain Lake in 2013

Three general observations can readily be made for the temperature depth profiles. The first is that thermal stratification had already taken place before the first sampling event. The second is that the thermocline was located at a depth of 5-8 meters. The third is that the temperature of the entire lake increased steadily from the first sampling event through the sixth sampling event.

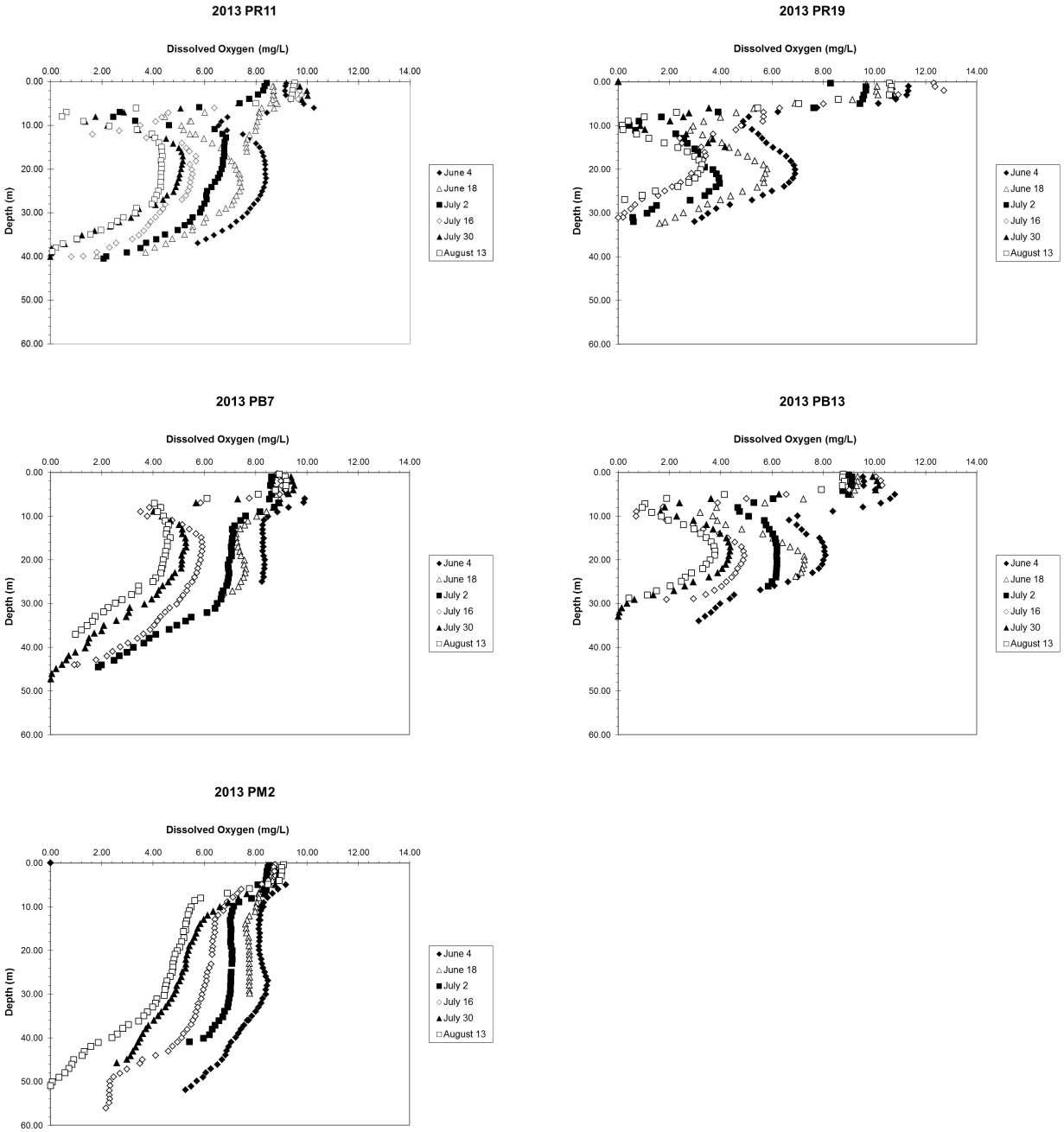


Figure 6.2. Dissolved oxygen depth profiles for Smith Mountain Lake in 2013

Dissolved oxygen concentrations below the thermocline decreased steadily over the course of the sampling season. Above the thermocline, all sample sites were supersaturated in oxygen for all sample dates, indicating algal photosynthesis. All five sites showed anoxic conditions near the lake bottom starting in July due to organic matter settling below the thermocline and decomposing (see discussion section).

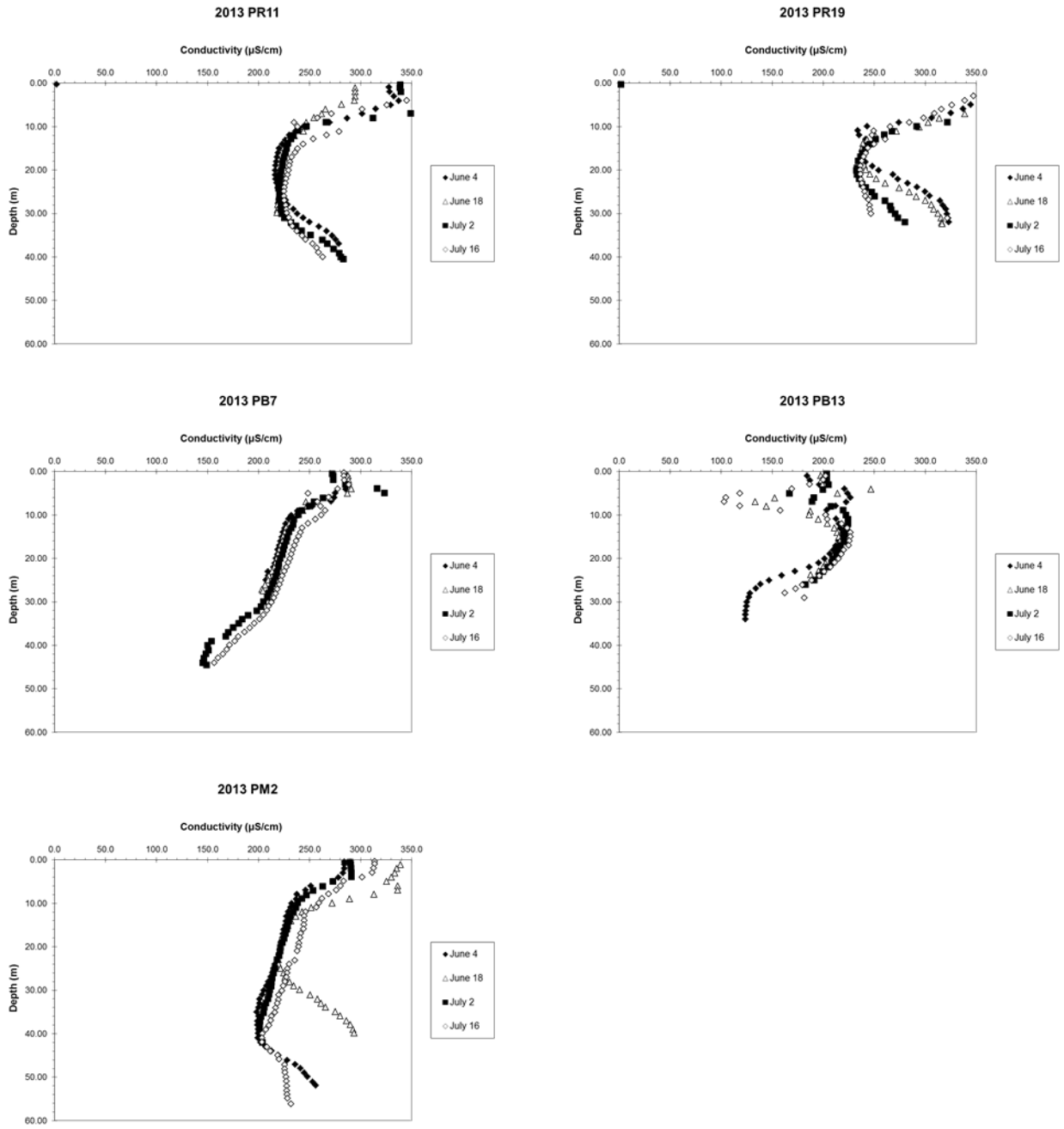


Figure 6.3. Conductivity depth profiles for Smith Mountain Lake for 2013

As in previous years, conductivity profiles for the main channel and the Roanoke River channel show a trend toward higher conductivity near the bottom of the lake, while those for the Blackwater River channel tend toward lower conductivity near the bottom. The conductivity sensor malfunctioned during the last two sampling events and was not included. Steps are being taken to identify and correct the problem.

Figure 6.4 shows the average depth profiles for 2013 and, based on a visual comparison, the depth profiles for 2013 show trends similar to those obtained in previous years.

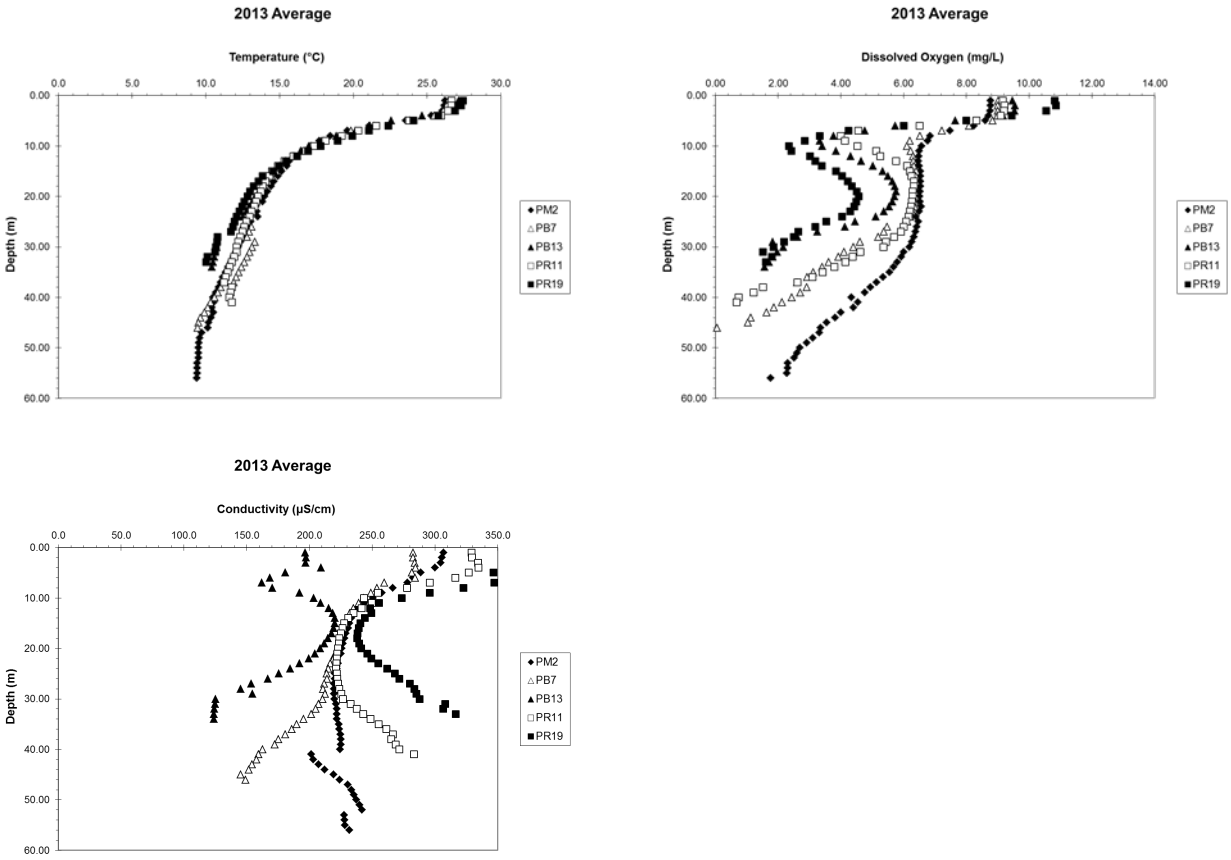


Figure 6.4. Average depth profiles for 2013 for each parameter sampled on Smith Mountain Lake by sample site

6.4 Discussion

As in past years, the variation of temperature with depth is consistent across profile stations while the DO and conductivity profiles vary across stations in a predictable way. Significant oxygen depletion below the thermocline was observed at all sites, the degree of hypolimnetic oxygen depletion increased during the summer, and the deficit was more severe with increasing distance to the dam (Figure 6.2). The increasing dissolved oxygen deficit is due to thermal stratification and the increasing deficit up-channel is consistent with the observation that there are higher concentrations of chlorophyll-*a* (and therefore algae) at sites further from the dam. It is also apparent that the settling organic material tends to hang up on the cooler, denser thermocline long enough for bacterial

decomposition to drive down the DO. By the last profile in August the DO is depleted at the thermocline of station PR19 and near zero at the thermocline of stations PB13 and PR11. This observation is typical of eutrophic lakes and contrasts with the DO profiles for stations PM2 and PB7. Indeed, the five DO profiles vary in a way that is indicative of a gradient from eutrophic, through mesotrophic, to near oligotrophic at the dam. Conductivity is lower in the Blackwater River than in the Roanoke River and, as in past years, mixing gives similar conductivities at a depth of about 15m. We continue efforts to more closely determine when thermal stratification begins in the spring and when it ends with the fall "turnover" and complete mixing is restored.

6.5 Conclusions

Sufficient depth profile data have now been collected to enable meaningful comparison between rates of change and absolute parameter values over the course of the summer. The depleted oxygen at lower depths (hypolimnion), especially in the more nutrient rich upper channels, is of concern because low dissolved oxygen is appearing earlier in the summer. The temperature profiles indicate that the thermocline is moving lower in the water column. Continued study of thermal stratification, using depth profiling, and of algal dynamics will provide the scientific data necessary to effectively manage Smith Mountain Lake as it ages.

7. BACTERIA IN SMITH MOUNTAIN LAKE

7.1 Introduction

Bacterial analysis in Smith Mountain Lake included *Escherichia coli* (*E. coli*) monitoring and bacterial source tracking using *Enterococcus faecalis*. This reflects the Commonwealth of Virginia's bacterial standard, which uses *E. coli* as the indicator organism. On occasion, the *E. coli* population exceeds the Virginia Department of Health standard for recreational water. Because this is a controversial water quality parameter and is related to human health, the Ferrum College Water Quality Lab has been tracking the source of the bacteria entering Smith Mountain Lake since 2002 because knowing the source of these bacteria could be valuable in developing strategies for controlling bacteria in the lake.

7.2 E. coli Methods

Samples were collected in sterile 125 mL polypropylene bottles at 0.25 m depth and stored according to standard methods (APHA). Two stations were sampled at each site and at each station a 100 mL sample was evaluated. A Colilert™ media packet was added to these 100 mL water samples and mixed thoroughly by shaking vigorously until the powdered media was dissolved. The mixture was poured into a sterile Quanti-Tray 2000™ and passed through the Quanti-Tray™ Sealer after being placed in a rubber insert to seal the sample into the wells in the Quanti-Tray 2000™. The sealed trays were incubated for 24 hours at 35° C. For the Colilert™ media, a color change from clear to yellow indicates a positive result for total coliform and fluorescence indicates a positive result for *E. coli*. The numbers of yellow and fluorescent wells (both large and small) are counted and the values are evaluated using a Most Probable Number (MPN) chart developed by the Colilert™ method developers (IDEXX Company). MPN is used instead of colony forming units (CFU) and is generally considered an equivalent measure of the microbial and bacterial populations. The IDEXX™ method for Colilert™ has been rated as the "best" in agreement with a reference lab, has the lowest detection limit and the Colilert™ method is EPA approved for ambient water (O'Brien, 2006).

The bacterial source tracking method used for Smith Mountain Lake was Antibiotic Resistance Analysis (ARA), which has become a common method for tracking bacteria. During initial method development, Dr. Charles Hagedorn from Virginia Tech and his associates shared

information with us about this method. The method is explained in Harwood et al. (2000). The ARA technique is based on enterococci becoming resistant to antibiotics used in certain species of animals, for example cattle and humans. Therefore, when a particular pattern of antibiotic resistance is observed, the probable source (animal) can be identified. A computer program (JMP-IN version 4, a discriminate analysis program) is used to analyze the data, find particular patterns of antibiotic resistance, and assign probable sources for the bacterial isolates.

In 2013, we took samples for ARA at tributary sites twice, at the beginning of the summer (May, 22 sites) and toward the end (August, 22 sites) of the summer.

Water samples were collected from 14 sites on Smith Mountain Lake on May 28, June 11/14, June 25, July 9, July 23, and August 6, 2013.

The sites on Smith Mountain Lake that were sampled included the following:

Non-Marina Sites

Main basin at the confluence of the Blackwater and Roanoke channels. (Site 10)
Forest Cove on the Bedford County side of the lake. (Site 8)
Fairway Bay on the Franklin County side of the lake. (Site 6)
Palmer's Trailer Park Cove on the Franklin County side of the lake. (Site 11)
Smith Mountain Lake State Park Cove on the Bedford County side of the lake. (Site 7)

Marina Sites

Bayside Marina and Yacht Club (formerly Shoreline Marina) on the Franklin County side of the lake. (Site 5)
Pelican Point Marina on the Franklin County side of the lake. (Site 12)
Smith Mountain Dock and Lodge on the Pittsylvania County side of the lake. (Site 9)
Crystal Shores Marina (formerly Smith Mountain Lake Yacht Club) on the Bedford County side of the lake. (Site 4)
Gills Creek Marina (formerly Foxsport Marina) on the Franklin County side of the lake. (Site 13)
Indian Point Marina on the Franklin County side of the lake. (Site 3)

Headwaters Sites

Bay Roc Marina at Hardy Ford Bridge on the Franklin County side of the lake. (Site 1)
Ponderosa Campground on the Franklin County side of the lake. (Site 14)
Beaverdam Creek on the Bedford County side of the lake. (Site 2)

These sites were selected as representative coves around Smith Mountain Lake to allow comparison between non-marina coves and marina coves and to allow evaluation of three headwater coves. The main basin site at the confluence of the Blackwater and Roanoke channels (site 10) was selected to provide samples not influenced by runoff from nearby shoreline. Forest Cove (site 8, Bedford County) is surrounded by a residential area of low density and is located after the confluence of the two main channels and in close proximity to Smith Mountain Lake Dam. Fairway Bay (site 6, Franklin County) is surrounded by homes and multi-family residences and is on the Roanoke channel. Palmer's Trailer Park Cove (site 11, Franklin County) is surrounded by trailers that have been there for a long time, each with a septic tank and drain field, and is located off Little Bull Run, a tributary of the Blackwater channel. Smith Mountain Lake State Park Cove (site 7) is sampled where it intersects the main channel.

The marina sites include: Bayside Marina and Yacht Club (site 5, formerly Shoreline Marina), which is up Becky's Creek, a tributary of the Roanoke channel in Franklin County. Pelican Point Marina (site 12) is on the Blackwater channel in Franklin County and is a storage place for many large sailboats. Smith Mountain Dock and Lodge (site 9) is in a cove off the main basin in Pittsylvania County, in close proximity to Smith Mountain Lake Dam and is a storage place for many houseboats. Crystal Shores Marina (formerly Smith Mountain Lake Yacht Club, site 4) is in a cove off the Roanoke channel in Bedford County and is a storage place for many houseboats. Gills Creek Marina (site 13, formerly Foxsport Marina) is on the channel of Gills Creek, a major tributary of the Blackwater River and has very few boats docked there. Indian Point Marina (site 3) is in a cove off the main channel of the Roanoke River, and is one of the newer marinas with very few permanently docked boats.

There are three headwaters sites, which primarily indicate specific watershed influences and not within-lake influences. Organic compounds and other nutrients in a body of water come from two possible sources, allochthonous inputs and autochthonous inputs. "Allochthonous" refers to input from outside the body of water (in other words, from the watershed) and "autochthonous" refers to input from within the body of water (for example, the algal population that is dependent on the in-lake process of photosynthesis). The three headwaters sites reflect three of the allochthonous inputs to Smith Mountain Lake. Bay Roc Marina (site 1) is located on the

Roanoke River at the "beginning of the lake" and as a result has been included as a headwaters site since 2006. The marina is one of the oldest marinas on the Franklin County side of the lake and was included in the marina designation until 2005. Ponderosa Campground (site 14) is located on a curve far upstream on the Blackwater River not far from the non-navigable portion of the river, and Beaverdam Creek (site 2) is a tributary of the Roanoke River on the Bedford County side of the lake

7.3 E. coli Results

Figure 7.1 indicates the mean *E. coli* most probable number in the population (commonly called MPN), for the six sample dates in 2013. Figure 7.2 indicates the 2013 comparison of marinas, non-marinas, and headwaters sites. Figure 7.3 indicates the average MPN for each sample site. Figure 7.4 indicates the comparison of the sum of the MPN of each sample site. Figure 7.5 shows a comparison of mean *E. coli* counts for 2004 to 2013 and the eight sample years that fecal coliform was measured (1996-2003) for combined marina bacterial counts, non-marina bacterial counts and headwater bacterial counts. Figure 7.6 is a map showing the results of bacterial sampling throughout the lake for 2013.

1. The means of *E. coli* populations for each station averaged over the six sample periods for 2013 were above the Virginia health standard for recreational waters (standard is 126 CFU/100 mL) on two of the sample dates (June 11 and July 9). Generally the bacteria populations increase with the increase in runoff that results from an increase in rainfall amount and frequency; in 2013 this area of southwest Virginia received more than average rainfall prior to these dates so higher than average bacterial counts would be expected as observed (92.0 ± 280.6 MPN). Of course there are other unidentified factors influencing the increase in bacteria populations (see Figure 7.1).

2. As in previous years, *E. coli* population counts in 2013 were highly variable over time (Figure 7.1), with week 2 (June 11, 14) and week 4 (July 9) exhibiting the highest mean number of bacteria (194.8 ± 652.2 and 185.3 ± 490.9 MPN). The lowest mean number of bacteria occurred in week 6 (August 6) again as in 2010, 2011 and 2012 and was 4.8 ± 5.5 MPN of bacteria. This is a very low bacterial count.

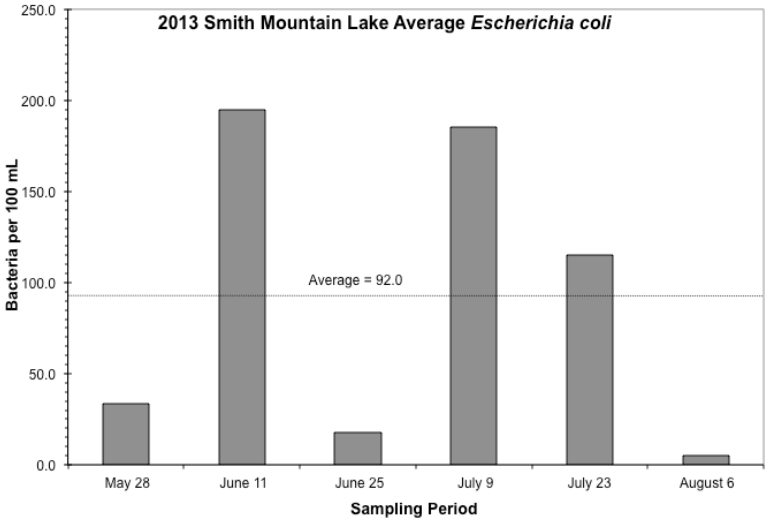


Figure 7.1. *E. coli* versus week sampled on Smith Mountain Lake in 2013
(Each sample date included 14 sites with 2 samples per site, n = 28)

3. The mean bacterial counts (*E. coli*) and variances for marinas in 2013 (12.6 ± 13.7 MPN) are 29.9 percent higher than the 2013 non-marinas' bacteria counts (9.7 ± 13.9 MPN) and the headwaters bacterial counts (387.9 ± 343.4 MPN) are 2,978.6 percent higher than the marina bacterial counts (Figure 7.2). For the first time the bacterial counts of the headwaters sites are statistically significantly different from the marina and non-marina sites and are significantly different from zero. The bacterial counts are higher in 2013 but significantly higher than in 2012 at both the non-marina sites (79.6 percent increase) and the headwaters sites (1,964 percent higher).

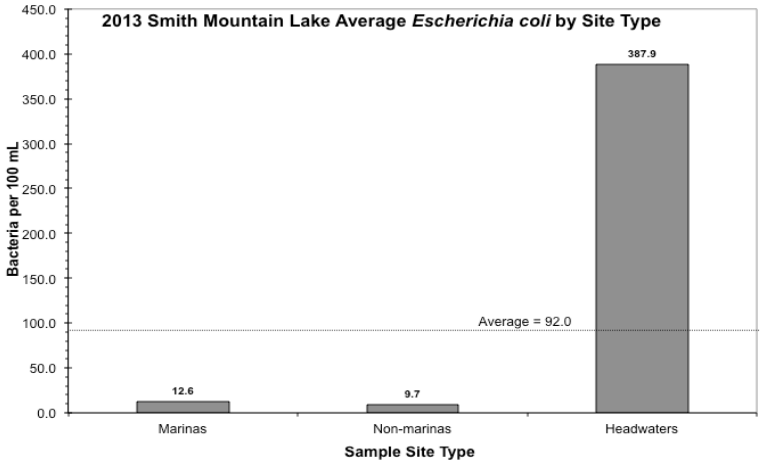


Figure 7.2. Mean *E. coli* count vs. site type on Smith Mountain Lake in 2013
(6 marina sites, 5 non-marina sites, and 3 headwater sites)

4. The highest *E. coli* counts of the summer were at Ponderosa Campground (headwaters site 14) on the Blackwater channel in weeks 1, 2, 4 and 5 (370.1, >2,500, 814.0 and 1251.8 MPN). Bay Roc Marina (headwaters site 1) on the Roanoke channel in weeks 2 and 4 (142.8 and 1,643.0 MPN) also had high bacterial counts in 2013. The bacterial counts at Ponderosa Campground at station 1 and 2 for weeks 1, 2 4, and 5 exceeded the Virginia Department of Health (VDH) standard for recreational waters (126 CFU/100 mL). The bacterial counts at Bay Roc Marina at station 1 for weeks 2, 4 and 5 and at station 2 for week 4 exceeded the Virginia Department of Health (VDH) standard for recreational waters (126 CFU/100 mL).

5. The sample site with the lowest mean *E. coli* count in 2013 was confluence of the Blackwater and Roanoke channels (site 10) with a mean of 0.35 MPN. Smith Mountain Lake State Park was the second lowest (site 7, 1.4 MPN). These sites had the lowest *E. coli* counts on all six of the sample dates, which has been true most sample years for those sites (Figures 7.3 and 7.4).

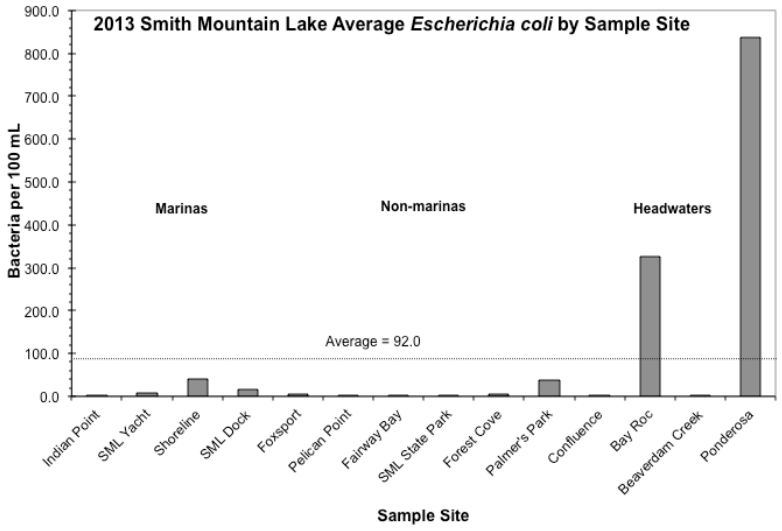


Figure 7.3. Mean *E. coli* count vs. sample site on Smith Mountain Lake in 2013
(Each site has two stations sampled 6 times during the summer)

6. The high variability of *E. coli* counts is shown by the large standard deviations of each mean. In fact, the standard deviations are greater than the mean values at most of the sites and therefore it is difficult to show significant statistical differences among sites again in 2013 as has been true for most years of data.

7. In a comparison of the sums of *E. coli* populations for sample dates and sites in 2013 (Figure 7.4), Bay Roc Marina and Ponderosa Campground have the highest sum of *E. coli* populations.

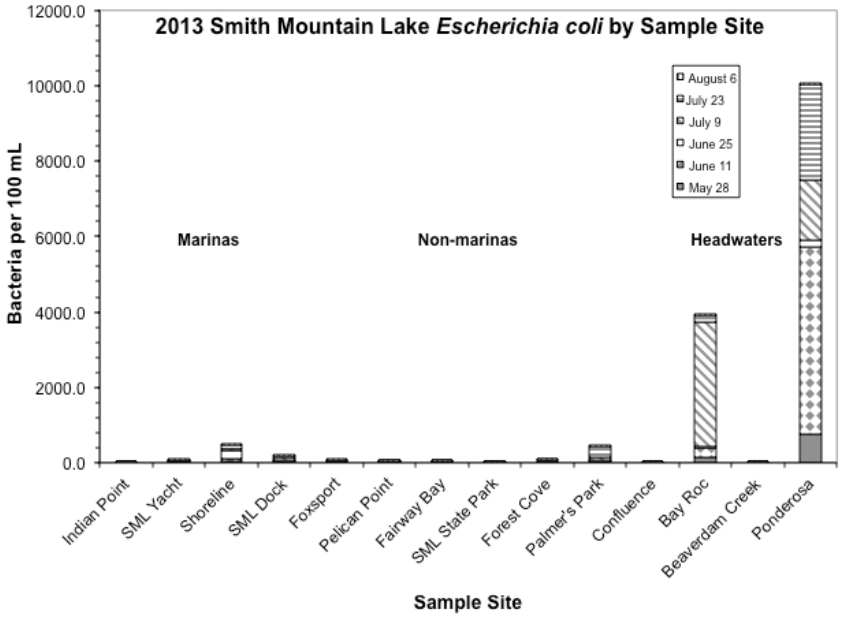


Figure 7.4. Sum of *E. coli* counts for Smith Mountain Lake in 2013 at each site for all sample dates (There are two sampling stations at each site)

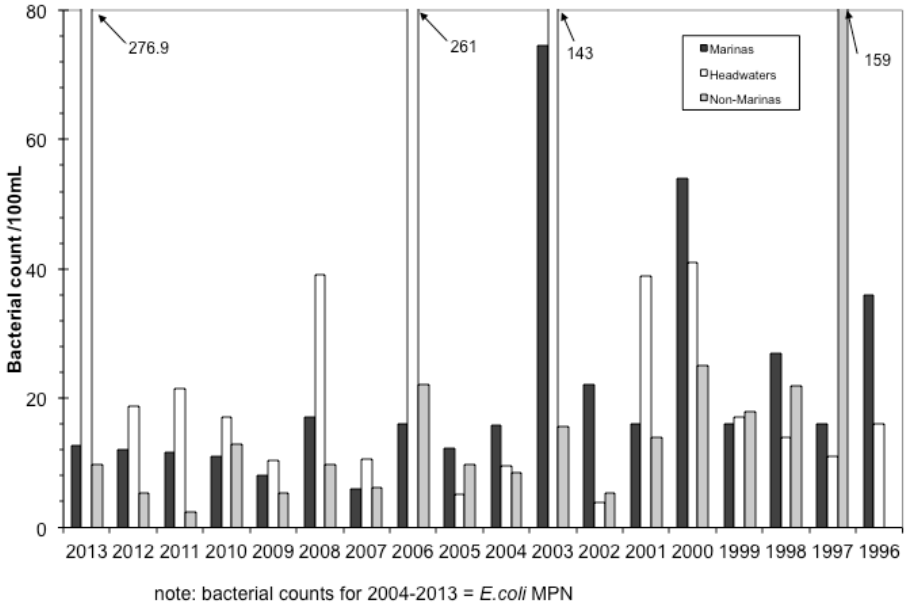


Figure 7.5. Mean *E. coli* or fecal coliform counts per site type and year sampled for Smith Mountain Lake from 1996-2013

7.4 E. coli Conclusions

The bacteria populations, specifically *E. coli*, in Smith Mountain Lake in 2013 were the highest they have been at two of the headwaters sites since 1995. In 2013 every bacterial sample week had at least one station that had *E. coli* values that exceeded the Virginia Health Department standards except the last sample week (August 6). Two of the sample sites on June 11, 14, July 9 and July 23 (second, fourth and fifth sample weeks) had *E. coli* values that exceeded the Virginia Health Department standard. The comparison of marinas and non-marinas showed a smaller difference in *E. coli* values in 2013, but still showed a higher mean than in 2012 despite the efforts of the Smith Mountain Lake Association Boater Education and Pump Out Program, our boaters' and marina owners' vigilance and the implementation of the Total Maximum Daily Load (TMDL) process. This comparison of marina, non-marina and headwater sites was completely overwhelmed by the high *E. coli* values at two of the headwaters sites.

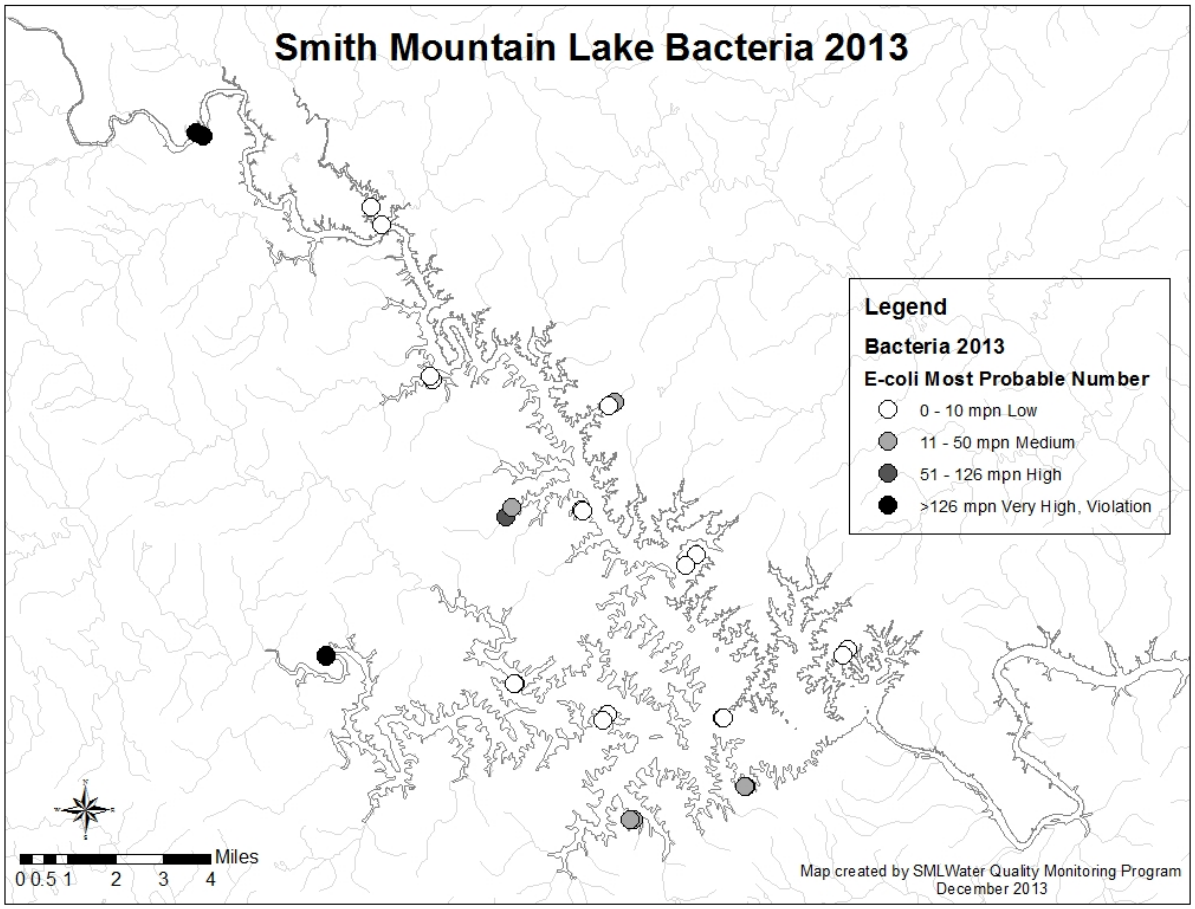


Figure 7.6. Bacterial sampling results in Smith Mountain Lake for summer 2013

7.5 Bacterial Source Tracking Methods

The sites sampled are the tributary sites that have been sampled for 18 years for nutrient levels and eleven years for enterococci. They are listed in Table 7.2, and a map of the sites is shown in Figure A.2 in the Appendix. In 2013, student technicians took samples at twenty-two tributary sites in both May and August. Enterococci bacteria are the coliform bacteria used in the Antibiotic Resistance Assay method (ARA), which is used for bacterial source tracking.

7.6 Bacterial Source Tracking Results

The results of the samples taken in 2013 will be reported here. The samples were compared with known sources of enterococci as listed in Table 7.1, which also indicates the percentage of confidence we have in the corresponding prediction of bacterial source; for example, we are 84.24 percent confident in our human source predictions. In general, the larger the number of isolates, as listed in Table 7.1, the more accurate is the prediction of the bacterial source detected in the samples (an isolate is a single colony of fecal streptococci taken from a nitrocellulose membrane for bacterial source tracking). The use of the word "found" or "had" in reference to the percentage of a certain predicted source is as stated, a prediction. The domestic designation includes isolates from pet dogs and cats. Livestock includes primarily cattle, and wildlife isolates includes deer, raccoon, and Canada geese.

The organism used for the Antibiotic Resistance Analysis (ARA), *Enterococcus faecalis*, is a common enteric bacterium found in mammals and birds and is found at lower population levels than the more common fecal coliform and *E. coli*.

Table 7.1. Known bacterial sources and the percent agreement with the prediction of source

Source Name	Domestic (%)	Human (%)	Livestock (%)	Wildlife (%)	Totals (%)	# of Isolates
Domestic	74.47	0.00	0.00	25.53	100.00	47
Human	0.47	84.24	11.29	4.00	100.00	425
Livestock	0.15	6.24	88.82	4.79	100.00	689
Wildlife	5.82	4.74	16.16	73.28	100.00	464

The following figures (Figures 7.7-7.14) show the predicted sources (based on comparison to known sources) of the bacterial isolates from tributary water samples taken in 2013. All

tributaries had between 14 and 48 isolates (48 is the maximum tested per site) in the water sample with ninety percent (41 of 44) having greater than 40 isolates (see Table 7.2) which makes those sample sites' source predictions valid.

Table 7.2. The number of enterococci isolates tested from each tributary in 2013

	# Isolates			# Isolates	
Tributary	May '13	Aug. '13	**Tributary**	May '13	Aug. '13
T0 (Gills Creek)	47	44	T11 (Old 103)	47	41
T1a (Maggodee Creek)	47	44	T12 (Surrey Drive)	48	46
T2a (Gills Creek)	48	25	T13 (Snug Harbor)	44	46
T3 (Blackwater)	47	37	T14 (Stoney Creek)	47	43
T4 (Poplar Camp Creek)	48	43	T15 (Jumping Run)	48	47
T5 (Standiford Creek)	48	47	T16 (Beaver Dam Creek)	48	48
T6 (Bull Run Creek)	48	48	T17 (Hardy Ford Bridge)	48	42
T7 (Cool Branch Creek)	47	42	T18 (Lynville Creek)	46	46
T8 (Lumpkins Marina)	46	45	T19a (Grimes Creek)	48	47
T9 (SML Dam)	48	14	T20 (Indian Creek)	47	48
T10 (Pigg River)	48	47	T21a (Roanoke River)	48	45

In 2013, as has been the case for many years, all of the Franklin County tributaries had some isolates coming from human sources and livestock sources, both of which are of concern in regard to human health (Figures 7.7 and 7.8). In 2013 the human sources percentages decreased to 14 percent in May and 7 percent in August when all tributaries are combined when compared to 2012. This preserves the trend found in 2010 and 2011, when the human sources were reduced significantly from 2009. In ten out of eleven of the Franklin County tributaries (exception is T5, Standiford Creek) we found evidence of human sources in May and in nine of the eleven tributaries in August. Seven of the Franklin County tributaries in May 2013 had human source percentages greater than 10 percent; however, in August 2013, only three tributaries had greater than 10 percent of the isolates from human sources. All eleven of the Franklin County tributaries had greater than 10 percent of the isolates from livestock sources in May and ten of the eleven tributaries had greater than 10 percent isolates from livestock sources in August 2013. The variability of the sources is demonstrated by the fact that a tributary with 46 percent human sources predicted in May had 0 percent human sources predicted in August (site T19a). The variability is because each sample date is merely a point in time not an average over time. These enterococci could come from leaking septic tanks or drain fields, straight waste pipes, cattle in the lake, runoff across pastures, or leaking animal waste holding ponds.

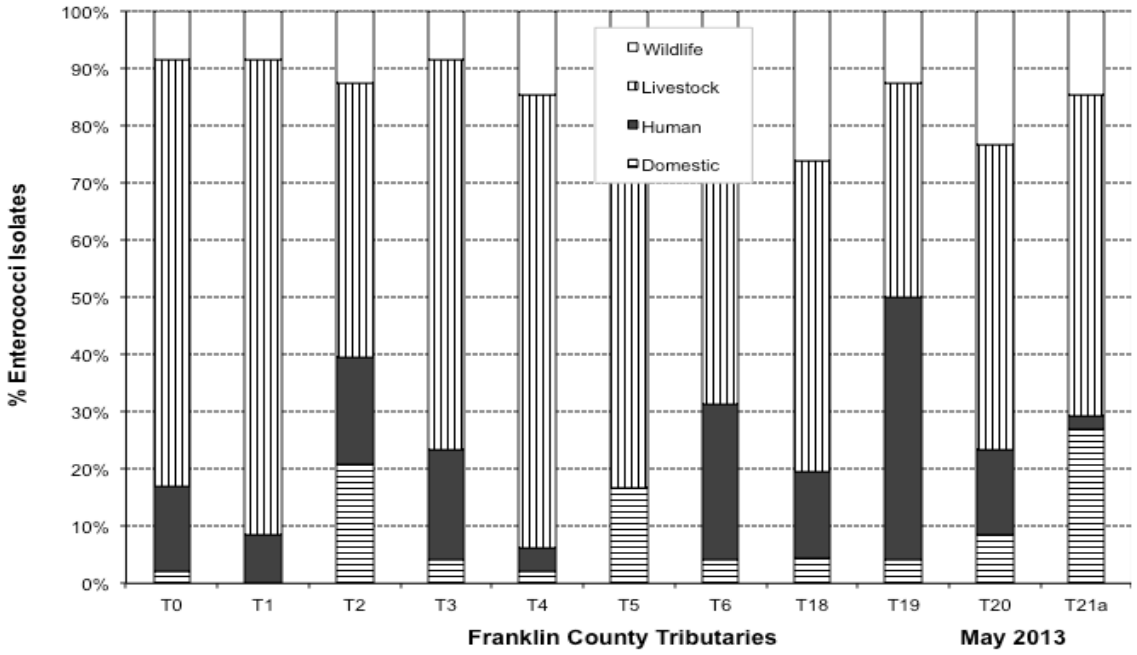


Figure 7.7. Percent of bacterial isolates from 4 sources in Franklin County tributaries in May 2013

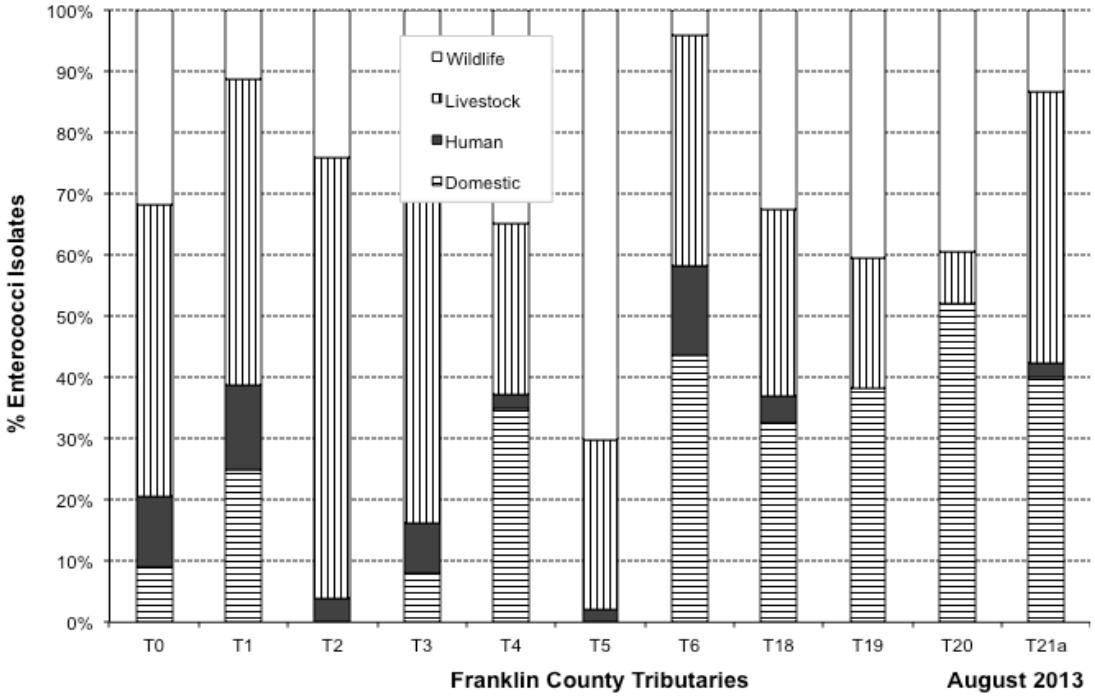


Figure 7.8. Percent of bacterial isolates from 4 sources in Franklin County tributaries in August 2013

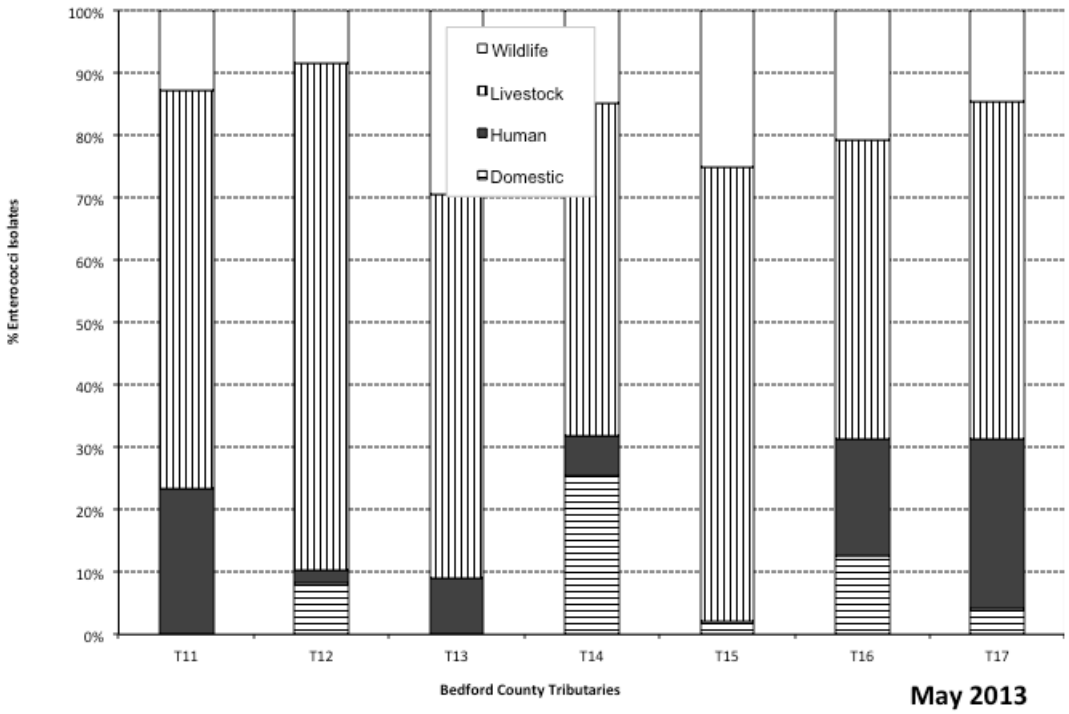


Figure 7.9. Percent of bacterial isolates from 4 sources in Bedford County tributaries in May 2013

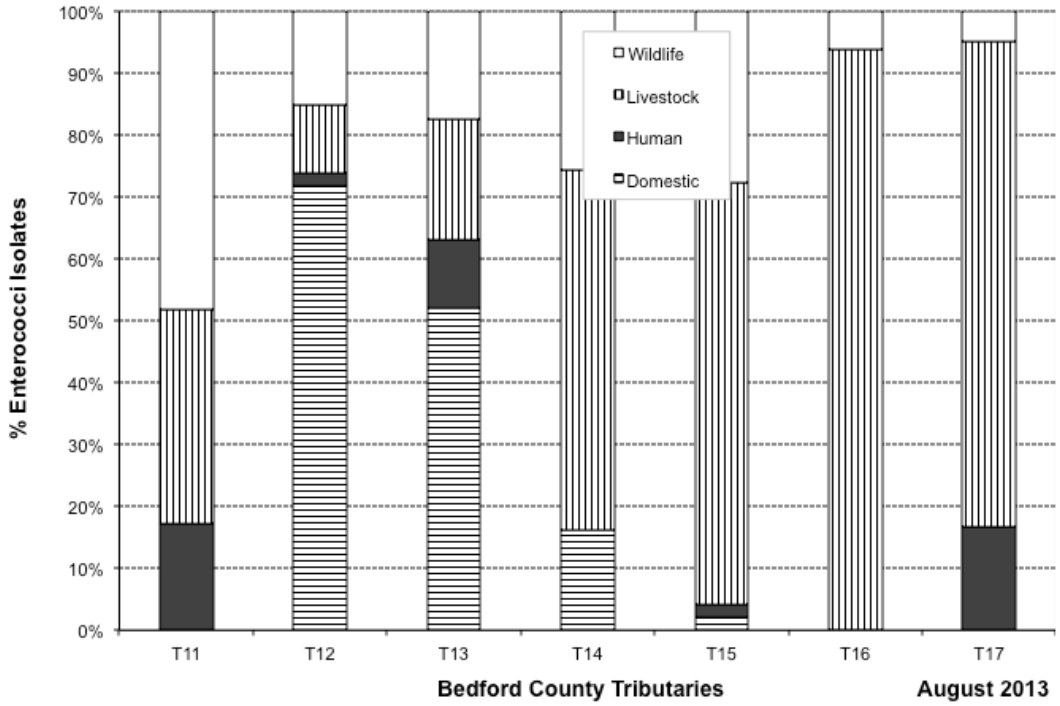


Figure 7.10. Percent of bacterial isolates from 4 sources in Bedford County tributaries in August 2013

Every Bedford County tributary had some isolates coming from human sources and livestock sources in May and August of 2013 except in May at T15 on Jumping Run Creek and in August at T14 on Stoney Creek and T16 on Beaverdam Creek (Figures 7.9 and 7.10). All of the seven of the Bedford County tributaries had greater than 10 percent of isolates from livestock sources in both May and August of 2013.

All samples from Pittsylvania County tributaries had some isolates coming from human sources and livestock sources in May and August of 2013 (Figures 7.12 and 7.13). Two of four tributaries in May and three of the four tributaries in August had human sources predicted in greater than 10 percent of the isolates.

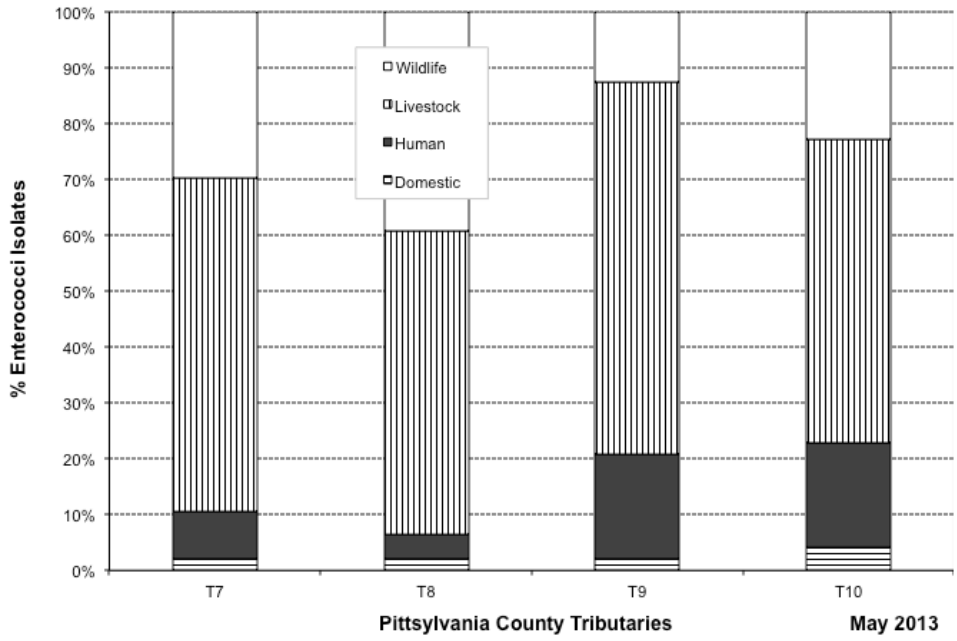


Figure 7.11. Percent of bacterial isolates from 4 sources in Pittsylvania County in May 2013

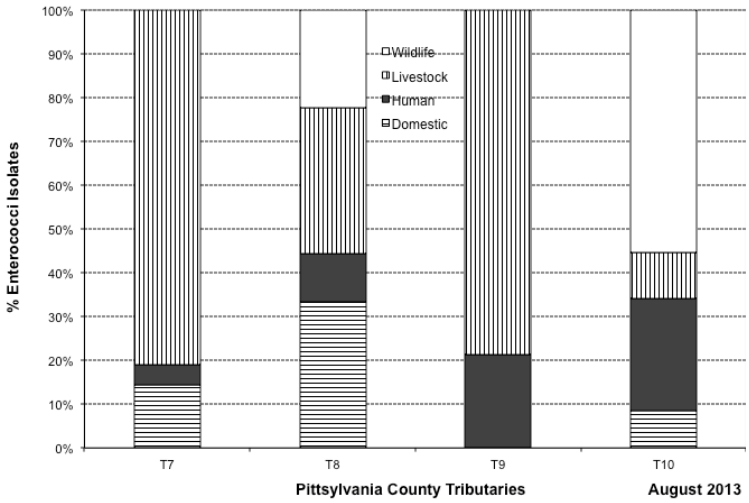


Figure 7.12. Percent of bacterial isolates from 4 sources in Pittsylvania County in August 2013

7.7 Bacterial Source Tracking Discussion

The isolates from human sources are of concern and should be investigated further as to the probable origins. Humans can carry disease-causing organisms in their intestines, and these isolates of enterococci (from human sources) indicate a potential health risk. The livestock source is probably cattle because of their prevalence in the Smith Mountain Lake watershed. Cattle are known to carry a toxic *E. coli* species (0157:H7) in their intestines, another health risk to humans using the water as drinking water or for recreational purposes. In May 2013 the wildlife predictions decreased below the previous four years' May predictions to 18 percent of isolates. The August predictions increased to 26 percent of isolates from 24 percent in 2012. The wildlife percentages increased slightly during the summer (as in previous years) and are problematic since no solution is readily available; however, wildlife is not known to carry human pathogenic organisms or to pose much of a health risk. When all tributaries are considered, the human and livestock source isolates account for 75 percent of the isolates in May 2013 and 50 percent in August 2013 (Figures 7.13 and 7.14). The concern is that when considering all tributaries the livestock source percentages are higher in May 2013 than in May 2012.

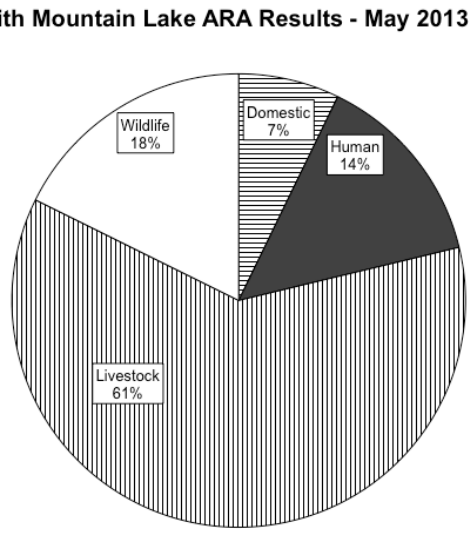


Figure 7.13. Percent of bacterial isolates from four potential sources for all sample sites in May 2013

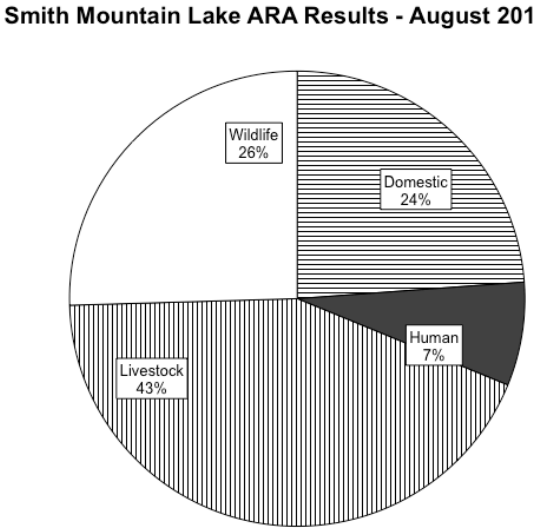


Figure 7.14. Percent of bacterial isolates from four potential sources for all sample sites in August 2013

7.8 Bacterial Source Tracking Results

The bacterial source tracking in 2013, as in 2012, is not showing an improvement in the human sources predicted in May or August in all three counties. The livestock source predictions also do not indicate any decrease. As more of the TMDL implementation plans are put into practice, the livestock sources should decrease over time so we will continue to monitor these bacterial sources.

8. WATER QUALITY TRENDS BY ZONE

8.1 Introduction

After monitoring water quality in Smith Mountain Lake for twenty-seven years it is clear that the lake cannot be described as if it is a homogeneous water body. There is a gradation in trophic status from the headwaters of the lake to the dam. This characteristic is typical of reservoirs and distinguishes them from most natural lakes that tend to be more homogeneous. Dr. William Walker has spent many years studying southern reservoirs for the Army Corps of Engineers and found that a generalized eutrophication model for reservoirs must be able to handle morphologically distinct sections that develop a distinct water quality (Walker, 1999). To give a more accurate representation, Smith Mountain Lake is described by zones delineated by distance to the dam. The need to evaluate water quality by zone indicates the potential for managing Smith Mountain Lake for multiple uses. For example, the more productive (i.e. greater algae growth) upper zones can support the large fish population desired by fishermen, while the less productive, clearer water found in the lower zones is ideal for water recreation and as a source of potable water.

8.2 Methods

The trophic status of a lake indicates the degree of nutrient enrichment and the resulting suitability of that lake for various uses. The process of eutrophication is nutrient enrichment of a body of water resulting in a significant increase in aquatic plant life (including algae). Phosphorus is most often the nutrient that limits algal production when concentration is low and attempts have been made to relate the trophic status of a lake to concentration of phosphorus. In other words, the concentration of phosphorus controls the algal population. Table 8.1 shows one such effort (note that the relationships shown are for northern temperate lakes and will not represent southeastern lakes as well).

Table 8.1. Proposed relationships among phosphorus concentration, trophic state, and lake use for northern temperate lakes (Reckhow and Chapra, 1983)

Phosphorus Concentration (ppb)	Trophic State	Lake Use

< 10	Oligotrophic	Suitable for water-based recreation and cold water fisheries. Very high water clarity and aesthetically pleasing.
10-20	Mesotrophic	Suitable for recreation, often not for cold water fisheries. Clarity less than in oligotrophic lakes.
20-50	Eutrophic	Reduction in aesthetic properties reduces enjoyment from body contact recreation. Generally productive for warm water fish.
> 50	Hypereutrophic	A typical "old-aged" lake in advanced succession. Some fisheries, but high levels of sedimentation and algae or macrophyte growth diminish open water surface area.

The algal growth resulting from inputs of phosphorus can also be used to evaluate the trophic status of a lake. This is done by extracting the green pigment, chlorophyll-*a*, from algae filtered from lake water samples and measuring its concentration. Table 8.2 shows the trophic status delineation based on the concentration of chlorophyll-*a*. It also shows that the evaluation of trophic status is a matter of professional judgment, not a parameter to be measured exactly.

Trophic status can also be evaluated from Secchi disk measurements since algal growth decreases water clarity. Researchers have also attempted to relate water quality parameters such as conductivity and total organic nitrogen to trophic status. Regardless of how trophic status is evaluated, a particular parameter is used to summarize the water quality in a lake with respect to certain uses. The particular summary term, such as mesotrophic, is assigned to a lake based on a summary statistic, such as the average total phosphorus concentration. Researchers have devised water quality indices based on one or more summary statistics to better communicate water quality information to the general public. Using an index, trophic status can be placed on a scale from 1 to 100, with 1 being the least eutrophic or least nutrient enriched. An index can be derived from any summary statistic by means of a mathematical transformation and provides a way of directly comparing different parameters, measured in different units. For example, without indexing most people would have a hard time comparing the water quality significance of a 14 ppb total phosphorus concentration with a 3.5 meter Secchi depth.

Table 8.2. Trophic status related to chlorophyll-*a* concentration in different studies (Reckhow and Chapra, 1983)

	Chlorophyll-*a* Concentration (ppb)			
Trophic Status	**Sakamoto**	**NAS**	**Dobson**	**EPA-NES**
Oligotrophic	0.3-2.5	0-4	0-4.3	< 7
Mesotrophic	1-15	4-10	4.3-8.8	7-12
Eutrophic	5-140	> 10	> 8.8	> 12

One of the best-known trophic state indices is the Carlson Trophic State Index (TSI) named after the researcher who developed it. This index is used to help interpret the water quality data collected on Smith Mountain Lake. The Carlson TSI may be calculated from total phosphorus concentration (TP), chlorophyll-*a* concentration (CA), or Secchi disk depth (SD). In addition, the index obtained from each of these parameters can be averaged to give a combined TSI. This is important because any of the individual parameters can be misleading in some situations. Secchi disk readings are a misleading indicator of trophic status in lakes with non-algal turbidity caused by soil erosion, such as in the upper river channels and near shore areas of Smith Mountain Lake. Phosphorus will not be a good indicator in lakes where algal growth is not limited by availability of phosphorus (algal growth in Smith Mountain Lake is phosphorus-controlled). Chlorophyll-*a* may be the best indicator during the growing season and the worst at other times.

The following equations are used for the calculation of TSI (TSI-C is the combined trophic state index):

$$TSI\text{-}TP = 14.42 \ln TP + 4.15$$
$$TSI\text{-}CA = 9.81 \ln CA + 30.6$$
$$TSI\text{-}SD = 60 - 14.41 \ln SD$$
$$TSI\text{-}C = [TSI(TP) + TSI(CA) + TSI(SD)]/3$$

The lake zones have been delineated as follows:

Zone 1 = 0-5 miles
Zone 2 = 5-10 miles
Zone 3 = 10-15 miles
Zone 4 = 15-20 miles
Zone 5 = 20-25 miles
Zone 6 = 25 + miles

8.3 Results

The average annual value for each of the three trophic parameters is displayed by zone in the figures that follow; total phosphorus in Figure 8.1, chlorophyll-*a* in Figure 8.2, and Secchi depth in Figure 8.3 (data has been collected in zones 5 and 6 for periods of fourteen to nineteen years). No strong trends are apparent in any of the trophic parameters after twenty- years of monitoring. The low R^2 values are

included to show that no significant trend through the years is indicated. The lack of a measurable trend is not surprising because twenty-seven years is short compared with the life of a natural lake (hundreds of years). On the other hand, there is a highly significant trend toward higher water quality closer to the dam, displayed in Figure 8.4. Settling is the likely mechanism that leads to the improved water quality.

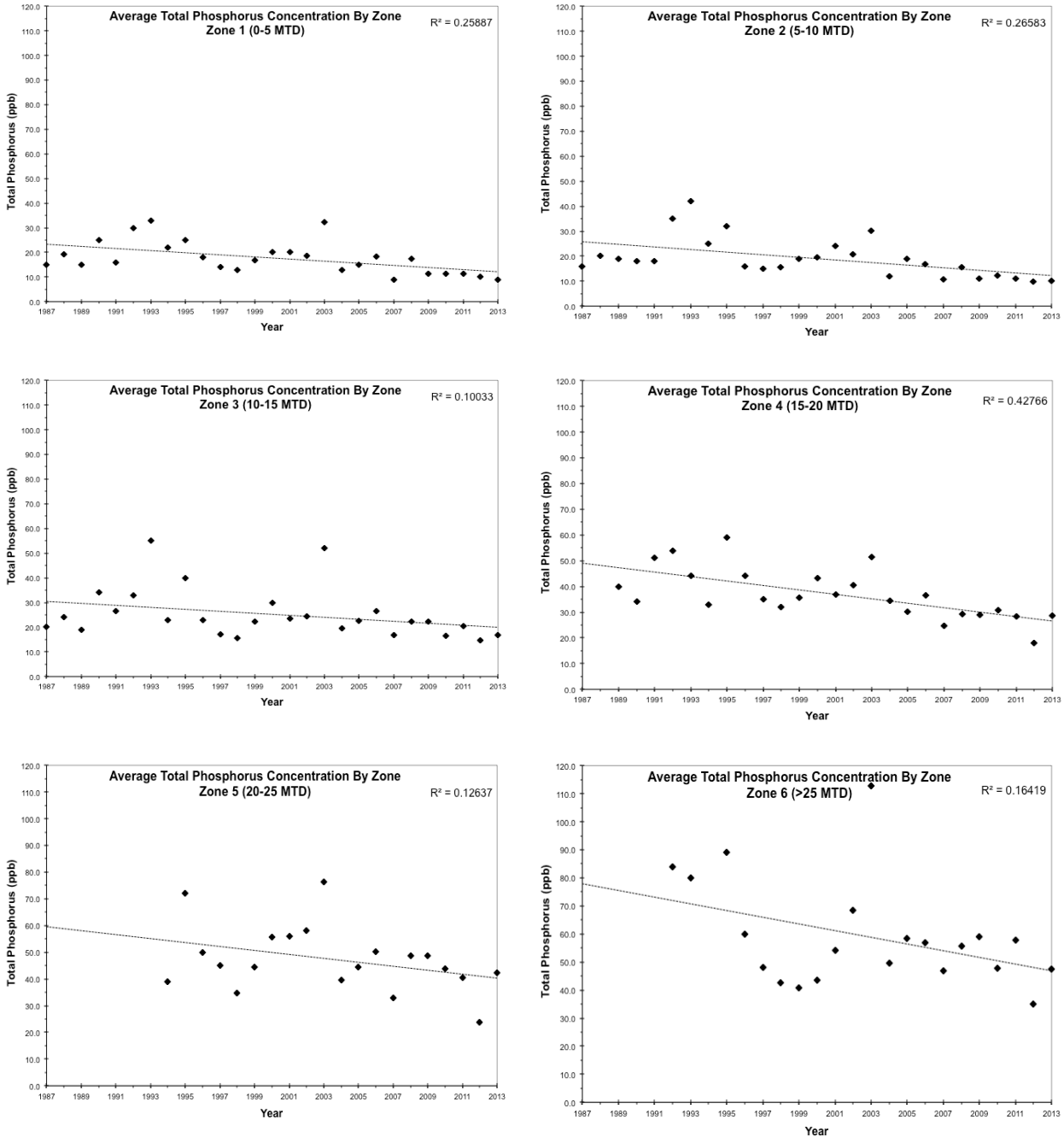


Figure 8.1. Average annual total phosphorus concentration by year and zone in Smith Mountain Lake

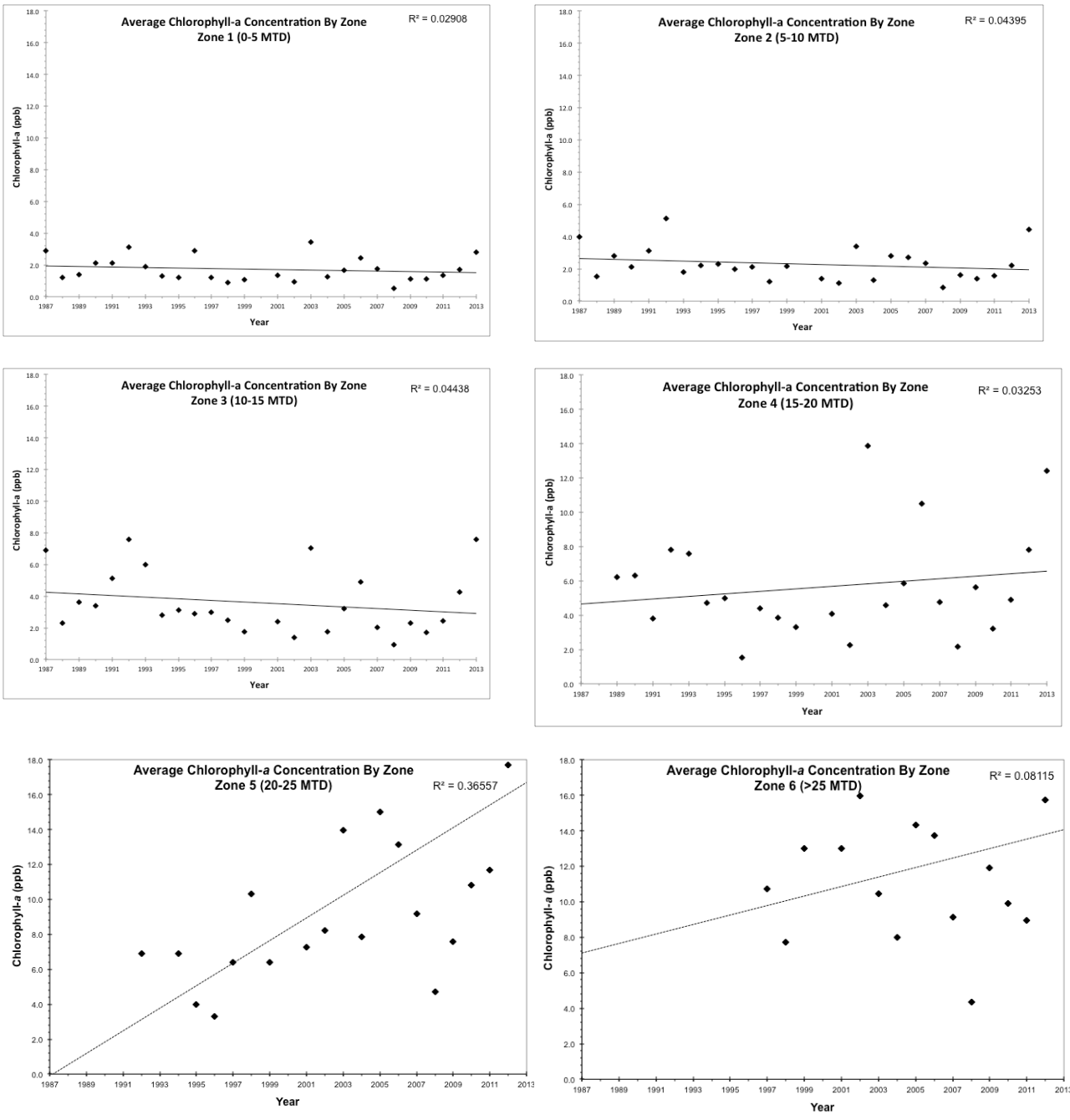


Figure 8.2. Average annual chlorophyll-*a* concentration by year and zone in Smith Mountain Lake

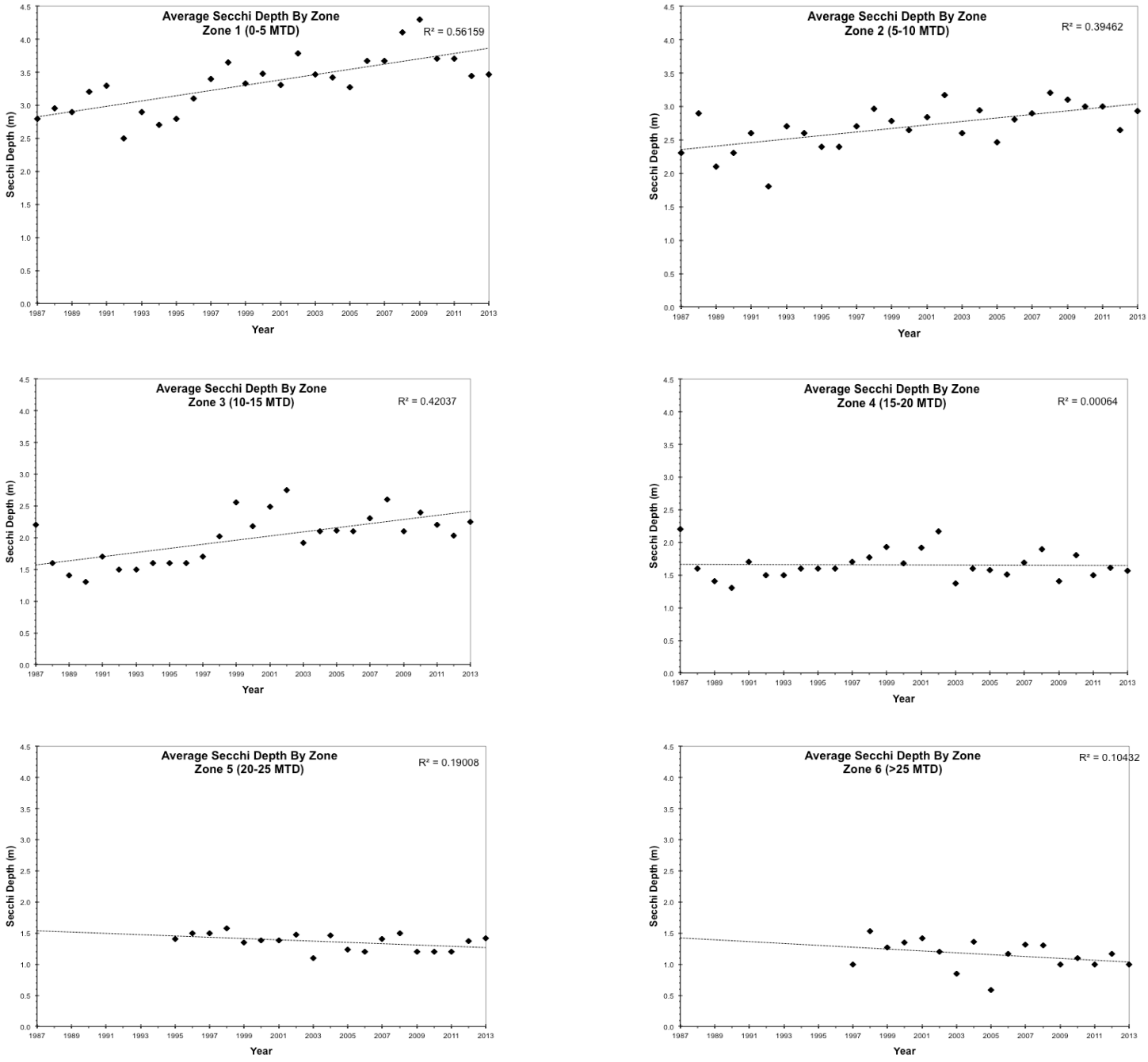


Figure 8.3. Average annual Secchi depth by year and zone in Smith Mountain Lake

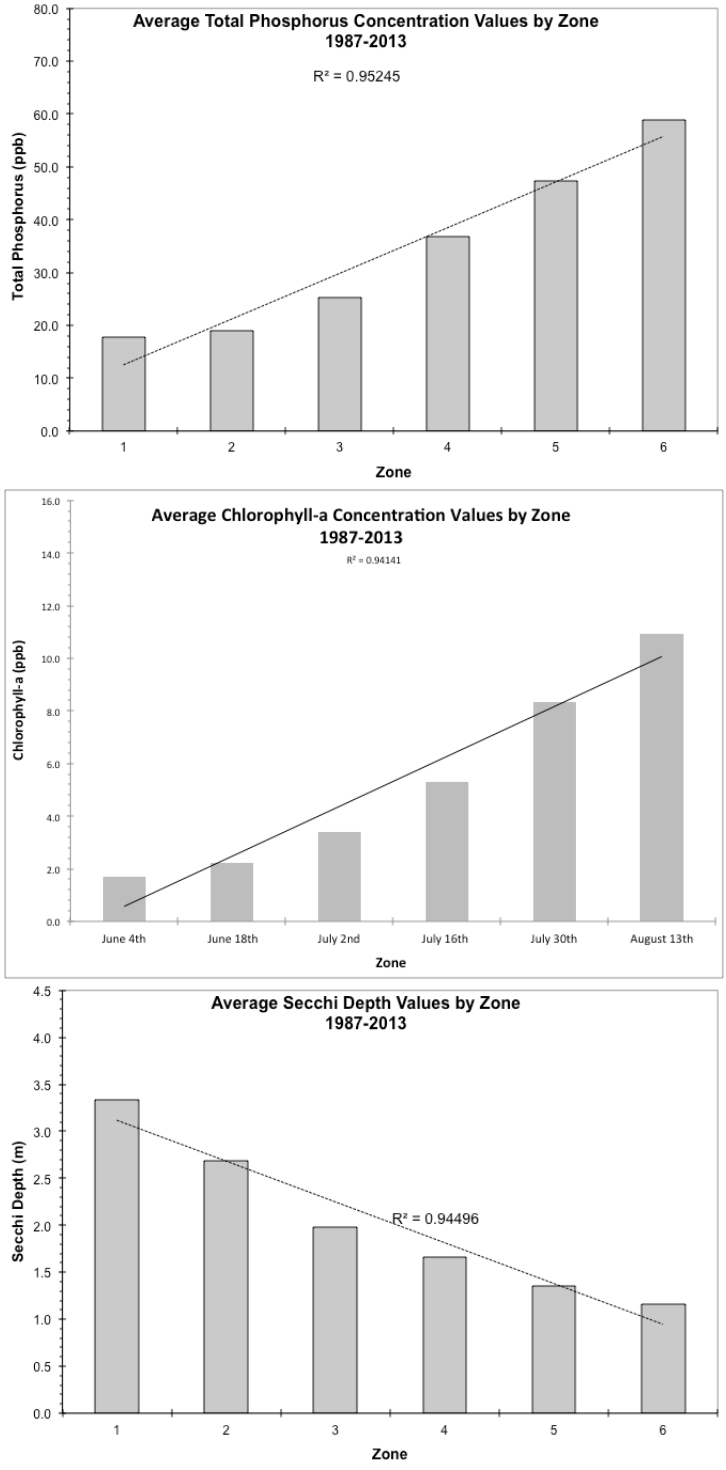


Figure 8.4. Average parameter value by zone for 1987-2013 Carlson's Trophic State Index

8.4 Discussion

In Figure 8.5, the combined trophic state index has been plotted as a function of its distance from the dam. Figure 8.6 shows the spatial distribution of the combined trophic state index throughout the lake. The results again demonstrate the trend toward improved water quality near the dam and the trend is statistically significant.

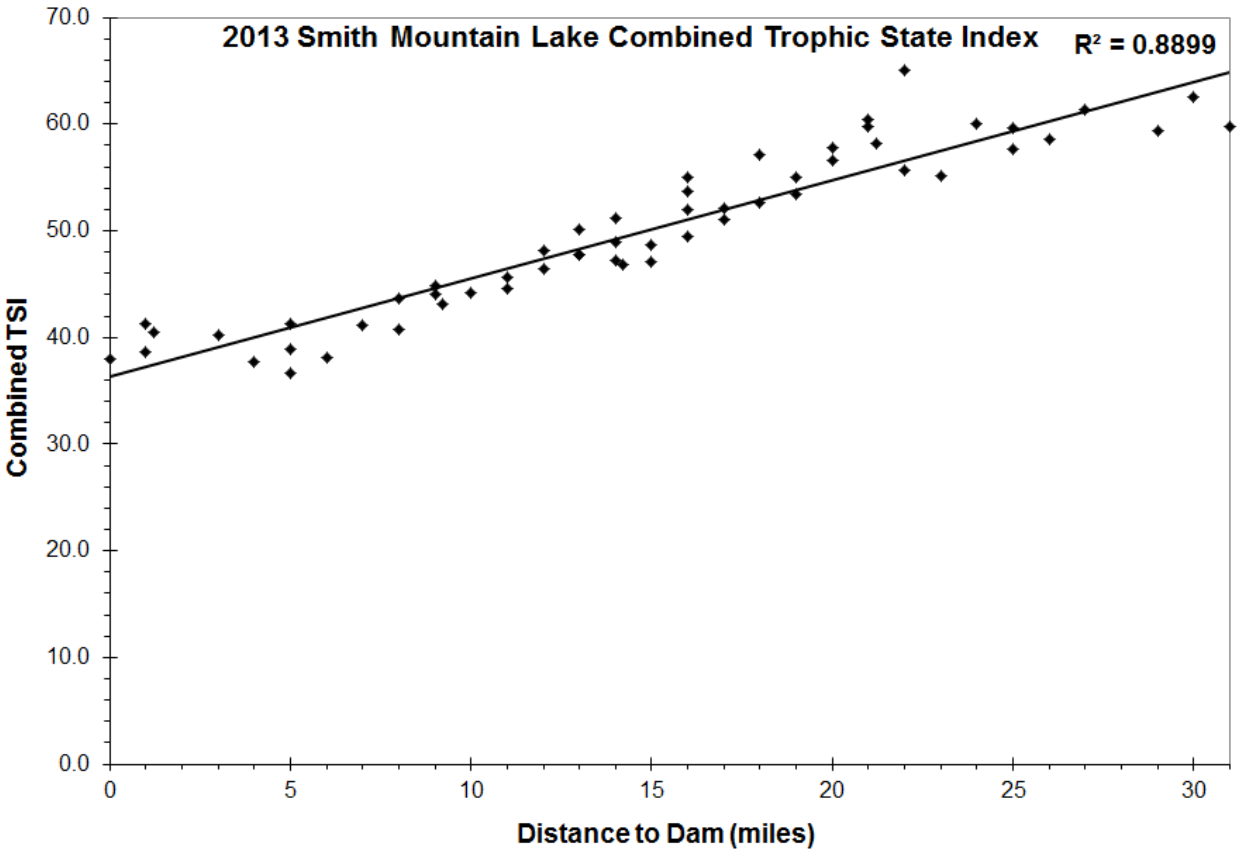


Figure 8.5. Combined Trophic State Index as a function of distance from dam

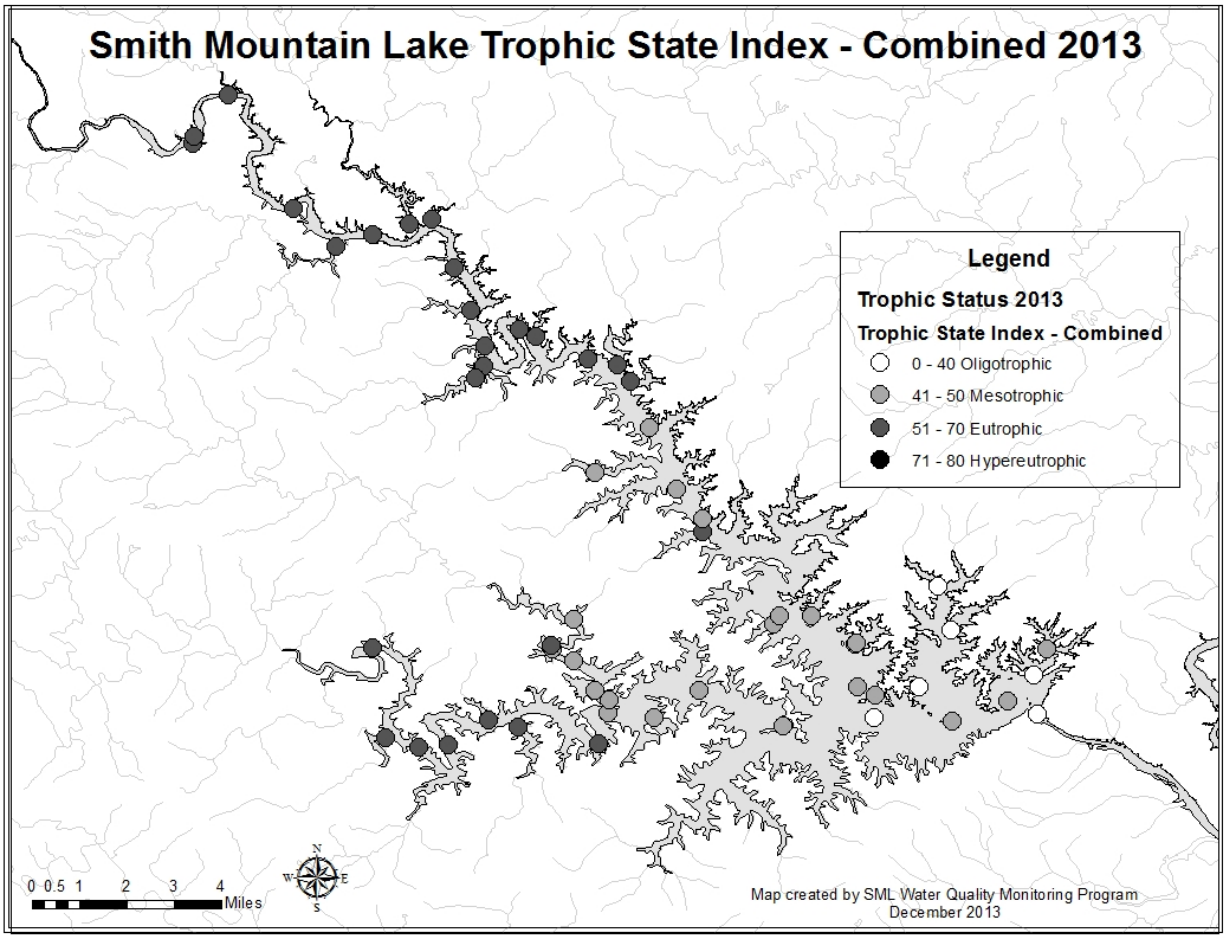


Figure 8.6. Map showing the Combined Trophic State Index results throughout the lake

Table 8.3 gives the monitoring stations ordered according to the combined TSI. For each station, especially those with high TSI-C values, it is useful to look at the TSI calculated on the basis of each trophic parameter to examine the contribution of each. The highest TSI-C value (62.7) was at Station B22 this year, while the lowest TSI-C value (34.4) was at Station CM1.2.

For Smith Mountain Lake in 2012, the average TSI-CA (46.0) is slightly lower than the TSI-TP (46.5), which is lower than the average TSI-SD (50.9). The higher value for TSI-SD compared to TSI-CA is easily explained because silt carried into the lake from the tributaries adds a non-algal component to turbidity. The average combined TSI (TSI-C = 46.5) was lower in 2012 than in 2011 (TSI-C = 56.6).

Table 8.3. Monitoring stations arranged in order of Combined Trophic State Index

Station	DTD (mi)	TP (ppb)	CA (ppb)	SD (m)	TSI-TP	TSI-CA	TSI-SD	TSI-Comb
C5	5	5.5	2.8	3.8	28.6	40.8	40.6	36.7
C4	4	8.4	2.2	4.0	34.8	38.3	40.2	37.8
M0	0	7.1	2.5	3.5	32.4	39.5	41.9	38.0
C6	6	6.3	2.8	3.3	30.7	40.7	43.0	38.1
CM1	1	7.2	2.8	3.3	32.7	40.5	42.8	38.7
M5	5	6.9	3.1	3.3	32.0	41.8	43.0	38.9
M3	3	11.3	2.6	3.6	39.2	40.1	41.6	40.3
CM1.2	1.2	10.5	2.7	3.3	38.0	40.5	43.0	40.5
CR8	8	7.3	4.3	2.9	32.8	44.9	44.6	40.8
R7	7	8.4	4.4	3.2	34.9	45.1	43.4	41.1
CM5	5	10.2	3.4	3.1	37.7	42.7	43.6	41.3
M1	1	11.9	3.2	3.5	39.9	42.0	42.1	41.3
CR9.2	9.2	7.5	5.3	2.1	33.2	46.9	49.1	43.1
B8	8	16.2	4.0	3.4	44.3	44.1	42.5	43.6
CR9	9	12.0	3.9	2.3	39.9	44.0	48.3	44.1
B10	10	12.5	5.4	2.9	40.6	47.1	44.8	44.2
CB11	11	10.8	5.4	2.3	38.4	47.1	48.3	44.6
R9	9	11.0	5.3	2.2	38.8	47.0	48.6	44.8
R11	11	12.2	7.2	2.5	40.3	49.9	46.6	45.6
B12	12	14.3	5.7	2.1	42.5	47.6	49.4	46.5
CR14.2	14.2	12.7	7.3	2.0	40.8	50.1	49.7	46.9
G15	15	13.7	7.2	2.1	41.9	50.0	49.4	47.1
G14	14	16.3	5.6	2.0	44.4	47.5	49.7	47.2
R13	13	19.9	6.7	2.5	47.3	49.2	46.8	47.8
G13	13	17.7	7.7	2.5	45.6	50.7	47.0	47.8
G12	12	17.5	7.5	2.2	45.4	50.4	48.9	48.2
R15	15	15.2	11.0	2.2	43.4	54.1	48.6	48.7
R14	14	17.1	9.9	2.2	45.0	53.1	48.9	49.0
G16	16	20.3	6.9	1.8	47.5	49.6	51.3	49.5
CR13	13	26.7	9.0	2.5	51.5	52.2	46.6	50.1
CR17	17	21.0	11.6	2.0	48.0	54.7	50.3	51.0
B14	14	23.3	7.7	1.6	49.6	50.6	53.4	51.2
CB16	16	18.4	9.3	1.2	46.2	52.4	57.3	52.0
R17	17	21.3	13.1	1.7	48.2	55.8	52.3	52.1
G18	18	24.3	10.6	1.5	50.2	53.7	54.2	52.7
R19	19	23.0	16.5	1.6	49.3	58.1	53.0	53.5
B16	16	22.6	10.7	1.1	49.1	53.9	58.3	53.8
CR16	16	55.3	10.1	2.0	62.0	53.3	49.7	55.0
CR19	19	26.6	17.7	1.4	51.5	58.8	55.0	55.1
R23	23	30.5	13.9	1.4	53.4	56.4	55.4	55.1
CR22	22	34.2	13.3	1.3	55.1	56.0	55.9	55.6
B20	20	35.5	11.1	1.0	55.6	54.2	60.0	56.6
B18	18	42.1	9.6	1.0	58.1	52.8	60.6	57.2
CR25	25	33.8	24.0	1.3	54.9	61.8	56.3	57.7
CB20	20	32.9	21.4	1.1	54.5	60.6	58.3	57.8
CR21.2	21.2	36.7	38.6	1.8	56.1	66.4	51.9	58.2
CR26	26	46.7	18.8	1.3	59.6	59.4	56.8	58.6
R29	29	38.8	32.8	1.3	56.9	64.8	56.2	59.3
R25	25	37.6	39.3	1.3	56.5	66.6	55.9	59.6
CR21	21	42.5	52.2	1.8	58.2	69.4	51.6	59.7
R31	31	49.8	10.9	0.7	60.5	54.0	65.0	59.8
CR24	24	41.8	39.7	1.4	58.0	66.7	55.4	60.0
R21	21	41.2	62.9	1.7	57.8	71.2	52.3	60.4
R27	27	47.8	36.2	1.1	59.9	65.8	58.3	61.3
R30	30	54.4	27.8	0.8	61.8	63.2	62.6	62.5
B22	22	82.5	27.8	0.8	67.8	63.2	64.1	65.1
Average	**14.7**	**23.9**	**13.3**	**2.2**	**46.8**	**52.2**	**50.6**	**49.9**

The annual average TSIs from 2004–2013 are shown in Table 8.4. In 2013 the average combined TSI was below 50 (49.9), indicating that, on average, the lake is in the early stages of eutrophic conditions. The TSI did increase from the 2012 value of 46.4. Similar to 2012, all three trophic

status indicators (total phosphorus, chlorophyll-*a*, and Secchi depth) are fairly similar in value and consistent with beginning stages of eutrophication. All parts of the lake further than 17 miles from the dam are eutrophic.

Table 8.4. Combined Trophic State Index summary for 2004-2013

Year	Avg Combined TSI	TSI Range	R^2 (TSI vs. MTD)
2004	46.4	36.4 – 58.4	0.847
2005	48.9	38.3 – 63.8	0.877
2006	50.3	38.2 – 62.9	0.855
2007	45.9	34.9 – 58.4	0.867
2008	44.2	31.4 – 58.7	0.823
2009	47.0	31.8 – 60.5	0.900
2010	45.5	34.2 – 62.0	0.824
2011	56.6	35.1 – 62.2	0.889
2012	46.5	34.4 – 62.7	0.889
2013	49.9	36.7 – 65.1	0.890

The combined trophic state index, averaged by zone from 1987 to 2013, is displayed in Figure 8.7. The value of the correlation coefficient (R^2 = 0.9941), based on thousands of individual measurements, increased slightly from the 2012 value and has a very high statistical significance.

For the period of record (1987-2013) over 99 percent of the variation in trophic status is explained by proximity of the sample sites to the upper channels of the lake where inputs of nutrients and silt are received from the lake's watershed. In terms of explaining water quality, there is very little left to be accounted for by direct inputs from the shoreline and the many smaller tributaries that flow directly into Smith Mountain Lake. Local impacts are discernible in the trend line displayed in Figure 8.5 by those stations that deviate from the trend line. Lake-friendly and lake-unfriendly conditions can be discovered and described by investigating shoreline land use near those stations that don't follow the anticipated trend. The monitoring program can then begin acting more as a "watchdog" as areas of unusually low water quality are investigated.

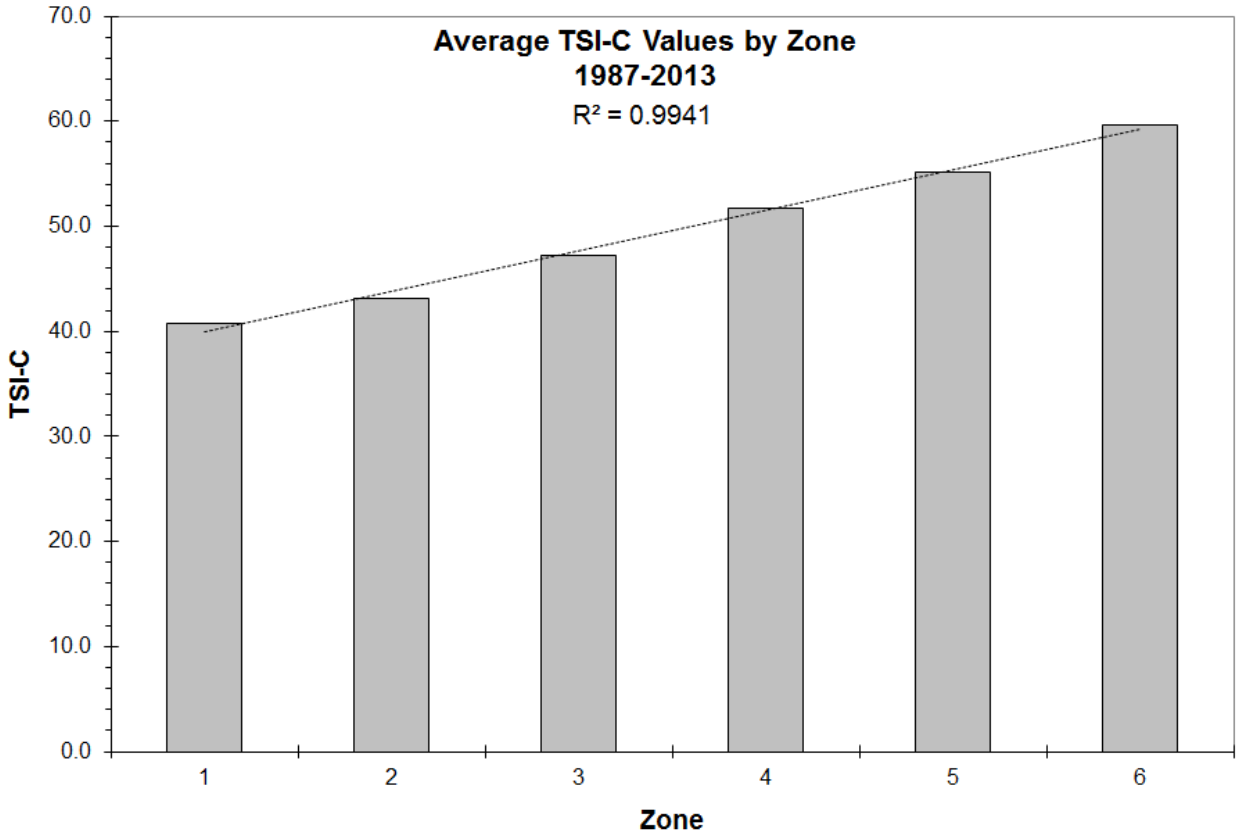


Figure 8.7. Combined Trophic Index by zone from 1987 – 2013

8.5 Conclusions

At the present time, water quality in Smith Mountain Lake is much more dependent on silt and nutrient inputs from the 1000 square-mile watershed than from the 500 mile shoreline. However, Virginia's Total Maximum Daily Load (TMDL) Program is addressing water quality problems in the impaired streams of the Smith Mountain Lake watershed and nonpoint source pollution is being reduced. It will be interesting to see how much the continued development of the land around the lake, coupled with the reduced inputs from its watershed, will alter the relative contributions to the trophic status of Smith Mountain Lake.

9. QUALITY ASSURANCE/QUALITY CONTROL

The full QA/QC plan for the monitoring program is described in detail in the QA/QC Manual for the Smith Mountain Lake Volunteer Monitoring Program. This manual has been updated in 2013 with input from James Beckley, water quality data liaison for DEQ's Citizen Water Quality Monitoring Program. Also, QA procedures are included as part of each analysis method.

9.1 Calibration Data for Total Phosphorus

Every time samples are analyzed, a set of standards is prepared so that a calibration curve can be constructed to determine the relationship between total phosphorus concentration in a sample and its absorption of light at 880 nm. The concentrations of the standards used are as follows: 0 ppb, 10 ppb, 20 ppb, 40 ppb, 80 ppb, and 160 ppb. The calibration curve is constructed using the readings from standards run at the beginning and end of the analysis. Table 9.1 summarizes the calibration data for 2013. The slope indicates the relationship between concentration and absorption and was consistent from analysis to analysis. This gives us confidence that the instrument was stable and that the standards were prepared in a consistent manner. The intercept is the absorbance of the reagent blank (0 ppb) and indicates the extent to which the standards are contaminated with phosphorus during the analytical process. This background is subtracted from each sample to compensate, and the contamination is due almost entirely to sample digestion. During digestion, reagents are added which contain small amounts of phosphorus, leading to some inevitable increase in total phosphorus concentration. The correlation coefficient (R^2) is a measure of how well the calibration line fits the data points with values ranging from 0 (no fit) to 1 (perfect fit).

Table 9.1. Summary of 2013 calibration data for total phosphorus

Analysis Date	Slope	Intercept	R^2
6/27 (WK 1)	0.0199	0.0542	0.9989
7/30 (WK 2)	0.0192	0.0751	0.9966
7/10 (WK 3)	0.0158	-0.0659	0.9944
8/2 (WK 4)	0.0204	-0.0207	0.9914
8/20 (WK 5)	0.0186	0.0113	0.9812
8/15 (WK 6)	0.0221	0.0022	0.9734
Average	**0.0193**	**0.0094**	**0.9893**
Standard Deviation	**0.0021**	**0.0509**	**0.0099**

9.1.1 Summary of Calibration Data

With a value close to 0.99, the average correlation coefficient indicates excellent precision and shows both the care with which the standards were prepared and the stability of the instrument and reagents.

9.2 Comparison of Standards over the Course of Analysis for Total Phosphorus

In past years, the procedure for measuring total phosphorus involved the formation of a blue dye which faded over time. One of the advantages of using flow injection analysis is that the reagents are mixed and the blue dye is formed in real time, during the course of an individual measurement. This means there is no longer any concern that the dye will fade during the time required for analysis. To assure that no changes in detector sensitivity occurred during the analysis, the concentration of two of the standards were periodically checked, as has been done in previous years.

In 2013, the 40 and 80 ppb standards were run periodically during the analysis for a total of eight readings of each of those two standards (n=8). The readings obtained were compared to 40 and 80 ppb respectively, and average relative percent differences (RPD) were calculated. These are reported, along with maximum and minimum relative percent differences, in Table 9.2.

Table 9.2. Comparison of 40 and 80 ppb standards over the course of analysis for 2013

Analysis Date	Avg. RPD 40ppb std. (%)	Max. RPD 40ppb std. (%)	Min. RPD 40ppb std. (%)	Avg. RPD 80ppb std. (%)	Max. RPD 80ppb std. (%)	Min. RPD 80ppb std. (%)
6/27 (WK 1)	5.5	9.0	1.5	4.8	6.9	1.0
7/30 (WK 2)	12.6	15.9	0.1	7.6	9.6	1.4
7/10 (WK 3)	17.5	20.4	14.6	8.8	10.7	7.2
8/2 (WK 4)	25.0	27.2	22.8	15.5	16.7	13.8
8/20 (WK 5)	30.5	49.7	21.4	24.0	42.7	19.9
8/15 (WK 6)	22.3	24.4	20.6	18.5	19.9	16.5
Overall Averages	**18.9**			**13.2**		

9.2.1 Summary of Precision of Analysis over Analysis Time

The precision of analysis for the 40 and 80 ppb standards over the course of the entire analysis was fair for the 40 ppb standard with an average of 18.9 percent and slightly better for the 80 ppb

standard with an average of 13.2 percent. The target value for RPD is 0 percent and less than 10 percent is considered very good.

9.3 Blanks and Spiked Blanks for Total Phosphorus

In 2013, one blank (distilled water) and two spiked blanks (5.0 ml distilled water spiked with 0.1 ml of 2 ppm phosphate standard to give a final concentration of 39 ppb) were run with each analysis of samples. The results are shown in Table 9.3.

Table 9.3. Average recovery of total phosphorus for 2013 lab blanks and average percent recovery for spiked blanks

Analysis Date	Blanks - average recovery (ppb)	Spiked blanks - average % recovery
6/27 (WK 1)	1.2	32.1
7/30 (WK 2)	2.3	87.6
7/10 (WK 3)	5.4	86.2
8/2 (WK 4)	5.8	79.0
8/20 (WK 5)	3.4	84.9
8/15 (WK 6)	0.1	80.7
AVERAGES	**3.0**	**75.1**

9.3.1 Summary of Blank and Spiked Blank Analysis

The average for lab blanks is excellent for all sample periods (target value is 0 ppb). The overall average of 3.0 ppb is excellent and shows stability of the instrument and little carry-over contamination from previous samples. The overall average percent recovery for the spiked blanks for all analyses is low at 75.1 percent (target value is 100 percent). This is somewhat due to the very low value in the week 1 analysis (32.1 percent recovery), but is still low even without that week included in the average. The percent recoveries of the spiked blanks were low, but not alarmingly so. This is most likely due to the newness of the analysis technique and should improve as the analysis becomes routine.

9.4 Duplicate and Spiked Sample Analysis for Total Phosphorus

During every analysis, five samples were divided and run as duplicates. Five additional samples were divided and one of the aliquots was spiked by the addition of a very small quantity of total phosphorus standard solution (0.1 ml of 2 ppm solution in 5.0 ml sample) to give a known final

added concentration. The duplicate samples were compared to their initial analyzed values and relative percent differences (RPD) were calculated. The results are reported in Table 9.4. The spiked samples were compared to their initial analyzed concentrations plus the value of the added phosphorus, and percent recovery was calculated. The results are also reported in Table 9.4.

Table 9.4. Results of analysis of 2013 duplicates and spikes for total phosphorus

	REPLICATES			SPIKES		
Analysis Date	**Average RPD**	**Maximum RPD**	**Minimum RPD**	**Average % Recovery**	**Maximum % Recovery**	**Minimum % Recovery**
6/27 (WK1)	6.3	15.1	1.9	49.8	116.6	21.6
7/30 (WK 2)	8.6	13.3	3.7	34.0	62.2	22.3
7/10 (WK 3)	14.9	14.9*	14.9*	97.2	112.2	61.2
8/2 (WK 4)	16.1	41.2	1.6	101.4	102.8	100.4
8/20 (WK 5)	10.9	40.1	0.0	89.1	123.1	72.2
8/15 (WK 6)	10.9	19.6	2.4	92.8	96.4	90.4
Overall Avg.	**11.3**			**77.4**		

9.4.1 Summary of Duplicate and Spiked Samples

The precision of duplicate analysis was good this year at 11.3 average relative percent difference (target value is 0 percent) but low for spiked samples with 77.4 average percent recovery (target value is 100 percent). The percent recoveries of the spiked blanks were low, but not alarmingly so. This is most likely due to the newness of the analysis technique and should improve as the analysis becomes routine.

9.5 Analysis of Purchased Standard

Each time samples were analyzed, a certified standard purchased from Environmental Resource Associates (ERA) was also analyzed. These results are reported in Table 9.5.

Table 9.5. Results of analysis of purchased standard for 2013

Analysis Date	Analyzed conc.(ppb)	ERA conc.(ppb)	Average (ppb)	Difference (ppb)	RPD
6/27 (WK 1)	72.2	78.3	75.3	6.1	8.1
7/30 (WK 2)	68.5	78.3	73.4	9.8	13.4
7/10 (WK 3)	74.4	78.3	76.4	3.9	5.1

8/2 (WK 4)	66.2	78.3	72.3	12.1	16.7
8/20 (WK 5)	80.5	78.3	79.4	2.2	2.8
8/15 (WK 6)	68.2	78.3	73.3	10.1	13.8
Averages					**10.0**

9.5.1 Summary of Analysis of Purchased Standard

The results of the analysis of the purchased standard were good with average relative percent difference (RPD) of 10.0 percent (target value is 0 percent).

9.6 QA/QC for Chlorophyll-a

At the beginning of every sampling season, the fluorometer is calibrated using a standard purchased from Turner Designs (Sunnyvale, CA) and secondary solid standards (supplied with the instrument) are checked. Before every sample analysis, the instrument is calibrated to the values established for these solid standards. These standards, along with a reagent blank (buffered acetone) are read periodically throughout the sample analysis. A method blank (glass fiber filter) is also analyzed each time samples are run. No duplicate filters were analyzed this year.

9.7 QA/QC for Secchi Disk Depth

The training received by the volunteer monitors, the simplicity of the technique, and the fact that Secchi depth is recorded to the nearest quarter meter gives inherent reliability to this measurement.

9.8 QA/QC for E. coli

Sterile distilled water is run with each set of lake samples analyzed for *E. coli*. In every analysis, the sterile distilled water gave readings of <1.0, which is the lowest MPN (most probable number) that can be obtained. Replicates are run for one site from each sample set. The replicates are obtained by collecting a large duplicate sample at the site at the same time as the original sample. At the lab, this duplicate sample is divided into four replicate samples which are analyzed along with the rest of the samples. Results of the replicate analysis are shown in Table 9.6.

Table 9.6. Results of replicate analysis of *E. coli* samples for 2013

Sampling Date	Replicate Site	MPN *E. coli*	Replicate Avg. (MPN)	Replicate Range (MPN)
5/28	1-1	77.1	89.8	78.9-103.4
6/14	1-2	101.4	131.7	104.3-157.6
6/25	none			
7/9	2-1	4.1	1.5	<1.0-4.4
7/23	3-2	5.2	3.9	3.1-5.2
8/6	1-1	6.2	6.0	5.1-8.5

In addition, a QuantiCult™ kit was processed along with the June 11 and August 6 samples. This kit is made by the manufacturer of the Colilert media and consists of three cultures: *Escherichia coli* (*E. coli*)*, Pseudomonas aeruginosa,* and *Klebsiella pneumoniae.* The cultures are rehydrated according to the kit directions and analyzed. *E. coli* should give a positive reading for color change as well as fluorescence. *Klebsiella* should give a positive reading for color (coliform test) but none of the wells should fluoresce (since it is not *E. coli*). *Pseudomonas* should give a negative test for color (since it is not a coliform) and none of the wells should fluoresce (since it is not *E. coli*). Additionally, where there is a reading, the MPN obtained should fall within specified limits (1-50 MPN). Results are shown in Table 9.7.

Table 9.7. Results of QuantiCult™ analysis for 2013

Quanti-Cult 6/11/13	MPN total coliforms	MPN *E. coli*
E. coli	14.8	<1.0
K. pneumoniae	18.7	18.7
P. aeruginosa	<1.0	<1.0

Quanti-Cult 8/6/13	MPN total coliforms	MPN *E. coli*
E. coli	13.2	13.2
K. pneumoniae	16.1	<1.0
P. aeruginosa	<1.0	<1.0

An additional QC measure, begun in 2008, was the analysis of a BioBall® (BTF Precise Microbiology Inc.) with every batch of samples analyzed. BioBall® is a small, water soluble ball containing a precise number of microorganisms – product specification for the lot used in

2013 is a mean of 28.9 cfu with a standard deviation of 2.5. An *E. coli* strain was used. The results are displayed in Table 9.8.

Table 9.8. Results of BioBall® analysis for 2013

Sampling Date	BioBall MPN
5/28	23.1
6/11	23.5
6/14	22.8
6/25	27.5
7/9	23.5
7/23	24.1
8/6	28.5
AVG.	24.7

9.8.1 Summary of QA/QC for *E. coli*

The BioBall® results fell below the 95% prediction interval lower limit of 23.7 cfu on four occasions. The overall season average of 24.7 MPN, however, does fall within the 95% prediction interval limits (lower limit is 23.7 cfu and upper limit is 34.0 cfu). The results of the sterile distilled water assure that reagents and supplies are sterile and that the technicians are following good sterile technique when processing samples. The Quanti Cult™ results for the June 11 sampling are not correct and are almost certainly due to technician error. The results for the August 6 sample date are as expected.

10. SAMPLING EFFICIENCY

The monitoring program depends on volunteers for sample collection and one measure of success for the program is the consistency with which these volunteers attend to their stations. Table 10.1 indicates the sampling efficiency data for 2013 and Table 10.2 presents the collection efficiencies from 2001 through 2013. The figures show that the volunteer monitors are very conscientious about sample collection. Volunteer monitor sample efficiency for total phosphorus, total nitrogen and chlorophyll-a samples was 99.7 percent, and 98.8 percent for Secchi readings. The volunteer monitor sampling efficiency is remarkably high for any monitoring program, voluntary or otherwise. The volunteers' sampling efficiency is as good as that of professionals in agencies responsible for environmental sampling. This degree of commitment no doubt carries over to the care with which samples are collected and is evidence of the volunteers' dedication to the program.

Table 10.1. Sampling efficiency data for 2013

Sample Type	Monitoring Stations	Possible Samples	Samples Collected	Percent Efficiency
TP/TN/CA	55	330	329	99.7%
Secchi Depth	84	504	498	98.8%
Profiles	6	30	30	100%
Phytoplankton	14	60	60	100%

Table 10.2. Comparison of sampling efficiencies for 2001-2013

% Efficiencies/ Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Secchi Depth	89	93	99	94	94	93	97	97	97	94	95	92	99
TP/TN	94	98	97	98	98	96	97	99	98	98	98	98	100
CA	98	98	97	98	98	96	97	99	98	98	98	98	100

11. CONCLUSIONS

In general, water quality improves significantly as the water moves from the upper channels toward the dam. This is consistent with observations that have been made since the second year of the monitoring project. Eroded soil is carried to the lake by silt-laden streams, but sedimentation begins in the quiescent lake water. Phosphorus, primarily in the form of phosphate ions, strongly associates with the soil particles and settles out during the sedimentation process. Concentrations of total phosphorus and chlorophyll-*a* and Secchi depth all correlate significantly with distance from the dam. We will continue to monitor total nitrogen to assess its influence on trophic status of Smith Mountain Lake. If results prove significant, results will be reported with other trophic parameters.

In 2013, water quality improved from the upper channels to the dam, as usual. All three trophic parameters increased in 2013. The average total phosphorus concentration increased by just over 50 percent; although the average total phosphorus concentration was slightly lower than the ten-year average. This large increase is most likely due to the very low total phosphorus concentrations observed last year, which were significantly lower than the ten-year average. Chlorophyll-a increased again this year by 77.3 percent. The average chlorophyll-a concentration of 13.3 ppb is the highest average concentration observed in over ten years. The average Secchi depth increased by 9.5 percent in 2013, which is an improvement in water quality.

In 2013 the overall dominant algal population group found in Smith Mountain Lake was the diatom group (Figure 5.9). These algae are indicators of a clean lake. Green and blue-green algae comprised 24 percent and 22 percent of the total algal population.

We must continue to monitor these parameters and compare the algal populations to the corresponding total phosphorus and chlorophyll-*a* levels in order to continue to keep Smith Mountain Lake water quality high and prevent future algal blooms. It is possible that warming trends in the climate, along with earlier spring and longer lasting summer temperatures, may intensify the increasing algal populations resulting in unwanted algal blooms and deterioration of water quality.

Sufficient depth profile data have now been collected to enable meaningful comparison between rates of change and absolute parameter values over the course of the summer. The depleted oxygen at lower depths (hypolimnion), especially in the more nutrient rich upper channels, is of concern because low dissolved oxygen is appearing earlier in the summer. The temperature profiles indicate that the thermocline is moving lower in the water column. Continued study of thermal stratification, using depth profiling, and of algal dynamics will provide the scientific data necessary to effectively manage Smith Mountain Lake as it ages.

The bacteria populations, specifically *E. coli*, in Smith Mountain Lake in 2013 were the highest they have ever been at two of the headwaters sites (since 1995). In 2013 every bacterial sample week had at least one station that had *E. coli* values that exceeded the Virginia Health Department standards except the last sample week (August 6). Two of the sample sites on June 11, July 9 and July 23 (second, fourth and fifth sample weeks) had *E. coli* values that exceeded the Virginia Health Department standard. The comparison of marinas and non-marinas showed a smaller difference in *E. coli* values in 2013, but still showed a higher mean than in 2012 despite of the Smith Mountain Lake Association Boater Education and Pump Out Program, our boaters' and marina owners' vigilance and the implementation of the Total Maximum Daily Load (TMDL) process. This comparison of the marina, non-marina and headwaters sites was completely overshadowed by the high *E. coli* values at two of the headwaters sites.

The bacterial source tracking in 2013 as in 2012 is not showing an improvement in the human isolates predicted in May or August of the enterococci, in all three counties. The livestock source isolates also do not indicate that they are decreasing. As more of the TMDL implementation plans are put into practice, the livestock sources should decrease over time so we will continue to monitor these bacterial sources.

At the present time, water quality in Smith Mountain Lake is much more dependent on silt and nutrient inputs from the 1000 square-mile watershed than from the 500 mile shoreline. However, Virginia's Total Maximum Daily Load (TMDL) Program is addressing water quality problems in the impaired streams of the Smith Mountain Lake watershed and nonpoint source pollution is being reduced. It will be interesting to see how much the continued development of the land

around the lake, coupled with the reduced inputs from its watershed, will alter the relative contributions to the trophic status of Smith Mountain Lake.

With a value close to 0.99, the average correlation coefficient indicates excellent precision and shows both the care with which the standards were prepared and the stability of the instrument and reagents.

The precision of analysis for the 40 and 80 ppb standards over the course of the entire analysis was fair for the 40 ppb standard with an average of 18.9 percent and somewhat better for the 80 ppb standard with an average of 13.2 percent. The target value for RPD is 0 percent and less than 10 percent is considered very good.

The average for lab blanks is excellent for all sample periods (target value is 0 ppb). The overall average of 3.0 ppb is excellent and shows stability of the instrument and little carry-over contamination from previous samples. The overall average percent recovery for the spiked blanks for all analyses is low at 75.1 percent (target value is 100 percent). This is somewhat due to the very low value in the week 1 analysis (32.1 percent recovery), but is still low even without that week included in the average.

The precision of duplicate analysis was good this year at 11.3 average relative percent difference (target value is 0 percent) but low for spiked samples with 77.4 average percent recovery (target value is 100 percent).

The results of the analysis of the purchased standard were good with average relative percent difference (RPD) of 10.0 percent (target value is 0 percent).

The BioBall® results fell below the 95% prediction interval lower limit of 23.7 cfu on four occasions. The overall season average of 24.7 MPN, however, does fall within the 95% prediction interval limits (lower limit is 23.7 cfu and upper limit is 34.0 cfu). The results of the sterile distilled water assure that reagents and supplies are sterile and that the technicians are following good sterile technique when processing samples. The Quanti Cult™ results for the June 11 sampling are not correct and are almost certainly due to technician error. The results for the August 6 sample date are as expected

The volunteer monitor sampling efficiency is remarkably high for any monitoring program, voluntary or otherwise, but slightly higher for Secchi Depth observations in 2013 than in 2012. The volunteers' sampling efficiency is as good as that of professionals in agencies responsible for environmental samples.

12. ACKNOWLEDGEMENTS

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APPENDIX

Table A.1. 2013 Smith Mountain Lake monitoring stations with monitor names and station locations

Station	Monitor	Longitude	Latitude
B8	Scott	-79.62	37.04
B10	Scott	-79.64	37.05
B12	Brinckerhoff	-79.67	37.04
B14	Jamison	-79.67	37.03
B16	Jamison	-79.71	37.04
B18	Mattox / Peach	-79.72	37.03
B20	Mattox / Peach	-79.73	37.03
B22	DeCesare / LeCleir	-79.74	37.06
C4	Hill	-79.57	37.05
C5	Hill	-79.56	37.07
C6	Hill	-79.57	37.08
CB11	Brinckerhoff	-79.66	37.04
CB16	Jamison	-79.70	37.04
CB20	DeCesare / LeCleir	-79.74	37.04
CM1	Rice	-79.54	37.06
CM1.2	Rice	-79.54	37.06
CM5	Anderson / Kelso	-79.59	37.05
CR8	Anderson / Kelso	-79.59	37.06
CR9	Okeson	-79.61	37.07
CR9.2	Okeson	-79.62	37.07
CR13	MacMullan/Marshall/Servidea	-79.64	37.10
CR14.2	Weidenbacher	-79.67	37.12
CR16	McCord	-79.66	37.15
CR17	McCord	-79.67	37.15
CR19	Mocksfield	-79.69	37.16
CR21	Leroy	-79.71	37.15
CR21.2	Leroy	-79.71	37.15
CR22	Cusumano	-79.71	37.17
CR24	Gascoyne/Mauney/Shoudel	-79.72	37.19
CR25	Gascoyne/Mauney/Shoudel	-79.73	37.19
CR26	Reus	-79.75	37.19
G12	Brinckerhoff	-79.67	37.05
G13	Toone	-79.67	37.05
G14	Iceman	-79.68	37.07
G15	Toone	-79.68	37.06
G16	Iceman	-79.69	37.06
G18	Iceman	-79.69	37.06
M0	Rice	-79.54	37.04
M1	Sakayama	-79.55	37.05
M3	Sakayama	-79.56	37.04
M5	Sakayama	-79.59	37.04
R7	Anderson / Kelso	-79.59	37.05
R9	Okeson	-79.62	37.07
R11	Anderson / Kelso	-79.59	37.06
R13	MacMullan/Marshall/Servidea	-79.64	37.10

Table A.1. 2013 SML monitoring stations with monitor names and station locations (cont.)

Station	Monitor	Longitude	Latitude
R14	Weidenbacher	-79.65	37.11
R15	McCord	-79.66	37.13
R17	Mocksfield	-79.68	37.15
R19	Mocksfield	-79.70	37.16
R21	Leroy	-79.71	37.16
R23	Cusumano	-79.72	37.18
R25	Gascoyne/Mauney/Shoudel	-79.74	37.19
R27	Reus	-79.77	37.20
R29	Reus	-79.80	37.22
R30	Ferrum College	-79.79	37.23
R31	Ferrum College	-79.80	37.22
SCB8	Hurt	-79.60	37.02
SCB10	Hurt	-79.64	37.02
SCB11	Hurt	-79.63	37.02
SCB11.5	Hurt	-79.65	37.07
SB12	Taylor / Ralph	-79.66	37.04
SCB14	Taylor / Ralph	-79.68	37.03
SCB16	Taylor / Ralph	-79.69	37.04
SCM5	Over	-79.59	37.05
SCR7	Over	-79.59	37.06
SCR8	Over	-79.59	37.07
SCR10.1	Gore	-79.64	37.08
SCR10.2	Gore	-79.63	37.07
SCR10.3	Gore	-79.63	37.07
SCR11.1	Collins	-79.60	37.11
SCR11.2	Collins	-79.62	37.11
SCR11.3	Collins	-79.63	37.10
SCR14	Noesner	-79.64	37.11
SCR14.1	Noesner	-79.66	37.12
SCR14.2	Noesner	-79.67	37.11
SCR14.3	Noesner	-79.66	37.11
SCR15	Mutchler	-79.65	37.12
SCR15.1	Noesner	-79.65	37.12
SCR15.2	Noesner	-79.67	37.12
SCR17	Mutchler	-79.67	37.16
SCR17.1	Mutchler	-79.68	37.16
SCR18	McNulty	-79.69	37.15
SCR19.2	McNulty	-79.69	37.16
SCR20	McNulty	-79.70	37.16

Figure A.1. Smith Mountain Lake trophic monitoring stations

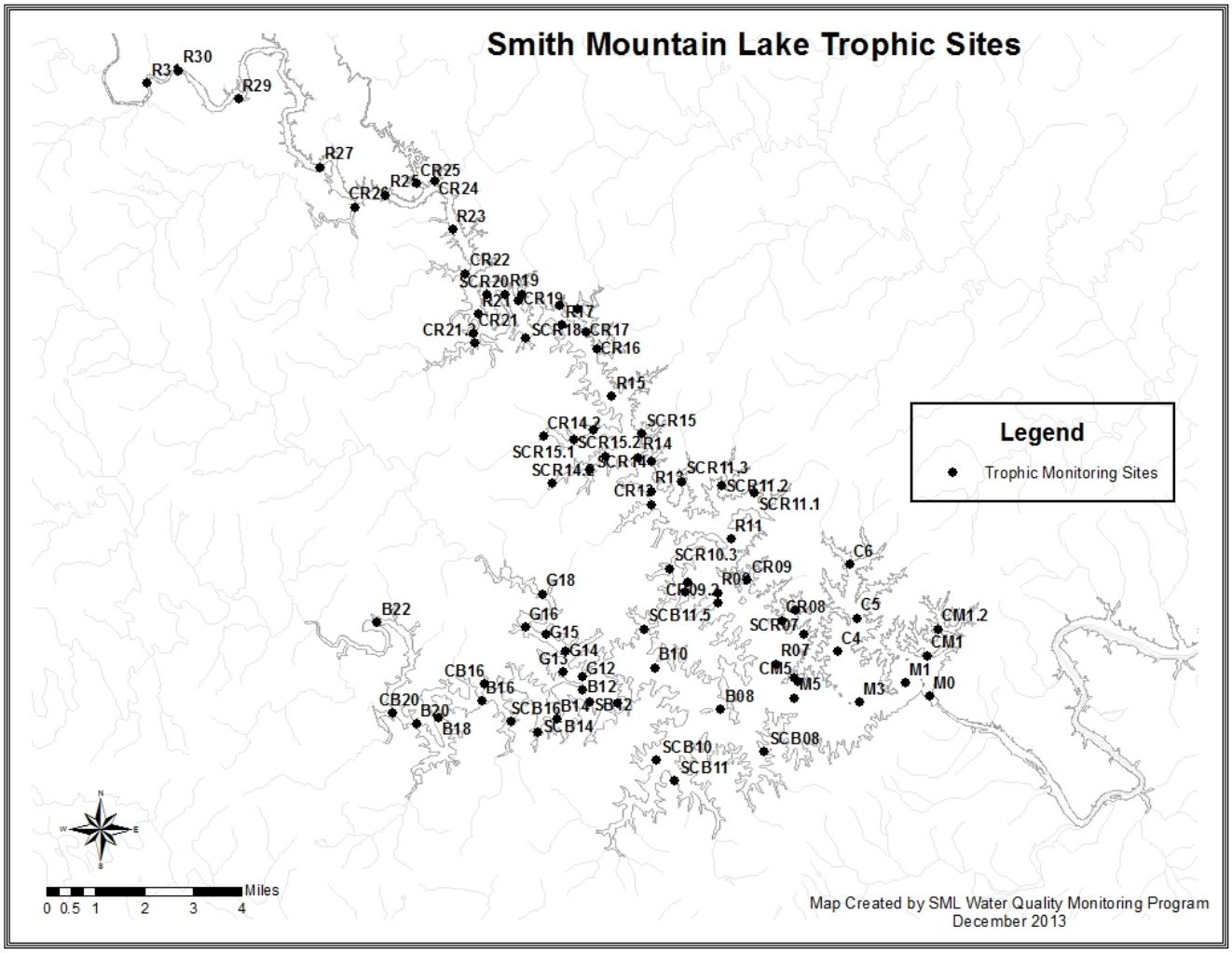

Table A.2. 2013 Smith Mountain Lake tributary stations and other downstream stations

Tributary Station Number	Stream Name (monitor, if applicable)
T0	Upper Gills Creek (Snoddy)
T1a	Maggodee Creek
T2a	Lower Gills Creek
T3	Blackwater River
T4	Poplar Camp Creek
T5	Standiford Creek
T6	Bull Run
T7	Cool Branch
T8	Branch at Lumpkin's Marina
T9	Roanoke River below Smith Mountain Dam
T10	Pigg River
T11	Leesville Lake
T12	Creek at Surrey Drive
T13	Creek at Snug Harbor
T14	Stoney Creek
T15	Jumping Run
T16	Beaverdam Creek
T17	Roanoke channel at Bay Roc Marina
T18	Lynville Creek
T19a	Grimes Creek
T20	Indian Creek
T21a	Roanoke channel below Back Creek

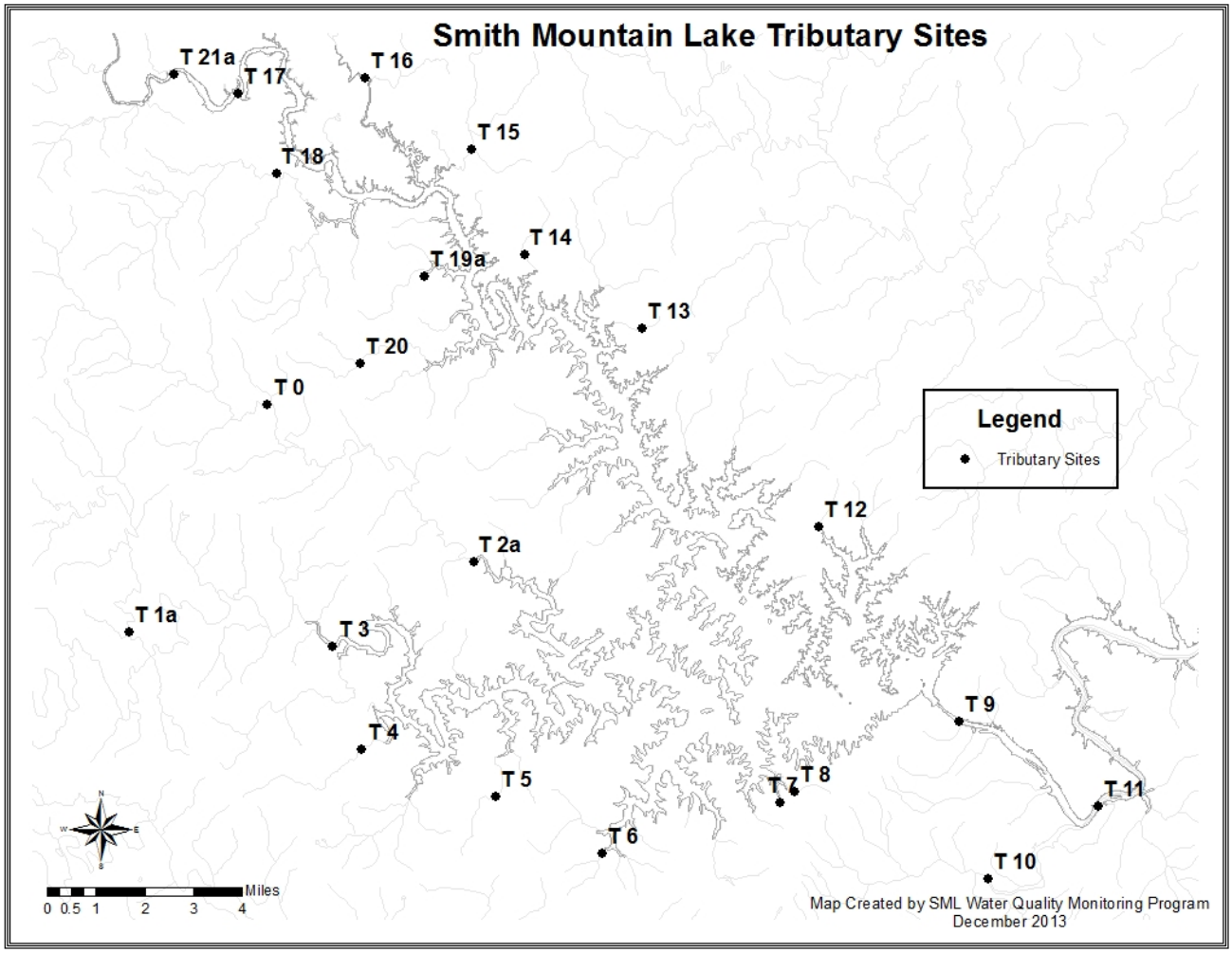

Figure A.2. Smith Mountain Lake tributary stations and downstream stations

Table A.3. 2013 Total phosphorus data for Smith Mountain Lake sample stations

Station	5/26 - 6/1 conc (ppb)	6/9 - 6/15 conc (ppb)	6/23 - 6/29 conc (ppb)	7/7 - 7/13 conc (ppb)	7/21 - 7/27 conc (ppb)	8/4 - 8/10 conc (ppb)	Station Avg (ppb)	Std. Dev.
B8	13.2	13.1	6.5	28.1	14.8	21.3	**16.2**	**7.5**
B10	10.5	9.9	6.9	15.5	13.3	19.0	**12.5**	**4.3**
B12	15.4	13.9	9.0	14.0	15.8	17.4	**14.3**	**2.9**
B14	20.6	29.4	11.5	42.3	19.6	16.5	**23.3**	**11.0**
B16	23.0	23.6	20.4	32.1	18.5	17.7	**22.6**	**5.2**
B18	92.8	47.2	29.9	22.7	42.6	17.5	**42.1**	**27.3**
B20	49.0	51.8	26.6	26.4	33.8	25.1	**35.5**	**12.0**
B22	62.6	146.6	105.4	45.4	89.7	45.1	**82.5**	**39.6**
C4	9.9	8.0	1.8	10.4	14.0	6.3	**8.4**	**4.1**
C5	4.1	9.6	0.6	6.0	6.6	6.0	**5.5**	**3.0**
C6	7.1	9.2	3.8	4.6	5.5	7.5	**6.3**	**2.0**
CB11	13.7	11.3	5.4	11.3	10.2	12.7	**10.8**	**2.9**
CB16	15.1	26.6	15.1	19.8	17.1	17.0	**18.4**	**4.3**
CB20	53.1	32.2	29.2	24.9	31.6	26.6	**32.9**	**10.3**
CM1	11.5	11.8	1.2	6.7	5.1	7.1	**7.2**	**4.0**
CM1.2	19.1	7.3	2.4	16.8	8.8	8.5	**10.5**	**6.3**
CM5	10.8	11.6	5.2	10.8	12.1	10.8	**10.2**	**2.5**
CR8	13.2	4.8	1.0	8.0	8.0	8.7	**7.3**	**4.1**
CR9	19.8	8.5	3.3	7.1	24.8	8.2	**12.0**	**8.4**
CR9.2	10.8	9.3	3.1	5.4	8.1	8.2	**7.5**	**2.8**
CR13	44.5	38.9	11.3	23.7	19.8	22.0	**26.7**	**12.5**
CR14.2	8.7	21.7	11.7	10.9	9.9	13.2	**12.7**	**4.7**
CR16	241.5	14.3	7.4	35.0	23.2	10.6	**55.3**	**91.7**
CR17	20.7	13.8	8.1	49.3	16.0	18.0	**21.0**	**14.5**
CR19	35.7	34.7	11.7	34.6	21.3	21.8	**26.6**	**9.9**
CR21	76.2	51.8	15.2	16.7	71.7	23.3	**42.5**	**27.8**
CR21.2	44.1	39.4	20.4	63.3	20.6	32.7	**36.7**	**16.2**
CR22	15.7	45.4	31.6	68.7	27.3	16.6	**34.2**	**20.1**
CR24	40.1	46.7	31.6	56.9	45.7	29.8	**41.8**	**10.2**
CR25	40.8	39.2	28.7	36.0	36.7	21.1	**33.8**	**7.5**
CR26	39.0	65.4	36.5	42.5	66.4	30.5	**46.7**	**15.3**
G12	29.9	11.9	13.7	16.7	14.2	18.5	**17.5**	**6.5**
G13	16.5	11.7	7.4	40.3	14.5	15.7	**17.7**	**11.6**
G14	21.5	20.4	11.6	12.4	16.0	15.7	**16.3**	**4.0**
G15	11.3	18.4	7.2	12.5	18.4	14.2	**13.7**	**4.3**
G16	18.1	24.7	13.3	12.3	23.6	29.5	**20.3**	**6.8**
G18	24.6	31.5	16.1	26.0	24.0	24.1	**24.3**	**4.9**
M0	12.1	13.5	0.8	6.0	5.1	5.2	**7.1**	**4.8**
M1	16.1	19.0	7.6	4.1	13.3	11.4	**11.9**	**5.5**
M3	7.5	9.4	5.5	24.3	11.2	10.2	**11.3**	**6.7**
M5	9.1	9.6	0.7	3.1	3.6	15.4	**6.9**	**5.4**
R7	10.9	11.7	1.9	9.1	8.0	9.1	**8.4**	**3.5**

Table A.3. 2013 Total phosphorus data for SML sample stations (cont.)

	5/26 - 6/1	6/9 - 6/15	6/23 - 6/29	7/7 - 7/13	7/21 - 7/27	8/4 - 8/10	Station Avg	Std. Dev.
Station	conc (ppb)	conc (ppb)	conc (ppb)	conc (ppb)	conc (ppb)	conc (ppb)	(ppb)	
R9	15.6	6.6	2.9	24.6	9.9	6.7	**11.0**	**7.9**
R11	14.0	8.3	5.2	28.5	8.0	9.3	**12.2**	**8.5**
R13	17.5	15.2	7.9	33.4	15.6	29.7	**19.9**	**9.7**
R14	24.3	10.8	9.9	28.6	14.9	13.8	**17.1**	**7.6**
R15	11.2	13.5	6.9	17.4	24.9	17.4	**15.2**	**6.2**
R17	20.7	29.3	5.4	42.3	11.8	18.2	**21.3**	**13.1**
R19	19.3	30.6	10.8	36.0	24.7	16.4	**23.0**	**9.3**
R21	38.4	76.3	19.7	62.3	31.2	19.3	**41.2**	**23.4**
R23	25.9	40.7	19.2	48.8	25.4	22.9	**30.5**	**11.6**
R25	38.9	42.4	25.3	70.6	27.0	21.5	**37.6**	**18.1**
R27	40.9	54.9	42.5	67.2	43.9	37.5	**47.8**	**11.2**
R29	57.1	51.3	29.1		27.0	29.6	**38.8**	**14.2**
R30	43.9	37.8	98.5	44.0	49.2	52.8	**54.4**	**22.2**
R31	55.6	24.8	47.1	65.2	60.2	46.1	**49.8**	**14.3**

Table A.4. 2013 Total phosphorus data for Smith Mountain Lake tributaries

	6/4	6/18	7/2	7/16	7/30	8/13	Station Avg	Std. Dev.
Station	conc (ppb)	conc (ppb)	conc (ppb)	conc (ppb)	conc (ppb)	conc (ppb)	(ppb)	
T0*	82.2	65.6	89.3	183.4	63.7	54.2	**89.7**	**47.6**
T1a	105.3	232.7	78.4	100.0	88.0	81.8	**114.4**	**58.9**
T2a	176.2	71.3	84.1	106.9	75.6	173.7	**114.6**	**48.3**
T3	109.3	574.4	56.0	137.8	44.8	47.9	**161.7**	**205.6**
T4	24.5	37.6	18.6	27.9	23.7	116.6	**41.5**	**37.4**
T5	37.2	64.0	30.2	37.3	19.0	34.0	**37.0**	**14.9**
T6	24.7	47.1	31.1	28.2	25.8	47.4	**34.1**	**10.5**
T7	11.1	1.9	15.0	12.6	3.8	8.1	**8.8**	**5.1**
T8	15.1	15.0	11.7	16.0	9.7	8.9	**12.7**	**3.0**
T9	19.7	3.9	5.1	18.3	4.3	11.8	**10.5**	**7.2**
T10	77.2	73.2	39.3	95.6	20.3	90.4	**66.0**	**29.8**
T11	36.2	29.4	30.1	22.0	27.8	28.7	**29.0**	**4.5**
T12	40.7	49.1	28.5	17.1	10.0	22.6	**28.0**	**14.7**
T13	15.1	75.7	16.5	10.2	12.7	16.7	**24.5**	**25.2**
T14	128.9	101.0	110.7	241.7	167.7	114.8	**144.1**	**53.2**
T15	75.7	95.9	111.2	148.1	25.9	90.4	**91.2**	**40.4**
T16	47.1	299.1	111.7	105.9	49.2	90.9	**117.3**	**93.3**
T17	30.4	45.1	87.2	79.9	30.2	69.1	**57.0**	**25.1**
T18	44.9	92.8	43.7	24.6	30.4	53.3	**48.3**	**24.2**
T19a	60.1	58.0	64.8	62.8	52.7	79.1	**62.9**	**9.0**
T20						46.5	**46.5**	
T21a	76.7	48.1	55.5	711.8	67.3		**191.9**	**290.9**

*****T0 samples collected in the same sampling period as the lake samples

Table A.5. 2013 Chlorophyll-*a* data for Smith Mountain Lake sample stations

	5/26 - 6/1	6/9 - 6/15	6/23 - 6/29	7/7 - 7/13	7/21 - 7/27	8/4 - 8/10	Station Avg	Std. Dev.
Station	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**(ppb)**	
B8	2.64	2.44	2.80	3.75	4.53	7.61	**3.96**	**1.95**
B10	2.49	4.96	4.00	4.25	6.67	9.93	**5.38**	**2.61**
B12	4.91	3.49	6.44	4.75	5.70	8.64	**5.66**	**1.77**
B14	4.91	8.09	6.88	10.58	6.28	9.45	**8.43**	**1.64**
B16	9.30	14.76	6.19	14.68	8.42	10.89	**11.06**	**3.40**
B18	11.40	11.82	6.02	7.21	11.31	10.03	**9.63**	**2.44**
B20	12.23	7.12	29.34	4.50	4.17	9.19	**11.09**	**9.43**
B22	54.45	19.82	3.22	16.81	49.13	23.53	**27.82**	**19.86**
C4	2.10	3.59	0.68	1.15	2.35	3.31	**2.20**	**1.15**
C5	2.32	3.19	2.20	4.42	2.82	1.98	**2.82**	**0.90**
C6	1.55	2.80	0.88	4.45	3.88	3.19	**2.79**	**1.37**
CB11	3.35	2.26	6.16	5.89	5.06	9.57	**5.38**	**2.55**
CB16	6.83	12.40	6.42	13.86	7.33	8.78	**9.27**	**3.13**
CB20	31.16	15.16	20.42	16.74	27.30	17.34	**21.35**	**6.45**
CM1	3.67	2.60	1.15	2.09	3.44	3.59	**2.76**	**1.00**
CM1.2	2.08	3.64	1.68	2.90	2.09	4.06	**2.74**	**0.95**
CM5	3.53	2.65	2.15	2.84	5.09	4.26	**3.42**	**1.10**
CR8	3.57	2.96	2.58	4.07	6.33	6.28	**4.30**	**1.63**
CR9	3.08	2.62	2.15	4.27	4.57	6.84	**3.92**	**1.71**
CR9.2	3.43	2.89	3.05	6.52	6.61	9.24	**5.29**	**2.57**
CR13	7.28	4.28	4.32	22.23	10.01	6.00	**9.02**	**6.82**
CR14.2	2.50	6.36	4.59	5.82	6.77	17.69	**7.29**	**5.33**
CR16	4.52	7.69	3.80	21.71	6.57	16.55	**10.14**	**7.29**
CR17	5.03	8.84	3.67	16.38	11.10	24.78	**11.63**	**7.88**
CR19	9.32	23.74	7.25	25.13	17.43	23.06	**17.65**	**7.75**
CR21	4.94	99.47	19.88	67.38	46.83	74.42	**52.15**	**35.40**
CR21.2	27.68	60.53	12.09	57.11	25.08	48.96	**38.57**	**19.67**
CR22	6.15	26.51	8.04	18.11	11.19	9.73	**13.29**	**7.66**
CR24	24.24	101.96	24.06	46.46	15.93	25.50	**39.69**	**32.16**
CR25	18.14	39.99	18.37	27.81	25.12	14.78	**24.03**	**9.19**
CR26	14.83	29.86	18.59	17.54	12.85	19.39	**18.84**	**5.92**
G12	7.18	5.42	4.51	7.62	6.26	14.02	**7.50**	**3.39**
G13	4.72	5.70	4.44	8.93	9.13	13.52	**7.74**	**3.49**
G14	4.08	3.14	3.35	5.59	5.88	11.56	**5.60**	**3.13**
G15	6.71	4.49	2.99	8.55	11.40	8.99	**7.19**	**3.10**
G16	6.62	6.52	3.48	5.51	8.89	10.41	**6.91**	**2.45**
G18	14.31	10.34	5.68	8.24	11.49	13.31	**10.56**	**3.21**
M0	1.81	2.35	0.84	3.38	2.19	4.32	**2.48**	**1.22**
M1	2.68	2.91	3.80	2.54	3.81	3.50	**3.21**	**0.57**
M3	2.85	1.62	1.84	2.48	3.99	3.02	**2.63**	**0.86**

M5	2.82	0.93	2.01	3.97	5.07	3.95	**3.12**	**1.51**
R7	3.71	2.98	2.73	3.92	6.02	7.05	**4.40**	**1.74**
R9	3.06	2.34	3.24	8.04	6.89	8.50	**5.35**	**2.77**

Table A.5. 2013 Chlorophyll–*a* data for SML sample stations (cont.)

	5/26 - 6/1	**6/9 - 6/15**	**6/23 - 6/29**	**7/7 - 7/13**	**7/21 - 7/27**	**8/4 - 8/10**	**Station Avg**	**Std. Dev.**
Station	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**(ppb)**	
R11	5.70	4.71	5.41	8.29	8.82	10.07	**7.17**	**2.18**
R13	5.92	3.41	4.76	12.88	5.93	7.07	**6.66**	**3.29**
R14	6.66	6.38	5.40	12.42	9.85	18.62	**9.89**	**5.01**
R15	4.74	5.49	3.99	19.15	15.05	17.49	**10.98**	**6.98**
R17	4.47	18.70	3.50	16.87	12.88	22.06	**13.08**	**7.65**
R19	7.39	28.18	4.21	25.63	10.79	22.76	**16.49**	**10.25**
R21	6.98	159.12	20.14	75.42	51.74	63.92	**62.89**	**53.84**
R23	5.75	24.15	5.66	18.52	11.62	17.92	**13.94**	**7.51**
R25	19.40	75.33	23.36	65.43	26.98	25.26	**39.29**	**24.41**
R27	16.99	51.14	41.34	52.01	28.50	27.14	**36.18**	**14.21**
R29	13.23	51.83	24.64		28.72	45.56	**32.79**	**15.74**
R30	9.63	18.75	37.34	23.09	53.82	24.29	**27.82**	**15.58**
R31	0.55	2.88	5.34	1.64	41.04	13.88	**10.89**	**15.53**

Table A.6. 2013 Secchi disk data for Smith Mountain Lake sample stations

	5/26 - 6/1	6/9 - 6/15	6/23 - 6/29	7/7 - 7/13	7/21 - 7/27	8/4 - 8/10	Station Avg	Std. Dev.
Station	depth (m)	depth (m)	depth (m)	depth (m)	depth (m)	depth (m)	(m)	
B8	3.50	5.50	4.25	3.00	2.25	1.75	**3.38**	**1.37**
B10	3.25	4.50	4.00	2.25	1.75	1.50	**2.88**	**1.23**
B12	2.00	2.75	3.00	2.00	1.50	1.25	**2.08**	**0.68**
B14	2.00	1.75	1.50	1.50	1.50	1.25	**1.58**	**0.26**
B16	1.25	1.00	1.25	1.25	1.00	1.00	**1.13**	**0.14**
B18	1.00	0.75	1.00	1.00	1.00	1.00	**0.96**	**0.10**
B20	1.00	0.75	1.00	1.00	1.00	1.25	**1.00**	**0.16**
B22	0.75	0.50	0.50	1.00	0.75	1.00	**0.75**	**0.22**
C4	3.50	4.75	4.75	3.75	4.00	3.00	**3.96**	**0.70**
C5	3.75	4.25	4.25	3.75	4.00	3.00	**3.83**	**0.47**
C6	3.00	3.50	3.25	3.25	3.75	2.75	**3.25**	**0.35**
CB11	2.50	3.25	2.75	2.25	1.50	1.25	**2.25**	**0.76**
CB16	1.25	1.25	1.50	1.25	1.00	1.00	**1.21**	**0.19**
CB20	1.00	1.00	1.00	1.25	1.00	1.50	**1.13**	**0.21**
CM1	3.50	3.75	4.00	3.00	2.75	2.75	**3.29**	**0.53**
CM1.2	3.75	3.75	3.50	3.00	2.75	2.75	**3.25**	**0.47**
CM5	2.75	4.50	4.25	3.00	2.25	2.00	**3.13**	**1.03**
CR8	3.00	3.50	3.50	3.00	2.75	1.75	**2.92**	**0.65**
CR9	2.25	2.25	3.25	2.50	1.75	1.50	**2.25**	**0.61**
CR9.2	2.25	2.25	3.50	2.00	1.50	1.25	**2.13**	**0.79**
CR13	3.00	3.50	3.50	1.75	1.75	1.75	**2.54**	**0.89**
CR14.2	2.50	1.75	2.50	2.50	1.75	1.25	**2.04**	**0.53**
CR16	2.50	2.50	3.00	1.50	1.50	1.25	**2.04**	**0.71**
CR17	2.00	2.00	3.00	1.75	1.50	1.50	**1.96**	**0.56**
CR19	1.25	1.00	2.50	1.50	1.25	1.00	**1.42**	**0.56**
CR21	1.75	1.75	2.50	1.50	1.50	1.75	**1.79**	**0.37**
CR21.2	1.75	1.50	2.25	1.75	1.50	1.75	**1.75**	**0.27**
CR22	1.50	1.25	2.00	1.25	0.75	1.25	**1.33**	**0.41**
CR24	1.50	1.00	2.00	1.00	1.50	1.25	**1.38**	**0.38**
CR25	1.50	1.00	1.75	1.00	1.25	1.25	**1.29**	**0.29**
CR26	1.75	1.00	1.50	1.00	1.25	1.00	**1.25**	**0.32**
G12	2.00	3.00	3.00	2.25	1.50	1.25	**2.17**	**0.74**
G13	3.00	3.00	3.00	2.50	1.75	1.50	**2.46**	**0.68**
G14	2.25	2.25	2.75	2.00	1.50	1.50	**2.04**	**0.49**
G15	2.75	2.50	2.00	2.00	1.75	1.50	**2.08**	**0.47**
G16	2.00	1.75	2.50	1.75	1.50	1.50	**1.83**	**0.38**
G18	1.50	1.50	2.00	1.50	1.25	1.25	**1.50**	**0.27**
M0	3.75	3.75	4.75	3.25	2.75	2.75	**3.50**	**0.76**
M1	4.00	3.00	4.50	4.00	3.00	2.25	**3.46**	**0.84**

M3	4.00	4.00	4.75	4.00	2.75	2.00	**3.58**	**1.01**
M5	3.50	3.00	4.50	4.25	2.50	1.75	**3.25**	**1.05**
R7	3.00	4.50	4.25	3.25	2.25	1.75	**3.17**	**1.08**
R9	2.00	2.50	4.00	2.00	1.50	1.25	**2.21**	**0.98**

Table A.6. 2013 Secchi disk data for SML sample stations (cont.)

	5/26 - 6/1	**6/9 - 6/15**	**6/23 - 6/29**	**7/7 - 7/13**	**7/21 - 7/27**	**8/4 - 8/10**	**Station Avg**	**Std. Dev.**
Station	**depth (m)**	**depth (m)**	**depth (m)**	**depth (m)**	**depth (m)**	**depth (m)**	**(m)**	
R11	2.00	3.50	4.25	2.50	1.75	1.25	**2.54**	**1.13**
R13	3.25	3.00	3.50	1.75	1.75	1.75	**2.50**	**0.84**
R14	2.75	1.75	3.75	1.75	1.50	1.50	**2.17**	**0.90**
R15	2.50	2.50	3.50	1.50	1.75	1.50	**2.21**	**0.78**
R17	1.50	1.25	3.00	1.75	1.50	1.25	**1.71**	**0.66**
R19	1.50	1.50	2.75	1.50	1.25	1.25	**1.63**	**0.56**
R21	1.75	1.50	2.25	1.50	1.50	1.75	**1.71**	**0.29**
R23	1.75	1.00	1.75	1.50	0.75	1.50	**1.38**	**0.41**
R25	1.50	1.25	1.75	1.00	1.25	1.25	**1.33**	**0.26**
R27	1.50	1.00	1.50	0.75	1.00	1.00	**1.13**	**0.31**
R29	1.25	1.00	1.25		1.75	1.25	**1.30**	**0.27**
R30	0.75	0.75	0.75	0.75	0.75	1.25	**0.83**	**0.20**
R31	0.75	0.75	0.75	0.50	0.50	1.00	**0.71**	**0.19**
SB12	2.50	2.50	2.50	2.00	1.75	1.25	**2.08**	**0.52**
SCB 8	3.50	3.25	4.75	3.25	2.50	2.25	**3.25**	**0.88**
SCB10	3.00	3.75	3.75	3.00	2.75	2.00	**3.04**	**0.66**
SCB11	3.25	4.00	3.50	3.50	2.50	2.25	**3.17**	**0.66**
SCB11.5	3.25	3.75	3.50	3.50	2.50	2.00	**3.08**	**0.68**
SCB14	1.50	2.00	1.75	1.25	1.50	1.50	**1.58**	**0.26**
SCB16	1.25	1.75	1.75	1.25	1.25	1.25	**1.42**	**0.26**
SCM5	4.25	4.25	3.75	3.50	2.50	2.00	**3.38**	**0.93**
SCR7	4.50	4.25	4.00	3.00	2.50	2.00	**3.38**	**1.02**
SCR8	4.50	4.50	3.75	3.00	2.75	1.75	**3.38**	**1.08**
SCR10.1	3.00	2.50	2.50	2.50	1.75		**2.45**	**0.45**
SCR10.2	3.00	2.75	2.50	2.50	1.75		**2.50**	**0.47**
SCR10.3	3.00	2.75	2.50	2.50	1.75		**2.50**	**0.47**
SCR11.1	2.50	3.20	3.00	2.50	1.75	1.50	**2.41**	**0.67**
SCR11.2	2.25	2.00	2.25	2.25	2.00	1.50	**2.04**	**0.29**
SCR11.3	2.50	2.50	4.50	2.25	1.50	1.50	**2.46**	**1.10**
SCR14	3.00	3.00	4.25	2.25	1.75	1.50	**2.63**	**1.01**
SCR14.1	3.00	3.00	3.00	2.25	1.75	1.25	**2.38**	**0.75**
SCR14.2	2.25	2.25	2.25	3.25	1.75	1.50	**2.21**	**0.60**
SCR14.3	2.25	2.50	3.25	3.50	1.75	1.75	**2.50**	**0.74**

SCR15	2.00	1.75	2.75	1.50	1.25		**1.85**	**0.58**
SCR 15.1	3.00	3.00	3.00	2.50	1.75	1.75	**2.50**	**0.61**
SCR 15.2	3.00	2.25	3.00	2.75	1.75	1.50	**2.38**	**0.65**
SCR17	1.50	1.25	1.75	1.25	1.00		**1.35**	**0.29**
SCR17.1	1.75	1.50	2.00	1.25	1.25		**1.55**	**0.33**
SCR18	2.00	2.00	2.50	1.50	1.25	1.25	**1.75**	**0.50**
SCR19.2	2.00	1.75	2.00	1.50	1.25	1.25	**1.63**	**0.34**
SCR20	2.00	1.50	2.25	1.50	1.25	1.25	**1.63**	**0.41**

Figure A.3. Site locations for depth profiling

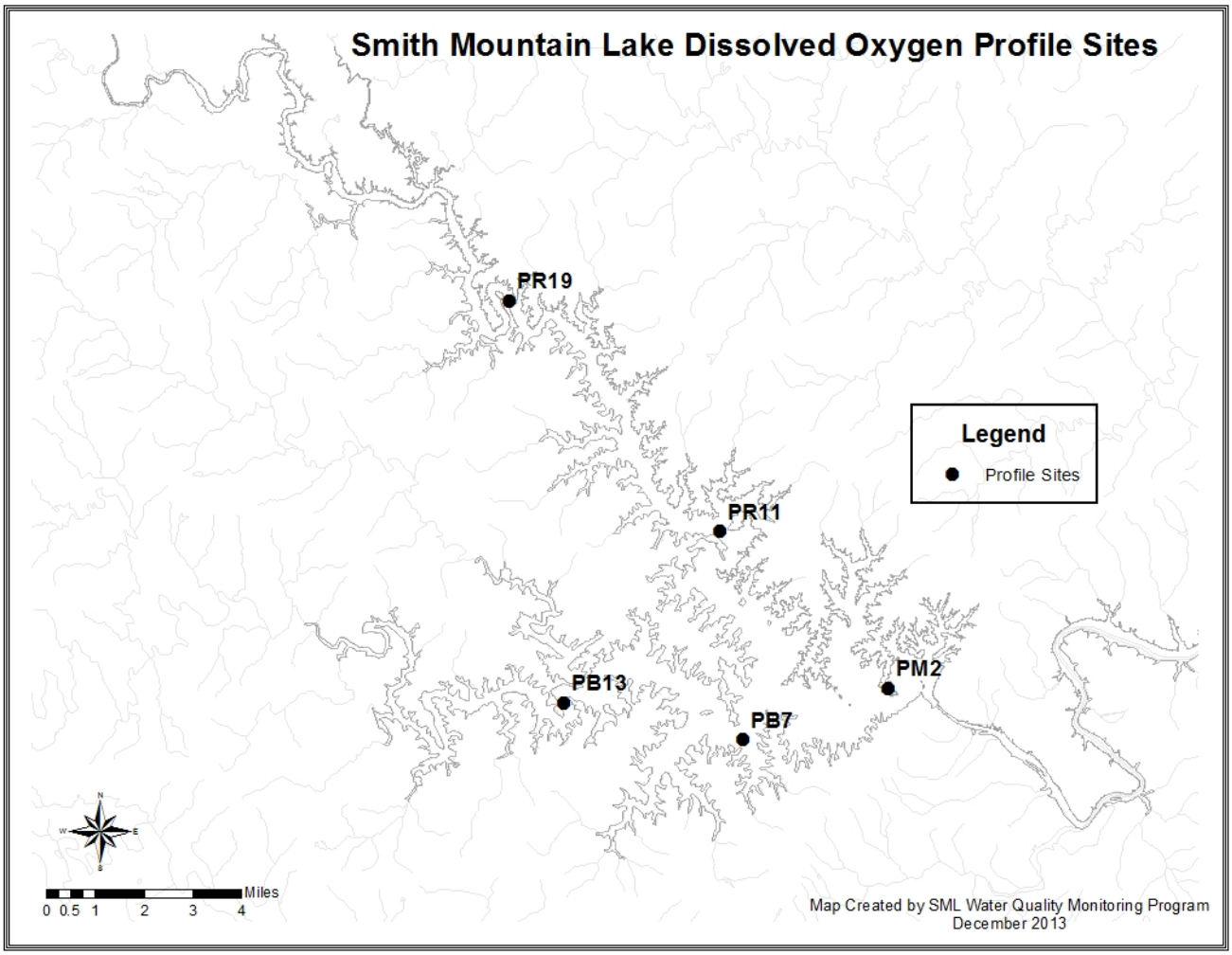

Figure A.4. Bacterial sampling sites

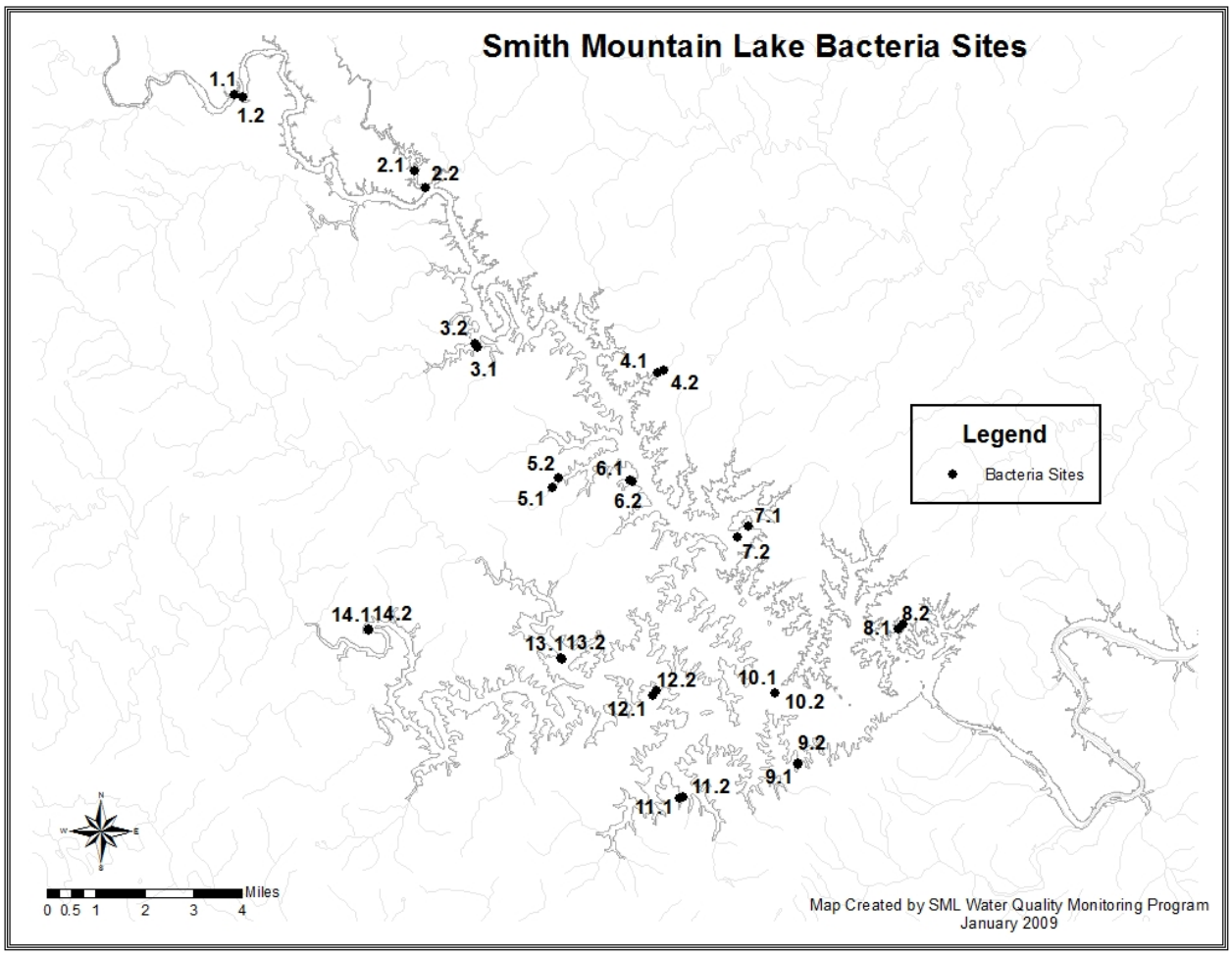

Table A.7. 2013 *E. coli* data for Smith Mountain Lake sample stations

	5/28	6/11, 6/14	6/25	7/9	7/23	8/6	Average	Std. Dev.
Station	**MPN**	**MPN**	**MPN**	**MPN**	**MPN**	**MPN**	**MPN**	**MPN**
1-1	77.1	184.2	17.3	1553.1	152.9	6.2	**331.8**	**602.5**
1-2	47.3	101.4	6.3	1732.9	30.9	7.5	**321.1**	**692.5**
2-1	2.0	3.1	0.0	4.1	0.0	2.0	**1.9**	**1.6**
2-2	2.0	0.0	0.0	2.0	0.0	1.0	**0.8**	**1.0**
3-1	4.1	0.0	0.0	1.0	3.1	0.0	**1.4**	**1.8**
3-2	0.0	4.1	2.0	0.0	5.2	0.0	**1.9**	**2.3**
4-1	2.0	10.9	3.1	13.5	14.8	23.3	**11.3**	**7.9**
4-2	2.0	5.2	3.1	1.0	4.1	5.1	**3.4**	**1.7**
5-1	13.4	64.4	204.6	35.5	71.2	17.1	**67.7**	**71.1**
5-2	6.3	19.5	7.3	14.8	38.9	3.1	**15.0**	**13.2**
6-1	2.0	9.7	1.0	1.0	12.2	3.1	**4.8**	**4.9**
6-2	2.0	0.0	1.0	0.0	6.3	5.2	**2.4**	**2.7**
7-1	3.0	0.0	0.0	2.0	8.3	0.0	**2.2**	**3.2**
7-2	0.0	0.0	0.0	0.0	1.0	2.0	**0.5**	**0.8**
8-1	1.0	6.3	3.1	13.5	6.3	2.0	**5.4**	**4.5**
8-2	0.0	6.3	2.0	25.9	0.0	3.1	**6.2**	**9.9**
9-1	13.4	9.8	10.9	63.1	8.5	11.0	**19.5**	**21.4**
9-2	7.4	1.0	12.2	27.9	22.8	12.1	**13.9**	**9.9**
10-1	0.0	0.0	0.0	0.0	1.0	0.0	**0.2**	**0.4**
10-2	0.0	1.0	0.0	1.0	0.0	1.0	**0.5**	**0.5**
11-1	5.2	5.2	40.2	37.3	110.0	7.4	**34.2**	**40.5**
11-2	9.8	4.1	13.4	21.8	188.7	4.1	**40.3**	**73.0**
12-1	1.0	5.2	1.0	6.3	4.1	4.1	**3.6**	**2.2**
12-2	2.0	1.0	7.5	0.0	3.1	2.0	**2.6**	**2.6**
13-1	1.0	5.2	16.1	4.0	22.1	1.0	**8.2**	**8.8**
13-2	0.0	7.4	5.2	0.0	2.0	0.0	**2.4**	**3.2**
14-1	579.4	2500.0	98.7	1413.6	1986.3	6.3	**1097.4**	**1030.9**
14-2	160.7	2500.0	48.7	214.3	517.2	4.1	**574.2**	**960.6**