Smith Mountain Lake

Water Quality Monitoring Program

2010 Report

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Moneta, Virginia

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Tony and Marilyn Cusumano, Hardy
Tony and Alice DeCesare, Glade Hill
Paul Gascoyne, Goodview
Richard and Janet Hill, Huddleston
Larry Hutson, Union Hall
Daphne Jamison, Wirtz
Rusty MacMullan, Moneta
Charles Marshall, Moneta
Luther and Judy Mauney, Goodview
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Robert Gore, Moneta
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Mike Mutchler, Moneta
Carol and Gary Noesner, Moneta
Jerry and Karin Over, Moneta
Doug Pafford, Moneta
Bobby Waters, Penhook

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 the resource.

The 2010 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 (22 in June and 21 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. Bacterial water quality is assessed by enumerating the bacterial species chosen as indicator organisms. The Virginia Department of Environmental Quality has changed bacterial water quality standards and as of 2008 the indicator organism is *Escherichia coli* rather than fecal coliform for all Virginia streams and lakes. In 2009, *E. coli* was enumerated to assess the bacterial populations in Smith Mountain Lake as it has been since 2004.

Depth profile monitoring, which was begun in 2005, is an interesting addition to the program. 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.

Algal monitoring was initiated in 2007. In 2010, 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

Overall, the trophic status of Smith Mountain Lake improved slightly in 2010 compared to 2009. Secchi depth increased while chlorophyll-*a* and total phosphorus concentration decreased on average for the lake. Only the total phosphorus concentration monitored at tributary sites increased from 2009.

1.2 Conclusions – Escherichia coli Measurements and Bacterial Source Tracking

The level of bacteria found in the lake and its tributaries, as measured by the presence of *E. coli*, was low in 2010 for the second year in a row. The average *E. coli* MPN in 2010 was 12.9 MPN/100 mL and in 2009 the *E. coli* count was 7.5 MPN/100 mL. The 2010 measurements in general indicate that the lake is safe for normal recreational use. The averages for 2010 of marina sites (10.9 MPN/100 mL) were lower than non-marina sites (12.9 MPN/100 mL), but both were lower than headwaters sites (17.0 MPN/100 mL). In 2010 four of the sample sites on one of the sample dates (July 27, 2010) violated the Virginia Department of Health standard for recreational waters. The four sample sites that violated the standard were Bay Roc Marina, Smith Mountain Lake Dock, Palmer's Trailer Park Cove and Forest Cove. In 2010, the student sampling team took samples at tributary sites (22 in June and 21 in August) for bacterial source tracking (BST) using the antibiotic resistance assay (ARA). The sites were sampled on two occasions, at the beginning of the summer (June) and toward the end of the summer (August). Results indicated a lower percentage of isolates from human sources in 2010, as compared to 2008 or 2009, which shows progress in preventing human waste contamination of the tributaries flowing into Smith Mountain Lake. The livestock sources of bacterial isolates are not decreasing however, which indicates more work needs to be done to prevent livestock waste from entering the tributaries of Smith Mountain Lake.

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

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. For 2010, we can conclude that the depth profile data are consistent with a healthy lake with a small amount of nutrient enrichment and an appropriate level of resulting algal activity.

1.4 Conclusions – Algae in Smith Mountain Lake

In 2007 algae population measurements, including identification to genus when possible, were made as a program enhancement to help evaluate the trophic status of Smith Mountain Lake. This program was continued in 2010. The algae were also grouped by major algal divisions: blue-green algae, green algae, and diatoms. The algae community is known to go through a natural succession through the summer as conditions become warmer and light availability increases. The succession usually observed indicates diatoms in spring and the first part of the summer, then the community is dominated by green algae and lastly, toward the end of summer and early fall, the blue-green algae predominate. This typical algal succession was not true for Smith Mountain Lake in 2010. All of the algal populations were fairly low again in 2010, with green algae found to be the dominant algal group. Blue-green algae are not a problem in Smith Mountain Lake, since they have decreased to 13 percent (from 35 percent in 2009) of the total algal population. Algal populations increase with increasing distance to the dam, which is expected due to the dependence of algae on nutrients whose concentrations also increase with increasing distance to the dam.

2. INTRODUCTION

The Smith Mountain Lake Water Quality Monitoring Program (SMLWQMP), now in its twenty-fourth 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 2009 monitoring season. Secchi depths were recorded and water samples collected every other week from the first week of June to the second week of August.

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 samples are picked up at the homes of the monitors by Ferrum College interns and analyzed for total phosphorus and chlorophyll-*a* concentrations in the Water Quality Laboratory at Ferrum College. The monitoring network includes "trend stations" on the main channels and "watchdog stations" in coves off the main channels. In 2010, there were 84 stations in the lake monitoring network; 56 advanced stations and an additional 28 basic stations, with all but one of the basic stations located in coves.

Beginning in 1995, Ferrum College personnel began collecting 20 tributary samples each sampling period in order to assess tributary inputs of nutrients to the lake. In 1996 a volunteer monitoring team began collecting samples in the upper Roanoke channel just below the confluence of Back Creek, 34 miles from the dam. This sample site was designated T21 and is considered the headwaters station for the Roanoke channel. In recent years, Ferrum College technicians continued the sampling at this site from the shoreline (T21a). Sample site T3 is the headwaters station designated for the Blackwater channel; it is located at the Route 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.

Collection of lake samples for fecal coliform enumeration also began in 1995 with samples collected at 8 sites on three occasions. In 1996 and 1997, the number of sampling sites was increased to 12 and, 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 Commonwealth of Virginia's bacterial standard, which uses *E. coli* as the indicator organism rather than fecal coliform. Ferrum College investigators collected bacterial samples every other week in 2010, for a total of six samples at each station.

Ferrum College scientists Carolyn Thomas, Jason Powell and the SMLA Volunteer Monitoring Coordinator, Stan Smith, carried out the 2010 training session in May, with assistance from student technicians Rebecca Crabtree, Kevin Reynolds, Jaleesa Scott, Rachel Thomas, Annesha Basu and lab coordinator Carol Love. Delia Heck and Bob Pohlad also assisted in the discussion and training program and some of the Virginia Department of Health Education and Pump out program Technicians assisted. The training session was held at the Smith Mountain Lake Association office in Moneta, Virginia. The program included a review of the previous year's findings and planning 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.

Sample collection began the week of May 30th through June 5th and the first sample bottles and filters were picked up on Tuesday, June 8th. The last week of sample collection was August 8th through August 14th and samples and filters were picked up on August 17th. 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. Three newsletters were published in 2010. In October, the annual end-of-the-season meeting and social event was held at Trinity Ecumenical Church in Moneta, Virginia. At this meeting the preliminary report of results was presented and a hard copy given out.

The Virginia Environmental Endowment (VEE) provided primary funding for the project during the first three years and the final report to the VEE describes the development of the project during the period from 1987-1990 (Johnson and Thomas, 1990). Beginning in 1990 and continuing through 2002, support for the project came from the Commonwealth of Virginia through the Smith Mountain Lake Policy Advisory Board, now known as Tri-County Lake Administrative Commission (TLAC), the SMLA, and Ferrum College. Funding from the Commonwealth of Virginia ended after the 2002 season. The SMLA Fund Drive, carried out by Friends of the Lake, provided financial support for the 2003 through 2006 seasons and included support from Appalachian Power Company (AEP). Significant support for the program in 2010 came from the Appalachian Power Company with some support from the Virginia Department of Environmental Quality (DEQ). The Western Virginia Water Authority of Roanoke Virginia has 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). Monitoring results from 1990 to 2009 can be found in the project's annual reports.

This year's monitoring results, data analyses, and comparisons with the other twenty-three years of data are discussed in the full report.

3. METHODS

Detailed descriptions of the methods of sample collection, preservation and analyses, and quality control/quality assurance procedures can be found in the VEE Report (Johnson and Thomas, 1990), in the *Volunteer Methods Manual* (Thomas and Johnson, 2000), and in the *Ferrum College Water Quality Procedures Manual* (Johnson, Thomas, Love, and Powell, 2007).

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; and chlorophyll-*a*, determined using the acetone extraction method and measured fluorometrically. Quality control and quality assurance procedures evaluate laboratory procedures and are described in a later section 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).

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 20–21 tributary stations on their rounds to pick up lake water samples. One of the tributary sample sites (T8) is often dry and no samples can be taken at that site. A volunteer monitor collects one additional tributary sample (T0), in upper Gills Creek.

In 2010 the method used in the algal analyses measured 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 five 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 fields of a Sedgwick Rafter cell, the algae were identified, counted and recorded.

Smith Mountain Lake was depth profiled six times in 2010 using an In-Situ Troll 9000 Profiler™ (which includes a multi-sensor probe with 200 feet of cable) and the Rugged Reader™. The parameters measured through a single profiling event are depth, temperature, dissolved oxygen concentration (DO), pH, and conductivity.

Bacterial analysis in Smith Mountain Lake included *Escherichia coli* (*E. coli*) monitoring and bacterial source tracking using *Enterococcus faecalis*. In 2010, as in 2004–2009, the method used in the bacterial analyses measured the *E. coli* populations instead of fecal coliform populations. This change reflects the revision in the Commonwealth of Virginia’s bacterial standard, which uses *E. coli* as the indicator organism rather than fecal coliform.

Water samples were collected from 14 sites on Smith Mountain Lake during the summer months of 2010. These 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 Quanti-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 (cfus) 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 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 2010, we took samples for ARA at tributary sites twice, at the beginning of the summer (June, 22 sites) and toward the end (August, 21 sites) of the summer. Other sample sites are not included because of the lack of significant numbers of enterococci found there.

To reflect the gradation present in the Smith Mountain Lake samples, maps generated by a Geographic Information System (GIS) were added to this annual report beginning in 2006. In addition, an executive summary including maps and initial descriptions of the data have been

produced annually since 2007. The summary provides preliminary results to the citizen monitors and the Smith Mountain Lake community prior to this final report. The maps in this report are printed in black and white, but the maps in the executive summary are printed in color.

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). The use of GIS in the Smith Mountain Lake Water Quality Monitoring Program is in its initial stages and as such is currently focused on data representation and not more powerful spatial analysis. Currently the objectives for the Smith Mountain Lake maps included highlighting "hot spots" or areas of concern to citizens and demonstrating the variation of the nutrient characteristics across the lake. Averages for bacteria, chlorophyll-*a*, total phosphorus, Secchi depth, and combined trophic status index (TSI-C) at each of the sampling locations were used in the maps.

The symbols, colors and scales were 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. In the bacteria map (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. The chlorophyll-*a* levels (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 (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 (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 (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. It is impacted by the amount of sediment load in the lake and also by the amount of algae present.

Phosphorus is a plant nutrient that stimulates 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. 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.

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)
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%)
2003	54.4 (+54%)	88.1 (–30%)	8.7 (+112%)	1.9 (–27%)
2002	35.4 (+6%)	125.8 (+87%)	4.1 (–1%)	2.6 (+13%)
2001	33.3 (–7%)	67.1 (–17%)	4.1	2.3 (+5%)
2000	35.9 (+24%)	80.9 (+31%)	NA*	2.2 (±0%)
Average	***32.6***	***84.9***	***5.0***	***2.2***

* CA value of unknown reliability due to equipment malfunction

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 Volunteer Methods Manual (Thomas and Johnson, 2000), and in the Ferrum College Water Quality Program Procedures Manual (Johnson, Thomas, Love, and Powell, 2007). The methods used are adapted from *Standard Methods* 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 84 sites for Secchi depth measurements. For total phosphorus analysis, samples are also collected from 22 tributary stations to provide information about inputs into 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).

4.3 Results

Figure 4.1 shows the comparison of the six sampling periods with the average value of each trophic status parameter monitored in 2010.

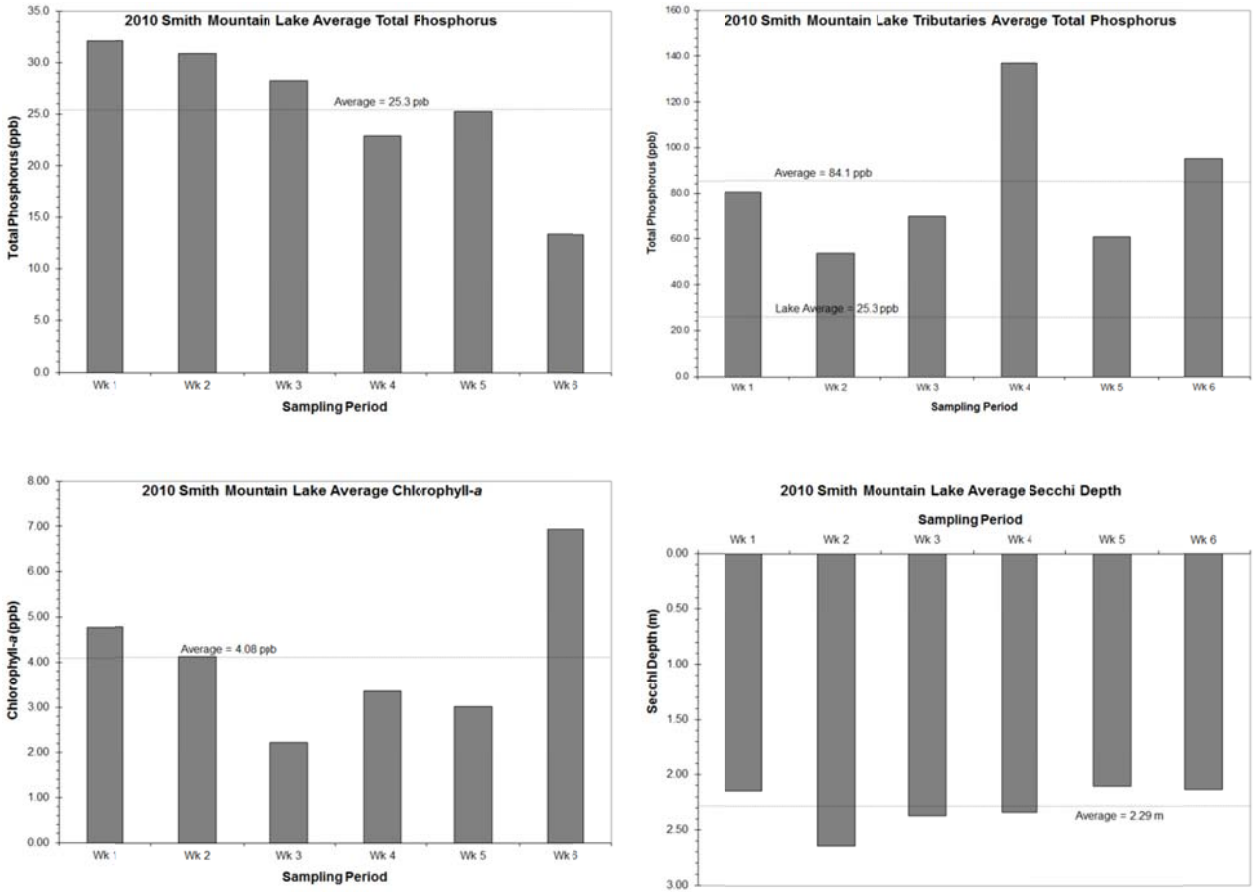


Figure 4.1. Trophic status parameters (total phosphorus, chlorophyll-*a*, and Secchi depth) for Smith Mountain Lake for each sampling period in 2010

The complete results for total phosphorus concentration for the 2010 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 six sampling periods was 25.3 ppb. The highest average lake concentration was observed in week 1 (32.1 ppb) and the lowest

average concentration was observed in week 6 (13.4 ppb). The average total phosphorus concentration for tributary sampling sites over all six sampling periods was 84.1 ppb. The highest average tributary concentration was observed in week 4 (136.8 ppb) and the lowest average concentration was observed in week 2 (53.9 ppb).

The complete results for chlorophyll-*a* concentration for the 2010 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 4.1 ppb. The highest average lake concentration was observed in week 6 (6.9 ppb) and the lowest average concentration was observed in week 3 (2.2 ppb).

The complete results for Secchi depth for the 2010 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 2.3 m. The highest average Secchi depth was observed in week 2 (2.6 m) and the lowest average Secchi depth was observed in week 5 (2.1 m). There is a very wide range of variance (±0.90 m over all sample sites and all dates sampled) due to the wide range of depth from the headwaters to the dam.

On average, the total phosphorus concentrations for 2010 were lower for the lake and slightly higher for the tributaries than in 2009 and the ten-year averages. Chlorophyll-*a* concentration decreased in 2010 relative to 2009 and Secchi depth increased (see Table 4.2).

Table 4.2. 2010 average trophic status parameters and relative change from 2009 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)
2010	25.3 (–10.3%)	84.1 (+1.2%)	4.1 (–4.9%)	2.3 (+4.3%)

4.4 Discussion

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.

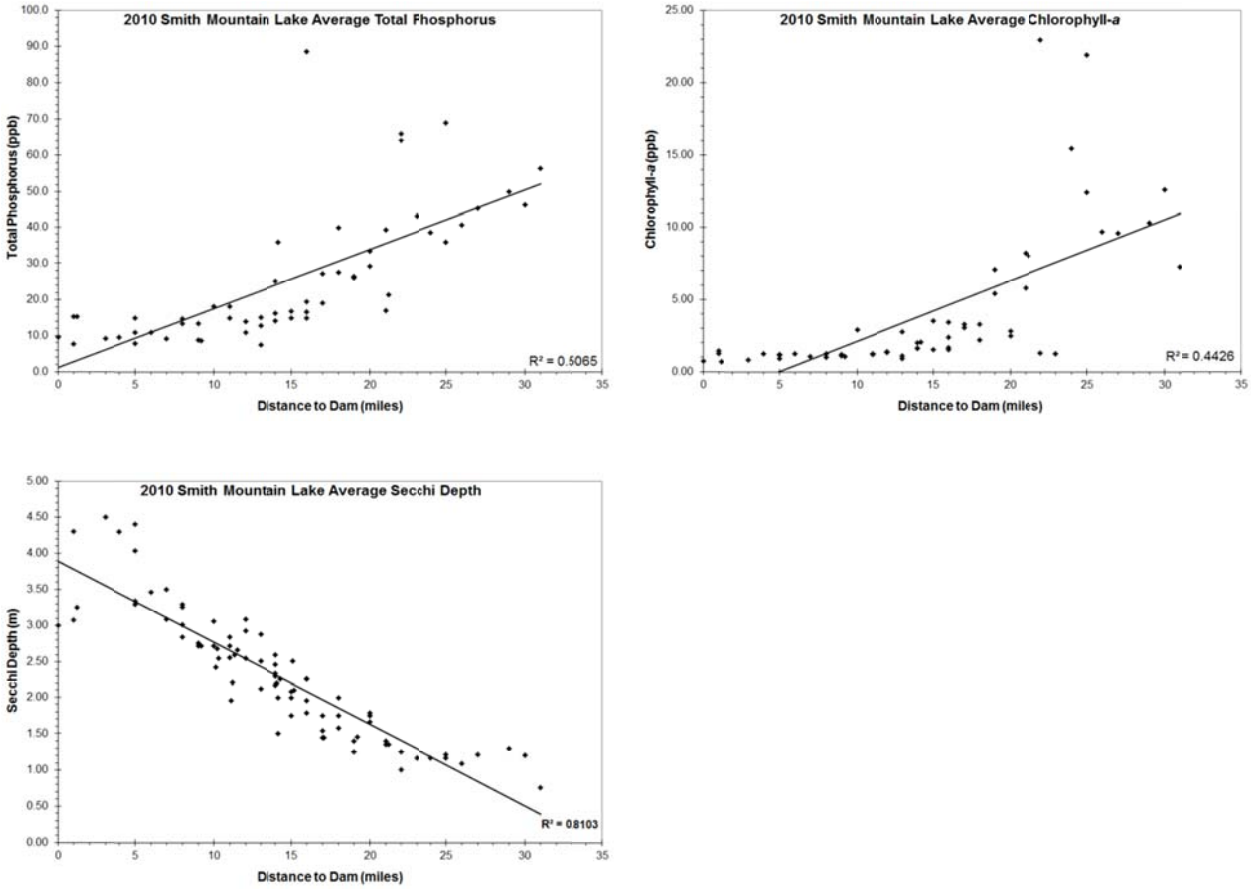


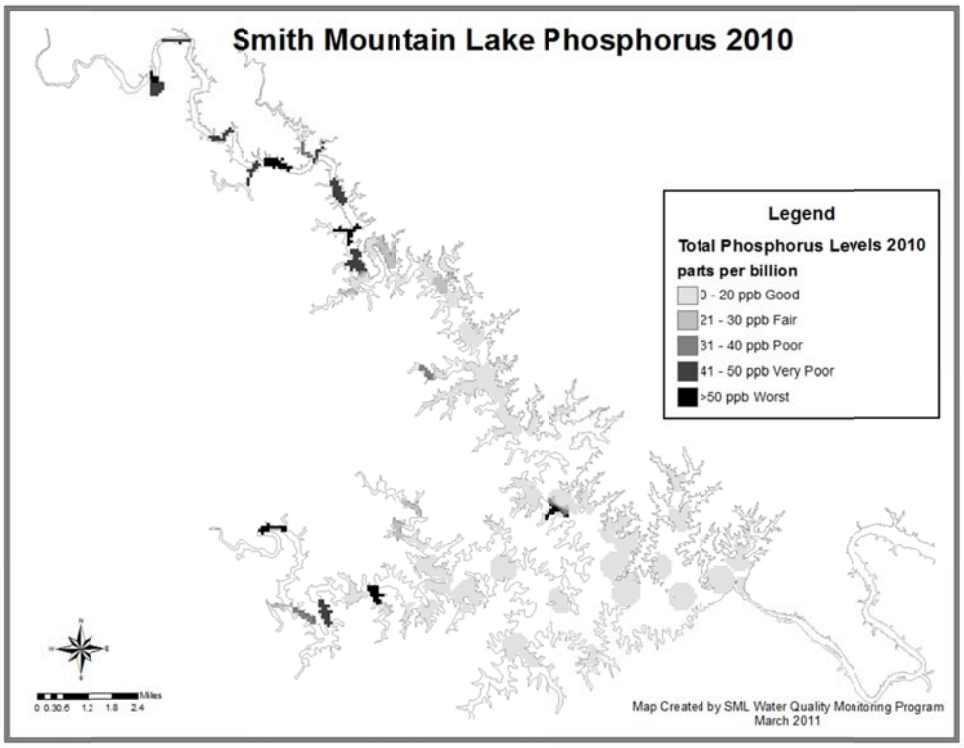
Figure 4.2. Variation of trophic status parameters with distance to the dam for Smith Mountain Lake in 2010

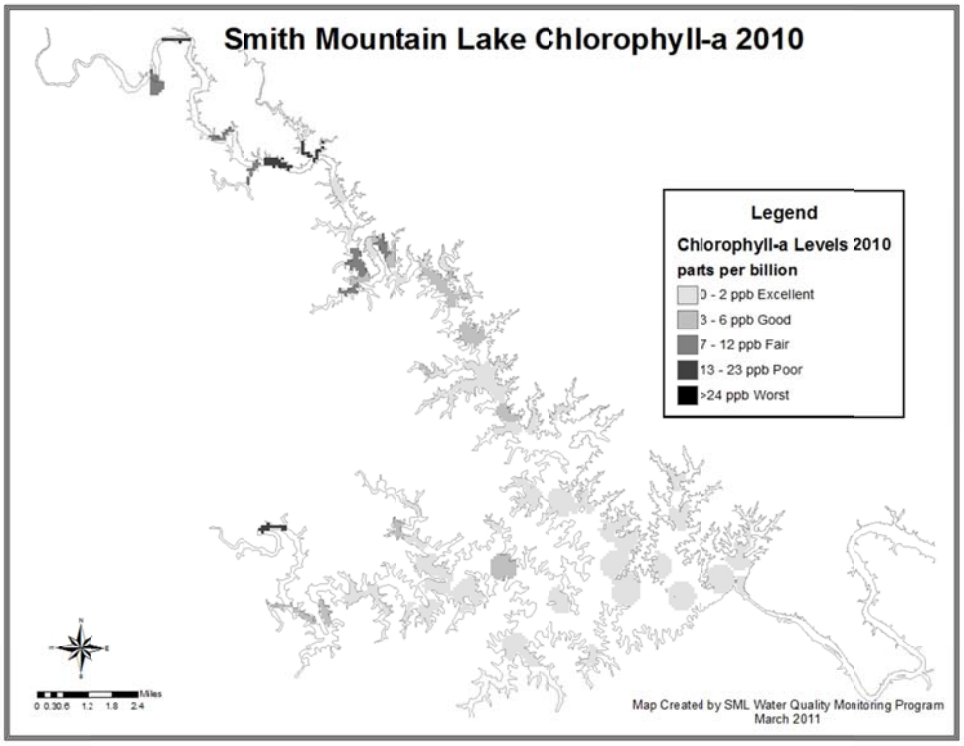
Total phosphorus concentration and chlorophyll-*a* concentration both show a significant trend (R^2 = 0.5065 and 0.4426, respectively) where concentration increases directly as distance to the dam increases. For total phosphorus, sample sites that differ from the general trend seem to fall into two general 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.

Chlorophyll-*a* shows a less significant trend than total phosphorus with distance to the dam. 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.

Secchi depth shows a significant inverse correlation with distance to the dam (Secchi depth decreases as distance to the dam increases, $R^2 = 0.8103$). This is consistent with the general observation that water is clearer in the main basin of the lake than it is in individual coves and in the channels that extend away from the dam and toward the tributaries. This decrease in clarity is due to increased sediment load and increased algal activity.

Figure 4.3 (below) shows GIS maps of the three trophic status parameters and gives a more intuitive display of the distance-to-dam correlations.





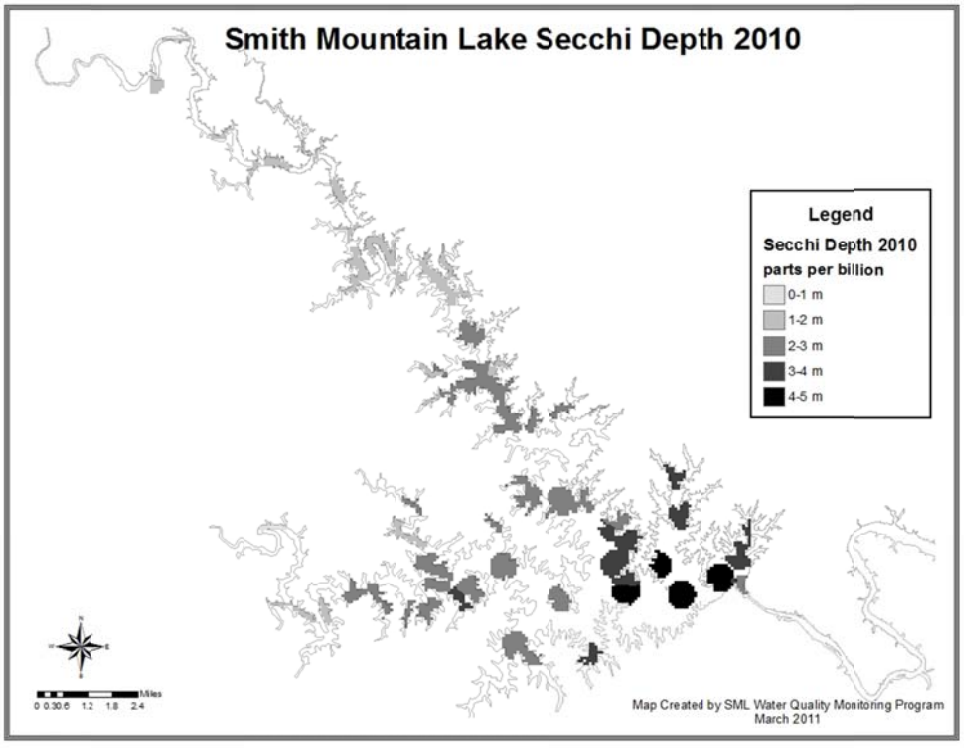


Figure 4.3. GIS maps showing variation in trophic status parameters across Smith Mountain Lake for 2010

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. 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	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***Avg***
Average Lake Total Phosphorus (ppb)	***33.3***	***35.8***	***59.2***	***28.0***	***28.9***	***32.2***	***34.5***	***29.3***	***27.9***	***25.3***	***33.4***
Average Tributary Total Phosphorus (ppb)	***67.1***	***125.8***	***88.1***	***87.9***	***95.3***	***76.8***	***67.1***	***76.5***	***65.8***	***84.1***	***83.4***
T9 (Roanoke River below dam)	25.1	26.3	29.2	17.8	19.0	14.0	14.0	18.1	14.4	8.7	***18.7***
T10 (Pigg River at Route 605)	86.0	119.1	114.6	76.6	158.9	64.5	50.8	74.2	59.5	51.9	***85.6***
T11 (Roanoke River at Route 608)	33.2	38.3	56.8	53.8	45.1	25.7	46.9	27.8	23.5	17.8	***36.9***
Annual Average	***48.1***	***61.2***	***66.9***	***49.4***	***74.3***	***34.7***	***37.2***	***40.0***	***38.6***	***39.0***	***48.9***

In 2010, the average total phosphorus concentration in the below-dam sites remained lower than their 10-year averages, as did the concentration in Smith Mountain Lake. The tributaries increased slightly in average total phosphorus. The below-dam sites average total phosphorus concentrations were only slightly higher than the overall average for Smith Mountain Lake.

4.5 Conclusions

Overall, the trophic status of Smith Mountain Lake improved slightly in 2010 compared to 2009. Although the tributaries showed a slight increase in nutrient input as total phosphorus, the other trophic status parameters all improved (decrease in total phosphorus and chlorophyll-*a* and increase in Secchi depth).

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.

5. ALGAE IN SMITH MOUNTAIN LAKE

5.1 Algae Monitoring Methods

In 2010 plankton tow samples were 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 five 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 ten meters. The tow sample was preserved by adding 1 ml of Lugol's solution to the 100 ml sample. The phytoplankton counting procedure follows the field method outlined in Standard Methods for Water and Wastewater analysis (APHA, 1999). Using fifty fields of a Sedgwick Rafter cell, the algae were identified, counted and recorded.

5.2 Algae Monitoring 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 for each sample date for the horizontal tows. Figure 5.5 shows the averages of algae type by sample site type. Figure 5.6 shows the average of algae types for each sample period across the entire lake. Figure 5.7 shows the algal totals by group for vertical tow samples of the profile sample sites, their relative distance from the dam, and the trend lines associated with the algal groups. Figure 5.8 shows the relative populations of the different algal groups averaged over all sites and all sample dates.

No significant trend is observed in algae populations relative to the type of site sampled or the date sampled. In 2009, the sites that have less influence from human activity (non-marina sites and profile sites) had higher levels of diatoms and lower levels of green algae and blue green algae, usually an indication of better water quality. In 2010, the headwaters had the highest algal populations with non-marina sites having the second highest algal populations. The highest blue green alga populations were observed at three sites on the first week of sampling (June 1): Ponderosa Campground Cove, Foxsport Marina, and Palmer's Trailer Park. Usually the highest populations of blue green algae occur at the end of the summer when the water is warm and sunlight is abundant but this is not true of Smith Mountain Lake this year.

When the sample sites are combined and compared to sample dates, the earliest sample date, June 1, has the greatest abundance of algae, which was also true in 2009. In 2010, the abundance of green algae is not expected because diatoms usually dominate over the other algal groups in early summer due to the colder water and lower light levels. This may be indicative of the input of phosphorus (algal nutrient which encourages growth) due to runoff in the spring of 2010. The blue green algal population decreases as the summer continues while an increase in green algae proceeds until it dominates the algal population in August (Figure 5.6). It should be noted that green algae dominated in 5 of 5 of the sampling dates (there is missing sample data from one sample date in 2010).

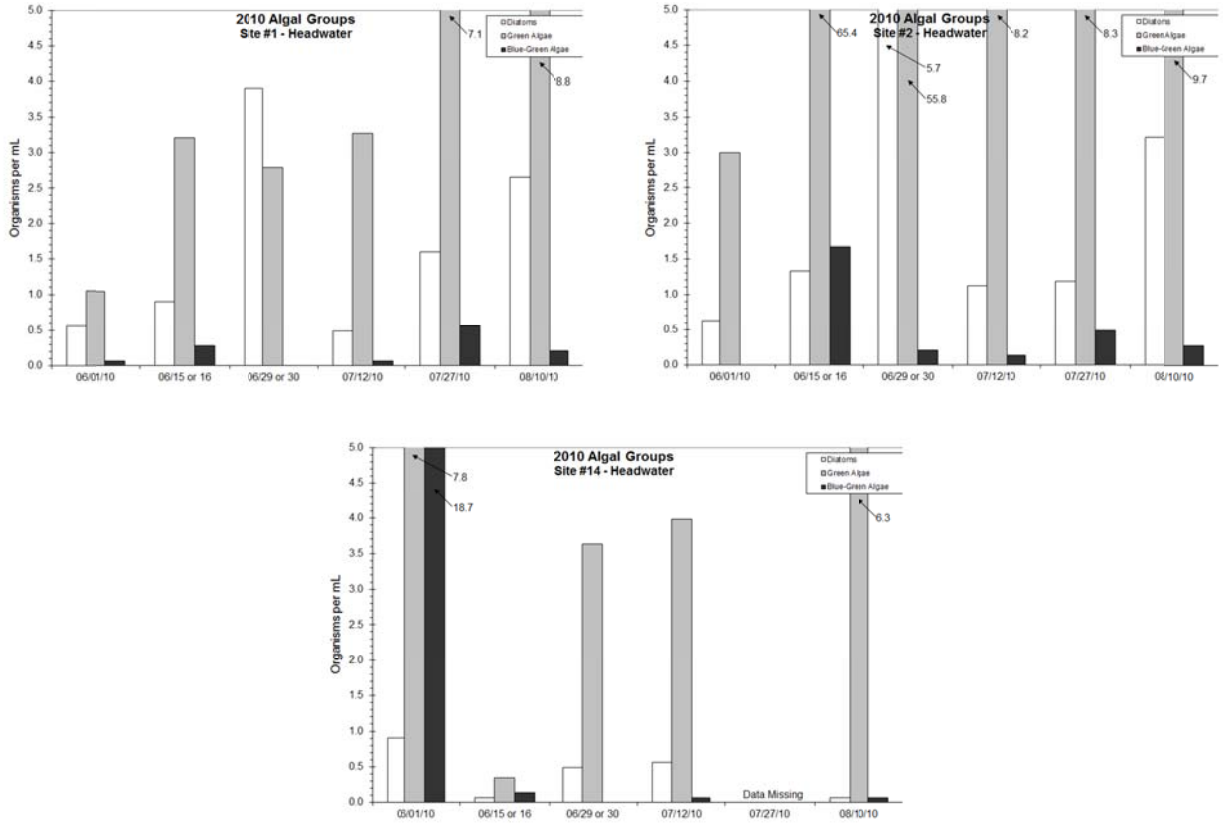


Figure 5.1. Algal groups vs. week sampled on Smith Mountain Lake in 2010 from headwaters sites (Sites 1, 2, and 14).

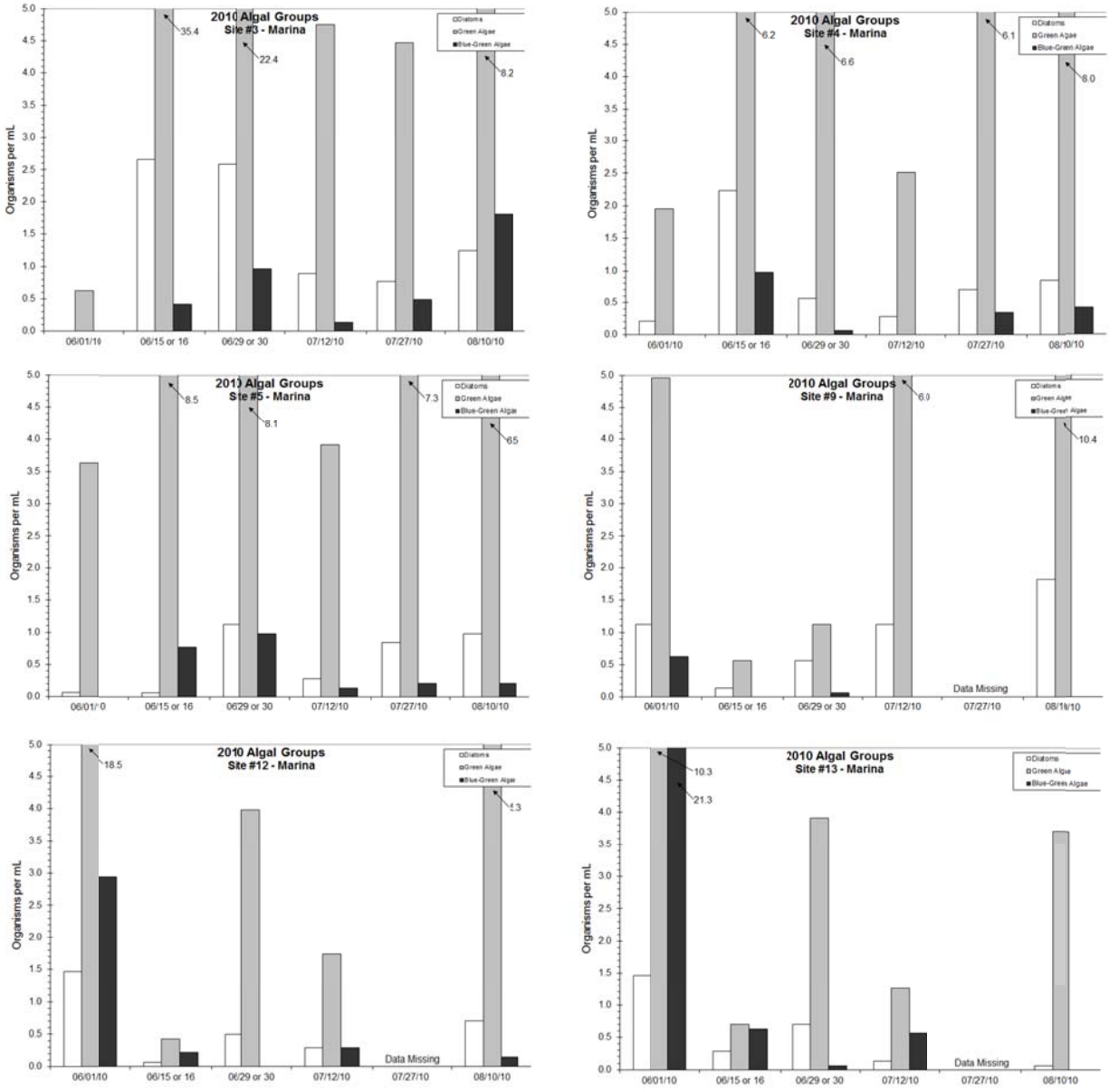


Figure 5.2. Algal groups vs. week sampled on Smith Mountain Lake in 2010 from marina sites (Sites 3, 4, 5, 9, 12, and 13).

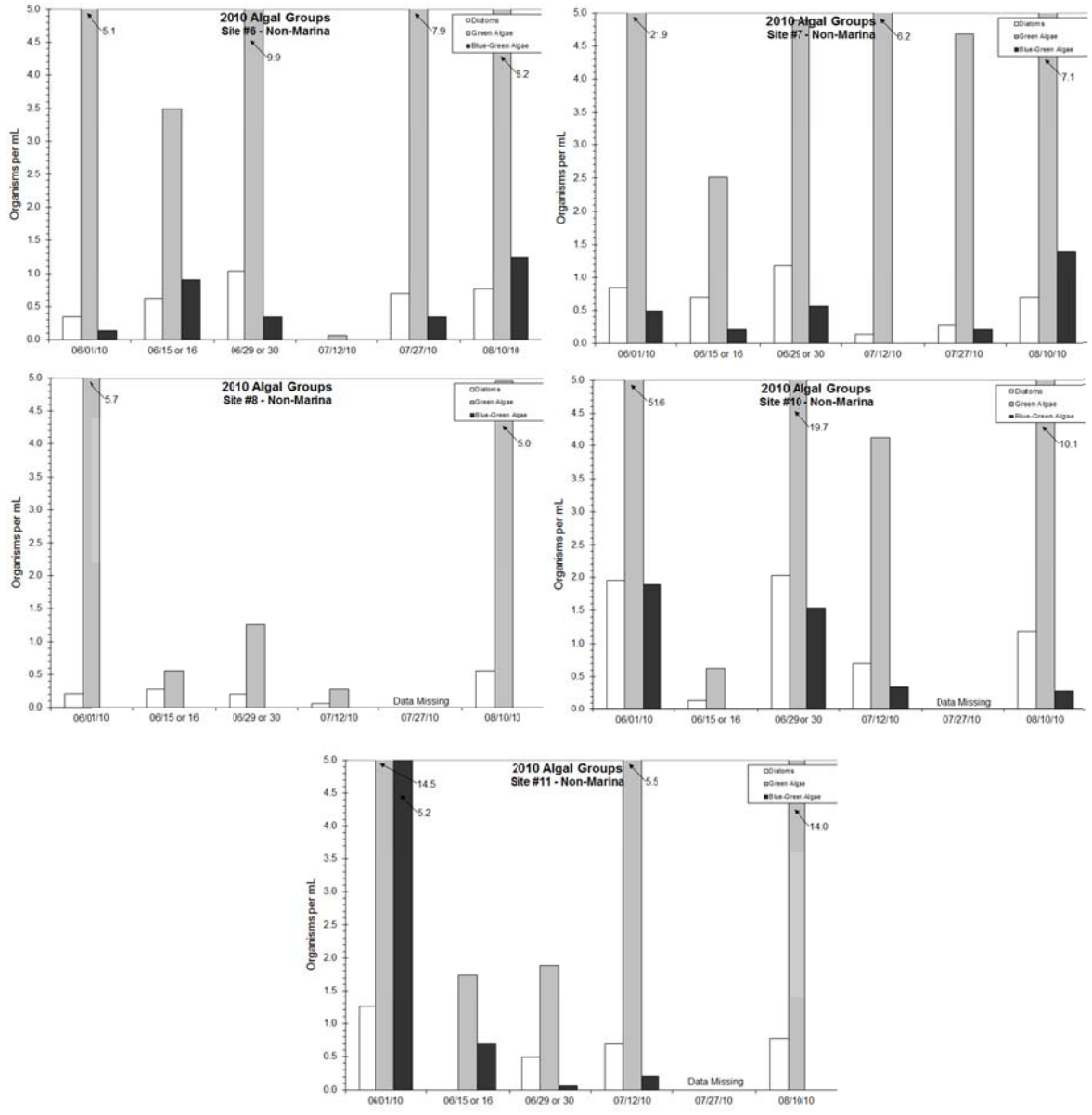


Figure 5.3. Algal groups vs. week sampled on Smith Mountain Lake in 2010 from non-marina sites (Sites 6, 7, 8, 10, and 11).

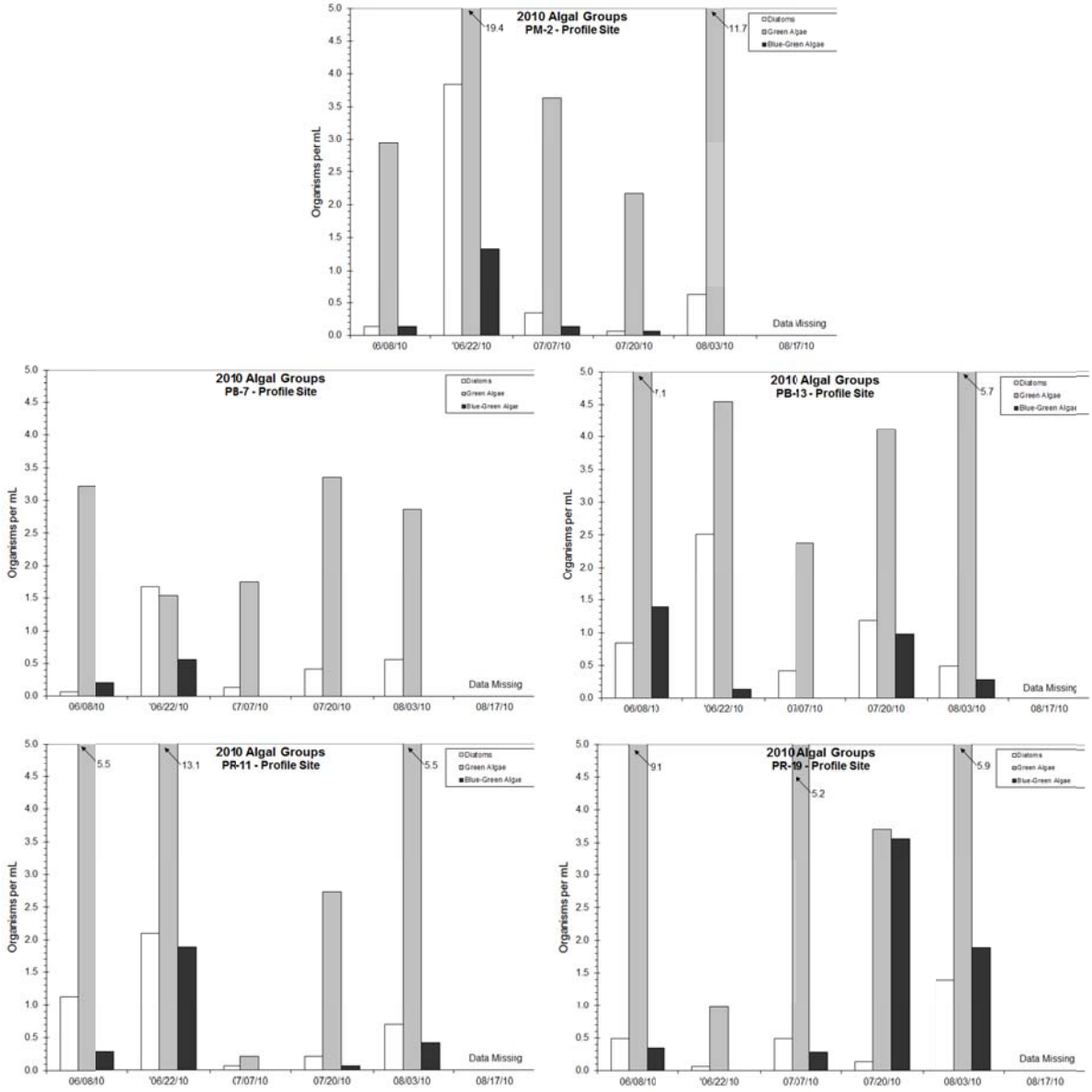


Figure 5.4. Algal groups vs. week sampled on Smith Mountain Lake in 2010 from profile sites (Sites PM-2, PB-7, PB-13, PR-11, and PR-19).

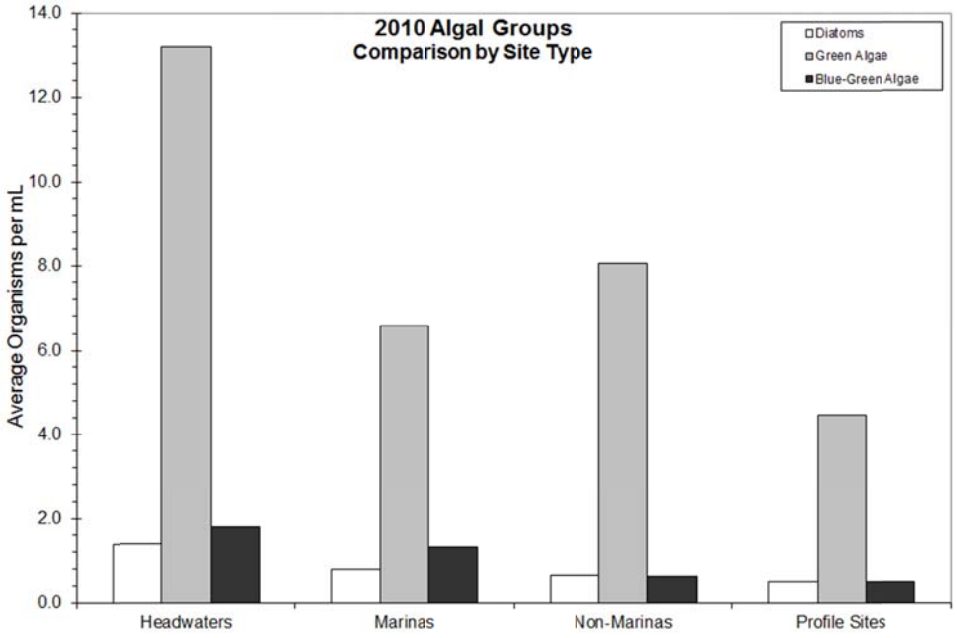


Figure 5.5. Comparison of algal groups' abundance sampled on Smith Mountain Lake in 2010 by site type

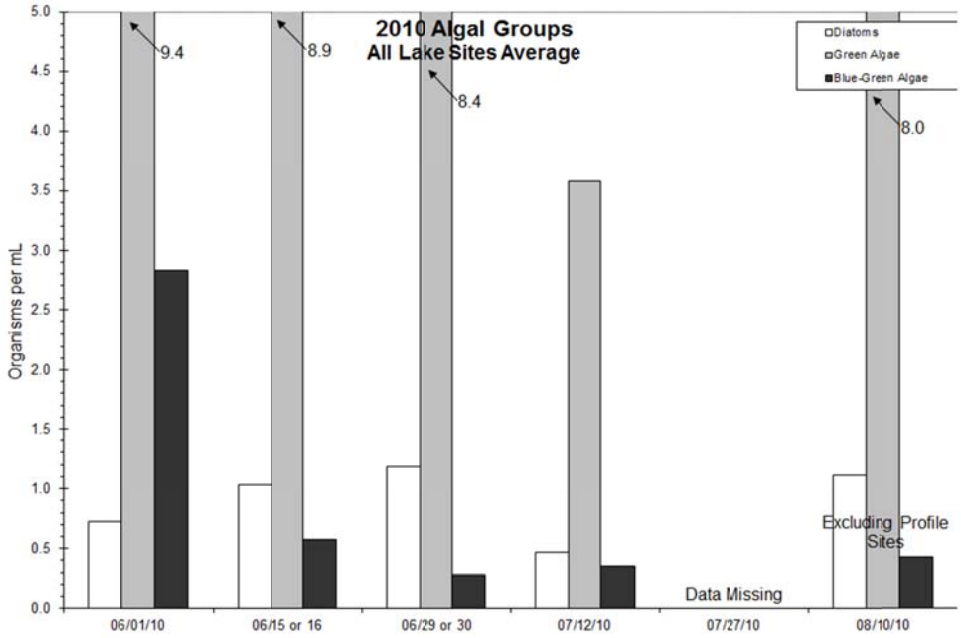


Figure 5.6. Algal groups vs. week sampled on Smith Mountain Lake in 2010 from all lake sites.

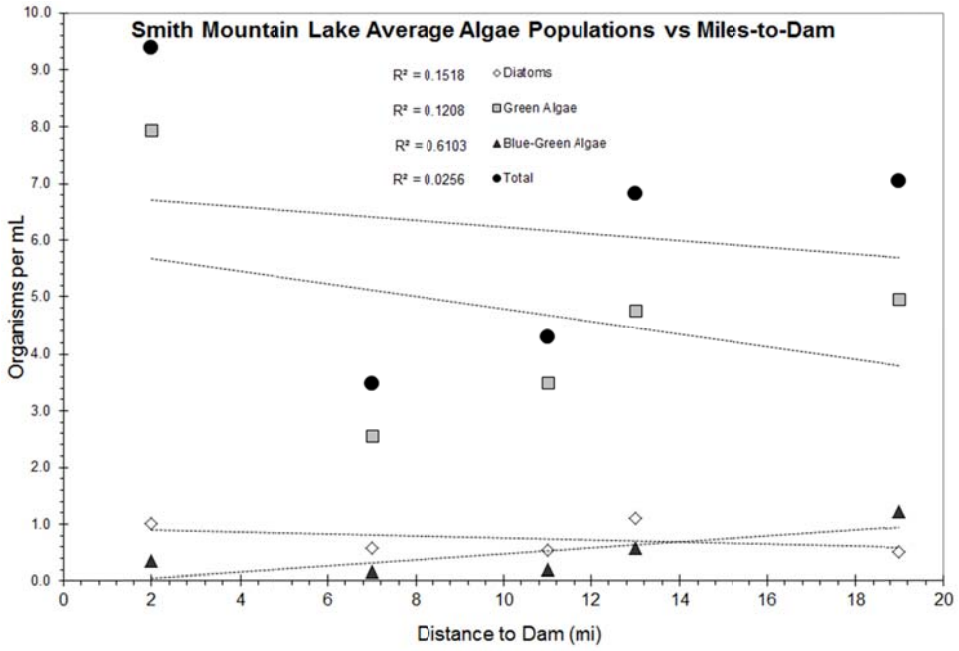


Figure 5.7. Algal groups vs. miles to the dam sampled on Smith Mountain Lake from the five profile sites sampled

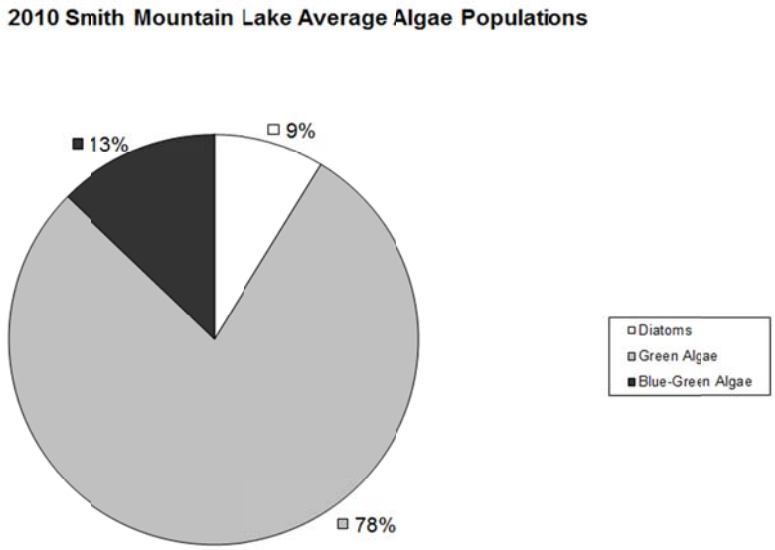


Figure 5.8. Algal groups' abundance sampled on Smith Mountain Lake in 2010 from all sample sites sampled over the summer

The graph showing the algal groups' abundance compared to miles from the dam (Figure 5.6) shows a weak trend in 2010 as in previous years in total algal abundance indicating that the farther up the Roanoke and Blackwater channels, the higher the algal populations, which correlates to higher phosphorus concentrations in those areas of the lake. There is an increase in the blue green populations with increasing miles from the dam in 2010 as in 2009.

In 2010 the most abundant algal population groups found in Smith Mountain Lake were the green algae (78 percent), with blue green algae at 13 percent and diatoms at 9 percent.

We must continue to monitor this trend 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.

In 2010 the results of the algae population studies is good news and reflects what we have found in both total phosphorus concentrations and chlorophyll-*a* concentrations.

6. DISSOLVED OXYGEN (DO) PROFILES

6.1 Introduction

Since 2005, we have been collecting dissolved oxygen (DO) depth profiles on Smith Mountain Lake. 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 where solar energy has increased the temperature of surface waters (called the *epilimnion*) and caused a transition zone of rapidly changing temperature (known as the *thermocline*) that acts as a physical barrier from lower-temperature bottom waters (called the *hypolimnion*). Nutrient enrichment permits an increase in algal production, and the resulting organic matter leads to oxygen depletion in the lower layer of the lake as it decomposes. This significantly affects the biota, including fish populations. DO depth profiles can increase the sensitivity of trophic state analysis and give early indications of nutrient enrichment.

6.2 Methods

Depth profiles were obtained using an In-Situ™ Troll 9000 Profiler multi-sensor probe with Rugged Reader™ and 200 feet of cable for five sample sites on Smith Mountain Lake on six days in 2010: June 8, June 22, July 7, July 20, August 3, and August 17. The five sample sites were selected to represent the major portions 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, respectively, and PR-11 and PR-19 are in the Roanoke River channel eleven and nineteen miles from the dam, respectively (See Figure A.3 in the Appendix of this report). For each depth profile, parameter readings were logged at the surface (approximately 0.250 m depth) and at each meter of depth 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 depth sensor provides accurate depth readings for each measurement and it is these depths that are used to determine when to record (“log”) data from all the sensors in the probe 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. Because of weather conditions on August 17, a depth profile was not obtained for site PR-19 on that date.

6.3 Results

The depth profile results are included in the following four figures: temperature (Figure 6.1), dissolved oxygen (Figure 6.2), pH (Figure 6.3), and conductivity (Figure 6.4). (Note that PR-19 has no data for August 17.)

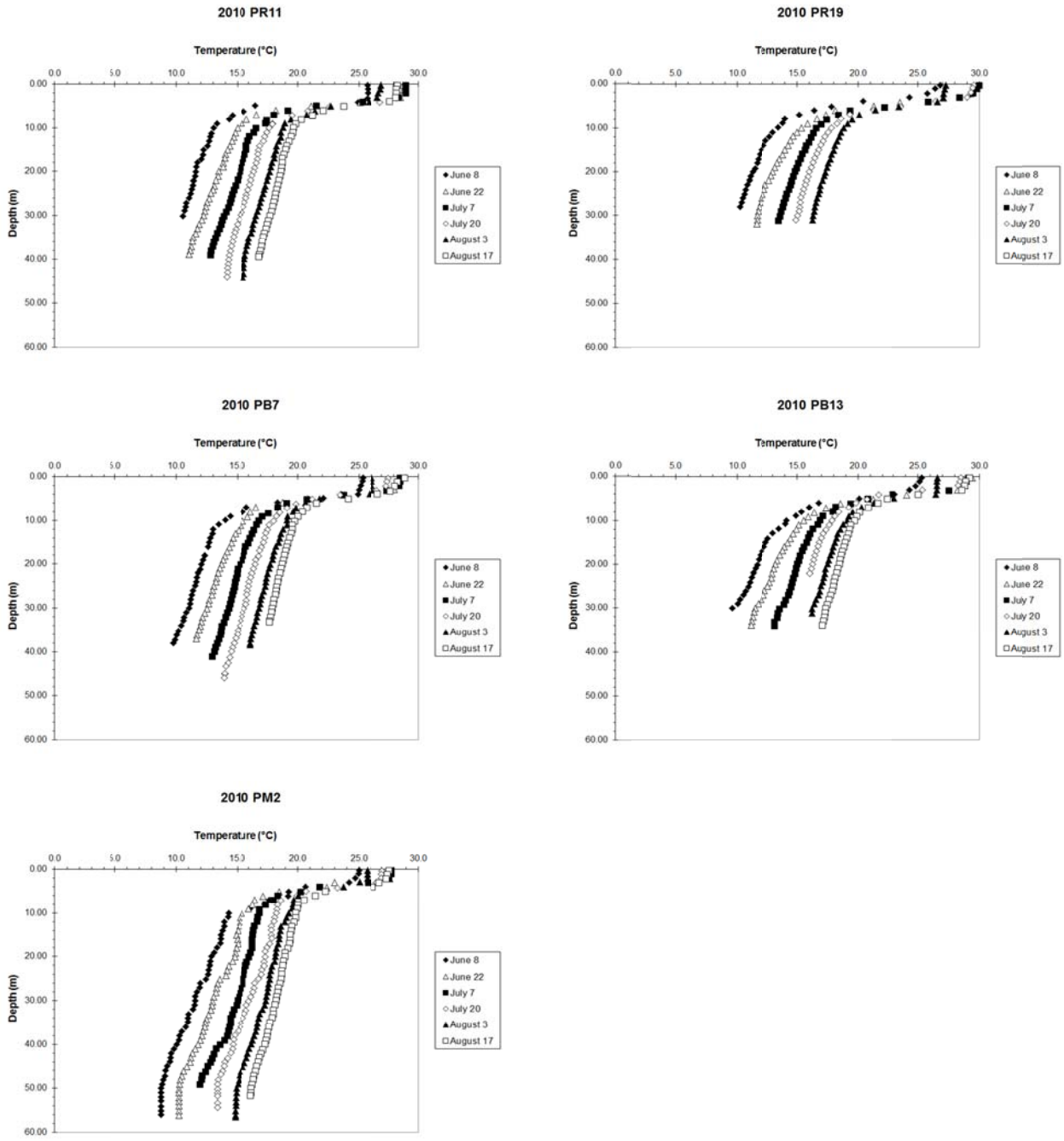


Figure 6.1. Temperature depth profiles for Smith Mountain Lake in 2010

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 and uniformly from the first sampling event through the sixth sampling event.

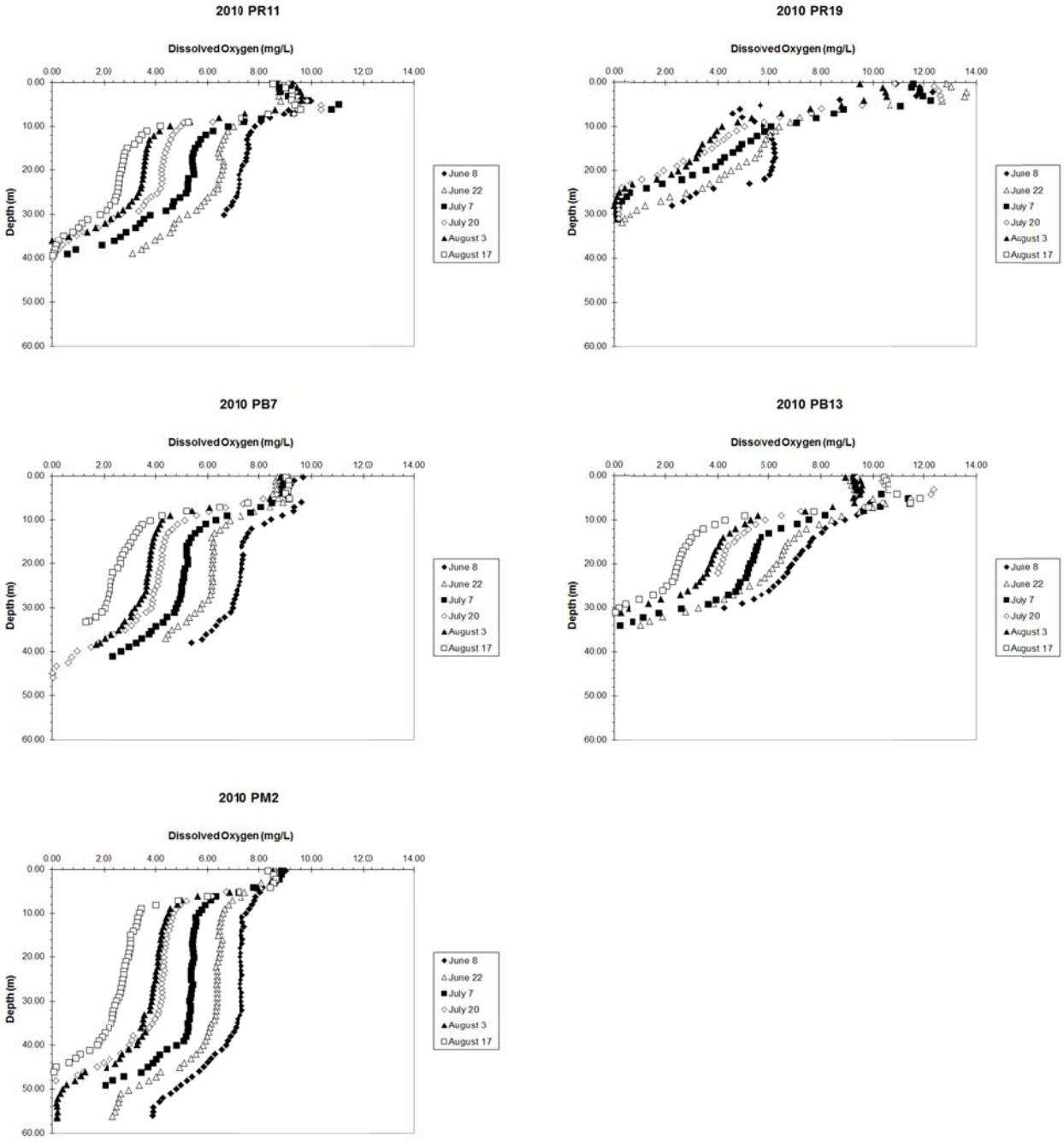


Figure 6.2. Dissolved oxygen depth profiles for Smith Mountain Lake in 2010

For the three sample sites closest to the dam, it appears that dissolved oxygen concentrations decreased steadily over the course of the sampling season. Above the thermocline, all sample sites were supersaturated in oxygen for all sample dates, indicating the presence of algal photosynthesis. All five sites showed anoxic conditions near the lake bottom starting in July.

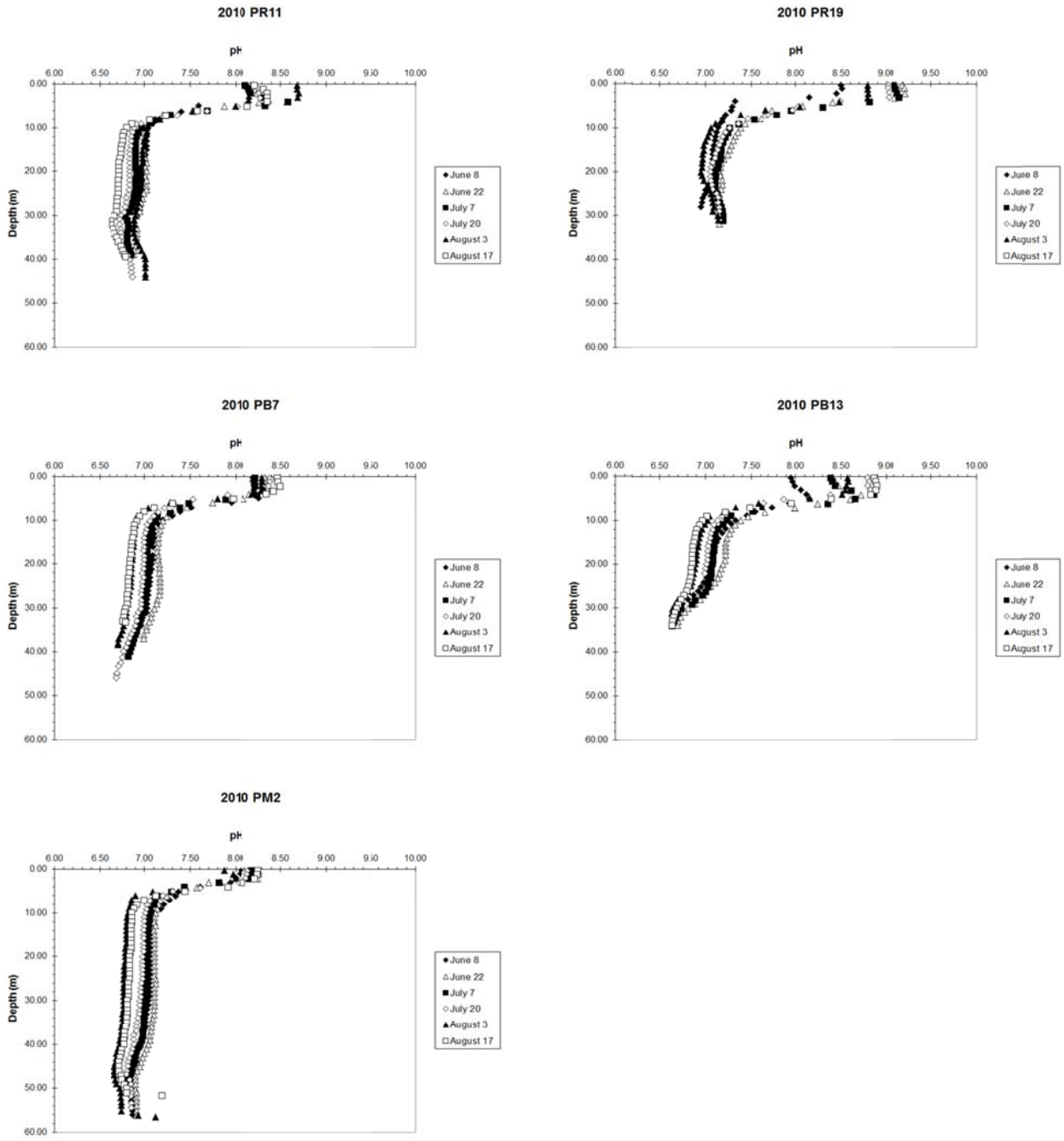


Figure 6.3. pH depth profiles for Smith Mountain Lake for 2010

All pH depth profiles showed slightly alkaline conditions in the epilimnion, which is to be expected given the level of photosynthetic activity demonstrated by the dissolved oxygen depth profiles. Below the thermocline, pH conditions were quite consistent at approximately 7.0.

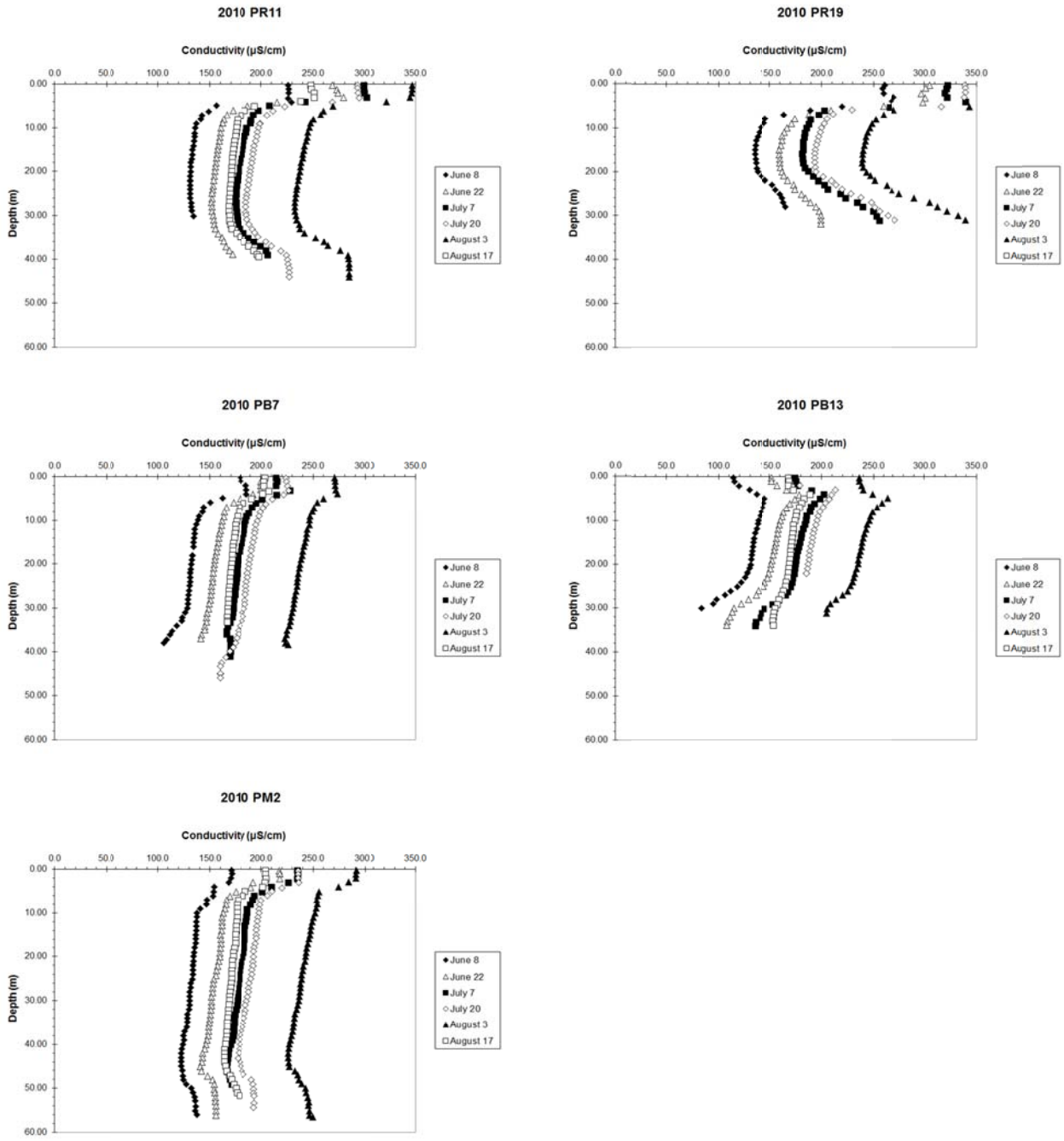


Figure 6.4. Conductivity depth profiles for Smith Mountain Lake for 2010

Conductivity depth 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 show a slight trend toward lower conductivity (if any trend at all).

6.4 Discussion

All of the depth profiles except conductivity showed similar trends to the data obtained in the previous four years. Figure 6.5 shows the average depth profiles for 2010; visual comparison with the same data for 2009 indicates that the average depth profiles for 2010 are indistinguishable from those for 2009.

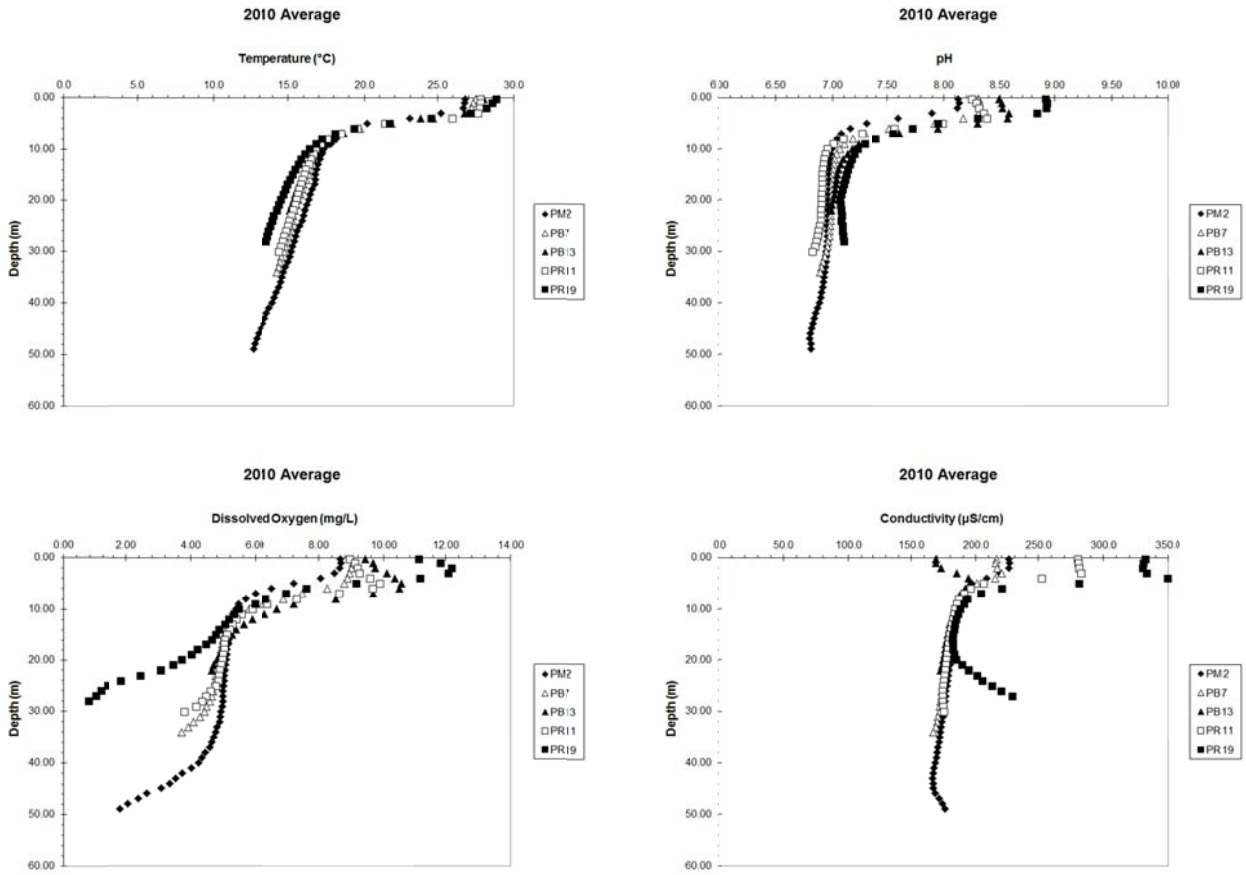


Figure 6.5. Average depth profiles for 2010 for each parameter sampled on Smith Mountain Lake by sample site

There was significant oxygen depletion observed for PR19, but some depletion was also taking place at PM2. Overall, the average depth profiles for each parameter were consistent with those obtained since the initiation of this study.

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. For 2010, we can conclude that the depth profile data are consistent with a healthy lake

with a small amount of nutrient enrichment and an appropriate level of resulting algal activity.

7. BACTERIA IN SMITH MOUNTAIN LAKE

7.1 Methods

Bacterial analysis in Smith Mountain Lake included *Escherichia coli* (*E. coli*) monitoring and bacterial source tracking using *Enterococcus faecalis*. In 2010, as in 2004–2008, the method used in the bacterial analyses measured the *E. coli* populations instead of fecal coliform populations. This change reflects the revision in the Commonwealth of Virginia's bacterial standard, which uses *E. coli* as the indicator organism rather than fecal coliform.

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 (cfus) 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 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 2010, we took samples for ARA at tributary sites twice, at the beginning of the summer (June, 22 sites) and toward the end (August, 21 sites) of the summer.

7.2 *Escherichia coli* Monitoring

Since 2004, the method used in the bacterial analyses measured the *Escherichia coli* (*E. coli*) populations instead of fecal coliform populations. This change reflects the revision in the Commonwealth of Virginia's bacterial standard as of 2008 which uses *E. coli* as the indicator organism rather than fecal coliform.

Water samples were collected from 14 sites on Smith Mountain Lake on June 1, June 15 and 16, June 29 and 30, July 12, July 27, and August 10. The methods employed to monitor bacteria are described earlier in this report. The quality control and quality assurance methods for bacterial monitoring are described in a later section of this report.

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 (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)
Smith Mountain Yacht Club on the Bedford County side of the lake. (Site 4)
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) 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 (site 5, formerly Shoreline Marina) which is up Becky's Creek, a tributary of the Roanoke channel in Franklin County and is a storage place for a few houseboats and may have people living aboard their boats. Pelican Point Marina (site 12) is on the Blackwater channel in Franklin County and is a storage place for many large sailboats and a few houseboats. Smith Mountain Lake Dock (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. 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. Foxsport Marina (site 13) 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 is being included in the headwaters sites again. The marina is one of the oldest marinas on the Franklin County side of the lake and has been included in the marina designation in previous reports. 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.

Figure 7.1 indicates the mean *E. coli* most probable number in the population (commonly called MPN), for the six sample dates in 2010. Figure 7.2 indicates the 2010 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 2010 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 GIS map showing the results of bacterial sampling throughout the lake for 2010.

7.2.1 Results

1. The means of *E. coli* populations for each station averaged over the six sample periods for 2010 were once again below the Virginia health standard for recreational waters (standard is 126 cfus/100 mL) at all sites. Generally the bacteria populations increase with the increase in runoff that results from an increase in rainfall amount and frequency; however, although 2010 (as in 2009) exhibited close to average rainfall amounts, the bacteria population only increased slightly from 7.5 MPN to 12.9 MPN.

2. The mean bacterial counts and variances for marinas in 2010 (10.9 $\pm$ 10.4 MPN) are 18 percent lower than the 2010 non-marinas' bacteria counts (12.9 $\pm$ 15.2 MPN) and 56 percent lower than the headwaters bacterial counts (17.0 $\pm$ 21.5 MPN). None of these bacterial counts

are significantly different from each other and are not significantly different than zero. In 2010 the bacterial counts were slightly higher than in 2009 for all site types.

3. As in previous years, *E. coli* population estimates in 2010 were highly variable over time (Figure 7.1), with week 5 exhibiting the highest mean number of bacteria (41.1 MPN). The lowest mean number of bacteria occurred week 6 and was 3.4 MPN of bacteria.

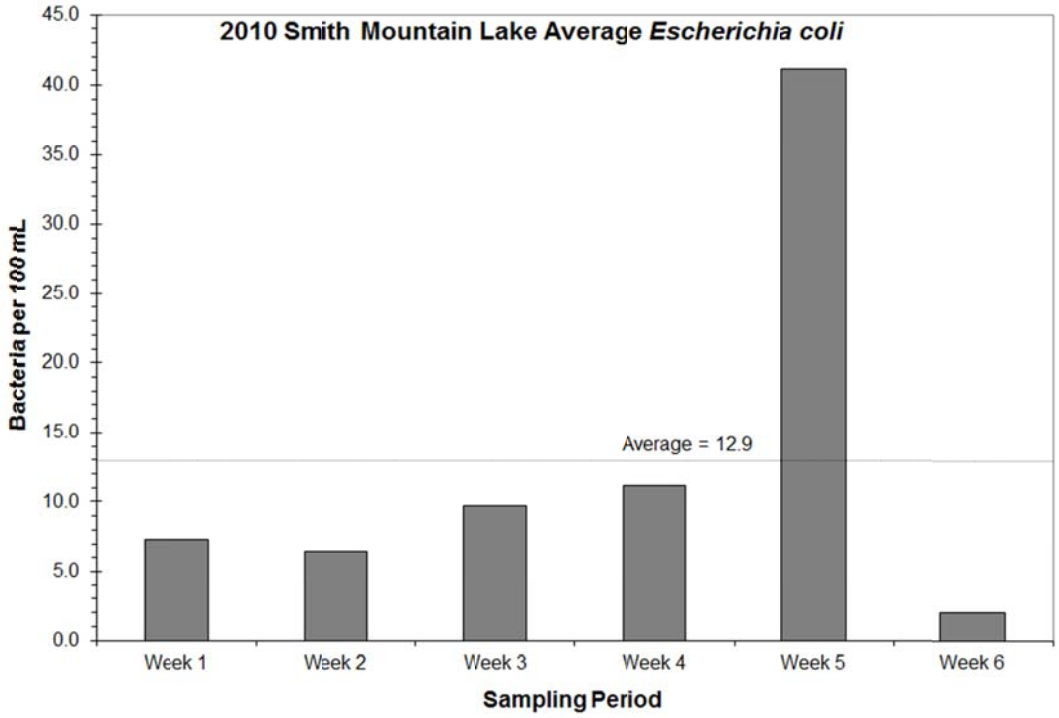


Figure 7.1. *E. coli* vs. week sampled on Smith Mountain Lake in 2010
(Each sample date included 14 sites with 2 samples per site, n =28)

4. The highest *E. coli* counts of the summer were at Bay Roc Marina on the Roanoke channel, (320.6 MPN), Forest Cove (261.4 MPN), Palmer' Trailer Park Cove (209.5 MPN), and Smith Mountain Dock and Lodge (158.0 MPN), all during week 5. All of these values exceeded the Virginia Department of Health (VDH) standard for recreational waters.

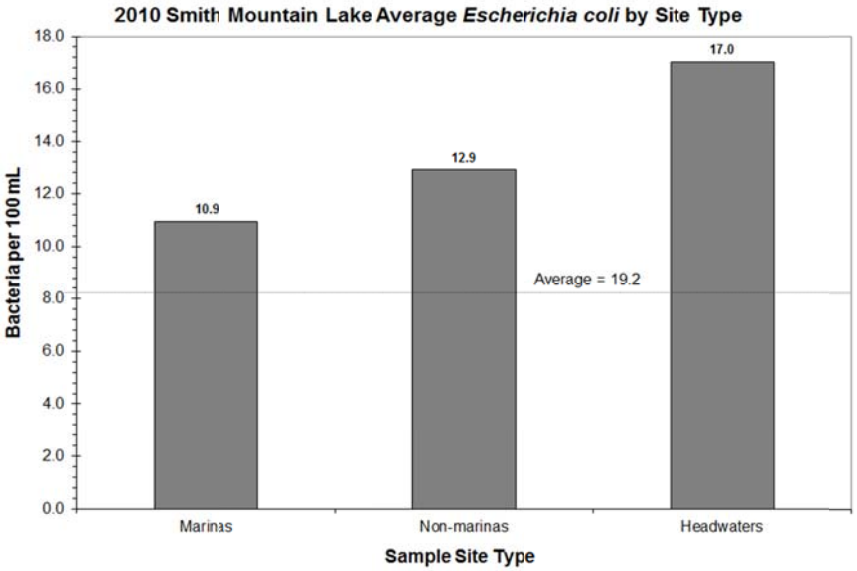


Figure 7.2. Mean *E. coli* count vs. site type on Smith Mountain Lake in 2010
(6 marina sites, 5 non-marina sites, and 3 headwater sites)

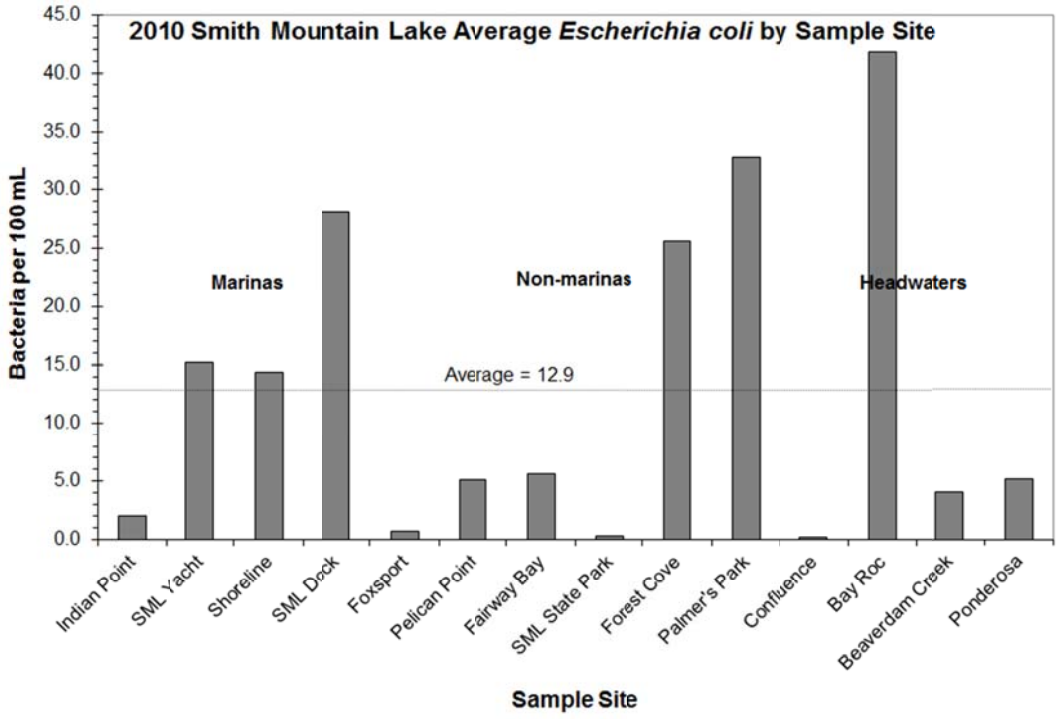


Figure 7.3. Mean *E. coli* count vs. sample site on Smith Mountain Lake in 2010
(Each site has two stations sampled 6 times during the summer)

5. The marina site with the lowest mean *E. coli* count was Foxsport Marina in 2010 as in 2009 (0.8 MPN) with Indian Point Marina being second lowest with a mean of 2.1 MPN. The confluence of the two main tributaries (site 10) and Smith Mountain Lake State Park Cove

(site 7) had the lowest mean *E. coli* counts (0.3 MPN) and 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).

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 and therefore it is difficult to show significant statistical differences among sites.

7. In a comparison of the sums of *E. coli* populations for sample dates and sites in 2010 (Figure 7.4), Bay Roc Marina and the Palmer's Trailer Park Cove (headwaters site and non-marina site, respectively) have the highest sum of *E. coli* populations, which is different than in 2009 (Ponderosa Campground Cove and the SML Yacht Club had the highest bacterial counts). Smith Mountain Lake State Park Cove, the confluence of the channels and Indian Point Marina had the lowest sums of *E. coli* populations for the summer of 2010 as they have for many years.

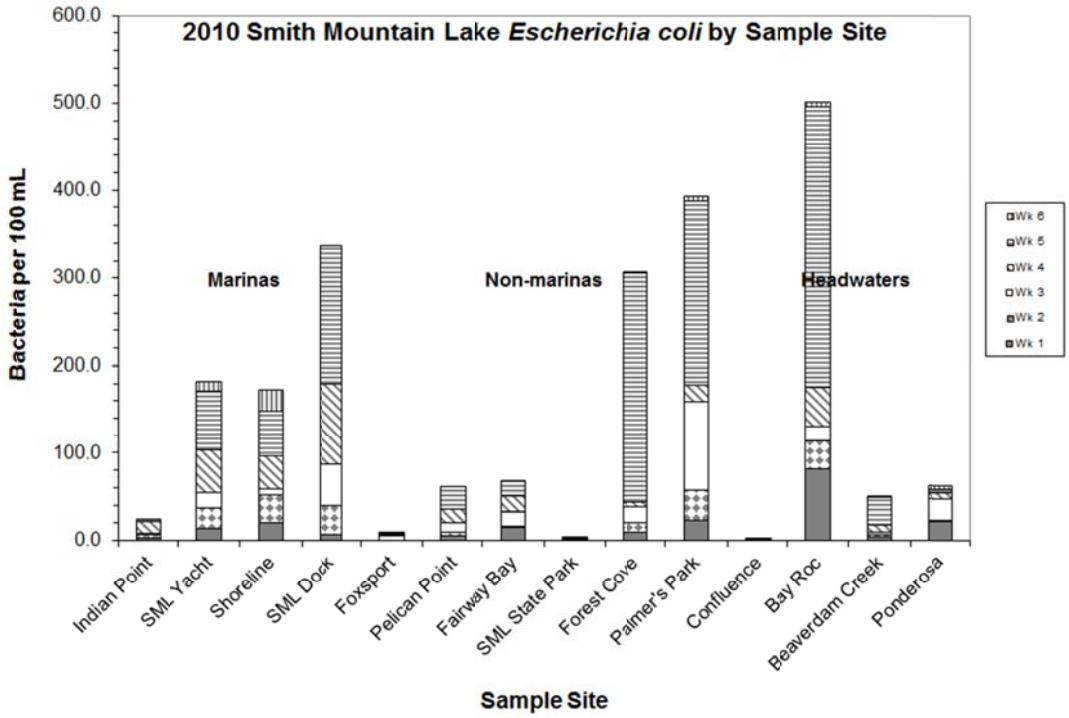


Figure 7.4. Sum of *E. coli* counts for Smith Mountain Lake in 2010 at each site for all sample dates

(There are two sampling stations at each site)

8. The mean fecal coliform counts for marina sites have been greater than the mean fecal coliform counts for the non-marina sites for six of the eight sample years (1996-2003). The two exceptions are 1997 and 1999. In 1999, the mean values were almost equal. In 2004 and in 2005, when *E. coli* populations were measured, the mean *E. coli* counts at marina sites were higher than the means at the non-marina and headwater sites; in 2006, the non-marina sites' mean was 37.9 percent higher than the marina sites' mean (Figure 7.5). Since 2007 the headwaters sites have been highest of all, followed by marina sites, and non-marina sites have been the lowest of all three site types.

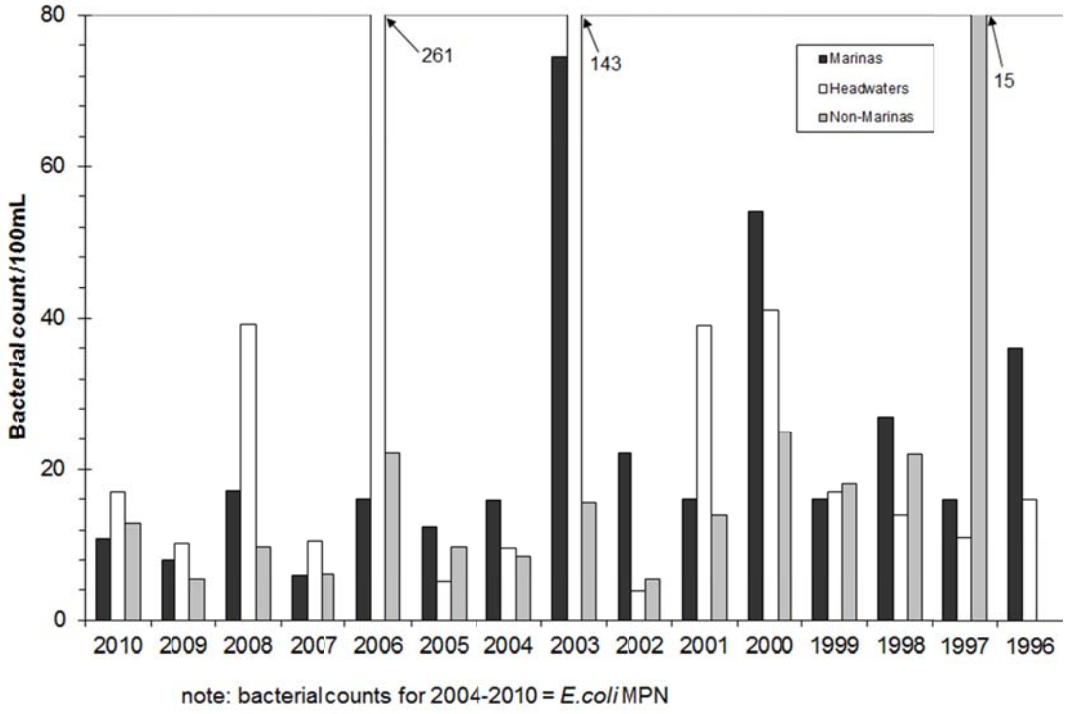


Figure 7.5. Mean *E. coli* or fecal coliform counts per site type and year sampled for Smith Mountain Lake from 1996-2010

7.2.2 Summary of Section

The bacteria populations, specifically *E. coli,* in Smith Mountain Lake in 2010 were higher than the 2008 and 2009 bacteria populations. Four of the sample sites on July 27th (fifth sample week) had *E. coli* values that exceeded the Virginia Health Department standards. The comparison of marinas and non-marinas showed no significant difference in *E. coli* values in 2010, which may be the result 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.

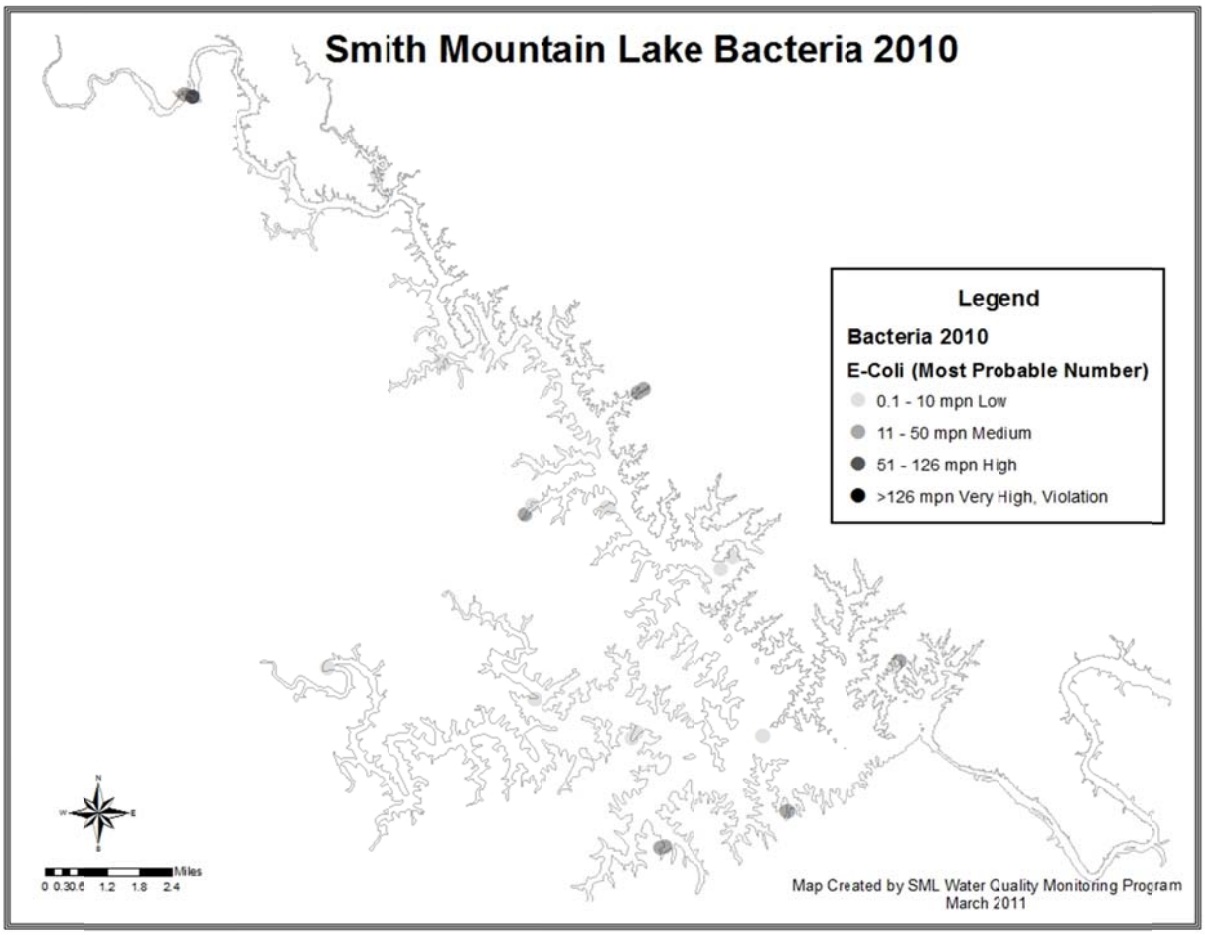


Figure 7.6. GIS map showing the results of bacterial sampling throughout the lake

7.3 Bacterial Source Tracking

7.3.1 Introduction

For 10 years (1995-2004) the fecal coliform population in the lake was evaluated by comparing 14 marina, non-marina, and headwater sites. From 2005 to 2010, only the *E. coli* populations were evaluated and, on occasion, the *E. coli* population exceeded 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 (beginning in 2002) since it was decided that knowing the source of these bacteria could be valuable in developing strategies for controlling bacteria in the lake.

In this report (2010) both the 2009 and the 2010 Bacterial Source Tracking will be reported because the 2009 report did not include the bacterial source tracking results. In 2009, the student sampling team took samples at twenty-one tributary sites in June and August. In 2010, the student sampling team took samples at twenty-two tributary sites in June and twenty-one tributary sites in August. Enterococci bacteria are the coliform bacteria used in the Antibiotic Resistance Assay method, which is used for bacterial source tracking.

7.3.2 Sample Sites

The sites sampled are the tributary sites that have been sampled for 13 years for nutrient levels and six years for enterococci. They are listed in Table 7.2, and a GIS map of the sites is shown in Figure A.2 in the Appendix.

7.3.3 Results

The results of the samples taken in 2009 and 2010 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 7.8-7.13) show the predicted sources (based on comparison to known sources) of the bacterial isolates from tributary water samples taken in 2009 and 2010. All tributaries had between 8 and 48 isolates (48 is the maximum tested per site) in the water sample with eighty-four percent (71 of 85) 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 from each tributary in 2009 and 2010

Tributary	# Isolates				Tributary	# Isolates			
Site	June '09	Aug. '09	June '10	Aug. '10	Site	June '09	Aug. '09	June '10	Aug. '10
T0 (Gills Creek)	42	48	44	48	T11 (Old 103)	32	42	16	29
T1 (Maggodee Creek)	38	48	41	45	T12 (Surrey Drive)	41	48	38	44
T2 (Gills Creek)	39	48	44	44	T13 (Snug Harbor)	48	48	48	48
T3 (Blackwater)	38	48	47	29	T14 (Stoney Creek)	44	48	45	48
T4 (Poplar Camp Creek)	39	48	48	43	T15 (Jumping Run)	47	46	48	48
T5 (Standiford Creek)	42	46	46	46	T16 (Beaver Dam Creek)	45	44	45	48
T6 (Bull Run Creek)	45	47	47	46	T17 (Hardy Ford Bridge)	48	8	13	47
T7 (Cool Branch Creek)	45	48	46	39	T18 (Lynville Creek)	45	46	43	47
T8 (Lumpkins Marina)	no sample	no sample	40	no sample	T19 (Grimes Creek)	45	47	48	48
T9 (SML Dam)	29	48	11	40	T20 (Indian Creek)	43	47	47	48
T10 (Pigg River)	46	45	41	43	T21a (Roanoke River)	44	24	46	48

The number of enterococci in the tributaries has not changed significantly over the years. August samples have 12 % more Enterococci colonies than are present in June (combining both years). The 2010 year had 6% more Enterococci colonies than were present in 2009. Enterococci are found primarily in warm blooded animals and therefore are not desirable to have in the tributaries that feed into Smith Mountain Lake. If we are taking actions to decrease animal and human waste in our tributaries and the lake the number of enterococci should be decreasing.

In both 2009 and 2010, all of the Franklin County tributaries had some isolates coming from human sources or livestock sources, both of which are of concern in regard to human health (Figures 7.7 and 7.8). However, in June and August of 2010 the human sources were reduced significantly from 2009 with only three or four of eleven Franklin County tributaries having human sources. None of the eleven Franklin County tributaries in June or August 2010 had greater than 8 percent of the isolates from human sources; however, all of the tributaries had greater than 20 percent of the isolates from livestock sources in June of both years. In August of both years, eight of the eleven tributaries in Franklin County had greater than 20 percent of the isolates from livestock sources. The variability of the sources is indicated by the fact that a tributary with no human sources predicted in June had human sources predicted in August. 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.

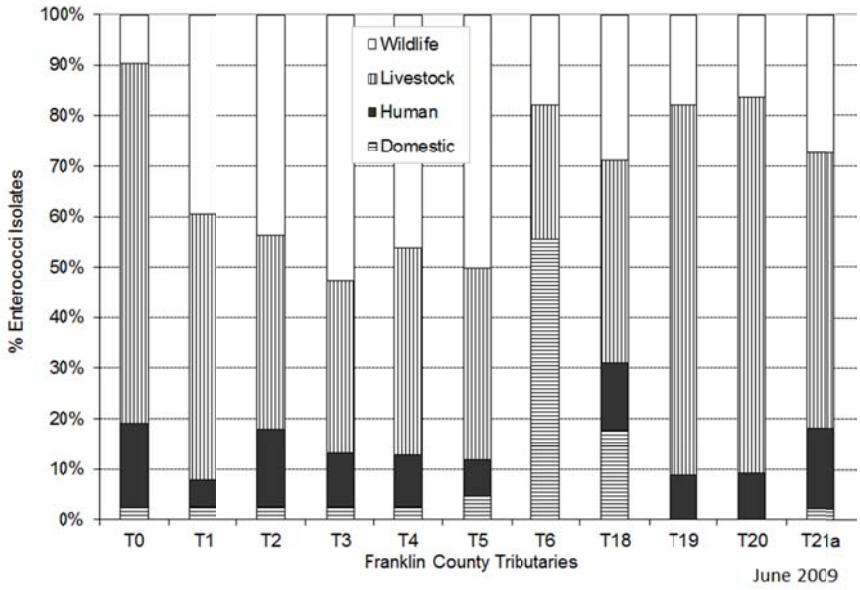


Figure 7.7 A. Percent of bacterial isolates from 4 sources in Franklin County tributaries in June 2009

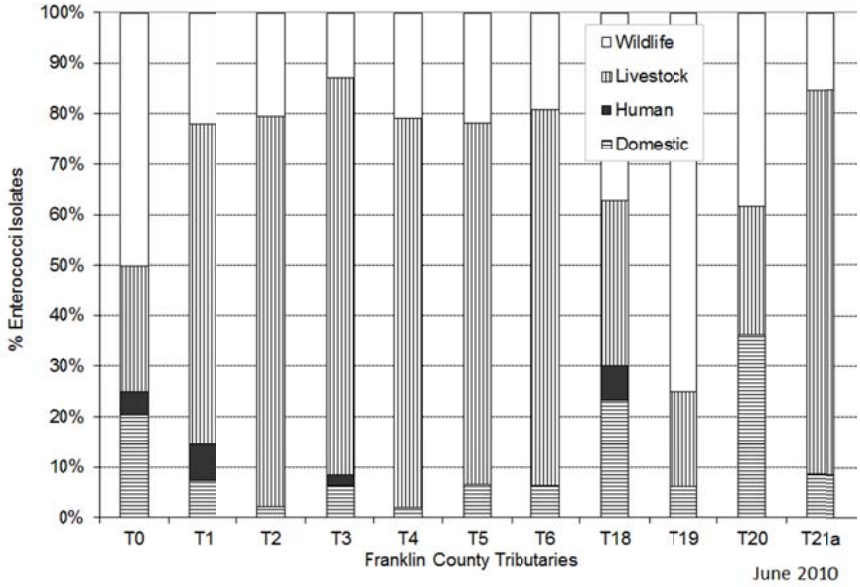


Figure 7.7 B. Percent of bacterial isolates from 4 sources in Franklin County tributaries in June 2010

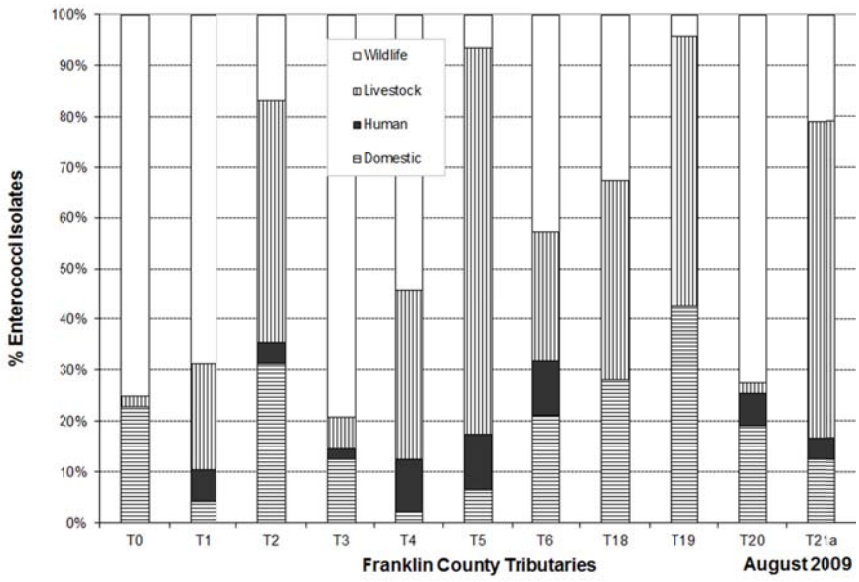


Figure 7.8 A. Percent of bacterial isolates from 4 sources in Franklin County tributaries in August 2009

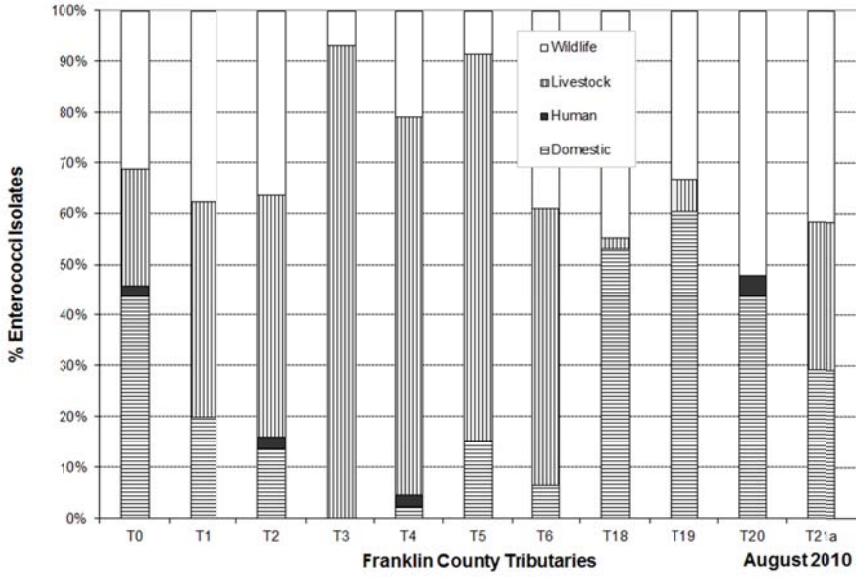


Figure 7.8 B. Percent of bacterial isolates from 4 sources in Franklin County tributaries in August 2010

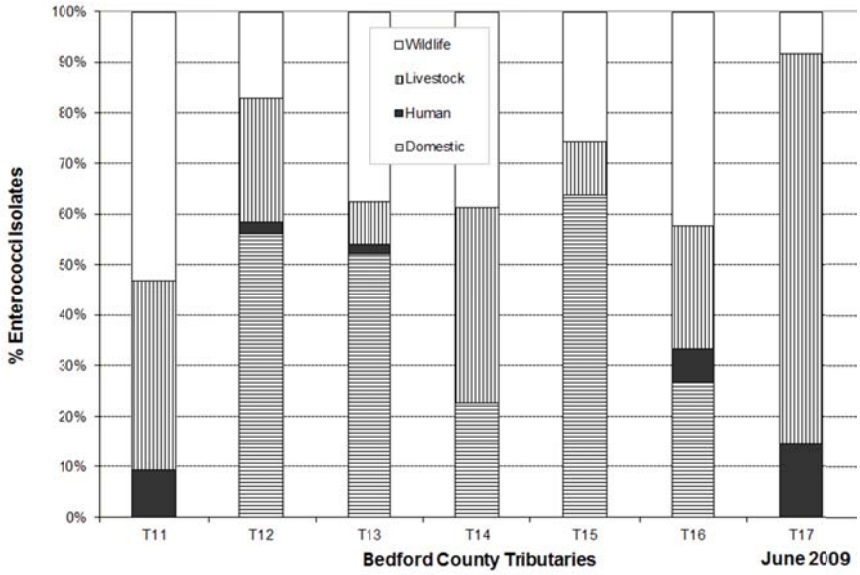


Figure 7.9 A. Percent of bacterial isolates from 4 sources in Bedford County tributaries in June 2009

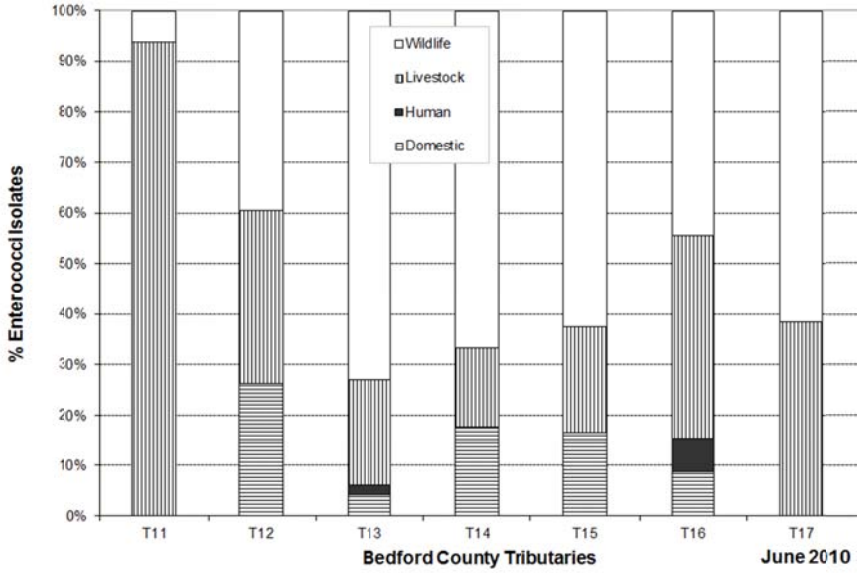


Figure 7.9 B. Percent of bacterial isolates from 4 sources in Bedford County tributaries in June 2010

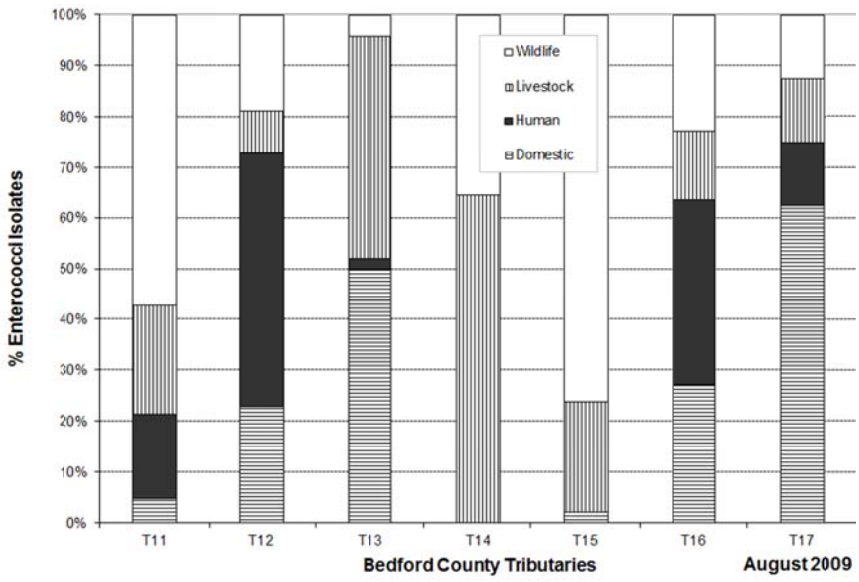


Figure 7.10 A. Percent of bacterial isolates from 4 sources in Bedford County tributaries in August 2009

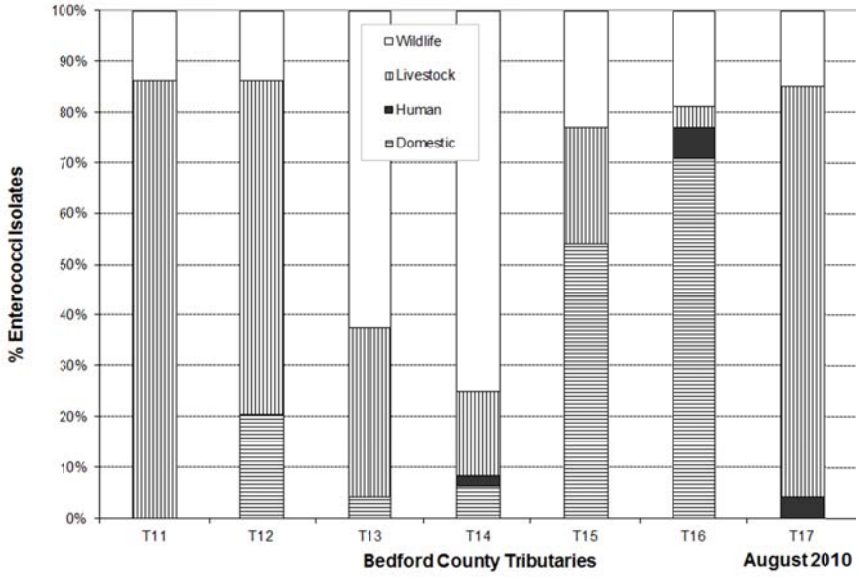


Figure 7.10 B. Percent of bacterial isolates from 4 sources in Bedford County tributaries in August 2010

Every Bedford County tributary had some isolates coming from human sources and/or livestock sources in June and August of 2009 and 2010 (Figures 7.9 and 7.10). In June and August of 2009, five of the seven Bedford County tributaries had isolates from human sources (one tributary having greater than 10 percent in June 2009 and four tributaries having greater than 10 percent in August 2009). Six or seven of the Bedford County tributaries had greater than 10 percent of isolates from livestock in both samplings in both years.

In June and August of 2010, two and three of the Bedford County tributaries had isolates from predicted human sources (all less than 10 %) however all seven Bedford County tributaries had isolates from predicted livestock sources in June and August of 2010 as in 2009. Livestock source isolates ranged from 4 % to 96 % with T 11 and T 17 having the highest percent livestock sources

All samples from Pittsylvania County tributaries had some isolates coming from human sources and/or livestock sources in June and August of 2009 and 2010 (Figures 7.12 and 7.13). In June and August of 2009, three and two of the Pittsylvania County tributaries tested had isolates predicting human sources and all three of the Pittsylvania County tributaries had isolates from livestock sources. The Smith Mountain Lake Dam sample site (T9) had 75 percent of isolates coming from livestock in June 2009 but the percentage went down significantly (to 2 percent) in August 2009. One of the Pittsylvania County tributaries had human sources predicted (August, T10). In June and August of 2009 and August of 2010, T8 was not sampled due to lack of water.

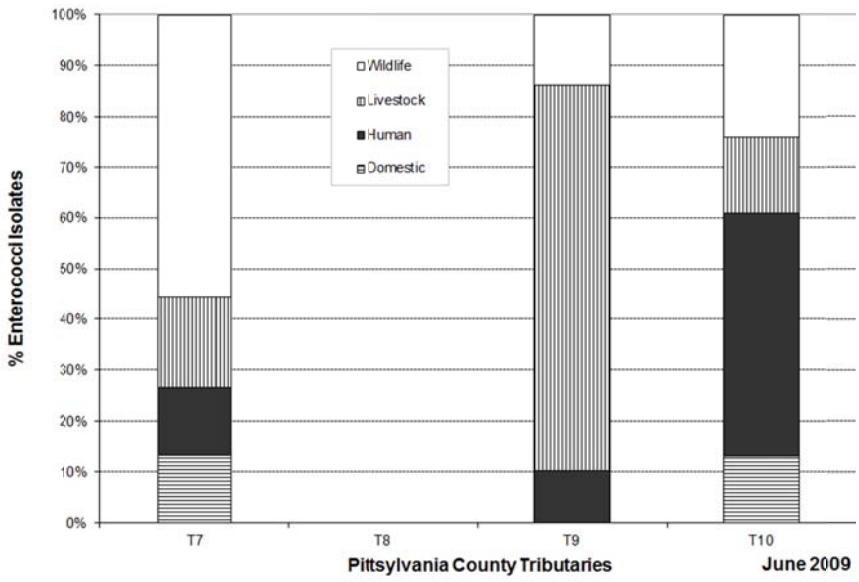


Figure 7.11 A. Percent of bacterial isolates from 4 sources in Pittsylvania County in June 2009

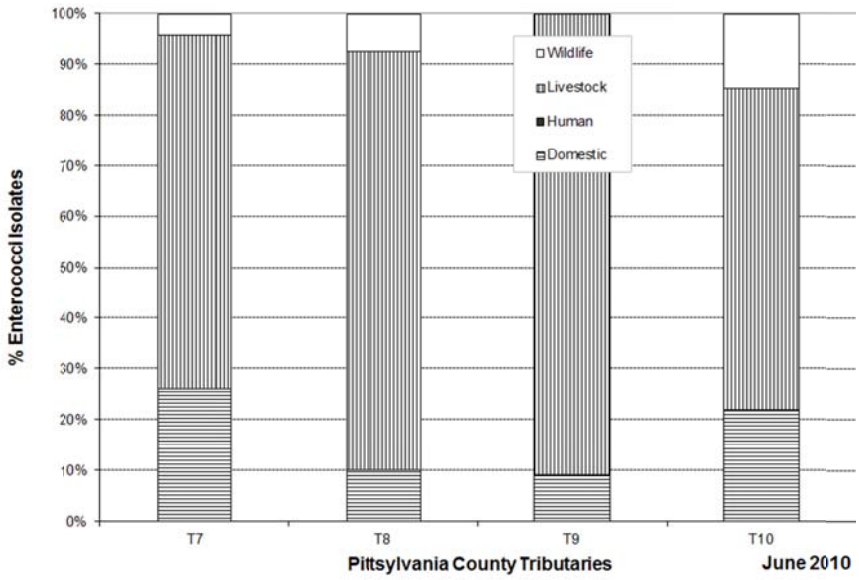


Figure 7.11 B. Percent of bacterial isolates from 4 sources in Pittsylvania County in June 2010

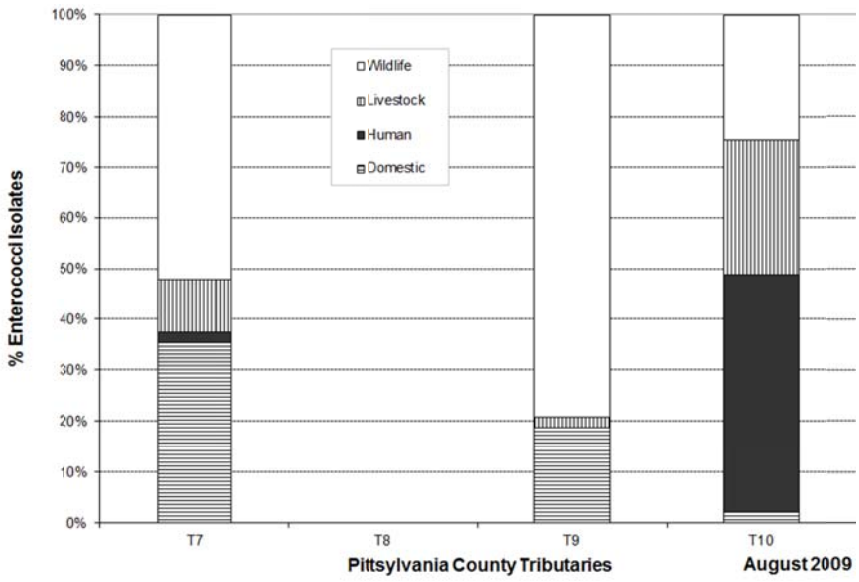


Figure 7.12 A. Percent of bacterial isolates from 4 sources in Pittsylvania County in August 2009

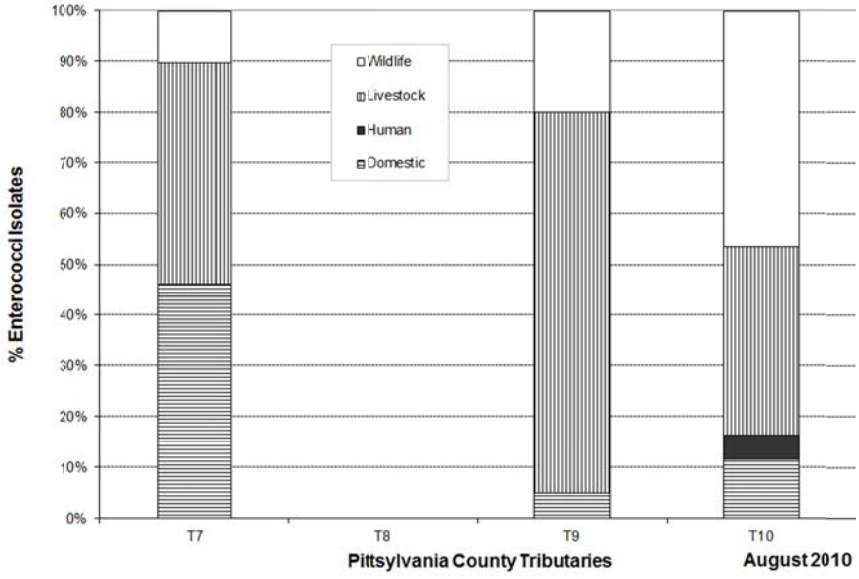


Figure 7.12 B. Percent of bacterial isolates from 4 sources in Pittsylvania County in August 2010

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. The wildlife predictions are a high percentage of the tributaries' predicted sources again in 2009 and 2010 as in previous years (37-43% 2008, 31-43% 2009, 30-32% 2010) and are problematic since no solution is readily available; however, wildlife are 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 52 percent of the isolates in June 2009 and 38 percent in August 2009 (Figures 7.13 A and 7.14 A). The human and livestock source isolates account for 53 percent of the isolates in June 2010 and 38 percent in August 2010 (Figures 7.13 B and 7.14 B). The good news is that in all tributaries the human source percentages are lower in 2009 than in 2010.

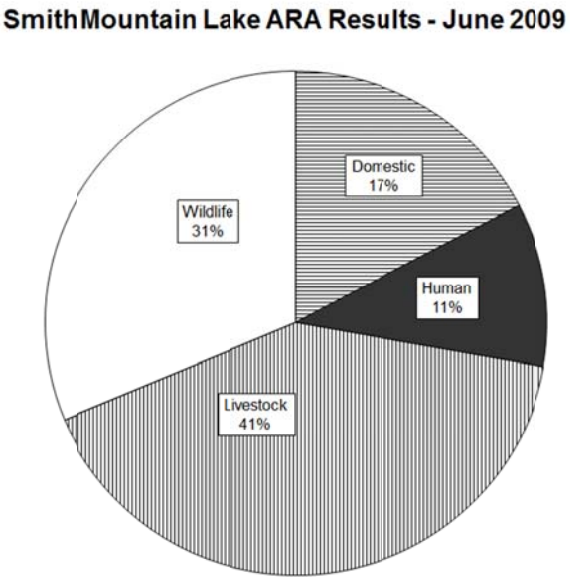


Figure 7.13 A. Percent of bacterial isolates from four potential sources for all sample sites in June 2009

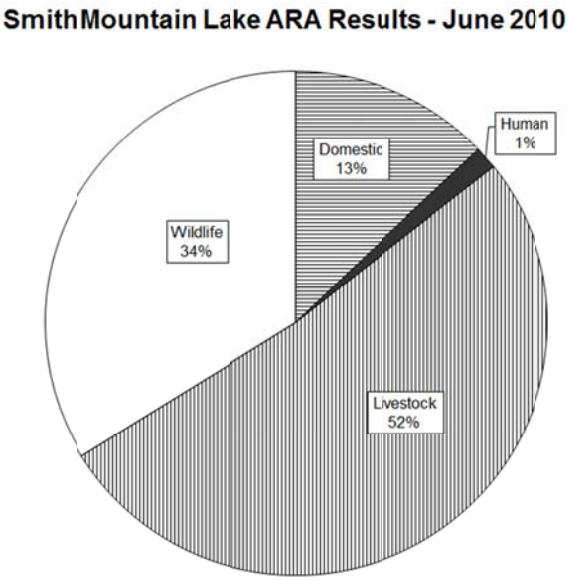


Figure 7.13 B. Percent of bacterial isolates from four potential sources for all sample sites in June 2010

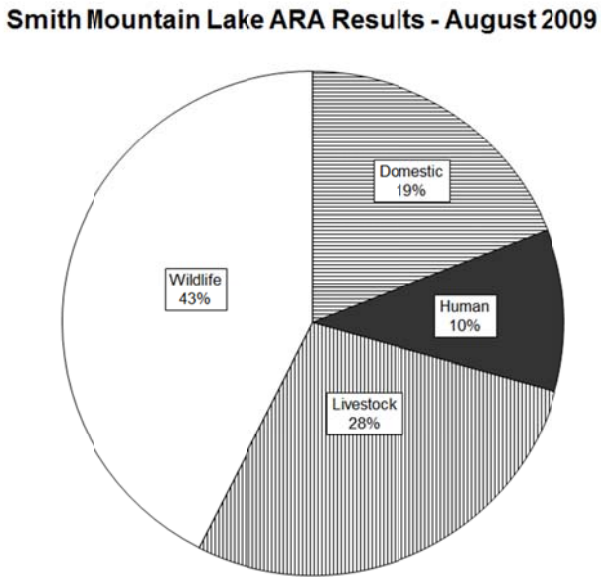


Figure 7.14 A. Percent of bacterial isolates from four potential sources for all sample sites in August 2009

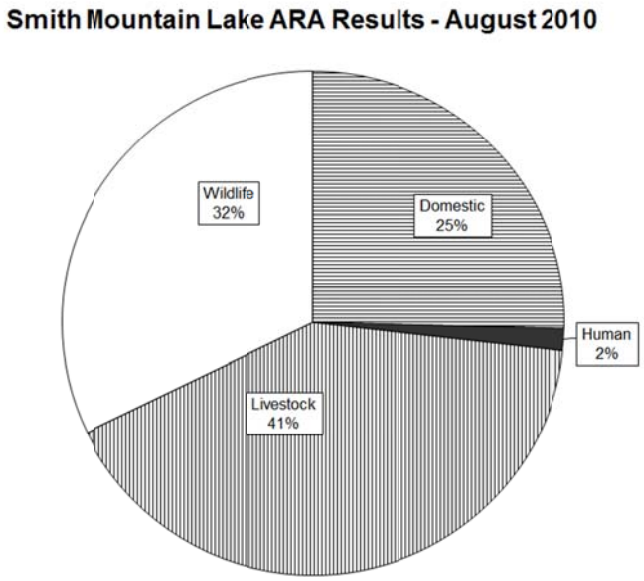


Figure 7.14 B. Percent of bacterial isolates from four potential sources for all sample sites in August 2010

7.3.4 Summary of Section

The bacterial source tracking is showing an improvement in the decrease in human isolates of the enterococci, especially in Bedford and Pittsylvania Counties. The livestock source isolates however do not seem to be 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.

8. WATER QUALITY TRENDS

8.1 Water Quality Trends by Zone

After monitoring water quality in Smith Mountain Lake for twenty-three 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.

The lake zones have been delineated as follows:

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

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 twelve to fifteen years). No strong trends are apparent in any of the trophic parameters after twenty-three 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 three 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.

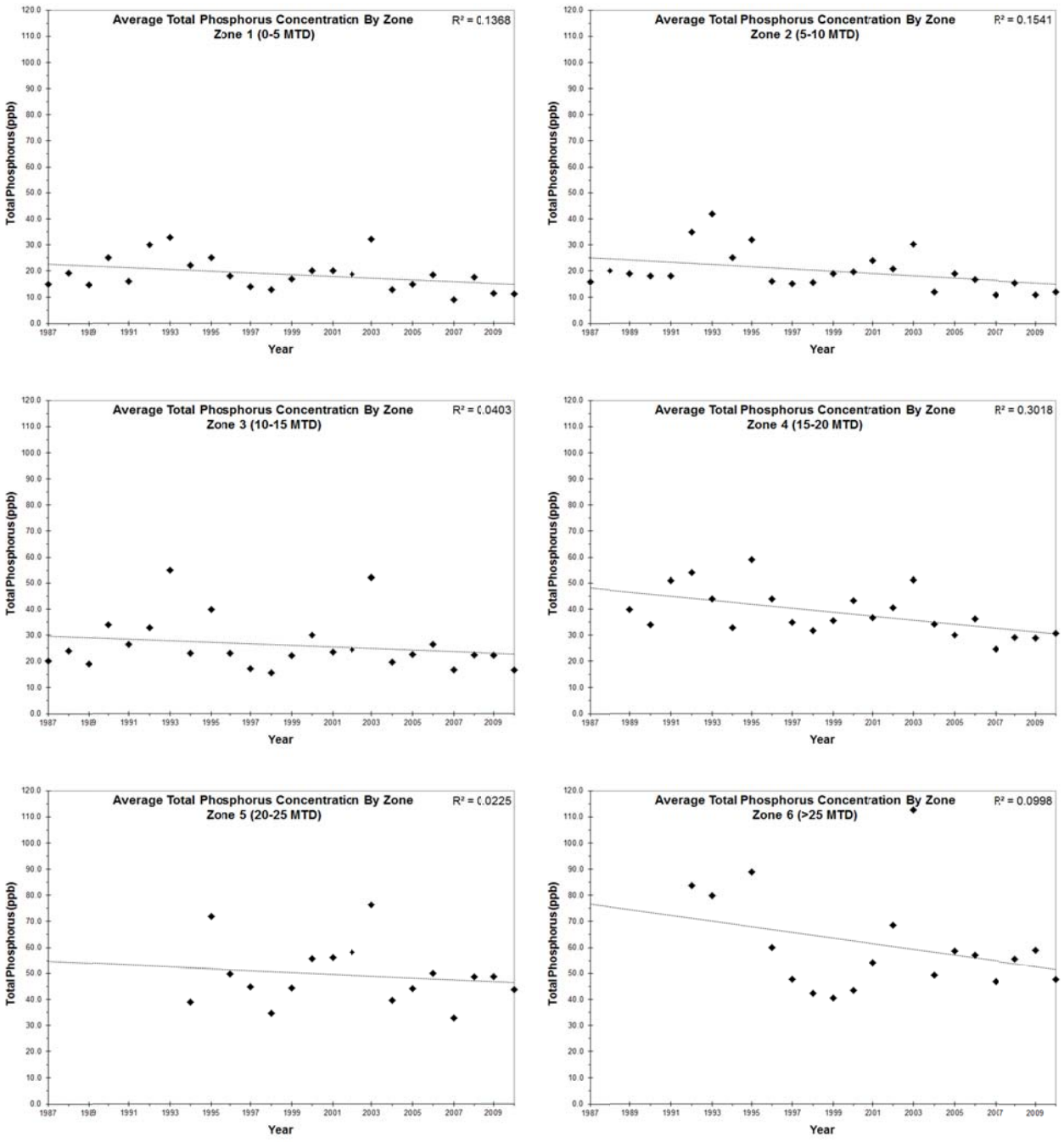


Figure 8.1. Average annual total phosphorus concentration by year and zone in Smith Mountain Lake

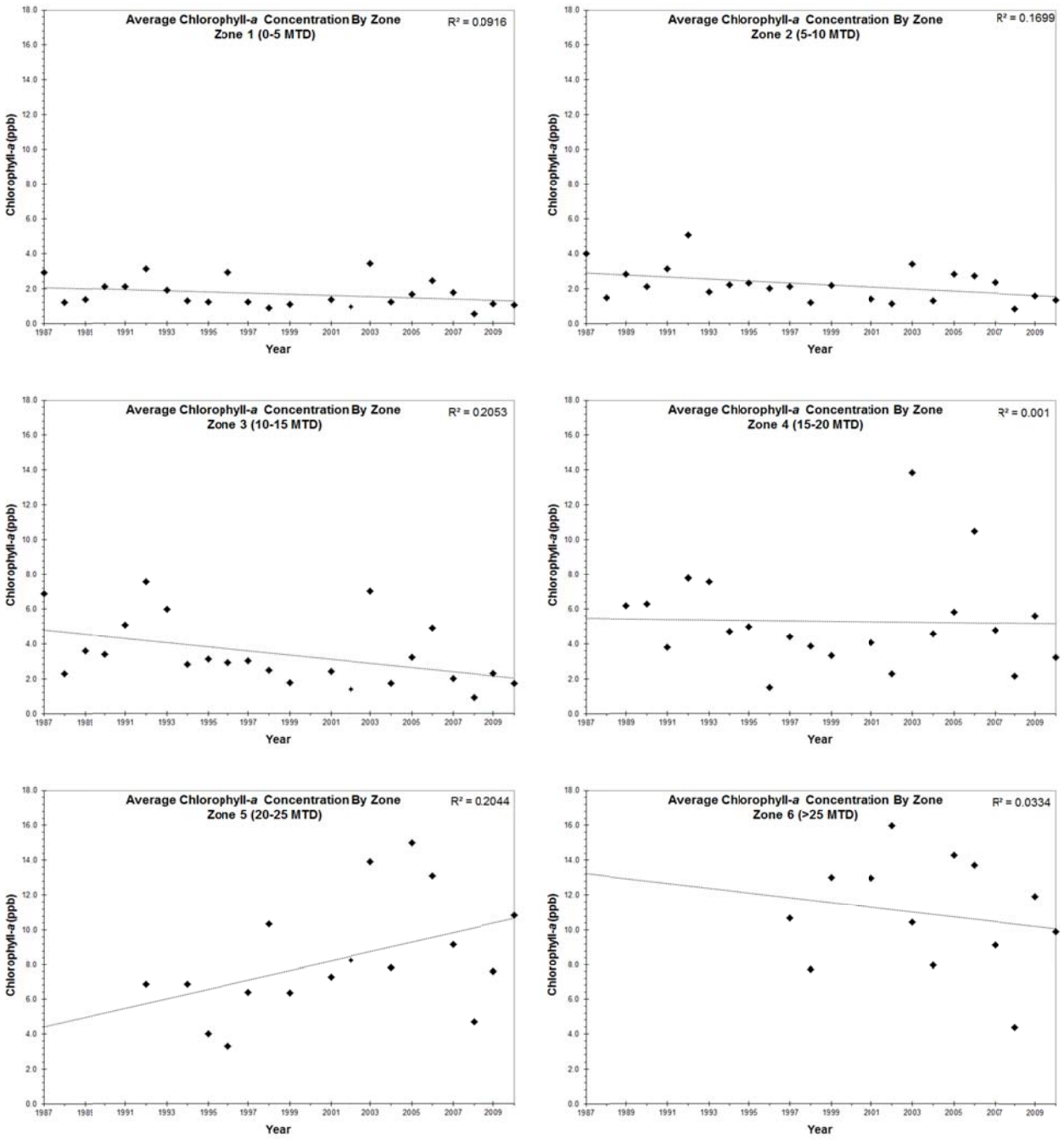


Figure 8.2. Average annual chlorophyll-*a* concentration by year and zone in Smith Mountain Lake

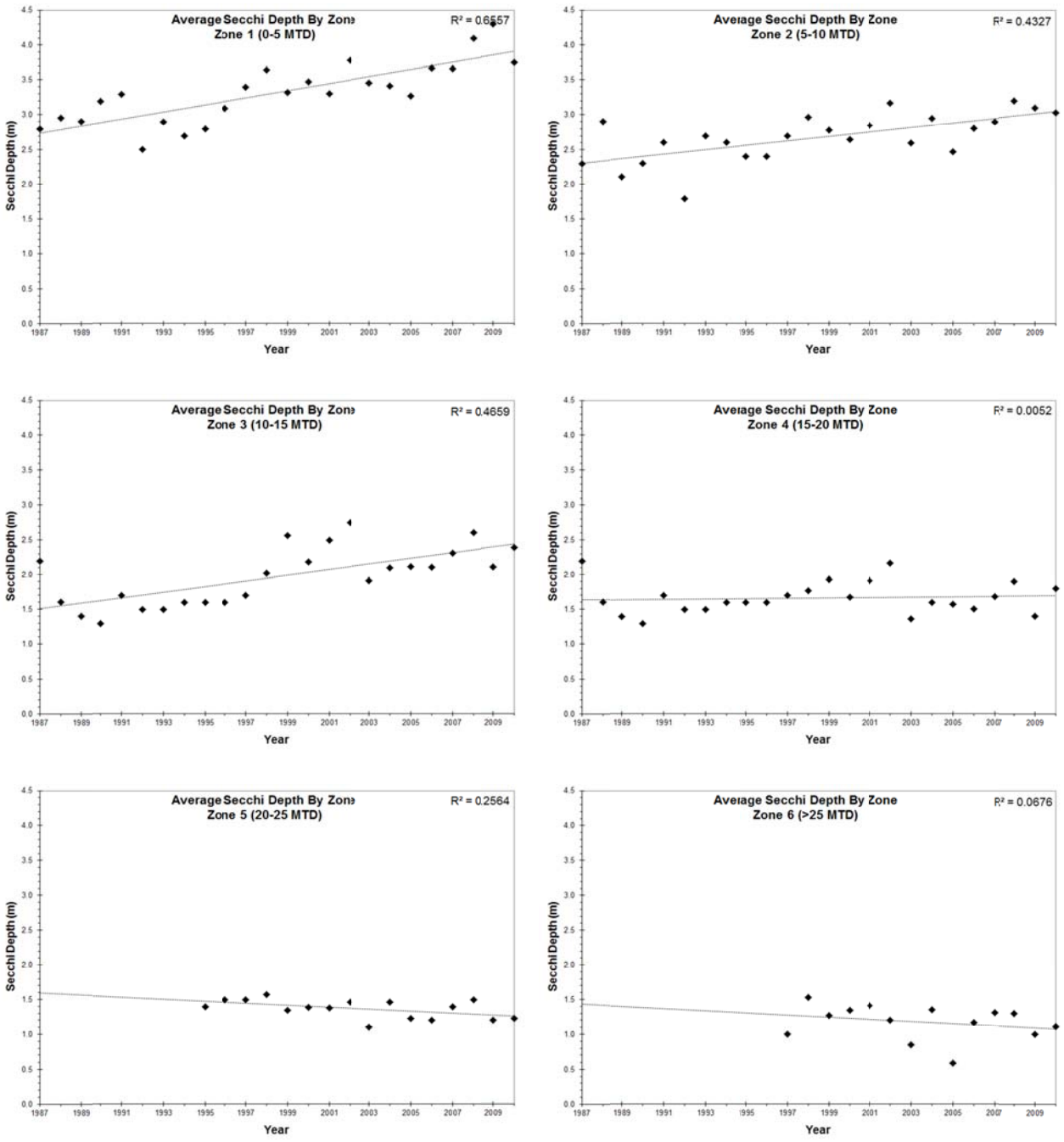


Figure 8.3. Average annual Secchi depth by year and zone in Smith Mountain Lake

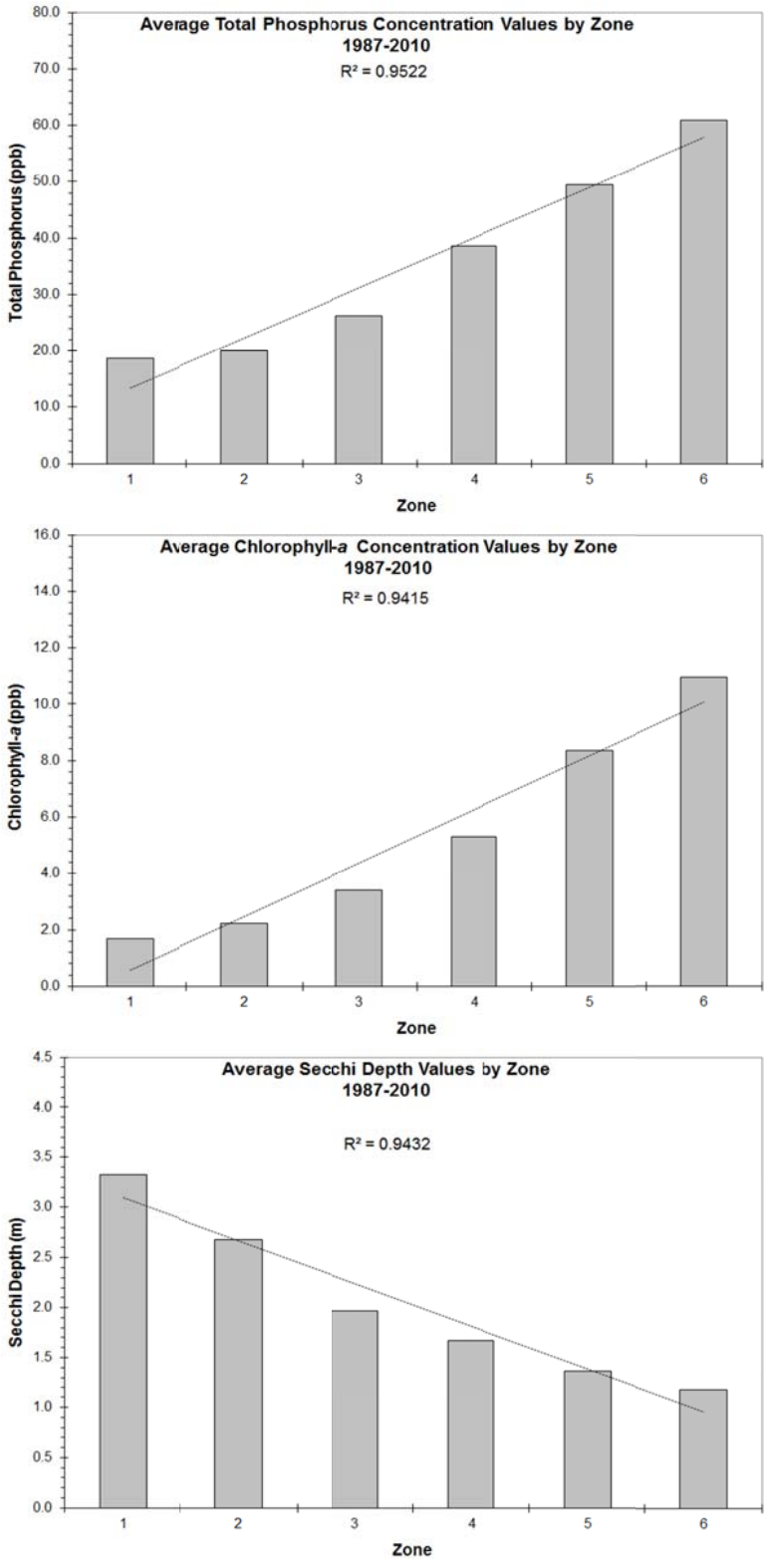


Figure 8.4. Average parameter value by zone for 1987-2010

8.2 Carlson's Trophic State Index

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-TP = 14.42 ln TP + 4.15

TSI-CA = 9.81 ln CA + 30.6

TSI-SD = 60 - 14.41 ln SD

TSI-C = [TSI(TP) + TSI(CA) + TSI(SD)]/3

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.

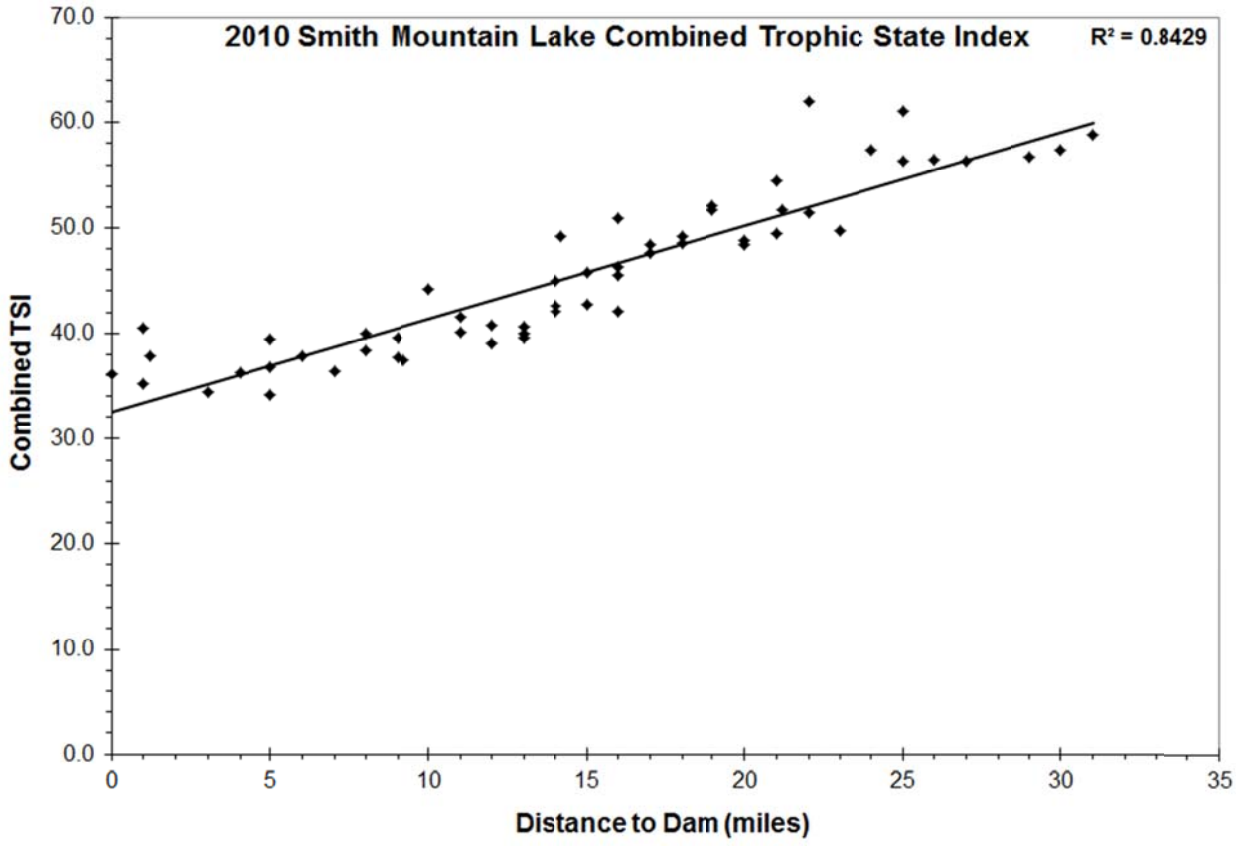


Figure 8.5. Combined Trophic State Index as a function of distance from dam

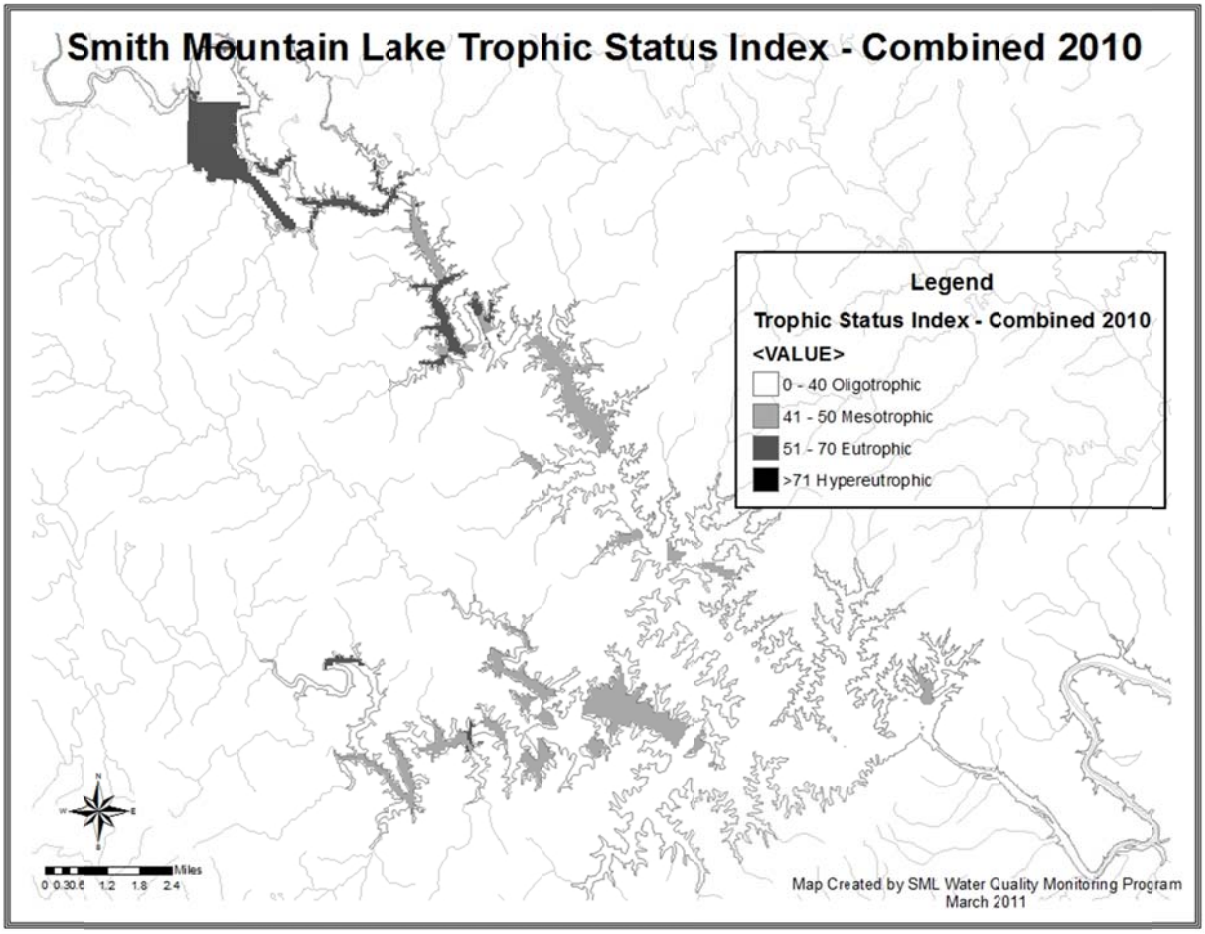


Figure 8.6. GIS map showing the Combined Trophic State Index results throughout the lake

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 (62.0) was at Station B22, while the lowest TSI-C value (34.2) was at Station M5.

In Smith Mountain Lake in 2010, the average TSI-SD (49.5) is slightly higher than the TSI-TP (47.6), which is higher than the average TSI-CA (39.5). This trend is exactly the same as what was observed in 2009. The average of the three is in the mesotrophic range; the combined TSI average is lower in 2010 (TSI-C = 45.5) than it was in 2009 (TSI-C = 47.0) but higher than it was in 2008 (TSI-C = 44.2). This is due to the slight decrease in the TSI-CA (39.5 in 2010 vs. 41.6 in 2009) the slight decrease in the TSI-SD (49.5 in 2010 vs. 50.2 in 2009), and the slight decrease in the TSI-TP (47.6 in 2010 vs. 49.2 in 2009).

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
M5	*5*	7.9	0.9	4.4	*34.0*	*29.9*	*38.7*	***34.2***
M3	*3*	9.1	0.8	4.5	*36.0*	*28.8*	*38.3*	***34.4***
M1	*1*	7.8	1.3	4.3	*33.7*	*32.8*	*39.0*	***35.2***
M0	*0*	9.6	0.7	3.0	*36.7*	*27.5*	*44.2*	***36.1***
C4	*4*	9.6	1.3	4.3	*36.8*	*33.0*	*39.0*	***36.3***
R7	*7*	9.1	1.1	3.5	*36.1*	*31.3*	*41.9*	***36.4***
C5	*5*	10.9	1.2	4.0	*38.6*	*32.0*	*39.9*	***36.8***
CR9.2	*9.2*	8.7	1.1	2.7	*35.3*	*31.4*	*45.6*	***37.4***
R9	*9*	8.8	1.2	2.8	*35.5*	*32.4*	*45.4*	***37.8***
CM1.2	*1.2*	15.2	0.7	3.3	*43.4*	*27.0*	*43.0*	***37.8***
C6	*6*	11.0	1.3	3.5	*38.7*	*32.9*	*42.1*	***37.9***
CR8	*8*	13.4	1.0	3.3	*41.5*	*30.6*	*42.8*	***38.3***
B12	*12*	10.9	1.4	2.9	*38.6*	*33.8*	*44.6*	***39.0***
CM5	*5*	15.0	1.2	3.3	*43.2*	*32.4*	*42.8*	***39.5***
R13	*13*	7.5	2.8	2.9	*33.2*	*40.7*	*44.8*	***39.6***
CR9	*9*	13.3	1.1	2.7	*41.5*	*31.7*	*45.6*	***39.6***
G13	*13*	12.7	0.9	2.1	*40.9*	*29.8*	*49.1*	***39.9***
B8	*8*	14.7	1.3	3.0	*42.9*	*32.8*	*44.2*	***40.0***
CB11	*11*	15.0	1.2	2.8	*43.2*	*32.3*	*45.0*	***40.1***
CM1	*1*	15.4	1.5	3.1	*43.6*	*34.3*	*43.8*	***40.6***
CR13	*13*	15.0	1.1	2.5	*43.2*	*31.9*	*46.8*	***40.6***
G12	*12*	13.9	1.4	2.5	*42.1*	*33.6*	*46.6*	***40.8***
R11	*11*	18.2	1.3	2.7	*46.0*	*32.9*	*45.6*	***41.5***
B14	*14*	14.1	2.0	2.6	*42.3*	*37.4*	*46.3*	***42.0***
B16	*16*	14.9	1.6	2.3	*43.1*	*34.9*	*48.3*	***42.1***
R14	*14*	16.1	1.6	2.3	*44.3*	*35.5*	*48.1*	***42.6***
G15	*15*	14.8	1.6	2.0	*43.0*	*35.0*	*50.0*	***42.7***
B10	*10*	18.1	2.9	2.7	*45.9*	*41.1*	*45.6*	***44.2***
G14	*14*	25.1	1.6	2.2	*50.6*	*35.3*	*48.9*	***44.9***
G16	*16*	19.4	2.4	2.0	*46.9*	*39.2*	*50.3*	***45.5***
R15	*15*	16.7	3.6	2.1	*44.8*	*43.0*	*49.4*	***45.7***
CR16	*16*	16.6	3.4	1.8	*44.6*	*42.7*	*51.6*	***46.3***
R17	*17*	19.0	3.3	1.5	*46.6*	*42.3*	*53.8*	***47.6***
CB20	*20*	29.3	2.8	1.8	*52.8*	*40.8*	*51.6*	***48.4***
CR17	*17*	27.3	3.0	1.8	*51.8*	*41.5*	*51.9*	***48.4***
B18	*18*	39.9	2.2	2.0	*57.3*	*38.3*	*50.0*	***48.5***
B20	*20*	33.4	2.5	1.8	*54.8*	*39.6*	*51.9*	***48.7***
CR14.2	*14.2*	35.9	2.1	1.5	*55.8*	*37.7*	*54.2*	***49.2***
G18	*18*	27.6	3.3	1.6	*52.0*	*42.3*	*53.4*	***49.2***
CR21	*21*	17.0	5.8	1.4	*45.0*	*47.8*	*55.7*	***49.5***
R23	*23*	43.2	1.3	1.2	*58.4*	*33.0*	*57.8*	***49.7***
CB16	*16*	88.5	1.7	2.3	*68.8*	*35.7*	*48.3*	***50.9***
CR22	*22*	64.1	1.3	1.3	*64.1*	*33.3*	*56.8*	***51.4***
CR21.2	*21.2*	21.3	8.0	1.4	*48.3*	*51.0*	*55.7*	***51.7***
CR19	*19*	26.1	5.4	1.3	*51.2*	*47.2*	*56.8*	***51.7***
R19	*19*	26.4	7.1	1.4	*51.4*	*49.8*	*55.2*	***52.1***
R21	*21*	39.4	8.2	1.4	*57.1*	*51.3*	*55.2*	***54.5***
CR25	*25*	36.0	12.4	1.2	*55.8*	*55.3*	*57.8*	***56.3***
R27	*27*	45.2	9.6	1.2	*59.1*	*52.8*	*57.3*	***56.4***
CR26	*26*	40.7	9.7	1.1	*57.6*	*52.9*	*58.8*	***56.5***
R29	*29*	49.9	10.3	1.3	*60.5*	*53.5*	*56.3*	***56.8***
CR24	*24*	38.7	15.5	1.2	*56.9*	*57.5*	*57.8*	***57.4***
R30	*30*	46.2	12.6	1.2	*59.4*	*55.4*	*57.4*	***57.4***
R31	*31*	56.3	7.3	0.8	*62.3*	*50.1*	*64.1*	***58.8***
R25	*25*	69.0	21.9	1.2	*65.2*	*60.9*	*57.3*	***61.1***
B22	*22*	65.9	23.0	1.0	*64.5*	*61.3*	*60.0*	***62.0***
avg	***14.7***	**25.3**	**4.1**	**2.3**	***47.6***	***39.5***	***49.5***	**45.5**

The annual average TSIs from 2001–2010 are shown in Table 8.4. In 2010 the average combined TSI was slightly under 50 (45.5), indicating that on average the lake is in the early stages of developing eutrophic conditions. All three trophic status indicators (total phosphorus, chlorophyll-*a*, and Secchi depth) are fairly similar in value and consistent with beginning stages of eutrophication. However it should be noted that all parts of the lake above 17 miles from the dam are eutrophic.

Table 8.4. Combined Trophic State Index summary for 2001-2010

Year	Avg Combined TSI	TSI Range	R^2 (TSI vs. MTD)
2001	47.6	38.4 – 59.7	0.830
2002	46.2	35.9 – 62.8	0.819
2003	53.6	41.9 – 66.3	0.803
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

The combined trophic state index, averaged by zone from 1987 to 2010, is displayed in Figure 8.7. The value of the correlation coefficient (R^2 = 0.9926), based on thousands of individual measurements, has a very high statistical significance.

For the period of record, 1987-2010, 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 discernable 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.

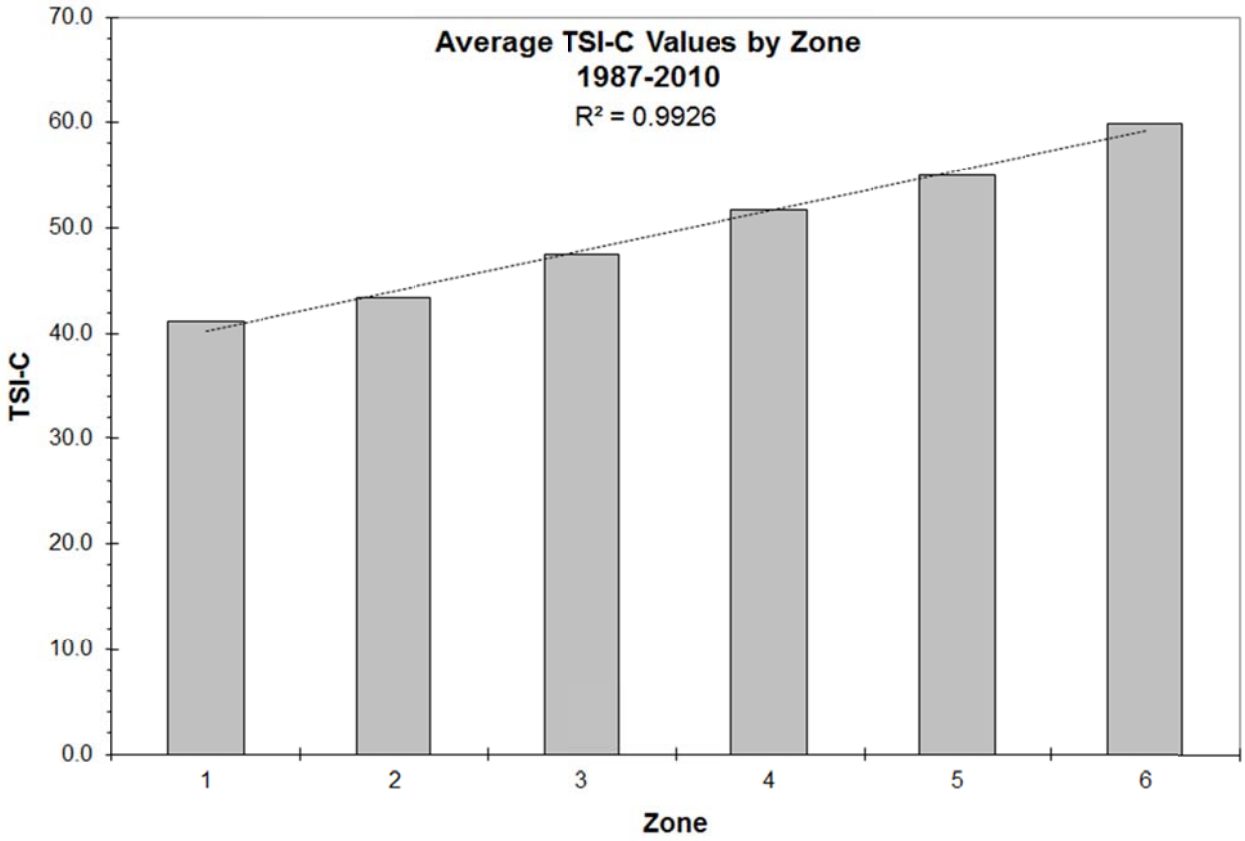


Figure 8.7. Combined Trophic Index by zone from 1987 – 2010

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 with input from Dr. Gary Du, former QA Specialist for the Virginia Department of Environmental Quality, and 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 combined readings from standards run at the beginning of the analysis and another set of standards run at the end of the analysis. Table 9.1 summarizes the calibration data for 2009. The slope indicates the relationship between concentration and absorption and was extremely consistent from week to week. This gives us confidence that the spectrophotometer used to measure absorbance 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, four reagents are added which contain small amounts of phosphorus. These additions, along with the extra handling and manipulation of the sample, lead 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 2010 calibration data for total phosphorus

Sampling Period	Slope	Intercept	R^2
5/30-6/5	0.0019	0.0342	0.9980
613-6/19	0.0020	0.0431	0.9966
6/27-7/3	0.0020	0.0061	0.9989
7/11-7/17	0.0020	0.0190	0.9965
7/25-7/31	0.0020	-0.0180	0.9962
8/8-8/14	0.0020	-0.0104	0.9987
Average	**0.0020**	**0.0123**	**0.9975**
Standard Deviation	**0.0000**	**0.0243**	**0.0012**

9.1.1 Summary of Calibration Data

With a value over 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

The procedure for measuring total phosphorus involves the formation of a blue dye, which begins to fade over time. It is the intensity of this blue color which is measured in the spectrophotometer. Due to the large number of samples collected in this program, the analysis takes longer than the 30 minutes recommended in Standard Methods. Therefore, it is necessary to evaluate the loss of precision during the analytical period. This is accomplished by periodically checking a known sample over the course of the analysis.

In 2010, the 40 and 80 ppb standards were run after every ten samples for a total of twelve readings of those two standards (n=12). 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 2010

Sampling Period	Avg. RPD 40ppb std. (%)	Max. RPD 40ppb std. (%)	Min. RPD 40ppb std. (%)	Avg. RPD 80ppb std. (%)	Max. RPD 80ppb std. (%)	Min. RPD 80ppb std. (%)
5/30-6/5	10.8	20.2	1.0	5.3	8.7	1.9
6/13-6/19	14.3	45.1	0.1	5.9	9.5	2.8
6/27-7/3	5.6	10.9	0.0	2.3	5.0	1.0
7/11-7/17	9.4	18.6	1.7	4.0	9.1	0.1
7/25-7/31	12.2	20.7	1.0	5.1	9.5	1.0
8/8-8/14	11.0	19.5	4.8	5.8	8.8	1.2
Overall Averages	**10.6**			**4.7**		

9.2.1 Summary of Precision of Analysis over Analysis Time

Although there were some occasional high individual values in the 40 ppb analysis, in general the precision of analysis for the 40 and 80 ppb standards over the course of the entire analysis was very good at an average of 10.6 percent for the 40 ppb standard and an average of 4.7 percent for the 80 ppb standard. The target value for RPD is 0 percent and less than 10 percent is considered very good. This indicates that there is minimal loss of dye intensity during the analysis and that the instrument is stable.

9.3 Blanks and Spiked Blanks for Total Phosphorus

In previous years, the QA/QC plan for the project included laboratory and field blanks and laboratory and field surrogate samples. These samples were analyzed to examine the effects of sample collection, handling, storage and sample bottles on the results of total phosphorus determinations. Insufficiently cleaned containers generally add phosphorus to a water sample, but a very clean container may actually reduce the phosphorus concentration in a sample due to adsorption of phosphate from the sample onto the container walls. To avoid container effects, a sample must be stored in a container that has been previously equilibrated with a solution of similar phosphate concentration. In practice this is impossible since we don't know concentrations before they have been analyzed. We minimize this source of contamination by designating particular sample bottles for each site and reusing those bottles each sampling week.

In 2008 we discontinued the analysis of surrogates and field blanks and began analyzing lab blanks (both unspiked and spiked with 0.2 ml of 2ppm stock solution). Three spiked blanks and two unspiked blanks were run with each analysis of samples. The results are shown in Table 9.3.

Table 9.3. Average recovery of total phosphorus for 2010 lab blanks and average percent recovery for spiked blanks

Sampling Period	Blanks - average recovery (ppb)	Spiked blanks - average % recovery
5/30-6/5	4.2	96.4
6/13-6/19	2.0	90.2
6/27-7/3	3.1	92.6
7/11-7/17	2.7	88.3
7/25-7/31	5.2	85.9
8/8-814	3.3	98.2
AVERAGES	**3.4**	**91.9**

9.3.1 Summary of Blank and Spiked Blank Analysis

The averages for lab blanks are very good for all sample periods (target value is 0 ppb). The overall average of 3.4 ppb is excellent and shows stability of the instrument and little carry-over contamination from previous samples. The average percent recoveries for the spiked blanks for each analysis are good (target value is 100 percent), and the overall average for the sampling season is very good at 91.9 percent.

9.4 Duplicate and Spiked Sample Analysis for Total Phosphorus

During every analysis, ten samples were divided and run as duplicates. Ten additional samples were divided and one of the aliquots was "spiked" by the addition of a very small quantity of total phosphorus standard solution (0.2 ml of 2ppm solution) 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 2010 duplicates and spikes for total phosphorus

	DUPLICATES			SPIKES		
Sampling Period	**Average RPD**	**Maximum RPD**	**Minimum RPD**	**Average % Recovery**	**Maximum % Recovery**	**Minimum % Recovery**
5/30-6/5	42.5	115.3	0.3	102.6	126.0	72.0
6/13-6/19	63.7	169.5	9.9	120.5	178.6	105.3
6/27-7/3	15.9	34.4	0.5	103.6	112.8	97.6
7/11-7/17	34.7	97.3	4.0	97.4	126.0	85.4
7/25-7/31	26.5	92.5	4.1	107.2	184.3	82.0
8/8-814	72.9	141.5	1.9	107.0	241.7	67.5
Overall Avg.	**42.7**			**106.4**		

9.4.1 Summary of Duplicate and Spiked Samples

The precision of duplicate analysis was poor again this year at 42.7 average relative percent difference (target value is 0 percent) but much better for spiked samples with 106.4 average percent recovery (target value is 100 percent). Often, poor average RPD for the duplicates can be attributed to a large number of samples with low phosphorus concentrations, since a small difference between two samples makes a large percentage difference when the values are low. However, there are several instances of good RPD values for low phosphorus concentrations and poor RPD values for samples with higher phosphorus concentrations in this year's sample set for duplicates. Poor mixing of the sample when the duplicate is poured could be a cause for the high duplicate RPD values.

9.5 Independent Lab Analysis and Analysis of Purchased Standard

Independent lab analysis was not performed during this sampling season. The Water Quality Lab did analyze a standard purchased from Environmental Resource Associates (ERA), Arvada, CO. This standard was made up early in the sampling season and run with every sample analysis. These results are reported in Table 9.5.

Table 9.5. Results of analysis of purchased standard for 2010

Analysis date	Analyzed conc.(ppb)	ERA conc.(ppb)	Average (ppb)	Difference (ppb)	RPD
6/21	38.8	40.3	39.6	1.5	3.8
6/24	33.3	40.3	36.8	7.0	19.0
7/7	36.2	40.3	38.3	4.1	10.7
7/21	34.8	40.3	37.6	5.5	14.6
8/6	32.5	40.3	36.4	7.8	21.4
8/19	35.9	40.3	38.1	4.4	11.5
Averages					**13.5**

9.5.1 Summary of Independent Analysis and Analysis of Purchased Standard

The results of the analysis of the purchased standard were good with average relative percent difference (RPD) of 13.5 percent (target value is 0 percent). The concentration of the purchased standard varies each year and the average RPD is similar to those obtained in the comparison of 40 and 80 ppb standards (around 10 percent in the 40 ppb range and around 5 percent in the 80 ppb range).

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 (after each ten percent of the total samples). A method blank (glass fiber filter) is also analyzed each time samples are run.

In previous years we have analyzed duplicate glass fiber filters which were distributed to randomly selected volunteer monitors to be filtered as replicates. These were analyzed along with the regular filters and relative percent differences were calculated. We have had extremely high RPD values for this procedure over the past several years (average RPD in 2009 was 121.6; in 2008, average RPD was 53.2) and are currently investigating the possible causes. Therefore, 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 at least 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 2010

Sampling Date	Replicate Site	MPN *E. coli*	Replicate Avg. (MPN)	Replicate Range (MPN)
6/1	14-2	10.8	42.9	32.3 - 57.8
6/16	14-1	1.0	4.2	3.1 - 7.4
6/29	7-2	1.0	0.5	<1.0 - 1.0
7/13	1-2	21.3	14.4	12.1 - 20.1
7/27	1-2	224.7	185.9	157.6 - 206.4
8/10	none taken			

In addition, a QuantiCult™ QA/QC Kit was run along with the June 15 and July 27 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. The *E. coli* should give a positive reading for color change as well as fluorescence. The *Klebsiella* should give a positive reading for color (coliform test) but none of the wells should fluoresce (since it is not *E. coli*). The *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 certain limits (1-50 MPN). All three cultures gave the expected

results both times they were run with the exception of K. pneumonia on the July 27. This is thought to be an error in data recording, and lab technicians will be extensively trained on this in the future. Results are shown in Table 9.7.

Table 9.7. Results of QuantiCult™ analysis for 2010

Quanti-Cult 6/15/10	MPN total coliforms	MPN *E. coli*
E. coli	17.3	17.3
K. pneumoniae	17.3	<1.0
P. aeruginosa	<1.0	<1.0

Quanti-Cult 7/27/10	MPN total coliforms	MPN *E. coli*
E. coli	26.2	26.2
K. pneumoniae	18.1	18.1
P. aeruginosa	<1.0	<1.0

A new QC parameter, 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 – standard product specification is a mean of 28-33 cfu with a standard deviation of less than 3. An *E. coli* strain was used. The results are displayed in Table 9.8.

Table 9.8. Results of BioBall® analysis for 2010

Sampling Date	BioBall MPN
6/1	35.9
6/15	24.6
6/29, 6/30	27.2, 28.5
7/13	24.6
7/27	31.3
8/10	30.9
AVG.	29.0

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

The BioBall results fell below the 95% prediction interval lower limit of 24.7 cfu for the batch number on two analyses (6/15 and 7/13) and was above the upper limit of 35.8 on one analysis (June 1). In each case, the deviation from 95% prediction interval was only 0.1 cfu.

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 2010 and Table 10.2 presents the collection efficiencies from 1998 through 2010. The figures show that the volunteer monitors are very conscientious about sample collection. Sample efficiency for total phosphate, and chlorophyll-*a* samples was 98 percent, and 94 percent for Secchi readings. This sampling efficiency is remarkably high for any monitoring program, voluntary or otherwise, and slightly lower than in 2009. 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 2010

Sample Type	Monitoring Stations	Possible Samples	Samples Collected	Percent Efficiency
CA/TP	55	330	323	98.0%
Secchi Depth	84	504	474	94.0%

Table 10.2. Comparison of sampling efficiencies for 2000-2010

% Efficiencies/year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Secchi Depth	89	89	93	99	94	94	93	97	97	97	94
TP	83	94	98	97	98	98	96	97	99	98	98
CA	81	98	98	97	98	98	96	97	99	98	98

11. CONCLUSIONS

The Smith Mountain Lake Water Quality Program again accomplished a thorough study of the trophic status of Smith Mountain Lake in 2010. Monitoring and source tracking of bacteria was continued and depth profiling of dissolved oxygen, temperature, pH and conductivity from surface to the bottom was completed for a fifth year. Algal populations studies continued for the fourth year and aquatic weeds occurrences were tracked and reported in a separate report.

Twelve students worked on water quality projects at Ferrum College over the summer. Five student technicians took primary responsibility for the monitoring program, two being part-time and a fifth acted as the liaison with the Claytor Lake program. A sixth student was responsible for the algal monitoring and the aquatic weed program. Six students worked on the Marina Education and Pump-Out Program, sponsored by the Virginia Department of Health.

Overall, the trophic status of Smith Mountain Lake improved slightly in 2010 compared to 2009. Although the total phosphorus concentration at tributary sites increased, total phosphorus concentration and chlorophyll-*a* concentration decreased and Secchi depth increased. As has been observed since the second year of the monitoring project, water quality improves significantly as the water moves from the upper channels toward the dam. Concentrations of total phosphorus, chlorophyll-*a* and Secchi depth all correlate significantly with distance from the dam.

Algal populations in 2010 were generally higher than in 2009; this does not coincide with the slightly lower chlorophyll-*a* values measured in 2010. In 2009 the dominant algal groups were blue green algae and diatoms whereas in 2010 the dominant group was the green algae, which indicates no or little change in nutrient enrichment and a potential change in the trophic status in 2010. Higher levels of green algae were found at headwaters sites and on the first sampling week of the summer, both reflecting the effect of the lake's watershed and not the immediate lakeshore land use. The sample sites with more influence from human activity (non-marina sites and marina sites) have not changed much from 2008 to 2010.

The parameter profiles (DO, pH, temperature and conductivity) indicate that the lake was already well stratified when the first profiles were collected and the thermocline was located at a depth of

5-10 meters again this year. The pattern of temperature profiles that developed over the summer was similar at all five stations; the thermocline remained well developed but moved down in the water column as the summer progressed. The DO profiles indicated that sub-surface DO levels moved toward lower values over the summer; the hypolimnetic oxygen deficit became more severe during the summer. At the sites farthest from the dam, higher nutrient levels and increased algal production lead to the highest surface DO levels, but they dropped off much more quickly. The profiles for pH were all quite similar and as would be expected. The epilimnion tends to have a pH ~ 8.5, while the hypolimnion tends to have a pH ~ 7. The conductivity profiles pattern tended to be consistent through the summer at each station, but varied considerably from one station to another.

In the yearly trends in the six zones through Smith Mountain Lake (based on miles from the dam) we see the differences in those zones very clearly defined by all three parameters (total phosphorus, chlorophyll-*a* and Secchi depth) in 2010. It has also become more evident that the differences in water quality are a result of sedimentation processes as water moves down the channels toward the dam. There are no statistically significant trends in water quality over time in any of the zones.

Overall, the trophic status as measured by the Trophic State index (TSI) decreased by 3.3 percent in 2010 compared to 2009. The Secchi depth Trophic State Index (TSI) was the highest of the three parameters, 49.5, total phosphorus TSI was 47.6 and the lowest of all was the chlorophyll-a TSI that was 39.5. The analysis of the TSI for Smith Mountain Lake gave an average combined TSI of 45.5, from a value of 47.0 in 2009. This TSI value still indicates the mesotrophic status of Smith Mountain Lake.

The bacterial measurements (*E. coli*) made on Smith Mountain Lake in 2010 indicate a slight increase in the bacterial count when compared to 2009. The bacteria counts were the low again in 2010 with a mean of 12.9 MPN. The means for 2010 were: marinas = 10.9 MPN, non-marinas = 12.9 MPN, headwaters = 17.0 MPN. Yearly comparisons are more difficult because of the changes in techniques in 2003. The highest *E. coli* counts were at a headwaters site and a non-marina site late in the summer (July 27). Four sample stations exceeded the Virginia Department of Health (VDH) recreational waters' standard on July 27, 2010. These sites were Bay Roc

Marina (headwaters), Smith Mountain Lake Dock (marina), Forest Cove and Palmer's Trailer Park (both non-marinas).

The Antibiotic Resistance Assay (ARA) of the twenty-two tributaries sampled around the lake in 2009 and 2010 indicate a decrease in the number of tributaries affected by human bacterial sources; however, in 2009 and 2010, no decrease in livestock sources of bacteria was found.

The quality control and quality assurance analyses indicate that the analysis procedures give reliable, consistent results and were rated as good or very good. In 2010 the accuracy and precision of the laboratory analyses was consistent and rated as good as with previous years.

The sample efficiencies of the volunteer monitors were excellent again in 2010 (98.0 percent for TP and CA, 94.0 percent for SD), indicating the commitment and conscientiousness of the volunteer monitors.

12. ACKNOWLEDGEMENTS

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APPENDIX

Table A.1. 2010 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	Tully	-79.72	37.03
B20	Tully	-79.73	37.03
B22	DeCesare	-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	-79.74	37.04
CM1	Rice	-79.54	37.06
CM1.2	Rice	-79.54	37.06
CM5	Anderson	-79.59	37.05
CR8	Anderson	-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	Persche	-79.67	37.12
CR16	Vincent	-79.66	37.15
CR17	Vincent	-79.67	37.15
CR19	Mocksfield	-79.69	37.16
CR21	Rogers	-79.71	37.15
CR21.2	Rogers	-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	Hutson	-79.67	37.05
G14	Salley	-79.68	37.07
G15	Hutson	-79.68	37.06
G16	Salley	-79.69	37.06
G18	Salley	-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	-79.59	37.05
R9	Okeson	-79.62	37.07
R11	Anderson	-79.59	37.06
R13	MacMullan/Marshall/Servidea	-79.64	37.10

Table A.1. 2010 SML monitoring stations with monitor names and station locations (cont.)

Station	Monitor	Longitude	Latitude
R14	Persche	-79.65	37.11
R15	Vincent	-79.66	37.13
R17	Mocksfield	-79.68	37.15
R19	Mocksfield	-79.70	37.16
R21	Rogers	-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	Pafford	-79.60	37.02
SCB10	Pafford	-79.64	37.02
SCB11	Pafford	-79.63	37.02
SCB11.5	Pafford	-79.65	37.07
SB12	Waters	-79.66	37.04
SCB14	Waters	-79.68	37.03
SCB16	Waters	-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

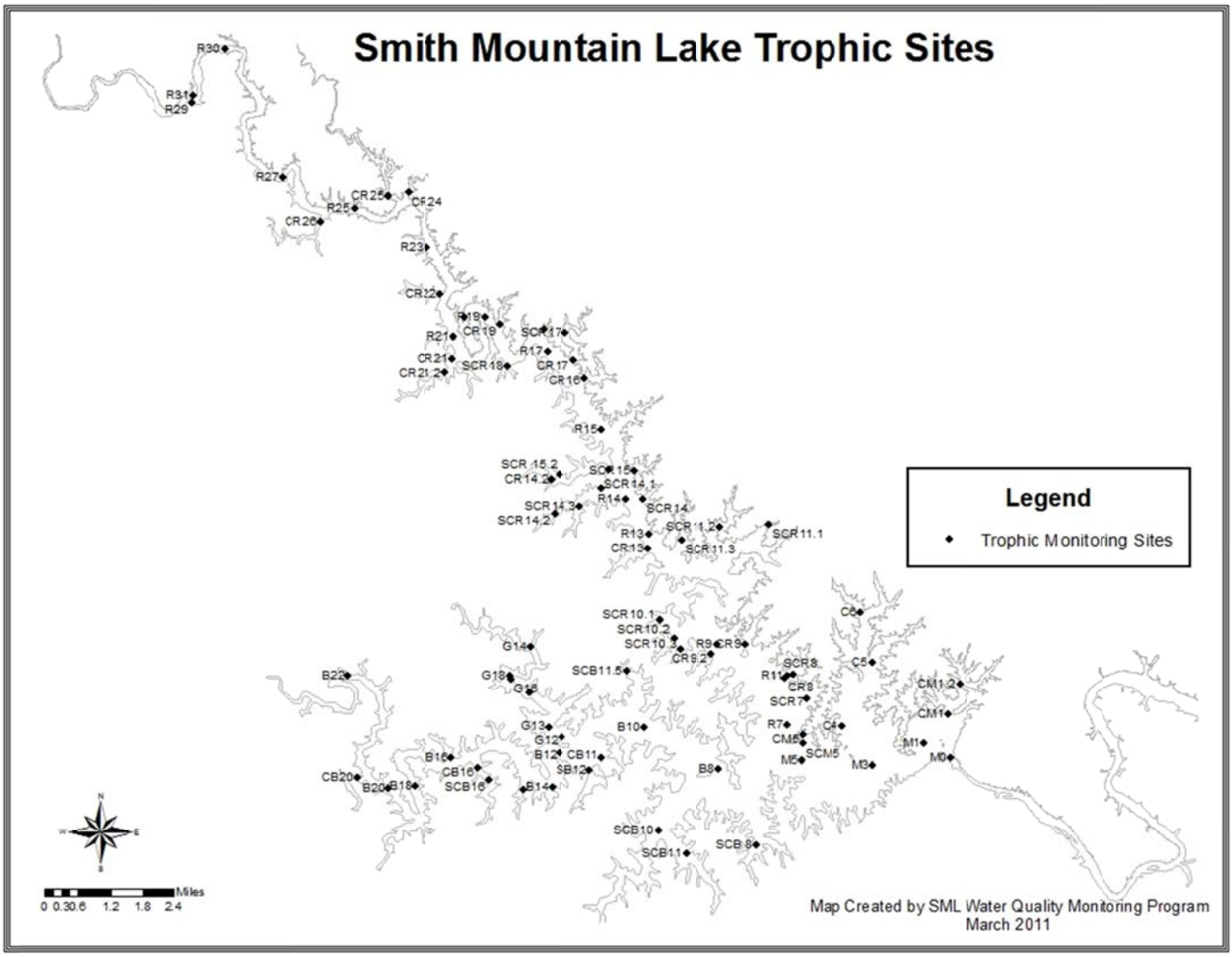

Table A.2. 2010 Smith Mountain Lake tributary stations and other downstream stations

Tributary Station Number	Stream Name
T0	Upper Gills Creek
T1a	Maggodee Creek
T2	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	Below Dam - Former Station 105
T10	Pigg River - Former Station 104
T11	Leesville Lake - Former Station 103
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
T19	Grimes Creek
T20	Indian Creek
T21a	Roanoke channel below Back Creek (sampled from shore)

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

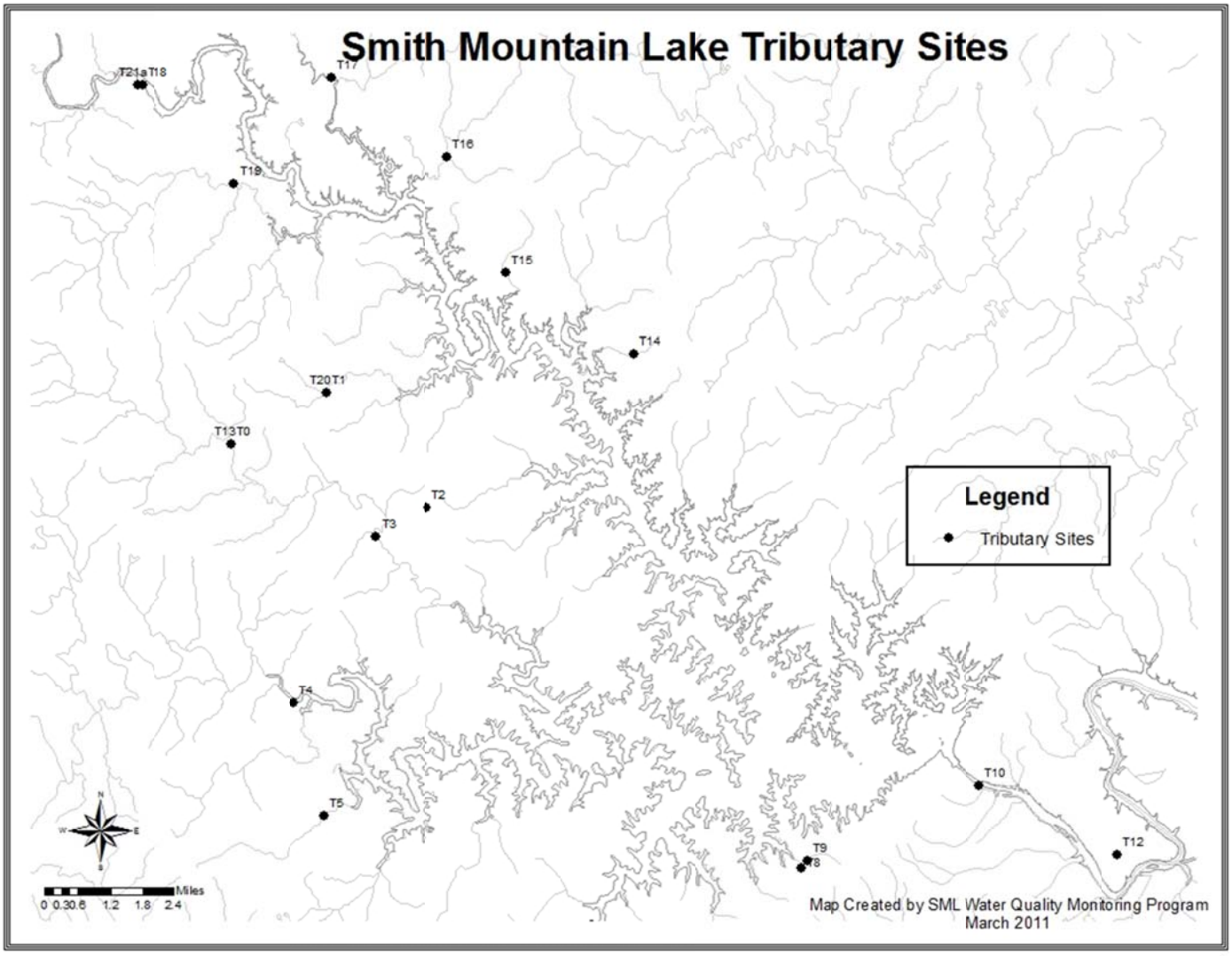

Table A.3. 2010 Total phosphorus data for Smith Mountain Lake sample stations

	5/30-6/5	6/13-6/19	6/27-7/3	7/11-7/17	7/25-7/31	8/8-8/14	Station Avg.	Std. Dev.
Station	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**(ppb)**	
B8	20.8	14.2	20.4	11.8	12.5	8.7	**14.7**	**4.9**
B10	13.7	38.5	15.9	17.9	12.8	9.9	**18.1**	**10.4**
B12	14.1	10.7	9.8	7.0	16.0	7.6	**10.9**	**3.6**
B14	15.1	15.9	13.0	15.1	19.9	5.5	**14.1**	**4.8**
B16	10.1	18.0	18.0	12.6	19.7	11.2	**14.9**	**4.1**
B18	80.2	42.8	50.3	25.2	22.5	18.3	**39.9**	**23.4**
B20	47.3	43.6	37.5	24.6	33.0	14.6	**33.4**	**12.2**
B22	66.3	58.1	81.5	64.7	64.3	60.3	**65.9**	**8.2**
C4	12.4	10.4	20.0	8.6	5.6	0.6	**9.6**	**6.6**
C5	10.7	10.6	15.8	15.6	9.1	3.8	**10.9**	**4.5**
C6	16.5	10.6	11.9	21.9	5.3	-0.3	**11.0**	**7.9**
CB11	28.6	13.6	20.6	8.9	13.3	4.7	**15.0**	**8.5**
CB16	15.8	296.8	18.6	21.7	161.7	16.5	**88.5**	**117.1**
CB20	45.8	21.9	52.4	20.9	29.8	5.0	**29.3**	**17.5**
CM1	38.0	19.2	11.2	10.0	8.0	5.9	**15.4**	**12.0**
CM1.2	40.5	12.8	9.9	9.2	15.8	3.2	**15.2**	**13.1**
CM5	30.9	13.1	18.6	7.8		4.4	**15.0**	**10.4**
CR8	17.5	32.5	13.1	5.2	9.2	2.7	**13.4**	**10.8**
CR9	31.9	16.7	11.5	6.6	10.4	2.8	**13.3**	**10.2**
CR9.2	10.7	9.6	15.1	6.9	8.2	1.4	**8.7**	**4.5**
CR13	7.4	13.7	26.2	17.0	14.1	11.7	**15.0**	**6.3**
CR14.2	14.5	116.8	17.6	20.5	27.0	19.2	**35.9**	**39.8**
CR16	11.4	16.5	22.6	23.5	15.9	9.5	**16.6**	**5.7**
CR17	34.2	20.4	47.7	28.2	20.0	13.2	**27.3**	**12.4**
CR19	5.5	16.9	25.9	38.7	60.7	8.6	**26.1**	**20.8**
CR21	12.7	19.5	11.0	22.4	27.1	9.2	**17.0**	**7.1**
CR21.2	11.4	32.2	23.9	23.6	18.5	18.2	**21.3**	**7.0**
CR22	87.0	59.2	73.7	52.6	57.0	54.9	**64.1**	**13.5**
CR24	64.6	38.2	32.0	47.9	22.4	27.1	**38.7**	**15.5**
CR25	40.7	48.4	41.6	31.2	27.0	27.2	**36.0**	**8.8**
CR26	52.6	42.7	38.3	28.4	50.4	32.1	**40.7**	**9.7**
G12	11.8	14.7	17.2	16.6	20.4	2.9	**13.9**	**6.1**
G13	16.1	7.6	20.5	13.4	14.6	4.3	**12.7**	**5.9**
G14	11.3	41.1	26.6	24.2	34.1	13.4	**25.1**	**11.6**
G15	16.9	15.3	23.9	13.1	16.2	3.5	**14.8**	**6.6**
G16	17.5	19.8	21.5	22.6	18.2	16.7	**19.4**	**2.3**
G18	18.5	25.8	37.2	33.9	22.1	28.0	**27.6**	**7.0**
M0	9.5	8.0	18.3	10.1	8.6	2.9	**9.6**	**5.0**
M1		7.0	11.4	10.0	4.9	5.6	**7.8**	**2.8**
M3		5.4	9.1	16.7	4.3	10.2	**9.1**	**4.9**
M5		4.3	10.7	7.6	13.3	3.9	**7.9**	**4.1**
R7	14.5	4.8	12.1	7.1	6.9	9.5	**9.1**	**3.6**

Table A.3. 2010 Total phosphorus data for SML sample stations (cont.)

	5/30-6/5	6/13-6/19	6/27-7/3	7/11-7/17	7/25-7/31	8/8-8/14	Station avg.	Std. Dev.
Station	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	(ppb)	
R9	14.7	7.8	22.0	4.3	4.6	-0.7	**8.8**	**8.2**
R11	19.4	13.4	36.6	16.5	20.0	3.1	**18.2**	**10.9**
R13	5.8	-2.0	18.3	8.4	6.2	8.2	**7.5**	**6.5**
R14	8.8	19.4	19.6	15.2	22.2	11.6	**16.1**	**5.2**
R15	24.4	15.1	25.0	16.0	10.4	9.4	**16.7**	**6.7**
R17	31.5	18.8	19.2	25.2	10.1	9.4	**19.0**	**8.5**
R19	26.7	25.8	42.8	29.5	13.4	20.3	**26.4**	**9.9**
R21	104.3	24.6	35.6	27.5	30.0	14.3	**39.4**	**32.6**
R23	45.3	69.1	35.9	41.6	33.8	33.3	**43.2**	**13.5**
R25	113.4	59.5	78.6	87.2	63.2	12.1	**69.0**	**33.9**
R27	86.4	37.8	50.0	37.9	38.7	20.4	**45.2**	**22.3**
R29	83.9	61.8	44.6	38.4	57.0	13.7	**49.9**	**23.7**
R30	33.0		39.0	60.9	48.6	49.6	**46.2**	**10.7**
R31	80.3	59.2	82.5	40.3	50.9	24.8	**56.3**	**22.6**

Table A.4. 2010 Total phosphorus data for Smith Mountain Lake tributaries

	6/8	6/22	7/6	7/20	8/3	8/17, 8/18	Station Avg.	Std. Dev.
Station	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	(ppb)	
T0	382.9	128.6	131.4	166.5	42.9	82.9	**155.9**	**119.2**
T1a	116.4	72.8	85.7	158.6	48.0	45.8	**87.9**	**43.4**
T2	40.5	10.9	79.0	76.5	64.8	161.4	**72.2**	**50.7**
T3	47.8	47.5	52.7	54.0	47.7	112.2	**60.3**	**25.6**
T4	48.3	29.4	29.9	39.7	17.9	46.9	**35.3**	**11.8**
T5	42.6	35.3	46.2	35.4	11.3	34.1	**34.2**	**12.2**
T6	35.3	34.9		43.8	28.8	39.0	**36.4**	**5.5**
T7	5.4	6.9	11.3	2.0	86.5	6.8	**19.8**	**32.8**
T8	9.4					32.0	**20.7**	**16.0**
T9	15.4	5.3	13.9	4.9	9.5	3.3	**8.7**	**5.1**
T10	75.7	55.6	55.9	28.0	36.0	60.3	**51.9**	**17.3**
T11	29.9	12.7	30.1	16.5	13.6	4.2	**17.8**	**10.3**
T12	41.2	30.1	41.0	25.1	27.2	26.2	**31.8**	**7.4**
T13	41.4	29.1	36.7	19.1	24.8	18.6	**28.3**	**9.3**
T14	161.9	121.1	127.2	1476.3	116.2	100.7	**350.6**	**551.9**
T15	187.2	142.4	111.5	77.8	35.5		**110.9**	**58.3**
T16		101.1	117.8	50.6	69.6	46.0	**77.0**	**31.4**
T17		69.0	81.9	291.8	53.9	813.7	**262.1**	**323.4**
T18		46.2	69.8	38.1	55.1	100.0	**61.8**	**24.4**
T19		null	133.8	73.1			**103.4**	**42.9**
T20		57.9	73.5	58.2	62.8	145.7	**79.6**	**37.5**
T21a		40.5			368.6	22.7	**143.9**	**194.8**

Table A.5. 2010 Chlorophyll-*a* data for Smith Mountain Lake sample stations

	5/30-6/5	6/13-6/19	6/27-7/3	7/11-7/17	7/25-7/31	8/8-8/14	Station Avg.	Std. Dev.
Station	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	(ppb)	
B8	2.02	0.41	0.76	1.14	1.64	1.54	**1.25**	**0.60**
B10	0.92	0.66	0.47	2.27	1.10	11.99	**2.90**	**4.50**
B12	0.34	0.76	0.98	2.30	2.03	1.91	**1.38**	**0.80**
B14	3.39	1.58	0.95	1.29	3.20	1.86	**2.00**	**0.95**
B16	3.15	1.99	0.88	1.37	1.27	1.91	**1.56**	**0.45**
B18	1.92	1.78	1.24	2.70	1.52	3.96	**2.19**	**1.00**
B20	2.94	2.36	1.52	4.04	1.73	2.36	**2.49**	**0.91**
B22	6.11	11.44	9.10	4.93	5.39	100.82	**22.96**	**38.22**
C4	0.88	0.71	1.32	1.28	1.00	2.47	**1.28**	**0.63**
C5	1.81	0.26	0.70	0.60	1.08	2.47	**1.15**	**0.83**
C6	1.09	1.03	0.77	0.25	1.99	2.45	**1.26**	**0.81**
CB11	1.40	1.24	0.67	0.73	1.69	1.40	**1.19**	**0.41**
CB16	1.47	2.05	1.04	2.19	2.33	0.96	**1.67**	**0.60**
CB20	3.36	1.58	4.84	1.74	3.03	2.39	**2.82**	**1.21**
CM1	0.65	0.71	0.73	0.57	0.95	5.18	**1.46**	**1.83**
CM1.2	0.72	0.37	0.46	0.48	0.80	1.30	**0.69**	**0.34**
CM5	2.46	0.68	0.46	0.34	1.17	2.11	**1.20**	**0.89**
CR8	2.52	0.71	0.36	0.42	0.48	1.52	**1.00**	**0.86**
CR9	1.15	0.66	1.58	0.62	1.20	1.52	**1.12**	**0.41**
CR9.2	0.75	0.73	0.81	0.74	1.88	1.59	**1.08**	**0.52**
CR13	1.21	1.56	1.09	1.01	1.11	0.85	**1.14**	**0.24**
CR14.2	1.96	2.88	0.74	1.53	3.42	1.87	**2.07**	**0.96**
CR16	6.12	2.03	3.44	2.55	3.18	3.34	**3.44**	**1.42**
CR17	3.79	1.74	2.83	3.06	2.44	4.40	**3.05**	**0.95**
CR19	1.24	5.61	4.58	11.73	3.81	5.59	**5.43**	**3.48**
CR21	2.48	3.23	6.27	9.89	7.62	5.26	**5.79**	**2.76**
CR21.2	2.32	7.25	6.75	21.85	4.27	5.77	**8.04**	**7.00**
CR22	1.56	3.09	1.27	1.66	0.12	0.19	**1.31**	**1.10**
CR24	19.31	35.25	4.71	13.15	11.47	8.90	**15.46**	**10.83**
CR25	19.73	8.76	4.91	11.52	7.96	21.49	**12.39**	**6.73**
CR26	19.85	6.80	7.41	8.79	5.76		**9.72**	**5.76**
G12	2.02	0.81	0.47	1.60	1.34	1.93	**1.36**	**0.62**
G13	0.68	0.53	0.38	0.88	1.28	1.74	**0.92**	**0.51**
G14	3.28	0.69	0.56	2.02	1.13	2.04	**1.62**	**1.03**
G15	0.84	1.79	1.28	1.31	1.57	2.61	**1.57**	**0.60**
G16	4.58	1.74	1.16	1.92	1.55	3.44	**2.40**	**1.33**
G18	3.63	3.28	2.43	5.03	2.15	3.32	**3.31**	**1.02**
M0	0.85	0.87	0.56	0.73	0.71	0.66	**0.73**	**0.12**
M1		3.50	0.62	0.62	0.96	0.57	**1.25**	**1.27**
M3		0.79	0.17	0.60	1.05	1.57	**0.84**	**0.52**
M5		1.06	0.64	0.94	0.54	1.46	**0.93**	**0.37**
R7	1.96	0.83	0.75	0.48	0.34	2.07	**1.07**	**0.75**
R9	1.47	0.95	1.25	0.81	1.39	1.36	**1.20**	**0.27**

Table A.5. 2010 Chlorophyll–*a* data for SML sample stations (cont.)

	5/30-6/5	6/13-6/19	6/27-7/3	7/11-7/17	7/25-7/31	8/8-8/14	Station Avg.	Std. Dev.
Station	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	(ppb)	
R11	1.50	0.70	0.32	1.33	1.53	2.17	**1.26**	**0.66**
R13	3.91	0.97	2.69	2.18	3.07	3.97	**2.80**	**1.13**
R14	3.42	0.37	0.20	2.14	1.50	2.21	**1.64**	**1.22**
R15	3.46	3.55	2.77	4.31	3.89	3.33	**3.55**	**0.52**
R17	2.70	2.83	2.93	5.71	1.77	3.91	**3.31**	**1.36**
R19	5.56	24.78	1.90	4.56	1.63	4.24	**7.11**	**8.79**
R21	1.85	27.91	4.21	5.47	4.13	5.80	**8.23**	**9.74**
R23	0.29	1.90	2.00	1.25	1.27	0.96	**1.28**	**0.63**
R25	17.07	12.41	4.74	4.30	11.75	81.05	**21.89**	**29.39**
R27	17.74	9.10	3.32	4.35	13.42		**9.59**	**6.09**
R29	14.91	10.26	8.58	8.23	9.74		**10.34**	**2.68**
R30	29.72		2.29	6.54	10.82	13.58	**12.59**	**10.49**
R31	13.17	4.47	4.08	4.01	3.75	14.24	**7.29**	**4.99**

Table A.6. 2010 Secchi disk data for Smith Mountain Lake sample stations

	5/30-6/5	6/13-6/19	6/27-7/3	7/11-7/17	7/25-7/31	8/8-8/14	Station Avg.	Std. Dev.
Station	depth (m)	depth (m)	depth (m)	depth (m)	depth (m)	depth (m)	(m)	
B8	3.00	3.00	3.00	3.00	2.75	3.25	**3.00**	**0.16**
B10	3.00	3.00	2.50	2.50	2.50	2.75	**2.71**	**0.25**
B12	3.00	3.00	3.00	3.00	2.50	3.00	**2.92**	**0.20**
B14	3.00	3.00	2.75	2.25	2.50	2.00	**2.58**	**0.41**
B16	2.75	2.50	2.00	2.00	2.00	2.25	**2.25**	**0.32**
B18	2.25	2.25	2.25	1.75	1.50	2.00	**2.00**	**0.32**
B20	1.75	2.00	2.00	1.50	1.50	1.75	**1.75**	**0.22**
B22	1.00	1.25	0.75	0.75	1.25	1.00	**1.00**	**0.22**
C4	3.75	5.00	4.50	4.75	4.00	3.75	**4.29**	**0.53**
C5	3.50	4.75	4.50	4.00	3.75	3.75	**4.04**	**0.49**
C6	3.00	4.00	3.50	4.00	3.00	3.25	**3.46**	**0.46**
CB11	3.50	3.00	3.00	2.50	2.50	2.50	**2.83**	**0.41**
CB16	2.75	2.25	2.50	2.00	2.00	2.00	**2.25**	**0.32**
CB20	2.00	2.50	1.75	1.25	1.50	1.75	**1.79**	**0.43**
CM1	3.00	3.50	2.75	3.25	3.00	3.00	**3.08**	**0.26**
CM1.2	2.75	3.50	3.25	4.00	3.00	3.00	**3.25**	**0.45**
CM5	2.00	4.00	3.00	4.00	3.50	3.25	**3.29**	**0.75**
CR8	2.00	4.00	4.00	3.75	3.00	3.00	**3.29**	**0.78**
CR9	1.75	3.25	2.50	2.75	3.00	3.00	**2.71**	**0.53**
CR9.2	1.75	3.50	2.75	3.25	2.75	2.25	**2.71**	**0.64**
CR13	2.50	2.75	2.25	2.75	2.50	2.25	**2.50**	**0.22**
CR14.2	1.50	1.75	1.75	1.50	1.25	1.25	**1.50**	**0.22**
CR16	2.00	1.75	1.75	1.50	1.75	2.00	**1.79**	**0.19**
CR17	2.00	2.00	1.50	1.25	1.75	2.00	**1.75**	**0.32**
CR19	1.25	1.50	1.25	1.00	1.25	1.25	**1.25**	**0.16**
CR21	1.25	1.25		1.25	1.50	1.50	**1.35**	**0.14**
CR21.2	1.25	1.50		1.25	1.50	1.25	**1.35**	**0.14**
CR22	1.00	1.25	1.00	1.25	1.50	1.50	**1.25**	**0.22**
CR24	1.25	1.00	1.25	1.25	1.25	1.00	**1.17**	**0.13**
CR25	1.25	1.00	1.25	1.25	1.25	1.00	**1.17**	**0.13**
CR26	1.00	1.00	1.25	1.25	1.00	1.00	**1.08**	**0.13**
G12	2.50	3.00	2.25	2.50	2.50	2.50	**2.54**	**0.25**
G13	1.75	2.75	2.50	1.75	2.00	2.00	**2.13**	**0.41**
G14	2.50	2.00	2.25	2.25	2.50	1.50	**2.17**	**0.38**
G15	1.75	2.75	1.50	2.00	2.00	2.00	**2.00**	**0.42**
G16	1.75	2.50	2.00	2.00	2.00	1.50	**1.96**	**0.33**
G18	1.50	2.00	1.75	1.50	1.50	1.25	**1.58**	**0.26**
M0	3.00	3.25	2.00	3.75	3.25	2.75	**3.00**	**0.59**
M1		5.25	4.25	4.25	4.00	3.75	**4.30**	**0.57**
M3		4.75	4.50	4.50	4.25	4.50	**4.50**	**0.18**
M5		4.50	4.25	5.00	4.00	4.25	**4.40**	**0.38**
R7	2.25	4.25	4.00	4.00	3.50	3.00	**3.50**	**0.76**
R9	1.75	3.50	2.75	3.00	2.75	2.75	**2.75**	**0.57**

Table A.6. 2010 Secchi disk data for SML sample stations (cont.)

	5/30-6/5	6/13-6/19	6/27-7/3	7/11-7/17	7/25-7/31	8/8-8/14	Station Avg.	Std. Dev.
Station	depth (m)	depth (m)	depth (m)	depth (m)	depth (m)	depth (m)	(m)	
R11	2.00	4.25	2.50	3.00	2.25	2.25	**2.71**	**0.83**
R13	2.50	2.25	4.50	3.00	2.50	2.50	**2.88**	**0.83**
R14	2.25	2.75	2.50	2.25	1.75	2.25	**2.29**	**0.33**
R15	2.25	2.25	2.00	1.75	2.00	2.25	**2.08**	**0.20**
R17	1.50	2.00	1.50	1.25	1.50	1.50	**1.54**	**0.25**
R19	1.75		1.25	1.25	1.50	1.25	**1.40**	**0.22**
R21	2.00	1.25		1.25	1.25	1.25	**1.40**	**0.34**
R23	1.25	1.00	1.25	1.25	1.00	1.25	**1.17**	**0.13**
R25	1.25	1.25	1.25	1.25	1.25	1.00	**1.21**	**0.10**
R27	1.25	1.25	1.25	1.25	1.25	1.00	**1.21**	**0.10**
R29	1.25	1.50	1.25	1.25	1.25	1.25	**1.29**	**0.10**
R30	0.75		1.50	1.50	1.25	1.00	**1.20**	**0.33**
R31	0.25	0.50	1.00	0.75	1.00	1.00	**0.75**	**0.32**
SB12	3.25	3.50	4.00	3.00	2.25	2.50	**3.08**	**0.65**
SCB 8	2.75	4.00	3.50	3.00		3.00	**3.25**	**0.50**
SCB10	2.50	4.00	3.50	2.75		2.50	**3.05**	**0.67**
SCB11	2.25	3.25	2.75	2.50		2.00	**2.55**	**0.48**
SCB11.5	2.25	2.75	2.75	2.75		2.75	**2.65**	**0.22**
SCB14	2.25	2.50	2.50	2.50	2.00	2.25	**2.33**	**0.20**
SCB16	2.25	2.50	2.75	2.25	1.75	2.00	**2.25**	**0.35**
SCM5	3.50		3.25			3.25	**3.33**	**0.14**
SCR7	3.25		3.00			3.00	**3.08**	**0.14**
SCR8	3.00		3.00			2.50	**2.83**	**0.29**
SCR10.1	2.25	2.75	2.50	2.75	2.25	2.00	**2.42**	**0.30**
SCR10.2	2.50	3.00	2.75	3.00	2.50	2.25	**2.67**	**0.30**
SCR10.3	2.50	3.00	2.50	3.00	2.25	2.00	**2.54**	**0.40**
SCR11.1	2.00	1.75	2.00	2.00	2.00	2.00	**1.96**	**0.10**
SCR11.2	2.00	2.50	2.25	2.50	2.25	1.75	**2.21**	**0.29**
SCR11.3	2.25	3.50	2.00	3.25	2.00	2.50	**2.58**	**0.65**
SCR14	3.00		2.00	3.00	2.25	2.00	**2.45**	**0.51**
SCR14.1	2.50		2.25	2.50	1.75	2.00	**2.20**	**0.33**
SCR14.2	2.25		2.50	2.25	1.50	1.50	**2.00**	**0.47**
SCR14.3	3.00		2.00	2.50	2.00	1.75	**2.25**	**0.50**
SCR15	2.00		1.50	1.75	1.50	2.00	**1.75**	**0.25**
SCR 15.1	2.50		2.25	3.25	2.25	2.25	**2.50**	**0.43**
SCR 15.2	2.50		2.00	2.50	1.75	1.75	**2.10**	**0.38**
SCR17	1.50		1.25	1.50	1.50	1.50	**1.45**	**0.11**
SCR17.1	1.75		1.25	1.25	1.50	1.50	**1.45**	**0.21**
SCR18	2.00	2.00	1.50	1.50	1.75	1.75	**1.75**	**0.22**
SCR19.2	1.50	1.50	1.50	1.25	1.50	1.50	**1.46**	**0.10**
SCR20	2.00	1.75	1.75	1.50	1.50	1.50	**1.67**	**0.20**

Figure A.3. Site locations for depth profiling

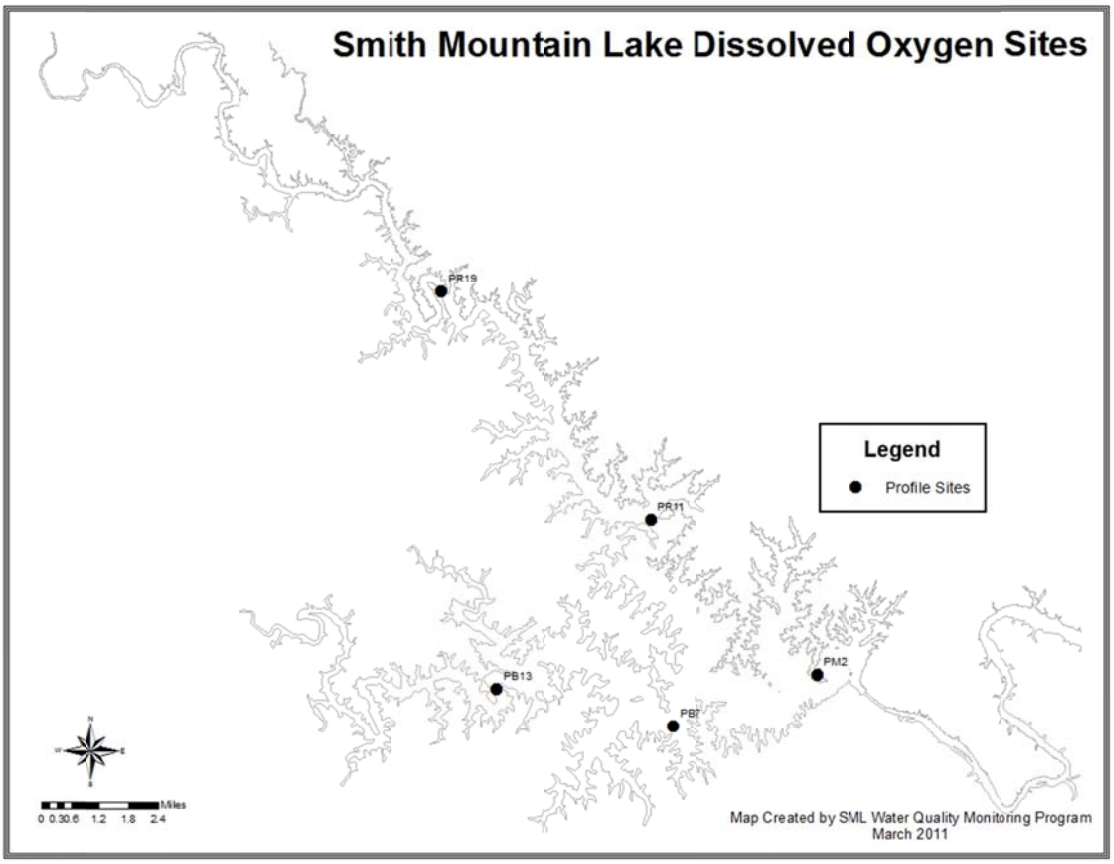

Figure A.4. Bacterial sampling sites

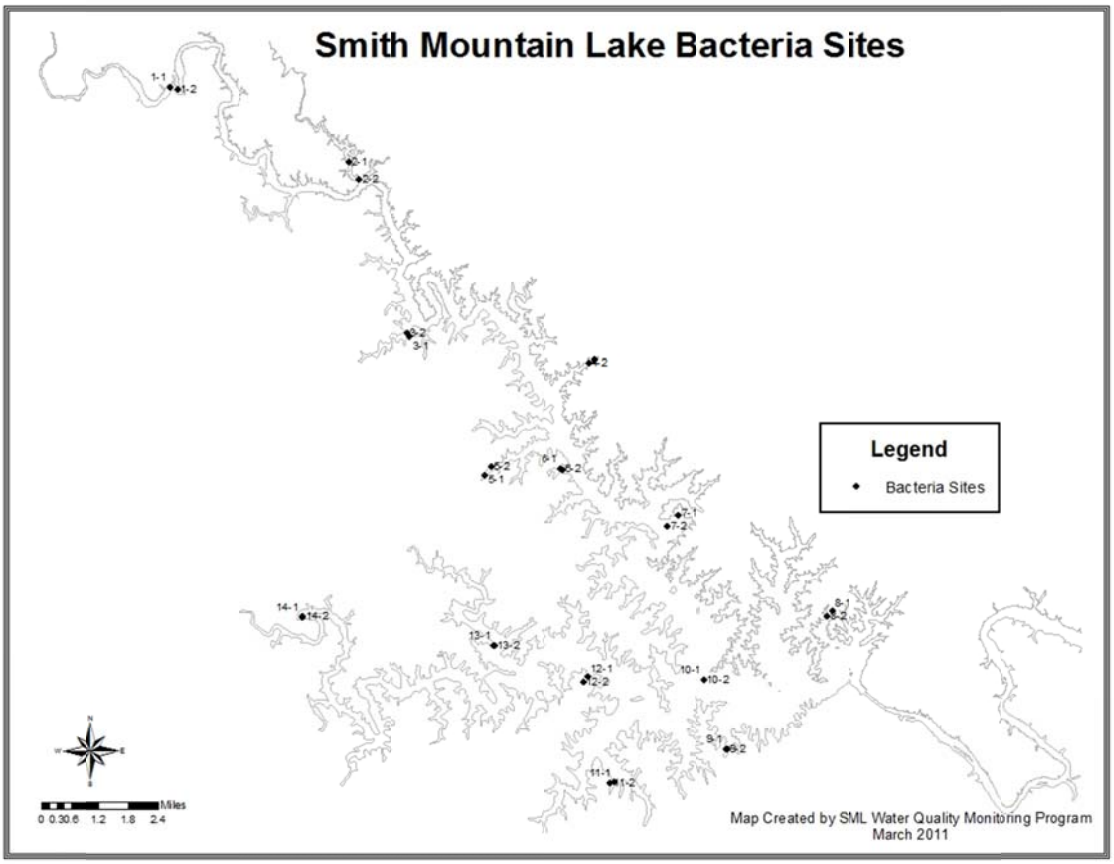

Table A.7. 201 *E. coli* data for Smith Mountain Lake sample stations

	6/1	6/15, 6/16	6/29, 6/30	7/12	7/27	8/10
Station	**MPN**	**MPN**	**MPN**	**MPN**	**MPN**	**MPN**
1-1	41.4	16.9	10.8	23.3	95.9	5.1
1-2	40.2	16.0	5.2	21.3	224.7	1.0
2-1	3.1	3.1	0.0	8.5	16.1	0.0
2-2	1.0	0.0	2.0	0.0	14.6	1.0
3-1	2.0	2.0	0.0	10.6	3.1	0.0
3-2	1.0	2.0	1.0	3.0	0.0	0.0
4-1	2.0	22.6	7.4	20.6	67.0	1.0
4-2	12.2	0.0	9.8	28.1	2.0	9.8
5-1	13.4	24.3	7.5	24.3	29.8	22.8
5-2	6.3	7.5	0.0	13.5	21.1	2.0
6-1	13.4	1.0	14.5	3.1	16.0	0.0
6-2	2.0	0.0	2.0	14.8	1.0	0.0
7-1	1.0	0.0	1.0	0.0	0.0	0.0
7-2	0.0	0.0	1.0	1.0	0.0	0.0
8-1	7.4	5.1	14.8	5.2	228.2	0.0
8-2	2.0	6.3	3.1	0.0	33.2	2.0
9-1	6.3	18.5	29.2	65.0	118.7	0.0
9-2	0.0	14.8	18.7	26.5	39.3	0.0
10-1	0.0	0.0	0.0	1.0	1.0	0.0
10-2	0.0	0.0	0.0	0.0	0.0	1.0
11-1	8.4	22.8	62.0	5.2	101.9	0.0
11-2	14.1	12.0	39.9	13.5	107.6	5.2
12-1	3.1	2.0	7.5	12.2	25.6	0.0
12-2	2.0	2.0	4.1	2.0	1.0	0.0
13-1	0.0	0.0	0.0	0.0	1.0	0.0
13-2	0.0	0.0	5.2	2.0	0.0	1.0
14-1	10.6	1.0	14.5	3.1	2.0	2.0
14-2	10.8	0.0	10.9	4.1	1.0	2.0