Smith Mountain Lake
Water Quality Monitoring Program
2022 Report

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Sponsored by
The Smith Mountain Lake Association
Funded by
American Electric Power
Bedford County Regional Water Authority
Smith Mountain Lake Association
Virginia Department of Environmental Quality
Western Virginia Water Authority

February 1, 2023

TABLE OF CONTENTS

FIGURES

TABLES

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1. EXECUTIVE SUMMARY

The 2022 monitoring season began in May with the annual training session which was held in person for the first time in two years. Volunteer monitors measured water clarity and collected water samples every other week until mid-August. Student technicians 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 (one tributary is sampled by a volunteer monitor). Also on a bi-weekly schedule, Ferrum College personnel collected additional lake samples for bacterial analysis.

The overall conclusion in regard to the water quality in Smith Mountain Lake is that it is very good. The lake is not aging as fast as would have been predicted for a reservior. However, the weather and climate are a significant driving factor for the trophic status of the lake. We will continue to monitor the water quality of the lake in order to provide data to help ensure a healthy lake and help protect this valuable resource in the region.

1.1 *Conclusions – Trophic Status*

In general, water quality improves greatly 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, chlorophyll-*a*, and Secchi depth are all influenced by different degrees by the distance to the dam with Secchi depth showing the strongest linear relationship.

In 2022, average total phosphorus and chlorophyll-*a* concentrations were slightly decreased, as was the average Secchi depth.

1.2 *Conclusions – DO, Temperature, pH and Conductivity Lake Depth Profiles*

The temperature profiles indicate that the thermocline at most sample sites continues to be slightly higher in the water column. As has been the case since 2015, the bottom of the lake becomes anaerobic (DO is depleted) in June rather than July. This trend has a negative effect on aquatic life by forcing them to move closer to the surface earlier in the summer, thus increasing thermal stress. Atmospheric carbon dioxide is increasing globally and may be affecting Smith Mountain Lake. Increased carbon dioxide decreases pH and promotes photosynthesis, increasing algal production. While DO will increase at the surface, the amount of organic matter settling into the hypolimnion will also increase and the hypolimnetic oxygen deficit will become more severe. Continued depth profiling and study of algal dynamics will provide scientific data to support effective management of Smith Mountain Lake as it ages.

1.3 *Escherichia coli Measurements*

The *E. coli* populations in Smith Mountain Lake in 2022 were much higher than the levels in 2021. In 2022, the mean *E. coli* count was 75.9 MPN compared to the 2021 mean *E. coli* count of 6.8 MPN. Since we began monitoring *E. coli* in 2004, the overall mean counts were their highest in

2013 and overall mean counts were their lowest in 2014. The 2022 overall mean is the second highest in the past ten years.

The comparison of marinas, non-marinas, and headwaters shows differences in *E. coli* values consistent with data collected over the last ten years, and shows that the majority of bacteria entering Smith Mountain Lake comes from the headwaters. In the first years of bacterial sampling, Bay Roc Marina (Site 1) was not included as a headwaters site. Beaverdam Creek was originally included as the headwaters site for the Roanoke channel. In 2006, the Bay Roc designation was changed to a headwaters site, along with Beaverdam Creek. Since then the headwaters sites have had the highest mean counts of all site types, except in 2021.

1.4 *Algae in Smith Mountain Lake*

The lower rainfall throughout the Smith Mountain Lake watershed during most of the 2022 sampling season reduced the overall algae population counts except for the May sampling dates. The green algae as a percentage of the total number of algae was lower in 2022 compared to 2021. Fortunately, the blue-green counts were the same percentage of the total algae this year. The one algal bloom found this season occurred soon after the May rains and the overall lack of algae bloom reports file via the VDH State Reporting Tool is consistent with the favorable decrease in chlorophyll-*a* and total phosphorus concentrations. *Anabaena* and *Microcystis* found in some samples suggest we should continue to monitor closely especially during heavy rains. The new statewide online reporting tool and NOAA satellite maps that are available to the program should help in rapid response to these blooms if and when they occur for identification of potential HAB hot spots. Certainly, sites around the lake are changing annually as weather patterns and lake land use changes. Sites that have higher numbers of any species need to be monitored to see if nutrient inputs or other causes could be impacting areas where higher numbers are found such as those that were reported near Bull Run, Smith Mountain Lake State Park, Beaver Dam Creek, Crystal Shores and Bayside Marina. The highest levels of algae in the lake are still found at the headwater sites. Rainfall timing and run-off and water level fluctuations may have the highest influence on algae growth, which is likely tied to higher nitrogen and phosphorus levels from run-off into the lake. As mentioned in the past, rainfall and lake levels should continue to be studied. We are fortunate not to have had flooding this year up in the tributaries but runoff is still a potential problem. We should also continue to monitor Smith Mountain Lake water temperature to attempt to correlate increases and impact on lake water quality. Extended sampling by some of the volunteer monitors at profile sites is a great addition to our data set. Providing plankton nets and Lugol's preservative for vertical tows would be a great addition to the extended season volunteer sampling if feasible. As water temperatures are anticipated to warm over time, it will be important to continue to sample regular sites and sites in shallow coves around the lake where algae blooms are reported so that we can also test for microcystin and other toxins in the lake where necessary. A look at the historical data from the 36 years of the Water Quality Program studies will be useful to compare temperature trends and algal changes much like we have done with the recent ten-year comparison.

2. INTRODUCTION

The Smith Mountain Lake Water Quality Monitoring Program (SMLWQMP), now in its thirty-sixth 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 2022 monitoring season.

The sampling season for the monitoring program runs roughly from Memorial Day to the middle of August. On a biweekly schedule, volunteer monitors measure water clarity at both basic and advanced monitoring stations and collect samples at the advanced monitoring stations. The monitoring network includes "trend stations" on the main channels and "watchdog stations" in coves off the main channels. In 2022, there were 84 stations in the monitoring network: 56 advanced stations and an additional 28 basic stations, with all but one of the basic stations located in coves (see *Methods*, page seven, for a description of the different station types). The samples are picked up at the homes of monitors by Ferrum College student technicians and then analyzed for total phosphorus and chlorophyll-*a* concentrations in the Water Quality Laboratory at Ferrum College. Sample collection began the week of May 22nd through 28th and the first sample bottles and filters were picked up on Tuesday, May 31st. The last week of sample collection was July 31st to August 6th, and the samples and filters were picked up on August 9th.

There are 22 tributary samples collected by student technicians during the weeks that samples are picked up from monitors' homes to assess tributary inputs of nutrients to the lake. Site T21a, in the upper Roanoke channel just below the confluence of Back Creek (34 miles from the dam), is considered the headwaters station for the Roanoke channel. (See *Methods,* page seven, for an explanation of the numbering system). Sample site T3 is the headwaters station designated for the Blackwater channel; it is located at the SR834 bridge. 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 pump-back) and the upper Gills Creek site. This site, T0, is several miles from the lake and a volunteer monitor collects the samples. This site is important because Gills Creek has been a water quality concern for many years due to the sediment coming into the lake from the creek banks. The tributary sites are listed in Table A.2 and shown in Figure 1.A and 1.A.1.

Since 1995 bacterial samples have been collected at 14 sites on six occasions each summer[1]. Ferrum College student technicians collected bacterial samples every other week in 2022, for a total of six samples at each site.

Depth profile measurements have been taken on Smith Mountain Lake since 2005 measuring dissolved oxygen, temperature, conductivity, and pH versus depth. Every other week during the summer season these measurements are made at five sites around the lake, including two sites on the Roanoke channel, two sites on the Blackwater channel and one site in the main basin near the dam. The depth of the profile varies according to the bottom depth of the specific site.

Since 2008 algal population samples have been collected weekly during the summer season by using ten-meter plankton tows. Horizontal plankton tows are taken at the 14 bacterial sites (at one station per site) and vertical plankton tows are taken at the five depth profile sites on alternating weeks.

Ferrum College scientists Clay Britton, Dana Ghioca Robrecht, Delia Heck, Carol Love, and Bob Pohlad, along with Tom Hardy, the SMLA Volunteer Monitoring Coordinator, carried out the 2022 training session in May. They were assisted by student technicians Emma Brubaker, Shane Hernandez, and Rene Settle. The program included a review of the previous year's findings and plans for the upcoming season. Experienced monitors reviewed their sample site locations and sample site identification numbers, received new supplies (sample bottles and filters), and had their monitoring equipment checked, if needed. New volunteer monitors were assigned sample station locations and identification numbers, practiced sampling procedures, and were issued sampling equipment and supplies. The Ferrum College student technicians delivered sampling equipment and supplies to the monitors who were unable to attend the training.

Newsletters were written and published by the program scientists and student technicians during the summer, reporting on activities of the program. Announcements were included in the

[1] In 2004 the method used in the bacterial analyses was changed to measure the *Escherichia coli* (*E. coli*) populations instead of fecal coliform populations.

newsletters in addition to advice and tips on sample collection. Two newsletters were published in 2022. Bi-weekly data summaries were provided to the SMLA and these were incorporated into press releases sent to local news outlets. The Annual Fall Meeting to recognize the contributions of the SMLA volunteers and present the preliminary report of results in the final newsletter was held this year after a two-year hiatus due to the COVID-19 pandemic.

Significant financial support for the program in 2022 came from the Appalachian Power Company with additional support from the Smith Mountain Lake Association, The Bedford Regional Water Authority, the Western Virginia Water Authority, and the Virginia Department of Environmental Quality. This year's monitoring results, data analyses, and comparisons with the other thirty-five years of data are discussed in the full detailed report, which follows.

Monitoring results from 1987 onward can be found in the project's annual reports for those years and are available electronically here.

3. METHODS

Detailed descriptions of the methods of sample collection, preservation and analyses, and quality control/quality assurance procedures can be found in the *Ferrum College Water Quality Lab Procedures Manual* (Love et al, 2022). The water quality parameters measured include water clarity (turbidity), measured as Secchi disk depth; total phosphorus, measured spectrophotometrically (λ =880 nanometers or nm) after persulfate digestion using the ascorbic acid method (QuikChem Method 10-115-01-1-F); and chlorophyll-*a*, determined using the acetone extraction method and measured fluorometrically with a Turner Trilogy Instrument. The specifics of each method are outlined in the appropriate section below. Additionally, quality control and quality assurance procedures evaluate laboratory procedures and are described later in this report.

These three water quality parameters are measured at trophic channel sampling stations 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 to the Hardy Ford Bridge on the Roanoke channel and to the B49 channel marker on the Blackwater channel. The trophic 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.

Trophic sampling station codes contain information on the location of the station. The sample station codes for trophic stations 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 (e.g. 23 miles from the dam would have a "23" in the station code).

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

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

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

An example of a sampling station code would be "CB14" which would indicate a cove station off the Blackwater channel approximately 14 miles from Smith Mountain Lake Dam. The trophic stations are listed in Table A.1 and shown in Figure A.1.

To evaluate tributary loading of nutrients, technicians collect grab samples (to fill a bottle with water) every other week at 21 tributary stations on their rounds to pick up lake water samples. A volunteer monitor collects one additional tributary sample (T0) in upper Gills Creek. The tributary stations are listed in Table A.2 and shown in Figures A.2 and A.2.a.

The five sample stations used for depth profiling and vertical phytoplankton sampling represent the major sections of Smith Mountain Lake. PM2 is in the main channel approximately two miles from the dam, PB7 and PB13 are in the Blackwater River channel approximately seven and 13 miles from the dam and PR11 and PR19 are in the Roanoke River channel approximately 11 and 19 miles from the dam. These sites are shown in Figure A.3.

The bacterial and horizontal phytoplankton sites were selected to allow comparison between Smith Mountain Lake non-marina sites and marina sites and to allow evaluation of three headwater sites. The non-marina sites include: the main basin site at the confluence of the Blackwater and Roanoke channels (Site 10), which was selected to provide samples not influenced by runoff from nearby shoreline; Forest Cove (Site 8, Bedford County), which is surrounded by a residential area and is located downstream from the confluence of the two main channels and in close proximity to Smith Mountain Lake Dam; Fairway Bay (Site 6, Franklin County), which is surrounded by homes and multi-family residences and is on the Roanoke channel; Palmer's Trailer Park Cove (Site 11, Franklin County), which 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; and Smith Mountain Lake State Park (Site 7), which is sampled where it intersects the main channel.

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

There are three headwaters sites, which primarily indicate specific watershed influences and not within-lake influences. Organic compounds and other nutrients in a body of water come from two possible sources, allochthonous inputs and autochthonous inputs. "Allochthonous" refers to input from outside the body of water (in other words, from the watershed) and "autochthonous" refers to input from within the body of water (for example, the algal population that is dependent on the in-lake process of photosynthesis). The three headwaters sites reflect three of the allochthonous inputs to Smith Mountain Lake. Bay Roc Marina (Site 1) is located on the Roanoke River at the "beginning of the lake" and as a result has been included as a headwaters site since 2006. The marina is one of the oldest marinas on the Franklin County side of the lake and was included in the marina designation until 2006. This change in designation occurred because it is the farthest site up the Roanoke channel. B49 (Site 14, formerly Ponderosa Campground) is located far upstream on the Blackwater River (Franklin County) not far from the non-navigable portion of the river. Beaverdam Creek (Site 2) is a tributary of the Roanoke River on the Bedford County side of the lake.

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

4. TROPHIC STATUS MONITORING

4.1 *Introduction*

Trophic status monitoring on Smith Mountain Lake this summer consisted of three components: 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 phytoplankton (algal cells) present in the water, so chlorophyll-*a* concentration is a good measure of the number of algae present in the lake. Secchi depth is a reliable and longstanding method of measuring water clarity. Secchi depth depends on the amount of sediment and algae in the lake water.

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.

4.2 *Methods*

Detailed descriptions of the methods of sample collection, preservation, analyses, and quality control/quality assurance procedures can be found in the *Training Manual for Smith Mountain Lake Volunteer Monitoring Program* (Thomas and Johnson 2012), and in the *Ferrum College Water Quality Lab Procedures Manual* (Love et al. 2022). The methods used are adapted from *Standard Methods for Water and Wastewater Analysis* (APHA 1999), and audited by the Virginia Department of Environmental Quality (DEQ). 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 B49 channel marker on the Blackwater River channel. Cove sampling stations are also monitored to provide additional information for trend analysis. Thus, the sample set consists of 56 sites for total phosphorus and chlorophyll-*a*, and 84 sites for Secchi depth measurements. Samples are also collected from 22 tributary stations and analyzed for total phosphorus to provide information about inputs to Smith Mountain Lake. Maps of the lake sampling stations and tributary sampling stations are provided in the Appendix of this report (Figures A.1 and A.2 and A.2.a).

At the sites below the dam (T9, T10, and T11), student technicians collect samples from bridges in the same manner as the other tributary samples. 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 Smith Mountain Visitor's Center, Station T10 is on the lower Pigg River, near its confluence with the Roanoke River, and Station T11 is on the Roanoke River after its confluence with the Pigg River.

A Lachat QuikChem 8500 Series 2 Flow Injection Analyzer (FIA) with an automated sampler is used for the analysis of TP. One of the advantages of the FIA is that the coloring reagents used to detect TP are mixed in real time, during the course of the measurement. Thus, there is no worry that the color will fade during the course of an analysis. The other advantage is that the instrument uses less reagent than the previous method, reducing analysis cost and time.

The samples are analyzed for TP based on the QuikChem method 10-115-01-1-F. This procedure requires an acidic digestion to convert the various forms of phosphorus into orthophosphate. The concentration of orthophosphate ion is determined using the FIA. The orthophosphate ion reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a complex. This complex is reduced with ascorbic acid to form a blue complex, which absorbs light at a wavelength of 880 nm. The absorbance measured by the FIA is proportional to the concentration of TP in the sample.

4.3 Results

The trophic status parameters for Smith Mountain Lake and its tributaries for the past 10 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 in parts per billion (ppb) and meters (m) 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)
2022	**27.5**	**66.1**	**4.9**	**2.0**
2021	31.2	65.3	5.4	2.1
2020	34.7	59.8	13.6	1.6
2019	41.2	70.5	12.6	1.8
2018	30.7	68.3	13.4	1.8
2017	30.6	58.7	12.9	1.8
2016	29.1	73.2*	8.7*	2.1
2015	22.7	84.9	6.8	2.3
2014	26.9	94.2	2.7	2.3
2013	23.9	69.6	13.3	2.2
10 Year Average	***28.6***	***68.5***	***9.2***	***2.0***

* See 2016 Smith Mountain Lake Water Quality Monitoring Report for explanation of data issues

Table 4.1 shows that the average TP concentration for the lake in 2022 (27.5 ppb) was lower than the 2021 average of 31.2 ppb. This value is the fourth lowest lake TP seen in the past ten years. The average TP concentration for the tributaries in 2022 (66.1 ppb) was higher than the 2021 average of 65.3 ppb. This value is also the fourth lowest in the past ten years. Chlorophyll-*a* concentration decreased in 2022 to 4.9 ppb, slightly lower than the 2021 concentration of 5.4 ppb and the lowest level since 2014. Average Secchi depth in 2022 (2.0 m) was slightly lower than the average in 2021 (2.1 m).

Figure 4.1 shows the comparison of the six sampling periods with the average value of each trophic status parameter monitored in 2022.

The average TP concentration for lake sampling sites over the sampling periods was 27.5 ppb. The highest average lake concentration was observed in week one (41.9 ppb) and the lowest average concentration was observed in week five (20.5 ppb). The average TP concentration for tributary sampling sites over the six sampling periods was 66.1 ppb. The highest average tributary concentration was observed in week five (84.5 ppb) and the lowest average concentration was observed in week three (54.8 ppb). The complete results for TP concentration for the 2022 sampling season are included in the Appendix of this report (Tables A.3 and A.4).

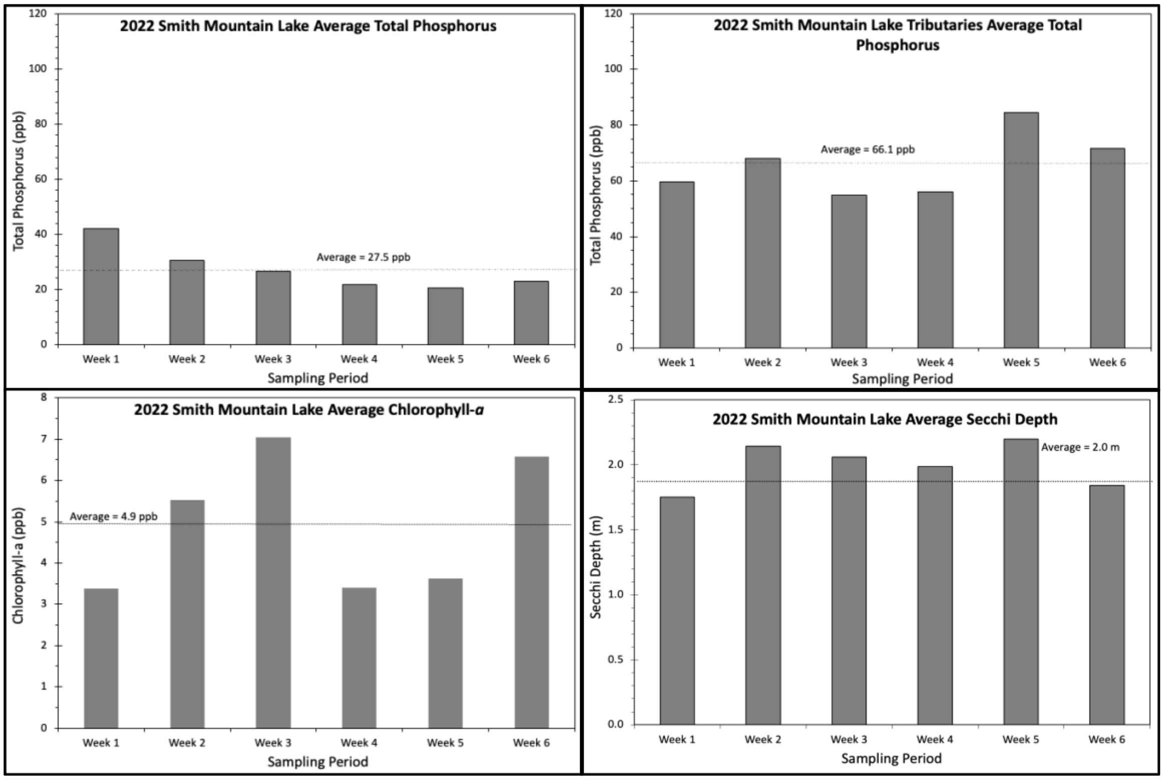


Figure 4.1. Trophic status parameters (total phosphorus, chlorophyll-*a*, and Secchi depth) for Smith Mountain Lake for each sampling period in 2022

The average chlorophyll-*a* concentration for lake sampling sites over all six sampling periods was 4.9 ppb. The highest average lake concentrations were observed in week three (7.0 ppb) and the lowest average concentration was observed in weeks one and four (3.4 ppb). The results for chlorophyll-*a* concentration for the 2022 sampling season are included in the Appendix of this report (Table A.6).

The average Secchi depth over all six sampling periods was 2.0 m. The shallowest average Secchi depth was observed in week one (1.8 m) and the deepest average Secchi depth was observed in week five (2.2 m). The complete results for Secchi depth for the 2022 sampling season are included in the Appendix of this report (Table A.7).

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.

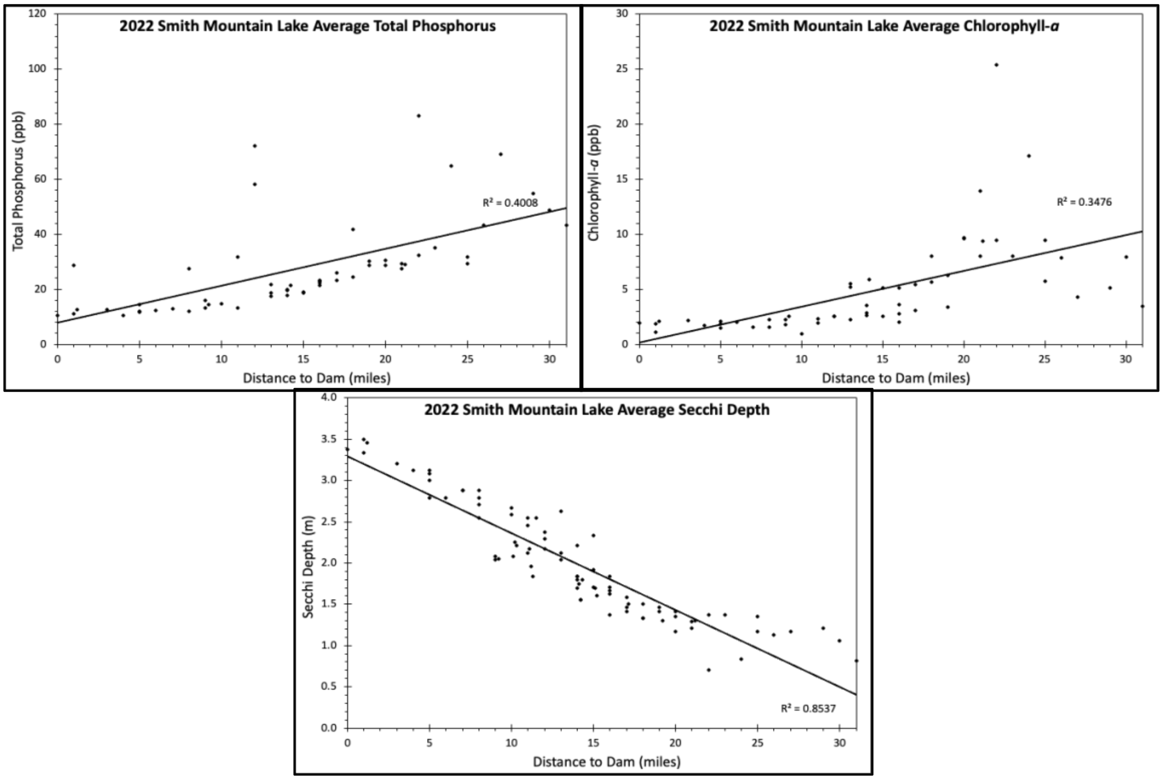


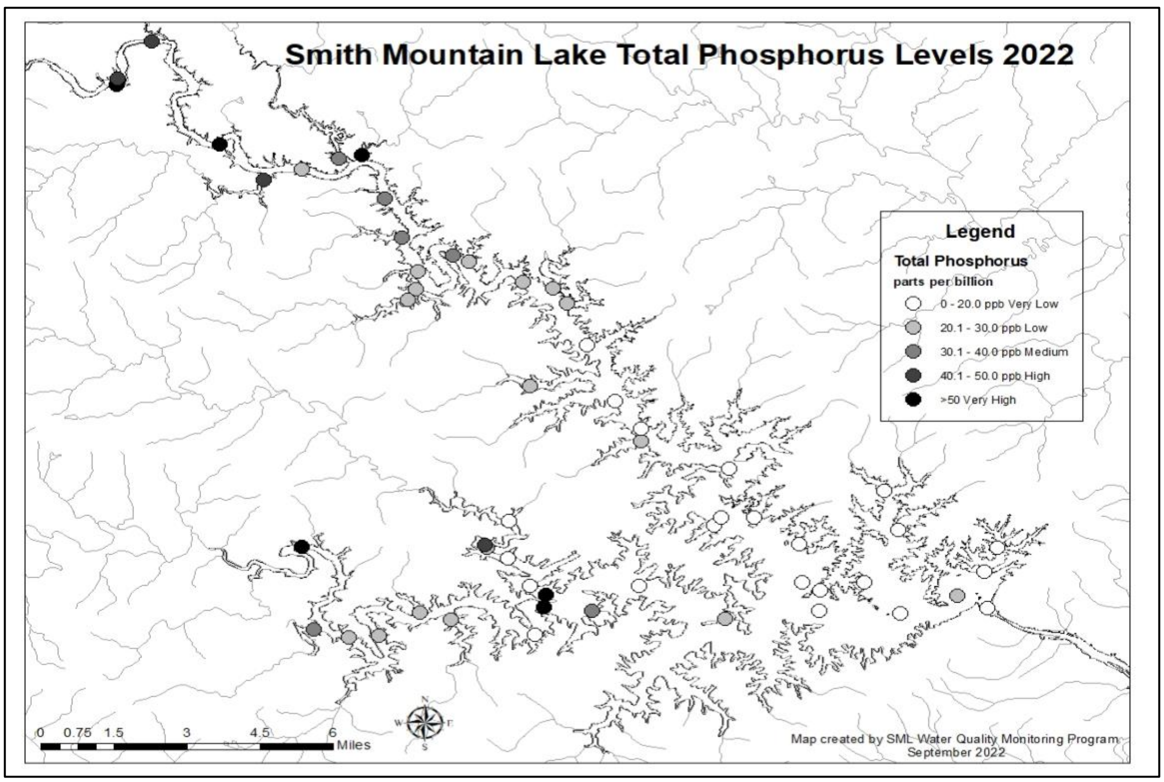
Figure 4.2. Variation of trophic status parameters with distance to the dam for Smith Mountain Lake in 2022

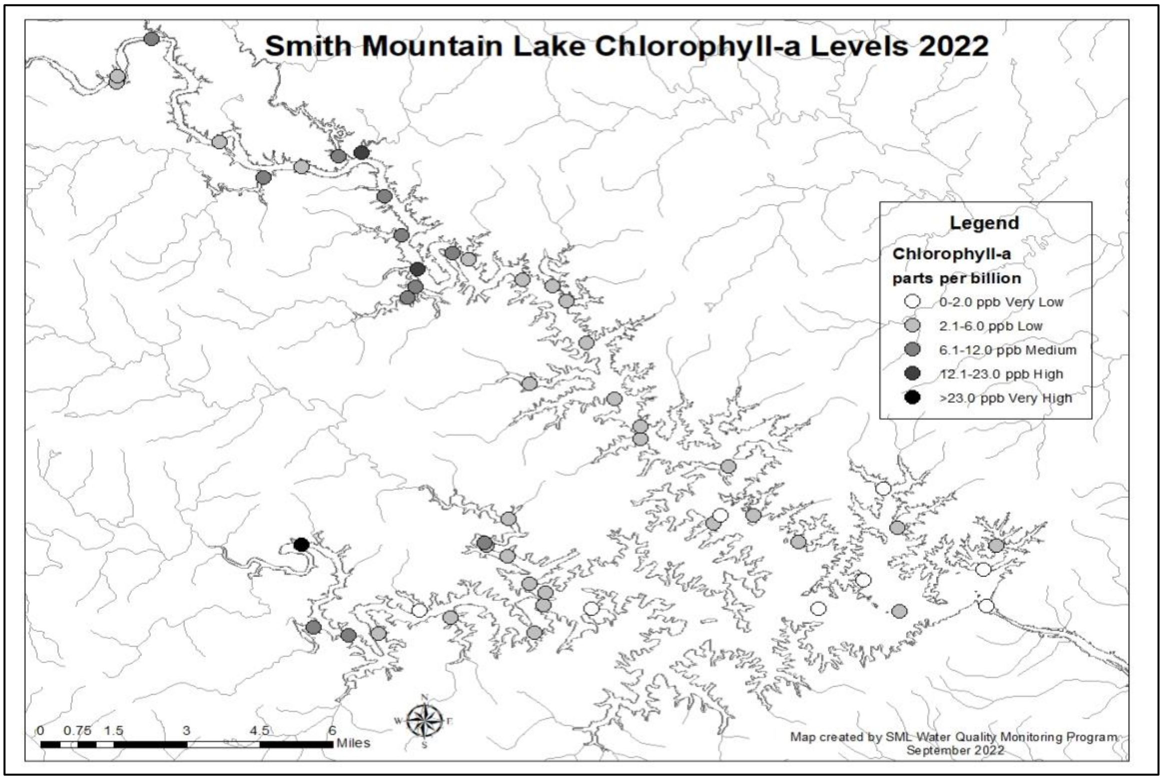
The first graph in Figure 4.2 shows that in general, phosphorus concentrations increase with increasing distance from the dam (R^2 = 0.40). This general trend can be attributed to increased sediment loads in waters further from the dam. The total phosphorus concentration outliers (defined as values at least twice the standard deviation) are B22 (83.1 ppb), CR24 (64.7 ppb), G12 (72.3 ppb), and R27 (69.1 ppb). These results are reflected in the map in Figure 4.3.

Sample sites that differ from the general trend seem to fall into two categories. One category consists of sites near the dam with higher total phosphorus concentrations than those predicted by the general trend. This difference can likely be attributed to pump-back of water from below the dam, including input from the Pigg River. The second category consists of sample sites distant from the dam that exhibit higher total phosphorus concentrations than those predicted by the general trend. In general, these are sample sites with high sediment loads, and it is likely that the observed increase in concentration is due to phosphorus that is closely associated with those sediments.

The second top graph in Figure 4.2 shows that 35 percent of the increase in chlorophyll-*a* concentrations is explained by the distance from the dam ($R^2 = 0.35$) possibly because of the presence of a non-linear relationship. There appears to be a baseline of chlorophyll-*a* levels approximately 15 miles from the dam, followed by a significant increase about 24 miles from the dam. There are three outliers (values twice or more the standard deviation) for chlorophyll-*a*: B22 (25.4 ppb), CR24 (17.1 ppb), and R21 (13.9 ppb). These results are seen in the map in Figure 4.3.

The Secchi depth graph in Figure 4.2 shows a strong inverse linear relationship with distance to the dam (Secchi depth decreases as distance to the dam increases, $R^2 = 0.85$). This is consistent with the general observation that water is clearer in the main basin of the lake than it is in the channels that extend away from the dam. This decrease in clarity is likely due to a combination of increased sediment load and increased algal activity. There are three outliers (at least twice the standard deviation) for Secchi depth, CM0 (3.4 m), CM1 (3.5 m), and CM1.2 (3.46 m). These results are reflected in the map in Figure 4.3.





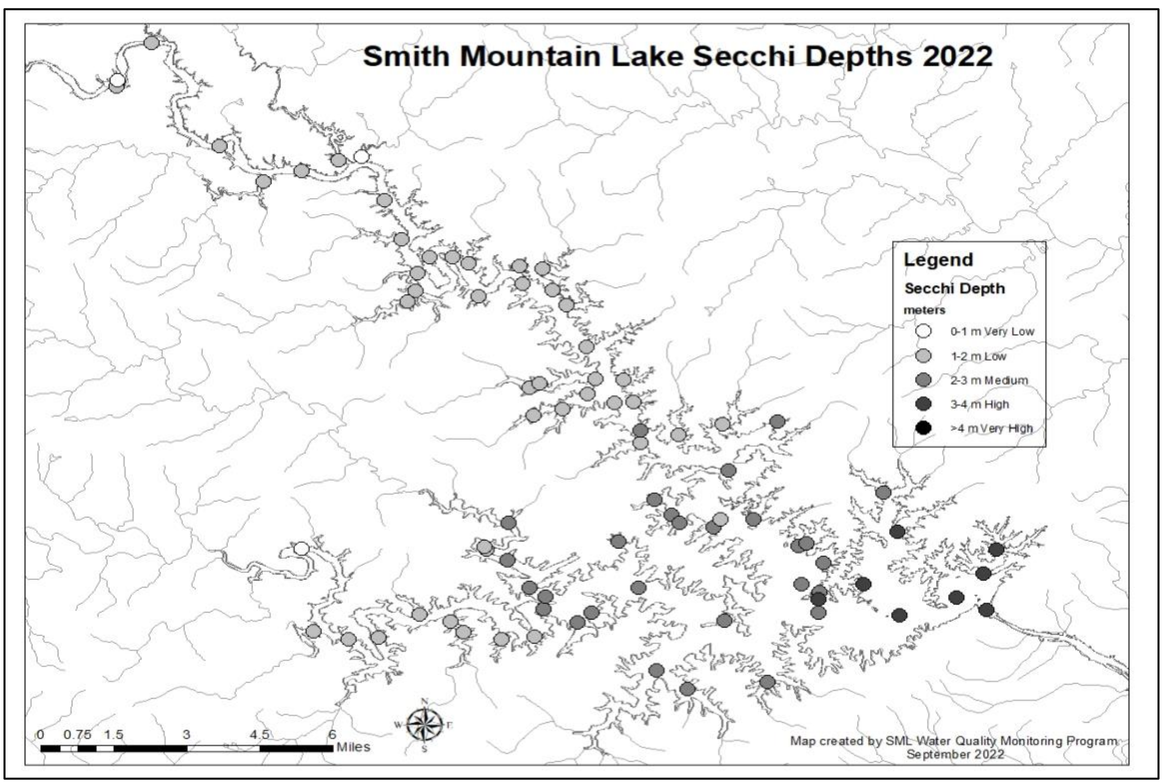


Figure 4.3. Maps showing variation in trophic status parameters for 2022

Table 4.2. 10-year comparison of average total phosphorus concentrations for Smith Mountain Lake and its tributaries including three sites below the dam

Total Phosphorus (ppb)	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	*AVG*
Average Lake Total Phosphorus	**27.5**	31.2	34.7	41.2	30.7	30.6	29.1	22.7	26.9	23.9	***29.9***
Average Tributary Total Phosphorus	**66.1**	65.3	59.8	70.5	68.3	58.7	73.2	84.9	94.2	69.6	***71.1***
Tributary Sites below Dam											
T9 Roanoke River	**14.3**	24.5	22.0	30.8	17.7	16.4	16.3	13.4	9.8	10.5	***17.6***
T10 Pigg River(before confluence)	**58.3**	53.1	74.4	66.5	63.1	59.0	61.0	83.5	68.2	66.0	***65.3***
T11 Roanoke River (after confluence with Pigg River)	**21.2**	35.0	44.8	49.8	22.0	37.5	50.9	41.8	27.8	29.0	***36.0***

Table 4.2 is a 10-year compilation of TP data for Smith Mountain Lake, its tributaries, and the three sites below the dam. The Pigg River (T10) has a relatively high TP concentration that increases the TP concentration in the Roanoke River from T9 to T11 (see Appendix Figure A.2.a). Because of pump-back, the Pigg River is a source of phosphorus to Smith Mountain Lake. There was a decrease in the average TP concentration in the three below-dam sites from 2021 (37.5 ppb) to 2022 (31.3 ppb).

4.5 *Conclusions*

In general, water quality improves greatly 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, chlorophyll-*a*, and Secchi depth are all influenced by different degrees by the distance to the dam with Secchi depth showing the strongest linear relationship.

In 2022, average total phosphorus and chlorophyll-*a* concentrations were slightly decreased, as was the average Secchi depth.

5. WATER QUALITY TRENDS BY ZONE

5.1 *Introduction*

After monitoring water quality in Smith Mountain Lake for over thirty-five 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 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 (greater algae growth) upper zones farther from the dam can support the large fish population desired by fishermen, while the less productive, clearer water found in the lower zones closer to the dam is ideal for water recreation and as a source of potable water.

5.2 *Methods*

The trophic status of a lake indicates the degree of nutrient enrichment and the resulting suitability of that lake for various uses. The process of eutrophication is nutrient enrichment of a body of water resulting in a significant increase in aquatic plant life (including algae). Phosphorus is most often the nutrient that limits algal production when concentration is low and attempts have been made to relate the trophic status of a lake to the concentration of phosphorus. In other words, the concentration of phosphorus controls the algal population. Table 5.1 shows one such effort (note that the relationships shown are for northern temperate lakes and will not represent southeastern lakes as well).

Table 5.1. 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 5.2 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 specific 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 5.2. 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 (Carlson 1977). 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):

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

The lake zones have been delineated as follows:

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

5.3 *Results*

The average annual value for the three trophic parameters is displayed by zone in the figures that follow: TP in Figure 5.1, chlorophyll-*a* in Figure 5.2, and Secchi depth in Figure 5.3. The low R^2 values in each zone show that there is no strong linear relationship between each of the three parameters and year given that most of the trendlines are close to horizontal lines, there is no high data spread, or the trends are non-linear. The lack of a measurable trend is not surprising because thirty-five years is short compared with the life of a natural lake (hundreds of years). On the other hand, there are very strong relationships ($R^2 >$ 0.9) when 35-year averages are computed for each of the three parameters and against the six zones which represent distance to the dam. There is a clear trend toward high water quality closer to the dam (Figure 5.4). Settling is the likely mechanism that leads to the improved water quality moving from the upper zones towards the dam.

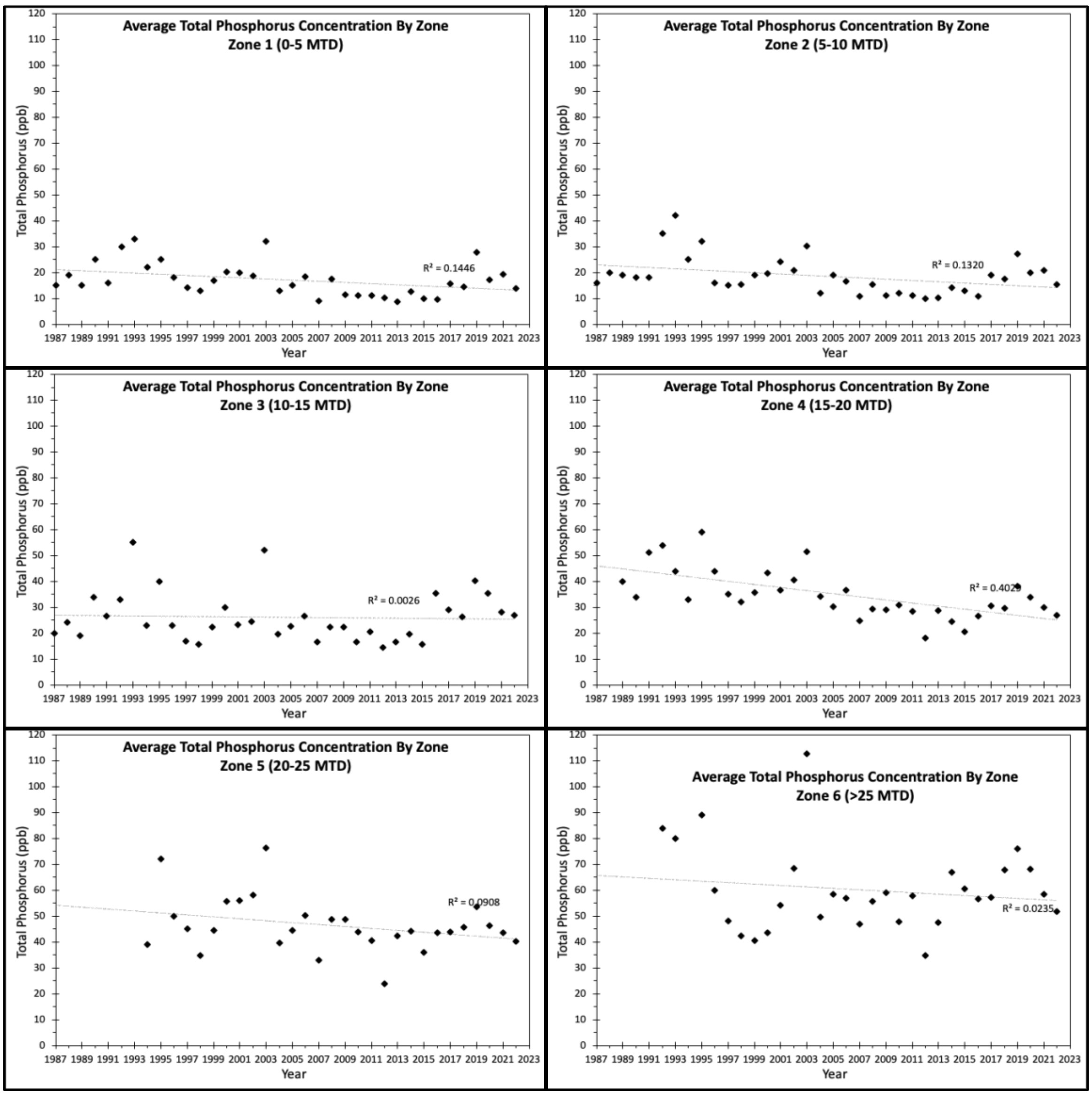


Figure 5.1. Average annual total phosphorus concentration by year and zone

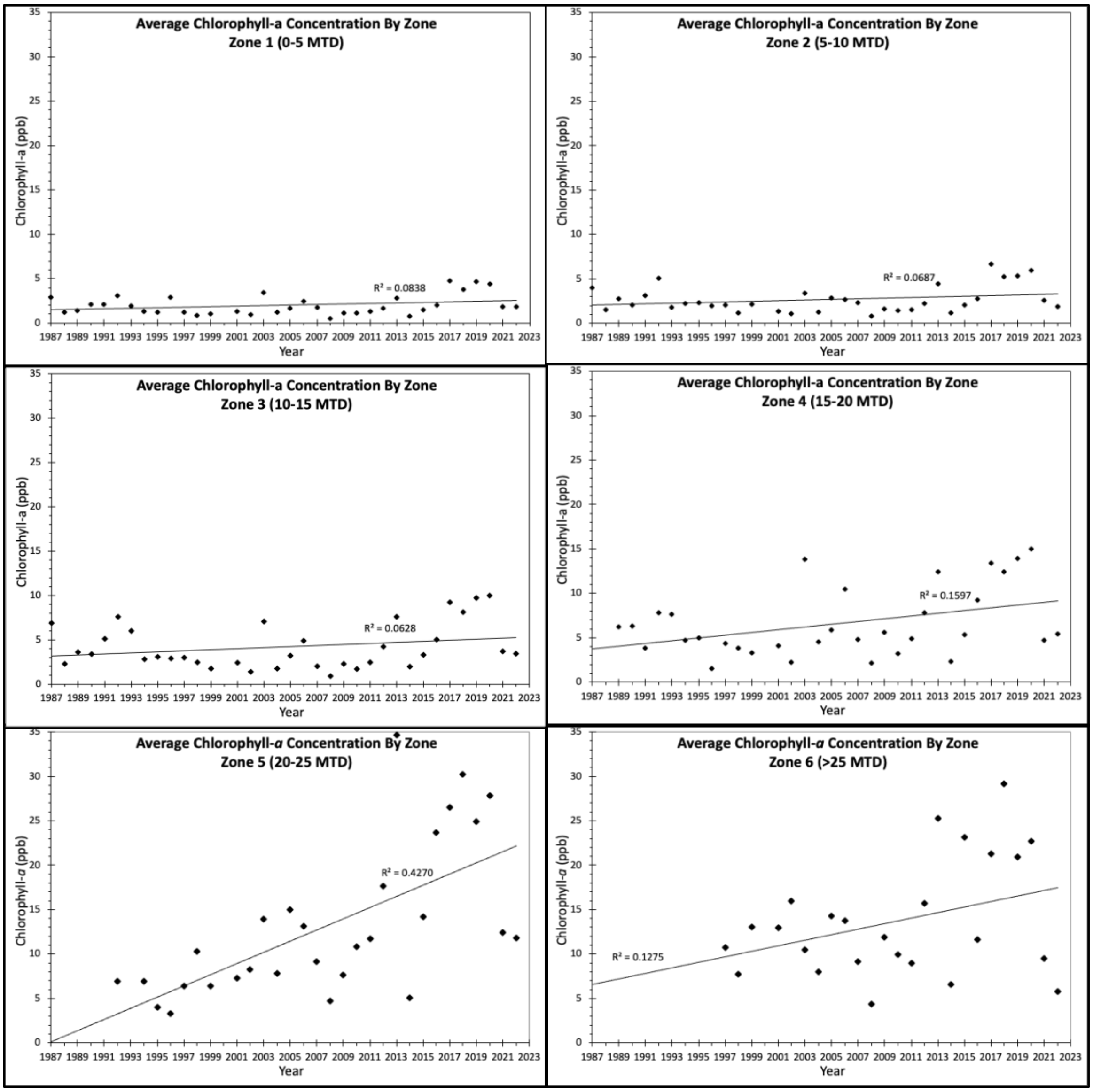


Figure 5.2. **Average annual chlorophyll-*a* concentration by year and zone**

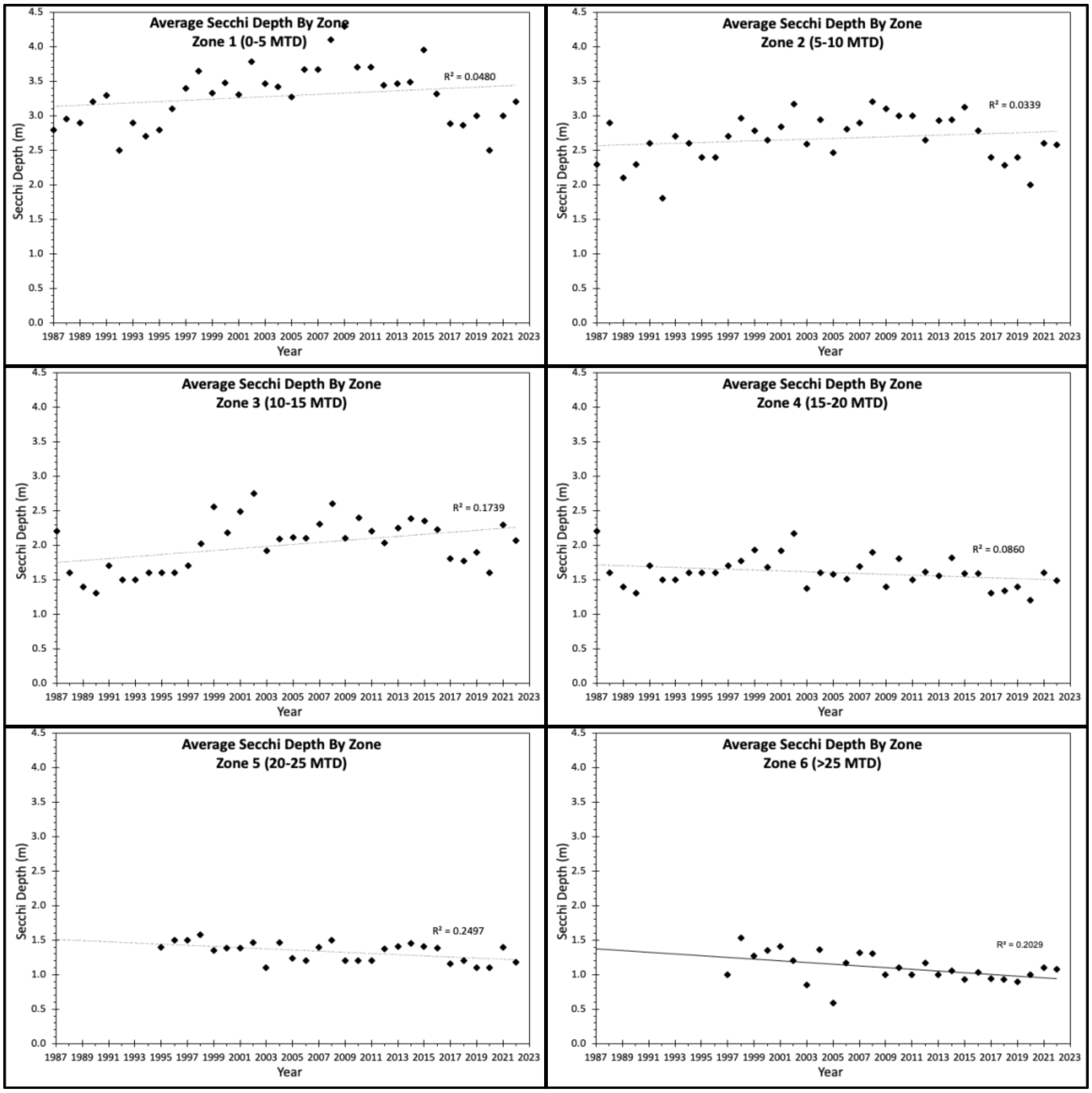


Figure 5.3. Average annual Secchi depth by year and zone

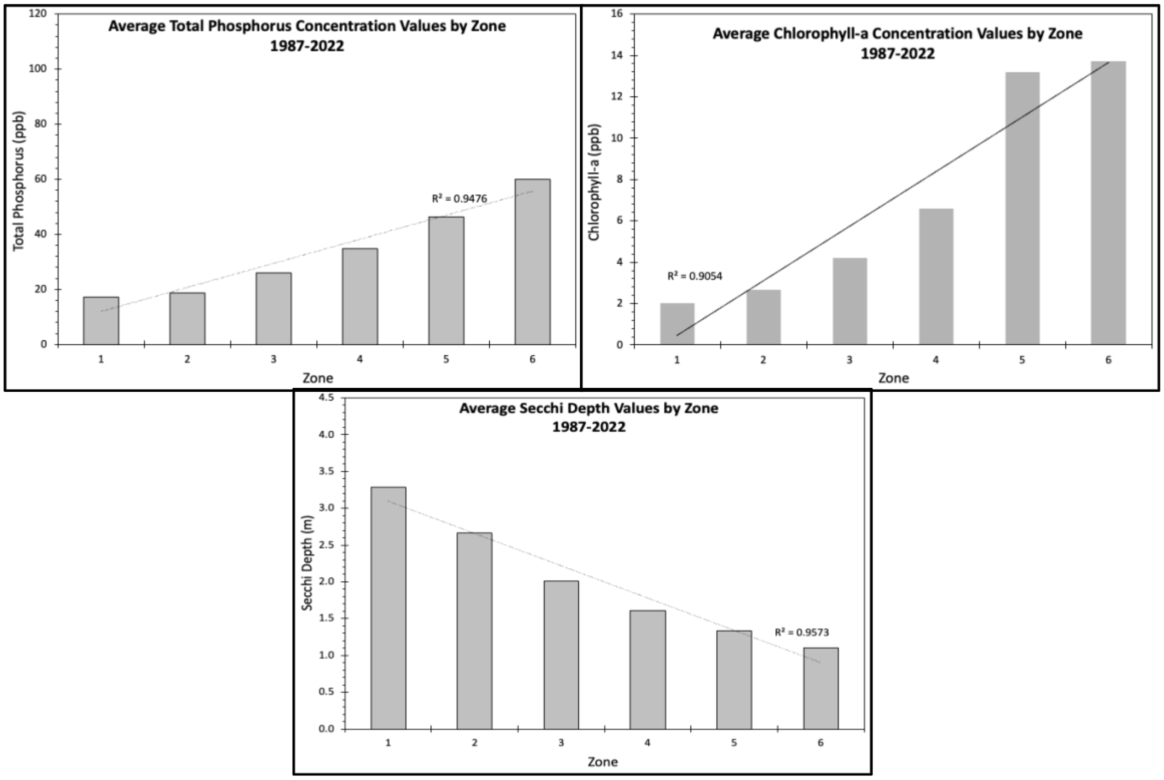


Figure 5.4. **Average parameter value by zone for 1987-2022 Carlson's Trophic State Index Components**

5.4 Discussion

In Figure 5.5, the combined trophic state index has been plotted as a function of its distance from the dam. Figure 5.6 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 strong ($R^2 = 0.79$).

Table A.5 gives the monitoring stations with miles-to-dam (MTD) 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 (65.1) was at B22 this year, while the lowest TSI-C value (39.1) was at CM1.

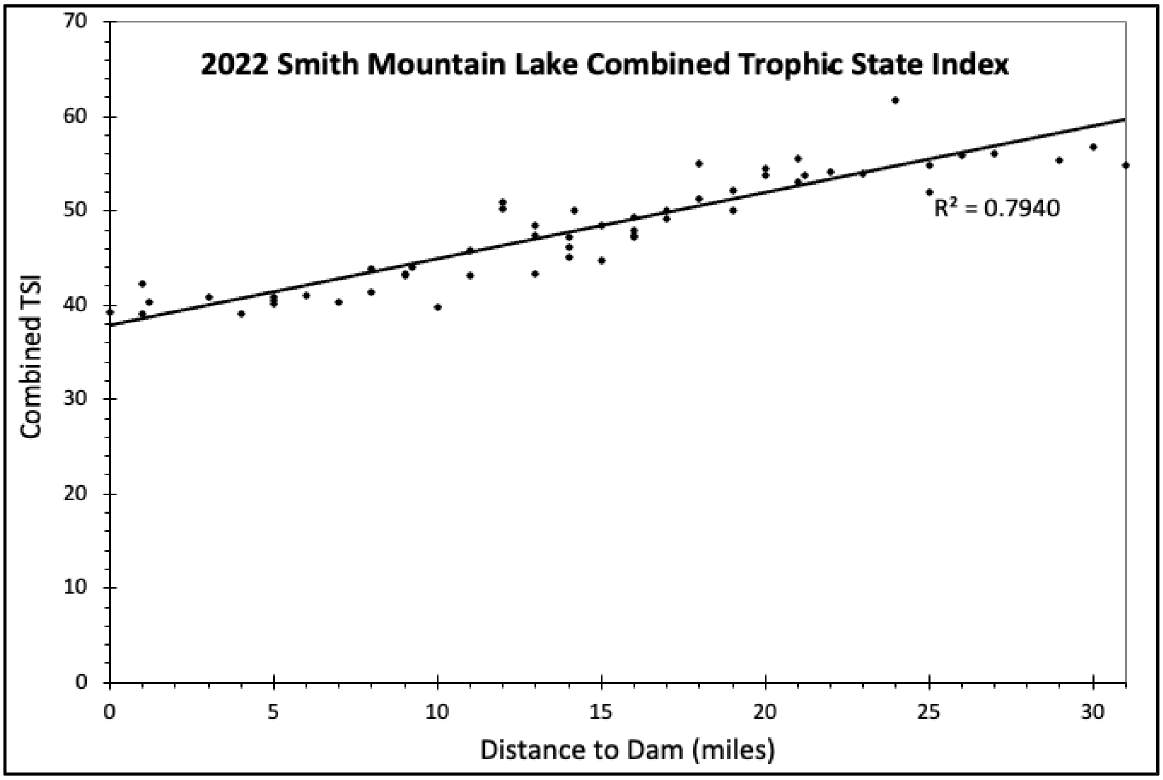


Figure 5.5. Combined Trophic State Index as a function of distance from dam

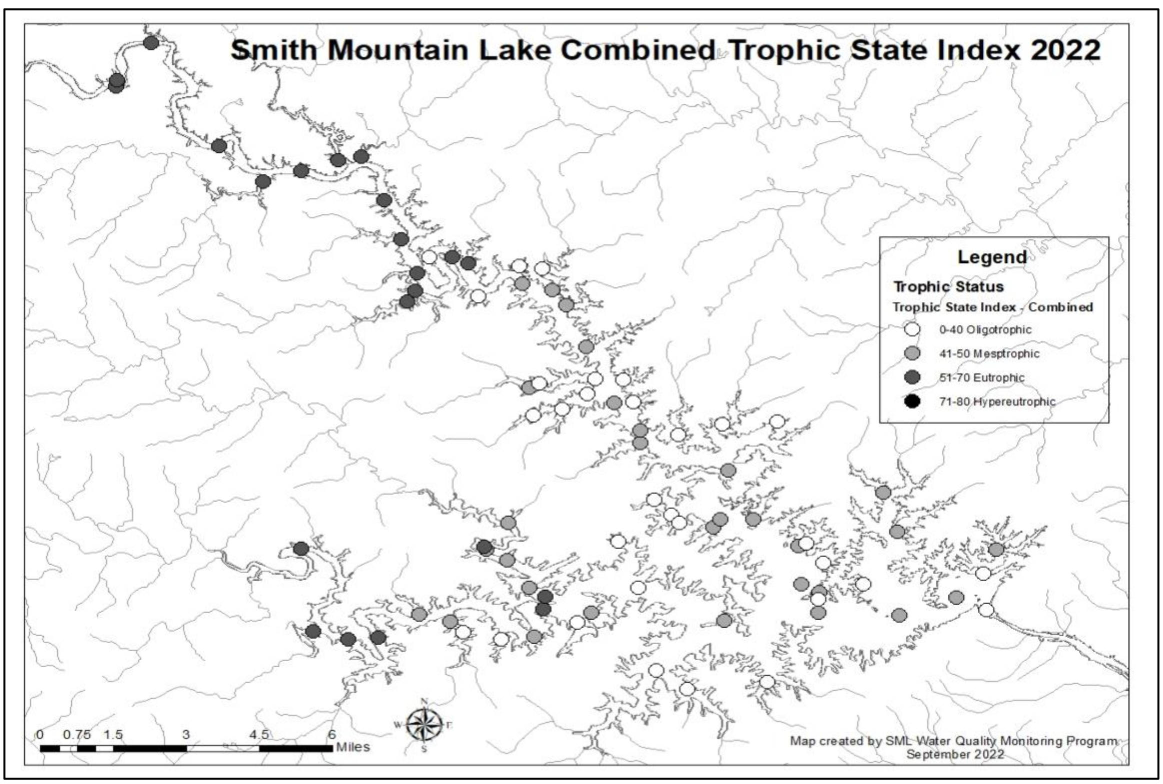


Figure 5.6. Map showing the Trophic State Index Combined results throughout the lake

For Smith Mountain Lake in 2022, the average TSI-TP (49.8), TSI-CA (43.5), and TSI-SD (51.4) are similar to 2021 values. The 2022 average combined TSI (TSI-C = 48.2) was slightly lower than in 2021 (TSI-C = 49.1). The lake is in the early stages of eutrophic conditions. Additionally, since TSI-TP, TSI-CA, and TSI-SD were again fairly similar, it indicates agreement between the three parameters.

The annual average TSIs from 2013–2022 are shown in Table 5.3. The average combined Trophic State Index has shown a generally increasing trend since 2014 before declining in 2020.

Table 5.3. Combined Trophic State Index for Smith Mountain Lake, 2013-2022

Year	Average Combined TS	TSI Range	R^2 (TSI vs. MTD)
2022	48.2	39.1 – 65.1	0.79
2021	49.1	40.3 – 63.3	0.83
2020	53.9	43.7 – 65.6	0.73
2019	54.1	44.0 – 68.2	0.80
2018	52.4	40.9 – 65.9	0.92
2017	52.9	42.4 – 65.2	0.87
2016	48.8	31.9 – 66.4	0.80
2015	46.9	34.3 – 65.8	0.91
2014	45.1	33.3 – 60.8	0.90
2013	49.9	36.7 – 65.1	0.89

The combined trophic state index, averaged by zone from 1987 to 2022, is displayed in Figure 5.7. The value of the coefficient of determination (R^2 = .99), based on thousands of individual measurements, shows a strong relationship between average TSI-C and the zone from which the samples were collected.

For the period of record (1987-2022), over 99 percent of the variation in trophic status is explained by proximity of the sample sites to the upper channels of the lake where inputs of nutrients and silt are received from the lake's watershed. In terms of explaining water quality, there is very little left to be accounted for by direct inputs from the shoreline and the many smaller tributaries that flow directly into Smith Mountain Lake. Local impacts are discernible in the trend line displayed in Figure 5.5 by those stations that deviate from the trend line. The monitoring program can then begin acting more as a "watchdog" as areas of unusually low water quality are investigated.

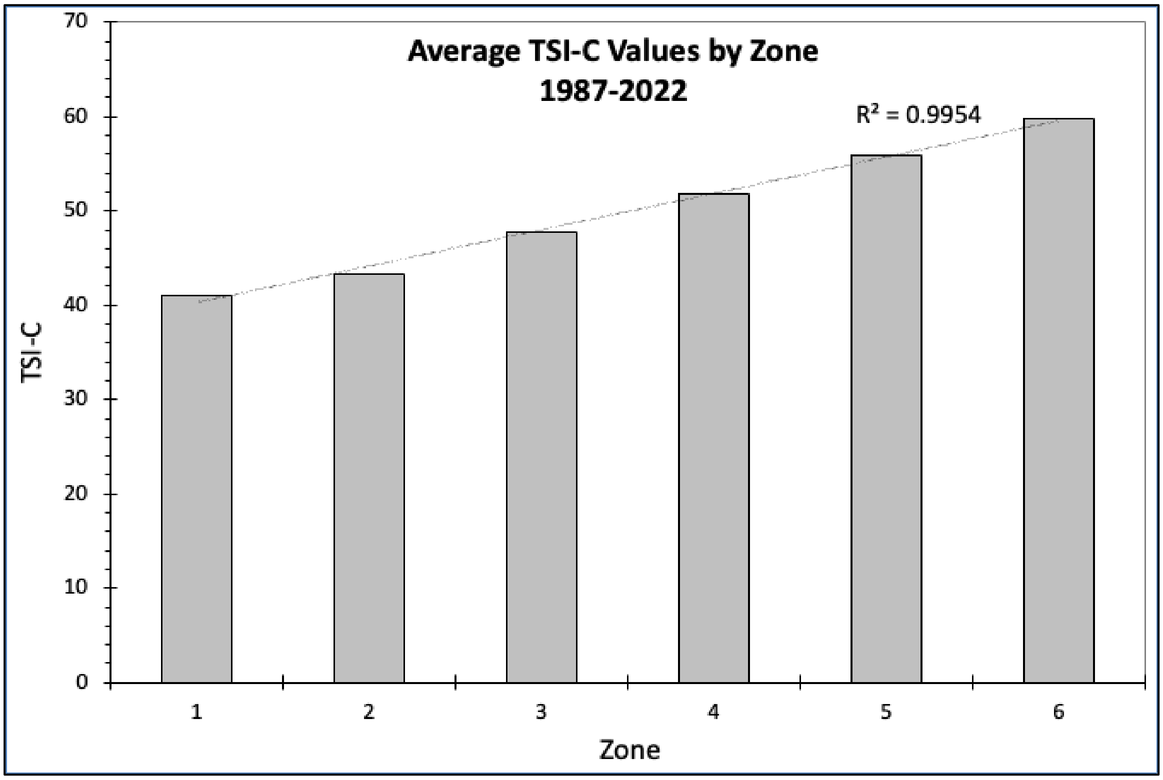


Figure 5.7. Combined Trophic State Index by zone from 1987 – 2022

5.5 *Conclusions*

At the present time, water quality in Smith Mountain Lake is much more dependent on silt and nutrient inputs from the 1,000 square-mile watershed than from the 500-mile shoreline. However, Virginia's Total Maximum Daily Load (TMDL) Program continues to address water quality problems in the impaired streams of the Smith Mountain Lake watershed and nutrient pollution from nonpoint sources is being reduced. Future commercial and residential development around the lake, coupled with inputs from its watershed, will continue to alter the relative contributions to the trophic status of Smith Mountain Lake.

6. VERTICAL PROFILES OF WATER QUALITY PARAMETERS

6.1 *Introduction*

In thermally stratified lakes, depth profiles provide important information on lake dynamics. In Smith Mountain Lake, vertical profiles of temperature, dissolved oxygen (DO), pH and conductivity are collected every two weeks during the sampling season. The variation of DO with depth is especially important and used in the evaluation of lake health and trophic status. During the warm season, surface water temperature increases and thermal stratification develops. Stratification results in the formation of three layers; a warm upper layer (the *epilimnion*) and a cool bottom layer (the *hypolimnion*), separated by a transition layer with rapidly changing temperature (the *metalimnion*). The *thermocline* is the depth at which the maximum rate of temperature change occurs. Thermal stratification is a stable condition because water density decreases with increasing temperature, so the warmer epilimnion floats on the cooler hypolimnion. The result is a density barrier that prevents mixing of the epilimnion and hypolimnion until the surface water cools again in the fall.

Algal production occurs where light is sufficient in the *photic zone* of the epilimnion, consuming carbon dioxide and producing oxygen. When algae cells die, they settle and bacteria consume DO as the organic matter undergoes biodecomposition. If nutrient enrichment occurs, photosynthesis and oxygen production increase near the surface while decomposition and oxygen consumption increase below the thermocline, depleting oxygen in the hypolimnion. The hypolimnetic oxygen deficit significantly affects the biota and nutrient dynamics. Cool water fish are stressed as DO decreases at depths where water remains cool. Depth profiles of temperature and oxygen increase the sensitivity of trophic state analysis and give early indications of nutrient enrichment and the degree of stress to cool water fish.

Because carbon dioxide is a weak acid, pH decreases as carbon dioxide concentration increases and increases with declining carbon dioxide concentration. As carbon dioxide is removed by photosynthesis, pH increases in the photic zone and, as carbon dioxide is produced by decomposition, pH decreases. This consumption-production pattern gives the typical pH profile. As atmospheric carbon dioxide increases, the pH of aquatic systems is decreasing and this may eventually affect the ecology of Smith Mountain Lake.

Conductivity is due to ionic substances (salts) dissolved in the water and, because salts do not tend to change form, conductivity profiles give valuable information on subsurface mixing. Conductivity is higher in the Roanoke River than the Blackwater River and this is reflected in the conductivities of the respective channels.

6.2 *Methods*

Depth profiles are collected at five sites in Smith Mountain Lake, as indicated on the map in Appendix A.3. Site PM2 is in the main basin, approximately two miles from the dam. Sites PB7 and PB13 are in the Blackwater channel, approximately one third (~seven miles) and two thirds (~13 miles) of the way up the channel. Sites PR11 and PR19 are approximately one third (~11 miles) and two thirds (~19 miles) of the way up the Roanoke channel. Depth profiles were obtained using an In-Situ™ Troll 600 Profiler multi-sensor probe with tablet and 200 feet of cable at five sample sites on Smith Mountain Lake on six days in 2022: May 31, June 14, June 28, July 12, July 26, and August 9. At each profile location, parameter readings are logged at the bottom and then at each meter up to the surface (~0.25 m). Because of currents, the sensor probe does not necessarily drop straight down, so a pressure sensor is used to provide accurate depth readings for each measurement and is used to determine when to record (or ‘log’) data from the sensors on the tablet. Between profile sites, the probe is kept hydrated in a jug of lake water. The probe sensor for temperature is calibrated periodically by the Department of Environmental Quality (DEQ) Auditor, and the sensors for DO, pH, and conductivity are calibrated less than 24 hours before each sampling event and checked against standards after each sampling event.

6.3 *Results*

The depth profile results are presented in the following four figures: temperature (Figure 6.1), DO (Figure 6.2), pH (Figure 6.3), and conductivity (Figure 6.4). The pH profiles clearly show the increase in pH accompanying photosynthesis and the decrease accompanying decomposition, consistent with theory and with the DO profiles. The DO profiles have immediate management implications because of the negative impact of hypolimnetic DO deficits on cool water fish. The temperature profiles in 2022 show warmer surface waters than in 2021 and a more defined epilimnion, while temperatures in the hypolimnion for 2021 and 2022 were similar. The DO profiles for 2022 are similar to those for 2021, and the anomalous pH and conductivity profiles observed in 2021 were back toward normal in 2022.

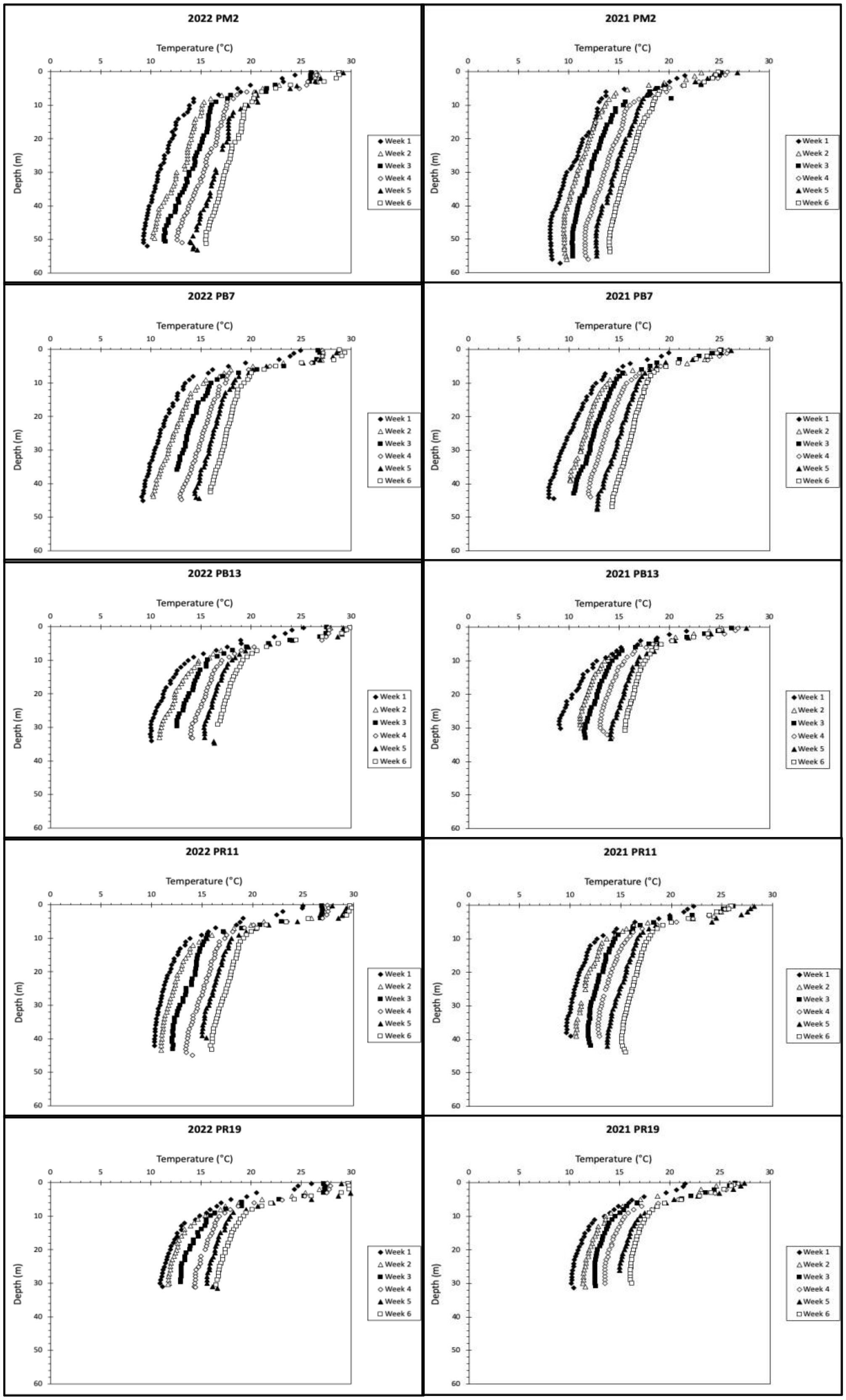

2022 PM2
2021 PM2
2022 PB7
2021 PB7
2022 PB13
2021 PB13
2022 PR11
2021 PR11
2022 PR19
2021 PR19
Temperature (°C)
Depth (m)
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6

Figure 6.1. Temperature depth profiles for Smith Mountain Lake in 2021 and 2022

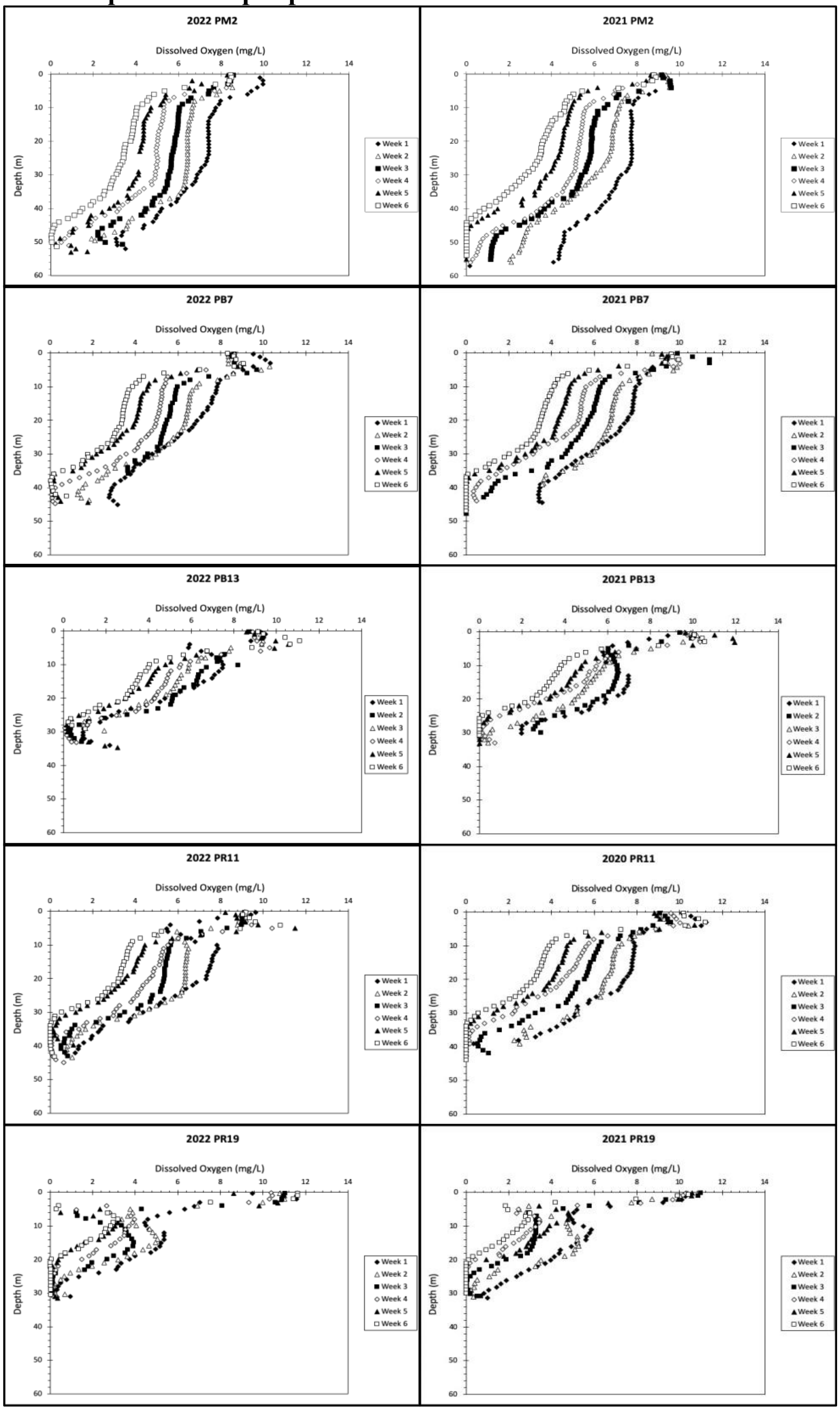


Figure 6.2.   Dissolved oxygen depth profiles for Smith Mountain Lake in 2021 and 2022

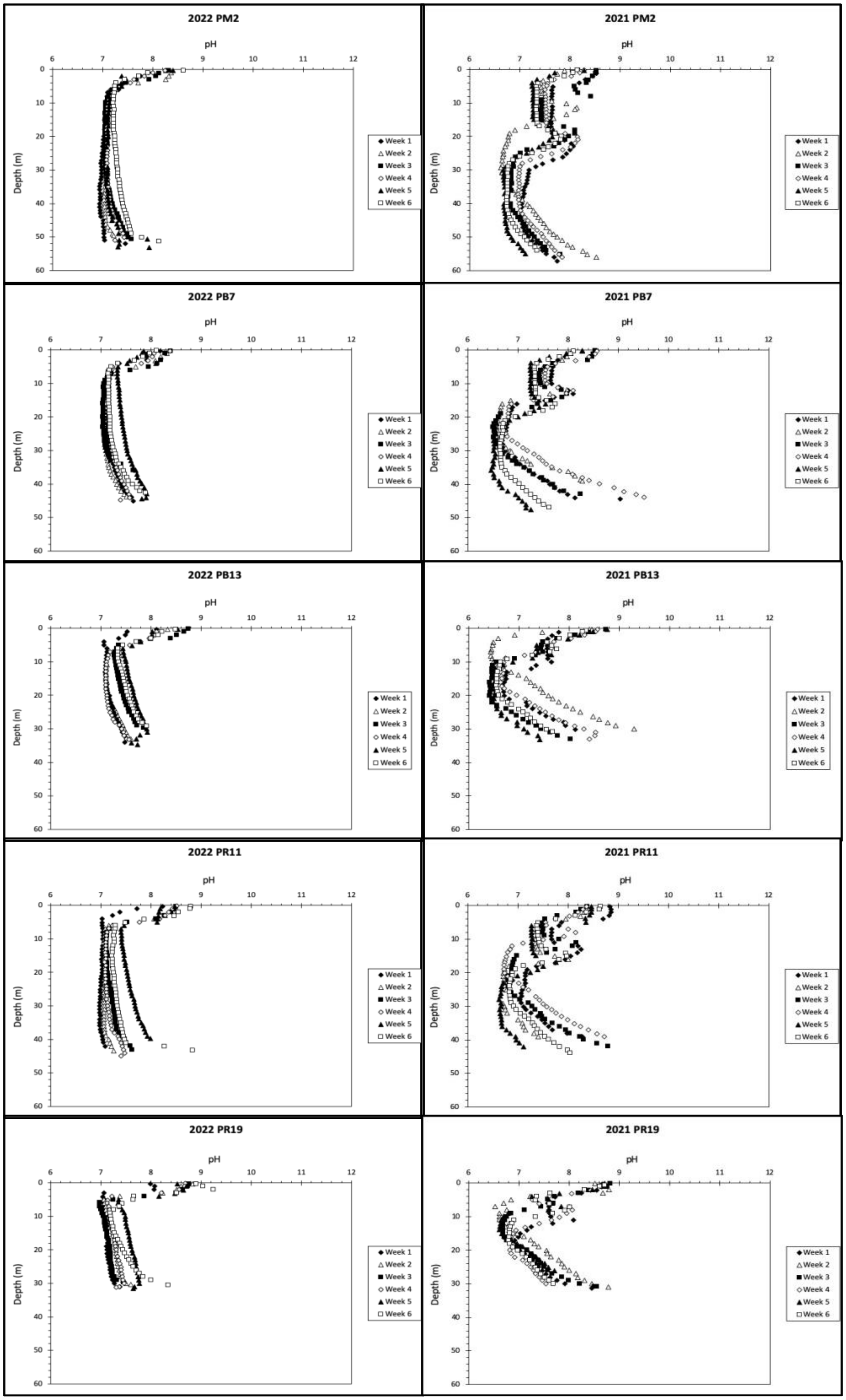

2022 PM2
2021 PM2
2022 PB7
2021 PB7
2022 PB13
2021 PB13
2022 PR11
2021 PR11
2022 PR19
2021 PR19
pH
Depth (m)
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6

Figure 6.3. pH depth profiles for Smith Mountain Lake in 2021 and 2022

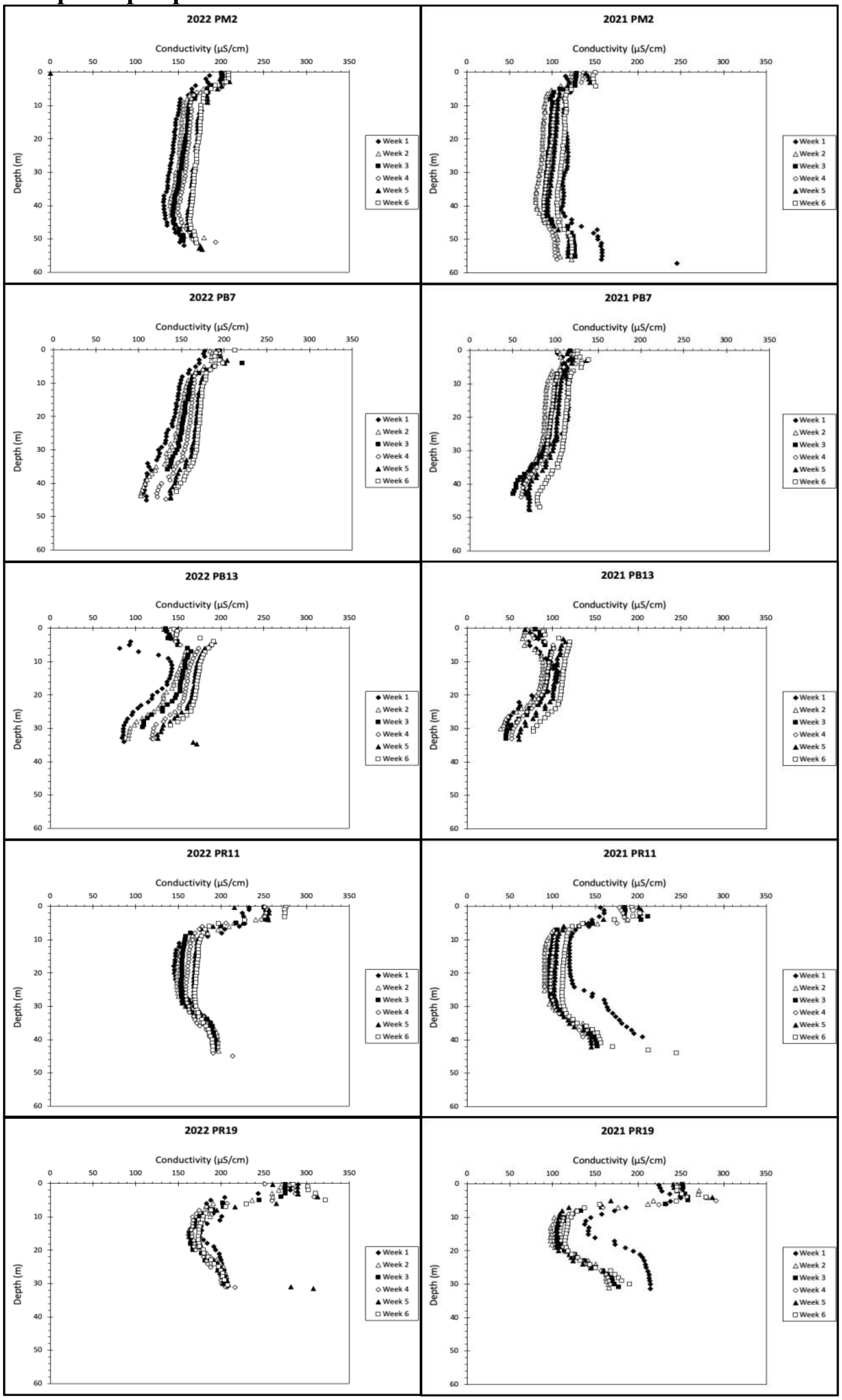


Figure 6.4. Conductivity depth profiles for Smith Mountain Lake in 2021 and 2022

The temperature depth profiles display three general characteristics: (1) Thermal stratification had occurred before the first profile was recorded. (2) The thermocline was located at a depth of approximately 5 meters. (3) The temperature of the entire lake increased steadily from the first to sixth profiling date. Stable, well-defined thermal stratification during the summer is an important characteristic of Smith Mountain Lake.

As usual, dissolved oxygen concentrations below the thermocline decreased steadily over the course of the sampling season. Above the thermocline, all sites were consistently supersaturated in DO, due to algal photosynthesis. Bottom waters were anoxic (depleted of DO) at all stations by the end of July but were anoxic in the upper channels by mid-June. The DO profiles at PM2 show a classic hypolimnetic DO deficit that increases through the summer. Last year (2021) we reported an anomalous DO profile at PM2 for week 4, perhaps a result of collecting profile data near the dam during pump back. However, the same anomaly was seen again this year and it did not seem plausible. The decision was made to trouble shoot the data flow and it was discovered that the spreadsheet generating Figure 6.2 was pulling pH values, rather than DO values, for week 4. Figure 6.2 displays the correct 2022 DO profile for PM2, and the corrected profile for 2021. The profiles for the two stations in the upper channels (PR19 and PB13) indicate high productivity with very high DO readings near the surface that crash at the thermocline where decaying algal cells accumulate on the cooler, denser water.

All pH depth profiles showed slightly alkaline (pH>7) conditions in the epilimnion and decreasing pH with depth due to carbon dioxide accumulation. This is to be expected because carbon dioxide forms a weak acid (carbonic acid) when dissolved in water. Photosynthesis removes carbon dioxide above the thermocline (photic zone), increasing the pH, while decomposition of settling organic matter releases carbon dioxide, decreasing the pH below the thermocline. Last year, the shapes of the pH depth profiles were dramatically different from previous years at all stations. The depth of the lowest pH (~ 6.5) indicates a maximum in carbon dioxide concentration, presumably due to a peak in decomposition, but this was not reflected in the DO profiles. Thus, the cause of the pH minimum was not clear, and we noted that it would be interesting to see if it persisted. It did not, this year the pH depth profiles were again very typical, with a consistent pH of 7-7.5 in the hypolimnion. It is worth noting that the negative pH peaks observed in the 2021 profiles occurred in the approximate depth range where conductivity values converge.

Conductivity is a conservative parameter, little affected by physiochemical processes, and variation is primarily due to mixing of waters with different conductivities. As usual, conductivity was higher in the Roanoke channel than the Blackwater channel. However, after two years of lower conductivities (2020 and 2021), the conductivities in 2022 increased by approximately 50 □S/cm, to more historically typical values. The conductivity profiles in 2022, averaged over time, were shaped much like the profiles in 2021, with the five profiles' combined averages forming an "octopus".

6.4 *Discussion*

Figure 6.5 shows the average depth profiles for each parameter in 2022.

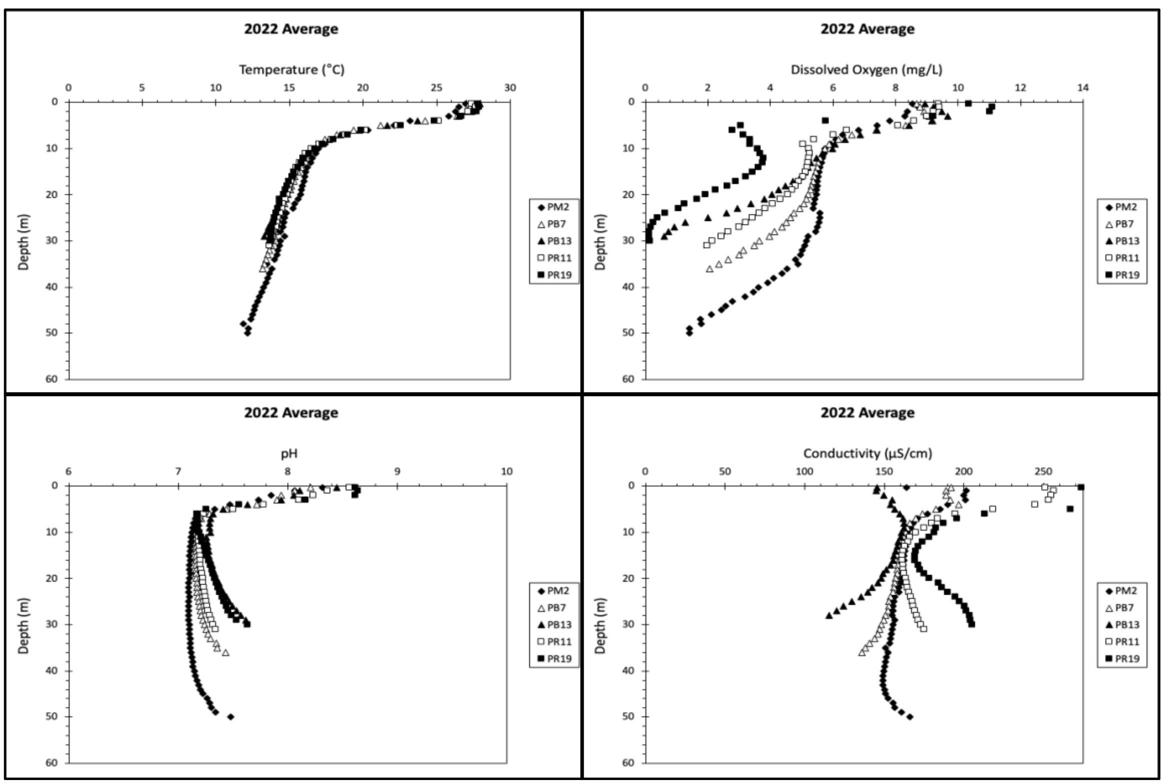


Figure 6.5. Average depth profiles for 2022 for each parameter sampled on Smith Mountain Lake by sample site

In 2022, the variation of temperature with depth is very consistent across profile stations and the DO and conductivity profiles differed across stations as expected. In 2022, the pH profiles were more typical after the abnormal profiles seen in 2021. Significant oxygen depletion below the thermocline was observed at all sites and the hypolimnetic oxygen deficit increased during the summer, more severely with increasing distance to the dam (Figure 6.2). The increasing dissolved oxygen deficit results from thermal stratification and the larger deficit up-channel is consistent with more eutrophic conditions at sites further from the dam. It is also apparent that organic matter settles on the cooler, denser thermocline long enough for bacterial decomposition to drive down the DO. Indeed, the five DO profiles vary in a way that is indicative of a gradient from eutrophic, through mesotrophic, to near oligotrophic at the dam. This is consistent with the classic trophic parameters TP, CA and SD.

6.5 Conclusions

Sufficient depth profile data have now been collected to enable meaningful comparison between rates of change and absolute parameter values over the course of the summer. The temperature profiles indicate that the thermocline at most sample sites continues to be slightly higher in the water column. As has been the case since 2015, the bottom of the lake becomes anaerobic (DO is depleted) in June rather than July. This trend has a negative effect on aquatic life by forcing them to move closer to the surface earlier in the summer, thus increasing thermal stress. Atmospheric carbon dioxide is increasing globally and may be affecting Smith Mountain Lake. Increased carbon dioxide decreases pH and promotes photosynthesis, increasing algal production. While DO will increase at the surface, the amount of organic matter settling into the hypolimnion will also increase and the hypolimnetic oxygen deficit will become more severe. Continued depth profiling and study of algal dynamics will provide scientific data to support effective management of Smith Mountain Lake as it ages.

7. BACTERIA IN SMITH MOUNTAIN LAKE

7.1 *Introduction*

Bacterial analysis in Smith Mountain Lake consisted of *Escherichia coli* (*E. coli*) monitoring. This reflects the Commonwealth of Virginia's bacterial standard, which uses *E. coli* as the indicator organism. Because this is a controversial water quality parameter and is related to human health, the Ferrum College Water Quality Lab has been monitoring bacteria levels in the lake using fecal coliforms as the indicator organism from 1995 until 2004 and *E. coli* as the indicator organism since 2004.

7.2 *E. coli Methods*

Samples were collected in sterile 125 mL polypropylene bottles at 0.25 m depth and stored according to Standard Methods for Water and Wastewater Analysis (APHA 1999). 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) were counted and the values were evaluated using a Most Probable Number (MPN) chart developed by the Colilert™ method developers (IDEXX Company). A geometric mean is then calculated for each site based on those two stations. MPN is used instead of colony forming units (CFU) and is generally considered an equivalent measure of the microbial and bacterial populations. The IDEXX™ method for Colilert™ has been rated as the "best" in agreement with a reference lab, has the lowest detection limit and the Colilert™ method is EPA approved for ambient water (O'Brien 2006).

Water samples for *E. coli* analysis were collected from 14 sites on Smith Mountain Lake on May 24, June 7, June 21, July 5, July 19, and August 2, 2022. The sites are described in Section 3 of this report and are listed/shown in Table A.8 and in Figure A.4 in the Appendix.

7.3 E. coli Results and Discussion

Figure 7.1 shows the mean *E. coli* most probable number (MPN) in the population for the six sample dates. In 2022, the overall mean *E. coli* count was 75.9 MPN, which is 1016.3 percent higher than the 2021 overall mean *E. coli* count (6.8 MPN). The means of *E. coli* populations for two of the fourteen sample sites averaged over the six sample periods for 2022 exceeded the Virginia Department of Health (VDH) standard for recreational waters (standard is 235 CFU/100 mL for greater than one sample geometric mean) and the Virginia Department of Environmental Quality (DEQ) standard of 126 CFU/100mL for greater than one sample geometric mean. Additionally, nine of 168 samples exceeded the VDH standard for recreational waters and an additional 5 samples exceeded the DEQ standard.

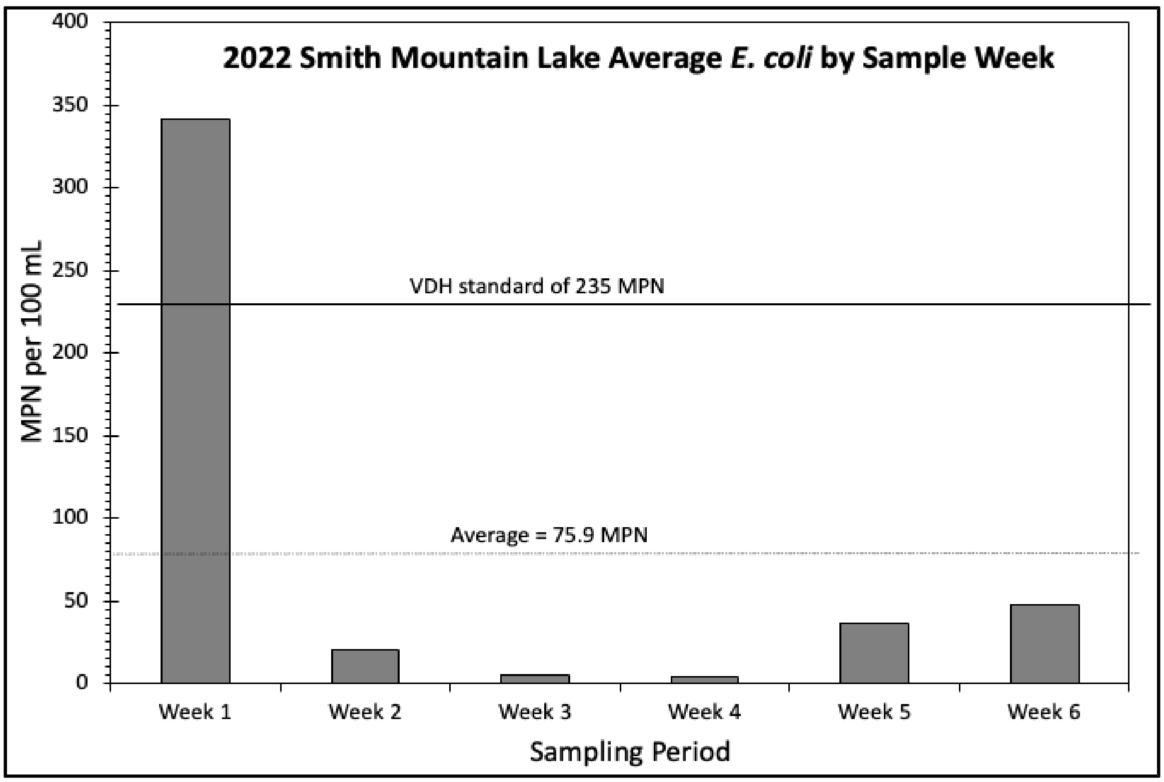


Figure 7.1. *E. coli* versus week sampled on Smith Mountain Lake in 2022 (Each sample date included 14 sites with 2 stations per site, n = 28)

This year the *E. coli* population counts were relatively stable over time (Figure 7.1), with the exception of week one (May 24), which exhibited the highest mean (341.9 MPN). This sampling occurred after significant rainfall. It is likely that the lack of rainfall runoff the rest of the summer contributed to the low *E. coli* populations. The lowest mean (4.5 MPN) occurred in week four (July 5), and all other weeks had averages of 47.6 MPN or less. The variability of *E. coli* counts is shown by the high standard deviations of some of the means (Table A.9).

E. coli populations are also highly variable based on site location. The mean *E. coli* counts for marinas in 2022 (58.3 MPN) are 66.1 percent higher than the mean *E. coli* counts for non-marinas (35.1 MPN). The mean *E. coli* counts for headwater sites (179.3 MPN) are 207.7 percent higher than the mean *E. coli* counts for marinas and 411.2 percent higher than the mean *E. coli* counts for non-marinas. This is shown in Figure 7.2 which compares marinas, non-marinas, and headwaters sites for 2022.

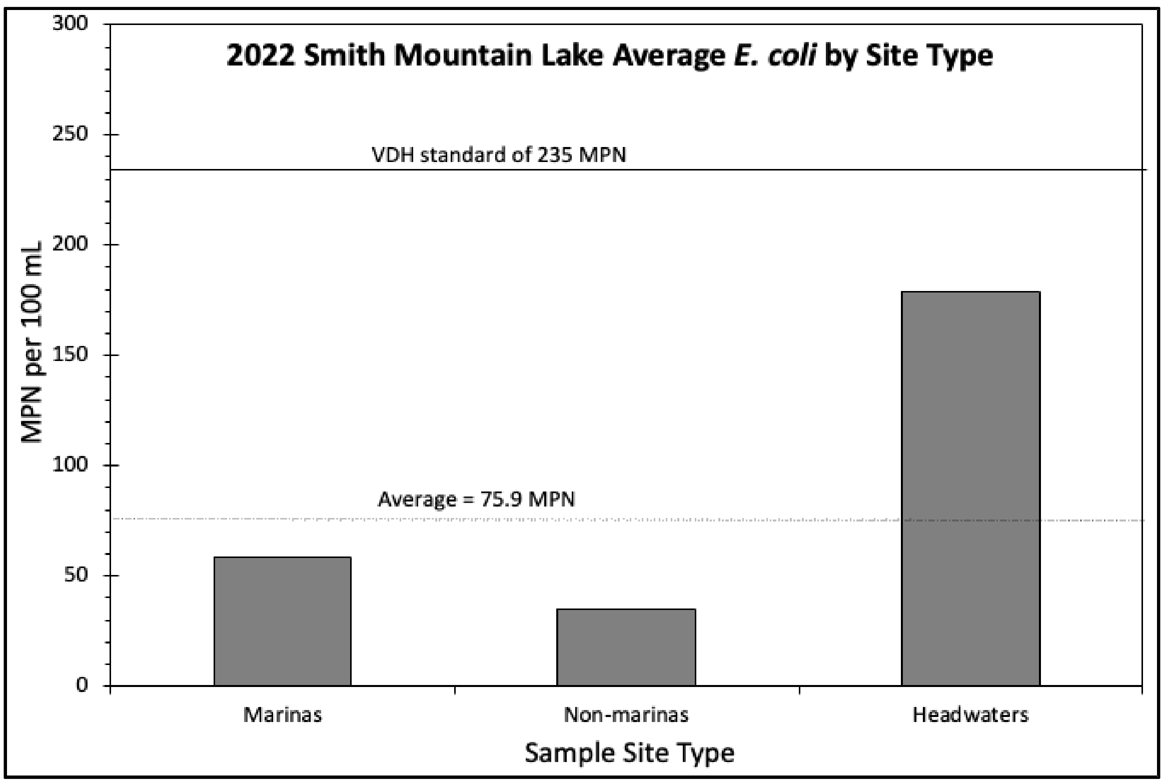


Figure 7.2. Mean *E. coli* count vs. site type in 2022 - 6 marina sites, 5 non-marina sites, and 3 headwater sites

The sample site with the highest mean *E. coli* count in 2022 was B49 (Site 14, headwaters) with a mean of 481.5 MPN. The sample site with the lowest mean *E. coli* count in 2022 was the confluence of the Roanoke and Blackwater channels (Site 10, non-marina) with a mean of 0.9 MPN.

The highest individual *E. coli* counts of the sampling season were at B49 (Site 14, headwaters) in week one at stations 1 and 2 (2500 MPN at each) and at Bayside Marina (Site 5, marina) in week one at station 2 (1413.6 MPN). These values exceeded both the VDH standard of 235 CFU/100 mL and the DEQ standard of 126 CFU/100 mL for recreational waters.

In a comparison of the sums of *E. coli* populations for sample dates and sites in 2022 (Figure 7.3), B49 (Site 14, headwaters) in Franklin County has the highest sum of *E. coli* populations.

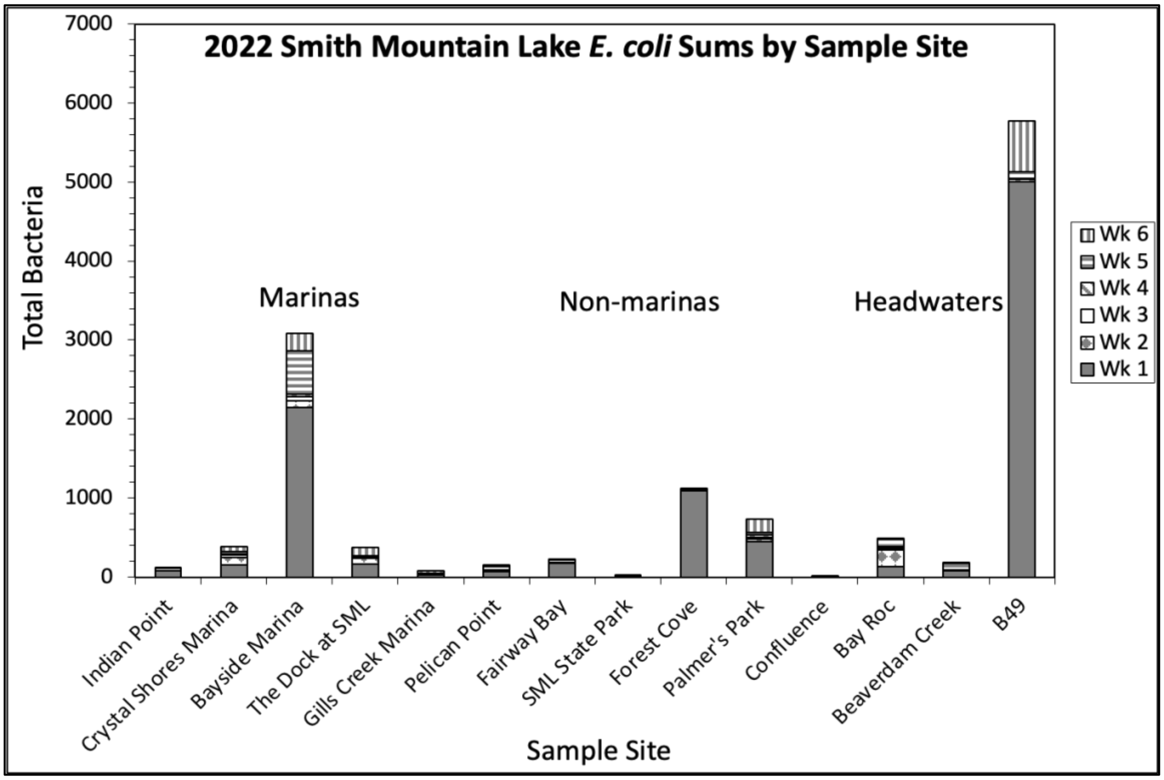


Figure 7.3. Sum of *E. coli* count vs. sample site in 2022 at each of the two sampling stations at each site for all sample dates

Figure 7.4 and Table 7.1 show a comparison of mean *E. coli* counts from 2013 to 2022 for combined marina sites, non-marina sites and headwater sites. Since *E. coli* bacteria have a short life in an aquatic system like Smith Mountain Lake, these data should not be interpreted as having a long lasting cumulative presence of the bacteria at any site as the samples and the analyses are only valid for a single point in time.

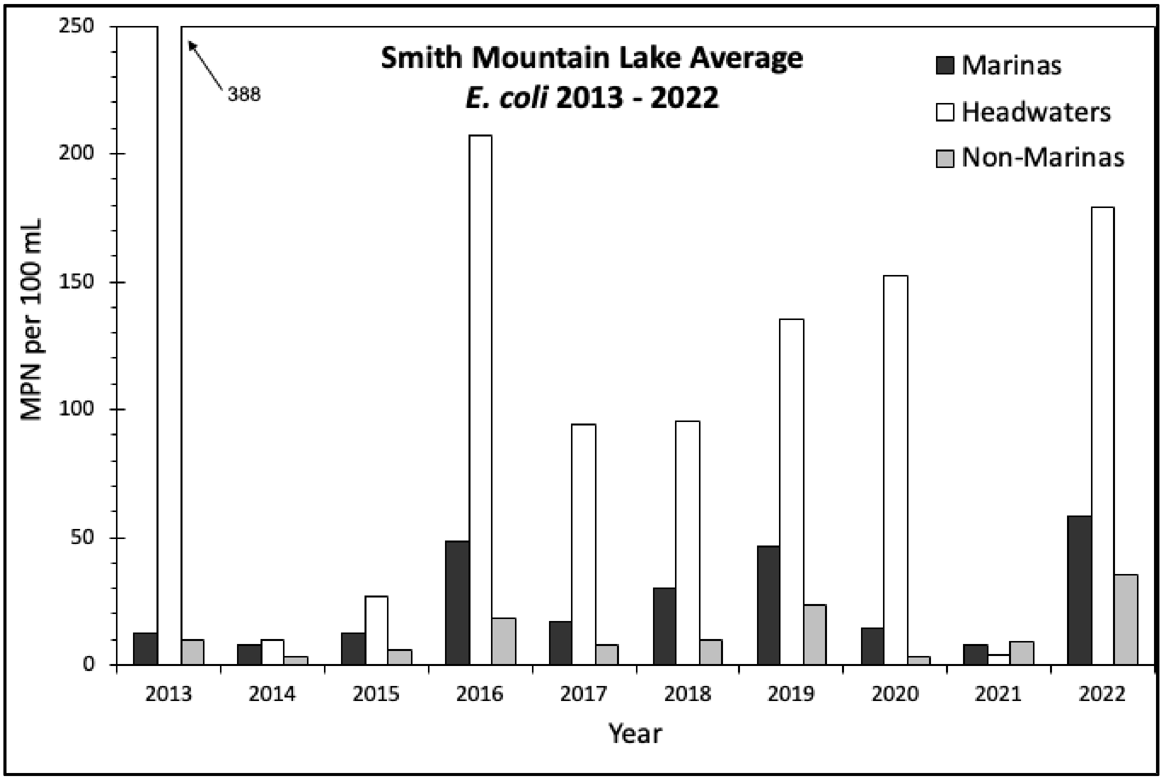


Figure 7.4. Mean *E. coli* counts per site type from 2013-2022

Table 7.1 10-year comparison of mean *E. coli* counts by site type

YEAR	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	10 YR AVG
Marinas avg MPN	**58.3**	7.9	14.3	46.6	30.1	17.1	48.3	12.4	7.6	12.6	**25.5**
Non-marinas avg MPN	**35.1**	3.9	3.1	23.5	10.2	7.8	18.5	5.7	3.3	9.7	**12.1**
Headwaters avg MPN	**179.3**	9.5	152.6	135.2	95.6	94.2	207.4	26.8	10.1	387.9	**129.9**
Overall lake avg MPN	**75.9**	**6.8**	**39.9**	**57.4**	**37.0**	**30.3**	**71.7**	**13.1**	**6.6**	**92.0**	**43.1**

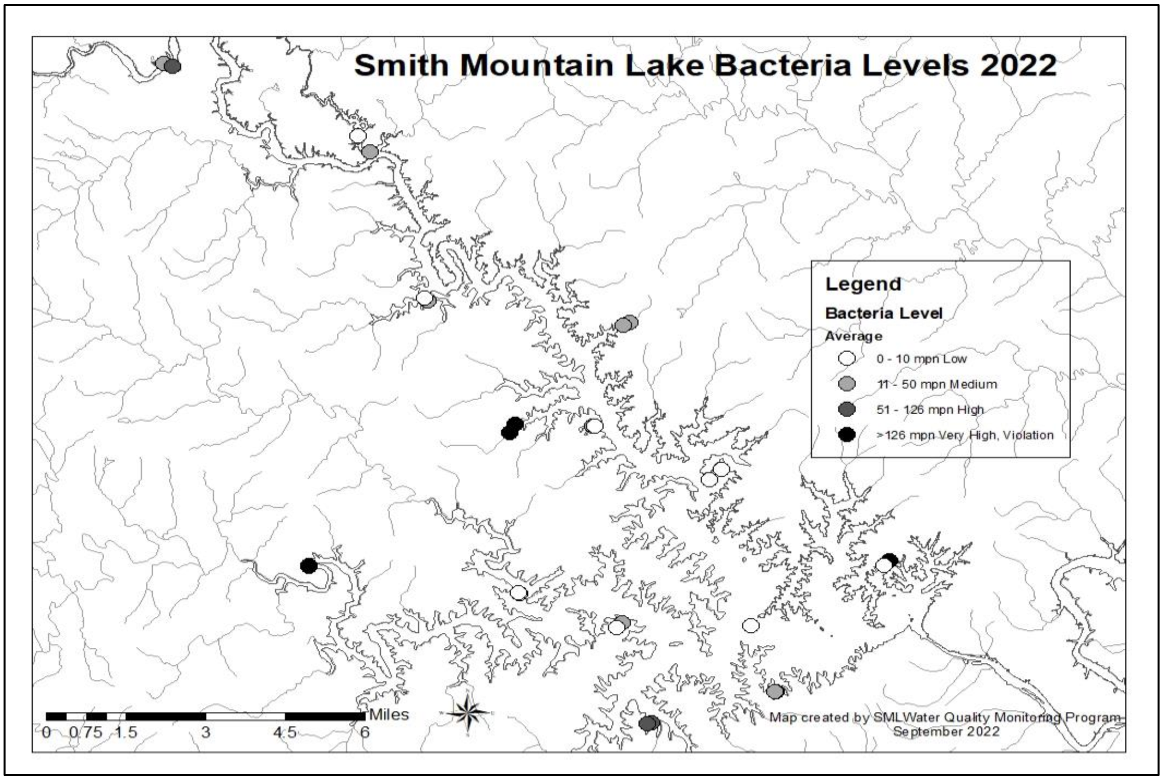


Figure 7.5. Map of bacterial sampling results in Smith Mountain Lake for 2022

7.4 E. coli Conclusions

The *E. coli* populations in Smith Mountain Lake in 2022 were much higher than the levels in 2021. In 2022, the mean *E. coli* count was 75.9 MPN compared to the 2021 mean *E. coli* count of 6.8 MPN. Since we began monitoring *E. coli* in 2004, the overall mean counts were their highest in 2013 and overall mean counts were their lowest in 2014. The 2022 overall mean is the second highest in the past ten years as shown in Table 7.1.

The comparison of marinas, non-marinas, and headwaters shows differences in *E. coli* values consistent with data collected over the last ten years, and shows that the majority of bacteria entering Smith Mountain Lake comes from the headwaters. In the first years of bacterial sampling, Bay Roc Marina (Site 1) was not included as a headwaters site. Beaverdam Creek was originally included as the headwaters site for the Roanoke channel. In 2006, the Bay Roc designation was changed to a headwaters site, along with Beaverdam Creek. Since then the headwaters sites have had the highest mean counts of all site types, except in 2021.

8. ALGAE IN SMITH MOUNTAIN LAKE

8.1 *Introduction*

Sampling for algae biodiversity in Smith Mountain Lake for this project began in 2007 because of concern over potential harmful algal blooms (HABs) which occur when toxin-producing algae grow excessively in a body of water. Algal toxins can cause serious harm to people, fish, animals and other parts of the ecosystem. The diversity of algae species is of interest in lake management because the presence of high numbers of blue-green (cyanobacteria) and green algae species would be an indication of potential pollutants in water. High numbers of green algae can indicate the presence of high nutrients while diatoms can be an indication of some nutrient increase but have also been found to increase with fluctuations in lake levels and often are found in relatively clean water as either floating or attached algae. In addition to our regular monitoring at bacterial and profile sites around the lake we now recommend the use of the Virginia Department of Health reporting tool for HABs (https://www.vdh.virginia.gov/waterborne-hazards-control/harmful-algal-blooms/). We monitor these reports for Smith Mountain Lake and follow-up with onsite monitoring and sampling to identify potential toxin producing cyanobacteria in the blooms.

Blue-green algae, such as some species of *Microcystis*, *Anabaena,* and *Aphanizomenon* may produce toxins that can be harmful to fish species and potentially harmful to humans. Other blue-greens have also been known to impart a bad taste to drinking water. The production of high levels of microcystin toxin in the water can be tested. Testing procedures for these toxins have been developed and are used when high levels of blue-green algae are found in samples. Microcystin testing is performed only when an algae bloom (visible green or blue-green water) involving certain species is reported from lake observations during the sampling season.

8.2 *Methods*

Plankton tow samples are used to collect representative populations of diatoms, green algae and blue-green algae in the water. Horizontal or surface plankton 10-meter tows were collected six times during the 2022 sampling season at the 14 sites used for bacterial sampling which are described in section three as well as listed in Table A.8 and shown in Figure A.4 in the Appendix.

Vertical water column 10-meter tows were conducted six times during the season at the sites which are used for depth profiling. These sites are described in section three and shown in Figure A.3 in the Appendix.

A standard plankton tow net (12" ring, 63-micron mesh) was towed for ten meters for each sample. Samples were preserved using 1 milliliter (mL) of Lugol's solution per 100 mL of sample. The phytoplankton counting method procedure followed the field method outlined in *Standard Methods for Water and Wastewater Analysis* (APHA 1999). The algae were identified and counted within 50 random Whipple Disk grid fields across a 1 mL sample in a Sedgwick Rafter counting cell and recorded on a Nikon Biphot compound microscope at 200X magnification. Counts were corrected by number of potential number of grids across the 1 mL Sedgwick Rafter chamber.

8.3 Results

Algae collected from plankton tows were identified to genus and recorded for grouping by taxonomic category. The major groups considered important for this study and reported are diatoms, green algae and blue-green algae (cyanobacteria). Figures 8.1, 8.2, and 8.3 demonstrate the differences in abundance of groups of algae from each sample site type (headwaters, marinas, and non-marinas) for each sample date in 2022 for the horizontal tows and Figure 8.4 shows the differences for the vertical tows in 2022. Figure 8.5 shows the averages of algae type for each sample site type with a comparison between 2021 and 2022. Figure 8.6 shows the average of algae types for each sample period across the entire lake for both 2021 and 2022 for comparison. Figure 8.7 shows the relative populations of the different algae groups averaged over all sites and all sample dates for both 2021 and 2022. Figure 8.8 pie chart shows the overall abundance of algae groups over all sample sites for both 2021 and 2022 for comparison. Figure 8.9 is a new comparsion of profile site algae counts grouped by location in the lake. Figure 8.10 is a representation of the trends of algae over the last 10 years including both cyanobacteria and total algae. Figure 8.11 is a statistical comparison of total cyanobacteria counts and total May rainfall amounts as taken from the Roanoke Regional Airport gauges recorded over the ten year period from 2013 to 2022.

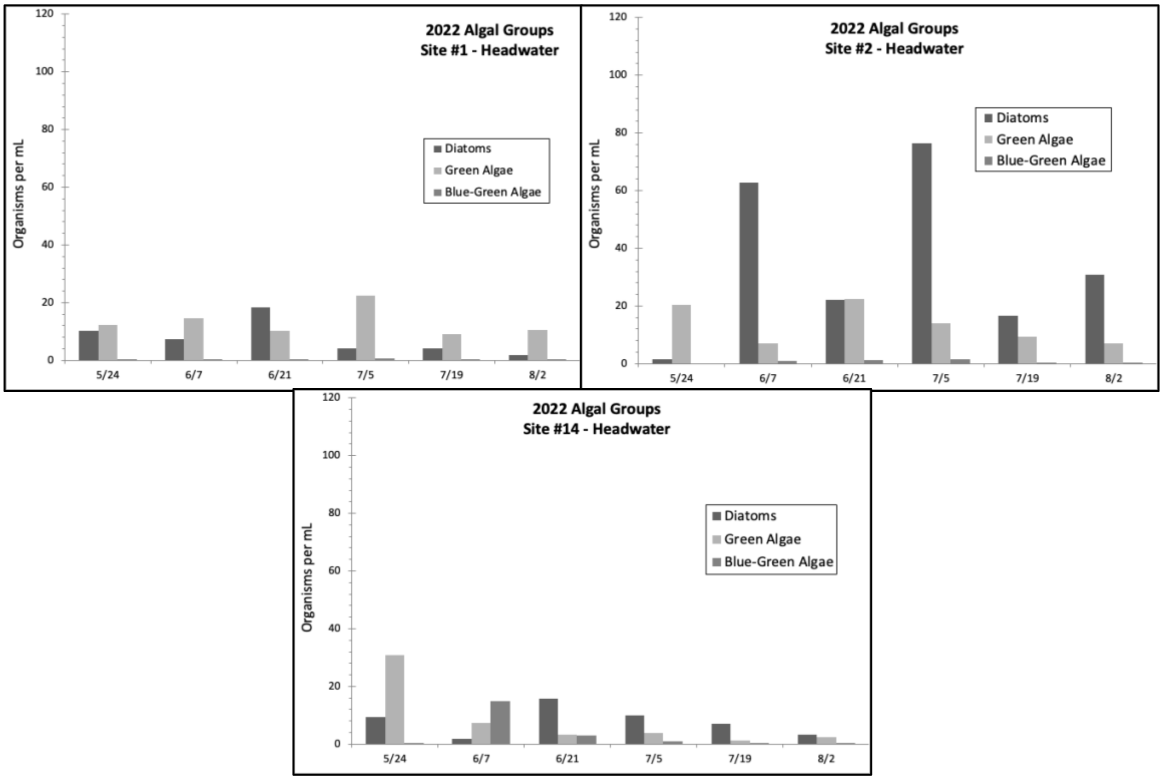


Figure 8.1. Algae groups versus week from headwaters sites (Sites 1, 2, and 14)

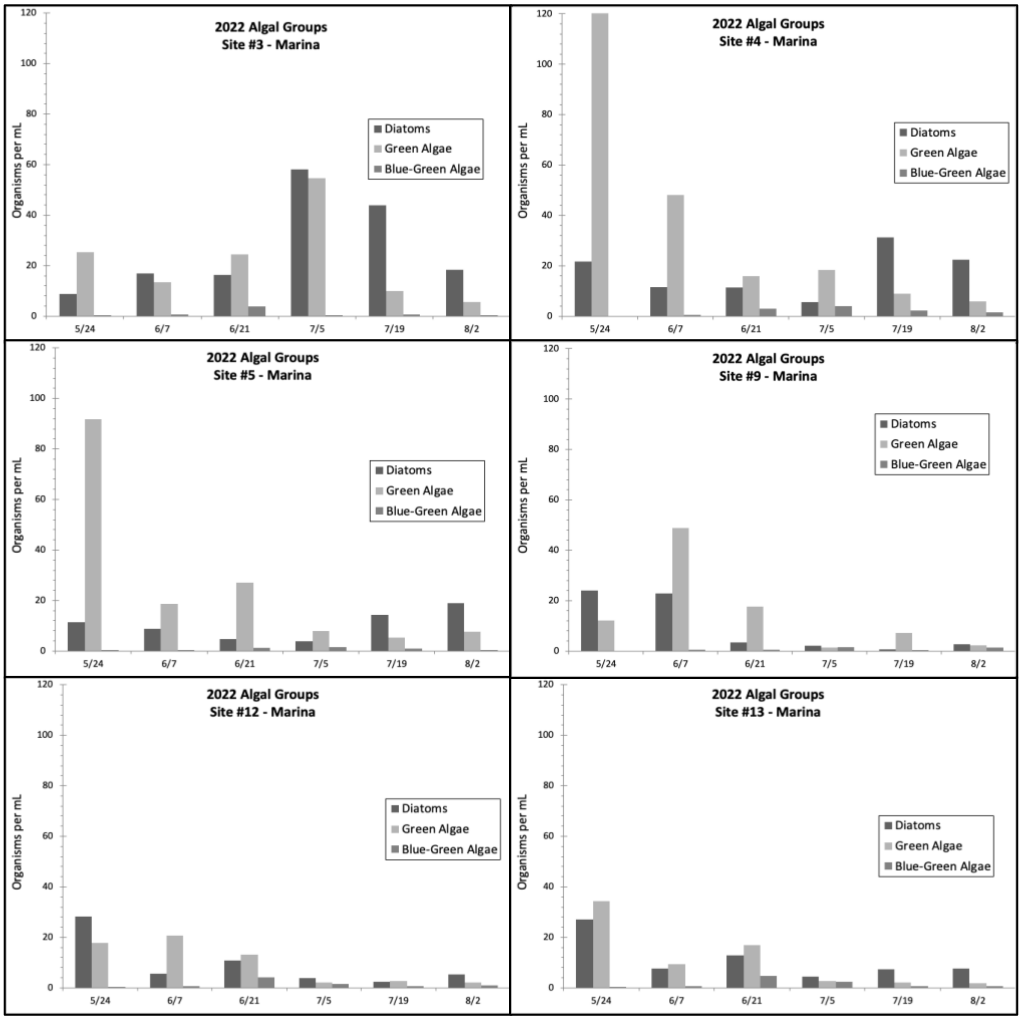


Figure 8.2. Algae groups versus week from marina sites (Sites 3, 4, 5, 9, 12, and 13)

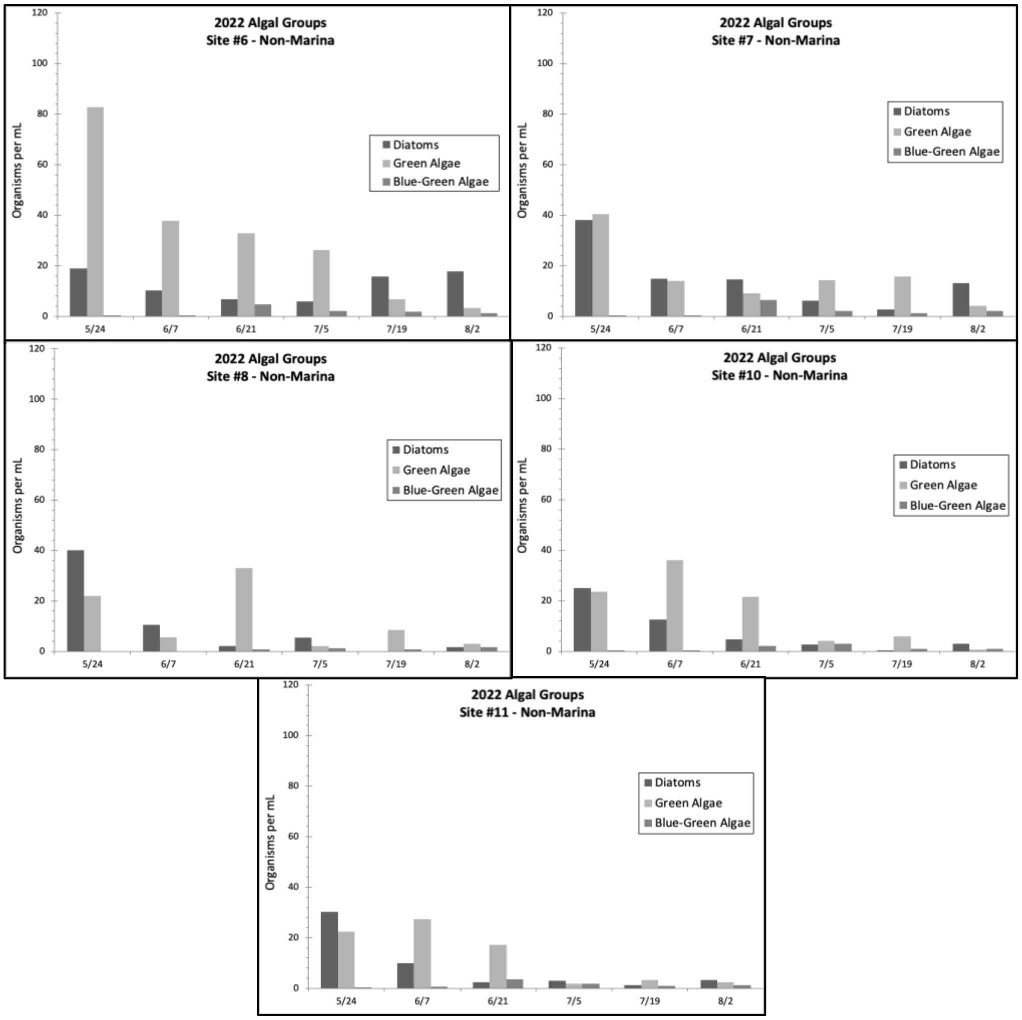


Figure 8.3. Algae groups versus week from non-marina sites (Sites 6, 7, 8, 10, and 11)

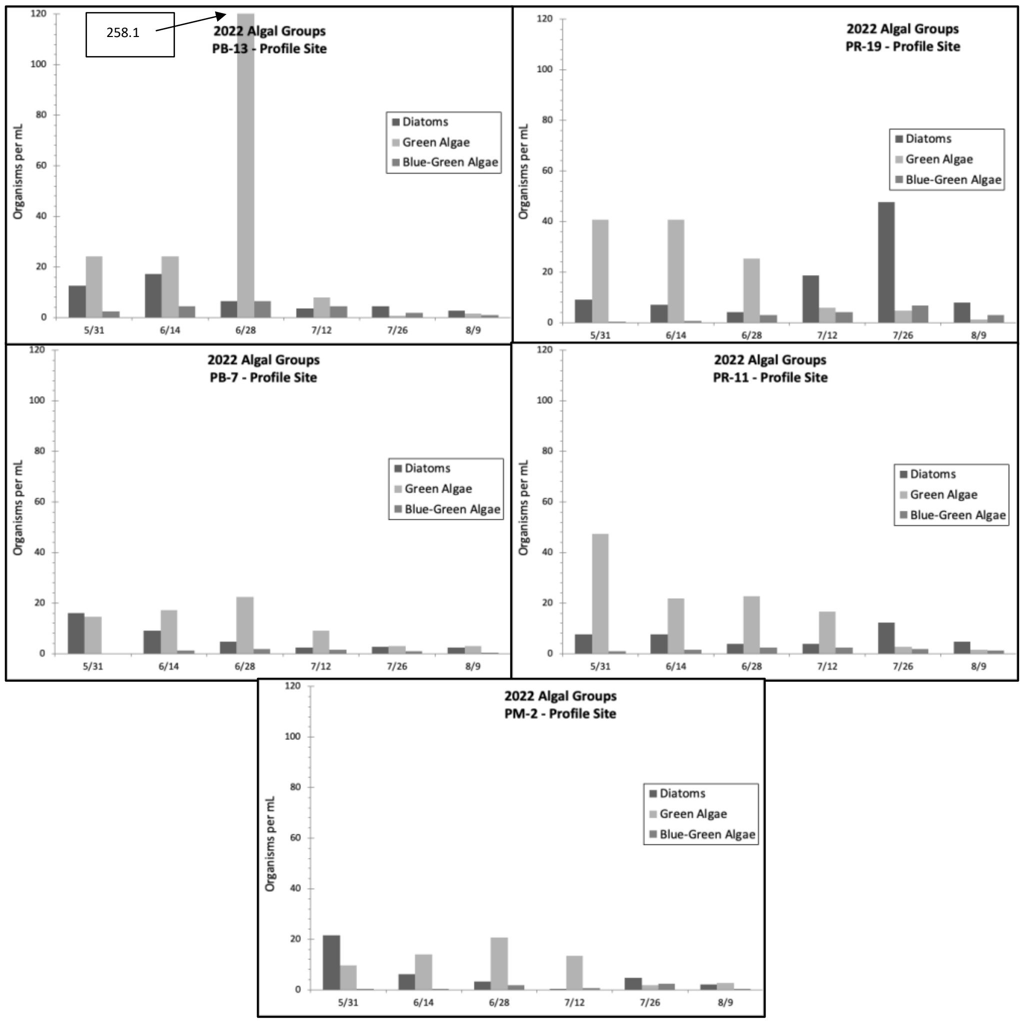


Figure 8.4. Algae groups versus week from profile sites (Sites PB7, PB13, PR11, PR19, and PM2)

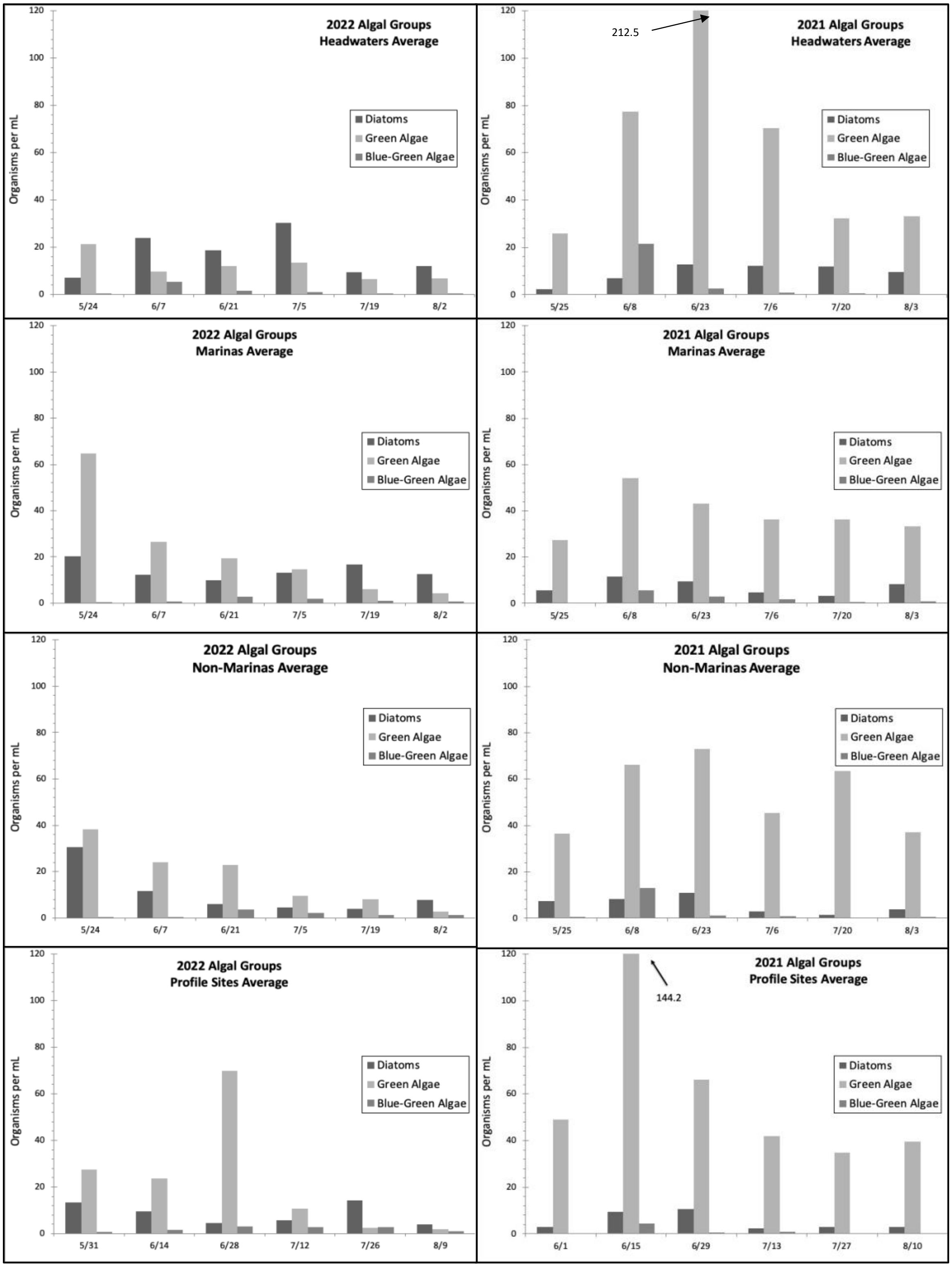


Figure 8.5. Average concentrations of algae groups versus week for 2022 and 2021 by site type

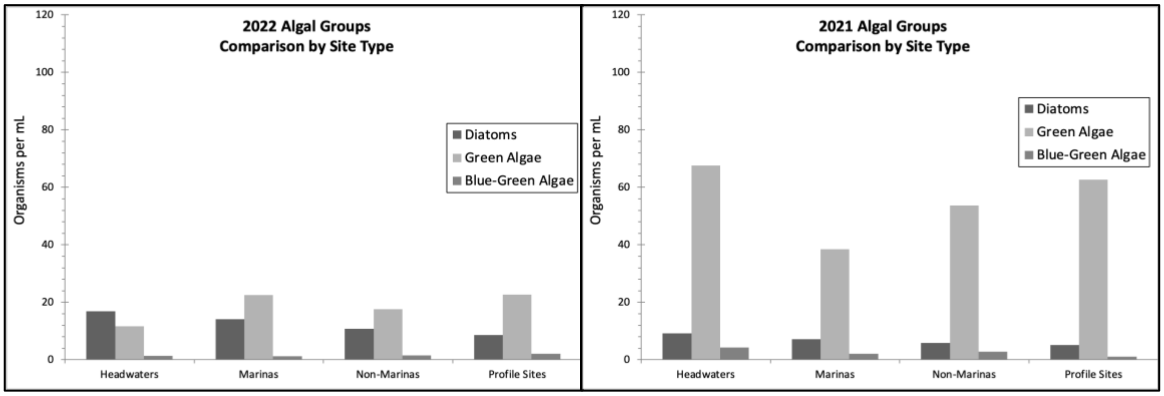


Figure 8.6. **A comparison of algae group abundance in 2022 to 2021 by site type**

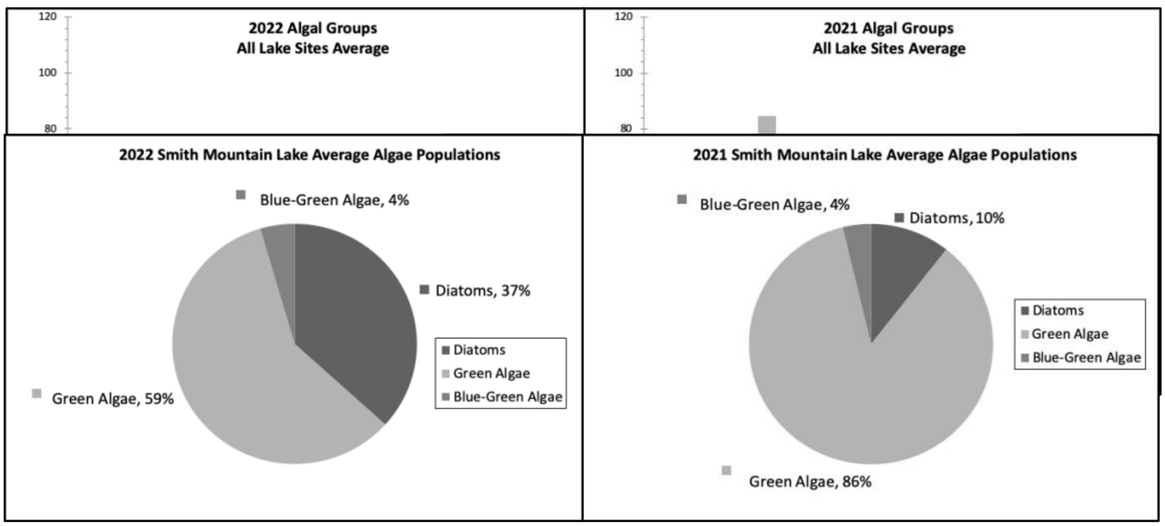


Figure 8.7. **A comparison of algae groups versus week sampled in 2022 and 2021 from all lake sites**

Figure 8.8. **Algae group abundance in 2021 and 2022 from all sample lake sites**

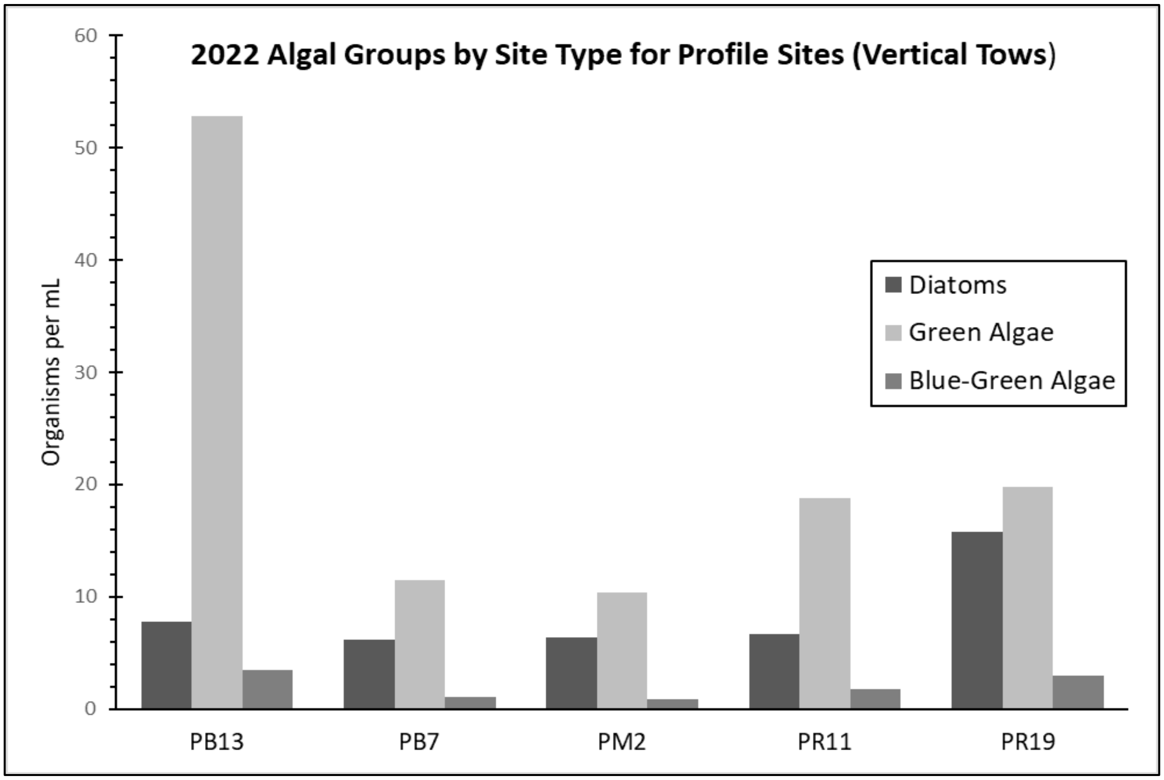


Figure 8.9. **Algal groups by site location for profile sites.**

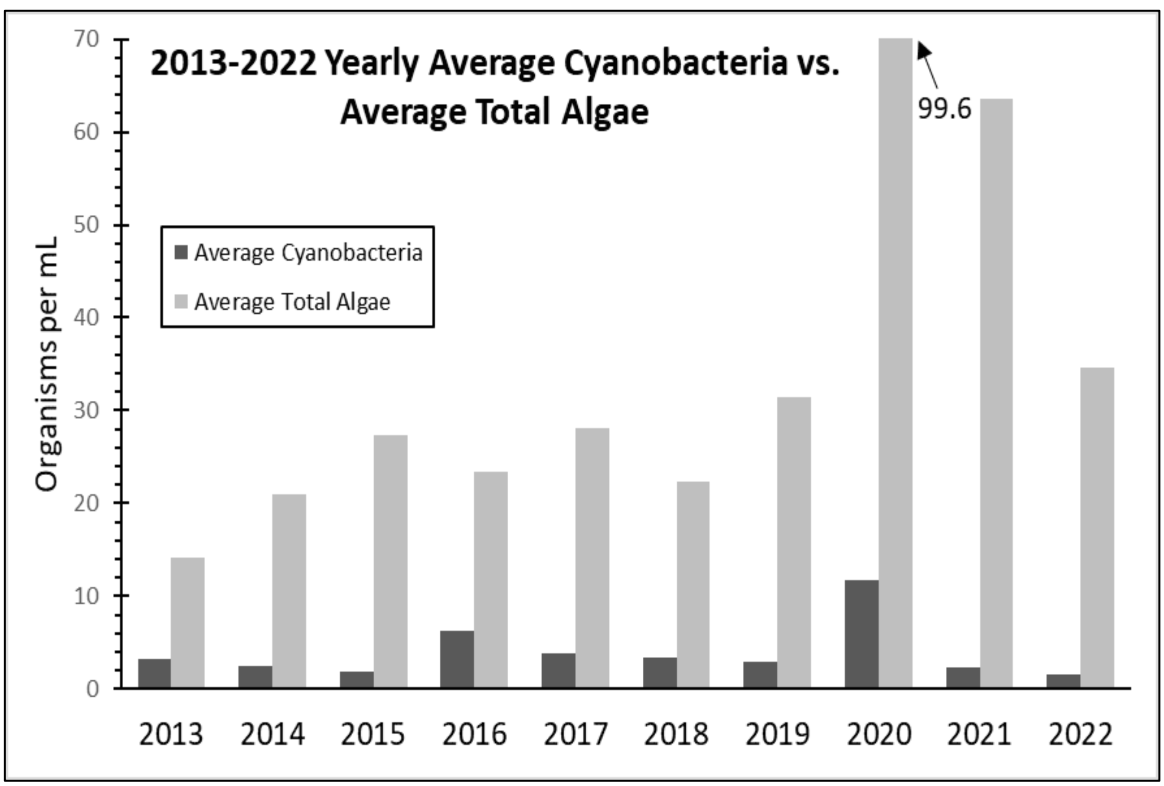


Figure 8.10. **Ten-year averages for blue-green algae (cyanobacteria) and total algae over all sample sites and dates**

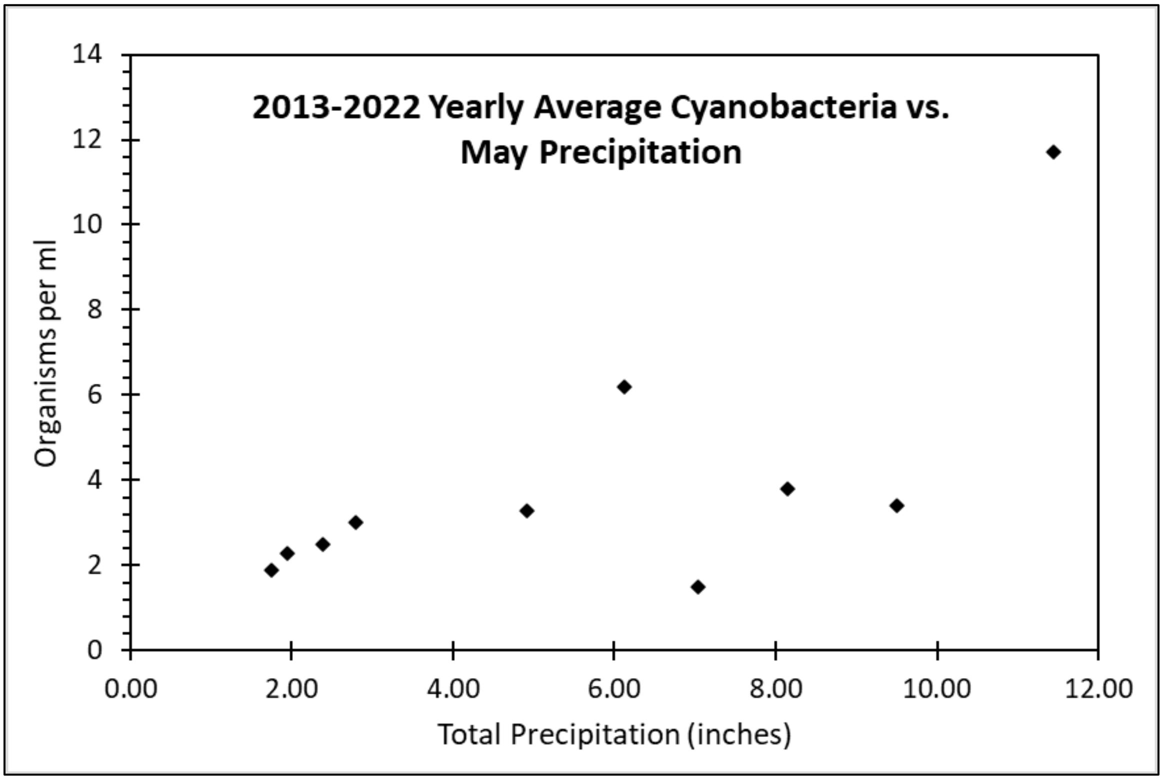


Figure 8.11. Statistical correlation of May precipitation from the Roanoke Regional Airport over a ten-year period and blue-green algae (cyanobacteria) level in lake samples during each year. (Pearson correlation of r = 0.67)

8.4 Discussion

The overall number of algae in our samples in 2022 was lower than in 2021 as can be seen on comparison graphs in Figures 8.5, 8.6, and 8.7. Relative to overall totals, green algae decreased in 2022 and diatom amounts were higher (Figure 8.8). Figure 8.10 shows a ten-year trend of both total algae and blue-greens (cyanobacteria). Although the total algal amounts have dropped since a high in 2020 when the lake flooded we are still not at the low levels found in earlier years. The exception to this is the presence of potentially harmful cyanobacteria. Their numbers have dropped back to levels found nearly 10 years ago in 2013 and 2014. Single celled *Chlorella* and filamentous *Microspora* dominated the green algae counts while single celled *Synedra* dominated the diatom counts. Both *Anabaena* and *Microcystis* are the main blue-green algae (cyanobacteria) found in samples again this year. There were some fluctuations in the algae populations again through the sampling season this year with typically higher numbers in May with the spring rains and flushing of nutrients from the tributaries around the lake. There were also slightly higher algal numbers during the July sample dates in some headwaters and marinas (Figures 8.1 and 8.2) but the lack of rain the rest of the season reduced the number of overall algae. Non-marina counts were fairly low throughout the sampling season (Figure 8.3) Overall most algal counts in 2022 were lower compared to 2021 (see Figures 8.5, 8.6 and 8.7).

The percentages of blue-green algae (cyanobacteria) in our samples were fairly low again this summer in relation to the total algae observed. The overall percentage was much lower in 2022 than in 2021 when flooding of the lake occurred. This can be seen in Figure 8.8. Only 4 percent of the algae counted were cyanobacteria. This is good since we monitor this group because it has the potential to produce toxins in water systems. No microcystin testing was done during the 2022 sampling season. There was only one reported algal bloom early in the season likely due to rain and that had dissipated within 24 hours and no sample identification was possible.

The average population percentage of each algae type for all samples is shown in the pie chart in Figure 8.8. The abundance of blue-green algae as a percentage of the total stayed the same in 2022 as it was in 2021 (4 percent). Green algae decreased from 86 percent in 2021 to 59 percent in 2022 with an increase in the percentage of diatoms from 10 percent in 2021 to 37 percent in 2022. Over the last nine years, algae percentages had shifted back and forth from high levels of diatoms to high levels of green algae. These last three years (2020 to 2022) green algae has been the dominant group. Precipitation levels and fluctuations of lake levels from year to year might cause trend changes and these will continue to be monitored if we have rain events. This year, a graph of the algal trends over the last years has been included to allow comparison of total algae as well as cyanobacteria abundance (Figure 8.10). In addition, Figure 8.9 has been added to show the differences in the channels up the Roanoke and Blackwater Rivers. Figure 8.9 clearly shows that as you move up the Blackwater River (PB7 to PB13) there is an increase in total algae, especially green algae. The same is true as you move up the Roanoke River (PR11 to PR19). Some of the lowest levels of algae are found closer to the dam at the confluence of both rivers at the sample site PM2. The spring rains also impact the algal blooms and levels of algae in our samples as has been discussed. In order to determine if there is such a relationship, Figure 8.11 has been added to show correlation between May rainfall and cyanobacteria sample amounts over the last 10 years. There is a positive, fairly strong correlation (Pearson correlation coefficient $r = .67$) between annual

May rainfall as recorded at the Roanoke regional airport over those years and the amount of cyanobacteria in our samples. Rainfall is sporadic around Smith Mountain Lake but this high level of correlation with the only consistent gauging station suggests that rainfall is an important factor to monitor as we watch for harmful algal blooms (HABs) in the future.

8.5 Conclusions

The lower rainfall throughout the Smith Mountain Lake watershed during most of the 2022 sampling season reduced the overall algae population counts except for the May sampling dates. The green algae as a percentage of the total number of algae was lower in 2022 compared to 2021. Fortunately, the blue-green counts were the same percentage of the total algae this year. The one algal bloom found this season occurred soon after the May rains and the overall lack of algae bloom reports file via the VDH State Reporting Tool is consistent with the favorable decrease in chlorophyll-*a* and total phosphorus concentrations. *Anabaena* and *Microcystis* found in some samples suggest we should continue to monitor closely especially during heavy rains. The new statewide online reporting tool and NOAA satellite maps that are available to the program should help in rapid response to these blooms if and when they occur for identification of potential HAB hot spots. Certainly, sites around the lake are changing annually as weather patterns and lake land use changes. Sites that have higher numbers of any species need to be monitored to see if nutrient inputs or other causes could be impacting areas where higher numbers are found such as those that were reported near Bull Run, Smith Mountain Lake State Park, Beaver Dam Creek, Crystal Shores and Bayside Marina. The highest levels of algae in the lake are still found at the headwater sites. Rainfall timing and run-off and water level fluctuations may have the highest influence on algae growth, which is likely tied to higher nitrogen and phosphorus levels from run-off into the lake. As mentioned in the past, rainfall and lake levels should continue to be studied. We are fortunate not to have had flooding this year up in the tributaries but runoff is still a potential problem. We should also continue to monitor Smith Mountain Lake water temperature to attempt to correlate increases and impact on lake water quality. Extended sampling by some of the volunteer monitors at profile sites is a great addition to our data set. Providing plankton nets and Lugol's preservative for vertical tows would be another great addition to the extended season volunteer sampling if feasible. As water temperatures are anticipated to warm over time, it will be important to continue to sample regular sites and sites in shallow coves around the lake where algae blooms are reported so that we can also test for microcystin and other toxins in the lake where necessary. A look at the historical data from the 36 years of the Water Quality Program studies will be useful to compare temperature trends and algal changes much like we have done with the recent ten-year comparison.

9. QUALITY ASSURANCE/QUALITY CONTROL

9.1 *Introduction*

The QA/QC procedures for each of the parameters described below are included as part of each analysis method in the *Ferrum College Water Quality Lab Procedures Manual* (Love et al. 2022).

9.2 *Calibration Data for Total Phosphorus Method and Results*

Every time samples are analyzed, sets of standards are prepared so that calibration curves 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 for total phosphorus are as follows: 0 ppb, 10 ppb, 20 ppb, 40 ppb, 80 ppb, and 160 ppb. The calibration curve is constructed using the readings from standards run at the beginning of the analysis. Table 9.1 summarizes the calibration data for 2022. The coefficient of determination (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).

Table 9.1. Summary of 2022 calibration data for total phosphorus (TP)

Sampling Period	TP - R^2
5/22-5/28	0.9991
6/5-6/11	0.9998
6/19-6/25	0.9997
7/3-7/9	0.9999
7/17-7/23	0.9958
7/31-8/6	0.9995
Average	**0.9990**
Standard Deviation	**0.0016**

9.3 *Calibration Data Discussion and Conclusions*

With an average value over 0.99, the average R^2 for total phosphorus indicates excellent precision and shows both the care with which the standards were prepared and the stability of the instrument and reagents.

9.4 *Comparison of Standards Method and Results*

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

In 2022, for total phosphorus, the 40 and 80 ppb standards were run periodically during each analysis for a total of eight readings of each of those two standards except in week 1 where seven readings were taken. 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 total phosphorus for 2022

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. (%)
5/22-5/28	1.1	2.7	0.0	21.8	125.6	4.0
6/5-6/11	3.9	5.2	2.0	0.5	0.7	0.3
6/19-6/25	2.8	3.2	1.9	21.4	164.1	0.1
7/3-7/9	0.5	1.2	0.2	0.9	1.6	0.0
7/17-7/23	7.2	8.1	5.2	2.8	4.4	2.3
7/31-8/6	1.4	2.9	0.1	1.6	2.6	0.9
Overall Averages	**2.8**			**8.2**		

9.5 *Comparison of Standards Discussion and Conclusions*

The results of analysis for the 40 and 80 ppb standards for total phosphorus over the course of the sampling season were very good for the 40 ppb standard with an overall average of 2.8 percent and acceptable for the 80 ppb standard with an overall average of 8.2 percent. The target value for RPD is 0 percent and 10 percent is the DEQ acceptable upper limit. The average RPD for the 80 ppb standard check for weeks 1 and 3 did not fall within this limit. In both cases this was due to single readings that were extremely high. These high readings were thought to be caused by too little sample in the vials which allowed air to enter the instrument lines. The procedure was changed to increase the amount of standards in these vials to prevent this issue in future runs. However, other QC checks for those weeks were within acceptable limits so the analyses were not repeated.

9.6 *Blank and Spiked Blank Method and Results*

In 2022, three blanks of deionized (DI) water and three spiked blanks were run with each analysis except for week 1 where two blanks and two spiked blanks were run. The spiked blanks were 5.0 mL DI water spiked with 0.1 mL of 2 ppm phosphate standard to give a final concentration of 39 ppb.

Table 9.3. Average error for total phosphorus for 2022 lab blanks and average percent recovery for spiked blanks

Sampling Period	TP blanks - average error (ppb)	TP spiked blanks - average % recovery
5/22-5/28	2.3	98.6
6/5-6/11	1.4	105.6
6/19-6/25	0.3	105.3
7/3-7/9	0.2	107.5
7/17-7/23	3.5	95.2
7/31-8/6	1.0	96.3
AVERAGES	**1.5**	**101.4**

9.7 *Blank and Spiked Blank Discussion and Conclusions*

The average for lab blanks for total phosphorus was very good for all sample periods (target value is 0 ppb). The overall average of 1.5 ppb was excellent and shows stability of the instrument and little carry-over contamination from previous samples. The overall average percent recovery for the spiked blanks for total phosphorus was also excellent at 101.4 percent (target value is 100 percent with $\pm$20 percent acceptable upper and lower limits).

9.8 *Duplicate and Spiked Sample Analysis Method and Results*

During every analysis, five samples were divided and run as duplicates. Five additional samples were divided and one of the aliquots was spiked by the addition of a very small quantity of total phosphorus standard solution (0.1 mL of 2 ppm solution in 5.0 mL sample) to give a known final added concentration. The duplicate samples were compared to their initial analyzed values and relative percent differences (RPD) were calculated. The results are reported in Table 9.4. The spiked samples were compared to their initial analyzed concentrations plus the value of the added phosphorus, and percent recovery was calculated. The results are also reported in Table 9.4.

Table 9.4 Results of analysis of 2022 duplicates and spikes for total phosphorus

	TP DUPLICATES			TP SPIKES		
Sampling Period	**Average RPD**	**Maximum RPD**	**Minimum RPD**	**Average % Recovery**	**Maximum % Recovery**	**Minimum % Recovery**
5/22-5/28	2.8	6.0	0.6	99.0	100.8	98.1
6/5-6/11	1.9	6.0	0.0	102.3	103.8	100.1
6/19-6/25	2.7	3.8	0.0	97.8	103.3	81.7
7/3-7/9	8.9	20.5	0.0	105.7	108.6	103.0
7/17-7/23	2.7	6.5	0.9	104.3	105.7	103.2
7/31-8/6	5.2	6.6	3.7	104.8	107.1	102.4
Overall Avg	**4.0**	**8.2**	**0.9**	**102.3**	**104.9**	**98.1**

9.9 Duplicate and Spiked Sample Analysis Discussion and Conclusions

The results of duplicate analysis for total phosphorus were very good this year at 4.0 average relative percent difference (acceptance criteria is RPD < 20 percent) and excellent for spiked samples with 102.3 average percent recovery (acceptance criteria is 80-120 percent recovery).

9.10 Analysis of Certified Standard Method and Results

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

Table 9.5. Results of analysis of purchased standard for total phosphorus for 2022

Sampling Period	ERA conc. - expected (ppb)	ERA conc. - measured, avg. (ppb)	Average RPD
5/22-5/28	69.3	67.9	2.1
6/5-6/11	69.3	71.7	3.4
6/19-6/25	69.3	70.0	1.0
7/3-7/9	69.3	69.7	0.6
7/17-7/23	69.3	65.9	5.0
7/31-8/6	69.3	67.8	2.2
Averages		**68.8**	**2.4**

9.11 Analysis of Certified Standard Discussion and Conclusions

The results of the analysis of the purchased standard for total phosphorus were very good with an overall average relative percent difference (RPD) of 2.4 percent (target value is 0 percent). All measured values fell within the QC performance acceptance limits established by ERA.

9.12 *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. An unfiltered glass fiber filter (method blank) is analyzed each time samples are run to assure that the processing of the samples does not introduce contamination or interferents. In 2022, the method blanks ranged from 0.01 ppb to 0.07 ppb with an average of 0.03 ppb.

9.13 *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.

9.14 *QA/QC for E. coli Methods and Results*

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. In 2022, replicates were run at two sites from each sample set for the six samplings. The replicates are obtained by collecting a large field duplicate sample along with the regular sample at the replicate site and dividing the larger sample into four replicate subsamples at the lab. These replicate samples are analyzed in the same manner as the rest of the samples, and the results are compared both to each other and to the regular sample collected at the replicate site. Results of the replicate analysis are shown in Table 9.6.

Table 9.6. Results of replicate analysis of *E. coli* samples for 2022

Sampling Date	Replicate Site	MPN E. coli at replicate site	Replicate Avg. (MPN)	Replicate Range (MPN)
5/24	9-1	93.3	78.4	68.4 - 88.2
5/24	6-1	140.1	161.8	142.1 - 178.5
6/7	8-1	4.1	2.8	2 - 5.1
6/7	2-1	1.0	0.8	0 - 3.1
6/21	5-1	40.8	32.2	21.6 - 41.1
6/21	12-1	3.0	5.3	3 - 9.7
7/5	1-1	16.0	18.4	13.5 - 21.6
7/5	14-2	5.2	6.6	4.1 - 9.7

7/19	6-1	13.4	2.3	1 - 4.1
7/19	11-2	18.5	1.5	1 - 2
8/2	12-1	24.1	11.7	7.5 - 19.7
8/2	4-1	41.4	35.6	24.6 - 44.3

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

Table 9.7. Results of QuantiCult™ analysis for 2022

5/24	**MPN total coliforms**	**MPN *E. coli***
E. coli	18.5	18.5
K. pneumoniae	37.3	0.0
P. aeruginosa	0.0	0.0
6/7	**MPN total coliforms**	**MPN *E. coli***
E. coli	40.2	40.2
K. pneumoniae	49.5	0.0
P. aeruginosa	0.0	0.0
6/21	**MPN total coliforms**	**MPN *E. coli***
E. coli	25.6	25.6
K. pneumoniae	37.9	0.0
P. aeruginosa	0.0	0.0
7/5	**MPN total coliforms**	**MPN *E. coli***
E. coli	24.9	24.9
K. pneumoniae	40.4	0.0
P. aeruginosa	0.0	0.0

7/19	**MPN total coliforms**	**MPN *E. coli***
E. coli	22.6	22.6
K. pneumoniae	45.0	0.0
P. aeruginosa	0.0	0.0

8/2	**MPN total coliforms**	**MPN *E. coli***
E. coli	26.5	26.5
K. pneumoniae	36.4	0.0

P. aeruginosa	0.0	0.0

9.15 *QA/QC for E. coli Discussion and Conclusions*

All QA/QC results for *E. coli* analysis for the 2022 sampling season were very good. The sterile distilled water gives assurance that the bottles, media, and Quanti-Tray 2000^{TM} trays are sterile and that good technique was used. There was no relevant difference between the results for the replicate analysis, the replicate average and the regular sample collected at the replicate site. The QuantiCult^{TM} results were as expected.

10. SAMPLING EFFICIENCY

The monitoring program depends on volunteers for sample collection and one measure of success for the program is the consistency with which these volunteers attend to their stations. Table 10.1 indicates the sampling efficiency data for 2022 and Table 10.2 presents the collection efficiencies from 2013 through 2022. The figures show that the volunteer monitors are very conscientious about sample collection. Volunteer monitor sample efficiency for total phosphorus was 99 percent, chlorophyll-*a* samples correctly collected at 98 percent, and 97 percent for Secchi readings. 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 for Smith Mountain Lake data for 2022

Sample Type	Monitoring Stations	Possible Samples	Samples Collected	Percent Efficiency
Secchi Depth	84	504	487	97
TP	56	336	332	99
CA	56	336	328	98
Profiles*	5	30	30	100
Bacteria*	28	168	168	100
Algae*	19	114	114	100

*Indicates samples taken by students and faculty from Ferrum College

Table 10.2. Ten-year sampling efficiencies for Smith Mountain Lake data

% Efficiencies/Year	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013
Secchi Depth	97	99	97	99	95	84	95	96	98	99
TP	99	100	98	100	96	97	98	99	99	100
CA	98	99	97	96	95	98	97	98	99	100

11. CONCLUSIONS

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

In 2022, average total phosphorus and chlorophyll-*a* concentrations were slightly decreased, as was the average Secchi depth.

Sufficient depth profile data have now been collected to enable meaningful comparison between rates of change and absolute parameter values over the course of the summer. The temperature profiles indicate that the thermocline at most sample sites continues to be slightly higher in the water column. As has been the case since 2015, the bottom of the lake becomes anaerobic (DO is depleted) in June rather than July. This trend has a negative effect on aquatic life by forcing them to move closer to the surface earlier in the summer, thus increasing thermal stress. Atmospheric carbon dioxide is increasing globally and may be affecting Smith Mountain Lake. Increased carbon dioxide decreases pH and promotes photosynthesis, increasing algal production. While DO will increase at the surface, the amount of organic matter settling into the hypolimnion will also increase and the hypolimnetic oxygen deficit will become more severe. Continued depth profiling and study of algal dynamics will provide scientific data to support effective management of Smith Mountain Lake as it ages.

The *E. coli* populations in Smith Mountain Lake in 2022 were much higher than the levels in 2021. In 2022, the mean *E. coli* count was 75.9 MPN compared to the 2021 mean *E. coli* count of 6.8 MPN. Since we began monitoring *E. coli* in 2004, the overall mean counts were their highest in 2013 and overall mean counts were their lowest in 2014. The 2022 overall mean is the second highest in the past ten years.

The lower rainfall throughout the Smith Mountain Lake watershed during most of the 2022 sampling season reduced the overall algae population counts except for the May sampling dates. The green algae as a percentage of the total number of algae was lower in 2022 compared to 2021. Fortunately, the blue-green counts were the same percentage of the total algae this year. The one algal bloom found this season occurred soon after the May rains and the overall lack of algae bloom reports file via the VDH State Reporting Tool is consistent with the favorable decrease in chlorophyll-*a* and total phosphorus concentrations. *Anabaena* and *Microcystis* found in some samples suggest we should continue to monitor closely especially during heavy rains. The new statewide online reporting tool and NOAA satellite maps that are available to the program should help in rapid response to these blooms if and when they occur for identification of potential HAB hot spots. Certainly, sites around the lake are changing annually as weather patterns and lake land use changes. Sites that have higher numbers of any species need to be monitored to see if nutrient inputs or other causes could be impacting areas where higher numbers are found such as those that were reported near Bull Run, Smith Mountain Lake State Park, Beaver Dam Creek, Crystal Shores and Bayside Marina. The highest levels of algae in the lake are still found at the headwater sites. Rainfall timing and run-off and water level fluctuations may have the highest influence on algae growth, which is likely tied to higher nitrogen and phosphorus levels from run-off into the lake. As mentioned in the past, rainfall and lake levels should continue to be studied. We are fortunate not to have had flooding this year up in the tributaries but runoff is still a potential problem. We should also continue to monitor Smith Mountain Lake water temperature to attempt to correlate increases and impact on lake water quality. Extended sampling by some of the volunteer monitors at profile sites is a great addition to our data set. Providing plankton nets and Lugol's preservative for vertical tows would be a great addition to the extended season volunteer sampling if feasible. As water temperatures are anticipated to warm over time, it will be important to continue to sample regular sites and sites in shallow coves around the lake where algae blooms are reported so that we can also test for microcystin and other toxins in the lake where necessary. A look at the historical data from the 36 years of the Water Quality Program studies will be useful to compare temperature trends and algal changes much like we have done with the recent ten-year comparison.

The results of the quality control and quality assurance procedures range from extremely good to acceptable. We measure precision and accuracy of our analyses in many ways including blank samples, spiked samples, and analyzing certified standards. The Smith Mountain Lake and Ferrum College Water Quality Program has been certified by the Virginia Department of Environmental

Quality for the following parameters: total phosphorus, chlorophyll-*a, Escherichia coli* populations, and temperature, dissolved oxygen, and conductivity depth profiles. With an average value over 0.99, the R^2 for total phosphorus indicates excellent precision and shows both the care with which the standards were prepared and the stability of the instrument and reagents. The average for lab blanks for total phosphorus is very good for all sample periods (target value is 0 ppb). The results of analysis for the 40 and 80 ppb standards for total phosphorus over the course of the sampling season was very good for the 40 ppb standard with an overall average of 2.8 percent and acceptable for the 80 ppb standard with an overall average of 8.2 percent. The target value for RPD is 0 percent and 20 percent is the DEQ acceptable upper limit. The overall average of 1.5 ppb was excellent and shows stability of the instrument and little carry-over contamination from previous samples. The overall average percent recovery for the spiked blanks for total phosphorus was also excellent at 101.4 percent (target value is 100 percent with $\pm$20 percent acceptable upper and lower limits). The results of duplicate analysis for total phosphorus was very good this year at 4.0 average relative percent difference (target value is 0 percent) and excellent for spiked samples with 102.3 average percent recovery (target value is 100 percent, 80-120 percent recovery is the acceptance criteria). The results of the analysis of the purchased standard for total phosphorus were excellent with an overall average relative percent difference (RPD) of 2.4 percent (target value is 0 percent). All QA/QC results for *E. coli* analysis for the 2022 sampling season were very good. There was no relevant difference between the results for the replicate analysis, the replicate average and the regular sample collected at the replicate site. The QuantiCult™ results were as expected.

The sampling efficiency of the Smith Mountain Lake and Ferrum College Water Quality Program was excellent in 2022. Volunteer monitor sample efficiency for total phosphorus was 99 percent, while chlorophyll-*a* samples were 98 percent and Secchi readings were 97 percent. These figures show that the volunteer monitors are very conscientious about sample and data collection and remain engaged in the program.

The overall conclusion in regard to the water quality in Smith Mountain Lake is that it is very good. The lake is not aging as fast as would have been predicted for a reservoir. However, the weather and climate are a significant driving factor for the trophic status of the lake. We will continue to monitor the water quality of the lake in order to provide data to help ensure a healthy lake and help protect this valuable resource in this region.

12. ACKNOWLEDGEMENTS

Thanks go out to all of our volunteer monitors who once again made this program possible with their dedication and support. We are especially grateful to those monitors who have worked with the program through the challenges of the last few years. The Smith Mountain Lake Association provided political and financial support. Emma Brubaker, Shane Hernandez and Rene Settle were the student technicians in 2022.

We would like to acknowledge the support and time of Gael & Smith Chaney for their gracious boat driving and sampling assistance in the program, and Tom Hardy for his leadership in communicating and understanding the science in the Water Quality Program. His innovation, statistical skills, questions and leadership are exceedingly helpful. We would also like to thank Bayside Marina and Yacht Club, and in particular Dale Runyon, for their assistance and advice on boat maintenance and for allowing us to dock our Boston Whaler at their marina. This program would not be possible without their support. Additional support this year was provided by Virginia Inland Sailing Association.

Finally, we wish to thank Appalachian Power (AEP), Bedford County Regional Water Authority, Smith Mountain Lake Association, Western Virginia Water Authority, and the Virginia Department of Environmental Quality for financial support, and Ferrum College for making space and equipment available to the project at no cost to the Water Quality Program as a community service.

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APPENDIX

Table A.1. 2022 Smith Mountain Lake trophic monitoring stations with monitor names and station locations

Station	Monitor	Latitude	Longitude
B8	Scott	37.0393	-79.6159
B10	Scott	37.0504	-79.6417
B12	Brinkerhoff	37.0422	-79.6686
B14	Jamison	37.0348	-79.6723
B16	Jamison	37.0412	-79.7027
B18	Flowers	37.0337	-79.7189
B20	Flowers	37.033	-79.7279
B22	Easter/Gross	37.0634	-79.7391
C4	Trinchere	37.0558	-79.5709
C5	Trinchere	37.0689	-79.5645
C6	Trinchere	37.0821	-79.5685
CB11	Brinkerhoff	37.0409	-79.6571
CB16	Jamison	37.0384	-79.697
CB20	Easter/Gross	37.0358	-79.7382
CM1	Rupnik/Edgerton	37.055	-79.539
CM1.2	Rupnik/Edgerton	37.063	-79.535
CM5	Anderson	37.0468	-79.5871
CR8	Anderson	37.0659	-79.5912
CR9	Leonard	37.0747	-79.6068
CR9.2	Leonard	37.0708	-79.6204
CR13	Servidea/MacMullan/Mallen	37.0989	-79.6409
CR14.2	Koontz	37.1172	-79.6739
CR16	McCord	37.145	-79.663
CR17	McCord	37.15	-79.667
CR19	Hamlin	37.159	-79.692
CR21	Gardner	37.1492	-79.7086
CR21.2	Gardner	37.146	-79.7091
CR22	Sanders	37.167	-79.712
CR24	McWilliams	37.1946	-79.7239
CR25	McWilliams	37.1928	-79.7281
CR26	Watson	37.1863	-79.7532
G12	Brinkerhoff	37.0469	-79.669
G13	Toone	37.0502	-79.6739
G14	Butterfield	37.0555	-79.6723
G15	Toone	37.0594	-79.6805
G16	Butterfield	37.0641	-79.6878

Table A.1. 2022 SML monitoring stations with monitor names and station locations (cont.)

Station	Monitor	Latitude	Longitude
G18	Butterfield	37.0716	-79.6799
M0	Rupnik/Edgerton	37.0447	-79.5392
M1	Sakayama/Earnhardt	37.0498	-79.5481
M3	Sakayama/Earnhardt	37.041	-79.564
M5	Sakayama/Earnhardt	37.042	-79.588
R7	Anderson	37.0518	-79.5931
R9	Leonard	37.0736	-79.6183
R11	Anderson	37.0898	-79.6135
R13	Servidea/MacMullan/Mallen	37.1029	-79.6409
R14	Koontz	37.1122	-79.6487
R15	McCord	37.131	-79.657
R17	Hamlin	37.152	-79.676
R19	Hamlin	37.161	-79.697
R21	Gardner	37.1564	-79.7081
R23	Sanders	37.18	-79.717
R25	McWilliams	37.19	-79.7419
R27	Watson	37.1981	-79.7663
R29	Watson	37.2153	-79.776
R30	Ferrum College	37.2327	-79.7864
R31	Ferrum College	37.2202	-79.7967
T0	Snoddy	37.0401	-79.6648
SB12	Ralph	37.0254	-79.5986
SCB 8	Hurt/Bleier	37.0208	-79.6382
SCB10	Hurt/Bleier	37.0168	-79.6267
SCB11	Hurt/Bleier	37.0649	-79.6448
SCB11.5	Hurt/Bleier	37.033	-79.6824
SCB14	Ralph	37.0356	-79.6937
SCB16	Ralph	37.048	-79.5879
SCM5	Jensen	37.0587	-79.5866
SCR7	Jensen	37.0683	-79.5883
SCR8	Jensen	37.0719	-79.6295
SCR10.1	Goodnight	37.0763	-79.6289
SCR10.2	Goodnight	37.0797	-79.6368
SCR10.3	Goodnight	37.106	-79.6001
SCR11.1	Heyroth	37.1051	-79.6166
SCR11.2	Heyroth	37.1015	-79.6295
SCR11.3	Heyroth	37.0716	-79.6799

Table A.1. 2022 SML monitoring stations with monitor names and station locations (cont.)

Station	Monitor	Latitude	Longitude
SCR14	Noesner	37.1125	-79.6429
SCR14.1	Noesner	37.1097	-79.6648
SCR14.2	Noesner	37.108	-79.6729
SCR14.3	Noesner	37.1135	-79.6603
SCR15	Bull	37.12	-79.646
SCR 15.1	Noesner	37.1203	-79.6544
SCR 15.2	Noesner	37.1186	-79.6711
SCR17	Bull	37.157	-79.67
SCR17.1	Bull	37.158	-79.677
SCR18	Reingarber	37.148	-79.6892
SCR19.2	Reingarber	37.1605	-79.6918
SCR20	Reingarber	37.1609	-79.7037

Figure A.1. Smith Mountain Lake trophic monitoring stations

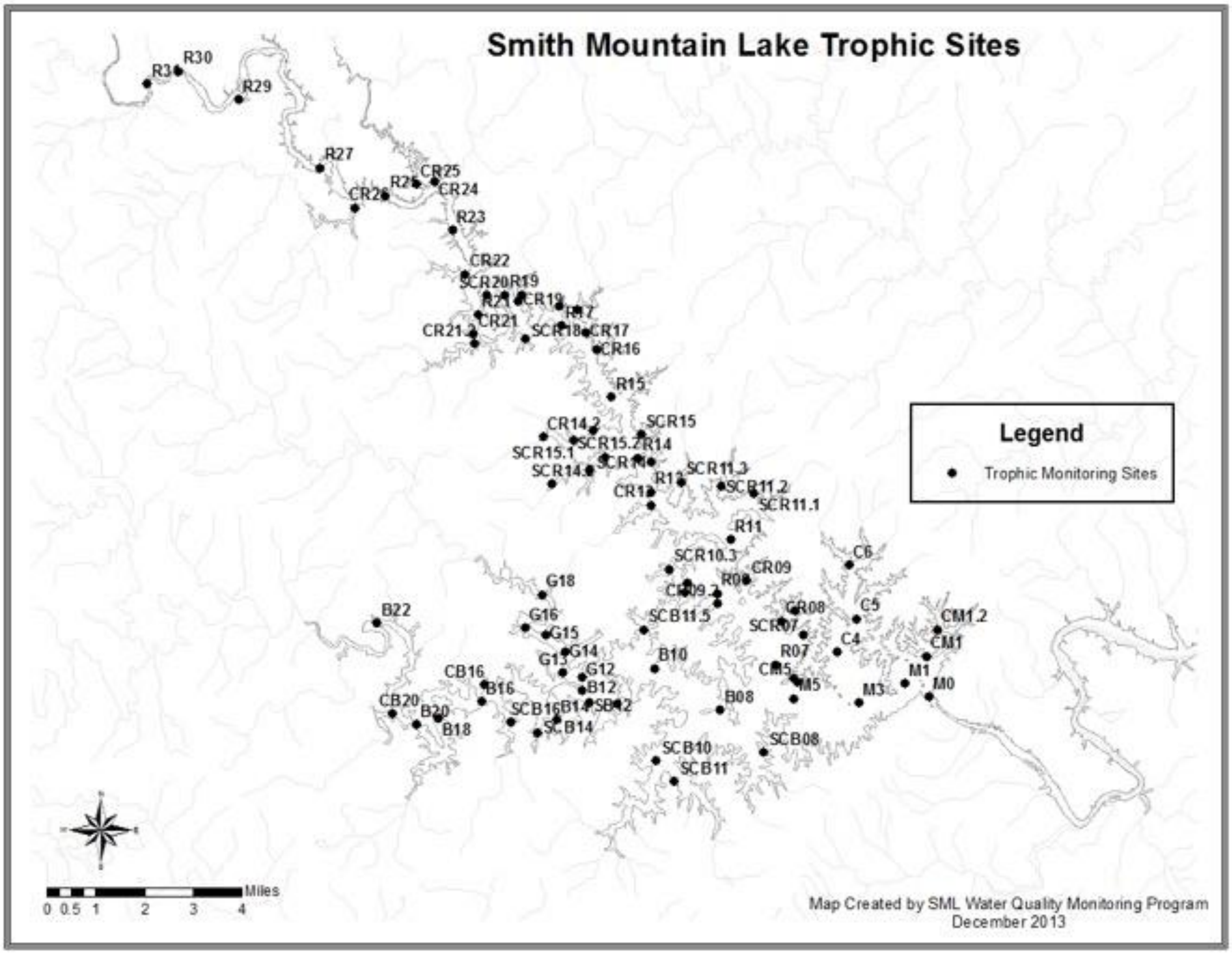

Table A.2. 2022 Smith Mountain Lake tributary stations and other downstream stations

Tributary Station Number	Stream Name
T0	Upper Gills Creek
T1a	Maggodee Creek
T2a	Gills Creek
T3	Blackwater
T4	Poplar Camp Creek
T5	Standiford Creek
T6	Bull Run
T7	Cool Branch
T8	Lumpkins Marina Creek
T9	Below SML dam
T10	Pigg River
T11	Leesville lake
T12	Surrey Drive
T13	Snug Harbor
T14	Stoney Creek
T15	Jumping Run
T16	Beaver Dam Creek
T17	Bay Roc Marina
T18	Lynville Creek
T19a	Grimes Creek
T20	Indian Creek
T21a	Roanoke River

Figure A.2. Smith Mountain Lake Tributary monitoring stations

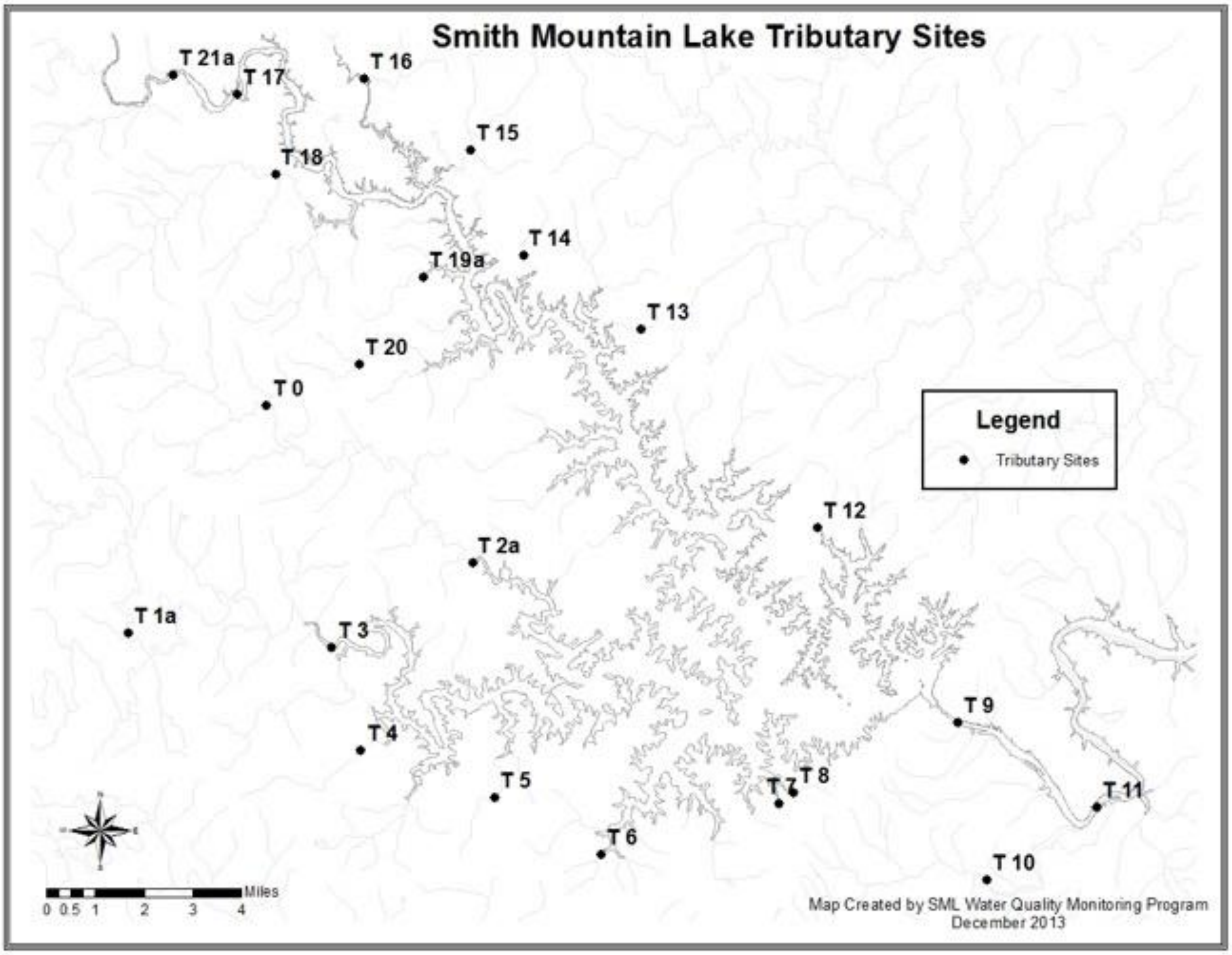

Figure A.2.a Map showing tributary sites below Smith Mountain Lake Dam

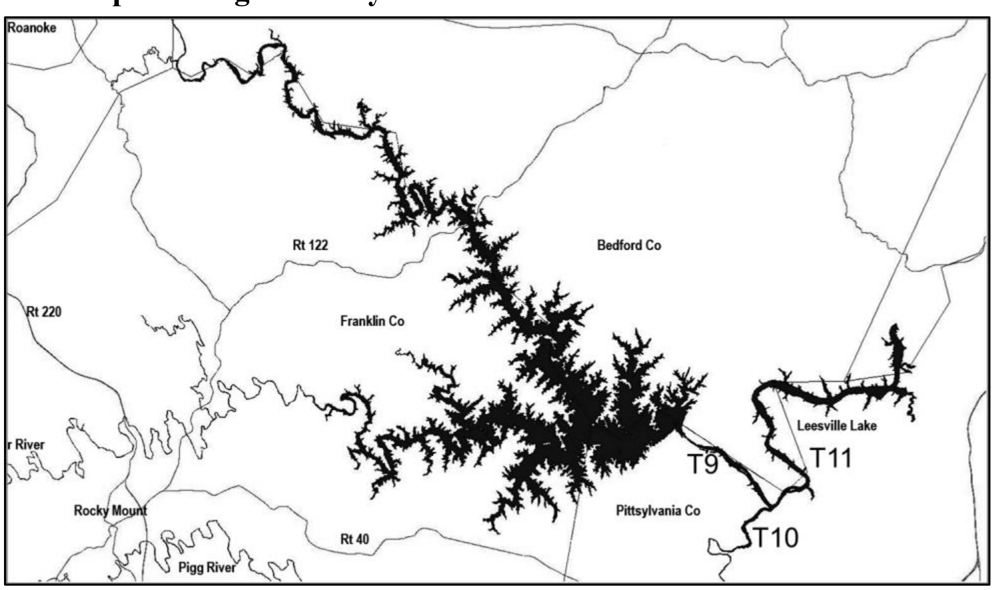

Table A.3. 2022 Total phosphorus data for Smith Mountain Lake sample stations

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Station Avg.	Std. Dev.
Station	**conc (ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**(ppb)**	
B8	45.5	61.1	22.7	10.9	13.6	11.9	**27.6**	**20.9**
B10	B10	23.9	16.7	17.3	11.0	9.1	**10.1**	**14.7**
B12	B12	217.0	31.3	43.7	20.5	20.2	**16.5**	**58.2**
B14	B14	33.2	17.8	24.1	14.1	12.4	**18.1**	**20.0**
B16	B16	32.4	21.2	21.5	19.3	19.6	**19.0**	**22.2**
B18	B18	23.5	28.0	29.3	23.0	19.3	**24.2**	**24.5**
B20	B20	26.1	40.3	28.4	25.7	25.1	**26.7**	**28.7**
B22	B22	67.7	88.8	98.8	70.3	95.1	**77.9**	**83.1**
C4	C4	12.3	12.2	10.8	11.6	4.9	**11.4**	**10.5**
C5	C5	16.3	18.7	10.4	10.6	6.5	**9.4**	**12.0**
C6	C6	15.4	16.1	13.0	13.8	7.1	**8.6**	**12.3**
CB11	CB11	75.9	22.4	31.4	16.4	25.6	**18.5**	**31.7**
CB16	CB16	22.9	21.0	30.1	23.2	23.1	**19.3**	**23.3**
CB20	CB20	27.9	37.6	38.6	28.0	24.3	**26.4**	**30.5**
CM1	CM1	13.2	14.3	12.7	10.0	5.8	**10.0**	**11.0**
CM1.2	CM1.2	20.1	17.2	12.0	10.8	5.9	**10.3**	**12.7**
CM5	CM5	15.6	19.4	17.2	11.9	10.8	**11.6**	**14.4**
CR8	CR8	13.3	16.2	13.4	9.9	8.3	**10.6**	**12.0**
CR9	CR9	19.0	15.9	17.5	9.3	7.6	**10.7**	**13.3**
CR9.2	CR9.2	28.5	14.3	15.0	10.8	7.3	**11.3**	**14.5**
CR13	CR13	31.6	22.4	24.2	20.6	15.5	**15.6**	**21.6**
CR14.2	CR14.2	28.7	26.6	21.2	16.8	16.5	**19.3**	**21.5**
CR16	CR16	22.9	28.9	21.9	23.2	13.6	**17.0**	**21.3**
CR17	CR17	28.7	29.1	23.3	22.9	18.1	**17.6**	**23.3**
CR19	CR19	32.7	35.5	31.9	28.8	22.2	**21.9**	**28.8**
CR21	CR21	29.0	31.8	30.9	22.9	23.6	**26.2**	**27.4**
CR21.2	CR21.2	32.7	29.7	30.9	25.1	29.7	**26.6**	**29.1**
CR22	CR22	30.0	42.4	41.0	25.5	27.8	**27.5**	**32.4**
CR24	CR24	78.2	72.4	57.9	61.1	50.0	**68.5**	**64.7**
CR25	CR25	33.4	41.1	27.7	34.5	24.7	**28.4**	**31.6**
CR26	CR26	55.4	42.9	50.9	30.9	38.2	**41.7**	**43.4**
G12	G12	240.0	48.2	43.4	37.2	28.6	**36.1**	**72.3**
G13	G13	23.2	24.7	19.9	12.3	9.6	**14.8**	**17.4**
G14	G14	19.5	24.0	16.4	13.2	17.2	**15.8**	**17.7**
G15	G15	24.7	23.0	20.5	15.7	11.5	**16.5**	**18.6**
G16	G16	22.2	31.0	23.1	17.7	20.9	**22.4**	**22.9**
G18	G18	33.7	48.8	51.5	38.7	31.8	**46.5**	**41.8**
M0	M0	12.2	13.1	12.9	8.8	6.2	**9.9**	**10.5**

Table A.3. 2022 Total phosphorus data for SML sample stations (cont.)

Station	Week 1 conc(ppb)	Week 2 conc(ppb)	Week 3 conc(ppb)	Week 4 conc(ppb)	Week 5 conc(ppb)	Week 6 conc(ppb)	Station avg. (ppb)	Std. Dev.
M1	M1	103.6	19.9	15.0	10.5	10.7	**12.0**	**28.6**
M3	M3	20.6	14.5	14.7	9.7	6.0	**11.0**	**12.8**
M5	M5	19.1	13.8	11.2	11.5	3.6	**10.1**	**11.5**
R7	R7	15.1	20.9	13.1	11.1	6.9	9.7	**12.8**
R9	R9	19.8	21.3	14.5	13.8	12.0	13.6	**15.8**
R11	R11	16.4	18.2	15.1	11.1	7.5	11.3	**13.3**
R13	R13	21.8	21.3	26.8	16.0	11.7	15.0	**18.8**
R14	R14	26.1	27.2	19.6	16.8	13.4	13.7	**19.5**
R15	R15	24.0	27.7	19.5	16.1	12.8	13.6	**18.9**
R17	R17	36.3	36.3	26.8	23.2	15.0	18.1	**25.9**
R19	R19	38.4	35.8	33.5	24.8	26.4	22.3	**30.2**
R21	R21	34.2	35.0	29.3	28.5	23.6	25.2	**29.3**
R23	R23	41.8	43.7	36.2	28.8	30.5	30.1	**35.2**
R25	R25	29.0	40.5	29.8	21.8	22.9	31.8	**29.3**
R27	R27	177.7	55.9	35.4	39.0	54.9	51.9	**69.1**
R29	R29	110.7	51.1	40.5	41.9	41.2	42.8	**54.7**
R30	R30		42.4		37.2	55.1	60.1	**48.7**
R31	R31		37.6		36.9	33.9	65.2	**43.4**
Average	**41.9**	**30.5**	**26.6**	**21.7**	**20.5**	**23.1**	**27.5**	
St. Dev.	**46.7**	**15.4**	**15.1**	**12.5**	**15.9**	**16.1**	**16.8**	

Table A.4. 2022 Total phosphorus data for Smith Mountain Lake tributaries

Station	Week 1 conc(ppb)	Week 2 conc(ppb)	Week 3 conc(ppb)	Week 4 conc(ppb)	Week 5 conc(ppb)	Week 6 conc(ppb)	Station Avg. (ppb)	Std. Dev.
T0	127.9	126.7	66.2	90.0	231.0	134.6	**129.4**	**56.4**
T1a	104.1	81.4	75.0	70.3	142.0	121.3	**99.0**	**28.6**
T2a	89.5	109.8	92.1	101.8	428.0	122.2	**157.2**	**133.2**
T3	113.8	56.7	42.1	102.3	78.7	102.7	**82.7**	**28.6**
T4	27.2	29.9	26.4	22.5	34.8	28.3	**28.2**	**4.1**
T5	36.8	40.3	37.3	31.4	28.1	32.1	**34.3**	**4.5**
T6	31.6	35.5	31.1	24.2	23.4	38.6	**30.8**	**6.0**
T7	14.2	14.4	9.9	10.0	8.4	28.2	**14.2**	**7.3**
T8	16.3	15.0	14.2	12.7	10.0	21.2	**14.9**	**3.8**
T9	11.0	22.5	18.7	16.0	6.0	11.6	**14.3**	**5.9**
T10	61.5	36.0	34.4	78.4	53.8	85.5	**58.3**	**21.2**
T11	23.2	23.4	19.5	21.8	19.8	19.3	**21.2**	**1.9**
T12	26.1	25.0	20.7	18.8	21.4	22.0	**22.3**	**2.8**
T13	21.7	24.8	20.8	16.2	20.8	46.8	**25.2**	**11.0**
T14	167.5	305.0	133.5	166.5	265.9	186.0	**204.1**	**66.4**
T15	105.4	152.7	94.8	66.1	95.6	105.8	**103.4**	**28.2**
T16	74.3	114.3	78.5	67.1	50.3	94.2	**79.8**	**22.2**
T17	30.3	40.5	48.3	32.2	71.2	65.2	**47.9**	**17.0**
T18	43.4	45.6	44.2	44.0	60.5	61.2	**49.8**	**8.6**
T19a	58.3	66.8	67.5	64.2	71.8	84.3	**68.8**	**8.8**
T20	71.4	60.4	57.1	43.0	69.3	55.3	**59.4**	**10.4**
T21a	55.4		174.5	133.9	68.5	109.0	**108.3**	**48.5**
Average	**59.6**	**67.9**	**54.8**	**56.1**	**84.5**	**71.6**	**66.1**	
St. Dev.	**42.7**	**67.1**	**41.2**	**42.6**	**102.0**	**46.4**	**50.7**	

Table A.5. 2022 Chlorophyll-*a* data for Smith Mountain Lake sample stations

Station	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Station Avg.	Std. Dev.
	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	**(ppb)**	
B8	3.58	1.43	1.70	0.99	0.92	0.74	**1.56**	**1.05**
B10	1.61	0.31	1.53	0.62	0.68	0.87	**0.94**	**0.52**
B12	1.56	5.81	3.38	1.05	2.43	1.23	**2.58**	**1.81**
B14	2.25	0.99	8.06	1.06	1.66	1.56	**2.60**	**2.72**
B16	1.94	1.41	3.26	1.54	2.06	1.66	**1.98**	**0.67**
B18	4.42	8.13		3.94	4.22	7.67	**5.68**	**2.04**
B20	4.92	18.68	19.37	3.17	4.57	7.44	**9.69**	**7.36**
B22	4.81	45.10	60.06	10.28	18.57	13.71	**25.42**	**22.02**
C4	1.59	2.56	2.59	1.12	1.28	1.04	**1.70**	**0.71**
C5	1.56	4.15	3.31	1.12	0.99	1.27	**2.07**	**1.33**
C6	1.99	3.42	3.30	1.05	1.46	0.87	**2.02**	**1.11**
CB11	2.54	0.48	4.67	0.80	2.03	0.96	**1.91**	**1.56**
CB16	2.36	2.21	4.71	1.37	4.02	1.98	**2.78**	**1.30**
CB20	8.11	7.92	29.63	5.34	0.70	6.04	**9.62**	**10.16**
CM1	5.93	1.41	1.39	0.80	0.38	1.13	**1.84**	**2.04**
CM1.2	6.24	2.31	1.12	0.95	0.64	1.26	**2.09**	**2.11**
CM5	0.95	1.64	3.51	0.73	0.87	1.17	**1.48**	**1.04**
CR8	3.55	1.66	3.56	1.47	1.38	1.85	**2.25**	**1.03**
CR9	2.89	5.05	1.50	1.24	1.19	1.49	**2.23**	**1.52**
CR9.2	4.81	2.83	1.61	1.25	2.59	2.40	**2.58**	**1.25**
CR13	3.15	5.64	5.66	7.25	3.02	8.11	**5.47**	**2.08**
CR14.2	4.21	3.97	17.22	3.78	2.59	3.37	**5.86**	**5.60**
CR16	5.22	4.61	5.56	3.69	4.21	7.56	**5.14**	**1.36**
CR17	3.68	5.38	6.25	3.19	6.43	7.55	**5.41**	**1.69**
CR19	0.27	0.20	5.05	1.19	2.09	11.63	**3.41**	**4.41**
CR21	5.58	4.61	5.64	4.92	6.61	20.54	**7.98**	**6.19**
CR21.2	3.80	10.33	8.61	8.07	5.48	20.10	**9.40**	**5.74**
CR22	4.44	18.26	6.04	7.68	12.03	8.06	**9.42**	**5.02**
CR24	7.40	30.60	19.85	9.63	16.99	18.35	**17.14**	**8.26**
CR25	3.31	8.29	16.95	7.10	6.79	14.23	**9.45**	**5.11**
CR26	4.10		13.42	3.60	6.65	11.70	**7.89**	**4.46**
G12	2.30	1.69	4.66	0.51	1.93	3.95	**2.51**	**1.53**
G13	4.14	1.80	4.49	1.27	0.82	1.10	**2.27**	**1.62**
G14	4.95	2.78	5.07	1.27	1.28	1.75	**2.85**	**1.76**
G15	1.89	4.88	4.76	0.80	1.25	1.78	**2.56**	**1.79**
G16	2.06		7.64	4.62	1.80	1.78	**3.58**	**2.56**
G18	3.97	11.40	11.61	14.34	2.87	3.75	**7.99**	**5.01**
M0	5.32	1.68	1.67	1.58	0.34	0.98	**1.93**	**1.74**
M1	1.94	1.05	1.71	0.53	0.57	0.74	**1.09**	**0.60**

Table A.5. 2022 Chlorophyll–*a* data for SML sample stations (cont.)

Station	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Station Avg.	Std. Dev.
	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	(ppb)	
M3	1.67	3.80	4.01	1.01	0.99	1.73	**2.20**	**1.36**
M5	1.97	1.69	4.06	0.97	1.12	1.36	**1.86**	**1.14**
R7	1.70	1.14	3.12	0.95	1.10	1.52	**1.59**	**0.80**
R9	2.67	1.93	2.49	1.55	0.99	0.94	**1.76**	**0.73**
R11	2.03	1.64	4.74	2.02	1.59	2.01	**2.34**	**1.19**
R13	5.47	6.12	5.93	8.54	2.43	2.58	**5.18**	**2.33**
R14	2.50	5.84	6.80	2.16	1.69	2.21	**3.53**	**2.20**
R15	4.32	2.85	5.24	7.68	3.15	7.66	**5.15**	**2.13**
R17	0.11	0.84	1.97	0.27	0.64	14.73	**3.09**	**5.74**
R19	0.92	0.04		1.15	1.75	27.42	**6.26**	**11.85**
R21	2.98	6.55	15.20	4.01	9.13	45.50	**13.90**	**16.09**
R23	3.32	4.57	0.80	9.29	12.48	17.64	**8.02**	**6.33**
R25	3.01	5.27	0.64	6.94	9.97	8.45	**5.71**	**3.47**
R27	3.20	2.74	0.55	3.47	5.50	10.40	**4.31**	**3.38**
R29	7.03		0.56	5.81	4.14	8.23	**5.15**	**2.98**
R30		11.88		6.44	6.84	6.56	**7.93**	**2.64**
R31		1.06		3.10	3.39	6.28	**3.46**	**2.15**
Average	**3.37**	**5.52**	**7.04**	**3.40**	**3.63**	**6.58**	**4.92**	
St. Dev.	**1.78**	**7.73**	**9.51**	**3.18**	**3.97**	**8.14**	**4.36**	

Table A.6. 2022 TSI-Combined data for Smith Mountain Lake sample stations

Station	MTD (mi)	TP (ppb)	CA (ppb)	SD (m)	TSI-TP	TSI-CA	TSI-SD	TSI-C
B8	8	27.6	1.6	2.9	52.0	35.0	44.8	43.9
B10	10	14.7	0.9	2.6	42.9	30.0	46.3	39.7
B12	12	58.2	2.6	2.3	62.8	39.9	48.1	50.2
B14	14	20.0	2.6	1.8	47.3	40.0	51.3	46.2
B16	16	22.2	2.0	1.4	48.8	37.3	55.4	47.2
B18	18	24.5	5.7	1.3	50.3	47.6	55.9	51.3
B20	20	28.7	9.7	1.2	52.6	52.9	57.8	54.4
B22	22	83.1	25.4	0.7	67.9	62.3	65.0	65.1
C4	4	10.5	1.7	3.1	38.1	35.8	43.6	39.2
C5	5	12.0	2.1	3.1	40.0	37.7	43.6	40.4
C6	6	12.3	2.0	2.8	40.4	37.5	45.2	41.0
CB11	11	31.7	1.9	2.5	54.0	37.0	46.6	45.8
CB16	16	23.3	2.8	1.7	49.5	40.6	52.3	47.5
CB20	20	30.5	9.6	1.4	53.4	52.8	55.0	53.7
CM1	1	11.0	1.8	3.5	38.7	36.6	41.9	39.1
CM1.2	1.2	12.7	2.1	3.5	40.8	37.8	42.1	40.3
CM5	5	14.4	1.5	2.8	42.6	34.4	45.2	40.8
CR8	8	12.0	2.2	2.7	39.9	38.5	45.6	41.4
CR9	9	13.3	2.2	2.1	41.5	38.5	49.4	43.1
CR9.2	9.2	14.5	2.6	2.1	42.7	39.9	49.7	44.1
CR13	13	21.6	5.5	2.0	48.5	47.3	49.7	48.5
CR14.2	14.2	21.5	5.9	1.6	48.4	47.9	53.7	50.0
CR16	16	21.3	5.1	1.6	48.2	46.7	53.0	49.3
CR17	17	23.3	5.4	1.6	49.5	47.2	53.4	50.0
CR19	19	28.8	3.4	1.4	52.6	42.6	55.0	50.1
CR21	21	27.4	8.0	1.3	51.9	51.0	56.3	53.1
CR21.2	21.2	29.1	9.4	1.3	52.8	52.6	56.2	53.9
CR22	22	32.4	9.4	1.4	54.3	52.6	55.4	54.1
CR24	24	64.7	17.1	0.8	64.3	58.5	62.6	61.8
CR25	25	31.6	9.4	1.2	54.0	52.6	57.8	54.8
CR26	26	43.4	7.9	1.1	58.5	50.9	58.3	55.9
G12	12	72.3	2.5	2.4	65.9	39.6	47.5	51.0
G13	13	17.4	2.3	2.6	45.4	38.6	46.1	43.4
G14	14	17.7	2.9	2.2	45.6	40.9	48.6	45.0
G15	15	18.6	2.6	2.3	46.3	39.8	47.8	44.7
G16	16	22.9	3.6	1.8	49.3	43.1	51.3	47.9
G18	18	41.8	8.0	1.3	58.0	51.0	55.9	54.9
M0	0	10.5	1.9	3.4	38.1	37.0	42.5	39.2
M1	1	28.6	1.1	3.3	52.5	31.4	42.7	42.2
M3	3	12.8	2.2	3.2	40.9	38.3	43.2	40.8

Table A.6. 2022 TSI-combined data for SML sample stations (cont.)

Station	MTD (mi)	TP (ppb)	CA (ppb)	SD (m)	TSI-TP	TSI-CA	TSI-SD	TSI-C
M5	5	11.5	1.9	3.0	39.4	36.7	44.2	40.1
R7	7	12.8	1.6	2.9	40.9	35.1	44.8	40.3
R9	9	15.8	1.8	2.0	44.0	36.2	49.7	43.3
R11	11	13.3	2.3	2.1	41.4	38.9	49.1	43.2
R13	13	18.8	5.2	2.1	46.4	46.7	49.1	47.4
R14	14	19.5	3.5	1.8	47.0	43.0	51.6	47.2
R15	15	18.9	5.2	1.7	46.6	46.7	52.3	48.5
R17	17	25.9	3.1	1.5	51.1	41.7	54.6	49.1
R19	19	30.2	6.3	1.5	53.3	48.6	54.6	52.1
R21	21	29.3	13.9	1.2	52.9	56.4	57.3	55.5
R23	23	35.2	8.0	1.4	55.5	51.0	55.4	54.0
R25	25	29.3	5.7	1.4	52.9	47.7	55.7	52.1
R27	27	69.1	4.3	1.2	65.2	44.9	57.8	56.0
R29	29	54.7	5.2	1.2	61.9	46.7	57.3	55.3
R30	30	48.7	7.9	1.1	60.2	50.9	59.1	56.7
R31	31	43.4	3.5	0.8	58.5	42.8	63.0	54.8
Average		**27.5**	**4.9**	**2.0**	**49.8**	**43.5**	**51.4**	**48.2**

Table A.7. 2022 Secchi disk data for Smith Mountain Lake sample stations

Station	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Station Avg.	Std. Dev.
	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	(m)	
B8	2.00	3.00	2.50	3.25	3.50	3.00	**2.88**	**0.54**
B10	2.00	3.00	2.50	2.50	3.00	2.50	**2.58**	**0.38**
B12	1.75	3.50	1.50	2.50	2.00	2.50	**2.29**	**0.71**
B14	2.00	2.00	2.00	1.75	1.75	1.50	**1.83**	**0.20**
B16	1.50	2.00	1.00	1.00	1.50	1.25	**1.38**	**0.38**
B18	1.75	1.75	1.00	1.00	1.25	1.25	**1.33**	**0.34**
B20	1.50	1.25	1.00	0.75	1.25	1.25	**1.17**	**0.26**
B22	0.75	0.75	0.50	0.75	0.75	0.75	**0.71**	**0.10**
C4	2.25	2.75	3.25	3.75	4.00	2.75	**3.13**	**0.67**
C5	2.25	3.00	3.25	3.50	3.75	3.00	**3.13**	**0.52**
C6	2.25	2.25	3.00	3.00	3.50	2.75	**2.79**	**0.49**
CB11	1.75	3.50	2.50	2.75	2.75	2.00	**2.54**	**0.62**
CB16	2.00	2.25	1.50	1.50	1.50	1.50	**1.71**	**0.33**
CB20	1.75	1.25	1.25	1.25	1.25	1.75	**1.42**	**0.26**
CM1	2.25	3.25	3.50	4.00	4.50	3.50	**3.50**	**0.76**
CM1.2	2.25	3.50	3.50	3.75	4.00	3.75	**3.46**	**0.62**
CM5	1.75	2.50	3.25	3.00	3.75	2.50	**2.79**	**0.70**
CR8	1.75	3.00	3.00	2.50	3.50	2.50	**2.71**	**0.60**
CR9	1.50	2.50	1.75	2.00	2.75	2.00	**2.08**	**0.47**
CR9.2	1.75		2.25	1.75	2.75	1.75	**2.05**	**0.45**
CR13	1.75	2.25	2.25	1.75	2.25	2.00	**2.04**	**0.25**
CR14.2	1.50	1.50	1.75	1.50	1.50		**1.55**	**0.11**
CR16	1.75	1.50	2.00	1.50	1.50	1.50	**1.63**	**0.21**
CR17	1.75	1.50	1.75	1.50	1.50	1.50	**1.58**	**0.13**
CR19	1.75	1.25	1.25	1.25	1.50	1.50	**1.42**	**0.20**
CR21	1.50	1.50	1.50	1.25	1.00	1.00	**1.29**	**0.25**
CR21.2	1.25	1.75	1.50		1.00	1.00	**1.30**	**0.33**
CR22	1.50	1.50	1.50	1.50	1.00	1.25	**1.38**	**0.21**
CR24	1.00	0.75	1.00	0.75	0.75	0.75	**0.83**	**0.13**
CR25	1.75	1.00	1.25	1.25	1.00	0.75	**1.17**	**0.34**
CR26	1.75	1.00	1.50	1.00	0.75	0.75	**1.13**	**0.41**
G12	1.75	3.50	2.00	2.00	2.50	2.50	**2.38**	**0.63**
G13	2.00	4.00	2.25	2.50	2.75	2.25	**2.63**	**0.72**
G14	2.00	2.25	2.00	2.25	2.50	2.25	**2.21**	**0.19**
G15	1.75	3.50	2.00	2.25	2.50	2.00	**2.33**	**0.63**
G16	1.75	2.00	1.75	2.00	2.00	1.50	**1.83**	**0.20**
G18	1.75	1.25	1.25	1.50	1.25	1.00	**1.33**	**0.26**
M0	2.50	3.50	3.25	3.50	4.50	3.00	**3.38**	**0.67**
M1	2.25	3.00	3.25	3.75	4.25	3.50	**3.33**	**0.68**

Table A.7. 2022 Secchi disk data for SML sample stations (cont.)

Station	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Station Avg.	Std. Dev.
	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	(m)	
M3	2.00	2.75	3.50	3.75	4.00	3.25	**3.21**	**0.73**
M5	2.00	3.25	3.25	3.00	3.25	3.25	**3.00**	**0.50**
R7	2.00	3.00	3.25	3.00	3.75	2.25	**2.88**	**0.65**
R9	1.50	2.00	1.75	2.25	3.00	1.75	**2.04**	**0.53**
R11	1.75	2.25	2.50	2.00	2.50	1.75	**2.13**	**0.34**
R13	1.75	3.00	2.25	1.75	2.00	2.00	**2.13**	**0.47**
R14	1.75	1.75	2.00	1.75	2.00	1.50	**1.79**	**0.19**
R15	1.75	1.50	2.00	1.75	1.75	1.50	**1.71**	**0.19**
R17	1.75	1.50	1.25	1.25	1.50	1.50	**1.46**	**0.19**
R19	1.75	1.50	1.25	1.25	1.75	1.25	**1.46**	**0.25**
R21	1.50	1.50	1.25	1.00	1.00	1.00	**1.21**	**0.25**
R23	1.50	1.25	1.75	1.50	1.00	1.25	**1.38**	**0.26**
R25	1.75	1.25	1.75	1.25		0.75	**1.35**	**0.42**
R27	1.50	1.25	1.50	1.25	0.75	0.75	**1.17**	**0.34**
R29	1.25	1.50	1.50	1.25	0.75	1.00	**1.21**	**0.29**
R30		1.25		1.00	1.00	1.00	**1.06**	**0.13**
R31		1.00		0.75	0.75	0.75	**0.81**	**0.13**
SB12	1.50	3.00	2.00	2.00	2.25	2.25	**2.17**	**0.49**
SCB 8	2.25	2.50	3.25	2.75	3.00	3.00	**2.79**	**0.37**
SCB10	2.00	2.75	2.50	3.00	3.00	2.75	**2.67**	**0.38**
SCB11	2.00	2.75	2.25	2.25	2.75	2.75	**2.46**	**0.33**
SCB11.5	2.00	2.75	2.50	2.50	2.75	2.75	**2.54**	**0.29**
SCB14	1.75	2.50	1.75	1.50	2.00	1.50	**1.83**	**0.38**
SCB16	1.75	2.25	1.50	1.25	1.75	1.50	**1.67**	**0.34**
SCM5	2.00	2.50	3.25	3.75	4.00	3.00	**3.08**	**0.75**
SCR7	1.75	2.75	3.00	3.00	4.00	2.75	**2.88**	**0.72**
SCR8	1.50	2.50	2.75	2.75	3.25	2.50	**2.54**	**0.58**
SCR10.1	1.75	2.00	2.00	2.25	2.50	2.00	**2.08**	**0.26**
SCR10.2	1.50	2.25	2.25	2.25	3.25	2.00	**2.25**	**0.57**
SCR10.3	1.75	2.00	2.00	2.25	3.25	2.00	**2.21**	**0.53**
SCR11.1	1.75	2.50	3.00	2.00	2.00	1.75	**2.17**	**0.49**
SCR11.2	1.50	2.50	2.25	2.00	2.00	1.50	**1.96**	**0.40**
SCR11.3	1.75	2.00	2.00	1.75	2.00	1.50	**1.83**	**0.20**
SCR14		1.75	1.75	1.50	2.00	1.50	**1.70**	**0.21**
SCR14.1		1.50	2.00	1.75	2.00	1.50	**1.75**	**0.25**
SCR14.2		1.75	1.50	1.75	1.50	1.25	**1.55**	**0.21**
SCR14.3		1.75	2.00	1.75	2.00	1.50	**1.80**	**0.21**
SCR15	1.75	2.00	2.25	1.75	2.00	1.75	**1.92**	**0.20**

Table A.7. 2022 Secchi disk data for SML sample stations (cont.)

Station	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Station Avg.	Std. Dev.
	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	(m)	
SCR 15.1		1.75	1.75	1.50	2.00	1.50	**1.70**	**0.21**
SCR 15.2		1.75	1.75	1.75	1.50	1.25	**1.60**	**0.22**
SCR17	1.50	1.25	1.50	1.50	1.25	1.50	**1.42**	**0.13**
SCR17.1	1.25	1.50	2.00	1.50	1.25	1.50	**1.50**	**0.27**
SCR18	2.00		1.75	1.25	1.25	1.25	**1.50**	**0.35**
SCR19.2	1.50		1.25	1.25	1.25	1.25	**1.30**	**0.11**
SCR20	1.50		1.50	1.50	1.00	1.25	**1.35**	**0.22**
Average	**1.75**	**2.14**	**2.06**	**1.99**	**2.20**	**1.84**	**2.00**	
St. Dev.	**0.30**	**0.78**	**0.72**	**0.83**	**1.05**	**0.76**	**.69**	

Figure A.3. Smith Mountain Lake depth profiling sites

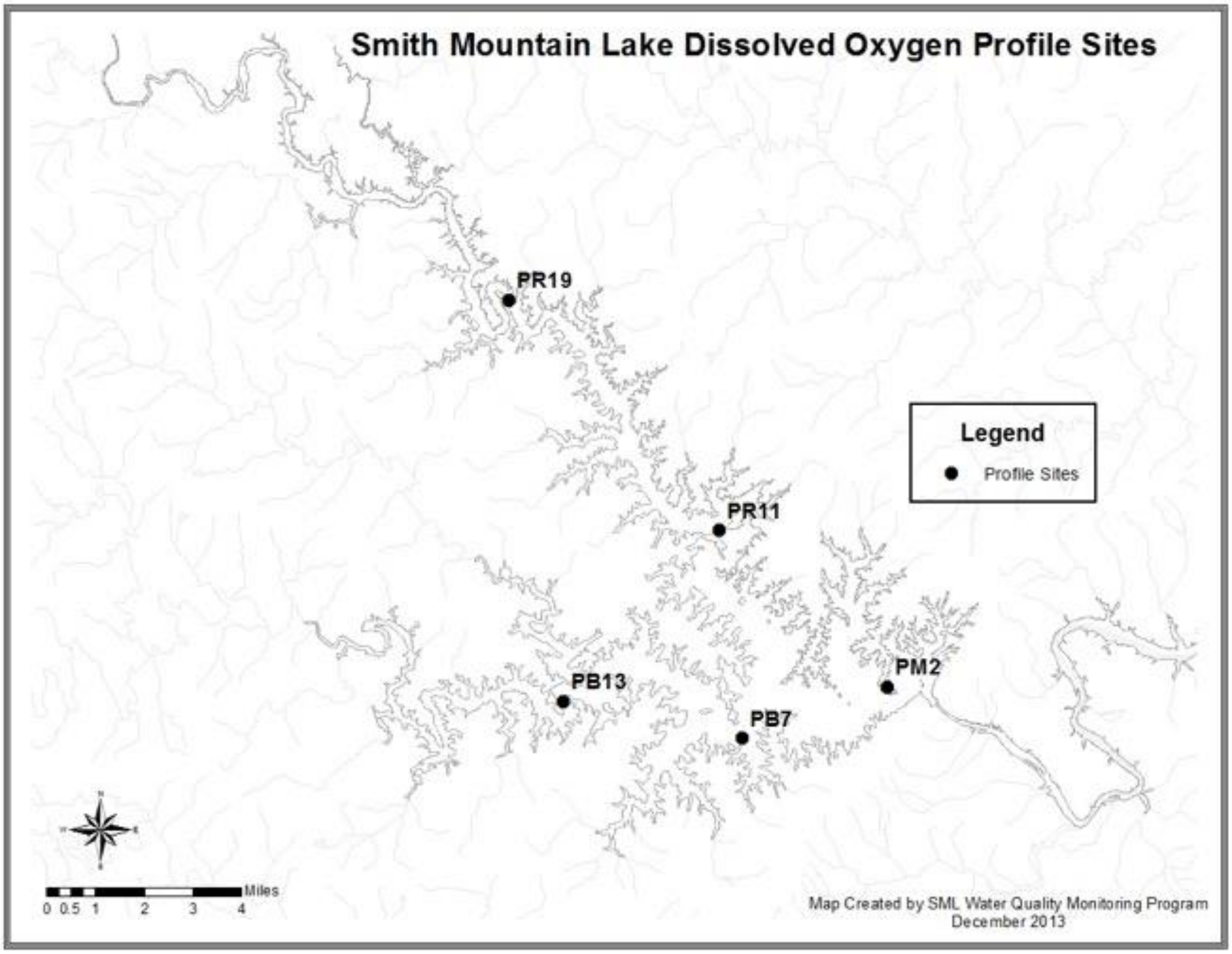

Figure A.4. Smith Mountain Lake bacterial sampling sites

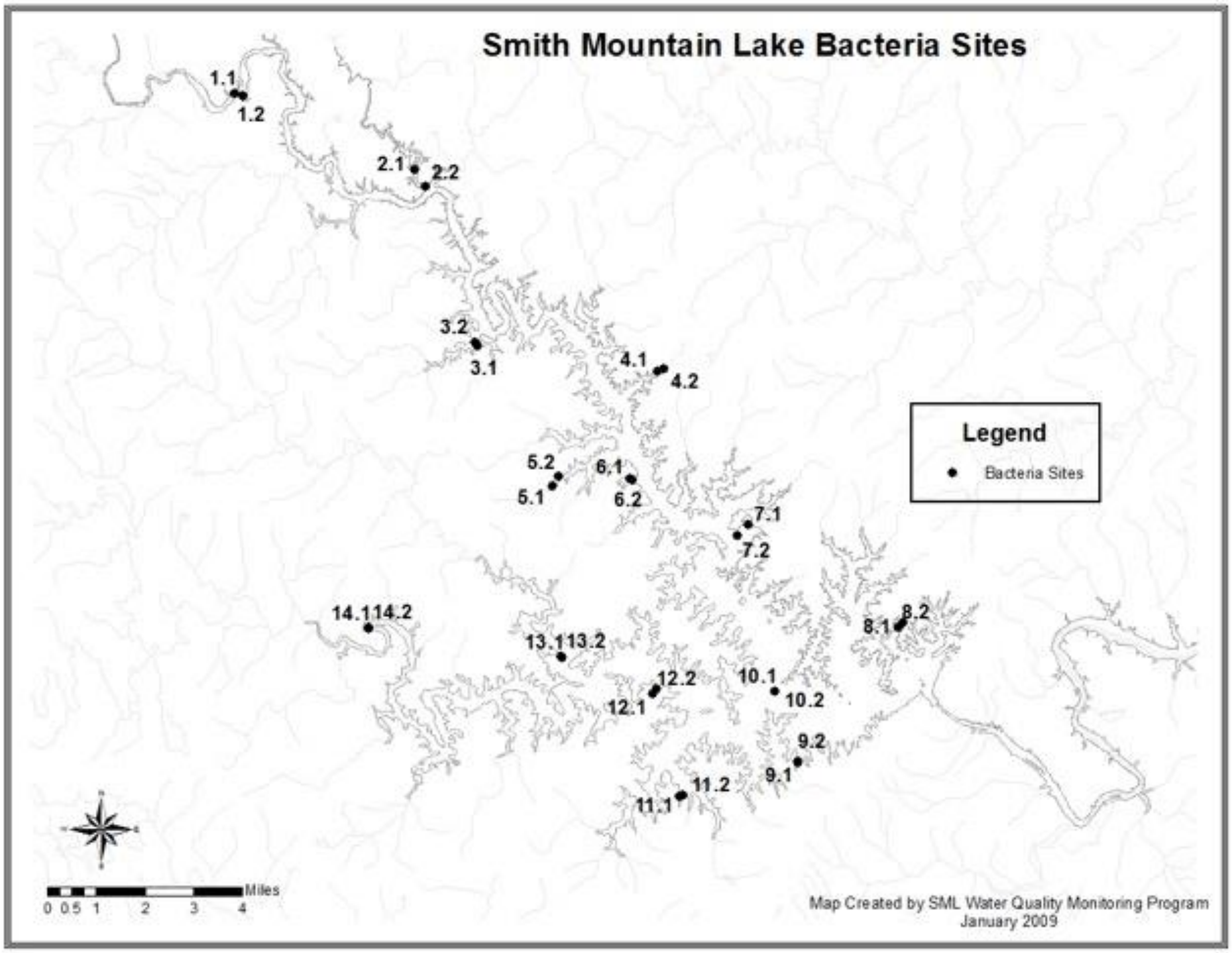

Table A.8. Smith Mountain Lake bacterial monitoring sites

Type	Site	Description
Headwater	1-1	Approx. 50' downstream of center of Hardy Ford bridge (Rt 634)
Headwater	1-2	Just behind boat slips near seawall at marina
Headwater	2-1	Mid-channel at BE5 marker
Headwater	2-2	At mouth of creek approx. 250' upstream from confluence w/ Roanoke channel
Marina	3-1	Mid-cove off paved boat launch at marina
Marina	3-2	Midway between gas docks and opposite shore across Indian Creek from marina
Marina	4-1	Mid-cove just off service dock
Marina	4-2	At beginning of long boat shed near gas dock
Marina	5-1	Mid-cove near second dock past marina
Marina	5-2	Between E dock and covered boat slips
Non- Marina	6-1	Mid-cove off the second set of Fairway Bay condo boat slips
Non- Marina	6-2	Middle of Fairway Bay cove just inside No Wake buoys
Non- Marina	7-1	Mid-cove between beach area docks and boat docks on opposite shore
Non- Marina	7-2	Mid-Roanoke channel between state park beach and marker R19
Non- Marina	8-1	First cove on left past marker R2, keep right past Azalea Point, as far into cove as possible
Non- Marina	8-2	Directly off large house known as Azalea Point
Marina	9-1	Mid-cove past marina, as far as possible
Marina	9-2	Off marina gas dock
Non- Marina	10-1	At confluence of the Blackwater and Roanoke channels, 1/3 way from marker R8
Non- Marina	10-2	At confluence of the Blackwater and Roanoke channels, 1/3 way from marker B1
Non- Marina	11-1	Mid-cove past Palmer’s Marina at road that enters water on left
Non- Marina	11-2	Middle of trailer-dense covelet past marina on right as you enter cove
Marina	12-1	Mid-cove as far as possible past Pelican Point Marina
Marina	12-2	At boat slips closest to marina clubhouse
Marina	13-1	At Gills Creek Marina gas dock
Marina	13-2	Approx. 15' off marker G2 (towards channel)
Headwater	14-1	Mid-channel at marker B49
Headwater	14-2	Mid-channel approx. 150' downstream from marker B49

Table A.9 2022 *E. coli* data for Smith Mountain Lake sample stations

Station	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Station Avg.	Std. Dev.
	MPN	MPN	MPN	MPN	MPN	MPN	MPN	
1-1	58.1	5.2	8.6	16.0	15.8	11.9	**19.3**	**19.5**
1-2	73.8	204.6	14.5	8.1	75.9	0.0	**62.8**	**77.0**
2-1	20.9	1.0	4.1	0.0	26.2	7.5	**10.0**	**11.0**
2-2	60.2	1.0	1.0	0.0	60.2	1.0	**20.6**	**30.7**
3-1	34.1	3.0	0.0	2.0	15.8	10.8	**11.0**	**12.8**
3-2	41.4	1.0	0.0	1.0	9.6	3.0	**9.3**	**16.1**
4-1	88.8	23.1	20.1	2.0	18.5	41.4	**32.3**	**30.4**
4-2	63.1	76.7	6.3	6.3	16.0	22.6	**31.8**	**30.4**
5-1	727.0	45.9	40.8	30.9	328.2	139.0	**218.6**	**273.3**
5-2	1413.6	41.1	12.2	2.0	218.7	81.6	**294.9**	**553.7**
6-1	140.1	2.0	0.0	2.0	13.4	4.1	**26.9**	**55.6**
6-2	31.7	4.1	0.0	1.0	17.3	5.2	**9.9**	**12.4**
7-1	3.0	0.0	0.0	0.0	1.0	3.1	**1.2**	**1.5**
7-2	8.5	0.0	0.0	0.0	3.1	0.0	**1.9**	**3.4**
8-1	1046.2	4.1	0.0	0.0	6.3	14.6	**178.5**	**425.1**
8-2	42.6	0.0	0.0	0.0	2.0	8.6	**8.9**	**16.9**
9-1	93.3	79.4	1.0	0.0	8.6	70.3	**42.1**	**43.3**
9-2	67.0	1.0	0.0	1.0	17.3	32.3	**19.8**	**26.4**
10-1	5.2	1.0	0.0	0.0	1.0	1.0	**1.4**	**1.9**
10-2	1.0	0.0	0.0	0.0	1.0	1.0	**0.5**	**0.5**
11-1	214.3	10.8	13.1	24.3	13.5	83.6	**59.9**	**80.5**
11-2	238.2	12.0	12.1	7.4	18.5	81.3	**61.6**	**90.9**
12-1	41.0	5.1	3.0	5.2	24.6	24.1	**17.2**	**15.2**
12-2	30.9	0.0	1.0	7.4	9.8	1.0	**8.4**	**11.7**
13-1	22.6	1.0	0.0	0.0	8.4	17.3	**8.2**	**9.8**
13-2	7.5	0.0	1.0	2.0	6.3	16.9	**5.6**	**6.3**
14-1	2500.0	13.2	5.1	2.0	44.1	290.0	**475.7**	**997.8**
14-2	2500.0	18.5	2.0	5.2	37.3	360.9	**487.3**	**995.7**
Average	**341.9**	**19.8**	**5.2**	**4.5**	**36.4**	**47.6**	**75.9**	
St. Dev.	**694.3**	**42.3**	**8.9**	**7.5**	**70.8**	**86.2**	**134.3**	