Smith Mountain Lake
Water Quality Monitoring Program
2023 Report

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1. EXECUTIVE SUMMARY

The 2023 monitoring season began in May with the annual training session. 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, historically.

In 2023, average total phosphorus was slightly increased, while the chlorophyll-*a* concentrations were notably increased, while the average Secchi depth remained the same as 2022.

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

Sufficient depth profile data have now been collected to enable meaningful comparison between rates of change and absolute parameter values over the course of the summer. 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 2023 were much lower than the levels in 2022. In 2023, the overall mean *E. coli* count was 29.1 MPN, which is 61.7 percent lower than the 2022 overall mean *E. coli* count (75.9 MPN).

The comparison of marinas, non-marinas, and headwaters sites shows differences in *E. coli* values consistent with data collected over the last ten years. This year we looked at bacterial numbers in the Roanoke and Blackwater channels as well as at headwaters, flow, and static sites. These new designations will continue to be analyzed to determine possible patterns or nuances that might be gleaned from the data.

1.4 Algae in Smith Mountain Lake

The 2023 sampling season provided some of the highest number of reports for harmful algal blooms in the 36-year history of the Smith Mountain Lake Water Quality Project. This is a testament to the residents and volunteers that keep a watchful eye for unusual and atypical conditions on the lake. The phytoplankton diversity of the lake remains high, but the trend of seeing increased numbers of cyanobacteria (i.e., *Aphanizomenon*) associated with harmful algal blooms is a concern. Future research will need to analyze correlations between lake characteristics (e.g., water temperature and phosphorous levels) as well as changes in land usage and other practices (e.g., fertilizer application) around the lake to see what might be leading to the spike of HABs that were noticed this season.

2. INTRODUCTION

The Smith Mountain Lake Water Quality Monitoring Program (SMLWQMP), now in its thirty-seventh year, is a water quality program designed to monitor the water quality and the trophic status of Smith Mountain Lake, a large (20,000+ 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 2023 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 2023, 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 21st through 27th and the first sample bottles and filters were picked up on Tuesday, May 30th. The last week of sample collection was July 30th to August 5th, and the samples and filters were picked up on August 8th (Table 2.1).

Table 2.1. Description of Sample Periods for the 2023 Sampling Season

Sample Period 1	Start Date	Purpose	Monitor's Parameters	Ferrum's Parameters
Week 1	5/21/2023	Trophic Levels & Bacteria	TP, SD, CA*	*E.coli* & Horz. Algal Tow
Week 2	5/28/2023	Depth Profile	N/A	Temp, DO, pH, Vert Algal Tow, Trib TP
Sample Period 2				
Week 3	6/4/2023	Trophic Levels & Bacteria	TP, SD, CA*	*E.coli* & Horz. Algal Tow
Week 4	6/11/2023	Depth Profile	N/A	Temp, DO, pH, Vert Algal Tow, Trib TP
Sample Period 3				
Week 5	6/18/2023	Trophic Levels & Bacteria	TP, SD, CA*	*E.coli* & Horz. Algal Tow
Week 6	6/25/2023	Depth Profile	N/A	Temp, DO, pH, Vert Algal Tow, Trib TP
Sample Period 4				
Week 7	7/2/2023	Trophic Levels & Bacteria	TP, SD, CA*	*E.coli* & Horz. Algal Tow
Week 8	7/9/2023	Depth Profile	N/A	Temp, DO, pH, Vert Algal Tow, Trib TP
Sample Period 5				
Week 9	7/16/2023	Trophic Levels & Bacteria	TP, SD, CA*	*E.coli* & Horz. Algal Tow
Week 10	7/23/2023	Depth Profile	N/A	Temp, DO, pH, Vert Algal Tow, Trib TP
Sample Period 6				
Week 11	7/30/2023	Trophic Levels & Bacteria	TP, SD, CA*	*E.coli* & Horz. Algal Tow
Week 12	8/6/2023	Depth Profile	N/A	Temp, DO, pH, Vert Algal Tow, Trib TP

* TP - Total Phosphorous; SD - Secchi Depth; CA - Chlorophyll a

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 Section 3. Methods) 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, T0a, is several miles from the lake and 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 A.2 and A.2.a.

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 2023, 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, Chekka Lash, Carol Love, and Bob Pohlad, along with Tom Hardy, the SMLA Volunteer Monitoring Coordinator, carried out the 2023 training session in May. They were assisted by student technicians Riley Hines Joe Presinzano, Andrew Porter, and Rylee Smith. 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 newsletters in addition to advice and tips on sample collection. Three newsletters were published in 2023. 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

[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.

of the SMLA volunteers and present the preliminary report of results in the final newsletter was held this year.

Significant financial support for the program in 2023 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-six 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 most are available electronically in the Ferrum archives.

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 22 tributary stations on their rounds to pick up lake water samples. 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. The non-marina sites include: Beaverdam Creek (Site 2), a tributary of the Roanoke River; Fairway Bay (Site 6), which is surrounded by homes and multi-family residences and is on the Roanoke channel; Smith Mountain Lake State Park (Site 7), which is sampled where it intersects the main channel; Forest Cove (Site 8), 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; 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; Palmer's Trailer Park Cove (Site 11), 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 B49 (Site 14), located far upstream on the Blackwater River not far from the non-navigable portion of the river.

The marina sites include: Bay Roc Marina (Site 1), which is located on the Roanoke River at the "beginning of the lake"; 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; Crystal Shores Marina (Site 4), which is in a cove off the Roanoke channel in Bedford County and is a storage place for many houseboats; Bayside Marina and Yacht Club (Site 5), which is up Becky's Creek, a tributary of the Roanoke channel in Franklin County; 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; Pelican Point Marina (Site 12), which is on the Blackwater channel in Franklin County and is a storage place for many large sailboats; Gills Creek Marina (Site 13), which is on the channel of Gills Creek, a major tributary of the Blackwater River.

Beginning this year, a new designation of headwater, flow and static has been added to the analysis. There are two 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). The two headwaters sites reflect the allochthonous inputs to Smith Mountain Lake: Bay Roc Marina (Site 1) and B49 (Site 14). "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 remaining sites are all autochthonous. These sites are further designated as either flow or static. Sites which are located closer to the main body of the lake and are more influenced by channel currents are classified as flow sites. Sites which are located in coves and are further from the main flow of the channel currents are classified as static. Beaverdam Creek (Site 2), Indian Point (Site 3), SML State Park (Site 7), the Confluence (Site 10), and Gills Creek Marina (Site 13) are the flow sites where water is moving and relatively less sedimentation is occurring. Crystal Shores Marina (Site 4), Bayside Marina (Site 5), Fairway Bay (Site 6), Forest Cove (Site 8), The Dock at SML (Site 9), Palmer's Park (Site 11) and Pelican Point (Site 12) are the static sites where water and sediments are more likely to settle. Finally, this year an analysis was done relative to which of the three channels the sites are located: Roanoke channel, Blackwater channel or main basin (at or below the confluence of the two channels). It is hypothesized that *E. coli* values will be lower at sites with flowing water than at sites with static water due to the *E. coli* being flushed out of the flowing sites. These new classifications with marina type, flow type and river are shown in Table 3.1.

Table 3.1. New classification system for *E-coli* analysis

Site Number	Name	Old Type	New Marina Type	New Flow Type	Channel
1	Bay Roc	Headwater	Marina	Headwater	Roanoke
2	Beaverdam Creek	Headwater	Non-marina	Flow	Roanoke
3	Indian Point	Marina	Marina	Flow	Roanoke
4	Crystal Shores Marina	Marina	Marina	Static	Roanoke
5	Bayside Marina	Marina	Marina	Static	Roanoke
6	Fairway Bay	Non-marina	Non-marina	Static	Roanoke
7	SML State Park	Non-marina	Non-marina	Flow	Roanoke
8	Forest Cove	Non-marina	Non-marina	Static	Main basin
9	SML Dock	Marina	Marina	Static	Main basin
10	Confluence	Non-marina	Non-marina	Flow	Main basin
11	Palmer's Park	Non-marina	Non-marina	Static	Blackwater
12	Pelican Point	Marina	Marina	Static	Blackwater
13	Gills Creek Marina	Marina	Marina	Flow	Blackwater
14	B 49	Headwater	Non-marina	Headwaters	Blackwater

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.

Chlorophyll-*a* is determined using the Flourometric Method (Method 10200H). Water samples are passed through glass fiber filters that retain algal cells. The chlorophyll-*a* is extracted in a buffered acetone solution and the chlorophyll-*a* concentration is measured on a Turner Trilogy™ fluorometer equipped with chlorophyll-*a* non-acidification module.

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.

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)
2023	**29.0**	**56.7**	**11.1**	**2.0**
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
10 Year Average	***30.4***	***69.8***	***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 2023 (29.0 ppb) was higher than the 2022 average of 27.5 ppb. This value is the fourth lowest lake TP seen in the past ten years. The average TP concentration for the tributaries in 2023 (56.7 ppb) was lower than the 2022 average of 66.1 ppb. This value is the lowest in the past ten years. Chlorophyll-*a* concentration increased in 2023 to 11.1 ppb, higher than the 2022 concentration of 4.9 ppb and the fifth highest level in the last ten years. Average Secchi depth in 2023 (2.0 m) was the same average as in 2022.

Figure 4.1 shows the comparison of the six sampling periods with the average value of each trophic status parameter monitored in 2023. The maps in Figure 4.2 show the spatial variations of the average values of these parameters at each sampling location in 2023.

The average TP concentration for lake sampling sites over the sampling periods was 29.0 ppb. The highest average lake TP concentration was observed in sample period 1 (week two, 33.3 ppb) and the lowest average TP concentration was observed in sample period 6 (week twelve, 20.7 ppb). The average TP concentration for tributary sampling sites over the six sampling periods was 56.7 ppb. The highest average tributary concentration was observed in sample period 1 (week two, 81.2 ppb) and the lowest average concentration was observed in sampling period 6 (week twelve, 35.8 ppb). The complete results for TP concentration for the 2023 sampling season are included in the Appendix of this report (Tables A.3 and A.4).

The average chlorophyll-*a* concentration for lake sampling sites over all six sampling periods was 11.1 ppb. The highest average lake CA concentrations were observed in sampling period 3 (week six, 13.1 ppb) and the lowest average CA concentration was observed in sampling period 1 (week two, 9.8 ppb). The results for chlorophyll-*a* concentration for the 2023 sampling season are included in the Appendix of this report (Table A.5).

The average Secchi depth over all six sampling periods was 2.0 m. The shallowest average Secchi depth was observed in sample period 1 (week two, 1.8 m) and the deepest average Secchi depth was observed in sample period 2 (week four, 2.0 m) and sample period 4 (week eight, 2.0 m). The complete results for Secchi depth for the 2023 sampling season are included in the Appendix of this report (Table A.7).

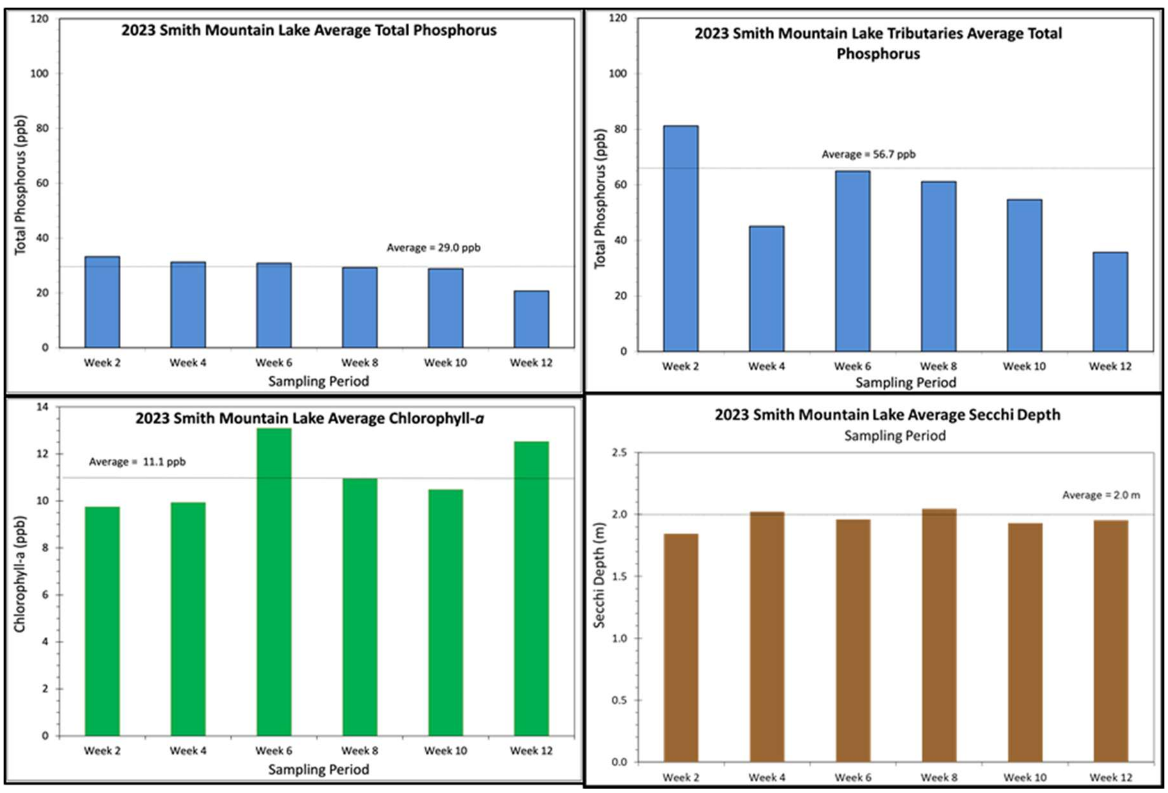
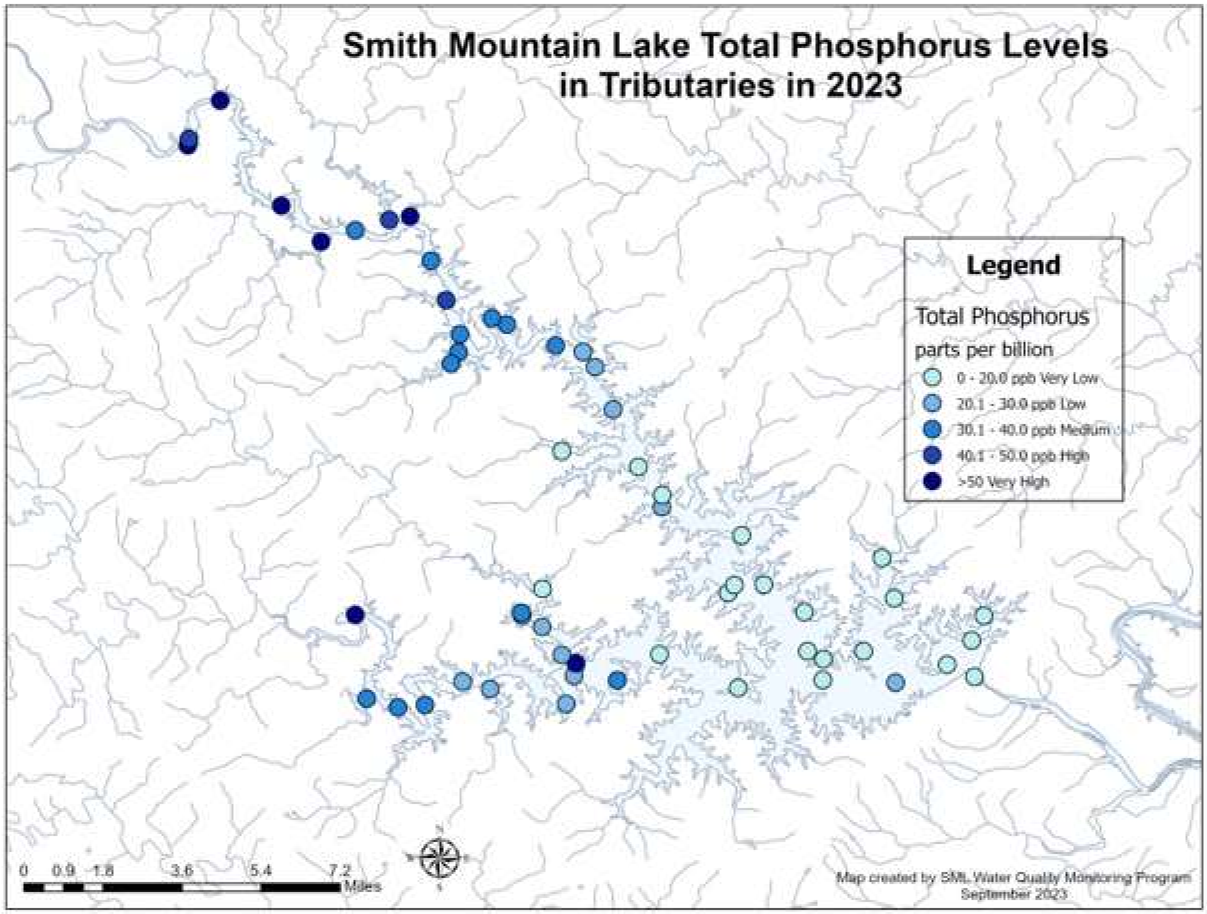
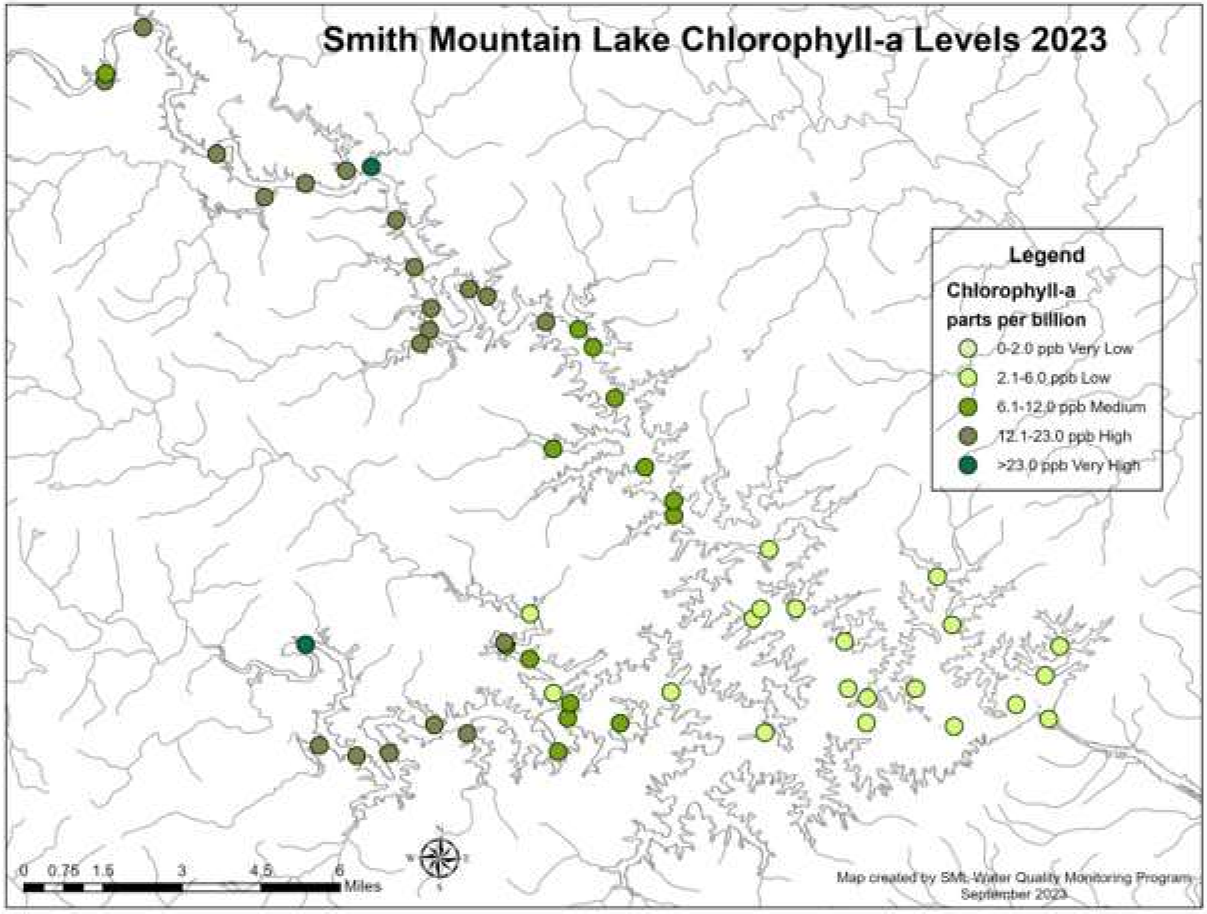


Figure 4.1. Trophic status parameters (total phosphorus, chlorophyll-*a*, and Secchi depth) for Smith Mountain Lake for each sampling period in 2023


Smith Mountain Lake Total Phosphorus Levels in Tributaries in 2023
Legend
Total Phosphorus
parts per billion
0 - 20.0 ppb Very Low
20.1 - 30.0 ppb Low
30.1 - 40.0 ppb Medium
40.1 - 50.0 ppb High
>50 Very High
0 0.9 1.8 3.6 5.4 7.2 Miles
Map created by SML Water Quality Monitoring Program
September 2023


Smith Mountain Lake Chlorophyll-a Levels 2023
Legend
Chlorophyll-a
parts per billion
0-2.0 ppb Very Low
2.1-6.0 ppb Low
6.1-12.0 ppb Medium
12.1-23.0 ppb High
>23.0 ppb Very High
0 0.75 1.5 3 4.5 6
Miles
Map created by SML Water Quality Monitoring Program
September 2023

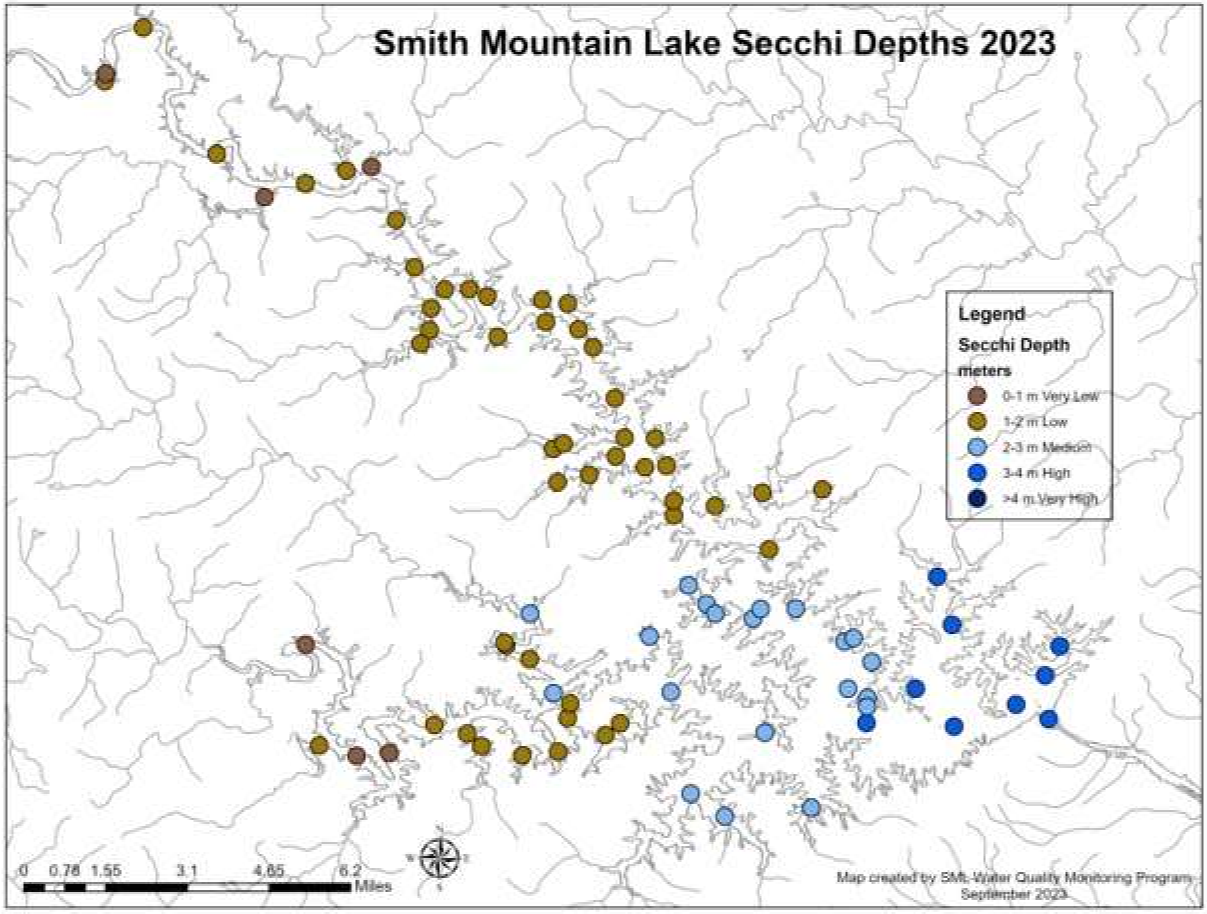


Figure 4.2. Maps showing variation in trophic status parameters for 2023 (top, total phosphorous; middle, chlorophyll-a; bottom, Secchi depth).

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)	2023	2022	2021	2020	2019	2018	2017	2016	2015	2014	*AVG*
Average Lake Total Phosphorus	**29.0**	27.5	31.2	34.7	41.2	30.7	30.6	29.1	22.7	26.9	***30.4***
Average Tributary Total Phosphorus	**56.7**	66.1	65.3	59.8	70.5	68.3	58.7	73.2	84.9	94.2	***69.8***
Tributary Sites below Dam											
T9 Roanoke River	**18.7**	14.3	24.5	22.0	30.8	17.7	16.4	16.3	13.4	9.8	***18.4***
T10 Pigg River (before confluence)	**60.1**	58.3	53.1	74.4	66.5	63.1	59.0	61.0	83.5	68.2	***64.7***
T11 Roanoke River (after confluence with Pigg River)	**38.6**	21.2	35.0	44.8	49.8	22.0	37.5	50.9	41.8	27.8	***36.9***

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 an increase in the average TP concentration in the three below-dam sites from 2022 (31.3 ppb) to 2023 (39.1 ppb).

4.4 Discussion

During the 2023 sampling season, water samples were generally found to have higher total phosphorous and chlorophyll-a levels, along with lower Secchi depth levels in the tributaries and locations farther from the dam (Figure 4.2). Also, the average total phosphorous was found to be higher in the tributaries than for the whole lake (Figure 4.1), with the Pigg River (T10) being one of the greatest contributors to the total phosphorous readings in the lake.

Comparing the results between 2023 and 2022, the average total phosphorous increased slightly in 2023 from 2022; however; the contributions from the tributaries dropped between 2023 and 2022 (Table 1). There can be a number of reasons for this change, one of the most likely is rainfall differences contributing to runoff. The largest difference when comparing the 2023 season to both the 2022 and 2021 seasons is the marked increase in chlorophyll-a levels. This increase in chlorophyll-a is most likely attributed the increased concentration of algae, specifically cyanobacteria, during the middle of the sampling season (see Section 8). Despite the higher chlorophyll-a concentrations in 2023 the levels are still not as high as levels seen from 2017-2020 (Table 4.1). The average Secchi depths between 2023 and 2022 remained the same.

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, historically. In 2023, average total phosphorus were slightly increased, while the chlorophyll-*a* concentrations were notably increased, while the average Secchi depth remained the same.

5. WATER QUALITY TRENDS BY ZONE

5.1 *Introduction*

After monitoring water quality in Smith Mountain Lake for over thirty-six 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):

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

The lake zones have been delineated as follows:

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

5.3 *Results*

The average annual value for the three trophic parameters and TSI-C are displayed by zone in Figure 5.1. 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 higher water quality closer to the dam (Figure 5.1). Settling is the likely mechanism that leads to the improved water quality moving from the upper zones towards the dam. The 2023 TSI-combined data for each sampling station for the 2023 season can be found in Table A.6.

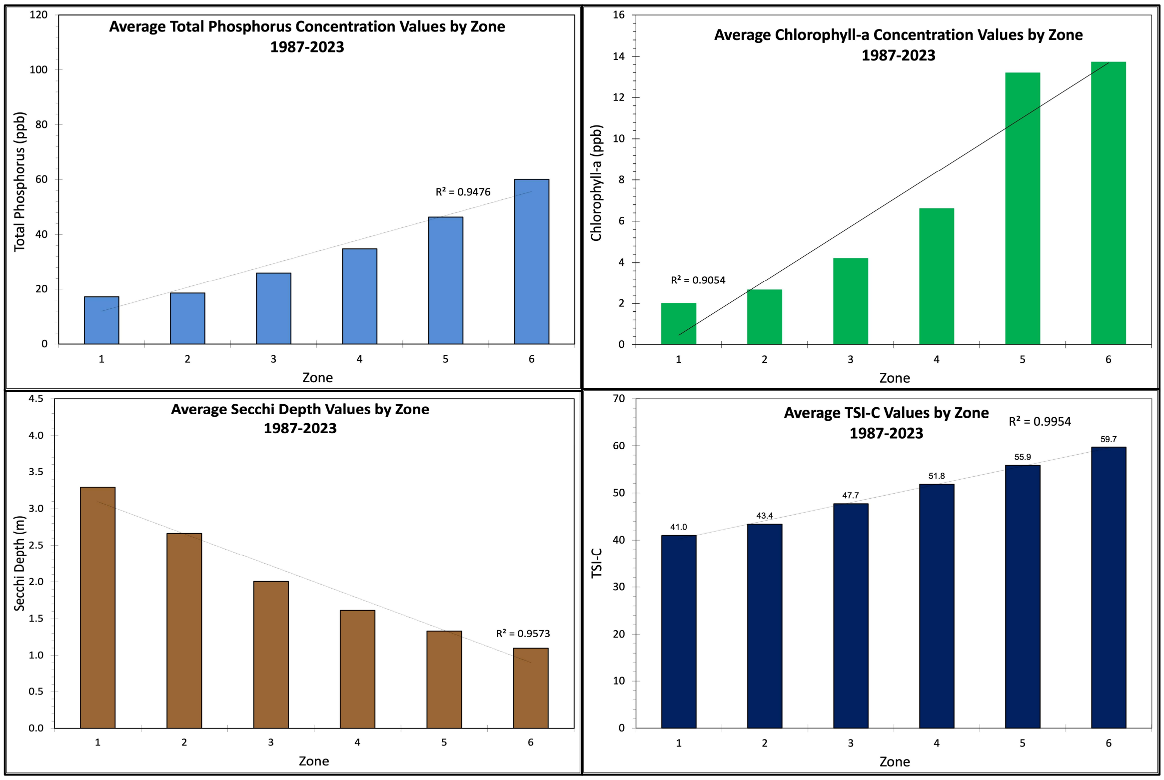


Figure 5.1. Average parameter value by zone for 1987-2023 Carlson's Trophic State Index and its Components

5.4 Discussion

The combined trophic state index, averaged by zone from 1987 to 2023, is displayed in Figure 5.1. The value of the coefficient of determination (R^2 = 0.99), based on thousands of individual measurements, shows a strong relationship between average TSI-C and the zone from which the samples were collected.

In Figure 5.2, the combined trophic state index has been plotted as a function of its distance from the dam. Figure 5.3 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 = 0.85).

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 (64.6) was at B22 this year, while the lowest TSI-C value (40.1) was at M0.

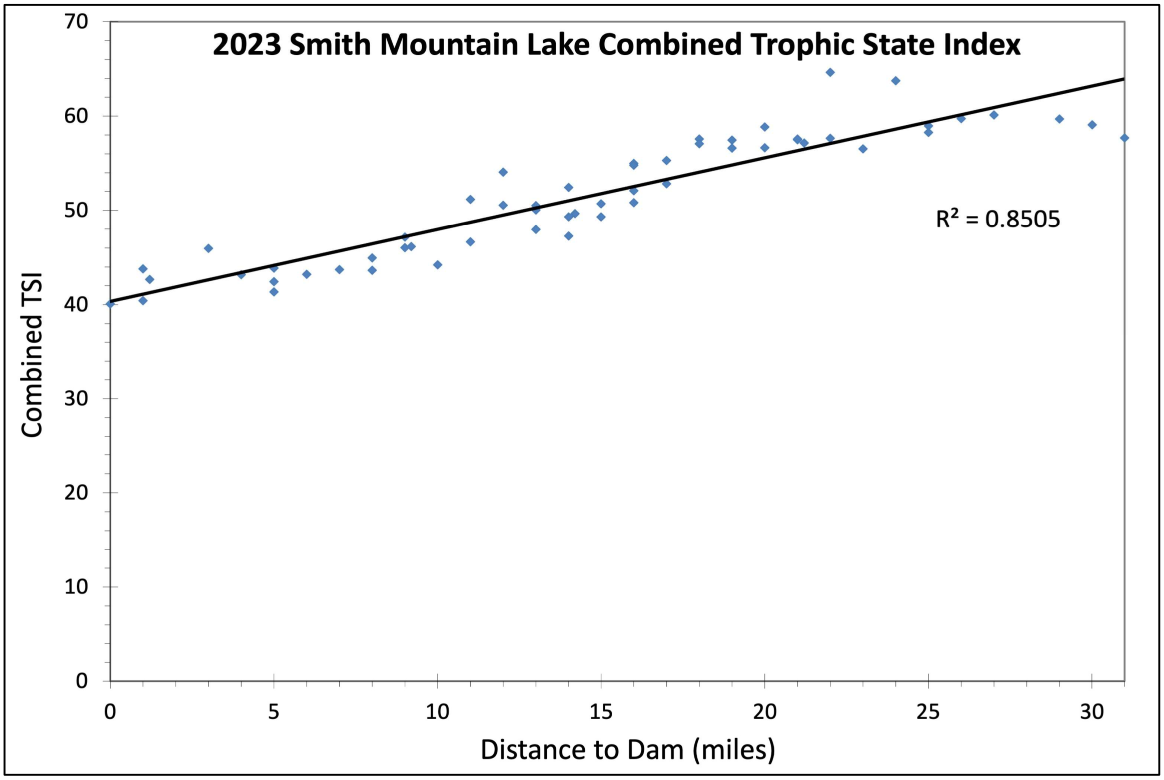


Figure 5.2. Combined Trophic State Index as a function of distance from dam

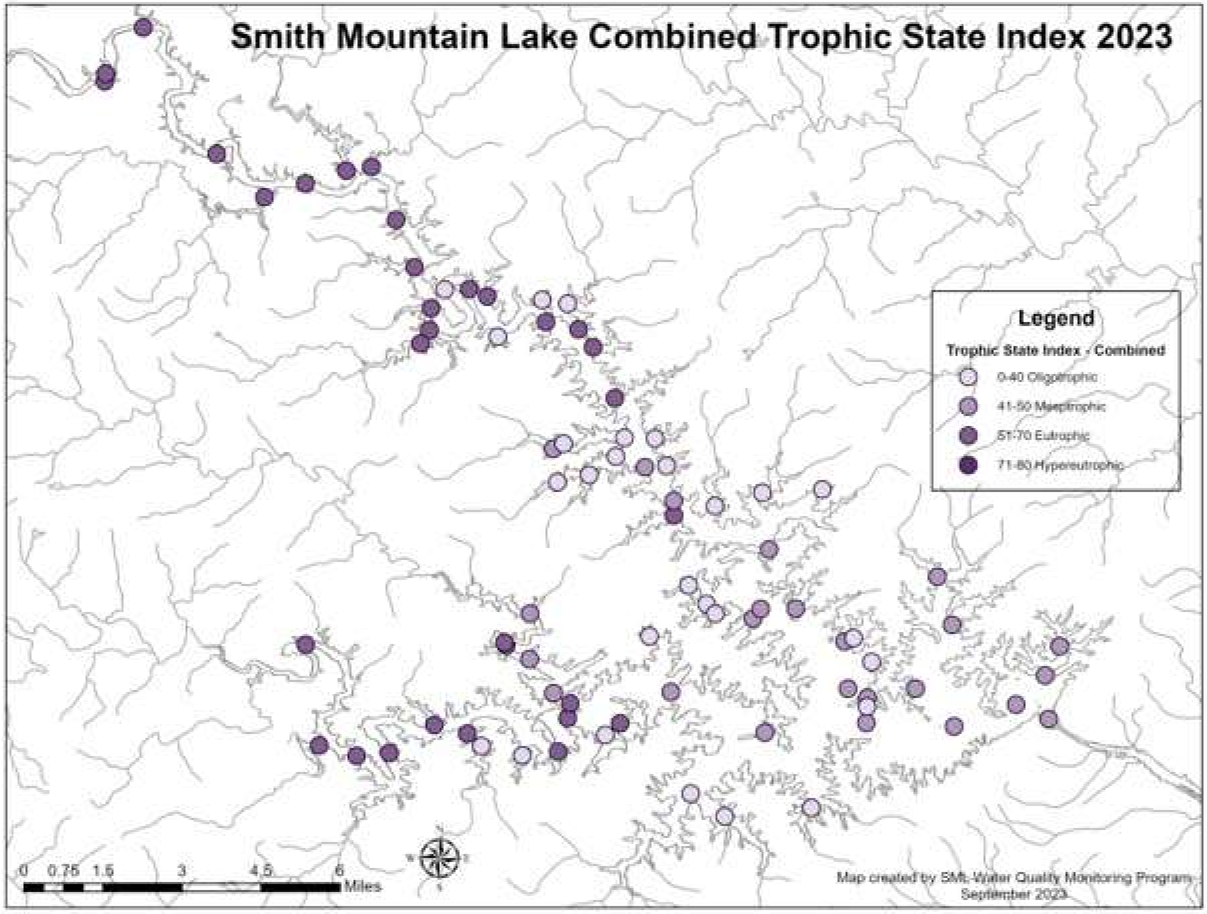


Figure 5.3. Map showing the Trophic State Index Combined results throughout the lake

For Smith Mountain Lake in 2023, the average TSI-TP (50.9), TSI-CA (51.9), and TSI-SD (51.8) are slightly higher than 2022 values. The 2023 average combined TSI (TSI-C = 51.5) was slightly higher than in 2022 (TSI-C = 48.2). The lake is in the early stages of eutrophic conditions. Additionally, since the 2023 TSI-TP, TSI-CA, and TSI-SD were again fairly similar, it indicates agreement between the three parameters.

The annual average TSIs from 2014–2023 are shown in Table 5.3. The average combined Trophic State Index had shown a general increasing trend since 2014 before declining in 2020, but has increased in 2023.

Table 5.3. Combined Trophic State Index for Smith Mountain Lake, 2013-2023

Year	Average Combined TSI	TSI Range	R^2 (TSI vs. MTD)
2023	51.5	40.1 – 64.6	0.85
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

For the period of record (1987-2023), 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 5.2 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.

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 2023: May 30, June 13, June 27, July 11, July 25, and August 8. 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 in the Appendix: temperature (Figure A.5), DO (Figure A.6), pH (Figure A.7), and conductivity (Figure A.8). The depth profile for the current sample year and the ten-year average 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 2023 average depths per site calculated averages for each of the five sites only to the smallest depth each site reached during the six sampling dates, not to the maximum.

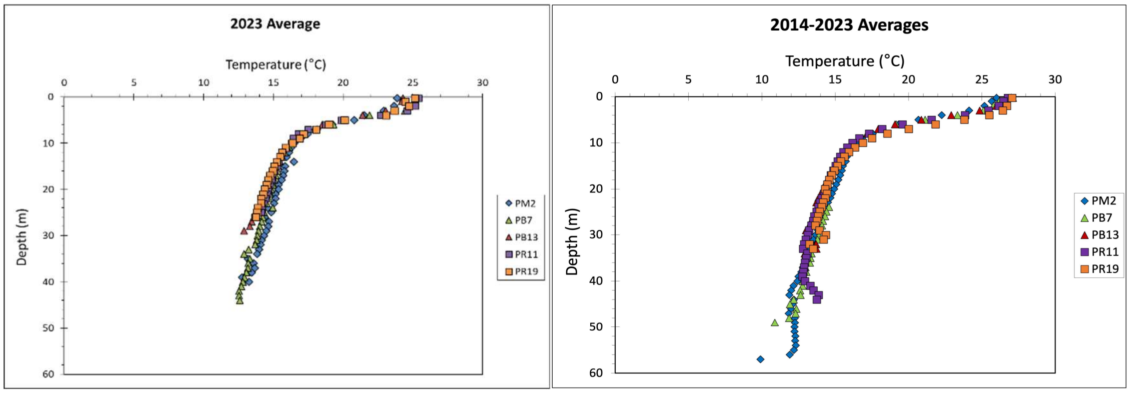


Figure 6.1. Average temperature depth profiles for 2023 and the 10-year average depth profile from 2014-2023 sampled in Smith Mountain Lake.

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 as expected. A stable, well-defined thermal stratification during the summer is an important characteristic of Smith Mountain Lake. The 2023 temperature profile is consistent with the 10-year average temperature profile.

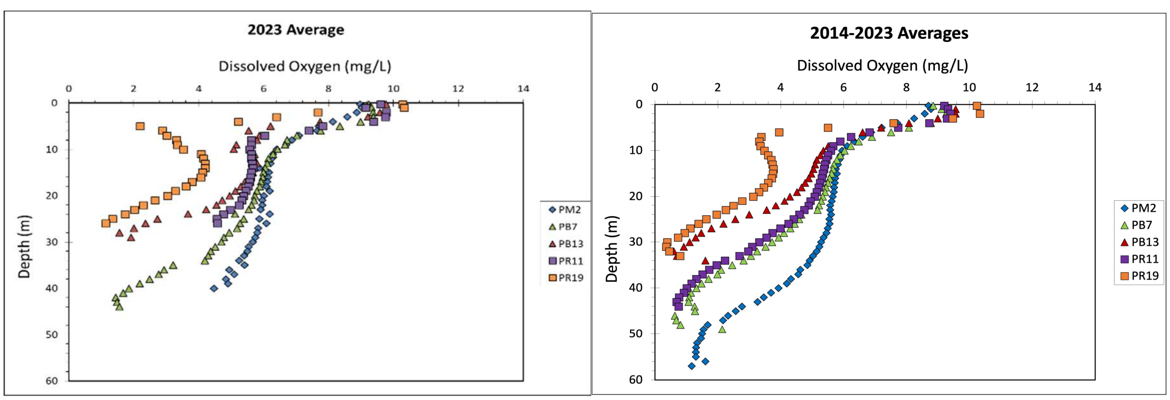


Figure 6.2 Average dissolved oxygen depth profiles for 2023 and the 10-year average depth profile from 2014-2023 sampled in Smith Mountain Lake.

As usual, dissolved oxygen concentrations below the thermocline decreased steadily over the course of the sampling season. Above the thermocline, most sites were consistently supersaturated in DO, due to algal photosynthesis. Increased organic matter produced through these blooms settle on the benthos and bacterial decomposition decreases oxygen. Bottom waters were anoxic (depleted of DO) at all stations by the end of July. The DO profiles at PM2 show a classic hypolimnetic DO deficit that increases through the summer. 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.

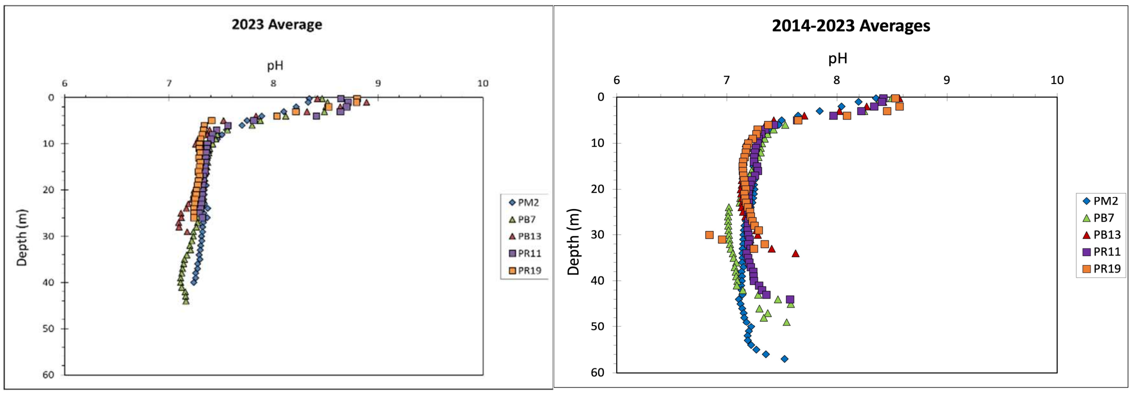


Figure 6.3 Average pH depth profiles for 2023 and the 10-year average depth profile from 2014-2023 sampled in Smith Mountain Lake.

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 the decomposition of settling organic matter releases carbon dioxide, decreasing the pH below the thermocline. The pH depth profiles were very typical, with a consistent pH of 7-7.5 in the hypolimnion. The pH in the productive epilimnion for the two stations in the upper channels (PR19 and PB13) for the 2023 average were higher than the 10-year average.

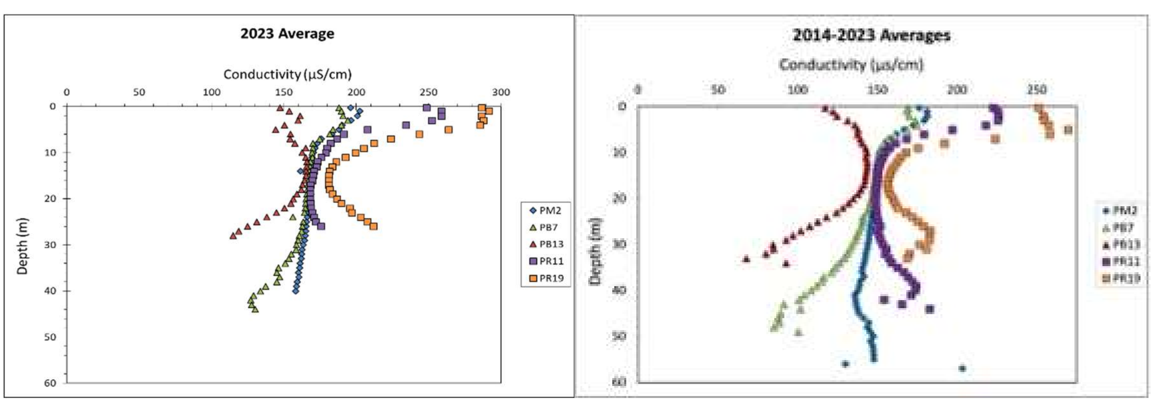


Figure 6.4 Average conductivity depth profiles for 2023 and the 10-year average depth profile from 2014-2023 sampled in Smith Mountain Lake.

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". The conductivity of the upper Roanoke channel (PR 19) for 2023 average was higher than the 10-year average.

6.4 Discussion

In 2023, the variation of temperature with depth is very consistent across profile stations and the DO and conductivity profiles differed across stations as expected. 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. 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 in Figure 6.5 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.

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. Increased carbon dioxide due to climate change is expected to reduce the acidity of the lake, but increased productivity in the summer increases the pH in the epilimnion. Algal blooms occurred in the upper Blackwater Channel (PB13) of the lake in mid-June and the profile data for Week 4 showed increased temperature, increased pH and increased DO. The pH values at PB13 Week 4 were the highest values (>9) observed for all of the sites during the 2023 sampling season. The higher pH is due to the productivity of the algal bloom and a subsequent crash of the algal population correlates with the decrease of pH in Week 6.

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 23, June 6, June 20, July 5, July 18, and August 1, 2023. The sites are described in Section 3 of this report and are listed and shown in Table A.8 and Figure A.4 in the Appendix.

7.3 *E. coli Results and Discussion*

The mean *E. coli* most probable number (MPN) in the population for the six sample dates are shown in Figure 7.1. In 2023, the overall mean *E. coli* count was 29.1 MPN, which is 61.7 percent lower than the 2022 overall mean *E. coli* count (75.9 MPN). None of the means of *E. coli* populations of the fourteen sample sites averaged over the six sample periods for 2023 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 only one (Site 5) exceeded the Virginia Department of Environmental Quality (DEQ) standard of 126 CFU/100mL for greater than one sample geometric mean. Additionally, four of 168 total samples exceeded the VDH standard for recreational waters and a total of seven samples exceeded the DEQ standard.

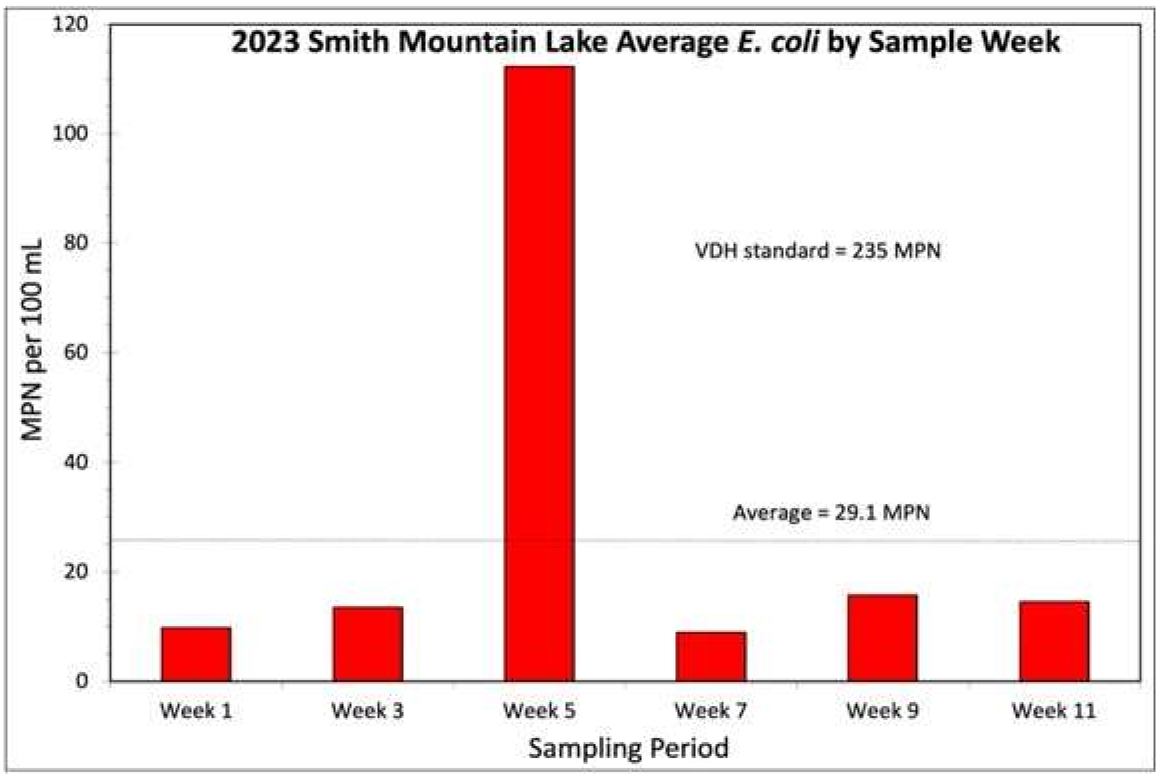


Figure 7.1. ***E. coli* versus week sampled on Smith Mountain Lake in 2023 (Each sample date included 14 sites with 2 stations per site, n = 28)**

This year the *E. coli* population means were relatively stable over time (Figure 7.1), with the exception of week five (June 20), which exhibited the highest mean (112.2 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 (8.9 MPN) occurred in sampling period 4 (week seven, July 5), and all other weeks had averages of 15.7 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 2023 (38.1 MPN) are 88.6 percent higher than the mean *E. coli* counts for non-marinas (20.2 MPN) as shown in Figure 7.2. As mentioned in Section 3. Methods, Bay Roc is now included in both the marina and headwater classifications. Beaverdam Creek and B49 are now classified as non-marinas with Beaverdam Creek a flow site and B49 a headwater site.

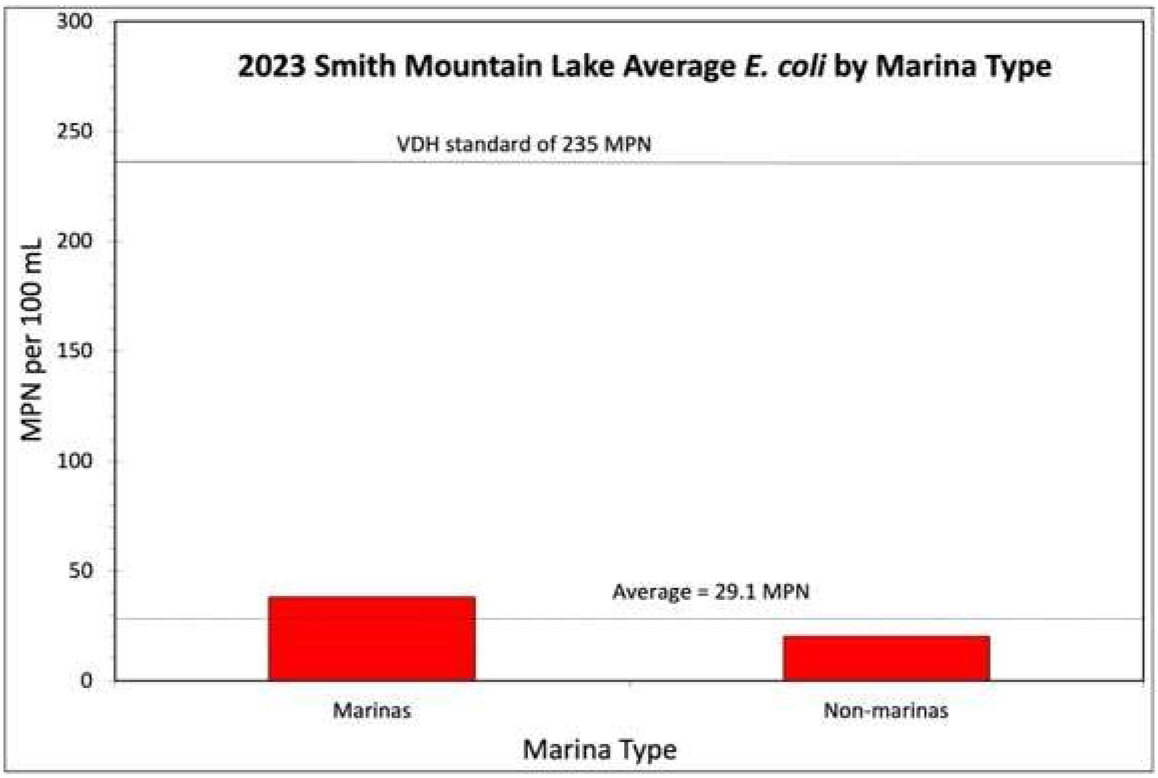


Figure 7.2. Mean *E. coli* count vs. site type in 2023 - 7 marina sites, 7 non-marina sites.

The mean *E. coli* counts for headwater sites (32.3 MPN) are 29.5 percent lower than the mean *E. coli* counts for static sites (45.8 MPN) and 602.2 percent higher than the mean *E. coli* counts for flow sites (4.6 MPN). The static sites are 895.7 percent higher than the flow sites. This is shown in Figure 7.3.

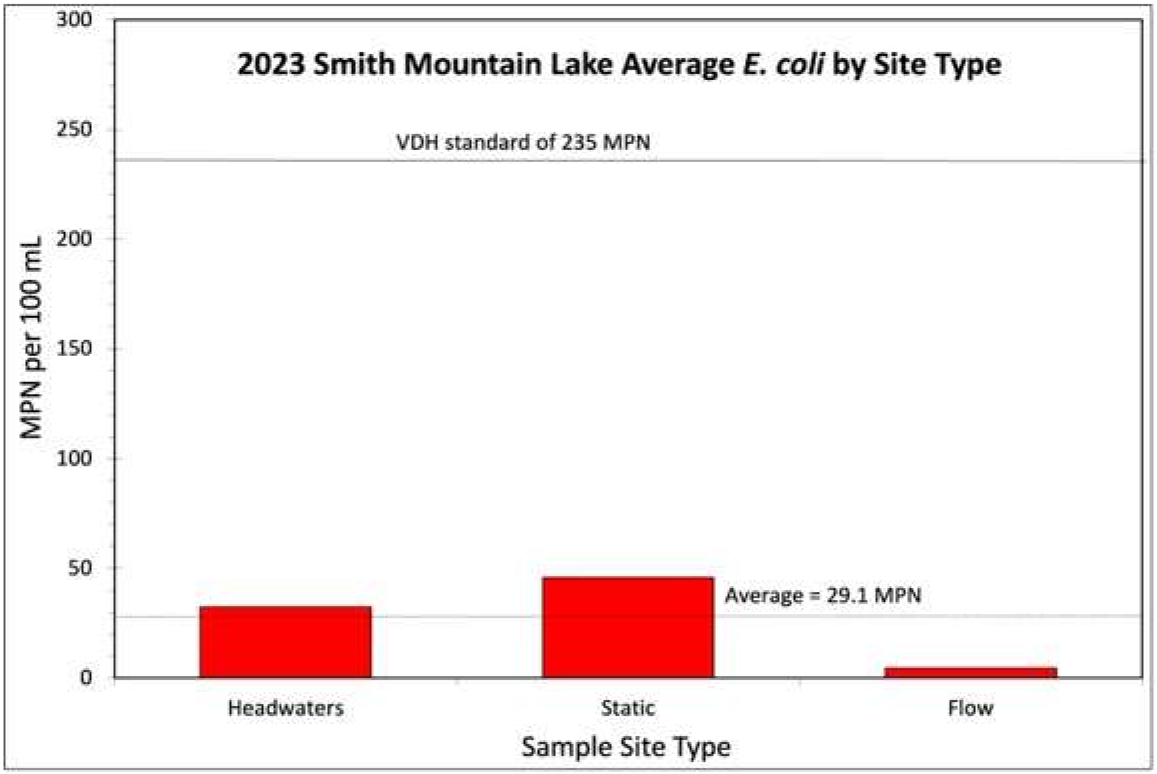


Figure 7.3. Mean *E. coli* count vs. site type in 2023 – 2 headwater sites, 7 static sites, 5 flow sites.

The mean *E. coli* counts for the Roanoke channel (33.6 MPN), Blackwater channel (32.2 MPN) and the main basin (i.e., confluence and below) (14.7 MPN) also reflect the spatial variability found at Smith Mountain Lake. The mean *E. coli* counts for all sample sites on the Roanoke channel and Blackwater channel were only 4.2 percent different, with the Roanoke channel slightly higher. However, the difference between both of the channels and the main basin was 129.1 percent higher in the Roanoke channel and 119.6 higher in the Blackwater channel (Figures 7.4 and 7.6).

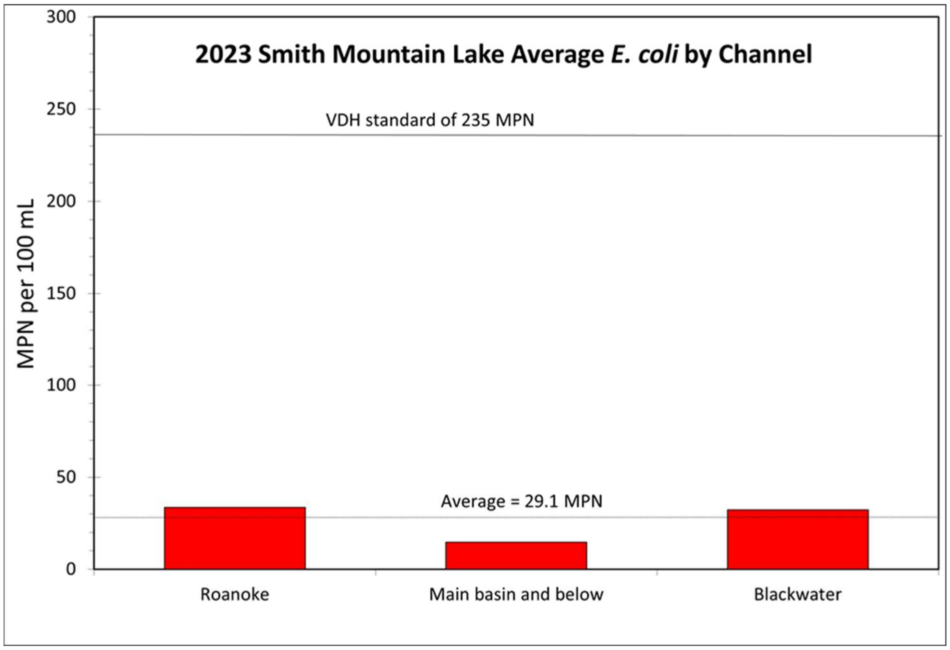


Figure 7.4. Mean *E. coli* counts in 2023 – 7 Roanoke channel, 4 Blackwater channel, and 3 main basin sites.

Figure 7.5 and Table 7.1 show a comparison of mean *E. coli* counts from 2013 to 2023 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. These data will be included in yearly reports until enough data is accumulated using the new site-type designations.

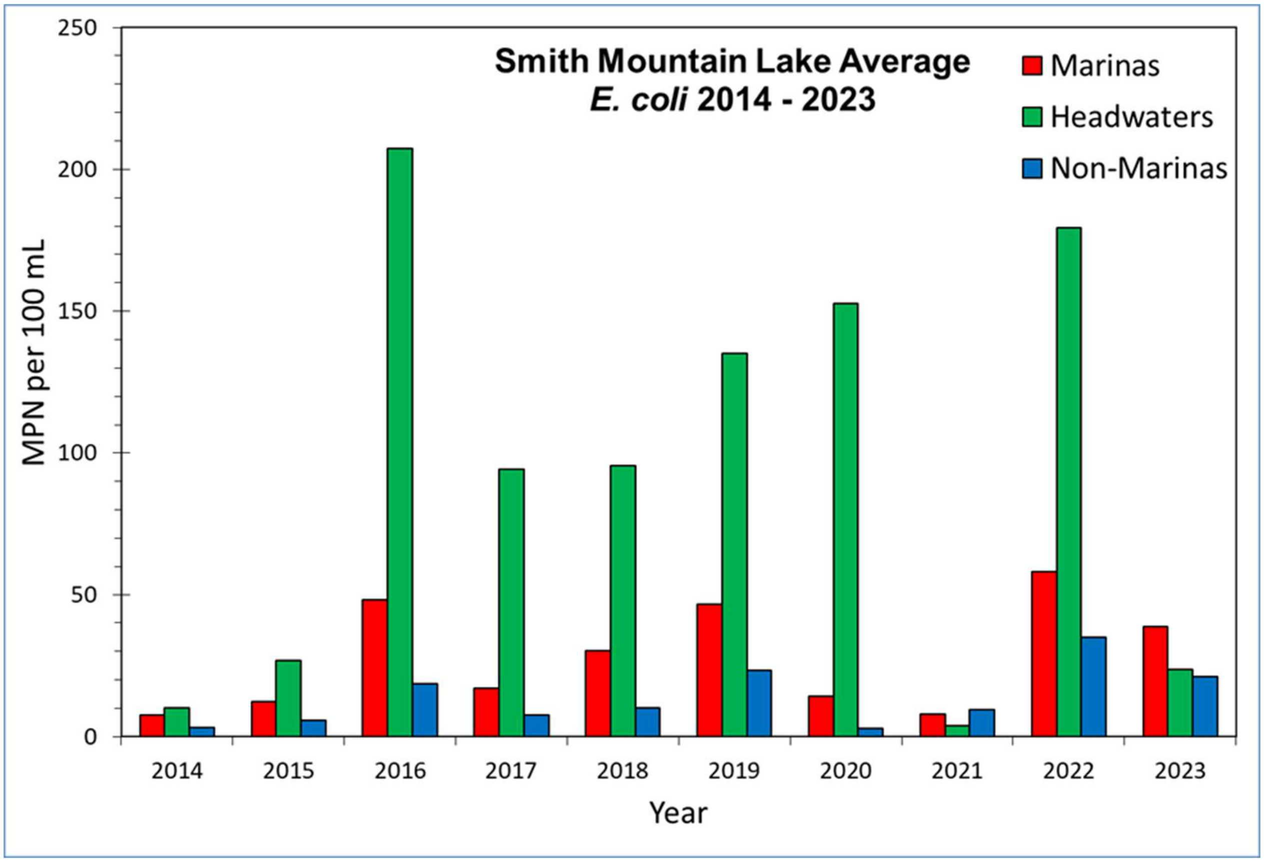


Figure 7.5. Mean *E. coli* counts per site type from 2014-2023

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

YEAR	**2023**	**2022**	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**10 YR AVG**
Marinas avg MPN	**38.6**	58.3	7.9	14.3	46.6	30.1	17.1	48.3	12.4	7.6	**28.1**
Non-marinas avg MPN	**21.0**	35.1	3.9	3.1	23.5	10.2	7.8	18.5	5.7	3.3	**13.8**
Headwaters avg MPN	**23.7**	179.3	9.5	152.6	135.2	95.6	94.2	207.4	26.8	10.1	**92.9**
Overall lake avg MPN	**29.1**	**75.9**	**6.8**	**39.9**	**57.4**	**37.0**	**30.3**	**71.7**	**13.1**	**6.6**	**36.8**

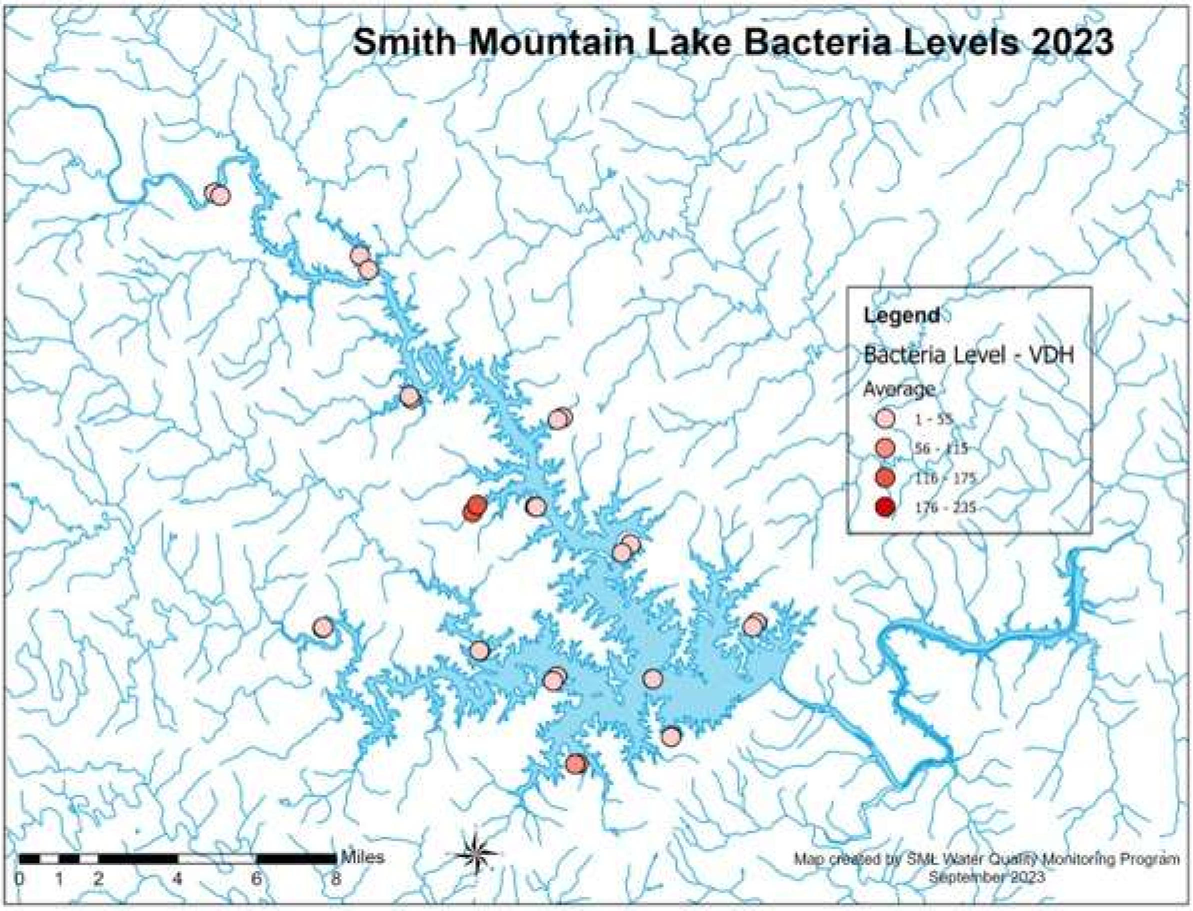


Figure 7.6. Map of bacterial sampling results in Smith Mountain Lake for 2023

7.4 E. coli Conclusions

The *E. coli* populations in Smith Mountain Lake in 2023 were much lower than the levels in 2022. In 2023, the overall mean *E. coli* count was 29.1 MPN, which is 61.7 percent lower than the 2022 overall mean *E. coli* count (75.9 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 2023 overall mean is lower than the ten-year average as shown in Table 7.1.

The comparison of marinas, non-marinas, and headwaters sites shows differences in *E. coli* values consistent with data collected over the last ten years. This year we looked at bacterial numbers in the Roanoke and Blackwater channels as well as at headwaters, flow, and static sites. These new designations will continue to be analyzed to determine possible patterns or nuances that might be gleaned from the data.

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. 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. 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 (VDH) 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 sampling to identify potential toxin producing cyanobacteria in the blooms.

With the numerous new reports of algal blooms and HABs in 2023, the Ferrum team was involved in sample collection and identification of HAB species. Analyzed samples were received from members of the Smith Mountain Lake Association, volunteer monitors, and lake residents. In addition, the Ferrum team collected numerous samples during regular and additional water quality sampling. Microscopic examination of samples found to contain potential HAB Cyanobacteria species were reported to both VDH and the Virginia Department of Environmental Quality (DEQ). Monitoring of HABs will continue in the next sample season. Members of the Ferrum team are part of the SMLA HAB working group and will assist with the continued monitoring of this water quality issue.

Because cyanobacteria (blue-green algae), such as some species of *Microcystis*, *Anabaena, Dolichospermum*, and *Aphanizomenon* found in the lake may produce toxins that can be harmful to fish species and potentially harmful to humans, the levels of toxin (e.g., microcystin) 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. Toxin testing may be performed when an algal bloom (visible green or blue-green water) involving certain species is reported from lake observations during the sampling season and beyond. These tests could potentially be performed in the future at Ferrum College. Ferrum is working with VDH and DEQ to determine processes that can decrease the time required to determine toxicity in more effective and efficient ways.

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 2023 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. This year, the counting methodology remained the same as previous years; however, the genera that were enumerated became more targeted.

8.3 Results

In 2023, the focus shifted to counting specific indicator genera of phytoplankton which reduced the number of genera counted. Four genera of diatoms (*Asterionella*, *Dinobryon*, *Fragilaria* and *Navicula*), three genera of green algae (*Pediastrum*, *Scenedesmus*, and *Staurastrum*) and three genera of blue-green algae (*Dolichospermum* [formerly known as *Anabaena*], *Microcystis*, and *Oscillatoria*) were still counted in 2023 as they were in 2022. *Woronochinia* and *Aphanizomenon* (both blue-green algae) were added to the counts in 2023 starting in period 2 at one site, and at all sites for the rest of the season.

Figure 8.1 compares the overall counts of the three groups of algae between 2022 and 2023. The graph shows the total counts. There were more than twice the number of the four genera of diatoms in 2023 than in 2022, while there were less than 10 percent of the three genera of green algae counted. When comparing the same genera counted both in 2022 and 2023, Blue-green algae counts were more than twice as high in 2023 (solid orange bar) compared to 2022 (solid blue bar). The addition of *Woronichinia* and *Aphanizomenon* counts (hatched orange bar) highlights the abundance of blue-green algae in Smith Mountain Lake that was found in 2023.

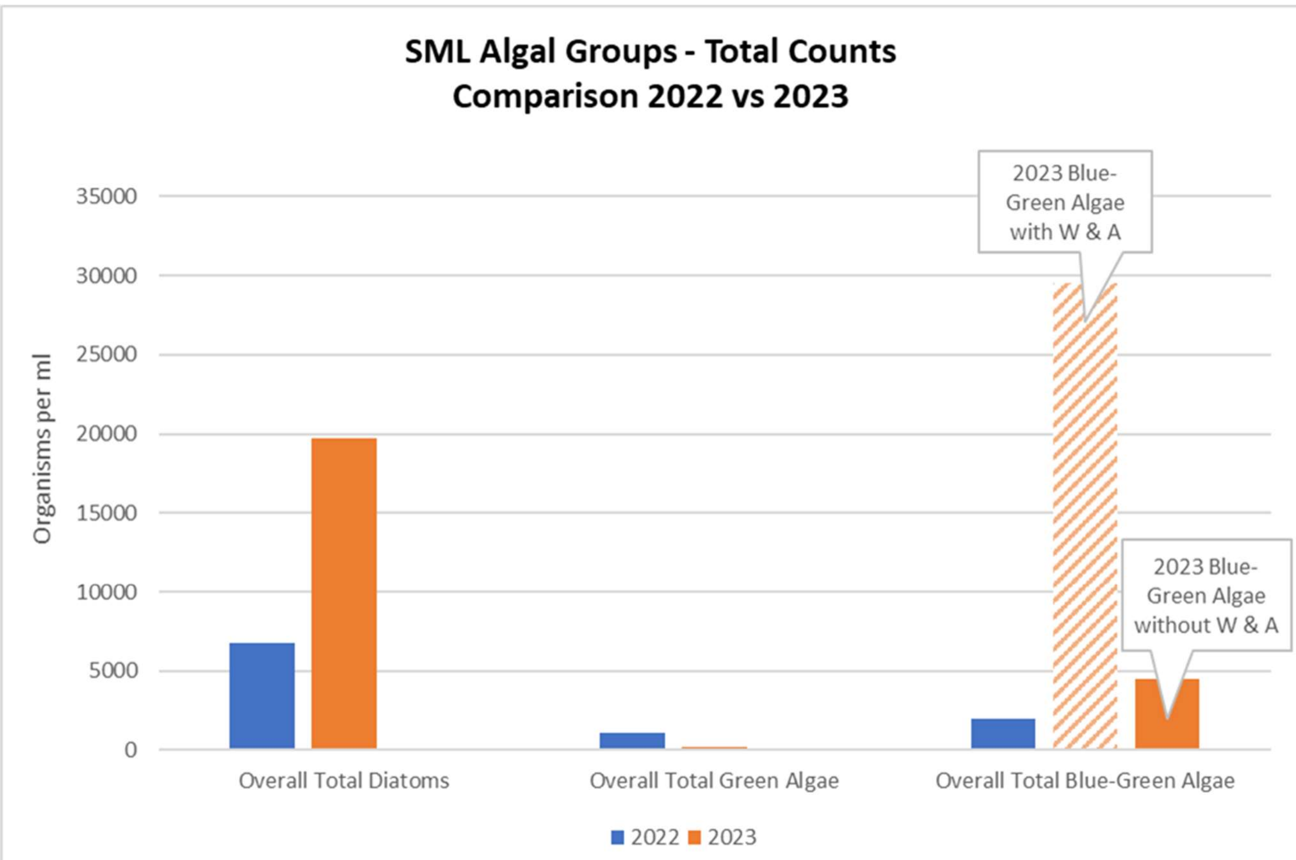


Figure 8.1. Algae groups counted during the 2022 and 2023 sampling seasons. The solid blue and orange bars represent only the four genera of diatoms, three genera of green algae, and three genera of blue-green algae which were counted in both sampling seasons. The hatched orange bar, includes the same three blue-green algae genera plus the addition of the *Woronichinia* (W) and *Aphanizomenon* (A) counts.

Figures 8.2 shows the overall patterns of the three algal groups (four genera of diatoms, three genera of green algae and three genera blue-green algae) counted during the 2023 (top left) and 2022 (top right) sampling seasons for both vertical and horizontal tows. The bottom graph of the group shows the pattern of the three algal groups for 2023 including the *Woronichinia* and *Aphanizomenon* counts added during period 2 in 2023. The spike in blue-green algae in periods 2 and 3 on this graph can be mostly attributed to the *Aphanizomenon* counts. The two additional genera were added to the phytoplankton counts as a result of the sharp increase in potential Harmful Algal Blooms (HABs) being reported to the Virginia Department of Health in May and June of 2023.

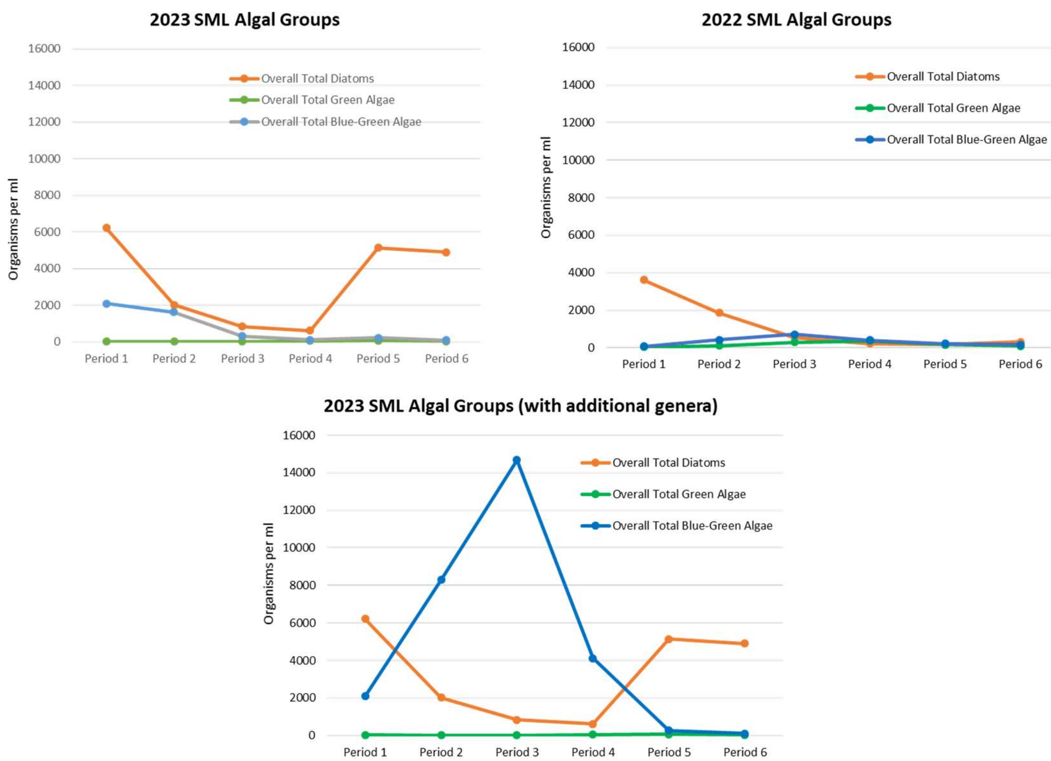


Figure 8.2. Overall patterns of algae groups counted in both 2022 and 2023

8.4 *Discussion.*

The 2023 sampling season implemented several changes to the number of genera that were counted from the horizontal and vertical tow samples. Focus was placed on those genera that were morphological distinct within each algal group, but also are representative of a historical presence in the lake. Additionally, some genera (e.g., as *Chlorella*) were removed because their concentrations in previous years has potentially skewed the percentage of algal groups represented during the sampling season. Finally, by reducing the number of genera, across all groups, that were being enumerated it allowed for focus on the more concerning and potentially problematic genera of cyanobacteria associated with harmful algal blooms.

Generally, analysis of the algae in Smith Mountain Lake shows a high diversity of genera across the groups of algae. This season, however, was highlighted by a notable spike of cyanobacteria during May and June (Periods 2 and 3, Figure 8.2), most notably of *Aphanizomenon*. *Aphanizomenon* is one genus of cyanobacteria that is well-known for potential toxin production. Numerous reports from residents of the Lake were submitted to Ferrum College, Virginia Department of Environmental Quality (DEQ), and Virginia Department of Health (VDH).

Please note that in contrast to the 2022 report, there are fewer comparisons that can be made between the algal counts from 2023 and past years due to changing the number and types of genera being enumerated.

8.5 Conclusions

The 2023 sampling season provided some of the highest number of reports for harmful algal blooms in the 36-year history of the Smith Mountain Lake Water Quality Project. This is a testament to the residents and volunteers that keep a watchful eye for unusual and atypical conditions on the lake. The phytoplankton diversity of the lake remains high, but the trend of seeing increased numbers of cyanobacteria (i.e., *Aphanizomenon*) associated with harmful algal blooms is a concern. The cyanobacteria most commonly associated with the current HABs experienced at Smith Mountain Lake are nitrogen-fixing general; therefore, nitrogen is not a limiting nutrient for these organisms. Future research will need to analyze correlations between lake characteristics (e.g., water temperature and phosphorous levels) as well as changes in land usage and other practices (e.g., fertilizer application) around the lake to see what might be leading to the spike of HABs that were noticed this season.

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 2023 calibration data for total phosphorus (TP)

Sampling Period*	TP - R^2
1	0.9998
2	0.9997
3	0.9997
4	0.9996
5	0.9998
6	0.9998
Average	**0.9997**
Standard Deviation	**0.0001**

*See Table 2.1

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 2023, 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 2023

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.
	(%)	(%)	(%)	(%)	(%)	(%)
1	2.8	3.2	1.9	1.1	2.0	0.6
2	3.3	4.3	2.4	0.6	1.3	0.3
3	1.2	2.3	0.3	0.6	1.5	0.2
4	0.8	1.9	0.1	0.6	1.0	0.0
5	1.3	2.5	0.1	0.4	0.9	0.1
6	1.5	3.7	0.4	0.6	0.9	0.4
Overall Averages	**1.8**			**0.7**		

*See Table 2.1

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 excellent for both the 40 ppb standard with an overall average of 1.8 percent RPD and for the 80 ppb standard with an overall average of 0.7 percent RPD. The target value for RPD is 0 percent and 10 percent is the DEQ acceptable upper limit.

9.6 *Blank and Spiked Blank Method and Results*

In 2023, 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 2023 lab blanks and average percent error for spiked blanks

Sampling Period*	TP blanks - average error (ppb)	TP spiked blanks - average % recovery
1	1.5	108.0
2	2.7	108.5
3	0.9	105.4
4	1.8	106.8
5	1.0	107.9
6	0.9	109.9
AVERAGES	**1.5**	**107.8**

*See Table 2.1

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 good at 107.8 percent (target value is 100 percent with ±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 2023 duplicates and spikes for total phosphorus

	TP DUPLICATES			TP SPIKES		
Sampling Period*	Average RPD	Maximum RPD	Minimum RPD	Average % Recovery	Maximum % Recovery	Minimum % Recovery
1	2.5	4.3	0.5	101.9	108.9	92.1
2	2.5	5.2	1.2	87.8	-8.9	151.0
3	25.6	105.3	0.2	99.7	94.2	103.1
4	0.9	1.8	0.1	100.0	103.6	93.1
5	3.1	11.5	0.0	104.7	109.9	101.1
6	5.2	10.4	1.1	101.7	117.7	90.2
Overall Avg	**6.6**	**23.1**	**0.5**	**99.3**	**87.6**	**105.1**

*See Table 2.1

9.9 Duplicate and Spiked Sample Analysis Discussion and Conclusions

The results of duplicate analysis for total phosphorus were very good this year at 6.6 average relative percent difference (acceptance criteria is RPD < 20 percent) and excellent for spiked samples with 99.3 average percent recovery (acceptance criteria is 80-120 percent recovery). The high and low values in sampling periods 2 and 3 are likely due to technician error in the spiking process.

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 in triplicate. These results are reported in Table 9.5.

Table 9.5. Results of analysis of purchased standard for total phosphorus for 2023

Sampling Period	ERA conc. - expected (ppb)	ERA conc. - measured, avg. (ppb)	Average RPD
1	58.5	63.1	7.6
2	58.5	60.3	3.1
3	58.5	59.0	0.9
4	58.5	59.0	0.8
5	58.5	59.4	1.6
6	58.5	58.9	0.7
Averages		**60.0**	**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. A method blank (glass fiber filter through which 100 mL of DI water has been filtered and is stored frozen) is analyzed each time samples are run to assure that the processing of the samples does not introduce contamination or interferents. In 2023, the method blanks ranged from 0.01 ppb to 0.08 ppb with an average of 0.02 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 most probable number (MPN) that can be obtained. In 2023, 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 2023

Sampling Date	Replicate Site	MPN *E. coli* at replicate site	Replicate Avg. (MPN)	Replicate Range (MPN)
5/23	4-1	137.6	15.5	8.5 - 24.1
5/23	12-1	12.1	20.9	16.9 - 24.9
6/6	13-2	2.0	2.8	1.0 - 4.1
6/6	2-1	0.0	4.4	3.1 - 6.3
6/20	1-2	54.6	44.1	35.9 - 54.8
6/20	11-2	261.3	223.8	178.5 - 261.3
7/5	1-2	30.5	31.3	22.8 – 35.0
7/5	12-2	5.2	4.4	1.0 - 6.3
7/18	9-1	7.4	9.7	7.4 – 11.0
7/18	5-1	27.5	30.3	26.9 - 35.5
8/01	1-1	12.1	7.7	4.1 - 9.7
8/01	8-1	135.4	95.7	84.2 - 103.9

In addition, a QuantiCult^{TM} 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^{TM} analysis for 2023

5/23	MPN total coliforms	MPN *E. coli*
E. coli	31.3	31.3
K. pneumoniae	27.5	0.0
P. aeruginosa	0.0	0.0
6/6	**MPN total coliforms**	**MPN *E. coli***
E. coli	32.7	32.7
K. pneumoniae	25.9	0.0
P. aeruginosa	0.0	0.0
6/20	**MPN total coliforms**	**MPN *E. coli***
E. coli	33.1	33.1
K. pneumoniae	26.2	0.0
P. aeruginosa	0.0	0.0
7/5	**MPN total coliforms**	**MPN *E. coli***
E. coli	29.9	29.9
K. pneumoniae	24.9	0.0
P. aeruginosa	0.0	0.0
7/18	**MPN total coliforms**	**MPN *E. coli***
E. coli	23.3	23.3
K. pneumoniae	16.1	0.0
P. aeruginosa	0.0	0.0
8/01	**MPN total coliforms**	**MPN *E. coli***
E. coli	24.6	24.6
K. pneumoniae	12.2	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 2023 sampling season were very good with the exception of the site 4-1 replicate taken on 5/23/2023. This replicate sample was collected at a different location on the boat from the original 4-1 sample (one from the bow of the boat, and one from the stern). The sterile distilled water gives assurance that the bottles, media, and Quanti-Tray 2000^{TM} trays are sterile and that good technique was used. With the exception of the 4-1 replicate collected on 5/23/2023 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 2023 and Table 10.2 presents the collection efficiencies from 2014 through 2023. The figures show that the volunteer monitors are very conscientious about sample collection. Volunteer monitor sample efficiency for total phosphorus was 98 percent, chlorophyll-*a* samples correctly collected at 98 percent, and 98 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 2023

Sample Type	Monitoring Stations	Possible Samples	Samples Collected	Percent Efficiency
Secchi Depth	84	504	492	98
TP	56	336	330	98
CA	56	336	330	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	2023	2022	2021	2020	2019	2018	2017	2016	2015	2014
Secchi Depth	98	97	99	97	99	95	84	95	96	98
TP	98	99	100	98	100	96	97	98	99	99
CA	98	98	99	97	96	95	98	97	98	99

11. 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, historically.

In 2023, average total phosphorus were slightly increased, while the chlorophyll-*a* concentrations were notably increased, while the average Secchi depth remained the same.

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 2023 were much lower than the levels in 2022. In 2023, the overall mean *E. coli* count was 29.1 MPN, which is 61.7 percent lower than the 2022 overall mean *E. coli* count (75.9 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 2023 overall mean is lower than the ten-year average as shown in Table 7.1.

The comparison of marinas, non-marinas, and headwaters sites shows differences in *E. coli* values consistent with data collected over the last ten years. This year we looked at bacterial numbers in the Roanoke and Blackwater channels as well as at headwaters, flow, and static sites. These new designations will continue to be analyzed to determine possible patterns or nuances that might be gleaned from the data.

The 2023 sampling season provided some of the highest number of reports for harmful algal blooms in the 36-year history of the Smith Mountain Lake Water Quality Project. This is a testament to the residents and volunteers that keep a watchful eye for unusual and atypical conditions on the lake. The phytoplankton diversity of the lake remains high, but the trend of seeing increased numbers of cyanobacteria (i.e., *Aphanizomenon*) associated with harmful algal blooms is a concern. Future research will need to analyze correlations between lake characteristics (e.g., water temperature and phosphorous levels) as well as changes in land usage and other practices (e.g., fertilizer application) around the lake to see what might be leading to the spike of HABs that were noticed this season.

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 were excellent for the 40 ppb standard with an overall average of 1.8 percent and acceptable for the 80 ppb standard with an overall average of 0.7 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 good at 107.8 percent (target value is 100 percent with ±20 percent acceptable upper and lower limits). The results of duplicate analysis for total phosphorus was very good this year at 6.6 average relative percent difference (target value is 0 percent) and excellent for spiked samples with 99.3 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 2023 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 2023. Volunteer monitor sample efficiency for total phosphorus was 98 percent, while chlorophyll-*a* samples were 98 percent and Secchi readings were also 98 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. Riley Hines, Joe Presinzano, Andrew Porter, and Rylee Smith were the student technicians in 2023.

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APPENDIX

Table A.1. 2023 Smith Mountain Lake trophic monitoring stations with monitor names and station locations

Station	Monitor	Latitude	Longitude
B8	Chaney	37.0393	-79.6159
B10	Chaney	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	Sanders	37.159	-79.692
CR21	Gardner	37.1492	-79.7086
CR21.2	Gardner	37.146	-79.7091
CR22	Lovatt	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. 2023 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	Sanders	37.152	-79.676
R19	Sanders	37.161	-79.697
R21	Gardner	37.1564	-79.7081
R23	Lovatt	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
SB12	Ralph	37.0254	-79.5986
SCB 8	Hurt	37.0208	-79.6382
SCB10	Hurt	37.0168	-79.6267
SCB11	Hurt	37.0649	-79.6448
SCB11.5	Hurt	37.033	-79.6824
SCB14	Ralph	37.0356	-79.6937
SCB16	Ralph	37.048	-79.5879
SCM5	Hardy	37.0587	-79.5866
SCR7	Hardy	37.0683	-79.5883
SCR8	Hardy	37.0719	-79.6295
SCR10.1	West	37.0763	-79.6289
SCR10.2	West	37.0797	-79.6368
SCR10.3	West	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. 2023 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

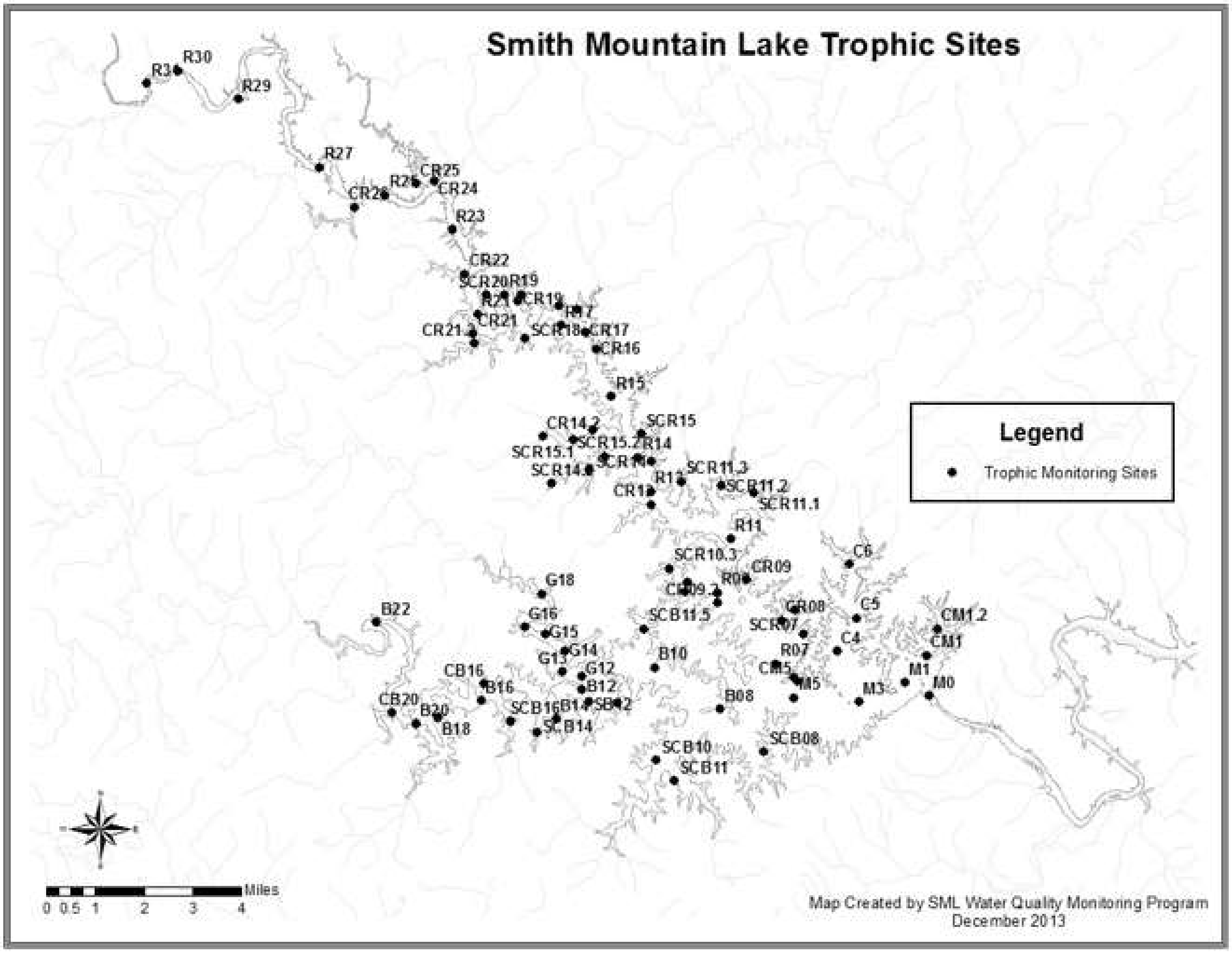

Table A.2. 2023 Smith Mountain Lake tributary stations and other downstream stations

Tributary Station Number	Stream Name
T0a	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

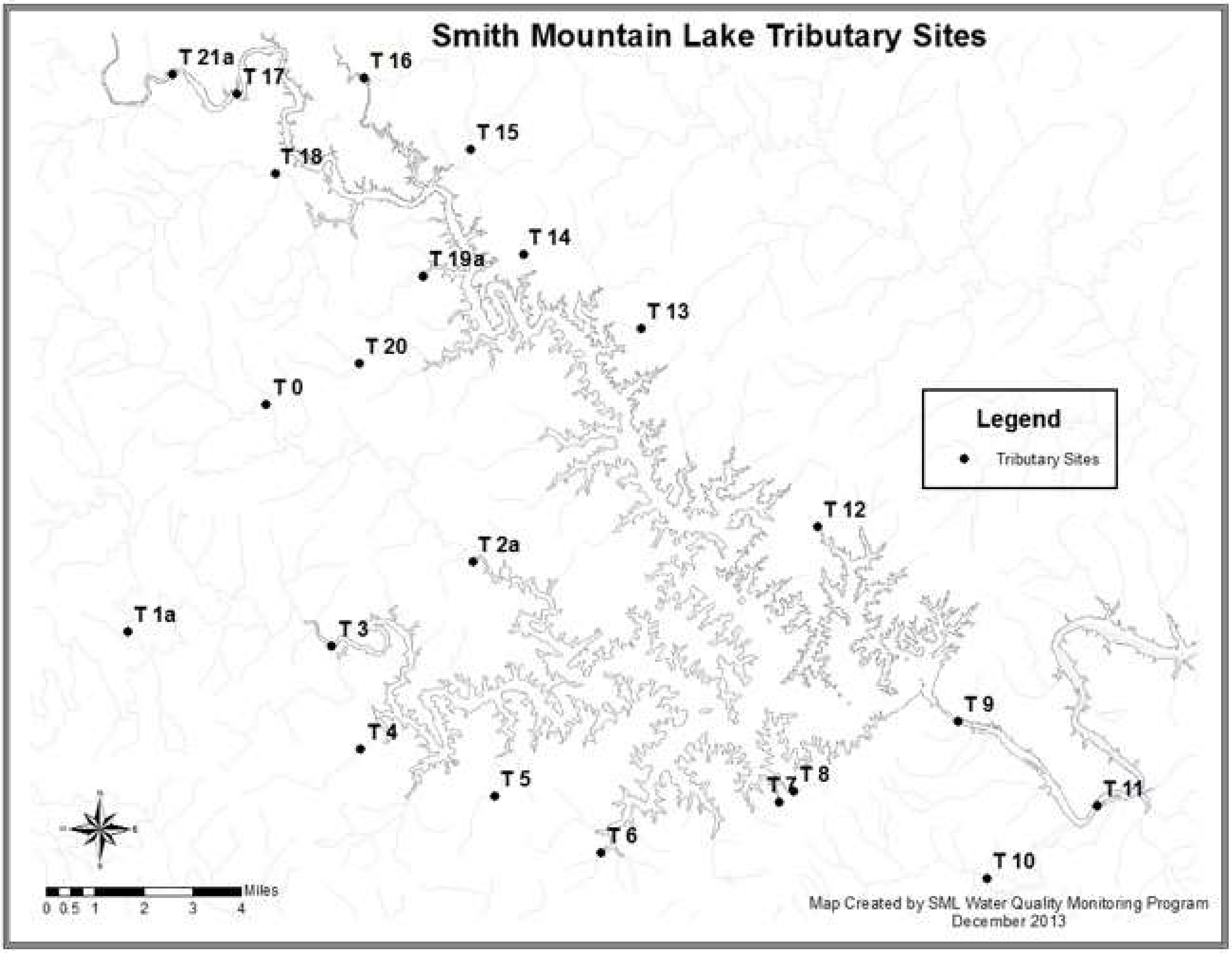

Figure A.2.a Map showing tributary sites below Smith Mountain Lake Dam

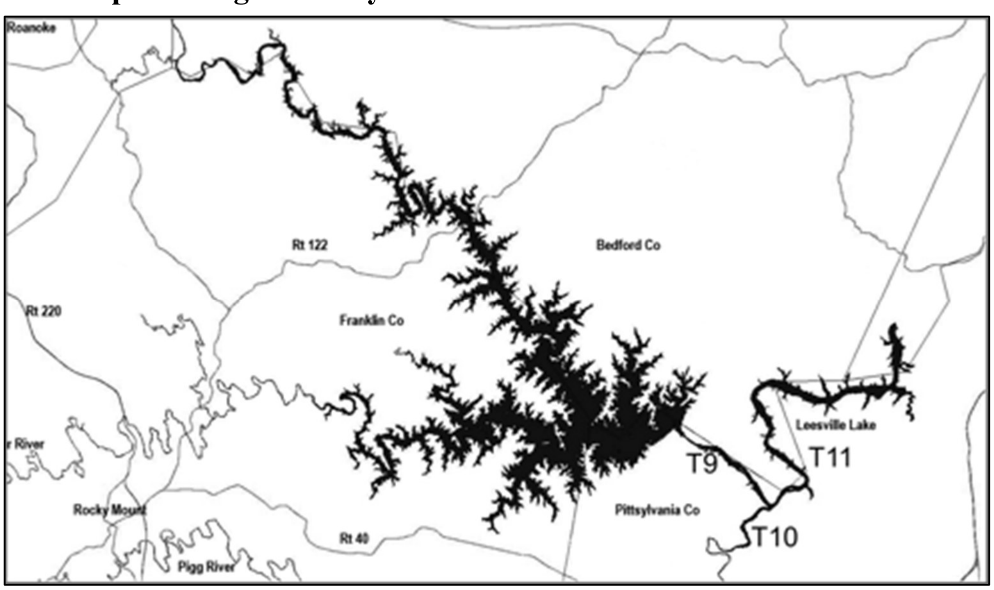

Table A.3. 2023 Total phosphorus data for Smith Mountain Lake sample stations

	Sampling Period 1	Sampling Period 2	Sampling Period 3	Sampling Period 4	Sampling Period 5	Sampling Period 6	Station Avg.	Std. Dev.
Station	**conc (ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**conc(ppb)**	**(ppb)**	
B8	22.3	18.2	16.4	16.9	15.6	14.9	**17.4**	**2.6**
B10	14.4	18.1	13.7	15.5	15.9	11.3	**14.8**	**2.3**
B12	29.9	35.2	20.7	19.3	22.6	20.1	**24.6**	**6.4**
B14	40.3	20.5	25.5	24.1	21.6	20.6	**25.4**	**7.6**
B16	27.7	24.8	26.8	31.6	29.9	24.6	**27.6**	**2.8**
B18	38.7	31.7	32.6	39.7	33.8	27.7	**34.0**	**4.5**
B20	33.4	41.5	36.1	46.7	37.8	26.3	**37.0**	**7.0**
B22	54.3	58.0	89.5	84.6	109.1	58.3	**75.6**	**22.2**
C4	15.5	16.5	25.5	10.8	13.9	9.6	**15.3**	**5.7**
C5	13.0	10.8	10.2	10.3	12.9	10.6	**11.3**	**1.3**
C6	13.0	12.1	26.5	10.8	12.0	10.0	**14.1**	**6.2**
CB11	58.3	44.7	22.5	21.5	27.2	14.1	**31.4**	**16.7**
CB16	30.1	27.5	35.0	24.5	25.8	20.5	**27.2**	**5.0**
CB20	30.4	38.9	41.2	37.0	34.0	25.3	**34.5**	**5.9**
CM1	13.4	13.5	11.0	13.3	11.4	9.5	**12.0**	**1.6**
CM1.2	27.1	17.7	12.2	13.4	13.4	11.0	**15.8**	**6.0**
CM5	18.2	15.0	12.8	15.3	13.6	12.0	**14.5**	**2.2**
CR8	14.0	16.9	11.3	12.9	11.9	10.1	**12.9**	**2.4**
CR9	19.9	29.2	17.6	11.7	11.2	9.7	**16.6**	**7.4**
CR9.2	13.0	17.8	18.1	14.6	12.9	10.1	**14.4**	**3.1**
CR13	33.6	29.5	24.7	20.7	19.9	17.5	**24.3**	**6.2**
CR14.2	22.4	19.3	21.7	18.2	18.1	15.8	**19.2**	**2.4**
CR16	23.2	28.4	39.6	21.5	22.7	15.8	**25.2**	**8.1**
CR17	28.2	25.7	30.7	24.8	26.7	18.0	**25.7**	**4.3**
CR19	37.1	43.6	65.4	35.1	32.1	26.8	**40.0**	**13.6**
CR21	38.2	31.4	37.7	37.3	28.7	22.6	**32.7**	**6.3**
CR21.2	30.1	17.1	35.6	72.5	30.5	23.9	**35.0**	**19.5**
CR22	55.9	39.4	58.1	49.1	36.2	26.0	**44.1**	**12.4**
CR24	70.1	77.1	60.8	65.0	63.1	61.5	**66.3**	**6.2**
CR25	47.0	47.4	42.3	43.7	39.7	34.7	**42.5**	**4.8**
CR26	39.7	56.1	77.4	44.5	51.3	32.3	**50.2**	**15.8**
G12	148.5	44.4	27.3	25.1	34.6	36.6	**52.7**	**47.4**
G13	25.0	23.5	23.8	21.3	20.2	15.3	**21.5**	**3.5**
G14	18.2	22.0		18.5	20.4		**19.8**	**1.8**
G15	21.0	21.8	24.1	27.4	18.4	15.4	**21.4**	**4.2**
G16	22.3	26.8		21.1	30.3		**25.1**	**4.2**
G18	33.6	45.2		47.5	54.5		**45.2**	**8.7**
M0	14.0	13.4	11.1	13.4	11.7	8.5	**12.0**	**2.1**
M1	32.0	20.6	16.1	18.1	19.3	12.8	**19.8**	**6.6**

Table A.3. 2023 Total phosphorus data for Smith Mountain Lake sample stations (cont.)

M3	19.2	63.0	14.2	15.1	14.0	12.2	**22.9**	**19.8**
M5	17.7	12.1	13.9	14.7	11.1	10.9	**13.4**	**2.6**
R7	15.9	16.3	13.1	13.3	12.6	10.5	**13.6**	**2.2**
R9	16.3	14.1	49.0	15.6	14.2	10.5	**19.9**	**14.4**
R11	16.2	16.8	17.7	14.7	13.8	11.6	**15.1**	**2.2**
R13	18.1	27.6	20.3	16.2	19.9	14.3	**19.4**	**4.6**
R14	20.5	18.2	20.0	17.2	17.4	14.5	**18.0**	**2.2**
R15	21.8	24.0	18.9	21.6	19.5	15.0	**20.2**	**3.1**
R17	32.8	44.7	28.0	29.1	34.0	25.7	**32.4**	**6.8**
R19	29.6	35.9	38.8	32.7	32.1	25.4	**32.4**	**4.7**
R21	28.8	34.9	35.8	48.8	31.9	24.8	**34.2**	**8.2**
R23	28.5	37.0	39.6	45.3	42.6	24.5	**36.3**	**8.2**
R25	39.8	45.2	35.0	43.2	39.7	30.7	**38.9**	**5.3**
R27	113.1	76.3	49.8	56.9	72.3	45.3	**68.9**	**24.8**
R29	73.9	50.0	57.3	56.1	56.9	57.5	**58.6**	**8.0**
R30	47.6	50.0	41.2	60.7	61.8	48.3	**51.6**	**8.0**
R31	56.2	43.6	39.9	39.9	59.9	36.1	**45.9**	**9.7**
AVG.	**33.3**	**31.3**	**30.8**	**29.3**	**28.9**	**21.9**	**29.3**	
STD. DEV.	**24.0**	**16.0**	**17.5**	**17.5**	**18.8**	**13.1**	**15.5**	

Table A.4. 2023 Total phosphorus data for Smith Mountain Lake tributaries

Station	Sampling Period 1 conc(ppb)	Sampling Period 2 conc(ppb)	Sampling Period 3 conc(ppb)	Sampling Period 4 conc(ppb)	Sampling Period 5 conc(ppb)	Sampling Period 6 conc(ppb)	Station Avg. (ppb)	Std. Dev.
T0a	176.4	64.9	106.4	79.2	73.9	54.8	**92.6**	**44.6**
T1a		55.6	93.8	105.6	73.3	67.8	**79.2**	**20.2**
T2a		69.6	106.2	115.5	91.9	89.1	**94.5**	**17.6**
T3		48.9	64.8	57.2	52.3	46.9	**54.0**	**7.2**
T4	43.6	25.0	25.0	25.6	25.7	18.8	**27.3**	**8.4**
T5	63.7	31.7	45.0	29.4	28.9	21.8	**36.7**	**15.2**
T6	60.2	29.3	31.3	29.4	29.5	13.5	**32.2**	**15.2**
T7	21.1	18.9	23.8	18.0	12.8	11.9	**17.8**	**4.7**
T8	22.8	15.9	27.0	14.6	12.4	10.2	**17.1**	**6.4**
T9	14.2	19.5	21.0	21.5	21.2	14.6	**18.7**	**3.4**
T10	123.3	33.6	56.8	48.8	72.3	25.7	**60.1**	**35.1**
T11	97.8	26.2	43.1	24.9	23.7	15.7	**38.6**	**30.4**
T12	31.5	23.4		22.7	25.9	22.7	**25.2**	**3.7**
T13	24.2	20.5	20.5	23.5	19.8	11.4	**20.0**	**4.6**
T14	168.3	120.5	128.7	155.9	146.3	70.2	**131.7**	**34.8**
T15	84.3	72.3	93.3	81.9	102.1	58.3	**82.0**	**15.5**
T16	112.2	65.4	70.7	71.7	85.4	35.8	**73.6**	**25.1**
T17	121.6	40.2	159.6	50.2	47.5	45.0	**77.4**	**50.6**
T18	80.3	36.5	44.7	41.6	41.8	27.5	**45.4**	**18.1**
T19a	68.5	54.2	63.8	64.7	66.1	44.5	**60.3**	**9.1**
T20	83.8	52.1	51.9	170.7	56.4	32.6	**74.6**	**49.9**
T21a	145.8	67.5	86.6	92.7	93.5	48.0	**89.0**	**32.9**
Average	**81.2**	**45.1**	**65.0**	**61.1**	**54.7**	**35.8**	**56.7**	
St. Dev.	**50.0**	**25.1**	**38.7**	**44.5**	**35.0**	**22.2**	**31.5**	

Table A.5. 2023 Chlorophyll-*a* data for Smith Mountain Lake sample stations

Station	Sampling Period 1	Sampling Period 2	Sampling Period 3	Sampling Period 4	Sampling Period 5	Sampling Period 6	Station Avg.	Std. Dev.
	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	conc(ppb)	(ppb)	
B8	6.31	4.76	1.64	5.93	3.31	4.41	**4.39**	**1.73**
B10	2.36	5.41	2.96	5.76	4.33	3.21	**4.01**	**1.38**
B12	10.01	10.21	9.42	7.10	1.41	3.89	**7.01**	**3.64**
B14	6.33	6.48	30.9	10.21	6.73	6.22	**11.15**	**9.80**
B16	9.48	16.32	34.3	10.12	9.97	14.16	**15.73**	**9.50**
B18	18.29		9.57	19.00	17.79	14.32	**15.79**	**3.92**
B20	15.90		25.15	27.42	18.96	10.42	**19.57**	**6.90**
B22	18.38	63.81	18.99	18.87	20.68	26.22	**27.83**	**17.87**
C4	7.96	3.21	1.77	2.82	2.73	3.30	**3.63**	**2.19**
C5	7.77	2.25	2.89	4.53	0.79	3.41	**3.61**	**2.39**
C6	8.28	3.32	4.33	4.71	0.62	3.07	**4.06**	**2.52**
CB11	7.12	10.6	3.51	10.42	4.83	3.90	**6.73**	**3.19**
CB16	12.68	14.55	33.30	12.63	9.42	11.31	**15.65**	**8.81**
CB20	18.45	40.34	19.42	15.89	16.30	11.72	**20.35**	**10.15**
CM1	3.76	2.98	1.85	2.09	1.32	1.82	**2.30**	**0.90**
CM1.2	6.70	3.91	1.63	3.19	1.72	1.92	**3.18**	**1.95**
CM5	6.69	2.74	2.38	3.95	2.44	4.63	**3.81**	**1.68**
CR8	6.51	3.28	2.78	3.49	3.00	5.60	**4.11**	**1.55**
CR9	7.16	3.87	2.91	4.95	3.54	3.19	**4.27**	**1.58**
CR9.2	3.83	3.40	4.35	12.30	4.44	5.95	**5.71**	**3.34**
CR13	4.66	6.58	9.04	9.07	6.47	9.32	**7.52**	**1.90**
CR14.2	5.45	5.81	2.25	10.59	8.36	10.61	**7.19**	**3.29**
CR16	5.13	8.93	7.70	7.56	9.09	17.97	**9.40**	**4.43**
CR17	11.77	1.4	11.10	9.05	13.08	14.87	**10.21**	**4.74**
CR19	18.20	9.87	11.04	23.95	18.36	28.57	**18.33**	**7.23**
CR21	15.10	16.32	36.00	26.13	17.67	19.60	**21.80**	**7.97**
CR21.2	15.86	13.69	42.20	13.37	14.51	18.03	**19.61**	**11.20**
CR22	10.57	17.48	20.55	11.58	23.22	4.41	**14.64**	**7.03**
CR24	36.8	29.13	59.10	28.90	32.70	21.39	**34.67**	**13.00**
CR25	22.43	16.04	37.00	4.87	22.55	21.36	**20.71**	**10.44**
CR26	9.15	4.77	22.27	18.21	7.29	29.87	**15.26**	**9.82**
G12	5.83	9.11	9.32	9.36	5.09	4.16	**7.15**	**2.38**
G13	4.07	6.84	10.57	3.80	1.03	5.24	**5.26**	**3.23**
G14	7.17	4.82		5.74	6.02		**5.94**	**0.97**
G15	5.38	9.69	4.88	7.33	6.77	5.11	**6.53**	**1.83**
G16	10.22	6.85		9.17	12.92		**9.79**	**2.52**
G18	14.45	17.81		15.23	20.77		**17.07**	**2.86**
M0	4.03	2.72	1.22	2.20	1.66	1.59	**2.24**	**1.02**
M1	6.69	3.14	1.40	2.81	1.82	2.05	**2.99**	**1.92**

Table A.5. 2023 Chlorophyll-*a* data for Smith Mountain Lake sample stations (cont.)

M3	5.43	3.57	1.54	3.85	11.30	2.89	**4.76**	**3.44**
M5	4.21	3.46	1.44	4.47	3.23	2.76	**3.26**	**1.09**
R7	6.13	2.90	3.49	4.37	4.38	5.11	**4.4**	**1.15**
R9	6.47	4.04	5.26	4.18	4.69	3.71	**4.73**	**1.01**
R11	3.86	6.39	4.48	5.06	2.81	9.16	**5.29**	**2.24**
R13	5.76	6.70	14.31	7.29	14.31	8.07	**9.41**	**3.87**
R14	7.81	8.13	5.82	10.16	9.43	9.51	**8.48**	**1.58**
R15	5.36	11.14	5.77	8.83	10.10	13.90	**9.18**	**3.27**
R17	13.10	12.30	6.76	13.74	26.41	23.56	**15.98**	**7.46**
R19	13.04	12.79	16.15	20.59	25.08	34.2	**20.81**	**8.28**
R21	14.84	16.21	36.60	18.41	15.38	29.50	**21.82**	**9.06**
R23	8.57	8.66	13.38	21.31	19.66	24.11	**15.95**	**6.68**
R25	13.48	20.71	31.10	23.92	16.11	28.17	**22.25**	**6.83**
R27	2.27	7.66	18.36	18.55	17.39	27.98	**15.37**	**9.09**
R29	2.78	10.61	8.07	17.69	19.82	38.90	**16.31**	**12.71**
R30	13.95	7.29	18.10	20.22	21.59	27.49	**18.11**	**6.91**
R31	21.91	1.25	3.31	6.11	1.45	18.00	**8.67**	**9.00**
AVG.	**9.75**	**9.93**	**13.09**	**10.95**	**10.48**	**12.53**	**11.13**	
St.Dev.	**6.31**	**10.34**	**13.27**	**7.26**	**8.13**	**10.19**		**3.89**

Table A.6. 2023 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	17.4	4.4	3.0	45.3	45.1	44.4	44.9
B10	10	14.8	4.0	2.8	43.0	44.2	45.4	44.2
B12	12	24.6	7.0	1.8	50.3	49.7	51.6	50.5
B14	14	25.4	11.1	1.7	50.8	54.3	52.3	52.4
B16	16	27.6	15.7	1.4	52.0	57.6	55.4	55.0
B18	18	34.0	15.8	1.0	55.0	57.7	60.0	57.6
B20	20	37.0	19.6	1.0	56.2	59.8	60.6	58.9
B22	22	75.6	27.8	0.8	66.5	63.2	64.1	64.6
C4	4	15.3	3.6	3.3	43.5	43.3	42.8	43.2
C5	5	11.3	3.6	3.5	39.1	43.2	41.8	41.4
C6	6	14.1	4.1	3.3	42.3	44.3	43.0	43.2
CB11	11	31.4	6.7	2.0	53.9	49.3	50.3	51.2
CB16	16	27.2	15.6	1.4	51.8	57.6	55.0	54.8
CB20	20	34.5	20.4	1.5	55.2	60.2	54.6	56.6
CM1	1	12.0	2.3	3.4	40.0	38.8	42.5	40.4
CM1.2	1.2	15.8	3.2	3.5	44.0	41.9	42.1	42.7
CM5	5	14.5	3.8	2.8	42.7	43.7	45.2	43.9
CR8	8	12.9	4.1	2.8	41.0	44.5	45.4	43.6
CR9	9	16.6	4.3	2.2	44.6	44.8	48.6	46.0
CR9.2	9.2	14.4	5.7	2.3	42.6	47.7	48.1	46.1
CR13	13	24.3	7.5	1.9	50.2	50.4	50.9	50.5
CR14.2	14.2	19.2	7.2	1.7	46.8	49.9	52.3	49.7
CR16	16	25.2	9.4	1.6	50.7	52.6	53.0	52.1
CR17	17	25.7	10.2	1.5	51.0	53.4	54.2	52.8
CR19	19	40.0	18.3	1.3	57.4	59.1	55.9	57.4
CR21	21	32.7	21.8	1.2	54.4	60.8	57.3	57.5
CR21.2	21.2	35.0	19.6	1.3	55.4	59.8	56.3	57.2
CR22	22	44.1	14.6	1.2	58.8	56.9	57.3	57.7
CR24	24	66.3	34.7	0.9	64.6	65.4	61.3	63.8
CR25	25	42.5	20.7	1.1	58.2	60.3	58.3	58.9
CR26	26	50.2	15.3	0.9	60.6	57.3	61.3	59.7
G12	12	52.7	7.1	1.9	61.3	49.9	50.9	54.1
G13	13	21.5	5.3	2.2	48.4	46.9	48.6	48.0
G14	14	16.0	5.9	2.1	44.1	48.1	49.6	47.3
G15	15	21.4	6.5	1.9	48.3	49.0	50.6	49.3
G16	16	20.3	9.8	1.8	47.6	53.0	51.9	50.8
G18	18	36.3	17.1	1.3	55.9	58.4	56.8	57.1
M0	0	12.0	2.2	3.5	40.0	38.5	41.8	40.1
M1	1	19.8	3.0	3.3	47.2	41.3	42.8	43.8

Table A.6. 2023 TSI-Combined data for Smith Mountain Lake sample stations (cont.)

M5	5	13.4	3.3	3.1	41.6	42.2	43.6	42.4
R7	7	13.6	4.4	3.0	41.8	45.1	44.2	43.7
R9	9	19.9	4.7	2.3	47.3	45.8	48.3	47.1
R11	11	15.1	5.3	2.0	43.3	46.9	49.7	46.7
R13	13	19.4	9.4	1.9	46.9	52.6	50.6	50.0
R14	14	18.0	8.5	1.9	45.8	51.6	50.6	49.3
R15	15	20.2	9.2	1.7	47.5	52.4	52.3	50.7
R17	17	32.4	16.0	1.5	54.3	57.8	53.8	55.3
R19	19	32.4	20.3	1.4	54.3	60.1	55.4	56.6
R21	21	34.2	21.8	1.3	55.1	60.8	56.8	57.6
R23	23	36.3	15.9	1.3	55.9	57.8	55.9	56.5
R25	25	38.9	22.2	1.3	57.0	61.0	56.8	58.3
R27	27	68.9	15.4	1.2	65.2	57.4	57.8	60.1
R29	29	58.6	16.3	1.1	62.9	58.0	58.3	59.7
R30	30	51.6	18.1	1.2	61.0	59.0	57.3	59.1
R31	31	45.9	8.7	0.9	59.3	51.8	61.9	57.7
Average		**29.0**	**11.1**	**2.0**	**50.9**	**51.9**	**51.8**	**51.5**

Table A.7. 2023 Secchi disk data for Smith Mountain Lake sample stations

Station	Sample Period 1	Sample Period 2	Sample Period 3	Sample Period 4	Sample Period 5	Sample Period 6	Station Avg.	Std. Dev.
	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	depth(m)	(m)	
B8	2.25	3.75	3.00	2.50	3.00	3.25	**2.96**	**0.53**
B10	2.25	3.25	2.75	2.25	3.00	3.00	**2.75**	**0.42**
B12	2.00	1.25	1.50	2.00	2.00	2.00	**1.79**	**0.33**
B14	2.25	2.00	1.50	1.50	1.50	1.50	**1.71**	**0.33**
B16	1.75	1.50	1.25	1.25	1.00	1.50	**1.38**	**0.26**
B18	1.00	1.00	0.75	1.00	1.00	1.25	**1.00**	**0.16**
B20	1.00	0.75	0.75	1.00	1.00	1.25	**0.96**	**0.19**
B22	0.75	0.75	0.75	0.75	0.50	1.00	**0.75**	**0.16**
C4	2.50	3.50	3.25	3.50	3.75	3.25	**3.29**	**0.43**
C5	2.50	3.50	4.25	3.75	4.00	3.25	**3.54**	**0.62**
C6	2.50	3.00	4.00	3.75	3.25	3.00	**3.25**	**0.55**
CB11	2.00	1.50	1.75	2.25	2.00	2.25	**1.96**	**0.29**
CB16	1.75	1.75	1.00	1.25	1.50	1.25	**1.42**	**0.30**
CB20	2.50	1.00	1.25	1.50	1.00	1.50	**1.46**	**0.56**
CM1	2.50	3.50	3.50	3.50	3.50	3.75	**3.38**	**0.44**
CM1.2	2.75	3.25	3.75	3.75	3.75	3.50	**3.46**	**0.40**
CM5	2.50	2.75	3.00	2.75	3.00	2.75	**2.79**	**0.19**
CR8	2.25	3.25	2.50	2.75	3.00	2.75	**2.75**	**0.35**
CR9	2.50	2.50	2.00	2.50	1.75	2.00	**2.21**	**0.33**
CR9.2	2.50	2.50	2.25	2.50	1.75	2.25	**2.29**	**0.29**
CR13	2.25	1.75	1.75	2.25	1.50	1.75	**1.88**	**0.31**
CR14.2	1.75	1.75	1.75	1.75	1.75	1.50	**1.71**	**0.10**
CR16	1.50	1.50	1.50	1.75	1.75	1.75	**1.63**	**0.14**
CR17	1.25	1.50	1.50	1.75	1.50	1.50	**1.50**	**0.16**
CR19	1.25	1.25	1.50	1.50	1.25	1.25	**1.33**	**0.13**
CR21	1.50	1.25	1.25	1.25	1.00	1.00	**1.21**	**0.19**
CR21.2	1.50	1.50	1.25	1.50	1.00	1.00	**1.29**	**0.25**
CR22	1.25	1.25	1.25	1.25	1.25	1.00	**1.21**	**0.10**
CR24	1.00	1.00	0.75	1.25	0.75	0.75	**0.92**	**0.20**
CR25	1.25	1.25	1.00	1.25	1.00	1.00	**1.13**	**0.14**
CR26	1.00	1.25	0.75	1.00	0.75	0.75	**0.92**	**0.20**
G12	2.00	1.50	1.75	2.00	2.00	2.00	**1.88**	**0.21**
G13	2.00	2.25	1.75	2.50	2.25	2.50	**2.21**	**0.29**
G14	2.00	2.50		2.00	1.75		**2.06**	**0.31**
G15	1.75	2.00	1.50	2.00	2.00	2.25	**1.92**	**0.26**
G16	1.75	2.00		1.50	1.75		**1.75**	**0.20**
G18	1.25	1.25		1.25	1.25		**1.25**	**0.00**
M0	2.50	3.75	3.75	3.75	3.50	4.00	**3.54**	**0.53**
M1	2.75	3.25	3.75	3.00	3.25	3.75	**3.29**	**0.40**
M3	2.75	3.25	3.75	3.50	3.50	3.25	**3.33**	**0.34**

Table A.7. 2023 Secchi disk data for Smith Mountain Lake sample stations (cont.)

M5	2.50	3.00	3.50	3.25	3.00	3.50	**3.13**	**0.38**
R7	2.50	3.25	3.00	3.00	3.25	3.00	**3.00**	**0.27**
R9	2.50	2.50	2.00	2.25	2.00	2.25	**2.25**	**0.22**
R11	2.25	1.75	2.00	2.00	2.00	2.25	**2.04**	**0.19**
R13	2.25	1.75	2.00	2.25	1.50	1.75	**1.92**	**0.30**
R14	1.75	1.75	2.00	2.25	2.00	1.75	**1.92**	**0.20**
R15	1.50	1.75	1.75	1.75	1.75	1.75	**1.71**	**0.10**
R17	1.50	1.50	1.50	1.75	1.75	1.25	**1.54**	**0.19**
R19	1.25	1.50	1.50	1.50	1.25	1.25	**1.38**	**0.14**
R21	1.50	1.50	1.25	1.25	1.00	1.00	**1.25**	**0.22**
R23	1.25	1.50	1.25	1.25	1.50	1.25	**1.33**	**0.13**
R25	1.25	1.50	1.25	1.25	1.25	1.00	**1.25**	**0.16**
R27	1.25	1.50	1.25	1.00	1.00	1.00	**1.17**	**0.20**
R29	1.25	1.25	1.25	1.00	1.00	1.00	**1.13**	**0.14**
R30	1.25	1.50	1.25	1.00	1.00	1.25	**1.21**	**0.19**
R31	0.75	0.75	1.00	1.25	0.50	1.00	**0.88**	**0.26**
SB12	2.25	1.75	1.50	2.00	2.25	2.00	**1.96**	**0.29**
SCB 8	2.50	3.00	3.00	2.75	3.00	3.25	**2.92**	**0.26**
SCB10	2.50	2.50	2.50	2.75	2.50	2.75	**2.58**	**0.13**
SCB11	2.25	3.00	2.75	2.75	2.75	2.75	**2.71**	**0.25**
SCB11.5	2.25	2.75	2.25	2.50	2.25	2.75	**2.46**	**0.25**
SCB14	1.75	1.75	1.25	1.75	1.75	1.50	**1.63**	**0.21**
SCB16	1.25	1.50	1.00	1.75	1.50	1.25	**1.38**	**0.26**
SCM5	3.00	3.25	2.75	2.75	3.00	3.25	**3.00**	**0.22**
SCR7	2.50	3.25	2.25	2.75	3.50	3.00	**2.88**	**0.47**
SCR8	2.25	2.75	2.50	2.50	2.75	2.75	**2.58**	**0.20**
SCR10.1	1.50	2.50	2.00	2.25	2.50	2.50	**2.21**	**0.40**
SCR10.2	1.75	2.50	2.25	2.25	2.25	2.25	**2.21**	**0.25**
SCR10.3	1.50	2.25	2.25	2.25	2.25	2.00	**2.08**	**0.30**
SCR11.1	1.75	1.75	1.75	2.00	2.25	1.75	**1.88**	**0.21**
SCR11.2	1.75	2.00	2.00	2.25	2.00	1.75	**1.96**	**0.19**
SCR11.3	1.75	1.75	2.00	2.25	1.75	1.50	**1.83**	**0.26**
SCR14	1.75	2.00		2.25	1.50	1.75	**1.85**	**0.29**
SCR14.1	1.50	1.50		2.00	1.50	1.50	**1.60**	**0.22**
SCR14.2	1.50	1.75		2.00	1.50	1.50	**1.65**	**0.22**
SCR14.3	1.50	1.50		2.25	1.50	1.75	**1.70**	**0.33**
SCR15	2.00	2.00	1.75	2.00	1.75	1.50	**1.83**	**0.20**
SCR 15.1	1.50	1.50		2.00	1.25	1.50	**1.55**	**0.27**
SCR 15.2	1.75	1.50		2.00	1.75	1.75	**1.75**	**0.18**
SCR17	1.50	1.50	1.50	1.50	1.50	1.25	**1.46**	**0.10**
SCR17.1	1.50	1.75	1.75	1.25	1.50	1.50	**1.54**	**0.19**
SCR18	1.50	1.75	1.75	1.75	1.50	1.25	**1.58**	**0.20**

Table A.7. 2023 Secchi disk data for Smith Mountain Lake sample stations (cont.)

SCR19.2	1.75	1.75	1.50	1.50	1.50	1.25	**1.54**	**0.19**
SCR20	1.75	1.75	1.75	1.75	1.50	1.25	**1.63**	**0.21**
AVG.	**1.84**	**2.02**	**1.96**	**2.04**	**1.93**	**1.95**	**1.96**	
STD. DEV.	**0.53**	**0.78**	**0.87**	**0.74**	**0.84**	**0.84**		**0.77**

Figure A.3. Smith Mountain Lake depth profiling sites

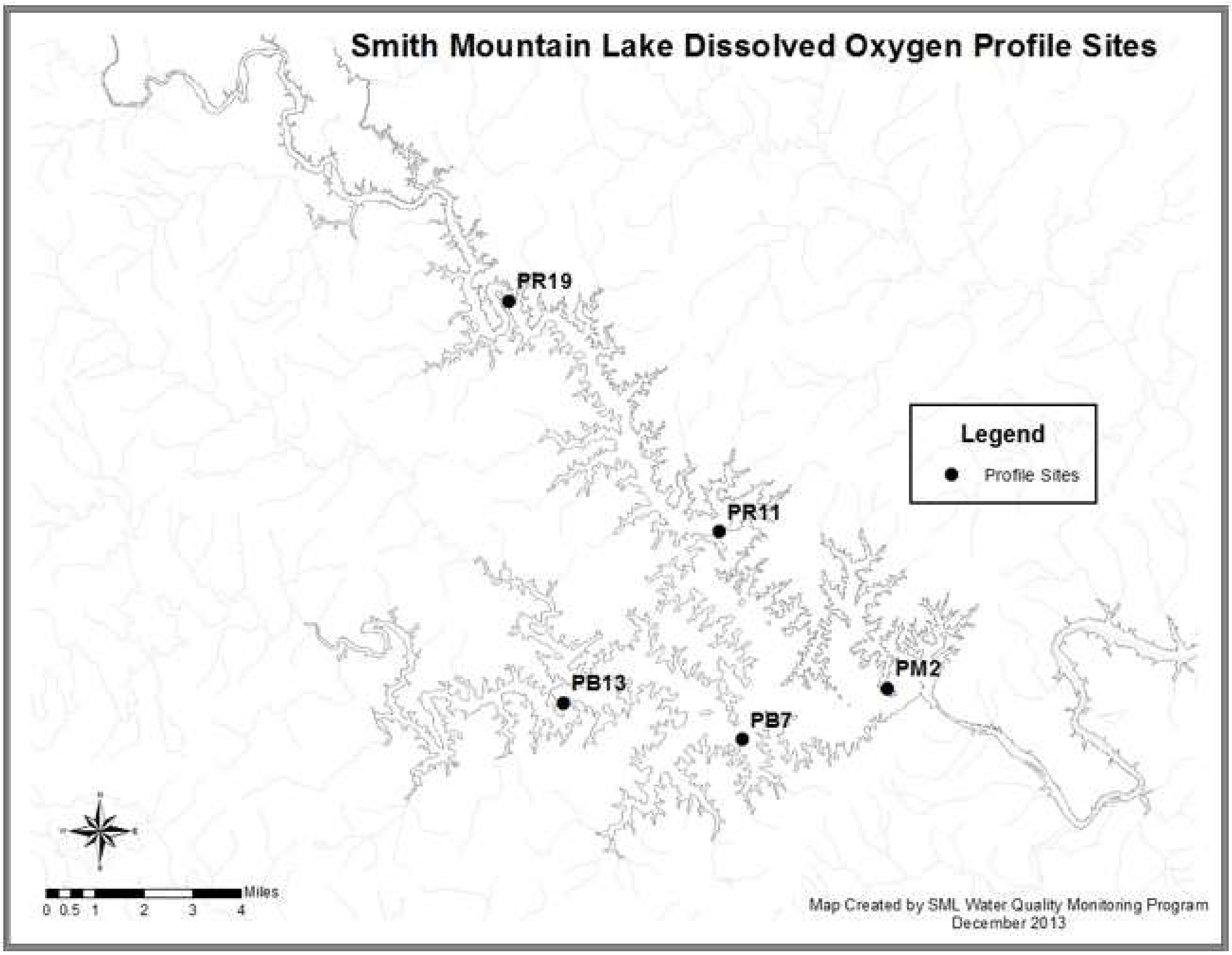

Figure A.4. Smith Mountain Lake bacterial sampling sites

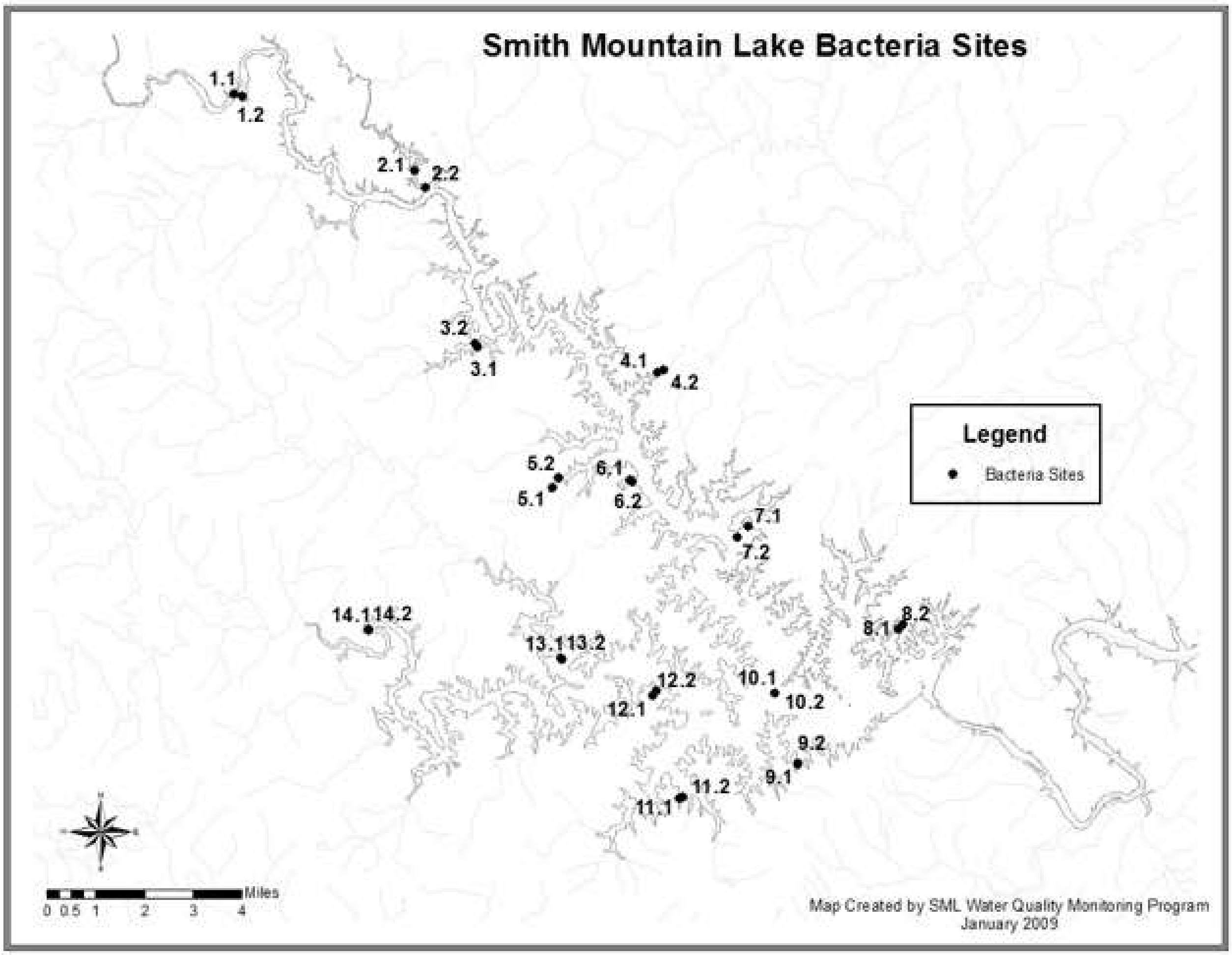

Table A.8. Smith Mountain Lake bacterial monitoring sites

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. 2023 *E. coli* data for Smith Mountain Lake sample stations. MPN = most probable number.

Station	Sample Period 1	Sample Period 2	Sample Period 3	Sample Period 4	Sample Period 5	Sample Period 6	Station Avg.	Std. Dev.
	MPN	MPN	MPN	MPN	MPN	MPN	MPN	
1-1	4.1	46.4	27.9	9.7	90.8	12.1	**31.8**	**32.7**
1-2	11.9	26.5	54.6	30.5	98.7	6.3	**38.1**	**34.2**
2-1	2.0	0.0	7.5	1.0	1.0	4.1	**2.6**	**2.8**
2-2	0.0	0.0	55.4	5.2	1.0	0.0	**10.3**	**22.2**
3-1	1.0	3.0	59.4	2.0	2.0	0.0	**11.2**	**23.6**
3-2	0.0	2.0	5.2	1.0	3.1	1.0	**2.1**	**1.9**
4-1	137.6	7.5	71.7	2.0	18.7	11.9	**41.6**	**53.4**
4-2	3.1	12.0	79.8	1.0	6.3	8.5	**18.5**	**30.3**
5-1	14.5	52.1	816.4	57.1	27.5	30.1	**166.3**	**318.9**
5-2	7.4	14.2	727.0	34.1	12.1	19.3	**135.7**	**289.8**
6-1	1.0	3.0	24.1	4.1	0.0	7.3	**6.6**	**9.0**
6-2	0.0	1.0	13.4	2.0	1.0	1.0	**3.1**	**5.1**
7-1	1.0	0.0	4.1	0.0	0.0	1.0	**1.0**	**1.6**
7-2	1.0	1.0	6.3	0.0	0.0	0.0	**1.4**	**2.5**
8-1	3.1	1.0	107.1	2.0	2.0	135.4	**41.8**	**62.2**
8-2	2.0	1.0	85.7	0.0	1.0	17.3	**17.8**	**33.9**
9-1	10.7	22.6	52.9	3.1	7.4	4.1	**16.8**	**19.0**
9-2	6.3	4.1	37.4	5.2	5.1	3.0	**10.2**	**13.4**
10-1	1.0	0.0	0.0	1.0	1.0	0.0	**0.5**	**0.5**
10-2	1.0	0.0	3.1	0.0	1.0	0.0	**0.9**	**1.2**
11-1	4.1	3.1	365.4	5.2	23.3	19.3	**70.1**	**144.9**
11-2	25.9	3.1	261.3	3.1	13.5	95.9	**67.1**	**101.3**
12-1	12.1	3.1	172.3	2.0	8.6	12.0	**35.0**	**67.4**
12-2		2.0	37.3	5.2	3.1	3.1	**10.1**	**15.2**
13-1	1.0	0.0	18.5	8.6	4.1	0.0	**5.4**	**7.2**
13-2	1.0	2.0	15.3	2.0	40.4	1.0	**10.3**	**15.8**
14-1	6.3	71.2	16.0	35.4	29.4	6.3	**27.4**	**24.5**
14-2	5.2	95.9	17.3	27.5	38.8	7.2	**32.0**	**33.8**
Average	**9.8**	**13.5**	**112.2**	**8.9**	**15.7**	**14.5**	**29.1**	
St. Dev.	**26.2**	**24.1**	**203.9**	**14.2**	**25.3**	**30.0**		54.0

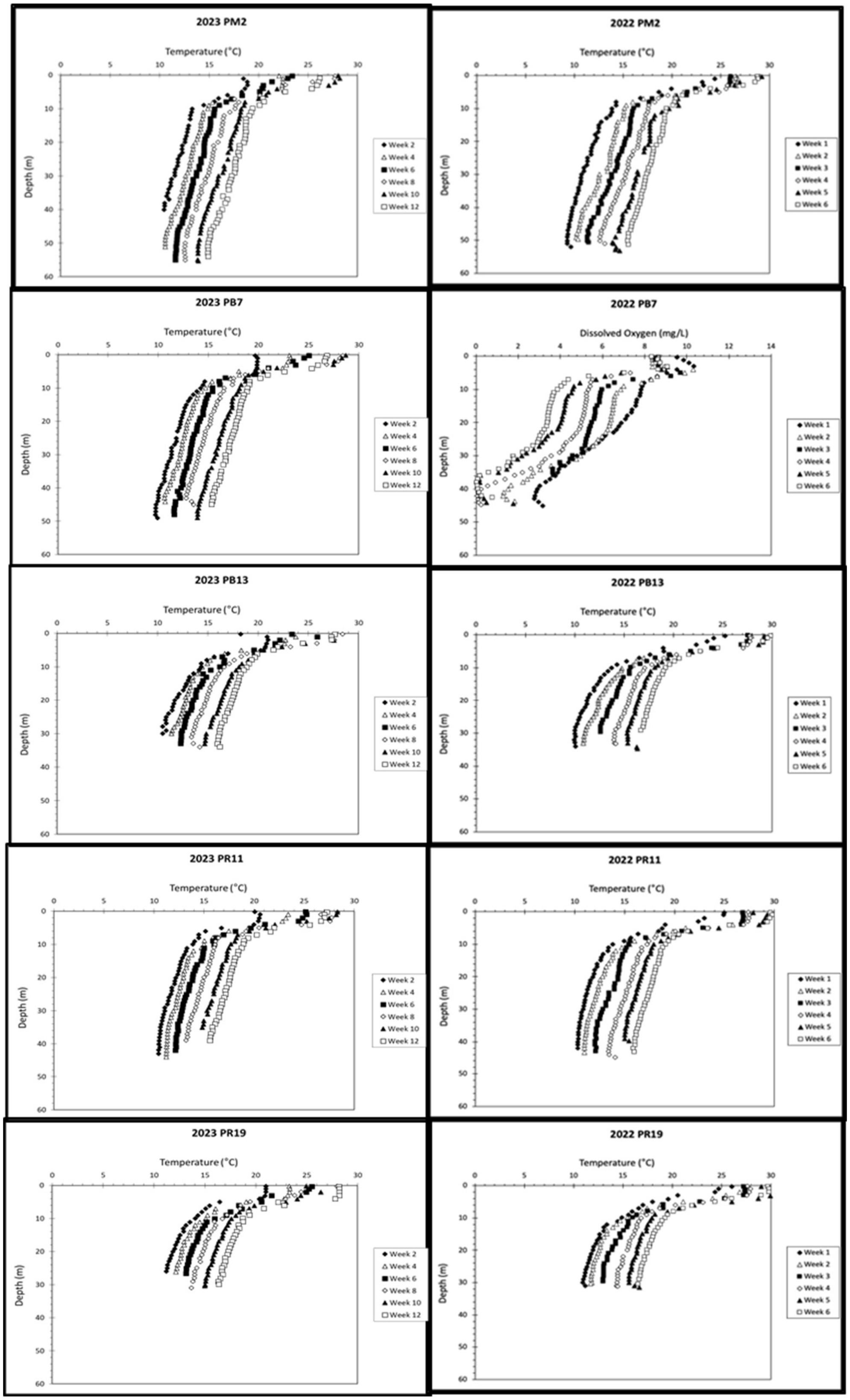

Figure A.5. Temperature depth profiles for Smith Mountain Lake in 2022 and 2023

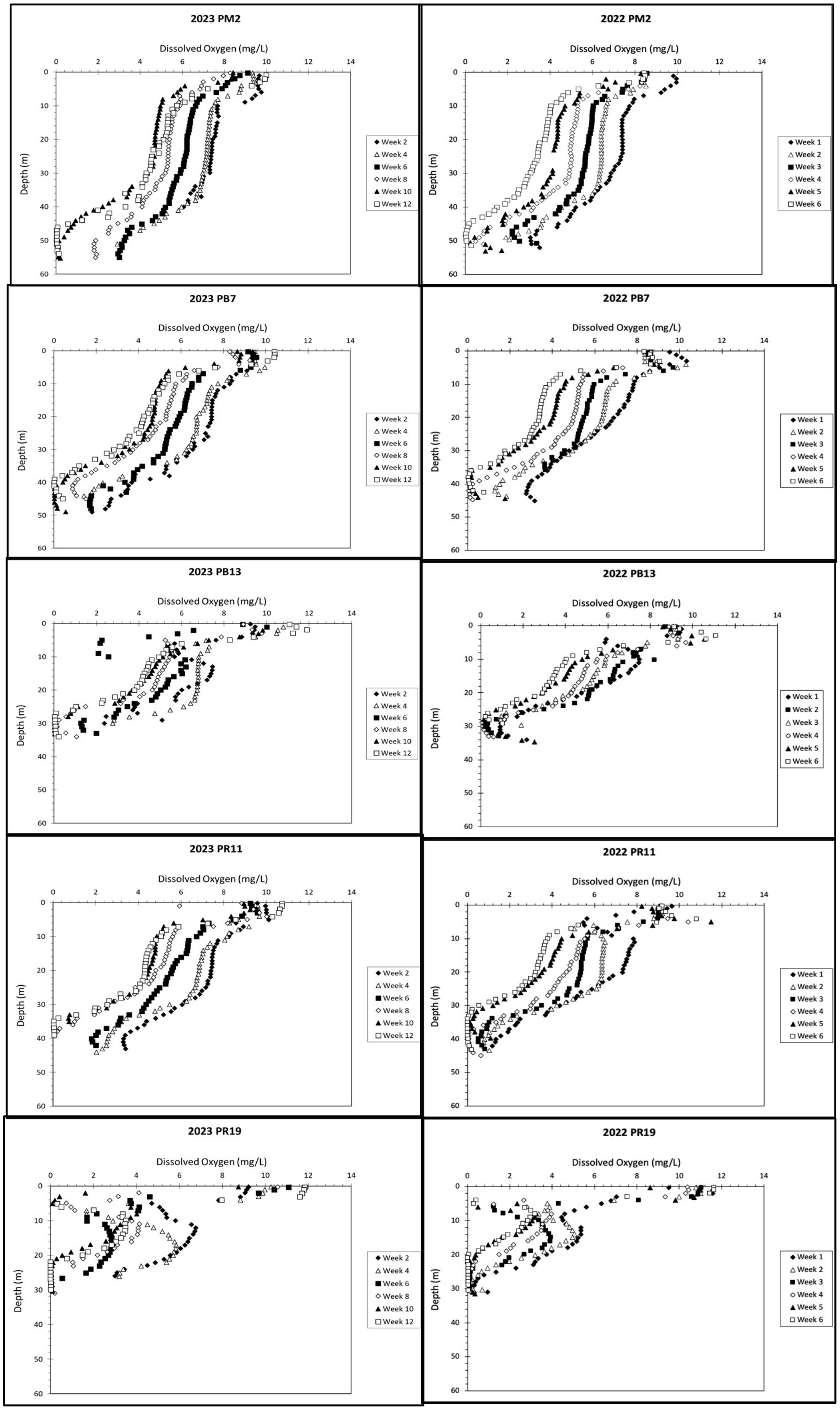

Figure A.6. Dissolved oxygen depth profiles for Smith Mountain Lake in 2022 and 2023

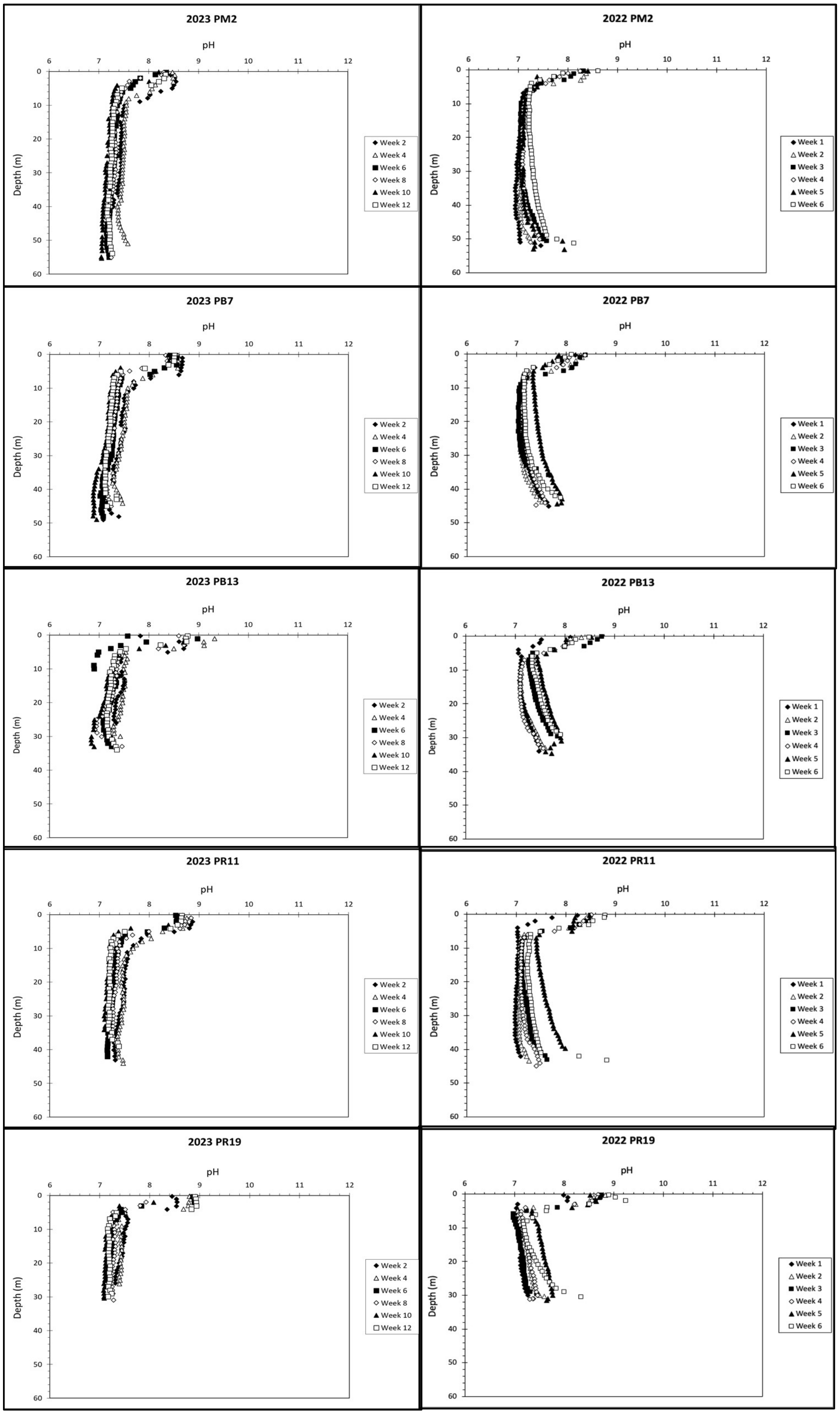

Figure A.7. pH depth profiles for Smith Mountain Lake in 2022 and 2023

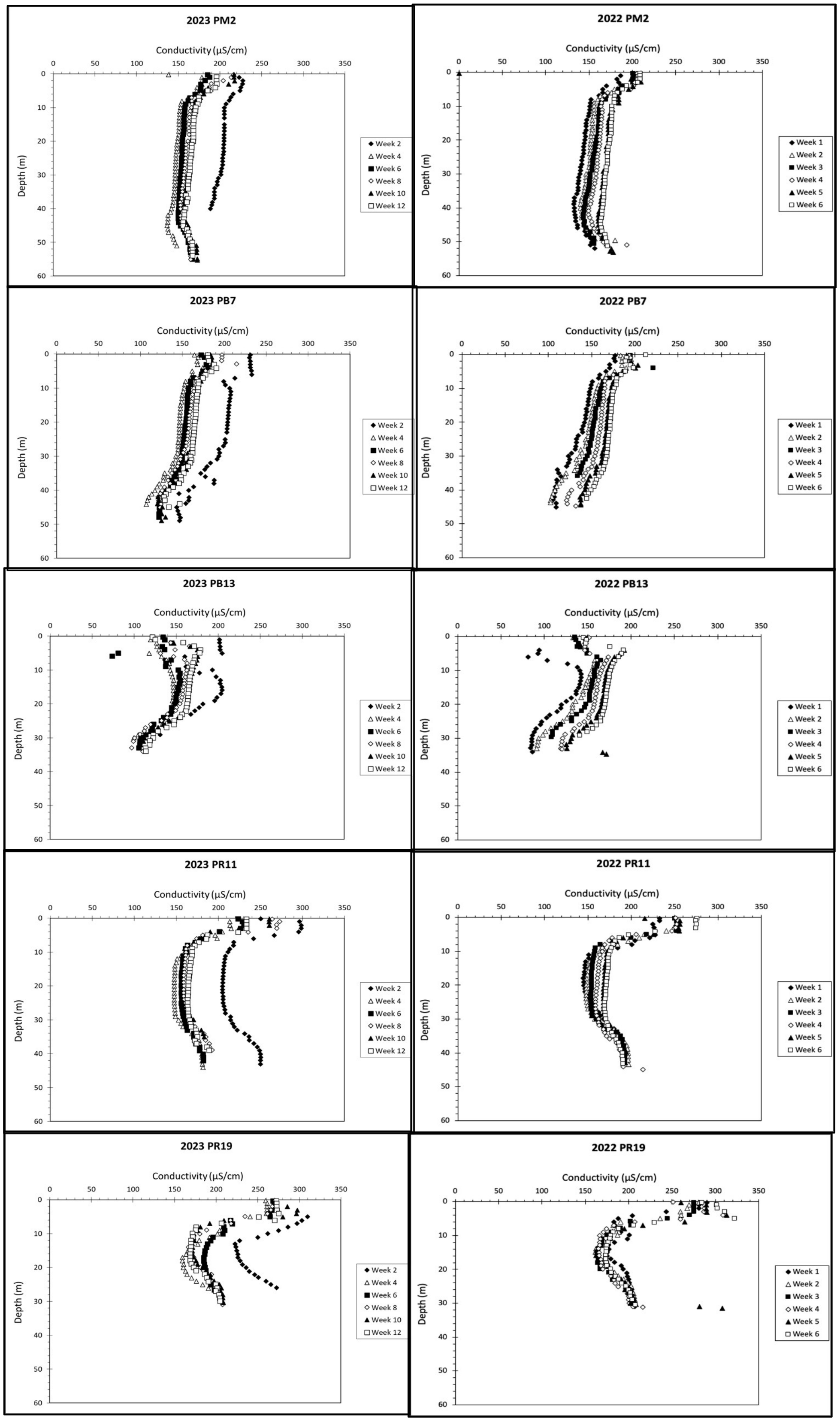

Figure A.8. Conductivity depth profiles for Smith Mountain Lake in 2022 and 2023