Appalachian Power
Hydro Generation
P O Box 2021
Roanoke, VA 24022-2121
aep.com

Ms. Kimberly Bose, Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington DC 20426

VIA ELECTRONIC FILING

May 11, 2023

Re: Smith Mountain Project No. 2210
Water Quality Monitoring Plan
2022 Annual Water Quality Monitoring Report

Dear Secretary Bose:

In accordance with the Water Quality Monitoring Plan (WQMP) for the Smith Mountain Hydroelectric Project (Project), Appalachian Power Company (Appalachian) is to file an annual report of the water quality monitoring results of the previous year. Enclosed is the 2022 Annual Water Quality Monitoring Report. A draft of the annual report was provided to the Water Quality Technical Review Committee (WQTRC) via email attachment on March 14, 2023. Comments were received from the Leesville Lake Association (LLA) and the Tri-County Lakes Administrative Commission (TLAC) via email attachment on April 5, 2023 and April 13, 2023, respectively. TLAC's comments were general in nature and not specific to the draft report. LLA's comments are addressed below. Documentation of consultation is attached.

In addition, the WQMP requires that the WWTRC meet at least once per year to review the monitoring results. During a meeting on January 31, 2023 between Appalachian and LLA representatives, LLA requested that a WQTRC meeting be held to discuss the 2022 water quality monitoring results with several limnologists. Therefore, on March 1, 2023, a meeting was held at Appalachian's facility in Rocky Mount, Virginia, which attendees joined both in-person and virtually online. A second WQTRC meeting was held at the same location on April 21, 2023 to again review the 2022 water quality monitoring results, to discuss LLA comments on the draft report, to update the WQTRC on the status of dissolved oxygen (DO) enhancement feasibility study, and for the Virginia Department of Environmental Quality (VDEQ) representatives to discuss the Virginia Water Protection (VWP) permitting process. Again, attendees joined the meeting both in-person and virtually online.

<u>LLA comments</u>

Comment 1

> Leesville Lake Association appreciates the opportunity to comment on the "SMITH MOUNTAIN HYDROELECTRIC PROJECT 2022 Annual Water Quality Monitoring Report ". The articulation of the Dissolved Oxygen challenges is well documented and continues to show that Appalachian Power Company (APCo) is not meeting its operating license requirements regarding the minimal DO content permissible in water released during SML dam operations. Table 4.3 (page 27) provides the best snapshot of this noncompliance.

Table 4.3 Annual Percentage of Time Instantaneous and Daily Average DO Standards Met During Generation (page 27)

Year	% Time Instantaneous DO Standard Met (4.0 mg/L)	% Time Daily Average DO Standard Met (5.0 mg/L)
2015	75%	83%
2016	87%	60%
2017	97%	48%
2018	60%	47%
2019	66%	37%
2020	69%	40%
2021	81%	60%
2022	76%	42%

In 2022 Appalachian Power Company (APCo) average DO values were consistently below 5.0 mg/l between 25 July and 15 October 2022 (Permit lower DO boundary).

Response 1

As discussed during the April 21, 2023 WQTRC meeting, the percentages in Table 4.3 of the report serve as a general comparison between monitoring years. However, due to refinements in monitoring equipment and methodologies over time, data gaps have been significantly reduced since 2020. Data gaps occurring in any given year from mid-July through September (i.e., the warmest air temperature period during stratified conditions in Smith Mountain Lake) would skew the percentages higher. Conversely, data gaps occurring in any given year during the cooler months of the monitoring season would skew the percentages lower. Thus, an absolute comparison of the percentages requires matching periods between any two or more years without data gaps. The dates when the instantaneous and daily average DO concentrations were below the Virginia state standards are included in tabular format in each annual report.

Comment 2

APCo has been studying the DO issue for 14 years. APCO is currently in the middle of Phase 3 of their Feasibility Study, which will:

1) evaluate the practicality, effectiveness and cost efficiency of methods that increases dissolved oxygen in the tailrace without causing other water quality issues (e.g., increased water temperature).
2) Determine life cycle costs and decide whether to act, or not.

APCo has indicated that results of the Phase 3 Feasibility Study will be made available at the 21 April 2023 WQ TRC. LLA recommends that those results be documented in this Annual Report Pursuant to bullet 5 in the Recommendations (page 33) "Continue to evaluate engineering measures that are feasible to enhance DO in the Project tailwater".

Response 2

The DO enhancement feasibility study presented during the April 21, 2023 meeting has been added to the report as Appendix C.

Comment 3

> Appalachian's VDEQ Virginia Water Protection Individual Permit No 08-0572 (Permit) expires on March 31, 2025. LLA believes APCo's resolution of the DO challenge should be central to whether Permit 08- 0572 is renewed, or not.

Response 3

As stated above, representatives from the VDEQ discussed the VWP permitting process during the WQTRC meeting held on April 21, 2023. The LLA representative at the meeting directly questioned the VDEQ representatives and provided comments regarding Appalachian's VWP permit. The LLA representatives, in turn, provided direct responses to the LLA representative.

Comment 4

> Additionally, (page 27) there are conflicting statements and lack of data in the "First on-Last Off" operational scenarios. In 2018 unit 5 was not operational and as a result compliance with DO standards worsened. It would seem lack of operation of unit 5 would increase compliance as it is lowest in the water column and along with unit 1 operated at a minimum to improve DO and compliance. The report hypothesizes it is actually the return of oxygenated water from Unit 5 that improves DO in SML and thus improves overall DO. This is antithetical to the idea of 'first on first off'. Page 19 does acknowledge that "First on-Last Off' operating regime does not result in achieving the standards every year.
>
> Recommend that Bullet 1 of the Summary and Recommendations (page 33) incorporate additional data collection and analysis to validate the "First on -Last Off' operating regime to achieve DO goals.

Response 4

As discussed during the WQTRC meeting held on April 21, 2023, the operational procedure whereby Units 2, 3, and 4 are the first units to be turned on and the last units to be turned off during the months of July through September at the Smith Mountain powerhouse is specified in the approved Water Quality Monitoring Plan (WQMP). The purpose of this operational procedure in the WQMP is to maximize the percentage of water from the upper portion of the forebay water column (i.e., where DO concentrations are higher) within the Project discharge during generation. The different intake elevations for the units and their relative depth in the forebay water column was further explained by Appalachian representatives during the meeting. Therefore, the LLA's suggested edit to Section 5.0 of the draft report were not made.

Comment 5

> Additionally, two other scenarios are suggested to influence compliance rates both through regression: Annual precipitation and air temperature (pages 28 and 29). Correlations are provided to suggest these scenarios do impact the compliance rate. This suggests environmental factors are influential and must be incorporated into the Phase 3 Feasibility study and ways to improve compliance rather than just turbine engineering.

Response 5

As stated above, the LLA's comment were received prior to the WQTRC meeting held on April 21, 2023. An update to the DO enhancement feasibility study was given during the meeting. Appalachian acknowledges that multiple environmental factors affect DO concentrations in the Smith Mountain Dam tailwater, and pages 28 and 29 in the draft report cover precipitation and air temperature as environmental factors. However, since environmental factors are naturally occurring, they are not incorporated into engineering measures that are considered feasible to enhance DO concentrations at a hydroelectric facility.

Appalachian believes this to be a complete and timely filing of the 2022 Annual Water Quality Monitoring Report. If you have any additional questions or require additional information, please contact me at 540-985-2984 or esbrennan@aep.com.

Sincerely,

Edward S. Brennan
Plant Environmental Coordinator Principal

Attachment

Enclosure

Cc: Liz Parcell, American Electric Power
Kristina Sage, Tri-County Lakes Administrative Commission
Tom Hardy, Smith Mountain Lake Association
Charlie Hamilton, Leesville Lake Association
Dan Wilson, Virginia Department of Wildlife Resources
Joe Grist, Virginia Department of Environmental Quality (VDEQ)
Mary Dail, VDEQ
George Devlin, VDEQ
Jason Hill, VDEQ
Tom Shahady, University of Lynchburg
Delia Heck, Ferrum College

From:	cshamilton2@gmail.com
To:	Edward S Brennan; mary.dail@deq.virginia.gov; George.Devlin@deq.virginia.gov; jason.hill@deq.virginia.gov; "Joe Grist"; thardy8@verizon.net; ksage.tlac@sml.us.com; wqc@leesvillelake.org; shahady@lynchburg.edu; dheck@ferrum.edu; "Wilson, Daniel (DWR)"; "Revelle, Leah (DEQ)"
Cc:	Elizabeth B Parcell; Anna E Painter; "Dave Czayka"; "Dave Rives"
Subject:	[EXTERNAL] RE: Draft 2022 Smith Mountain Project Water Quality Report
Date:	Wednesday, April 5, 2023 12:17:45 PM
Attachments:	image001.png Signed LLA Comments on APCo 2022 Annual WQ Report 5 April 2023.pdf

Ed, Many thanks for the opportunity to comment on the Draft 2022 Smith Mountain Project Water Quality Report. Attached are LLA comments.

I hope you and your family have a Happy Easter. Thanks Charlie

---

From: Edward S Brennan <esbrennan@aep.com>
Sent: Tuesday, March 14, 2023 4:21 PM
To: mary.dail@deq.virginia.gov; George.Devlin@deq.virginia.gov; jason.hill@deq.virginia.gov; Joe Grist <joseph.grist@deq.virginia.gov>; thardy8@verizon.net; ksage.tlac@sml.us.com; wqc@leesvillelake.org; shahady@lynchburg.edu; dheck@ferrum.edu; Wilson, Daniel (DWR) <Dan.Wilson@dwr.virginia.gov>; Revelle, Leah (DEQ) <Leah.Revelle@deq.virginia.gov>
Cc: Elizabeth B Parcell <ebparcell@aep.com>; Anna E Painter <aepainter@aep.com>; Dave Czayka <dczayka@enviroscienceinc.com>
Subject: Draft 2022 Smith Mountain Project Water Quality Report

All,

Please find attached the draft 2022 Smith Mountain Project Water Quality Report. Please provide me with your review comments by April 13, 2022. Much of the figures and tables you will recognize from the slides presented during the meeting at Appalachian's Rocky Mount Service Center on March 1, 2023. If you have no comments, kindly reply as well so that Appalachian Power may prepare the final report at the earliest possible date.

Thank you,

Ed Brennan

AMERICAN ELECTRIC POWER
BOUNDLESS ENERGY

EDWARD S BRENNAN | **PLANT ENVIRONMENTAL COORD PRIN**
ESBRENNAN@AEP.COM | D:540.985.2984
40 FRANKLIN ROAD SW, ROANOKE, VA 24011

5 April 2023

Leesville Lake Association appreciates the opportunity to comment on the "SMITH MOUNTAIN HYDROELECTRIC PROJECT 2022 Annual Water Quality Monitoring Report". The articulation of the Dissolved Oxygen challenges is well documented and continues to show that Appalachian Power Company (APCo) is not meeting its operating license requirements regarding the minimal DO content permissible in water released during SML dam operations. Table 4.3 (page 27) provides the best snapshot of this noncompliance.

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In 2022 Appalachian Power Company (APCo) average DO values were consistently below 5.0 mg/l between 25 July and 15 October 2022 (Permit lower DO boundary).

APCo has been studying the DO issue for 14 years. APCO is currently in the middle of Phase 3 of their Feasibility Study, which will:

1) evaluate the practicality, effectiveness and cost efficiency of methods that increases dissolved oxygen in the tailrace without causing other water quality issues (e.g., increased water temperature).
2) Determine life cycle costs and decide whether to act, or not.

APCo has indicated that results of the Phase 3 Feasibility Study will be made available at the 21 April 2023 WQ TRC. LLA recommends that those results be documented in this Annual Report Pursuant to bullet 5 in the Recommendations (page 33) "Continue to evaluate engineering measures that are feasible to enhance DO in the Project tailwater".

5.0 Summary and Recommendations: (Page 33)

Improvements to both the implementation and monitoring of the DO enhancement operational regime have occurred at Smith Mountain Lake. These improvements have resulted in providing DO enhancement in the Smith Mountain Dam discharge. However, as stated in previous annual water quality reports, the current enhancement measures are not sufficient to achieve the DO standards in the Project tailwater at all times and under all operational scenarios during the monitoring period. Several recommendations suggested for 2023 are provided below:

- Continue to use the "first on, last off" operating protocol from July 1 to November 15.
- Continue to follow the monitoring period of June 1 through December 1, as agreed upon by the WQTRC, to target the time of year when DO concerns are likely to occur.
- Continue with the procedures implemented to ensure the stilling basins are free from debris.
- Continue to evaluate historical data to establish correlations between environmental and operational factors and DO in the Project tailwater.
- Continue to evaluate engineering measures that are feasible to enhance DO in the Project tailwater

Appalachian's VDEQ Virginia Water Protection Individual Permit No 08-0572 (Permit) expires on March 31, 2025. LLA believes APCo's resolution of the DO challenge should be central to whether Permit 08-0572 is renewed, or not.

Additionally, (page 27) there are conflicting statements and lack of data in the "First on-Last Off" operational scenarios. In 2018 unit 5 was not operational and as a result compliance with DO standards worsened. It would seem lack of operation of unit 5 would increase compliance as it is lowest in the water column and along with unit 1 operated at a minimum to improve DO and compliance. The report hypothesizes it is actually the return of oxygenated water from Unit 5 that improves DO in SML and thus improves overall DO. This is antithetical to the idea of 'first on first off'. Page 19 does acknowledge that "First on-Last Off" operating regime does not result in achieving the standards every year.

> "The primary goal of the DO monitoring effort is to assess whether the operational modifications implemented at the Project are effective at maintaining DO levels in the Project discharge. As discussed above, the implemented operational measures consist of a "first on, last off" mode of operation during the July through mid-November period, where Units 2, 3, and 4 are the first to operate followed by Units 1 and 5, respectively. Units are then shutdown in reverse order. While these modified operations have been successful in achieving the desired result, there is an ongoing learning process on how to implement the operational modifications within generation obligations. Therefore, while there has been some success in achieving DO goals, this operating regime does not result in achieving the standards every year."

Recommend that Bullet 1 of the Summary and Recommendations (page 33) incorporate additional data collection and analysis to validate the "First on –Last Off" operating regime to achieve DO goals.

Additionally, two other scenarios are suggested to influence compliance rates both through regression: Annual precipitation and air temperature (pages 28 and 29). Correlations are provided to suggest these scenarios do impact the compliance rate. This suggests environmental factors are influential and must be incorporated into the Phase 3 Feasibility study and ways to improve compliance rather than just turbine engineering.

Thank you for the opportunity to comment on the "SMITH MOUNTAIN HYDROELECTRIC PROJECT 2022 Annual Water Quality Monitoring Report".

Charlie Hamilton
Chair, Leesville Lake Association
Water Quality Committee

Edward S Brennan

From: ksage.tlac@sml.us.com
Sent: Thursday, April 13, 2023 1:17 PM
To: Edward S Brennan; mary.dail@deq.virginia.gov; George.Devlin@deq.virginia.gov; jason.hill@deq.virginia.gov; 'Joe Grist'; thardy8@verizon.net; wqc@leesvillelake.org; shahady@lynchburg.edu; dheck@ferrum.edu; 'Wilson, Daniel (DWR)'; 'Revelle, Leah (DEQ)'
Cc: Elizabeth B Parcell; Anna E Painter; 'Dave Czayka'
Subject: [EXTERNAL] RE: Draft 2022 Smith Mountain Project Water Quality Report

Hello Ed,

TLAC appreciates the opportunity to comment on the Smith Mountain Hydroelectric Project 2022 Annual Water Quality Monitoring Report. The ongoing programs of Appalachian Power, the Smith Mountain Lake Association in conjunction with Ferrum College, and the Leesville Lake Association in conjunction with University of Lynchburg provide comprehensive water quality monitoring programs. The legacy data and continued refinement of the programs produce reliable and actionable results.

There are no questions regarding the Appalachian Power report. As noted in 1.1 Background, "15. The goal of the Plan's revised operating mode is to facilitate DO levels in the dam tailrace are meeting state standards,…" The TLAC board and lake communities look forward learning about feasible engineering measures to reduce the occurrence of insufficient DO levels in Smith Mountain's turbine discharge as was one of the recommendations in the summary of the report. We are anxious to have improvements implemented.

Sincerely,

Kristina Sage
Executive Director
Tri-County Lakes Administrative Commission
400 Scruggs Road, Suite 200
Moneta, VA 24121
(540) 721-4400

TRI-COUNTY LAKES
ADMINISTRATIVE COMMISSION

From: Edward S Brennan <esbrennan@aep.com>
Sent: Tuesday, March 14, 2023 4:21 PM
To: mary.dail@deq.virginia.gov; George.Devlin@deq.virginia.gov; jason.hill@deq.virginia.gov; Joe Grist <joseph.grist@deq.virginia.gov>; thardy8@verizon.net; ksage.tlac@sml.us.com; wqc@leesvillelake.org; shahady@lynchburg.edu; dheck@ferrum.edu; Wilson, Daniel (DWR) <Dan.Wilson@dwr.virginia.gov>; Revelle, Leah (DEQ) <Leah.Revelle@deq.virginia.gov>
Cc: Elizabeth B Parcell <ebparcell@aep.com>; Anna E Painter <aepainter@aep.com>; Dave Czayka

<dczayka@envirosciencеinc.com>
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Thank you,

Ed Brennan

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SMITH MOUNTAIN HYDROELECTRIC PROJECT
2022 Annual Water Quality Monitoring Report

Prepared for:

APPALACHIAN POWER
An AEP Company

EnviroScience Project Number: 13361
Date: 2/28/2022

Prepared by:

EnviroScience
Excellence In Any Environment
1100 Athens Ave., Suite F
Richmond, VA 23227
800-940-4025
www.EnviroScienceInc.com

Smith Mountain Hydroelectric Project
Water Quality Monitoring Program (2022)

Prepared for:
Appalachian Power Company

EnviroScience Project Number: 13361
Document Date: 2/28/2022

Authorization for Release

The analyses, opinions, and conclusions in this document are based entirely on EnviroScience's unbiased, professional judgement. EnviroScience's compensation is not in any way contingent on any action or event resulting from this study.

The undersigned attest, to the best of their knowledge, that this document and the information contained herein is accurate and conforms to EnviroScience's internal Quality Assurance standards.

Cory Fox
Project Scientist

David Czayka
Manager of Regional Operations / Senior Aquatic Biologist

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APPENDICES

1.0 INTRODUCTION

License requirements associated with the Smith Mountain Hydroelectric Project (Project) require the licensee, Appalachian Power Company (Appalachian), to implement a Water Quality Monitoring Plan (Plan) as part of license Article 405. The order approving the Plan was issued on April 15, 2011. The Plan lists the following requirements:

1. Operate the turbines at Smith Mountain Dam from July 1 through September 30 to minimize or eliminate violations of water quality standards for dissolved oxygen (DO) in the tailwaters downstream from the Smith Mountain Dam, whereby the turbines with intakes that are highest in the water column are operated first and taken offline last.
2. Develop and file, in accordance with the requirements of Article 401(a) for Condition F.4 found in Part I of the Virginia Department of Environmental Quality's (Virginia DEQ) water quality certification (WQC), a feasibility study and plan for physical or mechanical alterations of water release procedures, developed in consultation with the Water Quality Technical Review Committee (WQTRC[1]), to address violations of water quality standards for DO caused by turbine discharge from Smith Mountain Lake, should the operating practices employed prove insufficient at improving DO levels in Smith Mountain's turbine discharge.
3. Monitor DO and water temperature in the tailrace of the Smith Mountain Development at the first bridge leading to the Visitors Center. The monitoring will be conducted for the first five years following issuance of the new license. For the first two years of monitoring, DO and temperature will be recorded continuously year-round. If after two years of data collection it is determined that year-round data is not warranted, the monitoring period would be reduced accordingly. (Note: as agreed to by the WQTRC during the annual meeting on June 5, 2014, the monitoring period was adjusted to include June 1 through December 1. This modified schedule was approved by FERC order dated October 21, 2015.)
4. Provide the WQTRC with the water quality data collected on a monthly (May 1 to October 31) and bi-monthly (November 1 to April 30) basis.
5. At least once per year during the five-year monitoring period, DO and temperature monitoring will be conducted along a transect just upstream of the Smith Mountain Dam, near the forebay. The forebay monitoring will be conducted during the generation mode and during the anticipated stratification period between the beginning of July and the end of September. Measurements will be taken at 2-meter intervals from the lake surface to the bottom of the lake at four locations across the transect.
6. Consult annually with the WQTRC. The WQTRC will meet at least once per year to review the monitoring results and discuss the success of the operational modifications in maintaining state standards for DO in the Project discharge water.

[1] The WQTRC consists of the Virginia Department of Wildlife Resources (formerly named Game and Inland Fisheries), Virginia DEQ, Tri-County Administrative Commission, Smith Mountain Lake Association, LLA, Ferrum College, and the University of Lynchburg.

7. Annually monitor, or arrange for the annual monitoring of, water quality on Smith Mountain and Leesville Lakes that (i) is consistent[2] with the programs implemented prior to the issuance of the current license by the Smith Mountain Lake Association (SMLA) and the Leesville Lake Association (LLA) and (ii) is developed in consultation with the Virginia Department of Wildlife Resources (Virginia DWR), the Virginia DEQ, the SMLA, the LLA, Ferrum College, and the University of Lynchburg.

   Smith Mountain Lake Monitoring Program

   - Monitor, or arrange for the monitoring of, water quality at 26 sites on Smith Mountain Lake. The sites correspond to locations included in the SMLA water quality monitoring program and are identified in the Plan. At these 26 sites, total phosphorus, chlorophyll-a, and secchi depth will be measured monthly between June 1 and September 30, for a total of four sampling events each year. At the same time, sampling for the bacteria *Escherichia coli* (*E. coli*) will be conducted at the fourteen sampling sites identified in the 2008 SMLA water quality monitoring plan.

   Leesville Lake Monitoring Program

   - Monitor, or arrange for the monitoring of, water quality on Leesville Lake. Sampling for total phosphorus, DO, and secchi depth will be monitored at six sites identified in the licensee's plan and chlorophyll-a will be monitored at three of those six sites. In addition, sampling for bacteria (*E. coli*) will be conducted at seven sites identified in the licensee's plan. The monitoring sites correspond to locations included in the LLA's water quality monitoring program for Leesville Lake. Sampling will occur monthly between May 1 and September 30, for a total of five sampling events each year.

8. Prepare annual reports of the water quality monitoring results of the previous year. The annual reports would include the following: all monitoring data; an analysis of the effects of power generation on DO levels in the Smith Mountain Tailrace; recommendations for continued monitoring or revisions to the following year's monitoring plan; a summary of other water quality monitoring results that have been completed outside of the Project license; and any other support documents including documentation of consultation with the WQTRC. The licensee will submit the reports to the WQTRC for a 30-day review and comment period and then file final reports with the Commission.

The approved Water Quality Monitoring Plan (Plan) for the Smith Mountain Project requires Appalachian Power Company, a unit of American Electric Power Company (AEP), to monitor dissolved oxygen (DO) levels and water temperatures at one location downstream of Smith Mountain Dam on the Roanoke River. The monitoring location downstream of Smith Mountain Dam is illustrated in Figure 1.1 Water quality data will be provided to the Water Quality/Water Management Technical Review Committee (TRC) monthly for data collected from June 1 to November 30. This annual report presents water quality monitoring data collected from June 1 – November 30, 2022 and is the 2022 annual report required by provision No. 8 above. This also addresses provision Nos. 1, 3, and 5. The monitoring results from provision No. 7 are

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[2] In the Commission's Final Environmental Impact Statement (FEIS) for the relicensing of the Project (issued August 7, 2009) staff defined the term consistent used in this context to mean that the licensee's water quality monitoring program for the lakes would, at a minimum, be similar to (or comparable to) the existing programs implemented by the SMLA and the LLA. The licensee's program would be conducted in such a way to facilitate the use of the data to establish long-term trends for nutrients and other measured parameters.

provided in Appendices A and B. With regard to the Smith Mountain Lake Monitoring Program, Article 405 identifies a monitoring program between June 1 and September 30 of each year. Article 405 further states that monitoring should be consistent with efforts conducted by SMLA prior to the issuance of the new license. As in the past, the 2022 monitoring efforts were conducted by SMLA in conjunction with Ferrum College. Also, consistent with recent years, the Smith Mountain Lake Monitoring Program was implemented between May 1 and August 31. While different from the aforementioned time period specified in Article 405, it is similar and comparable to previous monitoring efforts. The timing of these efforts was established by SMLA and Ferrum College.

Past monitoring has shown that while the implemented operational measures for DO enhancement provide benefits, the DO standards are not achieved 100% of the time. Therefore, beginning in 2016 an investigation of other DO enhancement techniques suitable for the Project began. The investigation is an iterative process where initial concepts are designed and then tested. Information from test results then informs subsequent decisions regarding methods and testing. For example, in 2016 turbine venting was identified as a potential DO enhancement method for the Project; however, subsequent testing in 2017 indicated that the turbine units were not conducive to venting. Appalachian continues to compare data to different operational statuses and environmental influences over the past five years.

1.1 BACKGROUND

The Smith Mountain powerhouse contains five generating units. The intakes are at three different elevations. Intakes for Units 1 and 5 are the deepest in the water column with the centerline (CL) of the intake openings at an elevation of 202 meters (m) (665 feet (ft)) and 186 m (610 ft), respectively. The CL intakes for Units 2, 3, and 4 are each located at an elevation of 750 ft. The penstocks for Units 1 and 5 are each 6 m (20 ft) in diameter, and those for Units 2, 3, and 4 are each 8 m (26 ft) in diameter. Units 1, 3, and 5 have dual function; that is, they are used to generate power and to pump back water from Leesville Lake (i.e., lower development) into Smith Mountain Lake (i.e., upper development). The adjusted water surface elevation at full operating pool is 242 m (795 ft). (Note that all elevations are relative to the National Geodetic Vertical Datum). During periods of lake stratification, the lower portions of the Smith Mountain Lake water column are characterized by low DO levels and cooler water temperatures, as is typical of many reservoirs during warm summer/fall periods. Upper portions of the water column generally exhibit higher DO levels and warmer water temperatures. Intakes generally withdraw water from the immediate region of the water column in which they are located and, therefore, the water passing through them is characterized by the physical and chemical properties occurring in those regions. As a result, if an intake is located in a portion of the water column with low DO, it can be expected that the water passing through that intake would have a similar low DO level. It should be noted, however, that the withdrawal zone of a given intake can encompass a much larger portion of the water column than what is represented by the intake itself. The withdrawal zone is influenced by factors such as intake geometry, flow, and water density.

As part of the Plan to improve DO levels during warmer water temperatures, Appalachian implemented a “first on, last off” operating mode for units with intakes higher in the water column. In this mode of operation, Appalachian prioritizes the use of Units 2, 3, and 4 over Units 1 and 5 during the months of July through September since they pull water from shallower depths that are relatively higher in DO. Based on data collected during monitoring to date, the first on / last off operational mode occurs July 1 through November 15.The goal of the Plan’s revised operating mode is to facilitate DO levels in the dam tailrace are meeting state standards, which are 4.00 milligrams per liter (mg/l) on an instantaneous basis and 5.00 mg/l on a daily average basis. As part of the annual review process, Appalachian will provide the data from the tailwaters of the Smith Mountain Dam to the WQTRC to determine if operational modifications are enhancing DO readings and that they meet Virginia DO requirements. DO, water temperature, and project operations have been summarized and are presented in this report.

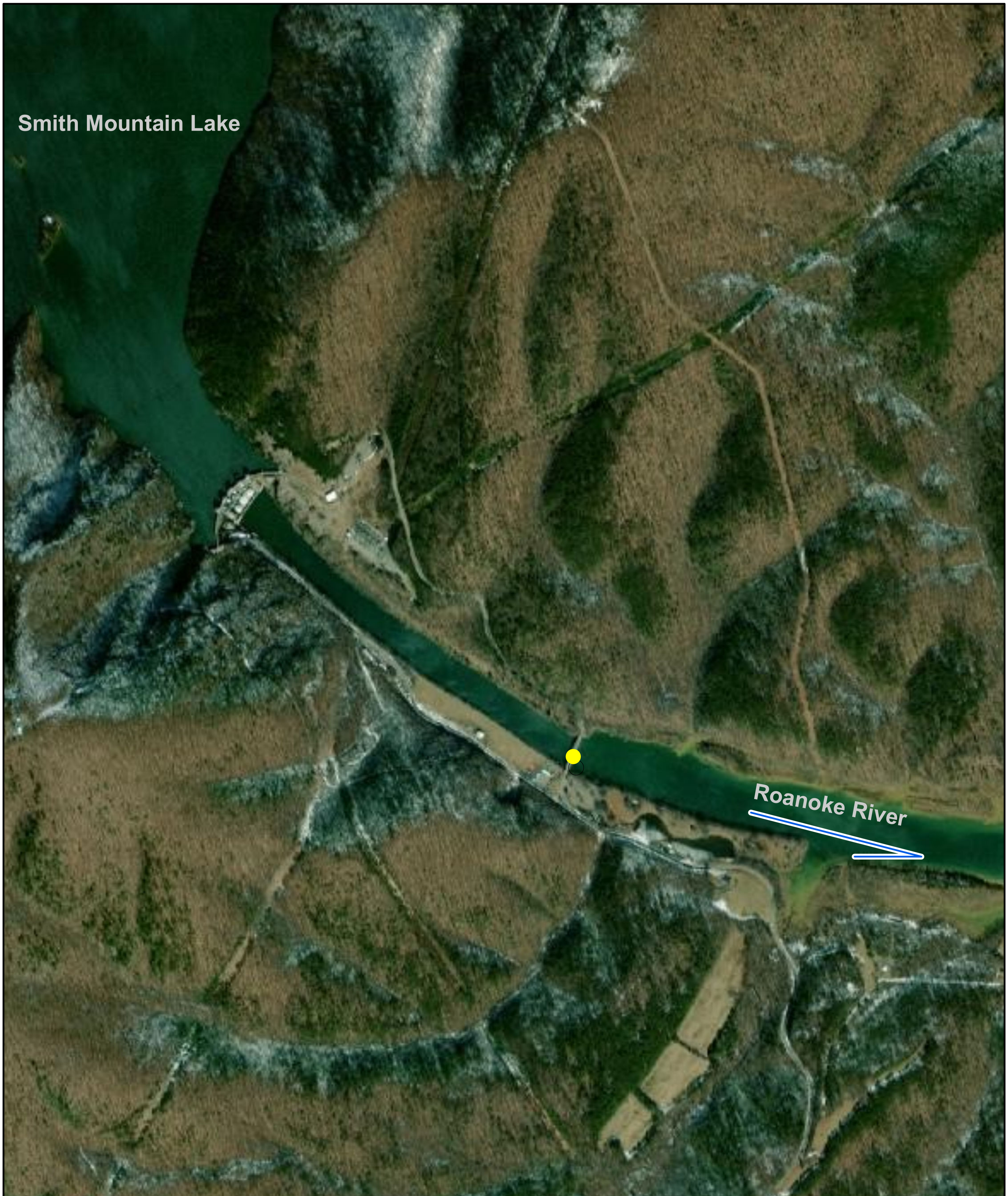

Figure 1.1 AEP
Water Quality Study
Monitoring Location
Roanoke River, VA

Monitoring Station

0 500 1,000 Feet
0 150 300 Meters

EnviroScience
Excellence In Any Environment

Path: C:\AEP\GIS\AEP_SmithMountain_Map1.mxd

Date: 8/24/2020

Basemap courtesy of Esri.

2.0 METHODS AND EQUIPMENT

2.1 WATER QUALITY MONITORING

The water quality monitoring location is in the stilling basin fixed to one of the tailrace bridge piers, which helps protect and prevent loss of data loggers. The station includes two HOBO® Dissolved Oxygen Loggers (replicates A and B) that record and store both water temperature and DO at 15-minute (min.) intervals. All loggers are calibrated on site; temperature is factory calibrated, and both parameters were verified with duplicate loggers and field measurements using a YSI PRODSS handheld meter during each monthly maintenance visit to help assess data accuracy.

Table 2.1 HOBO® Dissolved Oxygen Logger Specifications

Range	0 mg/L to 30 mg/L
Accuracy	± 0.2 mg/L up to 8 mg/L; ± 0.5 mg/L from 8 to 20 mg/L
Resolution	0.02 mg/L

2.2 RESERVOIR PROFILE

Water temperature and DO readings were collected in the forebay of the Smith Mountain Development using a YSI EXO2® Water Quality Sonde calibrated per the manufacturer's recommendations. One round of data was collected at four locations in the forebay and one location in the main reservoir (Figure 2.1). Locations were consistent with those used during the relicensing study efforts and time frame of previous years sampling efforts. Readings were collected at 2-meter intervals from the surface to the bottom.

Table 2.2 YSI EXO2® Water Quality Sonde Specifications

Range	0 mg/L to 50 mg/L
Accuracy	± 0.1 mg/L up to 20 mg/L; ± 5 % of reading from 20 to 50 mg/L
Resolution	0.01 mg/L

Figure 2.1 Smith Mountain Lake Temperature and Dissolved Oxygen Sampling Locations

Sampling Locations

0 500 1,000 2,000 Feet

0 160 320 640 Meters

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Path: P:\10_Projects\AAEP\490CS\13361 Smith Mountain and Claytor lake\Figures\Figure 1_Smith_Map_121020.mxd

Date: 12/11/2020

Basemap courtesy of Esri.

3.0 RESULTS

Data were collected at the Smith Mountain Dam tailwater using HOBO loggers from June 1 through November 30, 2022. During this period, water temperature (°C) and dissolved oxygen (mg/L) levels were measured. A handheld YSI PRODSS meter was also used to record water temperature and DO measurements at the monitoring location. This data was collected during monthly maintenance activities. Additionally, water quality was monitored in Smith Mountain and Leesville lakes by SMLA and LLA, respectively. Annual reports for these monitoring efforts are provided in Appendices A and B, respectively.

3.1 DOWNSTREAM WATER QUALITY

Water quality data was collected at 15-min. intervals June 1, 2022, through November 30, 2022 (183 days). Data are from the primary logger (A) was used except on 11/1/2022 at 1215 hours (replicated B used) due to maintenance on the primary logger (A).

Data were analyzed based on Project operation. Operation logs, which provide discharge in cubic feet per second, were obtained for each of the five generating units. Data utilized during 2022 were based on 15-minute intervals aligned to the quarter hour (e.g., 12:00, 12:15, etc.). Water quality data were evaluated in two groups with regards to the state standards: during all operation periods and during times of generation only. Daily average dissolved oxygen values during generation were determined by using dissolved oxygen data for each day only from those times when the Project was discharging.

Instantaneous DO values ranged from 2.6 mg/L (during September) to 9.5 mg/L (during November), and instantaneous water temperature values ranged from 10.8 ˚C (during November) to 25.7 ˚C (during July). A summary of instantaneous DO concentrations and water temperatures during all operational conditions (generation mode, pump-back mode, and non-operation) is presented in Table 3.1 and also illustrated in Figure 3.1 (All raw data is submitted electronically with this report).

Daily average DO concentrations ranged from 3.2 mg/L (during September) to 9.0 mg/L (during November). Daily average temperatures ranged from 11.9 ˚C (during November) to 22.4 ˚C (during July). A summary of daily average DO concentrations and water temperatures during all operational conditions (generation mode, pump-back mode, and non-operation) is presented in Table 3.2 and illustrated in Figure 3.2.

Instantaneous DO readings during generation periods ranged from 2.71 mg/L (September 8) to 9.13 mg/L (November 26); an illustration of instantaneous DO levels during generation are shown in Figure 3.3. Daily Average DO levels during generation ranged from 3.0 mg/L (September 8) to 9.1 mg/L (November 26). All average daily DO values during generation periods are illustrated in Figure 3.4 and presented in Table 3.3

Table 3.1 Smith Mountain Hydroelectric Project Maximum, Minimum, Average, and Median Instantaneous Dissolved Oxygen and Temperature Readings per Month for All Operational Scenarios, June 1, 2022 – November 30, 2022.

Month	DO (mg/L)				Temperature (˚C)			
	Min	Max	Average	Median	Min	Max	Average	Median
June	4.9	9.0	7.0	7.0	11.8	23.1	16.6	16.2
July	4.3	7.3	5.6	5.6	16.7	25.7	19.5	19.1
August	2.7	7.2	4.4	4.4	19.1	24.7	20.5	20.2
September	2.6	6.4	4.0	3.8	20.0	23.5	21.1	21.0
October	3.2	8.2	5.6	5.7	15.8	20.4	18.7	18.8
November	5.9	9.5	7.4	7.2	10.8	18.6	15.9	16.5

Table 3.2 Smith Mountain Hydroelectric Project Maximum, Minimum, and Median Daily Average Dissolved Oxygen and Temperature Readings per Month for All Operational Scenarios, June 1, 2022 – November 30, 2022.

Month	DO (mg/L)			Temperature (˚C)		
	Min	Max	Median	Min	Max	Median
June	6.3	7.9	7.0	14.3	20.7	16.4
July	4.9	6.4	5.6	17.6	22.4	19.6
August	3.6	5.4	4.4	19.7	21.5	20.5
September	3.2	5.3	3.9	20.2	21.8	21.1
October	3.8	7.5	5.8	16.7	20.0	18.7
November	6.4	9.0	7.2	11.9	18.0	16.6

Figure 3.1. Smith Mountain Hydroelectric Project Instantaneous Dissolved Oxygen and Water Temperature Data During All Operational Scenarios, June 1, 2022 – November 30, 2022

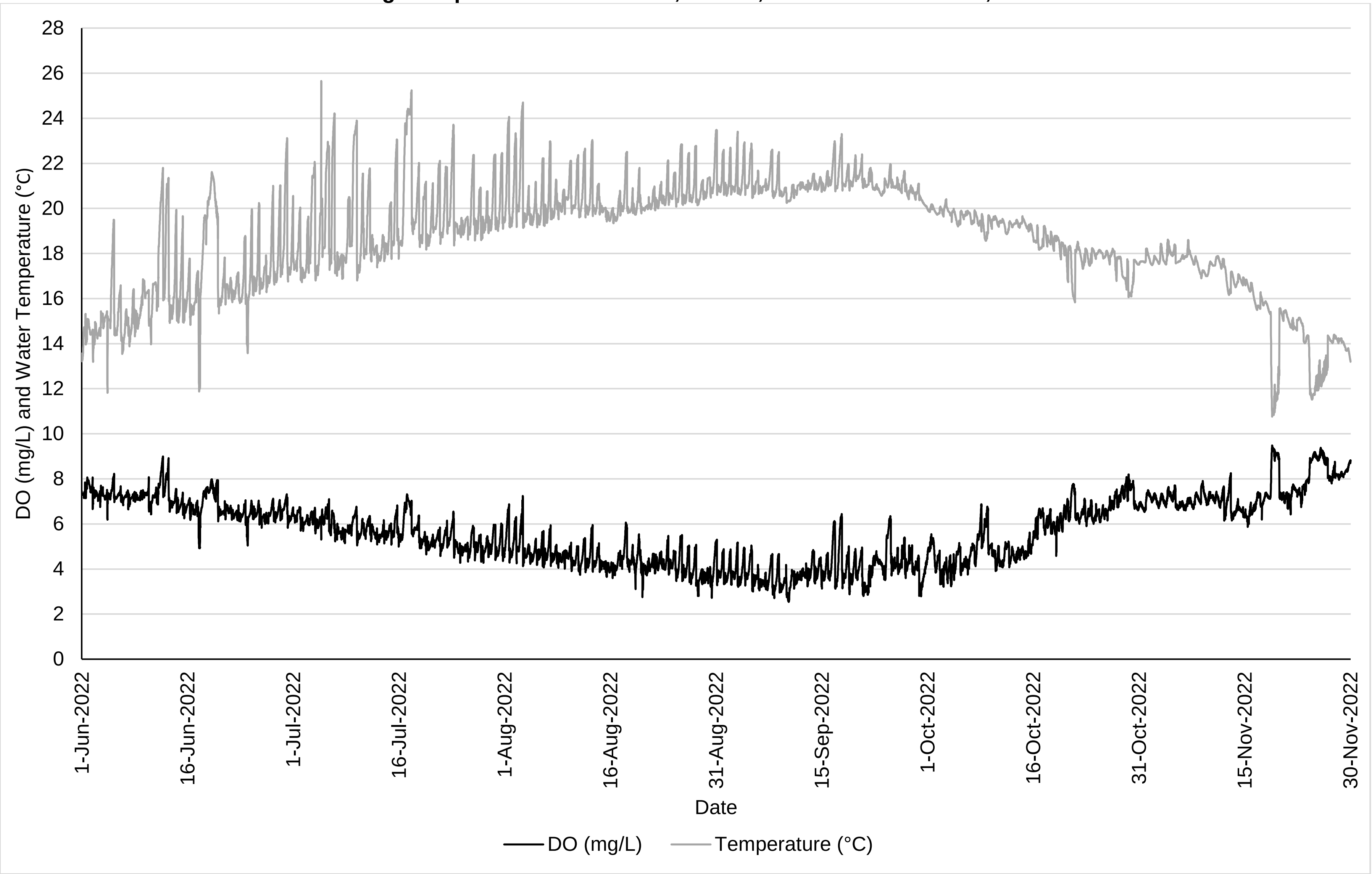


Figure 3.2. Smith Mountain Hydroelectric Project Daily Average Dissolved Oxygen and Temperature Data During All Operaional Scenarios, June 1, 2022 – November 30, 2022

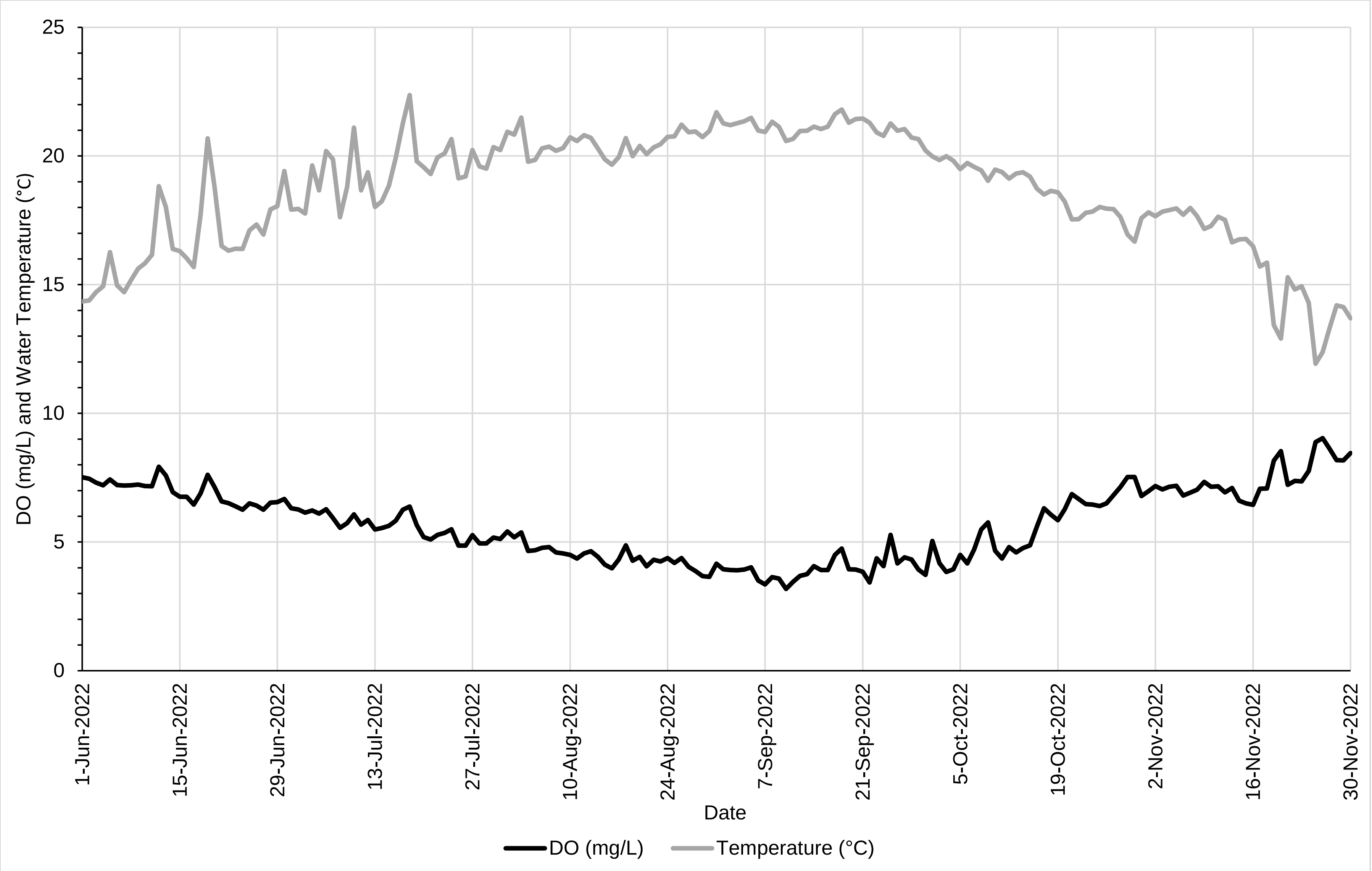


Figure 3.3. Smith Mountain Hydroelectric Project Instantaneous Dissolved Oxygen Data During Generation, June 1, 2022 – November 30, 2022.

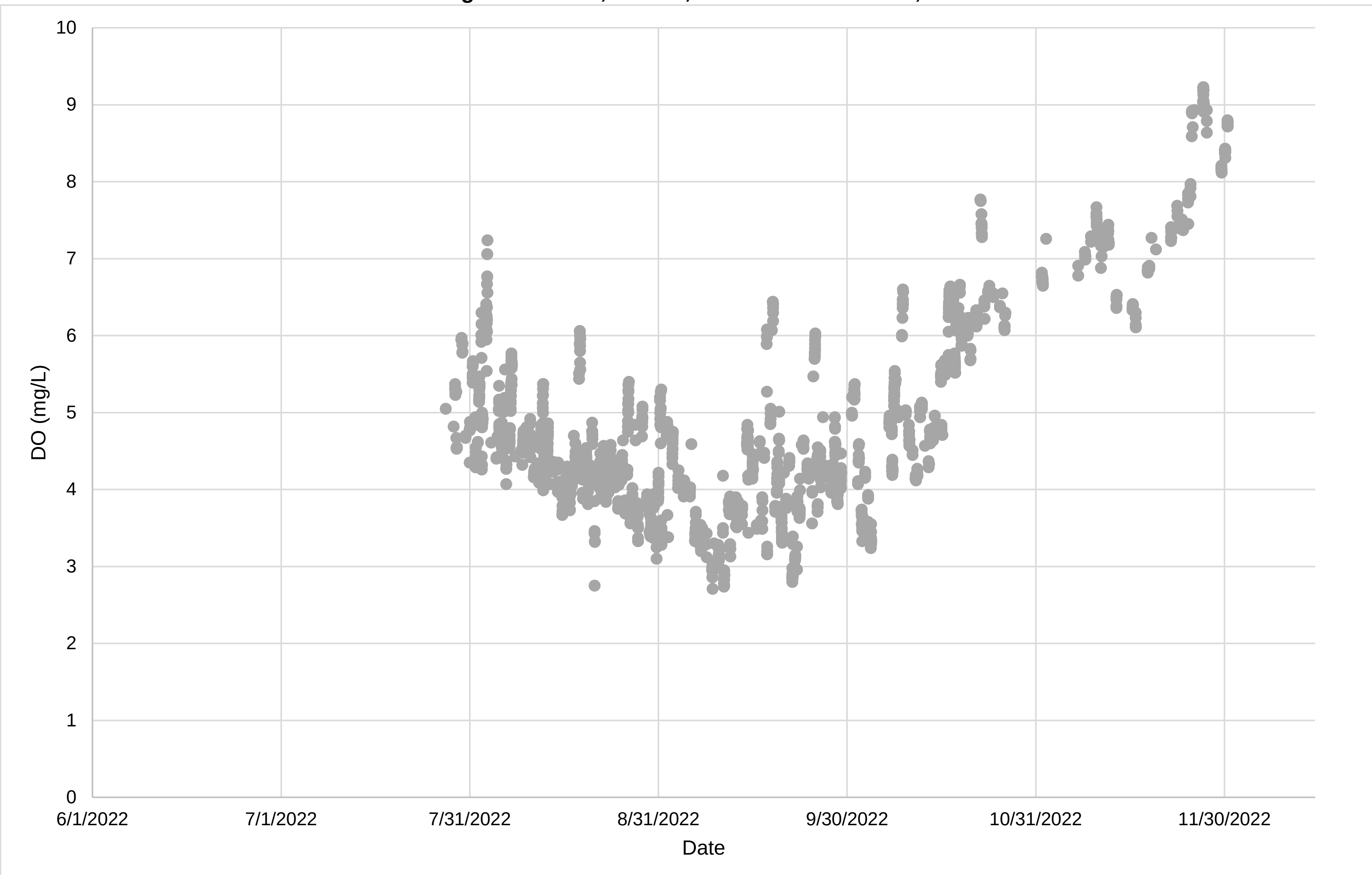


Figure 3.4. Smith Mountain Hydroelectric Project Daily Average Dissolved Oxygen Data During Generation, June 1, 2022 – November 30, 2022.

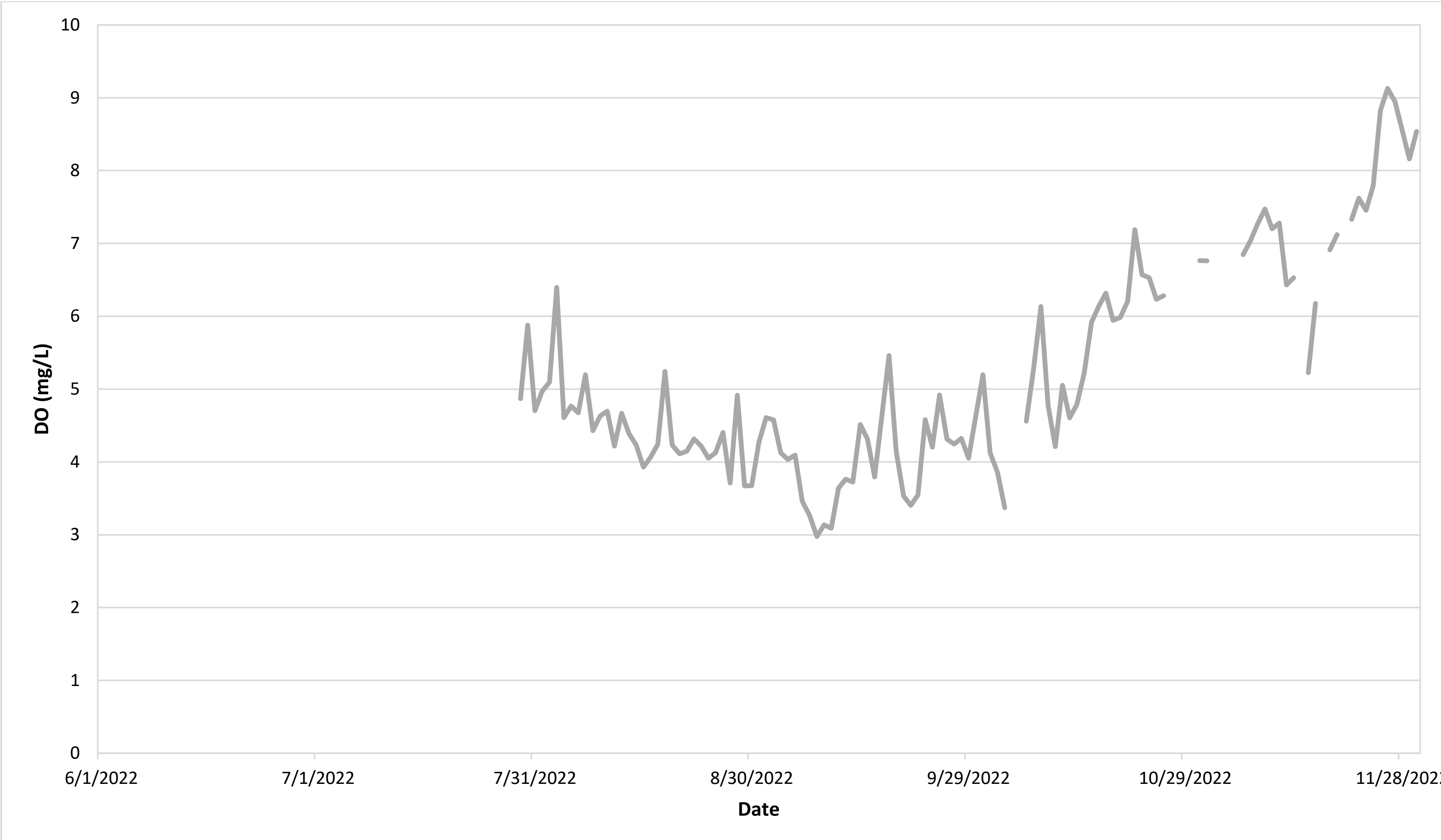


Table 3.3 Smith Mountain Hydroelectric Project Daily Average Dissolved Oxygen Levels during Generation, 2022.

Date	Daily Average DO, mg/L	Date	Daily Average DO, mg/L	Date	Daily Average DO, mg/L	Date	Daily Average DO, mg/L
7/27/2022	5.1	8/27/2022	3.7	9/25/2022	4.9	10/31/2022	6.8
7/29/2022	4.9	8/28/2022	4.9	9/26/2022	4.3	11/1/2022	6.8
7/30/2022	5.9	8/29/2022	3.7	9/27/2022	4.2	11/6/2022	6.8
7/31/2022	4.7	8/30/2022	3.7	9/28/2022	4.3	11/7/2022	7.0
8/1/2022	5.0	8/31/2022	4.3	9/29/2022	4.1	11/8/2022	7.3
8/2/2022	5.1	9/1/2022	4.6	10/1/2022	5.2	11/9/2022	7.5
8/3/2022	6.4	9/2/2022	4.6	10/2/2022	4.1	11/10/2022	7.2
8/4/2022	4.6	9/3/2022	4.1	10/3/2022	3.9	11/11/2022	7.3
8/5/2022	4.8	9/4/2022	4.0	10/4/2022	3.4	11/12/2022	6.4
8/6/2022	4.7	9/5/2022	4.1	10/7/2022	4.6	11/13/2022	6.5
8/7/2022	5.2	9/6/2022	3.5	10/8/2022	5.3	11/15/2022	5.2
8/8/2022	4.4	9/7/2022	3.3	10/9/2022	6.1	11/16/2022	6.2
8/9/2022	4.6	9/8/2022	3.0	10/10/2022	4.8	11/18/2022	6.9
8/10/2022	4.7	9/9/2022	3.1	10/11/2022	4.2	11/19/2022	7.1
8/11/2022	4.2	9/10/2022	3.1	10/12/2022	5.1	11/21/2022	7.3
8/12/2022	4.7	9/11/2022	3.6	10/13/2022	4.6	11/22/2022	7.6
8/13/2022	4.4	9/12/2022	3.8	10/14/2022	4.8	11/23/2022	7.5
8/14/2022	4.2	9/13/2022	3.7	10/15/2022	5.2	11/24/2022	7.8
8/15/2022	3.9	9/14/2022	4.5	10/16/2022	5.9	11/25/2022	8.8
8/16/2022	4.1	9/15/2022	4.3	10/17/2022	6.1	11/26/2022	9.1
8/17/2022	4.2	9/16/2022	3.8	10/18/2022	6.3	11/27/2022	8.9
8/18/2022	5.2	9/17/2022	4.6	10/19/2022	5.9	11/29/2022	8.2
8/19/2022	4.2	9/18/2022	5.5	10/20/2022	6.0	11/30/2022	8.5
8/20/2022	4.1	9/19/2022	4.1	10/21/2022	6.2		
8/21/2022	4.1	9/20/2022	3.5	10/22/2022	7.2		
8/22/2022	4.3	9/21/2022	3.4	10/23/2022	6.6		
8/23/2022	4.2	9/22/2022	3.5	10/24/2022	6.5		
8/24/2022	4.1	9/23/2022	4.6	10/25/2022	6.2		
8/25/2022	4.1	9/24/2022	4.2	10/26/2022	6.3		
8/26/2022	4.4						

3.2 RESERVOIR PROFILE

Water temperature and DO readings were collected at 2-m depth intervals along the four established monitoring locations on the forebay transect and at one location in the main reservoir (See Figure 1.1) on August 31, 2022. Water temperature and DO are presented in Table 3.4 profile data are illustrated in Figure 3.5 and Figure 3.6, respectively. Dissolved oxygen readings generally fell below 4.0 mg/l at depths of 8 - 10 m. at all locations. Water temperature ranged from 26.8 °C to 27.3 °C at the surface and decreased substantially starting between depths of 4 to 8 m on the date sampled (Figure 3.6).

Table 3.4 Water Quality Profiles at the Forebay and Main Reservoir Monitoring Locations in Smith Mountain Lake, August 31, 2022.

SMX 1-01			SMX 1-02			SMX 1-03			SMX 1-04			Reservoir		
Depth (m)	Temp (ºC)	DO (mg/L)	Depth (m)	Temp (ºC)	DO (mg/L)	Depth (m)	Temp (ºC)	DO (mg/L)	Depth (m)	Temp (ºC)	DO (mg/L)	Depth (m)	Temp (ºC)	DO (mg/L)
0	27.01	7.89	0	26.78	7.86	0	26.76	7.84	0	27.33	7.99	0	27.13	8.35
2	26.86	7.83	2	26.68	7.75	2	26.71	7.81	2	26.32	7.52	2	27.07	8.36
4	23.86	5.87	4	23.35	5.55	4	24.98	6.68	4	23.62	5.66	4	26.84	8.3
6	22.80	5.08	6	21.33	4.01	6	23.20	5.39	6	22.32	4.68	6	22.34	4.73
8	21.27	3.85	8	21.08	3.79	8	21.21	3.9	8	21.45	4.02	8	20.47	3.33
10	20.90	3.61	10	21.00	3.72	10	21.01	3.71	10	21.02	3.65	10	20.21	3.08
12	20.78	3.52	12	20.92	3.63	12	20.81	3.5	12	20.75	3.45	12	20.09	2.98
14	20.59	3.35	14	20.77	3.47	14	20.65	3.38	14	20.51	3.19	14	19.94	2.85
16	20.49	3.24	16	20.53	3.28	16	20.61	3.33	16	20.35	3.02	16	19.84	2.75
18	20.34	3.09	18	20.36	3.11	18	20.38	3.13				18	19.73	2.64
20	20.27	3.02	20	20.23	2.98	20	20.21	2.96				20	19.59	2.5
22	20.23	2.97	22	20.19	2.96	22	20.07	2.83				22	19.45	2.33
24	20.08	2.83	24	20.12	2.9	24	19.76	2.53				24	19.41	2.31
26	20.10	2.84	26	19.85	2.63	26	19.71	2.49				26	19.19	2.09
28	19.98	2.75	28	19.74	2.52	28	19.60	2.38				28	19.04	1.93
30	19.94	2.71	30	19.60	2.39	30	19.31	2.14				30	18.88	1.76
			32	19.07	1.86	32	19.25	2.1				32	18.66	1.48
			34	18.93	1.79	34	19.04	1.91				34	18.59	1.36
			36	18.89	1.76	36	18.69	1.54						
			38	18.73	1.59	38	18.58	1.37						
			40	18.53	1.3	40	18.49	1.24						
			42	18.23	0.87	42	18.41	1.11						
			44	18.05	0.64	44	18.18	0.78						
			46	17.79	0.42	46	17.97	0.51						
			48	17.64	0.28	48	17.90	0.42						
			50	17.52	0.18	50	17.74	0.32						
			52	17.45	0.16									
			54	17.34	0.16									
			56	17.30	0.16									
			58	17.28	0.16									

Figure 3.5. Dissolved Oxygen Levels Per Depth at the Forebay and Main Reservoir Monitoring Locations in Smith Mountain Lake, August 31, 2022.

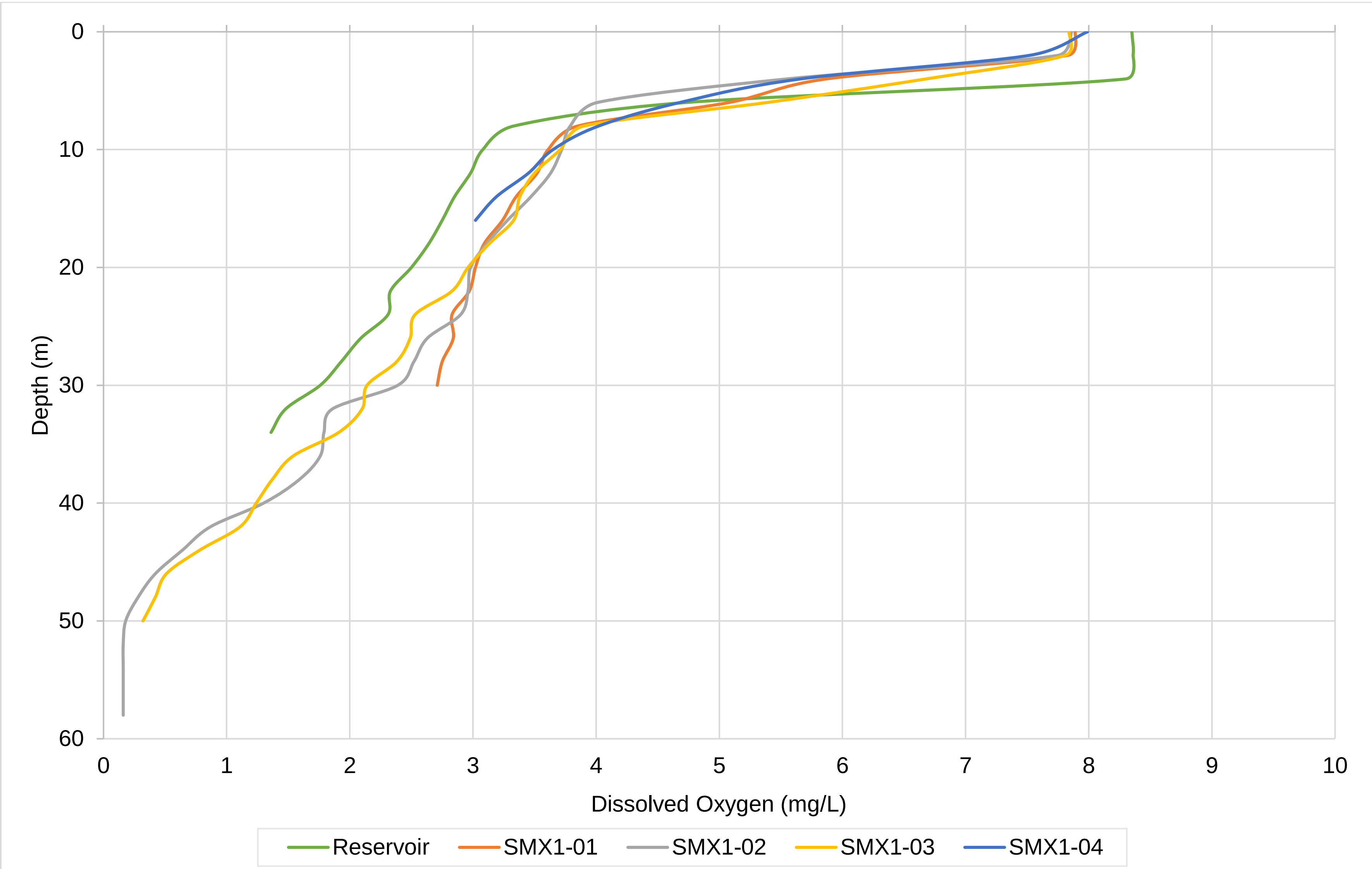
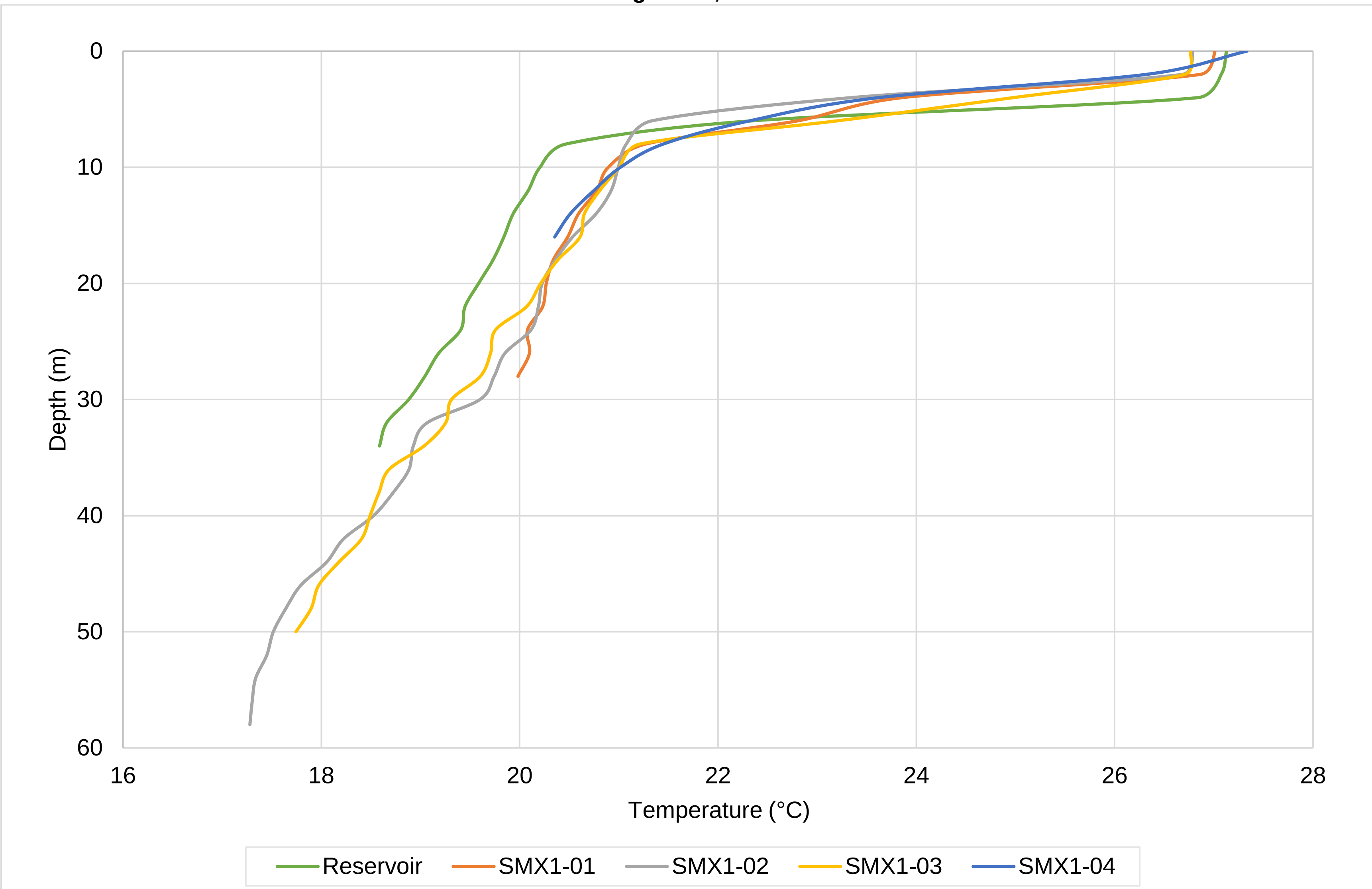


Figure 3.6. Water Temperatures Per Depth at the Forebay and Main Reservoir Monitoring Locations in Smith Mountain Lake, August 31, 2022.



4.0 DISCUSSION

Smith Mountain tailwater DO monitoring has evolved since its inception in the spring of 2011. Initial efforts were complicated by the inability to consistently collect reliable data. Continuously monitoring DO in an accurate manner over an extended period can be difficult in most locations. A dynamic environment, such as the Smith Mountain tailwater, represents unique challenges. Such challenges include the presence of high-water velocities that can flow in two directions, depending on whether the Project is pumping or generating, and substantial water level fluctuations. Initial efforts consisted of using temporary, self-contained monitoring units, the maintenance of which was labor intensive. These units were also prone to damage due to the site conditions and vandalism. In the fall of 2012, a more permanent monitoring system was installed which minimized the potential for monitor damage due to environmental conditions and vandalism. The permanent monitoring system is also better able to maintain accurate calibration as well as allow access for data retrieval. As such, the system provides a reliable method of collecting accurate DO data while minimizing the potential for periods of missing data. It should be noted that no monitoring system can eliminate all potential issues associated with in-field monitoring. However, there were no data gaps during the 2022 monitoring period.

The primary goal of the DO monitoring effort is to assess whether the operational modifications implemented at the Project are effective at maintaining DO levels in the Project discharge. As discussed above, the implemented operational measures consist of a “first on, last off” mode of operation during the July through mid-November period, where Units 2, 3, and 4 are the first to operate followed by Units 1 and 5, respectively. Units are then shutdown in reverse order. While these modified operations have been successful in achieving the desired result, there is an ongoing learning process on how to implement the operational modifications within generation obligations. Therefore, while there has been some success in achieving DO goals, this operating regime does not result in achieving standards every year.

In 2022 (June 1 through November 30), data collection during all operational scenarios (generation mode, pump-back mode, and non-operation) occurred over the course of 183 days during which 17,573 DO readings were recorded. A total of 85% of those readings were greater than or equal to the instantaneous minimum DO requirement of 4.00 mg/L, illustrated in Figure 4.1. A summary of instantaneous readings below 4.00 mg/L is presented in Table 4.1. The daily average DO minimum requirement of 5.00 mg/L was achieved approximately 61% of the time, illustrated in Figure 4.2. Daily average values below the 5.00 mg/L threshold are presented in Table 4.2.

Figure 4.1 Percent Exceedance for Instantaneous Dissolved Oxygen Values Measured in Smith Mountain Tailrace during all Operational Periods in 2022 (DO Values Greater than 4.00 mg/L 85% of the Time)

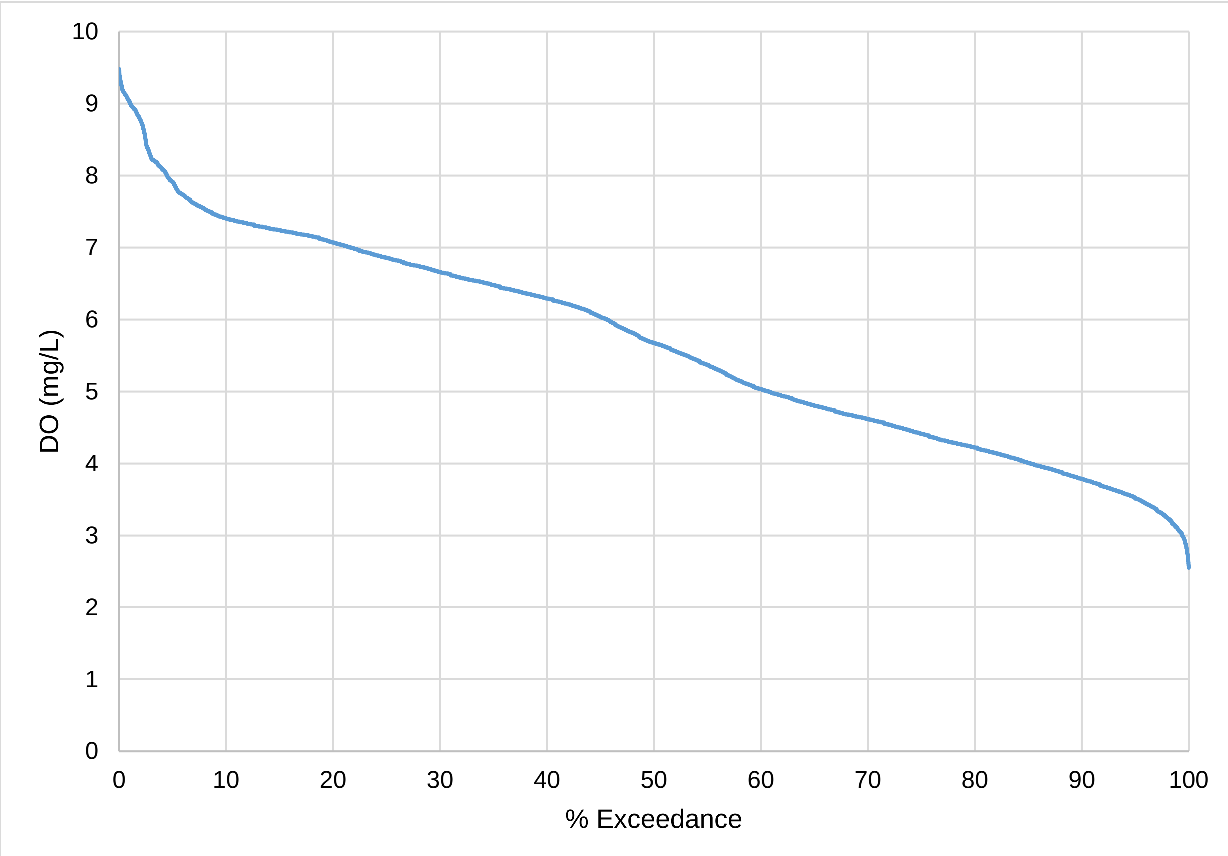


Table 4.1 Summary of Instantaneous Dissolved Oxygen Readings During all operational periods in 2022 Less than 4.00 mg/L

Date	Number of Readings < 4.00 mg/L	% < 4.00 mg/L	Date	Number of Readings < 4.00 mg/L	% < 4.00 mg/L
8/10/2022	3	3%	9/8/2022	63	66%
8/11/2022	19	20%	9/9/2022	73	76%
8/12/2022	9	9%	9/10/2022	95	99%
8/13/2022	2	2%	9/11/2022	96	100%
8/14/2022	8	8%	9/12/2022	96	100%
8/15/2022	11	11%	9/13/2022	89	93%
8/16/2022	55	57%	9/14/2022	51	53%
8/17/2022	15	16%	9/15/2022	56	58%
8/18/2022	2	2%	9/16/2022	64	67%
8/19/2022	17	18%	9/17/2022	43	45%
8/20/2022	25	26%	9/18/2022	40	42%
8/21/2022	34	35%	9/19/2022	59	61%
8/22/2022	10	10%	9/20/2022	63	66%
8/23/2022	9	9%	9/21/2022	50	52%
8/24/2022	17	18%	9/22/2022	85	89%
8/25/2022	31	32%	9/23/2022	9	9%
8/26/2022	46	48%	9/24/2022	43	45%
8/27/2022	56	58%	9/25/2022	4	4%
8/28/2022	63	66%	9/26/2022	19	20%
8/29/2022	95	99%	9/27/2022	13	14%
8/30/2022	90	94%	9/28/2022	19	20%
8/31/2022	53	55%	9/29/2022	38	40%
9/1/2022	65	68%	9/30/2022	64	67%
9/2/2022	69	72%	10/2/2022	29	30%
9/3/2022	69	72%	10/3/2022	64	67%
9/4/2022	63	66%	10/4/2022	54	56%
9/5/2022	54	56%	10/5/2022	14	15%
9/6/2022	92	96%	10/6/2022	15	16%
9/7/2022	96	100%	10/10/2022	5	5%

Figure 4.2 Percent Exceedance for Daily Average Dissolved Oxygen Values Measured in Smith Mountain Tailrace during all Operational Periods in 2022 (DO Values Greater than 5.00 mg/L 61% of the Time)

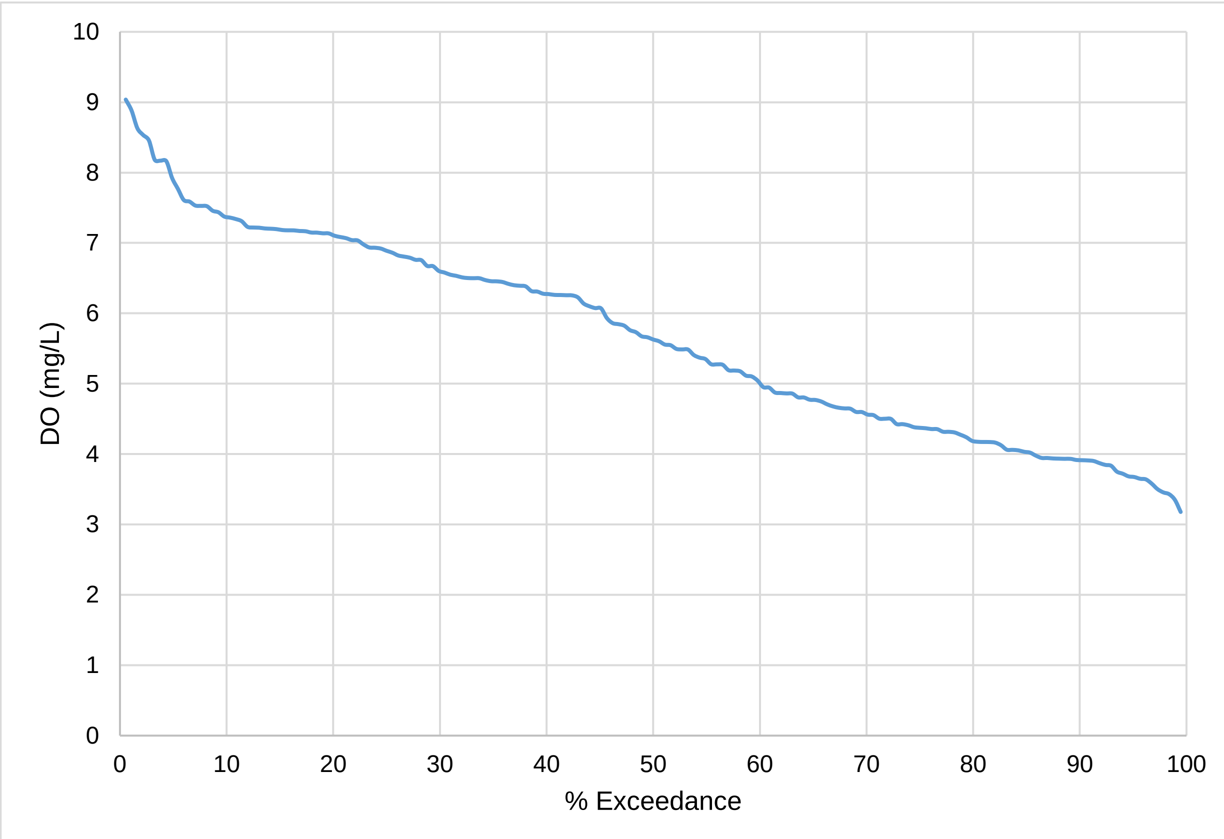


Table 4.2 Summary of Daily Average DO Values During All operational periods in 2022 Less than 5.00 mg/l

Date	Daily Average DO (mg/L)	Date	Daily Average DO (mg/L)
7/25/2022	4.9	9/6/2022	3.5
7/26/2022	4.9	9/7/2022	3.4
7/28/2022	4.9	9/8/2022	3.6
8/4/2022	4.6	9/9/2022	3.6
8/5/2022	4.7	9/10/2022	3.2
8/6/2022	4.8	9/11/2022	3.5
8/7/2022	4.8	9/12/2022	3.7
8/8/2022	4.6	9/13/2022	3.8
8/9/2022	4.6	9/14/2022	4.1
8/10/2022	4.5	9/15/2022	3.9
8/11/2022	4.4	9/16/2022	3.9
8/12/2022	4.6	9/17/2022	4.5
8/13/2022	4.6	9/18/2022	4.7
8/14/2022	4.4	9/19/2022	3.9
8/15/2022	4.1	9/20/2022	3.9
8/16/2022	4.0	9/21/2022	3.8
8/17/2022	4.3	9/22/2022	3.4
8/18/2022	4.9	9/23/2022	4.4
8/19/2022	4.3	9/24/2022	4.1
8/20/2022	4.4	9/26/2022	4.2
8/21/2022	4.1	9/27/2022	4.4
8/22/2022	4.3	9/28/2022	4.3
8/23/2022	4.2	9/29/2022	3.9
8/24/2022	4.4	9/30/2022	3.7
8/25/2022	4.2	10/2/2022	4.2
8/26/2022	4.4	10/3/2022	3.8
8/27/2022	4.0	10/4/2022	3.9
8/28/2022	3.9	10/5/2022	4.5
8/29/2022	3.7	10/6/2022	4.2
8/30/2022	3.6	10/7/2022	4.7
8/31/2022	4.2	10/10/2022	4.7
9/1/2022	3.9	10/11/2022	4.4
9/2/2022	3.9	10/12/2022	4.8
9/3/2022	3.9	10/13/2022	4.6
9/4/2022	3.9	10/14/2022	4.8
9/5/2022	4.0	10/15/2022	4.9

4.1 IMPACT OF GENERATION ON DO

The average 2022 instantaneous DO value during generation was 4.85 mg/L and the average instantaneous DO value during other operational scenarios (pump-back and non-operation) was 6.10 mg/L.

The instantaneous minimum DO requirement was met 76% of the time during generation (Figure 4.3). The daily average DO minimum requirement of 5.00 mg/L was achieved approximately 42% of the time (Figure 4.4) during generation. Compared to all operations meeting DO criteria for instantaneous and daily average at 85% and 61% respectively.

The percentage of readings when the instantaneous DO standard was met in 2022 during generation was lower than in 2021, but higher than in the three years prior (i.e., 2020, 2019, and 2018). The 2022 instantaneous DO percentage was lower than in 2016 and 2017 (87% and 97%, respectively). The percentage of readings when the daily average DO standard was achieved in 2022 during generation was appreciably lower than in 2021 and more on par with the four years prior. Overall, the 2022 data ranks as the fourth highest percentages of achievement for instantaneous DO and the third lowest percentage of meeting daily average DO. The percentage of readings when the instantaneous and daily average DO standards were achieved during generation over the last eight years is presented in Table 4.3.

Note that generation during the summer months (i.e., mid-June through mid-September) occurs during the afternoon when there is peak demand for electric power, which coincides with the period of maximum photosynthesis (i.e., naturally occurring DO production) in the tailwater. Conversely, pump-back occurs during the night when photosynthesis is not occurring.

Figure 4.3 Percent Exceedance for Instantaneous Dissolved Oxygen Values Measured in Smith Mountain Tailrace during Generation in 2022 (DO Values Greater than 4.00 mg/L 76% of the Time)

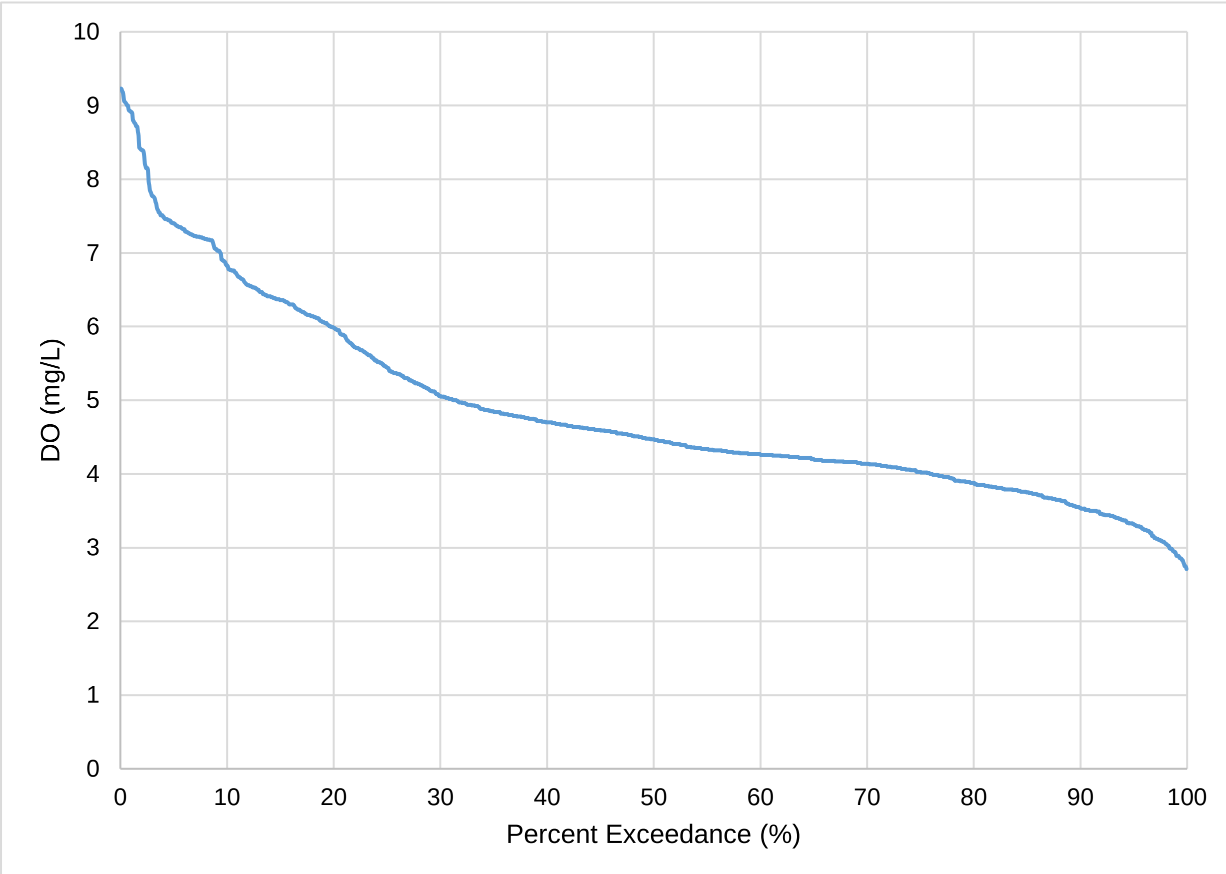


Figure 4.4 Percent Exceedance for Daily Average Dissolved Oxygen Values Measured in Smith Mountain Tailrace during Generation in 2021 (DO Values Greater than 5.00 mg/L 42% of the Time)

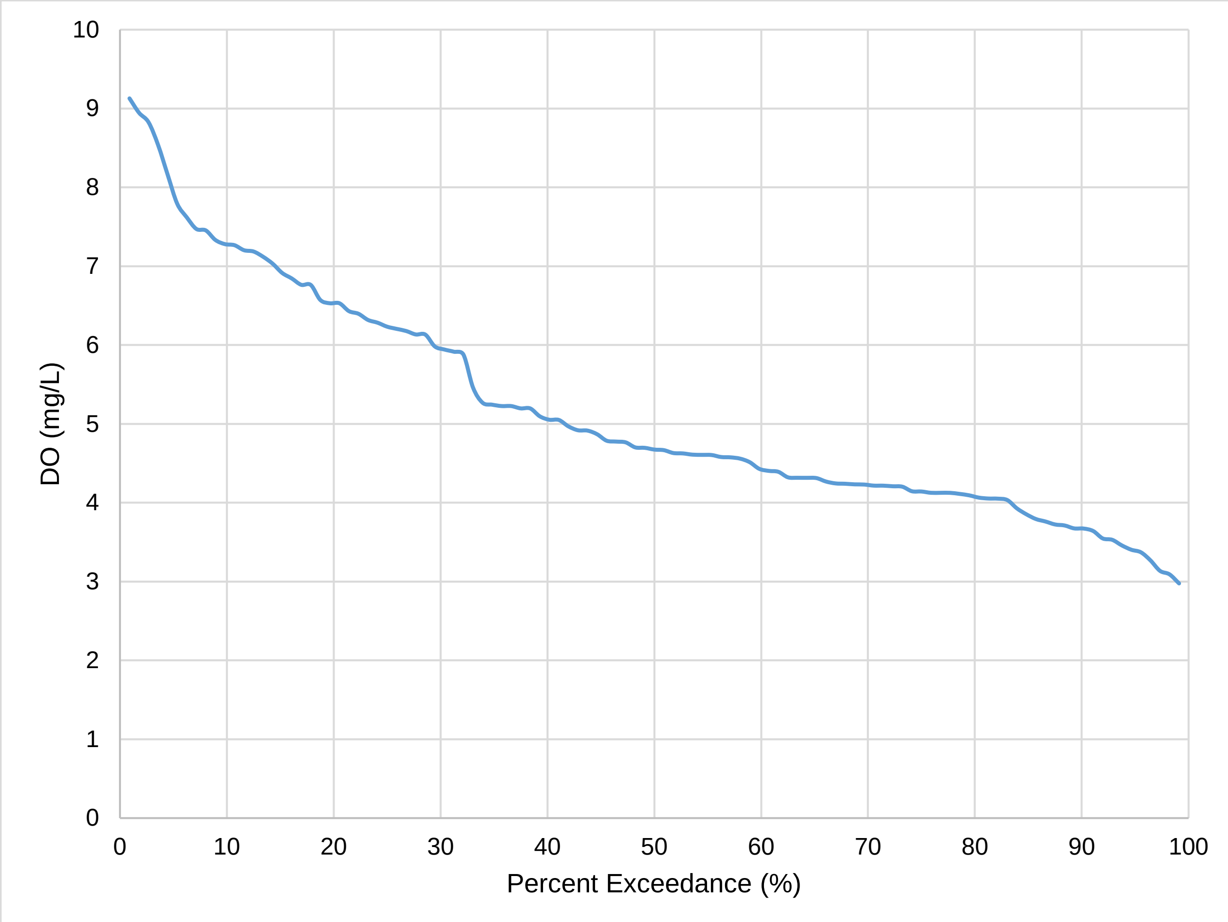


Table 4.3 Annual Percentage of Time Instantaneous and Daily Average DO Standards Met During Generation

Year	% Time Instantaneous DO Standard Met (4.0 mg/L)	% Time Daily Average DO Standard Met (5.0 mg/L)
2015	75%	83%
2016	87%	60%
2017	97%	48%
2018	60%	47%
2019	66%	37%
2020	69%	40%
2021	81%	60%
2022	76%	42%

The data presented in Table 4.3 illustrates the variability in instantaneous and daily average DO concentrations during generation in any given year and is reflective of the corresponding variability in flows and other environmental factors. This variability also applies to all operational scenarios. Tailwater DO concentrations will vary from year to year due to corresponding variations in air and water temperatures, when stratification occurs in Smith Mountain Lake, inflows to the Project, duration of generation, photosynthetic production, etc.

In 2015 through 2017, instantaneous results indicated a general trend of continued improvement in meeting the tailwater DO standards. The monitoring data varied between years but marked improvement in meeting the water quality standards was documented after 2012. This improvement was attributed to several factors, including better monitoring using the stilling basins and better implementation, and extension of the “first-on, last-off” protocols, and continued development of the low DO alarm system – overall, the DO enhancement and monitoring program.

In 2018 and 2019, the DO standards were achieved a relatively lower percentage of the time than for previous years, particularly for the instantaneous DO values. Multiple factors may have contributed to the lower DO values. Kleinschmidt (2019) theorized that the non-operation of Unit 5 in 2018 (due to a scheduled maintenance outage) might have been a reason for the drop in DO during that year. Because Unit 5 is a pump-turbine, when it does not operate, the deepest part of the forebay does not receive the benefit of higher DO water being pumped (back) from the tailrace. In relative terms, water from the tailrace is warmer and higher in DO than in the deeper part of the forebay. When Unit 5 operates in pump-back mode, this warmer, higher DO water enters the forebay and likely mixes to some degree and/or remains isolated due to density differences. In either case, this water may then be available for discharge from not only Unit 5, but potentially the other units as well.

However, Unit 5 was in operation in 2019, 2020, 2021, and 2022 the % exceedance of the instantaneous DO concentration varied from 60-79% in those years. Therefore, while operation of Unit 5 may ultimately affect DO, the yearly fluctuations during years when Unit 5 is operating indicate that there are other significant factors affecting the DO concentrations in the tailwater.

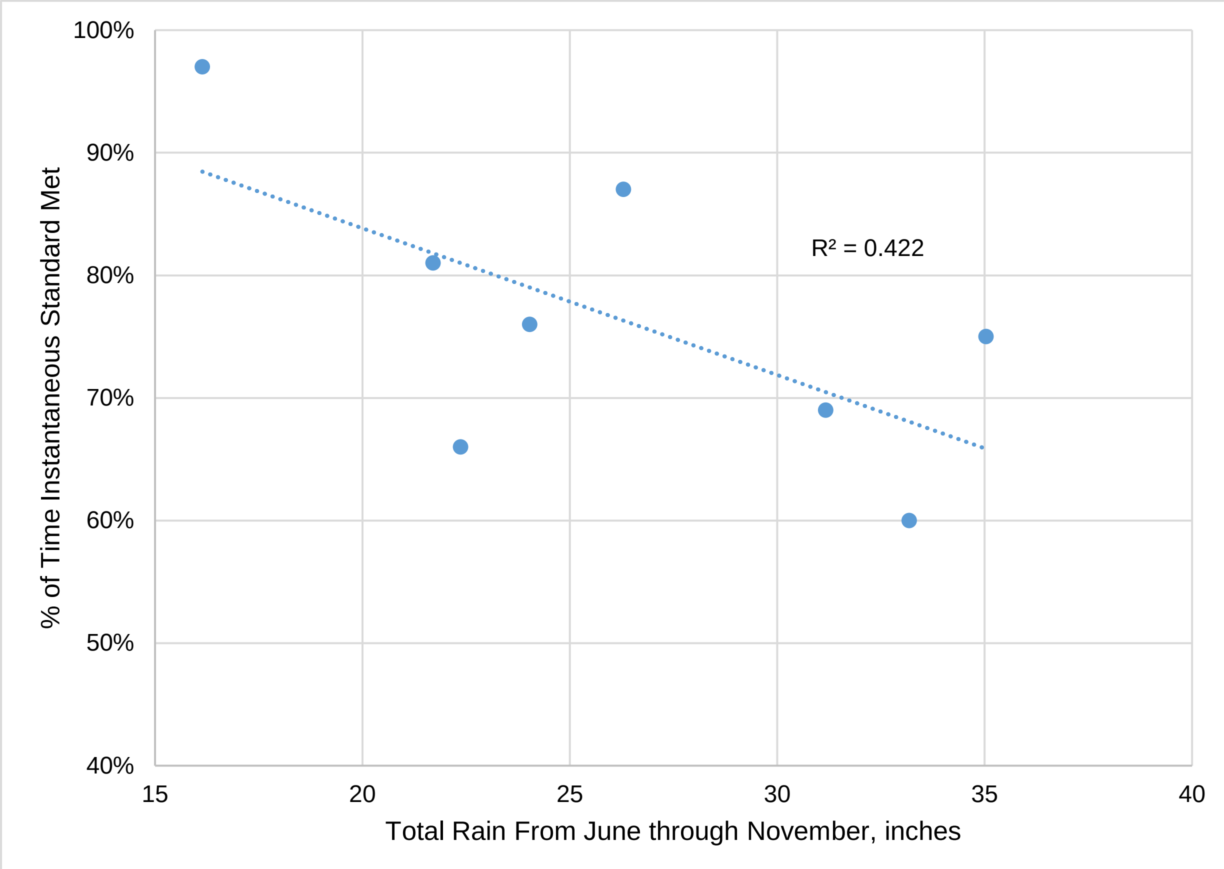
Precipitation throughout the Project watershed is a potential factor affecting DO concentrations there seems to be a correlation between low precipitation years and meeting the instantaneous DO standards. Higher amounts of rainfall throughout the water quality monitoring period result in increased inflows to the Project. Higher inflows to the Project, in turn, result in increased generation to pass the water through the Project, particularly during flood operations. Increased generation results in a greater period of time when low DO water in the Smith Mountain Dam forebay is being discharged to the tailwater. Table 4.4 provides the total precipitation in the months of June-November for years 2015-2022 as recorded at the Roanoke, VA airport. A scatterplot of the percentage of readings when the instantaneous standard is met versus the total precipitation is presented in Figure 4.5. It is clear from the figure that there is a trend between these two variables, with lower rain years generally having a higher percentage of readings when the DO standard achieved. However, there is no such correlation between precipitation and the percentage of time the daily average standard is met.

Table 4.4 Total June-November Monthly Precipitation (inches) During 2015-2022 as Recorded at the Roanoke, VA Airport.

Month	2015	2016	2017	2018	2019	2020	2021	2022
June	9.07	6.03	4.50	3.63	5.53	7.72	4.37	1.42
July	4.29	5.55	2.07	4.47	4.70	3.53	3.01	5.28
August	3.09	4.46	2.31	5.17	3.13	4.17	5.39	4.32
September	8.48	4.75	2.38	9.92	1.36	5.33	4.84	4.19
October	6.10	4.42	4.18	5.21	6.33	4.57	3.13	3.10
November	4.00	1.08	0.70	4.78	1.31	5.84	0.96	5.72
TOTAL	**35.03**	**26.29**	**16.14**	**33.18**	**22.36**	**31.16**	**21.70**	**24.03**

*Source: NOAA Online Weather Data, http://nowdata.rcc-acis.org/rnk/

Figure 4.5 Percent Exceedance for Instantaneous Dissolved Oxygen Values Measured in Smith Mountain Tailrace during Generation versus Total Precipitation, June - November



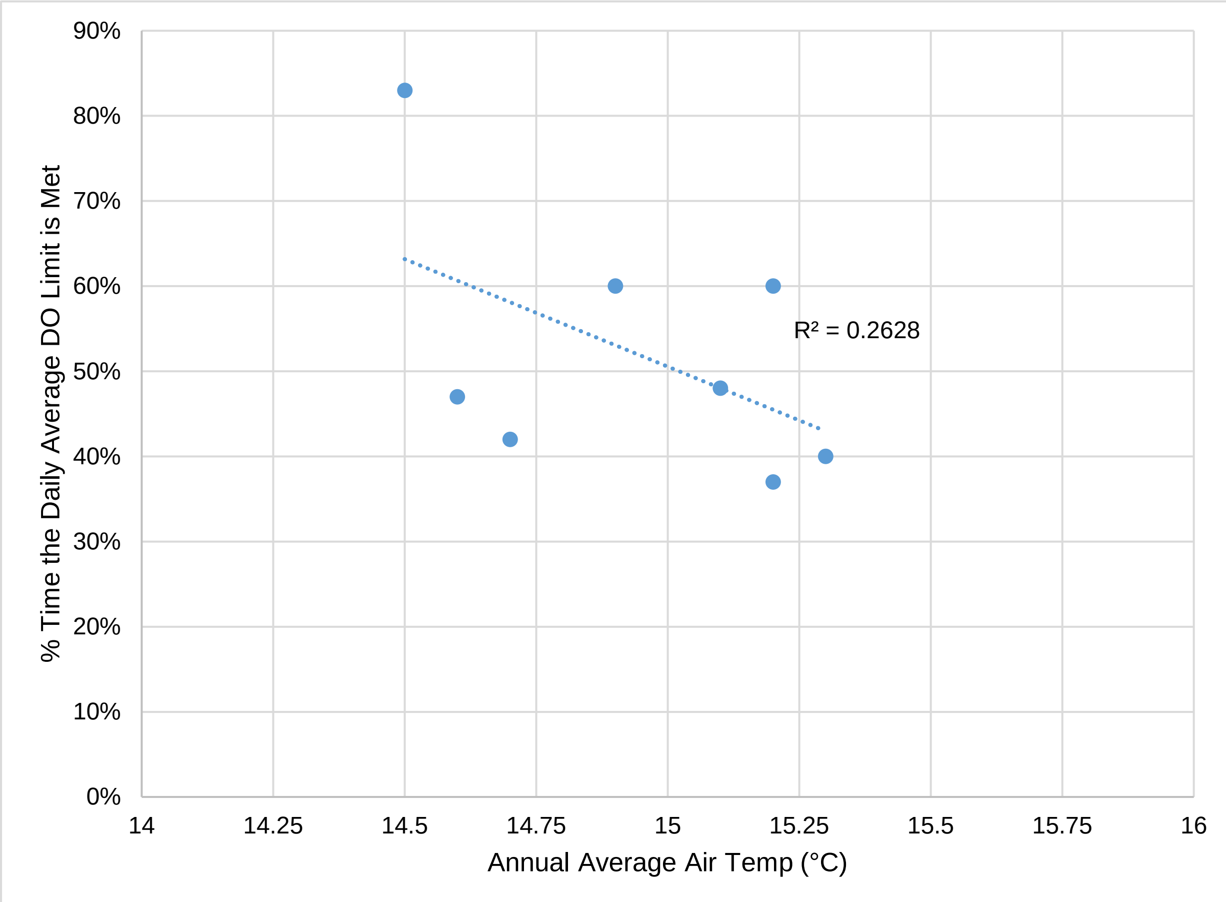
Another potential impact on DO concentrations is the water temperature of the lake. While several environmental factors, such as solar radiation, cloud cover, and retention time contribute to lake water temperature, air temperature is a reasonable basis for inferring water temperature trends. Table 4.5 provides the monthly average air temperatures for the years 2015 through 2022 as recorded at the Roanoke, VA airport. A scatterplot of the percentage of readings when the daily average standard is met versus the annual average air temperature is presented in Figure 4.6. It is evident from the figure that there is a weak correlation between these two variables, with lower temperature years having a higher percentage of times with the daily average DO standard achieved. However, there is not a correlation between average temperature and percentage of readings when the instantaneous standard is met. This trend is opposite of the aforementioned impact of precipitation.

Table 4.5 Monthly Average Air Temperature (°C) From 2015 to 2022 as Recorded at the Roanoke, VA Airport.

Month	2015	2016	2017	2018	2019	2020	2021	2022
January	2.1	0.8	5.3	1.2	2.3	5.3	3.4	1.4
February	-0.8	3.6	9.1	8.0	6.6	6.6	3.7	6.1
March	8.4	12.3	9.2	6.2	7.8	12.4	10.4	11.5
April	13.9	14.4	16.7	12.5	15.8	13.2	14.3	14.6
May	20.5	17.9	18.6	22.5	22.2	16.9	18.1	19.5
June	24.1	23.4	22.6	24.2	22.7	23.1	23.8	24.3
July	25.2	26.2	25.9	24.9	26.4	27.7	25.9	26.6
August	24.1	25.3	23.9	24.7	25.0	25.2	26.3	24.7
September	21.2	23.1	20.4	23.1	24.2	20.1	21.9	20.9
October	14.1	16.7	16.3	15.9	16.7	15.9	17.8	13.3
November	11.3	10.9	8.6	7.0	6.8	11.8	7.8	10.4
December	9.9	4.6	3.9	5.1	6.2	4.8	9.0	3.7
Yearly	14.5	14.9	15.1	14.6	15.2	15.3	15.2	14.7

*Source: NOAA Online Weather Data, http://nowdata.rcc-acis.org/rnk/

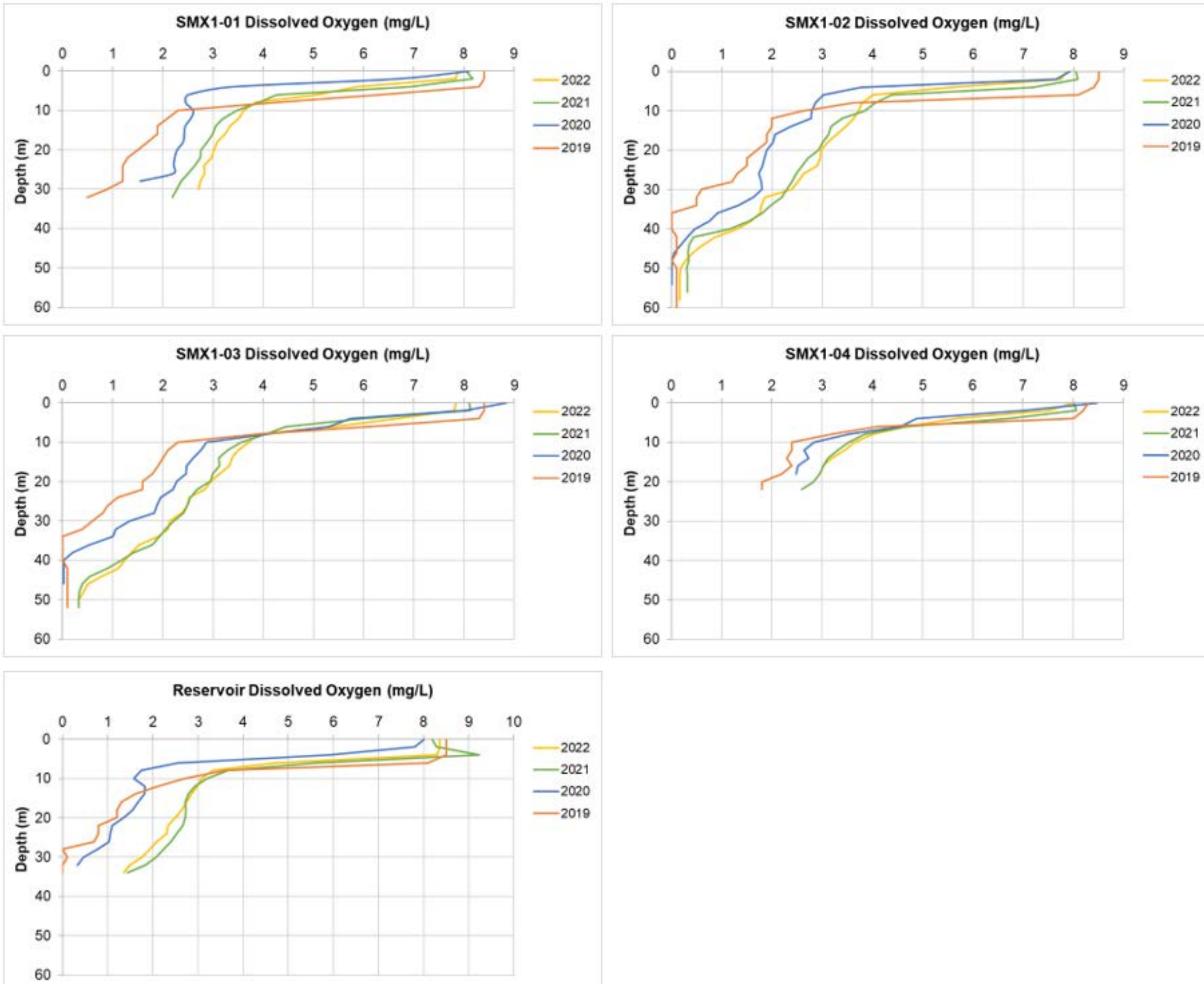
Figure 4.6 Percent Exceedance for Daily Average Dissolved Oxygen Values Measured in Smith Mountain Tailrace during Generation versus Annual Average Air Temperature



4.2 LAKE PROFILE DISSOLVED OXYGEN COMPARISON

Figure 4.7 shows the DO profile data collected at Smith Mountain Lake in late August / early September for 2019 - 2022. The DO concentrations above 4.00 mg/L in the water column for 2022 and 2021 fit in between those for 2020 and 2019, whereas the DO profile concentrations below roughly 10 meters in depth were higher in 2022 and 2021 than in 2019 and 2020.

Figure 4.7. Smith Mountain Lake Dissolved Oxygen Profile Data Collected 2019 - 2022.



5.0 SUMMARY AND RECOMMENDATIONS

The above discussion of water quality results illustrates the many factors that potentially influence DO concentrations in the Smith Mountain Dam tailwater. Because these factors are variable within any given monitoring year, identifying trends and/or correlations via relative comparison of the DO results from multiple years is, understandably, challenging. Therefore, such relative comparisons are understood to be general/limited.

Improvements to both the implementation and monitoring of the DO enhancement operational regime have occurred at Smith Mountain Lake. These improvements have resulted in providing DO enhancement in the Smith Mountain Dam discharge. However, as stated in previous annual water quality reports, the current enhancement measures are not sufficient to achieve the DO standards in the Project tailwater at all times and under all operational scenarios during the monitoring period. Several recommendations suggested for 2023 are provided below:

- Continue to use the “first on, last off” operating protocol from July 1 to November 15.
- Continue to follow the monitoring period of June 1 through December 1, as agreed upon by the WQTRC, to target the time of year when DO concerns are likely to occur.
- Continue with the procedures implemented to ensure the stilling basins are free from debris.
- Continue to evaluate historical data to establish correlations between environmental and operational factors and DO in the Project tailwater.
- Continue to evaluate engineering measures that are feasible to enhance DO in the Project tailwater. The DO enhancement feasibility study presented during the April 21, 2023 meeting is provided as Appendix C

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Appendix A

2022 Smith Mountain Lake Water Quality Monitoring Report

Smith Mountain Lake Association

Smith Mountain Lake
Water Quality Monitoring Program
2022 Report

Prepared by
Dr. Delia R. Heck, Dr. Clay Britton, Dr. Dana Ghioca Robrecht,
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Bedford County Regional Water Authority
Smith Mountain Lake Association
Virginia Department of Environmental Quality
Western Virginia Water Authority

February 1, 2023

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Bacteria Monitors

Gael and Smith Chaney, Union Hall

1. EXECUTIVE SUMMARY

The 2022 monitoring season began in May with the annual training session which was held in person for the first time in two years. Volunteer monitors measured water clarity and collected water samples every other week until mid-August. Student technicians from Ferrum College traveled around the lake every other week to pick up the samples for analysis at the Ferrum College Water Quality Lab. During this trip, the interns also collected grab samples from 21 tributaries that were analyzed for total phosphorus (one tributary is sampled by a volunteer monitor). Also on a bi-weekly schedule, Ferrum College personnel collected additional lake samples for bacterial analysis.

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

1.1 *Conclusions – Trophic Status*

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

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

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

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

1.3 *Escherichia coli Measurements*

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

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

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

1.4 *Algae in Smith Mountain Lake*

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

2. INTRODUCTION

The Smith Mountain Lake Water Quality Monitoring Program (SMLWQMP), now in its thirty-sixth year, is a water quality program designed to monitor the water quality and the trophic status of Smith Mountain Lake, a large (25,000+ acre) pump-storage reservoir located in southwestern Virginia. Scientists from Ferrum College and designated members of the Smith Mountain Lake Association (SMLA) jointly manage the project. This report describes the 2022 monitoring season.

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

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

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

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

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

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

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

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

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

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

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

3. METHODS

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

These three water quality parameters are measured at trophic channel sampling stations located approximately every two miles on the Roanoke and Blackwater channels to monitor the movement of the silt and nutrient laden waters moving toward the main basin of the lake. These sites begin at the dam and extend to the Hardy Ford Bridge on the Roanoke channel and to the B49 channel marker on the Blackwater channel. The trophic cove sampling stations are also important for trend analysis and help us fulfill the role of "watchdogs". In the "watchdog" mode, we monitor as much of the lake as possible for signs of localized deterioration of water quality, which may be due to site-specific problems such as malfunctioning septic systems.

Trophic sampling station codes contain information on the location of the station. The sample station codes for trophic stations are based on:

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

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

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

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

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

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

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

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

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

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

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

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

4. TROPHIC STATUS MONITORING

4.1 *Introduction*

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

Phosphorus is a plant nutrient that stimulates the growth of algae. Phosphate, the form of phosphorus most immediately available to algae, is the limiting nutrient in Smith Mountain Lake. As a result, monitoring of total phosphorus (TP) concentrations in Smith Mountain Lake can provide early warning of increased nutrient enrichment and the possibility of algal blooms.

4.2 *Methods*

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

At the sites below the dam (T9, T10, and T11), student technicians collect samples from bridges in the same manner as the other tributary samples. These samples are collected below the dam and are not tributaries flowing directly into the lake. Because of the pump-back system, some water from these sites does enter the lake. Station T9 is on the Roanoke River just below the dam at the Smith Mountain Visitor's Center, Station T10 is on the lower Pigg River, near its confluence with the Roanoke River, and Station T11 is on the Roanoke River after its confluence with the Pigg River.

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

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

4.3 Results

The trophic status parameters for Smith Mountain Lake and its tributaries for the past 10 years are presented in Table 4.1. The parenthetical values indicate the relative change in percent in the parameter from each previous year.

Table 4.1. Average trophic parameter values in parts per billion (ppb) and meters (m) for Smith Mountain Lake and its tributaries

Year	**Smith Mountain Lake Average Total Phosphorus** (ppb)	**Tributaries Average Total Phosphorus** (ppb)	**Smith Mountain Lake Average Chlorophyll-*a*** (ppb)	**Smith Mountain Lake Average Secchi Depth** (m)
2022	**27.5**	**66.1**	**4.9**	**2.0**
2021	31.2	65.3	5.4	2.1
2020	34.7	59.8	13.6	1.6
2019	41.2	70.5	12.6	1.8
2018	30.7	68.3	13.4	1.8
2017	30.6	58.7	12.9	1.8
2016	29.1	73.2*	8.7*	2.1
2015	22.7	84.9	6.8	2.3
2014	26.9	94.2	2.7	2.3
2013	23.9	69.6	13.3	2.2
10 Year Average	***28.6***	***68.5***	***9.2***	***2.0***

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

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

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

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

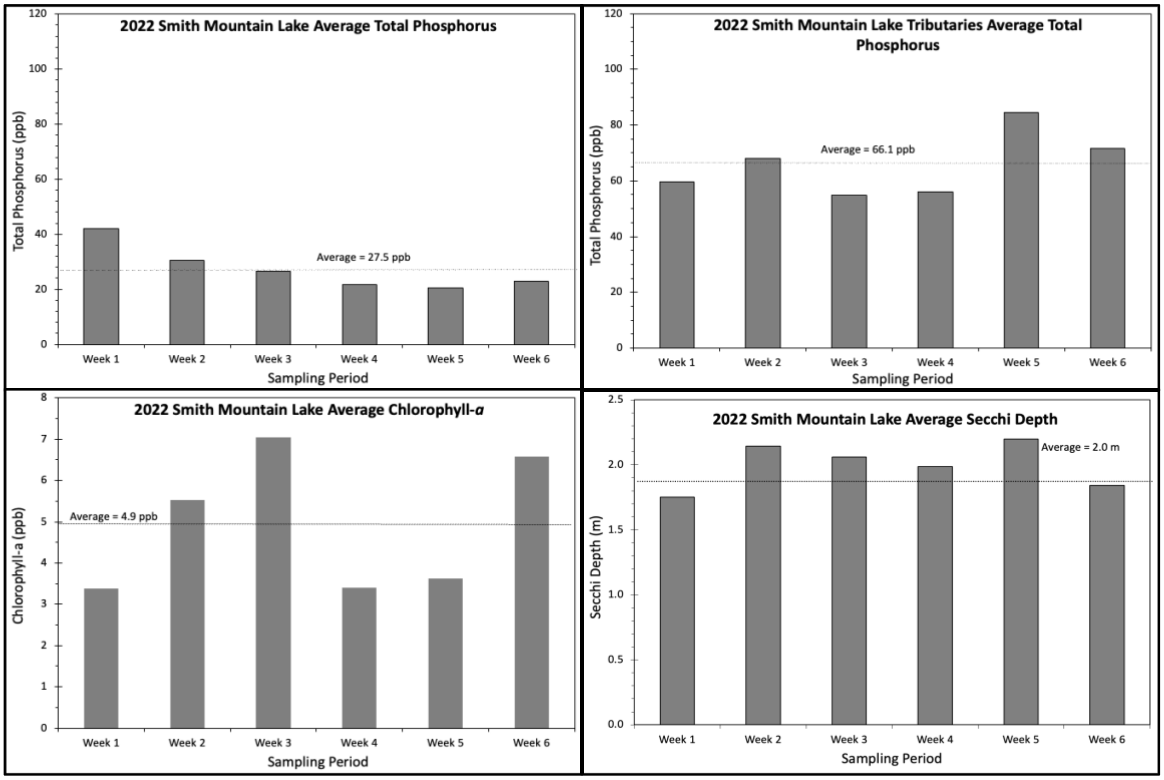


Figure 4.1. Trophic status parameters (total phosphorus, chlorophyll-*a*, and Secchi depth) for Smith Mountain Lake for each sampling period in 2022

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

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

4.4 Discussion

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

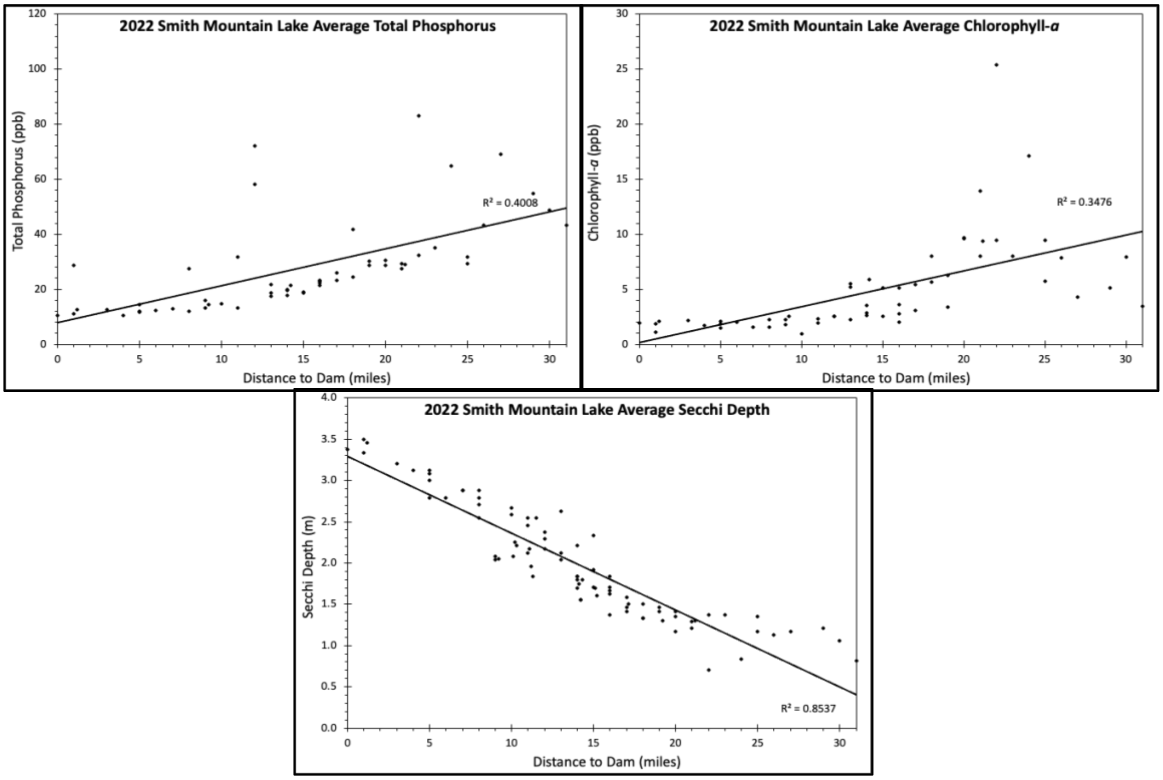


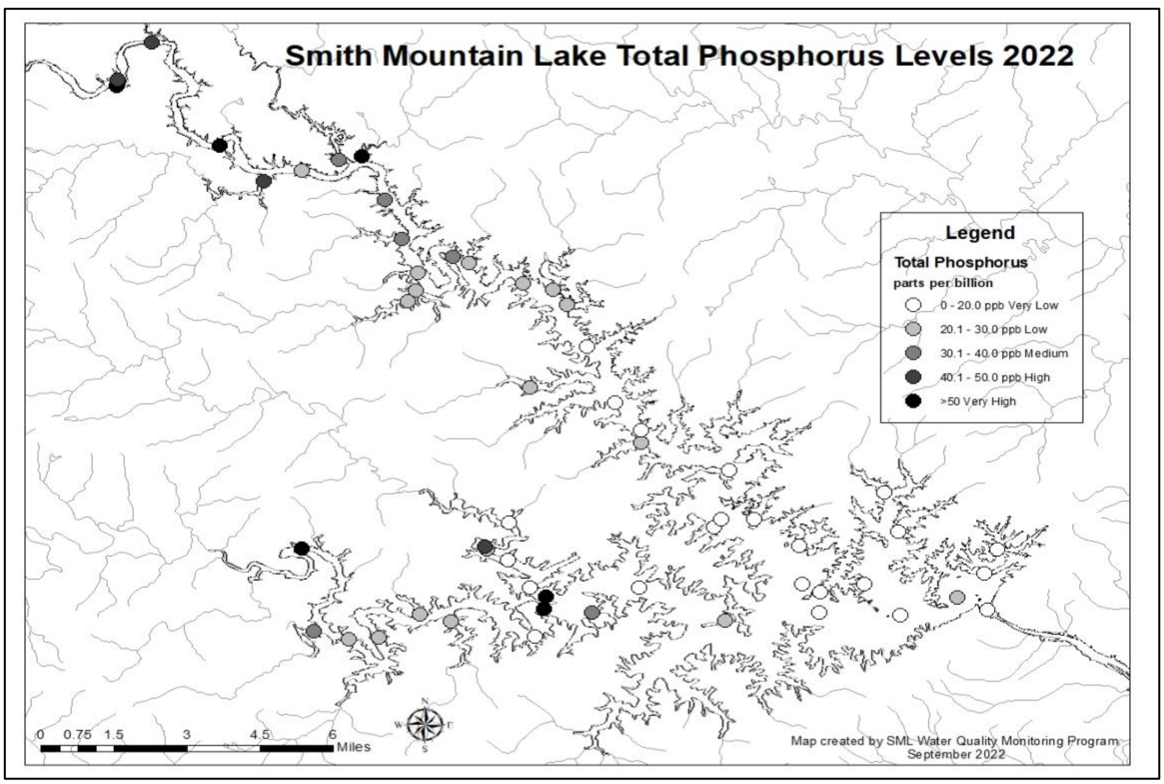
Figure 4.2. Variation of trophic status parameters with distance to the dam for Smith Mountain Lake in 2022

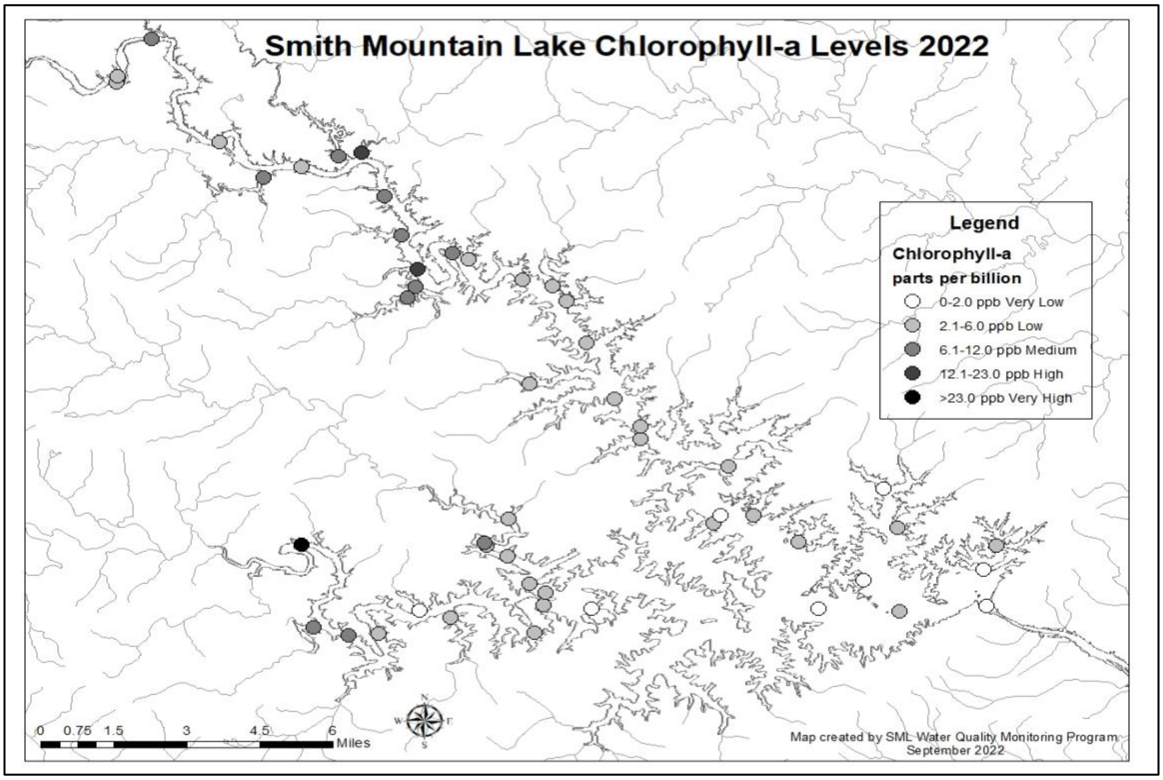
The first graph in Figure 4.2 shows that in general, phosphorus concentrations increase with increasing distance from the dam ($R^2 = 0.40$). This general trend can be attributed to increased sediment loads in waters further from the dam. The total phosphorus concentration outliers (defined as values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

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

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

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





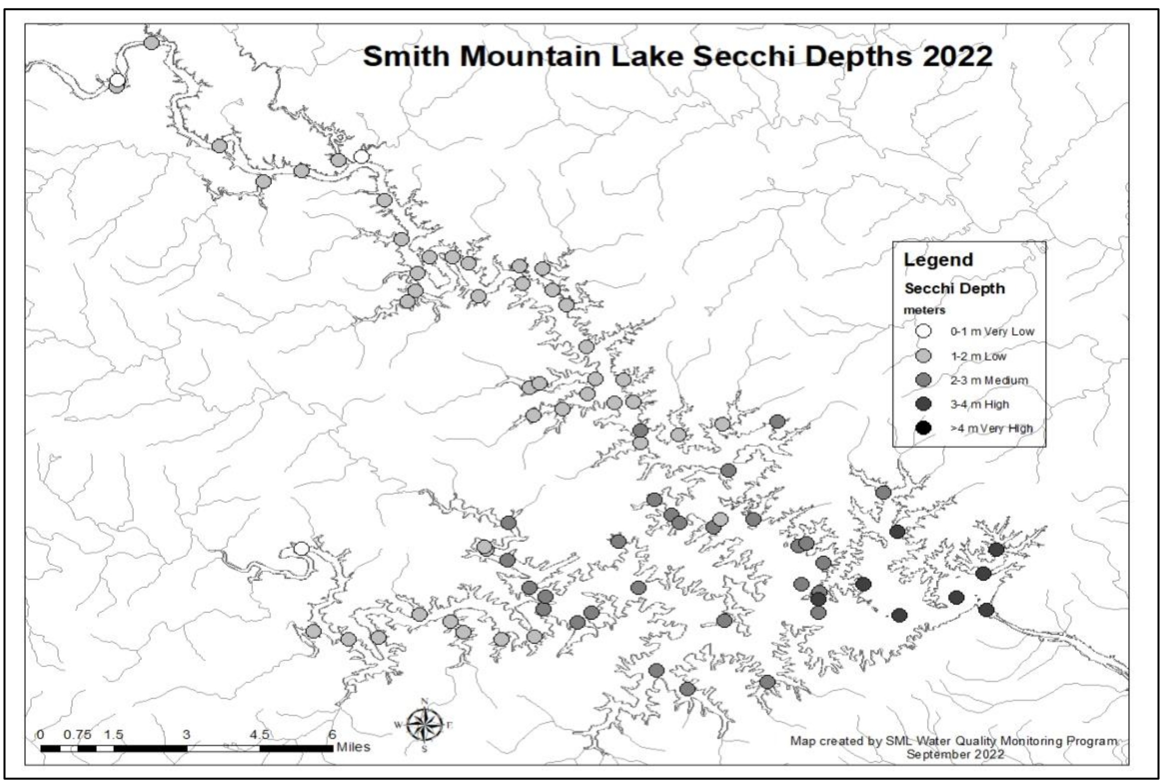


Figure 4.3.　Maps showing variation in trophic status parameters for 2022

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

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

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

4.5 *Conclusions*

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

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

5. WATER QUALITY TRENDS BY ZONE

5.1 *Introduction*

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

5.2 *Methods*

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

Table 5.1. Proposed relationships among phosphorus concentration, trophic state, and lake use for northern temperate lakes (Reckhow and Chapra 1983)

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

The algal growth resulting from inputs of phosphorus can also be used to evaluate the trophic status of a lake. This is done by extracting the green pigment, chlorophyll-*a*, from algae filtered from lake water samples and measuring its concentration. Table 5.2 shows the trophic status delineation based on the concentration of chlorophyll-*a*. It also shows that the evaluation of trophic status is a matter of professional judgment, not a parameter to be measured exactly.

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

Table 5.2. Trophic status related to chlorophyll-*a* concentration in different studies (Reckhow and Chapra 1983)

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

One of the best-known trophic state indices is the Carlson Trophic State Index (TSI) named after the researcher who developed it (Carlson 1977). This index is used to help interpret the water quality data collected on Smith Mountain Lake. The Carlson TSI may be calculated from total phosphorus concentration (TP), chlorophyll-*a* concentration (CA), or Secchi disk depth (SD). In addition, the index obtained from each of these parameters can be averaged to give a combined TSI. This is important because any of the individual parameters can be misleading in some situations. Secchi disk readings are a misleading indicator of trophic status in lakes with non-algal turbidity caused by soil erosion, such as in the upper river channels and near shore areas of Smith Mountain Lake. Phosphorus will not be a good indicator in lakes where algal growth is not limited by availability of phosphorus (algal growth in Smith Mountain Lake is phosphorus-controlled). Chlorophyll-*a* may be the best indicator during the growing season and the worst at other times.

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

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

The lake zones have been delineated as follows:

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

5.3 Results

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

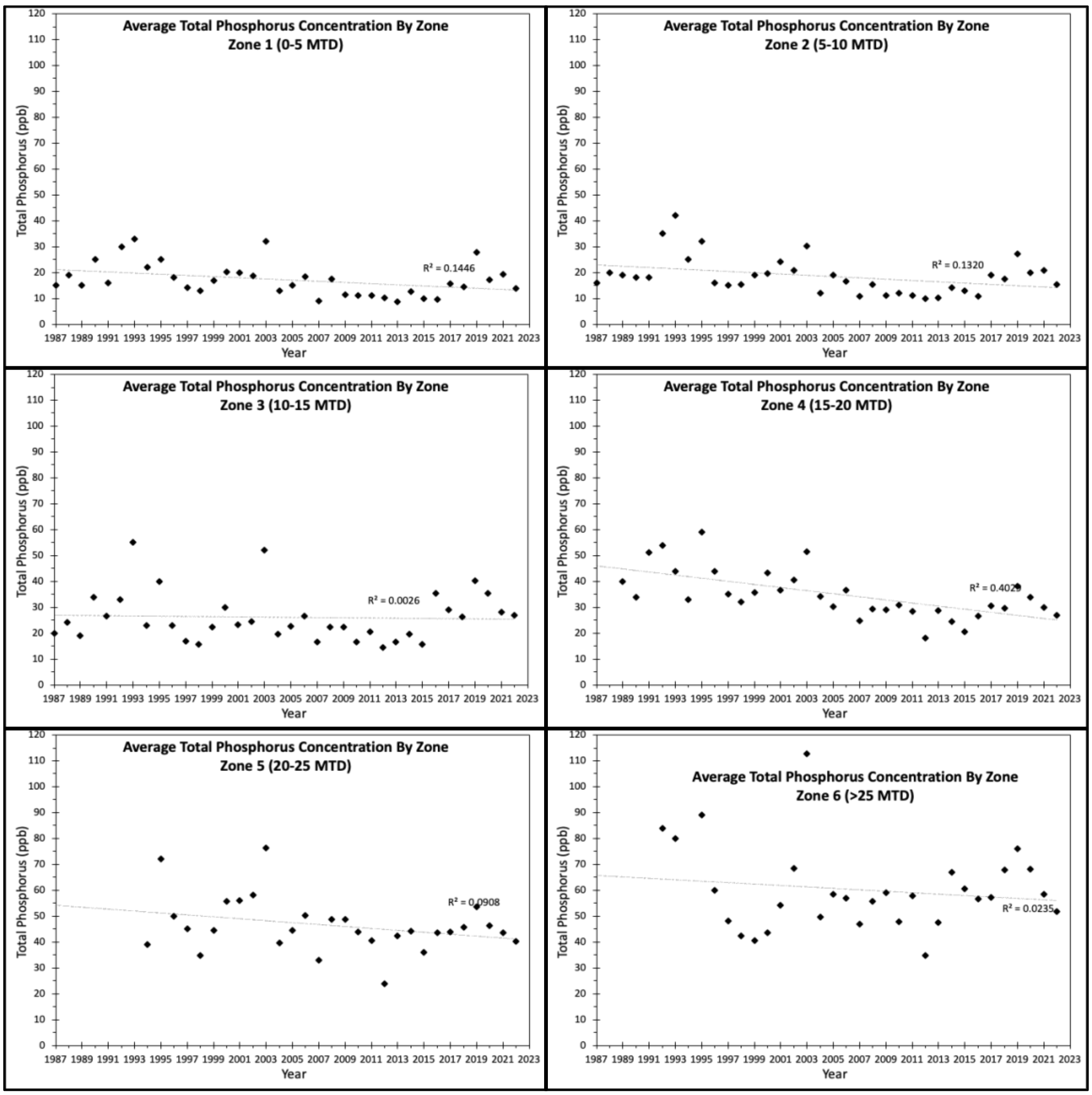


Figure 5.1. Average annual total phosphorus concentration by year and zone

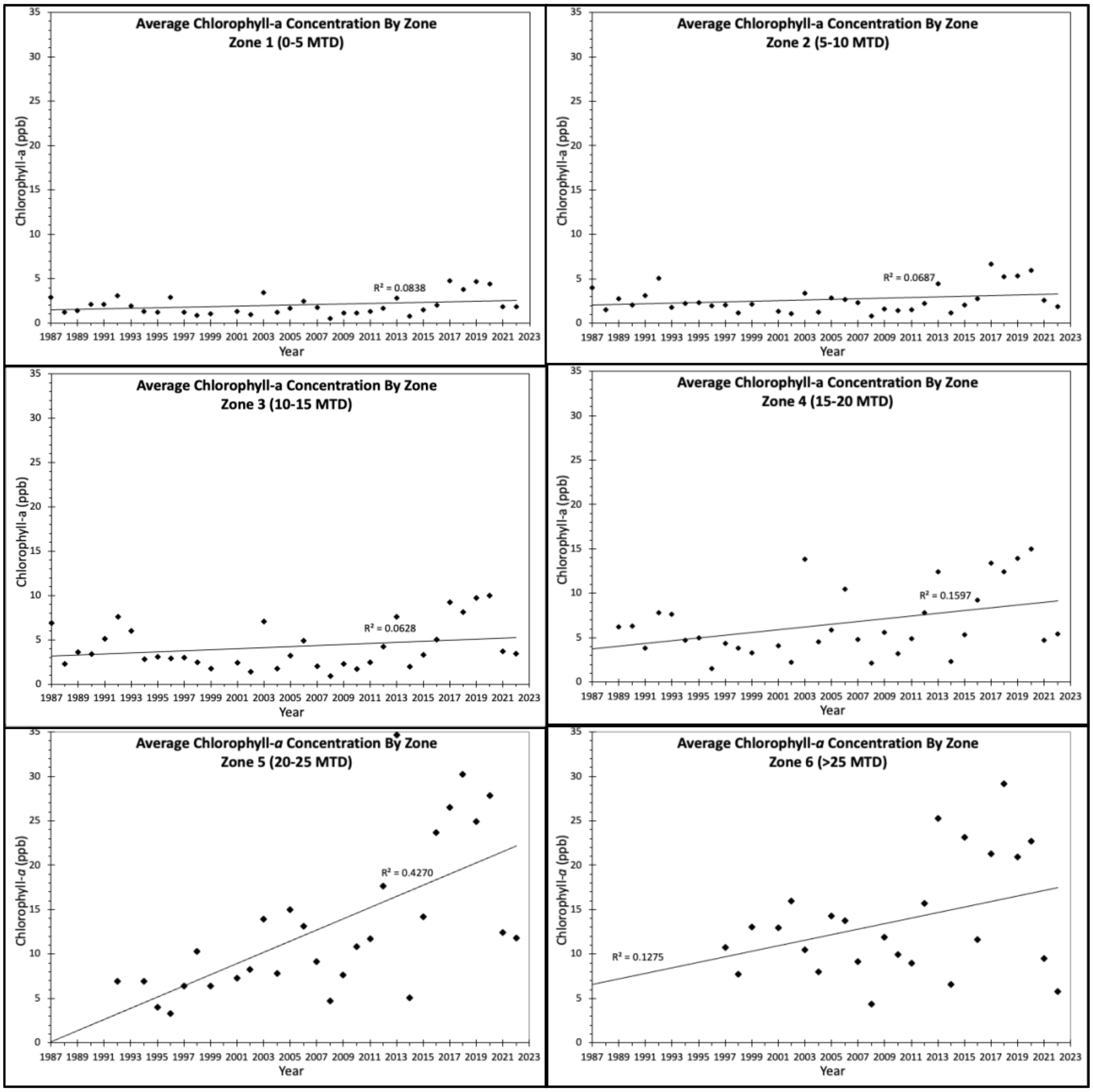


Figure 5.2. Average annual chlorophyll-*a* concentration by year and zone

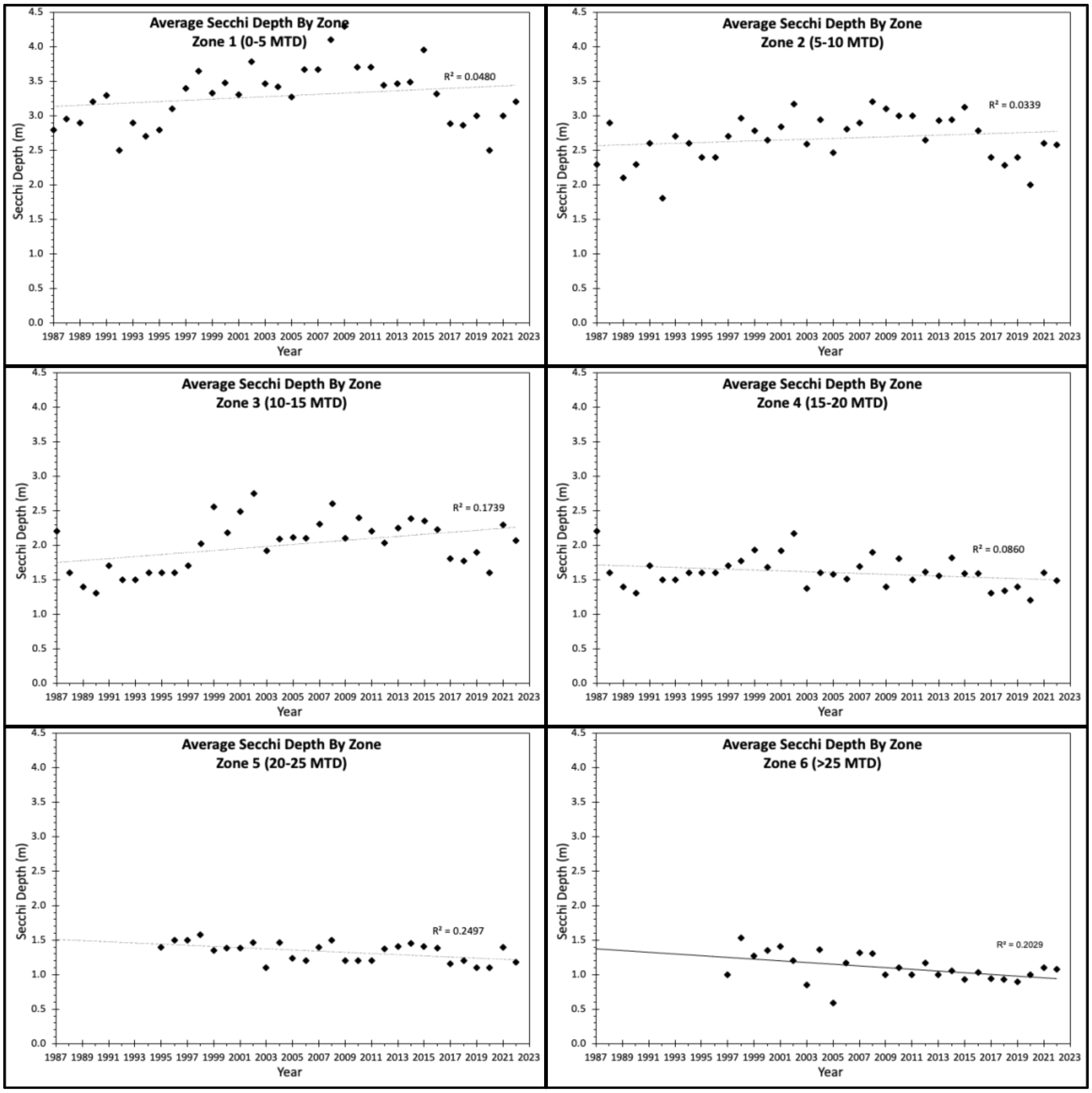


Figure 5.3. **Average annual Secchi depth by year and zone**

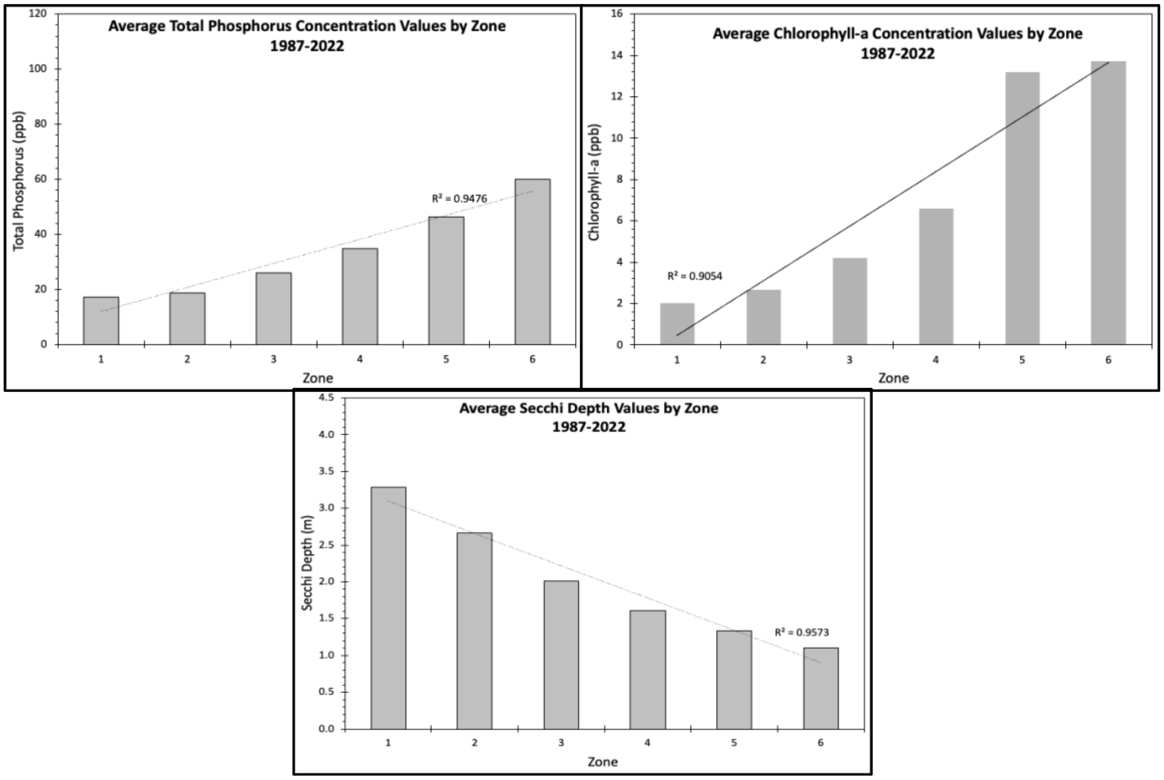


Figure 5.4. Average parameter value by zone for 1987-2022 Carlson's Trophic State Index Components

5.4 *Discussion*

In Figure 5.5, the combined trophic state index has been plotted as a function of its distance from the dam. Figure 5.6 shows the spatial distribution of the combined trophic state index throughout the lake. The results again demonstrate the trend toward improved water quality near the dam and the trend is strong ($R^2 = 0.79$).

Table A.5 gives the monitoring stations with miles-to-dam (MTD) ordered according to the combined TSI. For each station, especially those with high TSI-C values, it is useful to look at the TSI calculated on the basis of each trophic parameter to examine the contribution of each. The highest TSI-C value (65.1) was at B22 this year, while the lowest TSI-C value (39.1) was at CM1.

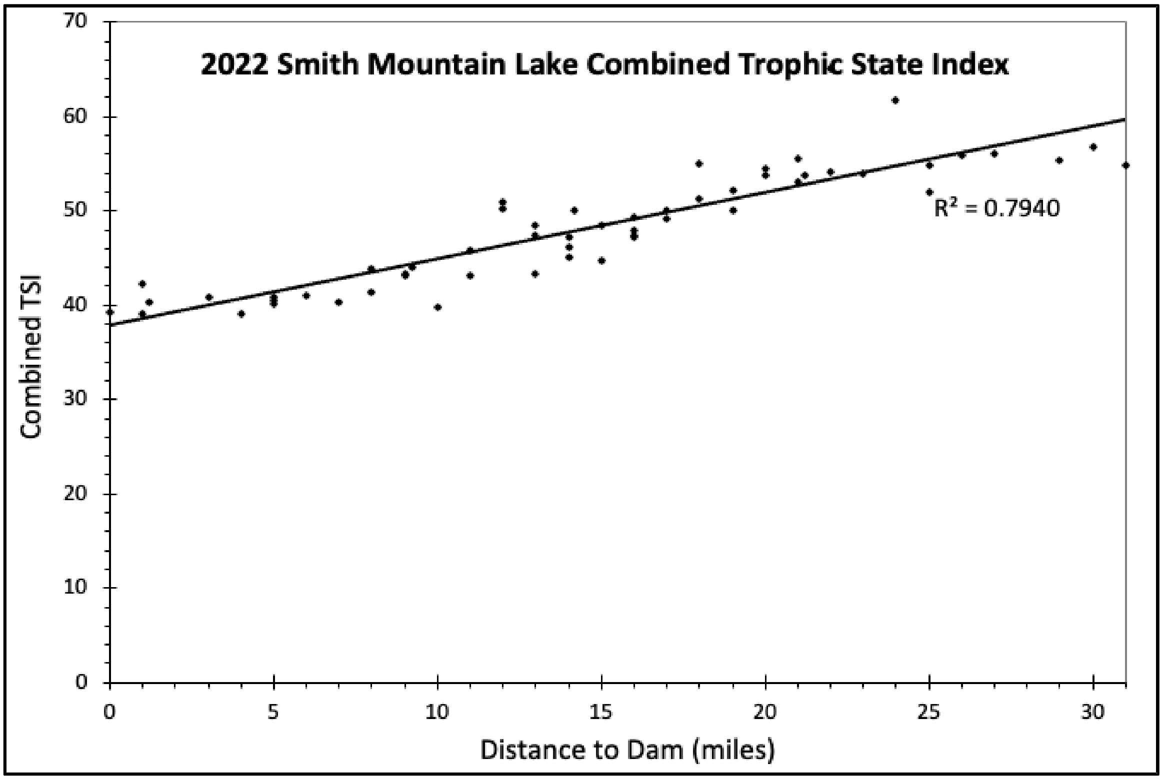


Figure 5.5. Combined Trophic State Index as a function of distance from dam

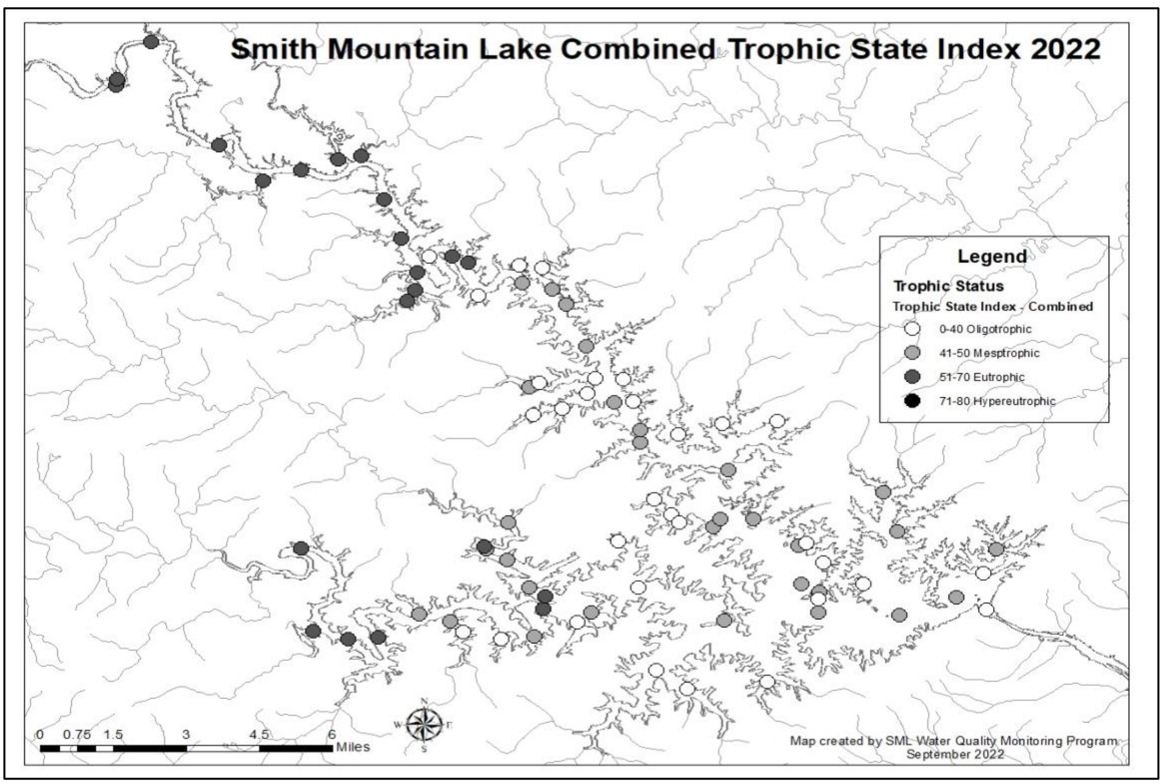


Figure 5.6. Map showing the Trophic State Index Combined results throughout the lake

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

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

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

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

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

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

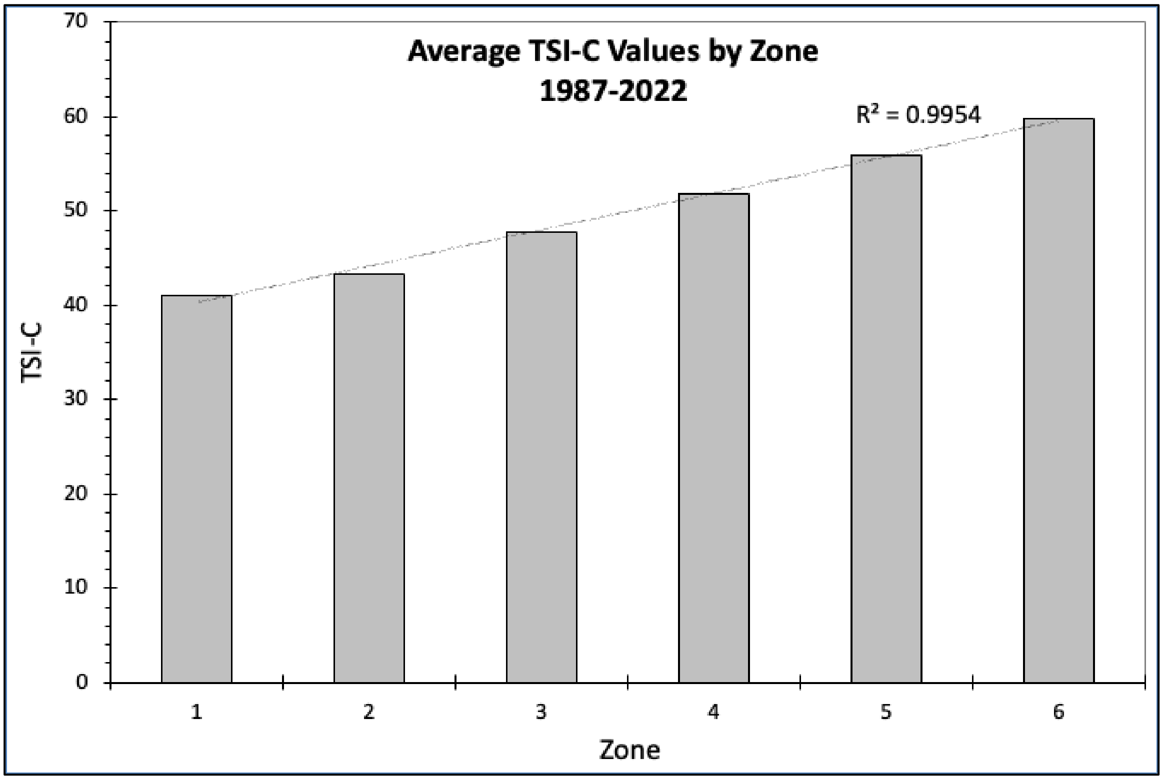


Figure 5.7. Combined Trophic State Index by zone from 1987 – 2022

5.5 Conclusions

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

6. VERTICAL PROFILES OF WATER QUALITY PARAMETERS

6.1 *Introduction*

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

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

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

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

6.2 *Methods*

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

6.3 *Results*

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

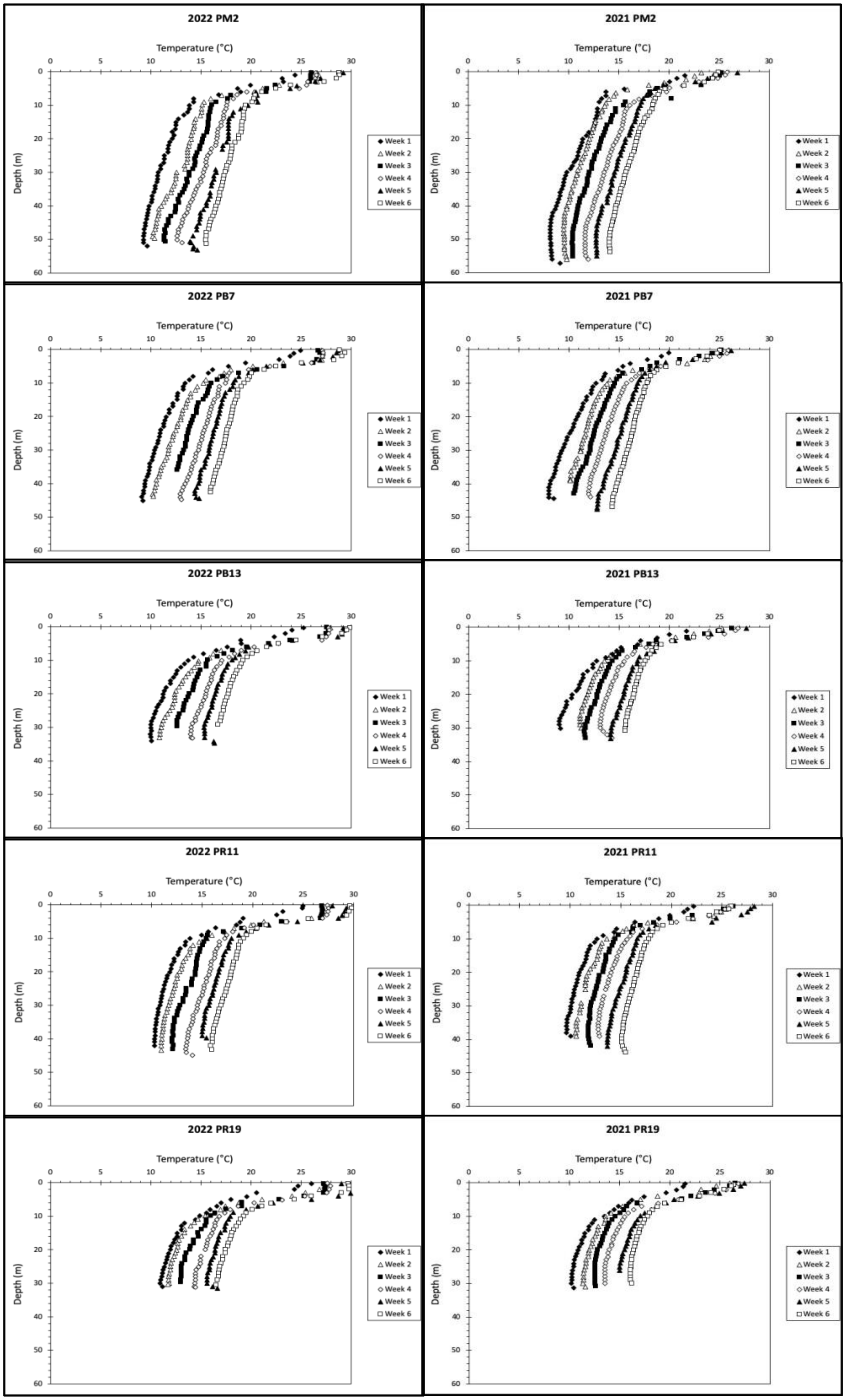

2022 PM2
2021 PM2
2022 PB7
2021 PB7
2022 PB13
2021 PB13
2022 PR11
2021 PR11
2022 PR19
2021 PR19
Temperature (°C)
Depth (m)
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6

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

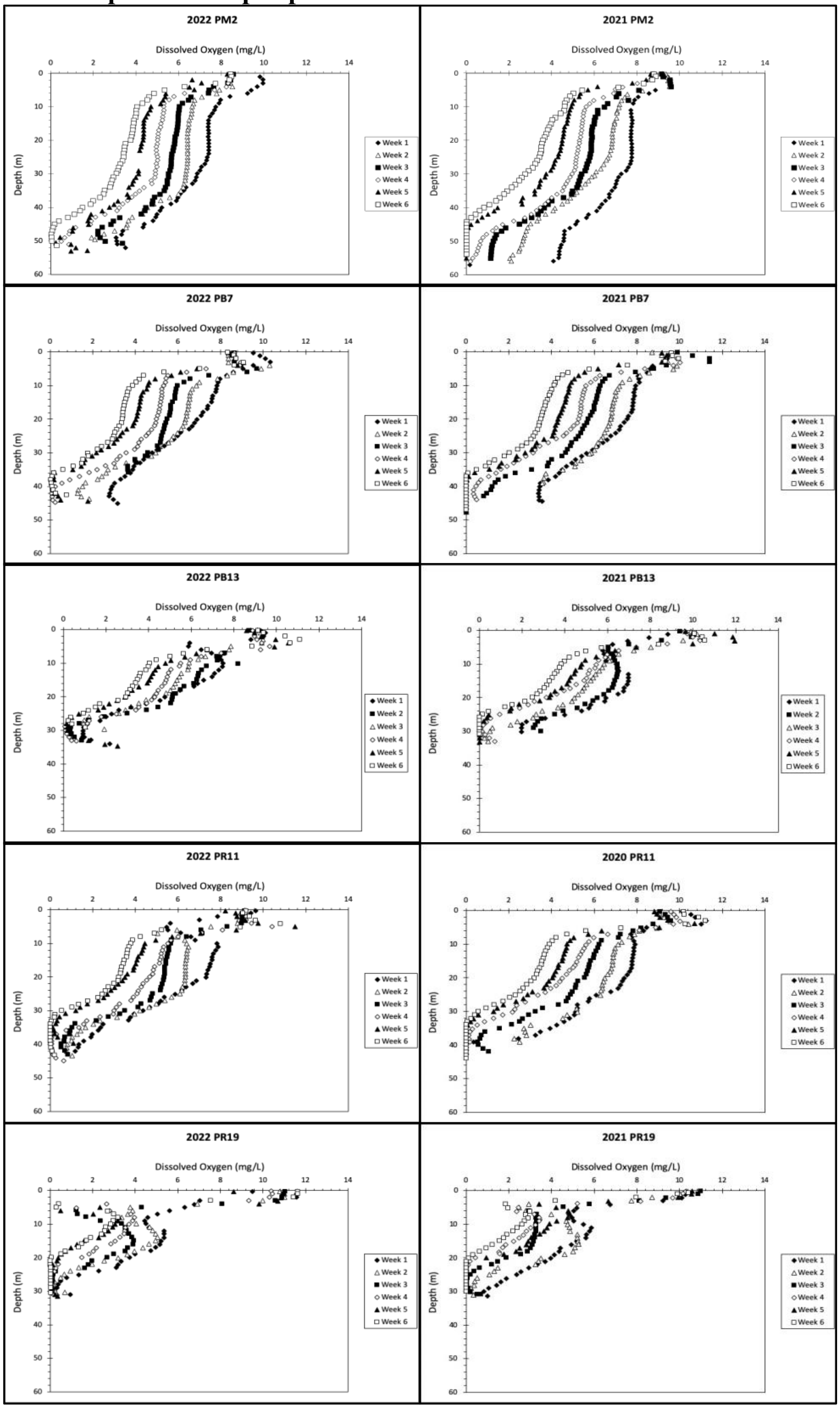


Figure 6.2. Dissolved oxygen depth profiles for Smith Mountain Lake in 2021 and 2022

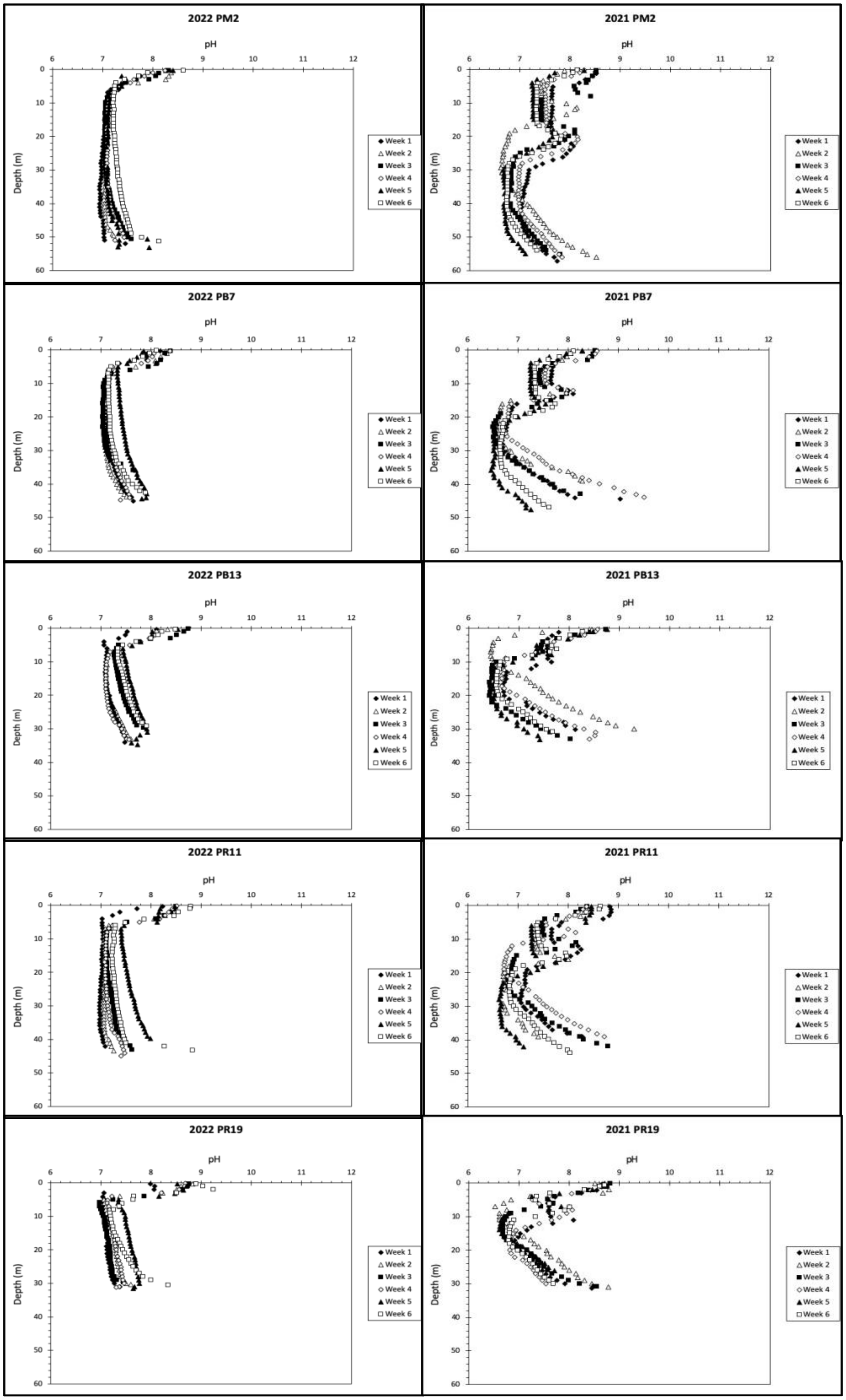

2022 PM2
2021 PM2
2022 PB7
2021 PB7
2022 PB13
2021 PB13
2022 PR11
2021 PR11
2022 PR19
2021 PR19
pH
Depth (m)
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6

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

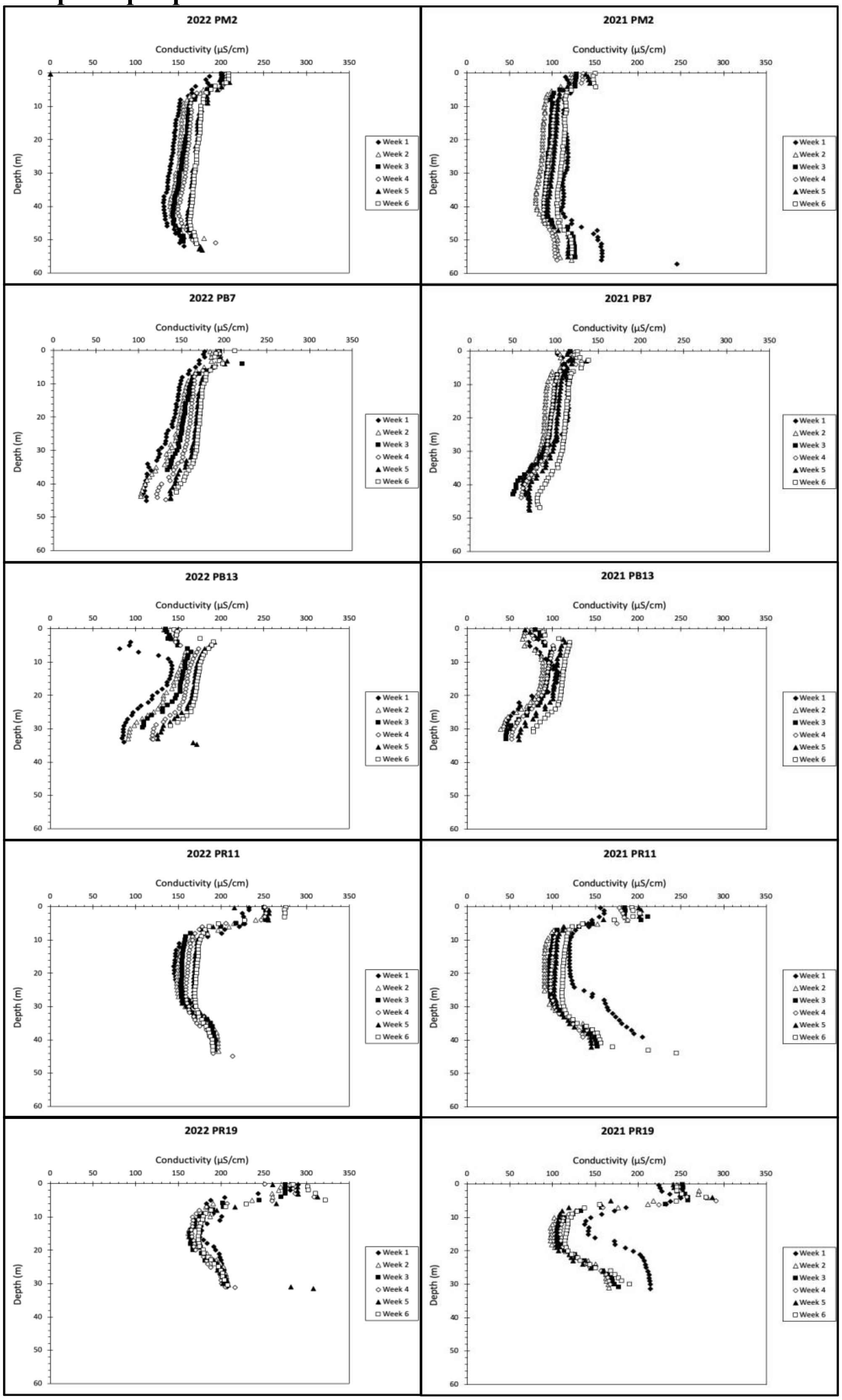


Figure 6.4. Conductivity depth profiles for Smith Mountain Lake in 2021 and 2022

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

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

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

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

6.4 Discussion

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

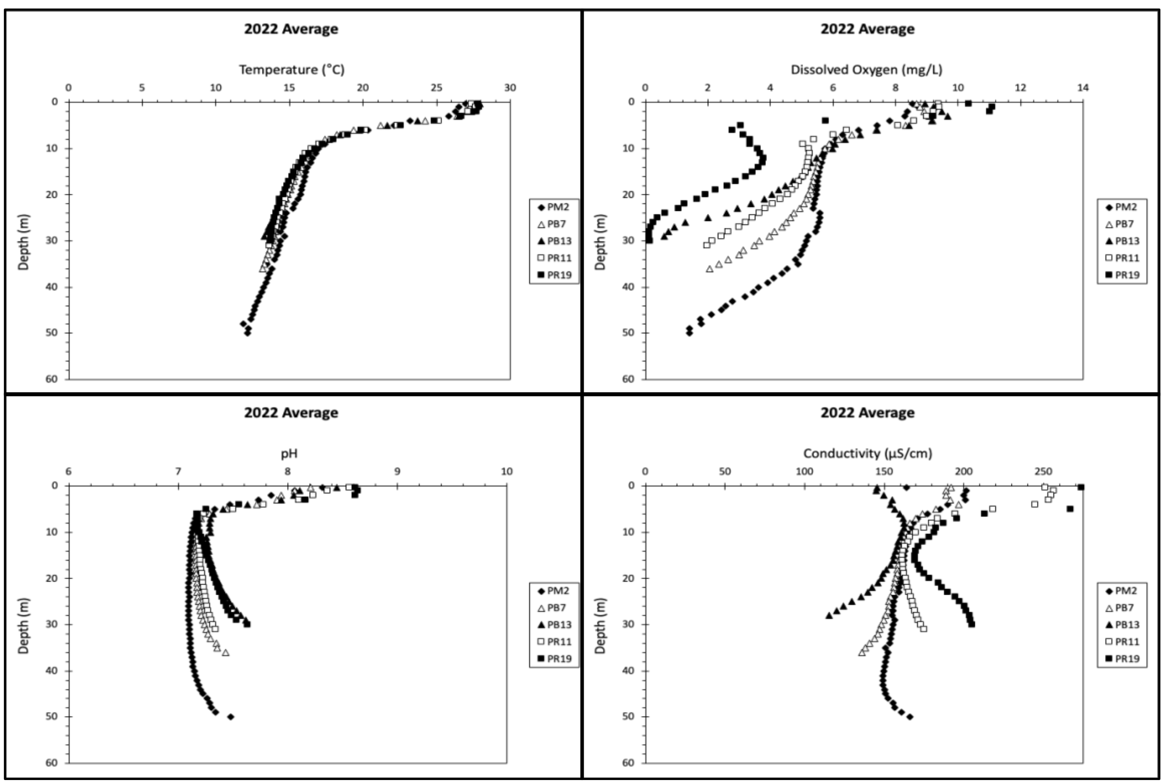


Figure 6.5. Average depth profiles for 2022 for each parameter sampled on Smith Mountain Lake by sample site

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

6.5 *Conclusions*

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

7. BACTERIA IN SMITH MOUNTAIN LAKE

7.1 *Introduction*

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

7.2 *E. coli Methods*

Samples were collected in sterile 125 mL polypropylene bottles at 0.25 m depth and stored according to *Standard Methods for Water and Wastewater Analysis* (APHA 1999). Two stations were sampled at each site and at each station a 100 mL sample was evaluated. A Colilert™ media packet was added to these 100 mL water samples and mixed thoroughly by shaking vigorously until the powdered media was dissolved. The mixture was poured into a sterile Quanti-Tray 2000™ and passed through the Quanti-Tray™ Sealer after being placed in a rubber insert to seal the sample into the wells in the Quanti-Tray 2000™. The sealed trays were incubated for 24 hours at 35 °C. For the Colilert™ media, a color change from clear to yellow indicates a positive result for total coliform and fluorescence indicates a positive result for *E. coli*. The numbers of yellow and fluorescent wells (both large and small) were counted and the values were evaluated using a Most Probable Number (MPN) chart developed by the Colilert™ method developers (IDEXX Company). A geometric mean is then calculated for each site based on those two stations. MPN is used instead of colony forming units (CFU) and is generally considered an equivalent measure of the microbial and bacterial populations. The IDEXX™ method for Colilert™ has been rated as the "best" in agreement with a reference lab, has the lowest detection limit and the Colilert™ method is EPA approved for ambient water (O'Brien 2006).

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

7.3 *E. coli Results and Discussion*

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

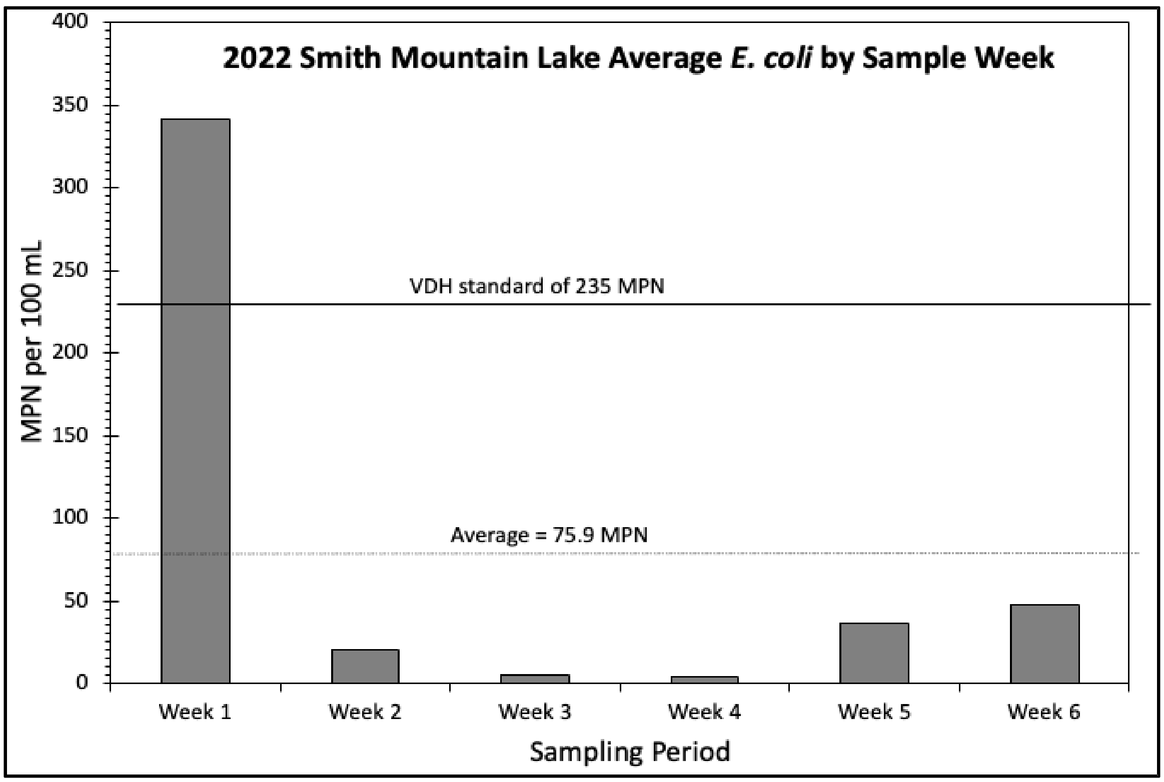


Figure 7.1. ***E. coli* versus week sampled on Smith Mountain Lake in 2022 (Each sample date included 14 sites with 2 stations per site, n = 28)**

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

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

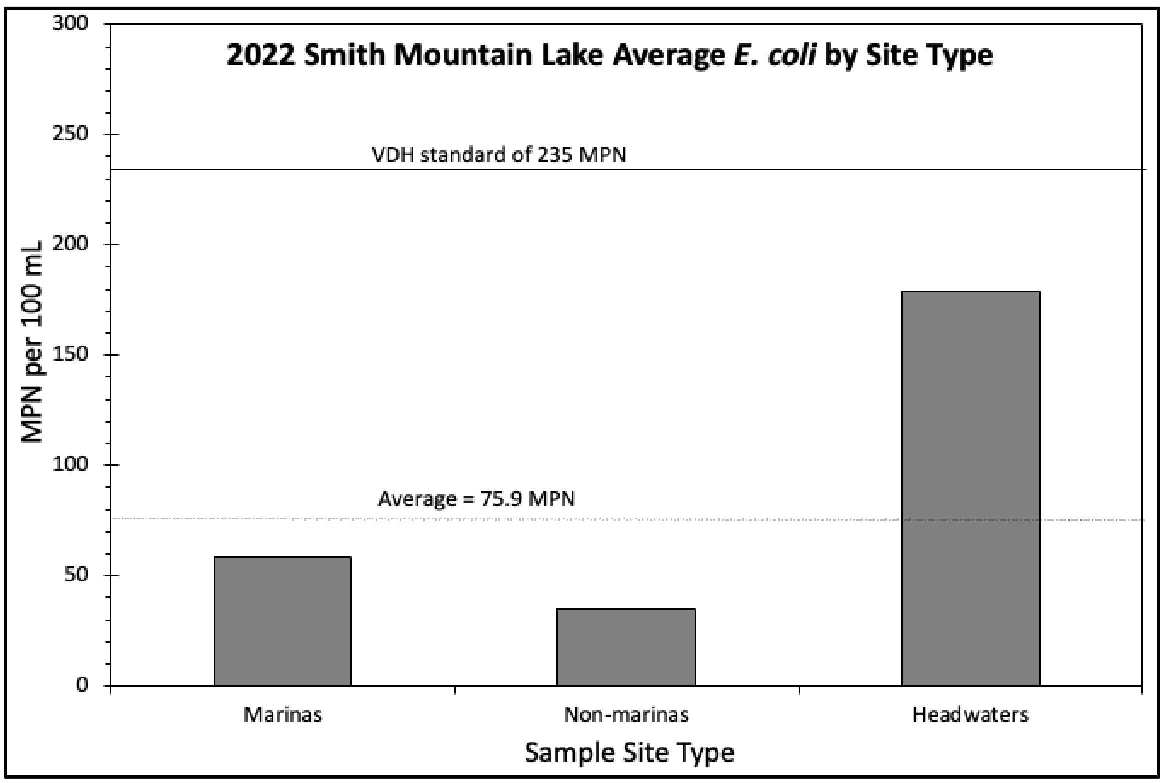


Figure 7.2. Mean *E. coli* count vs. site type in 2022 - 6 marina sites, 5 non-marina sites, and 3 headwater sites

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

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

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

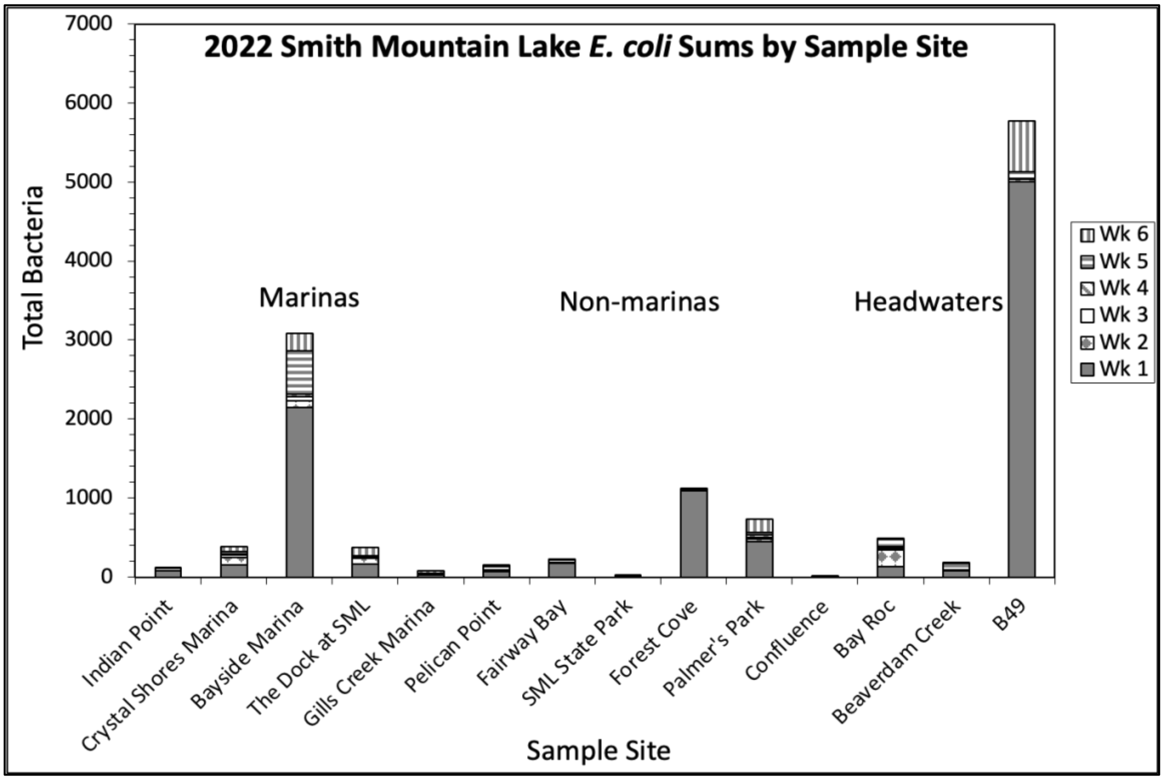


Figure 7.3. Sum of *E. coli* count vs. sample site in 2022 at each of the two sampling stations at each site for all sample dates

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

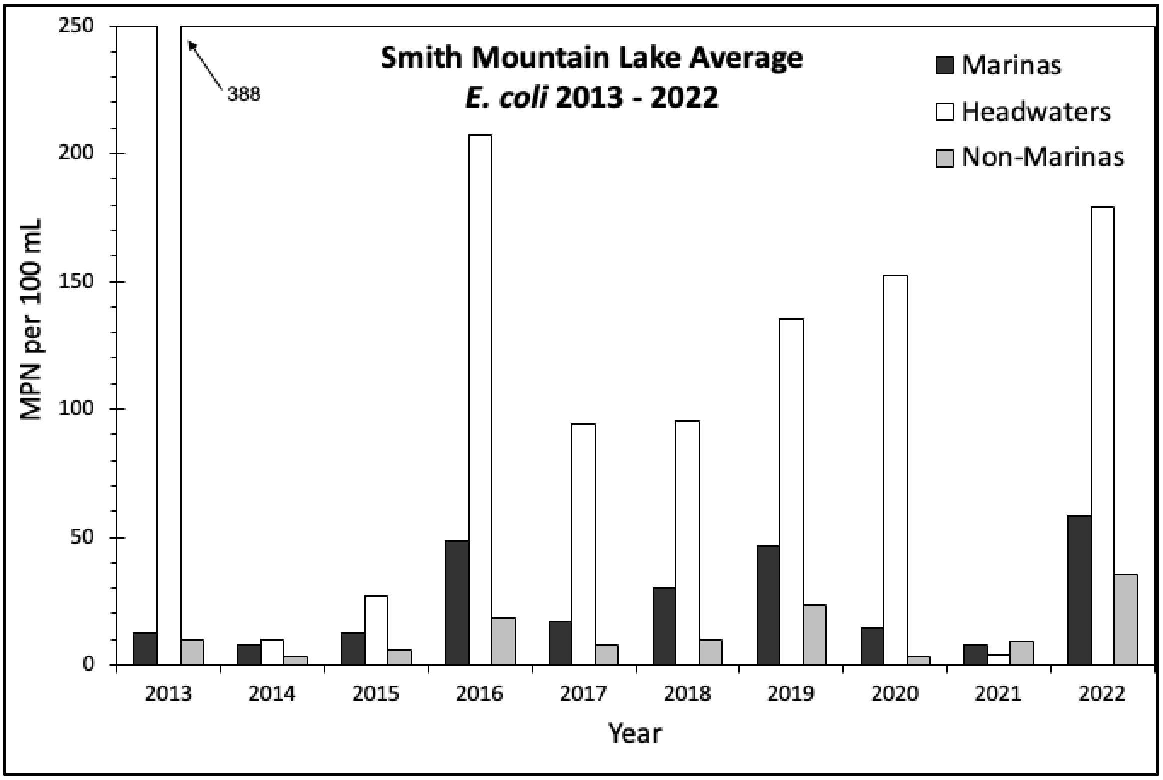


Figure 7.4. **Mean *E. coli* counts per site type from 2013-2022**

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

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

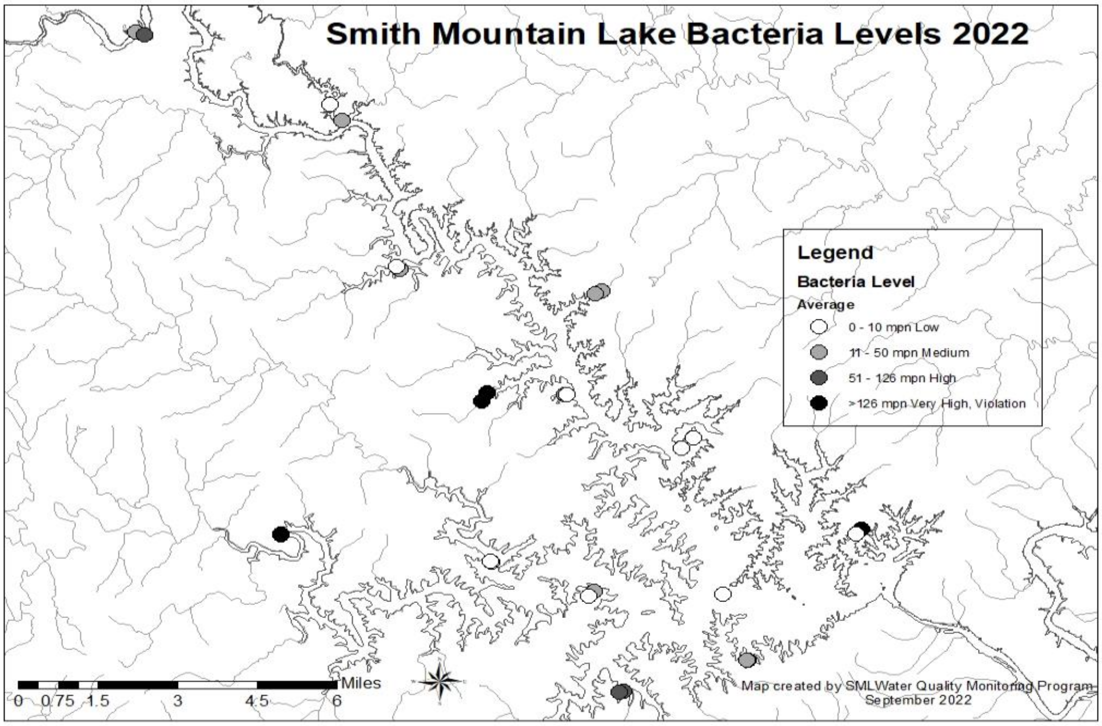


Figure 7.5. Map of bacterial sampling results in Smith Mountain Lake for 2022

7.4 *E. coli Conclusions*

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

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

8. ALGAE IN SMITH MOUNTAIN LAKE

8.1 *Introduction*

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

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

8.2 *Methods*

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

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

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

8.3 Results

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

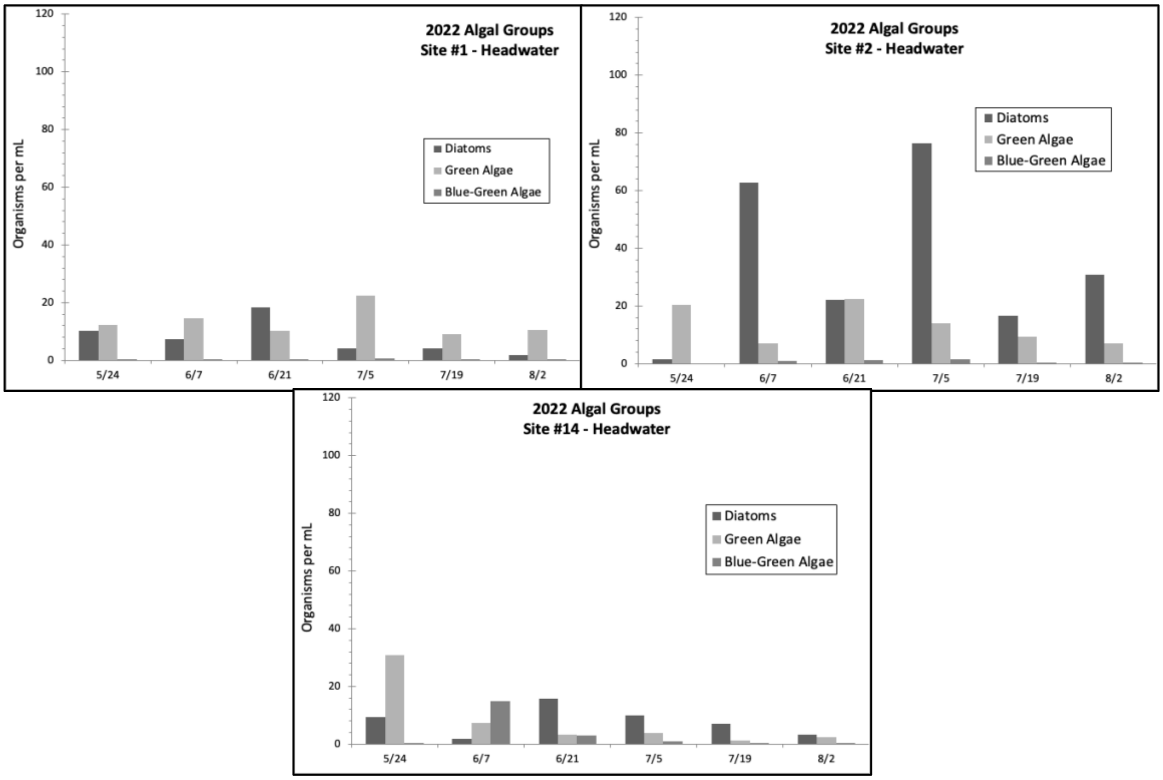


Figure 8.1. Algae groups versus week from headwaters sites (Sites 1, 2, and 14)

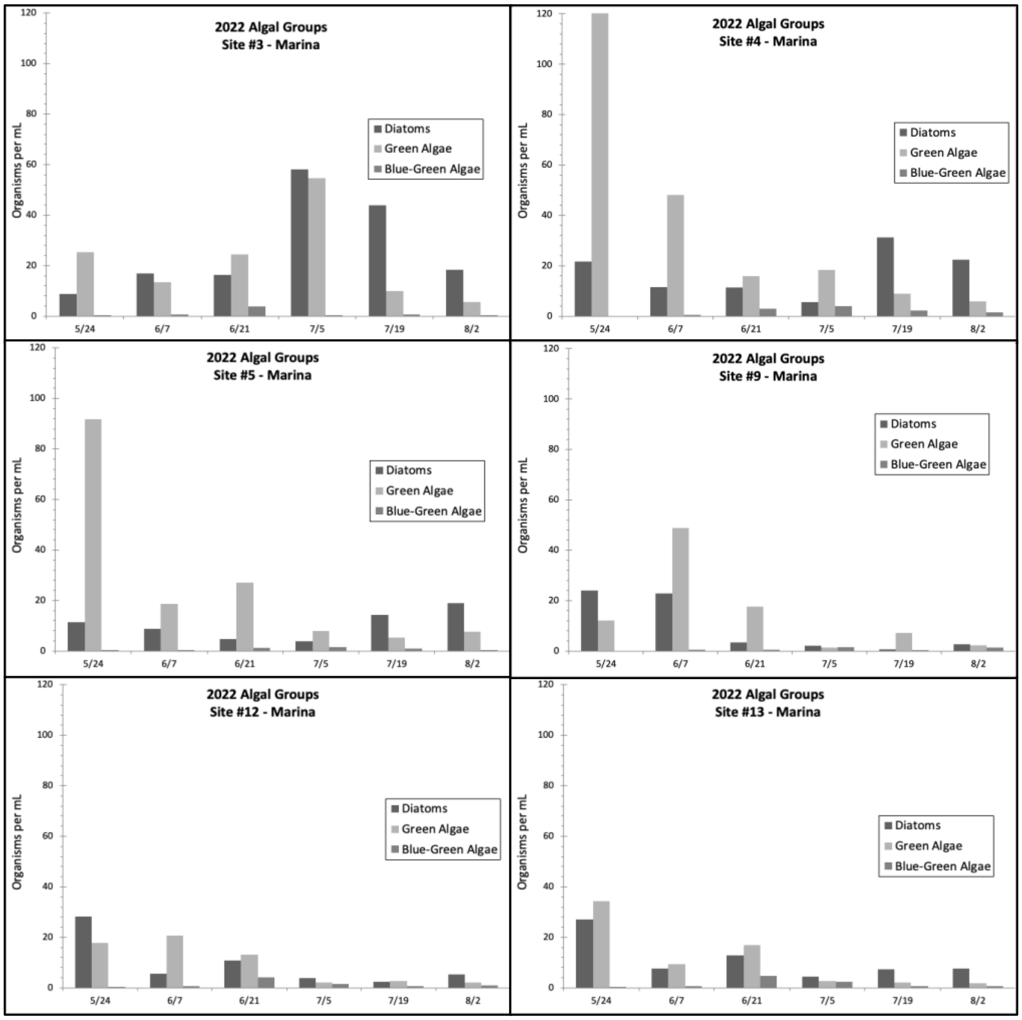


Figure 8.2. Algae groups versus week from marina sites (Sites 3, 4, 5, 9, 12, and 13)

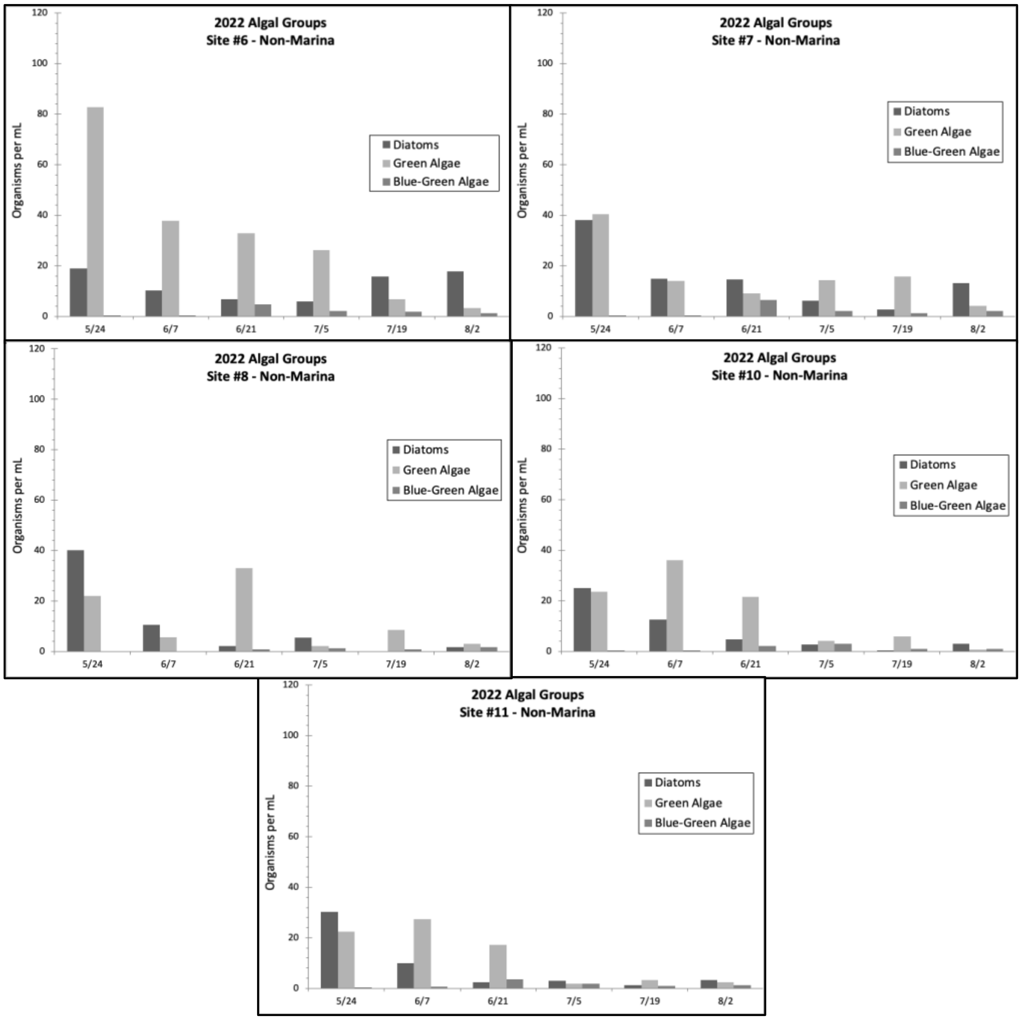


Figure 8.3. Algae groups versus week from non-marina sites (Sites 6, 7, 8, 10, and 11)

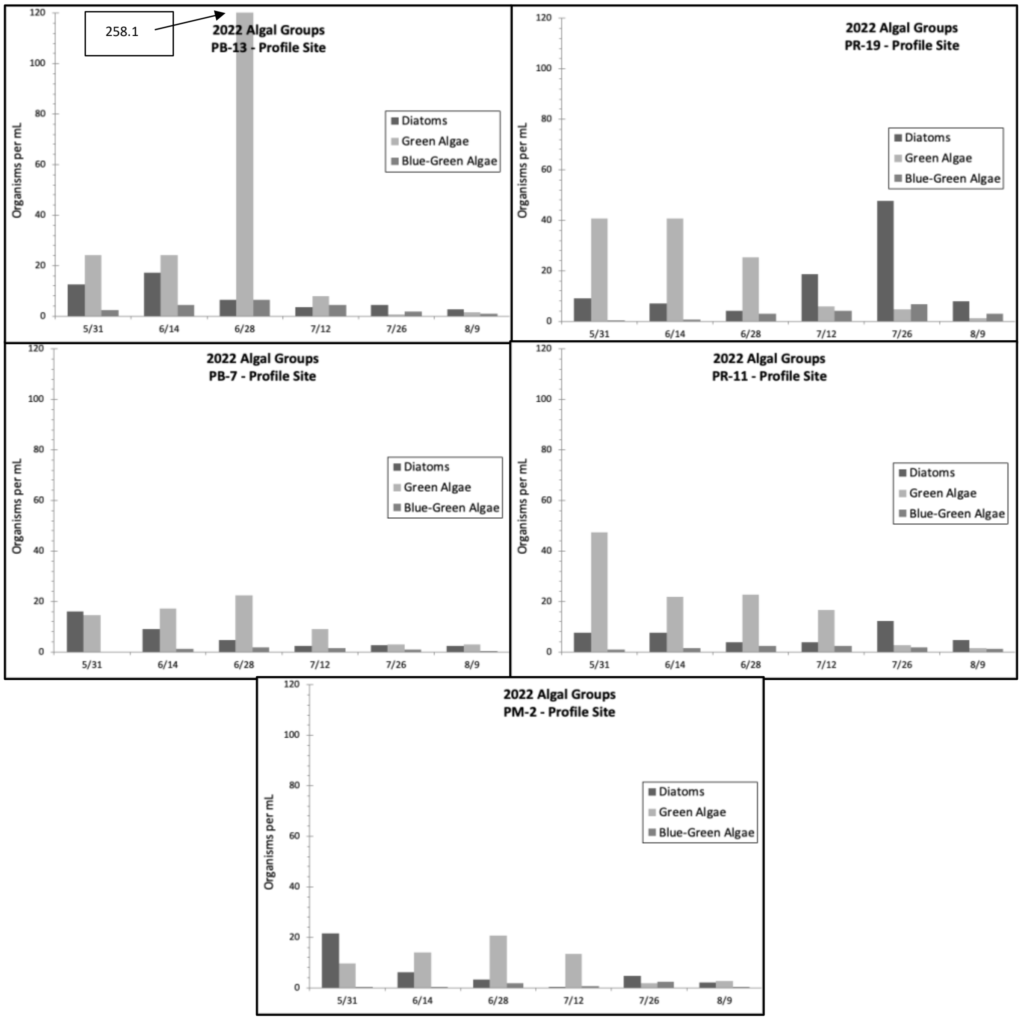


Figure 8.4. Algae groups versus week from profile sites (Sites PB7, PB13, PR11, PR19, and PM2)

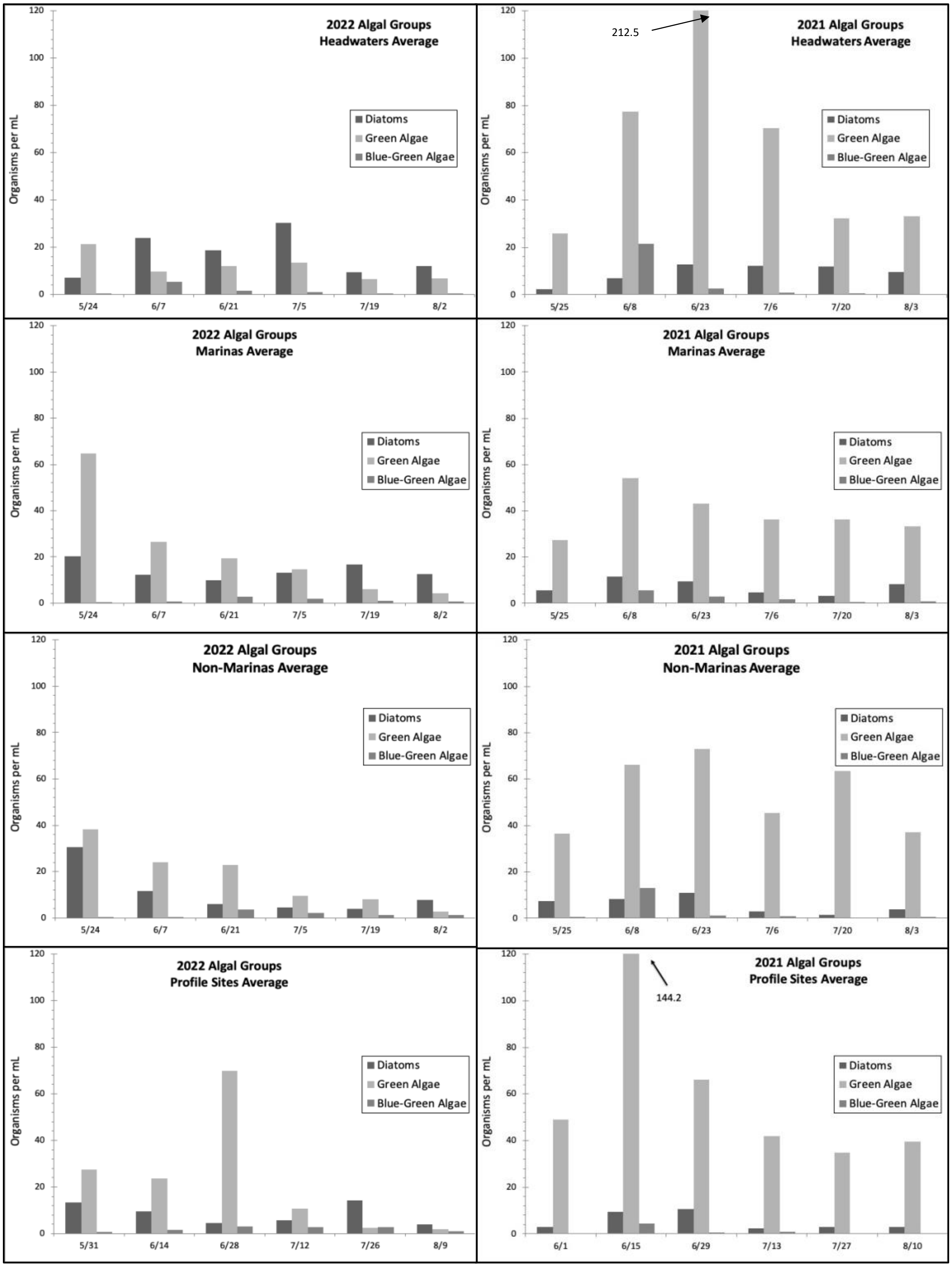


Figure 8.5. Average concentrations of algae groups versus week for 2022 and 2021 by site type

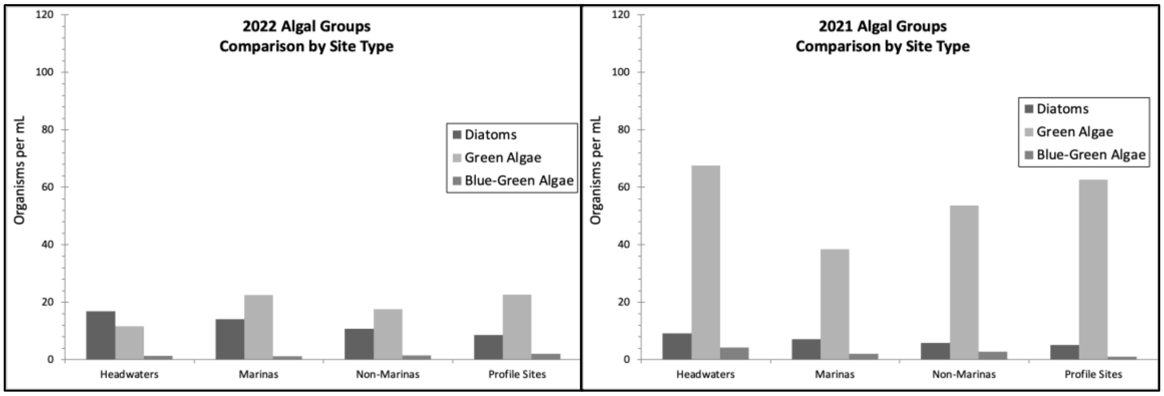


Figure 8.6. **A comparison of algae group abundance in 2022 to 2021 by site type**

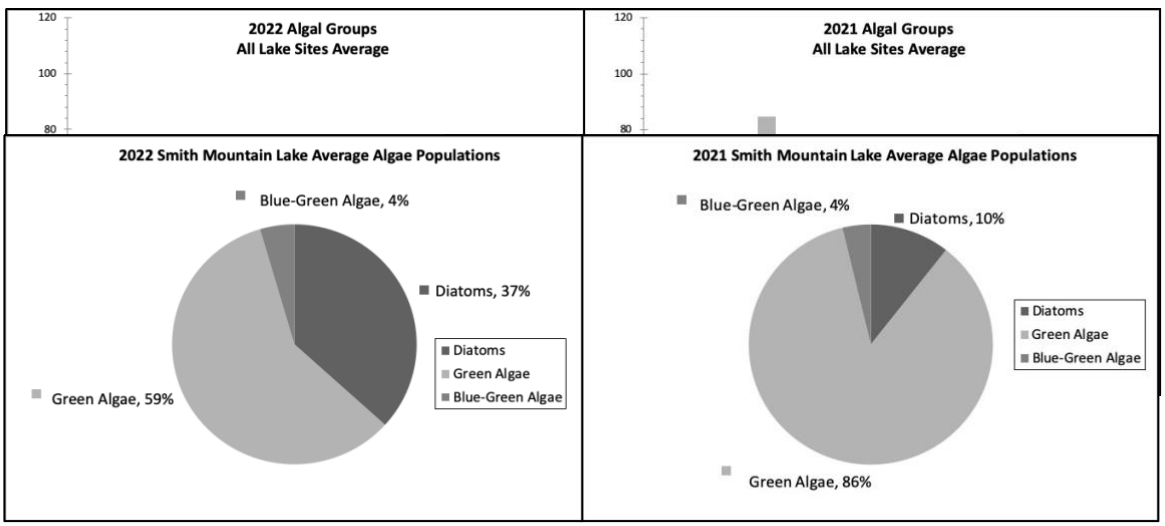


Figure 8.7. **A comparison of algae groups versus week sampled in 2022 and 2021 from all lake sites**

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

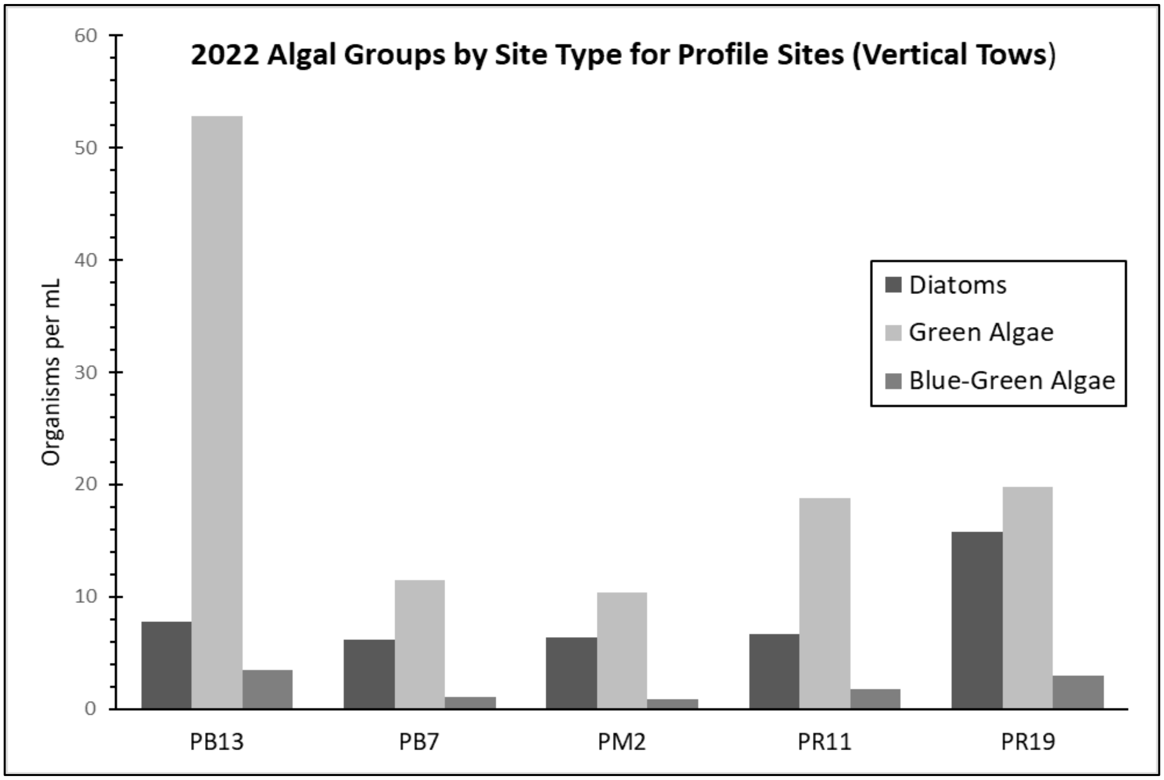


Figure 8.9. **Algal groups by site location for profile sites.**

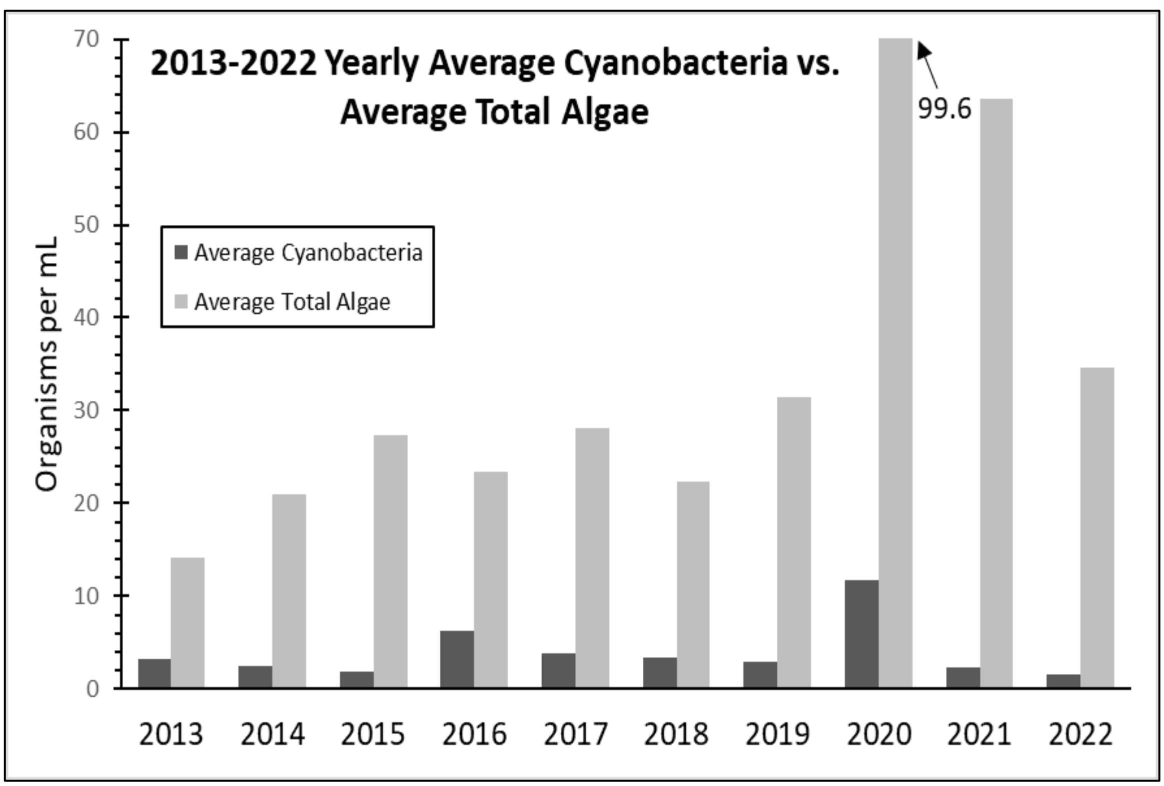


Figure 8.10. **Ten-year averages for blue-green algae (cyanobacteria) and total algae over all sample sites and dates**

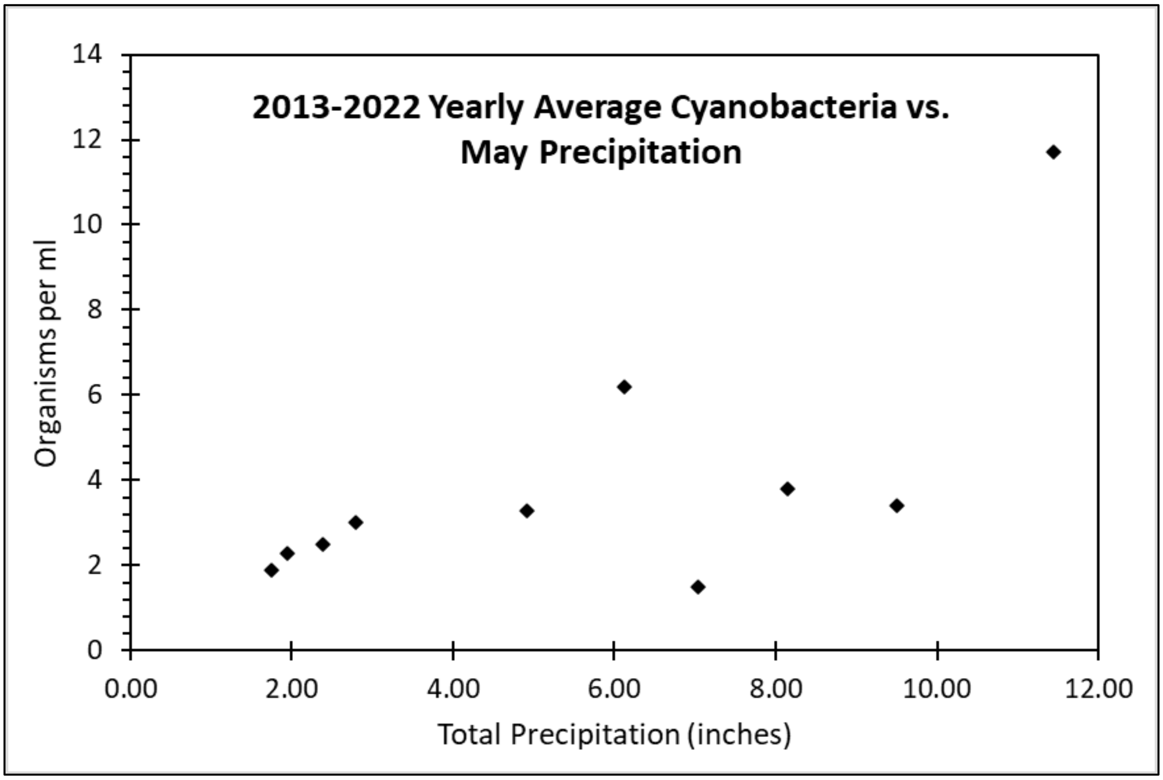


Figure 8.11. Statistical correlation of May precipitation from the Roanoke Regional Airport over a ten-year period and blue-green algae (cyanobacteria) level in lake samples during each year. (Pearson correlation of r = 0.67)

8.4 Discussion

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

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

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

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

8.5 Conclusions

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

9. QUALITY ASSURANCE/QUALITY CONTROL

9.1 *Introduction*

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

9.2 *Calibration Data for Total Phosphorus Method and Results*

Every time samples are analyzed, sets of standards are prepared so that calibration curves can be constructed to determine the relationship between total phosphorus concentration in a sample and its absorption of light at 880 nm. The concentrations of the standards used for total phosphorus are as follows: 0 ppb, 10 ppb, 20 ppb, 40 ppb, 80 ppb, and 160 ppb. The calibration curve is constructed using the readings from standards run at the beginning of the analysis. Table 9.1 summarizes the calibration data for 2022. The coefficient of determination (R^2) is a measure of how well the calibration line fits the data points with values ranging from 0 (no fit) to 1 (perfect).

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

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

9.3 *Calibration Data Discussion and Conclusions*

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

9.4 *Comparison of Standards Method and Results*

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

In 2022, for total phosphorus, the 40 and 80 ppb standards were run periodically during each analysis for a total of eight readings of each of those two standards except in week 1 where seven readings were taken. The readings obtained were compared to 40 and 80 ppb respectively, and average relative percent differences (RPD) were calculated. These are reported, along with maximum and minimum relative percent differences, in Table 9.2.

Table 9.2 Comparison of 40 and 80 ppb standards over the course of analysis for total phosphorus for 2022

Sampling Period	Avg. RPD 40ppb std. (%)	Max. RPD 40ppb std. (%)	Min. RPD 40ppb std. (%)	Avg. RPD 80ppb std. (%)	Max. RPD 80ppb std. (%)	Min. RPD 80ppb std. (%)
5/22-5/28	1.1	2.7	0.0	21.8	125.6	4.0
6/5-6/11	3.9	5.2	2.0	0.5	0.7	0.3
6/19-6/25	2.8	3.2	1.9	21.4	164.1	0.1
7/3-7/9	0.5	1.2	0.2	0.9	1.6	0.0
7/17-7/23	7.2	8.1	5.2	2.8	4.4	2.3
7/31-8/6	1.4	2.9	0.1	1.6	2.6	0.9
Overall Averages	**2.8**			**8.2**		

9.5 *Comparison of Standards Discussion and Conclusions*

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

9.6 *Blank and Spiked Blank Method and Results*

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

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

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

9.7 *Blank and Spiked Blank Discussion and Conclusions*

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

9.8 *Duplicate and Spiked Sample Analysis Method and Results*

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

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

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

9.9 *Duplicate and Spiked Sample Analysis Discussion and Conclusions*

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

9.10 *Analysis of Certified Standard Method and Results*

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

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

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

9.11 *Analysis of Certified Standard Discussion and Conclusions*

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

9.12 *QA/QC for Chlorophyll-a*

At the beginning of every sampling season, the fluorometer is calibrated using a standard purchased from Turner Designs (Sunnyvale, CA) and secondary solid standards (supplied with the instrument) are checked. Before every sample analysis, the instrument is calibrated to the values established for these solid standards. These standards, along with a reagent blank (buffered acetone) are read periodically throughout the sample analysis. An unfiltered glass fiber filter (method blank) is analyzed each time samples are run to assure that the processing of the samples does not introduce contamination or interferents. In 2022, the method blanks ranged from 0.01 ppb to 0.07 ppb with an average of 0.03 ppb.

9.13 *QA/QC for Secchi Disk Depth*

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

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

Sterile distilled water is run with each set of lake samples analyzed for *E. coli*. In every analysis, the sterile distilled water gave readings of <1.0, which is the lowest MPN (most probable number) that can be obtained. In 2022, replicates were run at two sites from each sample set for the six samplings. The replicates are obtained by collecting a large field duplicate sample along with the regular sample at the replicate site and dividing the larger sample into four replicate subsamples at the lab. These replicate samples are analyzed in the same manner as the rest of the samples, and the results are compared both to each other and to the regular sample collected at the replicate site. Results of the replicate analysis are shown in Table 9.6.

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

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

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

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

Table 9.7. Results of QuantiCult™ analysis for 2022

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

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

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

P. aeruginosa	0.0	0.0

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

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

10. SAMPLING EFFICIENCY

The monitoring program depends on volunteers for sample collection and one measure of success for the program is the consistency with which these volunteers attend to their stations. Table 10.1 indicates the sampling efficiency data for 2022 and Table 10.2 presents the collection efficiencies from 2013 through 2022. The figures show that the volunteer monitors are very conscientious about sample collection. Volunteer monitor sample efficiency for total phosphorus was 99 percent, chlorophyll-*a* samples correctly collected at 98 percent, and 97 percent for Secchi readings. The volunteers' sampling efficiency is as good as that of professionals in agencies responsible for environmental sampling. This degree of commitment no doubt carries over to the care with which samples are collected and is evidence of the volunteers' dedication to the program.

Table 10.1. Sampling efficiency for Smith Mountain Lake data for 2022

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

*Indicates samples taken by students and faculty from Ferrum College

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

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

11. CONCLUSIONS

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

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

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

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

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

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

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

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

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

12. ACKNOWLEDGEMENTS

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

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APPENDIX

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

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

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

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

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

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

Figure A.1. Smith Mountain Lake trophic monitoring stations

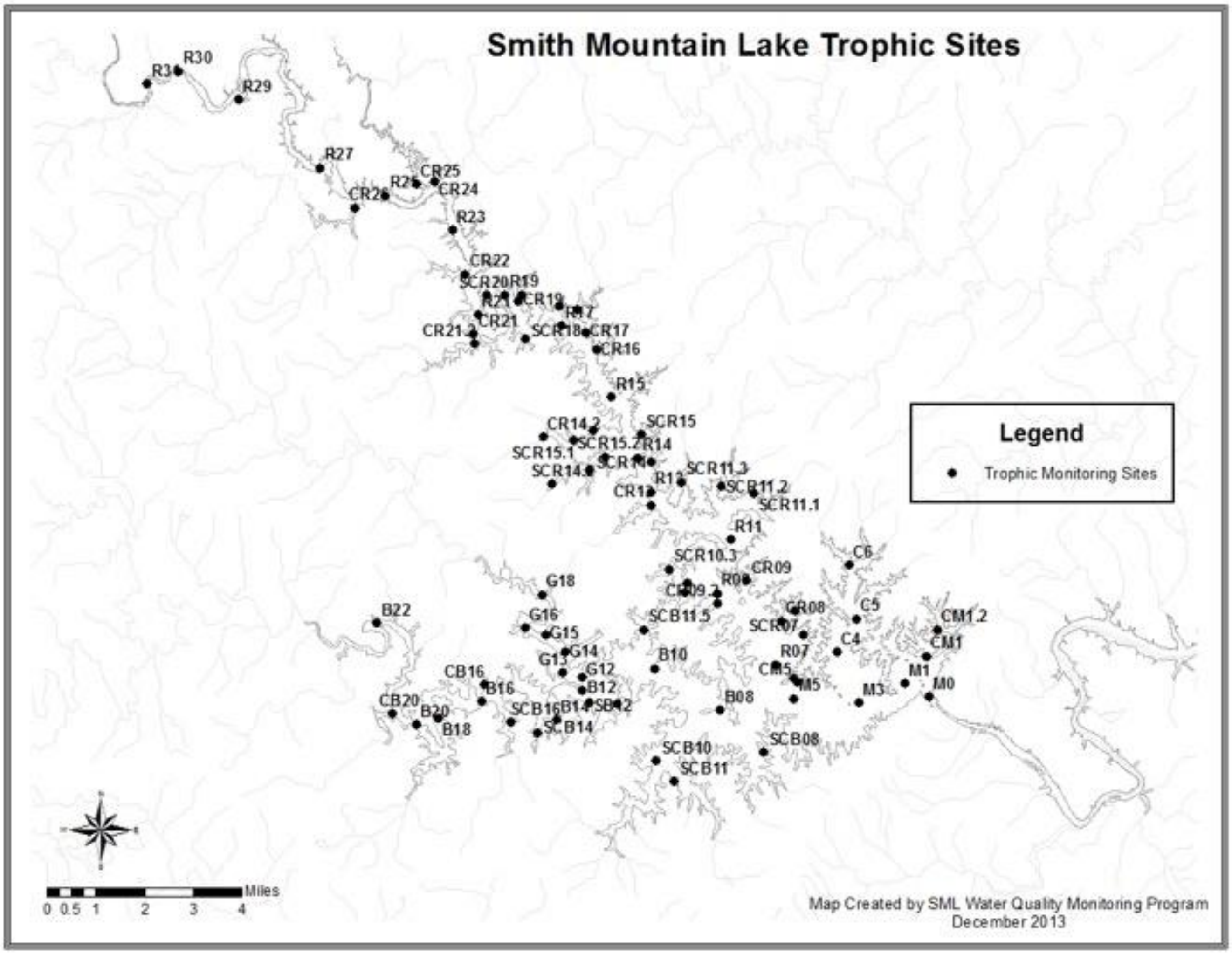

Table A.2. 2022 Smith Mountain Lake tributary stations and other downstream stations

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

Figure A.2. Smith Mountain Lake Tributary monitoring stations

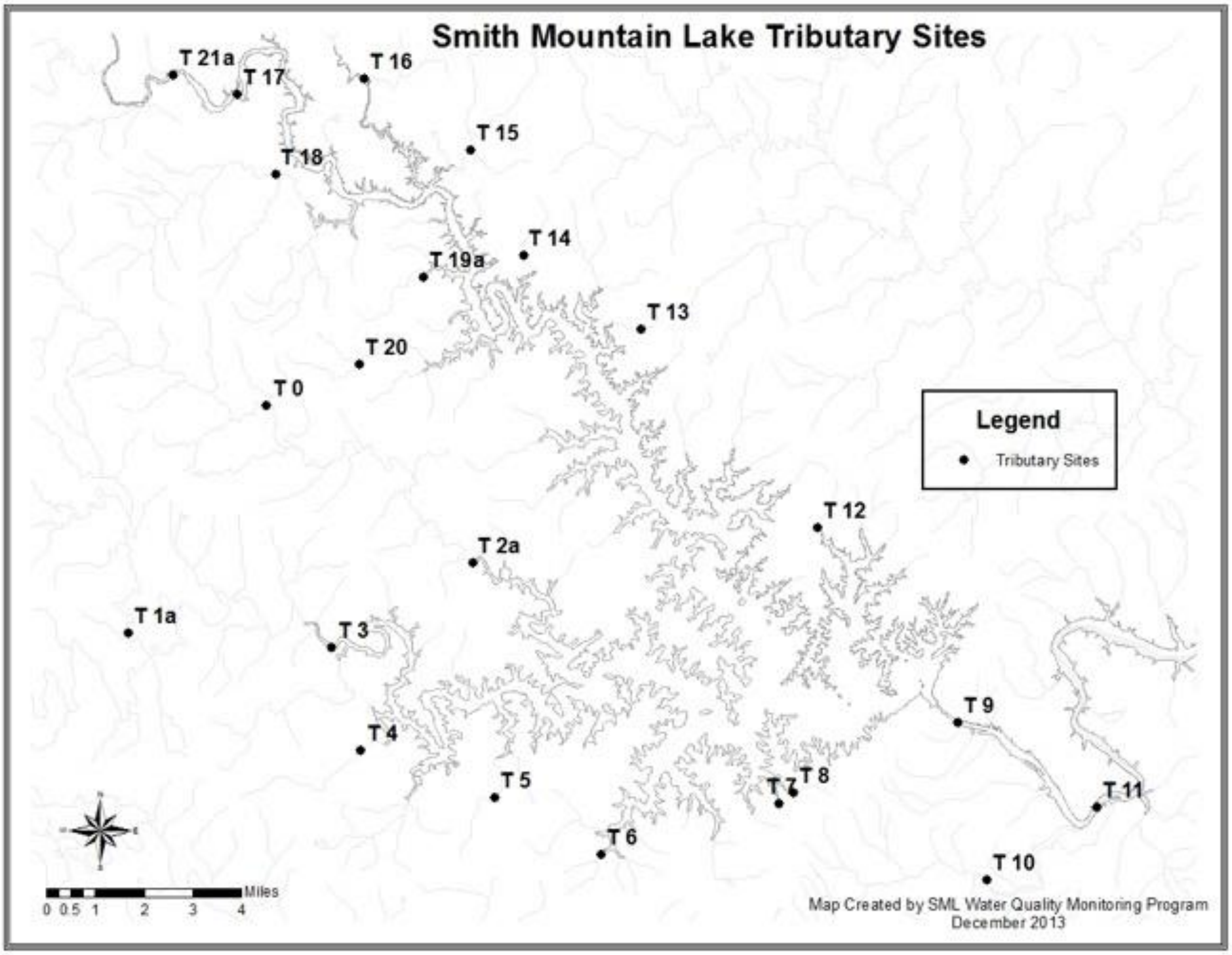

Figure A.2.a Map showing tributary sites below Smith Mountain Lake Dam

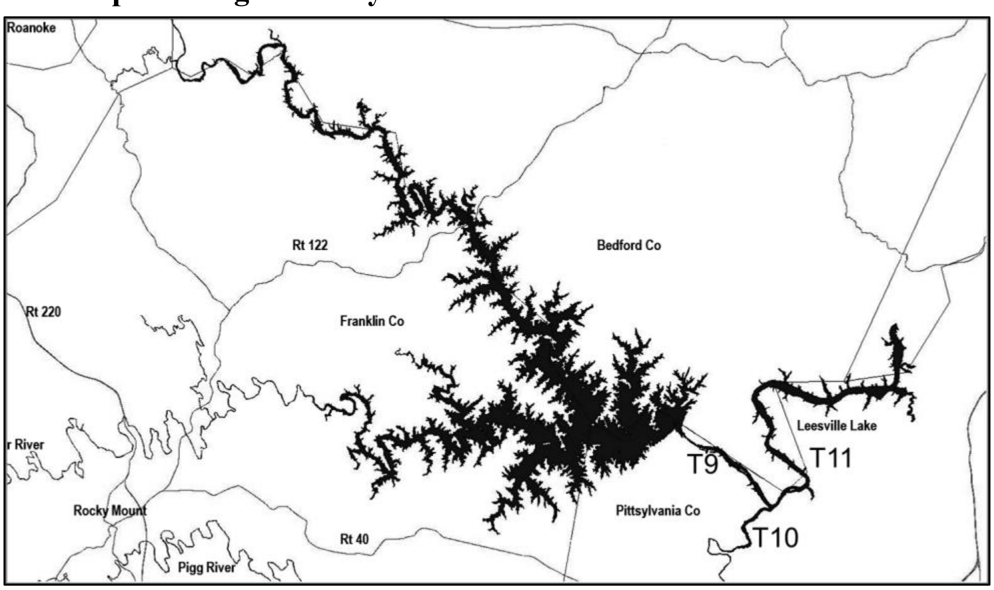

Table A.3. 2022 Total phosphorus data for Smith Mountain Lake sample stations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Figure A.3. Smith Mountain Lake depth profiling sites

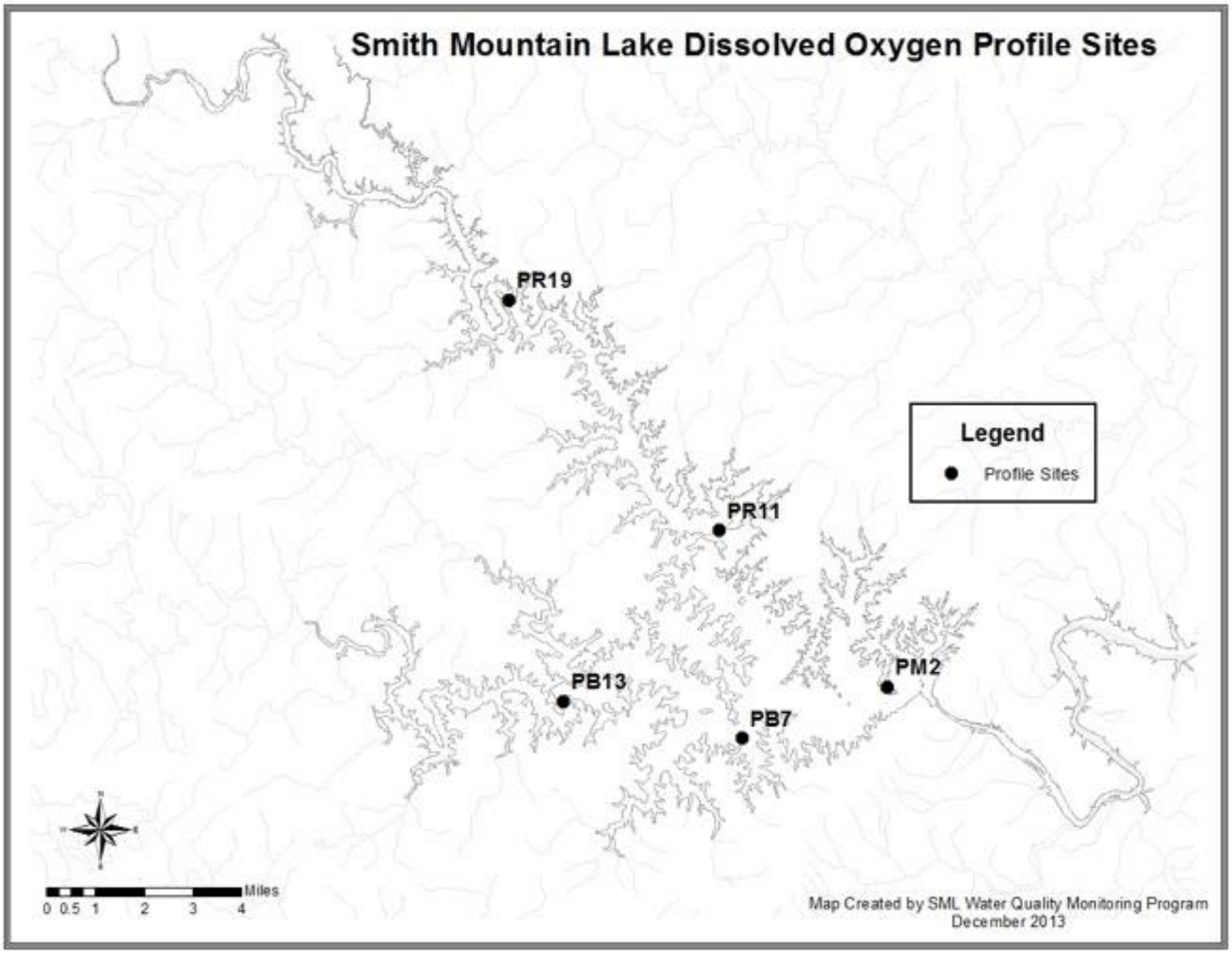

Figure A.4. Smith Mountain Lake bacterial sampling sites

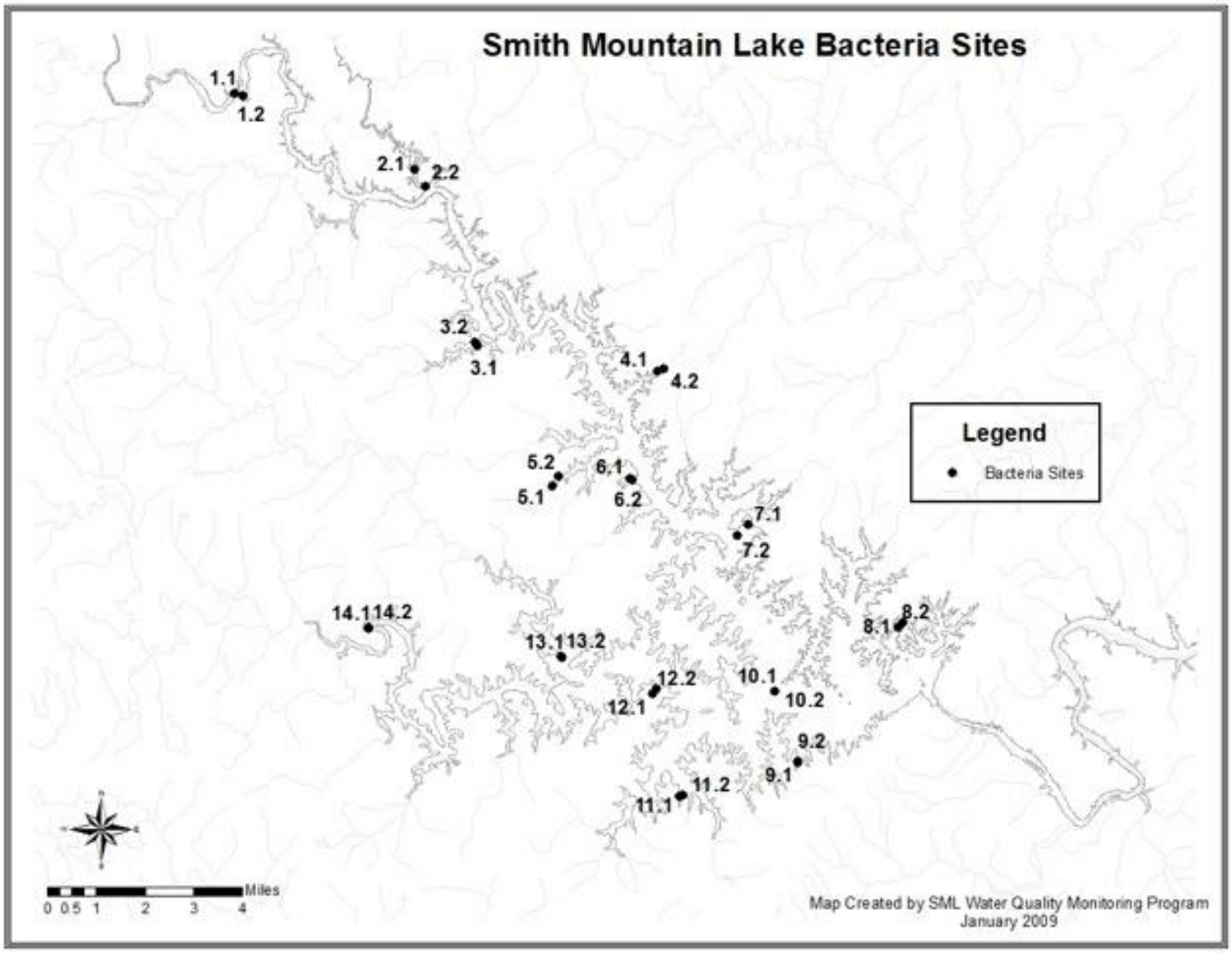

Table A.8. Smith Mountain Lake bacterial monitoring sites

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

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

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

Appendix B

2022 Leesville Lake Water Quality Monitoring Report

Leesville Lake Association

Leesville Lake 2022 Water Quality Monitoring

Prepared for:
Leesville Lake Association

Prepared by:
Dr. Thomas Shahady University of Lynchburg

February 2023

Funds Supplied by: American Electric Power & Leesville Lake Association

Table of Contents
Page

List of Acronyms and Abbreviations

AEP	American Electric Power
DCR	Virginia Department of Conservation & Recreation
DEQ	Virginia Department of Environmental Quality
DO	Dissolved Oxygen
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
FPA	Federal Power Act
LLA	Leesville Lake Association
mV	Millivolts
MPN	Most Probable Number
NTU	Nephelometric Turbidity Unit
ORP	Oxygen Reduction Potential
TP	Total Phosphorus
SML	Smith Mountain Lake
SMP	Shoreline Management Plan
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSI	Trophic State Index
TSS	Total Suspended Solids
VDEQ	Virginia Department of Environmental Quality

Jargon is used in this report to describe certain aspects of lake function and water concerns in the lake. Here we define key terms to facilitate comprehension of the document and the trends that the research reveals.

Lake or Reservoir – These terms, while not technically synonymous, are used interchangeably and in accordance with lay usage. The term reservoir is reserved for a river system with a dam to create a lake. In the southeastern United States, all of these bodies of water are reservoirs with a few notable exceptions. Lakes are the natural bodies of water typically formed through glacial processes (great lakes) or other geological phenomenon (Mountain Lake Virginia). Reservoirs are always deepest at the dam while lakes are deepest in the center.

Riverine and Lacustrine – These are terms we used to describe reservoirs. Riverine describes conditions that are dominated by river conditions and often occur in the upper portions of a reservoir. Lacustrine is a term used to describe conditions dominated by lake processes and often occur near the dam. The term **transition** is used often throughout the center of the reservoir to describe a blend between riverine and lacustrine.

Pelagic and Littoral – This is a term used to describe the deepest part of the reservoir. It is more often used to describe the open water of a lake. Littoral is the term used to describe the shallow portion of a lake and is often an area covered by floating or rooted plants. These terms are not as often associated with reservoirs because water movement prevents development of significant littoral zones.

Eutrophic – This is the condition of lakes and other bodies of water resulting from the input of excess nutrients. As this condition worsens it leads to algae blooms, formation of toxic algae growth, high pH, low dissolved oxygen and poor water quality. All of these conditions are harmful to beneficial aquatic life and enjoyment of the reservoir.

Trophic State – this is a convenient method to translate measured conditions of eutrophication into a scale. We consider lakes and reservoirs to be eutrophic (high levels of eutrophication), mesotrophic (moderate levels of eutrophication) or oligotrophic (low levels of eutrophication). Often these levels must be balanced as oligotrophic conditions are not good for fishery productivity and eutrophic conditions lead to severe water quality problems. One additional classification is **Dystrophic,** which is characterized by high levels of tannins in the water. Tannins are created when leaf litter degrades. Dystrophic water is often tea colored and found more often in coastal systems.

Polymictic – a term used to describe lakes that turn over multiple times in a year. Turn over reflects the condition where the lake is the same temperature from top to bottom, allowing the water to mix. Many lakes in temperate climates such as Leesville Lake stratify during summer months characterized by warm water floating on top of colder water. During this period of "stratification," the warm water is isolated from the lower cooler water. When the lake is stratified it only mixes in the upper layer. When the lake warms or cools to the same temperature it mixes throughout. If this only occurs in the spring and the fall a lake is considered dimictic – or mixing only twice in a year. Leesville Lake is considered polymictic because in addition to the spring and fall stratification heavy rain input and water movement by Smith Mountain Lake will break up the stratification. After these events, stratification occurs. This causes the lake to mix many times in a year hence the term polymictic.

Hypolimnion and Epilimnion – These are terms used by limnologists (a person who studies lakes) to describe the layers that form during stratification. The epilimnion is the upper layer and the hypolimnion is the lower layer. The term **Metalimnion** is also used to describe the layer of changing conditions between the two other layers. Temperature is the most common measure used to define these layers, and the most often referenced criterion to define a new layer is a temperature in excess of 1 degree centigrade per one meter of depth. But, because these lakes are polymictic, this clear definition is often not applicable.

Heterogrades – These are terms to describe the shape of oxygen curves throughout the water column. Oxygen is influenced by many factors and the heterograde curves help describe these influences. When phytoplankton accumulate at the thermocline, they tend to photosynthesize creating a visible increase of oxygen in that area. This is called a **positive heterograde**. When oxygen decreases due to bacterial consumption of oxygen with depth without change this is a **clinograde**. Within a clinograde, an increase in oxygen below the thermocline due to the physical characteristics of the water is termed a **positive heterograde**. Oxygen that remains unchanged with depth is an **orthograde**.

Thermocline – Area in the lake defined from a depth profile where water temperature decreases at a rate greater than 1 degree centigrade per meter.

Phytoplankton and Chlorophyll *a* – These are terms to describe the algae or plant life that occupies the pelagic portion of the reservoir. Phytoplankton are single celled or filamentous microscopic plants that grow in the water and are stimulated by water movement, depth of light penetration and nutrients such as phosphorus and nitrogen. Chlorophyll *a* is the photosynthetic pigment found in all plants and a very convenient way to measure the amount of phytoplankton in the reservoir. These terms are often used interchangeably.

E. coli – This term is used to describe a group of bacteria that are associated with health risk in water. They are typically not pathogenic but are easy to quantify in the laboratory. Because their presence is associated with presence of pathogens, we measure their concentration and issue warnings when levels are high. Sediment that is brought into reservoir is often associated with high levels of *E. coli*.

Executive Summary

The Leesville Lake Association and University of Lynchburg, in partnership with American Electric Power Company, monitored water quality of Leesville Lake between April and October of 2022. The lake was monitored at the end of each month by The University of Lynchburg while additional samples were collected by the Leesville Lake Water Quality Committee during June, July and August at mid-month. The results of that monitoring are reported here with analysis of lake trends at each station and additional analysis on problems of concern. The intent of this report is to provide a technical and scientific background for sound management of Smith Mountain Lake and Leesville Lake in order to protect and improve these lake resources for future generations.

Leesville Lake continues to meet prescribed water quality parameters measured in the main stem of the reservoir. While concerns are discussed related to changing water quality conditions in the Pigg River and SML tailwater release, trophic state index calculations suggest Leesville Lake is very resilient and stable around a slightly eutrophic condition.

It is important to state that while some water quality indicators are worsening, Leesville Lake appears very resistant to those inputs and has remained in good condition (Figure 2.4). Leesville Lake is maintaining a constant TSI index between 50-60 demonstrating only inter year variations. All indicators in 2022 suggest this condition of the reservoir continues and should continue through the foreseeable future. While it is always the aim of any long-term study such as this to improve the condition of the resource being monitored, considering the problems surrounding the lake this is a good result and possibly an improvement.

Other conclusions based on observations from this years (2022) study and analysis of long-term trends include:

Leesville Lake behaves as a pump storage reservoir with headwaters impacted by tail release from the upper reservoir and this impact is seen throughout the reservoir. Pumping operations have a very strong impact on LVL water quality. The influence of SML tail water throughout the reservoir is generally a positive result as hypolimnion in SML contains water that is very clear and approaching oligotrophic conditions. However, oxygen depletion is very problematic late in the season (Sept-Oct.) and seems to be worsening. Low dissolved oxygen (<5 mg/L) persists in tail water release at the end of the season. These low oxygen conditions can be detected down through the reservoir past the station at Toler Bridge.

This oxygen loss when coupled with the high nutrient input from the Pigg River is cause greater eutrophication in LVL due to phosphorus release. This trend is worsening although not being expressed as Chlorophyll *a* biomass yet. Time lags are a concern.

Specific management recommendations from this years report:

1. **The two greatest threats to water quality in LVL are the high nutrient inputs from Pigg River and low oxygen levels of SML release late in the season.** These two phenomena work together to compound this problem.
2. Monitoring of the Pigg River by the Leesville Lake Association's Water Quality Committee must continue (see separate report of these findings). This is the only current study in this watershed and water quality of the Pigg River is critical to the health of LVL. This river must be studied and monitored to help make beneficial management decisions for Leesville Lake. Every effort needs to be extended to understand nutrient pollution and control it.
3. Land use and deleterious inputs in all watersheds (Pigg River, Blackwater and Roanoke) need to be addressed. While Pigg River Watershed is of the greatest concern to Leesville Lake, deteriorating water quality in SML is impacting tail release into Leesville Lake and this must be addressed and managed.
4. It is clear from our water monitoring of Leesville Lake and data collected at the tail release that water does not meet permit standards late in the season. The following must be noted and addressed by AEP:

    a. License requirements associated with the Smith Mountain Hydroelectric Project (Project) require the licensee, Appalachian Power Company (Appalachian), to implement a Water Quality Monitoring Plan (Plan) as part of license Article 405. The order approving the Plan was issued on April 15, 2011.
    b. Develop and file, in accordance with the requirements of Article 401(a) for Condition F.4 found in Part I of the Virginia Department of Environmental Quality's (Virginia DEQ) water quality certification (WQC), a feasibility study and plan for physical or mechanical alterations of water release procedures, developed in consultation with the Water Quality Technical Review Committee (WQTRC1), to address violations of water quality standards for DO caused by turbine discharge from Smith Mountain Lake, should the operating practices employed prove insufficient at improving DO levels in Smith Mountain's turbine discharge.

Section 1: Current Conditions

1.1 General:

This is the 11th year of water quality monitoring of Leesville Lake by University of Lynchburg (formerly Lynchburg College in previous years of study) in partnership with Leesville Lake Association (LLA). Eleven years of data continue to strengthen our understanding of Leesville Lake's water quality and support our effort to manage this important natural resource. In addition, the Leesville Lake Water Quality Committee in partnership with University of Lynchburg is entering its 5th year of a study throughout the Pigg River Watershed to pinpoint problems and diagnose potential solutions. Understandings from this study will continuously be incorporated into our understanding of lake function and management. Findings from the Pigg River are published separately.

Section 1 documents results for the current year's sampling. Data are reported in graphical form with interpretations. In **Appendix D**, all data are reported in tabular form to facilitate future analysis and use with other projects. This project continues to provide essential baseline data for the condition of the lake and interpretation of changing conditions. A full background of the study and its rationale is located in **Appendix A**.

1.2 Methods:

Data were collected by University of Lynchburg through a series of water samplings and testing monthly from April through October. These dates coincide with the most productive period of the reservoir or when lake productivity is greatest. Leesville Lake Association (LLA) supplements sampling over the three summer months of June, July and August to provide biweekly analysis. LLA collection is not as extensive as the university sampling but adds vital data to understanding trends in the lake. The following eight sites (Table 1.0) continue to be sampled, as stated in the Leesville Lake Water Quality Monitoring Plan:

Table 1.0. Leesville Lake Sampling Sites

LC Station	LLA Station	Site ID	DEQ Station ID	Latitude	Longitude
Leesville Lake Dam	11	2636	LVLAROA140.66	37.0916	-79.4039
Leesville Lake Marina	5	1275	LLAOQC000.58	37.05939	-79.39574
Tri County Marina	3	1273	LLATER000.33	37.05942	-79.44489

Mile Marker 6	8	1373	LLAROA146.87	37.06320	-79.47110
Mile Marker 9	2	1272	LLAROA149.94	37.03993	-79.48233
Toler Bridge	1	1271	LLLAROA153.47	37.01090	-79.47530
Pigg River	9	1374	LLAPGG000.47	37.00430	-79.48590
SML Tail Waters	12	2637	LVLAROA157.92	37.0382	-79.531306

Detailed methodologies used by University of Lynchburg and Leesville Lake Association are located in **Appendix B** for reference. Quality Control and Quality Assurance are located in **Appendix C** for reference.

Site Descriptions

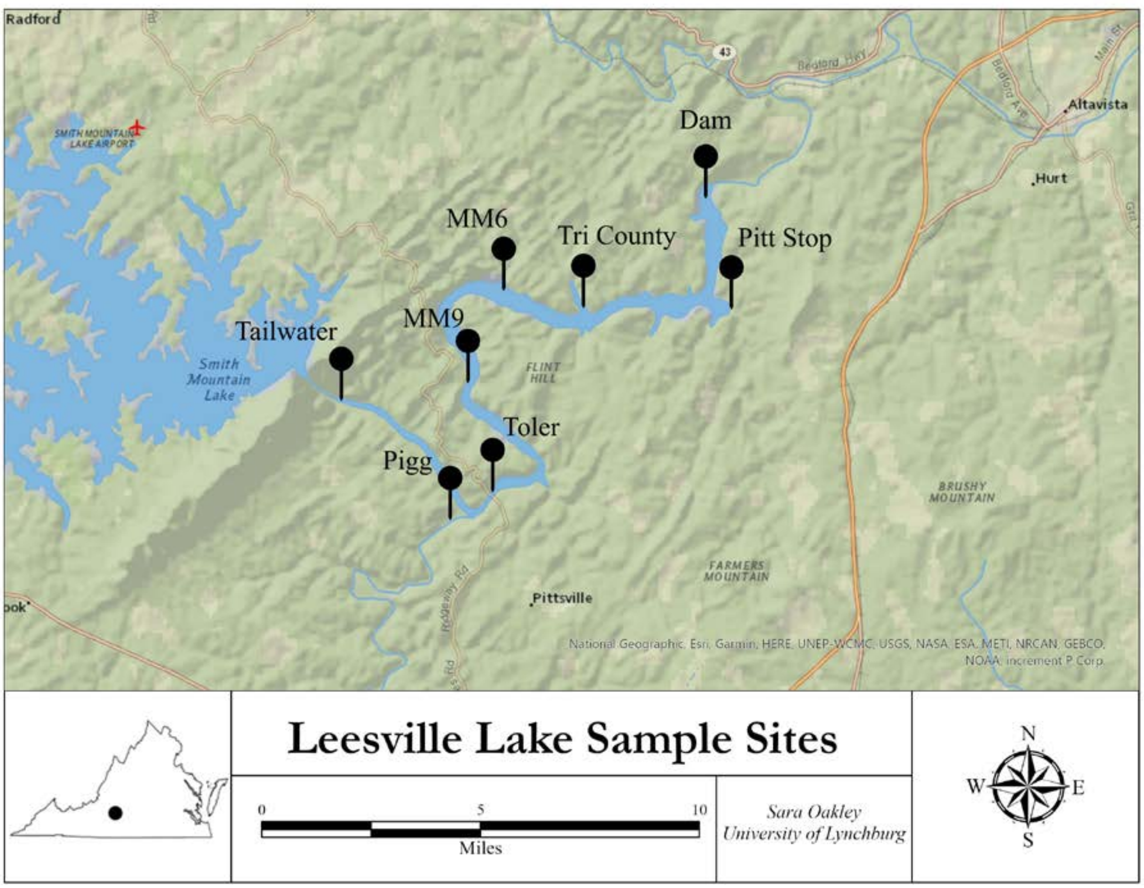

Figure 1.0 – Map of Leesville Lake showing locations of sampling stations along the reservoir.

Old Womans Creek-Leesville Lake Subwatershed

1.3.1.1 Dam

The Dam sampling site is located on the northwest (N 37° 5' 35.215", W 79° 24' 9.809") quadrant of the Old Womans Creek subwatershed (Figure 1). This part of the reservoir is considered as **lacustrine** and its characteristic resembles lake qualities. The water upstream progresses into this station as the season progresses and water characteristics are expected to be isolated from the influence from Smith Mountain Lake Operations.

1.3.1.2 Leesville Lake Marina

The Leesville Lake Marina sampling site is located on the northwest quadrant (N 37˚ 5' 35.21, W 79˚ 24' 10.425) of the Old Womans Creek subwatershed (Figure 1). This portion of the reservoir is potentially impacted by Old Womens creek and identified by DEQ as an impacted watershed.

1.3.1.3 Tri County Marina

Tri County Marina sampling site is located further south of the northwest quadrant (N 37˚ 3' 35.158, W 79˚ 23' 219) of the Old Womans Creek subwatershed (Figure 1). This part of the reservoir is considered as a **transition zone** between **riverine** and **lacustrine**. Water in this zone is expected to not be as influenced from Smith Mountain Lake Operations, but more so by transition position. This tributary is expected to deposit nutrients and other pollutants, with periods of drawback potentially enhancing impact of effluents spent in the reservoir.

1.3.1.4 Mile Marker 6 (MM6)

MM6 sampling site is located further south of the mid- southeast quadrant (N 37° 3' 46.501, W 79° 26' 48.006") of the Old Womans Creek subwatershed (Figure 1). This part of the reservoir is also considered as a **transition zone**. Positioned further upstream the patterns observed here provide a point to compare and discern trends of that are comprised moving up or down the reservoir.

1.3.1.5 Mile Marker 9(MM9)

MM9 sampling site is located further south of the southeast quadrant (N 37° 4' 5.7325", W 79° 28' 21.015") of the Old Womans Creek subwatershed (Figure 1). This part of the reservoir is considered as a **riverine zone**. Water transported upstream from the Toler Bridge sampling site subject this sampling site to further mixing from influxes of the tail waters of Smith Mountain Lake Dam and Pigg River are expected to be heavy influencers and expect to reflect degradation of water quality from water transported from Toler Bridge.

1.3.1.6 Toler Bridge

The Toler Bridge sampling site is located south of the southeast quadrant (N 37° 2' 23.3955", W 79° 28' 53.152") of the Old Womans Creek subwatershed (Figure 1). This part of the reservoir is also considered as a **riverine zone.** This sampling site is of interest to study as it is the confluence point of dichotic water qualities from expected poor water conditions quality from Pigg river and the expected good water quality conditions from Smith Mountain Lake. Since the resulting water quality is driven from mechanistic (SML Dam) and stochastic (Pigg River), the qualities here will be challenging to interpret.

1.3.1.7 Pigg River

The Rig River sampling site is located on the furthest southeast aspect (N 37° 0' 17.333", N 37° 0' 17.333) of the Old Womans Creek subwatershed (Figure 1). This area is considered a **riverine** zone. The water quality measures reflected clearly impact water quality in the reservoir. This sampling site here is to reflect the impacted water quality that merges into the reservoir compared to the relatively unimpaired water quality released by the Smith Mountain Lake Tail waters.

Clay Branch-Leesville Lake *Subwatershed*

1.3.1.8 Smith Mountain Lake Tail waters

The Smith Mountain Lake Tail waters sampling site is located further north the southeast aspect of the Clay Branch-Leesville Lake subwatershed (Figure 1). This area is considered as a **riverine** zone as the input patterns are similarly reflective of a river. The water inputs at this location are of very good water quality because of the inputs of nutrient concentration and the settling sediments from the water column. This site is of interest to sample due to the quality demonstrating which areas are of interest for sound management of Smith Mountain Lake and Leesville Lake.

1.3 Leesville Lake Water Quality: Current Test Results

1.3.1 Temporal Analysis by Station

Background

Leesville Lake is a reservoir by definition (a listing of terms used in this report is provided on page 8 for easy reference). It is a river course with a dam constructed and filled to form this reservoir. Leesville Lake is somewhat different than a typical reservoir because it serves as a storage source (pump back operations) for the generation of electricity by the Smith Mountain Lake Hydroelectric Plant. The reservoir receives water input primarily from Smith Mountain Lake but secondarily from several other stream systems with the Pigg River the most significant. This river drains a considerably large watershed with agriculture and urban land disturbance throughout. These inputs and pumping operations in Leesville Lake create a unique hydrology that impacts the water quality of the reservoir.

In any reservoir, water quality is best evaluated along a spatial gradient. This gradient begins in the headwaters of the reservoir where river inputs generate patterns similar to a river. This section, characterized as riverine, is often the area with the highest productivity and nutrient input and the poorest water quality. As water travels further into the reservoir, these riverine conditions begin to lessen and more lake qualities (lacustrine), influence water quality. This middle portion of the reservoir is considered a transition zone as the riverine and lacustrine portions of the reservoir mix. This area may have the highest overall productivity in the reservoir as sediments associated with river flow settle from the water column yet nutrient concentrations are plentiful. The final sections of a reservoir are considered lacustrine and resemble lake qualities. This area often is lower in productivity due to settling of particulates and lower nutrient concentrations. If stratification is continuous, upper layers become very isolated from lower portions of the reservoir further isolating nutrients and other pollutants. The best water quality for the reservoir is located in this section.

Leesville Lake does not necessarily follow this typical pattern. First, the headwaters are fed by release of tail water from Smith Mountain Lake lacustrine zone. This release is of very good quality water because of the aforementioned typical water quality in a reservoir. Thus, one source of incoming water to Leesville Lake is excellent and often mesotrophic or even oligotrophic in quality. However, during later portions of the year the oxygen content of water released from Smith Mountain Lake may have very low oxygen content due to the reservoir properties of stratification that depletes oxygen in the hypolimnion of eutrophic reservoirs. A secondary source of water into Leesville Lake is the Pigg River. This is an impaired river delivering high concentrations of nutrients, sediment and bacteria into Leesville Lake.

Additionally, the headwater region of Leesville Lake is subject to a bidirectional movement of water. This forces water flow from the Pigg River into the Smith Mountain Lake (SML) lacustrine zone. The fate of this mixing depends on hydroelectric operations, amount of water pumped back and time this water remains in the upper reservoir. The impacted area within Leesville Lake is 4 miles from the Pigg River mouth to the SML dam. Then during energy production, Pigg River water mixed with SML lacustrine discharge flows into Leesville Lake headwaters. This pattern is variable and at any time the water in this 4 mile stretch may consist of Pigg River water, SML release or a combination of both. This pattern significantly altered by stormwater.

The transition portion of the reservoir is not as heavily influenced by Smith Mountain Lake Operations. Water is drawn back and forth above this zone but the volume of water buffers the influence these operations exert on water quality. During periods of heavy rain, sediment-laden water does travel into the transition portions of the reservoir. Water in this zone is influenced by Smith Mountain Operations but more so by its position as the transition zone. The dam area of Leesville Lake is isolated from influence of Smith Mountain Operations and reflects the water quality of the lacustrine area. At multiple points along the reservoir, tributaries of various water quality empty into the lake. These tributaries do not account for a bulk of the water flowing through Leesville Lake but do deposit nutrients and other pollutants. And during periods of drawback, these pollutants are pulled back through the reservoir potentially enhancing impact and time spent in the reservoir.

The analyses in this report examine the data to support or revise the above described limnology of Leesville Lake. Section 1 analyzes each station relative its position (Riverine, Transition or Lacustrine) and the potential impact of each tributary has on observed water quality. Section 2 examines lake-wide trending and consideration of problems that should be investigated further. Section 3 presents management recommendations.

1.3.1.1 Dam (Lacustrine)[1]

Background

The area near the Leesville Lake Dam is considered a Lacustrine section. It exhibits characteristics similar to a natural lake, allowing analysis for similarities to lake conditions.

Conductivity

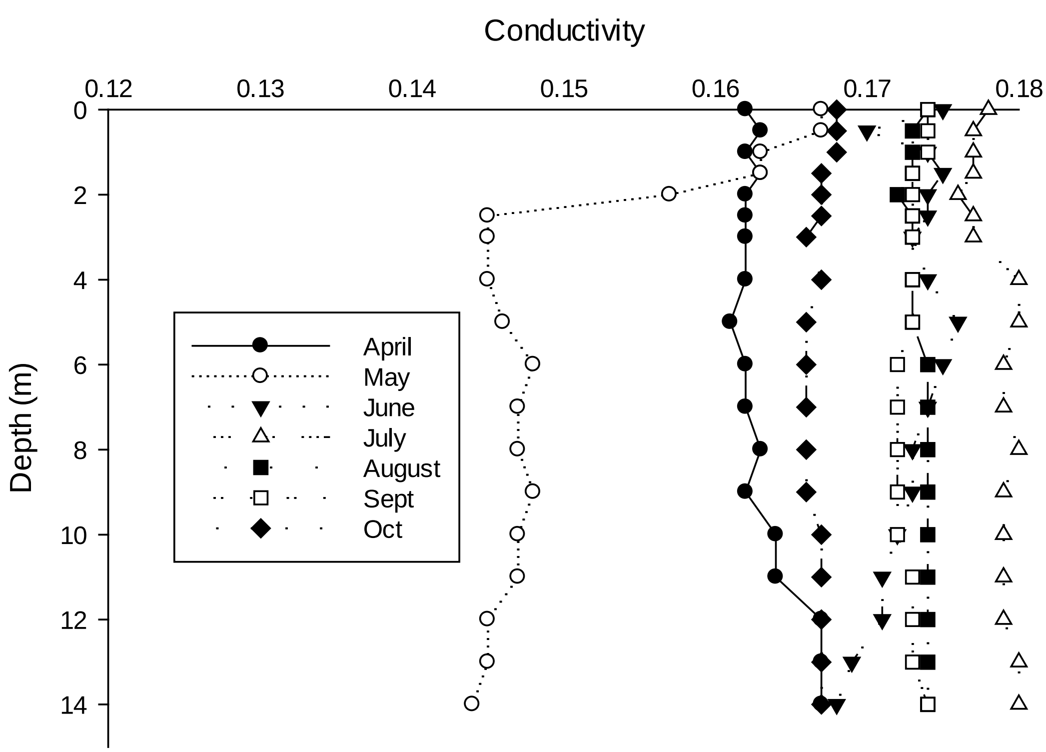

Figure 1.1. Dam (Lacustrine) Conductivity (ms/cm) measures over study period (2022)

Seasonal Analysis

Conductivity reflects the presence or absence of pollution or particulates that conduct an electrical current in the water. It is possible to correlate pollution with levels of conductivity as this measure reflects the concentration of dissolved material in the water. More importantly, conductivity can be used to track water movement as Pigg River contains a lower conductivity than SML tail water release.

Conductivity usually does not stratify and remains between 0.135 and 0.18 mS/cm. It is generally higher in the summer months and lower in spring and fall. This suggests greater contributions from Smith Mountain Lake (higher conductivities) in the summer in LVL all the way through the dam station.

May was the only sampling date with a somewhat differing pattern. The pattern observed clearly suggest a significant storm filled the reservoir lowering conductivity with water from the Pigg River and then starting the process of refilling with SML tailwater release. This pattern supports the idea that SML tailwater release is the predominate water flow in LVL in times other than storm events.

Comparisons Across Years

All data collected in this study suggest conductivity is strongly driven by stormwater flow. Because Pigg River conductivity is considerably lower than water release from SML Dam, lower conductivity measures during any sampling date reflect increasing content of water from the Pigg River. Lower conductivity at the dam station suggests high flow from Pigg River and water quality will likely reflect this condition. While it is typically suggestive that higher conductivity reflects greater pollution, in this instance Pigg River water is of lower conductivity and will contain the greater concentration of pollutants, particularly sediment. While LVL does operate as a Run of the River Reservoir during storm events, at other time periods it does reflect the lower portions of SML. This creates conditions of complexity between water quality of Pigg River and that of SML tailwater release.

Dissolved Oxygen

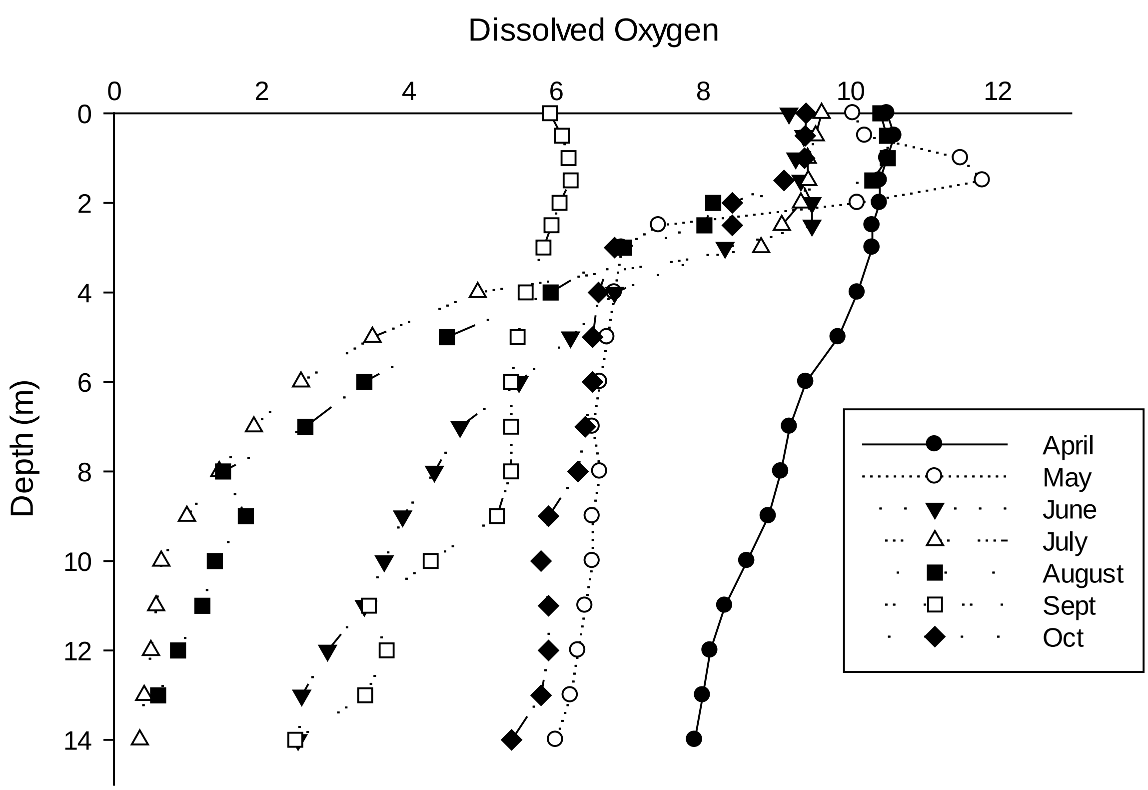

Figure 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2022)

Seasonal Analysis

Dissolved oxygen patterns in the reservoir demonstrate that the lake is eutrophic. Stratification begins in May with depletion of oxygen below the thermocline (about 4 meters depth). Between 2-4 meters depth the loss of oxygen is variable. Water depleted of oxygen tends to be evident higher into the water column as the season progresses. Oxygen loss is continual with concentrations at depth moving below 2 mg/L in July and August. With some variation, this is the typical pattern for the reservoir.

Comparisons Across Years

Oxygen profiles are very consistent throughout the years of study. Oxygen peaks occur between 2-3 meters of depth during months outside of July and August. These two months (July and August contain the lowest oxygen measures at depth (often below 2 mg/L). Turnover of water occurs either in September or November when temperatures in the upper water column match those lower in the column and depends on the season and temperatures. Oxygen in the water during turnover is generally close to 6 mg/L but varies between 5-7 mg/L depending on the year.

Oxygen loss throughout the reservoir is dependent upon the strength of stratification. Thus, while the reservoir is polymictic it takes a very strong storm event for mixing to occur at the dam. Thus, oxygen loss in the hypolimnion is a function of strength of stratification. Water temperature and stormwater inflow have tremendous impact on this parameter, which may at time become problematic.

Temperature

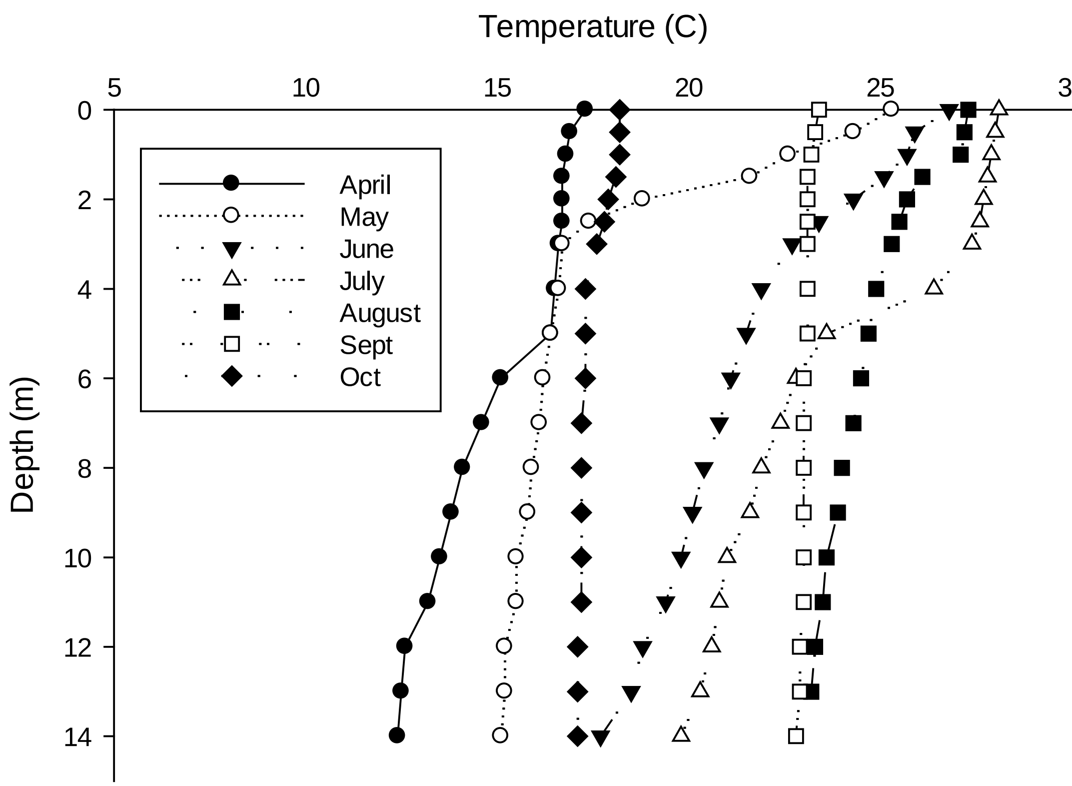

Figure 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2022)

Seasonal Analysis

With the exception of September, the reservoir was stratified during all sampling periods. The reservoir continued to warm into the summer months (both in the epilimnion and hypolimnion) and temperature stratification was visible throughout the summer with peaks nearing 30C in July. September temperatures were still very warm and these measures demonstrate the time of turnover.

Comparisons Across Years

We do see variability in these profiles over time. Some years July is the warmest month while in other years August may be the warmest in the epilimnion (In 2022 it was July). In 2015, June was the warmest month. It is not uncommon to see temperatures reach 30C in these profiles but in some years (2019) the water does not warm to this extent. Stratification is consistent across years usually starting in April or May. The epilimnion establishes above 2 meters depth. The depths of 2-4 meters are the transition zone or metalimnion. The hypolimnion is below 4 meters depth. Throughout the seasons this is a consistent pattern in the reservoir.

Chlorophyll *a*

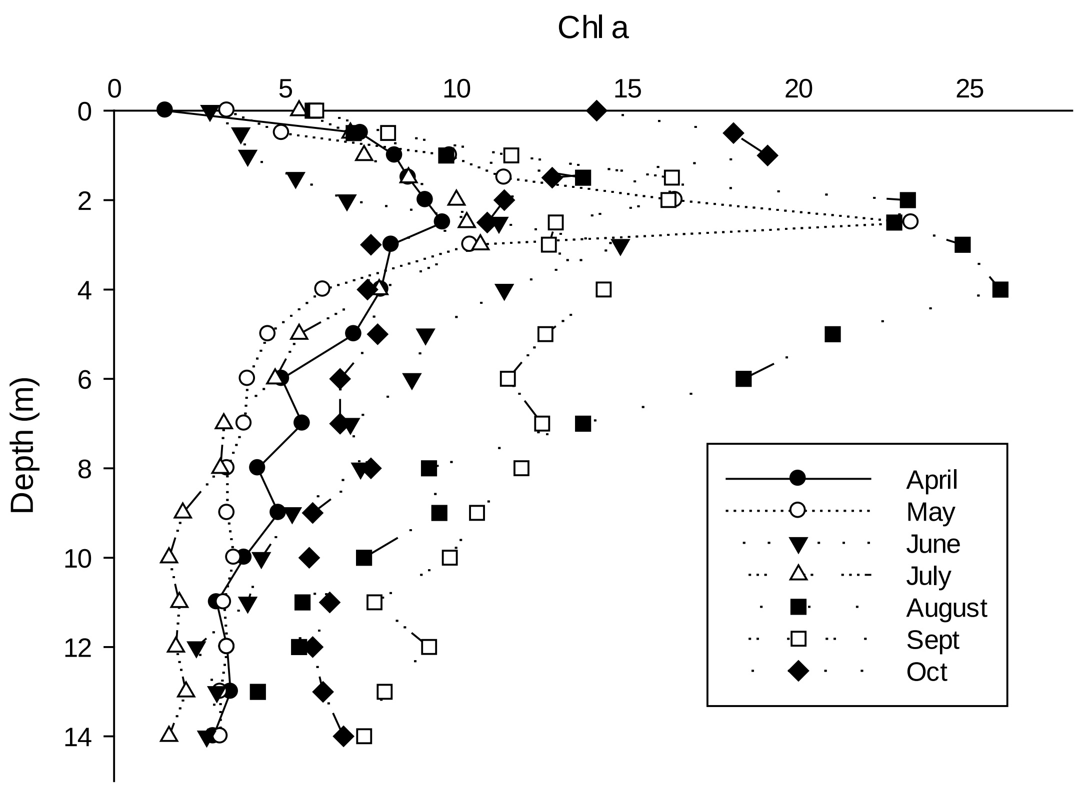

Figure 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2022)

Seasonal Analysis

The reservoir continues to demonstrate a pattern of greatest phytoplankton growth, as indicated by increased chlorophyll content, just above the thermocline (between 2-4 meters). In 2022, phytoplankton seasonal peaks were observed at 4 meters depth. The increase in productivity at 4 meters began in May and peaked in August. This is a typical pattern for eutrophic reservoirs where phytoplankton growth is photo-inhibited at the surface and blooms along the thermocline occur where nutrients are more available and temperatures very conducive for growth. It is instructive to see the amount of phytoplankton development in August as the area with concentrations in the eutrophic range extended into 8 meters depth. These increased peaks in Chlorophyll abundance are most observable in the summer months. In September during turnover greater concentrations were observed at greater depths.

Comparisons Across Years

The pattern of increased phytoplankton along the 2-4 meter thermocline in the reservoir is a well-established phenomenon in eutrophic lakes and in Leesville Lake. In most seasons, this pattern occurs throughout the summer months. The ultimate peak in phytoplankton growth usually occurs in July or August and it is variable in concentration. This season's peak was lower than observations in the past peaking near 25 mg/L. These are lower levels than we have been observed in the past. Certainly, this is cyclic and related to the amount of stormwater entering the reservoir and flushing phytoplankton biomass throughout the season and preventing its buildup.

<u>pH</u>

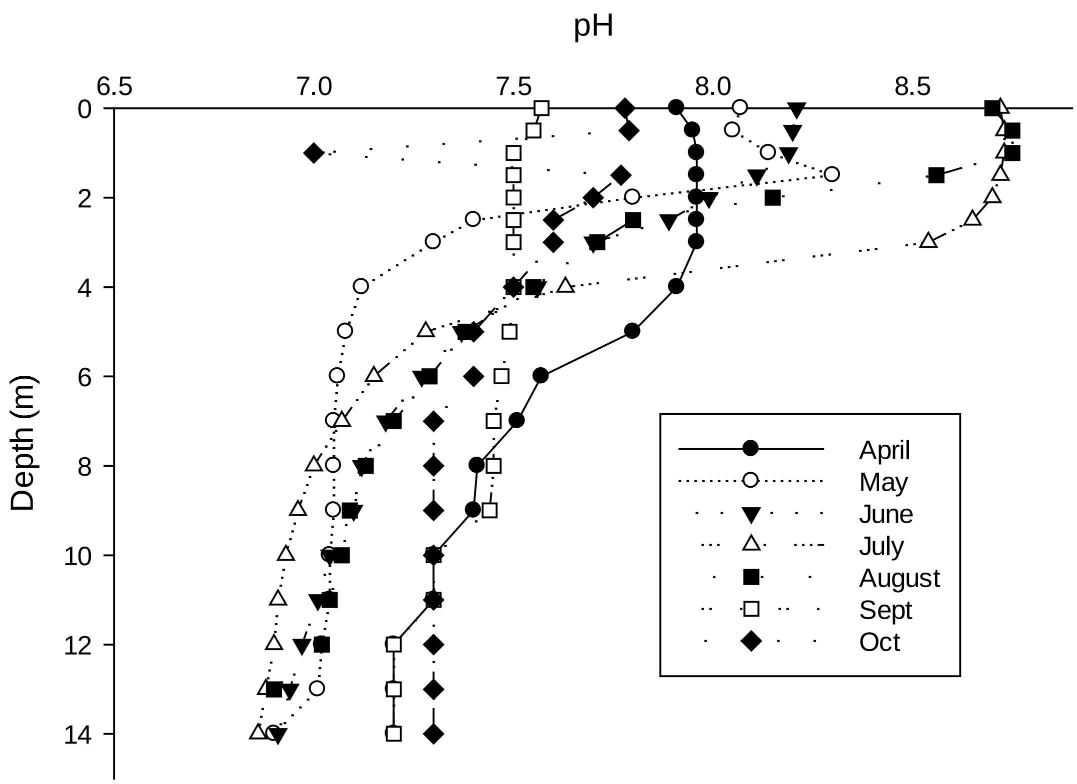

Figure 1.5. Dam (Lacustrine) pH measures over study period (2022)

Seasonal Analysis

The pH of water in the reservoir follows a typical curve for a eutrophic reservoir with soft water. The July and August measures were the highest observed for the season and this is a phenomenon related to phytoplankton growth. These pH changes are generated through phytoplankton photosynthesis as these organisms consume CO_2 and generate oxygen. In soft water (poorly buffered with compounds like calcium carbonate) this causes the pH to change quite rapidly. Carbon dioxide acts like an acid in water so its removal raises the pH. The very high chlorophyll *a* measures in August are consistent with the high pH measures.

Comparisons Across Years

The pattern of pH observed in the reservoir is relatively consistent across years. High pH (above 9) can sometimes be expected in the summer months when phytoplankton growth is at its peak with this measure strongly correlated to phytoplankton biomass. But peak pH is variable. In many seasons, the pH does not exceed 8.5. This season the peak was 8.8. In 2018, pH peak was near 10. Multiple factors help drive this pattern. It is important to note that high pH is very stressful to fish and due to the limited habitat available in the summer months and can generate toxic conditions in the presence of excess nutrient concentrations.

ORP

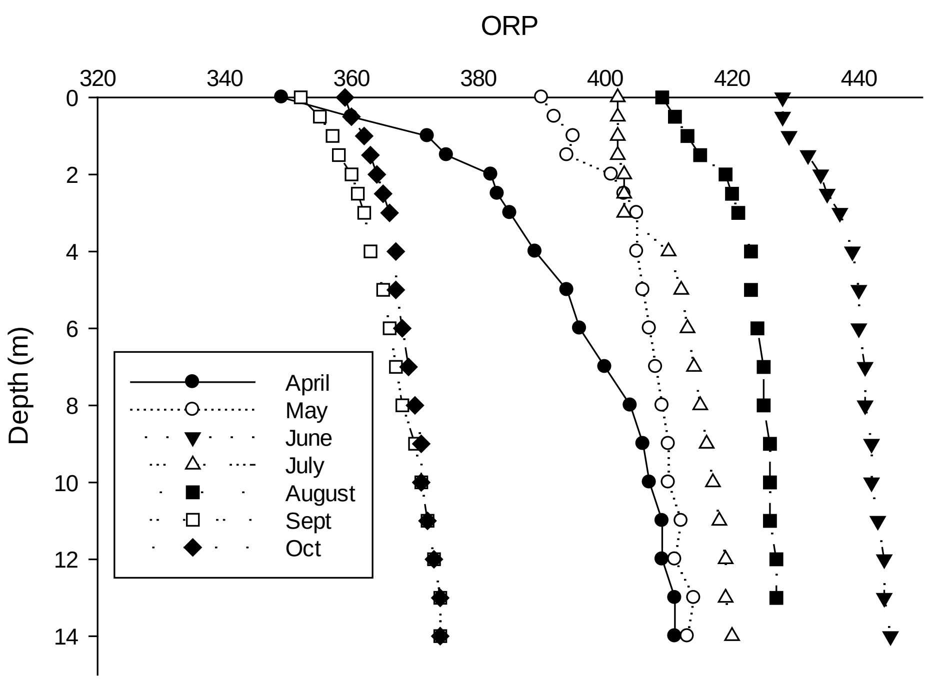

Figure 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2022)

Seasonal Analysis

There is a pattern of slightly increased ORP with increasing water depth across seasons. Also, the lake is in a greater oxidized state during the summer, which is expected as oxygen concentrations tend to increase during this period of time. ORP values near 400mV and above are in the expected range for a productive reservoir.

Comparisons Across Years

On an annual scale, ORP measures differ from year to year. In some years we have observed seasonal values up to 700 or as low as 100 mV. This shows the tremendous variability with this measure. Consistently, the cooler and well-mixed months in the reservoir tend to have the greatest ORP measures. While this parameter only measures the potential for a redox reaction occurring, the values in the higher range (greater than 400) suggest better water quality.

Turbidity

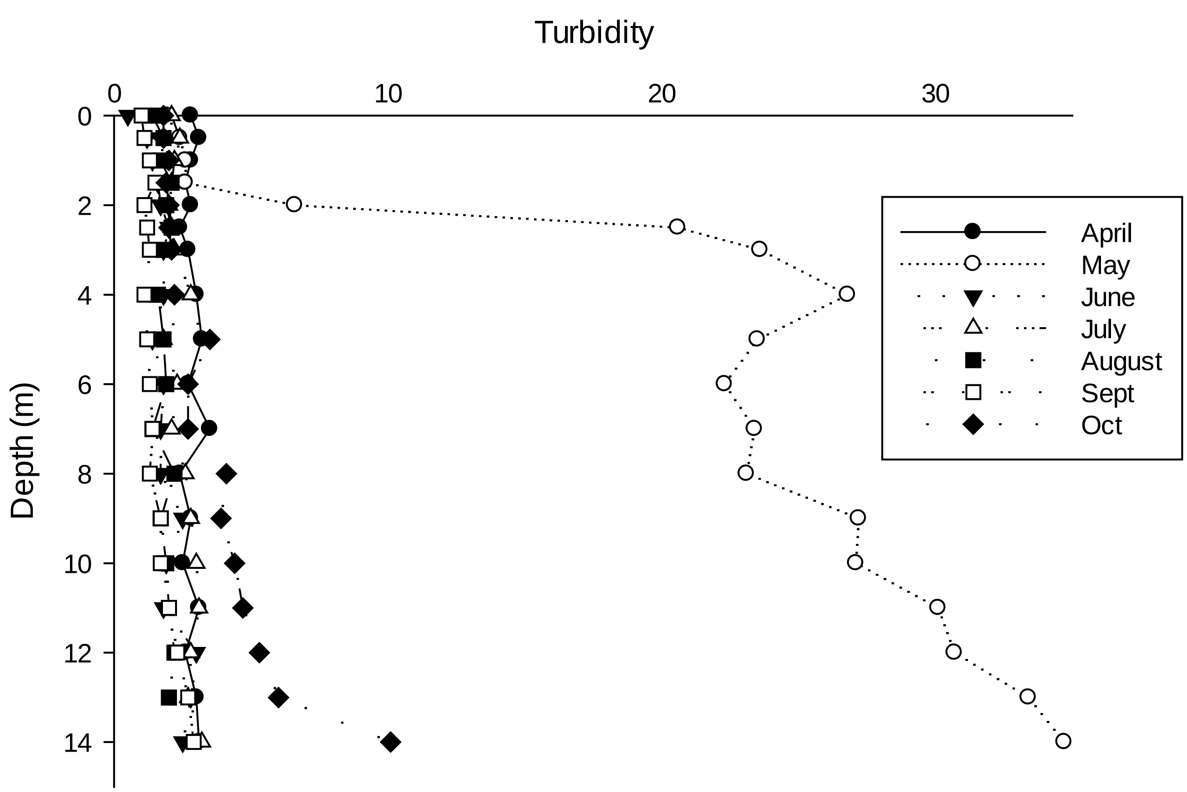

Figure 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2022)
Seasonal Analysis

Turbidity at the dam is generally low, with values well below 10 NTU throughout the entire sampling season. The exception this season was in May and this was due to stormwater throughout the reservoir. This condition was reflected through other measures as well (i.e., Conductivity). Turbidity is generally unimpacted by increasing Chlorophyll *a* productivity, with non-algal turbidity (sediment) being the most significant influence on this measure.

Comparisons Across Years

When turbidity is elevated, it generally increases with depth. More recently, we have not seen this pattern develop. Turbidity in previous seasons (2017 and earlier) can be observed to have a biological component as it increased from the surface into the thermocline. In observations since 2018, only non-algal turbidity appeared to register. This may suggest the reservoir is becoming more turbid with sediment input exerting more control.

Other Parameters Measured

Table 1.8. Other parameters measured over study period (2022). Dates represent sampling of both the volunteers and University of Lynchburg. First Column represents each parameter measured along with units of measure.

	29-Apr	31-May	15-Jun	29-Jun	14-Jul	28-Jul	12-Aug	29-Aug	28-Sept	26-Oct
Time	1:01 PM	11:55 AM	9:05 AM	12:32 PM	9:08 AM	11:40 AM	9:00 AM	10:50 AM	12:30 PM	3:20 PM
Secchi (M)	2.20	2.30	2.3	3.40	2.4	2.30	2.2	2.40	1.90	1.90
TP Surface	0.056	0.011	0.06	0.075	0.077	0.129	0.105	0.007	0.002	0.098
TP 8 Meters		0.097		0.307		0.112		0.047	0.017	0.019
Integrate Chl	5.72	6.70		6.30		5.24		13.36	11.04	9.23
TSI S	49	48	48	42	47	48	49	47	51	51
TSI TP	59	39	60	63	63	71	68	35	26	67
TSI CHL	48	49		49		47		56	54	52
TSI AVG	52	45	54	51	55	55	58	46	44	57
Daphnia	0.56	0.81		2.43		0.61		0.20	0.20	0.10
Bosmina	7.58	3.89		1.31		1.21		1.42	0.91	1.31
Diaptomus	1.36	1.42		1.62		0.40		0.20	0.51	0.00
Cyclops	8.64	0.56		1.42		0.40		0.81	0.81	0.30
Nauplii	3.29	1.16		1.21		1.01		0.91	0.91	1.21
Cerodaphnia	0.05	0.00		0.00		0.00		0.00	0.20	0.00
Diaphanosom	0.05	0.81		0.71		1.62		0.10	0.10	0.20
Chydorus	0.00	0.00		0.10		0.00		0.00	0.00	0.00
E. coli MPN	3.10	5.20	9.9	0.00	16.1	2.00	3	1.00	5.20	3.10

1.3.1.2 Leesville Lake Marina / Old Woman's Creek

Photograph of Leesville Lake Marina taken by Jade Woll.

Table 1.10. Leesville Lake Marina other parameters measured over study period (2022).

	29-Apr	31-May	15-Jun	29-Jun	14-Jul	28-Jul	12-Aug	29-Aug	28-Sept	26-Oct
Time	1:45 PM	12:33 PM	9:39 AM	1:15 PM	9:25 AM	11:56 AM	9:13 AM	11:30 AM	12:55	3:39 PM
Secchi (M)	1.70	1.60	1.7	2.6	1.9	2.20	1.8	2.20	1.60	1.60
(PPM)	0.050	0.181		0.113		0.223		0.063	0.029	2.206
TSI S	52	53	52	46	51	49	52	49	53	53
TSI TP	58	75		69		78		61	50	111
TSI AVG	55	64	52	57	51	63	52	55	52	82
cfu/100ml	6.30	7.50	2	6.3	6.3	1.00	10.7	0.00	181.00	1.00

Table 1.11. Tri County Marina other parameters measured over study period (2022).

	29-Apr	31-May	15-Jun	29-Jun	14-Jul	28-Jul	12-Aug	29-Aug	28-Sept	26-Oct
Time	1:55 PM	12:40 PM	9:51 AM	1:26 PM	9:38 AM	12:05 PM	9:27 AM	11:41 AM	1:03	3:46 PM
Secchi (M)	2.10	1.10	1.7	2.5	1.7	1.90	1.5	2.10	1.40	1.50
TP Surface (PPM)	0.047	0.063		0.156		0.073		0.142	0.012	0.012
TSI S	49	59	52	47	52	51	54	49	55	54
TSI TP	57	61		73		63		72	40	40
TSI AVG	53	60	52	60	52	57	54	61	48	47
E. coli cfu/100ml	4.10	48.00	4.2	2	7.4	6.30	4.1	5.00	4.10	1.00

1.3.1.3 Tri County Marina

Photograph of Tri County Marina taken by Jade Woll.

1.3.1.4 Mile Marker 6 (Transition)[2]

<u>Background</u>

In discussing water quality at the transition station (MM6), comparisons are made back to Lacustrine and Riverine portions of the lake. This section does not provide further discussions of the patterns observed at the Dam (Lacustrine) or Toler Bridge (Riverine), but to discern any trends the data provides on a spatial scale moving up or down the lake.

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[2] *Photograph of Leesville Lake taken by Jade Woll*

Conductivity

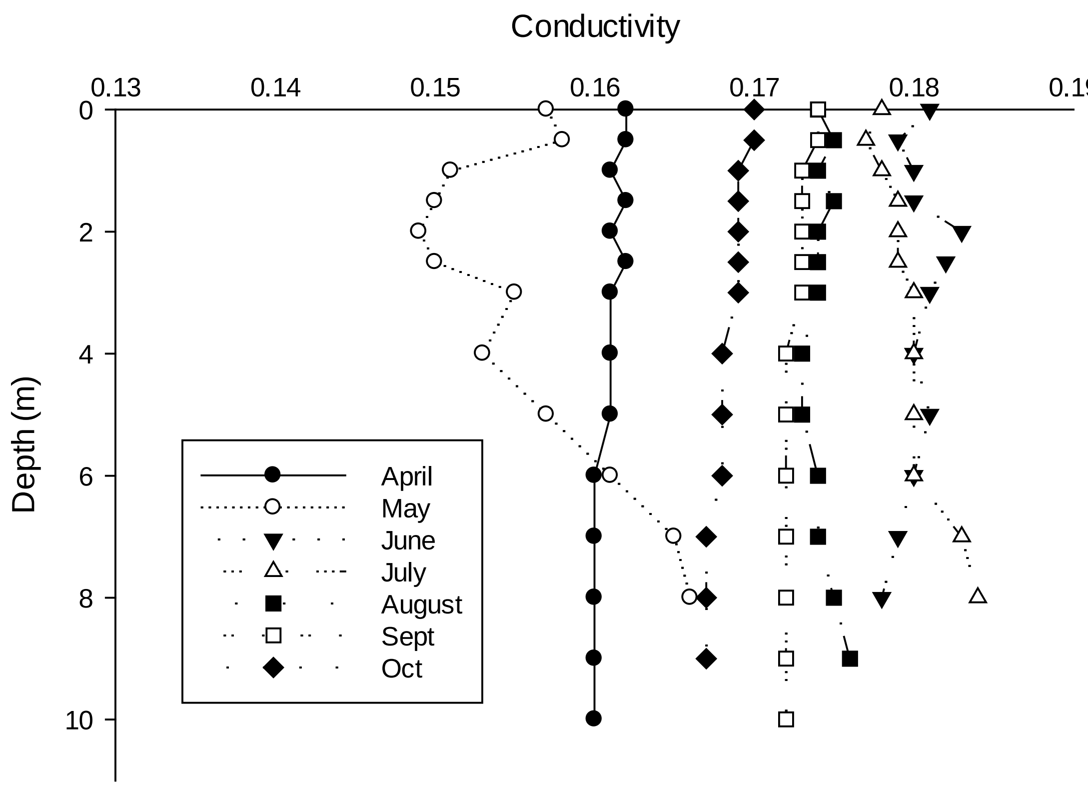


Figure 1.8. Mile Marker 6 (Transition) Conductivity (ms/cm) measures over study period (2022)

Seasonal Analysis

Conductivity patterns at the transition region are reflective of a mixed condition, i.e., a general absence of stratification. We do not see the same stratification pattern observed at the dam. Consistent readings from surface to depth at this station support this conclusion. The one exception, as with the last several seasons, was observed in May. Lower conductivities overall (compared with other stations) and higher conductivity at depth suggest a preponderance of Pigg River water in the reservoir at this station and movement of Pigg River water at the water's surface. This gives us insights into how water masses move throughout the lake and this pattern differs at this station when compared to the dam.

Comparisons Across Years

Comparisons among years suggests that conductivity is declining in Leesville Lake. This pattern strongly suggests the Pigg River is exerting greater influence on the patterns of observed water quality observed because Pigg River water is of lower conductivity. A portion of this observation can be assumed to originate from the water mass in the reservoir as the season begins due to lower electricity demand and much of the water in Leesville Lake originating from Pigg River flow. Winter lake data are not collected but April readings can provide inferences suggesting this is the condition. Initial readings in April are variable across the years of study and may reflect the primary source of water input at the beginning of the season. In 2021, April conductivity readings were lowest recorded suggesting the influence of the Pigg is greatest in winter and then minimizes as SML operations intensify. This relationship will be further discussed in the analysis section.

Dissolved Oxygen

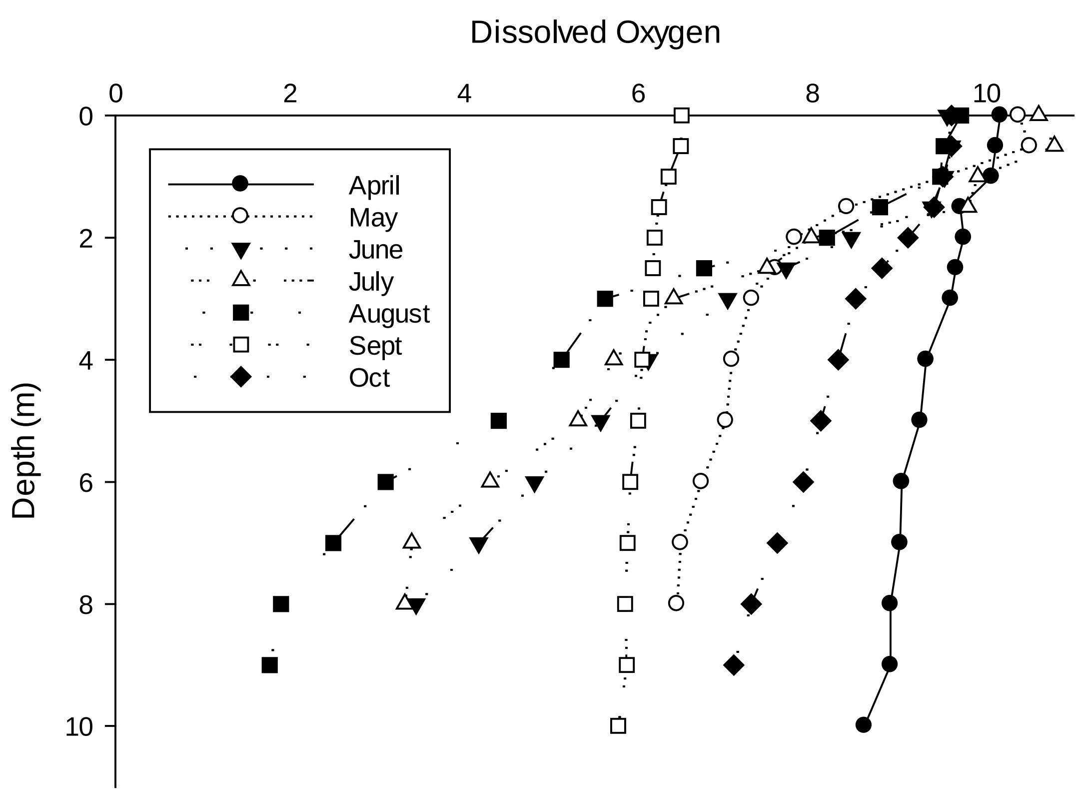


Figure 1.9. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2022)

Seasonal Analysis

This portion of the reservoir is completely mixed in the cooler months and stratified in summer. During those three months, we observed a strong enough stratification pattern for dissolved oxygen to reach levels below 4 mg/L. This suggests that not only is MM6 a transition area in the reservoir but that it may provide a good refuge for fish in the reservoir as the oxygen and temperature combination may provide better habitat in those months due to deteriorating conditions in the upper portions of the reservoir. The suggestion here is a combination of temperature and oxygen providing the refuge for fish.

Comparisons Across Years

Oxygen observations are variable across seasons and within season. In some seasons, stratification is strong and we see oxygen depletion at greater depths during the summer months. In other seasons, such as 2021, dissolved oxygen is present at reasonable levels most of the season, even at the lower depths in a stratified column of water. Whereas during other years, dissolved oxygen is very low (below 4 mg/L) throughout the water column at all times. The best conclusion is that this station is variable both on a spatial scale (from dam to headwaters) and temporal scale (across and within seasons). This pattern has a strong influence on water quality from year to year.

Temperature

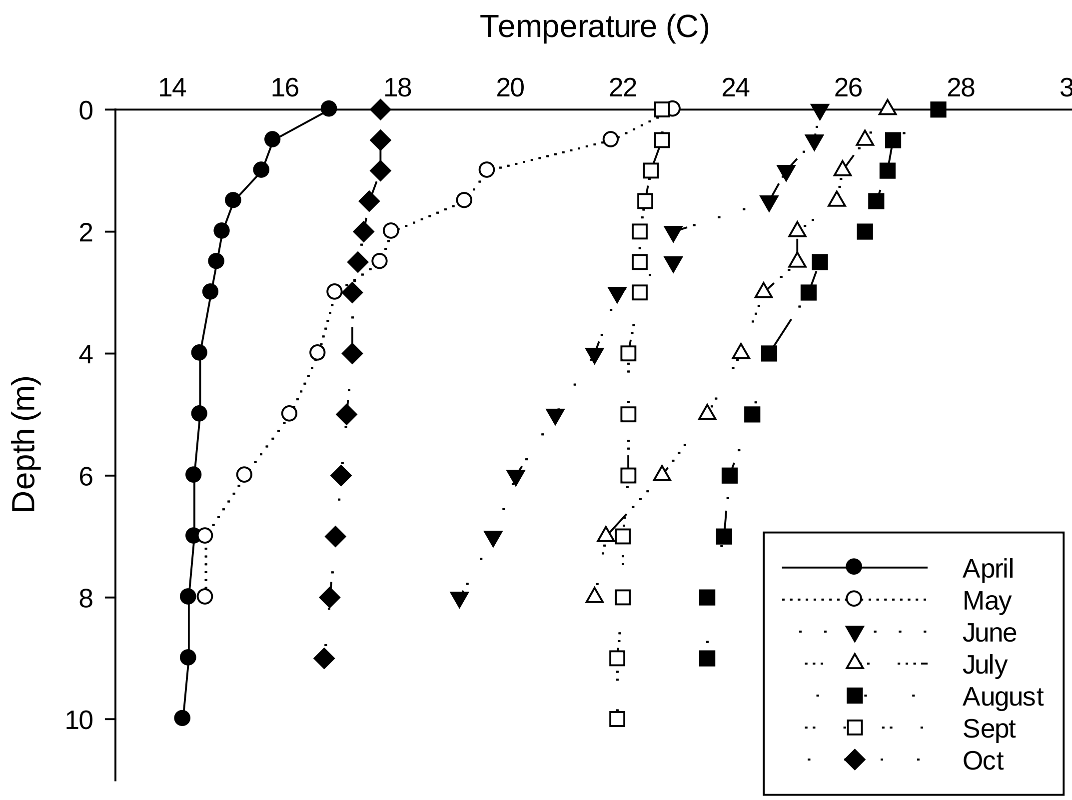


Figure 1.10. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2022)

Seasonal Analysis

Thermal stratification in this section of the reservoir is weak (subject to fluctuation and mixing due to weather and water movement). This correlates well with the previous observations concerning oxygen content. The benefit of this weak stratification is that it increases oxygen content, which has become a significant concern. Conceptually, this station is situated between the LVL dam (stronger stratification because of depth and restricted water movement) and Toler Bridge headwaters (limited stratification due to water movement from Pigg River and SML dam release) each with oxygen loss problems.

Comparisons Across Years

While temperatures at this station parallel the influence of season throughout the reservoir, the pattern of minimal stratification at this site is consistent across and within years. Thus, this station is a good example of a transition zone, influenced by both riverine and lacustrine forces.

Chlorophyll *a*

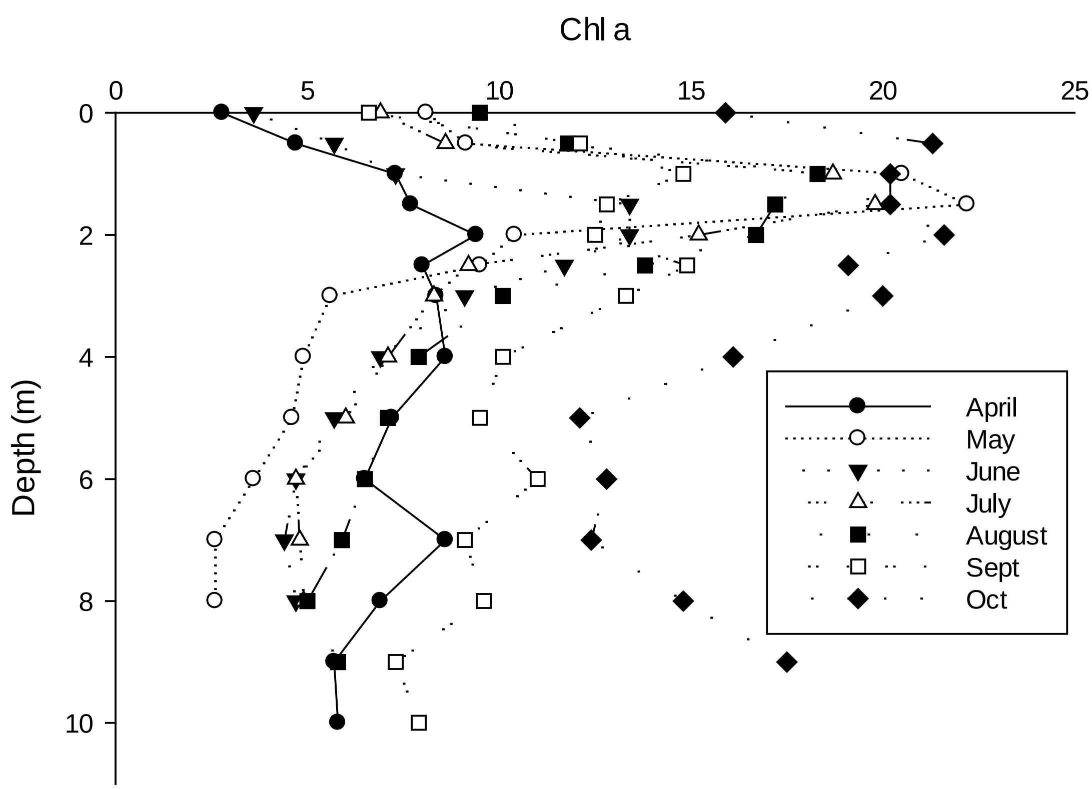


Figure 1.11. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2022)

Seasonal Analysis

The transition area is theoretically the portion of the reservoir where phytoplankton abundance measured by Chlorophyll *a* can be very high. Nutrient input from the upper portions of the reservoir mixes with the warmer and slowly moving water mass to create ideal conditions for phytoplankton growth. Interestingly, this year the peaks in chlorophyll a were observed in the water column, but their magnitude was limited and did not exceed concentrations at other stations. In fact, here and at the dam Chlorophyll *a* was relatively low. Additionally, Chlorophyll *a* increased in October over concentrations observed over summer. While phytoplankton speciation was not quantified in years past this represented a transition from Blue-greens and Greens to diatoms due to colder weather and the availability of nutrients. Drivers of the relationship between phytoplankton, water flow and nutrient levels drive observed productivity at this station.

Comparisons Across Years

High peaks in phytoplankton biomass and pattern of growth above the thermocline are not consistently observed at this station across years. Typically, phytoplankton biomass is elevated throughout the water column from 2-5 meters depth and at concentrations of 20-30 ug/L. Greater than average measures of Chlorophyll a may be a function of reduced stormwater flow flushing Leesville Lake or setup of water and nutrients available from winter/early spring water flow and SML operation.

pH

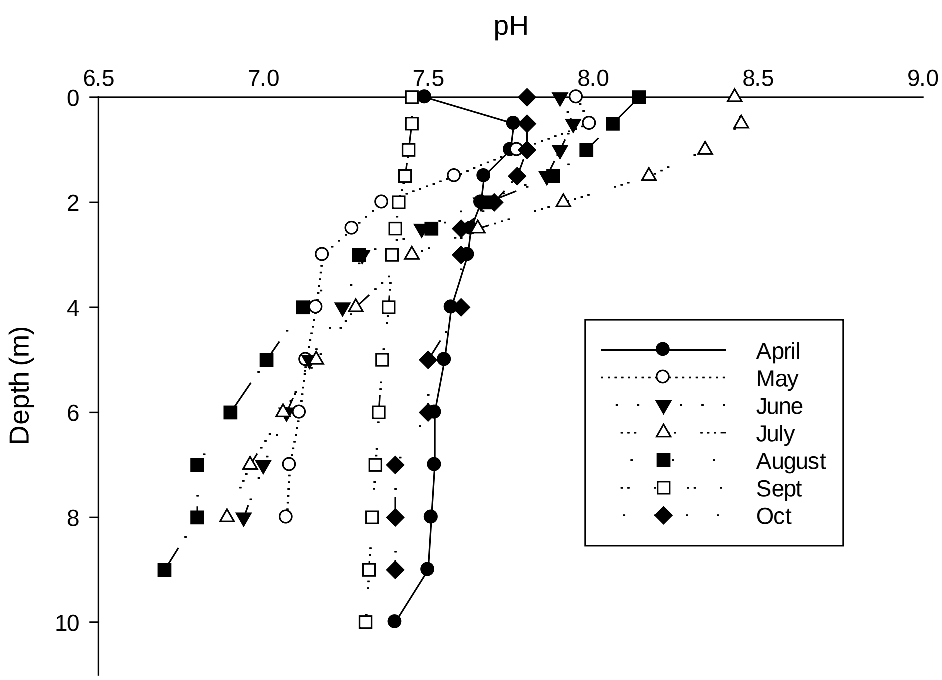


Figure 1.12. Mile Marker 6 (Transition) pH measures over study period (2022)

Seasonal Analysis

The pH pattern is very similar to that observed at the dam and the pattern of stratification in the reservoir. In cooler months, pH is lower than summer months and during all months other than September (with turnover) shows a patterns of stratification. Elevated pH does follow the pattern of Chlorophyll *a*, with July demonstrating higher pH measures. This pattern is also influenced by temperature.

Comparisons Across Years

This is a variable station and influenced by a multitude of factors. The lower readings this year suggest many physical factors influenced the biology in the reservoir and this is reflected in the pH values.

ORP

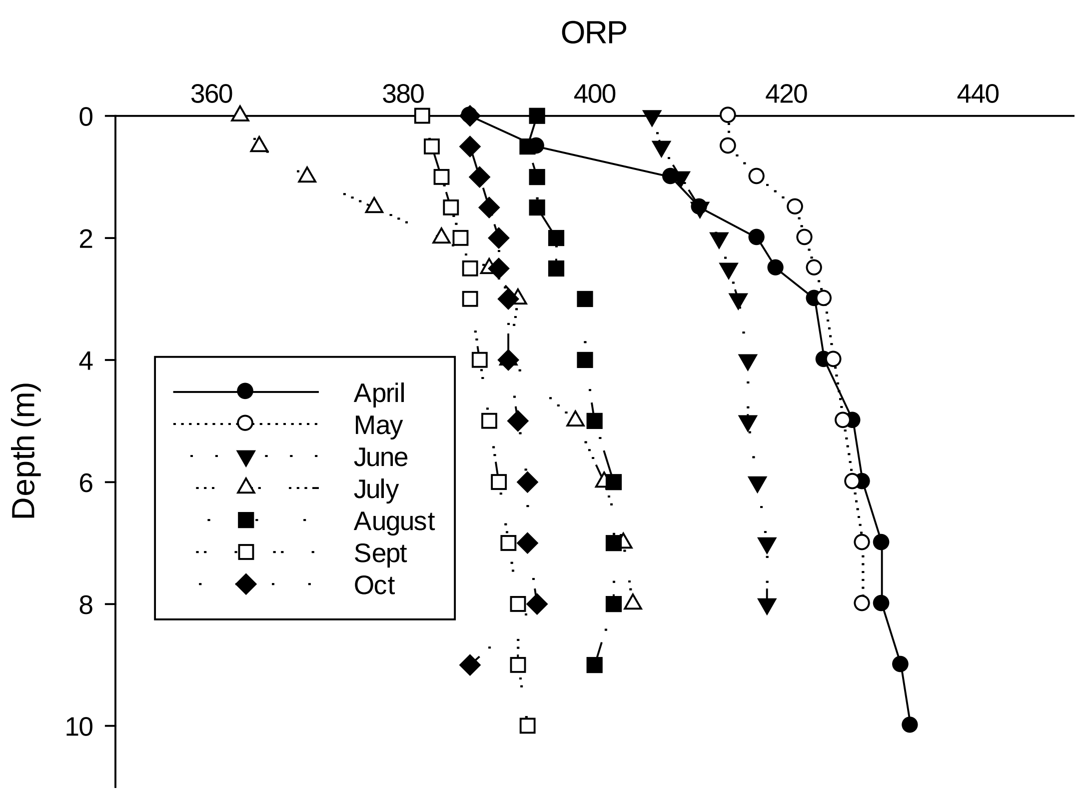


Figure 1.13. Mile Marker 6 (Transition) ORP (mV) measures over study period (2022)

Seasonal Analysis

Patterns of ORP at this station are similar to those observed at the dam. The high ORP during April and May reflect the changes that occur in this transition zone particularly during the spring months. By summer, the patterns are similar to those at other station. he most import aspect of ORP is the oxidized environment in the lake and the importance of this condition to the chemical speciation.

Comparisons Across Years

ORP has been variable over multiple years at this station. It is hard to pinpoint particular conditions that may have contributed to this pattern but lower ORP during recent years suggest a worsening water quality. Still, observations in this year's sampling are in the expected range for this reservoir.

Turbidity

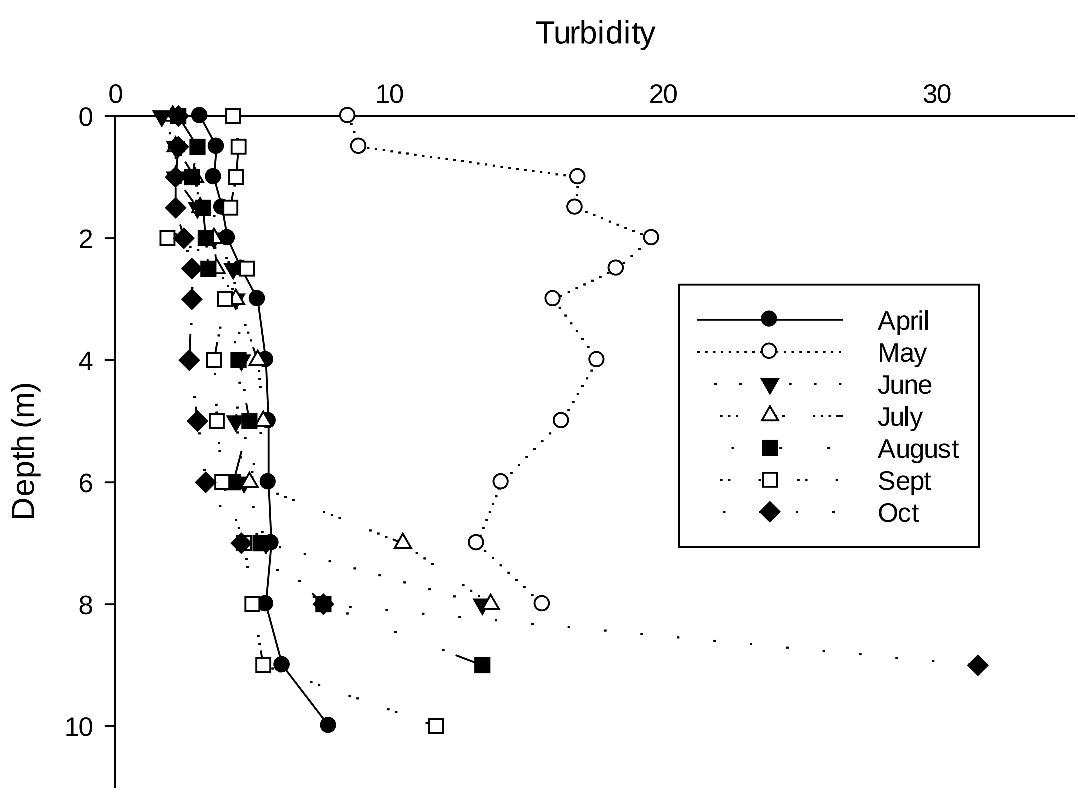


Figure 1.14. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2022)

Seasonal Analysis

Turbidity at this station is consistent with that at the rest of the reservoir, with elevated turbidity during May due to stormwater. Some of the elevated measures at greatest depth are due to stirring of the bottom sediments during measurement. The variable depth of the reservoir influences reservoir depth at this station.

Comparisons Across Years

Turbidity patterns at this station are variable across years. Turbidity during some years has been much higher and other seasons has been lower than this year’s observations. This station as a transition zone is variably influenced by both clearer water due to lacustrine conditions and more turbid water from the upper portions of the reservoir. These conditions are reflected throughout the many seasons of measurement.

Other Parameters Measured

Table 1.19. Other parameters measured over study period (2022). Dates represent sampling of both the volunteers and university. First column lists each parameter measured along with units of measure. All TSI measures are unitless and zooplankton are in animal per liter.

	29-Apr	31-May	15-Jun	29-Jun	14-Jul	28-Jul	12-Aug	29-Aug	28-Sept	26-Oct
Time	2:10 PM	12:50 PM	10:02 AM	1:40 PM	9:50 AM	12:11 PM	9:37 AM	11:50 AM	1:17 PM	3:51 PM
Secchi (M)	1.6	8.2	1.7	2.5	1.7	1.9	1.6	1.75	1.3	1.5
TP Surface (PPM)	0.063	0.059	0.067	0.096	0.091	0.061	0.088	0.108	0.031	0.036
TP 8 (6) Meters (PPM)		0.039		0.307		1.34		0.038	0	0.046
Integrate Chl a (PPB)	5.61	7.74		8.64		7.70		10.43	10.82	17.23
TSI S	53	30	52	47	52	51	53	52	56	54
TSI TP	61	60	61	66	66	60	65	68	51	53
TSI CHL	48	51		52		51		54	54	59
TSI AVG	54	47	57	55	59	54	59	58	54	55
Daphnia	0.51	0.24		1.11		0.00		0.00	0.20	0.10
Bosmina	11.83	3.30		1.31		0.10		0.61	0.61	0.61
Diaptomus	0.30	1.06		0.51		0.10		0.00	0.10	0.00
Cyclops	1.82	1.18		0.91		0.10		0.30	0.61	0.51
Nauplii	1.31	1.06		0.81		0.61		0.00	0.91	0.71
Cerodaphnia	0.00	0.24		0.10		0.00		0.00	0.10	0.00
Diaphanosoma	0.10	0.35		0.61		1.01		0.20	0.30	0.20
Chydorus	0.00	0.00		0.00		0.00		0.00	0.00	0.00
E. coli MPN/100ml	4.10	46.40	1	1	12.1	8.40	6.3	3.00	5.2	5.20

1.3.1.5 Mile Marker 9 (Riverine)

Photograph of Leesville Lake taken by Jade Woll.

Table 1.21. Mile Marker 9 other parameters measured over study period (2022)

	29-Apr	31-May	15-Jun	29-Jun	14-Jul	28-Jul	12-Aug	29-Aug	28-Sept	26-Oct
Time	2:35 PM	1:15 PM	10:13 AM	1:54 PM	10:05 AM	12:35 PM	9:55 AM	12:17 PM	13:10	4:15 PM
Secchi (M)	1.90	0.90	1.5	2	1.1	1.40	1.2	1.60	1.55	1.40
TP Surface	0.044	0.150		0.178		0.100		0.128	0.069	0.048
TSI S	51	62	54	50	59	55	57	53	54	55
TSI TP	56	73		75		67		70	62	57
TSI AVG	53	67	54	63	59	61	57	62	58	56
cfu/100ml	8.40	187.20	1	2	8.5	6.30	5.2	2.00	6.30	8.60

1.3.1.6 Toler Bridge (Riverine)[3]

Background

Riverine conditions as well as influx of tail waters of Smith Mountain Lake and influx of Pigg River water heavily influence waters at the Toler Bridge station. We see a combination of the water qualities from Pigg River discharge and SML hypolimnion release. The resulting water quality is completely driven by hydrological dynamics of the SML Dam (a mechanistic event) with river flow from the Pigg River (a stochastic event) thus creating a very dynamic system that is challenging to interpret.

[3] *Photograph of Toler Bridge taken by Jade Woll.*

Conductivity

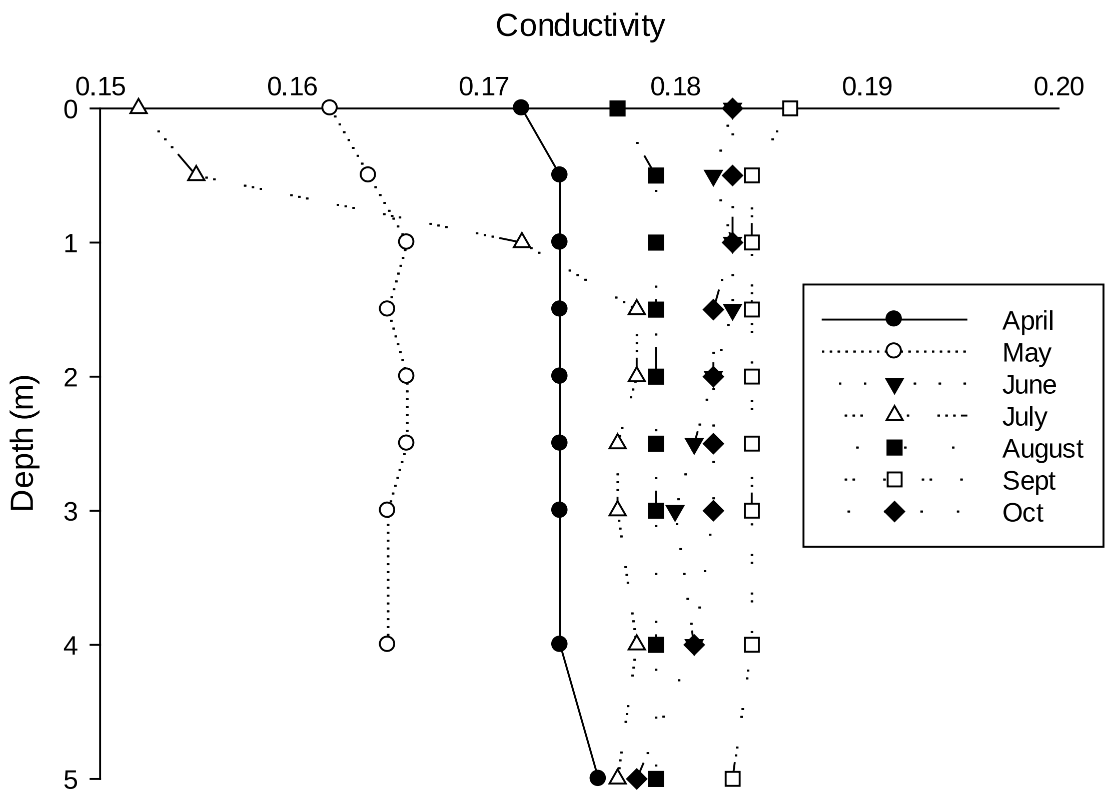


Figure 1.15. Toler Bridge (Riverine) Conductivity (ms/cm) measures over study period (2022).

Seasonal Analysis

Conductivity in this portion of the reservoir is usually consistent (minimal change) from top to bottom unless some type of pumping or heavy flow from the Pigg River stratifies it. Only observations in July suggest water from the Pigg over water from other portions of the reservoir. Otherwise, this station is mixed and mostly dominated by SML release.

Comparisons Across Years

Observations of conductivity at this station over time demonstrate that SML release is the predominate controlling hydrology in the headwaters of LVL. Only during certain periods of time (most likely driven by stormwater flow) does Pigg River contribute enough water to influence readings at this station. This strongly suggests that LVL headwaters are an extension of SML hypolimnion with the addition of Pigg River pollutants. Sound water quality management of SML has profound impact on both reservoirs.

Dissolved Oxygen

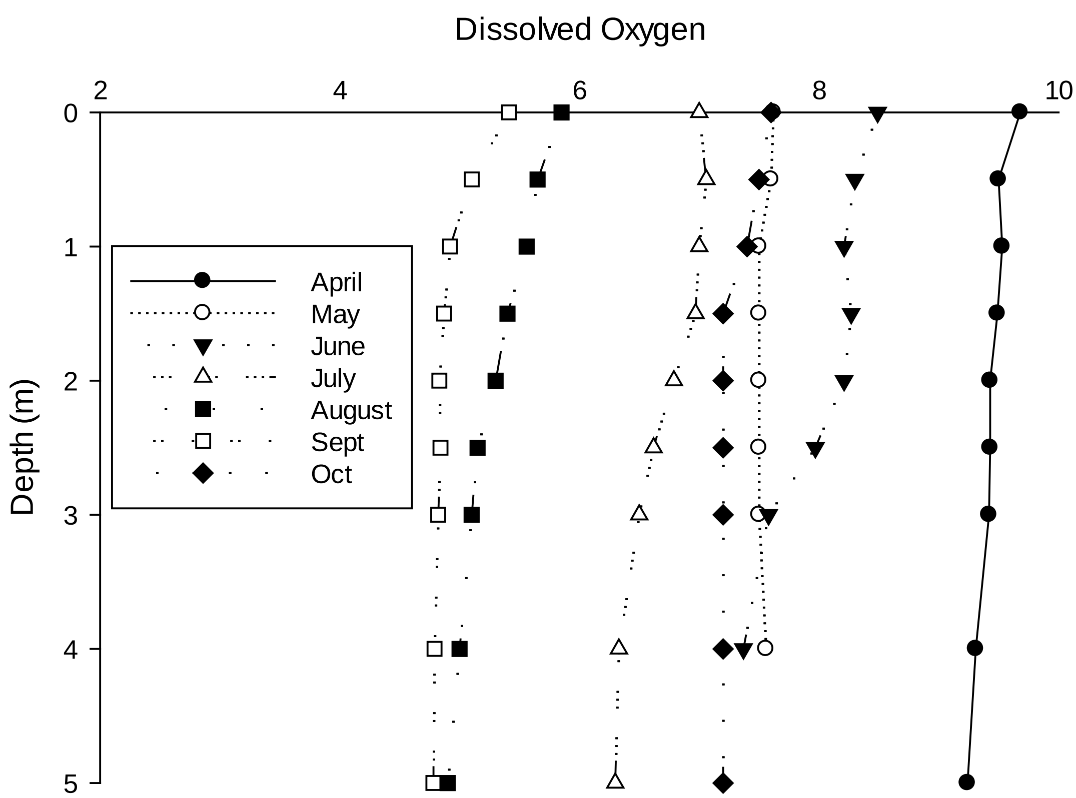


Figure 1.16. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2022)

Seasonal Analysis

Dissolved oxygen here is often a reflection of SML release but can be elevated due to Pigg River input. Observations are highly dependent on water movement. Several generalizations from this data are possible. First, water is not stratified at this station. Depth and water movement prevent this from occurring. Secondly, oxygen concentration here decline throughout the season as the hypolimnion of SML that discharges into LVL declines. This pattern is apparent and in several instances approaches levels below 5 mg/L.

Comparisons Across Years

Dissolved oxygen at this station is a function of water release. When conductivity is elevated, dissolved oxygen is low. In the later months of the season, dissolved oxygen levels below 5 mg/L can be observed throughout the upper portion of the reservoir here suggesting tailwater release has far reaching impacts in LVL.

Temperature

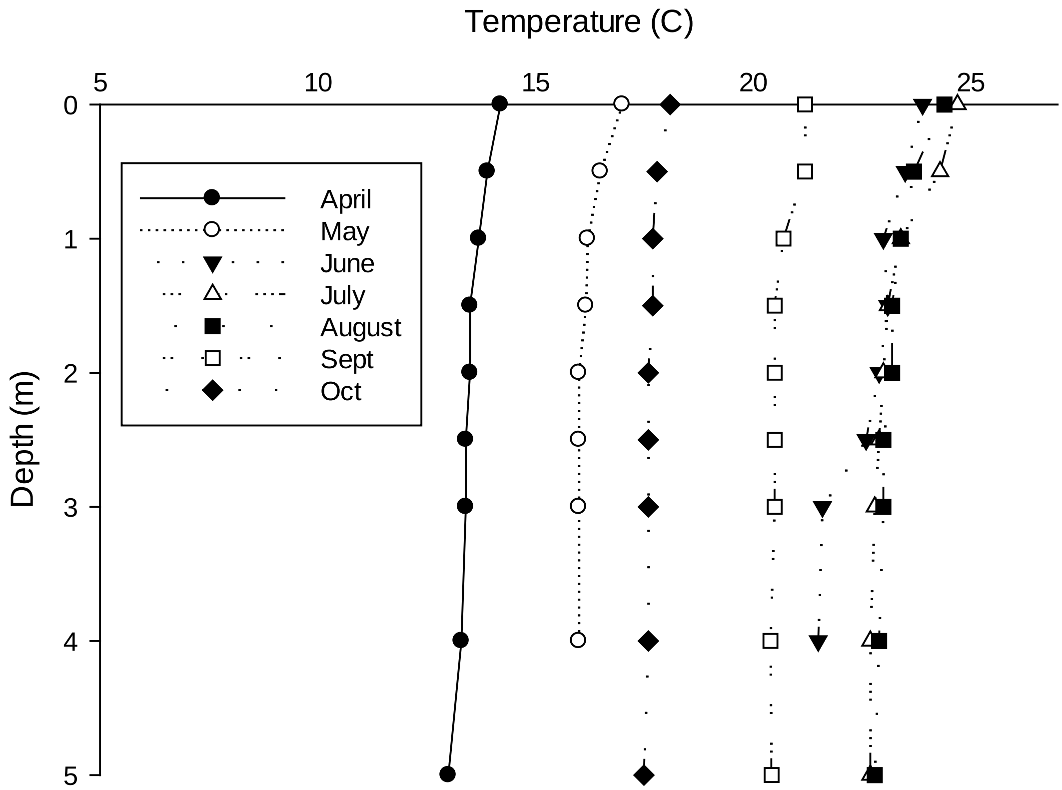


Figure 1.17. Toler Bridge (Riverine) Temperature (°C) measures over study period (2022)

Seasonal Analysis

This station does not stratify because water released from SML creates flowing conditions at this station. The water movement is frequently too strong to allow the water enough time to develop layers. Measures of this parameter reflect this strong water flow with the cooler temperatures than in other portions of the reservoir. This again supports the idea LVL headwaters are strongly influenced by SML tailwaters.

Comparisons Across Years

Lack of stratification at Toler Bridge is consistently observed across the years. Water flow from SML causes constant movement of the water at this station limiting the opportunity for stratification. We usually see this only during the spring months. During the summer, electricity demand and typically lower stormwater flow set up conditions for extensive water movement from pump back and release in LVL headwaters.

Chlorophyll *a*

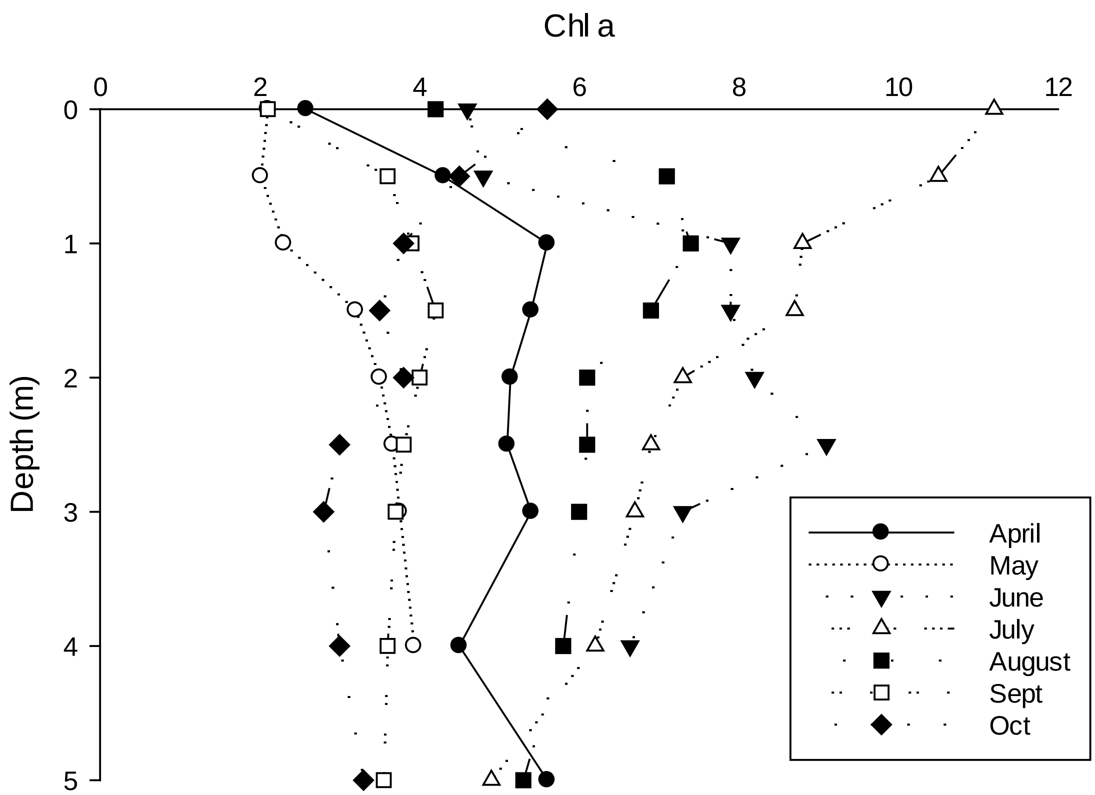


Figure 1.18. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2022)

Seasonal Analysis

This station typically contains the lowest readings of phytoplankton biomass throughout the entire reservoir each season. But the pattern this year provides some insight into how water flow in LVL influences productivity throughout the lake. In June, phytoplankton biomass attained one of the highest concentrations measured at Toler Bridge. During this historical increase in phytoplankton, water was clearly composed primarily of Pigg River input based on conductivity readings (Figure 1.15). Without flushing and movement of water into and out of SML and along with warming temperatures (Figure 1.17), phytoplankton increases occurred very rapidly. This increase was measured through MM6 (Figure 1.11) with Chlorophyll a concentrations up to 100 ug/L or hypereutrophic conditions. The inference is quite clear. Inputs of water from SML hypolimnion mitigates nutrient laden water from Pigg River during periods of power generation. When these mechanisms are minimized in the absence of significant power generation, LVL has the capacity to create hypereutrophic conditions.

Comparisons Across Years

Growth of phytoplankton in this area is completely dependent on flow and movement of water. In some seasons we can detect a buildup and increase in Chlorophyll *a* during the summer months. But as demonstrated this season, buildup of phytoplankton biomass in June can be quickly mitigated later in the summer and fall due to SML hypolimnion release. This is a very positive impact of dam operations for LVL. The negative side effect is the low dissolved oxygen of the water released.

pH

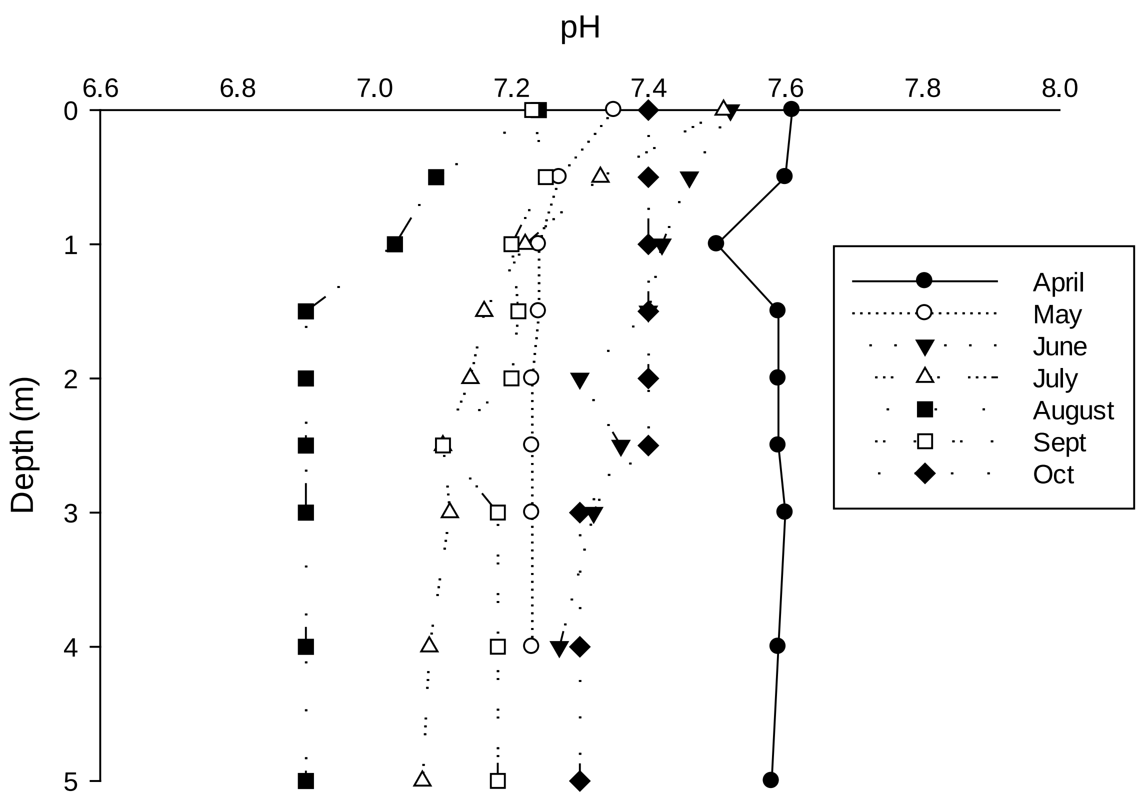


Figure 1.19. Toler Bridge (Riverine) pH measures over study period (2022)

Seasonal Analysis

The pH at this station is strongly influenced by water flow and reflects the chemical constituents in the water rather than phytoplankton productivity as it does at other stations. Water movement may push water with higher pH readings into this area from LVL but more likely it is driven from the mix of Pigg River and SML tailwaters. While phytoplankton productivity may be lower, pH can remain elevated until acid – base chemistry equilibrates.

Comparisons Across Years

The pH at this station can exceed a pH of 8 during the summer months. It is hard to pinpoint the cause, as these higher readings do not correlate well with observed Chlorophyll *a* concentrations. Without knowledge of pH in SML or the exact movement of water between the two reservoirs it is difficult to predict this pattern. Nevertheless, in all instances pH elevation is lower than observed downstream in the lake where readings may exceed 9.

ORP

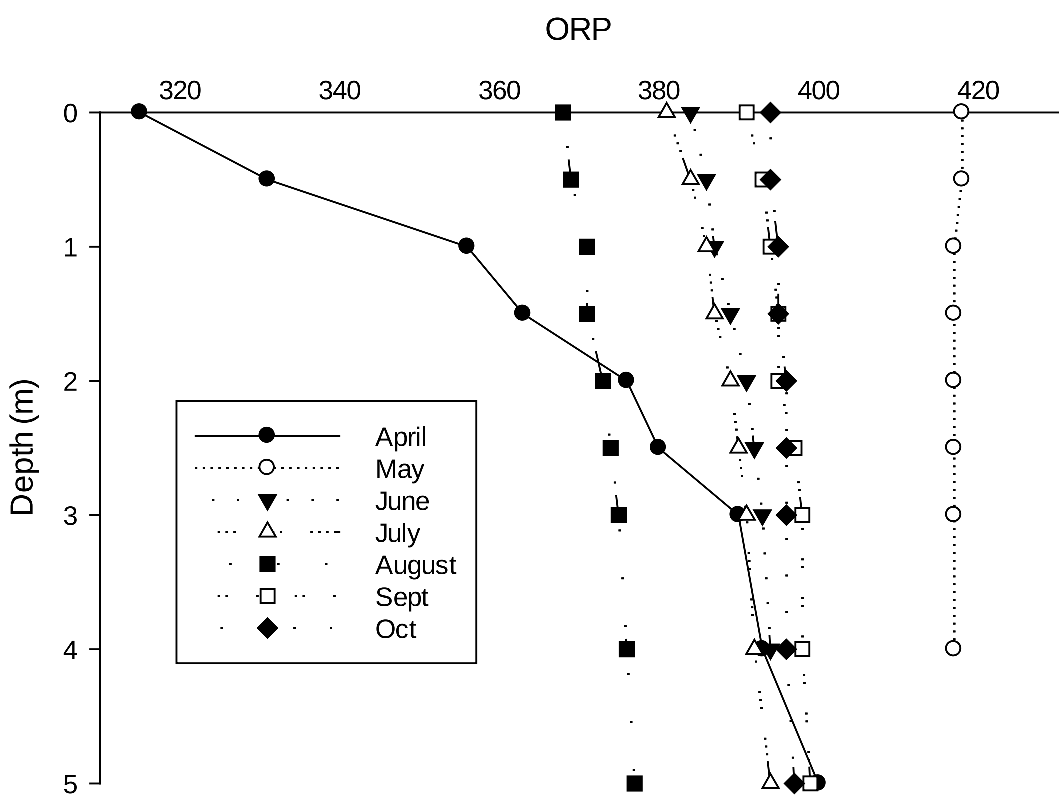


Figure 1.20. Toler Bridge (Riverine) ORP (mV) measures over study period (2022)

Seasonal Analysis

The ORP measures in this section of the reservoir do not provide any new interpretation between stations. Importantly, we do not observe reductions in ORP here creating concerns for reduced rather than oxidized conditions.

Comparisons Across Years

ORP is generally between 250 – 500 mV at this station. Some exceptions to this pattern have occurred but return to this range in the following season. ORP remains in a favorable range for the reservoir.

Turbidity

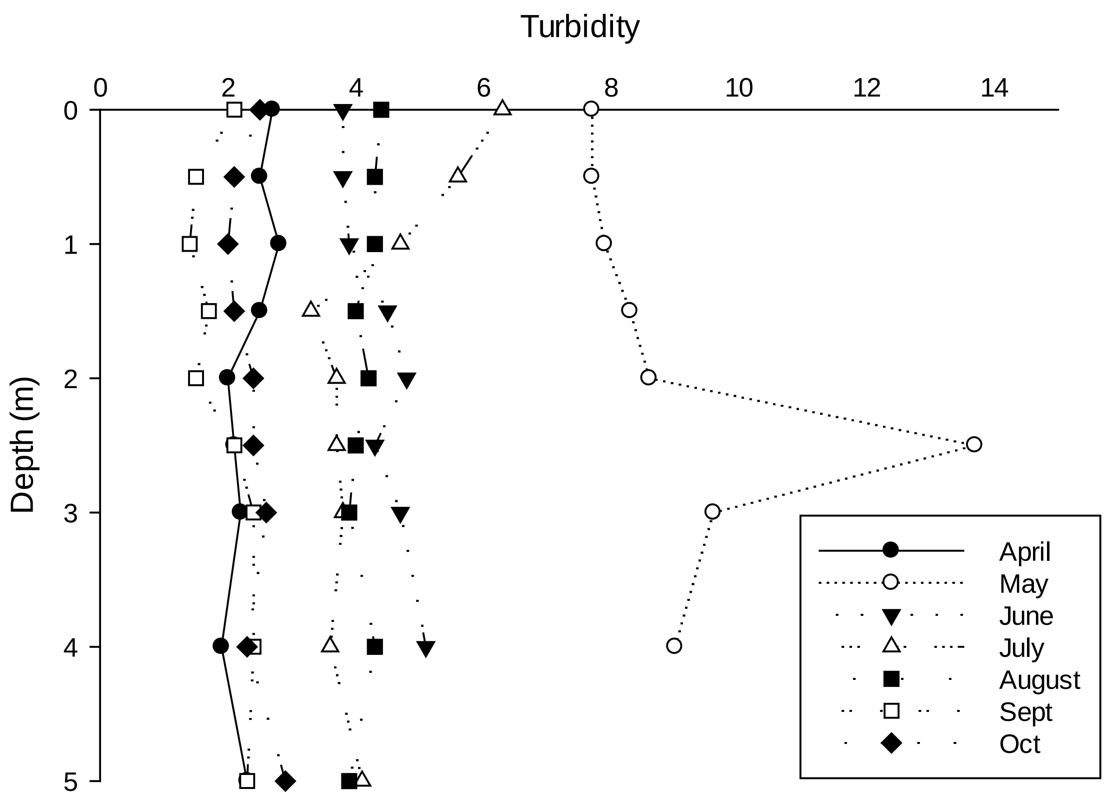


Figure 1.21. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2022)

Seasonal Analysis

Turbidity observations at this station impact the entire reservoir. We did not observe any extreme turbidity events during 2021. The increase in June Chlorophyll a was not a turbidity increasing event, which suggests that it was driven by dissolved nutrients entering the lake from the Pigg River.

Comparisons Across Years

Turbidity reveals storm events that impact the reservoir at this station. At times when the water is dominated by SML release or low Pigg River flow turbidity is low. Often below 20 NTU. Various storm events elevate turbidity above 50 NTU and very strong storms above 100 NTU.

Other Parameters Measured

Table 1.29 Other parameters measured over study period (2022). Dates represent sampling of both the volunteers and university. First Column represents each parameter measured along with units of measure.

	29-Apr	31-May	15-Jun	29-Jun	14-Jul	28-Jul	12-Aug	29-Aug	28-Sept	28-Oct
Time	2:50 PM	1:25 PM	10:30	2:05 PM	10:20	12:52 PM	10:17	12:28 PM	2:00 PM	4:24 PM
Secchi (M)	2.4	1.25	1.1	1.6	1	1.1	1.3	1.6	1.8	1.9
TP Surface (PPM)	0.118	0.092	0.045	0.07	0.159	0.219	0.179	0.198	0.032	0.032
TP 8 (3) Meters (PPM)										
Integrate Chl a (PPB)	4.00	5.06		7.06		7.91		6.10	3.61	3.70
TSI S	47	57	59	53	60	59	56	53	52	51
TSI TP	69	66	56	62	73	78	75	77	52	52
TSI CHL	44	46		50		51		48	43	43
TSI AVG	54	56	57	55	67	62	66	59	49	49
Daphnia	0.05	0.00		0.45		0.30		0.00	0.00	0.00
Bosmina	5.26	2.01		0.30		3.64		1.01	1.42	0.81
Diaptomus	0.05	0.12		1.16		0.10		0.00	0.00	0.20
Cyclops	0.35	0.12		0.05		0.71		0.10	0.00	0.20
Nauplii	0.40	0.12		0.05		0.81		0.40	0.30	0.20
Cerodaphnia	0.00	0.12		0.00		0.00		0.00	0.00	0.00
Diaphanosoma	0.00	0.24		0.61		0.51		0.10	0.10	0.20
Chydorus	0.00	0.00		0.00		0.00		0.00	0.00	0.00
E. coli MPN/100ml	8.50	172.30	6.3	8.6	14.6	111.20	8.6	5.00	7.4	5.20

1.3.1.7 Pigg River

Photograph of Pigg River taken by Jade Woll.

Table 1.31. Pigg River other parameters measured over study period (2022). Measures are integrative throughout the entire water column. Profile data located in the appendix.

	29-Apr	31-May	15-Jun	29-Jun	14-Jul	28-Jul	12-Aug	29-Aug	28-Sept	26-Oct
Time	3:07 PM	1:40 PM	10:40 AM	2:18 PM	10:30 AM	12:59 PM	10:25 AM	12:45 PM	14:03	4:36 PM
Temp C	18	24.6		26.88		26.8		26.3	20	13.1
Conductivity (ms/cm)	0.078	0.071		0.09		0.09		0.119	0.11	0.089
DO mg/L	8.28	7.3		8.14		6.89		6	7.89	9.9
DO %	89.9	88.9		103.4		88.5		76.1	88.1	97.6
pH	7.4	7.4		7.33		7.07		6.96	7.36	7.4
ORP	428	411		413		404		402	412	
Turbidity NTU	7.7	34.5		27.7		14.6		8.7	10.8	7.7
Chlorophyll a ug/L	6.4	3.3		8.3		4.7		5.5	7	3.2
Secchi (M)	1.00	0.50	0.5	0.75	0.3	0.60	0.6	0.90	0.90	1.20
TP Surface (PPM)	0.063	0.061	0.052	0.401	0.271	0.250	0.64	0.031	0.074	0.120
TSI S	60	70	70	64	77	67	67	62	62	57
TSI TP	61	60	58	87	81	80	93	51	63	70
TSI AVG	60	65	64	75	79	74	80	56	62	63
E. coli cfu/100ml	27.90	733.85	93.2	52	150	275.50		29.30	47.90	75.40

1.3.1.8 Smith Mountain Lake Tail Waters

Table 1.32. Smith Mountain Lake Tail Waters other parameters measured over study period (2022). Measures are at the surface.

	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
Time	3:20 PM	1:55 PM	2:30 PM	1:11 PM	12:55 PM	14:16	4:48 PM
Temp C	11.8	15.6	21.07	20.6	21.6	21.2	18.3
Conductivity (ms/cm)	0.185	0.184	0.178	0.182	0.183	0.189	0.184
DO mg/L	8.28	8.14	7.25	5.53	4.16	5.45	7.7
DO %	89.9	83.6	82.7	62.9	48.1	62.4	85
pH	7.4	7.4	7.26	7.05	6.98	7.3	7.44
ORP	428	463	417	420	431	437	450
Turbidity NTU	0.6	0.8	4.1	3	2.6	1.4	1.2
Chlorophyll a ug/L	2.1	1.3	5.3	2.3	2.9	2.2	8.4
Secchi (M)	5.50	3.50	1.7	2.1	2.40	2.40	2.75
TP Surface (PPM)	0.081	0.038	0.083	0.050	0.026	0.01	0.003
TSI S	35	42	52	49	47	47	45
TSI TP	64	54	64	58	49	38	28
TSI AVG	50	48	58	53	48	43	37
E. coli cfu/100ml	42.00	10.90	8.5	24.60	6.10	3.00	9.80

Section 2: Lake-Wide Trends

The purpose of this section is to look at the functioning of the reservoir and establish trends. These trends are important to give a trajectory of lake health and allow us to manage the lake for optimum water quality. These trends are based on collected water quality parameters over the entirety of this study, and their compilation into trophic state indices (TSI) and other predictive indicators help track the health of the lake. The use of these indices allows ease of comparison among known parameters for lake and reservoir function and facilitates the translation of raw data into a useable management tool. As with any index, confounding parameters may, at times, reduce the value of a given index necessitating alternate interpretations and hypotheses. However, within the science of limnology (the study of lakes), use of indices is widespread and offers good explanations. There are 3 main categories under TSI; eutrophic, mesotrophic, and oligotrophic. Eutrophic lakes are highly productive and concentrated in nutrients; mesotrophic lakes experience moderate productivity and have lower nutrient levels; oligotrophic lakes have little productivity and low nutrient levels. When the TSI value is greater than 51, lakes are classified as eutrophic. Eutrophic lakes can be plagued by low water clarity, loss of oxygen in the hypolimnion, high sediment turbidity and high nutrient levels. This stimulates an abundance of algae growth and even noxious forms throughout the summer months. Excessive eutrophication is to be avoided. A TSI > 61 is considered excessive. Water has more clarity in oligotrophic and mesotrophic lakes, low concentrations of algae and typically an abundance of oxygen throughout the water. This is a desired state in management of a lake.

Three additional areas of inquiry were launched based on the analysis of the data. First and very concerning is the changes observed in water quality emanating from the Pigg River. Precipitation patterns suggest we are entering a period were storm intensity and magnitude will increase. These changes coupled with existing land use appear to be forcing rapid change on the river water entering Leesville Lake. This is a concern that needs our greatest attention.

Two other trends are examined in this year’s analysis due to the need to understand the impact in the reservoir. First is the predictions of mid-summer Chlorophyll *a* peaks. This season mid-summer peaks reached over 50 ug/L and are of concern. What might be the possible mechanisms contributing to this are explored. The other issue is oxygen loss in reservoirs and how this is predictive through time. What is driving this phenomenon from August through October, often to levels that are very harmful to aquatic life?

2.1 Analysis of Trophic State[4]

In this analysis, trends of all the measurable trophic state indices (TSI) are evaluated for all of the sampling data collected during this project. The usefulness of this is many-fold. First, we can examine several parameters that are used to predict TSI or lake health (Carlson 1977). The use of multiple parameters always strengthens any scientific investigation. Second, each parameter measured provides a predictor based on differing influences within the reservoir. Secchi depth is influenced by both sediment input and phytoplankton growth, whereas total phosphorus (TP) simply reflects the concentrations of this limiting nutrient but also dynamics within the reservoir. Additionally, Chlorophyll *a* concentrations reflect use of TP for phytoplankton growth within the limitations of shading (sediment inputs) and grazing by zooplankton (*Daphnia* abundance). It is interesting and useful to note how each parameter (Secchi Depth, TP and Chlorophyll *a*) differ in predictive power. While each parameter differs, often the predictions are within similar ranges. We are also interested in trends over time. What are the trends we observe in the reservoir? How is the reservoir changing over time? These observations will guide our management decisions and conclusions as well as future work.

It is important to understand sediment input in this reservoir and how it may influence trophic state. Within reservoirs of the southeastern United States, sediment input constantly occurs. While sediment consists of many forms, clay is the predominate component in this region. Clay is problematic for many reasons. First, it stays in suspension for extended periods of time. Secondly, it binds with phosphorus helping to transfer this nutrient into reservoirs and depositing it into the sediments causing long term problems. It also competes for phosphorus and shades select species of phytoplankton. While lowering phytoplankton growth can be beneficial, clay often limits desirable forms of plankton and replacing them with undesirable species.

[4] *Photograph of Leesville Lake taken by Jade Woll*

In this analysis we use the three main stations in the reservoir for ease of comparison: Dam, MM6 and Toler Bridge. This demonstrates the spatial pattern from the headwaters to the dam. Reservoirs are typically most productive (eutrophic) in the headwaters with decreasing productivity near the dam. Mid stations in a reservoir (MM6 for Leesville Lake) reflect an area of mixing. This is the portion of the reservoir where the river flow (area higher in sediment and nutrients with greater input of water and water movement) meets the lake portions (area low in sediment and nutrients with very slow water movement). This area can be highly productive due to a multitude of factors.

Leesville Lake is unique due to headwater input from Smith Mountain Lake (a slightly eutrophic reservoir) and the Pigg River (a highly timbered and agricultural developed watershed). This unique combination has a very profound impact on water quality. This trophic state analysis (Section 2.1), precipitation and Pigg River inputs (Section 2.2), predictions of mid-summer chlorophyll peak (Section 2.3) and SML oxygen loss (Section 2.4) explore this unique relationship in the context of Leesville Lake water quality. We try to quantify these inputs and speculate on impacts. This leads to our management recommendations.

Secchi Depth TSI

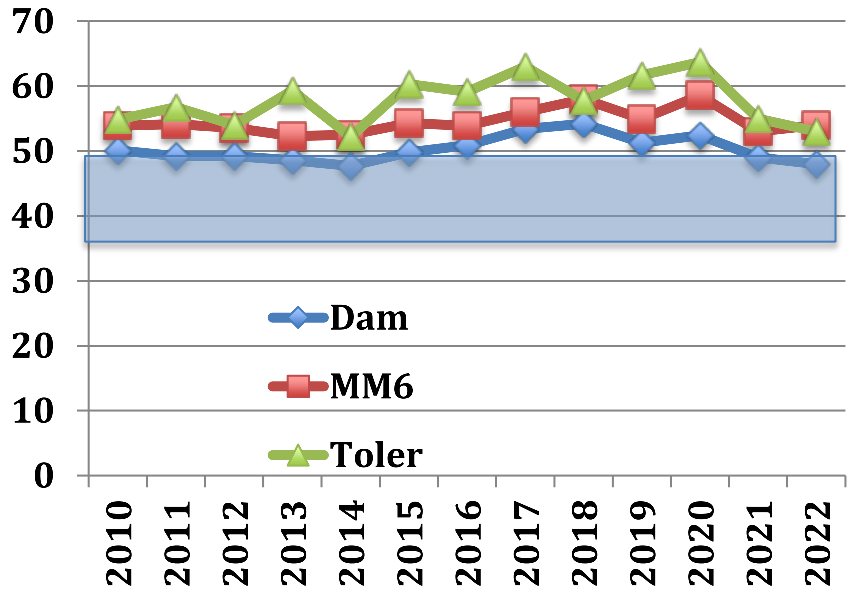


Figure 2.1. Trophic State Index (TSI) based upon Secchi disk (meters) measurements in Leesville Lake from 2010-2022. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Analysis

In 2022, predictions of trophic state using Secchi depth suggested LVL water clarity continued to improve (Figure 2.1). The reservoir continues to be eutrophic however the station at the dam continued to improve in clarity and measured as mesotrophic for the first time since 2014. This is an encouraging trend based on clarity.

Comparing this trend from the headwaters (Toler Bridge) through the Dam we see a very distinct pattern. Toler Bridge is expected to have the most eutrophic waters based on Secchi calculations with increasing clarity and improved TSI moving down lake to the dam. But this trend is variable and driven by two competing factors. Water from SML tail water release can be extremely clear even to the point of oligotrophic. Pigg River on the other hand can be very turbid to the point of hypereutrophy. Often what we see here is the predominance of tail release over Pigg River inputs. It is clear in 2022 that tailwaters were a strong influence on water quality clarity in the upper portion of the reservoir.

Total Phosphorous TSI

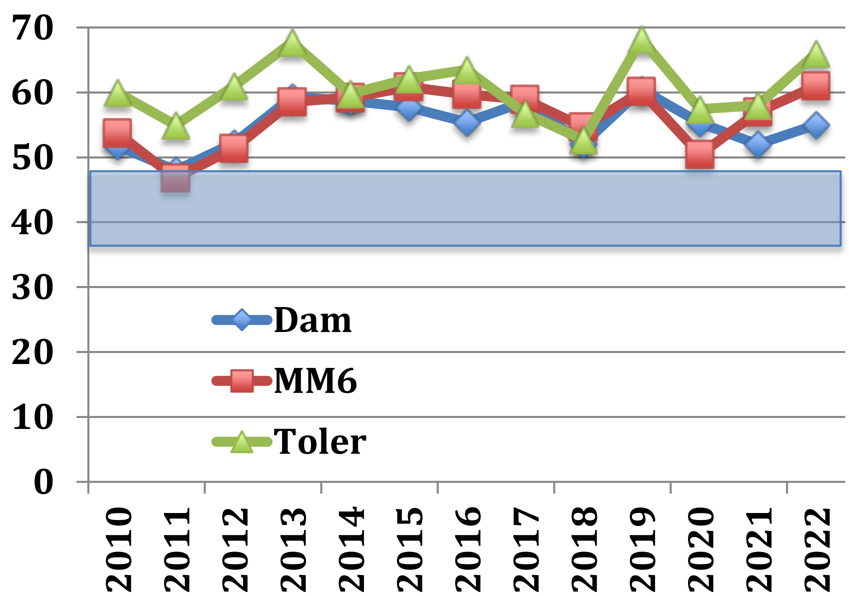


Figure 2.2. Same as Figure 2.1 but TSI based on Total Phosphorus (TP).

Analysis

Interesting that, based upon TP, the reservoir TSI trends back and forth along a eutrophic mean. This index does show greater variability and is dependent upon a more complex analysis. More importantly, this analysis suggests that the nutrients are entering into the lake possibly independent of turbidity. Further, this may be a direct result of a combination of low oxygenated water from SML release combining with Pigg

River inputs associated with turbidity. In this scenario, phosphorus would be released in the anoxic hypolimnion. **So, while water with high clarity is delivered to LVL, the key feature may be the anoxia that is exacerbated and causing a greater release of phosphorus. This is an extremely important observation with management implications.**

Chlorophyll *a* TSI

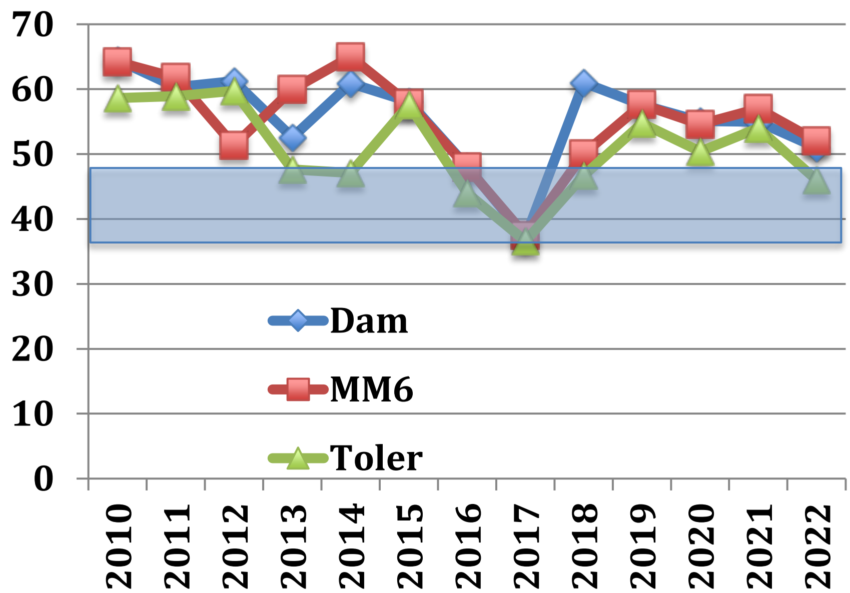


Figure 2.3. Same as Figure 2.1 but TSI is based on Chlorophyll *a*.

Analysis

Trophic state based upon Chlorophyll *a* remained stable in 2022. TSI Chlorophyll *a* (Figure 2.3) continues to suggest the lake is slightly eutrophic and regardless of the other changes in TSI, this measure remains relatively unchanged. This is a good result and suggests the lake is very resistant to change even as nutrient concentrations increase throughout the reservoir. One issue of concern with this interpretation is one of time lags. While we did not see increases in 2022, phosphorus is very pervasive, and the loss of oxygen continues throughout the reservoir suggesting conditions may worsen in the future.

TSI Average

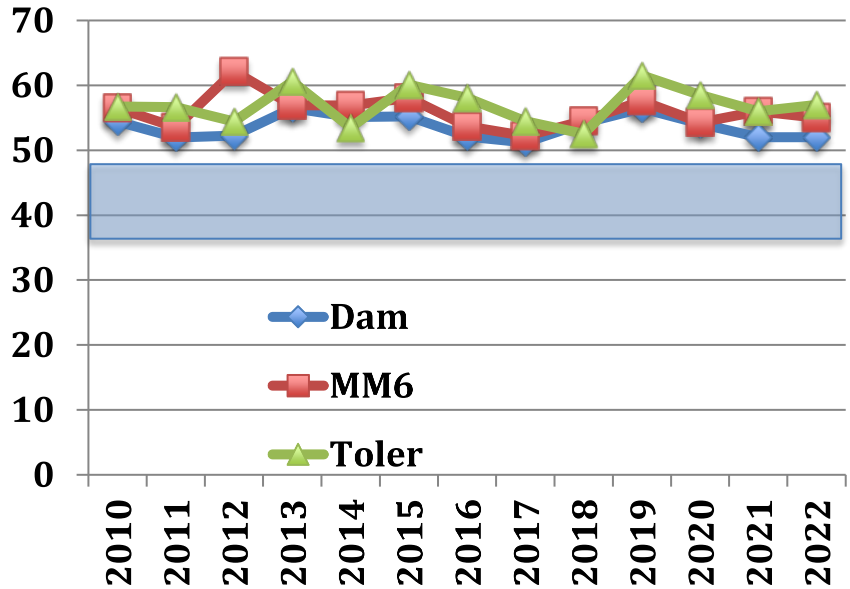


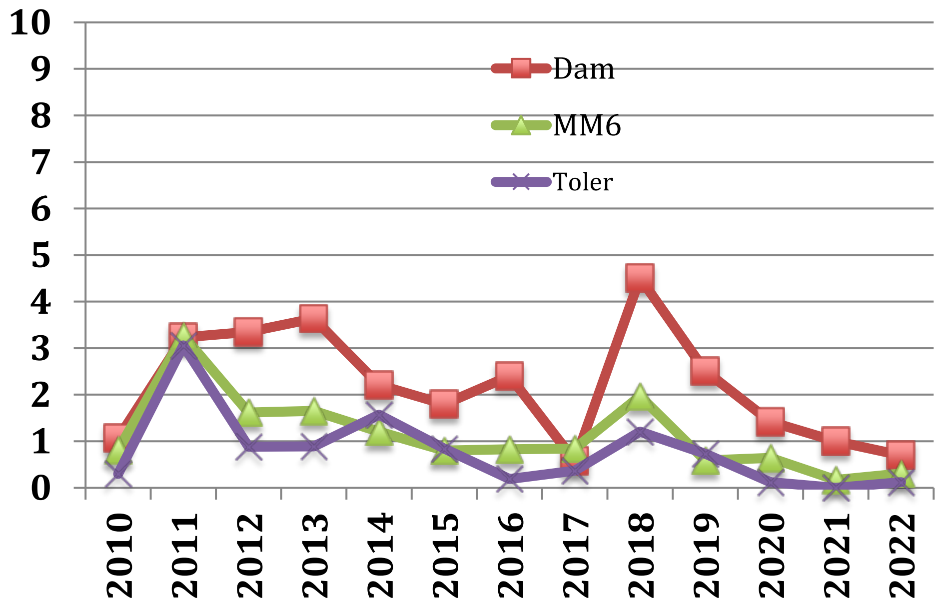
Figure 2.4. Same as Figure 2.1 but TSI presented is the average of TSI for all parameters evaluated (Secchi Depth, Total Phosphorous, Chlorophyll *a*).

Analysis

Averaging trophic state indices has value in determining if the lake is trending in a particular direction. Based upon multiple parameters the reservoir continues to be amazingly steady. The lake remains mildly eutrophic with some fluctuation but meeting desired uses. While we are observing some worsening of water quality entering the reservoir from the Pigg River, these symptoms are not expressed in the overall TSI or at the Toler Bridge station. Often, time lags are associated with changes thus it is not surprising these changes are not yet reflected in the overall TSI. It is important to note that we are not observing time lags at this point and can be confident the water quality in the reservoir is stable.

Daphnia Productivity

Figure 2.5. Average *Daphnia* concentrations in Leesville Lake from 2010-2022. Numbers on y-axis represent *Daphnia*/ liter.



Analysis

The abundance of *Daphnia* in the reservoir not only impacts the population of phytoplankton through grazing, but also impacts the influence of fisheries on water quality. Implications of this are two-fold. First, lower populations reduce the grazing pressure on phytoplankton. For 2022, we again recorded one of the lowest concentrations of *Daphnia* on record in this study. It is now becoming clear that in Leesville Lake, *Daphnia* populations respond to phytoplankton abundance *rather than* graze and control phytoplankton populations.

Theoretically, food chain construction in a reservoir suggests predatory fish regulate zooplankton by eating fish that regulate zooplankton which in turn control phytoplankton that are stimulated by nutrients such as phosphorus. We again found *Daphnia* with long spines and elongated helmet projections. The implications of this are clear. Invertebrate predation by *Leptodora* appears to be dominate in the reservoir regulating the populations of *Daphnia*. This suggests that plantivorous fish populations are low in turn enhancing the populations of both *Leptodora* and *Daphnia*. Phytoplankton are not excessive in the reservoir and do not appear to be controlled by *Daphina* grazing.

One additional analysis was undertaken again. Based on the literature (Sobolewski 2016), lakes in catchments with greater than 60% agricultural land use exhibit poorer water quality as measured by the following system than those in less agricultural dominated watersheds. Greater than 60% agricultural land use in the watershed had lakes with 0-5 on the following scale. Lakes in catchments with agricultural land use less than 60% (60-35) tended to have much better water quality (8-10).

Table 2.1.1 – measures of water quality for lake from around the world. Leesville Lake water quality is quite good based on this scale.

Pollutant Measures	Low	Medium	High	LVL 2021	LVL 2022
Secchi Depth (m)	>2.10	1.15-2.10	<1.15	2.15 = 2 pts.	2.33 = 2 pts.
Conductivity (uS/cm)	<289	289-402	>402	135 = 2 pts	168 = 2pts.
Total Nitrogen (mg/m3)	<1.04	1.04-1.67	>1.67	Not Measured	0.12 = 2 pts.
Total Phosphorus (mg/m3)	<0.043	0.043-0.08	>0.08	0.04 = 2 pts	0.06 = 1 pt.
Chl a (ug/L)	<12.5	12.5-31.5	>31.5	13.9 = 1 pt	8.23 = 2 pts
Points	2	1	0	7/8 points	9/10 points

The combination of lower than 60% agriculture in the watershed and influence of SML tailwater release keep Leesville Lake in the good zone of water quality (Table 2.1). Leeville Lake scored 9 points in the table as we were able to include nitrogen which puts it into the excellent range. These are averages and suggest the water quality is excellent yet at times when the lake is dominated by either Pigg River input or SML tailwater release these values can be skewed toward lower levels of quality. This situation must be continually monitored to determine if conditions are progressing toward these conditions.

2.2 Statistical Analysis

We conducted a Partial Least Squares Analysis to determine how water quality at main stem stations throughout LVL respond both on a spatial scale (from Dam up through Pigg River and SML Tail Water Release) and seasonally (April – October). Data was gathered from April 2015 through October 2022 then analyzed for each month. Hence, each analysis for each month represents data collected during that month from 2015-2022 for each station.

For this analysis, four parameters were selected. These parameters are the most responsive in the lake to pollution and change in water quality. We used surface measures of Dissolved Oxygen % and Turbidity and Total Phosphorus. The additional parameter was Secchi Depth. Tests were run comparing all parameters against the observations at LVL dam. Hence, we are asking the question – what stations using the four selected parameters – are most similar to LVL dam at each of the monitored months. The data is displayed as correlation showing how the lake is structured. Therefore, a stronger correlation (closer to 1) suggests the water quality is more closely associated with a station.

Table 2.2.1 – Correlation matrix for parameters related to water quality at LVL Dam. Data represents correlation between the LVL Dam and associated stations at each month. Each correlation represents 160 observations over the period of time from 2015-2022.

Month	Tailwater	Pigg	Toler	MM6
April	0.895	0.934	0.978	0.991
May	0.929	0.856	0.856	0.966
June	0.860	0.734	0.821	0.930
July	0.879	0.940	0.934	0.993
August	0.824	0.855	0.878	0.995
Sept.	0.856	0.464	0.723	0.987
Oct.	0.975	0.279	0.649	0.953

Table 2.2.2 - Correlation matrix for parameters related to water quality at SML Tail Water. Data represents correlation between the Tail Water and associated stations at each month. Each correlation represents 160 observations over the period of time from 2015-2022.

Month	Pigg	Toler	MM6	LVL Dam
April	0.876	0.905	0.901	0.895
May	0.931	0.908	0.960	0.929
June	0.932	0.986	0.938	0.860
July	0.961	0.975	0.913	0.879
August	0.923	0.969	0.849	0.824
Sept.	0.608	0.864	0.861	0.856

Oct.	0.428	0.768	0.957	0.975

This analysis is very insightful on the operation of the SML dam and water quality in LVL. As presented in Table 1, water quality at LVL dam is most closely aligned with MM6. This is expected as the stations are most closely aligned in space in the reservoir. More interesting is the close alignment with SML tail release. This suggests the strong regulating impact this release has on LVL and the close functional alliance each dam operates under. Hence, both SML and LVL dams appear very close in water quality. The other observation is the strong deviation away from Pigg River and Toler Bridge station in September and October. This requires a series of interpretations to understand.

If the deviation from Pigg River was due to reservoir or lacustrine processes this would strongly occur during the summer months (June-August). This is when the reservoir is strongly stratified and reservoir processes exert the greatest influence on water quality. Correlations are still quite strong between all stations through August. It is in September and October as to when the strong deviations occur. Water quality at LVL dam is very different than Pigg River and at Toler Bridge. All of these correlations strongly suggest SML Tailwaters and hence SML water quality strongly drive overall water quality in LVL. It is in September and October when we see the very low dissolved oxygen and poor water quality in the upper portions of the LVL and the strong difference with LVL dam.

Analyzing further, SML tailwater correlations weaken with Pigg River and Toler late in the season (Table 2) similar to LVL dam (Table 1). This strengthens the argument that SML operations are in strong control of LVL water quality. There are several concerning aspects to this conclusion. First, the very low dissolved oxygen concentrations from SML tailwater late in the season degrades the upper portion of LVL. This problem is not being controlled and may be getting worse as hydrology changes throughout the area. Secondly, the low dissolved oxygen concentrations late in the season appear to increase the availability of total phosphorus. This is very concerning as this will stimulate phytoplankton (measured as chlorophyll *a*) and worsen the overall water quality in LVL. To date, LVL has been very resilient to such changes but we are observing rising Trophic State Index (TSI) due to increasing total phosphorus concentrations. This will need further analysis and monitoring.

Section 3: Conclusions and Management Implications

Water quality indicators continue to suggest Leesville Lake is mildly eutrophic and continues to be stable around this condition. It is important to state that while some water quality indicators are worsening Leesville Lake appears very resistant to those inputs and has remained in good condition (Figure 2.4). Leesville Lake is maintaining a constant TSI index between 50-60. All indicators in 2022 suggest this condition of the reservoir should continue into the foreseeable future. While it is always the aim to improve the condition of the resource being monitored, this result is encouraging and perhaps an improvement in light of the problems surrounding the lake throughout the watershed.

Current trends continue to raise concern over inputs into LVL at the headwaters. In this report's statistical analysis, good evidence is presented suggesting LVL is strongly controlled by SML tail water release and hence operations at SML dam. It is also concluded that tail water release, low dissolved oxygen and nutrient inputs from Pigg River are the greatest threats. Continued work on Pigg River will help us understand the depth of this problem and how to exhibit some managerial control. Closer monitoring of Smith Mountain Lake hypolimnetic oxygen loss is warranted and close work with AEP is the best option to get this problem under control.

Overall, we make the following conclusions from our study of the reservoir:

1. Leesville Lake remains slightly eutrophic lake. It has maintained this status throughout the monitoring period of study (2010-2022) and this result is currently stable and not expected to worsen or improve in the foreseeable future.
2. The individual TSI parameters exhibit greater variability providing insight into reservoir operation and external input driving water quality.
3. TSI Secchi suggest increasing clarity as a trend in LVL. This is believed to be the result of increased influence from SML tail water release. TSI phosphorus and TSI Chlorophyll tend to show an upward trend and this is a concern.
4. Leesville Lake behaves as a pump storage reservoir with headwaters impacted by tail release from the upper reservoir and this impact is seen throughout the reservoir. Pumping operations have a very strong impact on LVL water quality.
5. The influence of SML tail water throughout the reservoir is generally a positive result as hypolimnion in SML contains water that is very clear and approaching oligotrophic conditions. However, oxygen depletion is very problematic late in the season (Sept-Oct.) and seems to be worsening. Low dissolved oxygen (<5 mg/L) persists in tail water release at the end of the season. These low oxygen conditions can be detected down through the reservoir past the station at Toler Bridge.
6. This oxygen loss when coupled with the high nutrient input from the Pigg River is cause greater eutrophication in LVL due to phosphorus release. This trend is worsening although not being expressed as Chlorophyll *a* biomass yet. Time lags are a concern.
7. In the forebay of SML, water below a depth of 5 contains less than 5 mg/L dissolved oxygen and reaches 0 mg/L between 30-40 meters of depth. Total average phosphorus in the reservoir exceeded 40 ppb for the first time in last 10 years and Secchi depth remained below 2 meters for third year in a row. While some areas in the dam area of the lake are oligotrophic water near the dam is mesotrophic.

Management recommendations:

5. It is now better understood that SML tail release controls water quality in LVL. The two greatest threats to water quality in LVL are the high nutrient inputs from Pigg River and low oxygen levels of SML release late in the season. These two phenomena work together to compound the problem.
6. Monitoring of the Pigg River by the Leesville Lake Association's Water Quality Committee must continue (see separate report of these findings). This is the only current study in this watershed and water quality of the Pigg River is critical to the health of LVL. This river must be studied and monitored to help make beneficial management decisions for Leesville Lake. Every effort needs to be extended to understand nutrient pollution and control it.
7. Land use and deleterious inputs in all watersheds (Pigg River, Blackwater and Roanoke) need to be addressed. While Pigg River Watershed is of the greatest concern of influence in Leesville Lake Water Quality our studies suggest that deteriorating water quality from SML may be of greater concern due to low oxygen tail release during the later part of summer.
8. It is clear from our water monitoring of Leesville Lake and data collected at the tail release that water does not meet permit standards late in the season. The following must be noted and addressed by AEP:

    c. License requirements associated with the Smith Mountain Hydroelectric Project (Project) require the licensee, Appalachian Power Company (Appalachian), to implement a Water Quality Monitoring Plan (Plan) as part of license Article 405. The order approving the Plan was issued on April 15, 2011.
    d. Develop and file, in accordance with the requirements of Article 401(a) for Condition F.4 found in Part I of the Virginia Department of Environmental Quality's (Virginia DEQ) water quality certification (WQC), a feasibility study and plan for physical or mechanical alterations of water release procedures, developed in consultation with the Water Quality Technical Review Committee (WQTRC1), to address violations of water quality standards for DO caused by turbine discharge from Smith Mountain Lake, should the operating practices employed prove insufficient at improving DO levels in Smith Mountain's turbine discharge.

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Appendix A

Background of Water Quality Program

For many years, the Virginia Department of Environmental Quality (DEQ) monitored Leesville Lake water quality either annually or biannually. Beginning in 2006, DEQ placed Leesville Lake on a six-year rotation for water monitoring. However, DEQ collected water quality data in 2009 and 2010.

In an effort to supplement DEQ water quality monitoring, the Leesville Lake Association (LLA) began a Citizen Water Quality Monitoring Program in April 2007. Citizen volunteers monitored bacteria, Secchi depth, temperature, dissolved oxygen (DO), pH, and conductivity. LLA outlined four goals for the program: (a) gain a greater understanding of the lake's water quality, (b) supplement the DEQ water quality monitoring, (c) increase the community's awareness of the importance of water quality, and (d) inform residents about harmful factors that damage water quality and age the lake (Lobue, 2010).

The Virginia DEQ provided LLA with a water quality monitoring probe to measure DO, temperature, and pH. With the DEQ Citizen Water Quality Monitoring Grant, LLA purchased Coliscan Easygel test kits for *E. coli* testing along with Secchi discs and other necessary equipment (Lobue, 2010). Over the next three years, LLA published annual reports of the water quality test results. As part of the water quality monitoring plan required by its new license, Appalachian Power Company committed $25,000 for a water quality monitoring program.

Under the Federal Power Act (FPA) and the U.S. Department of Energy Organization Act, the Federal Energy Regulatory Commission has the power to approve licenses for up to 50 years for the management of non-federal hydroelectric projects (FERC, 2009, p. ii). The Commission issued the first license for the Smith Mountain Pumped Storage Project to Appalachian Power on April 1, 1960 with a set expiration date of March 31, 2010 (FERC, 2009).

As part of its relicensing process, Appalachian Power was required by the Federal Energy Regulatory Commission to implement a Shoreline Management Plan (SMP). In July 2005, FERC approved a SMP proposed by Appalachian for the Smith Mountain Project. The purpose of this plan is *"to ensure the protection and enhancement of the project's recreational, environmental, cultural, and scenic resources and the project's primary function, the production of electricity."* (FERC, 2009, p. 22). The SMP works to preserve green space, wetlands, and wildlife habitats along the shoreline. Property owners may not remove vegetation within the project boundary unless they have received permission from Appalachian Power. The project boundary for Leesville Lake lies at the 620-foot contour elevation (LLA, 2009).

To renew their license, Appalachian Power Company (Appalachian Power), a unit of American Electric Power (AEP), submitted an application for a new license in March

2008. In August 2009, the Federal Energy Regulatory Commission issued a Final Environmental Impact Statement for the Smith Mountain Project relicensing. While reissuing, the Commission reviewed AEP's methods and proposals for "the protection, mitigation of damage to, and enhancement of fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality." (FERC, 2009, p. 1). In the final Environmental Impact Statement (EIS), FERC endorsed Appalachian Power's proposed $25,000 annually to the LLA to support the on-going water quality monitoring program (FERC, 2009, p. 25). The Commission approved the new license, effective April 1, 2010.

FERC recommended a few modifications to Appalachian Power's *Water Quality Monitoring Plan* including a proposal to develop a lake water quality monitoring plan. FERC determined that the primary water quality issues for Smith Mountain and Leesville lakes arise from nutrients and bacteria. Rather than coming from the dams' operations, the nutrients and bacteria come from shoreline development and overall watershed development. In conclusion, FERC recommended the (a) continuation of water-quality monitoring for Smith Mountain Lake, (b) establishment of a water quality monitoring program for Leesville Lake, and (c) ensuring the future health of the lakes by monitoring lake quality to verify that any changes in operational strategy at the Smith Mountain project do not harm water quality.

In summary, a timeline of significant events is outlined below:

- April 1960: First license for Smith Mountain Project issued
- April 2007: Development of Leesville Lake Citizen Water Quality Monitoring Plan
- 2007-2009: LLA annually reports on water quality
- 2008: AEP proposed $25,000 in 2010 to LLA for water quality monitoring plan
- August 2009: FERC issues a final EIS for Smith Mountain Project relicensing, recommending a water quality plan for Leesville Lake
- April 2010: AP's new license for Smith Mountain Project becomes effective
- June 2010: Lynchburg College begins water quality testing of Leesville Lake
- February 2011: Lynchburg College reports on 2010 water quality
- February 2012: Lynchburg College reports on 2011 water quality
- February 2013: Lynchburg College reports on 2012 water quality
- February 2014: Lynchburg College reports on 2013 water quality
- February 2015: Lynchburg College reports on 2014 water quality

Participants:

In August 2003, a group of Leesville Lake residents formed a non-profit 501(c)(3) corporation called the Leesville Lake Association. The association addresses the issues of debris, shoreline management, environmental and biological health, safety, future development, and fishing for Leesville Lake (LLA, 2003).

In 2007, the Department of Environmental Quality revised the Millennium 2000 Water Quality Monitoring Strategy. The Virginia DEQ maintains the "Water Quality Monitoring and Assessment (WQMA) Program" with the ultimate goal to *"provide representative data that will permit the evaluation, restoration and protection of the quality of the Commonwealth's waters at a level consistent with such multiple uses as prescribed by Federal and State laws (VDEQ, 2007)."*

LLA partnered with University of Lynchburg to establish the Water Quality Monitoring Plan. University of Lynchburg agreed to conduct the samplings and testing, and report results. LLA water monitoring volunteers for 2020 were: Tony Capuco, David Waterman and Kathleen Giangi.

For a description of Leesville Lake and communities, refer to Section 2 of Lynchburg College's report titled *Leesville Lake 2010 Water Quality Monitoring* dated February 28, 2011.

Statement of Goals and Objectives
(Also stated in the 2010 and 2011 Leesville Lake Water Quality Monitoring Reports):

Goals and Objectives of the Leesville Lake Water Quality Monitoring Plan:
The Federal Energy Regulatory Commission recommended that a water quality plan for Leesville Lake be developed. In a collaborative approach, Leesville Lake Association and Lynchburg College developed a plan in February 2010 to continue and expand the testing and monitoring of water quality, to monitor nutrients and trophic status, and to supplement data collected by the Virginia Department of Environmental Quality in order to better understand the current state of Leesville Lake.

Leesville Lake Association
The objectives of the Leesville Lake Association, according to its Articles of Incorporation, are as follows (http://www.leesvillelake.org):

- Plan projects and studies that:
  a. Monitor and protect the water quality of Leesville Lake
  b. Contribute to the clean-up and preservation of the lake's shorelines
  c. Promote safe recreational use
  d. Improve the condition of the surrounding land as a high-quality recreational and residential area
  e. Maintain favorable water levels in Leesville Lake for the Smith Mountain Pumped Storage Hydro Project

- Educate to individuals, organizations, and the general public information concerning:
  a. Water quality monitoring results
  b. Management techniques and practices to preserve the environmental quality of Leesville Lake and its watersheds
  c. Safe recreational activities

d. Commercial and government activities that could harm geographic area of Leesville Lake
e. How to maintain optimum water levels in Leesville Lake

Appendix B

Water Parameter Testing Details

Oxygen

Dissolved oxygen (DO) in Leesville Lake shows a lot about the lake's metabolism. At a certain depth, the concentration of oxygen represents the temporary equilibrium between oxygen-producing processes (such as photosynthesis and aeration) and oxygen-consuming processes (such as decomposition and respiration). The amount of dissolved oxygen that lake water can retain is dependent upon the water's temperature. As temperature increases, the solubility of DO decreases. Because the solubility of gas increases in a liquid as barometric pressure increases, the amount of DO is greater at deeper parts of the lake. Lake eutrophication increases the consumption of dissolved oxygen at the bottom layer of the lake (the hypolimnion), and lowers DO concentrations (Kaulff, 2002, p. 226-236). Dissolved oxygen levels are measured in milligrams per liter (mg/L) or "percent saturation." Percent saturation of dissolved oxygen (DO%) is calculated by taking the amount of oxygen in a liter of water over the total amount of oxygen that the liter can hold.

Large amounts of decaying vegetation lower DO levels in certain areas. In addition to decreasing DO levels, the decomposing material also lowers pH by producing acids. Highly colored acids such as tannic acids, humic acids, and fulvic acids build up and color the water.

DO and percent saturation of dissolved oxygen (DO%) were measured in the field using a Hydrolab probe. Prior to sampling at Leesville Lake, the Hydrolab probe was calibrated at University of Lynchburg.

DO and DO%, along with other Hydrolab parameters, were measured near the dam, at Mile Mark 6, downstream of Toler Bridge, and near the confluence of Pigg River and the lake. Measurements were taken in milligrams per liter. Starting at the surface, readings were typically taken every half meter for 3 meters. At 3 meters and deeper, readings were taken every meter.

Temperature

Measuring temperatures at various depths indicates if the lake is stratified. Freshwater lakes typically are stratified into three zones—the hypolimnion, the epilimnion, and the metalimnion (typically called the thermocline). The hypolimnion, the deep water zone, has little turbulence and contact with the atmosphere. Its respiratory processes use organic matter from the surface layer for fuel. The uppermost layer is the epilimnion, which is turbulent and provides the energy needs of the biota's animals and microbes. In the metalimnion layer, between the hypolimnion and epilimnion, is the temperature gradient called the thermocline. The temperature difference and resulting density difference of the thermocline disrupts nutrient and gas circulation, resulting in lake stratification (Kaulff, 2002, p. 154).

Temperature was measured at the same test sites as the other Hydrolab parameters by University of Lynchburg. The Hydrolab probe measured the temperature of the lake at specific depths in degrees Celsius. Before taking readings out in the field, the temperature probe was calibrated.

pH

pH indicates the alkalinity or acidity of water. For freshwater lakes, this parameter typically lies between 6 and 8. Measuring the pH shows the softness or hardness of water and the biological activities of the water zones. At pH values below 6 and above 8, species diversity and abundance decreases, although the few remaining species can be in high abundance.

A lake’s pH can change throughout the day due to photosynthesis. When phytoplankton and other aquatic plants use sunlight to synthesize energy, they remove carbon dioxide from the water and raise pH. Thus, the highest pH levels are typically found in the late afternoon while the lowest levels are found before sunrise.

pH levels can also depend on the amount of decaying vegetation. In a lake’s deeper waters, decomposing plants lower pH through the production of tannic acids, humic acids and fulvic acids. These acids are colored and are characteristic of marshes and heavily-vegetated areas.

pH readings were taken by using a Quanta Hydrolab in the field at the same test sites as the other hydrolab parameters. The process for calibrating the pH probe prior to field sampling is described in the Quality Control and Quality Assurance section.

Conductivity

Conductivity shows the capacity for water to carry electrical currents. Dissolved inorganic solids that carry positive and negative charges influence conductivity. Examples of anions (negatively charged ions) include chloride, nitrate, sulfate, and phosphate; examples of cations (positively charged ions) include sodium, magnesium, calcium, iron, and aluminum. Oil, phenol, alcohol, and sugar are organic solids that remain neutral in water, and thus do not affect conductivity.

Temperature and geology are other factors that influence conductivity. As temperature increases, so does conductivity. The bedrock of the land over which water flows can affect conductivity. In areas with clay soils, conductivity is higher because the dissolved soil ionizes. Areas composed of granite bedrock do not dissolve into ionic materials, and therefore do not affect conductivity as much as areas with clay. The discharge that flows into streams has the ability to raise or lower conductivity. Sewage overflow, which contains chloride, phosphate, and nitrate ions, increases conductivity, while oil leakages lower conductivity. The measurement for conductivity is micromhos per centimeter (μmhos/cm) or microsiemens per centimeter (μs/cm) (http://water.epa.gov/type/rsl/monitoring/).

Once established, a body of water's range of conductivity does not typically fluctuate. Noticeable differences in readings can mean that a source of discharge or pollution has entered the water.

University of Lynchburg measured conductivity with Quanta Hydrolab Monitoring Probe at the same test locations as the other Hydrolab parameters. Before sampling, the Hydrolab was calibrated. In the field, readings were taken by applying a voltage between two of the probe's electrodes in the water. The resistance of water creates a drop in voltage that the probe then uses to calculate the conductivity.

Turbidity

Turbidity focuses on levels of sediment pollution in water. Turbidity levels affect the passage of light: soil particles, algae, plankton, and microbes can block light and alter the water color. In addition to reducing light penetration, suspended particles also increase water temperatures due to their absorption of heat.

High turbidity levels also affect aquatic life by reducing photosynthesis, decreasing DO, clogging fish gills, and decreasing fish resistance to disease and growth rates. Once materials settle on the bottom of the lake or river, fish eggs and benthic macro invertebrates can be coated in sediment. According to the Environmental Protection Agency (EPA), high turbidity levels can result from soil erosion, waste discharge, urban runoff, eroding stream banks, large numbers of bottom feeders, and excessive algal growth (http://water.epa.gov/type/rsl/monitoring/). It is important to note that turbidity is a measurement often used in coordination with Secchi depth and total dissolved solid (TDS). Secchi depth, which measures a lake's transparency and clarity, is another good indicator of sediment levels. TDS measures sediment in water through filtration.

A turbidity meter was used for this parameter. Consisting of a light and a photoelectric cell, the meter measured the amount of light that was deflected at a 90-degree angle by the particles in the water sample. The units used for turbidity were nephelometric turbidity units, or NTUs.

The Hydrolab probe's transparency tube measured turbidity at the same stops as the other six Hydrolab parameters. Prior to measuring the lake's turbidity, the transparency tube in the probe was calibrated.

Oxidation-Reduction Potential

The oxidation-reduction potential (ORP), also called redox potential, of a lake defines the overall balance between oxidizing and reducing processes (Kaulff, 2002, p. 239). ORP measures the potential electrical energy of a liquid by measuring the specific electrical charges of either oxidizing or reducing agents. In water with a high pH value, there are more reducing agents (a negative ORP value), whereas in water with a low pH value, there are more oxidizing agents resulting in a positive ORP value (http://www.livingspringwaterionizer.com/water-essentials/water-ph-and-orp). Redox reactions are critical for aquatic systems: they lead to organic-matter oxidation, the recycling of nutrients, and the flow of energy from microbes to more complex organisms (Kaulff, 2002, p.246). University of Lynchburg and LLA called for the measurement of ORP in the final proposal to further understand chemical activity and developing eutrophication.

ORP is measured in millivolts (mV) by a sensor on the Hydrolab. Within the ORP sensor is a piece of platinum that built up charge without initiating any chemical reactions. This charge was then measured in comparison to the charge in the water. ORP was measured by the Hydrolab probe at three test sites by University of Lynchburg. For the lab calibration prior to field sampling, the same steps as the pH calibration were followed.

Total Phosphorus

Total phosphorus (TP) was measured to show nutrient levels in the water. TP levels were compared over time to determine if the lake had current or potential algae problems.
Phosphorus is a critical nutrient, often in short supply, for aquatic animals and plants. According to the U.S. Environmental Protection Agency, an increase in phosphorus may accelerate plant growth and algae blooms, lower dissolved oxygen, and contribute to the death of fish, invertebrates, and other aquatic animals. Phosphorus can originate from both natural and human sources such as soil and rocks, sewage, fertilizer, agricultural practices, animal manure, residential and commercial cleaning practices, and water treatment. In bodies of water, phosphorus is either organic or inorganic. Plant or animal tissue contains organic phosphate while inorganic phosphate is required by plants and used by animals (http://water.epa.gov/type/rsl/monitoring/).

Total phosphorus levels measure all forms of phosphorus, which are total orthophosphorus, total hydrolyzable phosphorus, and total organic phosphorus. Ortho phosphorus describes the plain phosphorus molecule, hydrolyzable refers to phosphorus that has undergone hydrolysis, and organic phosphorus is the phosphorus in animal or plant tissue (http://www.uga.edu/sisbl/epa-po4.html).

University of Lynchburg conducted total phosphorus testing at each test site. Leesville Lake samples were collected in labeled polyethylene bottles that had been cleaned and rinsed with tap water, soap, DI water, 10% HCl, and DI water. Samples were refrigerated until testing. At several test sites, water samples were taken at the surface and at a deeper depth.

The method for determining total phosphorus first involved digesting the sample to change all of the phosphate to orthophosphorus. Samples were then reacted with ascorbic acid to determine concentrations of both dissolved and un-dissolved ortho phosphorus. University of Lynchburg used a Systea EasyChem analyzer to test for TP in the samples. Samples were tested within 28 days of collection. Below is the Systea EasyChem method used for detecting total phosphorus.

Systea EasyChem Method
Summary:
Under this method for the determination of total phosphorus, the aqueous sample was mixed with sulfuric acid, ammonium molybdate and antimony potassium tartrate to form antimony-1, 2-phosphorous molybdenum acid. The resulting complex was then reduced by ascorbic acid to get a blue heteropoly acid (molybdenum blue). To determine the concentration of ortho-phosphate, the absorbance of the formed blue complex, was measured at 880nm.

Since only orthophosphorus formed a blue color in this test, polyphosphates (and some organic
phosphorus compounds) were converted to the ortho phosphorus form by manual sulfuric acid hydrolysis. Organic phosphorus compounds were converted to the orthophosphorus form by manual persulfate digestion. The developed color was then measured
automatically.

List of Chemicals:
- Ammonium Molybdate, $(NH_4)_6Mo_7O_{24}\bullet 4H_2O$
- Ammonium Persulfate, $(NH_4)_2S_2O_8$
- Antimony Potassium Tartrate, $K(SbO)C_4H_4O_6\bullet 3H_2O$
- Ascorbic Acid, $C_6H_8O_6$
- Isopropyl Alcohol, $(CH_3)_2CHOH$
- Phenolphthalein, $C_{20}H_{14}O_4$
- Potassium Dihydrogen Phosphate, KH_2PO_4
- Sulfuric Acid conc., H_2SO_4

Preparation of Reagents and Standards:
Stock Standards:
- 4.0g of ammonium molybdate were dissolved in 75mL DI water, and then the solution was diluted to 100mL with DI. The solution was transferred to a light-resistant polyethylene container and was stable for one month.
- 14.0mL of concentrated sulfuric acid were mixed with 70mL of DI water. The solution was diluted to 100mL with DI water and transferred to a glass container.
- 0.3g of antimony potassium tartrate were dissolved in 75mL DI water, diluted to 100mL with DI water, and transferred to a light-resistant container at 4ºC. The solution was stable for approximately 4 weeks.

Reagents:
- For a range up to 20mg/L, a working reagent made up of 50mL sulfuric acid stock, 5mL antimony stock, 15mL molybdate stock, and 50mL of DI water was made and transferred to an EasyChem reagent bottle.

- For the second reagent, 0.9g of ascorbic acid was dissolved in 40mL of DI water. The solution was then diluted to 100mL with DI water and transferred to an EasyChem reagent bottle.

Standards used in the digestion process:

- 15.5mL of sulfuric acid were added to 30mL of DI water. The solution was cooled, diluted to 50mL with DI water, and transferred to a glass container.
- 2.0mL of 11N sulfuric acid solution were added to 50mL of DI water and diluted to 100mL.
- 0.5g phenolphthalein were dissolved in 50mL isopropyl alcohol and 50mL DI water.

Standards:

- A phosphate stock standard of 1000mg/L was prepared by dissolving 4.395g of potassium dihydrogen phosphate in 1000mL of DI water in a 1000mL volumetric flask.
- The 100ppm and 10ppm phosphate stock standard were prepared by subsequently diluting the 1000ppm.

Dissolved Phosphorus

Dissolved phosphorus is the amount of total phosphorus that is in soluble form. This parameter indicates the amount of phosphorus immediately available for aquatic life and, just like one for total phosphate, shows potential algae growth problems.

Dissolved phosphate plays an important role in the aquatic environment. Inorganic dissolved phosphorus is consumed by plants and changed to organic phosphate as it's incorporated into the plant tissue. The organic phosphate then moves to animal tissues when aquatic animals eat the plants. Dissolved phosphate thus ends up in a continual cycle of inorganic phosphorus, organic phosphorus in plant tissue, organic phosphorus in animal tissue, and back to inorganic phosphorus once the animals die and bacteria converts the phosphorus (http://www.uga.edu/sisbl/epa-po4.html). Too much dissolved phosphorus can cause the same problems as increases in total phosphorus.

Dissolved phosphorus testing was completed for all test sites by University of Lynchburg. Leesville Lake samples were collected in labeled polyethylene bottles that had been cleaned and rinsed with tap water, soap, DI water, 10% HCl, and DI water. Samples were refrigerated until testing. At several test locations, water samples were taken at the surface and at a deeper depth.

The method for determining dissolved phosphate first involved filtering the samples to remove any suspended particles. Samples were then tested for phosphorus using the same method as total phosphorus. University of Lynchburg used a Systea EasyChem analyzer to test for dissolved phosphorus in the samples.

Nitrogen

In addition to phosphorus, nitrogen is also an important element that determines a lake's biota. Inputs of nitrogen include drainage basins and the atmosphere. The largest source of nitrogen comes from atmospheric deposits, which have doubled globally due to fossil fuel emission and other human activities (Kaulff, 2002, p. 270-271).

Excess nitrogen has detrimental effects on lake health. High nutrient levels accelerate eutrophication through algal growth. As the plants grow and decompose, the levels of dissolved oxygen (DO) in water decrease. Reduced DO levels can result in the die-off of fish, foul odors, and reduced recreational and atheistic value.

To determine nitrogen levels, University of Lynchburg tested water samples for nitrate (NO_3). Samples were collected in acid-washed, labeled polyethylene bottles, placed in a cooler with ice, and then transferred to a refrigerator upon the return to University of Lynchburg. Within 48 hours of collection, the samples were tested for NO_3 using the Systea EasyChem analyzer according to the following method.

Summary of Method:
In this method used to determine nitrate levels, nitrate was reduced to nitrite using Systea's Chemical RI. The resulting stream was treated with sulfanilamide and N-1-naptylethylenediamine dihydrochloride under acidic conditions to form a soluble dye, which was measured colormetrically at 546nm. The product was the sum of the original nitrite ion present plus the nitrite formed from nitrate. Systea has shown that, regardless of the sample matrix used, recovery of NO3 to NO2 is consistently between 95% and 105% recovery.
To determine the nitrate levels, the nitrite alone was subtracted from the total.

List of Chemicals:
Systea (1-Reagent) Nitrate Solution contained:

- Hydrochloric acid, (HCl)
- N-1-naptylethylenediamine dihydrochloride, (NEDD) $C_{12}H_{14}N_2 \bullet 2HCl$
- Sulfanilamide, $C_6H_8N_2O_2S$

Stock Standard contained:

- Potassium Nitrate, KNO_3

Preparation of Reagents and Standards:

Reagents:

- The Systea (1-Reagent) Nitrate Solution was transferred to an EasyChem reagent bottle and placed in the instrument.

Standards:

- A nitrate stock standard of 1000 mg/L was prepared by dissolving 7.218 grams of potassium nitrate in 1000 mL of DI water in a 1000mL volumetric flask.

- The 100 ppm and 10 ppm nitrate stock standard were prepared by subsequently diluting the 1000 ppm.

Summary of Run:

1. Standards and reagents were prepared by the above steps and then placed in the EasyChem instrument.
2. A standard curve for a range of 0.05-10mg/L (check) was created by the following steps:

- A 10ppm nitrate standard was placed in the instrument.
- The instrument made 5, 1, 0.5, 0.10, and 0.05ppm standards through dilutions.
- The instrument read the optical density of the calibrants. O.D. readings of a 0ppm standard and of two blanks (composed of DI water) were taken.
- A standard curve was set. The linear correlation coefficient (r^2) was always greater than 0.995.

3. The optical density of the samples was measured. By comparing the O.D. values to the standard curve set in Step 1, the concentration of nitrate in the lake samples was determined.
4. For every 10 samples, a check standard, spike, and a duplicate were included. Thus, for 40 cups of samples, there were 4 check standards of a known 10ppm nitrate solution, 4 spikes from different samples, and 4 different duplicates of lake samples. The check standards, serving as the Quality Control Samples (QCS), fell within 10% of the QCS true value.
5. The analysis ended with a blank to check the validity of the instrument's readings.

Fluorescence

Using a surface sample, University of Lynchburg measured fluorescence. Florescence measurements correlate with the concentration of Chlorophyll in water. University of Lynchburg field and lab verified and calibrated the barometer. A fluorescence probe connected to a monitoring screen was lowered into the water at half meter and whole meter intervals by University of Lynchburg.

Integrated Chlorophyll *a*

Water samples were measured for integrated Chlorophyll *a* to show the amount of productivity throughout the photic zone. Chlorophyll, a green pigment that synthesizes organic elements from sunlight in plants, is required for algal growth. Chlorophyll *a* is the most common type of pigment found in algae. High levels of Chlorophyll *a* demonstrate high algal levels (http://www.chesapeakebay.net/Chlorophylla.aspx?menuitem=14655).

University of Lynchburg took water samples at four test sites for Chlorophyll *a* testing. Water samples were collected in labeled polyethylene bottles that had been cleaned and rinsed with tap water, soap, DI water, 10% HCl, and DI water. Samples were placed in a cooler half-filled with ice at the site of the collection, and then stored in a refrigerator back at University of Lynchburg.

To determine Chlorophyll *a* levels, University of Lynchburg used the Chlorophyll *a* filtration method. Within 48 hours, the water samples were filtered through a vacuum pump. First, to prevent phytoplankton from licing to the filter, some magnesium carbonate was squirted onto a 0.45 micron 4.25 cm glass fiber filter. Then, about 150 mL or 200 mL of the lake sample was poured and drained through the filter using a vacuum pump. The filter was then folded, placed in aluminum foil, labeled, and refrigerated until it was tested.

<u>Secchi Depth</u>

Measured Secchi depth is one of the simplest ways to determine lake eutrophication and light transparence. The amount of nutrients in lake water determines a lake's cloudiness by accelerating the growth of phytoplankton (microscopic animals) and therefore the growth of zooplankton (microscopic animals). Inorganic solids from fertilizers, soil erosion, and sewage also increase a lake's cloudiness. Secchi disk transparency, Chlorophyll *a*, and total phosphorus together define a lake's trophic status (degree of eutrophication).

Typically Secchi depth is lowest during the spring and summer months, when water runoff and phytoplankton productivity is most vigorous. Water clarity often increases, sometimes doubling Secchi depths, during the fall and winter months. Weather is another factor: a drought will lead to increased water clarity while storms with heavy rain increase runoff and subsequently decrease Secchi depth.

A Secchi disk, consisting of a 20 cm black and white round disk attached to a line, is used to measure Secchi depth. The disk is lowered into the water until the lines separating the black and white sections on the disk are no longer distinguishable. Secchi depth is then recorded at that depth in the water column. University of Lynchburg measured Secchi depth at all of the eight stops. The rope attached to the disk was marked in meter increments. Measurements were recorded in meters and taken to the tenth decimal place. Volunteers from LLA also took Secchi depth readings on or around similar dates as University of Lynchburg.

<u>Trophic State</u>

Secchi depth, integrated Chlorophyll *a*, and total phosphorus (TP) are used to determine a lake's trophic status. Exposing a lake's health, a trophic state shows the lake's degree of eutrophication. There are 3 main categories under the Trophic State Index (TSI); eutrophic, mesotrophic, and oligotrophic. Eutrophic lakes are highly productive and concentrated in nutrients; mesotrophic lakes experience temperate productivity and have moderate nutrient levels; oligotrophic lakes have little productivity and low nutrient levels. When the TSI value is greater than 51, lakes are classified as eutrophic. Water has more clarity in oligotrophic lakes rather than in eutrophic lakes due to the lower nutrient levels (http://www.rmbel.info/reports/Static/TSI.aspx).

<u>E. coli</u>

To determine levels of bacteria and look for health hazards, University of Lynchburg and LLA took *E. coli* readings at Leesville Lake. Escherichia coli (*E. coli*) is the accepted indicator organism for bacteria levels in Virginia. For the purposes of this report, *E. coli* levels are representative of coliform levels.

High levels of coliform bacteria found in lakes may point to the presence of human or animal excrement. Coliform bacteria are not harmful; however their presence shows that disease-causing bacteria or viruses may be present. Waterborne diseases such as dysentery, giardiasis, typhoid and other gastrointestinal infections can be contracted by swimming or drinking water from a lake containing human sewage. To assure the safety of water from such diseases, the water must meet the state standard for bacteria. In Virginia, the calendar-month geometric mean concentration of *E. coli* cannot exceed 126 cfu/100 mL, and no sample can exceed a concentration of 235 cfu/100mL (Virginia Tech,2006).

Conducting a fecal coliform test will show if sewage pollution is the problem. Additional tests can distinguish between human and animal sources if necessary. Nonpoint sources are the primary reason for high bacteria levels. Agriculture, land-applied animal waste, and livestock manure are the main nonpoint sources. Cattle and wildlife directly dumping feces into streams cause a large bacteria load. Nonpoint sources from residential areas include straight pipes, failing septic systems, and pet waste (Virginia Tech, 2006).

Prior to 2011, Leesville Lake Association citizen volunteers used Coliscan Easygel® test kits for *E. coli* testing. Beginning in 2011 water samples collected by both LLA volunteers and University of Lynchburg were tested for *E. coli* with the Colilert™ test method. Samples were collected in sterile 125 ml polypropylene bottles and stored according to standard methods. A Colilert™ media packet was added to each water sample; the mixture was poured into a sterile Quanti-Tray, sealed and incubated. A color change from clear to yellow indicates a positive result for total coliform and fluorescence indicates a positive result for *E. coli*. The number of yellow and fluorescent wells are counted and the values are evaluated using a Most Probable Number (MPN) chart developed by the IDEXX Company, which developed the test method. MPN is used instead of colony forming units (cfus) and is generally considered an equivalent measure of the microbial and bacterial populations. The Colilert™ method has been rated as the "best" in agreement with a reference lab, has the lowest detection limit and the method is EPA approved for ambient water.

Zooplankton

To assess the health and structure of the lake's biological community, water samples were tested for zooplankton levels. Nutrient-rich (eutrophic) lakes, in comparison to nutrient-poor lakes have more zooplankton. As the levels of phytoplankton increase, zooplankton also increase but at a slower rate (Kaulff, 2002).

Appendix C

Quality Assurance (QA) / Quality Control (QC)

Sample Collection, Preservation, and Storage:

Leesville Lake samples were collected in labeled polyethylene bottles that had been cleaned and rinsed with tap water, soap, DI water, a 2M HCl (we used 1M HCl) acid wash and finally more DI water. Each label denoted date, location, station, and depth if relevant.

Samples were refrigerated.

For detecting nitrate, nitrite, orthophosphate, and ammonia, samples were analyzed within 48 hours of collection. For total phosphorus (TP) and Total Kjedahl nitrogen (TKN), the samples were analyzed within 28 days.

Hydrolab Calibration and Sampling post Calibration:

A Hydrolab Quanta Water Quality Instrument is used for all in situ water quality measurements. Each parameter is calibrated before use according to procedures established by the manufacturer.

The sensors were cleaned and prepared for the following parameters:

Specific Conductance - A calibration standard was poured to within a centimeter of the top of the cup. Any bubbles within the measurement cell of the specific conductance sensor were tapped out. The conductivity of the calibration standard was 1.412.

Dissolved Oxygen %Saturation and mg/L:

1. Cleaning and Preparation: The o-ring securing the DO membrane was removed, the old electrolyte was shaken out and the DO membrane was rinsed with fresh DO electrolyte. Fresh DO electrolyte was poured into the sensor until a meniscus of electrolyte rose above the entire electrode surface of the sensor. After checking to make sure there were no bubbles in the electrolyte, a new membrane was placed on the top of the DO sensor and secured with the o-ring. There were no wrinkles in the membrane or bubbles in the electrolyte. Excess membrane was trimmed away.
2. Calibration for DO: The Saturated Air-Method was used for the DO calibration. The Calibration cup was filled with DI water until the water was level with the o-ring. No water droplets were on the membrane. The black calibration cup cover, turned upside down, was placed on the top of the Calibration Cup. The barometric pressure, which was 762mmHg, was determined for entry as the calibration standard.

pH and ORP (Redox):

1. Cleaning and Preparation: The pH sensor was clean with a soft cloth wet with rubbing alcohol and then rinsed with DI water. The platinum band at the tip of

the ORP sensor was checked for any discoloration or contamination. Then the reference sleeve was pulled away from the Transmitter and the old electrolyte from the reference sleeve was discarded. Then two KCl salt pellets (or KCl rings) were dropped into the reference sleeve and the sleeve was refilled with reference electrolyte. With the Transmitter sensors pointed toward the floor, the full reference sleeve was pushed back onto its mount until the sleeve had just covered the first o-ring located on the mount. The Transmitter was then turned so that the sensors pointed towards the ceiling, and the sleeve was pushed the rest of the way onto its mount. The sensors were rinsed with DI water. Next, the Low-Ionic Strength Reference (LISRef) was cleaned and prepared. First the plastic LISRef soaking cap was removed and set aside. The sensor tip was then checked for any visible contamination. Following cleaning, the plastic LISRef soaking cap was filled with reference electrolyte, reinstalled over the LISRef tip, and soaked overnight. The plastic LISRef soaking cap was removed for calibration and field use.

2. Calibration for pH and ORP: A two-point calibration was used, with two pH standards. First, a pH standard of 7 was treated as the zero, and then a pH standard of 4 was treated as the slope. Both pH standards, when calibrated separately, were poured to within a centimeter of the top of the cup.

Turbidity:

1. Cleaning and Preparation: A non-abrasive, lint-free cloth was used to clean the quartz glass tube to remove any scratches that might reduce the sensors accuracy. The sensor was then rinsed with DI water.
2. Calibration for Turbidity: A Quick-Cal Cube was cleaned and dried with a non-abrasive, lint-free cloth. The cube was then placed in the turbidity sensors optical area. Turbidity analyzed and also checked at 0 with DI water.

□□□ Depth: Zero was entered for the standard at the water's surface.

□□ After all of the parameters were calibrated, the calibration cup was filled with ¼ of tap water to protect the sensors from damage and drying out during transportation to the lake and storage in University of Lynchburg.

□□□ The hydrolab was calibrated the morning of each day of lake sampling.

Post Calibration

Pre Sampling at Leesville Lake

□□ The bottled were washed according to above procedures, labeled, and placed in a milk crate. 18 bottles were taken: 3 for zooplankton, 12 for nutrients, and 3 for whole water.

□□□ The Hydrolab was calibrated and the information was recorded.

□□ An ice chest was half-filled with ice.

□□□ Batteries in the Hydrolab were checked.

□□ At the lake, the following parameters were recorded:

- o Smith Mountain Lake tailwaters: whole water for TP
- o Pigg River near its mouth: Secchi depth, TP, Hydrolab data
- o Toler Bridge (after confluence with Pigg River/riverine zone): Secchi depth, TP, no Hydrolab data was taken because the flow of water was too quick
- o Mile Mark 9 (mixing zone): Secchi depth, TP?
- o Mile Mark 6 (end of mixing zone/beginning of lacustrine): Secchi depth, TP, hydrolab data
- o Tri-County Marina: Secchi depth, TP
- o Leesville Lake Marina: Secchi depth, TP
- o Near dam (end point of lacustrine): Secchi depth, TP, Hydrolab data

No data for E. Coli was collected because of a lack of zithromax packs.

Nitrate Method

Summary of Method:

In this method used to determine nitrate levels, nitrate was reduced to nitrite using Systea's Chemical RI. The resulting stream was treated with sulfanilamide and N-1-naptylethylenediamine dihydrochloride under acidic conditions to form a soluble dye, which was measured colormetrically at 546nm. The product was the sum of the original nitrite ion present plus the nitrite formed from nitrate. Systea has shown that, regardless of the sample matrix used, recovery of NO3 to NO2 is consistently between 95% and 105% recovery.

To determine the nitrate levels, the nitrite alone was subtracted from the total.

Summary of Run:

1. The lake samples were chilled to about 4^0C and analyzed within 48 hours
2. Standards and reagents were prepared by the above steps and then placed in the EasyChem instrument.
3. A standard curve for a range of 0.05-10mg/L (check) was created by the following steps:

 A 10ppm nitrate standard was placed in the instrument.

Standards were prepared through dilutions at 5, 1, 0.5, 0.10, and 0.05ppm

The instrument read the optical density of the calibrants. O.D. readings of a 0ppm standard and of two blanks (composed of DI water) were taken.

 A standard curve was set. The linear correlation coefficient (r^2) was always greater than 0.995.

4. The optical density of the samples was measured. By comparing the O.D. values to the standard curve set in Step 1, the concentration of nitrate in the lake samples was determined.
5. For every 10 samples, a check standard, spike, and a duplicate were included. Thus, for 40 cups of samples, there were 4 check standards of a known 10ppm nitrate solution, 4 spikes from different samples, and 4 different duplicates of

lake samples. The check standards, serving as the Quality Control Samples (QCS), fell within 10% of the QCS true value.

6. The analysis ended with a blank to check the validity of the instruments readings.

Total Phosphate Method

Summary of Method:

Under this method for the determination of total phosphate, the aqueous sample was mixed with sulfuric acid, ammonium molybdate and antimony potassium tartrate to form antimony-1, 2-phosphorous molybdenum acid. The resulting complex was then reduced by ascorbic acid to get a blue heteropoly acid (molybdenum blue). To determine the concentration of ortho-phosphate, the absorbance of the formed blue complex, was measured at 880nm.

Since only orthophosphate formed a blue color in this test, polyphosphates (and some organic
phosphorus compounds) were converted to the orthophosphate form by manual sulfuric acid hydrolysis. Organic phosphorus compounds were converted to the orthophosphate form by manual persulfate digestion. The developed color was then measured
automatically.

Summary of Run:

1. The lake samples were chilled to about 4^0C and analyzed within 48 hours
2. Standards and reagents were prepared by the above steps and then placed in the EasyChem instrument.
3. A standard curve for a range of 0-5mg/L (check) was created by the following steps:
   - A 5ppm total phosphate standard was placed in the instrument.
   - Standards were prepared through dilutions at 5, 2, 1, 0.5, 0.1, and 0ppm
   - The instrument read the optical density of the calibrants. O.D. readings of a 0ppm standard and of two blanks (composed of DI water) were taken.
   - A standard curve was set. The linear correlation coefficient (r^2) was always greater than 0.995.
4. The optical density of the samples was measured. By comparing the O.D. values to the standard curve set in Step 1, the concentration of nitrate in the lake samples was determined.
5. For every 5 samples, a blank and a duplicate were included. Halfway through the run and at the end of the run there were 2 check standards. Thus, for 40 cups of samples, there were 2 check standards of a known 1ppm phosphate solution and 2 check standards of a known 0.5ppm phosphate solution, and 8 different duplicates of lake samples. The check standards, serving as the Quality Control Samples (QCS), fell within 10% of the QCS true value.
6. The analysis ended with a blank to check the validity of the instruments readings.

Quality Assurance/Quality Control

Initial demonstration of laboratory capability was established through the following methods:

Method Detection Limit (MDL): According to the Code of Federal Regulations, the MDL is the minimum concentration that can be determined with 99% confidence that the true concentration is greater than zero. This method guarantees the ability to detect nutrient concentrations at low levels. In order to proceed with testing, the MDL in reagent water for nutrients had to be less than or equal to the concentrations in the table below. These concentrations were taken from the Ambient Water Quality Monitoring Project Plan for the Department of Environmental Quality:

Nitrate	0.04 mg/L
Nitrite	0.01 mg/L
Orthophosphate	0.01 mg/L
Total Phosphate	0.01 mg/L
Ammonia	0.04 mg/L

Initial Precision and Recovery (IPR): This practice establishes the ability to generate acceptable precision and accuracy. 4 Laboratory Control Samples (LCS) were analyzed and the average percent of recovery (X) along with the standard deviation of the percent recovery (s) for nitrate was determined. Our tested recovery did not exceed the precision limit and X did not fall outside the 90-110% range for recovery. In instances were recover was not accomplished analysis was repeated to achieve the acceptable recover limits.

Matrix spikes (MS) and matrix spike duplicate (MSD) samples were analyzed to demonstrate method accuracy and precision and to monitor matrix interferences.

Out of each set of ten samples, one sample aliquot was analyzed. First, the background concentration (B) of analyte was determined. Then the sample was spiked with the amount of analyte stock solution to produce a concentration in the sample of 1mg/L, or a concentration 1 to 5 times the background concentration. Finally, two additional sample aliquots were spiked with the spiking solution, and the concentrations after spiking (A) were measured.

The percent recovery of analyte in each aliquot was determined using the follow equation:

$P = [100(A – B)]/T$

The spike recovery percentage had to lie within the QC acceptance criteria of 90 to 110%. The relative percent difference between the two spiked sample results also had to be less than 20%.

Laboratory reagent water blanks were analyzed with each analytical batch to demonstrate freedom from contamination and that detected nitrate is not at a concentration greater than the MDL.

To demonstrate that the analysis system was in control, the LCS procedure was performed on an ongoing basis, with results lying within +/-10% of the true value.

Records defining the quality of data generated, including LCS data and QC charts, were maintained. A statement of laboratory data quality for each analyte, with the average percent recovery (R) and the standard deviation of the percent recovery (s_r). The accuracy as a recovery interval was expressed as R – $3s_r$ to R + $3s_r$.

To demonstrate that the analytical system was in control, the laboratory periodically tested an external reference sample. We have not yet conducted this analysis but will strive to this standard in 2012.

Quality Assurance (QA) / Quality Control (QC) Checklist:

General Procedures:

- Checklist of all routine material and equipment:
  Checklist should include field data sheets showing sampling sites, QA sites if QC samples are collected, containers, preservatives, and labels including QC labels
- Also a topo map, GPS unit, safety gear, and cell phone
- Print field data sheets and labels from CEDS for the run
- Clean equipment, check its condition, and charge batteries

Sampling Requirements:

- For the collection of organic materials, se non-organic or inert materials such as Teflon or stainless steel
- Water matrices: 1. Rope on spool 2. Stainless steel bucket with fitting for bacteria sample bottle 3. Syringe, filter paper, filter holder etc.

Sampling Equipment Preparation and Cleaning:

- Water Sampling Equipment:
- Daily: Rinse buckets at the end of the day with analyte free water and allow to dry; if a pump/hose was used, pump 5 gallons of analyte free water through system and allow to drain; if using Kemmerer or Alpha Bottle sampling devices, follow manufacturer's instructions using analyte free water
- Weekly: Wash buckets with lab grade soap (Liquinox or Alconox) using a brush to remove particulate matter or surface film; rinse with tap water and then analyte free water, allow to dry
- Monthly: pump 5 gallons of a 5% solution (consists of 1 quart of vinegar mixed with 4 ¾ gallons of water) through hose and pump apparatus; pump 5 gallons of anaylte free water through hose and pump apparatus and completely drain

- Annually: replace hoses of pump and hose sampling devices
- Sample container handling and preservation:
- Refer to the DCLS laboratory catalog in CEDS for the appropriate preservation procedures. Samples not preserved properly may be rejected by DCLS.
- make sure the lids were on tight
- Sample containers should be stored with the tops fastened.
- Samples should be iced to 4°C in a cooler immediately after collection. In the cooler, samples shall be placed upright and if possible, covered with ice in such a manner that the container openings are above the level of ice. Chlorophyll a filter pad samples will be placed in appropriately sized Ziploc bags and placed on top of the layer of ice. Ziploc bags containing filters should be oriented so that the sealed opening of the Ziploc bag hangs outside the cooler lid when the lid is closed. Bacteria sample bottles should be stored in mesh bags, placed in coolers and surrounded with wet ice.
- Package glass sample containers in bubble wrap or other waterproof protective materials
- Make sure that every cooler used to ship samples to DCLS contains one temperature bottle to determine sample temp upon arrival at DCLS.
- Regional office should date boxed or packaged sample containers upon receipt and stock on shelves with the oldest dated box/packages used first.

Sample identification:

- Identify each sample by the station description, date, time, depth description, collector initials, parameter group code, sample type, container number, preservation used and volume filtered, if applicable.
- Print sample identification information on an adhesive Avery label and applied to the exterior of the container.
- Print labels for established sampling sites from CEDS

Field Sampling Procedures:

- Use protective gloves: latex or nitrile gloves may be used for common sampling conditions; disposable ones are needed for clean metal sampling
- Rinse sample equipment with sample water before taking actual sample. Dispose of rinse water away from sampling site.
- Take surface water samples facing upstream and in the center of main area of flow
- For bacteria samples, do not rinse bottle before collecting sample and always collect as a grab sample, do not composite

Sampling from a boat:

- Bacteria samples: grab from the water in direction of current, do not use a pump or hose
- Sample away from engine in direction of current (if possible)
- Clear the pump and hose using the air bubble method or calculate the clearing time

Secchi disk:

- Use disk 20 cm in diameter attached to a line/chain marked in 0.1 m increments, check these once a year
- Lower Secchi disk on shaded side of boat until black and white quadrants are no longer distinguishable
- Note the above depth, and then depth at which the quadrants are once again distinct
- Secchi depth is the average of the two depths to the closest 0.1 m

Vacuum Filtering Method (In-Line Filtering)

- Nitrogen, phosphorus, and Chlorophyll **a**
- conduct filtering as soon as possible after collection but no later than 2 hours after sample collection

Preparation:

- Muffle 25 mm diameter glass fiber filters utilized for PNC (Particulate Nitrogen and Particulate Carbon analysis),
- Acid wash the towers, graduated cylinders and plastic sample bottles
- Rinse the forceps with DI water
- Ensure proper delivery of uncontaminated, dry filter samples to DCLS.

Filtration of samples:

- Rinse acid washed and DI washed container with sample water, then fill container with enough sample water to filter more than one sample
- Rinse filtration towers and base with DI water, connect vacuum power pump to battery
- Place filters on bases, place clean NTNP bottles under PP bases, rinse graduated cylinders with sample, and transfer sample to towers
- Turn pump on
- Add $MgCO_3$ to last 25 ml of Chl a sample
- Close valves or turn off pump to remove filtration vacuum
- Bleed excess pressure off and then open vacuum valves of stacks slowly
- Rinse forceps with DI water
- Remove filters from base
- Record volume filtered
- Remove NTNP bottle from PP cylinder and cap tightly
- Label- station, date, time depth, unit code, collector's initials, group code, container #, volume of sample filtered
- Place samples on ice

Collection of samples for Chlorophyll a using syringe filtration p. 21

- Field filtration is done with positive pressure and a syringe
- Filter approx. 300 ml of site water through a 150cc polypropylene syringe

Field Quality Control Samples

- Equipment Blanks: need to be collected in field between stations, once for each 25

sites sampled, flush/rinse with analyte free water
- Field split samples: collect for each 25 sites sampled, obtain 1 bucket of water and fill 2 identical containers sequentially

<u>Field Testing Procedures (p. 69)</u>

pH/mV/Ion meter
- calibrate meter each day before use with minimum of 2 fresh standard buffer solutions that bracket expected pH
- check calibrations using standard buffer solutions at least once during or end of sampling and record in log sheet, if pH is off by more than 0.2 pH units, flag data collected
- check instrument at least once a month and record in log sheet

Dissolved oxygen and temperature meter
- Calibrate daily when in use, air calibration is the easiest
- Record the % saturated DO in the log sheet
- A DO% saturation confirmation needs to be performed in the middle of run
- Field probe maintenance: average life of membrane is 2-4 weeks, but may vary
- Some gases can contaminate the sensor, evidenced by discoloration of gold cathode
- Check probe performance every month when probe is in daily use
- For the DO meter, make calibration checks daily. Check calibration during sampling and at conclusion of day's sampling. Record onto log sheet; if check is off ±5%, flag data
- Monthly, place probe into a clean bucket full of analyte free or uncontaminated water, rinse BOD bottle 1 or 2 times with water, determine DO by Winkler method
- If the oxygen concentration of the air calibration disagrees with average results of Winkler value by more than 0.5 mg/l, have the electrode or meter serviced or replaced
- Check temperature probe against another multiprobe instrument's temp. probe semi-annually

<u>DO and conductivity meter calibration checks</u>
- Daily: check calibration during sampling and at conclusion of day's sampling, record and flag data if off by more than 5%
- Monthly: place probe in bucket of analyte free water, rinse BOD bottle with water from bucket, determine the DO by the Winkler method
- If oxygen concentration of air calibration disagrees with results of Winkler value by more than 0.5 mg/l, service or replace electrode

<u>Thermistor Verification</u>
- Check temperature probe against another multiprobe instrument's temperature probe semi-annually
- Check against 3 points such as an ice/water mixture, room water temperature, and warm water temperature

- Do not use thermistor if the difference is more than 0.5 degrees C

Sample Identification and Corrective Action

- Make entries in field data sheet for all field parameters
- Print label from pre-print label file in computer. Include station ID, date collected, time collected, depth, unit code, collector, group code, preservative, lab processing code, blank/dup designation, priority and container number
- Corrective Action: CAR form must be forwarded to QA officer for review and recommendations

Appendix D – Collected Data

Table 1.1. Dam (Lacustrine) Conductivity (μs/cm) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	0.162	0.167	0.175	0.178	0.174	0.174	0.168
0.5	0.163	0.167	0.17	0.177	0.173	0.174	0.168
1	0.162	0.163	0.174	0.177	0.173	0.174	0.168
1.5	0.163	0.163	0.175	0.177	0.173	0.173	0.167
2	0.162	0.157	0.174	0.176	0.172	0.173	0.167
2.5	0.162	0.145	0.174	0.177	0.173	0.173	0.167
3	0.162	0.145	0.173	0.177	0.173	0.173	0.166
4	0.162	0.145	0.174	0.18	0.173	0.173	0.167
5	0.161	0.146	0.176	0.18	0.173	0.173	0.166
6	0.162	0.148	0.175	0.179	0.174	0.172	0.166
7	0.162	0.147	0.174	0.179	0.174	0.172	0.166
8	0.163	0.147	0.173	0.18	0.174	0.172	0.166
9	0.162	0.148	0.173	0.179	0.174	0.172	0.166
10	0.164	0.147	0.172	0.179	0.174	0.172	0.167
11	0.164	0.147	0.171	0.179	0.174	0.173	0.167
12	0.167	0.145	0.171	0.179	0.174	0.173	0.167
13	0.167	0.145	0.169	0.18	0.174	0.173	0.167
14	0.167	0.144	0.168	0.18	0.174	0.174	0.167

Table 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	10.5	10.04	9.17	9.61	10.41	5.92	9.4
0.5	10.6	10.2	9.37	9.53	10.5	6.08	9.39
1	10.5	11.5	9.26	9.42	10.51	6.17	9.38
1.5	10.4	11.8	9.33	9.43	10.3	6.2	9.1
2	10.4	10.1	9.48	9.33	8.14	6.05	8.4
2.5	10.3	7.4	9.48	9.07	8.02	5.94	8.4
3	10.3	6.9	8.3	8.79	6.93	5.83	6.8
4	10.1	6.8	6.8	4.94	5.93	5.59	6.58
5	9.84	6.7	6.2	3.51	4.52	5.48	6.5
6	9.4	6.6	5.5	2.54	3.4	5.39	6.5

7	9.18	6.5	4.7	1.9	2.6	5.39	6.4
8	9.06	6.6	4.35	1.43	1.48	5.39	6.3
9	8.89	6.5	3.92	0.99	1.79	5.2	5.9
10	8.6	6.5	3.67	0.64	1.37	4.3	5.8
11	8.3	6.4	3.4	0.57	1.2	3.46	5.9
12	8.1	6.3	2.9	0.5	0.87	3.7	5.9
13	8	6.2	2.55	0.41	0.6	3.41	5.8
14	7.89	6	2.5	0.35		2.46	5.4

Table 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	17.3	25.3	26.8	28.1	27.3	23.4	18.2
0.5	16.9	24.3	25.9	28.0	27.2	23.3	18.2
1	16.8	22.6	25.7	27.9	27.1	23.2	18.2
1.5	16.7	21.6	25.1	27.8	26.1	23.1	18.1
2	16.7	18.8	24.3	27.7	25.7	23.1	17.9
2.5	16.7	17.4	23.4	27.6	25.5	23.1	17.8
3	16.6	16.7	22.7	27.4	25.3	23.1	17.6
4	16.5	16.6	21.9	26.4	24.9	23.1	17.3
5	16.4	16.4	21.5	23.6	24.7	23.1	17.3
6	15.1	16.2	21.1	22.8	24.5	23.0	17.3
7	14.6	16.1	20.8	22.4	24.3	23.0	17.2
8	14.1	15.9	20.4	21.9	24.0	23.0	17.2
9	13.8	15.8	20.1	21.6	23.9	23.0	17.2
10	13.5	15.5	19.8	21.0	23.6	23.0	17.2
11	13.2	15.5	19.4	20.8	23.5	23.0	17.2
12	12.6	15.2	18.8	20.6	23.3	22.9	17.1
13	12.5	15.2	18.5	20.3	23.2	22.9	17.1
14	12.4	15.1	17.7	19.8		22.8	17.1

Table 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	1.5	3.3	2.8	5.4	5.8	5.9	14.1
0.5	7.2	4.9	3.7	6.9	7	8	18.1
1	8.2	9.8	3.9	7.3	9.7	11.6	19.1
1.5	8.6	11.4	5.3	8.6	13.7	16.3	12.8
2	9.1	16.4	6.8	10	23.2	16.2	11.4
2.5	9.6	23.3	11.24	10.3	22.8	12.9	10.9

3	8.1	10.4	14.8	10.7	24.8	12.7	7.5
4	7.8	6.1	11.4	7.74	25.9	14.3	7.4
5	7.01	4.5	9.1	5.4	21	12.6	7.7
6	4.9	3.9	8.7	4.7	18.4	11.5	6.6
7	5.5	3.8	6.9	3.2	13.7	12.5	6.6
8	4.2	3.3	7.2	3.1	9.2	11.9	7.5
9	4.8	3.3	5.2	2	9.5	10.6	5.8
10	3.8	3.5	4.3	1.6	7.3	9.8	5.7
11	3	3.2	3.9	1.9	5.5	7.6	6.3
12	3.3	3.3	2.4	1.8	5.4	9.2	5.8
13	3.4	3.1	3	2.1	4.2	7.9	6.1
14	2.9	3.1	2.7	1.6		7.3	6.7

Table 1.5. Dam (Lacustrine) pH measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	7.91	8.07	8.21	8.72	8.7	7.57	7.78
0.5	7.95	8.05	8.2	8.73	8.75	7.55	7.79
1	7.96	8.14	8.19	8.73	8.75	7.5	7
1.5	7.96	8.3	8.11	8.72	8.56	7.5	7.77
2	7.96	7.8	7.99	8.7	8.15	7.5	7.7
2.5	7.96	7.4	7.89	8.65	7.8	7.5	7.6
3	7.96	7.3	7.7	8.54	7.71	7.5	7.6
4	7.91	7.12	7.56	7.63	7.55	7.5	7.5
5	7.8	7.08	7.37	7.28	7.38	7.49	7.4
6	7.57	7.06	7.27	7.15	7.29	7.47	7.4
7	7.51	7.05	7.18	7.07	7.2	7.45	7.3
8	7.41	7.05	7.12	7	7.13	7.45	7.3
9	7.4	7.05	7.1	6.96	7.09	7.44	7.3
10	7.3	7.04	7.04	6.93	7.07	7.3	7.3
11	7.3	7.04	7.01	6.91	7.04	7.3	7.3
12	7.2	7.02	6.97	6.9	7.02	7.2	7.3
13	7.2	7.01	6.94	6.88	6.9	7.2	7.3
14	7.2	6.9	6.91	6.86		7.2	7.3

Table 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	349	390	428	402	409	352	359
0.5	360	392	428	402	411	355	360

1	372	395	429	402	413	357	362
1.5	375	394	432	402	415	358	363
2	382	401	434	403	419	360	364
2.5	383	403	435	403	420	361	365
3	385	405	437	403	421	362	366
4	389	405	439	410	423	363	367
5	394	406	440	412	423	365	367
6	396	407	440	413	424	366	368
7	400	408	441	414	425	367	369
8	404	409	441	415	425	368	370
9	406	410	442	416	426	370	371
10	407	410	442	417	426	371	371
11	409	412	443	418	426	372	372
12	409	411	444	419	427	373	373
13	411	414	444	419	427	374	374
14	411	413	445	420		374	374

Table 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	2.8	1.9	0.5	2.1	1.4	1	1.8
0.5	3.1	2.4	1.2	2.4	1.8	1.1	1.8
1	2.8	2.6	1.4	2.2	1.7	1.3	2
1.5	2.6	2.6	1.6	2.1	2.1	1.5	1.9
2	2.8	6.6	1.7	2	1.9	1.1	2
2.5	2.4	20.6	2	2.1	2.1	1.2	2
3	2.7	23.6	1.8	2.2	1.8	1.3	2.1
4	3	26.8	1.8	2.8	1.6	1.1	2.2
5	3.2	23.5	1.4	1.8	1.8	1.2	3.5
6	2.7	22.3	1.8	2.3	1.9	1.3	2.7
7	3.5	23.4	1.7	2.1	1.4	1.4	2.7
8	2.4	23.1	1.7	2.6	2.2	1.3	4.1
9	2.8	27.2	2.5	2.8	1.7	1.7	3.9
10	2.5	27.1	1.9	3	1.9	1.7	4.4
11	3.1	30.1	1.8	3.1	2	2	4.7
12	2.6	30.7	3	2.8	2.2	2.3	5.3
13	3	33.4	2.8	2.7	2	2.7	6
14	3.1	34.7	2.5	3.2		2.9	10.1

Mile Marker 6

Table 1.9. Mile Marker 6 (Transition) Conductivity (µs/cm) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	0.162	0.157	0.181	0.178	0.174	0.174	0.17
0.5	0.162	0.158	0.179	0.177	0.175	0.174	0.17
1	0.161	0.151	0.18	0.178	0.174	0.173	0.169
1.5	0.162	0.15	0.18	0.179	0.175	0.173	0.169
2	0.161	0.149	0.183	0.179	0.174	0.173	0.169
2.5	0.162	0.15	0.182	0.179	0.174	0.173	0.169
3	0.161	0.155	0.181	0.18	0.174	0.173	0.169
4	0.161	0.153	0.18	0.18	0.173	0.172	0.168
5	0.161	0.157	0.181	0.18	0.173	0.172	0.168
6	0.16	0.161	0.18	0.18	0.174	0.172	0.168
7	0.16	0.165	0.179	0.183	0.174	0.172	0.167
8	0.16	0.166	0.178	0.184	0.175	0.172	0.167
9	0.16				0.176	0.172	0.167
10	0.16					0.172	

Table 1.10. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	38-Sep	26-Oct
0	10.16	10.37	9.55	10.6	9.71	6.5	9.6
0.5	10.11	10.5	9.6	10.78	9.51	6.49	9.6
1	10.06	9.5	9.52	9.9	9.47	6.35	9.5
1.5	9.7	8.4	9.37	9.79	8.78	6.24	9.4
2	9.74	7.8	8.45	7.99	8.17	6.19	9.1
2.5	9.65	7.58	7.7	7.48	6.76	6.17	8.8
3	9.59	7.31	7.03	6.41	5.62	6.15	8.5
4	9.31	7.08	6.12	5.72	5.12	6.05	8.3
5	9.24	7.01	5.57	5.31	4.4	6	8.1
6	9.03	6.73	4.81	4.3	3.1	5.91	7.9
7	9.01	6.49	4.17	3.4	2.5	5.88	7.6
8	8.9	6.45	3.45	3.32	1.9	5.85	7.3
9	8.9				1.77	5.87	7.1
10	8.6					5.77	

Table 1.11. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	26-Sep	28-Oct
0	16.8	22.9	25.5	26.7	27.6	22.7	17.7
0.5	15.8	21.8	25.4	26.3	26.8	22.7	17.7
1	15.6	19.6	24.9	25.9	26.7	22.5	17.7
1.5	15.1	19.2	24.6	25.8	26.5	22.4	17.5
2	14.9	17.9	22.9	25.1	26.3	22.3	17.4
2.5	14.8	17.7	22.9	25.1	25.5	22.3	17.3
3	14.7	16.9	21.9	24.5	25.3	22.3	17.2
4	14.5	16.6	21.5	24.1	24.6	22.1	17.2
5	14.5	16.1	20.8	23.5	24.3	22.1	17.1
6	14.4	15.3	20.1	22.7	23.9	22.1	17
7	14.4	14.6	19.7	21.7	23.8	22	16.9
8	14.3	14.6	19.1	21.5	23.5	22	16.8
9	14.3				23.5	21.9	16.7
10	14.2					21.9	

Table 1.12. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sep	26-Oct
0	2.78	8.1	3.6	6.9	9.5	6.6	15.9
0.5	4.7	9.13	5.7	8.6	11.8	12.1	21.3
1	7.3	20.5	7.3	18.7	18.3	14.8	20.2
1.5	7.7	22.2	13.4	19.8	17.2	12.8	20.2
2	9.4	10.4	13.4	15.2	16.7	12.5	21.6
2.5	8	9.5	11.7	9.2	13.8	14.9	19.1
3	8.36	5.6	9.1	8.3	10.1	13.3	20
4	8.6	4.9	6.9	7.1	7.9	10.1	16.1
5	7.2	4.6	5.7	6	7.1	9.5	12.1
6	6.5	3.6	4.7	4.7	6.5	11	12.8
7	8.6	2.6	4.4	4.8	5.9	9.1	12.4
8	6.9	2.6	4.7	4.9	5	9.6	14.8
9	5.7				5.8	7.3	17.5
10	5.8					7.9	

Table 1.13. Mile Marker 6 (Transition) pH measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sep	26-Oct
0	7.49	7.95	7.9	8.43	8.14	7.45	7.8
0.5	7.76	7.99	7.94	8.45	8.06	7.45	7.8
1	7.75	7.77	7.9	8.34	7.98	7.44	7.8
1.5	7.67	7.58	7.86	8.17	7.88	7.43	7.77
2	7.66	7.36	7.66	7.91	7.68	7.41	7.7
2.5	7.63	7.27	7.48	7.65	7.51	7.4	7.6
3	7.62	7.18	7.3	7.45	7.29	7.39	7.6
4	7.57	7.16	7.24	7.28	7.12	7.38	7.6
5	7.55	7.13	7.14	7.16	7.01	7.36	7.5
6	7.52	7.11	7.07	7.06	6.9	7.35	7.5
7	7.52	7.08	7	6.96	6.8	7.34	7.4
8	7.51	7.07	6.94	6.89	6.8	7.33	7.4
9	7.5				6.7	7.32	7.4
10	7.4					7.31	

Table 1.14. Mile Marker 6 (Transition) ORP (mV) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sep	26-Oct
0	387	414	406	363	394	382	387
0.5	394	414	407	365	393	383	387
1	408	417	409	370	394	384	388
1.5	411	421	411	377	394	385	389
2	417	422	413	384	396	386	390
2.5	419	423	414	389	396	387	390
3	423	424	415	392	399	387	391
4	424	425	416	391	399	388	391
5	427	426	416	398	400	389	392
6	428	427	417	401	402	390	393
7	430	428	418	403	402	391	393
8	430	428	418	404	402	392	394
9	432				400	392	387
10	433					393	

Table 1.15. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sep	26-Oct
0	3.1	8.5	1.7	2.1	2.3	4.3	2.3
0.5	3.7	8.9	2.2	2.2	3	4.5	2.3
1	3.6	16.9	2.2	2.9	2.8	4.4	2.2
1.5	3.9	16.8	3	3.1	3.2	4.2	2.2
2	4.1	19.6	3.6	3.6	3.3	1.9	2.5
2.5	4.6	18.3	4.3	3.7	3.4	4.8	2.8
3	5.2	16	4.4	4.4	4	4	2.8
4	5.5	17.6	4.6	5.2	4.5	3.6	2.7
5	5.6	16.3	4.4	5.4	4.9	3.7	3
6	5.6	14.1	4.7	4.9	4.3	3.9	3.3
7	5.7	13.2	5.5	10.5	5.3	4.7	4.6
8	5.5	15.6	13.4	13.7	7.6	5	7.6
9	6.1				13.4	5.4	31.5
10	7.8					11.7	

Toler Bridge

Table 1.16. Toler Bridge (Riverine) Conductivity (µs/cm) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	0.172	0.162	0.183	0.152	0.177	0.186	0.183
0.5	0.174	0.164	0.182	0.155	0.179	0.184	0.183
1	0.174	0.166	0.183	0.172	0.179	0.184	0.183
1.5	0.174	0.165	0.183	0.178	0.179	0.184	0.182
2	0.174	0.166	0.182	0.178	0.179	0.184	0.182
2.5	0.174	0.166	0.181	0.177	0.179	0.184	0.182
3	0.174	0.165	0.18	0.177	0.179	0.184	0.182
4	0.174	0.165	0.181	0.178	0.179	0.184	0.181
5	0.176			0.177	0.179	0.183	0.178

Table 1.17. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct

0	9.68	7.62	8.49	7	5.85	5.41	7.6
0.5	9.5	7.6	8.3	7.06	5.65	5.1	7.5
1	9.53	7.5	8.21	7	5.56	4.92	7.4
1.5	9.49	7.5	8.27	6.97	5.4	4.87	7.2
2	9.43	7.5	8.21	6.79	5.3	4.83	7.2
2.5	9.43	7.5	7.97	6.62	5.15	4.84	7.2
3	9.42	7.5	7.58	6.5	5.1	4.82	7.2
4	9.31	7.56	7.37	6.33	5	4.79	7.2
5	9.24			6.3	4.9	4.78	7.2

Table 1.18. Toler Bridge (Riverine) Temperature (°C) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	14.2	17	23.9	24.7	24.4	21.2	18.1
0.5	13.9	16.5	23.5	24.3	23.7	21.2	17.8
1	13.7	16.2	23	23.4	23.4	20.7	17.7
1.5	13.5	16.16	23.1	23.1	23.2	20.5	17.7
2	13.5	16	22.9	23	23.2	20.5	17.6
2.5	13.4	16	22.6	22.9	23	20.5	17.6
3	13.4	16	21.6	22.8	23	20.5	17.6
4	13.3	16	21.5	22.7	22.9	20.4	17.6
5	13			22.7	22.8	20.43	17.5

Table 1.19. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	2.58	2.1	4.6	11.2	4.2	2.1	5.6
0.5	4.3	2.01	4.8	10.5	7.1	3.6	4.5
1	5.6	2.3	7.9	8.8	7.4	3.9	3.8
1.5	5.4	3.2	7.9	8.7	6.9	4.2	3.5
2	5.14	3.5	8.2	7.3	6.1	4	3.8
2.5	5.1	3.66	9.1	6.9	6.1	3.8	3
3	5.4	3.75	7.3	6.7	6	3.7	2.8
4	4.5	3.93	6.64	6.2	5.8	3.6	3
5	5.6			4.9	5.3	3.55	3.3

Table 1.20. Toler Bridge (Riverine) pH measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	7.61	7.35	7.52	7.51	7.24	7.23	7.4
0.5	7.6	7.27	7.46	7.33	7.09	7.25	7.4
1	7.5	7.24	7.42	7.22	7.03	7.2	7.4
1.5	7.59	7.24	7.4	7.16	6.9	7.21	7.4
2	7.59	7.23	7.3	7.14	6.9	7.2	7.4
2.5	7.59	7.23	7.36	7.1	6.9	7.1	7.4
3	7.6	7.23	7.32	7.11	6.9	7.18	7.3
4	7.59	7.23	7.27	7.08	6.9	7.18	7.3
5	7.58			7.07	6.9	7.18	7.3

Table 1.21. Toler Bridge (Riverine) ORP (mV) measures over study period (2022)

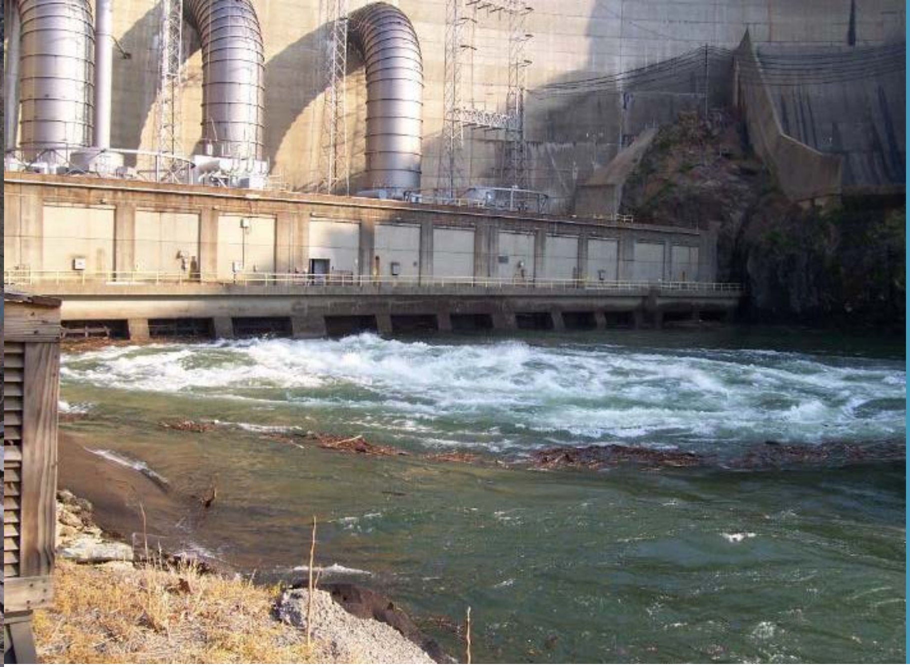
Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	315	418	384	381	368	391	394
0.5	331	418	386	384	369	393	394
1	356	417	387	386	371	394	395
1.5	363	417	389	387	371	395	395
2	376	417	391	389	373	395	396
2.5	380	417	392	390	374	397	396
3	390	417	393	391	375	398	396
4	393	417	394	392	376	398	396
5	400			394	377	399	397

Table 1.22. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2022)

Depth:	29-Apr	31-May	29-Jun	28-Jul	29-Aug	28-Sept	26-Oct
0	2.7	7.7	3.8	6.3	4.4	2.1	2.5
0.5	2.5	7.7	3.8	5.6	4.3	1.5	2.1
1	2.8	7.9	3.9	4.7	4.3	1.4	2
1.5	2.5	8.3	4.5	3.3	4	1.7	2.1
2	2	8.6	4.8	3.7	4.2	1.5	2.4
2.5	2.1	13.7	4.3	3.7	4	2.1	2.4
3	2.2	9.6	4.7	3.8	3.9	2.4	2.6
4	1.9	9	5.1	3.6	4.3	2.4	2.3
5	2.3			4.1	3.9	2.3	2.9

Appendix C

Dissolved Oxygen Feasibility Study



Smith Mountain Hydroelectric Project

Dissolved Oxygen Enhancement Evaluation

HDR

REMI

Reservoir Environmental Management

Presenters

Sarah Kulpa
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David Summers, PE
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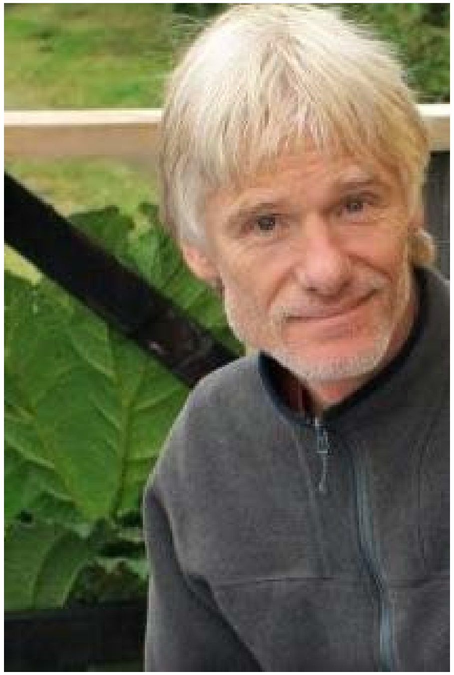
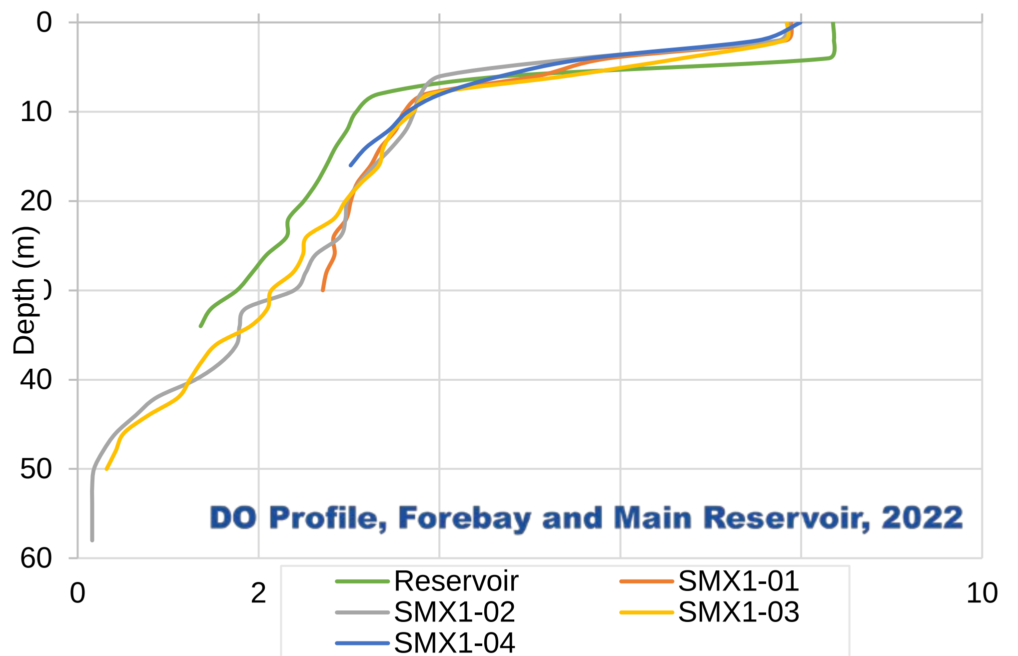
Sr. Mechanical Engineer



Paul J. Wolff, Ph.D.,
Reservoir Environmental
Management, Inc.

Background

- Dissolved Oxygen Enhancement Feasibility Study Plan (approved by FERC 11/27/2017)
  - Phase 1: Identification of potential operational changes
  - Phase 2: Identification of feasible physical changes to enhance DO
  - Phase 3: Evaluation of practicality, effectiveness, and cost efficiency of viable mitigation methods
- Summer DO in Smith Mountain tailwater/ Leesville Lake is frequently less than state water quality standards, which require an instantaneous minimum DO concentration of 4 mg/L and a 24-hour (i.e., daily) average of 5 mg/L.
  - Variability between years due to numerous factors
  - Refinements in monitoring equipment, tailwater deployment, and maintenance over monitoring period have reduced gaps in data collection/reliability



Year	% Time Instantaneous DO Standard Met (4.0 mg/L)	% Time Daily Average DO Standard Met (5.0 mg/L)
2015	75%	83%
2016	87%	60%
2017	97%	48%
2018	60%	47%
2019	66%	37%
2020	69%	40%
2021	81%	60%
2022	76%	42%

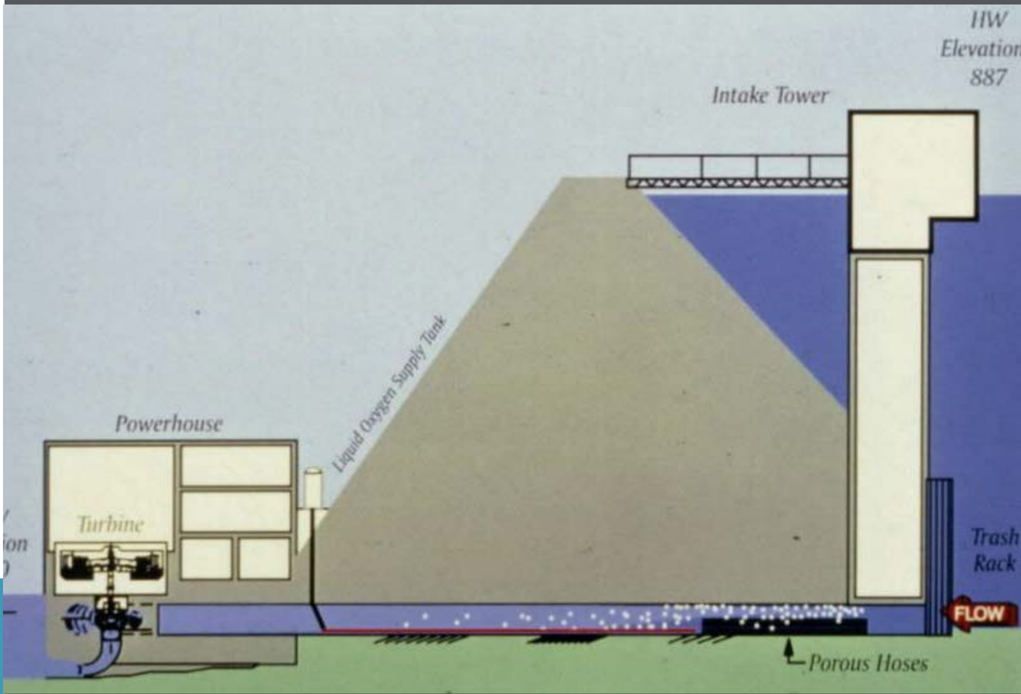
Smith Mountain Pumped Storage Project

Key Attributes

- Generation-only units (2 and 4) and pump-turbine units (1, 3, and 5)
- Variable elevations for unit discharge
  - Unit 1 at 39.6m & Unit 5 at 56.4m below surface
  - Units 2-4 at higher elevation, 13.7m below surface (though still below depth where lower DO concentrations occur under stratified conditions)
- Units 2-4 generate most of downstream flow (about 80% at full capacity)
- Units 2 and 4 are conventional Francis-type turbines set at or near average tailwater level

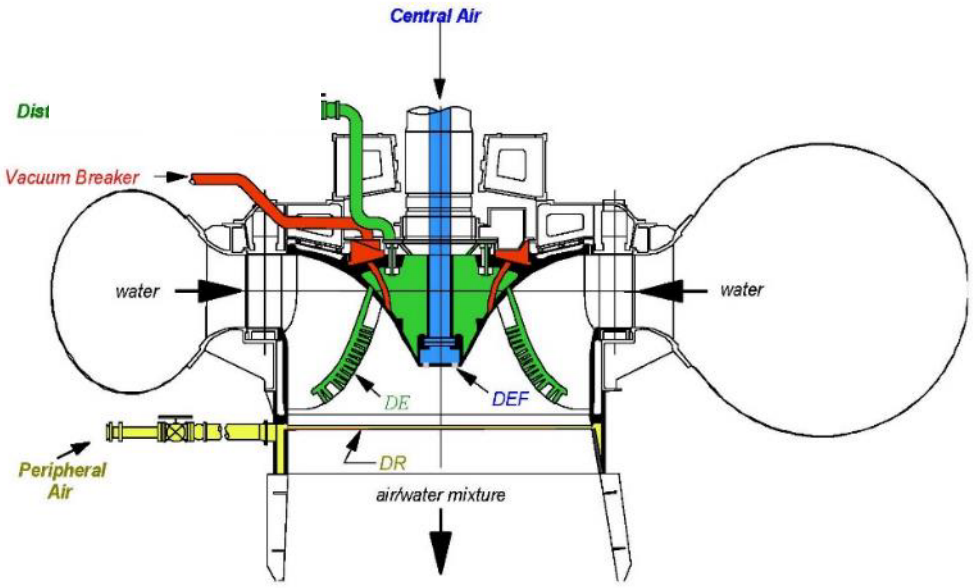
DO Enhancement Alternatives

- Air/Oxygen Injection
  - Reservoir Oxygenation (Forebay Line Diffuser)
  - Penstock Aeration
- Reservoir Mixing
- Selective Withdrawal
- Aeration Using Compressed Air
- Energy Dissipation Valves
- Passive Aeration
  - Aerating Weir
  - Surface Water Releases
- Tailrace Aeration
  - Line Diffusers with Air or Oxygen (same as Reservoir Line Diffusers)
  - Surface Water Aerators
- These methods have been evaluated and are not suitable for Smith Mt. operations



DO Enhancement Alternatives (cont'd)

- Mechanical Aeration
  - Turbine Aeration – General
    - Turbine aeration, also referred to as auto-venting turbine aeration methods, includes three primary types:
      - » **Central method**, typically through the runner cone;
      - » **Peripheral method**, a series of ports at the top of the draft tube which are fed air from a ring header; and
      - » **Distributed method**, utilizing hollow runner blades to route air to slots on the trailing edge of the blade.
    - In all cases, air at atmospheric pressure is drawn through ports in the turbine head cover by vacuum formed in the draft tube.
    - Distributed and peripheral types of aeration create a certain amount of vacuum due to velocity over air baffles or runner blades moving through the water.
    - Presently not suitable to pump-generating units

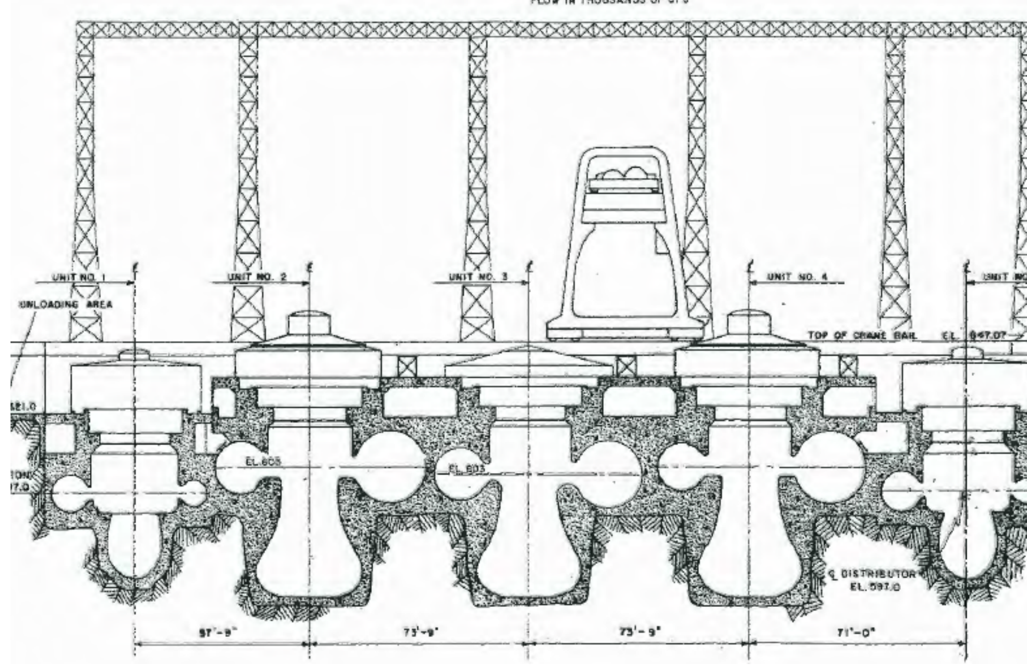


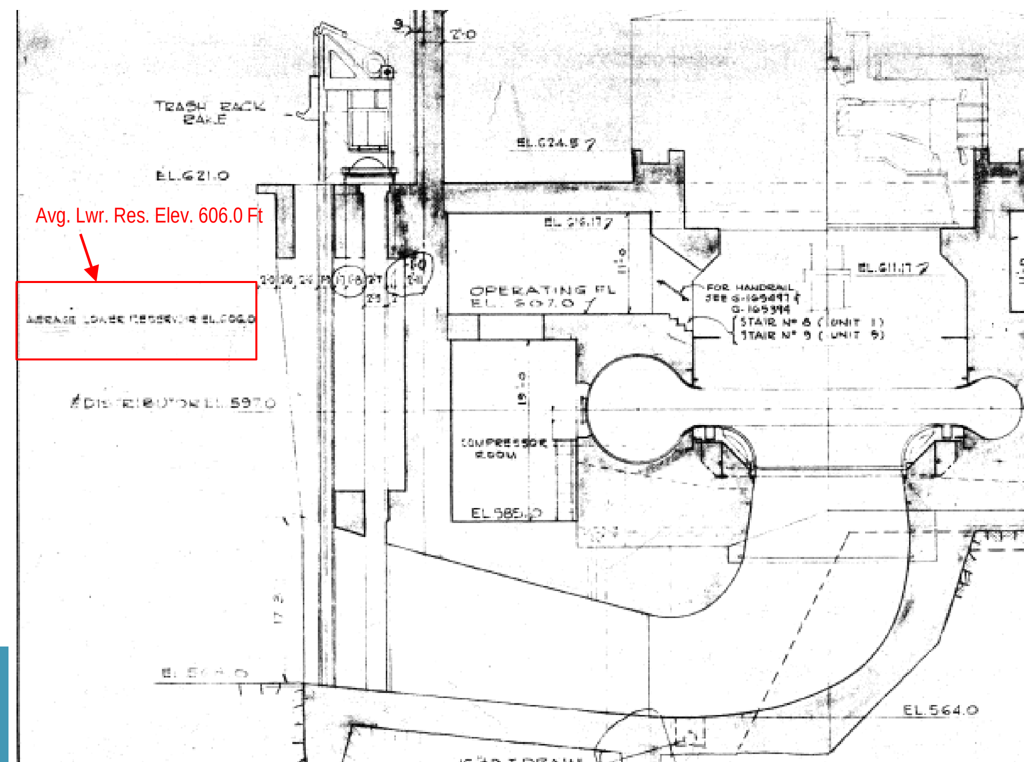
Alternative Recommended for Further Evaluation at Smith Mountain Project

- Turbine Aeration Method by Distributed Method
  - The turbine blades are designed to allow air flow to be introduced into the discharge stream by the runner vane trailing edges, or more recently, inter-blade vanes.
  - The runners have hollow vanes that allow air to be drawn through the headcover, into the runner crown, and down through the vane.
  - The movement of the blade through the water, in conjunction with the flow velocity over the blade, creates a low pressure region that can cause air to be drawn into the flow stream even if the vane trailing edge is located at or slightly below tailwater.
  - HDR consulted with a major turbine vendor offering distributed-type aeration about installations with similar tailwater characteristics as Smith Mountain, and they believe the option is viable.

Distributed-Type Turbine Discharge Aeration at Smith Mountain Project

- Turbine discharge aeration is a mature technology
  - Distributed-type discharge aeration has been successfully used in applications where the turbine setting is either equal to or slightly below tailwater level.
- Unit Setting is Acceptable
  - The distributor centerline for Units 2 and 4 is located at El. 605.0 ft per the Smith Mountain Supporting Technical Information Document.
  - The average tailwater elevation is El. 606.0 ft.
  - Submergence at the location of air entry points is considered to be acceptable for the majority of tailwater levels.
  - Turbine discharge aeration satisfies all criteria with regard to the fundamentals of gas transfer.





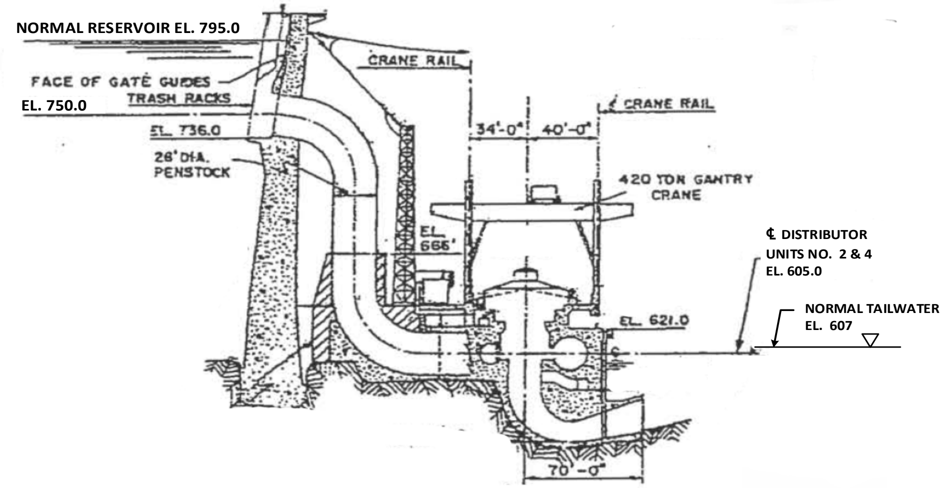
Distributed-Type Turbine Discharge Aeration at Smith Mountain Project

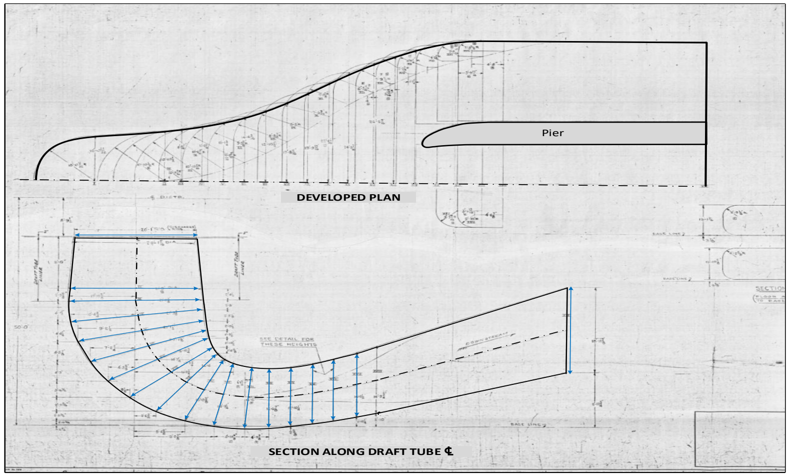
- Follow-Up Question / Subject of Assessment that Follows:
  - With two units operating in the aeration mode during key times of the year, can the dissolved oxygen downstream can be significantly enhanced to the extent it meets or more frequently meets State minimum water quality standards?

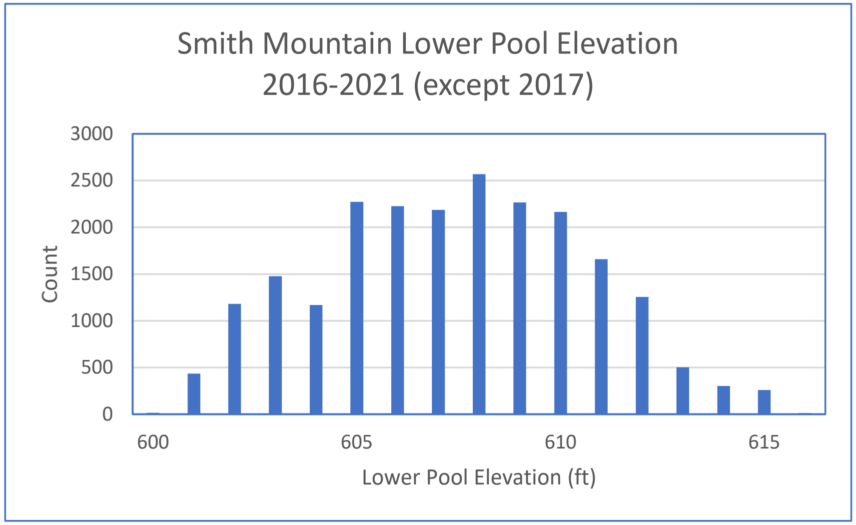
Assessment of Aerating Runners at Smith Mountain Project

- Principal Investigators:
  - Paul J. Wolff, Ph.D., Reservoir Environmental Management, Inc.
  - Charles W. Almquist, Ph.D., Hydropower Consultant
  - Daniel F. McGinnis, Professor, Ph.D., University of Geneva, Switzerland
- Objective:
  - Determine feasibility of meeting tailrace DO target by installing aerating runners in Units 2 and 4
- Approach:
  - Estimate air flow rates with a one-dimensional turbine air flow model
  - Compute DO increase in tailwater with a discrete bubble model (computes oxygen transfer) of the draft tube
  - Compute operation analyses to compute the tailrace DO for three years of operation

Turbine Air Flow Model (TAM) and Draft Tube Discrete Bubble Model (DBM)



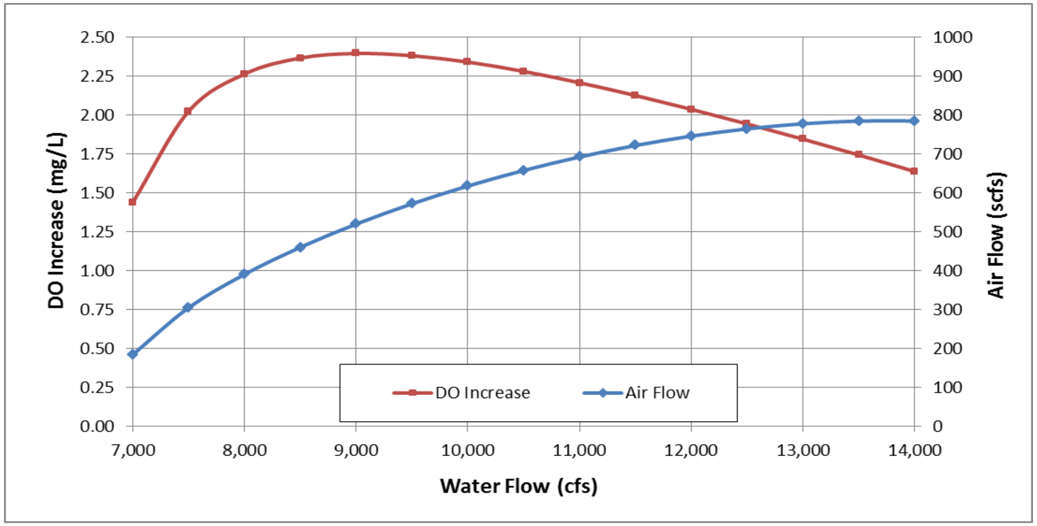


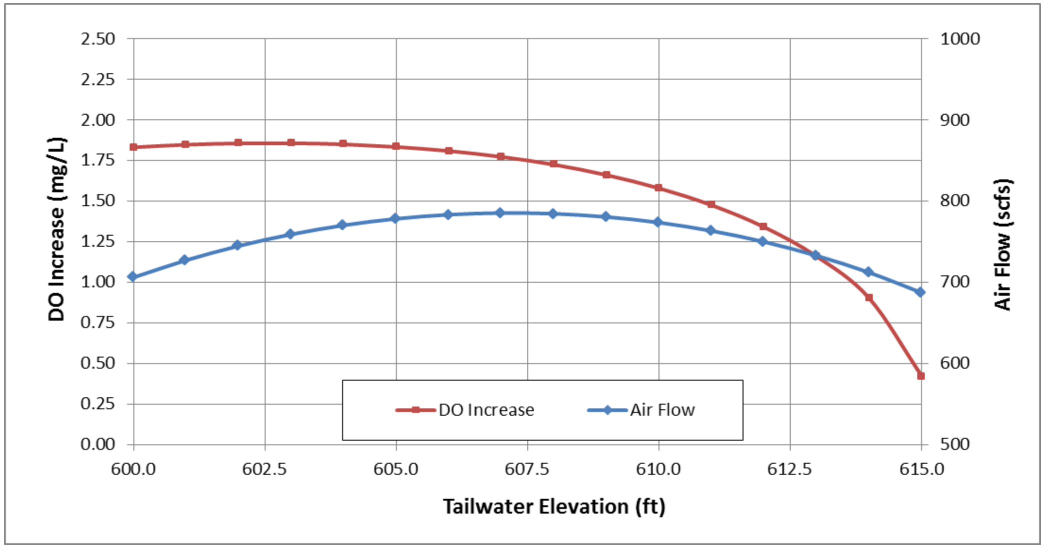


Parameters for Turbine Airflow Model (TAM)

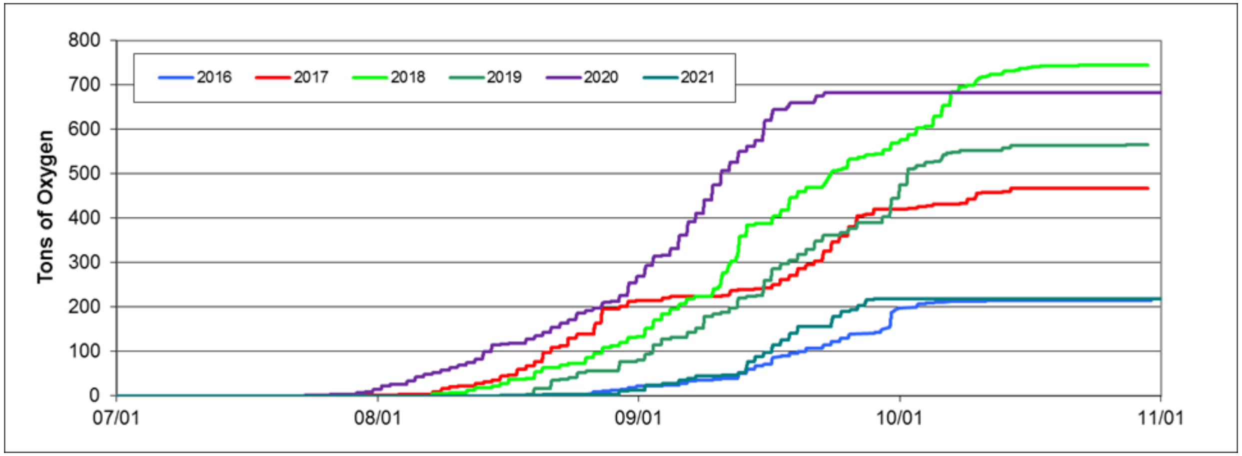
Turbine discharge, Q_W	13,500 cfs
Air admission elevation, Z_1	603 ft
Draft tube exit elevation, Z_2	575.9 ft
Area at air admission, A_1	317.6 ft^2
Area at draft tube exit, A_2	1009.8 ft^2
Draft tube length along ℄, S	100 ft
Number of air inlets, N	6
Diameter of air inlets, D_b	8 in
Air inlet loss coefficient, K_b	2.0

Turbine Air Flow Model (TAM)
and Draft Tube Discrete Bubble Model (DBM)

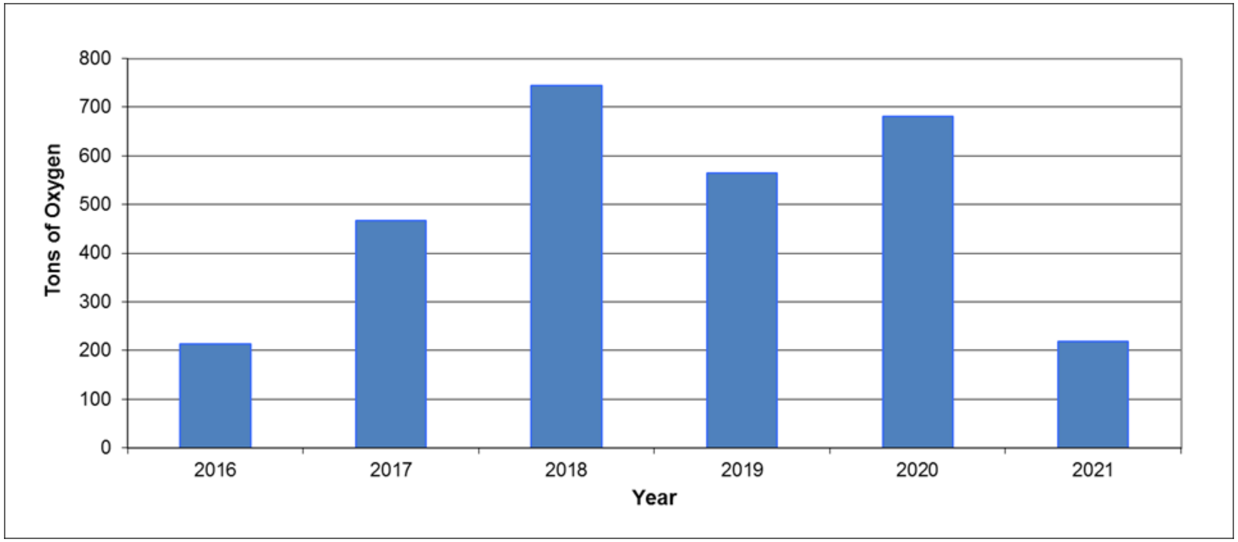




Operation Analyses – Oxygen Deficit

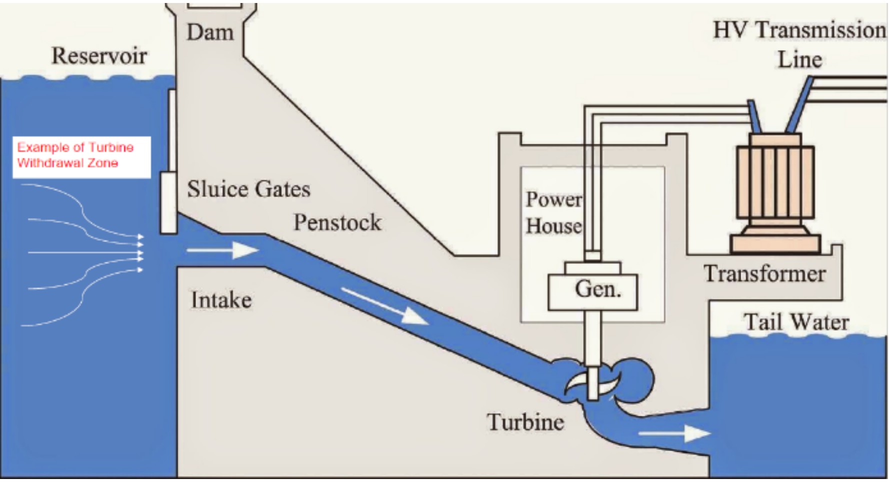


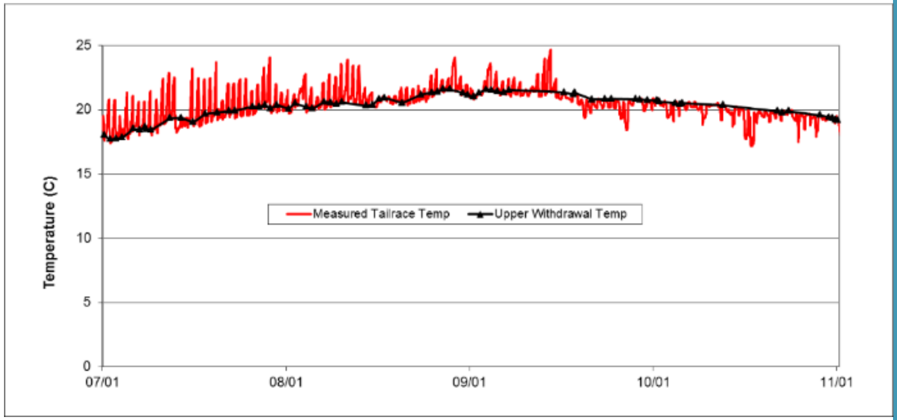
Cumulative Oxygen Deficit for the Instantaneous DO Target of 4.0 mg/L in the Smith Mountain Tailwater



Total Oxygen Deficits for the Instantaneous DO Target of 4.0 mg/L in the Smith Mountain Tailwater

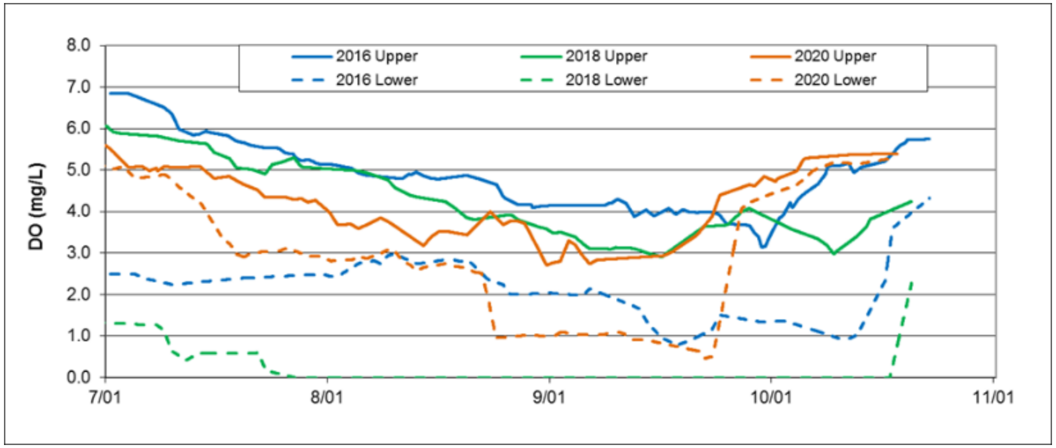
Withdrawal DO and Temperature





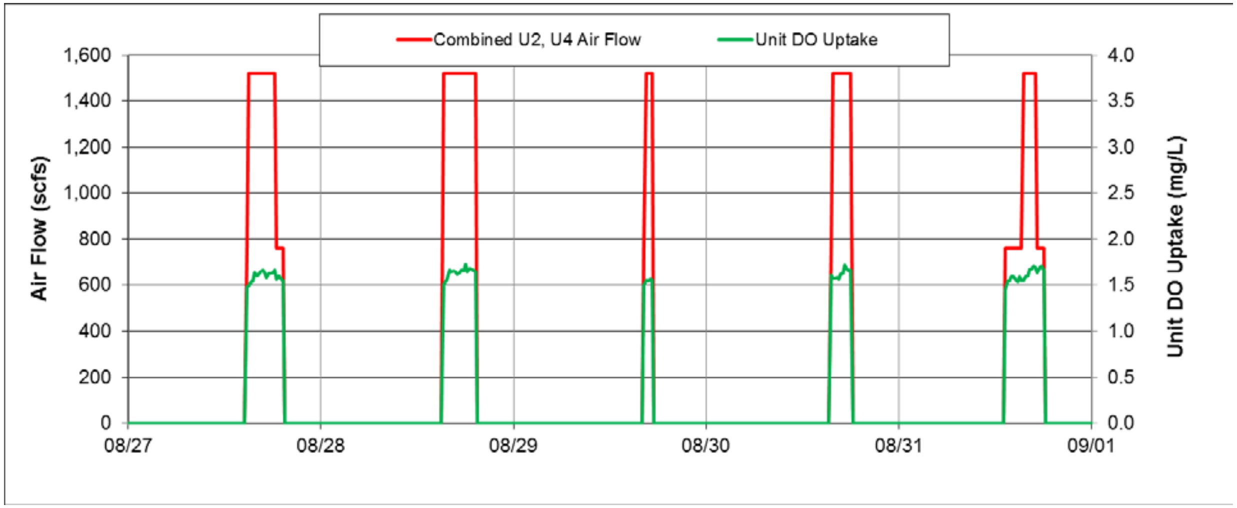
Temperature Withdrawal Curve

Depiction of a Turbine Withdrawal Zone

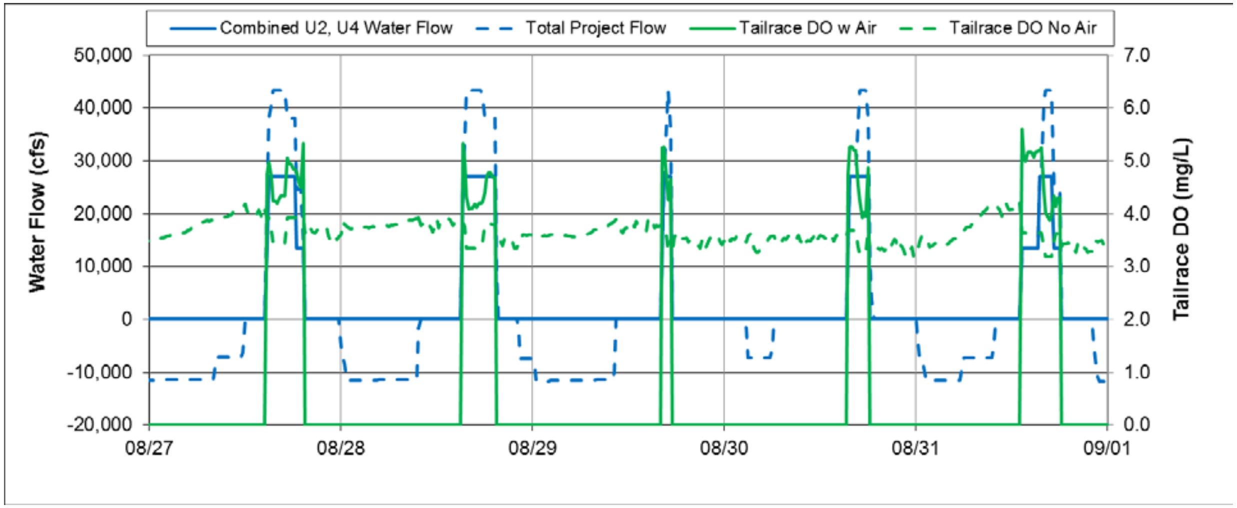


DO Withdrawal Curves for 2016, 2018, and 2020

Operation Analyses – Selected Results

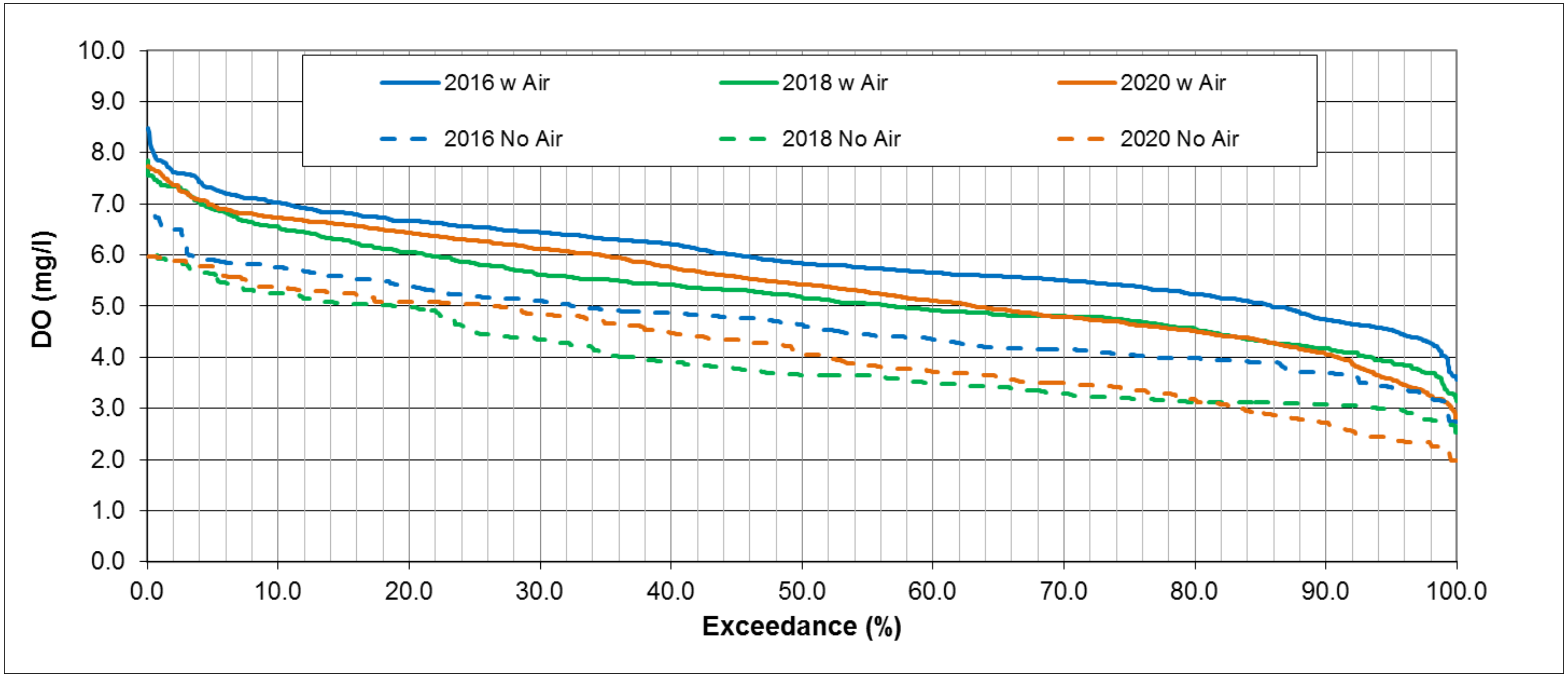


Example of Unit Air Flow and DO Uptake for a Five-Day Interval



Example of Tailwater DO with and without Air for a Five-Day Interval

Operation Analyses for 2016, 2018 and 2020– Exceedance Curves



DO Exceedance Curves (Project Flow>0)

Conclusions

- Installing aerating turbines at Units 2 and 4 represents a viable engineering measure for enhancing DO concentrations in the Smith Mountain Dam tailwater.
- Assessing the viability for aerating turbines at Units 2 and 4 to meet the daily average DO standard of 5.0 mg/L would require water quality modeling for both Smith Mountain Lake and Leesville Lake, which was beyond the scope of the current evaluation.
- Given the unique characteristics of the Smith Mountain Project, no engineering measure or combination of measures may enhance DO concentrations sufficient to meet the instantaneous and/or daily average standard 100% of the time during a given water quality monitoring year.
- This study utilized a turbine airflow model (TAM) based on a simplified air flow model, with proxy turbine specifications (i.e. from other projects). Turbine manufacturers are the best source of information for specifying the air flow and associated DO uptake that occur with aerating units.


Questions & Discussion

Extra Slides

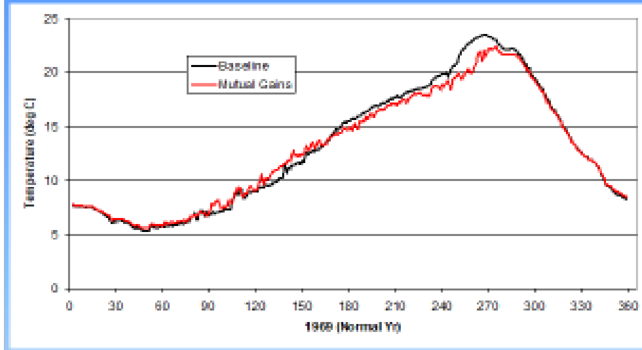
Additional Information

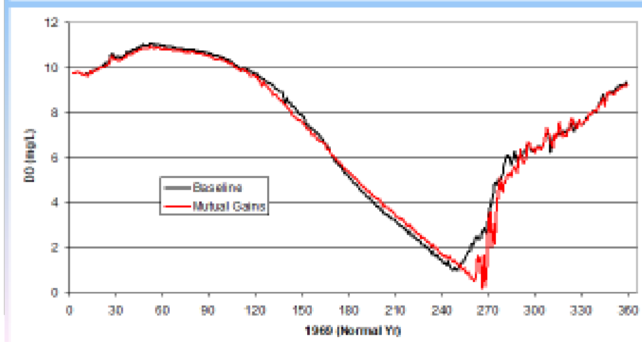
Basics of Gas Transfer

- Oxygen transfer is a function of the following:
  - Inlet dissolved oxygen (DO) level
  - Inlet temperature
  - Contact time
  - Contact surface area (bubble size)
  - Pressure during contact
- Air is 78% nitrogen, 21% oxygen, and 1% other inert gasses
- Nitrogen is transferred as well as oxygen, so care must be taken to analyze the Total Dissolved Gas (TDG) concentration.

Fundamentals of Low Dissolved Oxygen

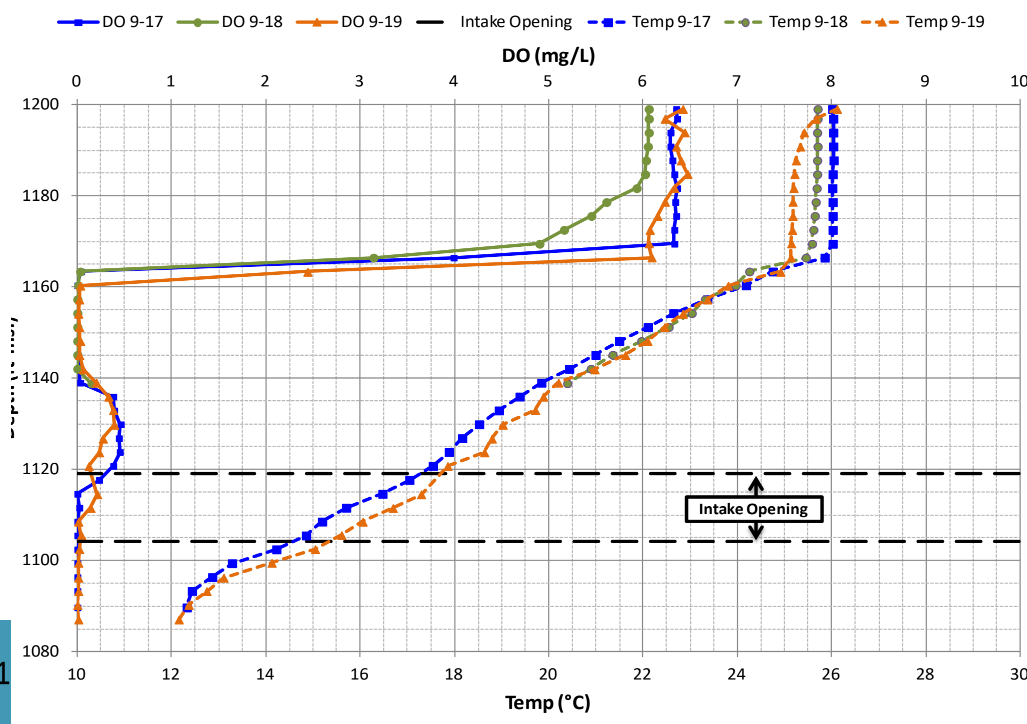
- The upper-right graphs are examples of how intake DO varies as a function of the calendar year, and how DO and temperature vary with depth of water column.
- The lower-right graph is typical of a deep reservoir with a deep turbine intake, similar to the Smith Mountain Project.
- Surface water is relatively rich in DO, but is also warm.
- DO falls off rapidly relatively high in the water column. Temperature declines as well.
- State water quality standards require an instantaneous minimum DO concentration of 4 mg/l and a 24-hour average of 5 mg/l.
- Limits on TDG are usually ≤112%. If TDG is too high, fish may get “the bends” and die.





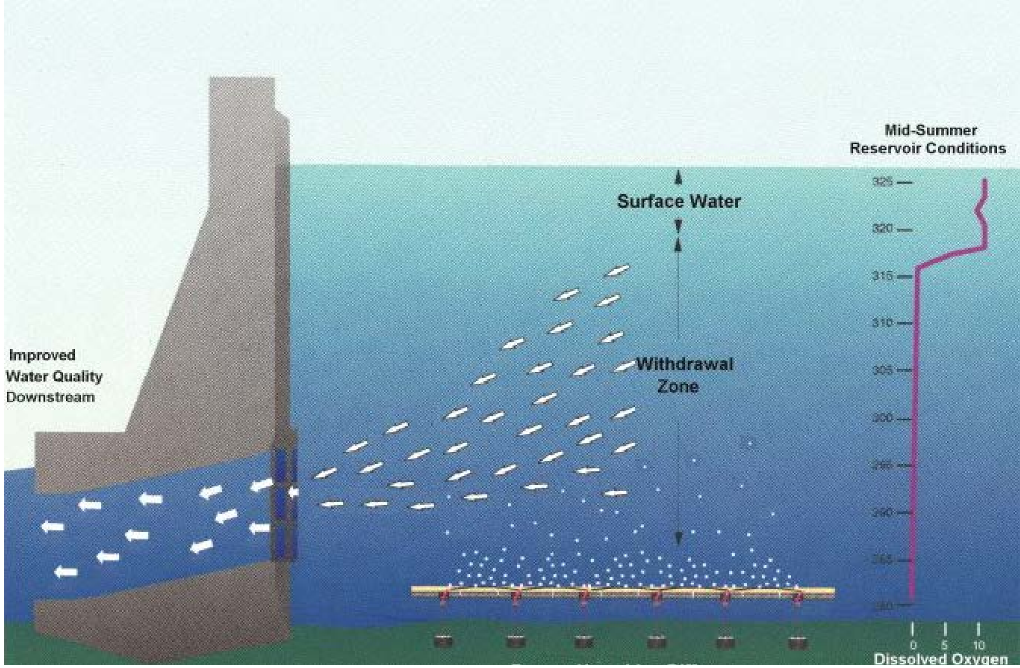
NOTE: Modeled release temperatures are estimated to be about 1 °C warm on day 180 and about 2 °C warm by day 270 in both Baseline and MG runs (based on regression of June and Oct release temperatures as function of Jan-Mar and April-Oct cumulative release flows using 1995-2002 data).

Lake James Release T and DO



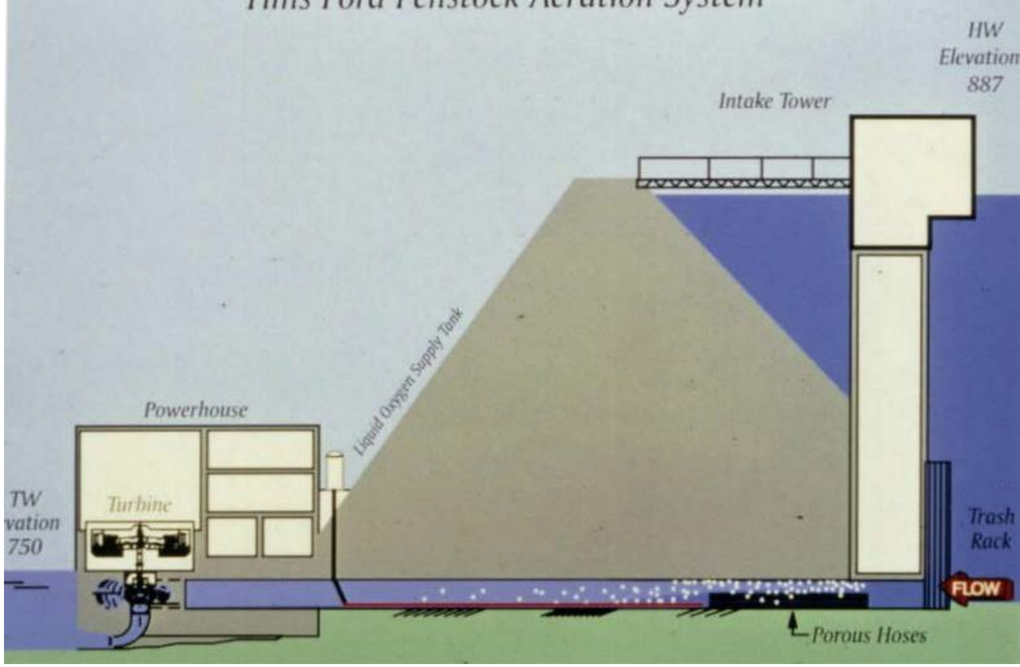
DO Enhancement Alternatives

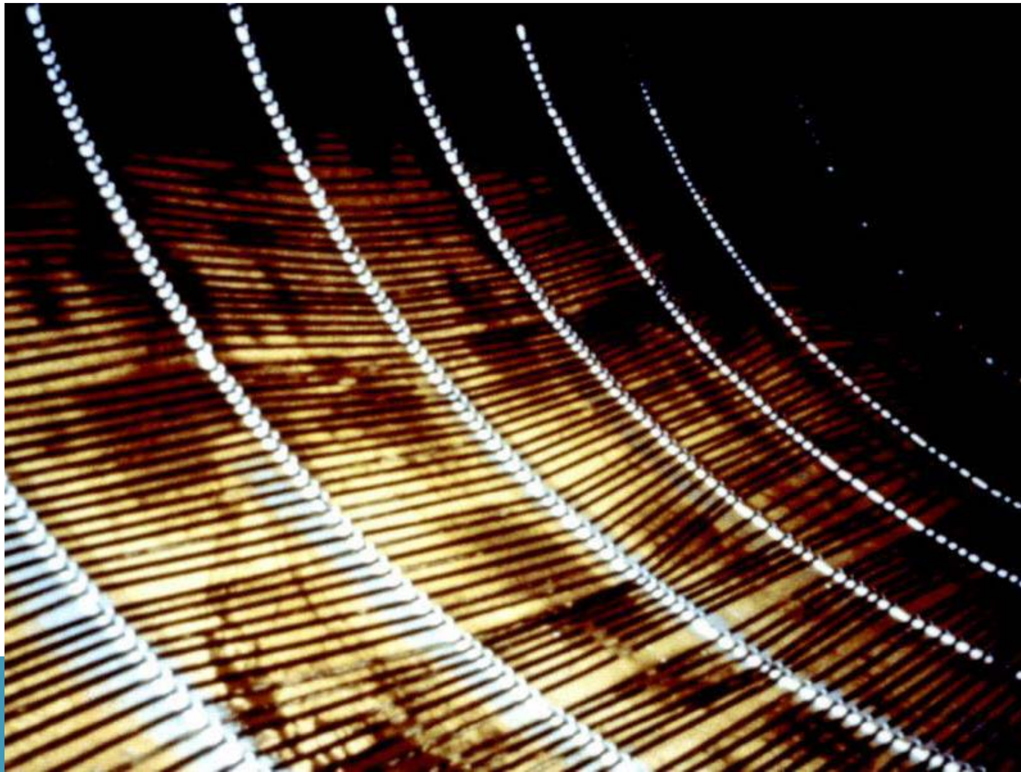
- Air/Oxygen Injection
  - Reservoir Oxygenation
    - Utilizes line diffusers placed upstream in the reservoir to increase DO levels. The line diffusers can be fed by liquid oxygen or air.
    - Line diffusers transfer oxygen efficiently and minimize temperature destratification / sediment disruption by providing a controllable flow rate and spreading gas bubbles over a very large area in the reservoir.
    - Oxygen is stored as liquid oxygen and then transitioned to gas via a vaporizer. The initial capital outlay for the equipment and reservoir line diffuser installation is not the controlling factor in a feasibility analysis. The annual O&M for the liquid oxygen as well as maintenance of the submerged line diffuser array is significant.
    - Line diffuser segments are covered with a porous material similar to a garden soaker hose that breaks the oxygen into a fine bubble plume.
    - Compressed air can be used in lieu of oxygen, but with reduced effectiveness.



DO Enhancement Alternatives **(cont'd)**

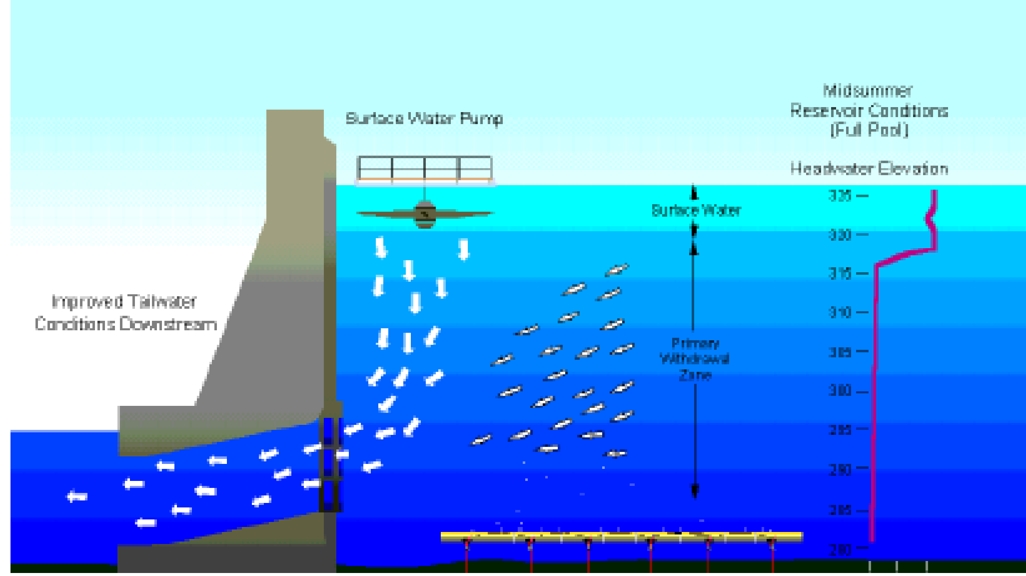
- Penstock Aeration
  - Penstock aeration involves injecting air or oxygen into the penstock just inside the intake using porous line diffusers.
  - When studying the feasibility of penstock aeration, usually field testing is performed. The objective is to inject air or oxygen into the penstock and measure the increase in DO at the draft tube and the tailrace.

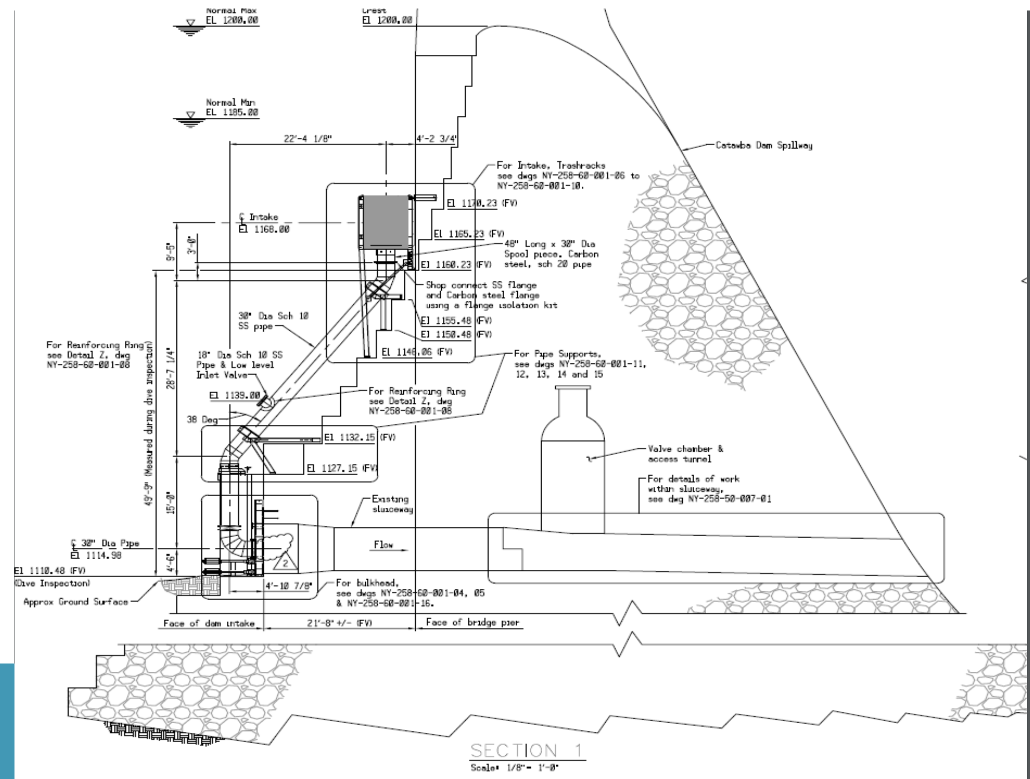




DO Enhancement Alternatives (cont'd)

- Reservoir Mixing
  - Thermal stratification of reservoir water causes water being drawn into the deep intakes of turbines to have DO concentrations that may be below state and federal minimum DO concentration requirements.
  - Reservoir mixing is the process of moving water with a higher DO concentration located at the top of the reservoir to the bottom by forcing it down with submerged, bladed equipment (i.e., surface water pumps).
- Selective Withdrawal
  - A curtain or barrier is placed in front of the intake, so only water from the oxygen-rich upper levels will be drawn into the turbine intake.
  - There are certain applications where a gated tower is used to allow selection of withdrawal levels to control temperature of the station discharge downstream.





DO Enhancement Alternatives (cont'd)

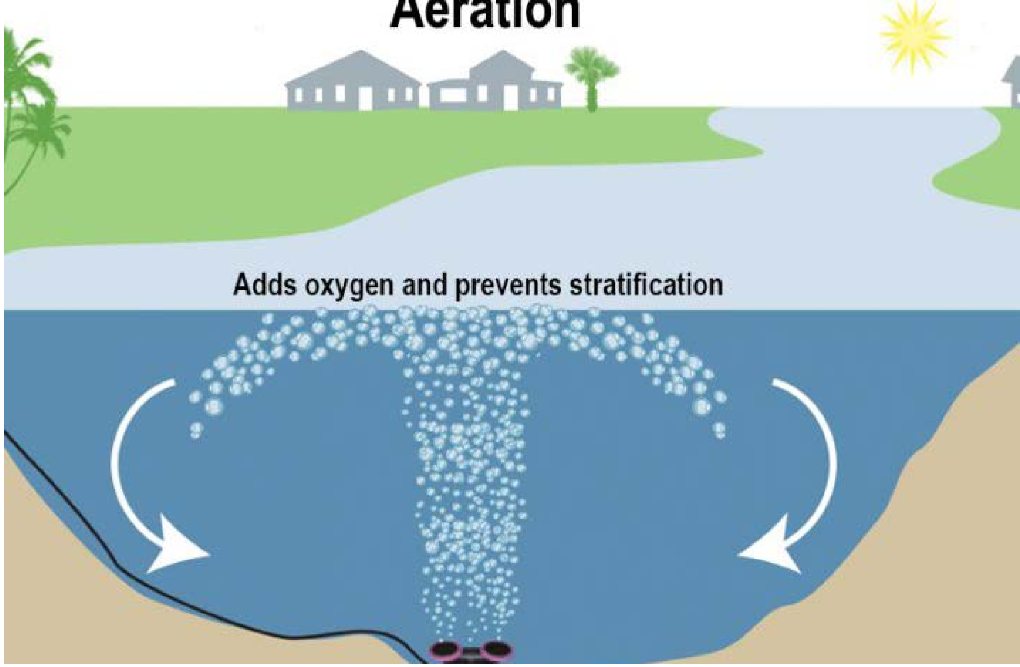
- Aeration using Compressed Air
  - This alternative utilizes an air compressor or centrifugal blower system to discharge compressed air either into the turbine discharge or to a diffuser fixed to the bottom of the tailrace immediately downstream of the draft tube discharge ring.
  - Temporary air compressor systems can be used to test the effectiveness of this alternative prior to proceeding with a full-scale installation.
  - This method is generally used when there is insufficient vacuum in the turbine draft tube to draw the needed amount of air under atmospheric pressure into the turbine discharge.
  - Compressed air is normally provided by low pressure and high volume air compressors or centrifugal-type blowers.
  - This method can be used for units set below tailwater like Kaplan-type units.
  - Air is injected below the runner through a manifold with small holes.

DO Enhancement Alternatives (cont'd)

- Energy Dissipation Valves
  - Typically hooded Howell-Bunger (i.e., ring jet) type valves are used. These valves facilitate the release of high energy water directly to atmosphere.
- Passive Aeration
  - Aerating Weir
    - Not applicable to pumped storage operation.
  - Surface Water Releases
    - This alternative involves aeration at project tailraces using selective withdrawal of upstream reservoir surface water through raised intakes, spillway gates, and trash sluice gates.

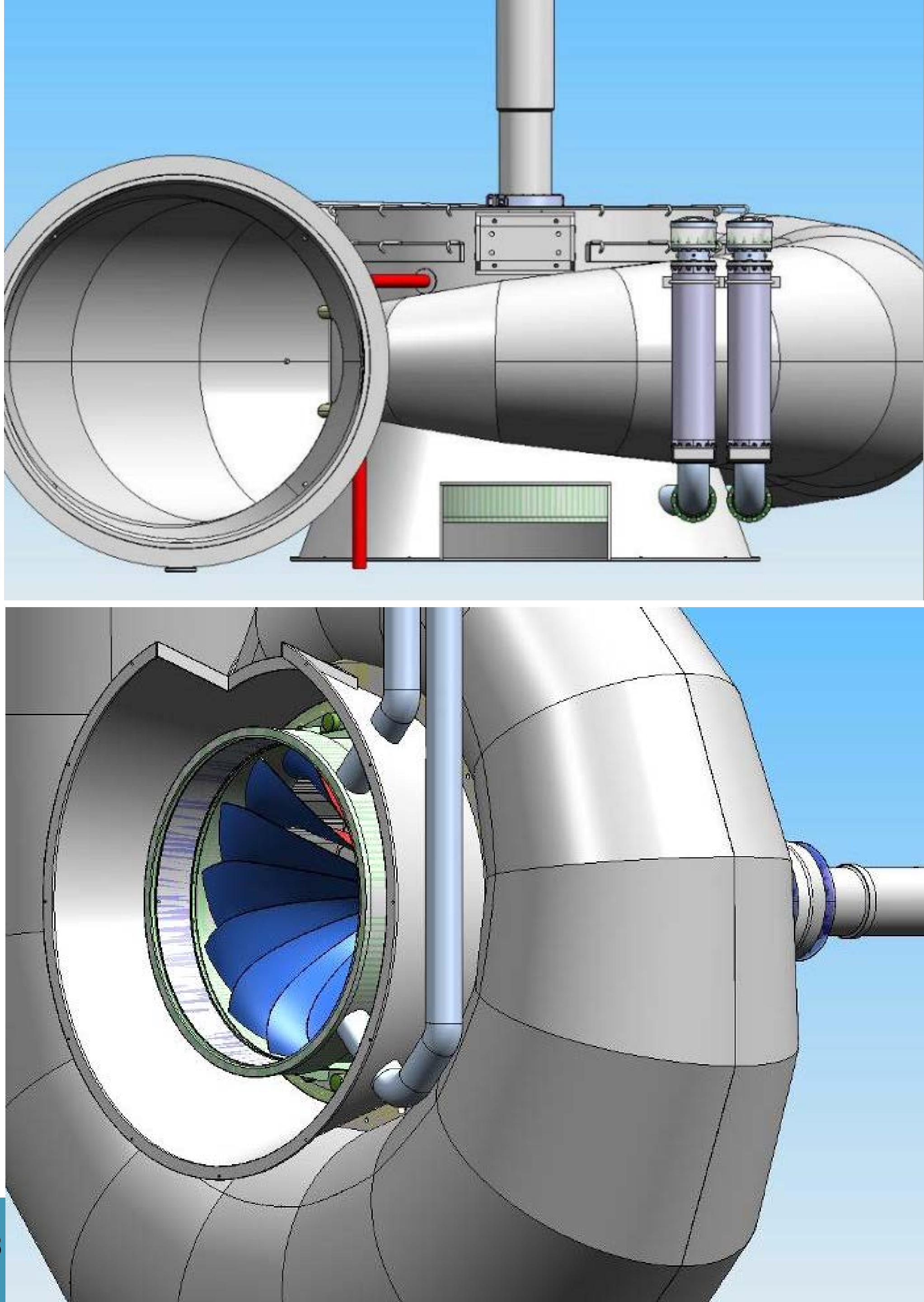
DO Enhancement Alternatives (cont'd)

- Tailrace Aeration
  - Line Diffusers with Air or Oxygen (same as Reservoir Line Diffusers)
    - This technology is applied in the tailrace, and is not generally considered to be technically feasible compared to other methods.
    - Oxygen Transfer Efficiency (OTE) values for tailrace locations compared to other available locations (i.e., forebay locations, penstocks, and draft tubes are low / unfavorable).
    - Line diffusers are subject to high flows from the dam, which can damage the equipment.
  - Surface Water Aerators
    - This technology is generally not effective for imparting any significant increase in DO due to low contact time and atmospheric pressure.
    - An array of these aerators would be required in the tailrace, perhaps a dozen or more. Even so, the transfer will be low (i.e., 2mg/l at most).



DO Enhancement Alternatives (cont'd)

- Turbine Aeration – Central Method
  - Very coarse method generally not recommended at this time.
- Turbine Aeration – Peripheral Method
  - Air is drawn into the turbine discharge through air baffles / ports or a slot located below the runner discharge.
  - For retrofit projects, excavation of the draft tube wall for installation of an air manifold is required.
  - The velocity of water flowing over the air baffles creates a region of low pressure, which generally boosts the vacuum.
  - As with the distributed type of aeration, air is drawn through silencers to muffle the sound created by the high velocity air.
- Turbine Aeration – Distributed Method
  - Discussed later in this presentation.



Alternatives <u>Not</u> Recommended for Smith Mountain Project

- Technologies that, at a high level, are either <u>not</u> considered to be viable or there are better alternatives for application at Smith Mountain:
  - Forebay Line Diffusers
  - Penstock Line Diffusers
  - Tailrace Line Diffusers
  - Forebay Surface Water Pumps
  - Tailrace Surface Aerators
  - Selective Withdrawal from the Upper Reservoir
  - Forced Aeration through the Turbine or Draft Tube
  - Turbine Discharge Aeration by the Central Method
  - Turbine Discharge Aeration by the Peripheral Method (Distributed Method Preferred)
- There are a variety of reasons why each of the types listed are not recommended.