Leesville Lake 2024
Water Quality Monitoring

Prepared for:
Leesville Lake Association

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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

Glossary of Terms

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 the water quality of Leesville Lake between April and October of 2024. University of Lynchburg monitored the lake seven times at the end of each month while the Leesville Lake Water Quality Committee monitored mid-month during June, July and August. The results of that monitoring are reported here with analysis of lake trends and a summary of management implications. The intent of this report is to provide technical and scientific background for sound management of Smith Mountain Lake (SML) and Leesville Lake (LVL) 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. The reservoir is quite stable in water quality as measured by the Trophic State Index showing slight eutrophy with measures between 50-60. Indicators in 2024 slightly worsened but these changes are within the variability observed year to year and do not suggest any negative trend. The upper portion of the reservoir continues to be plagued by low oxygen during late summer and early fall. This is attributable to low oxygen that develops in hypolimnion of SML during this time frame and has occurred since impoundment as reported in research from 1966. Management decisions to lower reservoir levels near the 600-foot minimum and then release large volumes of water from SML during the late summer early fall time frame significantly impacts LVL water quality.

An analysis of data from 2019-2024 was undertaken to provide a framework for characterization of the reservoir. These findings suggest upper regions of the reservoir are isolated from the lower with water constantly pumped back and forth. A significant water movement event is required to break up the pattern. Middle portions of the reservoir are characterized as riverine showing some characteristics of a lake while still influenced by river inputs. Lower portions of the reservoir near the dam show similar characteristics with water movement throughout a strong influence on water quality. It is believed that the size, shape and water flow in the reservoir is a strong organizing factor for water quality.

Data indicate that dissolved oxygen problems in the upper portion of the reservoir are generated by SML dam operations and suggest that greater attention to the implications of dam management during this timeframe would be beneficial. The remainder of the reservoir should be managed with concern to influx of nutrients and bacteria from the Pigg River and other tributaries. The lowering of lake levels in the fall should be done with caution and consideration over current water quality.

Section 1: Current Conditions

1.1 General:

This is the 14th year of water quality monitoring of Leesville Lake by University of Lynchburg (formerly known as Lynchburg College) in partnership with Leesville Lake Association (LLA). Twelve 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 order to further our understanding of watershed function we have gathered additional data in the watershed as each relates to water quality.

Section 1 documents results from 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. 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 measures are located in **Appendix C** for reference.

1.3 Site Descriptions

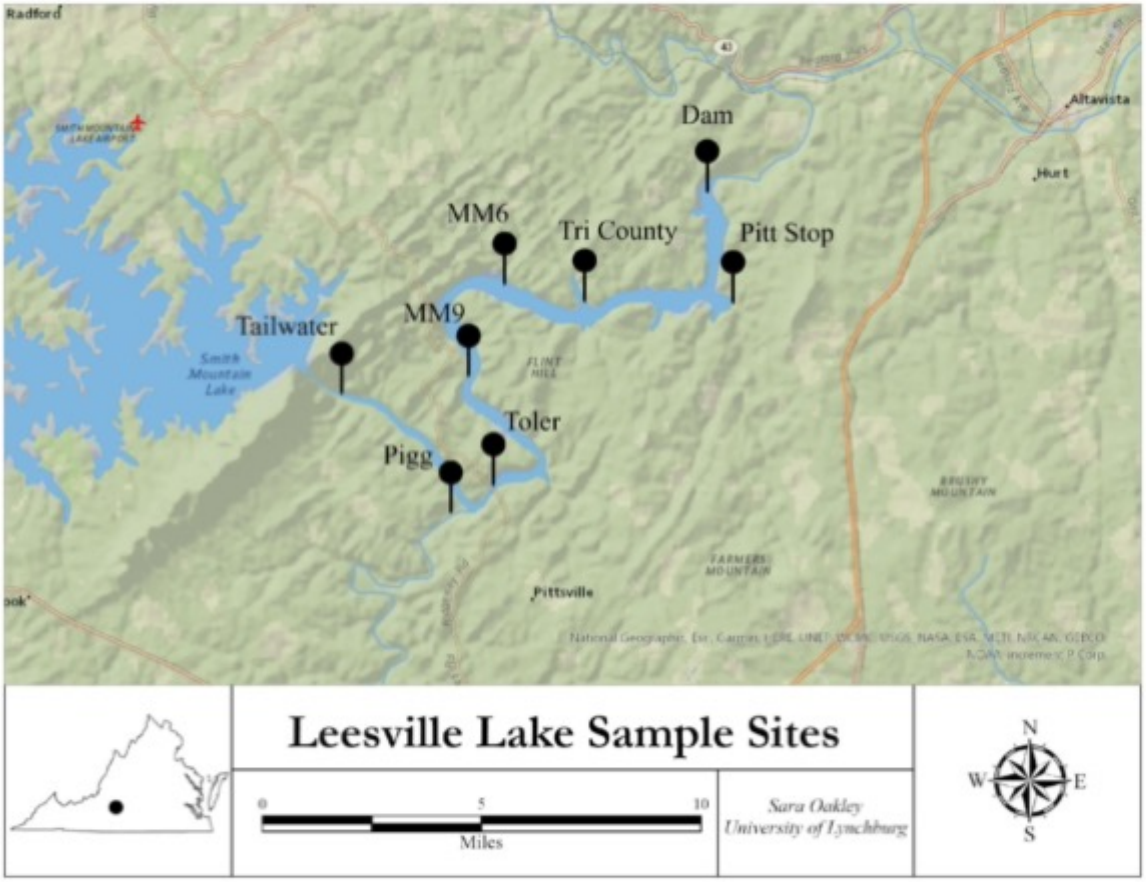


Figure 1.0 – Map of Leesville Lake showing locations of sampling stations along the reservoir.

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 (Originally Pitt Stop 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 Womans 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 1.0). 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.

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.

1.4 Leesville Lake Water Quality: Current Test Results

1.4.1 Temporal Analysis by Station

Background

Leesville Lake is a reservoir by definition (a glossary of terms used in this report is provided on page 8 for helpful 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 water 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 river systems with the Pigg River the most significant. This river drains a considerably large watershed with significant agriculture and some urban land disturbance throughout. These inputs and pumping operations at the Smith Mountain Lake Dam create a unique hydrology that impacts the water quality of the reservoir.

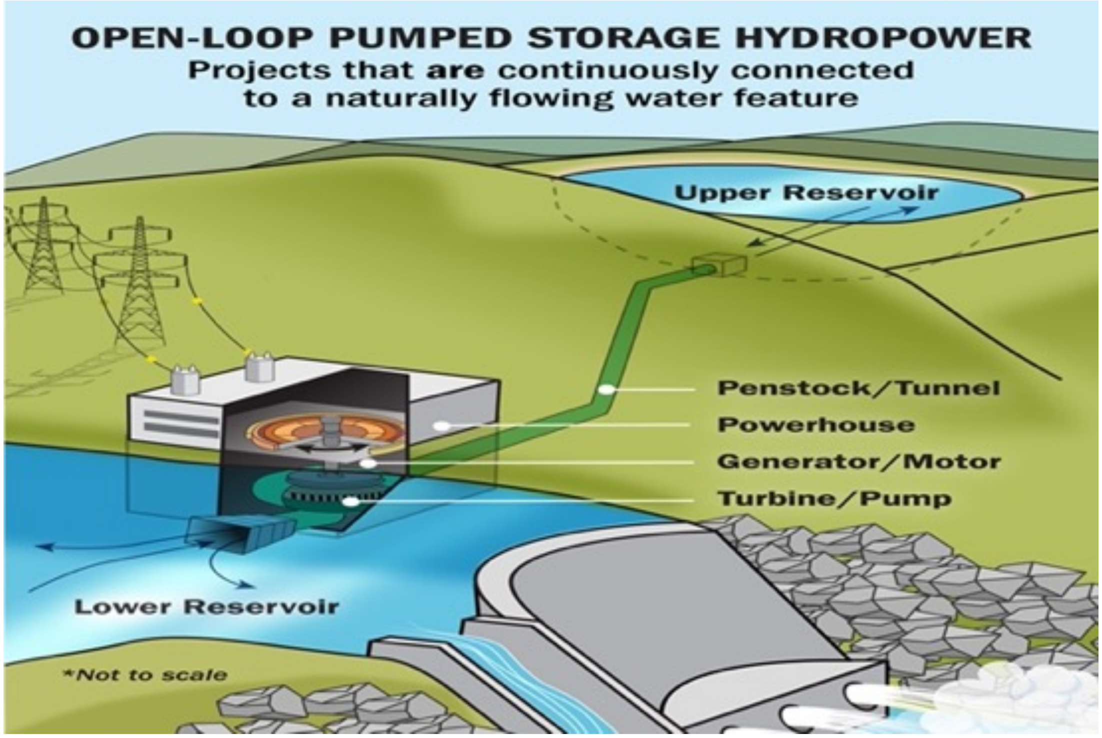


Figure 1.1 – Graphical representation of a pump-storage reservoir. Water from lower (storage reservoir) is pumped up to the upper reservoir to generate power by spinning turbines in the dam. (graphic from Dept. of Energy at energy.gov).

In any reservoir, water quality needs evaluation along a spatial and horizontal 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 exhibit 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.

Because Leesville Lake is a storage reservoir it does not necessarily follow this typical pattern (Fig 1.1). 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 particularly during storm events. While there are many pump-storage reservoir systems in the US, each one has unique properties due to the input of various river systems.

Additionally, the headwater region of Leesville Lake is subject to a bidirectional movement of water. During pump back operations water flows 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. During pump back, the strongly impacted area within Leesville Lake is the 4 mile segment from the Pigg River mouth to the SML dam. 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 is 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.

1.4.1.1 Dam (Lacustrine)

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

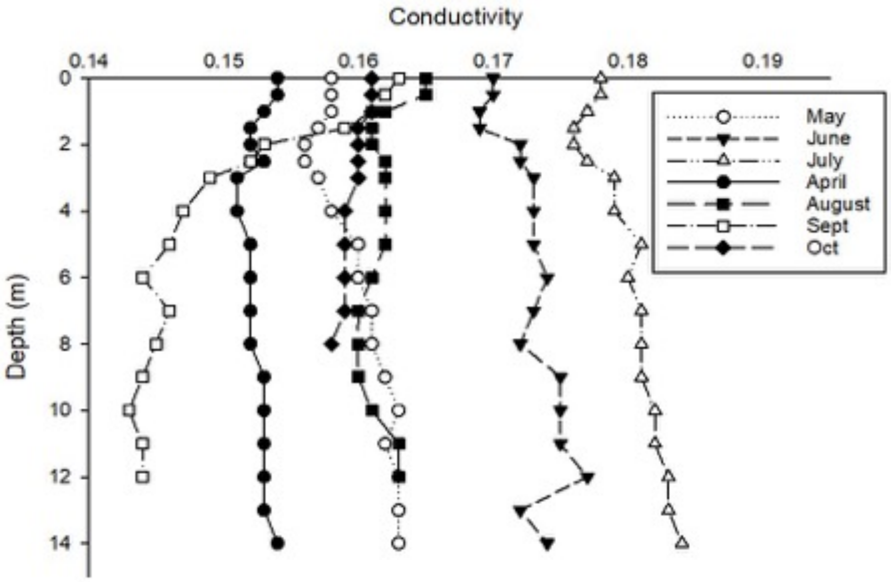


Figure 1.2. Dam (Lacustrine) Conductivity (ms/cm) measures over study period (2024)

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 is of lower conductivity than SML tail water. The resultant disparity in conductivities can be explained based by comparing the Roanoke River / SML data to Pigg River / LVL. As reported by Ferrum College in SML monitoring, conductivities in SML are between 150-200 us/cm. We measure conductivity at Pigg River between 70 – 80 us/cm. While tail water release contains less pollutants than Pigg River entering Leesville the tail water still reflects the higher conductivity of the Roanoke River that does contain a high pollution load when it enters SML. This pollutant loading from the Roanoke River with high Biological Oxygen Demand (BOD) creates the oxygen loss observed in the hypolimnion of SML.

In June and July of 2024, waters at the dam were relatively high in conductivity reflective of discharge from SML. As is typical, September conductivity were lowest and this was reflective of stormwater inputs and movement of water through the reservoir from river input rather than SML release. This trend is reflective in the other parameters.

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 impact throughout the reservoir. These trends are analyzed in the management section of this report.

Dissolved Oxygen

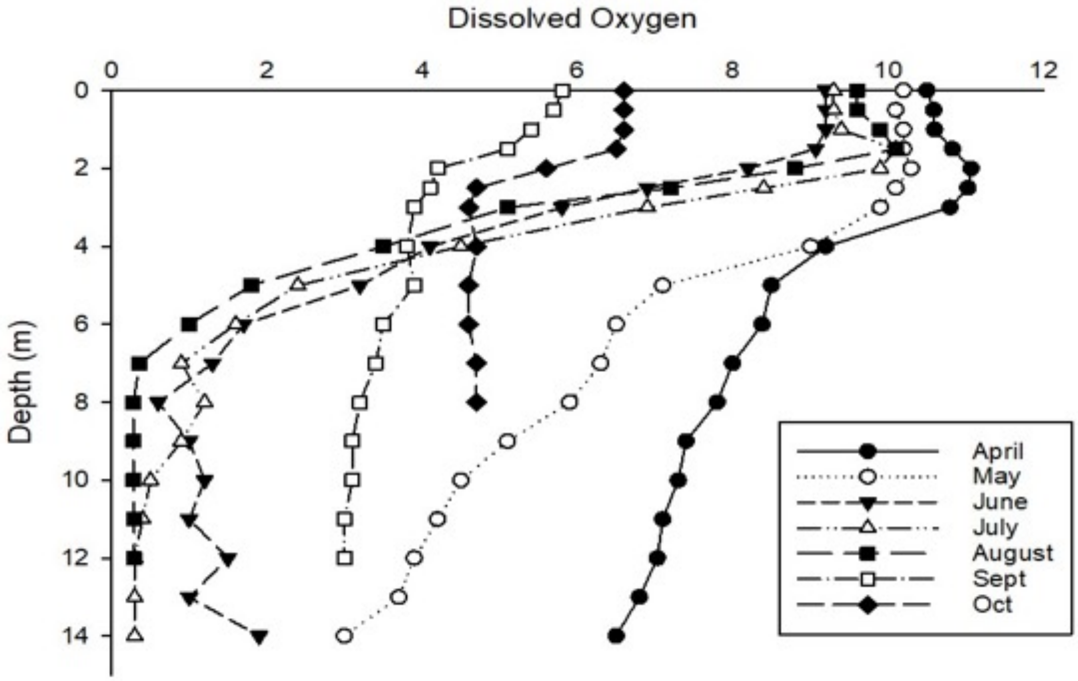


Figure 1.3. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2024)

Seasonal Analysis

Dissolved oxygen patterns in the reservoir demonstrate that the lake is eutrophic, that is stratifies throughout the sampling period and that oxygen loss occurs quickly beginning at approximately 2 meters depth. Between 2-4 meters depth the loss of oxygen is variable and dependent upon environmental conditions (temperature and precipitation). 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 from June through August. With some variation, this is the typical pattern for the reservoir. September was impacted by stormwater creating not only turnover but relatively low oxygen levels throughout the reservoir. Oxygen did increase in October. Stormwater has a significant impact in 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 can mix often due to precipitation events) it takes a very strong storm event for mixing to occur at the dam. This did occur this season in September. Alternatively, the reservoir may be considered monomictic only mixing in the fall. Also, the degree of oxygen loss (how low observed levels of oxygen are 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

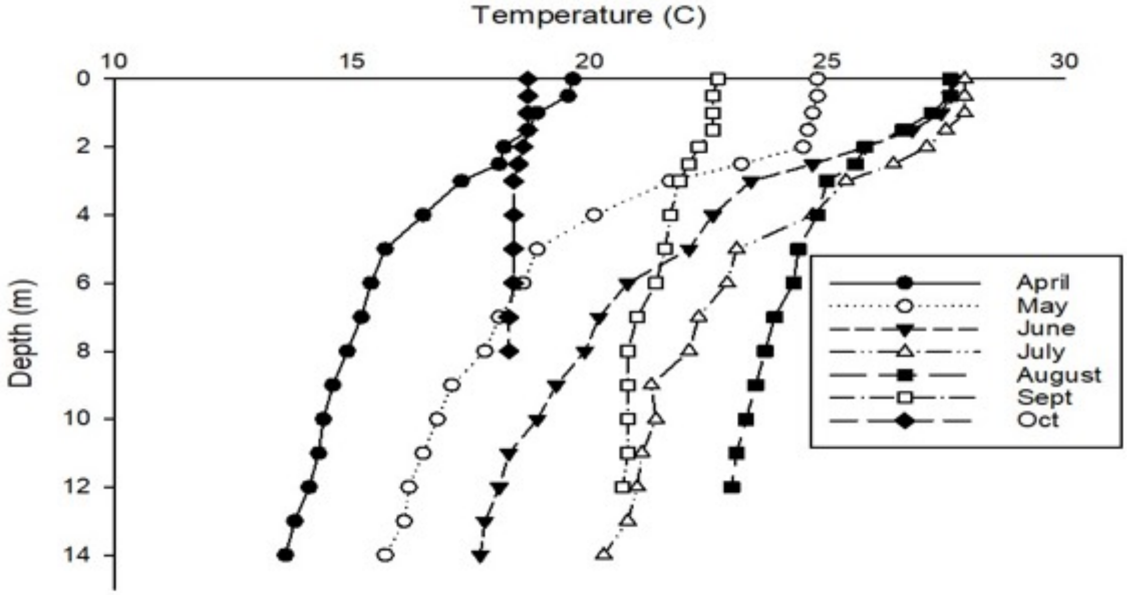


Figure 1.4. Dam (Lacustrine) Temperature (°C) measures over study period (2024)

Seasonal Analysis

Stormwater caused the reservoir to mix in September and this condition remained through the October sampling. Mixing occurs either when the temperature of the reservoir becomes homogeneous due to cooling air temperatures or a rain event pushes enough water into the reservoir to disrupt the established layers. Without a rain event to mix the reservoir it is typically stratified in April as we observed in 2024.

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. It is not uncommon to see temperatures reach 30C in these profiles but in some years (2019 and 2023 and 2024) the water did 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*

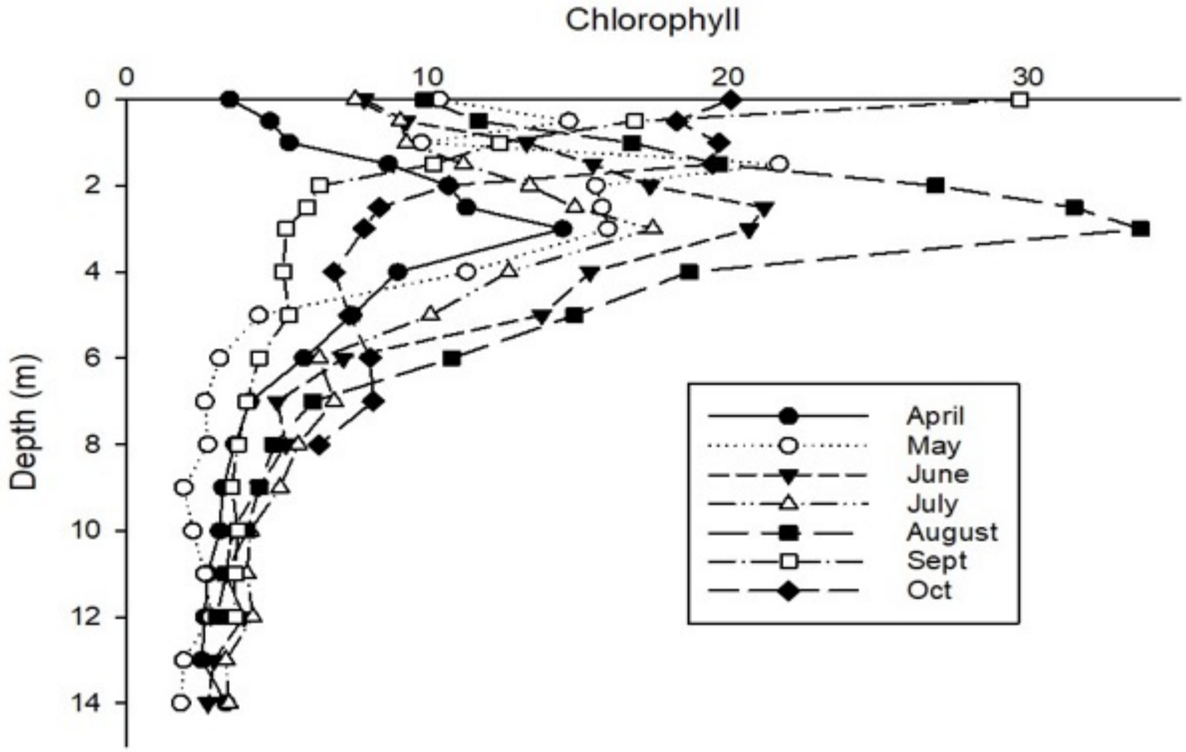


Figure 1.5. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2024)

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 2024, phytoplankton seasonal peaks were observed at 4 meters depth very similar to years past. The increase in productivity at 4 meters begins in May and peaked in August this season at over 30 ug/L. This is considerably eutrophic and concerning. Another seasonable observation was the breakup and apparent transport of chlorophyll maximum to the surface in September. This demonstrates the observed pattern during stormwater mixing in the reservoir.

Comparisons Across Years

The pattern of increased phytoplankton along the 2-4 meter thermocline (metalimnion) in the reservoir is a well-established phenomenon in eutrophic lakes. This season's peak was somewhat greater than observations in the past peaking over 30 ug/L. This measure has variability and must be monitored closely to track eutrophication. Certainly, as observed in September stormwater entering the reservoir and flushing of phytoplankton biomass is a strong driver of this variability.

pH

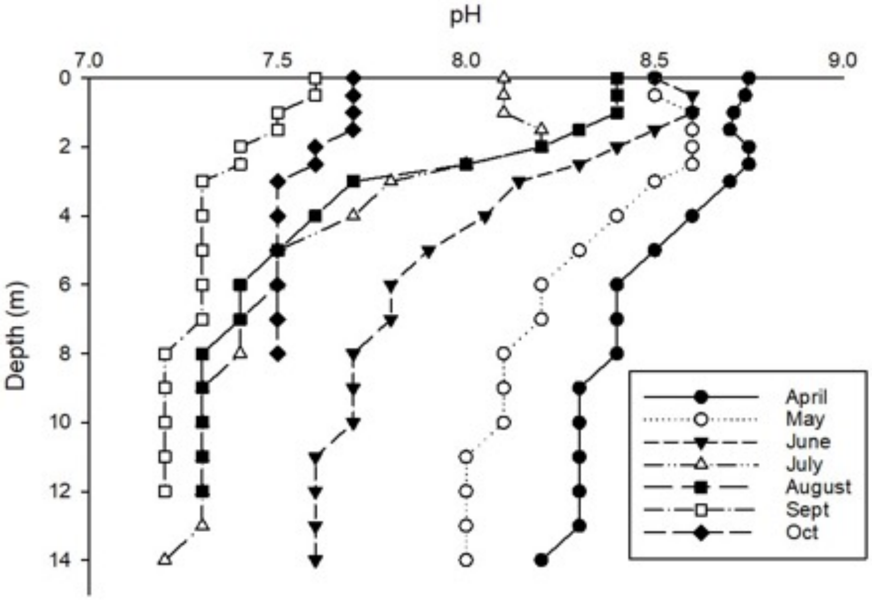


Figure 1.6. Dam (Lacustrine) pH measures over study period (2024)

Seasonal Analysis

The pH of water in the reservoir follows a typical curve for eutrophic reservoirs with soft water. Chlorophyll productivity is a strong driver of pH (wherein phytoplankton depletion of carbon dioxide increaes pH) so it is not clear why the early months (April and May) were highest in pH other than June – August did not see pH rise up to 9. Phytoplankton productivity is not solely responsible for pH change. As expected, stormwater input during September drove pH to lowest measures for the season.

Comparisons Across Years

The pattern of pH observed in the reservoir is relatively consistent across years. High pH (9 and above) 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 peaks were lower than seen in most years. Multiple factors help drive this pattern.

ORP

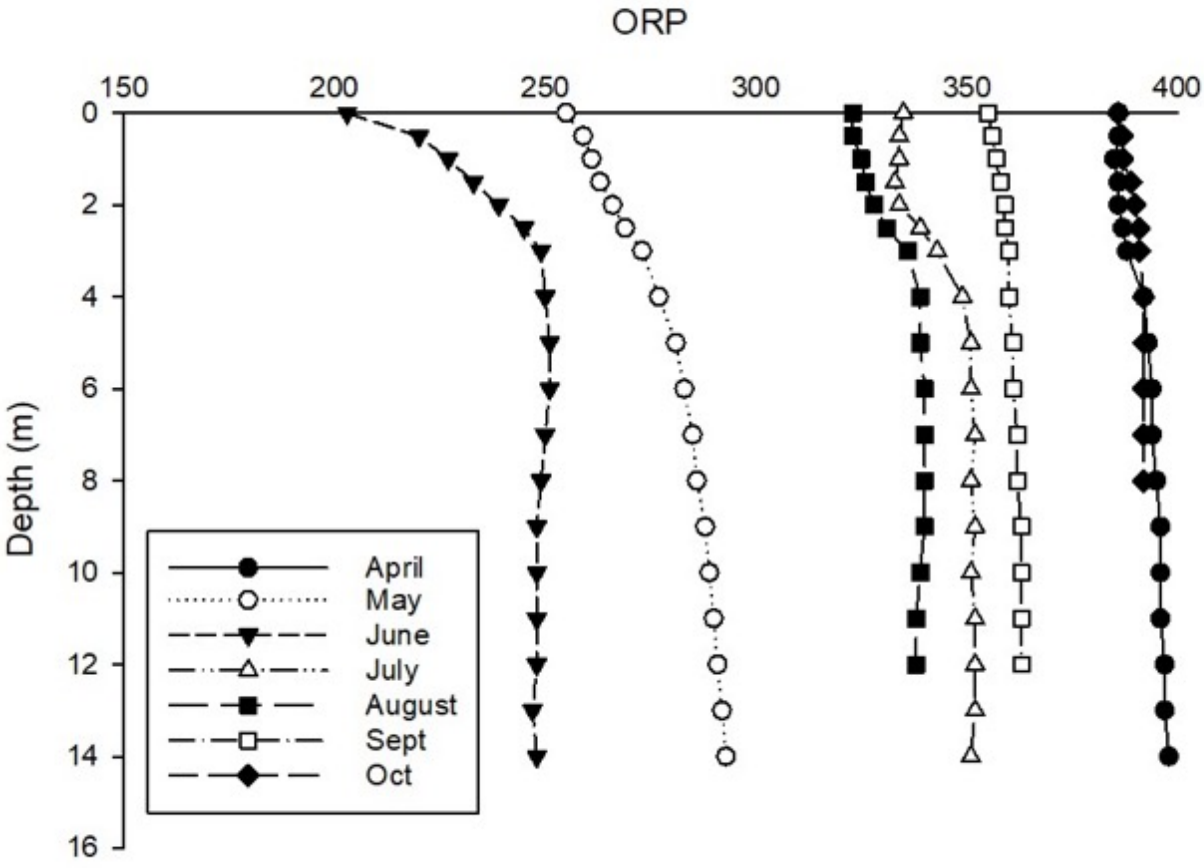


Figure 1.7. Dam (Lacustrine) ORP (mV) measures over study period (2024) Seasonal Analysis

ORP remains in the very oxidized region through the sampling period. There is a pattern of slightly increased ORP with increasing water depth. This season ORP increases did not necessarily correlate with any seasonal changes. This is not that unusual or concerning as the lake remains in a very oxidized state throughout.

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.

Nitrate

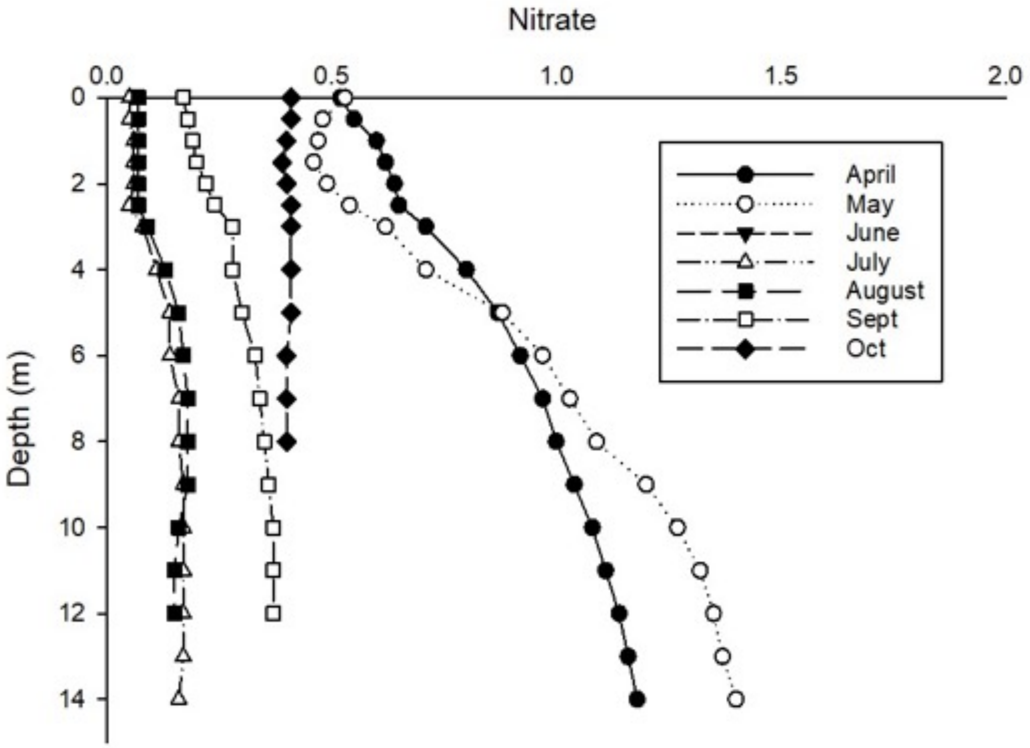


Figure 1.8. Dam (lacustrine) Nitrate (mg/L) measures over study period (2024)

Seasonal Analysis

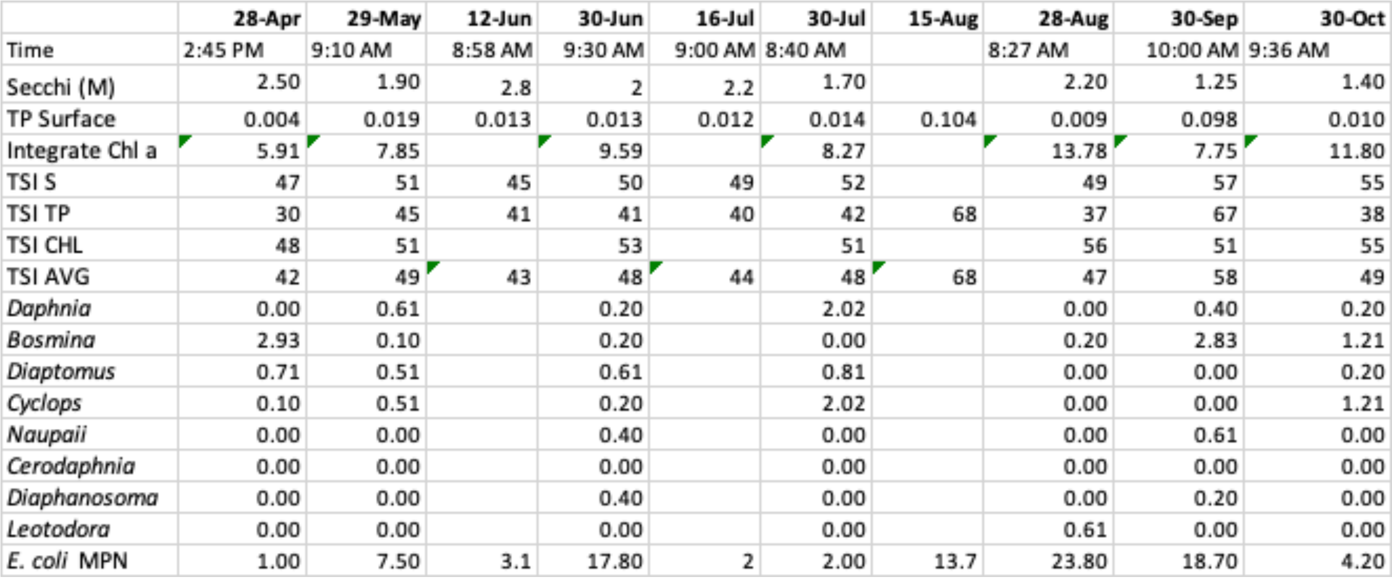
Nitrate patterns suggest general availability of nutrients during spring and fall and minimal availability during the summer months. This follows typical pattern as the uptake of nutrients during higher productivity periods reflects less available in the water for uptake. This is also reflective in the difference between levels measured in the epilimnion compared to the hypolimnion. The greatest concern is the amount of nitrate availability with concentrations exceeding 1 mg/L early in the season.

Comparisons Across Years

More data on Nitrate is needed for yearly comparisons.

Other Parameters Measured

Table 1.10. Other parameters measured over study period (2024). Dates represent sampling of both the volunteers and University of Lynchburg. First Column represents each parameter measured along with units of measure.

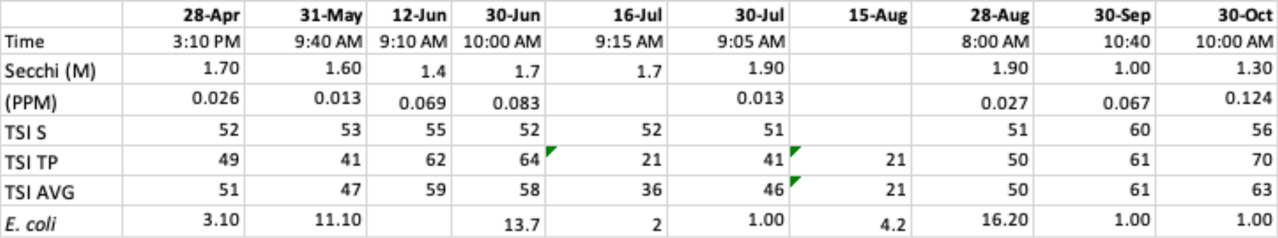


	28-Apr	29-May	12-Jun	30-Jun	16-Jul	30-Jul	15-Aug	28-Aug	30-Sep	30-Oct
Time	2:45 PM	9:10 AM	8:58 AM	9:30 AM	9:00 AM	8:40 AM		8:27 AM	10:00 AM	9:36 AM
Secchi (M)	2.50	1.90	2.8	2	2.2	1.70		2.20	1.25	1.40
TP Surface	0.004	0.019	0.013	0.013	0.012	0.014	0.104	0.009	0.098	0.010
Integrate Chl a	5.91	7.85		9.59		8.27		13.78	7.75	11.80
TSI S	47	51	45	50	49	52		49	57	55
TSI TP	30	45	41	41	40	42	68	37	67	38
TSI CHL	48	51		53		51		56	51	55
TSI AVG	42	49	43	48	44	48	68	47	58	49
Daphnia	0.00	0.61		0.20		2.02		0.00	0.40	0.20
Bosmina	2.93	0.10		0.20		0.00		0.20	2.83	1.21
Diaptomus	0.71	0.51		0.61		0.81		0.00	0.00	0.20
Cyclops	0.10	0.51		0.20		2.02		0.00	0.00	1.21
Naupaii	0.00	0.00		0.40		0.00		0.00	0.61	0.00
Cerodaphnia	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Diaphanosoma	0.00	0.00		0.40		0.00		0.00	0.20	0.00
Leotodora	0.00	0.00		0.00		0.00		0.61	0.00	0.00
E. coli MPN	1.00	7.50	3.1	17.80	2	2.00	13.7	23.80	18.70	4.20

1.4.1.2 Leesville Lake Marina / Old Woman's Creek

Photograph of Leesville Lake Marina taken by Jade Woll.

Table 1.11. Leesville Lake Marina other parameters measured over study period (2024).

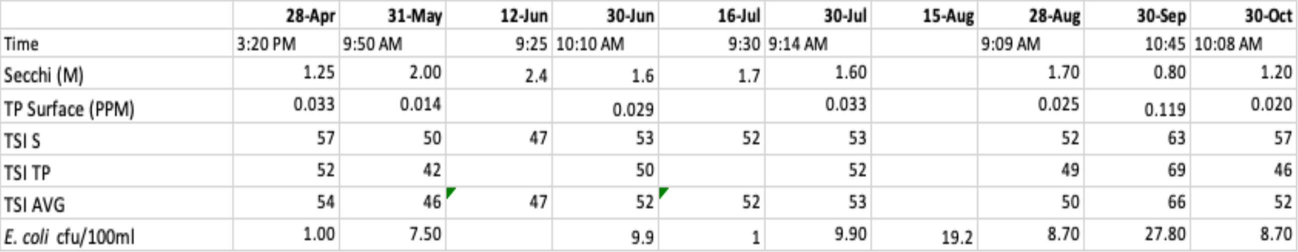


	28-Apr	31-May	12-Jun	30-Jun	16-Jul	30-Jul	15-Aug	28-Aug	30-Sep	30-Oct
Time	3:10 PM	9:40 AM	9:10 AM	10:00 AM	9:15 AM	9:05 AM		8:00 AM	10:40	10:00 AM
Secchi (M)	1.70	1.60	1.4	1.7	1.7	1.90		1.90	1.00	1.30
(PPM)	0.026	0.013	0.069	0.083		0.013		0.027	0.067	0.124
TSI S	52	53	55	52	52	51		51	60	56
TSI TP	49	41	62	64	21	41	21	50	61	70
TSI AVG	51	47	59	58	36	46	21	50	61	63
E. coli	3.10	11.10		13.7	2	1.00	4.2	16.20	1.00	1.00

1.4.1.3 Tri County Marina

Photograph of Tri County Marina taken by Jade Woll.

Table 1.12. Tri County Marina other parameters measured over study period (2024).



	28-Apr	31-May	12-Jun	30-Jun	16-Jul	30-Jul	15-Aug	28-Aug	30-Sep	30-Oct
Time	3:20 PM	9:50 AM	9:25	10:10 AM	9:30	9:14 AM		9:09 AM	10:45	10:08 AM
Secchi (M)	1.25	2.00	2.4	1.6	1.7	1.60		1.70	0.80	1.20
TP Surface (PPM)	0.033	0.014		0.029		0.033		0.025	0.119	0.020
TSI S	57	50	47	53	52	53		52	63	57
TSI TP	52	42		50		52		49	69	46
TSI AVG	54	46	47	52	52	53		50	66	52
E. coli cfu/100ml	1.00	7.50		9.9	1	9.90	19.2	8.70	27.80	8.70

1.4.1.4 Mile Marker 6 (Transition)[1]

Background

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

Conductivity

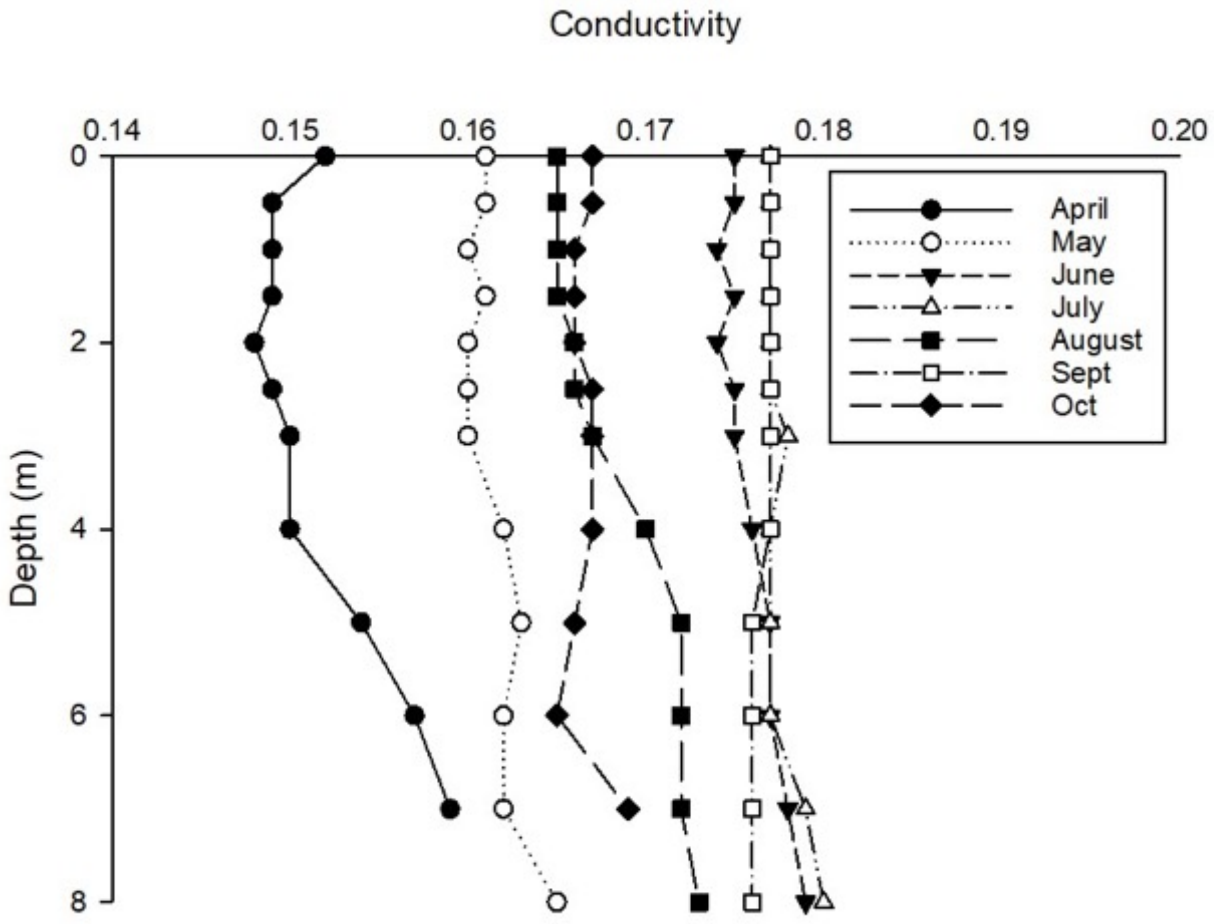


Figure 1.9. Mile Marker 6 (Transition) Conductivity (ms/cm) measures over study period (2024)

Seasonal Analysis

Conductivity patterns at the transition region are reflective of a mixed condition, i.e., a general absence of stratification as we see at the dam. Consistent readings from surface to depth at this station support this conclusion. In 2024, early season conductivities were between 0.16-0.17 ms/cm with conductivities increasing as the season progressed suggesting greater release from SML at this station. September readings were the confounding measure as conductivities were high similar to SML release and much greater than at the dam. This supports the idea that water moves as slugs in the reservoir and mixes as well. Other readings were suggestive of stormwater input influence yet this water is typically lower in conductivity as reflected in the Pigg River. While other parameters suggest this stormwater impact is occurring conductivity did not reflect this pattern. This needs to be taken into consideration when interpreting data.

Comparisons Across Years

Conductivity is a good predictor of water masses and movement in the reservoir. The complexity of this analysis occurs when water movement into the reservoir from the Pigg River and SML tail release mix and move below entrainment in the upper portion of the reservoir. An analysis of this idea is in the management section.

Dissolved Oxygen

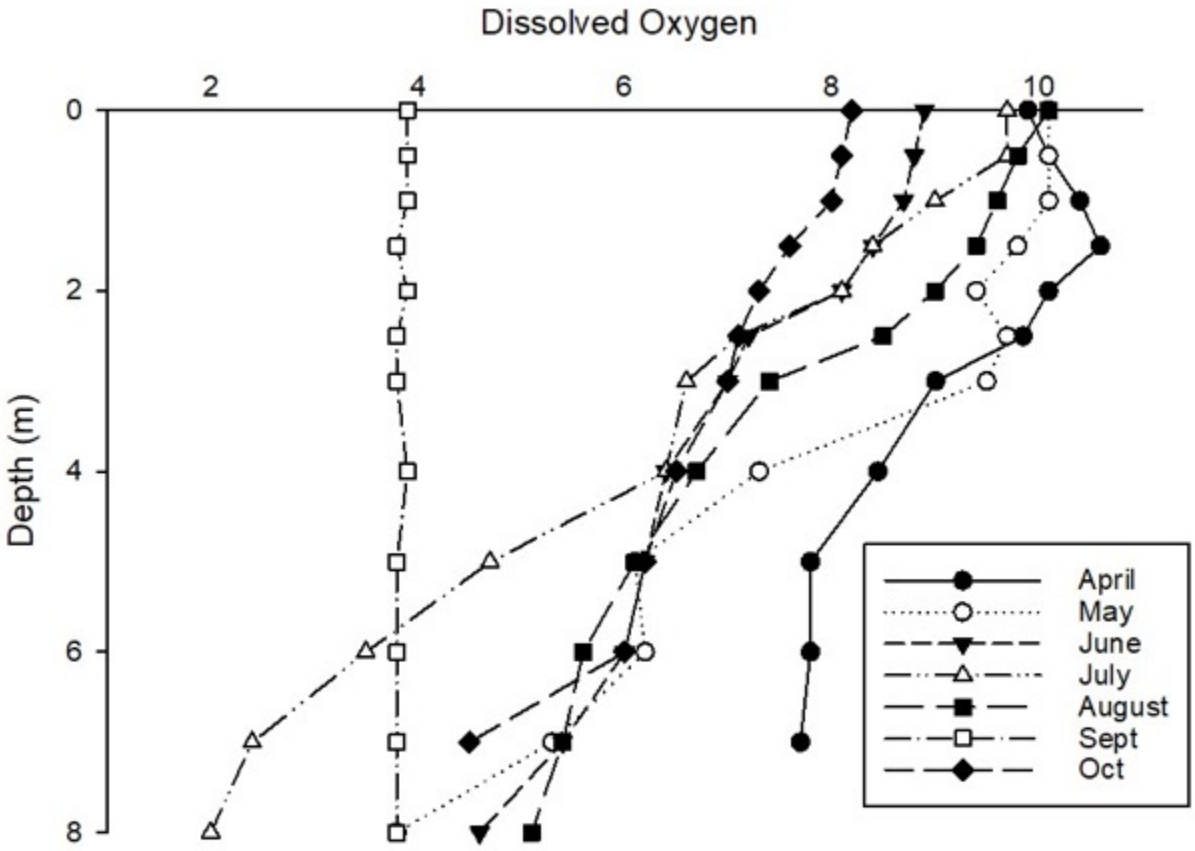


Figure 1.10. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2024)

Seasonal Analysis

This portion of the reservoir was stratified throughout the sampling season with the exception of September sampling. Most concerning observation during this season was the reduction of oxygen below 4 mg/L throughout the reservoir in September (as evidenced in Figs 1.3, 1.9, 1.16 at the Dam, MM6 and Toler Bridge, respectively). It appears that heavy hurricane rains broke up stratification and flooding concerns promoted excessive release of low oxygenated water from SML (3.8 mg/L measured at the tail release) into LVL while maintained at low water levels (near 600 ft).

Comparisons Across Years

Oxygen observations are variable across seasons and within season with supersaturated conditions in the epilimnion and hypoxic and anoxic conditions apparent in the hypolimnion typical of eutrophic lakes. However, it became very apparent this sampling season (2024) that SML operations have the ability to cause most of Leesville Lake to become deficient in oxygen (below 5 mg/L) throughout. The breaking up of stratification mixing the hypolimnion with the epilimnion due to water release coupled with SML hypolimnion release and low lake levels near 600 feet can create very poor water quality and concern. Further analysis is provided in the management section.

Temperature

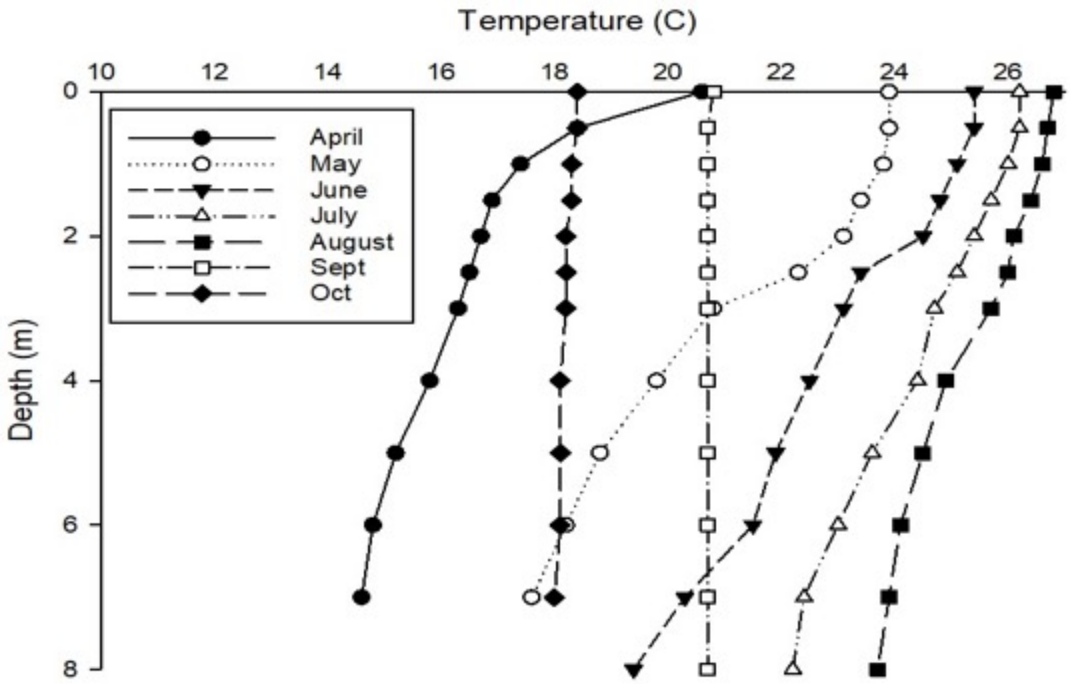


Figure 1.11. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2024)

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

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*

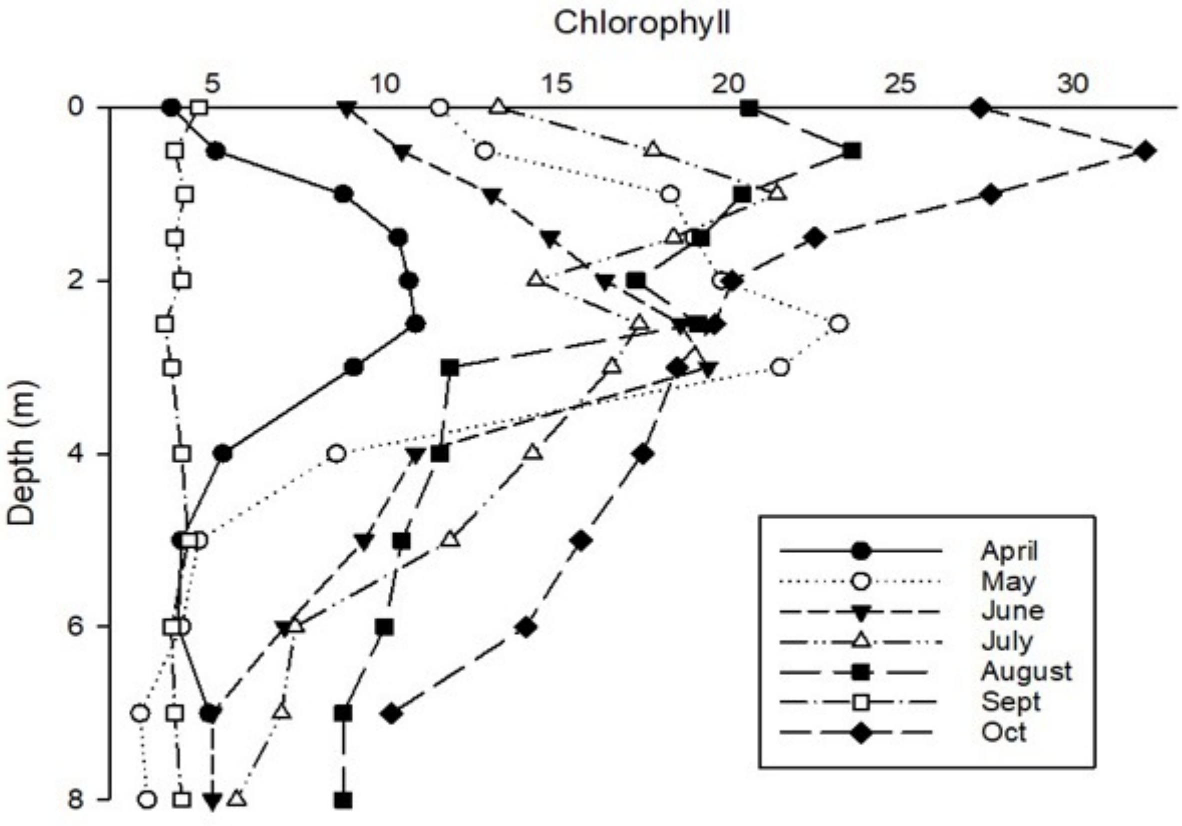


Figure 1.12. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2024)

Seasonal Analysis

The transition area is theoretically the portion of the reservoir where phytoplankton abundance measured by Chlorophyll *a* can be very high and may be the greatest in the entire reservoir. 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. This was not observed this season (Chlorophyll at the Dam and MM6 were similar, Fig 1.5 vs Fig 1.11) but peak concentrations exceeding 30 ug/L were observed at the dam in August and at MM6 in October. is likely due to the conditions created in September with stormwater and SML input elevating TP concentrations (0.115 mg/L) Table 1.19. Chlorophyll and productivity responded. This suggests again that operations can have a very profound impact on the condition of eutrophication in Leesville Lake.

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. This season's measures were clear. Chlorophyll *a* minima may occur during flushing and turnover but respond and increase when conditions normalize (flushing stops and levels stabilize) and phosphorus is readily available.

pH

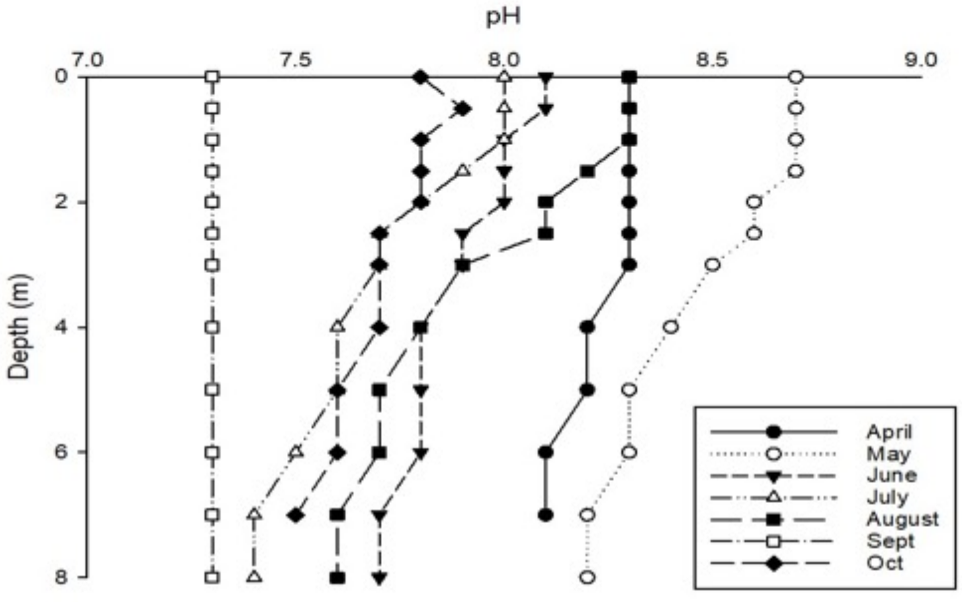


Figure 1.13. Mile Marker 6 (Transition) pH measures over study period (2024)

Seasonal Analysis

The pH pattern is very similar to that observed at the dam and the pattern of stratification in the reservoir. Elevated pH does follow the pattern of Chlorophyll *a* in some instances, with the summer months higher pH measures occurring during peak phytoplankton biomass. But it is clear that observations during this season suggest other factors impact pH as well.

Comparisons Across Years

This is a variable station and influenced by a multitude of factors. Readings generally reflect conditions that influence phytoplankton growth.

<u>ORP</u>

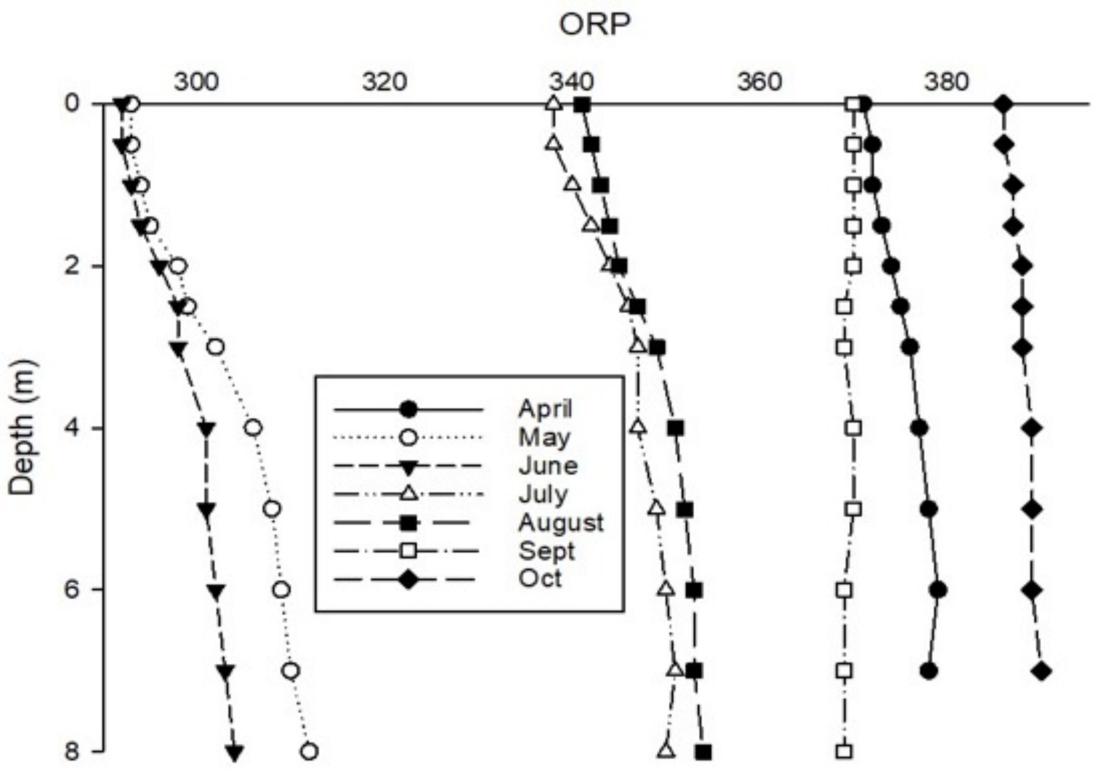


Figure 1.14. Mile Marker 6 (Transition) ORP (mV) measures over study period (2024)

Seasonal Analysis

Patterns of ORP at this station are similar to those observed at the dam. You might expect slightly more reduced conditions at the site (lower ORP) due to a greater influence from river inputs but this is not observed and late season ORP was much greater than early season. Certainly, oxygen production throughout the season will influence this measure but the turnover and flushing that occurred in September did not impact ORP.

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.

Nitrate

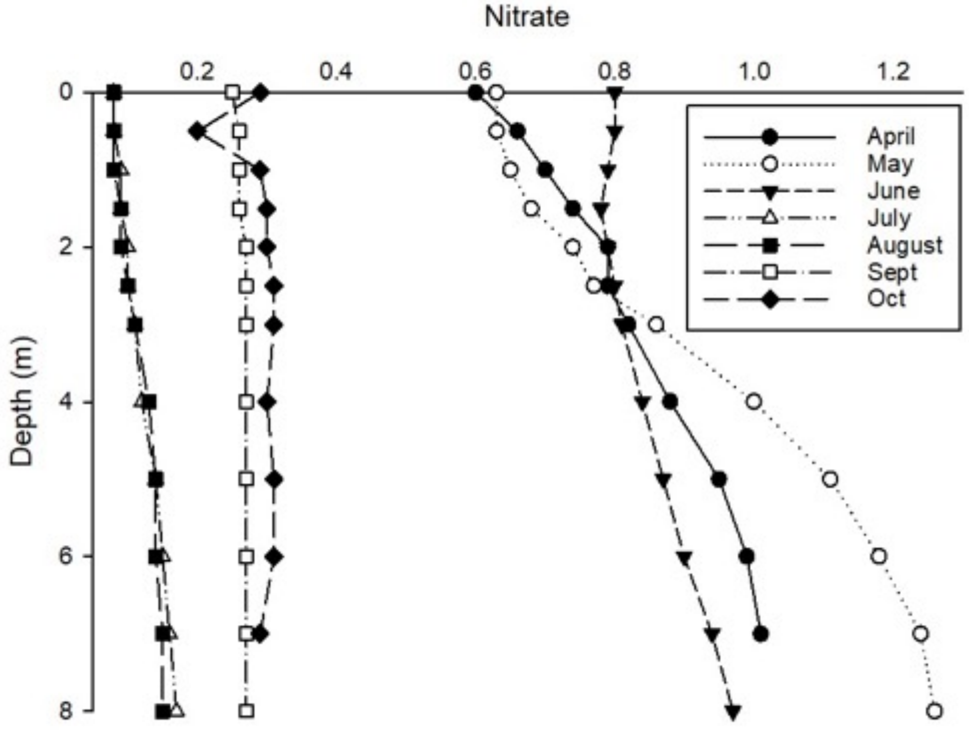


Figure 1.15. MM6 (Transition) Nitrate (mg/L) measures over study period (2024)

Seasonal Analysis

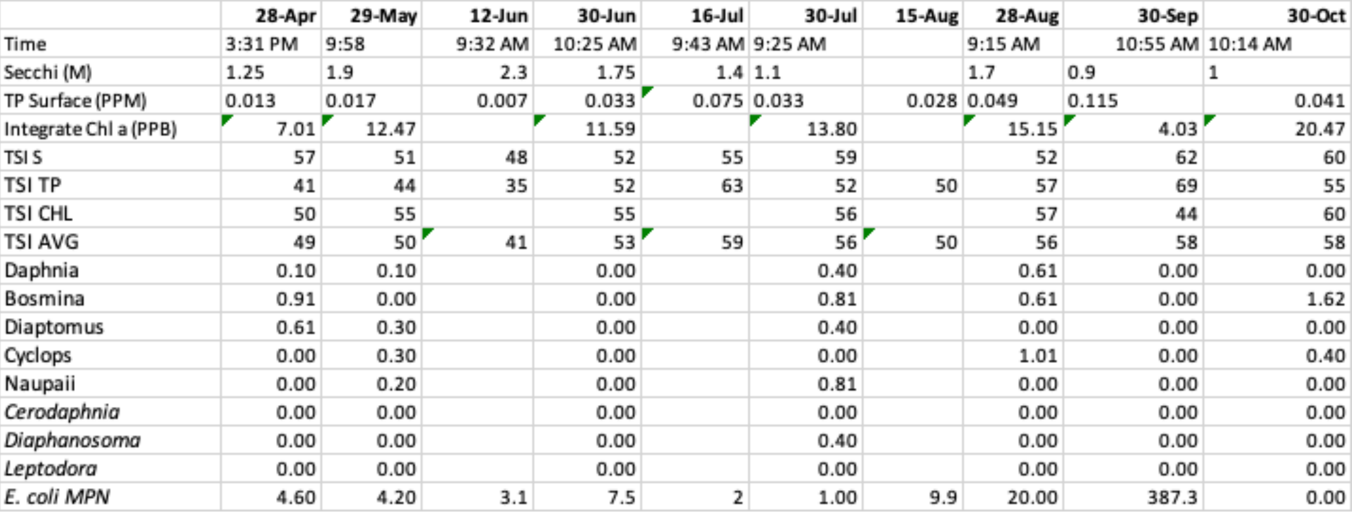
Nitrate patterns suggest general availability of nutrients during spring and fall and minimal availability during the summer months similar to the dam. Concentrations were lower than at the dam and only during May concentrations exceed 1 mg/L.

Comparisons Across Years

More data on Nitrate is needed for yearly comparisons.

Other Parameters Measured

Table 1.22. Other parameters measured over study period (2024). 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.

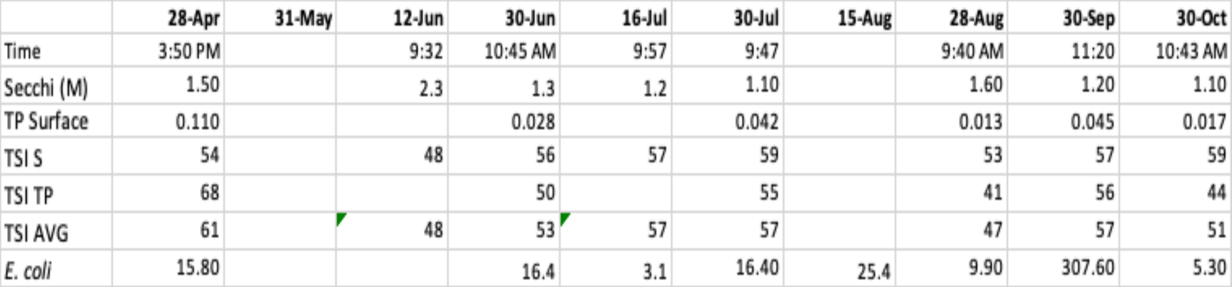


	28-Apr	29-May	12-Jun	30-Jun	16-Jul	30-Jul	15-Aug	28-Aug	30-Sep	30-Oct
Time	3:31 PM	9:58	9:32 AM	10:25 AM	9:43 AM	9:25 AM		9:15 AM	10:55 AM	10:14 AM
Secchi (M)	1.25	1.9	2.3	1.75	1.4	1.1		1.7	0.9	1
TP Surface (PPM)	0.013	0.017	0.007	0.033	0.075	0.033	0.028	0.049	0.115	0.041
Integrate Chl a (PPB)	7.01	12.47		11.59		13.80		15.15	4.03	20.47
TSI S	57	51	48	52	55	59		52	62	60
TSI TP	41	44	35	52	63	52	50	57	69	55
TSI CHL	50	55		55		56		57	44	60
TSI AVG	49	50	41	53	59	56	50	56	58	58
Daphnia	0.10	0.10		0.00		0.40		0.61	0.00	0.00
Bosmina	0.91	0.00		0.00		0.81		0.61	0.00	1.62
Diaptomus	0.61	0.30		0.00		0.40		0.00	0.00	0.00
Cyclops	0.00	0.30		0.00		0.00		1.01	0.00	0.40
Naupaii	0.00	0.20		0.00		0.81		0.00	0.00	0.00
Cerodaphnia	0.00	0.00		0.00		0.00		0.00	0.00	0.00
Diaphanosoma	0.00	0.00		0.00		0.40		0.00	0.00	0.00
Leptodora	0.00	0.00		0.00		0.00		0.00	0.00	0.00
E. coli MPN	4.60	4.20	3.1	7.5	2	1.00	9.9	20.00	387.3	0.00

1.4.1.5 Mile Marker 9 (Riverine)

Photograph of Leesville Lake taken by Jade Woll.

Table 1.23. Mile Marker 9 other parameters measured over study period (2024)



	28-Apr	31-May	12-Jun	30-Jun	16-Jul	30-Jul	15-Aug	28-Aug	30-Sep	30-Oct
Time	3:50 PM		9:32	10:45 AM	9:57	9:47		9:40 AM	11:20	10:43 AM
Secchi (M)	1.50		2.3	1.3	1.2	1.10		1.60	1.20	1.10
TP Surface	0.110			0.028		0.042		0.013	0.045	0.017
TSI S	54		48	56	57	59		53	57	59
TSI TP	68			50		55		41	56	44
TSI AVG	61		48	53	57	57		47	57	51
E. coli	15.80			16.4	3.1	16.40	25.4	9.90	307.60	5.30

1.4.1.6 Toler Bridge (Riverine)[2]

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.

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

Conductivity

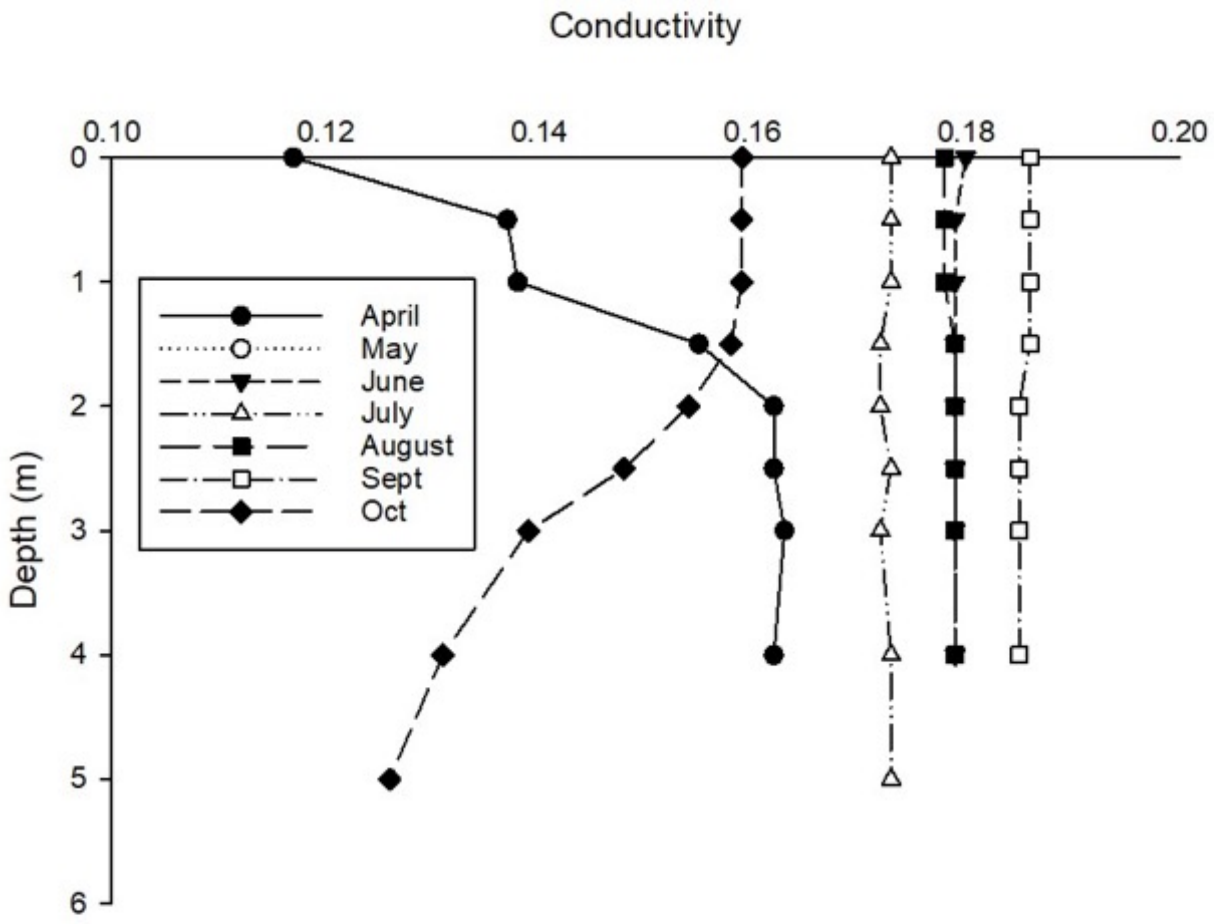


Figure 1.16. Toler Bridge (Riverine) Conductivity (ms/cm) measures over study period (2024).

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. This condition occurred in April and in October. It is clear that in October minimal water movement occurred and this is believed to have caused the increased chlorophyll observed at MM6. April exhibited the inverse relationship with Pigg River input overriding existing water at the Toler station. This is typical pattern when cool hypolimnion water release from SML meets warmer Pigg River waters.

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 traveling throughout the reservoir surface and into SML. This is dependent on flow however. During very high stormwater events, enough input from the Pigg River fills the entire headwater regions. Important to note that oxygen levels are often very low (below 5 mg/L) in September suggesting SML release is still the predominate driver of water quality in this region of the reservoir.

Dissolved Oxygen

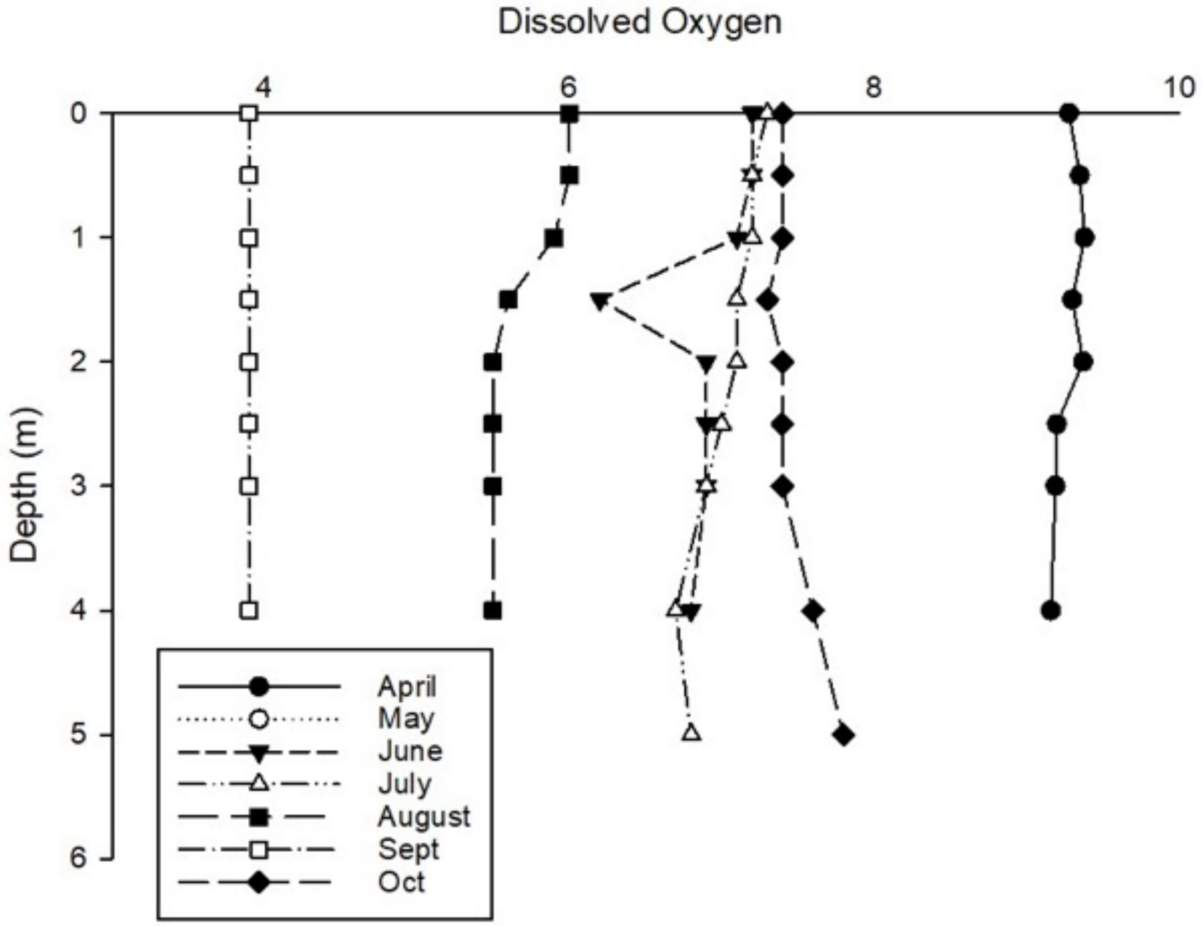


Figure 1.17. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2024)

Seasonal Analysis

Dissolved oxygen here is often a reflection of SML release but can be elevated due to Pigg River input if mixing occurs. Observations are highly dependent on water movement. Several generalizations from this data are possible. First, water does not stratify at this station because of constant movement but can stratify when water does not move as suggested in October. Secondly, oxygen concentration here declines throughout the season as the hypolimnion of SML declines. And as analyzed elsewhere, September readings below 4 mg/L were prevalent throughout the reservoir.

Comparisons Across Years

Dissolved oxygen at this station is a function of water release from SML and operations such as the lowering of water levels and input from Pigg River. When conductivity is elevated, dissolved oxygen is low. In the later months of the season, dissolved oxygen levels often fall below 5 mg/L. Tailwater release (and at times Pigg River input) have a very strong impact on water quality at this station. This trend is analyzed in the management section.

Temperature

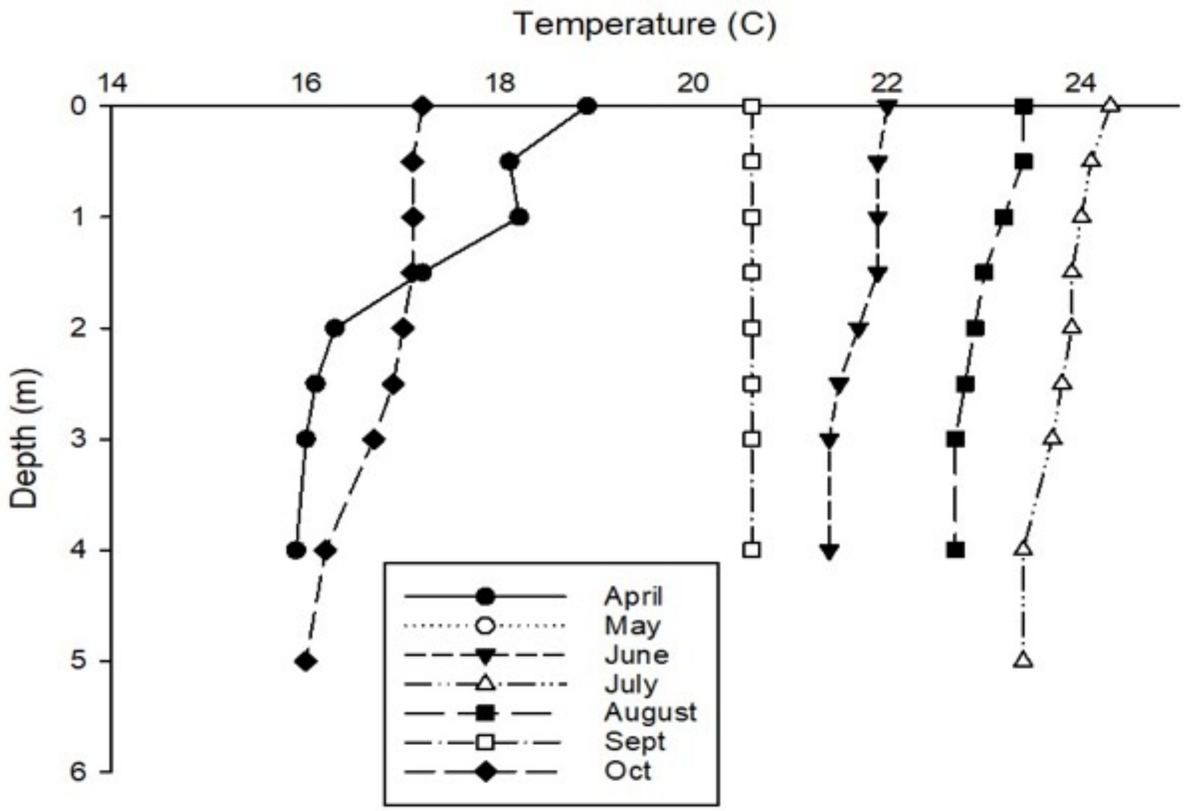


Figure 1.18. Toler Bridge (Riverine) Temperature (°C) measures over study period (2024)

Seasonal Analysis

This station does not stratify (or very weak and only slight) because of water release and pumpback. The water movement is frequently too strong to allow the water enough time to develop layers although during periods of operation where electricity demand is low this may occur due to limited water movement. This station tends to be cooler than the main stem of the reservoir due to SML release from the hypolimnion.

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*

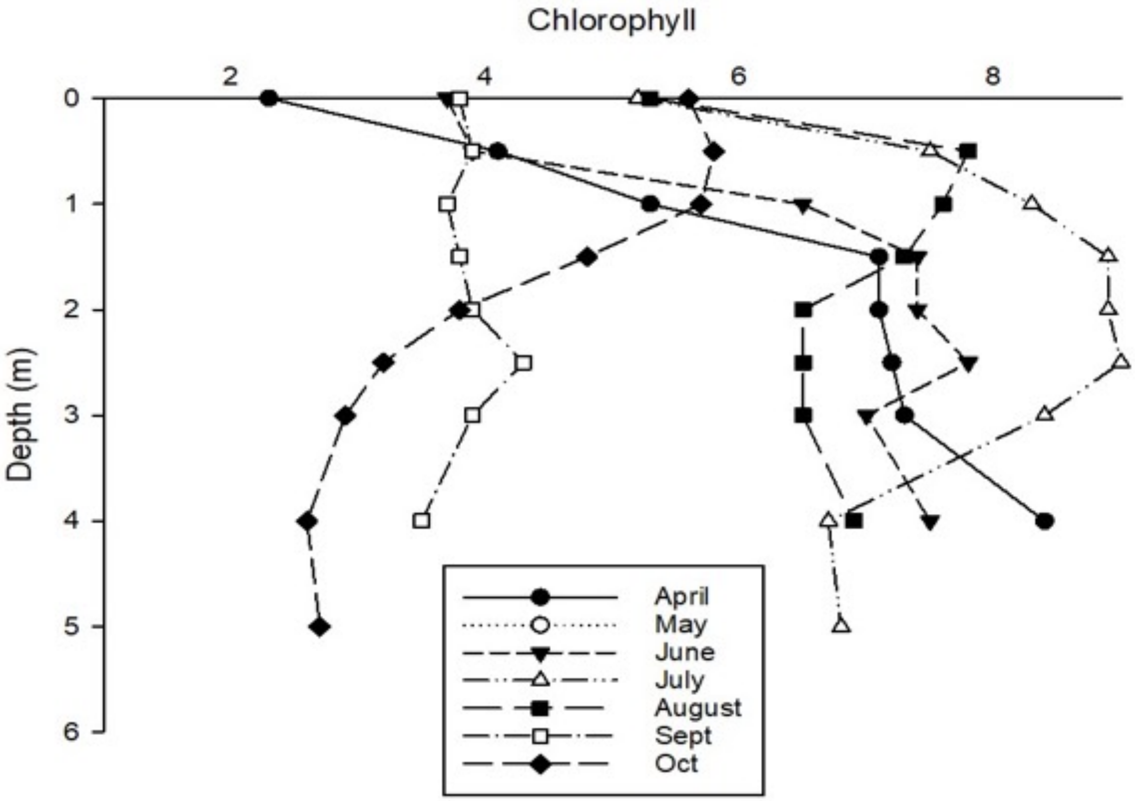


Figure 1.19. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2024)

Seasonal Analysis

This station typically contains the lowest readings of phytoplankton biomass throughout the entire reservoir. And the pattern in this portion of the reservoir is driven by water movement. However, one inference is clear. Phytoplankton abundance can increase in this portion of the reservoir when conditions allow and it may be rapid.

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

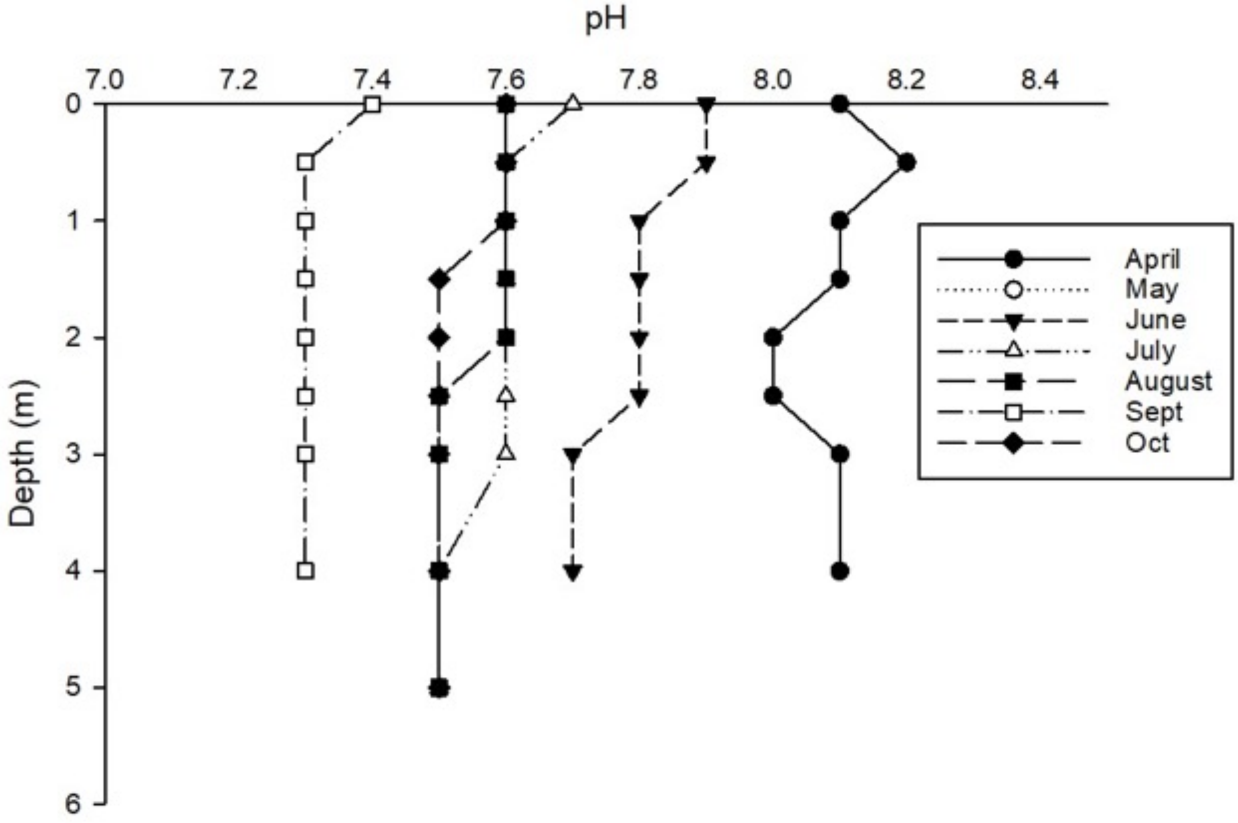


Figure 1.20. Toler Bridge (Riverine) pH measures over study period (2024)

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. 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 as was observed in April but typically does not. 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

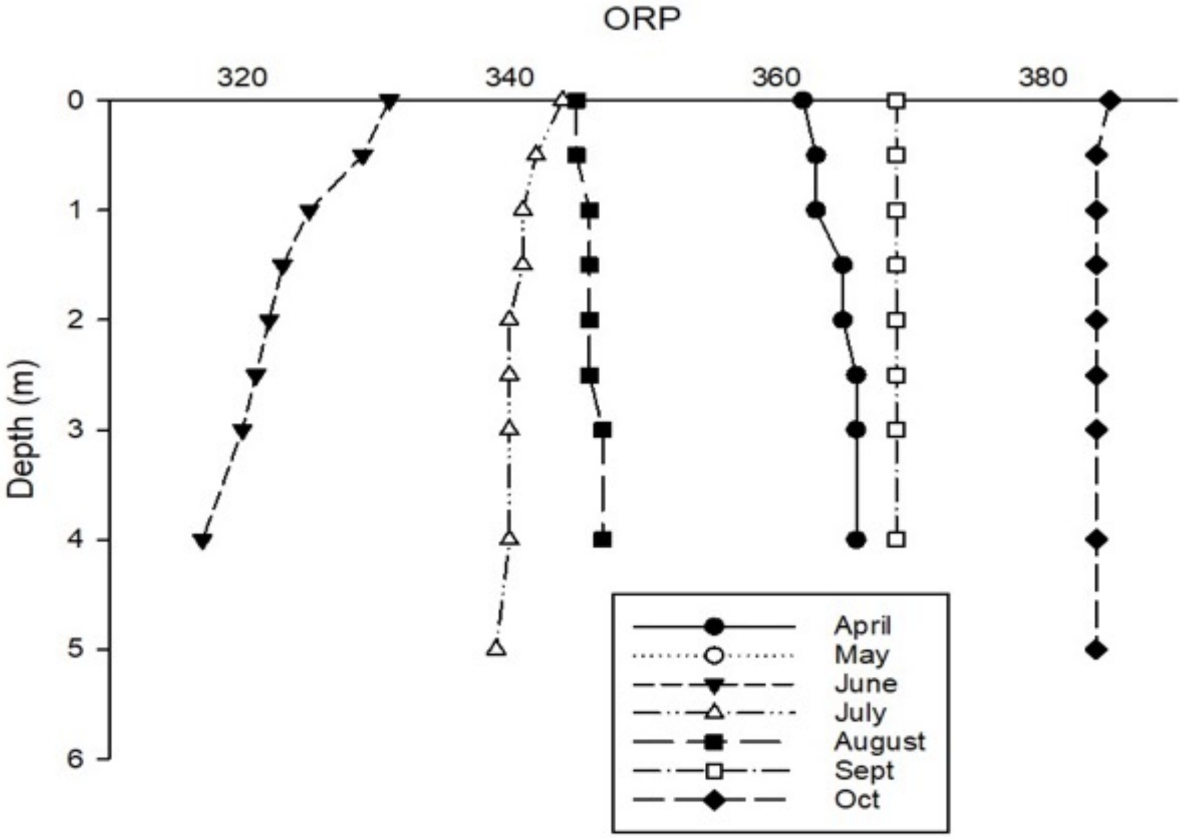


Figure 1.21. Toler Bridge (Riverine) ORP (mV) measures over study period (2024)

Seasonal Analysis

The ORP measures in this section of the reservoir do not provide any new interpretation between stations and the increased measures in June are discussed in MM6 section. 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.

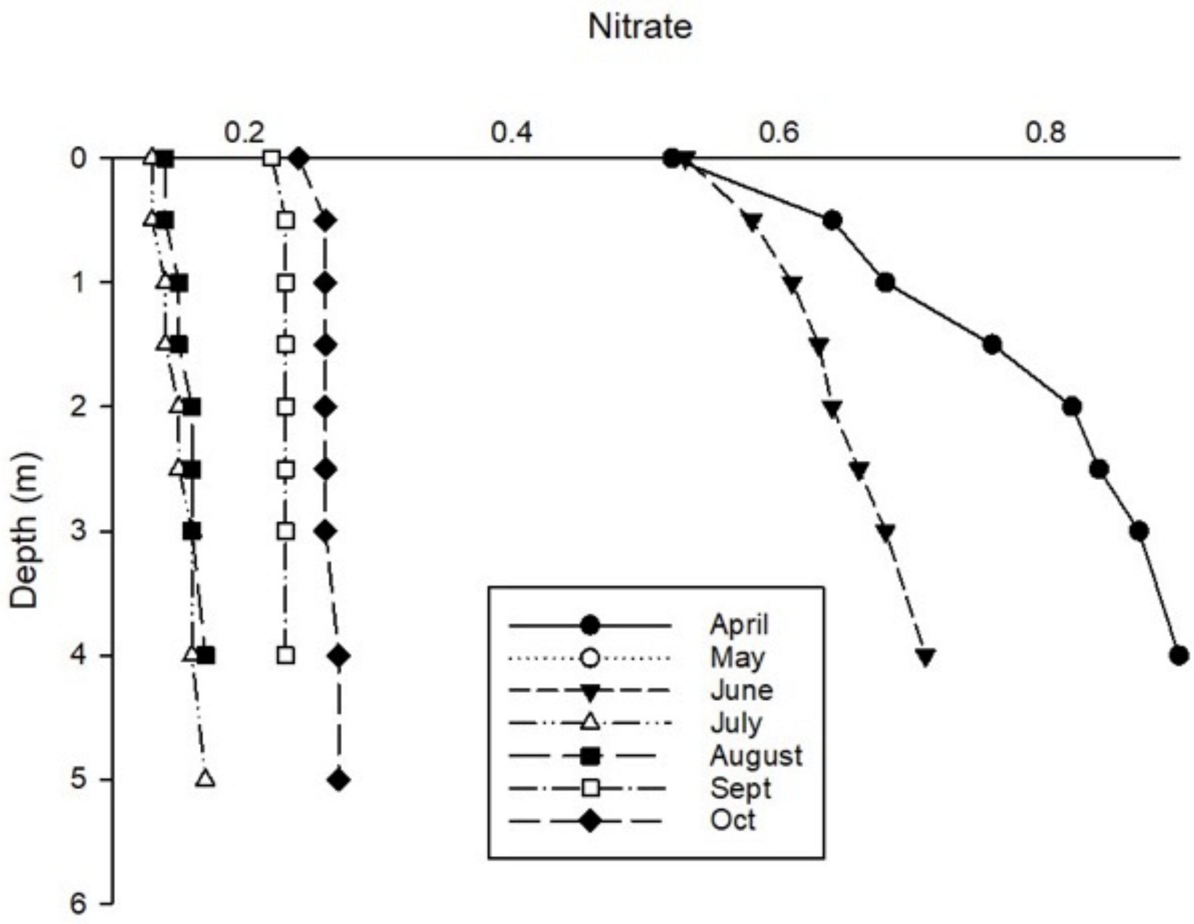


Figure 1.22. Toler Nitrate (mg/L) measures over study period (2024)

Seasonal Analysis

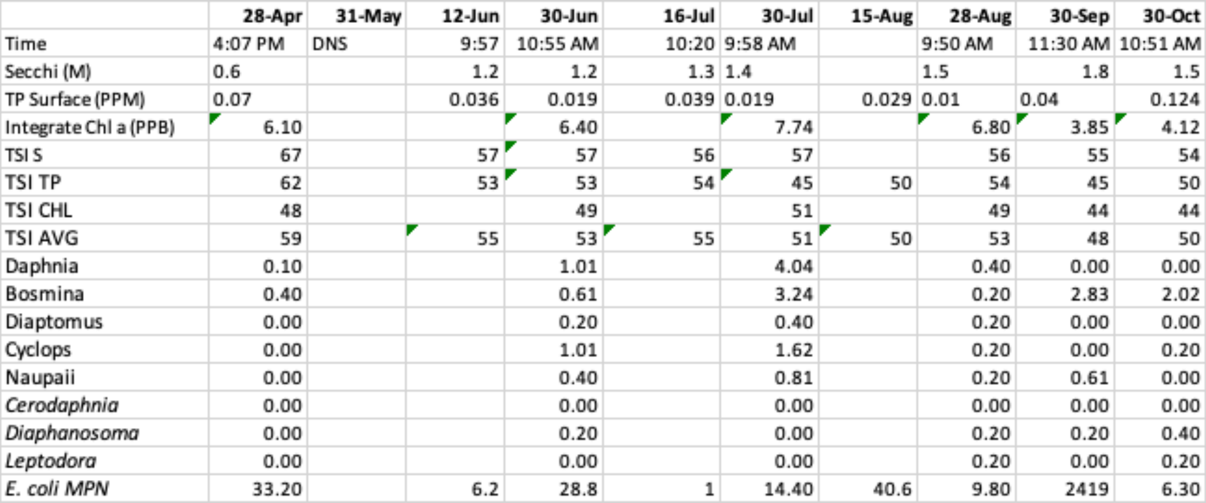
Nitrate patterns suggest greater availability during April and June. This is clearly driven by water movement rather than lake dynamics as suggested at the other portions of the reservoir. Concentrations were lower than in the other portions of the reservoir most likely driven by low levels released from SML dam.

Comparisons Across Years

More data on Nitrate is needed for yearly comparisons.

Other Parameters Measured

Table 1.32 Other parameters measured over study period (2024). Dates represent sampling of both the volunteers and university. First Column represents each parameter measured along with units of measure.

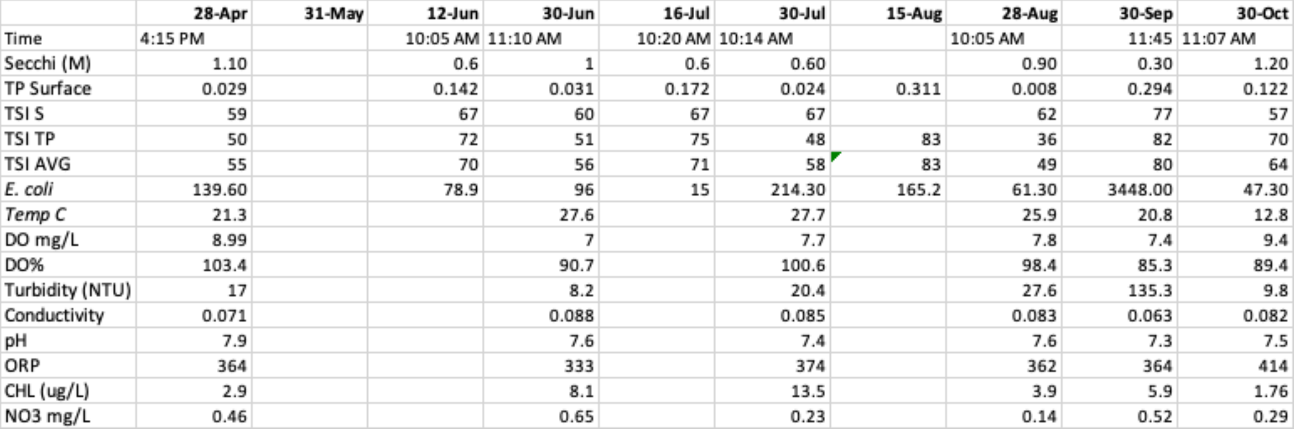


	28-Apr	31-May	12-Jun	30-Jun	16-Jul	30-Jul	15-Aug	28-Aug	30-Sep	30-Oct
Time	4:07 PM	DNS	9:57	10:55 AM	10:20	9:58 AM		9:50 AM	11:30 AM	10:51 AM
Secchi (M)	0.6		1.2	1.2	1.3	1.4		1.5	1.8	1.5
TP Surface (PPM)	0.07		0.036	0.019	0.039	0.019	0.029	0.01	0.04	0.124
Integrate Chl a (PPB)	6.10			6.40		7.74		6.80	3.85	4.12
TSI S	67		57	57	56	57		56	55	54
TSI TP	62		53	53	54	45	50	54	45	50
TSI CHL	48			49		51		49	44	44
TSI AVG	59		55	53	55	51	50	53	48	50
Daphnia	0.10			1.01		4.04		0.40	0.00	0.00
Bosmina	0.40			0.61		3.24		0.20	2.83	2.02
Diaptomus	0.00			0.20		0.40		0.20	0.00	0.00
Cyclops	0.00			1.01		1.62		0.20	0.00	0.20
Naupaii	0.00			0.40		0.81		0.20	0.61	0.00
Cerodaphnia	0.00			0.00		0.00		0.00	0.00	0.00
Diaphanosoma	0.00			0.20		0.00		0.20	0.20	0.40
Leptodora	0.00			0.00		0.00		0.20	0.00	0.20
E. coli MPN	33.20		6.2	28.8	1	14.40	40.6	9.80	2419	6.30

1.4.1.7 Pigg River

Photograph of Pigg River taken by Jade Woll.

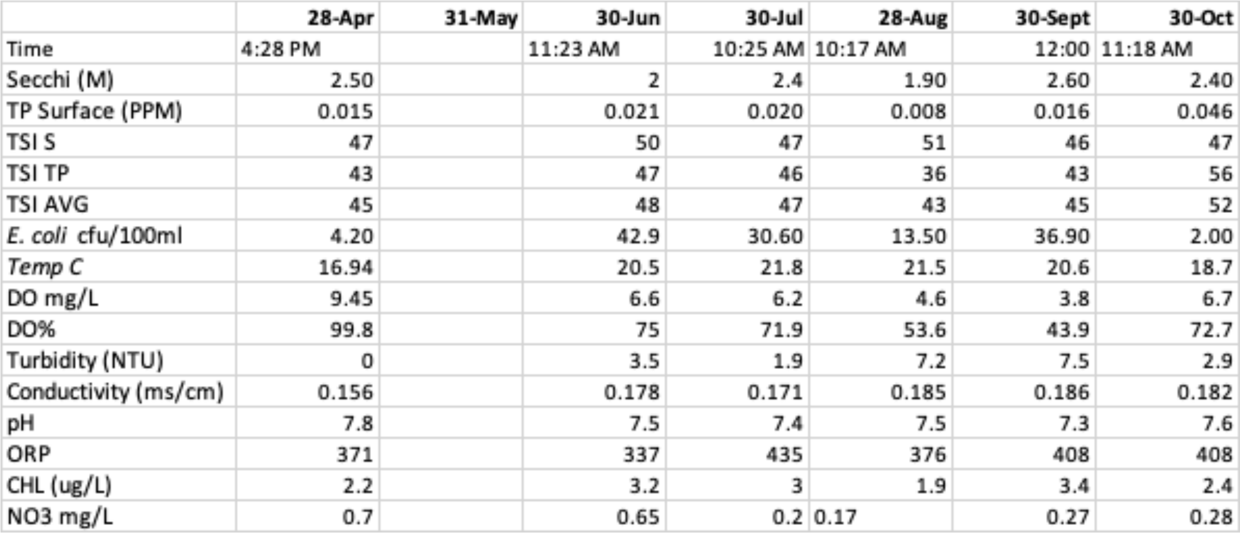
Table 1.33. Pigg River other parameters measured over study period (2024). Measures are integrative throughout the entire water column. Profile data located in the appendix.



	28-Apr	31-May	12-Jun	30-Jun	16-Jul	30-Jul	15-Aug	28-Aug	30-Sep	30-Oct
Time	4:15 PM		10:05 AM	11:10 AM	10:20 AM	10:14 AM		10:05 AM	11:45	11:07 AM
Secchi (M)	1.10		0.6	1	0.6	0.60		0.90	0.30	1.20
TP Surface	0.029		0.142	0.031	0.172	0.024	0.311	0.008	0.294	0.122
TSI S	59		67	60	67	67		62	77	57
TSI TP	50		72	51	75	48	83	36	82	70
TSI AVG	55		70	56	71	58	83	49	80	64
E. coli	139.60		78.9	96	15	214.30	165.2	61.30	3448.00	47.30
Temp C	21.3			27.6		27.7		25.9	20.8	12.8
DO mg/L	8.99			7		7.7		7.8	7.4	9.4
DO%	103.4			90.7		100.6		98.4	85.3	89.4
Turbidity (NTU)	17			8.2		20.4		27.6	135.3	9.8
Conductivity	0.071			0.088		0.085		0.083	0.063	0.082
pH	7.9			7.6		7.4		7.6	7.3	7.5
ORP	364			333		374		362	364	414
CHL (ug/L)	2.9			8.1		13.5		3.9	5.9	1.76
NO3 mg/L	0.46			0.65		0.23		0.14	0.52	0.29

1.4.1.8 Smith Mountain Lake Tail Waters

Table 1.34. Smith Mountain Lake Tail Waters other parameters measured over study period (2024). Measures are at the surface.



	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sept	30-Oct
Time	4:28 PM		11:23 AM	10:25 AM	10:17 AM	12:00	11:18 AM
Secchi (M)	2.50		2	2.4	1.90	2.60	2.40
TP Surface (PPM)	0.015		0.021	0.020	0.008	0.016	0.046
TSI S	47		50	47	51	46	47
TSI TP	43		47	46	36	43	56
TSI AVG	45		48	47	43	45	52
E. coli cfu/100ml	4.20		42.9	30.60	13.50	36.90	2.00
Temp C	16.94		20.5	21.8	21.5	20.6	18.7
DO mg/L	9.45		6.6	6.2	4.6	3.8	6.7
DO%	99.8		75	71.9	53.6	43.9	72.7
Turbidity (NTU)	0		3.5	1.9	7.2	7.5	2.9
Conductivity (ms/cm)	0.156		0.178	0.171	0.185	0.186	0.182
pH	7.8		7.5	7.4	7.5	7.3	7.6
ORP	371		337	435	376	408	408
CHL (ug/L)	2.2		3.2	3	1.9	3.4	2.4
NO3 mg/L	0.7		0.65	0.2	0.17	0.27	0.28

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.

2.1 Analysis of Trophic State[3]

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

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

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* concentration reflects 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.

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

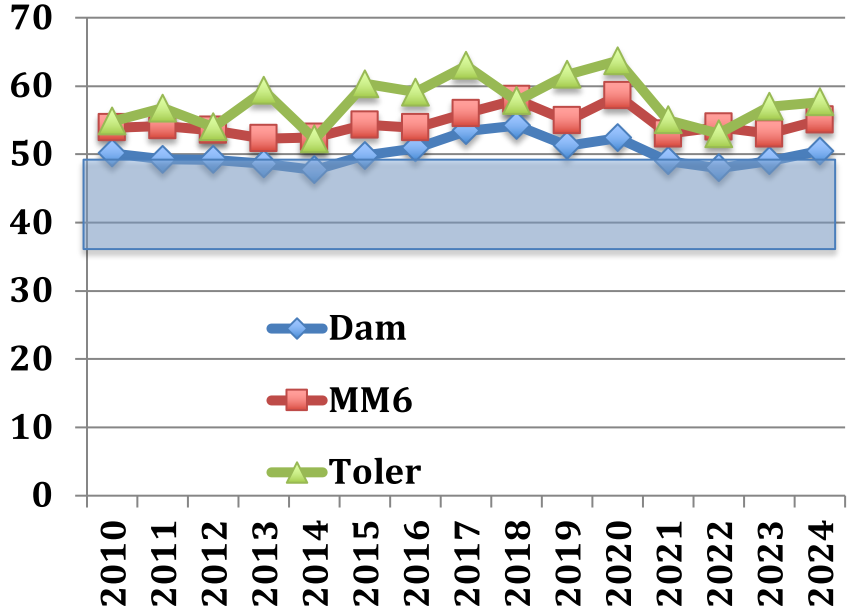

Figure 2.1.1 Trophic State Index (TSI) based upon Secchi disk (meters) measurements in Leesville Lake from 2010-2024. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Analysis

In 2024, trophic state using Secchi depth suggested LVL water clarity maintained a good trend started in 2021 (Figure 2.1). All stations slightly worsened but remained in the mildly eutrophic range. This encouraging trend suggests water quality is currently stable.

Comparing this trend from the headwaters (Toler Bridge) through the Dam we see a typical trend. 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. In 2024, these trends appeared consistent as we have observed in the past with Toler the most eutrophic of the stations in the lake.

Total Phosphorous TSI

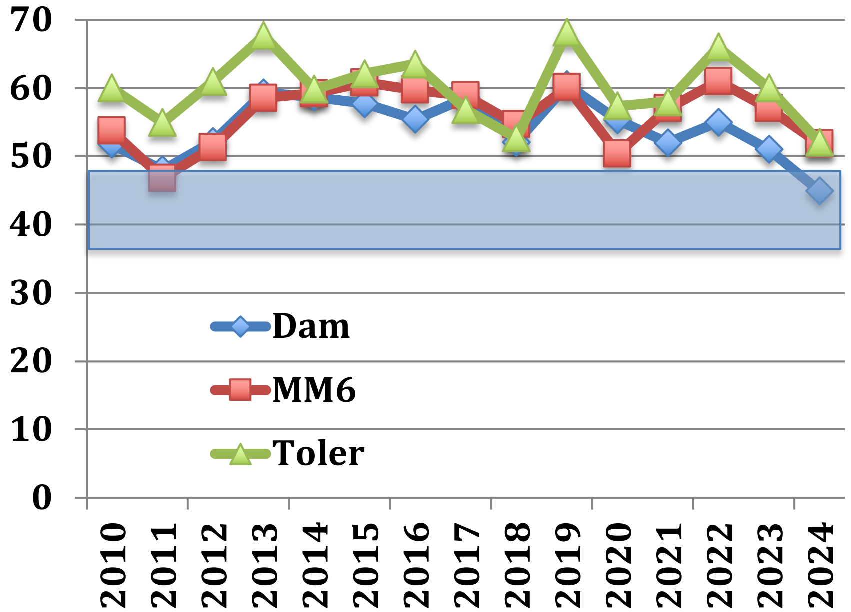

Figure 2.1.2. Same as Figure 2.1 but TSI based on Total Phosphorus (TP).

Analysis

For the first time since 2011, Dam TP trophic index was in the mesotrophic range. In fact, all measures were lower in 2024. While this is an encouraging trend, it seems more suggestive of drought conditions through much of the summer. TP was not transported in and the lake was dominated by SML release which is low in TP and phytoplankton uptake. During summer months before dissolved oxygen hypoxic conditions develop, SML release is very beneficial to Leesville Lake.

Chlorophyll *a* TSI

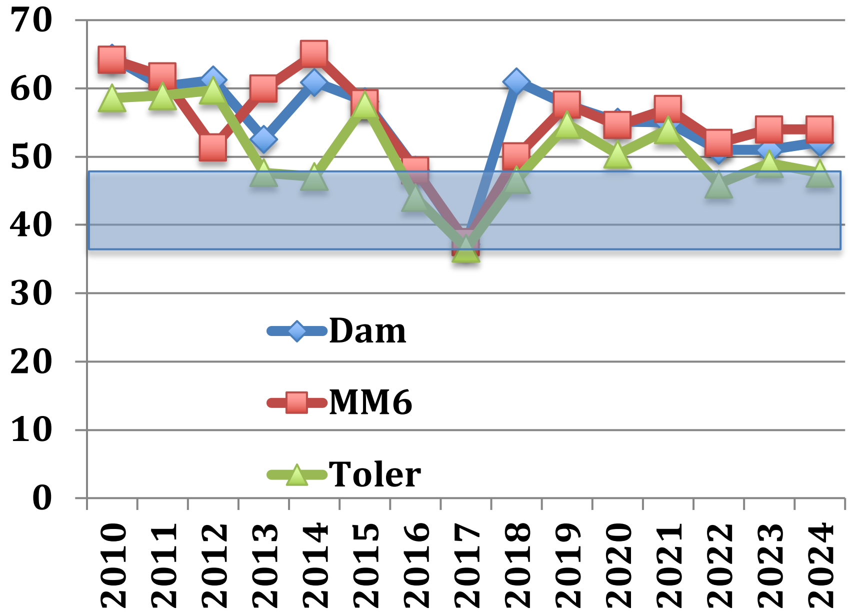

Figure 2.1.3. Same as Figure 2.1 but TSI is based on Chlorophyll *a*.

Analysis

Trophic state based upon Chlorophyll *a* remained very steady in 2024. 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 stable. Even with the drop in TP, Chlorophyll *a* remained consistent. This is a good result and suggests the lake is very resistant to change even as nutrient concentrations increase or decrease throughout the reservoir.

TSI Average

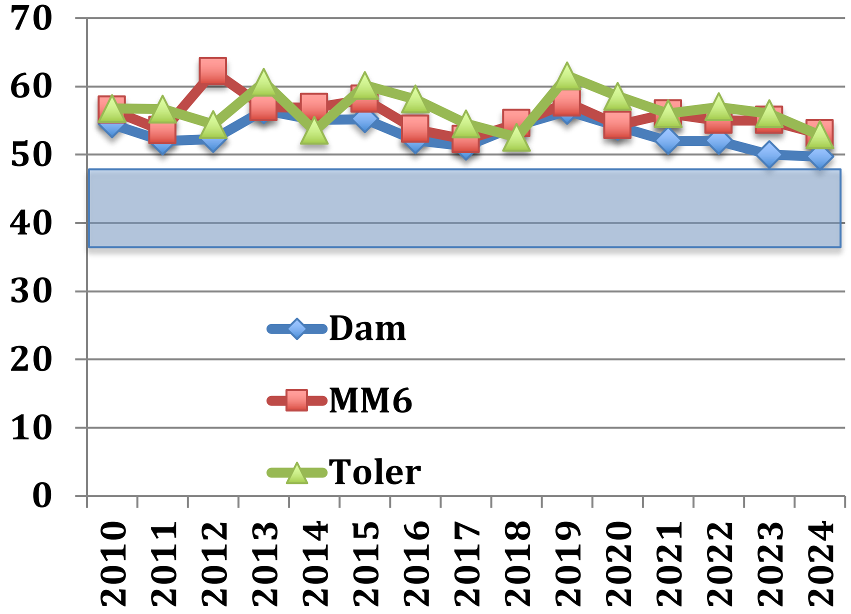

Figure 2.1.4. Same as Figure 2.1 but TSI presented is the average of TSI for all parameters evaluated (Secchi Depth, Total Phosphorous, Chlorophyll *a*).

Analysis

This is actually one of the most consistent measures we have of the reservoir exhibiting minimal change throughout the years of sampling. It can be argued that while this trend was increasing through 2019, it is certainly trending downward since. And the stations are very similar. This measure is an average of an average so not too much should be read into these findings other than no noticeable change in trophic state seems to be occurring. The reservoir shows excellent resilience to hydrology changes and river inputs when considering trophic state.

Daphnia Productivity

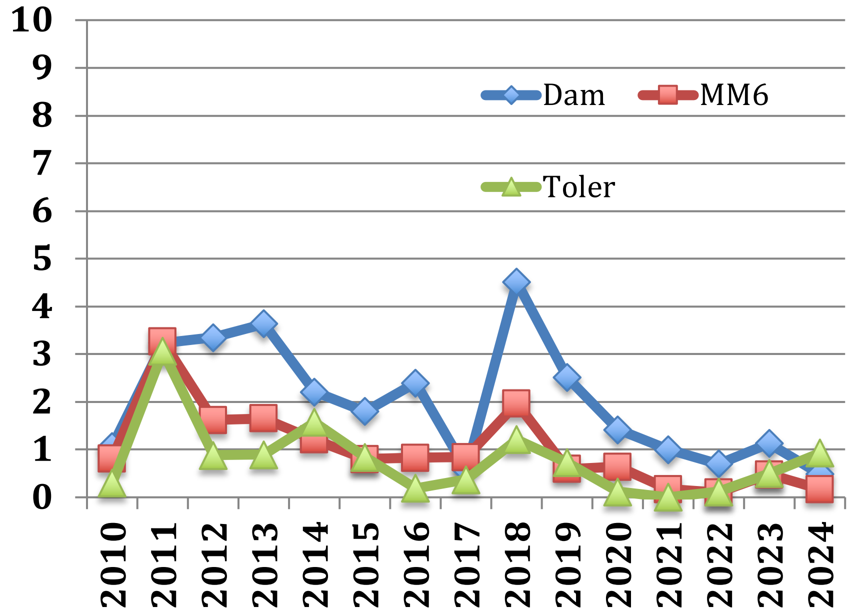

Figure 2.1.5. Average *Daphnia* concentrations in Leesville Lake from 2010-2024. Numbers on y-axis represent *Daphnia*/ liter.

Analysis

The abundance of *Daphnia* in the reservoir not only impacts the population of phytoplankton and chlorophyll *a* through grazing, but also influences fisheries impact on water quality. Implications of this are two-fold. First, lower *Daphnia* populations reduce the grazing pressure on phytoplankton. For 2024, we 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. Because long spines and elongated helmet projections in Daphnia are induced to protect them from predation, the implications of this morphology are clear. Invertebrate predation by *Leptodora* appears to dominate in the reservoir regulating the populations of *Daphnia*. This suggests that planktivorous 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. It should therefore be assumed that Leesville Lake is a bottom-up controlled reservoir and very sensitive to the addition of nutrients. This idea was consistent with the increased e phytoplankton chlorophyll a response in October at MM6 after the September enrichment.

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 lakes from around the world. Leesville Lake water quality is quite good based on this scale.

Pollutant Measures	Low	Medium	High	LVL 2021	LVL 2022	LVL 2023	LVL 2024
Secchi Depth (m)	>2.10	1.15-2.10	<1.15	2.15 = 2 pts.	2.33 = 2 pts.	2.13 = 2 pts.	1.99 = 1 pts
Conductivity (uS/cm)	<289	289-402	>402	135 = 2 pts	168 = 2pts.	175 = 2 pts.	164 = 2 pts
Total Nitrogen (mg/m3)	<1.04	1.04-1.67	>1.67	Not Measured	0.12 = 2 pts.	0.31 = 2 pts.	0.46 = 2 pts
Total Phosphorus (mg/m3)	<0.043	0.043-0.08	>0.08	0.04 = 2 pts	0.06 = 1 pt.	0.03 = 2 pts.	0.03 = 2 pts
Chl a (ug/L)	<12.5	12.5-31.5	>31.5	13.9 = 1 pt	8.23 = 2 pts	8.12 = 2 pts.	9.28 = 2 pts
Points	2	1	0	7/8 points	9/10 points	10/10 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 2.1.1). Leeville Lake scored 9 points in 2024 suggesting the reservoir exhibits excellent water quality even in an agriculturally dominated Pigg River Watershed. This strongly suggests that SML tailwater release mitigates the negative potential impacts from Pigg River input. This situation must be continually monitored to determine if conditions continue or are progressing toward greater expression of Pigg River Water quality. It is very encouraging that in 2024, even with the poor water quality measured in September and measures slightly worsening, water quality remained stable and very similar to previous years.

Section 2.2 An Analysis of Oxygen Loss, Reservoir Characterization and Green House Gas Release.

2.2.1 An Analysis of Water Quality and Dam Operations

An analysis to determine the possibility that SML release or pumpback during WQ assessment impacts findings on water quality in LVL . *The difference between tail water elevation and LVL pool at time of sampling was calculated. A negative value represents pumpback and a positive value release.* The magnitude of the number represents the difference (in feet) between SML dam and LVL pool and represents the amount of either release or pumpack. Calculations are represented in Table 2.1.

Table 2.2.1 – Calculated difference between SML tail water and LVL pool and used as the variable "difference" in the PCA and PLS analysis. Numbers represent difference in feet with a negative value LVL pool greater than SML tail water and positive value the reverse. DNS denotes dates LVL was not sampled.

Year	2019	2020	2021	2022	2023	2024
April	-0.2	-0.2	-0.2	-0.9	-0.2	0.1
May	1	-0.2	-0.4	-0.6	4.6	DNS
June	-0.2	-0.5	-0.2	0.2	0	0.1
July	-0.1	-0.4	0.2	0.3	-0.5	-2.3
August	0.1	6.5	3.6	-0.1	-0.1	-1.6
September	-1.9	-0.4	1.1	-0.1	5.3	2.5
October	-0.8	3.5	DNS	0.1	-0.1	-0.2

Data indicate that during 60% of the WQ sampling on the reservoir, operations were in pumpback (Table 2.1). This may be due to the sampling time and days when sampling occurred and the pattern for operation. And pumpback differences were often only slight (0.1-0.2 in difference). By contrast during release some of the differences were much greater in magnitude suggesting that release generates a much greater transfer of water to LVL than does pumpback during times when WQ sampling occurred.

The remainder of the data this analysis addressed included *E. coli* (cfu/100ml), Total Phosphorus or TP (mg/L), Chlorophyll *a* or CHL *a* (ug/L), Secchi Depth (meters), Conductivity or Cond (mS/cm) and Dissolved Oxygen or DO (mg/L). These are key parameters determined from limnological analysis. All measures represent the surface measure with the exception of CHL *a* that is an integrated measure. Because CHL *a* is a measure of phytoplankton in the reservoir with an ability to accumulate along the thermocline and the integrative measure is used to analyze trophic state this particular measure was used in the analysis. A surface measure would not be representative. The other measures used as surface measures to maintain consistency with the upper portion of the reservoir where integrated samples are not possible due to mixing.

Two types of statistical analysis were conducted to examine trends associated with dam operations at the time of water quality sampling: Principal Component Analysis and Variable Importance in the Projection Analysis.

Principal Component Analysis (PCA) determines relationships between collected variables. This analysis shows how variables cluster along various components (usually the first and second component). Interpretation of the output facilitates generation of ideas regarding functioning within the reservoir. These factors (F1 and F2) are shown in the graphs along with the variability percentage accounted for by these variables. This is an organizational statistical analysis.

An additional analysis, Partial Least Squares Regression (PLS Regression) Variable Importance in the Projection (VIP) is used. In this analysis, a particular variable of interest is chosen and then other variables are analyzed relative to that variable to determine the importance of each to the chosen variable. Hence, by selecting any variable of interest, we can determine how the other variables are related in importance to the chosen variable – the VIP analysis. Typically, a VIP score greater than 1 suggests a variable is of importance in predicting the chosen variable, further suggesting that each of these variables are strongly correlated. Thus, this analysis helps us determine what is a driving a variable in water quality prediction.

In the Tailwaters

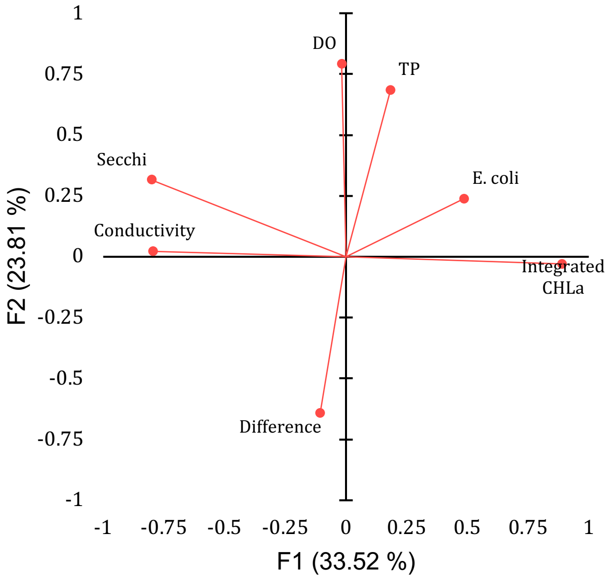

Figure 2.2.1 – PCA analysis for the 2019-2024 data at the tailwater release.

This analysis (Figure 2.2.1) suggests dam operations (identified on the graph as difference) are negatively correlated with both DO and TP concentrations along the second factor (Vertical Axis), i.e. with increasing pumpback DO and TP increase. Along the horizontal axis (First Factor), CHL *a* is negatively correlated to both conductivity and Secchi depth suggesting an increasing productivity is correlated to lower Secchi and conductivity. This implicates water from the Pigg River with increased Chl *a* productivity as it brings lower conductivity water and lower Secchi depths. Lower Secchi depths are also associated with increasing Chl *a*.

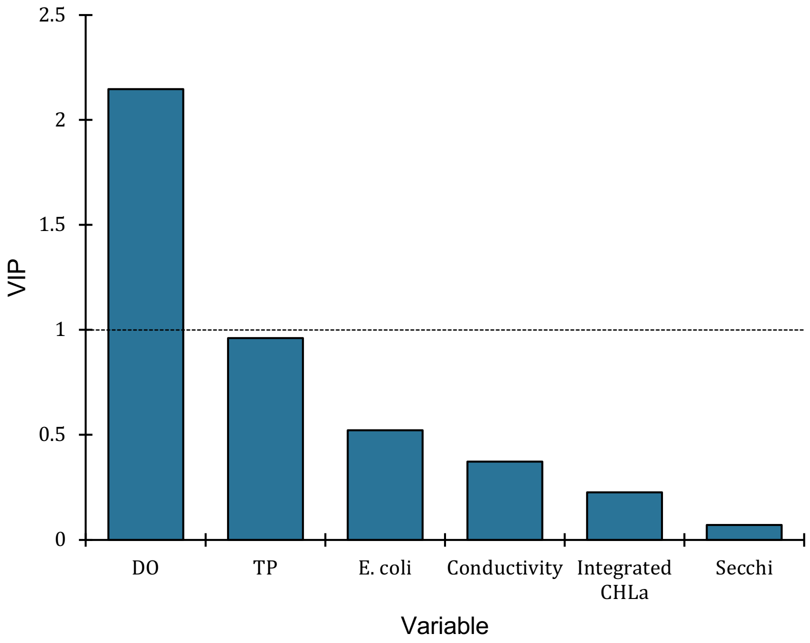

Figure 2.2.2 – PLS-VIP analysis selecting Dam Operation as difference (Table 2.1) as the dependent variable showing correlation to the other variables.

This analysis (Figure 2.2.2) clearly suggests that DO is the sole variable correlated to dam operations. No other variable is above 1 in the VIP analysis with DO greater than 2 suggesting a very strong relationship. While we did see TP in the PCA analysis correlated as well, this analysis suggests it is not a strong enough correlate to changes in DO.

Thus, this analysis strongly suggests that in the tailwater area operations drive the dissolved oxygen concentrations and is the overwhelming parameter impacted by dam operations.

Pigg River and Toler

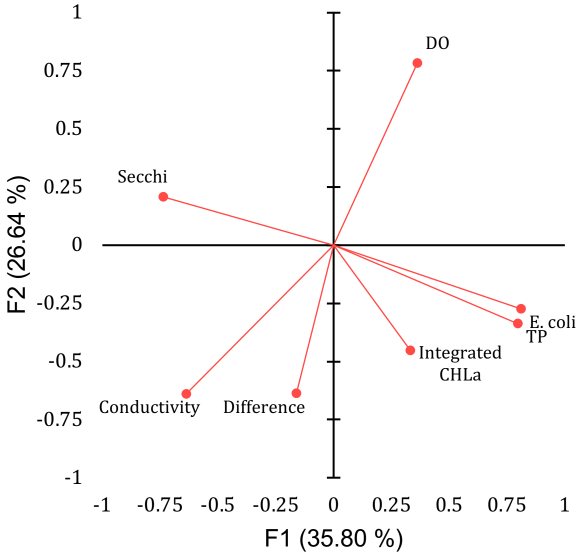

Figure 2.2.3 – PCA analysis for the 2019-2024 data at Pigg River.

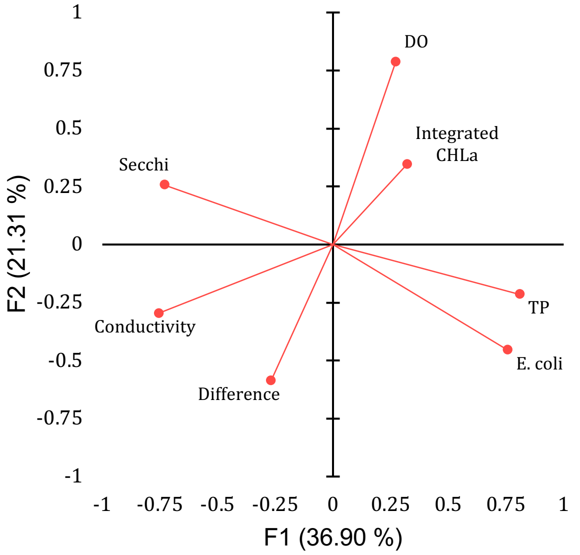

Figure 2.2.4 – PCA analysis for the 2019-2024 data at Toler Bridge.

Based upon the PCA analysis (Figure 2.2.3 and 2.2.4), Toler Bridge and Pigg River stations show a very similar pattern to tailwater in relationship to dam operation (difference) and DO. One difference is conductivity as it is correlated strongly with dam operations at the Pigg River. These relationships are expressed in the PLS analysis (Figures 2.2.5 and 2.2.6). Toler Bridge was very similar to Tailwater and Pigg River as well with DO a very strong correlate to dam operations. The exception is conductivity as it changes with dam operations. This is expected as conductivity in the Pigg River is much lower than conductivity in tailwater release.

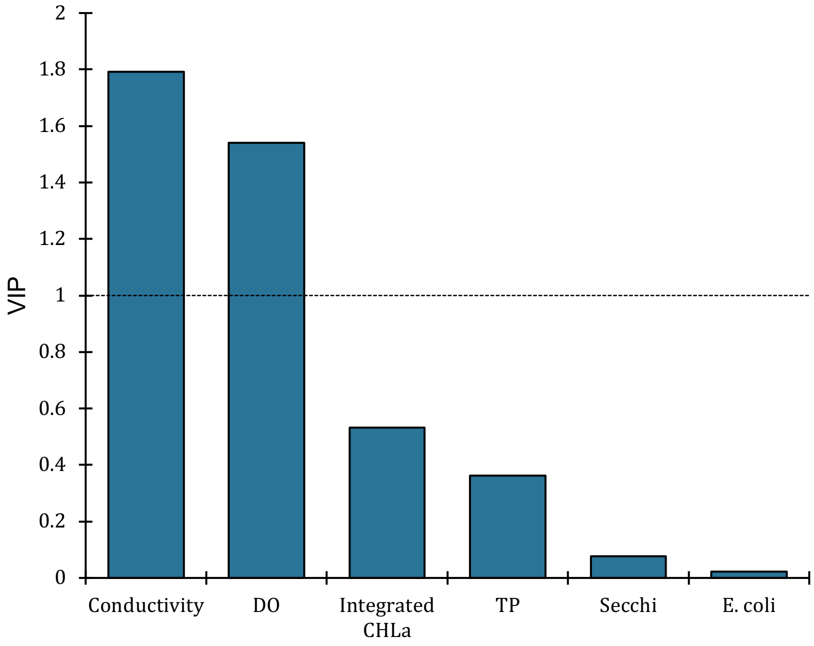

Figure 2.2.5 – PLS-VIP analysis selecting Dam Operation (Table 2.1) as the dependent variable with correlation for other variables at Pigg River.

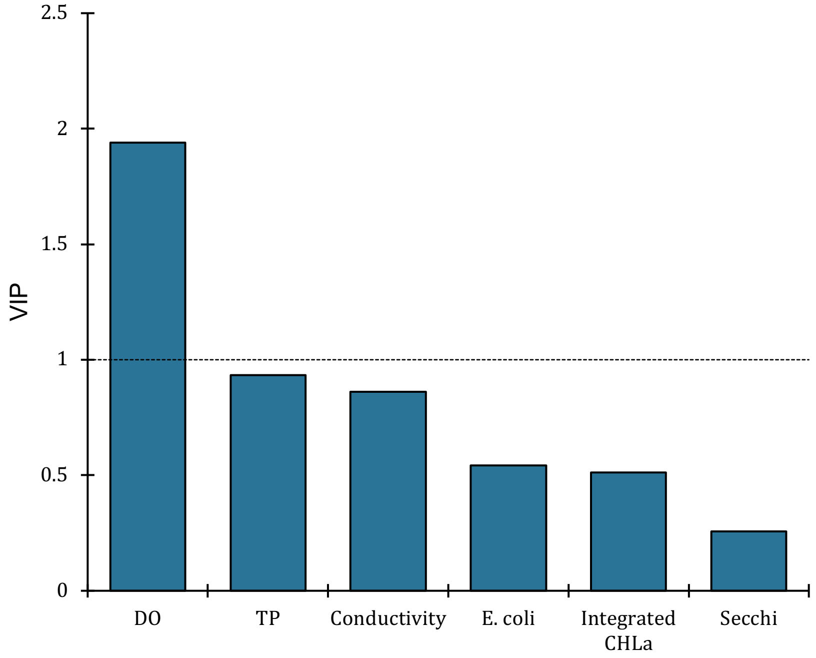

Figure 2.2.6 – PLS-VIP analysis selecting Dam Operation (Table 2.1) as the dependent variable with correlation for other variables at Toler Bridge.

These trends in the data support the idea that this area (Tailwater-Pigg River-Toler Bridge) is largely isolated with regard to direct impact of dam operations on water quality, with water moving back and forth and dam operations primarily impacting DO concentrations. Conductivity is good for tracking water flow from Pigg River back through SML dam during pump back. Here we can conclude that operations generally isolate water in the upper reaches of Leesville Lake and degrade dissolved oxygen concentrations. Other parameters not significantly impacted here.

MM6

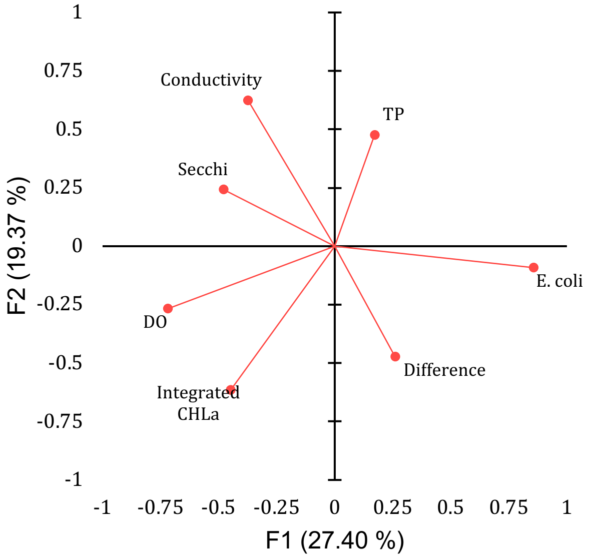

Figure 2.2.7 – PCA analysis for the 2019-2024 data at Mile Marker 6.

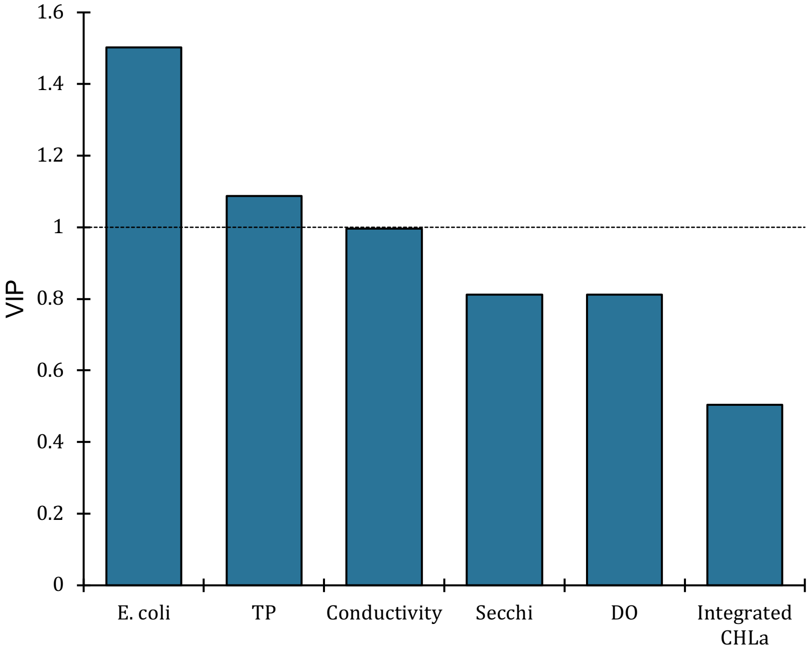

Figure 2.2.8 – PLS-VIP analysis selecting Dam Operation (Table 2.1) as the dependent variable with correlation to other variables at MM6.

At mile marker 6 (MM6), additional variables exhibit a level of importance in the analysis. *E. coli*, TP and conductivityare more strongly correlated with the variable of difference (that represents dam operations) than is DO. This suggests that the upper portion of the reservoir (Toler Bridge, Pigg River and Tailwater) operate almost separately than the rest of LVL as we see changing conditions at MM6 isolated from water quality impact driven by dam operations (compare Figures 2.2.7 and 2.2.8). It can be inferred at this station that Pigg River inputs of *E. coli* and TP are the important drivers at this station impacting what we see with Chl *a* and DO making it a true transition area. Dam operations are a very strong driver of water quality in the upper reservoir while river variables become greater in importance in this portion of the reservoir.

At the LVL Dam

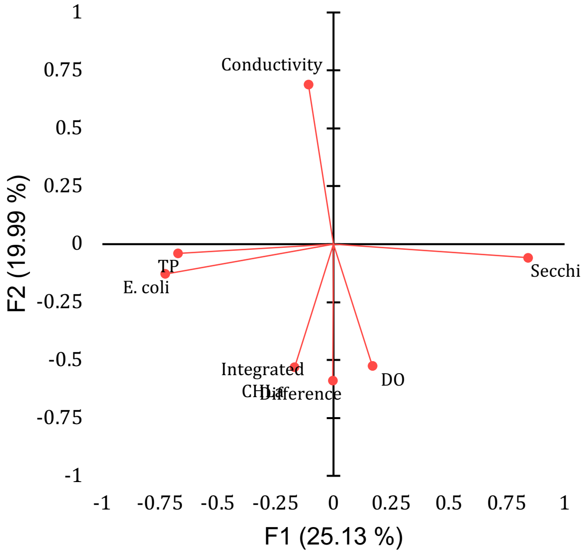

Figure 2.2.9 – PCA analysis for the 2019-2024 data at LVL Dam.

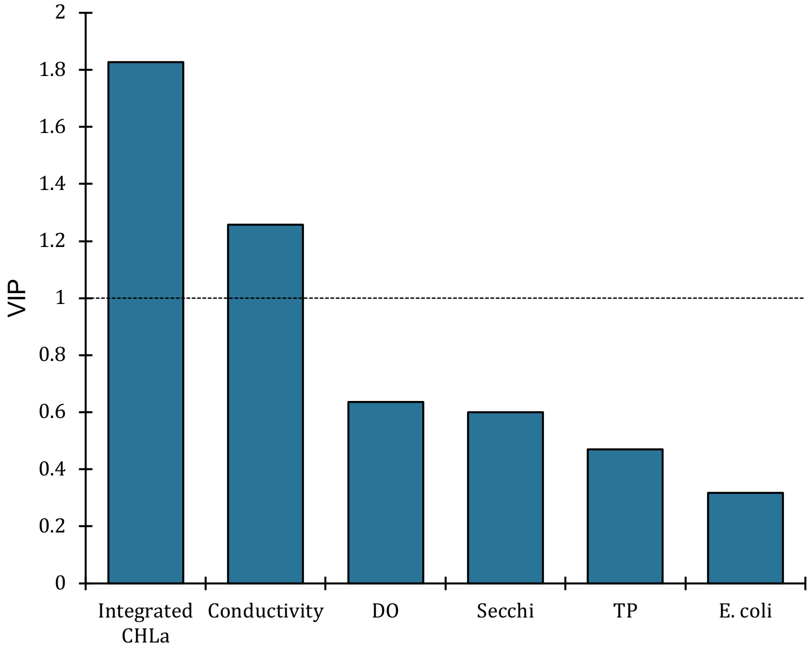

Figure 2.2.10 – PLS-VIP analysis selecting Dam Operation (Table 2.1) as the dependent variable with correlation for other variables for LVL Dam.

At LVL dam, limnological variables (interactions between nutrients, temperature, productivity) are more predictive. Secchi correlates to changes in TP and *E. coli* and CHL *a* correlates with conductivity (Figure 2.2.9). In relationship to dam operation, CHL *a* and conductivity are strong correlates with dam operations suggesting that this portion of the reservoir is strongly driven by the limnology unlike both MM6 and the upper reservoir because of the weaker relationship to DO that we know is driven by dam operations. Strong stratification and lesser movement of water at this station may account for this observation as well.

2.2.2 History of low oxygen in SML and importance of operations during low oxygen.

A PhD dissertation (Reynolds 1966) was reviewed to get a historical perspective on water quality of SML and the quality of tailwater release. This data was from 1966 or 2 years after filling of the SML reservoir and beginning of operations.

After filling of the SML lake, oxygen profiles demonstrated hypoxic hypolimnion during the summer months (Figure 2.2.11). Hypoxia was most pronounced in summer months (August) with dissolved oxygen falling below 2 mg/L. below 20 feet (6 meters). This is similar to current conditions in the reservoir (Figure 2.2.12). The nature of the Roanoke River Basin is implicated as causing high enough biological oxygen demand to cause the loss of oxygen in the hypolimnion during stratification. This pattern has not changed historically and is expected to continue creating low oxygen release to LVL from August – October each year.

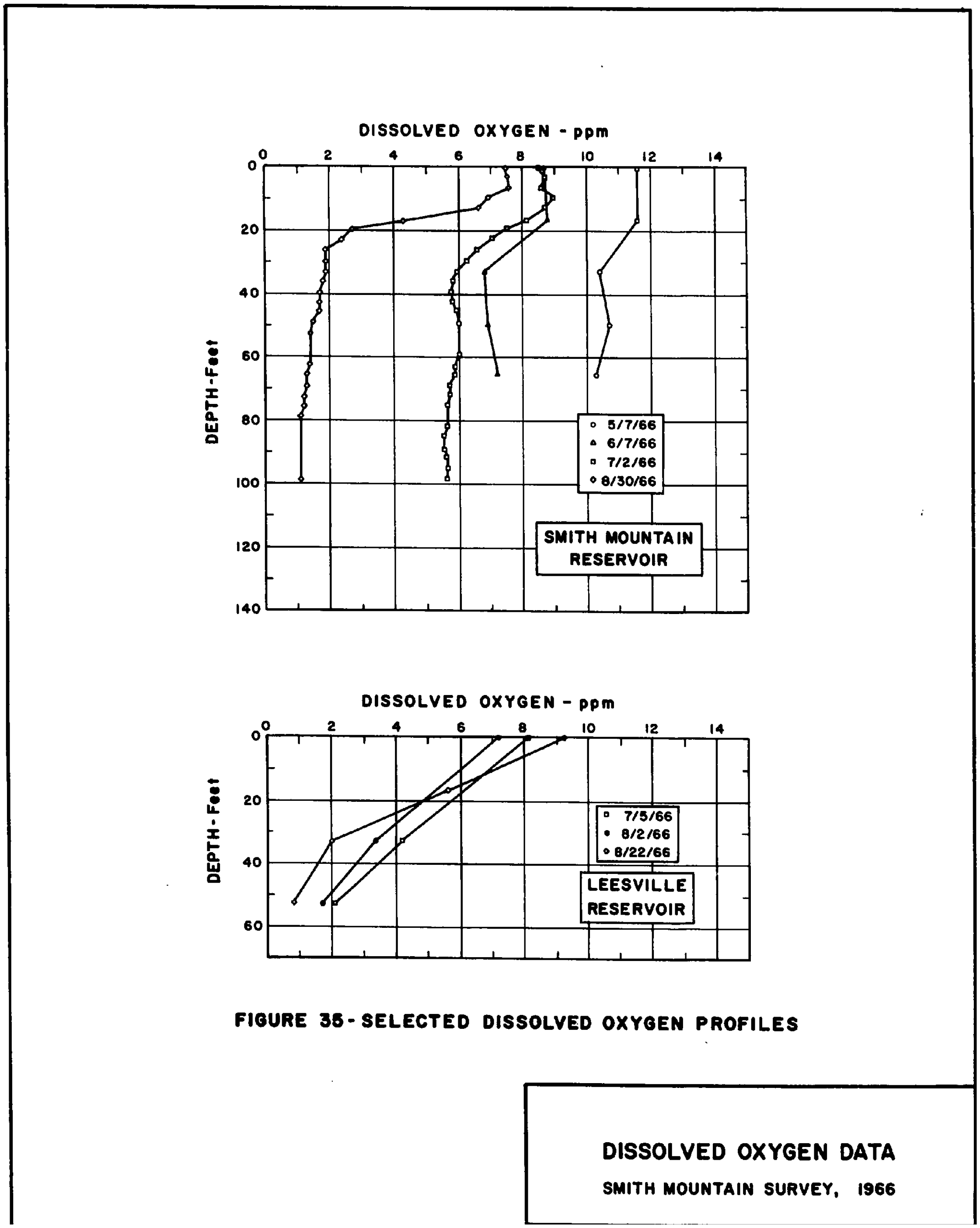

FIGURE 35 - SELECTED DISSOLVED OXYGEN PROFILES

DISSOLVED OXYGEN DATA

SMITH MOUNTAIN SURVEY, 1966

Figure 2.2.11 – Historical DO profiles in SML and LVL reservoirs in 1966.

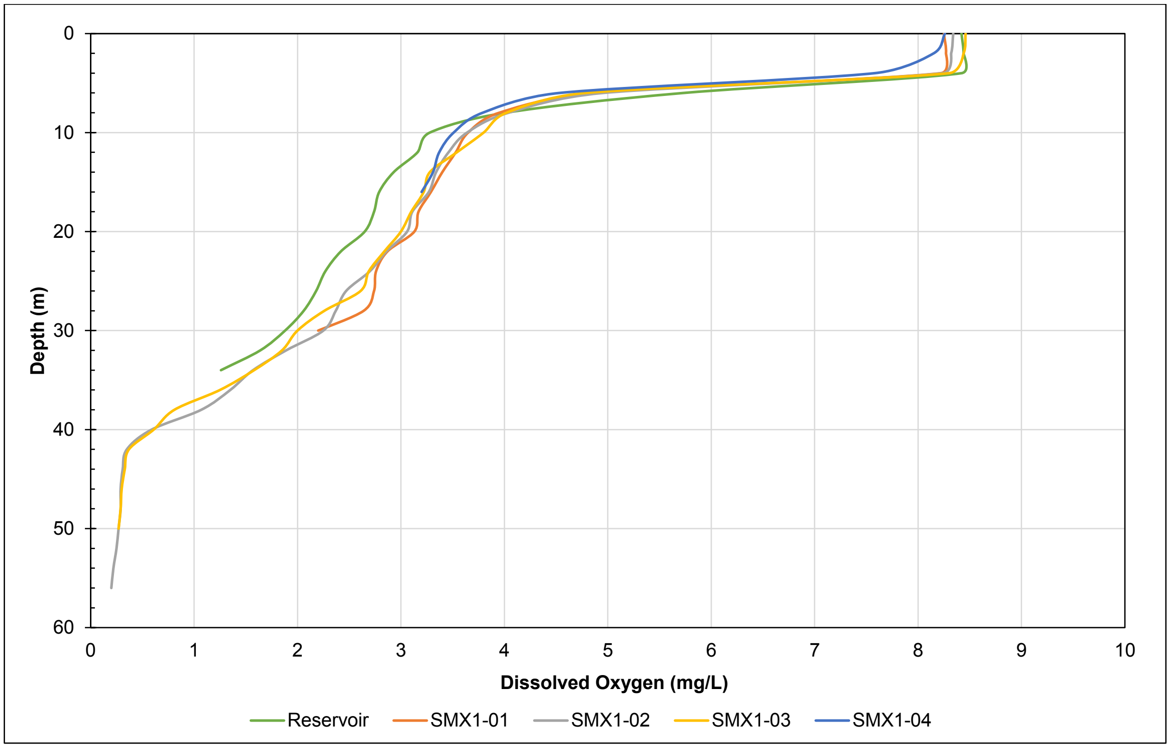
Figure 3.5. Dissolved oxygen levels per depth at the forebay and main reservoir monitoring locations on Smith Mountain Lake, August 30, 2023

Figure 2.2.12. Oxygen profiles of SML in August 2023.

Other takeaways from this research (Reynolds 1966) are two-fold. Much of the water (up to 5000 acre feet) stays entrained between SML Dam and upper portions of Leesville Lake during operation. A significant flow of water or change in operations is needed to move water downstream. This area is constantly pumped back and forth and thus remains isolated from other portions of the reservoirs. Secondly, observed variability in oxygen levels and determined pumped storage cycling at Smith Mountain assumes greater relative importance as oxygen levels decline. This becomes a critical point when oxygen is low and reaeration opportunities are limited and as such the same low oxygenated water is pumped back and forth in the reservoir. This idea is confirmed in the analysis conducted in the previous section.

2.2.3 Functioning of the Reservoir – Correlations to Other Parameters

At this point in the study of Leesville Lake, some general conclusions can be generated about the reservoir. Further analysis of the data from 2019-2024 was used to generate these conclusions and is presented with each generalization.

Tailwater – Pigg River – Toler Bridge Area

This area functions as a general pump to pump-back area for the project. Water quality is driven very strongly by operations. Conductivity is the driving variable correlated with oxygen levels (Figures 2.2.13-2.2.15). Thus, when considering Dissolved Oxygen the movement of water is the driving factor. This was also occurring with productivity (Figure 2.2.16). Conductivity is the most important correlate. All of this analysis suggests that water circulation is the driver factor for water quality at these stations.

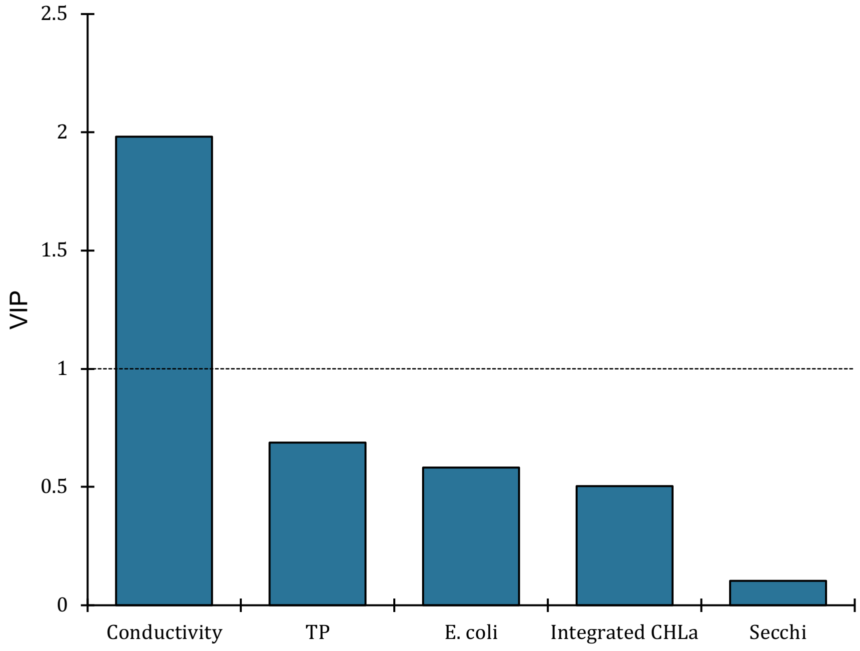

Figure 2.2.13. PLS analysis at Toler Bridge Station showing DO Relationship to other variables.

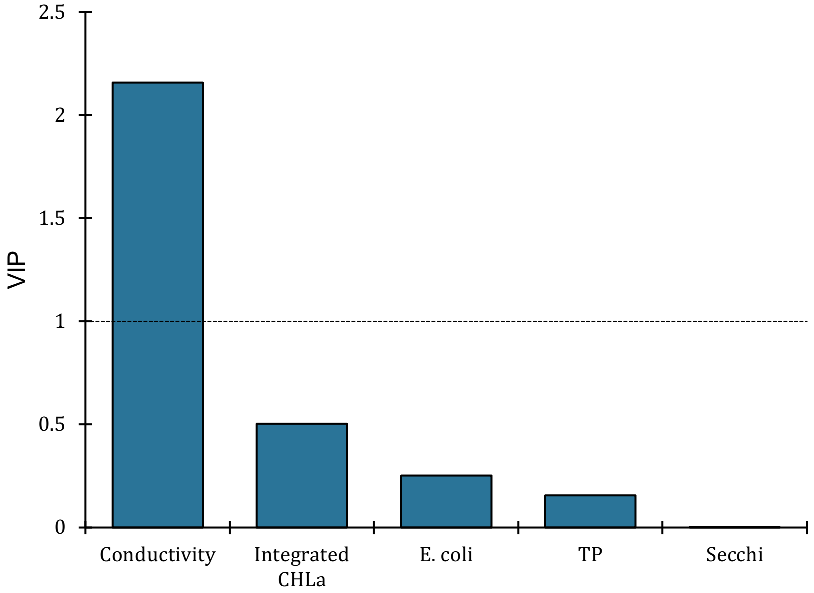

Figure 2.2.14. PLS analysis at Pigg River Station showing DO Relationship to other variables.

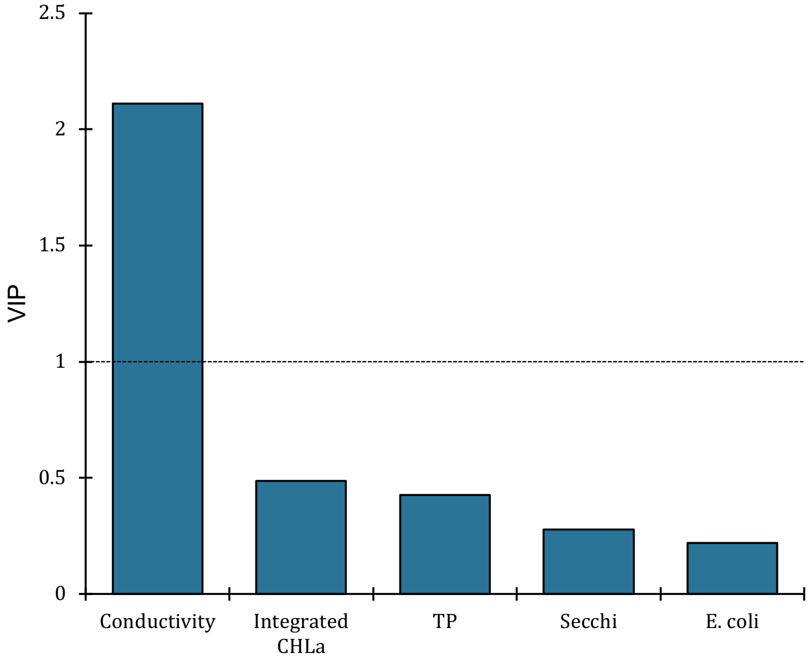

Figure 2.2.15. PLS analysis at Tailwater Station showing DO Relationship to other variables.

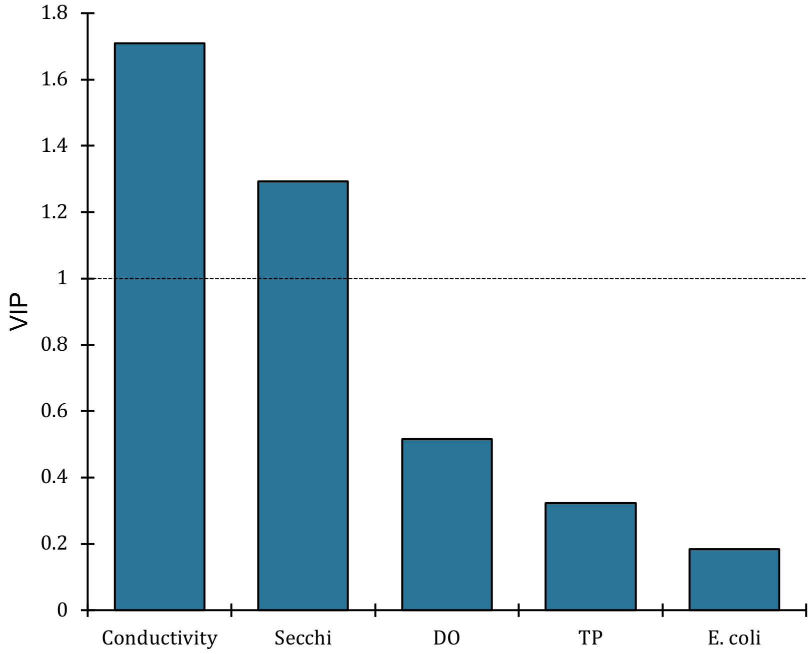

Figure 2.2.16. PLS analysis at Toler Bridge Station showing CHL *a* Relationship to other variables.

MM6

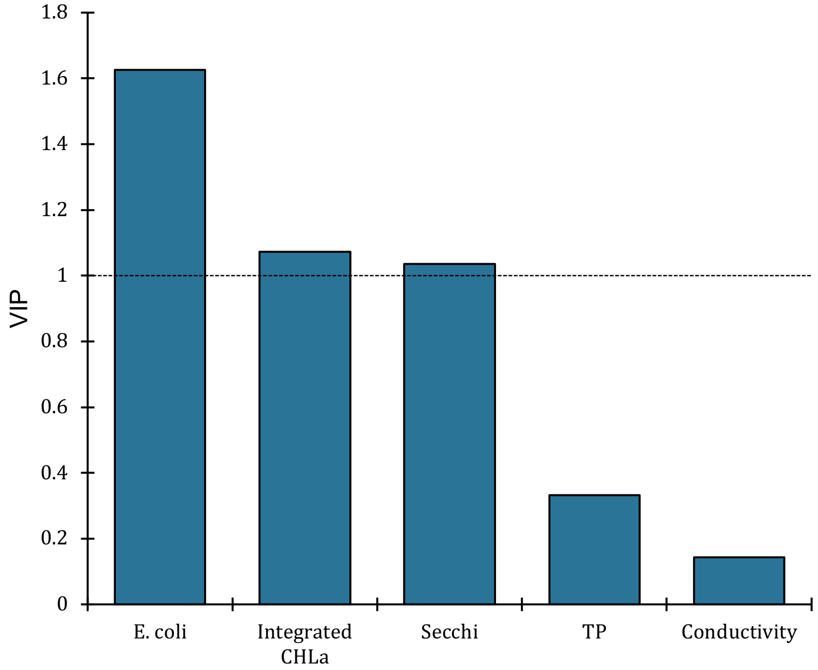

Figure 2.2.17. PLS analysis at MM6 Station showing DO Relationship to other variables.

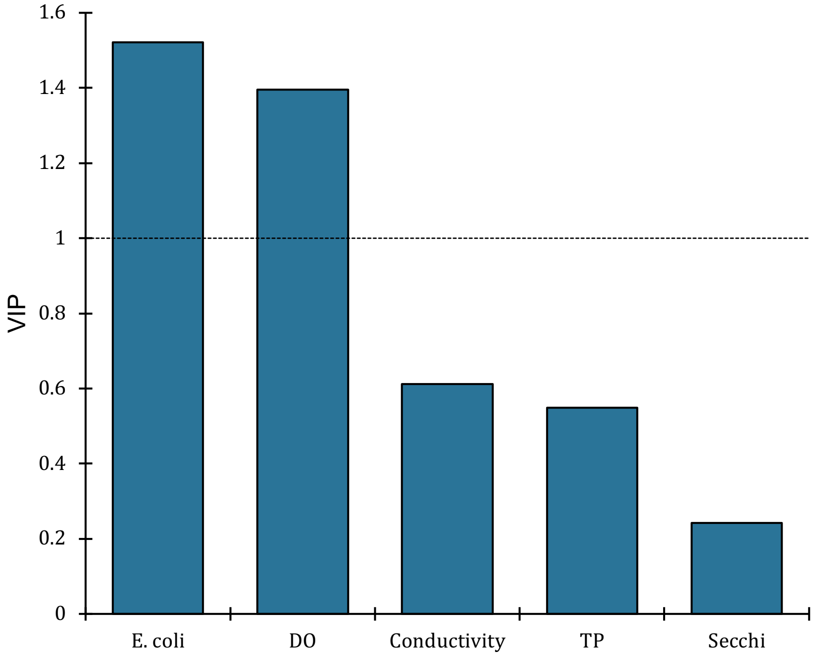

Figure 2.2.18. PLS analysis at MM6 Station showing CHL *a* Relationship to other variables.

At this station, conductivity is not influential but rather *E. coli*, CHL *a* and Secchi depth (Figure 2.2.17). This suggests MM6 is operating as a transition influenced by limnology rather than water circulation. Influence of CHL *a* and Secchi Depth as predictive parameters is expected as limnology becomes much more important. The importance of *E. coli* (Figure 2.2.18) appears to be an impact from the Pigg River in this area and the idea that the area is still influenced significantly by the Pigg River. The minimal impact of TP suggests river movement of water may be more influential than uptake of nutrients.

LVL Dam

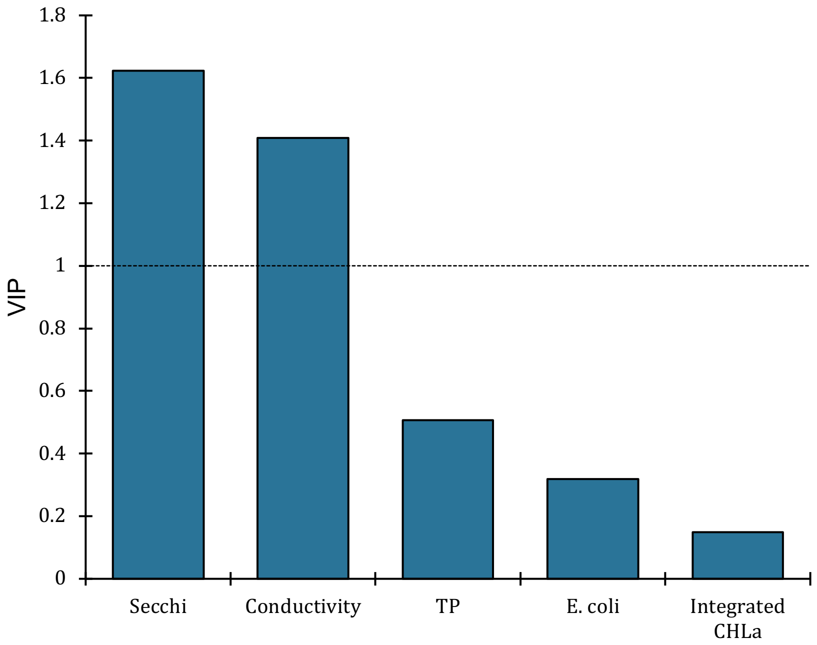

Figure 2.2.19. PLS analysis at Dam Station showing DO Relationship to other variables.

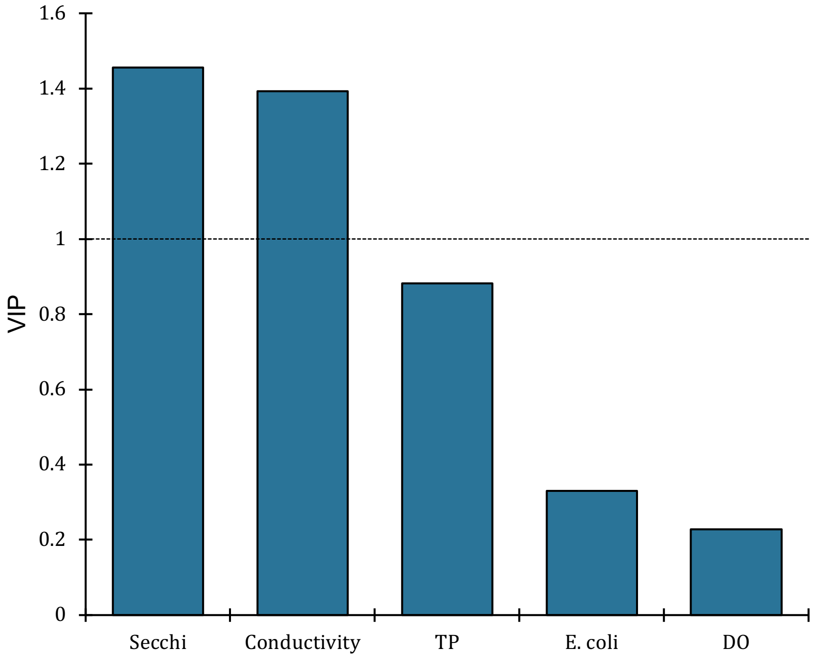

Figure 2.2.20. PLS analysis at MM6 Station showing CHL *a* Relationship to other variables.

In the LVL dam area, Secchi depth and conductivity were the most influential parameters (Figures 2.2.19 and 2.2.20). The lessening impact of some of the riverine parameters is expected in this area reducing the importance of *E. coli* and TP to oxygen and CHL *a*. However, the influence of conductivity at this station is unexpected. This result may indicate the nature of water flow-through the reservoir and the impact this does have on water quality. So while water quality is driven by limnology at this station it may be the pass through of storm water that is very important. As water in the upper portion of the reservoir is isolated and pumped back and forth between SML and LVL flow from the Pigg River may move through the remaining portions of LVL significantly impacting water quality through *movement* rather than pollutants. This result (and the E. coli result from MM6) suggest while the upper stations are strongly linked to SML operations the lower portions of LVL may be strongly influenced by the Pigg River. This idea is not meant to minimize the importance of *E coli* and TP to overall water quality rather to suggest these variables may be of less importance than water movement. Because of the size and shape and constant water movement in LVL this is a very reasonable conclusion. This has important implications for water quality management.

2.2.4 Methane release from LVL

Methane release continues to be a concern. While at this point any information reported here is anecdotal and primarily observational it is important to document concerns in LVL. An analysis of this problem was published in Shahady (2024). This should be considered in future management of the reservoir.

Figure 2.2.21 – Ebullition of Methane on Leesville Lake in late summer. Bubbles are visible rising to the surface throughout the upper portions of the reservoir when the winds are calm.

Figure 2.2.22 - close up showing the release of methane at the water surface. This release is considerable during the low oxygen and late summer/fall in the reservoir.

Section 3: Conclusions and Management Implications

3.1 Conclusions

As presented throughout this report, water quality in Leesville Lake (LVL) is relatively stable and meeting goals prescribed for the reservoir. While the lake remains eutrophic, it is not worsening in trophic condition and this is a positive result.

This season (2024) provided an opportunity to characterize the reservoir. It is important to understand how LVL functions and the overall importance of SML operations and input from the Pigg River combine to impact water quality. Data from key water quality parameters compiled during 2019-2024 seasons were examined to begin to generalize what these patterns might be. Historical data aided in this analysis.

The reservoir can be characterized as follows:

Mouth of Pigg River – Toler Bridge area – SML tailwater release. This area operates in general independent of the remainder of the LVL. It is characterized by constant movement between LVL and SML through power generation and pump-back. Water quality is reflective of SML hypolimnion with lowering levels of dissolved oxygen through September – October of each season. The turnover of the lakes and specific operational control of both pumping operations and lake levels can have a very profound impact on the water quality of this region. It takes a significant stormwater event or an operational change to move water from this area down through LVL.

MM9 – MM6 area. This region of the reservoir begins to be influenced by limnological forces due to the nature of impoundment (the area stratifies in the summer months) but still is impacted by river inputs (Pigg River impact is important here). E. coli is an important driver of water quality and needs to be closely monitored during stormwater impact of very low lake levels (down to 600 feet). Inputs of phosphorus can drive Chlorophyll productivity to high levels so this portion of the reservoir is suspectable to impacted water quality due to high productivity. It shows greater levels of eutrophy than the dam region.

LVL Dam – Marina region (Old Womans Creek and Tri County). This region is most strongly driven by lake limnology yet is also impacted by stormwater input. This is hypothesized to be from the Pigg River but also may occur from Old Womans Creek or other tributaries. Water quality is generally good with the input of stormwater flushing and diluting this area on occasion. This is very impactful when the reservoir is low (near 600 feet) and even during turnover when the oxygen throughout the area may be 5 mg/l or below. *E. coli* is not usually a problem and this water meets expected needs for the reservoir.

3.2 Management Implications

1. Data continues to support that Leesville Lake is a mildly eutrophic reservoir with a TSI index between 50-60. All indicators now through 2024 suggest this condition should continue into the foreseeable future. While it is always the aim to improve this condition and lower the trophic state index, the stability of this measure is encouraging and promises good and continued function of the reservoir into the foreseeable future.
2. Patterns in the reservoir are becoming clear with continued monitoring and analysis of data. The upper portions of LVL are influenced by operation of the SML dam with expected oxygen loss and hypoxia into the late summer and fall periods in this region. Remainder of the reservoir functions as expected and improvements in Pigg River Watershed would be realized in the remainder of the reservoir.
3. In 2024 and during concern over Hurricane Helene it appeared to create a condition where LVL was lowered to 600 feet (low pool) and water was pushed through LVL from SML release (Table 2.2.1). This was a unique event where water was released from SML *and* LVL lowered to low pool to make room for the

expected precipitation event. This created very poor water quality conditions throughout LVL by flooding it with very low oxygenated water from SML and breaking up stratification causing hypoxic hypolimnion of LVL to mix. The entire reservoir was at 5 mg/l or below in oxygen. Future use of this management technique for expected precipitation events in the fall must be done with careful consideration.

4. Clear plans on improving water quality in the reservoir (reduction of nutrients from Pigg River Watershed) and increasing oxygen concentrations to mitigate methane and habitat loss need to be developed. Nutrient reduction needs to work in conjunction with TMDL implementation plans currently underway with Department of Environmental Quality. Leesville Lake Association needs to be a continued part of this process. Additionally, work with Tri-county Lakes Administrative Commission to study impact from Pigg River should continue and recommendations from this work given to the counties to help administer state funds for the protection of the watersheds through the cost share program. The cost share program is administered through Soil and Water Conservation to help farmers better manage land to conserve soil and nutrients on fields rather than run-off into waterways. Leesville Lake Association should maintain contact with Soil and Water Conservation to get updates on this program. Finally, low dissolved oxygen from SML particularly in the Fall is a difficult problem. Leesville Lake Association needs to continue engagement with the Technical Review Committee at American Electric Power (AEP) to determine possible engineering solutions. Additionally, Soil and Water Conservation throughout the Roanoke River Basin can provide similar insights as the Pigg River to determine the extent of soil and nutrient control that is occurring. Engaging Ferrum College and work on SML is encouraged to determine trends in eutrophication. Watershed management plans in all 3 major basins (Pigg, Blackwater and Roanoke) are encouraged and funding should be pursued to control and minimize deleterious land use leading to degradation of both reservoirs.

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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

(⌠mhos/cm) or microsiemens per centimeter (⌠s/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, $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$
- Ammonium Persulfate, $(NH_4)_2S_2O_8$
- Antimony Potassium Tartrate, $K(SbO)C_4H_4O_6\cdot 3H_2O$
- 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 4°C. 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) $C_{12}H_{14}N_2 \cdot 2HCl$
- 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.

Secchi Depth

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.

Trophic State

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).

E. coli

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

- 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
- Mile Mark 9 (mixing zone): Secchi depth, TP?
- Mile Mark 6 (end of mixing zone/beginning of lacustrine): Secchi depth, TP, hydrolab data
- Tri-County Marina: Secchi depth, TP
- Leesville Lake Marina: Secchi depth, TP
- 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°C 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°C 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

Field Testing Procedures (p. 69)

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

DO and conductivity meter calibration checks

- 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

Thermistor Verification

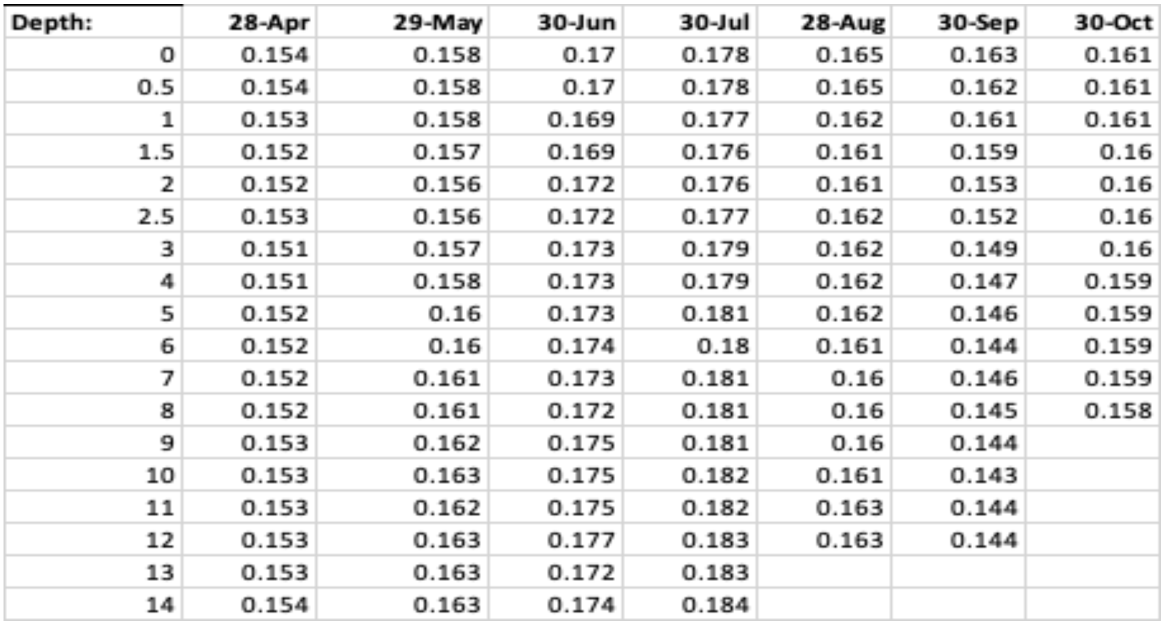
- Check temperature probe against another multiprobe instrument's temperature probe semi-annually
- Check against 3 points such as an ice/water mixture, room water temperature, and warm water temperature
- Do not use thermistor if the difference is more than 0.5 degrees C

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

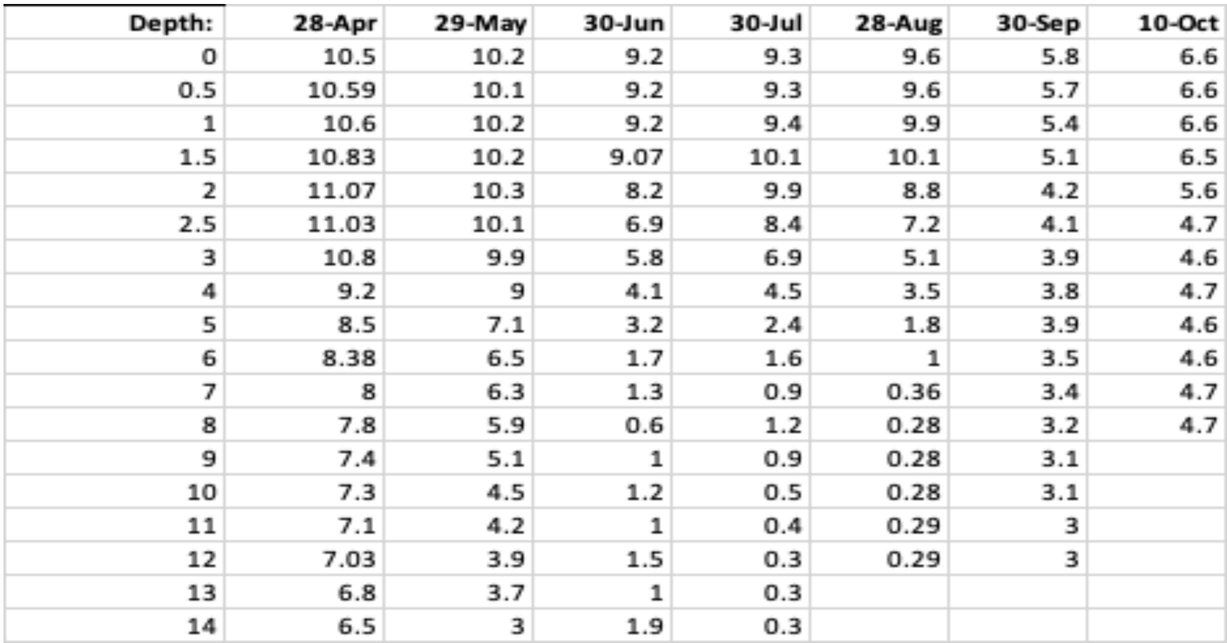
Appendix D – Collected Data

Table 1.1. Dam (Lacustrine) Conductivity (µs/cm) measures over study period (2024)



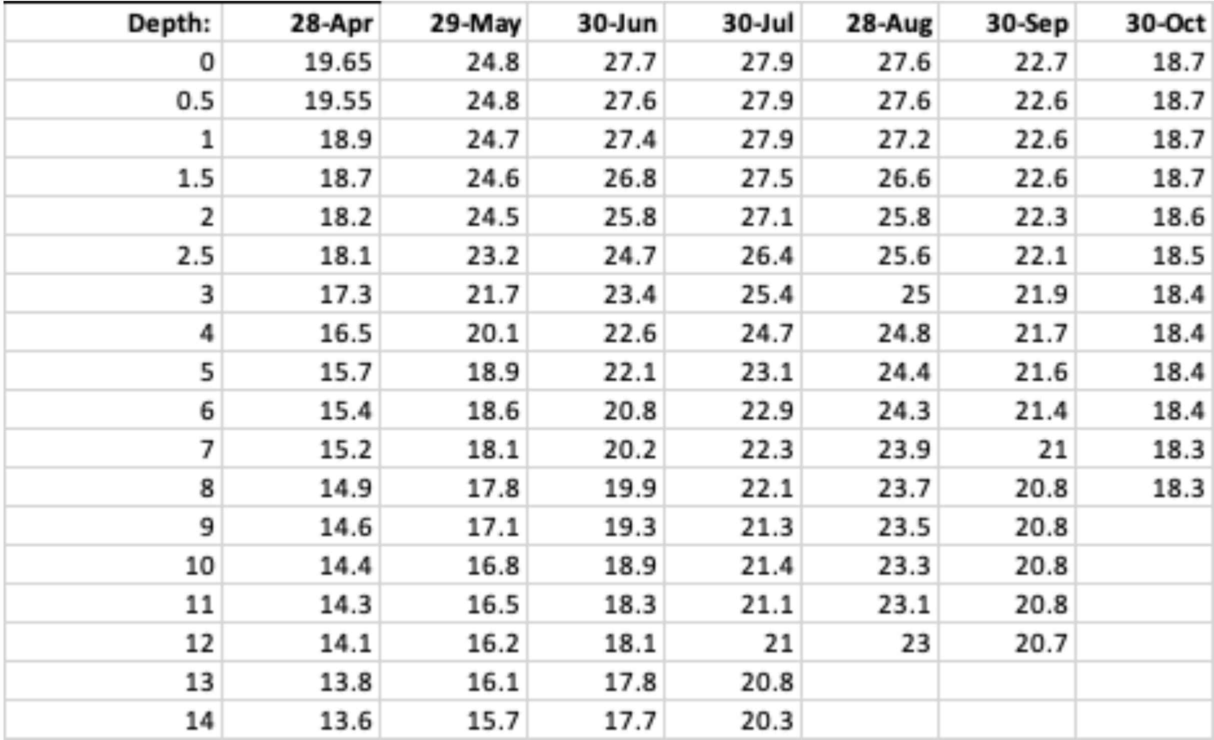
Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.154	0.158	0.17	0.178	0.165	0.163	0.161
0.5	0.154	0.158	0.17	0.178	0.165	0.162	0.161
1	0.153	0.158	0.169	0.177	0.162	0.161	0.161
1.5	0.152	0.157	0.169	0.176	0.161	0.159	0.16
2	0.152	0.156	0.172	0.176	0.161	0.153	0.16
2.5	0.153	0.156	0.172	0.177	0.162	0.152	0.16
3	0.151	0.157	0.173	0.179	0.162	0.149	0.16
4	0.151	0.158	0.173	0.179	0.162	0.147	0.159
5	0.152	0.16	0.173	0.181	0.162	0.146	0.159
6	0.152	0.16	0.174	0.18	0.161	0.144	0.159
7	0.152	0.161	0.173	0.181	0.16	0.146	0.159
8	0.152	0.161	0.172	0.181	0.16	0.145	0.158
9	0.153	0.162	0.175	0.181	0.16	0.144	
10	0.153	0.163	0.175	0.182	0.161	0.143	
11	0.153	0.162	0.175	0.182	0.163	0.144	
12	0.153	0.163	0.177	0.183	0.163	0.144	
13	0.153	0.163	0.172	0.183			
14	0.154	0.163	0.174	0.184			

Table 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2024)



Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	10-Oct
0	10.5	10.2	9.2	9.3	9.6	5.8	6.6
0.5	10.59	10.1	9.2	9.3	9.6	5.7	6.6
1	10.6	10.2	9.2	9.4	9.9	5.4	6.6
1.5	10.83	10.2	9.07	10.1	10.1	5.1	6.5
2	11.07	10.3	8.2	9.9	8.8	4.2	5.6
2.5	11.03	10.1	6.9	8.4	7.2	4.1	4.7
3	10.8	9.9	5.8	6.9	5.1	3.9	4.6
4	9.2	9	4.1	4.5	3.5	3.8	4.7
5	8.5	7.1	3.2	2.4	1.8	3.9	4.6
6	8.38	6.5	1.7	1.6	1	3.5	4.6
7	8	6.3	1.3	0.9	0.36	3.4	4.7
8	7.8	5.9	0.6	1.2	0.28	3.2	4.7
9	7.4	5.1	1	0.9	0.28	3.1	
10	7.3	4.5	1.2	0.5	0.28	3.1	
11	7.1	4.2	1	0.4	0.29	3	
12	7.03	3.9	1.5	0.3	0.29	3	
13	6.8	3.7	1	0.3			
14	6.5	3	1.9	0.3			

Table 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2024)



Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	19.65	24.8	27.7	27.9	27.6	22.7	18.7
0.5	19.55	24.8	27.6	27.9	27.6	22.6	18.7
1	18.9	24.7	27.4	27.9	27.2	22.6	18.7
1.5	18.7	24.6	26.8	27.5	26.6	22.6	18.7
2	18.2	24.5	25.8	27.1	25.8	22.3	18.6
2.5	18.1	23.2	24.7	26.4	25.6	22.1	18.5
3	17.3	21.7	23.4	25.4	25	21.9	18.4
4	16.5	20.1	22.6	24.7	24.8	21.7	18.4
5	15.7	18.9	22.1	23.1	24.4	21.6	18.4
6	15.4	18.6	20.8	22.9	24.3	21.4	18.4
7	15.2	18.1	20.2	22.3	23.9	21	18.3
8	14.9	17.8	19.9	22.1	23.7	20.8	18.3
9	14.6	17.1	19.3	21.3	23.5	20.8	
10	14.4	16.8	18.9	21.4	23.3	20.8	
11	14.3	16.5	18.3	21.1	23.1	20.8	
12	14.1	16.2	18.1	21	23	20.7	
13	13.8	16.1	17.8	20.8			
14	13.6	15.7	17.7	20.3			

Table 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	3.43	10.4	7.9	7.6	9.9	29.7	20.1
0.5	4.77	14.7	9.3	9.1	11.7	16.9	18.3
1	5.4	9.8	13.3	9.3	16.8	12.4	19.7
1.5	8.7	21.7	15.5	11.2	19.7	10.2	19.5
2	10.7	15.6	17.4	13.4	26.9	6.4	10.7
2.5	11.3	15.8	21.2	14.9	31.5	6	8.4
3	14.5	16	20.7	17.5	33.7	5.3	7.9
4	9.01	11.3	15.4	12.7	18.7	5.2	6.9
5	7.5	4.4	13.8	10.1	14.9	5.4	7.4
6	5.9	3.1	7.2	6.4	10.8	4.4	8.1
7	4.1	2.6	5	6.9	6.2	4	8.2
8	3.6	2.7	5.3	5.7	4.9	3.7	6.4
9	3.2	1.9	4.4	5.1	4.4	3.5	
10	3.1	2.2	3.5	4.1	4	3.7	
11	2.7	2.6	3.3	4	3.3	3.6	
12	2.6	2.8	3.9	4.2	3	3.6	
13	2.5	1.9	2.9	3.3			
14	3.3	1.8	2.7	3.4			

Table 1.5. Dam (Lacustrine) pH measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	8.75	8.5	8.5	8.1	8.4	7.6	7.7
0.5	8.74	8.5	8.6	8.1	8.4	7.6	7.7
1	8.71	8.6	8.6	8.1	8.4	7.5	7.7
1.5	8.7	8.6	8.5	8.2	8.3	7.5	7.7
2	8.75	8.6	8.4	8.2	8.2	7.4	7.6
2.5	8.75	8.6	8.3	8	8	7.4	7.6
3	8.7	8.5	8.14	7.8	7.7	7.3	7.5
4	8.6	8.4	8.05	7.7	7.6	7.3	7.5
5	8.5	8.3	7.9	7.5	7.5	7.3	7.5
6	8.4	8.2	7.8	7.5	7.4	7.3	7.5
7	8.4	8.2	7.8	7.4	7.4	7.3	7.5
8	8.4	8.1	7.7	7.4	7.3	7.2	7.5
9	8.3	8.1	7.7	7.3	7.3	7.2	
10	8.3	8.1	7.7	7.3	7.3	7.2	
11	8.3	8	7.6	7.3	7.3	7.2	
12	8.3	8	7.6	7.3	7.3	7.2	
13	8.3	8	7.6	7.3			
14	8.2	8	7.6	7.2			

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

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	386	255	203	335	323	355	386
0.5	386	259	220	334	323	356	387
1	385	261	227	334	325	357	387
1.5	386	263	233	333	326	358	389
2	386	266	239	334	328	359	390
2.5	387	269	245	339	331	359	391
3	388	273	249	343	336	360	391
4	392	277	250	349	339	360	392
5	393	281	251	351	339	361	392
6	394	283	251	351	340	361	392
7	394	285	250	352	340	362	392
8	395	286	249	351	340	362	392
9	396	288	248	352	340	363	
10	396	289	248	351	339	363	
11	396	290	248	352	338	363	
12	397	291	248	352	338	363	
13	397	292	247	352			
14	398	293	248	351			

Table 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.8	0.5	0	0.1	0.8	14.8	6.3
0.5	0.6	0.5	0	0	0.5	13.9	6.8
1	1.9	0.4	0.1	0	1.1	15.2	6.7
1.5	1.7	1	0.2	0	0.7	17.8	6.6
2	2	0.1	0.2	0	0.7	21.9	7.1
2.5	1.6	0.2	0.6	0	2.1	24.7	6.6
3	1.2	0.2	0.8	0	3.9	24	7.1
4	1.8	0.1	0.2	0	3.1	24	8.8
5	2	0	0	0	2.8	24	9.8
6	1.8	0	0	0	5	24	12.1
7	1.8	0	0	2.5	3.2	24	12.9
8	2.4	0	0	0.7	4.3	24	12.8
9	3.6	0	1	0.6	7.6	24	
10	4.3	0.1	1	1.3	3.7	24	
11	5	0.1	1.7	2	5.6	24	
12	7.6	1.1	2.6	5.5	3.4	24	
13	9.5	0.7	2.5	3.8			
14	13.5	1.5	3.4	5			

Table 1.8. Dam (lacustrine) Nitrate (mg/L) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.52	0.53		0.05	0.07	0.17	0.41
0.5	0.55	0.48		0.05	0.07	0.18	0.41
1	0.6	0.47		0.06	0.07	0.19	0.4
1.5	0.62	0.46		0.06	0.07	0.2	0.39
2	0.64	0.49		0.06	0.07	0.22	0.4
2.5	0.65	0.54		0.05	0.07	0.24	0.41
3	0.71	0.62		0.08	0.09	0.28	0.41
4	0.80	0.71		0.11	0.13	0.28	0.41
5	0.87	0.88		0.14	0.16	0.3	0.41
6	0.92	0.97		0.14	0.17	0.33	0.4
7	0.97	1.03		0.16	0.18	0.34	0.4
8	1.00	1.09		0.16	0.18	0.35	0.4
9	1.04	1.20		0.17	0.18	0.36	
10	1.08	1.27		0.17	0.16	0.37	
11	1.11	1.32		0.17	0.15	0.37	
12	1.14	1.35		0.17	0.15	0.37	
13	1.16	1.37		0.17			
14	1.18	1.40		0.16			

Table 1.9. Dam (lacustrine) total dissolved solids (mg/L) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sept	30-Oct
0	0.099	0.101	0.109	0.114	0.105	0.104	0.103
0.5	0.099	0.101	0.109	0.114	0.105	0.104	0.103
1	0.098	0.101	0.109	0.114	0.104	0.103	0.103
1.5	0.098	0.101	0.109	0.113	0.104	0.102	0.102
2	0.098	0.101	0.11	0.113	0.104	0.099	0.102
2.5	0.098	0.101	0.11	0.114	0.104	0.097	0.102
3	0.097	0.101	0.111	0.115	0.104	0.095	0.102
4	0.098	0.102	0.111	0.115	0.104	0.095	0.102
5	0.098	0.103	0.111	0.116	0.104	0.094	0.102
6	0.098	0.103	0.112	0.116	0.103	0.093	0.102
7	0.098	0.103	0.112	0.117	0.103	0.093	0.101
8	0.098	0.103	0.111	0.116	0.103	0.092	0.101
9	0.098	0.104	0.113	0.116	0.102	0.092	
10	0.098	0.104	0.112	0.117	0.104	0.092	
11	0.098	0.105	0.113	0.117	0.104	0.092	
12	0.098	0.105	0.114	0.117	0.105	0.092	
13	0.098	0.105	0.11	0.117			
14	0.099	0.105	0.112	0.118			

Mile Marker 6

Table 1.13. Mile Marker 6 (Transition) Conductivity (µs/cm) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.152	0.161	0.175	0.177	0.165	0.177	0.167
0.5	0.149	0.161	0.175	0.177	0.165	0.177	0.167
1	0.149	0.16	0.174	0.177	0.165	0.177	0.166
1.5	0.149	0.161	0.175	0.177	0.165	0.177	0.166
2	0.148	0.16	0.174	0.177	0.166	0.177	0.166
2.5	0.149	0.16	0.175	0.177	0.166	0.177	0.167
3	0.15	0.16	0.175	0.178	0.167	0.177	0.167
4	0.15	0.162	0.176	0.177	0.17	0.177	0.167
5	0.154	0.163	0.177	0.177	0.172	0.176	0.166
6	0.157	0.162	0.177	0.177	0.172	0.176	0.165
7	0.159	0.162	0.178	0.179	0.172	0.176	0.169
8		0.165	0.179	0.18	0.173	0.176	

Table 1.14. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	9.9	10.1	8.9	9.7	10.1	3.9	8.2
0.5	10.1	10.1	8.8	9.7	9.8	3.9	8.1
1	10.4	10.1	8.7	9	9.6	3.9	8
1.5	10.6	9.8	8.4	8.4	9.4	3.8	7.6
2	10.1	9.4	8.1	8.1	9	3.9	7.3
2.5	9.85	9.7	7.2	7.1	8.5	3.8	7.1
3	9.01	9.5	7	6.6	7.4	3.8	7
4	8.45	7.3	6.4	6.4	6.7	3.9	6.5
5	7.8	6.1	6.2	4.7	6.1	3.8	6.2
6	7.8	6.2	6	3.5	5.6	3.8	6
7	7.7	5.3	5.4	2.4	5.4	3.8	4.5
8		3.8	4.6	2	5.1	3.8	

Table 1.15. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	20.6	23.9	25.4	26.2	26.8	20.8	18.4
0.5	18.4	23.9	25.4	26.2	26.7	20.7	18.4
1	17.4	23.8	25.1	26	26.6	20.7	18.3
1.5	16.9	23.4	24.8	25.7	26.4	20.7	18.3
2	16.7	23.1	24.5	25.4	26.1	20.7	18.2
2.5	16.5	22.3	23.4	25.1	26	20.7	18.2
3	16.3	20.8	23.1	24.7	25.7	20.7	18.2
4	15.8	19.8	22.5	24.4	24.9	20.7	18.1
5	15.2	18.8	21.9	23.6	24.5	20.7	18.1
6	14.8	18.2	21.5	23	24.1	20.7	18.1
7	14.6	17.6	20.3	22.4	23.9	20.7	18
8			19.4	22.2	23.7	20.7	

Table 1.16. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	3.8	11.6	8.9	13.3	20.6	4.6	27.3
0.5	5.1	12.9	10.5	17.8	23.6	3.9	32.1
1	8.8	18.3	13.1	21.4	20.4	4.2	27.6
1.5	10.4	19	14.8	18.4	19.2	3.9	22.5
2	10.7	19.8	16.4	14.4	17.3	4.1	20.1
2.5	10.9	23.2	18.6	17.4	19.1	3.6	19.6
3	9.1	21.5	19.4	16.6	11.9	3.8	18.5
4	5.3	8.6	10.9	14.3	11.6	4.1	17.5
5	4.1	4.6	9.4	11.9	10.5	4.3	15.7
6	4	4.1	7.1	7.4	10	3.8	14.1
7	4.9	2.9	5	7	8.8	3.9	10.2
8		3.1	5	5.7	8.8	4.1	

Table 1.17. Mile Marker 6 (Transition) pH measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	8.3	8.7	8.1	8	8.3	7.3	7.8
0.5	8.3	8.7	8.1	8	8.3	7.3	7.9
1	8.3	8.7	8	8	8.3	7.3	7.8
1.5	8.3	8.7	8	7.9	8.2	7.3	7.8
2	8.3	8.6	8	7.8	8.1	7.3	7.8
2.5	8.3	8.6	7.9	7.7	8.1	7.3	7.7
3	8.3	8.5	7.9	7.7	7.9	7.3	7.7
4	8.2	8.4	7.8	7.6	7.8	7.3	7.7
5	8.2	8.3	7.8	7.6	7.7	7.3	7.6
6	8.1	8.3	7.8	7.5	7.7	7.3	7.6
7	8.1	8.2	7.7	7.4	7.6	7.3	7.5
8		8.2	7.7	7.4	7.6	7.3	

Table 1.18. Mile Marker 6 (Transition) ORP (mV) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	371	293	292	338	341	370	386
0.5	372	293	292	338	342	370	386
1	372	294	293	340	343	370	387
1.5	373	295	294	342	344	370	387
2	374	298	296	344	345	370	388
2.5	375	299	298	346	347	369	388
3	376	302	298	347	349	369	388
4	377	306	301	347	351	370	389
5	378	308	301	349	352	370	389
6	379	309	302	350	353	369	389
7	378	310	303	351	353	369	390
8		312	304	350	354	369	

Table 1.19. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2022)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	5.2	2.6	0.7	2.4	2.9	24.6	10.6
0.5	7.8	2.9	0.9	2.4	3.4	23.7	10.3
1	6.6	3.2	1.2	3.6	2.2	27.1	9
1.5	5.5	4.6	1.7	4.1	2.3	32.4	9.3
2	5.2	5.5	1.8	4.1	3.3	25.2	9.5
2.5	8.5	4.9	2.1	5.3	4.5	28.7	10.4
3	15.8	4.1	2.1	4.8	6.2	27.1	11.8
4	13.8	5	2.5	5.5	7.9	26.8	14.8
5	14.7	5.7	4.1	6.6	10.8	36.9	11.7
6	18.4	4.3	6.2	8.3	13.5	33.2	13.1
7	41	6	13.1	8.6	14.3	35.4	22.4
8		2.2	17	28.4	16.2	31.6	

Table 1.20. MM6 (lacustrine) Nitrate (mg/L) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.6	0.63	0.8	0.08	0.08	0.25	0.29
0.5	0.66	0.63	0.8	0.08	0.08	0.26	0.2
1	0.7	0.65	0.79	0.09	0.08	0.26	0.29
1.5	0.74	0.68	0.78	0.09	0.09	0.26	0.3
2	0.79	0.74	0.79	0.1	0.09	0.27	0.3
2.5	0.79	0.77	0.8	0.1	0.1	0.27	0.31
3	0.82	0.860	0.81	0.11	0.11	0.27	0.31
4	0.88	1.00	0.84	0.12	0.13	0.27	0.3
5	0.95	1.11	0.87	0.14	0.14	0.27	0.31
6	0.99	1.18	0.9	0.15	0.14	0.27	0.31
7	1.01	1.24	0.94	0.16	0.15	0.27	0.29
8		1.26	0.97	0.17	0.15	0.27	

Table 1.21. MM6 (lacustrine) TDS (mg/L) measures over study period (2024)

Depth:	28-Apr	29-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.097	0.103	0.112	0.113	0.106	0.113	0.107
0.5	0.097	0.103	0.112	0.114	0.106	0.113	0.107
1	0.096	0.103	0.112	0.114	0.106	0.113	0.107
1.5	0.096	0.103	0.112	0.114	0.106	0.113	0.106
2	0.096	0.104	0.112	0.114	0.105	0.113	0.107
2.5	0.096	0.103	0.112	0.114	0.107	0.113	0.107
3	0.097	0.103	0.112	0.114	0.108	0.113	0.107
4	.097	0.104	0.113	0.114	0.109	0.113	0.107
5	.1	0.104	0.113	0.114	0.111	0.113	0.106
6	.101	0.105	0.113	0.114	0.11	0.113	0.106
7	.102	0.106	0.114	0.115	0.111	0.112	0.108
8			0.115	0.116	0.111	0.113	

Toler Bridge

Table 1.24. Toler Bridge (Riverine) Conductivity (μs/cm) measures over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.117		0.18	0.173	0.178	0.186	0.159
0.5	0.137		0.179	0.173	0.178	0.186	0.159
1	0.138		0.179	0.173	0.178	0.186	0.159
1.5	0.155		0.179	0.172	0.179	0.186	0.158
2	0.162		0.179	0.172	0.179	0.185	0.154
2.5	0.162		0.179	0.173	0.179	0.185	0.148
3	0.163		0.179	0.172	0.179	0.185	0.139
4	0.162		0.179	0.173	0.179	0.185	0.131
5				0.173			0.126

Table 1.25. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	9.28		7.2	7.3	6	3.9	7.4
0.5	9.35		7.2	7.2	6	3.9	7.4
1	9.38		7.1	7.2	5.9	3.9	7.4
1.5	9.3		6.2	7.1	5.6	3.9	7.3
2	9.37		6.9	7.1	5.5	3.9	7.4
2.5	9.2		6.9	7	5.5	3.9	7.4
3	9.19		6.9	6.9	5.5	3.9	7.4
4	9.16		6.8	6.7	5.5	3.9	7.6
5				6.8			7.8

Table 1.26. Toler Bridge (Riverine) Temperature (°C) measures over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	18.9		22	24.3	23.4	20.6	17.2
0.5	18.1		21.9	24.1	23.4	20.6	17.1
1	18.2		21.9	24	23.2	20.6	17.1
1.5	17.2		21.9	23.9	23	20.6	17.1
2	16.3		21.7	23.9	22.9	20.6	17
2.5	16.1		21.5	23.8	22.8	20.6	16.9
3	16		21.4	23.7	22.7	20.6	16.7
4	15.9		21.4	23.4	22.7	20.6	16.2
5				23.4			16

Table 1.27. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	2.3		3.7	5.2	5.3	3.8	5.6
0.5	4.1		3.9	7.5	7.8	3.9	5.8
1	5.3		6.5	8.3	7.6	3.7	5.7
1.5	7.1		7.4	8.9	7.3	3.8	4.8
2	7.1		7.4	8.9	6.5	3.9	3.8
2.5	7.2		7.8	9	6.5	4.3	3.2
3	7.3		7	8.4	6.5	3.9	2.9
4	8.4		7.5	6.7	6.9	3.5	2.6
5				6.8			2.7

Table 1.28. Toler Bridge (Riverine) pH measures over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	8.1		7.9	7.7	7.6	7.4	7.6
0.5	8.2		7.9	7.6	7.6	7.3	7.6
1	8.1		7.8	7.6	7.6	7.3	7.6
1.5	8.1		7.8	7.6	7.6	7.3	7.5
2	8		7.8	7.6	7.6	7.3	7.5
2.5	8		7.8	7.6	7.5	7.3	7.5
3	8.1		7.7	7.6	7.5	7.3	7.5
4	8.1		7.7	7.5	7.5	7.3	7.5
5				7.5	7.5		7.5

Table 1.29. Toler Bridge (Riverine) ORP (mV) measures over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	362		331	344	345	369	385
0.5	363		329	342	345	369	384
1	363		325	341	346	369	384
1.5	365		323	341	346	369	384
2	365		322	340	346	369	384
2.5	366		321	340	346	369	384
3	366		320	340	347	369	384
4	366		317	340	347	369	384
5				339			384

Table 1.30. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	71		5.4	3.7	9.7	13.9	8.5
0.5	74.9		7.1	5.2	12.4	13.6	7.7
1	78.3		5.8	4.6	12.3	14.1	7.7
1.5	63.8		6.1	5.8	11.3	12.6	7.6
2	48.4		8	5.8	12.2	13.5	8.5
2.5	22.1		7.7	5.5	12.1	14.7	7.6
3	9.4		6.3	5.1	12.3	12.8	10.6
4	4.8		7.3	5.1	13.5	14.1	9.8
5				5.2			10.4

Table 1.31. Toler Bridge (Riverine) Nitrate (mg/L) measures over study period (2024)

0	0.52		0.53	0.13	0.14	0.22	0.24
0.5	0.64		0.58	0.13	0.14	0.23	0.26
1	0.68		0.61	0.14	0.15	0.23	0.26
1.5	0.76		0.63	0.14	0.15	0.23	0.26
2	0.82		0.64	0.5	0.16	0.23	0.26
2.5	0.84		0.66	0.5	0.16	0.23	0.26
3	0.87		0.68	0.16	0.16	0.23	0.26
4	0.9		0.71	0.16	0.17	0.23	0.27
5				0.17			0.27

Table 1.32. Toler Bridge (Riverine) TDS (mg/L) measures over study period (2024)

Depth:	28-Apr	31-May	30-Jun	30-Jul	28-Aug	30-Sep	30-Oct
0	0.076		0.115	0.111	0.113	0.119	0.102
0.5	0.083		0.115	0.111	0.114	0.119	0.102
1	0.088		0.115	0.111	0.114	0.119	0.101
1.5	0.104		0.115	0.11	0.115	0.119	0.101
2	0.104		0.115	0.11	0.115	0.119	0.098
2.5	0.104		0.115	0.111	0.115	0.119	0.093
3	0.104		0.115	0.111	0.115	0.119	0.086
4	0.104		0.114	0.111	0.115	0.118	0.082
5				0.111			0.8