Leesville Lake 2020 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
BOD	Biological Oxygen Demand
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

Executive Summary

The Leesville Lake Association and University of Lynchburg, in partnership with American Electric Power Company, monitored water quality of Leesville Lake between April and October 2020. The lake was monitored at the end of each month by The University of Lynchburg while additional samples were collected by the Leesville Lake Water Quality Committee during June, July and August at mid-month. The results of that monitoring are reported here with analysis of lake trends at each station and additional analysis on problems of concern. The intent of this report is to provide a technical and scientific background for sound management of Smith Mountain Lake and Leesville Lake in order to protect and improve these lake resources for future generations.

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

Analysis of trends and concerns about future water quality focused on three specific areas. Precipitation patterns generating excessive sediment and bacteria loading to the headwaters of Leesville. Secondly, the relationship between this response and Chlorophyll *a* summer observed maximums. Finally, controlling factors related to SML tailwater release and oxygen loss in the upper portions of the reservoir.

At the mouth of the Pigg River in the entry point to Leesville Lake, *E. coli* violations continue to occur and at times were excessive (>10,000 cfu/100 ml). This problem is associated with heavy rainfall and high turbidity. Excessive nutrient pollution is also associated with storm flow and contributes to eutrophication and worsening of water quality. The origins of the problem may rest with changing precipitation patterns and land use alteration in the watershed.

Summer chlorophyll *a* peaks may be directly related to TP and turbidity inputs from the Pigg River. We found a positive relationship suggesting that increased concentrations of TP from the Pigg River were associated with increased levels of Chlorophyll *a* maximums observed at both MM6 and the Dam in all data collected from 2013-2020. In isolated measures on given dates when turbidity is elevated we do see reduced Chlorophyll *a*.

An analysis of oxygen concentrations and water release from SML into its tail waters suggests SML hypolimnion release controlled headwater water quality in Leesville Lake most of the season. Oxygen loss in tail water (<5 mg/l) from August – October can create areas of anoxia in Leesville Lake from Toler Bridge up to SML dam. It also likely contributes to observed oxygen minimums during fall turnover.

From these conclusions the following management recommendations are suggested:

1. Based on inputs from the Pigg River it is imperative that we work diligently to control these pollutants to maintain the health of Leesville Lake. While the lake is showing excellent resiliency to these current inputs, the last two seasons (2019-2020) produced exponential increases in pollutant loads from the Pigg River (4x-7x historical loading). This is unprecedented and if it is the new baseline of loading to the lake it must be controlled. Ecosystems often exhibit time lags to new inputs/changes and this must be anticipated.
2. Oxygen loss mechanisms in SML hypolimnion need to be explored. Implications of this annual phenomenon are multifold. DEQ requires oxygen levels above 5 mg/L per permit regulations on tail water release. Current trending suggests that water containing oxygen levels below this threshold is being released more frequently. This creates low oxygen conditions in the headwaters of Leesville Lake, further compounding already low oxygen in this reservoir. Continued worsening of this condition could cause severe problems in Leesville Lake during a season when water oxygen is very low.
3. Continue to research water quality concerns throughout the Pigg River Watershed. AEP and DEQ need to engage in the study currently underway by Leesville Lake Association, TLAC and University of Lynchburg to understand the primary mechanisms driving water quality throughout this basin. Findings from this study will drive water quality decisions for Leesville Lake and the SML project in the future.

Section 1: Current Conditions (2020)

1.1 General:

This is the ninth year of water quality monitoring of Leesville Lake by University of Lynchburg (formerly Lynchburg College) in partnership with Leesville Lake Association (LLA). Nine years of data continue to strengthen our understanding of water quality and allows us to pinpoint areas of concern and offer management recommendations. In addition, the Leesville Lake Water Quality Committee in partnership with University of Lynchburg has completed its 3rd year of a study of the Pigg River Watershed to pinpoint problems and describe overall conditions. Understandings from this study will be incorporated into the conclusions drawn in this report. Findings from the Pigg River study will be published in a different report.

Section 1 provides results for the current year's water monitoring of LVL. Data are reported in graphical form, with interpretations of current water quality noting any significant changes. In **Appendix D**, all data are reported in tabular form to facilitate future analysis and use for other projects. This project continues to provide essential baseline results for the condition of the lake and interpretation of changing conditions if found. A full background of the study and its rationale are located in **Appendix A**.

1.2 Methods:

Data were collected by University of Lynchburg through a series of water samplings and testing monthly from April through October. These dates coincide with the most productive period of the reservoir or when lake productivity is highest. Leesville Lake Association supplements sampling in the most productive 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 the trends in the lake. The following eight sites continue to be sampled, as stated in the Leesville Lake Water Quality Monitoring Plan:

Table 1.0. Leesville Lake Sampling Sites

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

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

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

1.3 Water Quality: Current Test Results (2020)

1.3.1Temporal Analysis by Station

Background

Leesville Lake is a reservoir by definition. It is a river course with a dam constructed and filled to form this reservoir. Leesville Lake is somewhat different from a typical reservoir because it serves as a source of water (pump back operations) and a recipient of water for the generation of electricity by the Smith Mountain Lake Hydroelectric Plant. The reservoir receives water input primarily from Smith Mountain Lake and secondarily from several other stream systems but most importantly the Pigg River. This river drains a considerably large watershed with agriculture and urban land disturbance throughout. Therefore, Leesville Lake is subject to a unique hydrology that impacts the water quality of the reservoir.

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

Leesville Lake is very unique is these qualities. First, the headwaters are fed by release of tail water from Smith Mountain Lake's 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 (see definition of terms below) in quality. However, the oxygen content of water released from Smith Mountain Lake may have low oxygen due to the reservoir properties of stratification that depletes oxygen in the hypoliminion in 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 to Leesville Lake.

Water quality of Leesville Lake may be confounded due to multitude of factors related to the unique hydrology of this reservoir. The headwaters of Leesville Lake are subject to a bidirectional movement of water. Water from the Pigg River is pumped back and combined with water in Smith Mountain lacustrine zone. The fate of this mixing depends on hydroelectric operations. Pigg River water is drawn 4 miles to the dam released into the lacustrine areas of Smith Mountain Lake. During energy production, Pigg River water mixed with SML lacustrine discharge flows through Leesville Lake. This pattern is variable and can be significantly influenced by stormwater input both in flow direction of water and quality.

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 up through the reservoir potentially enhancing impact.

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 on the observed water quality. Section 2 examines lake-wide trending and consideration of problems that should be investigated further. Section 3 presents management recommendations.

Scientific terms are used in this report to describe certain aspects of lake function and water quality. Here we define key terms to facilitate comprehension of the document and the trends that the research has revealed.

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 of water movement and less development in these areas.

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 tannin 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 be mixed. In many lakes in temperate climates such as ours, warming summer months cause the warm water to float on top of colder water. During this period of “stratification” the upper portion is isolated from the lower portion. Thus the lake only mixes in the upper layer. When the lake warms or cools to the same temperature it mixes – thus a typical lake may be dimicitic – or mixing only twice in a year. These reservoirs are polymictic because heavy rain input and water movement by Smith Mountain Lake can break up the stratification causing the lake to mix many times in a year or polymictic.

Hypolimnion and Epilimnion – These are terms used by limnologists (a person who studies lakes) to describe the layers of water 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 – Depth in the lake 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 – *Escherichia coli* is a species 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*.

Biochemical Oxygen Demand – This term indicates the amount of dissolved oxygen required by aerobic organisms to to breakdown the organic matter present in that water.

1.3.1.1 Dam (Lacustrine)[1]

Background

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

Conductivity

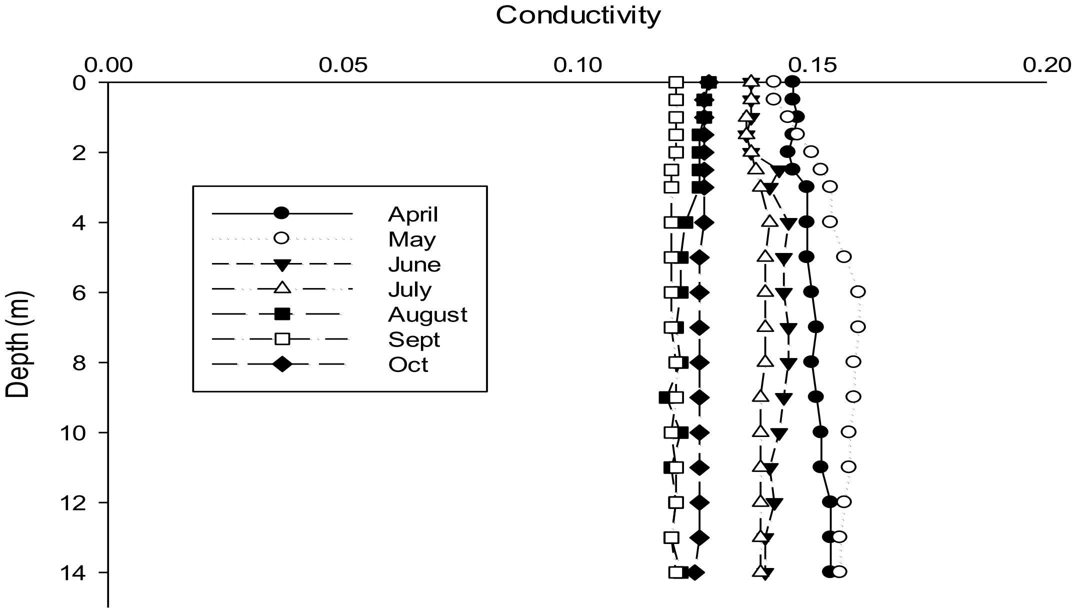

Figure 1.1. Dam (Lacustrine) Conductivity (ms/cm) measures over study period (2020)

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

Seasonal Analysis

Conductivity reflects the presence or absence of ions, pollution or particulates that conduct electricity in the water. It is a good measure of how water moves through the reservoir and is distributed. 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.

Conductivity does not stratify and remains between 0.125 and 0.155 mS/cm at Leesville dam. This measure is helpful to understand water flow. Pigg River water entering Leesville Lake has a conductivity between 0.07 – 0.05 mS/cm while water from Smith Mountain Lake has conductivity between 0.175 – 0.150 uS/cm. This suggests SML discharge is the predominant water in the lake. In 2020, conductivity diluted as the season progressed. This suggests greater influence from the Pigg River.

Comparisons Across Years

In 2020, conductivity was generally lower in the lake. In other years, we have seen higher trends up to 0.25 ms/cm in 2015. Because Pigg River conductivity is considerably lower than water release from Smith Mountain Dam lower conductivity measures during any sampling date reflect movement of water through the reservoir dominated by Pigg River. Conductivity will be a good measure moving forward to determine greater influences from the river.

Dissolved Oxygen

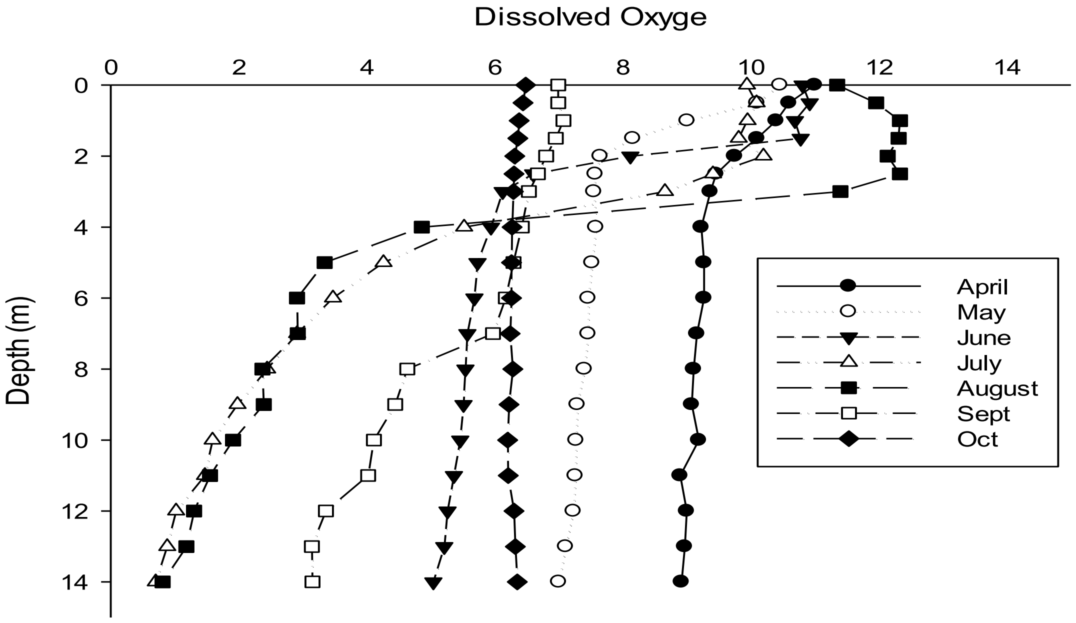


Figure 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2020)

Seasonal Analysis

Dissolved oxygen patterns in the reservoir continue to suggest the lake is eutrophic. Stratification begins in May with depletion of oxygen below the thermocline (about 4 meters depth). Stratification and loss of oxygen in the hypolimnion is greatest from July – August. Mixing occurs in September lowering overall oxygen concentration throughout the reservoir. Supersaturation of oxygen in the epilimnion is evident during the summer months but most pronounced in August. Of increasing concern is the low oxygen levels (< 3 mg/L) below 5 meters. This mass of water is extensive and must be monitored closely. We must document at what depth we annually see this level of oxygen loss, for how many months and the impact on oxygen levels in the fall, when water turnover occurs. In this season, during full fall turnover in October oxygen concentrations were above 6 mg/L.

Comparisons Across Years

Oxygen profiles are somewhat consistent. Oxygen levels peak between 2-3 meters. From that point, oxygen declines rapidly and in the summer months it is depeleted to zero at depths greater than 14 meters. Turnover occurs from September to November depending on seasonal 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.

It appears that the strength of stratification is extremely important in determining the mass of oxygen loss and impact from fall turnover. In 2020, oxygen loss was rapid below 4 meters entraining much greater volume of water in low oxygen. Readings went to near zero rapidly below 4 meters. This created very low (less than 5 mg/L) in the reservoir during fall turnover. This was a very wet year and perhaps increased sediment and organic matter entering the reservoir produced the strong stratification.

Temperature

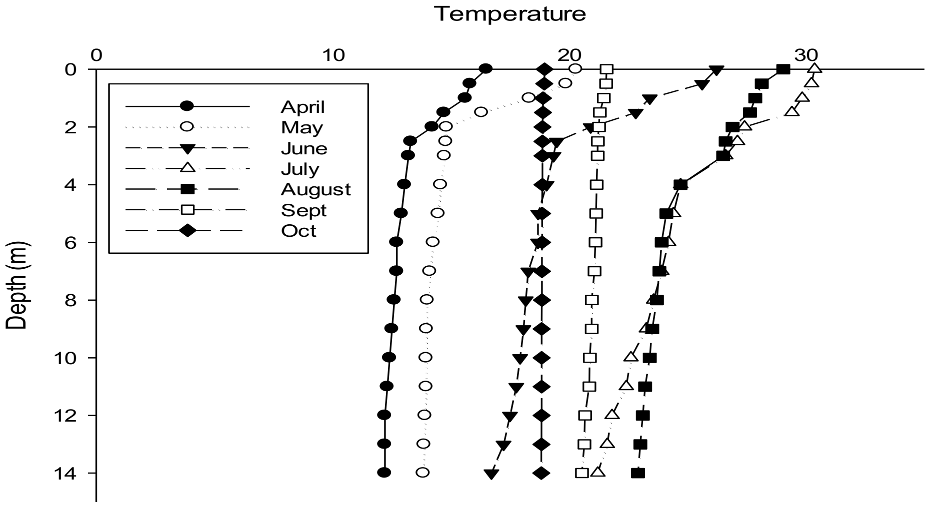


Figure 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2020)

Seasonal Analysis

Reservoir began warming in April but not enough for stratification. May through July the reservoir consistently warmed and stratified. Epilimnion water temperature reached 30C in July. Reservoir began cooling in August but remained stratified and then turned over in September.

Comparisons Across Years

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

Chlorophyll *a*

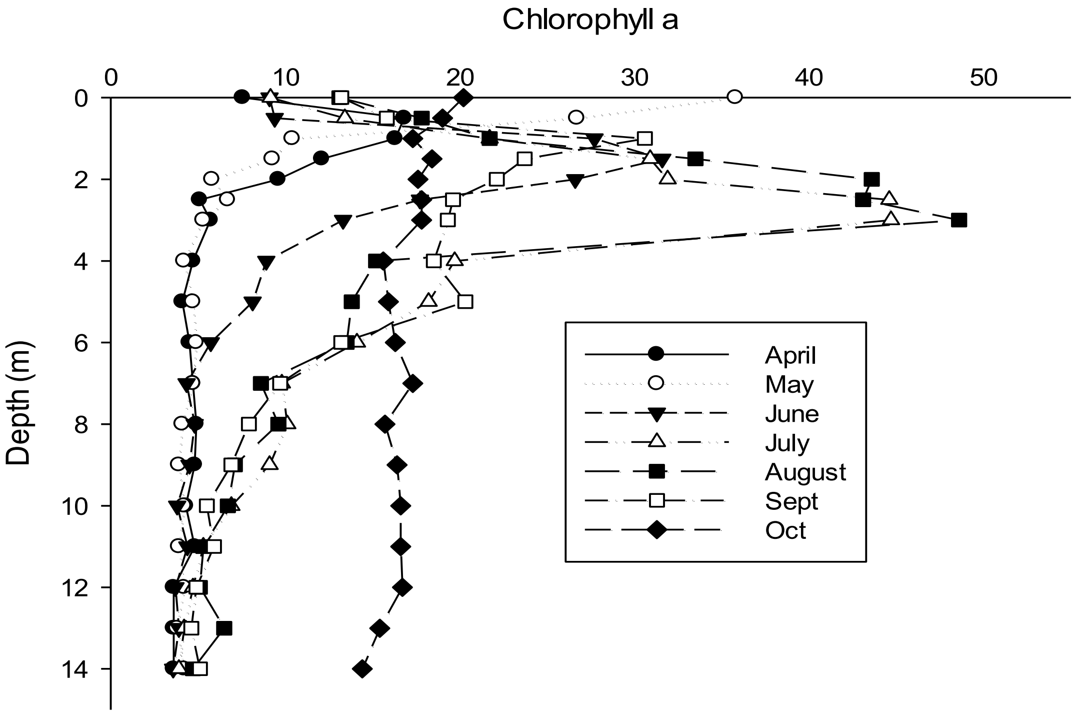


Figure 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2020)

Seasonal Analysis

The reservoir continues to demonstrate a pattern of greatest phytoplankton growth just above the thermocline (between 2-4 meters). Plankton are photo-inhibited at the surface and steadily increase down to 2 meters depth. This coincides with stratification patterns, pH elevation and oxygen observations. This is a typical pattern for eutrophic reservoirs where phytoplankton growth is photo-inhibited at the surface and blooms along the thermocline as nutrients are more available and temperatures very conducive for growth. These substantial peaks in Chlorophyll abundance occurred in the summer months of June, July and August.

Comparisons Across Years

The pattern of increased phytoplankton along the 2-4 meter thermocline in the reservoir is a well-established phenomenon in eutrophic lakes. In most seasons, this pattern is more pronounced in the summer months. The ultimate peak in phytoplankton growth usually occurs in July or August and it is variable in concentration. This season peak of near 50 mg/L is on the higher side of average peak. In 2015, peaks of biomass were near 100 mg/L which was near hypereutrophic levels. We look at ways to predict this peak in the analysis section.

pH

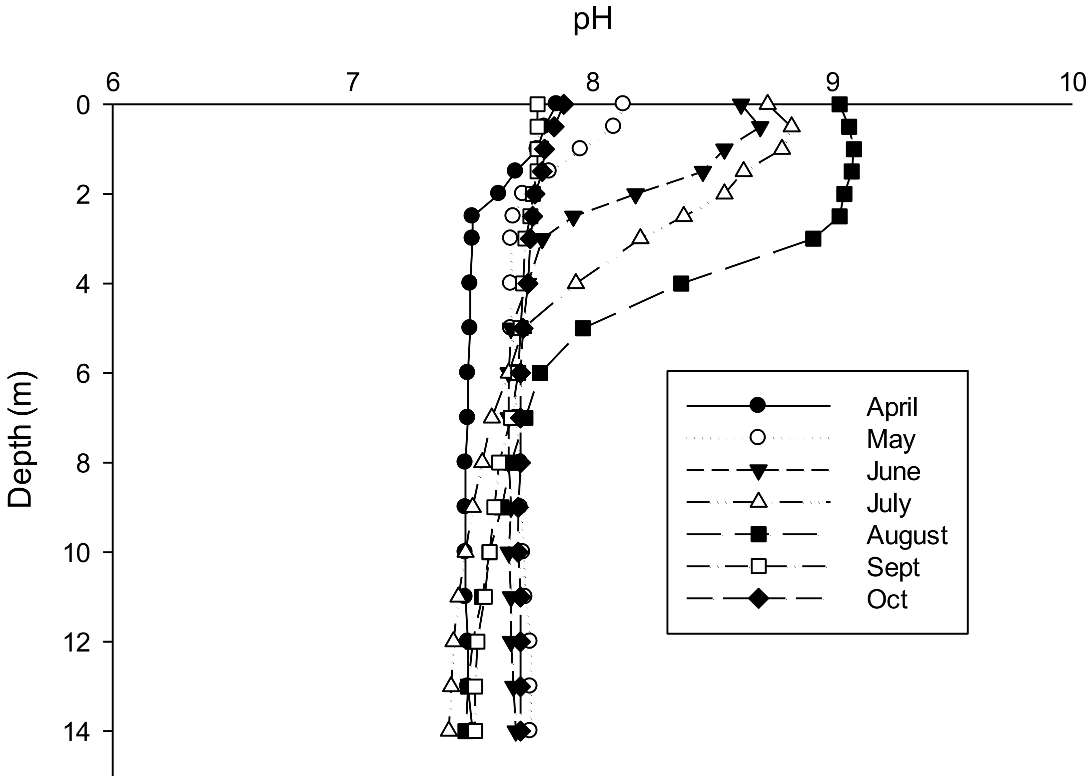


Figure 1.5. Dam (Lacustrine) pH measures over study period (2020)

Seasonal Analysis

The pH in the reservoir follows a curve for a eutrophic reservoir with soft water. The July and August measures were very high with August reaching 9. These pH changes are generated by phytoplankton growth as this parameter follows the stratification and buildup of chlorophyll measured. When phytoplankton growth, measured by chlorophyll, is reduced so is the pH. This is another measure supporting the designation of the reservoir as eutrophic.

Comparisons Across Years

The pattern of pH is relatively consistent across years in the reservoir. Increases in the summer months coincide with phytoplankton growth. But peak pH is variable. In most seasons, the pH does not exceed 8.5. This season it was 9. In 2018, pH peak was near 10. This variability is not associated with phytoplankton growth as peak Chlorophyll *a* was below 25 mg/L in 2018. Other factors help drive this pattern. It is important to note that high pH is very stressful to fish and due to the limited habitat generated in the summer months can be problematic.

ORP

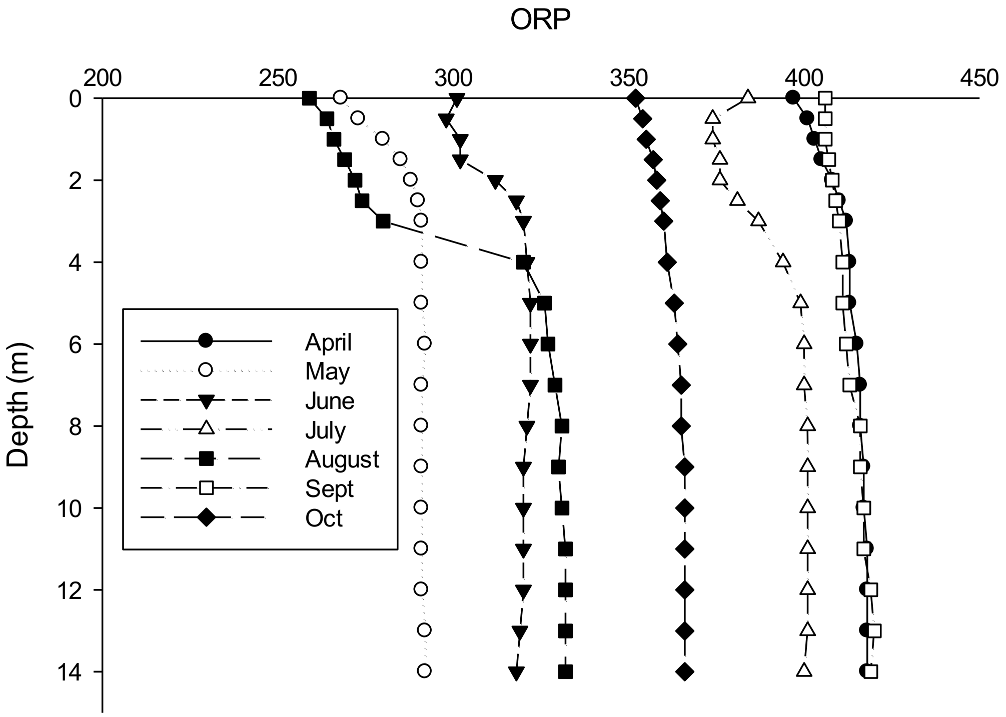


Figure 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2020)

Seasonal Analysis

There is a pattern of slightly increased ORP with depth through the summer months. Higher ORP occurs in the cooler months. Higher ORP reflects increased oxygen in the water and higher ORP during cooler months suggests the potential for redox reactions is decreased throughout the summer. ORP values near 400 and above are in the expected range for a productive reservoir.

Comparisons Across Years

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

Turbidity

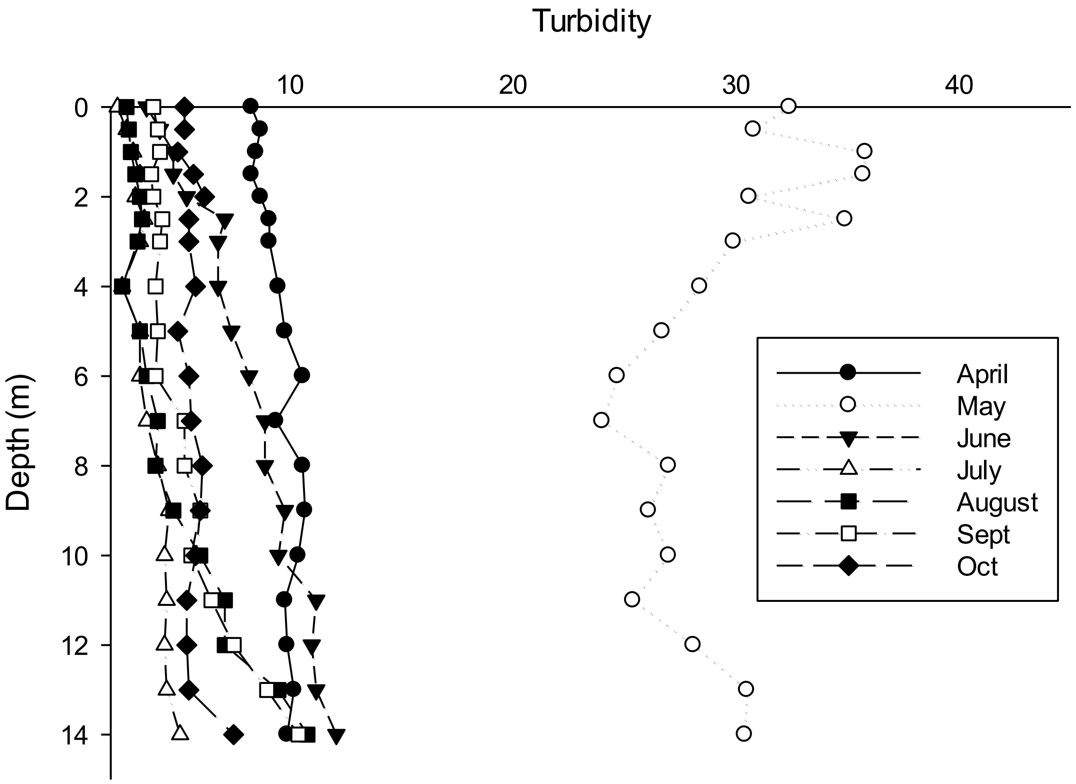


Figure 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2020)

Seasonal Analysis

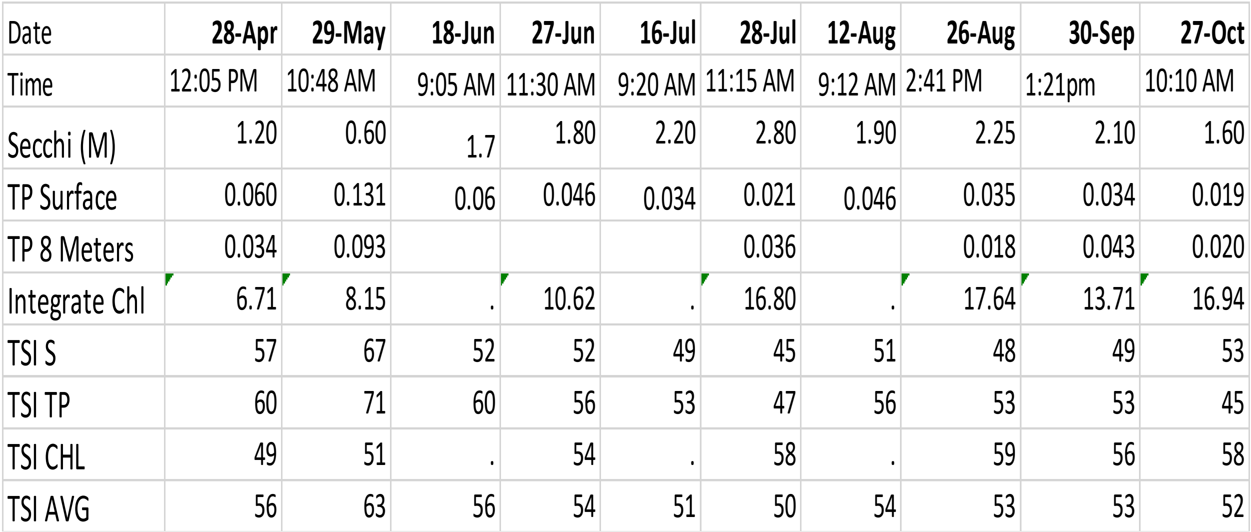
Turbidity at the dam is generally low. This season, values were below 10 NTU at every sampling with the exception of May. Sometimes, turbidity will increase with greater Chlorophyll *a* productivity but we did not see that pattern this season. The increased turbidity in May was due to heavy rain and flow into the reservoir during this period. This demonstrates the impact of rainfall and river input on water quality.

Comparisons Across Years

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

Other Parameters Measured

Table 1.8. Other parameters measured over study period (2020). Dates represent sampling of both the volunteers and University of Lynchburg. First Column represents each parameter measured along with units of measure.



Date	28-Apr	29-May	18-Jun	27-Jun	16-Jul	28-Jul	12-Aug	26-Aug	30-Sep	27-Oct
Time	12:05 PM	10:48 AM	9:05 AM	11:30 AM	9:20 AM	11:15 AM	9:12 AM	2:41 PM	1:21pm	10:10 AM
Secchi (M)	1.20	0.60	1.7	1.80	2.20	2.80	1.90	2.25	2.10	1.60
TP Surface	0.060	0.131	0.06	0.046	0.034	0.021	0.046	0.035	0.034	0.019
TP 8 Meters	0.034	0.093				0.036		0.018	0.043	0.020
Integrate Chl	6.71	8.15	.	10.62	.	16.80	.	17.64	13.71	16.94
TSI S	57	67	52	52	49	45	51	48	49	53
TSI TP	60	71	60	56	53	47	56	53	53	45
TSI CHL	49	51	.	54	.	58	.	59	56	58
TSI AVG	56	63	56	54	51	50	54	53	53	52

Table 1.9. Zooplankton, BOD and *E. coli* measured over study period (2020). Dates represent sampling of both the volunteers and University of Lynchburg. Zooplankton numbers are organisms per liter.

Date	**28-Apr**	**29-May**	**18-Jun**	**27-Jun**	**16-Jul**	**28-Jul**	**12-Aug**	**26-Aug**	**30-Sep**	**27-Oct**
Daphnia	0.0	0.2		1.6		1.0		0.2	6.5	0.4
Bosmina	2.4	2.6		2.4		0.0		0.0	0.0	1.2
Diaptomus	0.0	0.6		0.8		1.4		0.4	1.0	0.0
Cyclops	3.6	5.7		1.2		4.4		1.2	2.2	1.6
Nauplii	8.1	0.0		3.6		6.7		2.2	0.8	4.9
Cerodaphnia	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Diaphanosom	0.0	0.0		0.0		4.0		0.6	0.2	0.0
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.0
E. coli MPN	14.6	149.7	19.7	4.1	14.8	0.0	3.1	3.1	4.1	6.3
BOD	4.29	3.66		4.03		3.02		4.62	3.12	

1.3.1.2 Leesville Lake Marina / Old Womans Creek

Photograph of Leesville Lake Marina taken by Jade Woll.

Table 1.10. Leesville Lake Marina other parameters measured over study period (2020)

Date	**28-Apr**	**29-May**	**27-Jun**	**28-Jul**	**26-Aug**	**30-Sep**	**27-Oct**
Time	1:33 PM	10:30 AM	12:05 PM	11:47 AM	3:11 PM	1:58 PM	10:50 AM
Secchi (M)	1.3	0.7	1.5	2.0	1.8	2.0	1.6
TP Surface (PPM)	0.043	0.059	0.064	0.038	0.027	0.023	0.020
E. coli MPN	9.6	79.9	8.4	4.1	3.1	5.1	24.1
Turb	1.0	2.0	0.3	1.3	0.3	0.3	0.3

1.3.1.3 Tri County Marina

Photograph of Tri County Marina taken by Jade Woll.

Table 1.11. Tri County Marina other parameters measured over study period (2020)

Date	**28-Apr**	**29-May**	**18-Jun**	**27-Jun**	**16-Jul**	**28-Jul**	**12-Aug**	**26-Aug**	**30-Sep**	**27-Oct**
Time	1:42 PM	11:19 AM		12:16 PM		11:56 AM	9:40 AM	3:20 PM	2:08 PM	11:01 PM
Secchi (M)	1.1	0.6	1.3	1.4	1.5	1.9	1.6	1.6	1.3	0.9
TP Surface (PPM)	0.044	0.050		0.057		0.059		0.019	0.041	0.039
E. coli MPN	80.5	129.1	42.0	17.1	8.6	1.0		5.1	22.6	43.5
Turb	1.4	3.4		0.7		1.3	21.3	0.1	0.3	0.8

1.3.1.4 Mile Marker 6 (Transition)[2]

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

Conductivity

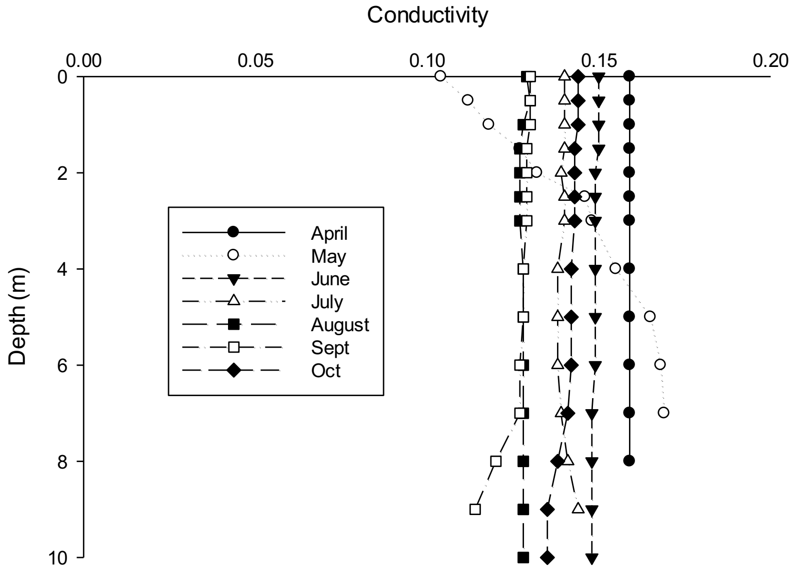

Figure 1.8. Mile Marker 6 (Transition) Conductivity (ms/cm) measures over study period (2020)

Seasonal Analysis

Conductivity patterns at the transition region were similar to those observed at the dam yet elevated by comparison. Consistent readings from surface to depth at this station reflect the mixing of water from the Pigg River and SML tail release at this area of Leesville Lake. The one exception this season was in May. During high rain events, excessive flow into Leesville Lake from the Pigg River is clearly visible at this station. While at the dam conductivity in May was elevated here it is much lower at the surface than at depth. This suggests that the warmer Pigg input (19.8 C and 0.05 mS/cm conductivity) is entering the reservoir and moving along the surface of SML dam release (14.58 C and 0.175 mS/cm conductivity) during these excessive flow events.

Comparisons Across Years

Comparisons among years suggest conductivity is trending lower in Leesville Lake. This suggests greater input from the Pigg River. This is a good station to measure this trend. Further discussion of this trend is provided in the analysis section.

Dissolved Oxygen

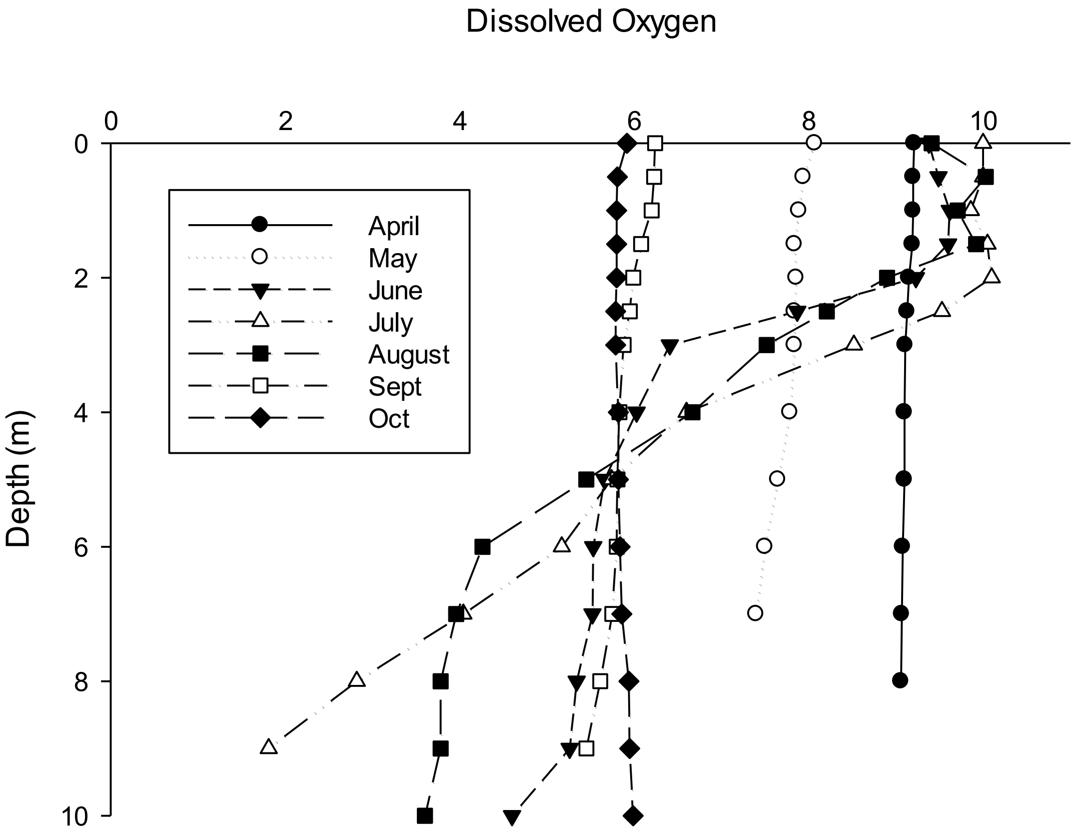

Figure 1.9. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2020)

Seasonal Analysis

This portion of the reservoir is completely mixed in the cooler months and stratified throughout the summer. The pattern of stratification is not as strong as observed at the dam (this is expected due to the transition characteristics of the reservoir at this station) nor is the production of oxygen above the thermocline as great at this station. At the dam station the influence of surface warming has greater visibility than at this station. Here the reservoir is stratified in the summer months unlike Toler Bridge where stratification is absent. Only in July and August did oxygen concentrations decline below 5 mg/l in the hypolimnion.

Comparisons Across Years

This years observations are typical for the reservoir. The one exception is the September stratification and oxygen concentrations. In some seasons, stratification remains through September and when this occurs oxygen concentrations in the hypolimnion can be the lowest observed for the entire season. In some, oxygen concentrations seasons at turnover are lower than those observed this season. The extent of stratification and loss of oxygen in the hypolimnion are good predictors of oxygen in the reservoir during turnover.

Temperature

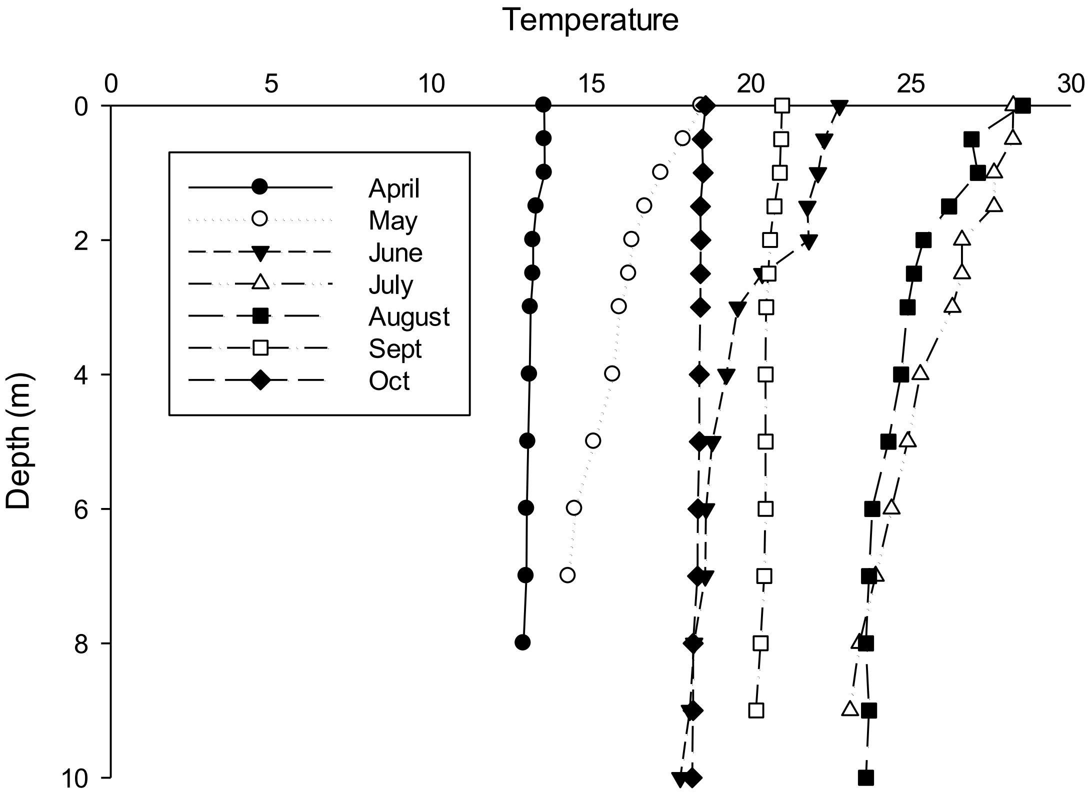

Figure 1.10. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2020)

Seasonal Analysis

Thermal stratification is not as evident at this station compared to the dam. This suggests influence of water movement from upstream of this station. Water does warm at a greater rate in this portion of the reservoir compared with Toler Bridge and the upper portions. Both SML operations and water flow from the Pigg River impact this observation. This portion of the reservoir clearly begins the warming of water entering the more lacustrine parts of the lake.

Comparisons Across Years

While temperatures at this station mimic seasonal influences observed throughout the reservoir, the pattern of minimal stratification is consistent across seasons. This suggests this station is a good representation of the transition zone influenced by both riverine and lacustrine forces.

Chlorophyll *a*

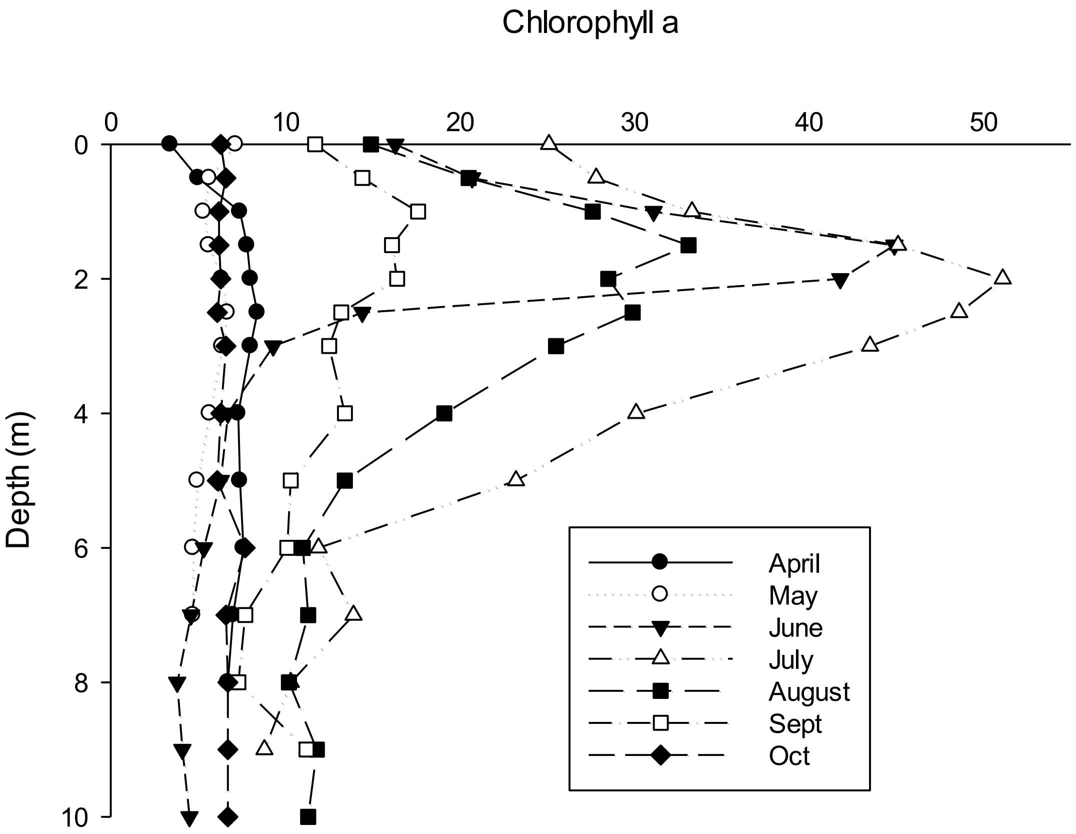

Figure 1.11. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2020)

Seasonal Analysis

The transition area is theoretically the portion of the reservoir where phytoplankton abundance measured by Chlorophyll *a* can be very high. Nutrient input from the upper portions of the reservoir mix with warmer waters and the slowly moving water mass creates ideal conditions for phytoplankton growth. This was apparent this year in the reservoir. Phytoplankton mass was just as great at this station in comparison with the dam. Peaks in Chlorophyll a occurred at 2 meters depth while at the dam the peaks were a bit deeper at 2.5 meters. In addition, August maximums were less than those observed at the dam. This may be due to retreat of maximums as water began to cool in this area while (25.1 C) remaining warmer at the dam (26.6 C). An increase in July phytoplankton was observed at Toler Bridge and could be contributing to the elevations here. This may be due to inputs from SML release.

Comparisons Across Years

The peak of phytoplankton biomass (50 ug/L) and pattern of growth above the thermocline has not been consistently observed at this station across years. The typical pattern is elevated phytoplankton biomass throughout the water column from 2-5 meters depth and at much lower concentrations (20-30 ug/L). This season mimicking of the dam station may be the result of the particular flow pattern observed. Input from Pigg River and SML tailwater release influence this pattern.

pH

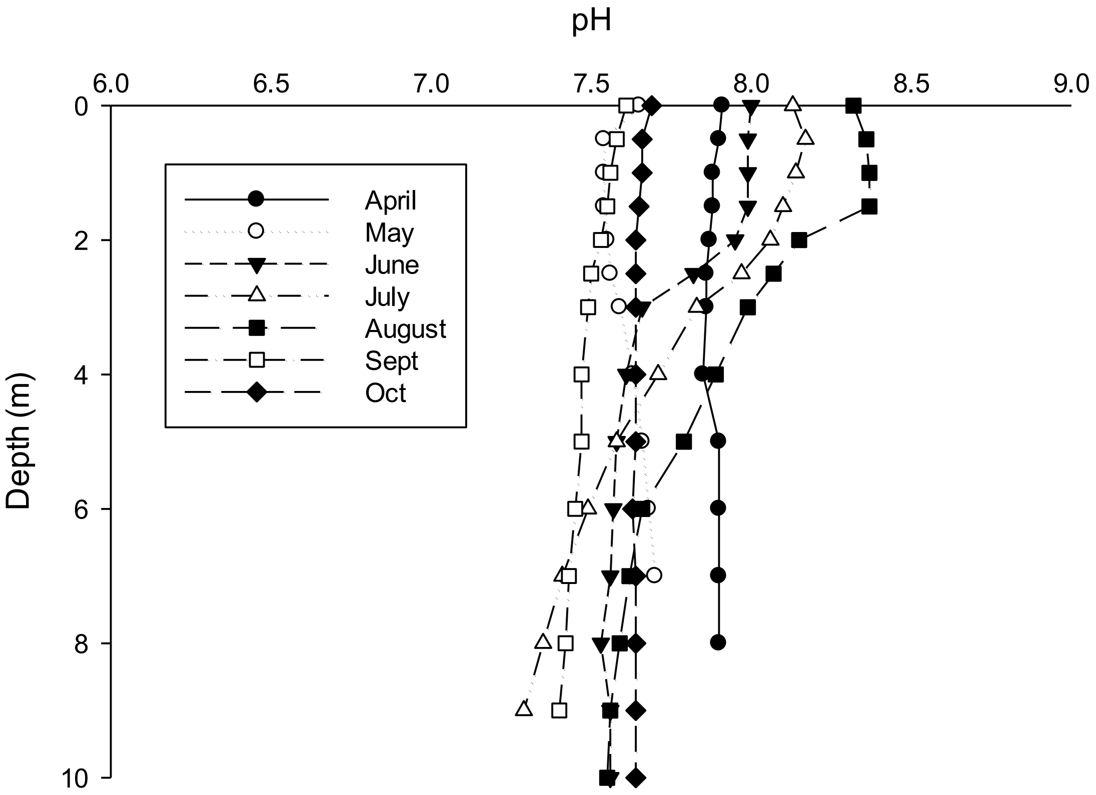

Figure 1.12. Mile Marker 6 (Transition) pH measures over study period (2020)

Seasonal Analysis

The pH pattern is very similar to that observed at the dam and the pattern of stratification in the reservoir. Elevated pH at this station in comparison to Toler Bridge reflects photosynthesis by phytoplankton at this transition station. Water released and flowing from Toler was not above 7.8 throughout the season. In cooler months pH is consistent throughout the reservoir but during summer it is strongly impacted by phytoplankton biomass.

Comparisons Across Years

This season showed greater resemblance to 2015 than other years as pH was relatively consistent throughout all sampling dates. In other years, we observed much greater variability between samplings. This is reflective of the influence of phytoplankton on this parameter. It is important to note that pH is lower in this area of the reservoir than at the dam. With the combination of a better oxygen environment and cooler temperatures, it provides a much better habitat for fish.

ORP

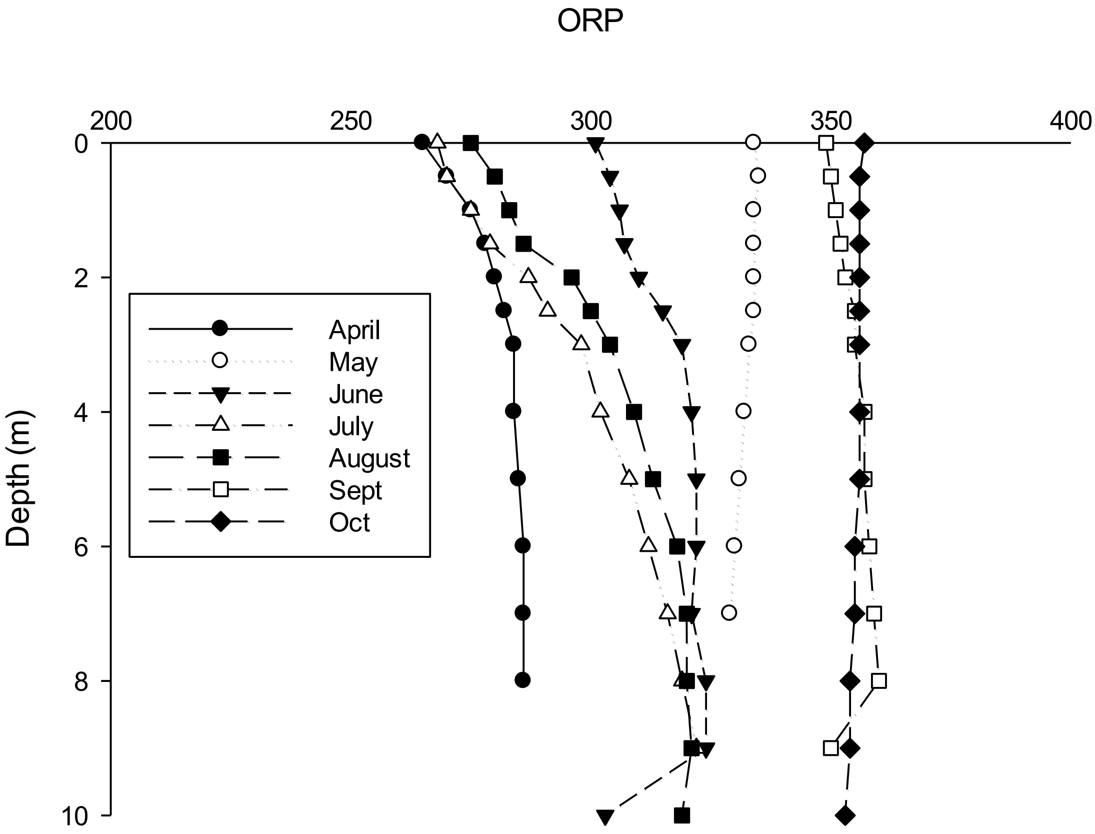

Figure 1.13. Mile Marker 6 (Transition) ORP (mV) measures over study period (2020)

Seasonal Analysis

ORP is greater at the dam than here at this station. This creates conditions of greater potential for chemical change at the dam. Conditions at Toler Bridge are similar with high ORP.

Comparisons Across Years

ORP has been variable over multiple seasons at this station. It is hard to pinpoint any particular conditions that may have contributed to this pattern, but years with lower ORP suggest a worsening water quality. Observations in this year's sampling are in the expected range for this reservoir and there is no clear trend toward lower ORP across years.

Turbidity

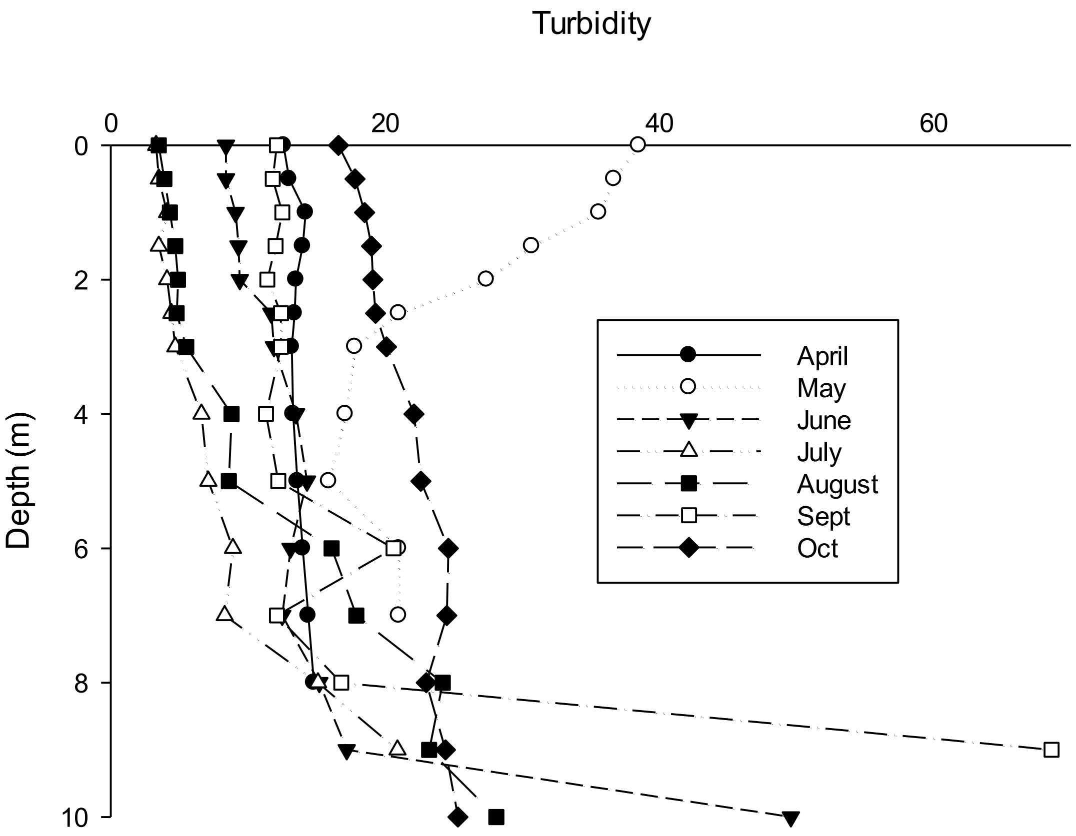

Figure 1.14. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2020)

Seasonal Analysis

Turbidity at this station is elevated compared to the Dam. Also observable is the heavy sedimentation that occurred in May likely from the Pigg River as discussed in other sections. Greater turbidity than at the dam suggests the influence from the upper portions of the reservoir and expected results for the transition station. Influence of Toler Bridge is visible here with the exception of September where turbidity was elevated at Toler but not here at MM6.

Comparisons Across Years

Turbidity patterns at this station are variable through the seasons. Some seasons have been much higher and other seasons have been lower than this year's observations. While we did not observe increases at depth as in years past the pattern of storm events or sampling dates much higher than others is observable in other seasons.

Other Parameters Measured

Table 1.19. Other parameters measured over study period (2020). Dates represent sampling of both the volunteers and university. First Column presents each parameter measured along with units of measure.

Date	28-Apr	29-May	18-Jun	27-Jun	16-Jul	28-Jul	12-Aug	26-Aug	30-Sep	27-Oct
Time	1:50 PM	11:25 AM	9:58 AM	12:30 PM	10:12 AM	12:05 PM	9:50 AM	3:36 PM	2:19 PM	11:15 AM
Secchi (M)	1.10	0.40	0.85	1.20	1.50	1.80	1.50	1.70	1.10	0.80
TP Surface (PPM)	0.006	0.084	0.006	0.06	0.026	0.024	DNA	0.035	0.063	0.031
TP 6 Meters (PPM)	0.006	0.035		0.049		0.014		0.018	0.200	0.098
Integrate Chl a	7.00	5.74		15.27		28.67		19.15	12.45	6.51
TSI S	59	73	62	57	54	52	54	52	59	63
TSI TP	33	65	33	60	49	48		53	61	51
TSI CHL	50	48		57		64		60	55	49
TSI AVG	47	62	48	58	52	54	54	55	58	55

Table 1.20. Zooplankton and *E. coli* measured over study period (2020). Dates represent sampling of both the volunteers and university. Zooplankton numbers are organisms per liter.

Date	28-Apr	29-May	18-Jun	27-Jun	16-Jul	28-Jul	12-Aug	26-Aug	30-Sep	27-Oct
Daphnia	0.0	0.0		0.9		0.2		0.2	2.8	0.2
Bosmina	13.2	4.0		1.2		0.4		0.9	0.0	6.1
Diaptomus	0.0	0.0		0.7		1.6		0.0	0.2	0.9
Cyclops	0.2	1.4		1.2		1.8		2.1	2.6	1.4
Nauplii	0.5	0.0		1.4		0.4		1.2	2.1	1.9
Cerodaphnia	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Diaphanosoma	0.0	0.0		0.7		0.8		1.2	0.7	0.0
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.0
E. coli MPN	238.2	1299.7	224.7	22.3	23.3	5.2	8.5	5.2	54.8	1119.9
BOD	1.2	3.8		4.1		4.6		4.7	3.5	

1.3.1.5 Mile Marker 9 (Riverine)

Photograph of Leesville Lake taken by Jade Woll.

Table 1.21. Mile Marker 9 other parameters measured over study period (2020)

Date	28-Apr	29-May	18-Jun	27-Jun	16-Jul	28-Jul	12-Aug	26-Aug	30-Sep	27-Oct
Time	2:20 PM	11:50 AM	10:25 AM	12:51 PM	10:23 AM	12:28 PM	10:07 AM	3:52 PM	2:47 PM	11:39 AM
Secchi (M)	1.2	0.4	0.2	0.8	1.4	1.4	1.2	0.9	1.1	1.0
TP Surface (PPM)	0.005	0.049		0.087		0.052		0.042	0.059	0.044
E. coli MPN	122.9	1413.6	7843.2	48.7	3.1	2.0	9.8	48.7	40.4	686.7
Turb	0.9	4.4		0.7		1.1		1.5	0.6	0.7

1.3.1.6 Toler Bridge (Riverine)[3]

Background

Riverine conditions as well as influx of tail waters of Smith Mountain Lake and influx of Pigg River water heavily influence 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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[3] *Photograph of Toler Bridge taken by Jade Woll.*

Conductivity

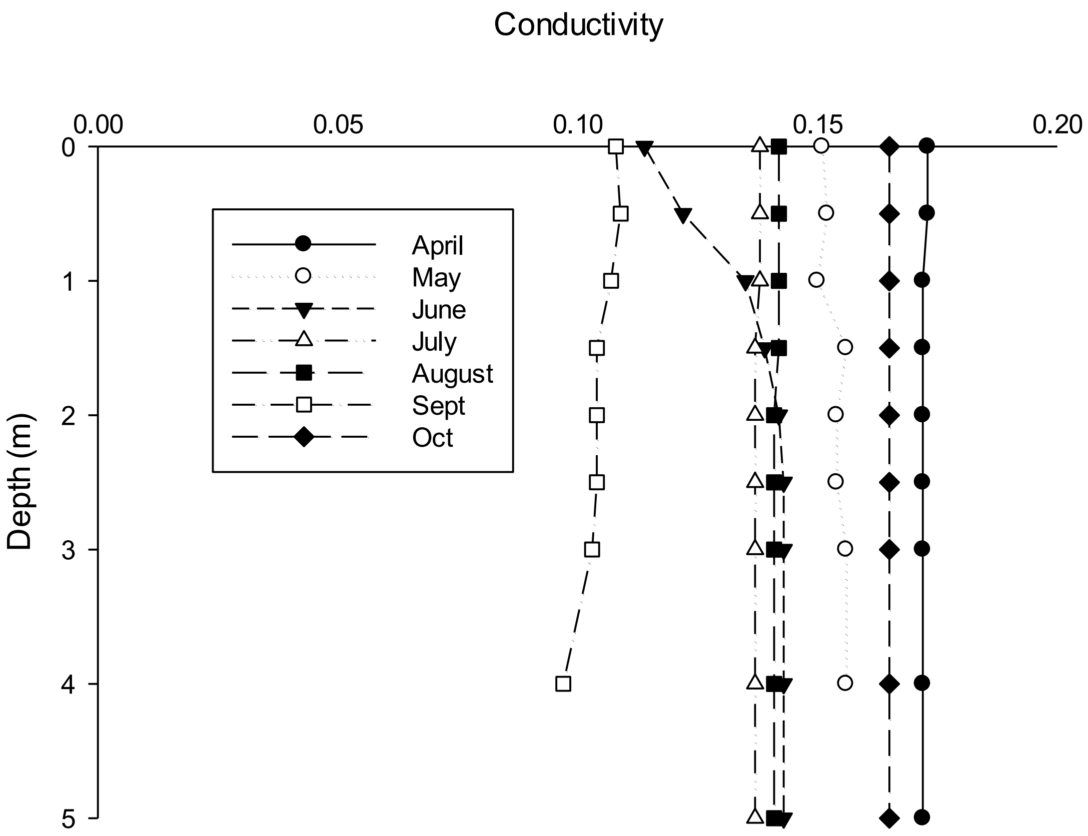

Figure 1.15. Toler Bridge (Riverine) Conductivity (ms/cm) measures over study period (2020).

Seasonal Analysis

Conductivity in this portion of the reservoir is usually consistent from top to bottom unless the cooler temperature of SML release vs and Pigg River inflow stratifies the water. Observations from this season appear to be a mix of both Pigg River (mean conductivity of 0.086 mS/cm) and SML Tailwater (mean conductivity of 0.153 mS/cm) with the exception of September. The September dominance by Pigg River Flow could be traced throughout the reservoir down to the dam station. Another interesting difference occurred in May. Conductivity at this station was 0.151-0.155 ms/cm whereas surface conductivity at MM6 measured 0.104 mS/cm and 0.141 mS/cm at the dam. This demonstrates the slug effect of flow through Leesville Lake. Different seasonal patterns are possible during high flow events. Clearly, high flow during May from Pigg River is pushed as a slug down lake affecting water quality in differeing sections of the lake as our observations demonstrate. Conductivity is variable at this station dependent on the mix between SML tailwater and Pigg River discharge.

Comparisons Across Years

Observations of conductivity at this station over time demonstrate the impact of Pigg River and SML mix on the reservoir. Readings are similar from top to bottom with the exception of Pigg River Flow. In these instances, warmer Pigg River water flows over the surface creating a strong contrast between layers. This can occur in any month of sampling. In years without this visible stratification conductivity tends to trend higher suggesting more dominance of SML tailwater.

Dissolved Oxygen

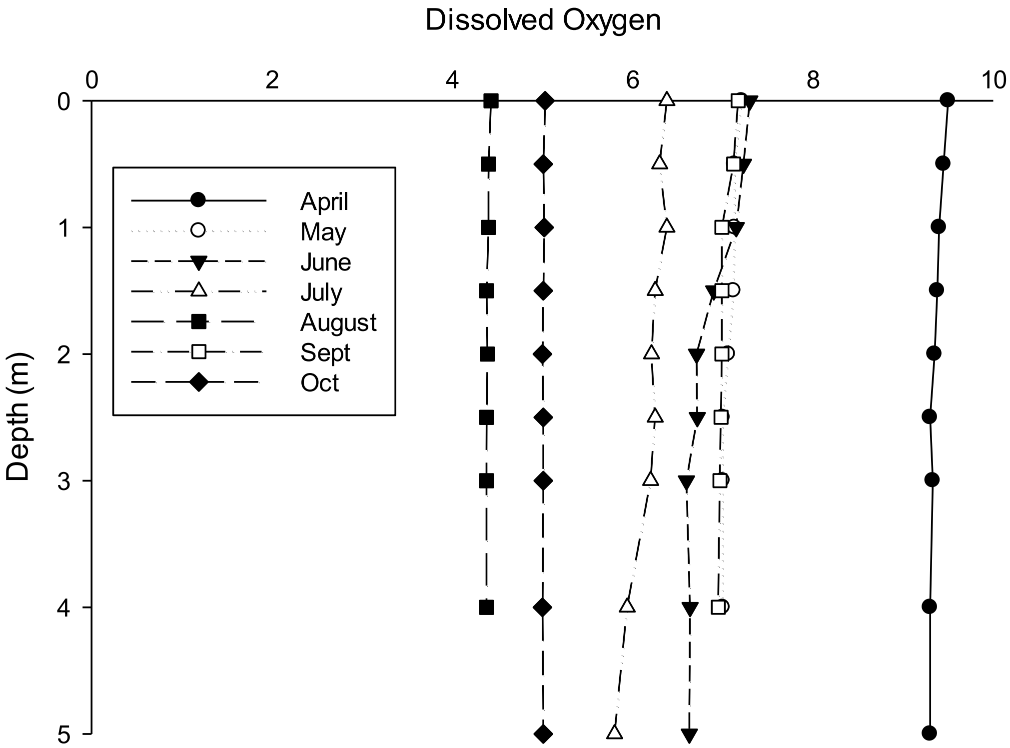

Figure 1.16. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2020)

Seasonal Analysis

Dissolved oxygen in this portion of the reservoir is strongly influenced by SML operations. First, the water does not stratify. Constant movement prevents this pattern here. Secondly, oxygen tends to decline as the season progresses hitting very low concentrations below 5 mg/L in August and October of this year. September oxygen was not at these low levels due to the Pigg River as observed in the conductivity measures. It is clear that as the season progresses oxygen levels at Toler Bridge are strongly controlled by the directional flow of water either from the Pigg River or SML tailwater.

Comparisons Across Years

Dissolved oxygen at this station is a function of water release. When conductivity is elevated, oxygen is lowered. In the later months of the season, this can lower levels below 5 mg/L throughout the upper portion of the reservoir. Concerning oxygen, SML tailwater release is the problem. This idea is discussed further in the analysis.

Temperature

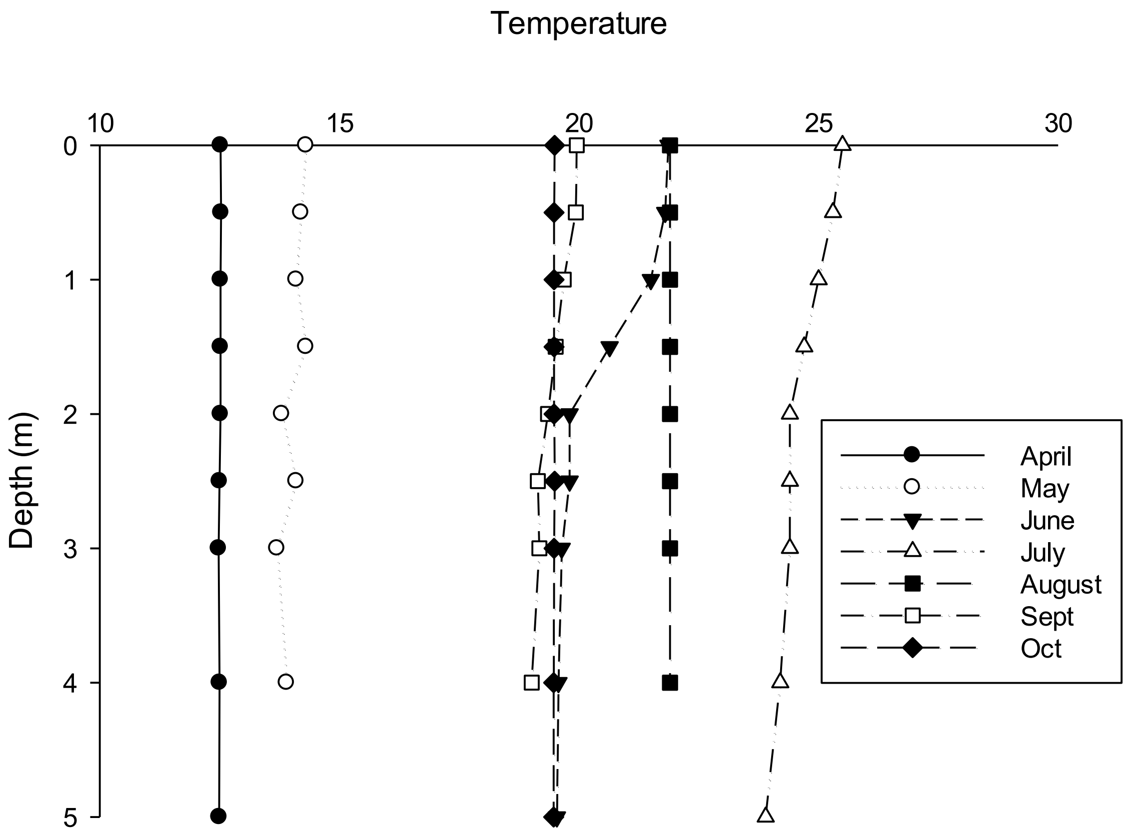

Figure 1.17. Toler Bridge (Riverine) Temperature (°C) measures over study period (2020)

Seasonal Analysis

This station typically does not stratify. The influence of water movement is too strong to allow the water enough time to develop layers in most instances. In the warmest months, some warming of the surface does occur and this must be throughout the upper region of the reservoir to be visible at this station. Warmer surface water in July and June did occur but it is not enough to change the physical environment in this area. This area operates under riverine conditions.

Comparisons Across Years

Lack of stratification throughout the years is consistent. The one exception may occur in May. This station has been stratified in some years in the May sampling. Rapid heating of the water surface with cool water below is the likely mechanism. In 2020, heavy flow prevented this from occurring.

Chlorophyll *a*

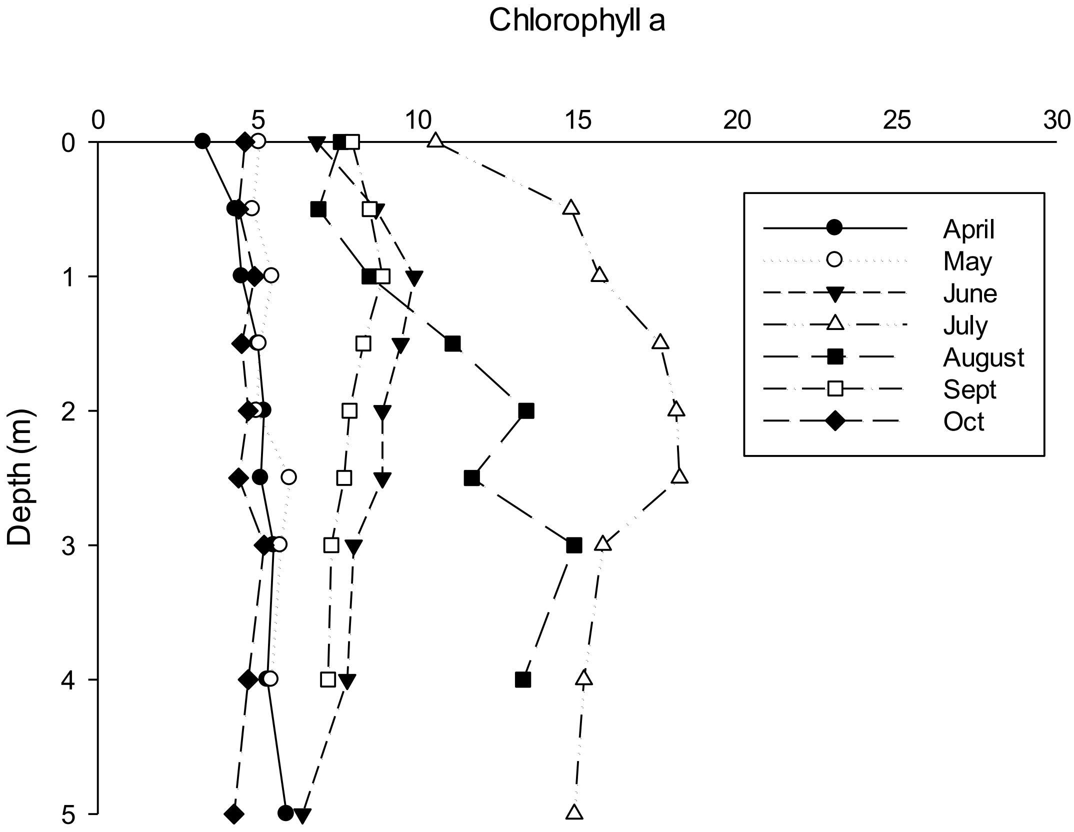

Figure 1.18. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2020)

Seasonal Analysis

This station contains the lowest readings of phytoplankton biomass throughout the entire reservoir. Some of the increases observed in July and August may be the result of productivity throughout the upper areas of the reservoir but the possibility of phytoplankton discharge from SML release must be considered. Lower phytoplankton biomass is expected in this area because of water movement, turbidity and cooler temperatures.

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 this is likely due to less movement of water, warm temperatures and low turbidity input from the Pigg River. In any month of the season Chlorophyll *a* can be driven to very low levels at this station due to hydrology.

pH

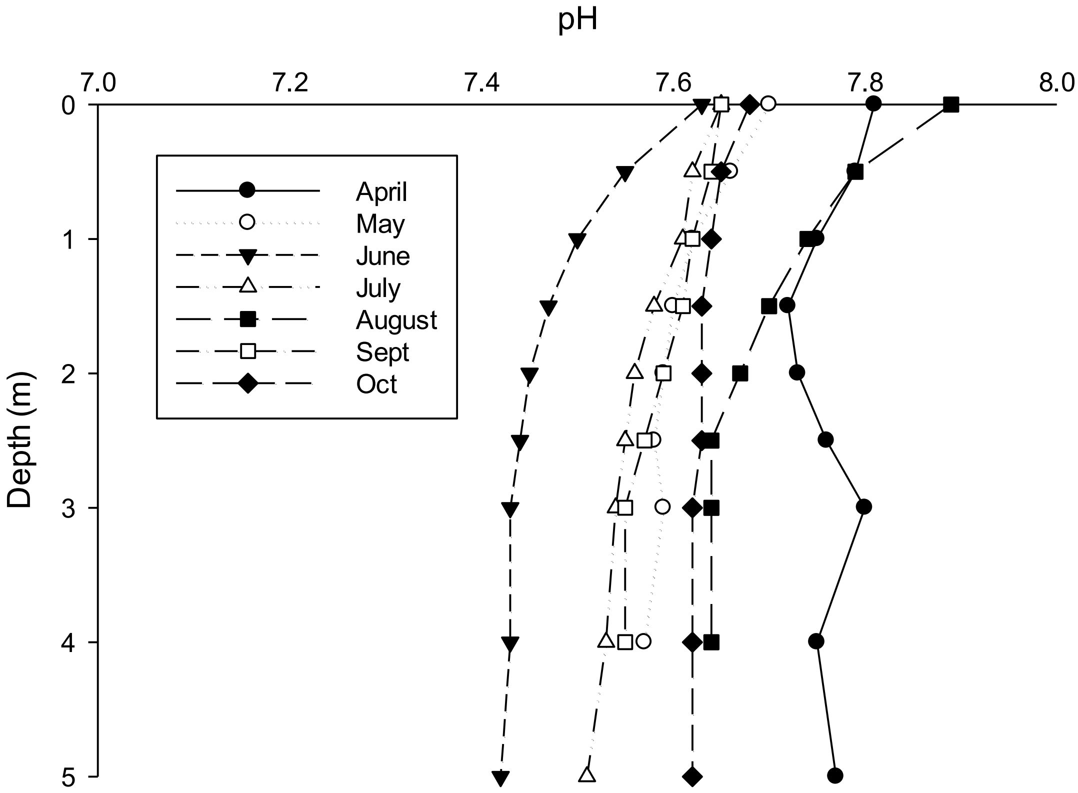

Figure 1.19. Toler Bridge (Riverine) pH measures over study period (2020)

Seasonal Analysis

pH has an inverse relationship with depth suggesting some phytoplankton productivity at the surface. The Pigg River pH (7.62) and SML Tailwaters (7.65) are very similar. Some elevation would occur when productivity is elevated but comparison of July Chlorophyll *a* and pH do not suggest this relationship. pH is generally a function of water movement and changes at this station do not contribute to the elevated conditions we see down the reservoir at MM6 and the dam. At mid-lake and the dam pH is a function of phytoplankton productivity.

Comparisons Across Years

pH does elevate above 8 at this station during the summer months. It is hard to pinpoint the exact mechanism 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 down lake and thus not of a greater concern than at MM6 or the dam where readings exceed 9.

ORP

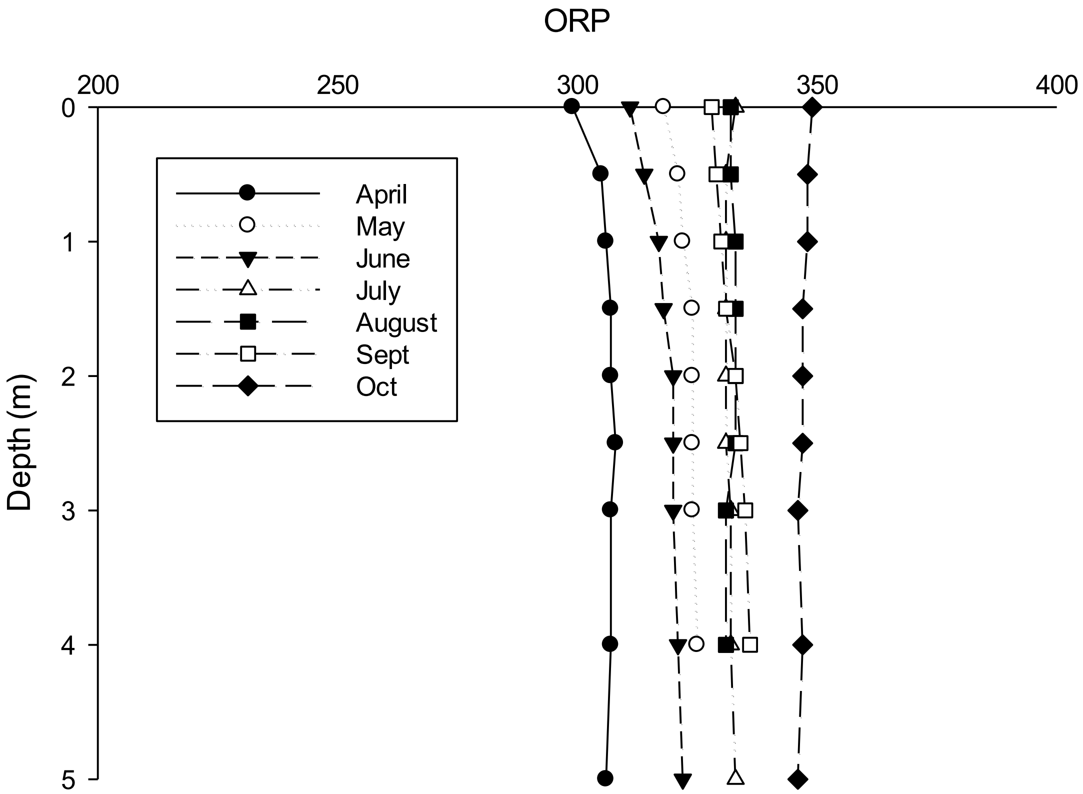

Figure 1.20. Toler Bridge (Riverine) ORP (mV) measures over study period (2020)

Seasonal Analysis

The ORP measures in this section of the reservoir do not provide any new interpretation between stations. ORP remained in a good range throughout the season.

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 happens in the following season. ORP is not a parameter of concern in the reservoir.

Turbidity

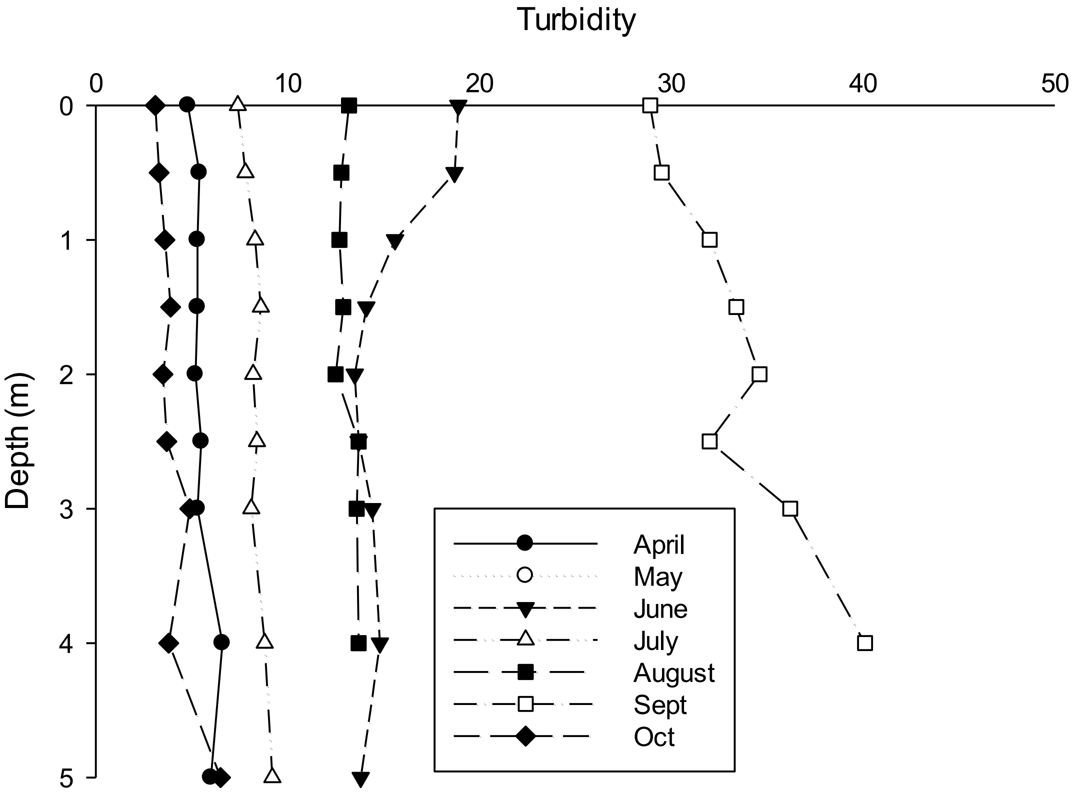

Figure 1.21. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2020)

Seasonal Analysis

Turbidity observations at this station impact the entire reservoir. The very high readings in May were seen all of the way to the dam causing excessive turbidity throughout the entire reservoir. In September, high turbidity readings here were detected at MM6 but not at the dam. Implications toward nutrients and bacteria carried throughout the reservoir need to be understood from these excessive turbidity events. At other sampling dates the turbidity was low.

Comparisons Across Years

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

Other Parameters Measured

Table 1.29 Other parameters measured over study period (2020). Dates represent sampling of both the volunteers and university. First Column represents each parameter measured along with units of measure.

Date	28-Apr	29-May	18-Jun	27-Jun	16-Jul	28-Jul	12-Aug	26-Aug	30-Sep	27-Oct
Time	2:35 PM	12:03 PM	9:05 AM	1:02 PM	9:20 AM	12:37 PM	10:23 AM		3:01 PM	112:50 pm
Secchi (M)	2.20	0.25	0.1	0.75	1.40	1.40	0.85	0.60	0.40	2.10
TP Surface (PPM)	0.017	0.064	0.302	0.064	0.042	0.027	0.023	0.047	0.132	0.020
Integrate Chl a	4.90	5.31		8.32		15.65		10.93	7.97	4.63
TSI S	49	80	93	64	55	55	51	67	73	49
TSI TP	44	61	83	61	55	50	48	57	71	46
TSI CHL	46	47		51		58		54	51	46
TSI AVG	46	63	88	59	55	54	49	59	65	47

Table 1.30. Zooplankton, BOD and *E. coli* measured over study period (2020). Dates represent sampling of both the volunteers and university. Zooplankton numbers are organisms per liter.

Date	28-Apr	29-May	18-Jun	27-Jun	16-Jul	28-Jul	12-Aug	26-Aug	30-Sep	27-Oct
Daphnia	0.0	0.0		0.0		0.0		0.0	0.8	0.0
Bosmina	12.5	1.7		0.3		3.4		1.7	4.5	13.0
Diaptomus	0.6	0.0		0.3		5.7		7.9	1.7	4.0
Cyclops	1.7	0.0		0.0		1.1		6.2	8.5	13.6
Nauplii	0.6	0.0		0.0		7.9		1.7	1.7	2.3
Cerodaphnia	0.0	0.0		0.0		0.0		0.0	0.0	0.0
Diaphanosoma	0.0	0.0		0.0		1.7		2.3	4.0	0.0
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.0
E. coli MPN	54.6	1450.0	10079.1	248.1	9.4	6.3	35.5	69.7	3957.5	131.4
BOD	2.23	2.91		2.28		2.8		1.80	4.2	

1.3.1.7 Pigg River

Photograph of Pigg River taken by Jade Woll.

Table 1.31. Pigg River other parameters measured over study period (2020). Measures are integrative throughout the entire water column. Profile data located in the appendix.

Date	**28-Apr**	**29-May**	**18-Jun**	**27-Jun**	**16-Jul**	**28-Jul**	**12-Aug**	**26-Aug**	**30-Sep**	**27-Oct**
Time	2:50 AM	12:20 PM	11:04 AM	1:14 PM	10:47 AM	12:50 PM	10:30 AM	4:14 PM	3:38 AM	12:10 PM
Temp	15.96	19.8		23.77		27.6		24.45	18.54	19.19
Cond	0.083	0.05		0.068		0.068		0.112	0.059	0.161
DO	9.2	8.13		7.92		7.47		5.77	8.55	5.4
pH	7.8	7.62		7.5		7.63		7.61	7.53	7.68
DO %	92.3	91		96.1		97.3		70.7	93.7	59.7
ORP	281	340		397		401		393	370	415
Turbidity	48.4	441		31.5		23.4		61.8	94	8.4
Secchi (M)	0.30	0.20	0.08	0.6	0.8	0.75	0.2	0.40	0.20	1.25
CHL	6.9	8.92		3.7		15.7		13.8	7.2	4.75
TP	0.114	1.049	1.185	0.042	0.045	0.061	0.1	0.149	0.25	0.038
TSI S	77	83	96	67	63	64	83	73	83	57
TSI TP	69	100	102	55	56	60	67	73	80	54
TSI CHL	50	52		43		58		56	50	46
TSI AVG	65	79	99	55	60	61	75	67	71	52
E. coli MPN	1119.9	6867	5503	579.4	105.4	75.9	3.1	413.7	3607.5	686.7

1.3.1.8 Smith Mountain Lake Tail Waters

Table 1.32. Smith Mountain Lake Tail Waters other parameters measured over study period (2020). Measures are at the surface.

Date	**28-Apr**	**29-May**	**27-Jun**	**28-Jul**	**26-Aug**	**30-Sep**	**27-Oct**
Time	3:10 PM	12:35 PM	1:28 PM	1:04 PM	4:28 PM	3:52 PM	12:10 PM
Temp	12.27	14.58	20.54	23.8	21.27	20.72	19.52
Cond	0.177	0.175	0.142	0.135	0.145	0.132	0.167
DO	9.2	8.3	7.01	5.99	3.74	6.77	4.8
pH	7.75	7.6	7.56	7.63	7.54	7.66	7.82
DO %	87.6	83.3	79.4	72.6	43.2	77.4	53.3
ORP	324	415	415	402	443	375	434
Turbidity	2.6	2.8	10.9	6.2	6	6	2.5
Secchi (M)	3.70	2.80	1.00	1.40	1.60	1.400	3.300
CHL	2.01	5.2	4.8	12.8	9.5	9.3	3.8
PHy	10.3	16.4	16.1	20.6	21.2	32.5	18.1
TP	0.049	0.216	0.052	0.05	0.047	0.01	0.018
E. coli MPN	0	9	67	15	30	62	82

Section 2: Lake-Wide Trends

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

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

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

2.1 Analysis of Trophic State[4]

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

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

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

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

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

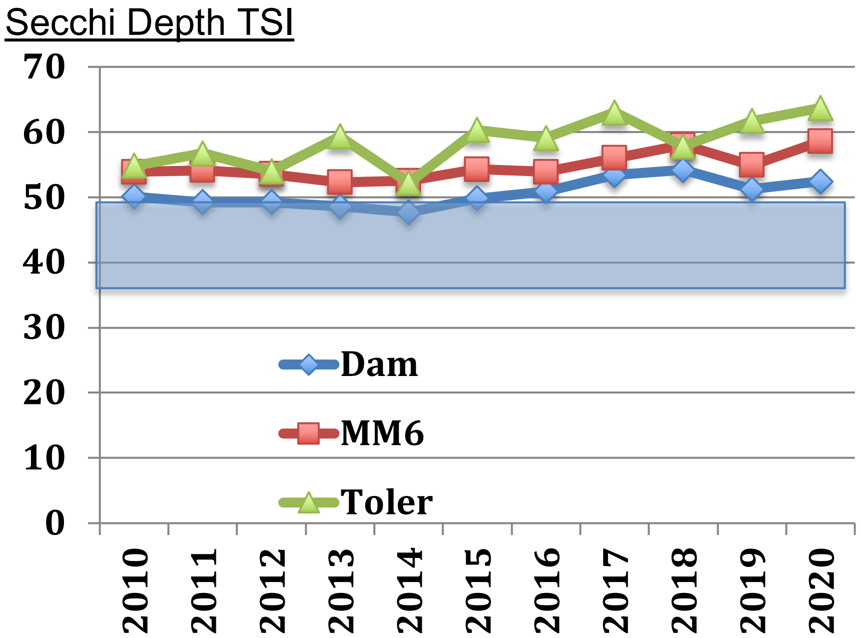

Figure 2.1. Trophic State Index (TSI) based upon Secchi disk (meters) measurements in Leesville Lake from 2010-2020. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Analysis

Predictions of trophic state using Secchi depth suggest these water quality predictions are very steady (Figure 2.1). There is some trending upward that is most noticeable at MM6 and Toler Bridge, but this is slight. The reservoir continues to be eutrophic.

Comparing this trend from the headwaters (Toler Bridge) through the Dam we see a very distinct pattern. Toler Bridge does have the most eutrophic waters based on Secchi calculations with increasing clarity and improved TSI moving down lake to the dam. This differential is not strong and in some years actually lower than other stations (2014 and 2018). This is reflective of the unique pump storage relationship with SML. Depending upon rainfall and electrical demand the water quality of Toler Bridge station will be impacted. It is encouraging to see TSI at the dam very near mesotrophic conditions. This is trending slightly higher and should be monitored closely if this trend continues.

Total Phosphorous TSI

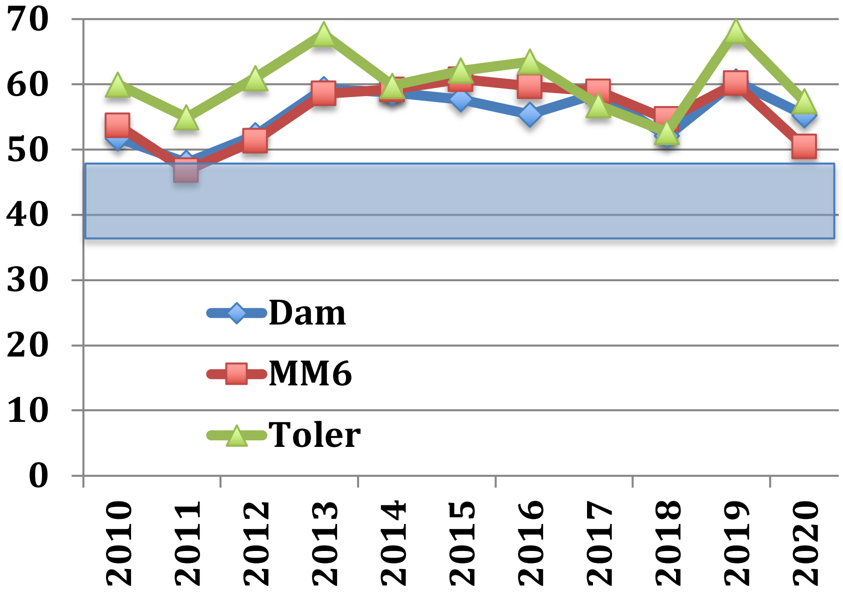

Figure 2.2. Same as Figure 2.1 but TSI based on Total Phosphorus (TP).

Analysis

Trophic state based on total phosphorus suggests the reservoir is eutrophic (Figure 2.2). This index shows greater variability than the others and is also more concerning. In some years this index is near 70 and that is a very concerning value for eutrophication. A combination of low phosphorus input from SML and movement of water seems to mitigate this concern in some years. In 2018 and 2020 measures were lower which is encouraging. Volatility in this parameter is a combination of internal mixing, input from Pigg River, mobilization from SML hypolimnion and turnover. 2020 similarities in this TSI index between the dam and Toler Bridge along with lower values at MM6 suggest hypolimnetic phosphorus release from sediment and anoxia may be a significant source of phosphorus to the reservoir. SML hypolimnion and Leesville Lake hypolimnion should be similar in concentration. MM6 would contain lower concentrations of phosphorus under this scenario. This couples with the concerns over loss of oxygen in the hypolimnion as TP uncouples from sediment under these anoxic conditions. This strengthens the concern over oxygen loss in the hypolimnion.

Chlorophyll *a* TSI

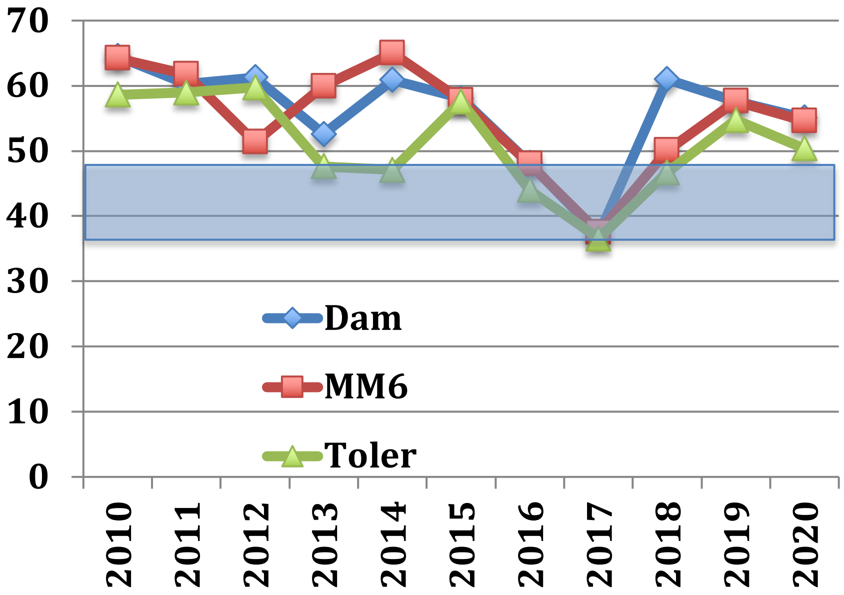

Figure 2.3. Same as Figure 2.1 but TSI is based on Chlorophyll *a*.

Analysis

Trophic state based upon Chlorophyll *a* is more difficult to interpret because of sediment interference in phytoplankton production. TSI Chlorophyll *a* (Figure 2.3) is relatively consistent, with the lake falling in the mesotrophic to slightly eutrophic range. As expected, Toler Bridge is lower due to low concentrations in SML and the possibility of shading from sediment in the Pigg River. Chlorophyll *a* is actually lowering through time and this is encouraging. Considering the other TSI parameters with Secchi depth decreasing and TP variability it may be sediment that is causing this pattern. If this is the case it is a concerning problem that will need to be addressed. Similarities between MM6 and dam for this parameter are good, suggesting we do not see an excessive bloom of phytoplankton at the mixing portion in the reservoir.

TSI Average

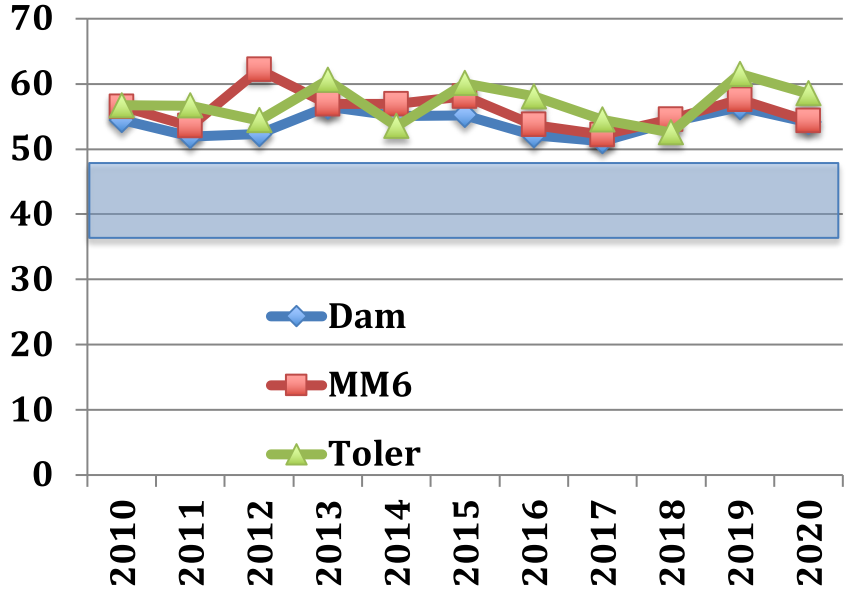

Figure 2.4. Same as Figure 2.1 but TSI presented is the average of TSI for all parameters evaluated (Secchi Depth, Total Phosphorous, Chlorophyll *a*).

Analysis

Averaging trophic state indices has value in determining if the lake is trending in a direction. Based upon multiple parameters the reservoir is amazingly steady. The lake remains mildly eutrophic with some fluctuation but meeting desired uses. While we are observing some worsening of water quality entering the reservoir from the Pigg River, these symptoms are not expressed in the overall TSI. Often, time lags are associated with changes thus it may be that potential changes due to worsening water quality of the Pigg River are not yet reflected in the overall TSI.

Daphnia Productivity

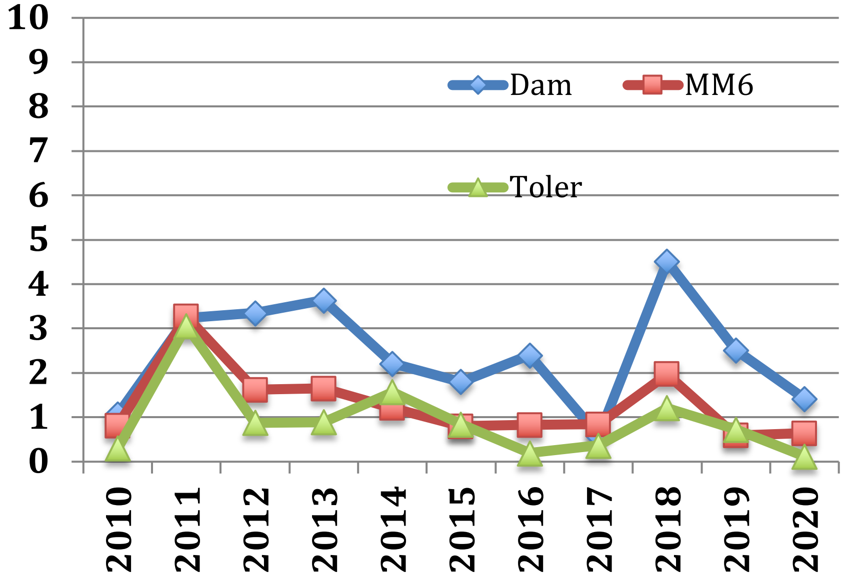

Figure 2.5. Average *Daphnia* concentrations in Leesville Lake from 2010-2018. Numbers on y-axis represent *Daphnia*/ liter.

Analysis

The abundance of *Daphnia* in the reservoir not only impacts the population of phytoplankton through grazing, but also impacts the influence of fisheries on water quality. Implications of this are two-fold. First, lower populations of *Daphnia* reduce the grazing pressure on phytoplankton. For 2020, 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. The most interesting finding this season was an abundance of *Daphnia* in September. They were very abundant in the samples and all contained long spines and elongated helmet projections. The implications of the armored *Daphnia* are clear. Invertebrate predation by *Leptodora* appears to be dominate in the reservoir regulating the populations of *Daphnia*. This suggests that plantivorous fish populations are low in turn enhancing the populations of both *Leptodora* and *Daphnia*. The water quality implications are an increasing grazing pressure on phytoplankton this season. This is important to document as less phytoplankton concentrations and lower Chlorophyll *a* is possible when grazing pressure is high.

2.2 Precipitation and Pigg River Inputs

This section is designed to analyze how precipitation and Pigg River inputs are changing. We interpret how this may impact the reservoir in the future.

We are currently in an increasingly wet weather pattern (Figure 2.6). Scientific literature strongly suggests that impacts due to anthropomorphic and climate impacts that now generate the patterns that we see in rivers (Read Gregory 2019 for a review). We can generate several likely outcomes based on this trend:

1. Water quality entering the reservoir from the Pigg River will worsen.
2. Greater amounts of water will enter from the Pigg River.
3. Operational patterns may change. If significant water flow occurs throughout the Smith Mountain hydroelectric project, less water will be needed in the pump back phase. This will impact water quality.
4. Water entering from the Pigg River will be more turbid, containing greater concentrations of silt.
5. Water entering LVL from the Pigg River will contain greater concentrations of bacteria.

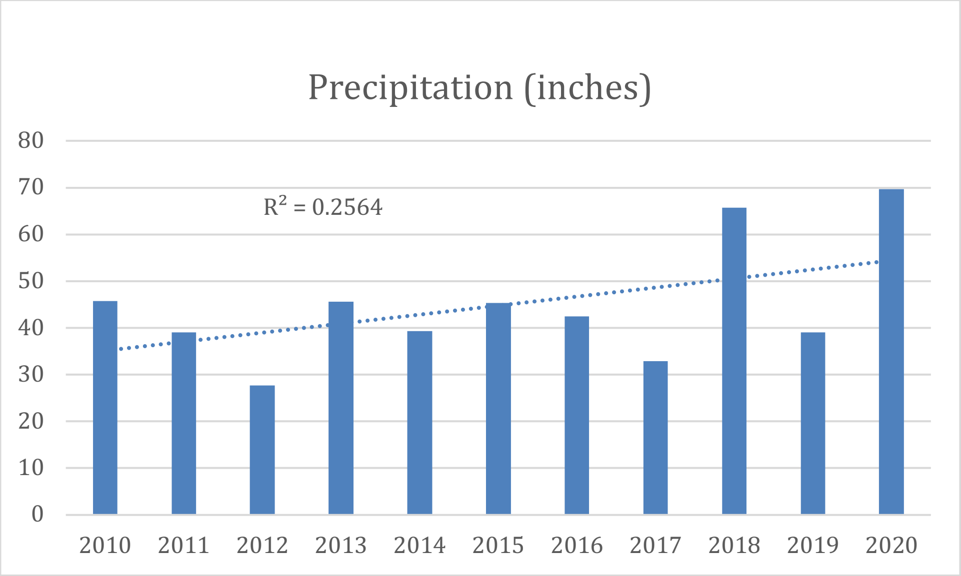

Figure 2.6. Total annual precipitation reported at Lynchburg Virginia weather station representing general pattern over the central Virginia Area.

We can begin to track these problems with data that we collect. Average annual turbidity from the Pigg River entering into Leesville Lake is clearly increasing (Figure 2.7). Turbidities since 2015 are significantly higher than years prior. What is driving this trend? Are changes occurring in the watershed due to land use or more significantly rainfall patterns (intensity and magnitude). It is our belief that the rainfall patterns are the primary driver of this pattern and not significant changes in land use. This is being explored in separate research. Whatever the generator, this is a concerning trend.

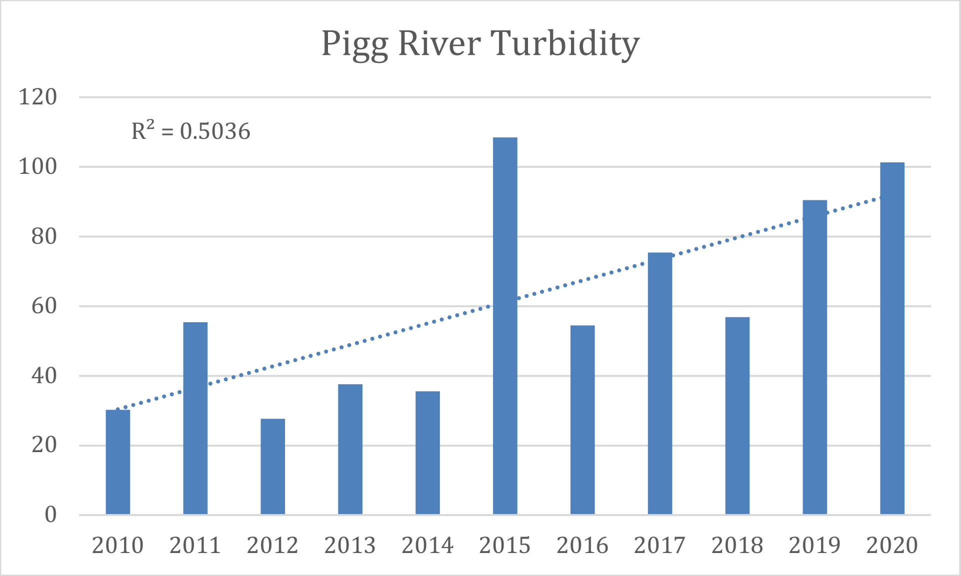

Figure 2.7 Turbidity (NTU) averages at Pigg River mouth entering Leesville Lake. N=7 for all data. Hashed line represents trend line over the period of study.

Additionally, *E. coli* concentrations delivered from the Pigg River are increasing (Figure 2.8). And not only are these levels increasing, but 4x-7x times the concentrations we have observed previously. The previous two seasons monitoring Leesville Lake have generated *E. coli* single observations in excess of 6,000 cfu/100ml in 2020 and 25,000 cfu/100 ml in 2019. These are extraordinary levels of bacterial contamination. This must be explored and ideas generated to control this problem now before it develops into problems in Leesville Lake.

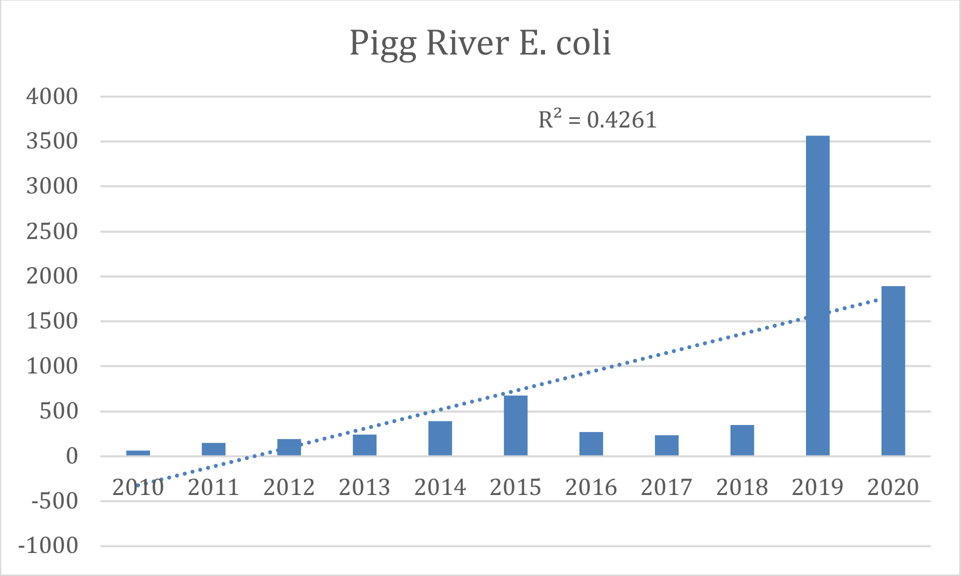

Figure 2.8. E. coli (cfu/100ml) averages at Pigg River mouth entering Leesville Lake. Years 2010-2013 n=7 and years 2014-2020 n=10. Hashed line represents trend line over the period of study.

2.3 Predications of Midsummer Chlorophyll Peak.

Based on pioneering work by Dillon and Rigler (1974) and Carlson (1977) and recently revisited by Yuan and Jones (2020), we examined the relationships of chlorophyll, TP and turbidity in Leesville Lake. Theoretically, spring TP concentrations set the maximum chlorophyll a concentrations observed during the summer peak. As Yuan and Jones (2020) suggest, this relationship can be confounded in reservoirs by high turbidity. Thus, turbidity was included in the analysis. The hypothesis was developed that we should see a relationship between inputs of TP and Turbidity from the Pigg River in either April or May or both and the Chlorophyll *a* max for the season. Data was compiled from 2013-2020 for this analysis (Table 2.1).

Table 2.1. Values used in PCA analysis. Dam and MM6 peak are peak seasonal Chlorophyll *a* (Chlor) concentrations in ug/L. TP represents total phosphorus measures in mg/L (surface) on the same date. Turbidity are measures at the surface at each station measured in NTUs.

	Dam Peak Chlor	MM6 Peak Chlor	Toler April TP	Toler May TP	Pigg April TP	Pigg May TP	Toler April Turb	Toler May Turb	Pigg April Turb	Pigg May Turb
2020	48.6	51.1	0.017	0.064	0.114	1.049	4.8	84	48.4	44.1
2019	73.2	37.3	0.14	0.111	0.092	0.105	9.2	7.8	17.2	12.5
2018	28.6	24.2	0.023	0.03	0.11	0.04	92.2	11.9	19	17
2017	7.5	10.2	0.01	0.029	0.084	0.053	122	102	29	118

2016	41.5	31.1	0.037	0.287	0.047	0.083	43.1	46.4	18.9	64.3
2015	91.7	99.6	0.135	0.093	0.283	0.075	46.3	44.9	40.6	21.6
2014	112.4	70.1	0.05	0.1	0.12	0.08	30.5	9	38	18.7
2013	49.3	55.2	0.42	0.15	0.08	0.3	20.8	96.6	14	122

Various peaks of differing magnitudes were observed in the reservoir over the study period examined. The years 2014-2015 recorded the highest peaks followed by lower peaks in 2017. So observed peaks in the reservoir are quite variable. Thus, we used the method of Principle Component Analysis (PCA) to statistically identify associations.

The PCA analysis (Figure 2.9) calculated up to 57.15% of the variability within the first two factors. Associated eigenvectors (Table 2.2) are presented as well.

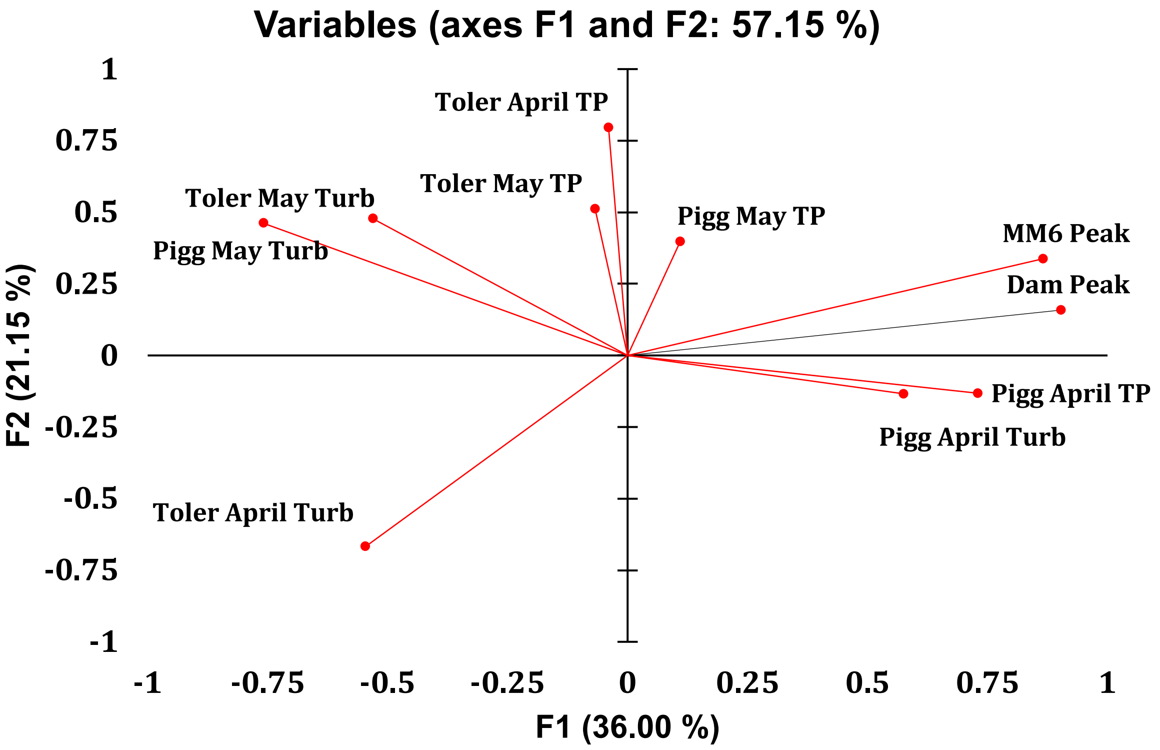

Figure 2.9. Principle Component Analysis of compiled data representing key parameters in Leesville Lake over the ten year sampling period. TP and turbidity are values measured each year at the indicated station and month. Peak measures at the Dam and MM6 represent the highest recorded Chlorophyll a measure for the season. Table 2.1 displays the data used in this analysis and Table 2.2 the eigenvectors.

Table 2.2. Table 2.2 Eigenvectors from PCA analysis. Values in bold represents significance at p<0.5 level.

	F1	F2
Dam Peak	**0.47**	0.11
MM6 Peak	**0.45**	0.23
Toler April TP	-0.02	**0.55**
Toler May TP	-0.03	0.35
Pigg April TP	**0.38**	-0.09
Pigg May TP	0.05	0.27
Toler Turb April	-0.28	**-0.46**
Toler Turb May	-0.28	0.33
Pigg Turb April	0.30	-0.09
Turb Pigg May	**-0.40**	0.32

The analysis found significant relationships between each Chlorophyll a peak and April TP concentrations in the Pigg River (F1 in Table 2.2). These were all positive relationships suggesting the increased concentrations of TP were associated with the increased levels of Chlorophyll *a* observed at both MM6 and the Dam. The other significant relationship was a negative observation between turbidity in Pigg River in May and the peaks. This suggests that turbidity in turn is driving down the concentration peaks of Chlorophyll *a*.

These observations align very well with current theory outlined in this section. The implications of these observations suggest TP and turbidity levels flowing in from the Pigg River have a strong controlling impact on observed Chlorophyll a peaks we observe in the lake. Based on this analysis it is imperative that we work diligently to control these pollutants in the Pigg River to maintain the health of the lake.

2.4 Oxygen Loss in SML Reservoir

Loss of oxygen in the hypolimnion of reservoirs is a very important process. This occurs in three domains as defined by Steinsberger et al. (2020). The first process is directly in the water column during the settling of organic material (Livingstone and Imboden 1996). Models determined that even a small reduction in dissolved oxygen at the end of spring turnover could produce large increases in the size of the anoxic zone during the summer months due to the breakdown of organic material. So it is important to control this input of organic material entering reservoirs to protect oxygen concentrations in the hypolimnion during the summer months.

The second zone of oxygen depletion is the sediment surfaces (Burns 1995). As these sediments become enriched with organic material oxygen loss in the hypolimnion becomes stronger over time and onset of this process occurs earlier in the season. This is problematic as it has a memory. Hence the organic material that enters the system does not go away but eventually breaks down. A third area of depletion is the deeper sediments that can continually reduce oxygen (Carigan and Lean 1991). With enrichment of these sediments, significant fluxes in oxygen can occur into depth layers of the sediment. Each year, layers of sediment are built and the decomposition rates are slow. The buildup of this material becomes problematic over time.

Due to the importance of this processes and the manner in which Leesville Lake is intricately linked to the SML hypolimnion, we investigated how pump storage operation influences Leesville Lake. In many respects, the upper region of Leesville Lake is reflective of the hypolimnion of SML. The Pigg River confounds this relations as it is a significant source of water into this area as well. Looking at data it is desirable to determine which of the two inputs drives oxygen dynamics in this portion of the reservoir. This generated the following hypothesis. Does Toler Bridge water quality primarily reflects SML tail release. To test this hypothesis, we looked at both conductivity and oxygen levels. Conductivity tracks water mass and oxygen is the direct measure of concentrations in the reservoir.

All the data (2011-2020) at each station was regressed to determine relationships (Table 2.3). The strongest relationship between all variables was a regression between tail water and Toler Bridge oxygen concentrations (Figure 2.10). The relationship was positively correlated and strongly significant ($p<0.0001$). The next strongest relationship was between Toler Bridge and tail water conductivity. This suggests that oxygen and other water quality parameters at Toler Bridge are strongly driven by tail water release. Most significantly, when oxygen levels at Toler bridge are low so is the tail water and not Pigg River. Furthermore, Pigg River and tail water oxygen content was significantly correlated, but conductivity was not. Thus, Pigg River influx exerts a significant impact on oxygen content of the tail water.

Table 2.3 – Regression strength of correlations (r^2 value) and significance (p value). N=43 for all relationships.

Regression	r^2 value	p value
Toler vs. Tail Water Conductivity	0.385	0.000
Pigg River vs. Toler Conductivity	0.185	0.015
Pigg River vs. Tail Water Conductivity	0.085	0.062
Toler vs. Tail Water Oxygen	0.738	<0.0001
Pigg River vs. Toler Oxygen	0.204	0.003
Pigg River vs. Tail Water Oxygen	0.217	0.002

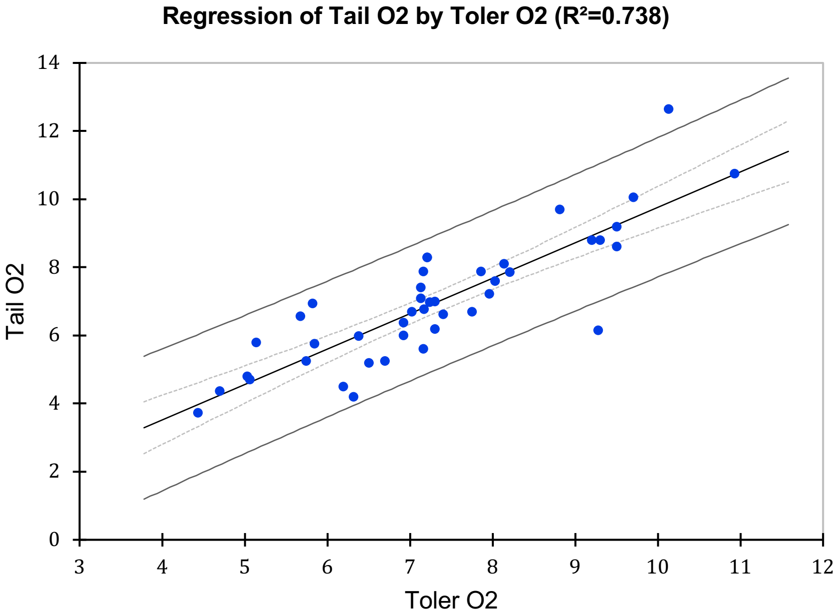

Figure 2.10. Regression of oxygen concentrations between Toler Bridge and Tail Water.

From this analysis we can conclude the importance of SML hypolimnion release on headwater water quality in Leesville Lake. Two important aspects must be pursued from these findings. First is the impact of pump back into SML from Pigg River. We know the Pigg River contains excessive concentrations of bacteria, sediment and nutrients. If the predominant pattern of flow is through SML hypolimnion then it is probable that Pigg River water is degrading and contributing to SML hypolimnion oxygen loss. This needs investigation. A second concern is the worsening of oxygen loss in the hypolimnion of SML. We are observing extensive oxygen loss in tail water (<5 mg/l) from August – October. Additionally, areas of anoxia in Leesville Lake are extensive throughout the summer and increases in this loss (driving oxygen levels below 3 mg/L) over extensive areas of the reservoir will result in additional oxygen loss despite fall turnover. This is the most pressing problem we now see in this reservoir and must be addressed.

In a final analysis, BOD was measured at the three main stations in 2020 to determine if noticeable problems could be discerned from this analysis. Results in Table 2.4 suggest a greater BOD load at the LVL dam than at Toler Bridge. This supports the idea of greater oxygen loss in the hypolimnion at the Dam and MM6 than at Toler Bridge. This may also be due to Toler Bridge water quality being strongly influenced by tail water release, which would contain much lower BOD. This analysis needs expansion into Pigg River to understand the impact the river may have on overall hypolimnion oxygen loss in SML.

Table 2.4. The means and standard deviations for BOD measures in Leesville Lake during 2020 sampling year. Samples taken from surface water. N=6 for this analysis with elimination of October sampling.

Station	BOD	Standard Deviation
Dam	3.79	0.64
MM6	3.66	1.28
Toler	2.69	0.82

Section 3: Conclusions and Management Implications

Water quality indicators suggest Leesville Lake is mildly eutrophic. It is important to state that, while some water quality indicators in the Pigg River and SML tail waters are worsening, Leesville Lake appears very resistant to those inputs and has remained in a stasis condition (Figure 2.4). Leesville Lake is maintaining a constant TSI index between 50-60 demonstrating only inter year variations. While it is always the aim of any long term study such as this to improve the condition of the resource being monitored, considering the issues impacting the lake this is a encouraging and possibly an improvement.

Current trends suggest increasing concern over the inputs to the lake at the headwaters. TSI at Toler Bridge has increased over the past two seasons and this situation needs to be monitored closely. Continued work on Pigg River will help this portion of the study. Closer monitoring of Smith Mountain Lake hypolimnetic oxygen loss is warranted.

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

1. Leesville Lake is a slightly eutrophic lake. It has maintained this status throughout the monitoring period of study (2010-2020).
2. Leesville Lake behaves as a pump storage reservoir with headwaters impacted by tail release from the upper reservoir and the Pigg River.
3. The Pigg River (part of the Roanoke River) drains 392 square miles of primarily forest (64.8%) and pasture (26.3%) and urban (4.7%) land use. Impervious surface is less than 1%. The City of Rocky Mount Virginia is in the drainage basin. Statistics from Streamstat operated by US Geological Survey (www.streamstat.usgs.org).
4. The previous two sampling seasons strongly suggest water quality of Pigg River is worsening. Indicators associated with turbidity (Figure 2.7) and *E. coli* (Figure 2.8) suggest increases of 4x – 7x times the loading into Leesville Lake than in previous years.
5. Work continues to determine the source of this increase. While land use changes throughout the Pigg River Watershed continue, it is believed that changing precipitation patterns and management of water quality in urban areas is causing the increase. These are working hypotheses.

6. Oxygen depletion in the upper portions of Leesville Lake is worsening. Oxygen losses (<5 mg/L) persist in tail water release beginning in mid-July and persisting through October. Readings as low as 1.5 mg/L were observed in September and October (Kleinschmidt 2020)
7. Water below 5 meters depth in SML at the dam contains <5 mg/L dissolved oxygen and reaches zero between 30-40 meters depth. Water quality in SML appears to be worsening. Total average phosphorus in the reservoir exceeded 40 ppb for the first time in last 10 years and Secchi depth remained below 2 meters for third year in a row. While some areas in the dam area of the lake are oligotrophic, water near the dam is mesotrophic. All of these trends are concerning for LVL. Data retrieved from Heck et al. (2019).
8. Concerns with SML oxygen depletion impacting Leesville Lake have been expressed. First, an analysis of oxygen concentrations and water release from SML tail waters suggested SML hypolimnion release controlled headwater water quality in Leesville Lake (Figure 2.10). Secondly, this problem has generated concern from the Leesville Lake Association. In a letter written to the Technical Review Committee of AEP, Water Quality Committee Chair Anthony Capuco expressed concern that these oxygen levels are unacceptably low and that action needs to be taken to fix this problem (Appendix F).
9. Chlorophyll *a* peaks in the reservoir may be driven by Pigg River TP and turbidity. Evidence was found suggesting early season (April and May) TP inputs correlate with Chlorophyll *a* max in the reservoir. High turbidity has a depression impact on these same maximums.
10. Debris problems persist. In May 2020, debris collected at the Leesville Lake dam shutting down the boat ramp and creating a cleanup scenario that took several months to rectify.

Figure 3.1. Debris collecting in front of Leesville Lake Dam from storm input.

These conclusions now create the following management recommendations:

4. Based on inputs from the Pigg River it is imperative that we work diligently to control these pollutants to maintain the health of the lake. While the lake is showing excellent resiliency to these inputs current, the last two seasons (2019-2020) have measured exponential increases in pollutant loads from the Pigg River (4x-7x historical loading). This is unprecedented and if it is the new baseline of loading to the lake it must be controlled. Ecosystems often exhibit time lags to new inputs/changes and this must be anticipated.
5. Oxygen loss mechanisms in SML hypolimnion need to be explored. Implications of this annual phenomenon are multifold. DEQ requires oxygen levels above 5 mg/L per permit regulations on tail water release. Current trending suggests release of water below this threshold is increasing. This problem creates low oxygen conditions in the headwaters of Leesville Lake further compounding already low oxygen in this reservoir. Continued worsening of this condition could cause severe problems in Leesville Lake during a season with very low oxygen.
6. Continue to research water quality concerns throughout the Pigg River Watershed. AEP and DEQ need to engage in the study currently underway by Leesville Lake Association, TLAC and University of Lynchburg to understand the primary mechanisms driving water quality throughout this basin. Findings from this study will drive water quality decisions for Leesville Lake and the SML project in the future.

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Appendix A

Background of Water Quality Program

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

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

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

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

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

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

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

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

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

Participants:

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

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

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

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

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

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

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

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

- Educate to individuals, organizations, and the general public information concerning:
  a. Water quality monitoring results

b. Management techniques and practices to preserve the environmental quality of Leesville Lake and its watersheds
c. Safe recreational activities
d. Commercial and government activities that could harm geographic area of Leesville Lake
e. How to maintain optimum water levels in Leesville Lake

Appendix B

Water Parameter Testing Details

Oxygen

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

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

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

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

Temperature

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

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

pH

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

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

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

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

Conductivity

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

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

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

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

Turbidity

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

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

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

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

Oxidation-Reduction Potential

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

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

Total Phosphorus

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

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

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

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

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

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

List of Chemicals:

- Ammonium Molybdate, $(NH_4)_6Mo_7O_{24}\bullet4H_2O$
- Ammonium Persulfate, $(NH_4)_2S_2O_8$
- Antimony Potassium Tartrate, $K(SbO)C_4H_4O_6\bullet3H_2O$
- 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^{o}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) $C_{12}H_{14}N_2 \bullet 2HCl$
- Sulfanilamide, $C_6H_8N_2O_2S$

Stock Standard contained:

- Potassium Nitrate, KNO_3

Preparation of Reagents and Standards:

Reagents:

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

Standards:

- A nitrate stock standard of 1000 mg/L was prepared by dissolving 7.218 grams of potassium nitrate in 1000 mL of DI water in a 1000mL volumetric flask.
- The 100 ppm and 10 ppm nitrate stock standard were prepared by subsequently diluting the 1000 ppm.

Summary of Run:

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

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

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

Fluorescence

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

Integrated Chlorophyll *a*

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

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

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

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

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

□□ A 10ppm nitrate standard was placed in the instrument.

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

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

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

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

Total Phosphate Method

Summary of Method:
Under this method for the determination of total phosphate, the aqueous sample was mixed with sulfuric acid, ammonium molybdate and antimony potassium tartrate to form antimony-1, 2-phosphorous molybdenum acid. The resulting complex was then reduced by ascorbic acid to get a blue heteropoly acid (molybdenum blue). To determine the concentration of ortho-phosphate, the absorbance of the formed blue complex, was measured at 880nm.
Since only orthophosphate formed a blue color in this test, polyphosphates (and some organic phosphorus compounds) were converted to the orthophosphate form by manual sulfuric acid hydrolysis. Organic phosphorus compounds were converted to the orthophosphate form by manual persulfate digestion. The developed color was then measured automatically.

Summary of Run:

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

Quality Assurance/Quality Control

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

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

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

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

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

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

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

$$P = [100(A - B)]/T$$

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

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

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

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

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

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

General Procedures:

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

Sampling Requirements:

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

Sampling Equipment Preparation and Cleaning:

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

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

Sample identification:

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

Field Sampling Procedures:

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

Sampling from a boat:

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

Secchi disk:

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

Vacuum Filtering Method (In-Line Filtering)

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

Preparation:

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

Filtration of samples:

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

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

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

Field Quality Control Samples

- Equipment Blanks: need to be collected in field between stations, once for each 25 sites sampled, flush/rinse with analyte free water
- Field split samples: collect for each 25 sites sampled, obtain 1 bucket of water and fill 2 identical containers sequentially

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 (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	0.146	0.142	0.137	0.137	0.128	0.121	0.128
0.5	0.146	0.142	0.137	0.137	0.127	0.121	0.127
1	0.147	0.145	0.137	0.136	0.127	0.121	0.127
1.5	0.146	0.147	0.136	0.136	0.126	0.121	0.127
2	0.145	0.15	0.137	0.137	0.126	0.121	0.127
2.5	0.146	0.152	0.143	0.138	0.126	0.12	0.127
3	0.149	0.154	0.141	0.139	0.126	0.12	0.127
4	0.149	0.154	0.145	0.141	0.123	0.12	0.127
5	0.149	0.157	0.144	0.14	0.122	0.12	0.126
6	0.15	0.16	0.144	0.14	0.122	0.12	0.126
7	0.151	0.16	0.145	0.14	0.121	0.12	0.126
8	0.15	0.159	0.145	0.14	0.122	0.121	0.126
9	0.151	0.159	0.144	0.139	0.119	0.121	0.126
10	0.152	0.158	0.143	0.139	0.122	0.12	0.126
11	0.152	0.158	0.141	0.139	0.12	0.121	0.126
12	0.154	0.157	0.142	0.139	0.121	0.121	0.126
13	0.154	0.156	0.14	0.139	0.12	0.12	0.126
14	0.154	0.156	0.14	0.139	0.122	0.121	0.125

Table 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	11	10.46	10.81	9.94	11.35	6.99	6.48
0.5	10.6	10.1	10.92	10.09	11.96	6.99	6.44
1	10.4	9.01	10.69	9.95	12.33	7.07	6.38
1.5	10.1	8.16	10.78	9.81	12.31	6.95	6.36
2	9.75	7.65	8.12	10.2	12.14	6.8	6.31
2.5	9.46	7.57	6.6	9.41	12.33	6.67	6.3
3	9.37	7.55	6.12	8.66	11.4	6.53	6.29
4	9.23	7.58	5.94	5.52	4.86	6.42	627
5	9.27	7.52	5.73	4.26	3.34	6.29	6.26
6	9.27	7.46	5.68	3.47	2.91	6.17	6.26
7	9.16	7.46	5.57	2.91	2.92	5.97	6.24
8	9.11	7.4	5.54	2.44	2.37	4.63	6.28
9	9.08	7.29	5.51	1.98	2.39	4.44	6.22
10	9.19	7.27	5.46	1.59	1.91	4.11	6.2
11	8.9	7.26	5.36	1.47	1.55	4.02	6.21
12	9	7.23	5.26	1.02	1.3	3.36	6.3
13	8.97	7.11	5.21	0.88	1.18	3.14	6.32
14	8.92	7	5.04	0.7	0.81	3.15	6.35

Table 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	16.49	20.28	26.22	30.36	29.04	21.57	18.95
0.5	15.8	19.86	25.61	30.23	28.13	21.55	18.94
1	15.6	18.31	23.4	29.84	27.86	21.45	18.88
1.5	14.7	16.29	22.8	29.4	27.63	21.28	18.88
2	14.2	14.8	20.9	27.4	26.9	21.25	18.86
2.5	13.3	14.78	19.46	27.1	26.6	21.2	18.86
3	13.2	14.72	19.33	26.6	26.5	21.19	18.86
4	13.04	14.56	19.04	24.7	24.7	21.15	18.86
5	12.9	14.45	18.68	24.4	24.1	21.13	18.85
6	12.7	14.25	18.67	24.19	23.9	21.1	18.85
7	12.7	14.1	18.26	23.9	23.8	21.06	18.84
8	12.6	14	18.15	23.56	23.7	20.95	18.84
9	12.5	13.96	18.05	23.25	23.5	20.94	18.83
10	12.4	13.94	17.91	22.6	23.4	20.86	18.83
11	12.3	13.95	17.75	22.4	23.2	20.84	18.83
12	12.2	13.9	17.48	21.8	23.1	20.66	18.83
13	12.2	13.86	17.21	21.6	23	20.63	18.82
14	12.2	13.82	16.7	21.2	22.9	20.53	18.81

Table 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	7.55	35.8	9.09	9.15	13.1	13.2	20.2
0.5	16.8	26.7	9.39	13.4	17.8	15.8	19
1	16.3	10.4	27.7	21.7	21.7	30.6	17.3
1.5	12.1	9.26	31.6	30.9	33.5	23.7	18.4
2	9.6	5.8	26.6	31.9	43.6	22.1	17.6
2.5	5.1	6.7	17.7	44.6	43.1	19.6	17.8
3	5.7	5.3	13.3	44.7	48.6	19.3	17.8
4	4.7	4.2	8.9	19.7	15.2	18.5	15.6
5	4.1	4.7	8.12	18.2	13.8	20.3	15.9
6	4.5	4.9	5.73	14.1	13.5	13.2	16.3
7	4.7	4.7	4.34	9.8	8.6	9.7	17.3
8	4.9	4.1	4.8	10.1	9.6	7.9	15.7
9	4.8	3.9	4.5	9.09	7.1	6.9	16.4
10	4.3	4.2	3.8	6.9	6.7	5.5	16.6
11	4.8	3.9	4.38	5.3	5.3	5.9	16.6
12	3.6	4.2	3.7	4.7	5.1	4.9	16.7
13	3.6	3.8	3.9	4.2	6.5	4.6	15.4
14	3.6	4.2	3.57	3.9	4.7	5.1	14.4

Table 1.5. Dam (Lacustrine) pH measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	7.85	8.13	8.62	8.73	9.03	7.77	7.88
0.5	7.8	8.09	8.7	8.83	9.07	7.77	7.84
1	7.77	7.95	8.55	8.79	9.09	7.77	7.8
1.5	7.68	7.82	8.46	8.63	9.08	7.77	7.79
2	7.61	7.71	8.18	8.55	9.05	7.75	7.76
2.5	7.5	7.67	7.92	8.38	9.03	7.74	7.75
3	7.5	7.66	7.79	8.2	8.92	7.72	7.74
4	7.49	7.66	7.73	7.93	8.37	7.71	7.73
5	7.49	7.66	7.66	7.71	7.96	7.7	7.71
6	7.48	7.68	7.65	7.65	7.78	7.69	7.7
7	7.48	7.68	7.65	7.58	7.72	7.66	7.7
8	7.47	7.7	7.65	7.54	7.66	7.61	7.7
9	7.47	7.7	7.66	7.5	7.62	7.59	7.69
10	7.47	7.71	7.65	7.47	7.57	7.57	7.69
11	7.47	7.72	7.66	7.44	7.54	7.55	7.7
12	7.48	7.74	7.66	7.42	7.5	7.52	7.7
13	7.48	7.74	7.67	7.41	7.48	7.51	7.7
14	7.5	7.74	7.68	7.4	7.47	7.51	7.7

Table 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	397	268	301	384	259	406	352
0.5	401	273	298	374	264	406	354
1	403	280	302	374	266	406	355
1.5	405	285	302	376	269	407	357
2	408	288	312	376	272	408	358
2.5	410	290	318	381	274	409	359
3	412	291	320	387	280	410	360
4	413	291	321	394	320	411	361
5	413	291	322	399	326	411	363
6	415	292	322	400	327	412	364
7	416	291	322	400	329	413	365
8	416	291	321	401	331	416	365
9	417	291	320	401	330	416	366
10	417	291	320	401	331	417	366
11	418	291	320	401	332	417	366
12	418	291	320	401	332	419	366
13	418	292	319	401	332	420	366
14	418	292	318	400	332	419	366

Table 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	8.3	32.4	3.6	2.3	2.7	3.9	5.3
0.5	8.7	30.8	4.2	2.7	2.8	4.1	5.3
1	8.5	35.8	4.8	3	2.9	4.2	5
1.5	8.3	35.7	4.8	3.3	3.1	3.8	5.7
2	8.7	30.6	5.4	3.1	3.3	3.9	6.2
2.5	9.1	34.9	7.1	3.5	3.4	4.3	5.5
3	9.1	29.9	6.8	3.3	3.2	4.2	5.5
4	9.5	28.4	6.8	2.5	2.5	4	5.8
5	9.8	26.7	7.4	3.3	3.3	4.1	5
6	10.6	24.7	8.2	3.3	3.6	4	5.5
7	9.4	24	8.9	3.6	4.1	5.3	5.6
8	10.6	27	8.9	4.1	4	5.3	6.1
9	10.7	26.1	9.8	4.6	4.8	6	6
10	10.4	27	9.5	4.4	6	5.6	5.8
11	9.8	25.4	11.2	4.5	7.1	6.5	5.4
12	9.9	28.1	11	4.4	7.1	7.5	5.4
13	10.2	30.5	11.2	4.5	9.5	9	5.5
14	9.9	30.4	12.1	5.1	10.8	10.4	7.5

Mile Marker 6

Table 1.9. Mile Marker 6 (Transition) Conductivity (μs/cm) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	0.159	0.104	0.15	0.14	0.129	0.13	0.144
0.5	0.159	0.112	0.15	0.14	0.13	0.13	0.144
1	0.159	0.118	0.15	0.14	0.128	0.13	0.144
1.5	0.159	0.127	0.15	0.14	0.127	0.129	0.143
2	0.159	0.132	0.149	0.139	0.127	0.129	0.143
2.5	0.159	0.146	0.149	0.14	0.127	0.129	0.143
3	0.159	0.148	0.149	0.14	0.127	0.129	0.143
4	0.159	0.155	0.149	0.138	0.128	0.128	0.142
5	0.159	0.165	0.149	0.138	0.128	0.128	0.142
6	0.159	0.168	0.149	0.138	0.128	0.127	0.142
7	0.159	0.169	0.148	0.139	0.128	0.127	0.141
8	0.159		0.148	0.141	0.128	0.12	0.138
9			0.148	0.144	0.128	0.114	0.135
10			0.148		0.128		0.135

Table 1.10. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	9.21	8.07	9.38	10	9.41	6.24	5.92
0.5	9.2	7.94	9.49	10	10.03	6.23	5.81
1	9.2	7.89	9.62	9.86	9.71	6.2	5.8
1.5	9.19	7.84	9.6	10.05	9.92	6.08	5.8
2	9.15	7.86	9.23	10.1	8.9	5.99	5.8
2.5	9.13	7.84	7.87	9.53	8.21	5.95	5.79
3	9.11	7.84	6.41	8.52	7.52	5.88	5.79
4	9.1	7.79	6.03	6.6	6.67	5.83	5.82
5	9.1	7.65	5.66	5.74	5.45	5.81	5.82
6	9.08	7.5	5.53	5.17	4.26	5.8	5.84
7	9.07	7.4	5.52	4.04	3.96	5.75	5.86
8	9.06		5.34	2.82	3.78	5.61	5.94
9			5.26	1.81	3.78	5.45	5.95
10			4.6		3.6		5.99

Table 1.11. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	13.54	18.45	22.77	28.2	28.5	20.98	18.59
0.5	13.55	17.9	22.3	28.19	26.9	20.95	18.48
1	13.56	17.2	22.1	27.6	27.1	20.91	18.51
1.5	13.3	16.7	21.77	27.6	26.2	20.74	18.43
2	13.2	16.3	21.82	26.6	25.4	20.6	18.44
2.5	13.2	16.2	20.36	26.6	25.1	20.55	18.43
3	13.12	15.9	19.59	26.3	24.9	20.48	18.43
4	13.09	15.7	19.24	25.3	24.7	20.46	18.39
5	13.04	15.1	18.8	24.9	24.3	20.46	18.39
6	13	14.5	18.6	24.4	23.8	20.46	18.35
7	12.99	14.3	18.58	23.9	23.7	20.42	18.34
8	12.9		18.23	23.4	23.6	20.31	18.2
9			18.1	23.1	23.7	20.17	18.2
10			17.8		23.6		18.17

Table 1.12. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	3.4	7.14	16.3	25.1	14.9	11.7	6.3
0.5	5	5.64	20.7	27.8	20.5	14.4	6.6
1	7.4	5.31	31.1	33.3	27.6	17.6	6.2
1.5	7.8	5.61	44.9	45.1	33.1	16.1	6.2
2	8	6.34	41.8	51.1	28.5	16.4	6.3
2.5	8.4	6.67	14.4	48.6	29.9	13.2	6.1
3	8	6.37	9.3	43.5	25.5	12.5	6.6
4	7.3	5.66	6.7	30.1	19.1	13.4	6.3
5	7.4	4.96	6.3	23.2	13.4	10.3	6.1
6	7.6	4.7	5.33	11.9	11	10.1	7.7
7	7	4.7	4.59	13.9	11.3	7.7	6.6
8	6.7		3.8	10.3	10.2	7.3	6.7
9			4.1	8.8	11.8	11.2	6.7
10			4.5		11.3		6.7

Table 1.13. Mile Marker 6 (Transition) pH measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	7.91	7.65	8	8.13	8.32	7.61	7.69
0.5	7.9	7.54	7.99	8.17	8.36	7.58	7.66
1	7.88	7.54	7.99	8.14	8.37	7.56	7.66
1.5	7.88	7.54	7.99	8.1	8.37	7.55	7.65
2	7.87	7.55	7.95	8.06	8.15	7.53	7.64
2.5	7.86	7.56	7.82	7.97	8.07	7.5	7.64
3	7.86	7.59	7.66	7.83	7.99	7.49	7.64
4	7.85	7.63	7.61	7.71	7.89	7.47	7.64
5	7.9	7.66	7.58	7.58	7.79	7.47	7.64
6	7.9	7.68	7.57	7.49	7.66	7.45	7.63
7	7.9	7.7	7.56	7.41	7.62	7.43	7.64
8	7.9		7.53	7.35	7.59	7.42	7.64
9			7.56	7.29	7.56	7.4	7.64
10			7.56		7.55		7.64

Table 1.14. Mile Marker 6 (Transition) ORP (mV) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	265	334	301	268	275	349	357
0.5	270	335	304	270	280	350	356
1	275	334	306	275	283	351	356
1.5	278	334	307	279	286	352	356
2	280	334	310	287	296	353	356
2.5	282	334	315	291	300	355	356
3	284	333	319	298	304	355	356
4	284	332	321	302	309	357	356
5	285	331	322	308	313	357	356
6	286	330	322	312	318	358	355
7	286	329	321	316	320	359	355
8	286		324	319	320	360	354
9			324	322	321	350	354
10			303		319		353

Table 1.15. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	12.6	38.5	8.4	3.3	3.5	12.1	16.6
0.5	13	36.7	8.4	3.5	3.9	11.8	17.8
1	14.2	35.6	9.1	4.1	4.3	12.5	18.5
1.5	14	30.7	9.3	3.5	4.7	12	19
2	13.5	27.4	9.4	4.1	4.9	11.4	19.1
2.5	13.4	21	11.7	4.4	4.8	12.4	19.3
3	13.2	17.8	11.9	4.7	5.5	12.4	20.1
4	13.3	17.1	13.5	6.6	8.8	11.3	22.1
5	13.6	15.9	14.3	7.1	8.6	12.2	22.6
6	14	21	13.1	8.9	16.1	20.6	24.6
7	14.4	21	12.5	8.3	17.9	12.1	24.5
8	14.8		15.2	15.1	24.2	16.8	23
9			17.2	20.9	23.2	68.6	24.4
10			49.6		28.1		25.3

Toler Bridge

Table 1.16. Toler Bridge (Riverine) Conductivity (µs/cm) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	0.173	0.151	0.114	0.138	0.142	0.108	0.165
0.5	0.173	0.152	0.122	0.138	0.142	0.109	0.165
1	0.172	0.15	0.135	0.138	0.142	0.107	0.165
1.5	0.172	0.156	0.139	0.137	0.142	0.104	0.165
2	0.172	0.154	0.142	0.137	0.141	0.104	0.165
2.5	0.172	0.154	0.143	0.137	0.141	0.104	0.165
3	0.172	0.156	0.143	0.137	0.141	0.103	0.165
4	0.172	0.156	0.143	0.137	0.141	0.097	0.165
5	0.172		0.143	0.137	0.141		0.165

Table 1.17. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	9.5	7.21	7.3	6.38	4.43	7.17	5.03
0.5	9.45	7.13	7.23	6.3	4.4	7.12	5.01
1	9.4	7.13	7.15	6.38	4.4	6.99	5.02
1.5	9.38	7.12	6.9	6.25	4.38	6.99	5.01
2	9.35	7.06	6.71	6.21	4.39	6.99	5
2.5	9.3	7	6.72	6.25	4.38	6.98	5.01
3	9.33	7	6.6	6.2	4.38	6.97	5.01
4	9.3	7	6.64	5.94	4.38	6.95	5
5	9.3		6.63	5.8			5.01

Table 1.18. Toler Bridge (Riverine) Temperature (°C) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	12.52	14.3	21.87	25.5	21.9	19.95	19.49
0.5	12.53	14.2	21.8	25.3	21.9	19.93	19.48
1	12.52	14.1	21.5	25	21.9	19.68	19.48
1.5	12.52	14.3	20.64	24.7	21.9	19.51	19.48
2	12.52	13.8	19.8	24.4	21.9	19.35	19.48
2.5	12.5	14.1	19.8	24.4	21.9	19.14	19.49
3	12.48	13.7	19.64	24.4	21.9	19.17	19.48
4	12.5	13.9	19.57	24.2	21.9	19.01	19.47
5	12.49		19.54	23.9			19.47

Table 1.19. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	3.3	5.04	6.85	10.56	7.6	7.95	4.6
0.5	4.3	4.84	8.7	14.8	6.9	8.5	4.4
1	4.5	5.45	9.9	15.7	8.5	8.9	4.9
1.5	5	5.05	9.47	17.6	11.1	8.3	4.5
2	5.2	4.96	8.9	18.1	13.4	7.87	4.7
2.5	5.1	6	8.9	18.2	11.7	7.7	4.4
3	5.5	5.71	8	15.8	14.9	7.3	5.2
4	5.3	5.42	7.8	15.2	13.3	7.2	4.7
5	5.9		6.4	14.9			4.26

Table 1.20. Toler Bridge (Riverine) pH measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	7.81	7.7	7.63	7.65	7.89	7.65	7.68
0.5	7.79	7.66	7.55	7.62	7.79	7.64	7.65
1	7.75	7.62	7.5	7.61	7.74	7.62	7.64
1.5	7.72	7.6	7.47	7.58	7.7	7.61	7.63
2	7.73	7.59	7.45	7.56	7.67	7.59	7.63
2.5	7.76	7.58	7.44	7.55	7.64	7.57	7.63
3	7.8	7.59	7.43	7.54	7.64	7.55	7.62
4	7.75	7.57	7.43	7.53	7.64	7.55	7.62
5	7.77		7.42	7.51			7.62

Table 1.21. Toler Bridge (Riverine) ORP (mV) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	299	318	311	333	332	328	349
0.5	305	321	314	331	332	329	348
1	306	322	317	331	333	330	348
1.5	307	324	318	331	333	331	347
2	307	324	320	331	333	333	347
2.5	308	324	320	331	333	334	347
3	307	324	320	332	331	335	346
4	307	325	321	332	331	336	347
5	306		322	333			346

Table 1.22. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2020)

Depth:	28-Apr	29-May	27-Jun	28-Jul	26-Aug	30-Sep	27-Oct
0	4.8	84	18.9	7.4	13.2	28.9	3.1
0.5	5.4	87	18.7	7.8	12.8	29.5	3.3
1	5.3	76.5	15.6	8.3	12.7	32	3.6
1.5	5.3	77.4	14.1	8.6	12.9	33.4	3.9
2	5.2	113.4	13.5	8.2	12.5	34.6	3.5
2.5	5.5	128.7	13.7	8.4	13.7	32	3.7
3	5.3	125.7	14.4	8.1	13.6	36.2	4.9
4	6.6	178.5	14.8	8.8	13.7	40.1	3.8
5	6		13.8	9.2			6.5

Appendix F: Letter to Technical Review Committee dated Dec 3, 2020 over concerns of low Dissolved Oxygen Content in tailwater release from SML.

December 3, 2020.

Liz, Ed and Water Quality Technical Review Committee,

Thank you for recently providing monthly reports of water quality monitoring for the Smith Mountain Hydroelectric Project. These monthly reports and previous annual reports of water quality monitoring for the Smith Mountain Hydroelectric Project have made it clear that the dissolved oxygen (DO) content of tailwater from Smith Mountain Lake is unacceptably low and action needs to be taken to improve water quality and meet required standards.

The operational standards for DO content in the tail waters from Smith Mountain Lake require an instantaneous minimum of 4.0 mg/L and a daily average minimum of 5.0 mg/L. However, measured concentrations of DO frequently fail to achieve these standards. Taking data throughout the 2019 season as an example, 33% of the instantaneous measures of DO failed to achieve the minimum DO content and 63% of the time failed to achieve the minimal daily required concentration. Failure to achieve required DO content is most prominent in the fall, during which DO content failed to meet standards from August-October 2019 (average daily DO were 4.1, 3.5 and 3.9 for Aug, Sept, Oct, respectively). This same pattern appears evident in recent monthly reports for 2020, wherein average DO content was well below the required daily average of 5.0 mg/L (4.0 and 3.8 mg/L for August and September, respectively). These DO concentrations are in line with our measures of DO in the riverine, upper portion of Leesville Lake. At times when water is being discharged at the dam this water with low oxygen levels flows past Toller Bridge and we have observed shad piping for air and dead fish in the area (image below). These low DO concentrations place undue stress on fish populations and need to be addressed.

Monitoring of DO was initiated in 2011. Since that time, strides have been made to install a permanent monitoring system that is now quite reliable. Initial attempts to improve the DO content of discharged water led to adoption of “first on, last off” operational standards for turbines during the months of July to mid-November. According to this protocol the first units to come on line are units 2, 3 and 4 followed by units 1 and 5. The units are shut down in reverse order, so that the units closer to the surface (units 2, 3, 4), where DO content is greatest, are in operation for the longest time. This operational protocol has improved the DO content of the tail water but has not enabled the hydroelectric project to meet required operational standards for DO. Furthermore, several years ago an attempt was made to promote oxygenation of water at the turbines. The method that was attempted was not effective.

Although AEP has made strides in DO monitoring and in dam operations to improve DO content of discharged water, these have been insufficient to meet operational standards. Additional measures to improve DO content of the tailwaters of Smith Mountain Lake need to be implemented. We will happily discuss remediation options.

Sincerely,

Tony Capuco, Chair Leesville Lake Water Quality Committee

Thomas Shahady, Environmental Science, University of Lynchburg