Leesville Lake 2018
Water Quality Monitoring

Prepared for:
Leesville Lake Association

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Table of Contents Page

List of Acronyms and Abbreviations

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

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 2018. The lake was monitored end of the month by University of Lynchburg while additional samples were collected by the Leesville Lake Water Quality Committee during June, July and August during mid-month. The 2018 yearly results are reported here with analysis of lake trends, statistical insights on the data collected since 2010 and current research pursuits. The intent of this report is to provide a technical and scientific foundation to develop a management plan for the Smith Mountain and Leesville Lake reservoirs in order to protect and improve these lake resources for the future.

Leesville Lake continues to meet prescribed water quality parameters measured in the main stem of the reservoir except for two notable exceptions. *E. coli* violations continue to occur periodically in the upper portions of the reservoir near Pigg River. As a result, we initiated the Pigg River study during summer months of 2018. Results from this initial study were clear. During storm water events the river flows with elevated concentrations of TP, *E. coli* and sediment. Concentrations of *E. coli* are in violation of state standards during storm water flow and TP and sediment concentrated enough to generate eutrophic conditions in the reservoir. Dissolved oxygen during the fall throughout the lake is below the standard of 5 mg/L. Eutrophic conditions and low DO release from Smith Mountain Lake are likely contributors. Chlorophyll *a* was noticeably higher this season, returning the lake to a eutrophic classification. The continued bloom of phytoplankton, as detected by Chlorophyll *a* at a depth of 2-4 meters below the lake surface, increased this season extending from the dam to MM6. Multiple factors are hypothesized as contributing to this bloom.

Water quality indicators suggest Leesville Lake is mildly eutrophic. Current trends suggest some improvement in trophic state and movement toward a mesotrophic condition. This is a very positive trend. Of concern is the increasing sediment loading. This increased sediment load may be confounding some of the other trophic state measures.

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

1. When spring months bring significant precipitation and input from the Pigg River, water quality degrades.
2. While significant inputs from Pigg River have the potential to degrade water quality, significant flow from Smith Mountain Lake provides dilution of these inputs potentially improving water quality.
3. Turbidity in the reservoir is increasing. Chlorophyll *a* is very responsive to this trend suggesting inputs from the Pigg River are highly influential on the trends we are observing in changing water quality.
4. Time lags are associated with changes in trophic state, thus changes may not yet fully impact the overall TSI.

5. It is now becoming clear that in Leesville Lake, *Daphnia* populations respond to phytoplankton abundance *rather than* graze and control phytoplankton populations.
6. Strong patterns of stratification may be the primary influence on decreased water quality particularily loss of oxygen in the hypoliminon, and a stronger driver than water inputs from Pigg River or SML release.
7. Pigg River input contaminates the lake with TP, *E. coli* and turbidity when it has a significant flow. These analyses demonstrate the need for increased management of Pigg River.
8. Rocky Mount WWTP does have some impact on Pigg River water quality but this is not a significant input by comparison to other inputs into the river.
9. All three contaminates, TP, *E. coli* and turbidity elevate significantly in the Pigg River during storm events as compared to low flow conditions. This is the primary source of contaminants to Leesville Lake.

Management recommendations suggested here are intended to improve the overall condition of the reservoir and potentially bring the trophic state into a mesotrophic classification.

1. Continue to research links between hydrology, Pigg River input and water quality. Pinpoint how Smith Mountain Lake operations influence these relationships.
2. Find focus areas of Pigg River to better quantify potential increases in sedimentation, nutrient inputs and changes in productivity. Intensively study these areas to affect change and improve water quality.
3. Information should be posted at the annual picnic or in public areas and as the annual Leesville Lake Association picnic, indicating that when turbidities elevate above 50 NTU, contact with lake water should be avoided. The Leesville Lake Association sends email notices to members regarding potential health hazards on the lake. However, it cannot provides continuous monitoring and health department services.
4. Conduct more intensive research on the Pigg River. Quantify the influence this river has during base flow and contrast this with storm flow on water quality.
5. Perform bacterial sopurce tracking in the upper regions of the watershed to determine the source of bacterial contamination (agricultural, human, wildlife, vegetative decay or sediment storage) in the urban and agricultural regions of the watershed. Engage the appropriate regulatory agencies and work cooperatively to find solutions to these issues.
6. Make recommendations to AEP operations related to Pigg River water quality and low oxygen conditions in the reservoir.

Section 1: Current Conditions (2018)

1.1 General:

This is the eighth year of water quality monitoring of Leesville Lake by University of Lynchburg (formerly Lynchburg College in previous years of study) in partnership with Leesville Lake Association (LLA). Eight years of data continue to strengthen our understanding of water quality and allows us to pinpoint areas of concern and management.

Section 1 documents results for the current year's sampling. Data are reported in graphical form with interpretations of current water quality. 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. A full background of the study and its rationale are located in **Appendix A**.

1.2 Methods:

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

Table 1.0. Leesville Lake 2016 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 (2018)

1.3.1 Temporal 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 an interesting 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. 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 an 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, called 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. 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. However, the oxygen content of water from Smith Mountain Lake may have low oxygen content due to multiple factors related to pumpback operations, Pigg River water quality and generators within the dam (as discussed subsequently). 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. The fate of this polluted water depends on hydroelectric operations. During energy production, Pigg River water is diluted and pushed through the reservoir. During pump back operations, Pigg River water is drawn 4 miles to the dam and the lacustrine areas of Smith Mountain Lake. And depending upon electric demand, a mix of both of these conditions is possible.

The transition portion of the reservoir is not as heavily influenced by Smith Mountain Lake Operations. Water is drawn back and forth but the volume of water buffers the influence these operations exert on the reservoir. During periods of heavy rain, sediment-laden water will travel into the transition portions of the reservoir. During electric generation, water is pushed down reservoir, yet this water from Smith Mountain Lake is of excellent quality and potentially increases the quality of water in Leesville Lake. The dam area of Leesville Lake is isolated from influence of Smith Mountain Operations and reflects the water quality of Leesville Lake. 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 the 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 overall limnology of the lake. Section 3 presents management recommendations.

Jargon is used in this report to describe certain aspects of lake function and water concerns in the lake. Here we define key terms to facilitate comprehension of the document and the trends that the research 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 that form during stratification. The epilimnion is the upper layer and the hypolimnion is the lower layer. The term **Metalimnion** is also used to describe the layer of changing conditions between the two other layers. Temperature is the most common measure used to define these layers, and the most often referenced criterion to define a new layer is a temperature in excess of 1 degree centigrade per one meter of depth. But, because these lakes are polymictic, this clear definition is often not applicable.

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

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

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

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

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.

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

Conductivity

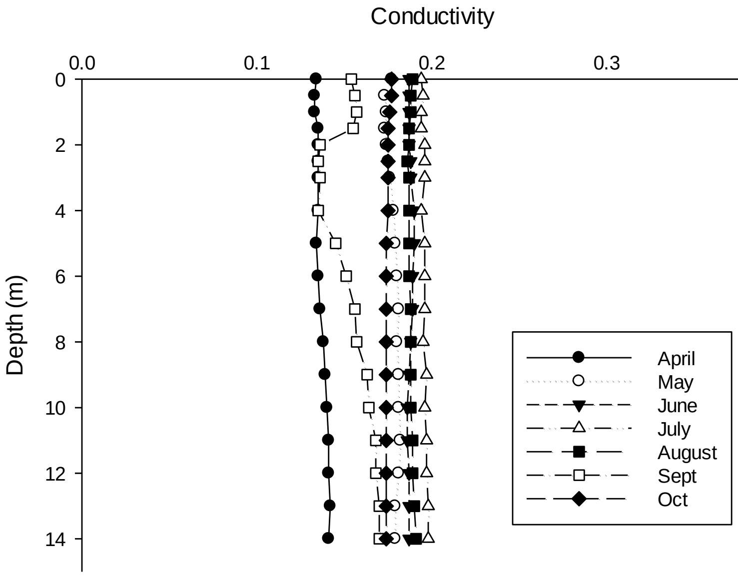

Figure 1.1. Dam (Lacustrine) Conductivity (ms/cm) measures over study period (2018)

Seasonal Analysis

Conductivity reflects the presence or absence of 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. Typically, there is not a strong vertical (depth) pattern in conductivity unless the stratification of the water creates a differential pattern in water movement. Water conductivity at the dam is generally between 0.14 and 0.2 ms/cm. Conductivity produced an unusual pattern in the lake this season. While April samples were lowest in conductivity as in previous years, September samples were lower than remaining sampling dates. Changes in patterns of conductivity appear directly associated with hydrological movement of water.

Comparisons Across Years

From our observations, conductivity measures in the reservoir are a good reflection of the hydrological movement of water. As 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 rather than SML dam release. Further analysis of this trend is discussed in Section 2 – Lake Wide Trending. Conductivity strongly correlated with Turbidity and Chlorophyll *a* and Total Phosphorus. .

Dissolved Oxygen

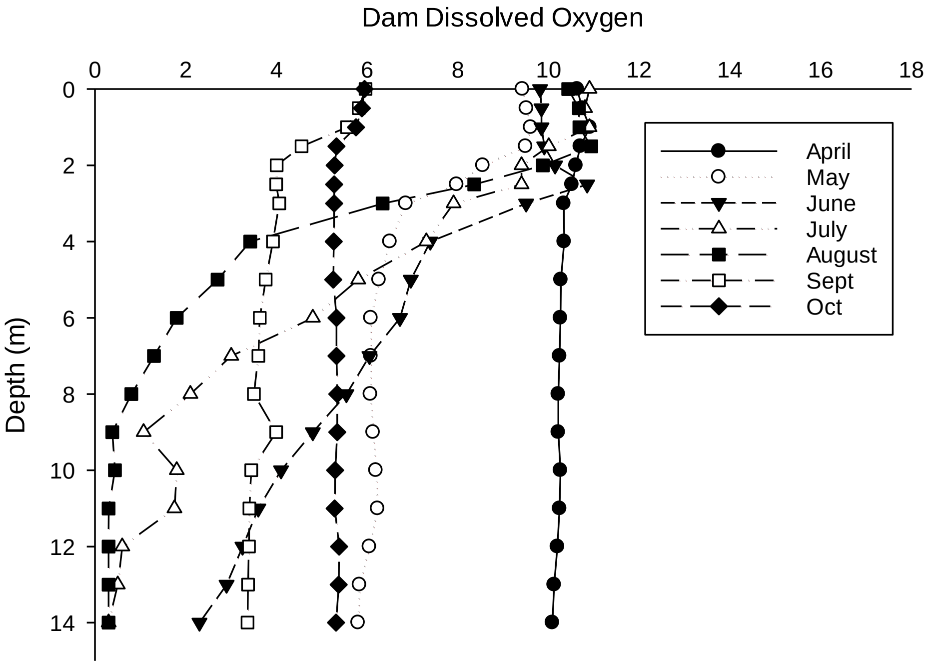

Figure 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2018)

Seasonal Analysis

Dissolved oxygen patterns in the reservoir continue to suggest that it is eutrophic.
At the start of the sampling season in April, water was well oxygenated throughout the entire water column. In May, a positive heterograde develops below the surface as productivity increases. Water remains oxygenated enough to support biological life at depth through this month. In June, the decrease in oxygen below the thermocline fell below 5 mg/L. Increased oxygen loss with depth occurs into July and through August. This pattern strongly suggests the reservoir is eutrophic. This low oxygen layer below the thermocline is a tremendous mass of water which, during the turnover month of September, drives the entire system to critically low oxygen concentrations throughout the reservoir. Some oxygen is entrained between the depths of 8-12 meters during these months most likely due to release from Leesville dam.

Comparisons Across Years

The observed 2018 pattern of oxygen in the reservoir is well established though our sampling. Well oxygenated water in April with onset of stratification in May and beginnings of oxygen loss below the thermocline. This oxygen loss intensifies through the summer months of June, July and August until September when turnover occurs and reduces oxygen levels throughout the reservoir. Depending upon the frequency of summer storm events and potential mixing of the entire reservoir from intensive rain events, the levels of oxygen depletion will worsen the longer the reservoir remains stratified without disturbance. It is important to note that 2018 was one of the wettest years for this area on record. This suggests the reservoir at the dam may be buffered from polymictic events throughout the summer influencing water quality throughout the reservoir due to prolonged stratification reducing oxygen levels that subsequently lower oxygen throughout during September mixing.

Temperature

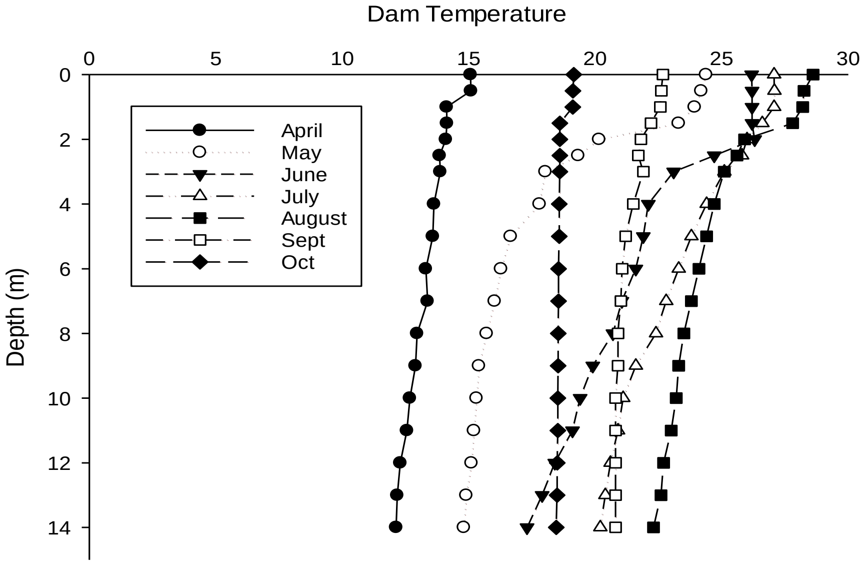

Figure 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2018)

Seasonal Analysis

April is the coolest sampling month and almost isothermal throughout. There is evidence of warming at the surface but this warming does not impact the other measured variables in the reservoir. Between April and May is the time period where the reservoir change is most rapid. Heat energy not only transfers throughout the water column but the pattern of stratification develops that will maintain itself until September. Interestingly, as the water continues to warm into the summer months of June, July and August, the strength of stratification is not as strong compared to May due in part to warming of the lower hypolimnion layer. Strength of stratification defined as relative difference between surface temperatures and those in the hypolimnion. During fall turnover in September the water is quite warm. This adds to concerns already discussed with low oxygen. Higher temperatures create greater physiological stress on fish and other aquatic life in the reservoir. These two factors, low oxygen and high temperature, create the poorest water quality conditions anywhere in the reservoir.

Comparisons Across Years

This pattern is very typical for the reservoir. Overall temperatures may vary by year and during heavy precipitation periods the polymictic nature of the reservoir demonstrates. Yet overall, the lake consistently stratifies throughout the summer months with strength of stratification (temperature differential) inversely related to water movement. Temperature amongst years was also impacted by days of direct sunlight, as prior years suggest an overall warming of the reservoir with fewer raining days. This years measures were coldest across years we have monitored..

Chlorophyll *a*

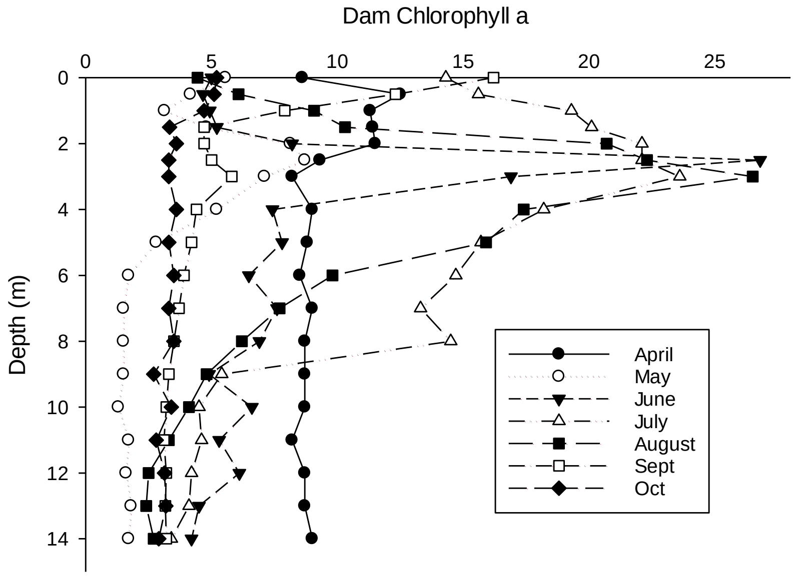

Figure 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2018)

Seasonal Analysis

The reservoir continues to demonstrate a pattern of greatest phytoplankton growth just above the thermocline (between 2-5 meters). 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 increased peaks in Chlorophyll abundance occurred in the summer months of June, July and August. This pattern was very similar to 2016 and data from previous years. This set-up of Chlorophyll *a* growth appears dependent upon rain and input of sediment and nutrients.

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. Unlike last season, higher concentrations of Chlorophyll *a* did occur along the thermocline this season. One hypothesis in lakes is that the spring TP often sets the Chlorophyll *a* summer maximum. However looking at data in this context did not support a pattern.

pH

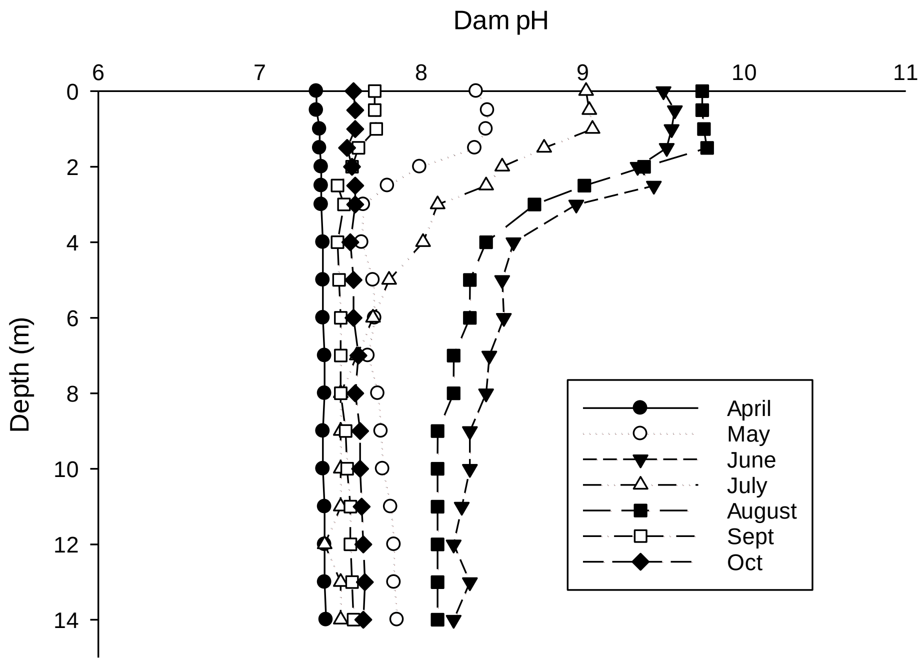

Figure 1.5. Dam (Lacustrine) pH measures over study period (2018)

Seasonal Analysis

The pH in the reservoir varied between 7.3 and 9.7 throughout the season, providing further evidence that the reservoir is eutrophic because high pH levels correlate with increased eutrophication. As the lake stratifies, the epilimnion becomes concentrated with phytoplankton and, through photosynthetic removal of CO_2, the pH increases. These high levels of pH suggest the eutrophic nature of the reservoir particularly in the warm summer months where photosynthetic activity is quite high.

Comparisons Across Years

As this season's phytoplankton production returned to previous years observation so did the pattern observed in pH. Summer months of June, July and August were the most productive months and produced the elevated pH. In 2017, these peaks were delayed. This further strengthens the idea that water movement drives water quality conditions in the reservoir, in this case influx of poor water quality (most evident in 2017) from the Pigg River.

ORP

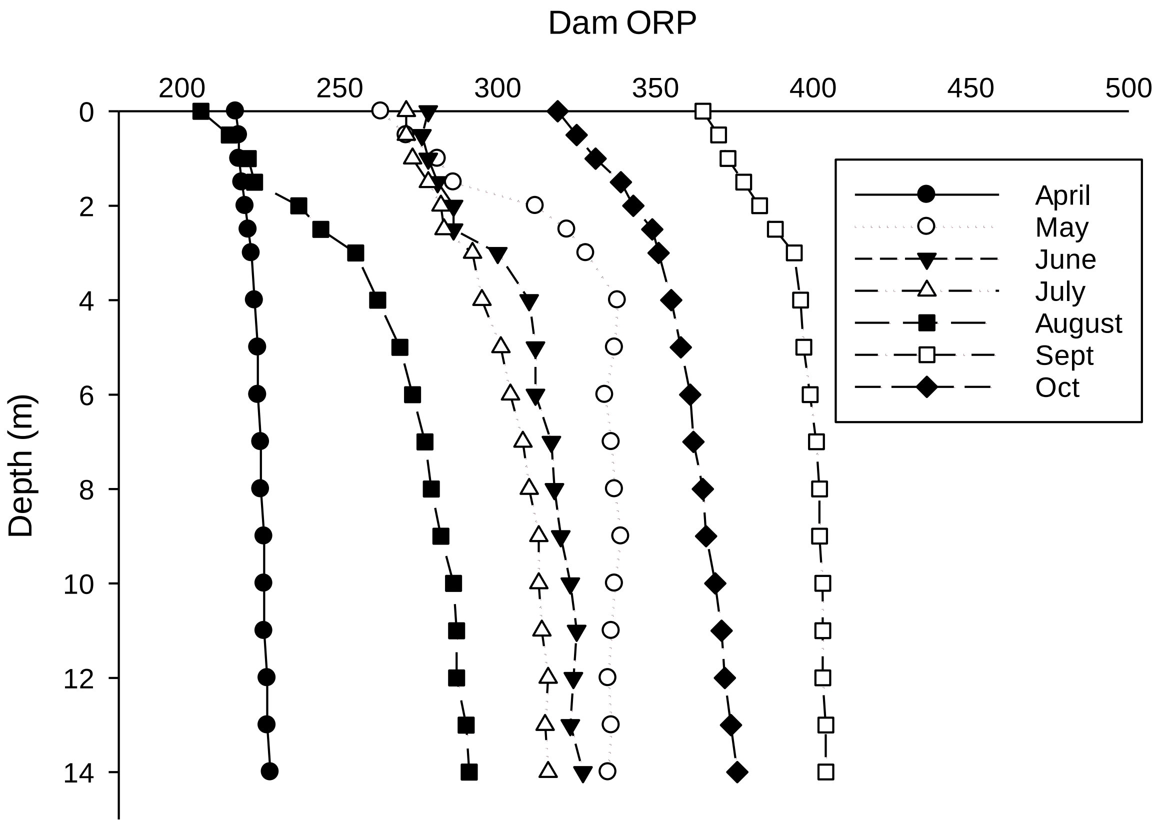

Figure 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2018)

Seasonal Analysis

It is often difficult to discern patterns in ORP in this reservoir. There is a pattern of slightly increased ORP with depth. In 2018, ORP varied month to month, with certain months clustered together. An increase in ORP with depth suggests that monthly changes in lake conditions are the drivers of redox reactions in the reservoir rather than changes in depth and loss of oxygen in the hypolimnion. Simply put, greater phytoplankton productivity tends to raise both pH and ORP in the reservoir. It is not completely understood why this increased ORP at the thermocline is then not reduced with depth. The transient nature of stratification in these types of polymictic reservoirs may not provide enough time to strongly establish chemical reactions in the reservoir.

Comparisons Across Years

On an annual scale, ORP measures differ from year to year. Yet similar to the analysis of productivity related to increased ORP, this pattern is consistent across years.

Turbidity

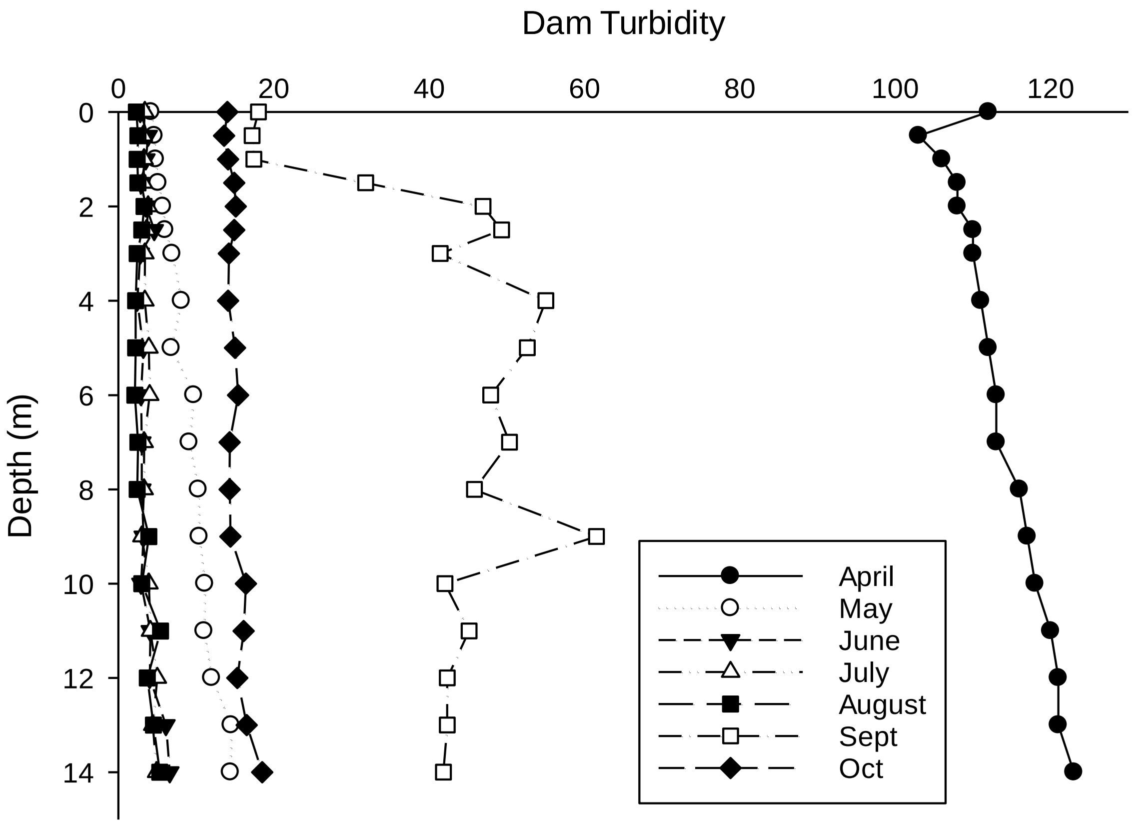

Figure 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2018)

Seasonal Analysis

Turbidity in the reservoir is strongly linked to hydrology as the Pigg River carries very high sediment loading while Smith Mountain Lake inputs contain no turbidity under most conditions. Thus, high turbidity levels observed in April and later in the fall reflect the nature of water flow through the reservoir. Plumes of turbidity from the Pigg River can become entrained in the reservoir as water is moved back and forth through power generation operations.

Comparisons Across Years

When turbidity is elevated it generally increased with depth. Variation in the observations throughout the epilimnion from year to year are hard to interpret. However, summer months contain low turbidity in the epilimnion and increases in turbidity with depth while other months are more susceptibility to storm water inputs and sediment turbidity. It is interesting that while the summer of 2018 was very wet, the reservoir did not demonstrate high turbidity levels at the dam. This is likely due to dam operations during these months and the lack of operations in the months where the lake is turbid throughout. This has multiple interpretations. Leesville Lake water is improved during these months while the fore bay of Smith Mountain Lake is degraded. Secondly, greater power generation during these months would theoretically improve Leesville Lake while degrading Smith Mountain Lake.

Other Parameters Measured

Table 1.8. Other parameters measured over study period (2018). Dates represent sampling of both the volunteers and University of Lynchburg. First Column represents each parameter measured along with units of measure.

Date	**30-Apr**	**31-May**	**14-Jun**	**26-Jun**	**10-Jul**	**30-Jul**	**15-Aug**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	9:38 AM	2:12 PM	9:06am	11:37 AM	9:00am	10:10am	9:25am	10:37am	9:30am	3:15pm	
Secchi (M)	0.50	1.90	2.20	2.52	2.10	2.20	1.70	2.20	0.70	0.90	**1.69**
TP Surface (PPM)	0.10	0.02		0.03	0.02	0.01	0.02	0.02	0.10	0.05	**0.04**
TP 8 Meters (PPM)	0.11	0.03		0.02		0.02		0.16	0.20	0.03	**0.08**
Integrate Chl a (PPB)	13.4	18.1		22.1		23.7		24.8	21.4	18.6	**20.3**
Integrate Phycocyanin		.		17.6		33.1		20.9	33.1	19.8	**24.9**
TSI S	70	51	49	47	49	49	52	49	65	62	**54.2**
TSI TP	67	47		51	47	39	45	47	66	59	**52.1**
TSI CHL	56	59		61		62		62	61	59	**60.0**
TSI AVG	64	52	49	53	48	50	49	53	64	60	**54.2**

Table 1.9. Zooplankton and *E. coli* measured over study period (2018). Dates represent sampling of both the volunteers and University of Lynchburg. Zooplankton numbers are organisms per liter.

Date	**30-Apr**	**31-May**	**14-Jun**	**26-Jun**	**10-Jul**	**30-Jul**	**15-Aug**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	9:38 AM	2:12 PM	9:06am	11:37 AM	9:00am	10:10am	9:25am	10:37am	9:30am	3:15pm	
Daphnia	0.0	9.3		12.1		3.6		1.6	0.8	4.0	**4.5**
Bosmina	5.7	31.5		0.0		2.0		2.8	1.6	4.4	**6.9**
Diaptomus	2.0	12.9		4.4		2.8		12.9	4.0	3.2	**6.1**
Cyclops	3.2	18.2		7.7		14.2		24.3	0.8	1.6	**10.0**
Nauplii	0.8	15.0		4.4		9.7		5.7	0.8	3.2	**5.7**
Cerodaphnia	0.0	0.8		0.0		0.0		0.4	0.0	0.4	**0.2**
Diaphanosoma	0.0	1.6		0.4		4.0		2.4	0.4	0.4	**1.3**
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.4	**0.1**
E. coli MPN	161.6	1.0	10.2	5.2	13.1	5.2	9.5	9.7	108.6	26.9	**35.1**

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 (2018)

Date	**30-Apr**	**31-May**	**25-Jun**	**30-Jul**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	10:11am	3:25pm	12:18pm	10:45am	11:22	10:00am	3:43pm	
Secchi (M)	0.6	1.5	1.40	1.80	2.10	0.60	0.70	**1.24**
TP Surface (PPM)	0.069	0.030	0.018	0.016	0.023	0.137	0.029	**0.046**
TSI S	67.4	54.6	55.2	51.5	49.3	67.4	65.1	**58.64**
TSI TP	61.9	50.9	44.7	43.3	47.6	71.4	50.5	**52.89**
TSI AVG	64.6	52.8	50	47	48	69	58	**55.77**
E. coli MPN	224.7	3.1	10.8	43.1	20.1	95.9	29.4	**61.01**

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 (2018)

Date	**30-Apr**	**31-May**	**26-Jun**	**30-Jul**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	10:22am	3:35pm	12:25pm	10:55am	11:33am	10:12am	3:54pm	
Secchi (M)	0.5	1.3	1.35	1.90	2.00	0.55	0.90	**1.21**
TP Surface (PPM)	0.070	0.042	0.015	0.028	0.032	0.142	0.039	**0.053**
TSI S	70.0	56.2	55.7	50.8	50.0	68.6	61.5	**58.97**
TSI TP	62.1	55.3	42.6	50.0	51.7	71.9	54.3	**55.41**
TSI AVG	66.0	55.7	49	50	51	70	58	**57.19**
E. coli MPN	290.9	2.0	2	23.8	12.2	96	24.5	**64.49**

1.3.1.4 Mile Marker 6 (Transition)[2]

<u>Background</u>

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

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

Conductivity

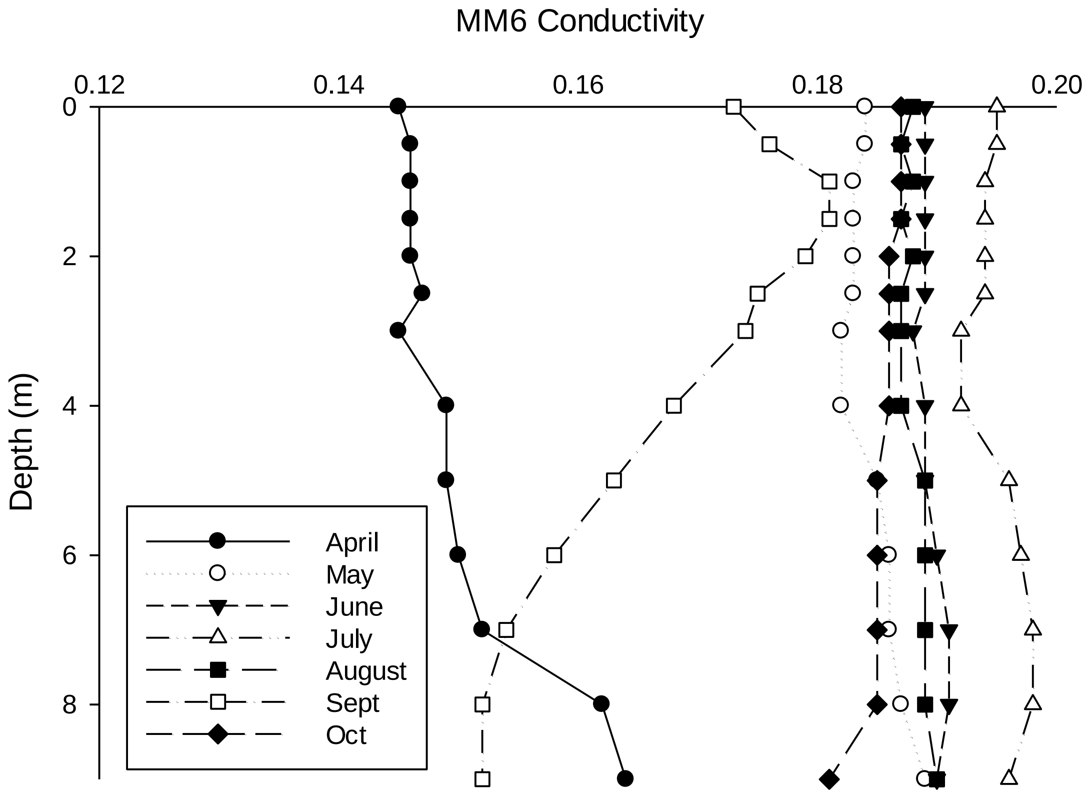

Figure 1.8. Mile Marker 6 (Transition) Conductivity (ms/cm) measures over study period (2018)

Seasonal Analysis

Conductivity patterns at the transition region were similar to those observed at the dam (between 0.14 and 0.2 ms/cm), except for measures in April and September. These months were the most turbid months in the reservoir and thus it follows that conductivity was lower, reflecting greater input of Pigg River water, characterized by greater turbidity and lower conductivity.

Comparisons Across Years

Comparisons among years reveal a similar trend related to Pigg River input, with a majority of the samples collected having conductivities between 0.14 and 0.2 us/cm.

Dissolved Oxygen

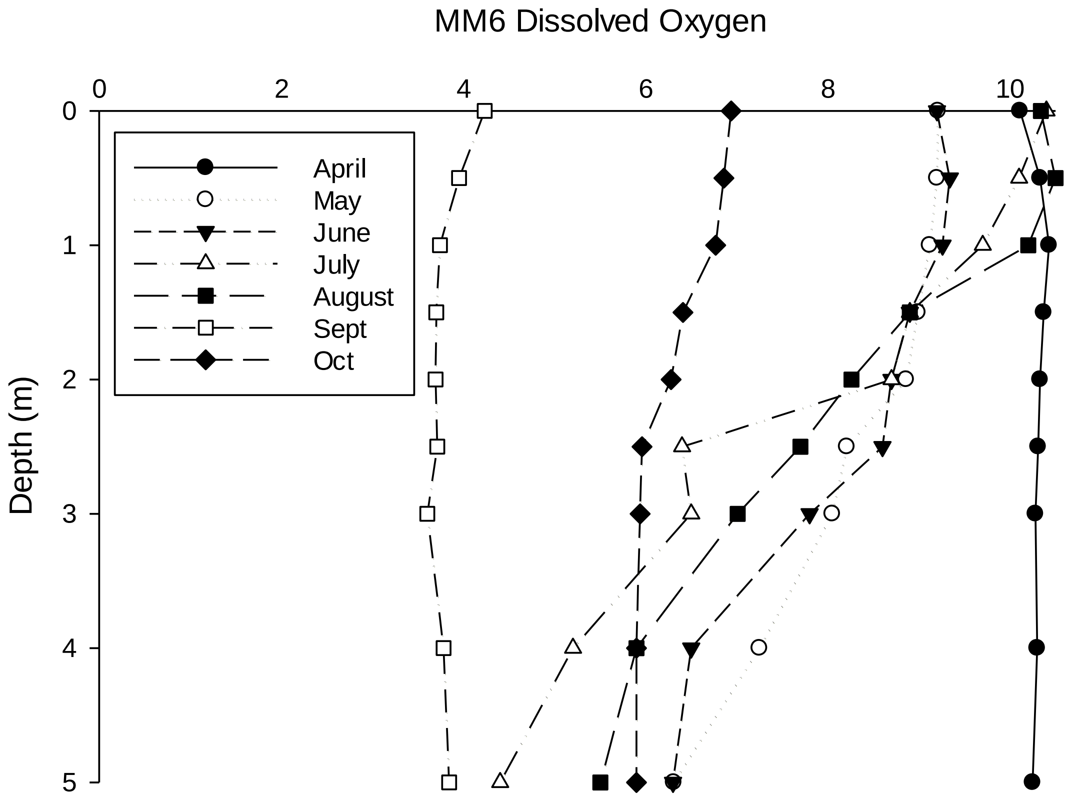

Figure 1.9. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2018)

Seasonal Analysis

The pattern of dissolved oxygen in the transition area is dissimilar from the dam in the following ways. During summer months, a strong stratification pattern is observed at 2 meters. This occurs at MM6 but the strength of dissolved oxygen differentiation (> 1 mg/L per meter of depth) is not as strong as in the Lacustrine region suggesting that mixing to lower depths occurs at this station with greater frequency. Additionally, the oxygen depletion in the reservoir during September is more severe at this station. Oxygen levels are depleted throughout and below 5 mg/L minimum. This portion of the reservoir exhibits very poor water quality and is a concern, particularily since the transition region is typically considered the most productive.

Comparisons Across Years

The lower levels of oxygen toward the end of the season is a phenomenon observed only recently at this station. In 2018, this trend continues and the very low September observations are concerning. Earlier trends (before 2014) did not exhibit as large a spread of oxygen concentrations throughout the sampling season (between 4 and 10 mg/L). This is an area of concern in the reservoir as it is an important source of impairment.

Temperature

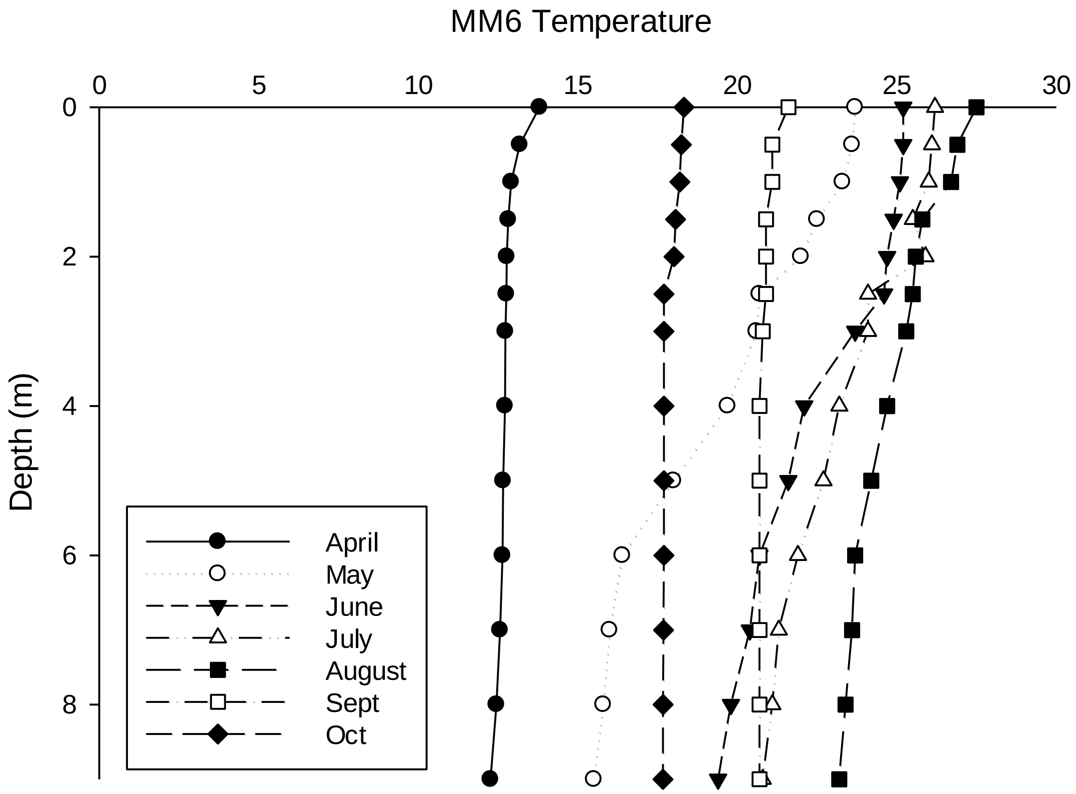

Figure 1.10. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2018)

Seasonal Analysis

Temperature range observed here is similar to that at the dam, but the pattern of stratification is not as strong. This reflects the shallower body of water and the influence of mixing from the above stations. Water is generally not strongly stratified as we observe at the dam (>1 degree change per meter). Stratification does occur at a lower depth (3-4 meters at this station vs. 2 meters at the dam). Again, the nature of the mixing zone and shallow depth compared to the dam influence these processes.

Comparisons Across Years

Patterns in water temperature were consistent across years. This station does not strongly stratify and is likely influenced by water movement at SML dam more than the development of lake conditions as was observed at Leesville Dam.

Chlorophyll *a*

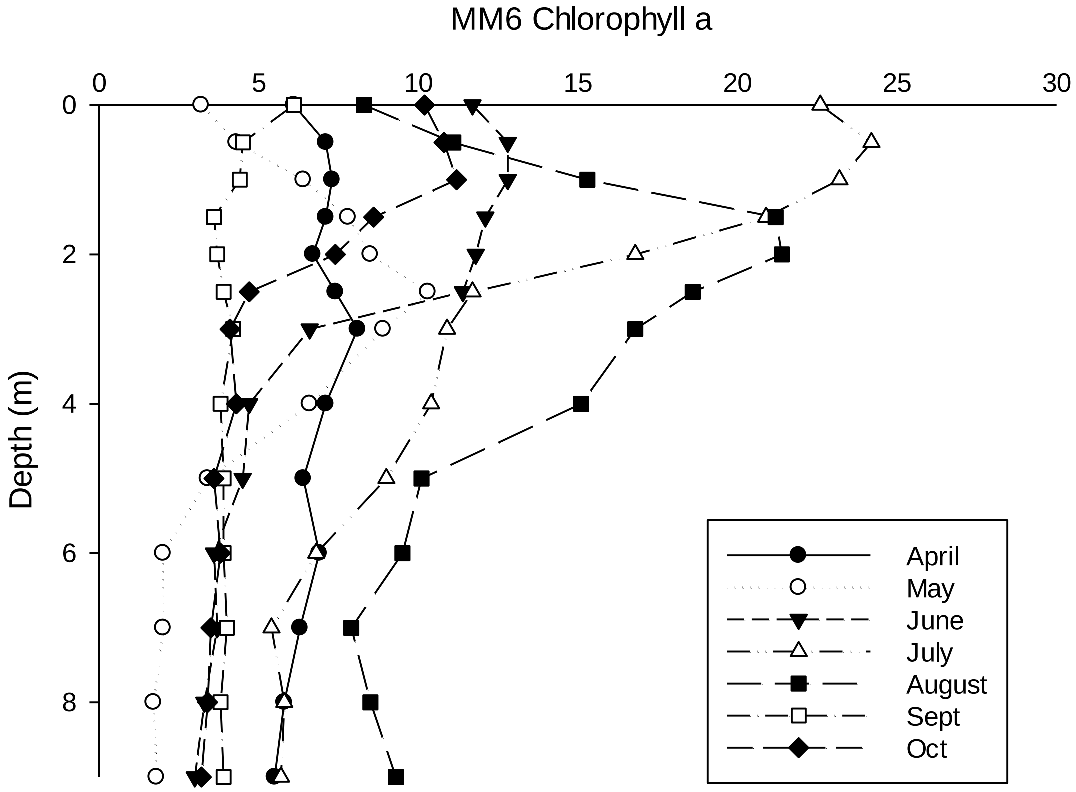

Figure 1.11. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2018)

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 and slow moving water mass creating ideal conditions for phytoplankton growth. This transition stations provides a good view of the phytoplankton blooms in the reservoir during the summer months. Extending the data from the dam to this station shows in July and to some extent in August an extensive concentration of phytoplankton (>20 ug/L) throughout the epilimnion. At the dam it is closer to the thermocline but nonetheless fairly extensive throughout. This bloom begins in June at the dam station (did not extend to MM6 during this portion of the growing season). High phytoplankton growth was confined to this transition portion of the reservoir.

Comparisons Across Years

Last season (2017) appeared to be an anomaly due to sedimentation in the reservoir creating light limitation on phytoplankton growth. During this season (2018), the reservoir returned to a pattern of dense phytoplankton growth at the thermocline during the summer months and just below the surface at the dam and extending up through the surface at MM6. In previous years this phytoplankton bloom has become quite dense and even hyper-eutrophic. This season it remained in the eutrophic catagory during July and August. The mechanisms controlling growth appear very dependent on sedimentation from Pigg River and availability of light. Constant water movement from SML dam operations or high flow disrupt this pattern as well.

pH

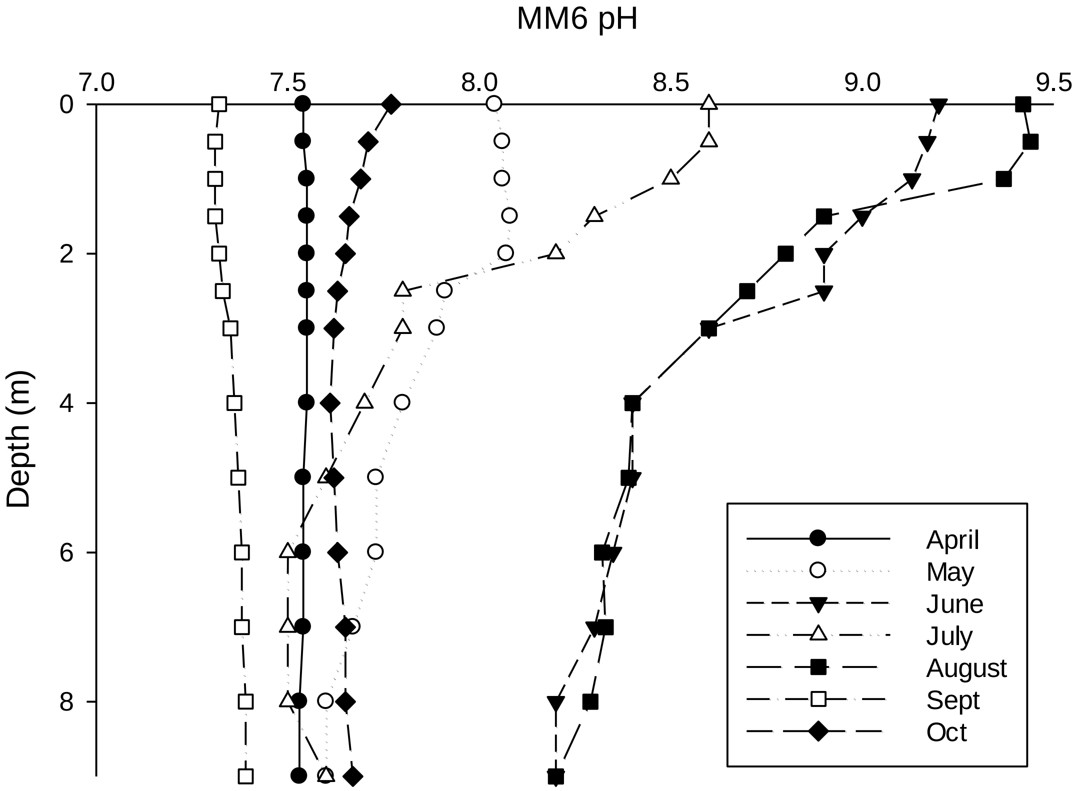

Figure 1.12. Mile Marker 6 (Transition) pH measures over study period (2018)

Seasonal Analysis

The pH pattern is similar to that observed at the dam. It is clear that high rates of photosynthesis, associated with excessive phytoplankton growth, push the pH near 10 in the epilimnion during the summer months. This is a trait of a eutrophic lake. It also converts less toxic ammonium ion to the more toxic ammonia that can reduce fish productivity. Along with concerns over the algae bloom occurring during the summer months,the associated high pH is concerning as well.

Comparisons Across Years

Patterns of pH values observed in 2018 are similar to patterns observed throughout the years of study.

ORP

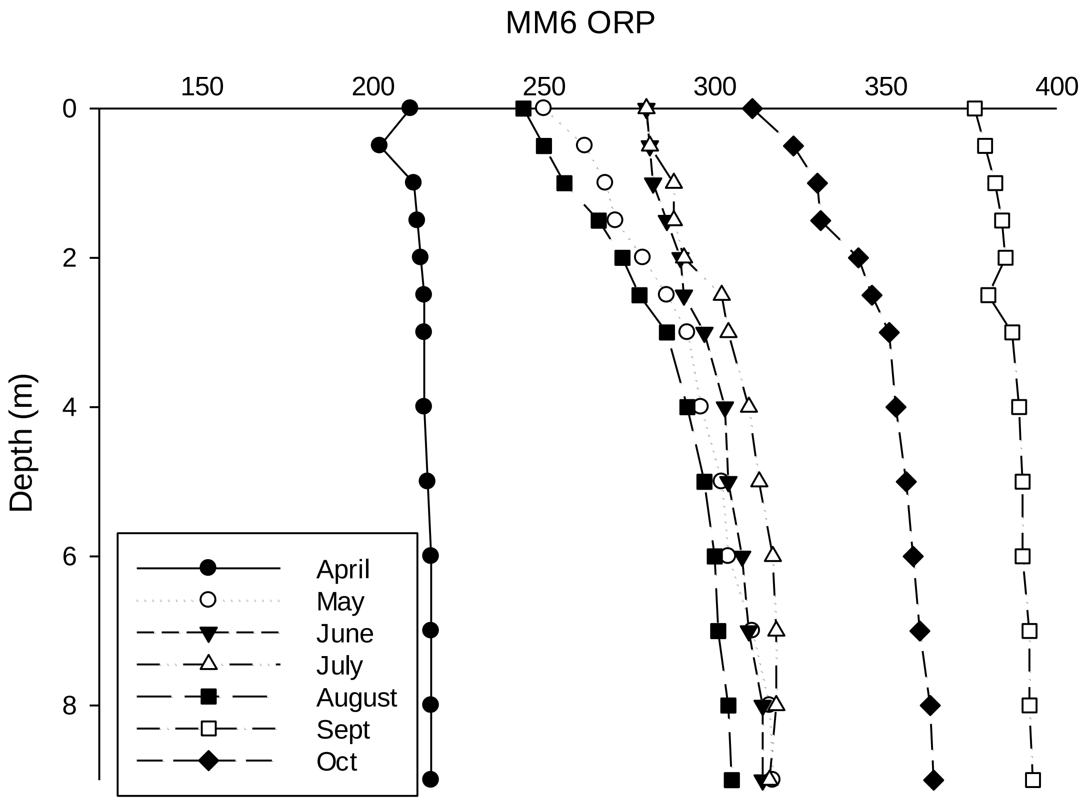

Figure 1.13. Mile Marker 6 (Transition) ORP (mV) measures over study period (2018)

Seasonal Analysis

No differences can be inferred between the Dam and MM6 using ORP as a measure. Some observations are lower at this site, but this is expected with a greater influence of riverine processes.

Comparisons Across Years

Measures of ORP fluctuate between higher and lower states of oxidation between the years. Phytoplankton productivity, increased or decreased, influence from river inflow and overall hydrology will contribute to this pattern.

Turbidity

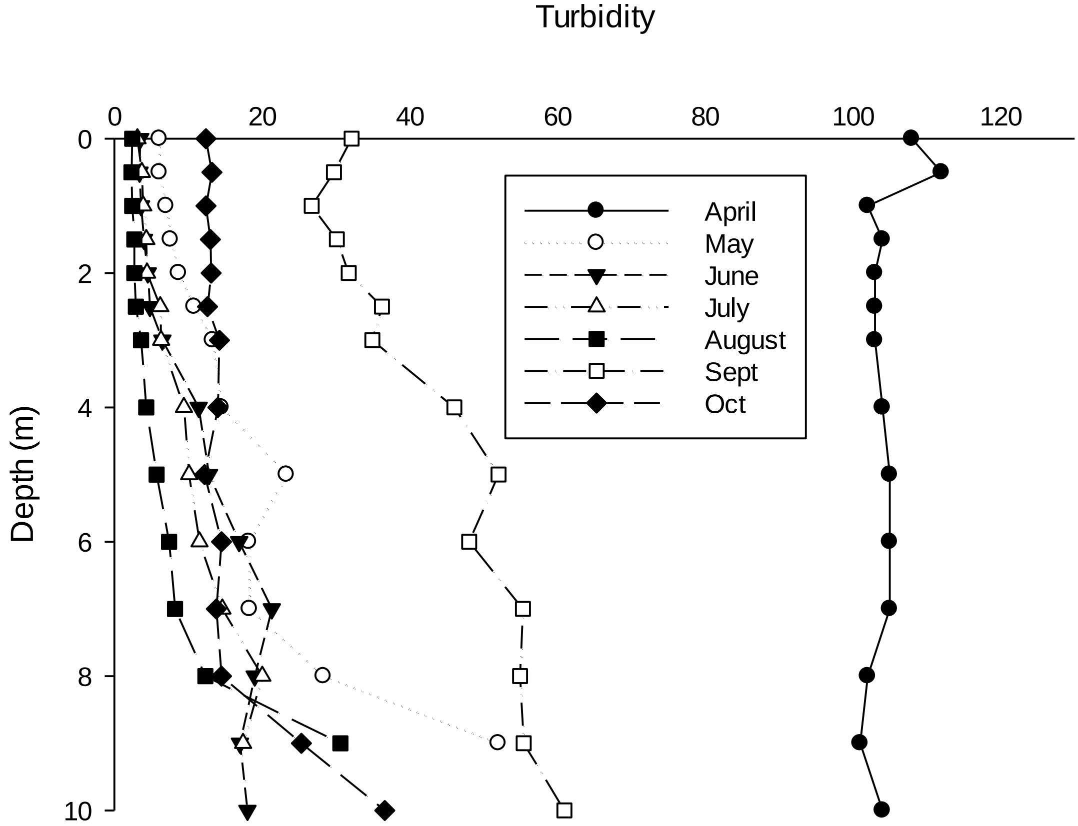

Figure 1.14. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2018)

Seasonal Analysis

Differences in turbidity between MM6 and other stations reflect the movement of water through this reservoir. Greatest turbidity was observed here in April and September similar to the dam. This reflects water movement throughout the reservoir and how SML dam operations and Pigg River flow interact. If significant amounts of Pigg River flow are pushed down into Leesville Lake they remain entrained further down the reservoir until this water is pushed out of Leesville Lake dam. If less water enters from Pigg River, that water is mixed with SML dam release influencing the turbidity down lake. Thus, it is better to visualize water movement through Leesville Lake in slugs moving back and forth until eventually pushed through Leesville dam. This creates the differentials we see between stations. This must be evaluated station by station.

Comparisons Across Years

Overall, turbidity is increasing in the reservoir. Historically, overall levels of turbidity have been lower in past years, and the increased turbidity along the lower portion of the epilimnion and into the hypolimnion is a more recent development. Turbidity between stations historically can only be evaluated through flow and movement of water. That analysis is beyond the scope of this project.

Other Parameters Measured

Table 1.19. Other parameters measured over study period (2018). Dates represent sampling of both the volunteers and university. First Column represents each parameter measured along with units of measure.

Date	**30-Apr**	**31-May**	**14-Jun**	**26-Jun**	**10-Jul**	**30-Jul**	**15-Aug**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	10:30am	3:50pm		12:33 PM		11:12am		11:45 AM	10:20am	4:08	
Secchi (M)	0.70	1.40		2.10		1.70		2.10	0.40	0.90	**1.33**
TP Surface (PPM)	0.057	0.019		0.026	0.032	0.032	0.031	0.023	0.171	0.066	**0.05**
TP 6 Meters (PPM)	0.066	0.044		0.026		0.065		0.047	0.218	.	**0.08**
Integrate Chl a (PPB)	6.65	5.15		7.47		13.34		13.32	4.09	5.83	**7.98**
Integrate Phycocyanin		.		27.36		25.54		36.46	31.00	32.14	**30.50**
TSI S	65	55		49		52		49	73	62	**58.00**
TSI TP	59	45		49	52	52	51	48	74	61	**54.66**
TSI CHL	49	47		50		56		56	44	48	**50.07**
TSI AVG	58	49		50		53		51	64	57	**54.54**

Table 1.20. Zooplankton and *E. coli* measured over study period (2018). Dates represent sampling of both the volunteers and university. Zooplankton numbers are organisms per liter.

Date	**30-Apr**	**31-May**	**14-Jun**	**26-Jun**	**10-Jul**	**30-Jul**	**15-Aug**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	10:30am	3:50pm		12:33 PM		11:12am		11:45 AM	10:20am	4:08	
Daphnia	0.0	8.0		2.8		2.0		0.5	0.5	0.0	**1.97**
Bosmina	10.4	48.1		2.8		0.8		5.7	23.6	2.4	**13.39**
Diaptomus	1.9	6.1		0.5		0.4		3.3	0.9	2.4	**2.21**
Cyclops	3.8	6.1		4.7		5.7		1.4	5.7	0.0	**3.91**
Nauplii	3.3	6.6		5.2		5.3		9.4	7.1	1.4	**5.47**
Cerodaphnia	0.0	0.0		0.0		0.0		0.0	0.0	0.0	**0.00**
Diaphanosoma	0.0	0.8		0.9		2.8		1.9	0.5	0.0	**0.99**
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.5	**0.07**
E. coli MPN	156.50	3.00	14.10	1.00	7.50	9.80	6.30	6.30	167.90	42.80	**41.52**

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 (2018)

Date	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct	Average
Time	11:04am	4:25pm	12:58pm	11:40am	12:15pm	10:55am	4:30pm	
Secchi (M)	1.4	0.9	1.45	1.50	1.50	0.80	0.80	**1.19**
TP Surface (PPM)	0.021	0.030	0.029	0.029	0.028	0.084	0.026	**0.04**
TSI S	55.2	61.5	54.6	54.2	54.2	63.2	63.2	**58.01**
TSI TP	46.5	50.9	50.5	50.5	50.0	64.6	49.1	**51.73**
TSI AVG	50.8	56.2	53	52	52	64	56	**54.87**
E. coli MPN	34.1	13.5	6.3	5.2	7.5	178.2	28.8	**39.08**

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

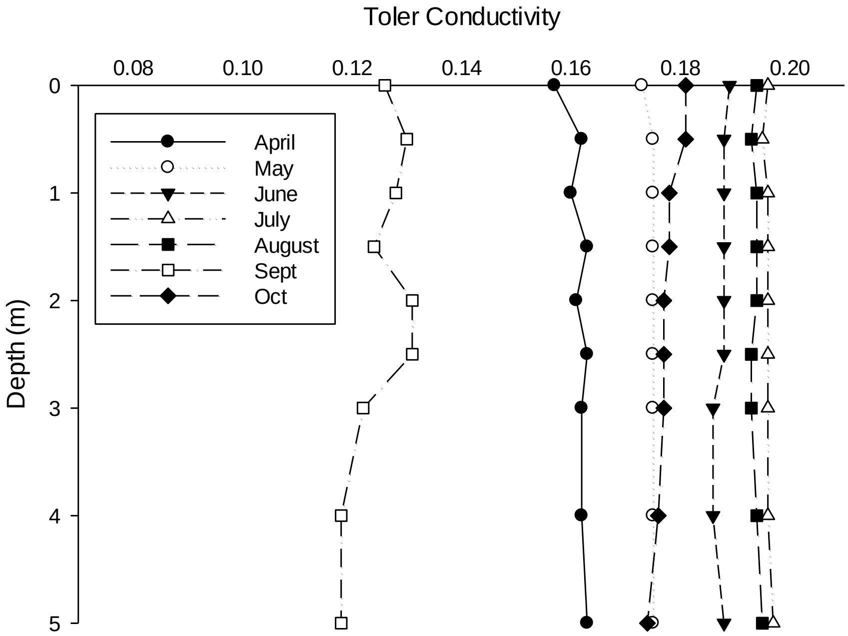

Figure 1.15. Toler Bridge (Riverine) Conductivity (ms/cm) measures over study period (2018).

Seasonal Analysis

Conductivity in this portion of the reservoir is different than the other stations, highlighting the hydrological dynamics of the reservoir. Pigg River water conductivity (0.11 average) is generally lower than SML dam release (0.2 average) (Tables 1.31 and 1.32). Thus, readings on the lower end of the scale reflect greater Pigg River influence, which occurs predominately during spring and fall. During summer months conductivity is greater and reflects SML operations and the predominance of SML tail waters at Toler Bridge Station.

Comparisons Across Years

Trends for conductivity in the reservoir are difficult to assess. In some years we have observed patterns where conductivity is lower at the surface increasing with depth. This pattern reflects warmer Pigg River water flowing over the top of cool SML release at this station. We did not observe this pattern in 2018, as the water was mixed at all sampling dates. This is a very dynamic station with changing conditions due to the proximity to SML dam and Pigg River.

Dissolved Oxygen

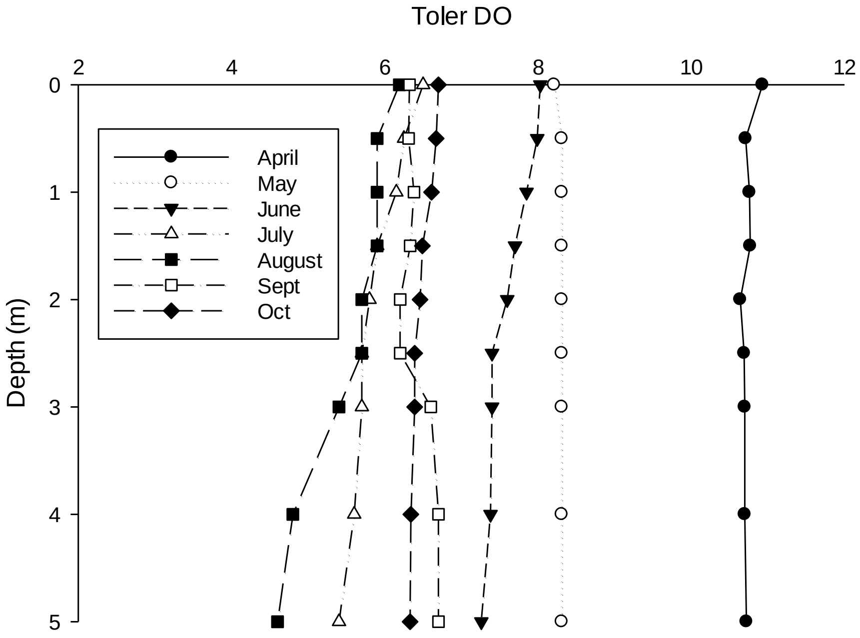

Figure 1.16. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2018)

Seasonal Analysis

Oxygen dynamics in this portion of the reservoir reflect constant water movement unlike other portions studied. Oxygen concentrations are consistent top to bottom suggesting hydropower operations prevent stratification. This station is strongly influence by hypolimnion release from SML. Higher flow from Pigg River additionally creates impacts on this station. Oxygen levels become lower as the season progresses to a low point in August and September. While the entire reservoir is very low in September, the low readings here in August reflect oxygen depletion in the hypolimnion of Smith Mountain Lake and thus tail water release into Leesville. This low oxygen portion of the reservoir coupled with turnover in Leesville likely lead to the problems observed throughout Leesville Lake during this season.

Comparisons Across Years

It is interesting to observe trends over time in the dissolved oxygen content in this portion of the reservoir. While other stations suggest a positive heterograde (oxygen increasing at the thermocline then decreasing) this station more often shows a clinograde (oxygen decreasing from the surface to the bottom). Often, conditions creating a clinograde result from decomposition of organic material or respiration. Influence of warmer Pigg River water flowing over cool hypolimnion of Smith Mountain release is likely the source of this pattern. Also, hypolimnetic release from SML alone is capable of creating these patterns as upper SML water is oxygenated and the lower water of the hypolimnion remains low in oxygen. These data emphasize the importance of efforts to release water from SML with an appropriate level of oxygenation.

Temperature

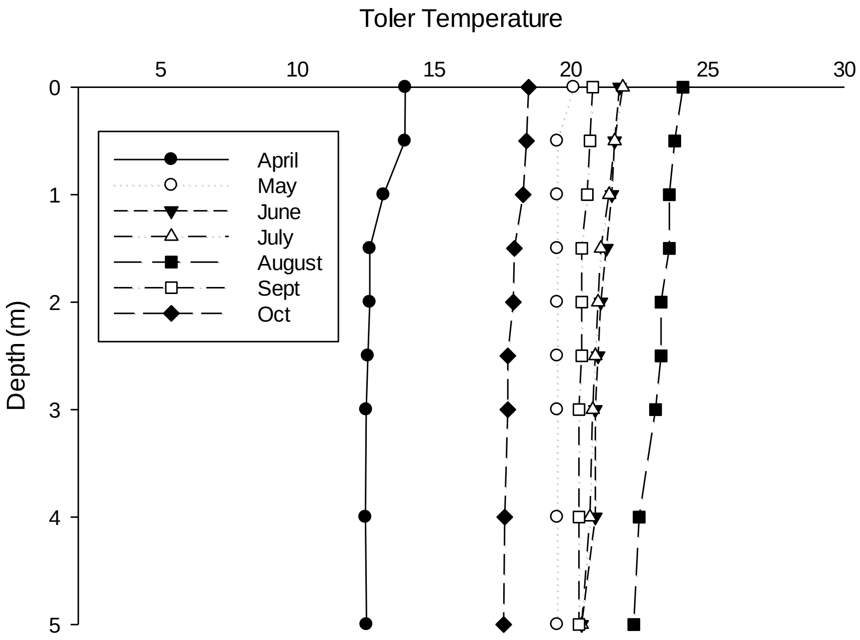

Figure 1.17. Toler Bridge (Riverine) Temperature (°C) measures over study period (2018)

Seasonal Analysis

The most significant difference observed at this station is minimization of thermal stratification when compared to the other stations on the reservoir. Many influences create this condition. Shallow depth, wind mixing, and water flow from the Pigg River and Smith Mountain operations do not keep the same body of water at this station for long enough periods of time to allow stratification to occur.

Comparisons Across Years

The lack of thermal stratification at this station is consistent throughout the years. It is interesting to note that September of this year was the warmest recorded with considerable cooling into October. Environmental warming may be impacting the reservoir or that there may be an impact by other undetermined processes in SML. Increased temperatures will increase the metabolism of aquatic organisms and lead to increased productivity and eutrophication.

Chlorophyll *a*

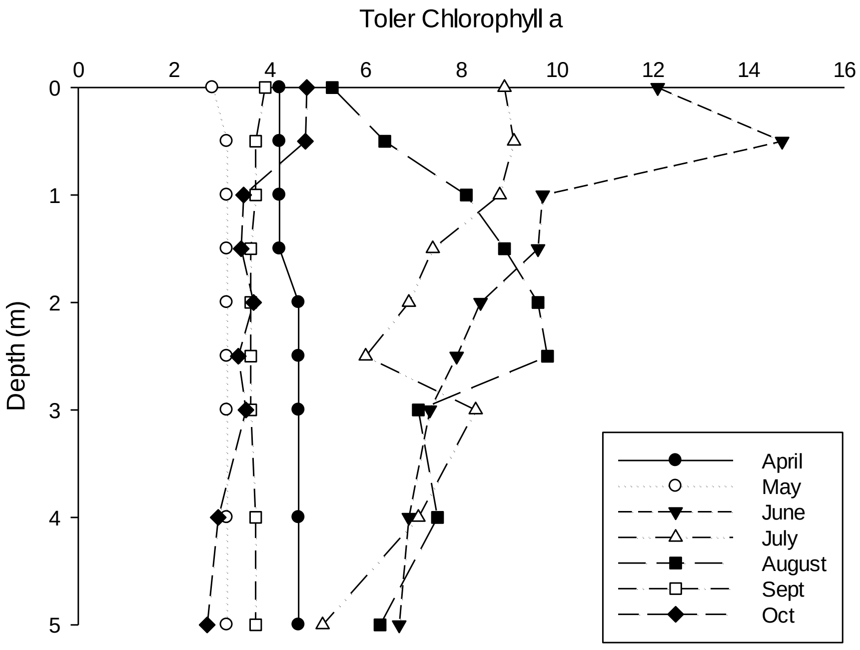

Figure 1.18. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2018)

Seasonal Analysis

This station contains the lowest readings of phytoplankton biomass throughout the entire reservoir. The observed 2018 pattern suggests water movement limits phytoplankton growth. In June we observed some increase most likely resulting from limited water movement. August pattern was similar to other portions of the reservoir, increasing below the surface. Other months are clearly influenced by water movements. Concentration of phytoplankton are much lower in this portion of the reservoir than elsewhere.

Comparisons Across Years

Readings from this year’s water samples were typical for the reservoir. Operationally, pump back of water drawing water from the transition portion of the reservoir would increase phytoplankton at this station. This is due to the greater growth of phytoplankton in the mid portion of the reservoir being drawn back into Toler Bridge Station. Thus, productivity of phytoplankton and water quality dynamics in this portion of the reservoir are hard to predict.

pH

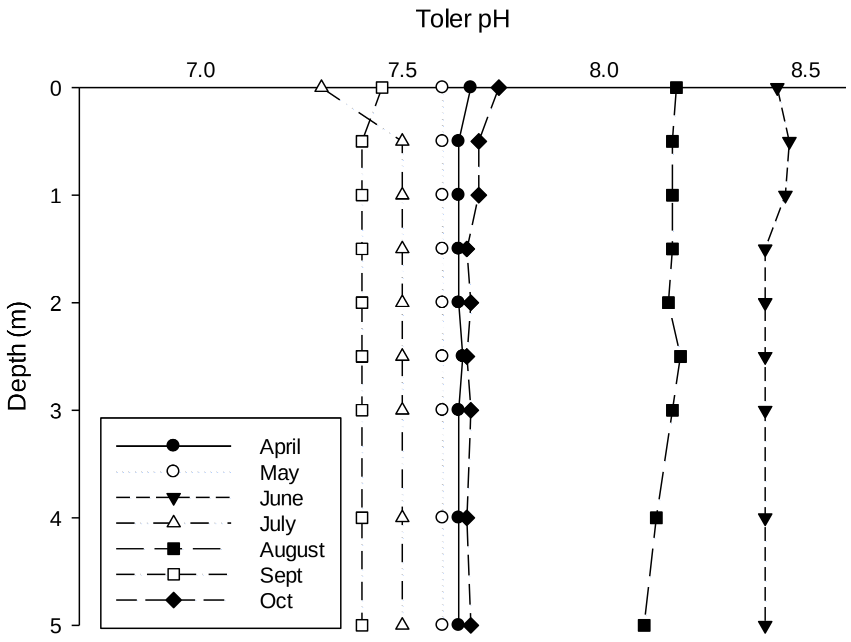

Figure 1.19. Toler Bridge (Riverine) pH measures over study period (2018)

Seasonal Analysis

The pH readings in this portion are lower than at stations further down the lake, as expected. Processes at this locale are driven more by water inputs than productivity. The rise in pH is associated with greater Chlorophyll *a* abundance at this station. This does suggest when phytoplankton growth occurs it influences dynamics at this station. Often, this will not occur because of the water movement.

Comparisons Across Years

No discernable patterns of pH distribution through the water column, as occur with stratification, were evident in 2018 or in previous years.. It is likely that pH is traceable to flow and phytoplankton growth throughout the years.

ORP

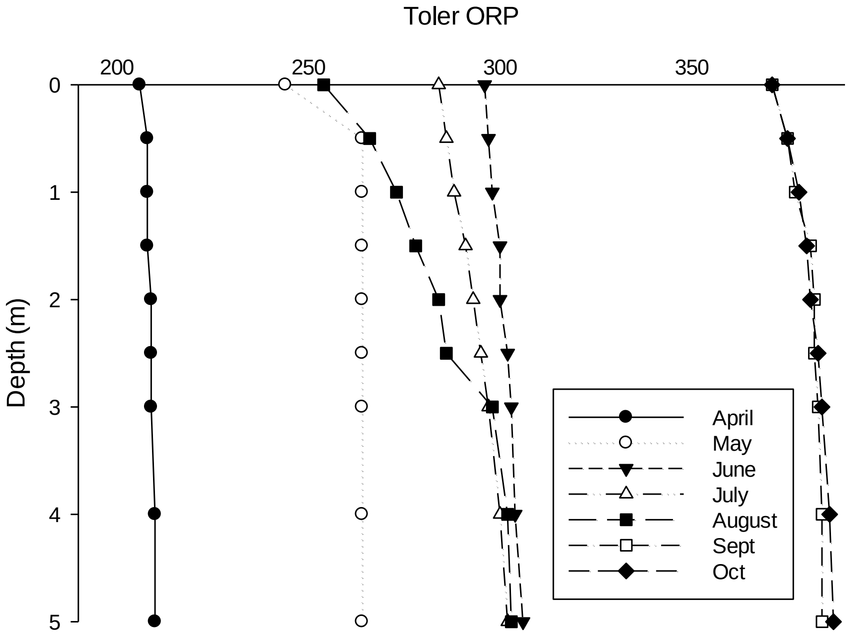

Figure 1.20. Toler Bridge (Riverine) ORP (mV) measures over study period (2018)

Seasonal Analysis

The ORP measures in this section of the reservoir do not provide any new interpretation between stations. Similar to other parameters, ORP was not influenced by any stratification.

Comparisons Across Years

As in past years, ORP was in the oxidized range throughout the sampling season. This is an expected result. In some years, ORP was much higher than in others. While this is an interesting result, coupled with the pH readings it does not suggest significant water quality changes at this locale across the years.

Turbidity

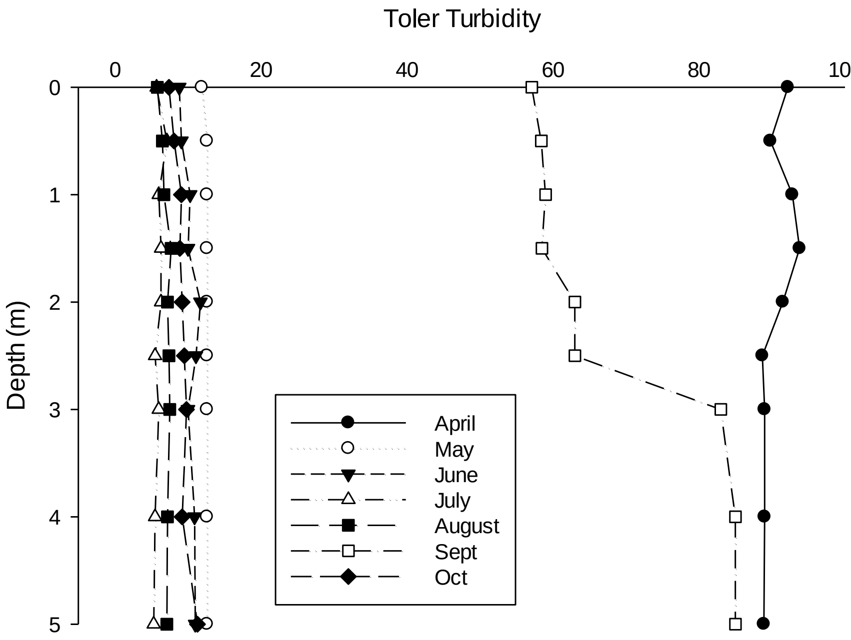

Figure 1.21. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2018)

Seasonal Analysis

Turbidity pattern in this portion of the reservoir was very similar to that at Leesville Dam. This suggests turbidity patterns that begin in this portion of the reservoir persist throughout the reservoir.

Comparisons Across Years

Turbidity consistently ranged between 15-50 NTU through previous years of study. Turbidity increases that occurred this year are significant. Very high turbidity readings are suggestive of increased sediment load from Pigg River and likely derived from the removal of the dam on the river. It is expected that these high readings will lower in following years. But this year’s samples strongly imply that removal of the dam on the Pigg influenced water quality throughout the season.

Other Parameters Measured

Table 1.29 Other parameters measured over study period (2018). Dates represent sampling of both the volunteers and university. First Column represents each parameter measured along with units of measure.

Date	**30-Apr**	**31-May**	**14-Jun**	**26-Jun**	**10-Jul**	**30-Jul**	**15-Aug**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	11:14am	4:40pm		1:09pm		11:55 AM		12:28pm	11:05am	4:45pm	
Secchi (M)	1.40	1.40		1.25		1.40		1.30	0.50	1.30	**1.22**
TP Surface (PPM)	0.023	0.030		0.036	0.029	0.013	0.032	0.039	0.165	0.030	**0.04**
TP 4 Meters (PPM)	0.051			0.038		0.029				.	**0.04**
Integrate Chl a (PPB)	4.42	3.07		9.26		7.51		7.67	3.68	3.61	**5.60**
Integrate Phycocyanin		.		30.96		15.82		25.59	41.87	27.32	**28.31**
TSI S	55	55		57		55		56	70	56	**57.81**
TSI TP	48	51		53	50	41	52	54	74	51	**52.68**
TSI CHL	45	42		52		50		51	43	43	**46.68**
TSI AVG	49	49		54		49		54	62	50	**52.54**

Table 1.30. Zooplankton and *E. coli* measured over study period (2018). Dates represent sampling of both the volunteers and university. Zooplankton numbers are organisms per liter.

Date	**30-Apr**	**31-May**	**14-Jun**	**26-Jun**	**10-Jul**	**30-Jul**	**15-Aug**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	11:14am	4:40pm		1:09pm		11:55 AM		12:28pm	11:05am	4:45pm	
Daphnia	0.0	0.6		6.2		1.1		0.0	0.0	0.6	**1.21**
Bosmina	7.9	22.1		1.7		4.0		33.4	4.0	2.3	**10.76**
Diaptomus	1.1	1.7		0.0		1.1		2.8	1.7	2.3	**1.54**
Cyclops	0.6	3.4		3.4		6.8		3.4	2.3	1.1	**2.99**
Nauplii	1.7	4.5		3.4		5.1		4.5	0.6	0.6	**2.91**
Cerodaphnia	0.0	0.0		0.0		0.0		0.0	0.0	0.0	**0.00**
Diaphanosoma	0.0	0.0		1.7		1.1		0.6	0.0	0.0	**0.49**
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.0	**0.00**
E. coli MPN	53.8	18.7	27.4	1.0	20.3	14.5	15.6	18.7	410.6	55.6	**63.62**

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 (2018). Measures are integrative throughout the entire water column. Profile data located in the appendix.

Date	**30-Apr**	**31-May**	**14-Jun**	**26-Jun**	**10-Jul**	**30-Jul**	**15-Aug**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	11:34am	0.21		0.06		12:15pm		12:50pm	11:25pm	5:03pm	
Secchi (M)	0.40	0.70		0.70		0.75		0.60	0.10	0.70	**0.56**
TP Surface (PPM)	0.11	0.04		0.03		0.06		0.07	0.64	0.09	**0.15**
Integrate Chl a (PPB)				13.80		13.87		6.14	3.90	1.60	**7.86**
Integrate Phycocyanin				33.77		33.83		23.00	62.47	25.93	**35.80**
TSI S	73.20	65.14		65.14		64.15		67.36	93.18	65.14	**70.47**
TSI TP	68.19	55.87		52.51		60.88		62.09	93.16	65.99	**65.53**
TSI CHL				56.35		56.40		48.40	43.95	35.21	**48.06**
TSI AVG	70.70	60.50		58.00		60.47		59.29	76.76	55.45	**63.02**
E. coli MPN	204.60	38.40	97.10	65.70	183.50	290.90	579.40	231.00	1553.10	218.70	**346.24**
Temp. (°C)	15.63	21.93		24.67		24.83		26.27	20.87	12.20	**20.91**
Cond. (µs/cm)	0.07	0.16		0.10		0.15		0.11	0.08	0.09	**0.11**
DO (mg/L)	9.59	8.22		7.24		6.63		83.03	7.99	10.65	**19.05**
pH	7.64	7.75		8.16		7.53		8.08	7.40	7.68	**7.75**
DO%	98.70	96.73		88.40		81.80		6.59	84.57	101.40	**79.74**
ORP (mV)	222.00	338.00		319.67		334.33		303.00	384.00	421.67	**331.81**
Turbidity (NTU)	123.00	17.70		21.93		21.23		23.93	170.87	19.27	**56.85**

1.3.1.8 Smith Mountain Lake Tail Waters

Table 1.32. Smith Mountain Lake Tail Waters other parameters measured over study period (2018). Measures are at the surface.

Date	**30-Apr**	**31-May**	**25-Jun**	**30-Jul**	**29-Aug**	**26-Sep**	**23-Oct**	**Average**
Time	11:50	5:15	1:40	12:15	1:10	11:45am	5:16pm	
Secchi (M)	3.5	2.90	1.80	2.40	1.60	2.30	2.10	**2.37**
TP Surface (PPM)	0.001	0.036	0.026	0.014	0.017	0.006	0.011	**0.016**
Integrate Chl a (PPB)			6.440	2.900	3.200	2.100	3.300	**3.59**
Integrate Phycocyanin			26.4	13.1	17.6	19.9	25.3	**20.46**
TSI S	41.9	44.7	51.5	47.4	53.2	48.0	49.3	**48.01**
TSI TP	23.6	53.2	49.1	41.8	44.0	33.4	39.2	**40.63**
TSI CHL			49	41	42	38	42	**42.42**
TSI AVG	32.8	49	50	43	46	40	44	**43.54**
E. coli MPN	9.8	1	12.2	18.6	17.3	2	9.6	**10.07**
Temp. (°C)	11.7	15.2	19.2	19.4	22.4	21.1	19.7	**18.38**
Cond. (µs/cm)	0.181	0.197	0.189	0.201	0.201	0.202	0.200	**0.20**
DO (mg/L)	10.8	7.9	7.6	5.2	4.5	4.2	5.3	**6.48**
pH	7.6	7.5	8.2	7.3	8.1	7.5	7.7	**7.69**
DO%	101.5	81.2	84.1	58.1	53.4	48.4	58.4	**69.30**
ORP (mV)	215.0	359.0	342.0	304.0	329.0	399.0	430.0	**339.71**
Turbidity (NTU)	19.2	2.1	6.4	3.9	4.8	3.1	2.9	**6.06**

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 entirety of this study and their compilation into trophic state indices (TSI) and other predictive indicators. 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 (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. Water has more clarity in oligotrophic lakes, low concentrations of algae and year around and an abundance of oxygen throughout the water. Eutrophic lakes can be plagued by low water clarity, high sediment, high nutrient levels and abundance of algae and even noxious forms throughout the summer months. Excessive eutrophication is to be avoided. A TSI > 61 is considered excessive.

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. 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 reflects dynamics within the

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

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.

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 very pristine and near oligotrophic input of water) 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), statistical analysis (Section 2.2) and Pigg River analysis (Section 2.3) explore this unique relationship. We try to quantify these inputs and speculate on impacts. This leads to our management recommendations.

Secchi Depth TSI

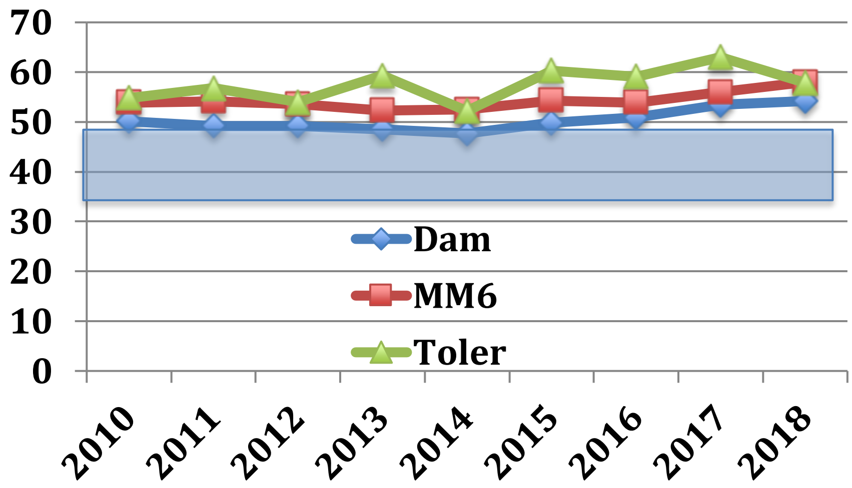

Figure 2.1. Trophic State Index (TSI) based upon Secchi disk (meters) measurements in Leesville Lake from 2010-2018. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Analysis

Predictions of trophic state using Secchi depth now suggest the reservoir is trending toward increased eutrophication Figure 2.1). While data suggests TSI before 2014 were stable or decreasing, since this point there is a trend toward increased eutrophication. The reservoir continues to be eutrophic and appears to be increasingly so.

Comparing this trend from the headwaters (Toler Bridge) through the Dam we see a very interesting pattern. In 2014 and 2018 trophic state at Toler Bridge was actually lower than trophic state at MM6 (transition) and near levels measured at the dam. This suggests the impact of Smith Mountain Dam release on the water quality at Toler Bridge Station is significant. To aid in some interpretation of this trend, we examined the annual precipitation in Central Virginia throughout the study period (Figure 2.2). Several patterns emerge. Trends of increasing eutrophication follow trends of increased precipitation. This pattern is very preliminary as 2018 was an extremely wet year and forced the trend line positive in Figure 2.2. However, the pattern exists. Secondly, while 2014 was a very average year for precipitation, April and May were very wet (precipitation > 5 inches in these months for 2014 and 2018) compared to other years studied. This suggests when our spring months have significant precipitation and input from the Pigg River, water quality degrades. This pattern is examined further in the statistical section (2.2) of the report.

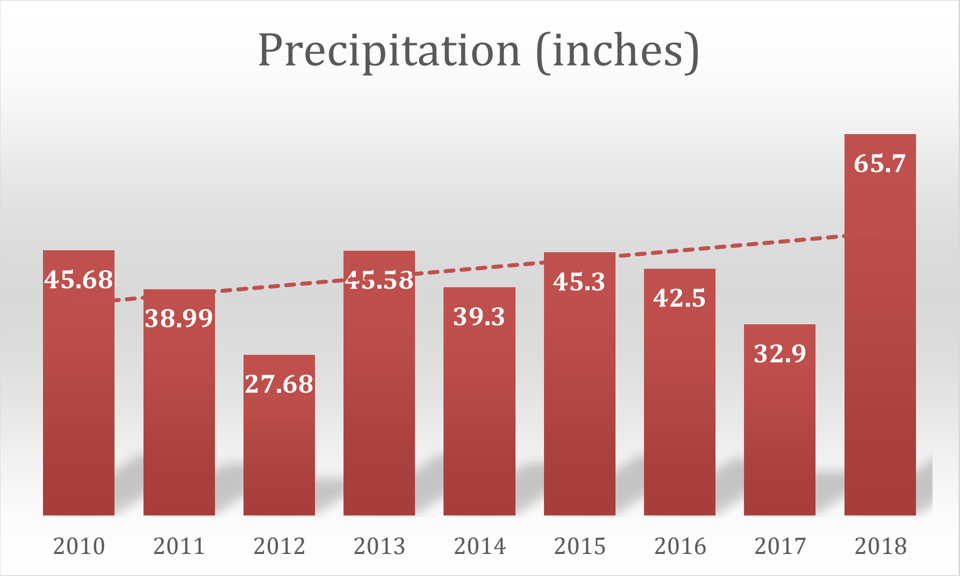

Figure 2.2. Annual precipitation in the Central Virginia area measured by National Weather Service reported in inches. Hashed line represents tend line over the period of study.

Total Phosphorous TSI

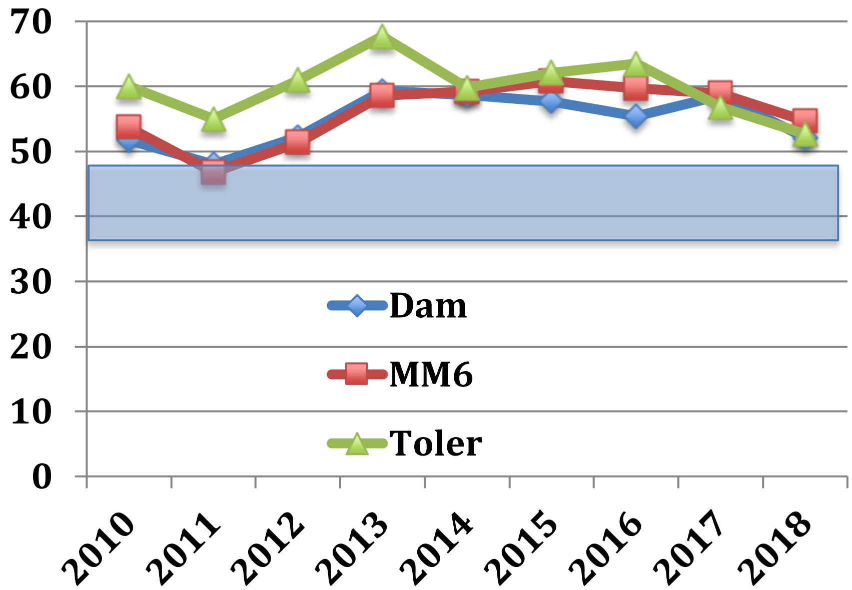

Figure 2.3. Same as Figure 2.1 but TSI based on Total Phosphorus (TP).

Analysis

Trophic state based on total phosphorus suggests the reservoir is eutrophic (Figure 2.3). Yet trending provides a different interpretation from TSI Secchi data. Since the mid-point of 2014, TSI phosphorus is declining. In 2018, and throughout the entire lake, TSI phosphorus predictions trend toward decline. This suggests while significant inputs from Pigg River have the potential to degrade water quality, significant flow from Smith Mountain Lake dilutes these inputs potentially improving water quality based on this parameter. Toler Bridge station TSI is lower or equal to the remainder of the lake. This supports this hypothesis. Additionally, this is the second year in a row where Toler Bridge station is lower than the remainder of the lake. Precipitation (Figure 2.2) supports this trend for years 2014 and 2018. It is unclear why we find this similar pattern in 2017 other than changing overall patterns in pump storage operations. Further data is needed to explore this pattern over time.

Chlorophyll *a* TSI

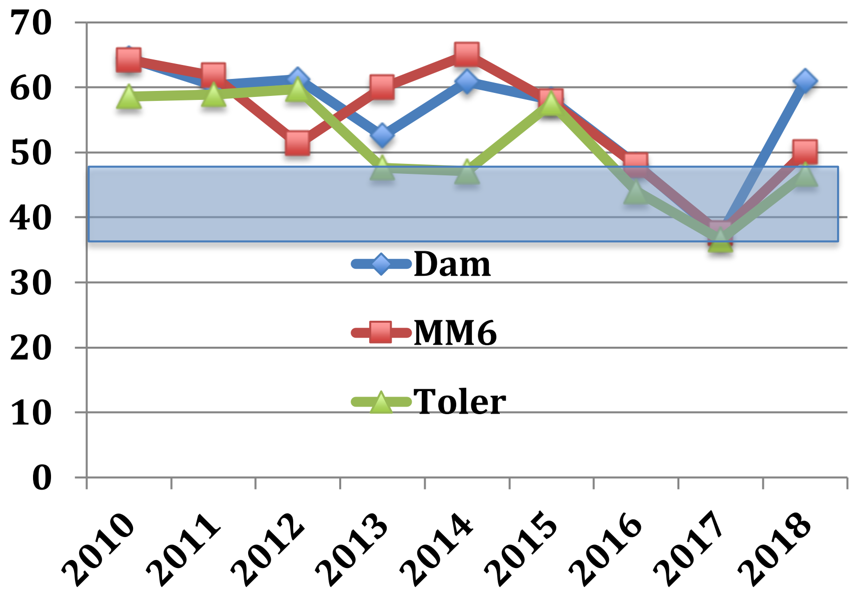

Figure 2.4. Same as Figure 2.1 but TSI is based on Chlorophyll *a*.

Analysis

Trophic state based upon Chlorophyll *a* is more difficult to interpret. TSI based on Secchi depth (Figure 2.1) is trending toward increased eutrophication while TSI phosphorus (Figure 2.3) is trending toward decreasing eutrophication. TSI Chlorophyll *a* (Figure 2.4) should naturally occur at the intersection of the other TSI measures and provide further interpretation. One clear interpretation suggests Chlorophyll *a* is very responsive to precipitation. As suggested in the previous TSI indices, high spring rains suggest higher Chlorophyll *a* productivity in the reservoir (compare Dam station in 2014 and 2018 Figure 2.4). Yet, other stations over the previous three years remain in the mesotrophic range for trophic state.

What is clear is that the turbidity in the reservoir is increasing (Figure 2.5). And Chlorophyll *a* throughout the reservoir to the dam appears very responsive to this trend (compare declining Chlorophyll *a* TSI Figure 2.4 with increasing turbidity Figure 2.5). Thus it seems that hydrology, driven by inputs from the Pigg River are highly influential on the trends we are observing in changing water quality.

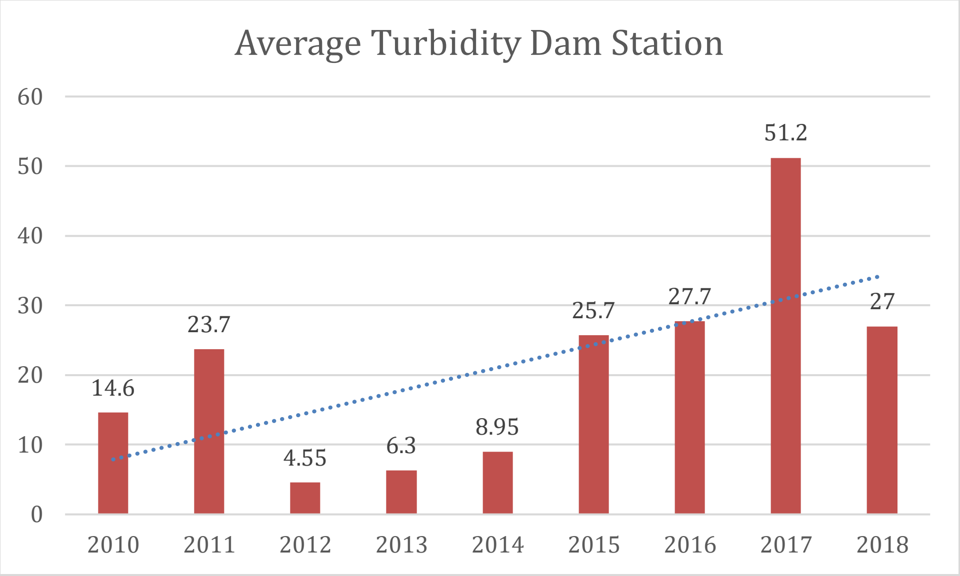

Figure 2.5. Turbidity (NTU) averages at dam station in Leesville Lake. Hashed line represents tend line over the period of study.

Thus, we now conclude that water quality entering the reservoir from the Pigg River not only influences the overall trends we now observe but the situation is clearly worsening. Turbidity data at the dam is clearly increasing. While this is suppressing Chlorophyll *a* (Figure 2.4) and TP (Figure 2.3) in some instances, these patterns may exist due to the unique hydrology present in the reservoir. Excessive river flow may create scenarios where pump-back is not necessary at Smith Mountain dam. In this instance, more Pigg River flow may enter Leesville Lake and create the patterns we have seen recently. In other instances, excessive pump-back may entrain Pigg River input into the fore bay of Smith Mountain Lake preventing entrance into Leesville Lake. It is clear that proper interpretation of these patterns requires greater understanding of Smith Mountain Lake operations.

What is now clear is that Pigg River input is worsening (Figure 2.6). This input is now considerably more turbid and worsening as indicated by the trend line. After 2014, significantly greater inputs of turbidity have appeared in this input along with other pollutants carried by this turbidity. And as demonstrated in Figure 2.5, increased turbidity into the dam. Further exploration and explanation of this trend is presented in Section 2.2 Statistical Analysis.

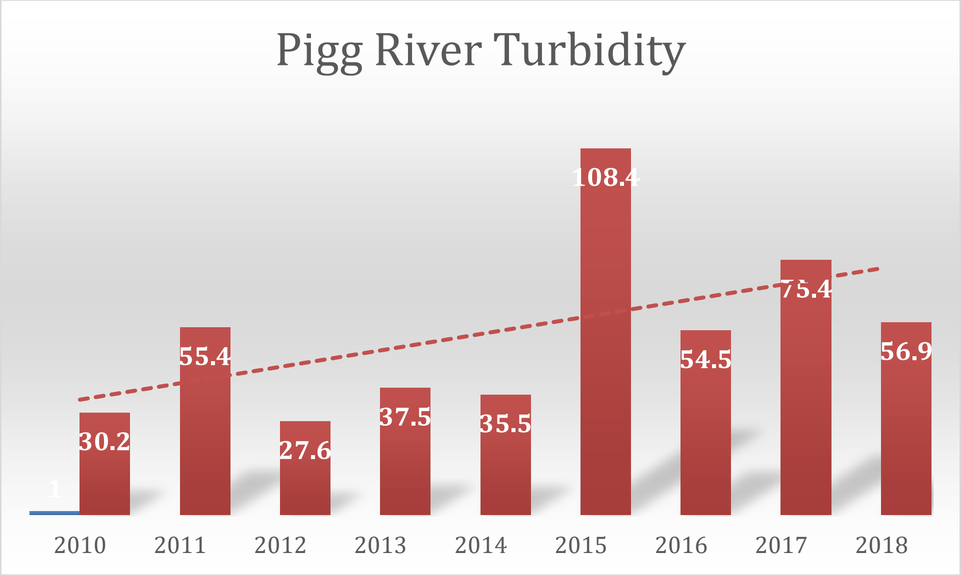

Figure 2.6. Turbidity (NTU) averages at dam station in Leesville Lake. Hashed line represents trend line over the period of study.

<u>TSI Average</u>

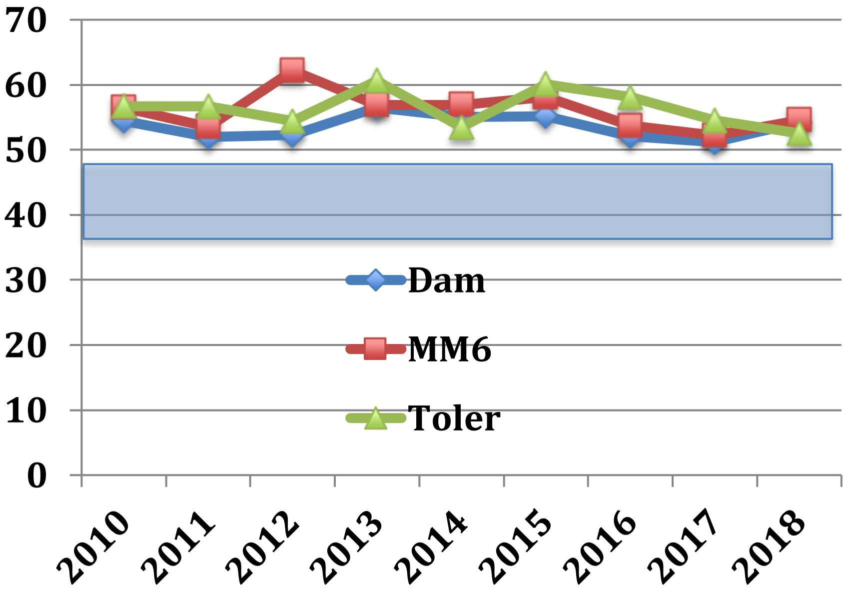

Figure 2.7. Same as Figure 2.1 but TSI presented is the average of TSI for all parameters evaluated (Secchi Depth, Total Phosphorous, Chlorophyll *a*).

Analysis

Averaging trophic state indices based upon multiple parameters leads to the conclusion that the trophic state in the reservoir has remained very consistent throughout the seven years of study. These data suggest that the lake is mildly eutrophic. While we are observing the 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 is not surprising these changes are not yet reflected in the overall TSI.

Daphnia Productivity

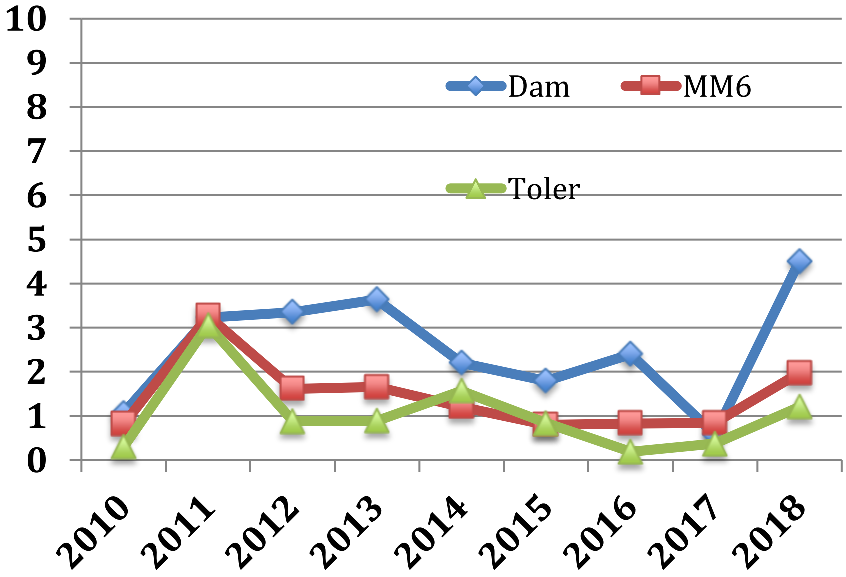

Figure 2.8. Average *Daphnia* concentrations in Leesville Lake from 2010-2018. Numbers on y-axis represent *Daphnia/* liter.

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 reduce the grazing pressure on phytoplankton. For 2017, we recorded 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. Data analyzed here suggest otherwise. Chlorophyll *a* in this reservoir appears to respond to water flow (conductivity measures) more than either the concentration of TP or the grazing pressure of *Daphnia* (see detailed analysis in Statistical Section 2.2). Implications for both reservoir water quality management and fisheries management of this finding are significant. If Chlorophyll *a* is not coupled to bottom up forces (TP) or top down forces (*Daphnia*) and driven primarily by water movement; all aspects of Leesville Lake management are dependent first and foremost upon Pigg River flow rates and secondly the water quality of Pigg River and operation of Smith Mountain Lake Dam.

2.2 Statistical Analysis

Two approaches are taken in this analysis to examine trends and explain overall function of the reservoir. The first is Principle Component Analysis (PCA). PCA is a procedure where variance is analyzed from all of the variables entered. Factors are developed where the variance among each variable is aligned or correlated. For each factor a variable may contribute to this alignment either through a positive or negative contribution. Then through examination, a researcher can look at the alignment of variables and draw conclusions about the data. The factors themselves are not the point of focus. Rather it is where each variable is aligned on that factor, the strength of that alignment and the direction of that variable is used to create the factor.

PCA results in this report are presented graphically. Each axis represents the factors with factor 1 (F1) represented on the x axis and factor 2 (F2) on the y axis. In parentheses, the amount of variance explained in each factor is represented. The combination of variance explained by both factor 1 and factor 2 is shown at the top of the graph. As a variable moves away from the center of both axes it becomes more relevant in the analysis. Thus, a variable in the center of a graph contributes nothing to the relationships developed by the analysis. Variables close to the F2 axis but toward either end of the F1 axis were significant contributors to that axis. Because F1 is the strongest and explains the greatest proportion of variance in this analysis we consider variables along this axis to be the most significant. In some cases where a variable is aligned toward the center of F1 axis but very strongly aligned with the F2 axis it is worth consideration. This type of analysis is excellent for large data sets examining data trends over time.

Data are examined at each station in the reservoir beginning at the Smith Mountain Lake tail water following the trends down lake to the Leesville Lake dam. This is a logical sequence as we examine the two initial sources of water to Leesville Lake; the Pigg River and SML tail water. We then follow these trends to Toler Bridge, MM6 and then Leesville Lake dam looking for changing trends and significance.

Regression analysis is the other statistical test used. Regression analysis examines two variables of interest looking for a direct relationship. This relationship can be positive or negative. The analysis aligns the variables along a linear curve. If all variables align perfectly there is no variance away from that line and we assign a correlation coefficient (r^2) of 1. As the relationship provides more scatter around the line, the strength of correlation diminishes. No relationship between the variables is assigned a $r^2 = 0$. We use this analysis to examine direct relationship among the variables that are important in predicting water quality and those suggested by the PCA analysis.

PCA Analysis

Tail Water

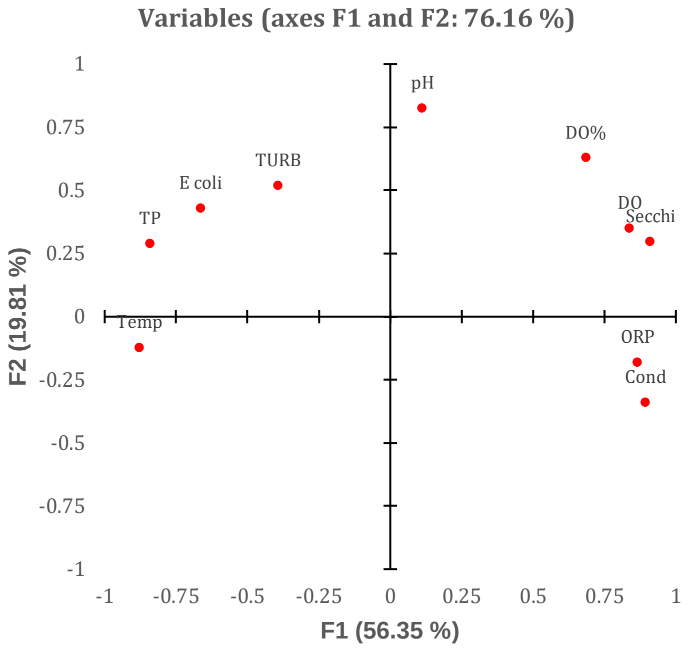

Figure 2.2.1. PCA analysis on tail water release from Smith Mountain Lake. Graph displays the two top factors (F1 and F2) and the alignment of variables (dots) between those two factors.

Water entering Leesville Lake from Smith Mountain dam operations is strongly aligned on the F1 axis (Fig 2.2.1). Oxygen, Secchi, conductivity and ORP increase or have a positive relationship to F1. Turbidity, *E. coli*, TP and temperature are negative in relationship to the same factor (F1). Thus, higher concentrations of oxygen, deeper Secchi depth, greater ORP and conductivity are associated with the water release from SML. This is typically what we observe. Conversely, lower turbidity, *E. coli* TP and Temperature are associated with the release. Again, these are the measures we observe in the reservoir. pH is not aligned along F1 suggesting it moves in both directions and is not relevant factor.

Pigg River

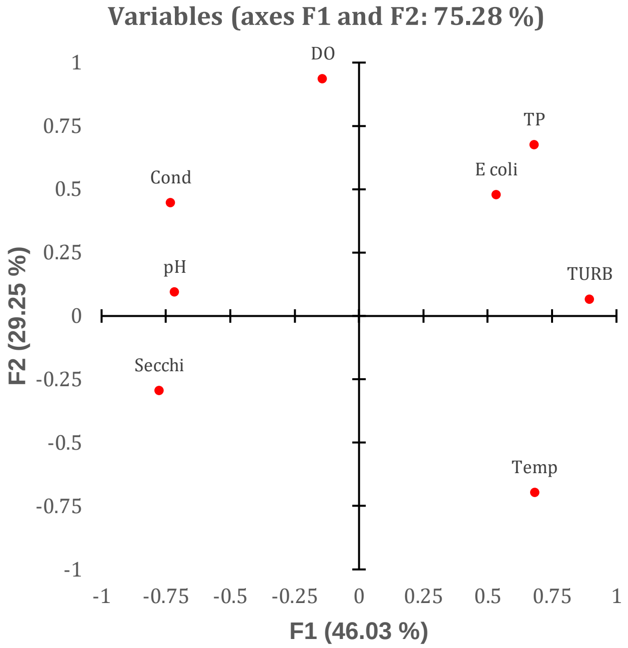

Figure 2.2.2. PCA analysis on Pigg River water entering Leesville Lake. Graph displays the two top factors (F1 and F2) and the alignment of variables (dots) between those two factors.

Water entering Leesville Lake from Pigg River is also strongly aligned on the F1 axis. F1 factor is not as strong (46.03 % here vs. 56.35 % at tail waters). This suggests greater variability in the data. This is a good observation as Pigg River is one of the most variable sites we monitor. Here, data is aligned in the opposite direction from tail water. Secchi, conductivity and here pH have a negative relationship to the factor. Turbidity, *E. coli*, TP and temperature have a positive relationship to the same factor (F1).

This analysis suggests water entering the lake from Pigg River tends in the opposite direction from Smith Mountain Lake. High turbidity, *E. coli*, TP and temperature with lower Secchi depths, conductivity and even pH. ORP is not relevant in this analysis as it did not align with any of the factors analyzed. These trends tend to be intuitive and expected based on our analysis. The statistics here reinforce these observations and allow further analysis down lake as we see the two inputs of water mix and make up the water quality of Leesville Lake.

Toler Bridge

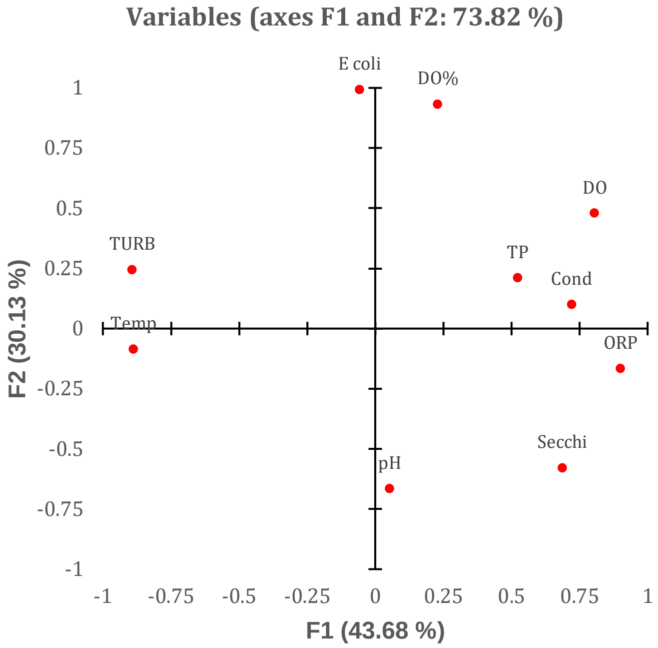

Figure 2.2.3. PCA analysis on Toler Bridge station in Leesville Lake. Graph displays the two top factors (F1 and F2) and the alignment of variables (dots) between those two factors.

Water from the two sources mixing at Toler Bridge generally reflects improving of water quality than would otherwise exist at Toler Bridge if it was dominated by Pigg River input Figure 2.2.3). Temperature and turbidity in a decreasing relationship along F1. TP, oxygen, conductivity, ORP and Secchi depth all increasing. Interesting at this station, *E. coli* is not well predicted by F1 but the strongest predictor for F2 along with DO% and pH. Thus, it is clearly suggested by this analysis SML release is improving many of the water quality parameters we measure and thus improving water quality of the lake at Toler Bridge. *E. coli* is not included in this trend as it appears influenced by other factors in the lake.

MM6

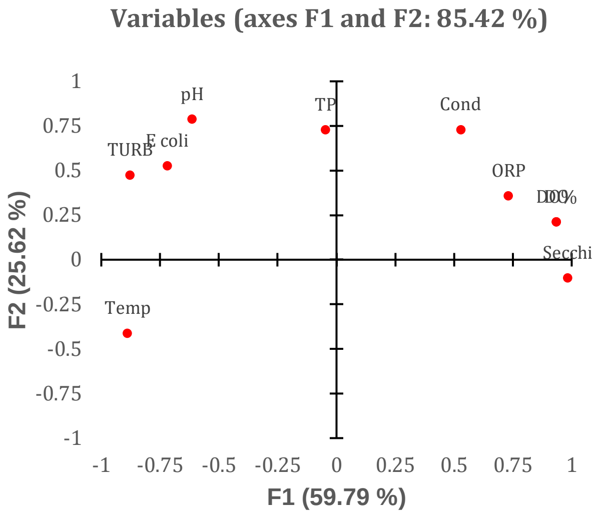

Figure 2.2.4. PCA analysis on MM6 station in Leesville Lake. Graph displays the two top factors (F1 and F2) and the alignment of variables (dots) between those two factors.

As water moves from Toler Bridge to MM6 additional changes in water quality are now observed. Secchi depth, oxygen, conductivity and ORP increase in relation to F1 while Temperature, turbidity and *E. coli* suggest a decreasing relationship. TP is aligned with the F2 axis. Each of these parameters continues to suggest a greater influence from Smith Mountain Lake than inputs from Pigg River. This suggests that over the period of study including multiple years and months, Smith Mountain Lake operation is the primary influence on the water quality of Leesville Lake. One concern however is the lack of alignment TP with factor F1. IF other factors influence changes in TP this is an important area to study and understand.

Dam

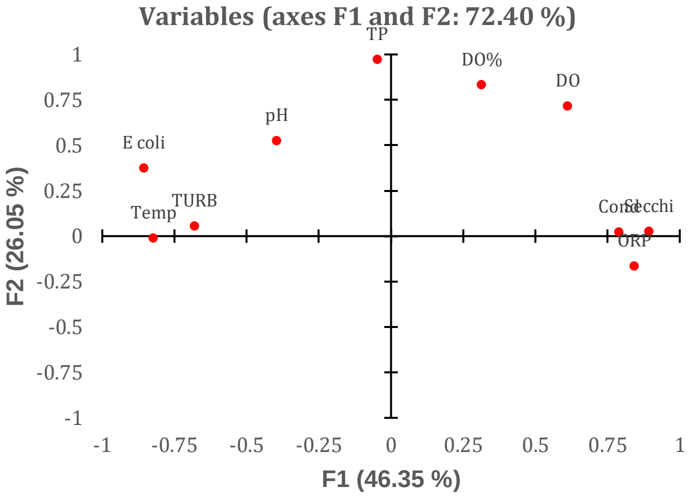

Figure 2.2.5. PCA analysis on Dam station in Leesville Lake. Graph displays the two top factors (F1 and F2) and the alignment of variables (dots) between those two factors.

Analysis at the dam strengthens the relationships from MM6. Conductivity, Secchi depth and ORP all increasing along F1 suggesting a positive influence from both Smith Mountain Lake and the general water quality improvement we see along a lake from headwaters to the dam. Decreasing *E. coli*, turbidity and temperature also agree with this trend. Dissolve oxygen, pH and TP however are not aligned in the same manner suggesting other influencing factors are involved. Strong patterns of stratification may be the primary influence as we see decreased oxygen, increased TP and pH during these periods. Stratification of the lake from MM6 to Leesville dam coupled with loss of oxygen in the hypoliminon for some of the water quality variables may be a stronger driver than water inputs from either source.

Regression Analysis

While long term trends suggested by PCA analysis group many of the measured variables in Leesville Lake by influence from Smith Mountain Lake, other variables remain independent of these conclusions and dependent to a greater extent on in lake processes or other factors such as periodic flooding that allows a large influx of Pigg River input through the reservoir. For regression analysis, we analyzed these parameters using 2018 data at all stations (Dam, MM6 and Toler Bridge) to determine what relationships were predominant in the reservoir.

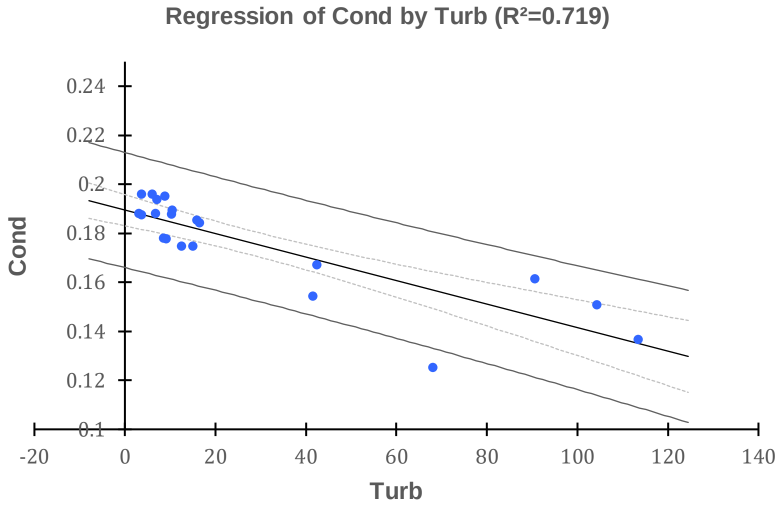

Figure 2.2.6. Regression analysis on 2018 data in Leesville Lake. Graph displays confidence intervals (light lines) and the relationship trend line (dark line). Dots represent individual data points. This relationship is significant with $p < 0.0001$.

Conductivity is an important measured variable in the lake as Pigg River conductivity is lower than SML release. Thus it is a good parameter to correlate with other variables in the lake as this would suggest decreasing conductivity would correlate with decreasing water quality if and when Pigg River input was predominating. This is exactly what Figure 2.2.6 suggests. Greater conductivity is associated with lower turbidity in the lake and high turbidity is associated with lower conductivity. This relationship is strongly and significantly correlated. Also looking at the data it is clear much of the observations are clustered around the higher conductivity and lower turbidity through much of the year. This agrees with the long term relationship established in the PCA analysis but adds another component. While SML input improves overall water quality in the lake in the long term data set, the periodic heavy inputs from Pigg River degrade water quality and often severely. This may be the variable making TP and oxygen difficult to interpret at the dam. This may also contribute to strong oxygen loss in the hypolimnion during the summer months as bacteria metabolize the organic and sediment inputs from the Pigg River.

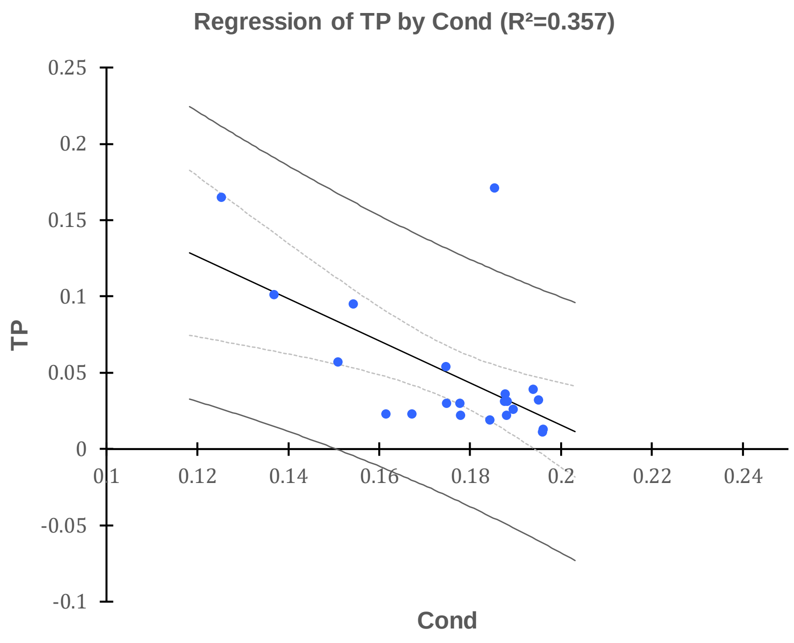

Figure 2.2.7. Regression analysis on 2018 data in Leesville Lake. Graph displays confidence intervals (light lines) and the relationship trend line (dark line). Dots represent individual data points. This relationship is significant with p = 0.004.

Similar relationship between TP and conductivity with lower TP associated with the higher conductivity in the reservoir. This strengthens the idea that Pigg River inputs associated with high levels of TP influence the dynamics of this nutrient in the reservoir. And this may be one of the most concerning trends in this analysis as TP stimulates phytoplankton growth and has profound influences on the food chain dynamics leading up to fisheries populations. And TP did not align with the first factor in our PCA analysis suggesting this dynamic is potentially and strongly influenced by the Pigg River throughout the reservoir.

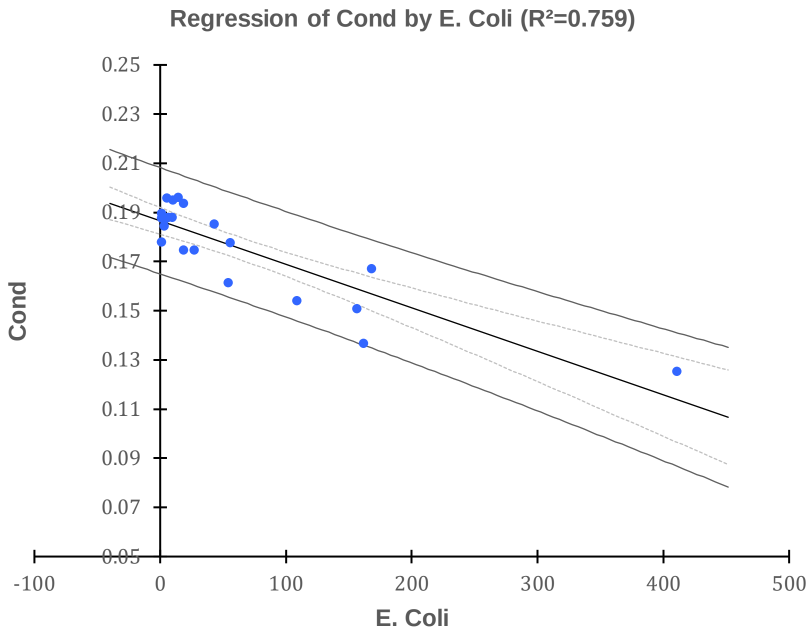

Figure 2.2.8. Regression analysis on 2018 data in Leesville Lake. Graph displays confidence intervals (light lines) and the relationship trend line (dark line). Dots represent individual data points. This relationship is significant with $p < 0.0001$.

Similar relationship with *E. coli* and conductivity. And it is a very strong relationship that is significantly significant. Thus it is clear that Pigg River input contaminates the lake with TP, *E. coli* and turbidity when it has a significant flow. These analyses demonstrate the need for increased management of Pigg River.

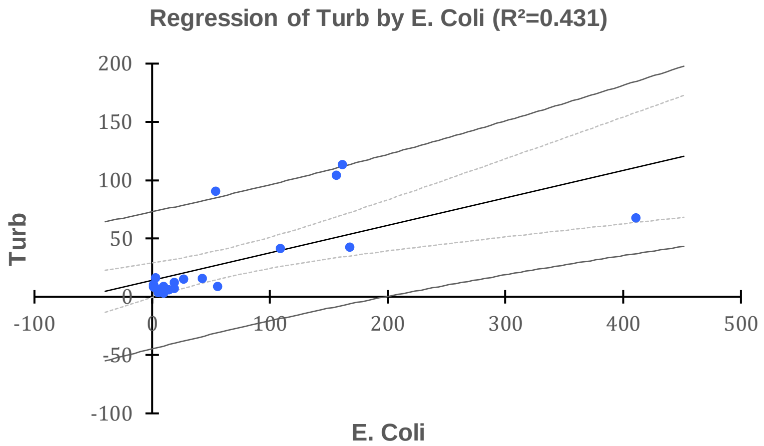

Figure 2.2.9 Regression analysis on 2018 data in Leesville Lake. Graph displays confidence intervals (light lines) and the relationship trend line (dark line). Dots represent individual data points. This relationship is significant with $p = 0.001$.

This relationship suggests that turbidity and *E. coli* are strongly correlated. This is an important relationship. As *E. coli* associates with turbidity it is easily transported into the reservoir. And if flow is significant, it can contaminate the entire reservoir with enough *E. coli* to make swimming prohibitive. Much of the data that is clustered toward the end of the relationship is not concerning. However, turbidities elevated up to 50 NTU are associated with concerning levels of *E. coli* and should be avoided. Hence, when the water shows signs of turbidity it is advisable for individuals to stay out of the water.

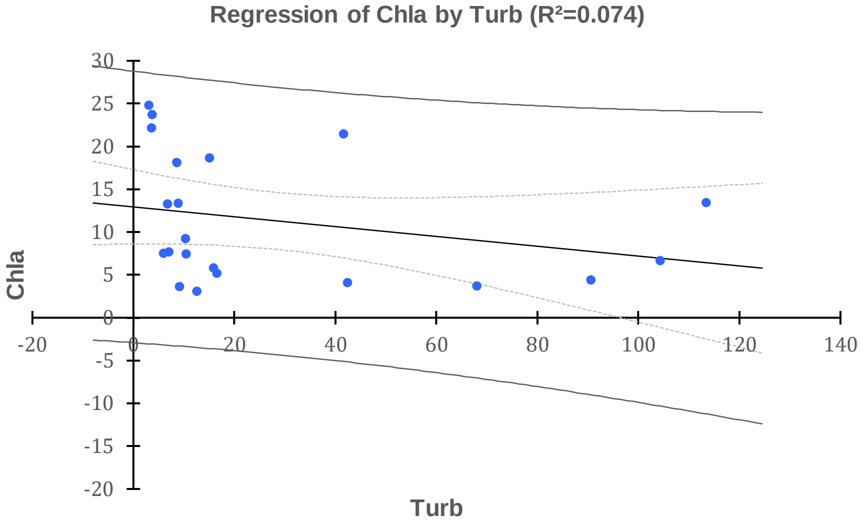

Figure 2.2.10. Regression analysis on 2018 data in Leesville Lake. Graph displays confidence intervals (light lines) and the relationship trend line (dark line). Dots represent individual data points. This relationship is not significant with p = 0.232

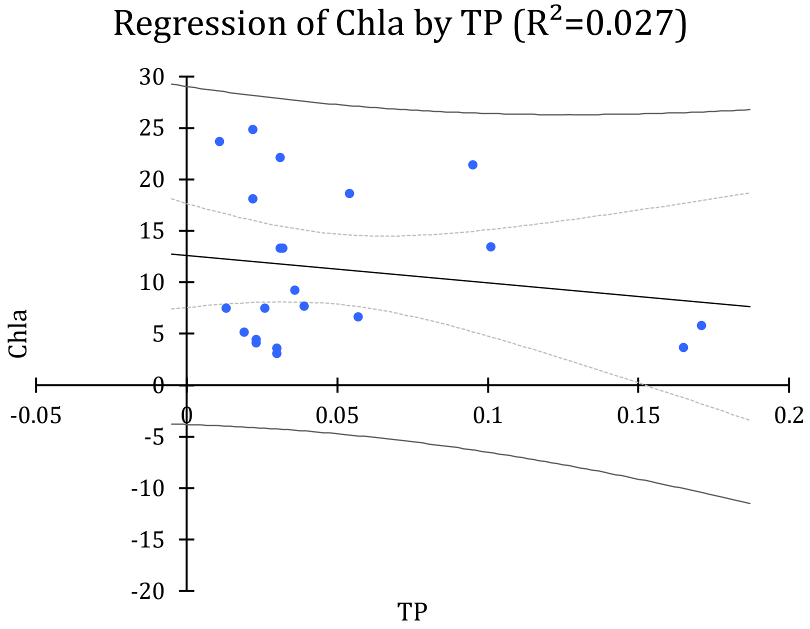

Figure 2.2.11. Regression analysis on 2018 data in Leesville Lake. Graph displays confidence intervals (light lines) and the relationship trend line (dark line). Dots represent individual data points. This relationship is not significant with p = 0.474

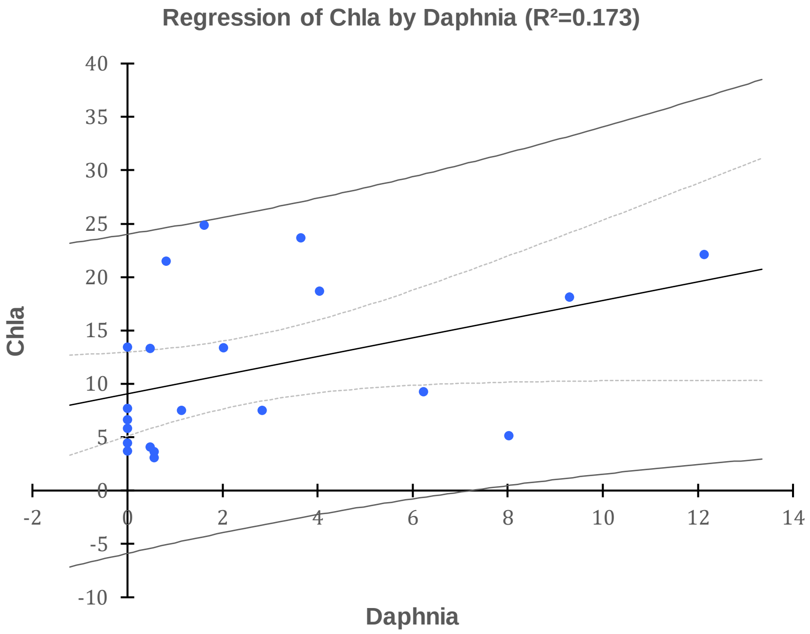

Figure 2.2.12. Regression analysis on 2018 data in Leesville Lake. Graph displays confidence intervals (light lines) and the relationship trend line (dark line). Dots represent individual data points. This relationship is not significant with p= 0.061

These remaining relationships examine Chlorophyll *a* in the reservoir. Turbidity is associated with not only sediment but also the density of algae. Turbidity and Chlorophyll *a* were not correlated (Figure 2.2.10). This suggests non algal turbidity or sediment dominate the reservoir providing further evidence for the importance of sediment inputs from the Pigg River. Further, TP and Chlorophyll *a* are unrelated (Figure 2.2.11). And Chlorophyll *a* is not associated with *Daphnia* abundance as well (Figure 2.2.12).

2.3 Pigg River Study

Introduction and Background

An investigation was initiated in the summer of 2018 to investigate water quality conditions in the Pigg River Watershed. This river system flows into Leesville Lake in the upper reaches of the reservoir within 5 miles of the dam for Smith Mountain Lake. This is significant because, during pump-back operations, water from the Pigg River is entrained into the fore-bay of SML. It is unclear the quantities of Pigg River flow that enters SML during pump-back but water quality measures at the tailrace during pump back suggest it is significant. Although the Pigg River supplies significant concentrations of sediment, TP and bacteria, the ultimate fate in each reservoir is poorly understood.

Another recent concern in this watershed was the removal of an obsolete power dam near Rocky Mount Virginia. Dam removal has become a popular river improvement strategy yet how a dam is removed and reasons for the removal should be carefully considered (see review by D. Orth http://vtichthyology.blogspot.com/2017/11/trends-in-dam-removal-reversing.html). In this instance, the removal of the dam without significant sediment management in place delivered considerable loads of bacteria and turbidity to Leesville Lake. It is important to study this problem as well.

The Virginia Total Maximum Daily Load (TMDL) Program, which addresses waters with bacteria levels exceeding state standards, published a report in 2006 on waters around Leesville Lake. This report addressed bacteria levels flowing from the lake’s two main tributaries; Pigg River and Old Woman’s Creek (Lobue, 2010, p. 10). Story Creek (a tributary to Leesville Lake-Pigg River) and Upper Pigg River have been on Virginia’s 303(d) list of impaired waters since 1996. Leesville Lake-Pigg River has been listed as impaired since 1998. Snow Creek (another tributary to Leesville Lake-Pigg River) and Old Woman's Creek have been listed as impaired since 2002.

The TMDL report identified three point sources discharging bacteria into the Pigg River basin, with one located in the Story Creek watershed area. There were no permitted dischargers in the Old Woman's Creek watershed. The TMDL reporting specifies nonpoint sources as the primary source for high bacteria levels; including agriculture, land-applied animal waste, and livestock manure as the main nonpoint sources. The report also specifies that 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).

Pigg River and Old Woman's Creek TMDL Implementation Plan published in 2009 identifies work necessary for *E. coli* reductions in the watershed to bring violation rates below 10% per year. Majority of the need is controlling pasture runoff with livestock fencing and point source reductions. Of concern for Leesville Lake are the elevated *E. coli* concentrations in Pigg River discharge. Additionally, cattle are frequently in the river at the Leesville site. The Leesville Lake community needs to support the work of both the soil and water conservation districts, VADEQ and VADCR as they work toward implementation of the TMDL effort. The community should also be active in controlling residential discharge directly in the lake and efforts to upgrade septic systems in the watershed.

It is the intent of this study to begin the process of quantifying overall water quality in the watershed. Previous TMDL studies identified pasture as significant contributors in *E. coli* studies (Virginia Tech 2006). It follows that sediment and TP also associated with storm water runoff are elevated due to pasture impacts. This study outlines an initial approach to quantify these concerns in the watershed. It is our hope subsequent studies can pinpoint significant problem areas and help policy makers control point and non-point pollution in this watershed.

Figure 2.3.1 – Removal of the Power Dam. This has created an ongoing concern about water quality in the Pigg River.

Figure 2.3.2 – July condition of dam on Power Dam Road after removal. Legacy sediment appear to be a continual problem. Note the discoloration of the water even during low flow conditions.

Figure 2.3.3 – Sampling the Pigg River by kayak following one of the storm events in September. Note the color of the water. This sampling method allowed direct measure of WWTP effluent.

Methods

We sampled 11 sites along the Pigg River and its associated tributaries. Each site was chosen for accessibility as we sampled water from a bridge crossing using an alpha bottle and other container to capture a water sample. Each sample was obtained by lowering the sampling device into the flowing water and capturing a grab sample.

Water was immediately transferred to acid washed bottles and stored in a cooler until TP analysis was performed. Another 100ml aliquot was transferred to a sterilized bottle for *E. coli* analysis. Remaining water was analyzed using a YSI multiprobe and Turner Tubidimiter to collect the remaining data.

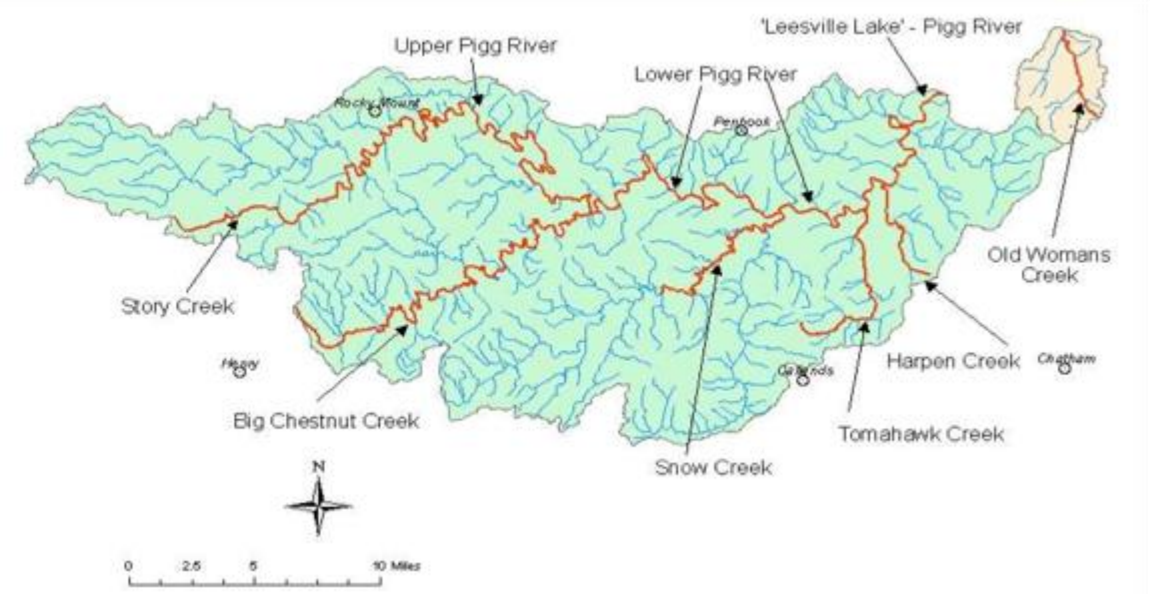

Figure 2.3.4 – Map of Pigg River watershed from Virginia Tech (2006). Samples were collected throughout the watershed including Lower Pigg, Upper Pigg, Snow Creek and Big Chestnut Creek.

Statistical Testing

Data was clustered in the following way for statistical testing:

- Scenario 1 - All stations for comparisons between testing dates of June, July, August and September
- Scenario 2 - Individual stations comparing mean measures over the four sampling dates looking for differences
- Scenario 3 - Clustering stations among specific locations (upper Pigg from Rocky Mount to Chestnut Hill Road), Snow Creek and Big Chestnut Creek Samples and then Lower Pigg including remaining stations to Leesville Lake
- Scenario 4 - Difference between stations under low turbidity (July and August) and high turbidity (June and September)

Results and Discussion

Table 2.3.1 – Summary of Collected Parameters during the study period including all sites along the Pigg River, Snow Creek and Big Chestnut Creek.

Date Of Collection	Turb NTU	*E. Coli* cfu/100ml	TP mg/L	DO mg/L	pH	Cond us/cm	Temp C
6/22/18	51.3± 10.3	1949.5± 271.4	0.34± 0.13	6.6 ± 0.2	8.0 ± 0.0	85.6± 5.6	25.0 ± 0.5
7/12/18	5.9 ± 1.2	513.8 ± 199.0	0.07 ± 0.02	7.6 ± 0.1	8.5 ± 0.0	92.8 ± 5.5	23.3 ± 0.3
8/6/18	16.4 ± 2.3	418.2 ± 50.1	0.15 ± 0.03	7.5 ± 0.2	8.2 ± 0.0	115.7 ± 8.5	24.7 ± 0.3
9/19/18	55.3 ± 8.6	1161.1 ± 222.2	0.48 ± 0.08	12.1 ± 0.3	DNS	92.0 ± 4.8	20.8 ± 0.1

E. coli – significant for season but not station

E. coli measures in Pigg River violated state standards on every sampling day. Pigg River is highly impaired by *E. coli*. This measure is strongly influenced by storm events and turbidity. Measures between seasons (Scenario 1) were highly significantly different (p<0.001). This is not an unusual discovery (literature) yet continual elevation of *E. coli* concentrations under low flow conditions is unusual (Table 1 measures in July and August). Comparisons among stations (Scenario 2) were not significantly different (p=0.950). Additional analysis including clustering of the stations (Scenario 3) were not significantly different (p=0.685). Final analysis clustering low flow conditions (Scenario 4) did not yield significant differences. Low flow analysis between stations (p=0.284) or high flow (p=0.520) were not significant. This suggests the river by river flow throughout. All analysis including high flow vs. low flow, watershed vs. lower watershed, and elimination of Snow Creek and Big Chestnut creek branches suggest the stations are equilevent under a variety of conditions.

The river shows a very significant impact from flooding events. June and August sampling dates were significantly different from the July and August sampling. The implications of this are obvious – it is the high flow events that create the highly contaminated water flowing through the river. It is the flood effect, not one or two specific spots that are creating the problems in the river. This suggests the strong need for storm water management and the high *E. coli* contamination problems that we documented.

Turbidity – Significant for season but not station

Turbidity relationships were very similar to *E. coli* for all measures. Highly significant differences ($p<0.001$) among comparisons for the season (Scenario 1). All other scenarios (2-4) did not yield significant differences ($p= 0.825$ Scenario 2, $p=0.117$ Scenario 3 and $p= 0.671$ low flow and $p= 0.667$ high flow Scenario 4).

Regression of *E. coli* and Turbidity

Comparisons of these variables yielded a highly significant relationship ($p<0.001$) and Figure 4.

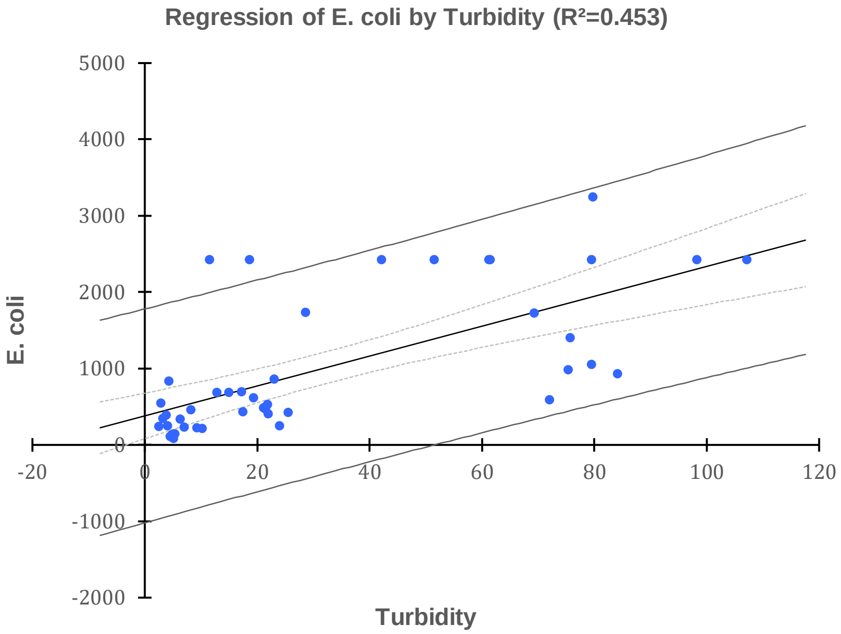

Figure 2.3.5 – regression of turbidity and *E. coli*. The relationship is highly significant ($p<0.001$). Lines represent 95% confidence interval.

Total Phosphorus (TP) – significant in season and station

Total Phosphorus (TP) measures in the river reflected greater contamination relationships than other variables. Significant differences (Scenario 1) were found between the seasons ($p=0.003$). Differences between the September sampling date and July ($p=0.003$), August ($p=0.015$) were most pronounced. As with the other variables, differences between stations (Scenario 2) were not significant ($p=0.235$). Under Scenario 3, a significant difference was found ($p=0.022$). This difference was attributed to the upper portion of the river near Rocky Mount and Chestnut Hill and the Snow and Big Chestnut Creeks ($p=0.02$). This is one of the most interesting results from the study suggesting greater levels of contamination of the river entering from the city and dam removal area than from side watersheds dominated by agriculture. We found that while WWTP from Rocky Mount was not contributing significant concentrations of *E. coli* to the river compared with the non-point pasture/agriculture, it was a major source of TP pollution. Direct measures of the effluent did not yield a different result.

Scenario 4 did not yield any significant results with low flow (p=0.126) and high flow (p=0.336). Stations are equally contaminated during differing flow conditions. However, as indicated above, the Rocky Mount region was significantly more polluted than the lower region. This was detected due to the greater power of comparison.

Regression of Total Phosphorus and Turbidity

Comparisons of these variables yielded a highly significant relationship (p<0.001) and Figure 5.

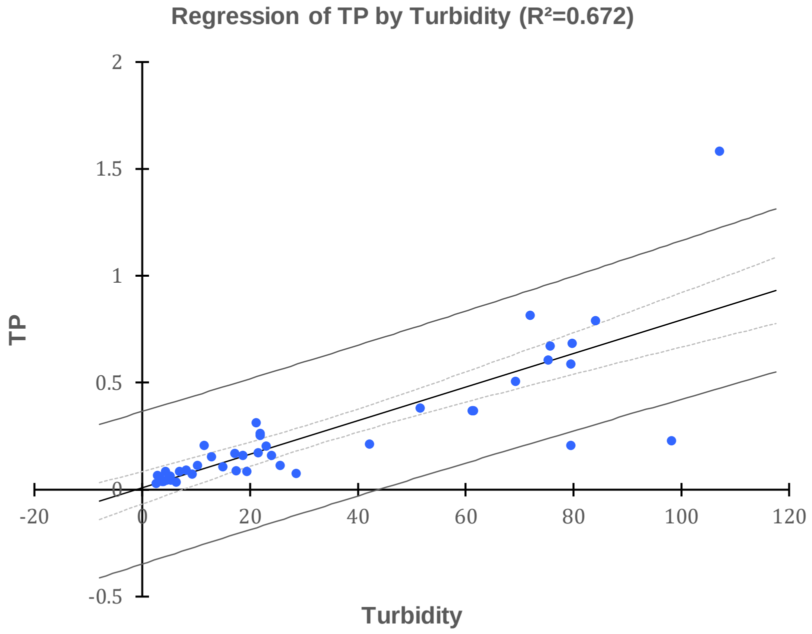

Figure 2.3.6 – regression of turbidity and TP. The relationship is highly significant (p<0.001). Lines represent 95% confidence interval.

Violation Rate

Out of 44 collected samples in this study, 37 violated the state standard of 325 cfu/100ml for a rate of violation of 84.1%.

Influence of Rocky Mount WWTP

During the September sampling we utilized a kayak to directly sample the WWTP effluent as it entered the river so that we could examine its potential impact on water quality.

Table 2.3.3 – Summary of Collected Parameters 9/19/2018 comparing the station above Rocky Mount WWTP (at Power Dam Road), immediately above WWTP discharge (WWTP 1), directly at the WWTP discharge (WWTP 2) and at a station below WWTP (Chestnut Hill).

Station	Turb (NTU)	TP (mg/L)	E. coli (cfu/100 ml	Temp (C)	Cond (us/cm)	DO (mg/L)	ORP (mv)
Power Dam	71.9	0.81	591	21.3	113	12.4	124
WWTP 1 Predischarge	71,8	0.75	572	23.8	121	12.4	102
WWTP 2 Discharge	71.1	1.09	657	23.3	151	11.8	114
Chestnut Hill	75.7	0.67	1404.5	21.7	116	11.2	122

Nutrient levels from WWTP effluent are elevated at the discharge but decline to ambient river concentrations by the time the river flows under Chestnut Hill station. There is also a modest elevation in *E. coli* at the discharge but other input to the river at Chestnut Hill station are much more significant. There is some increase in conductivity at the discharge, but again it is reduced by the time water reaches the next station. Thus, while WWTP does have some impact on Pigg River water quality it is not a major input by comparison to other inputs into the river.

Conclusions

Rain Events Significant. Results from this study yielded insights into functioning of Pigg River and contaminates entering Leesville Lake. First and foremost, contaminate loadings are a function of rainfall events. All three contaminates, TP, *E. coli* and turbidity elevate significantly during storm events compared to low flow conditions. This has several implications. Non-point storm water loading is implicated in causing impairments to Pigg River and Leesville Lake. Tying SML operations to rain events could make significant water quality improvements. Minimization of pump back operations during these events can create improvements. The significant relationship between turbidity and both TP and *E. coli* suggest land runoff is creating these impacts. Soil and water conservation need to work toward BMP improvements on all sectors.

River Reach and WWTP. Most scenarios looking at an effect of the stations on the river and water quality were inconclusive. Yet TP in the upper reach of the River was significantly different than water quality in the lower reach. Water from Snow Creek and Big Chestnut Creek are providing a dilution effect concerning TP. While a majority of the concern in this watershed is with pasture runoff these results, suggest it is the concentrated runoff from urban centers (Rocky Mount) that impair the river. Here, storm water BMPs within the town of Rocky Mount and potential nutrient trading between agricultural BMPs and WWTP is needed.

Future Directions

New study from Toshes (make the conclusions and assumptions from this study of the loading during storm events. The need to perform bacterial source tracking in the upper regions of the watershed is suggested to determine the ultimate source of bacterial contamination in the urban and agricultural regions of the watershed. Track the pump back operations and incorporation into fore bay – try to study fore bay water quality.

Section 3: Conclusions and Management Implications

Water quality indicators suggest Leesville Lake is mildly eutrophic. Current trends suggest some improvement in trophic state and movement toward a mesotrophic condition. This is a very positive trend. Of concern is the increasing sediment loading. This increased sediment load may be confounding some of the other trophic state measures.

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

1. When our spring months have significant precipitation and input from the Pigg River, water quality degrades.
2. While significant inputs from Pigg River have the potential to degrade water quality, significant flow from Smith Mountain Lake provides dilution of these inputs potentially improving water quality.
3. Turbidity in the reservoir is increasing. Chlorophyll *a* is very responsive to this trend suggesting driven by inputs from the Pigg River are highly influential on the trends we are observing in changing water quality.
4. Time lags are associated with changes in trophic state thus changes may yet be reflected in the overall TSI.
5. It is now becoming clear that in Leesville Lake, *Daphnia* populations respond to phytoplankton abundance *rather than* graze and control phytoplankton populations.
6. Strong patterns of stratification may be the primary influence on decreased water quality particularily loss of oxygen in the hypoliminon as the strongest driver rather than water inputs from Pigg River or SML release.
7. Pigg River input contaminates the lake with TP, *E. coli* and turbidity when it has a significant flow. These analyses demonstrate the need for increased management of Pigg River.
8. Rocky Mount WWTP does have some impact on Pigg River water quality but this is not a significant input by comparison to other inputs into the river.
9. All three contaminates, TP, *E. coli* and turbidity elevate significantly during storm events compared to low flow conditions in the Pigg River. This is the sorce of contamination to Leesville Lake.

Management recommendations suggested here are intended to improve the overall condition of the reservoir and potentially bring the trophic state into a mesotrophic classification.

7. Continue to research links between hydrology, Pigg River input and water quality. Pinpoint how Smith Mountain Lake operations influence these relationships.
8. Find focus areas of Pigg River to better quantify potential increases in sedimentation, nutrient inputs and changes in productivity. Intensively study these areas to affect change and improve water quality.
9. Information should be posted at the annual picnic or in public areas and as the annual Leesville Lake Association picnic, indicating that when turbidities elevate above 50 NTU, contact with lake water should be avoided. The Leesville Lake Association

sends email notices to members regarding potential health hazards on the lake. However, it cannot provides continuous monitoring and health department services.

10. Conduct more intensive research on the Pigg River. Quantify the influence this river has during base flow and contrast this with storm flow on water quality.
11. Perform bacterial sopurce tracking in the upper regions of the watershed to determine the source of bacterial contamination (agricultural, human, wildlife, vegetative decay or sediment storage) in the urban and agricultural regions of the watershed. Engage the appropriate regulatory agencies and work cooperatively to find solutions to these issues.
12. Make recommendations to AEP operations related to Pigg River water quality and low oxygen conditions in the reservoir.

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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 Lynchburg College to establish the Water Quality Monitoring Plan. Lynchburg College agreed to conduct the samplings and testing, and report results. LLA water monitoring volunteers for 2014 were: Tony Capuco and Mike Lobue.

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 Lynchburg College.

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 Lynchburg College. 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.

Lynchburg College 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). Lynchburg College 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 Lynchburg College. 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).

Lynchburg College 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. Lynchburg College 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, (NH4)6Mo7O24•4H2O
- Ammonium Persulfate, (NH4)2S2O8
- Antimony Potassium Tartrate, K(SbO)C4H4O6•3H2O
- Ascorbic Acid, C6H8O6
- Isopropyl Alcohol, (CH3)2CHOH
- Phenolphthalein, C20H14O4
- Potassium Dihydrogen Phosphate, KH2PO4
- Sulfuric Acid conc., H2SO4

Preparation of Reagents and Standards:

Stock Standards:

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

Reagents:

- For a range up to 20mg/L, a working reagent made up of 50mL sulfuric acid stock, 5mL antimony stock, 15mL molybdate stock, and 50mL of DI water was made and transferred to an EasyChem reagent bottle.
- For the second reagent, 0.9g of ascorbic acid was dissolved in 40mL of DI water. The solution was then diluted to 100mL with DI water and transferred to an EasyChem reagent bottle.

Standards used in the digestion process:

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

Standards:

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

Dissolved Phosphorus

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

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

Dissolved phosphorus testing was completed for all test sites by Lynchburg College. 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. Lynchburg College 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, Lynchburg College 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 Lynchburg College. 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, Lynchburg College measured fluorescence. Florescence measurements correlate with the concentration of Chlorophyll in water. Lynchburg College 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 Lynchburg College.

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).

Lynchburg College 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 Lynchburg College.

To determine Chlorophyll *a* levels, Lynchburg College 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. Lynchburg College 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 Lynchburg College.

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, Lynchburg College 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 Lynchburg College 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 Lynchburg College.

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:

- 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 Chla 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 (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	0.134	0.177	0.187	0.194	0.189	0.154	0.177
0.5	0.133	0.173	0.187	0.195	0.188	0.156	0.177
1	0.133	0.174	0.187	0.194	0.188	0.157	0.176
1.5	0.135	0.173	0.187	0.194	0.187	0.155	0.175
2	0.135	0.174	0.187	0.196	0.187	0.136	0.175
2.5	0.135	0.175	0.188	0.196	0.186	0.135	0.175
3	0.135	0.176	0.188	0.196	0.187	0.136	0.175
4	0.135	0.178	0.19	0.194	0.187	0.135	0.175
5	0.134	0.179	0.19	0.196	0.187	0.145	0.174
6	0.135	0.18	0.189	0.196	0.187	0.151	0.174
7	0.136	0.181	0.189	0.196	0.188	0.156	0.174
8	0.138	0.18	0.188	0.195	0.188	0.157	0.174
9	0.139	0.181	0.187	0.197	0.188	0.163	0.174
10	0.14	0.181	0.186	0.196	0.188	0.164	0.174
11	0.141	0.182	0.186	0.197	0.189	0.168	0.174
12	0.141	0.181	0.187	0.197	0.189	0.168	0.174
13	0.142	0.179	0.187	0.198	0.19	0.17	0.174
14	0.141	0.179	0.187	0.198	0.191	0.17	0.174

Table 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	10.63	9.42	9.81	10.9	10.43	5.96	5.94
0.5	10.74	9.51	9.84	10.8	10.67	5.81	5.88
1	10.91	9.6	9.84	10.9	10.68	5.55	5.75
1.5	10.7	9.49	9.9	10	10.94	4.55	5.32
2	10.6	8.55	10.14	9.4	9.87	4	5.28
2.5	10.51	7.97	10.85	9.4	8.36	3.99	5.27
3	10.33	6.85	9.5	7.9	6.34	4.06	5.27
4	10.34	6.5	7.39	7.3	3.42	3.92	5.26
5	10.27	6.26	6.96	5.8	2.7	3.76	5.25
6	10.26	6.08	6.72	4.8	1.8	3.63	5.32
7	10.24	6.08	6.05	3	1.3	3.6	5.32
8	10.21	6.07	5.54	2.1	0.8	3.5	5.34
9	10.21	6.13	4.8	1.07	0.38	3.99	5.34
10	10.26	6.19	4.1	1.8	0.44	3.44	5.29
11	10.24	6.23	3.6	1.75	0.3	3.4	5.28

12	10.19	6.05	3.25	0.6	0.3	3.39	5.38
13	10.12	5.83	2.9	0.5	0.3	3.37	5.37
14	10.08	5.8	2.3	0.3	0.3	3.36	5.31

Table 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	15.06	24.38	26.18	27.07	28.61	22.67	19.15
0.5	15.08	24.19	26.2	27.08	28.25	22.61	19.12
1	14.12	23.93	26.2	27.07	28.2	22.57	19.11
1.5	14.13	23.3	26.2	26.6	27.8	22.2	18.6
2	14.09	20.15	26.3	26	25.9	21.8	18.6
2.5	13.84	19.33	24.7	25.8	25.6	21.7	18.6
3	13.87	18.03	23.1	25.1	25.1	21.9	18.6
4	13.62	17.8	22.1	24.4	24.7	21.5	18.58
5	13.57	16.65	21.9	23.8	24.4	21.2	18.58
6	13.3	16.27	21.6	23.3	24.1	21.06	18.55
7	13.37	16.02	21.05	22.8	23.8	21.01	18.55
8	12.95	15.7	20.7	22.4	23.5	20.9	18.54
9	12.89	15.4	19.9	21.6	23.3	20.9	18.53
10	12.67	15.3	19.4	21.1	23.2	20.8	18.52
11	12.55	15.2	19.1	20.9	23	20.8	18.52
12	12.29	15.1	18.4	20.6	22.7	20.8	18.5
13	12.17	14.9	17.9	20.4	22.6	20.8	18.49
14	12.12	14.8	17.3	20.2	22.3	20.8	18.46

Table 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	15.06	24.38	26.18	27.07	28.61	22.67	19.15
0.5	15.08	24.19	26.2	27.08	28.25	22.61	19.12
1	14.12	23.93	26.2	27.07	28.2	22.57	19.11
1.5	14.13	23.3	26.2	26.6	27.8	22.2	18.6
2	14.09	20.15	26.3	26	25.9	21.8	18.6
2.5	13.84	19.33	24.7	25.8	25.6	21.7	18.6
3	13.87	18.03	23.1	25.1	25.1	21.9	18.6
4	13.62	17.8	22.1	24.4	24.7	21.5	18.58
5	13.57	16.65	21.9	23.8	24.4	21.2	18.58
6	13.3	16.27	21.6	23.3	24.1	21.06	18.55
7	13.37	16.02	21.05	22.8	23.8	21.01	18.55
8	12.95	15.7	20.7	22.4	23.5	20.9	18.54
9	12.89	15.4	19.9	21.6	23.3	20.9	18.53
10	12.67	15.3	19.4	21.1	23.2	20.8	18.52

11	12.55	15.2	19.1	20.9	23	20.8	18.52
12	12.29	15.1	18.4	20.6	22.7	20.8	18.5
13	12.17	14.9	17.9	20.4	22.6	20.8	18.49
14	12.12	14.8	17.3	20.2	22.3	20.8	18.46

Table 1.5. Dam (Lacustrine) pH measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	7.35	8.34	9.5	9.02	9.74	7.71	7.58
0.5	7.35	8.41	9.57	9.04	9.74	7.71	7.59
1	7.37	8.4	9.55	9.06	9.75	7.72	7.59
1.5	7.37	8.33	9.52	8.76	9.77	7.61	7.54
2	7.38	7.99	9.34	8.5	9.38	7.57	7.57
2.5	7.38	7.79	9.44	8.4	9.01	7.48	7.59
3	7.38	7.64	8.96	8.1	8.7	7.52	7.59
4	7.39	7.63	8.57	8.01	8.4	7.48	7.56
5	7.39	7.7	8.5	7.8	8.3	7.49	7.58
6	7.39	7.71	8.51	7.7	8.3	7.5	7.58
7	7.4	7.67	8.42	7.6	8.2	7.5	7.61
8	7.4	7.73	8.4	7.5	8.2	7.5	7.59
9	7.39	7.75	8.3	7.5	8.1	7.53	7.62
10	7.39	7.76	8.3	7.5	8.1	7.54	7.62
11	7.4	7.81	8.25	7.5	8.1	7.56	7.63
12	7.4	7.83	8.2	7.4	8.1	7.56	7.64
13	7.4	7.83	8.3	7.5	8.1	7.57	7.65
14	7.41	7.85	8.2	7.5	8.1	7.58	7.64

Table 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	217	263	278	271	206	365	319
0.5	218	271	276	271	215	370	325
1	218	281	278	273	221	373	331
1.5	219	286	281	278	223	378	339
2	220	312	286	282	237	383	343
2.5	221	322	286	283	244	388	349
3	222	328	300	292	255	394	351
4	223	338	310	295	262	396	355
5	224	337	312	301	269	397	358
6	224	334	312	304	273	399	361
7	225	336	317	308	277	401	362
8	225	337	318	310	279	402	365
9	226	339	320	313	282	402	366
10	226	337	323	313	286	403	369
11	226	336	325	314	287	403	371

12	227	335	324	316	287	403	372
13	227	336	323	315	290	404	374
14	228	335	327	316	291	404	376

Table 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	112	4.2	2.8	3.4	2.3	18	14
0.5	103	4.6	3.8	3.2	2.5	17.2	13.6
1	106	4.8	3.5	3.3	2.4	17.4	14.1
1.5	108	5.1	2.9	3.2	2.5	31.8	14.9
2	108	5.7	3.5	3.8	3.3	46.9	15.1
2.5	110	6	4.6	3.6	3	49.3	14.9
3	110	6.9	2.8	3.4	2.4	41.4	14.2
4	111	8.1	2.4	3.4	2.2	55	14.1
5	112	6.8	3.2	3.9	2.2	52.6	15
6	113	9.7	2.9	4	2.1	47.9	15.4
7	113	9.1	3	3.3	2.5	50.3	14.3
8	116	10.3	3	3.3	2.4	45.8	14.3
9	117	10.4	3.2	3	3.9	61.5	14.4
10	118	11.1	2.9	3.9	3	42	16.4
11	120	11	4.1	4.1	5.4	45.1	16.1
12	121	12	4	5	3.7	42.3	15.3
13	121	14.5	6.1	4.4	4.5	42.3	16.5
14	123	14.4	6.6	4.9	5.3	41.8	18.5

Table 1.8. Dam (lacustrine) Phycocyanin (ppb) measures over study period (2018)

Depth:	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	26.5	26.5	33.2	50.1	23.2
0.5	24	24	22.4	38.5	25.4
1	26.8	26.8	22.6	28.5	21.2
1.5	26.9	26.9	23.4	24.5	20.1
2	30.3	30.3	38.1	34.4	20.2
2.5	27.4	27.4	39.4	33.9	18.3
3	20.1	20.1	41.2	33.7	20.9
4	15.8	15.8	32.6	36.2	19.5
5	11.9	11.9	22.7	36.9	19.7
6	15.2	15.2	17.6	35.3	18.3
7	12.4	12.4	12.2	33.4	19.5
8	13.2	13.2	13.1	32	19.1
9	10.5	10.5	10.6	31	18.4
10	10.1	10.1	11.1	31.2	17.6

11	10.2	10.2	8.1	29.5	19.7
12	12.1	12.1	9.7	29.1	17.9
13	11.7	11.7	9	28.4	19
14	11.6	11.6	9.3	29.2	19.2

Mile Marker 6

Table 1.9. Mile Marker 6 (Transition) Conductivity (µs/cm) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	0.145	0.184	0.189	0.195	0.188	0.173	0.187
0.5	0.146	0.184	0.189	0.195	0.187	0.176	0.187
1	0.146	0.183	0.189	0.194	0.188	0.181	0.187
1.5	0.146	0.183	0.189	0.194	0.187	0.181	0.187
2	0.146	0.183	0.189	0.194	0.188	0.179	0.186
2.5	0.147	0.183	0.189	0.194	0.187	0.175	0.186
3	0.145	0.182	0.188	0.192	0.187	0.174	0.186
4	0.149	0.182	0.189	0.192	0.187	0.168	0.186
5	0.149	0.185	0.189	0.196	0.189	0.163	0.185
6	0.15	0.186	0.19	0.197	0.189	0.158	0.185
7	0.152	0.186	0.191	0.198	0.189	0.154	0.185
8	0.162	0.187	0.191	0.198	0.189	0.152	0.185
9	0.164	0.189	0.19	0.196	0.19	0.152	0.181
10	0.165		0.191			0.154	0.181

Table 1.10. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	10.11	9.21	9.2	10.4	10.34	4.23	6.94
0.5	10.33	9.2	9.34	10.1	10.5	3.95	6.86
1	10.43	9.12	9.26	9.7	10.2	3.74	6.77
1.5	10.37	8.99	8.9	8.9	8.9	3.7	6.41
2	10.33	8.86	8.7	8.7	8.26	3.69	6.28
2.5	10.31	8.21	8.6	6.4	7.7	3.71	5.96
3	10.28	8.05	7.8	6.5	7.01	3.6	5.94
4	10.3	7.25	6.5	5.2	5.9	3.78	5.9
5	10.25	6.31	6.3	4.4	5.5	3.84	5.9
6	10.2	6.24	4.8	3.4	4.95	4.02	5.91
7	10.18	6.06	4.2	3.1	4.92	4.1	5.88
8	10.26	5.9	3.4	3.5	4.6	4.18	5.84
9	10.25	5.71	3.1	4.8	3.97	4.08	5.77
10	10.32		2.4			3.8	5.61

Table 1.11. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	13.8	23.7	25.2	26.2	27.5	21.6	18.33
0.5	13.18	23.6	25.2	26.1	26.9	21.1	18.25
1	12.91	23.3	25.1	26	26.7	21.1	18.2
1.5	12.82	22.5	24.9	25.5	25.8	20.9	18.07
2	12.77	22	24.7	25.9	25.6	20.9	18.02
2.5	12.76	20.7	24.6	24.1	25.5	20.9	17.7
3	12.73	20.6	23.7	24.1	25.3	20.8	17.7
4	12.72	19.7	22.1	23.2	24.7	20.7	17.7
5	12.66	18	21.6	22.7	24.2	20.7	17.7
6	12.64	16.4	20.7	21.9	23.7	20.7	17.7
7	12.56	16	20.4	21.3	23.6	20.7	17.69
8	12.45	15.8	19.8	21.1	23.4	20.7	17.68
9	12.26	15.5	19.4	20.8	23.2	20.7	17.67
10	12.11		18.9			20.7	17.55

Table 1.12. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	6.1	3.2	11.7	22.6	8.3	6.1	10.2
0.5	7.1	4.3	12.8	24.2	11.1	4.5	10.8
1	7.3	6.4	12.8	23.2	15.3	4.4	11.2
1.5	7.1	7.8	12.1	20.9	21.2	3.6	8.6
2	6.7	8.5	11.8	16.8	21.4	3.7	7.4
2.5	7.4	10.3	11.4	11.7	18.6	3.9	4.7
3	8.1	8.9	6.6	10.9	16.8	4.2	4.1
4	7.1	6.6	4.7	10.4	15.1	3.8	4.3
5	6.4	3.4	4.5	9	10.1	3.9	3.6
6	6.9	2	3.6	6.8	9.5	3.9	3.8
7	6.3	2	3.7	5.4	7.9	4	3.5
8	5.8	1.7	3.3	5.8	8.5	3.8	3.4
9	5.5	1.8	3	5.7	9.3	3.9	3.2
10	5.3		2.6			3.6	2.8

Table 1.13. Mile Marker 6 (Transition) pH measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct

0	7.54	8.04	9.2	8.6	9.42	7.32	7.77
0.5	7.54	8.06	9.17	8.6	9.44	7.31	7.71
1	7.55	8.06	9.13	8.5	9.37	7.31	7.69
1.5	7.55	8.08	9	8.3	8.9	7.31	7.66
2	7.55	8.07	8.9	8.2	8.8	7.32	7.65
2.5	7.55	7.91	8.9	7.8	8.7	7.33	7.63
3	7.55	7.89	8.6	7.8	8.6	7.35	7.62
4	7.55	7.8	8.4	7.7	8.4	7.36	7.61
5	7.54	7.73	8.4	7.6	8.39	7.37	7.62
6	7.54	7.73	8.35	7.5	8.32	7.38	7.63
7	7.54	7.67	8.3	7.5	8.33	7.38	7.65
8	7.53	7.6	8.2	7.5	8.29	7.39	7.65
9	7.53	7.6	8.2	7.6	8.2	7.39	7.67
10	7.53		8.2			7.38	7.62

Table 1.14. Mile Marker 6 (Transition) ORP (mV) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	211	250	280	280	244	376	311
0.5	202	262	281	281	250	379	323
1	212	268	282	288	256	382	330
1.5	213	271	286	288	266	384	331
2	214	279	290	291	273	385	342
2.5	215	286	291	302	278	380	346
3	215	292	297	304	286	387	351
4	215	296	303	310	292	389	353
5	216	302	304	313	297	390	356
6	217	304	308	317	300	390	358
7	217	311	310	318	301	392	360
8	217	316	314	318	304	392	363
9	217	317	314	316	305	393	364
10	218		314			395	366

Table 1.15. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	108	6.1	3.5	3.1	2.4	32.1	12.4
0.5	112	6.1	3.4	3.7	2.3	29.7	13.2
1	102	7	3.6	3.9	2.4	26.7	12.4
1.5	104	7.6	4	4.3	2.7	30.1	13
2	103	8.7	4.5	4.4	2.7	31.7	13.1
2.5	103	10.8	4.8	6.2	2.9	36.2	12.6
3	103	13.3	6.5	6.3	3.6	34.9	14.2
4	104	14.5	11.4	9.4	4.3	46	14
5	105	23.3	12.8	10.1	5.7	52	12.2

6	105	18.2	16.9	11.5	7.4	48	14.5
7	105	18.3	21.3	14.6	8.2	55.3	13.8
8	102	28.3	19	20	12.3	54.9	14.5
9	101	52	17	17.4	30.6	55.4	25.3
10	104		18			60.9	36.6

Table 1.15. Mile Marker 6 (Transition) Phycocyanin (ppb) measures over study period (2018)

Depth:	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
	33.9	35	31.3	29.7	42.2
	34.1	37.3	35.2	26.3	40.7
	32.7	35.5	43.7	24	37.4
	34.3	34.7	47.7	22.1	35.5
	30.9	28.8	45.3	24.2	29.9
	29.2	26.8	44	26.8	30.9
	25.7	22.8	40.4	28.2	30.1
	24.5	21.3	33.8	30	29.6
	23.9	18.9	30.7	35.7	27.8
	22.1	17.3	28.9	35	25.3
	25.3	15.4	27.3	37.2	27.04
	20.5	18.9	29.1	36.6	25.9
	23.5	19.3	36.6	38.2	33.5
	22.5			40	34.1

Toler Bridge

Table 1.16. Toler Bridge (Riverine) Conductivity (µs/cm) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	0.157	0.173	0.189	0.196	0.194	0.126	0.181
0.5	0.162	0.175	0.188	0.195	0.193	0.13	0.181
1	0.16	0.175	0.188	0.196	0.194	0.128	0.178
1.5	0.163	0.175	0.188	0.196	0.194	0.124	0.178
2	0.161	0.175	0.188	0.196	0.194	0.131	0.177
2.5	0.163	0.175	0.188	0.196	0.193	0.131	0.177
3	0.162	0.175	0.186	0.196	0.193	0.122	0.177
4	0.162	0.175	0.186	0.196	0.194	0.118	0.176
5	0.163	0.175	0.188	0.197	0.195	0.118	0.174

Table 1.17. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	10.93	8.21	8.03	6.5	6.19	6.32	6.7
0.5	10.71	8.31	7.99	6.25	5.9	6.31	6.67
1	10.76	8.31	7.85	6.15	5.9	6.38	6.61
1.5	10.77	8.31	7.7	5.9	5.9	6.33	6.49
2	10.64	8.31	7.6	5.8	5.7	6.2	6.46
2.5	10.69	8.31	7.4	5.7	5.7	6.2	6.39
3	10.7	8.31	7.4	5.7	5.4	6.6	6.39
4	10.7	8.31	7.38	5.6	4.8	6.7	6.34
5	10.72	8.31	7.26	5.4	4.6	6.7	6.33

Table 1.18. Toler Bridge (Riverine) Temperature (°C) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	13.95	20.1	21.78	21.9	24.1	20.8	18.46
0.5	13.93	19.5	21.6	21.6	23.8	20.7	18.38
1	13.15	19.5	21.5	21.4	23.6	20.6	18.26
1.5	12.65	19.5	21.3	21.1	23.6	20.4	17.94
2	12.65	19.5	21.1	21	23.3	20.4	17.9
2.5	12.58	19.5	21	20.9	23.3	20.4	17.7
3	12.52	19.5	20.9	20.8	23.1	20.3	17.7
4	12.49	19.5	20.9	20.7	22.5	20.3	17.59
5	12.53	19.5	20.4	20.4	22.3	20.3	17.55

Table 1.19. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	4.2	2.8	12.1	8.9	5.3	3.9	4.77
0.5	4.2	3.1	14.7	9.1	6.4	3.7	4.74
1	4.2	3.1	9.7	8.8	8.1	3.7	3.45
1.5	4.2	3.1	9.6	7.4	8.9	3.6	3.4
2	4.6	3.1	8.4	6.9	9.6	3.6	3.66
2.5	4.6	3.1	7.9	6	9.8	3.6	3.34
3	4.6	3.1	7.34	8.3	7.1	3.6	3.5
4	4.6	3.1	6.9	7.1	7.5	3.7	2.92
5	4.6	3.1	6.7	5.1	6.3	3.7	2.69

Table 1.20. Toler Bridge (Riverine) pH measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct

0	7.67	7.6	8.43	7.3	8.18	7.45	7.74
0.5	7.64	7.6	8.46	7.5	8.17	7.4	7.69
1	7.64	7.6	8.45	7.5	8.17	7.4	7.69
1.5	7.64	7.6	8.4	7.5	8.17	7.4	7.66
2	7.64	7.6	8.4	7.5	8.16	7.4	7.67
2.5	7.65	7.6	8.4	7.5	8.19	7.4	7.66
3	7.64	7.6	8.4	7.5	8.17	7.4	7.67
4	7.64	7.6	8.4	7.5	8.13	7.4	7.66
5	7.64	7.6	8.4	7.5	8.1	7.4	7.67

Table 1.21. Toler Bridge (Riverine) ORP (mV) measures over study period (2018)

Depth:	30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	206	244	296	284	254	371	371
0.5	208	264	297	286	266	375	375
1	208	264	298	288	273	377	378
1.5	208	264	300	291	278	381	380
2	209	264	300	293	284	382	381
2.5	209	264	302	295	286	382	383
3	209	264	303	297	298	383	384
4	210	264	304	300	302	384	386
5	210	264	306	302	303	384	387

Table 1.22. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2018)

Depth:		30-Apr	31-May	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
	0	92.2	11.9	8.8	5.7	5.8	57.1	7.4
	0.5	89.8	12.6	9.1	7.1	6.5	58.4	8.1
	1	92.8	12.6	10.3	6	6.7	59	9.1
	1.5	93.8	12.6	10	6.3	7.7	58.5	8.9
	2	91.5	12.6	11.7	6.3	7.2	63	9.2
	2.5	88.7	12.6	11.1	5.5	7.4	63	9.5
	3	89	12.6	10	6	7.5	83	9.8
	4	89	12.6	10.9	5.5	7.2	85	9.2
	5	88.9	12.6	11	5.3	7.1	85	11.3

Table 1.23. Toler Bridge (Riverine) Phycocyanin (ppb) measures over study period (2018)

Depth:	26-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	37.6	19.2	26	40	29.6
0.5	37.9	18.4	26.4	40.2	29.8
1	31.3	18.2	35.1	42.5	28.1
1.5	31.3	17.1	33.6	43.1	27.4
2	30.6	14.1	34.4	41	25.1

2.5	29.2	14.1	32.5	45	27.1
3	28.1	13.5	15.6	42	27.7
4	26.8	15.8	15.1	42	26
5	25.8	12	11.6	41	25.1

Pigg River

Table 1.24. Pigg River Conductivity (µs/cm) measures over study period (2018)

Depth:	30-Apr	31-May	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	0.067	0.157	0.098	0.142	0.113	0.081	0.086
0.5	0.066	0.163	0.099	0.142	0.112	0.08	0.086
1	0.067	0.163	0.099	0.164	0.112	0.08	0.085

Table 1.25. Pigg River Dissolved Oxygen (mg/L) measures over study period (2018)

Depth:	30-Apr	31-May	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	9.42	8.11	7.26	6.8	83.5	8.01	10.68
0.5	9.64	8.36	7.22	6.7	82.9	7.98	10.65
1	9.72	8.2	7.23	6.4	82.7	7.98	10.61

Table 1.15. Pigg River Temperature (°C) measures over study period (2018)

Depth:	30-Apr	31-May	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	16.03	22.6	24.7	25.2	26.4	21.2	12.2
0.5	15.82	21.6	24.7	25.1	26.2	20.7	12.2
1	15.03	21.6	24.6	24.2	26.2	20.7	12.2

Table 1.16. Pigg River Chlorophyll *a* (ppb) concentrations over study period (2018)

Depth:	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	13.8	15.5	6.2	3.5	1.6
0.5	14.2	15.8	6.1	3.6	1.6
1	13.4	10.3	6.12	4.6	1.6

Table 1.17. Pigg River pH measures over study period (2018)

Depth:	30-Apr	31-May	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	7.63	7.73	8.17	7.5	8.1	7.43	7.68
0.5	7.65	7.76	8.15	7.6	8.07	7.38	7.67
1	7.63	7.76	8.17	7.5	8.07	7.38	7.68

Table 1.18. Pigg River ORP (mV) measures over study period (2018)

Depth:	30-Apr	31-May	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	221	340	319	333	298	384	428
0.5	222	339	321	334	304	385	421
1	223	335	319	336	307	383	416

Table 1.19. Pigg River Turbidity (NTU) measures over study period (2018)

Depth:	30-Apr	31-May	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	119	17	22	20.2	23.5	116.6	18.5
0.5	121	16.1	20.8	20.5	24.6	200	18.7
1	129	20	23	23	23.7	196	20.6

Table 1.20. Pigg River Phycocyanin (ppb) measures over study period (2018)

Depth:	25-Jun	30-Jul	29-Aug	26-Sep	23-Oct
0	35.3	34.2	22.3	69.2	27.8
0.5	32.6	41.7	24.3	93	24.4
1	33.4	25.6	22.4	25.2	25.6