Leesville Lake 2019 Water Quality Monitoring

Prepared for:
Leesville Lake Association

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List of Acronyms and Abbreviations

AEP	American Electric Power
BST	Bacterial Source Tracking
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 of 2019. The lake was monitored toward the end of the month by University of Lynchburg while additional samples were collected by the Leesville Lake Water Quality Committee June, July and August during mid-month. The 2019 yearly results are reported here with analysis of lake trends, statistical insights on the data collected since 2010. 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.

All water quality indicators suggest Leesville Lake is currently mildly eutrophic. This is consistent with the status of Leesville Lake since we began monitoring the reservoir in 2010. The summer of 2019 was very and an impact on trophic state and worsening of water quality was noted in the upper portions of the reservoir. It is hypothesized this was due to constant pump back of Pigg River water in this area. Interestingly, water quality at the Dam Station improved as a result. We infer that water quality improvement at the Dam and impairment in the upper reservoir is a function of the amount of Pigg River input into a given area. Thus, water quality in Leesville Lake seems very dependent on movement of Pigg River water through the reservoir and its dilution or lack thereof with SML tail water.

Considering lake water quality in terms of state code we find the following. Two DEQ criteria are listed for impairment in the Lacustrine portion of the reservoir (9VAC25-260-187 Criteria for man-made lakes and reservoirs to protect aquatic life and recreation) between April 1-October 31. In Leesville Lake for Chlorophyll a the standard is 25 ug/L and for TP it is 30 ug/L. In 2019, the lake was in violation of the Chlorophyll *a* standard in August and September. In 80% of the samples, TP was in excess of 30 ug/L.

Concerning *E. coli*, 9VAC25-260-170 specifies that primary contact recreational use surface waters (wading, swimming, diving, surfing or water skiing) shall not exceed a geometric mean of 126 counts/100ml and shall not have a greater than 10% excursion frequency of a statistical threshold value (STV) of 410 counts/100ml in an assessment period of up to 90 days. For 2019 at the Pigg River Station in Leesville Lake, the geometric mean was 421 and STV was 47178.6.

The Pigg River continues to be the greatest threat to the water quality of Leesville Lake. The study of this river has been incorporated into our Leesville Lake monitoring to determine how it may be improved to protect and improve water quality in the reservoir. Monitoring of various sites in the Pigg River watershed was initiated in 2018, with funding from AEP. In 2019, monitoring efforts were continued and supplemented with bacterial source tracking (BST) to determine the primary host species for bacterial contamination. The 2019 study was supported by discretionary funds from the Leesville Lake Association. We have the following conclusions on the Pigg River:

1. The Pigg River is a very contaminated river system. Contamination is both from human and agricultural sources. Areas in Rocky Mount VA have now been identified as polluters to the system with human sourced bacteria and nutrients.
2. Ruminant pollution is very significant during rain events. These sources originate at various locations throughout the watershed then appear to culimant at Toshes Road at the headwaters of Leesville Lake.
3. All trending suggests the contamination we have documented in the Pigg River is certainly worsening.
4. Pigg River station at Leesville Lake consistently violates state standards for *E. coli*. This station exceeds 126 counts/100 ml 70% of the time we sampled this year and is over 50% for the entire time we have studied the lake.

In addition to study of the Pigg River, we initiatied in 2019 a study of pump operations at SML to determine potential impact on water quality. We concluded based on 2019 data that the idea that only hypolimnetic release from SML creates the oxygen problems at the SML tail water station. Rather, it may be a cumulative direction and duration (intensity) of pumping operation that influnences oxygen. Thus, intensive periods of SML operation where the cumulative impact is a net pump back to SML is more influential on DO loss than only the release of SML tail water. It is possible that contamination of Pigg River may exaserbate the oxygen problem in the hypolimnion of SML.

The following management reccomendations were made:

1. Because **a reservoir is a direct reflection of its watershed,** continue research to evaluate the links between hydrology, Pigg River input and water quality. Further study and research how Smith Mountain Lake operations influence water quality in the reservoir and loss of oxygen at the tail waters.
2. Continue to monitor and research all aspects of the Pigg River. The isolation and determination of contamination inputs needs to be identified and quantified to begin the process of control and clean-up of this river. Additional funding for bacterial sources tracking, pollutant monitoring and land use identification needs to be pursued.
3. Develop a watershed management plan for the Pigg River. We need to seek funding from Virginia Environmental Endowment or DEQ or other entity to create the management plan.
4. Quantify the influence of the Pigg River during base flow and contrast this with storm flow on water quality.
5. 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 (2019)

1.1 General:

This is the ninth 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 2019 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 (2019)

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 most often of very good quality 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 tail water release from Smith Mountain Lake may have low oxygen content due to multiple factors including pumpback of Pigg River water into Smith Mountain Lake (discussed subsequently) and eutrophic conditions in Smith Mountain Lake itself. A secondary headwater 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 during rain events. The fate of this polluted water depends on hydroelectric operations. During energy production, Pigg River water is diluted and mixed with tail water release then pushed through the reservoir. During pump back operations, Pigg River water is drawn 4 miles to the dam entering the lacustrine areas of Smith Mountain Lake for periods of time dictated by operations. And depending upon electric demand, a mix of both of these conditions is possible in any 24 hour cycle.

The transition portion of Leesville 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 reservoir water quality. During periods of heavy rain, sediment-laden water does travel into the transition portions of the reservoir degrading water quality and is of concern. Conversely, during electric generation water pushed down reservoir 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, additional tributaries of various water quality empty into the lake. Old Womans Creek is of greatest concern but viewed in the context of a water budget these tributaries do not account for a bulk of the water flowing through Leesville Lake.

The analyses in this report examine the data to support or revise the above understanding of Leesville Lake limnology. Section 1 analyzes each station relative to its position (Riverine, Transition or Lacustrine) and the potential impact of water inputs and movement on the observed water quality. Section 2 examines lake-wide trending and 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 lakes 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 used to describe hydrological process. Riverine describes conditions of flowing water and often occur in the upper portions of a reservoir. Lacustrine is a term used to describe water that is still and 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 – These 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 in the fall and the spring. These reservoirs are polymictic because heavy rain input and water movement by Smith Mountain Lake can break up 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, Chlorophyll *a* and **Pheophytin–** 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. In some instances the term algae is used to described primary productivity. Chlorophyll *a* is the photosynthetic pigment found in all plants and a very convenient way to measure the total amount of phytoplankton in the reservoir. Pheophytin is a byproduct of chlorophyll decomposition. We can now measure this in conjunction with chlorophyll a to determine how fresh or viable those samples are at the time of collection. Sediment commonly interferes with algae growth and would produce higher ratios of pheophytin to chlorophyll in a sample.

***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)

Background

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

Conductivity

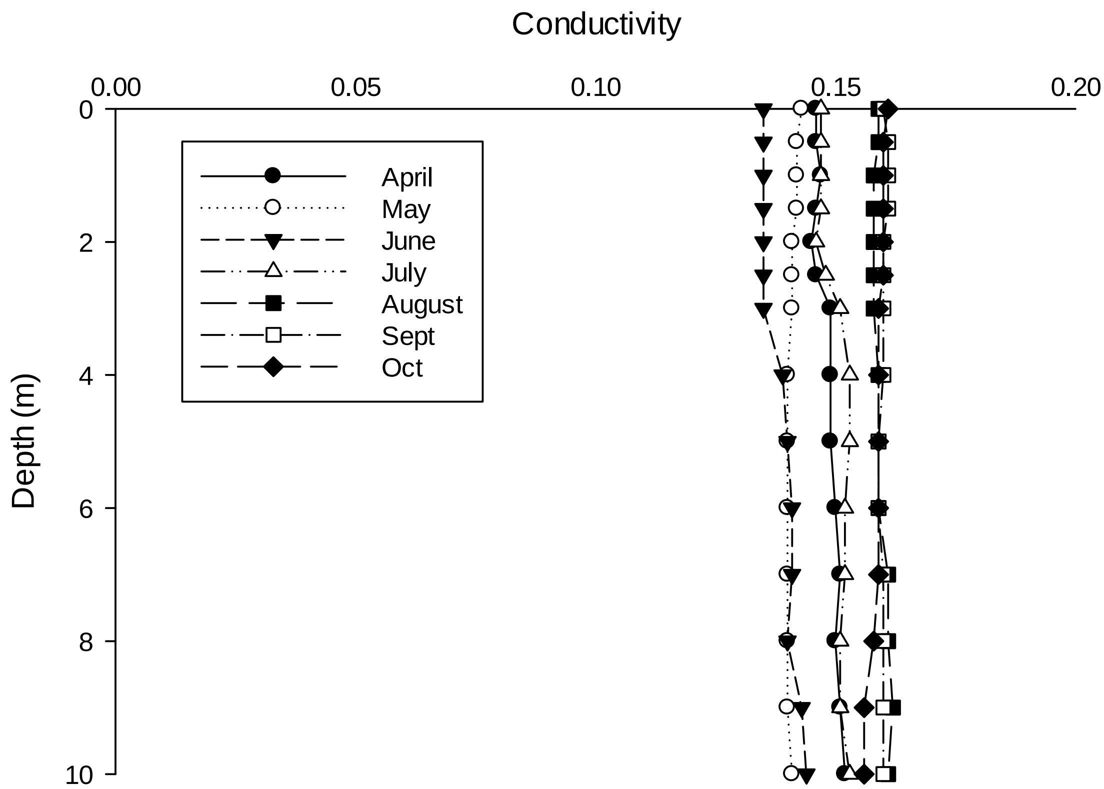


Figure 1.1. Dam (Lacustrine) Conductivity (ms/cm) measures over study period (2019)

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 varied between 0.13 and 0.17 ms/cm with no visible impact due to stratification. This years data certainly reflects differences in rainfall. The first portion of 2019 was rather wet before very dry conditions dominated our region from mid-summer through the fall. The conductivity data at the dam reflected this pattern with the final three sample dates the greatest conductivity. This supports the idea that water flow influences the entire reservoir from both Smith Mountain Lake and Pigg River.

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 (0.07-0.08 ms/cm) is considerably lower than water release from Smith Mountain Dam (0.13-0.17 ms/cm) 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.

Dissolved Oxygen

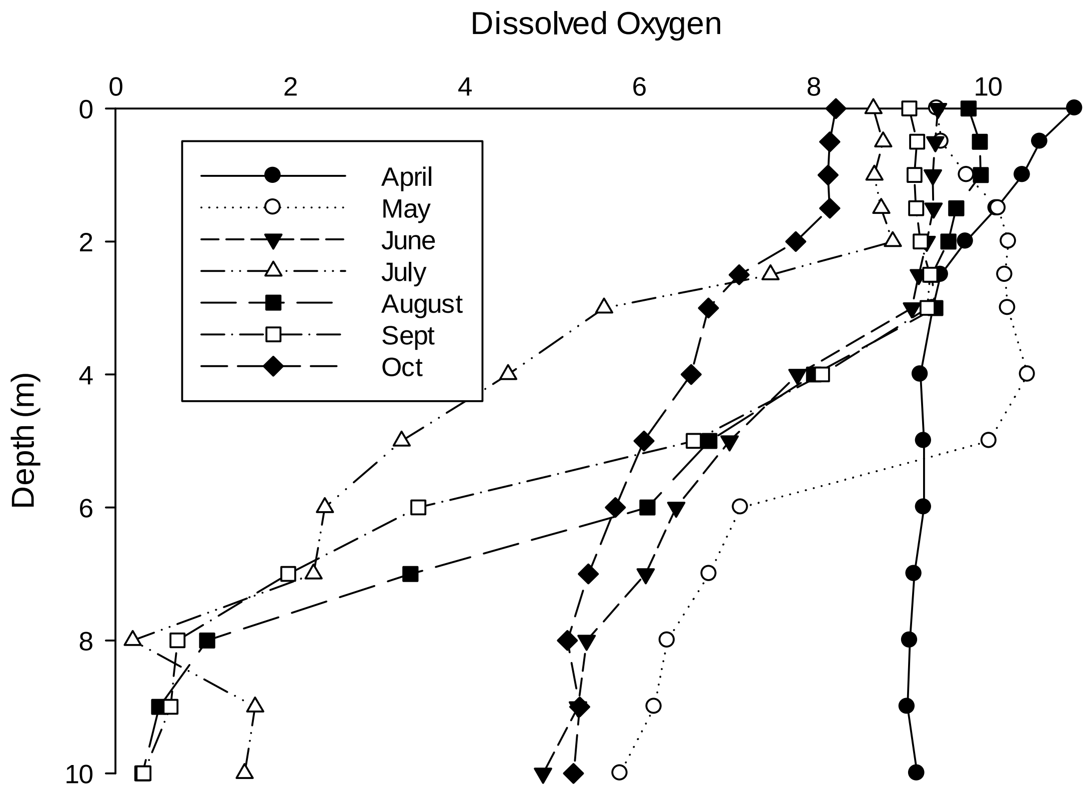


Figure 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2019)

Seasonal Analysis

Dissolved oxygen patterns in the reservoir continues to suggest eutrophication is the driving force for observable patterns. At the beginning of the sampling season in April, water is well oxygenated throughout the entire water column. In May, a positive heterograde develops below the surface to 6 meters followed by oxygen depletion below this depth. This pattern is strongly associated with stratification observed through temperature (Figure 1.3). Pattern continued to strengthen into June followed by a very strong pattern of stratification and oxygen loss in the hypolimnion in July, August and persisting into September. The strong setup into stratification and persistence in 2019 into September seem to be a byproduct of dry conditions. Fall turnover in the lake observed in October did not produce the low oxygen conditions anticipated throughout the water column. Oxygen was over 8mg/L at the surface and still showing some visible signs of stratification at this late date.

Comparisons Across Years

The 2019 pattern of oxygen in the reservoir is well established. The exceptions for this year relate to the strong pattern of stratification observed beginning in July. Dry weather stratified the water column and created conditions to keep it stratified without mixing. By 5 meters depth, oxygen is well below 5 mg/L and near zero by 8 meters depth. The other pattern observed this season was a prolonged period for this stratification. Arguably, the reservoir continued to be stratified even into October when temperatures finally lowered. The lake appeared to turn over in this month (due to oxygenation below the thermocline) yet still yielded a pattern of higher oxygen levels above the thermocline.

Temperature

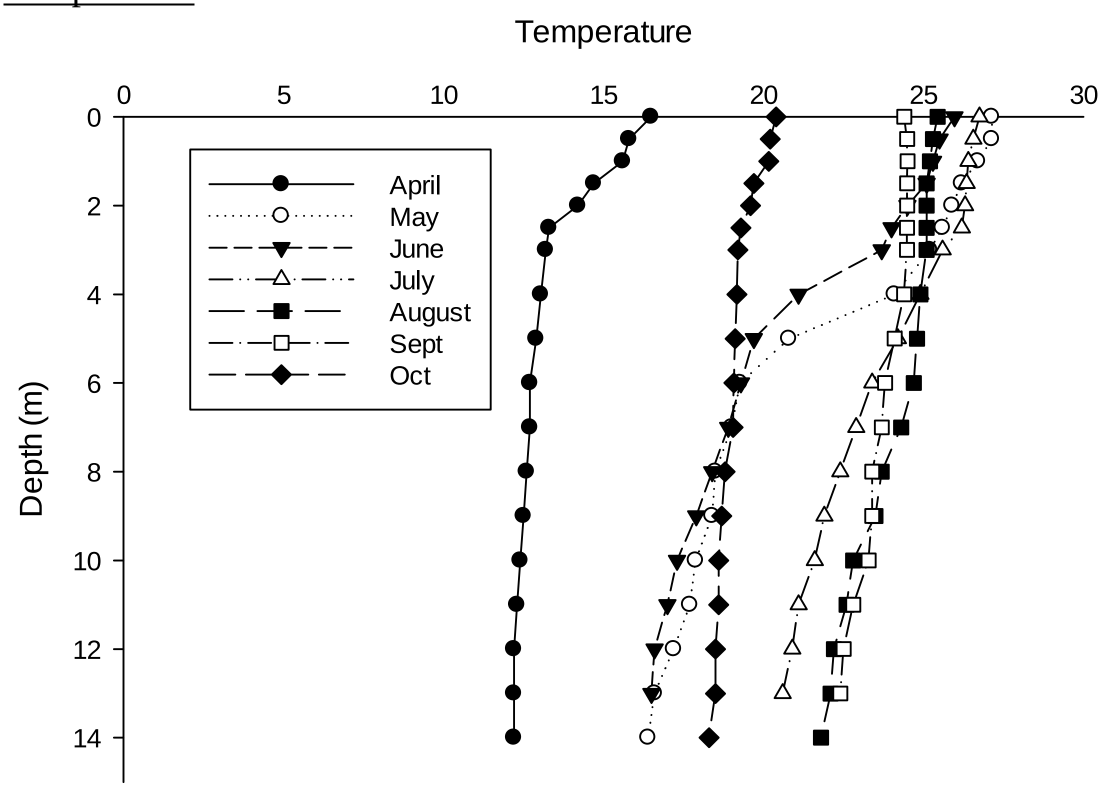


Figure 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2019)

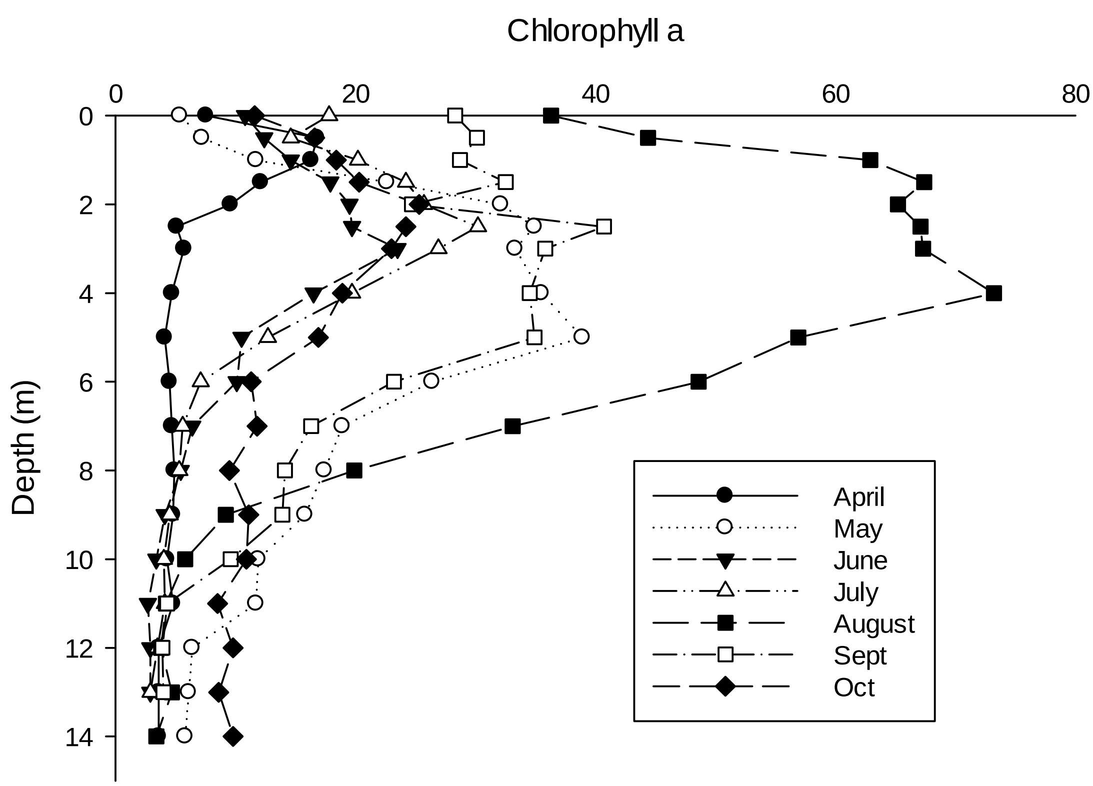
Seasonal Analysis

April is the coolest sampling month with this season exhibiting a pattern of stratification even in April. Rapid reservoir heating by May was surprising bringing a strong pattern of thermal stratification that continued into June. During the summer months of July – September, while demonstrating strong patterns of oxygen depletion and stratification, the reservoir has limited thermal stratification.

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.

Chlorophyll *a* and Pheophytin



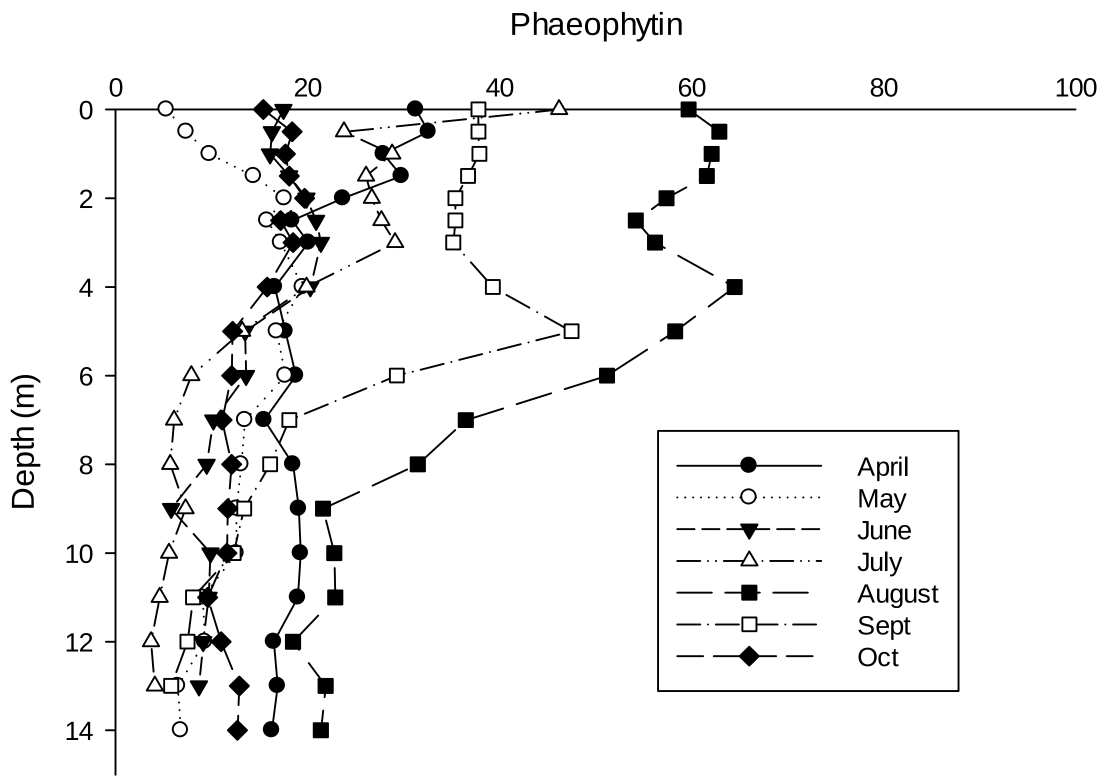


Figure 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) and Pheophytin (ppb) concentrations over study period (2019)

Seasonal Analysis

In this seasons analysis a comparison with pheophytin can be used in conjunction with chlorophyll *a* to describe productivity in the reservoir. The reservoir continues to demonstrate a pattern of greatest phytoplankton growth just above the thermocline and between 2-4 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 close to the surface and blooms occur above the thermocline as nutrients are more available and temperatures very conducive for growth. Peaks in August were the highest observed in many years and may have been fueled by the dry conditions.

Microspora, a filamentous green algae known to bloom in September and October completely overwhelmed the sampling in October. It is often observed in the upper portions of the reservoir but in October, possibly due to turnover, was very abundant and most likely contributed to the high Chlorophyll *a* observations. This algae was very dense in the samples and although not quantified as such appeared to be in bloom stage. These types of blooms can get very problematic and concerning as related to water quality.

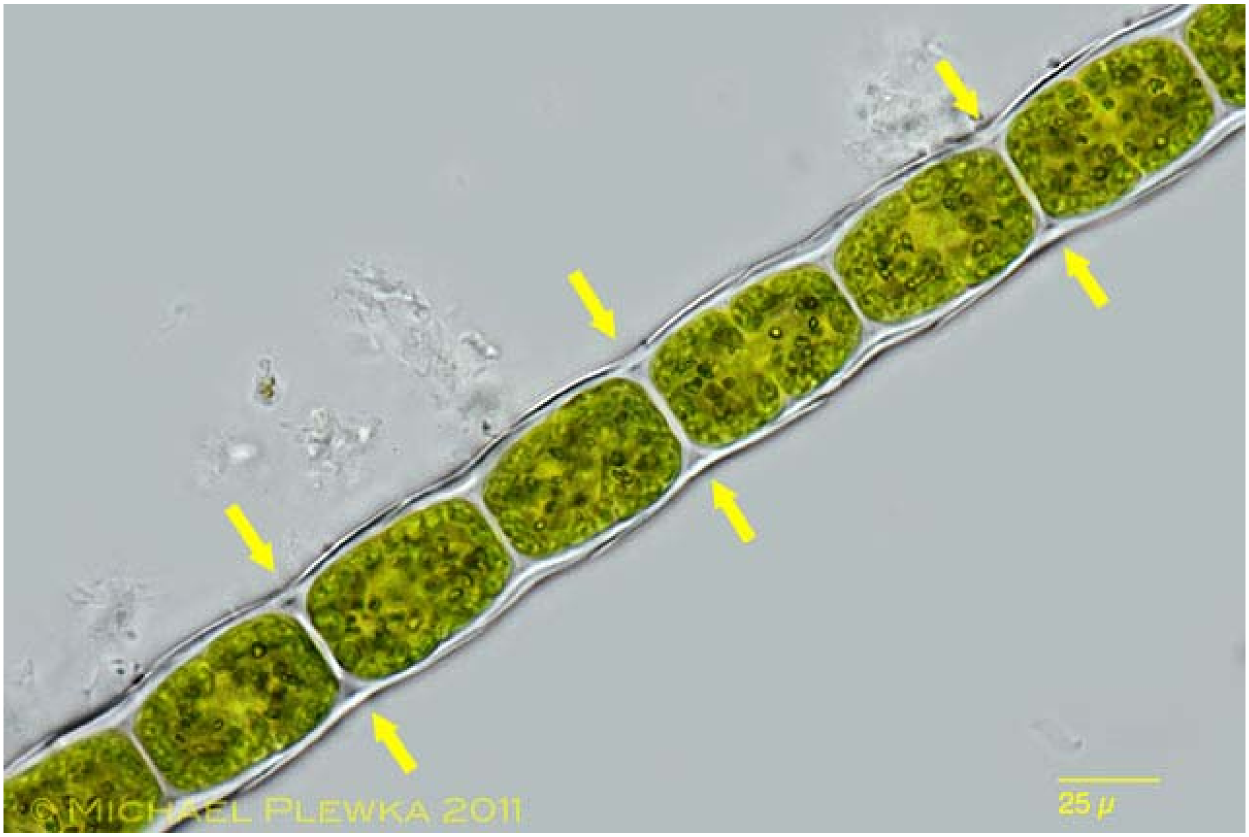


Figure 1.4.1 – Example of a Microspora filament (not the specific filaments observed in the reservoir in October).

Comparisons Across Years

The pattern of increased phytoplankton productivity along the 2-4 meter thermocline in the reservoir is a well-established phenomenon in Leesville Lake and in general eutrophic lakes. In most seasons, this pattern is more pronounced in the summer months. Looking at this pattern the reservoir is again increasing in phytoplankton productivity and in a problematic way. The months of May, July, August and September all violated the 25 ug/L standard for Leesville Lake. In August, measures approached 80 ug/L. This is a problem that needs addressed going forward in management of the reservoir.

pH

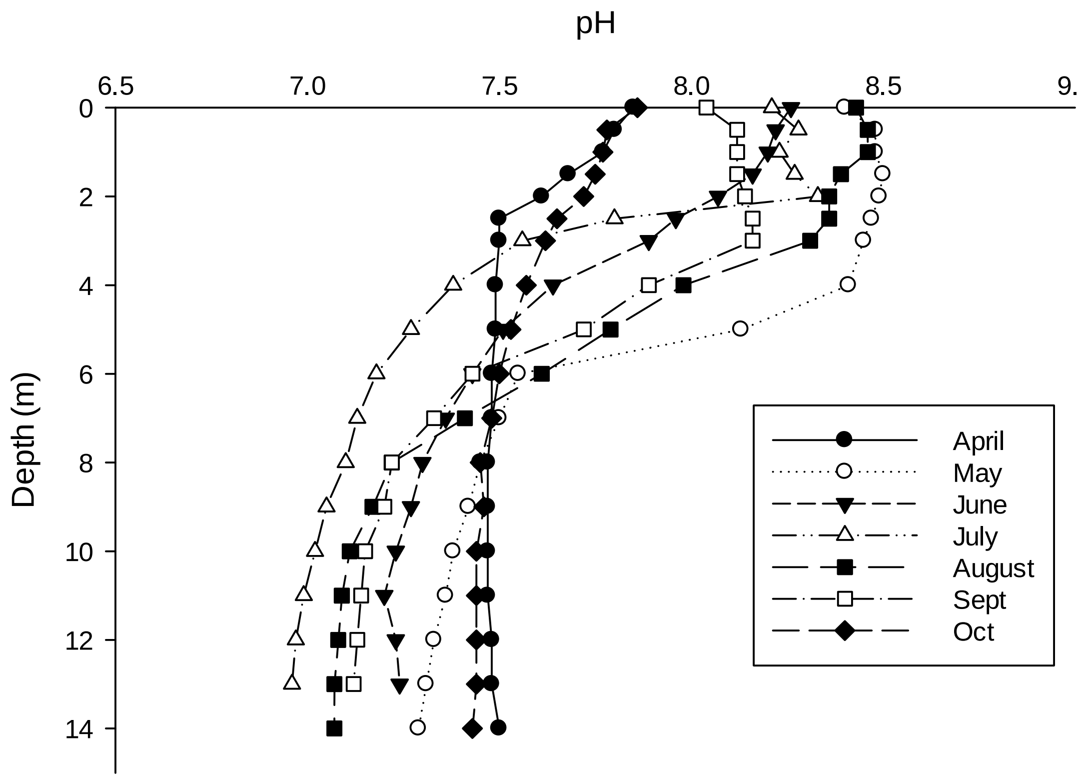


Figure 1.5. Dam (Lacustrine) pH measures over study period (2019)

Seasonal Analysis

The pH in the reservoir varied between 7.0 and 8.5 throughout the season and with depth. Both the pattern with depth and elevation of pH in the epilimnion are typical for eutrophic reservoirs in the southeastern US. Soft water along with photosynthetic removal of CO_2 creates 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

This season's phytoplankton production continued the pattern observed in 2018 with observations again on the hypereutrophication levels in August. With this productivity, pH levels respond accordingly.

ORP

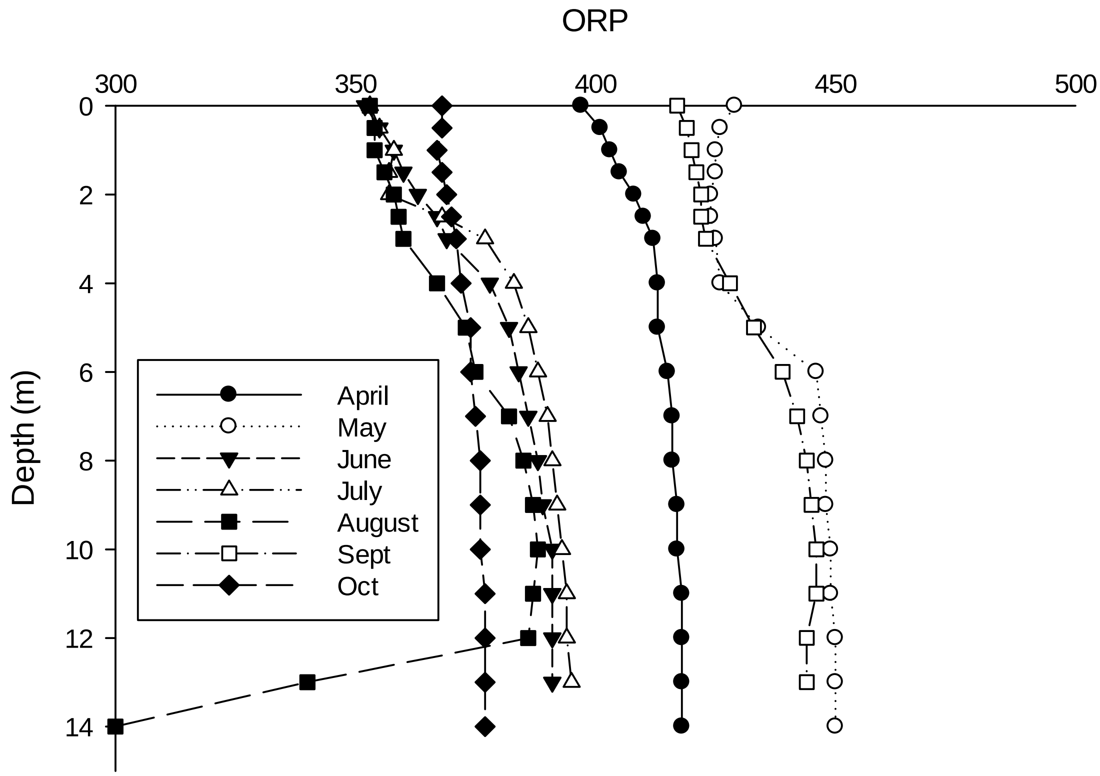


Figure 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2019)

Seasonal Analysis

It is often difficult to discern patterns in ORP in this reservoir. ORP is typically greater in the early and later portions of the sampling season. This suggests more reduced conditions are found during the summer months.

Comparisons Across Years

While the reservoir is slightly reduced during the summer months this reduction is generally inconsequential. All values are in the 300+ range which is still quite oxidized and unlikely to impact chemical changes. If ORP readings move below the 100 readings often changes will occur.

Turbidity

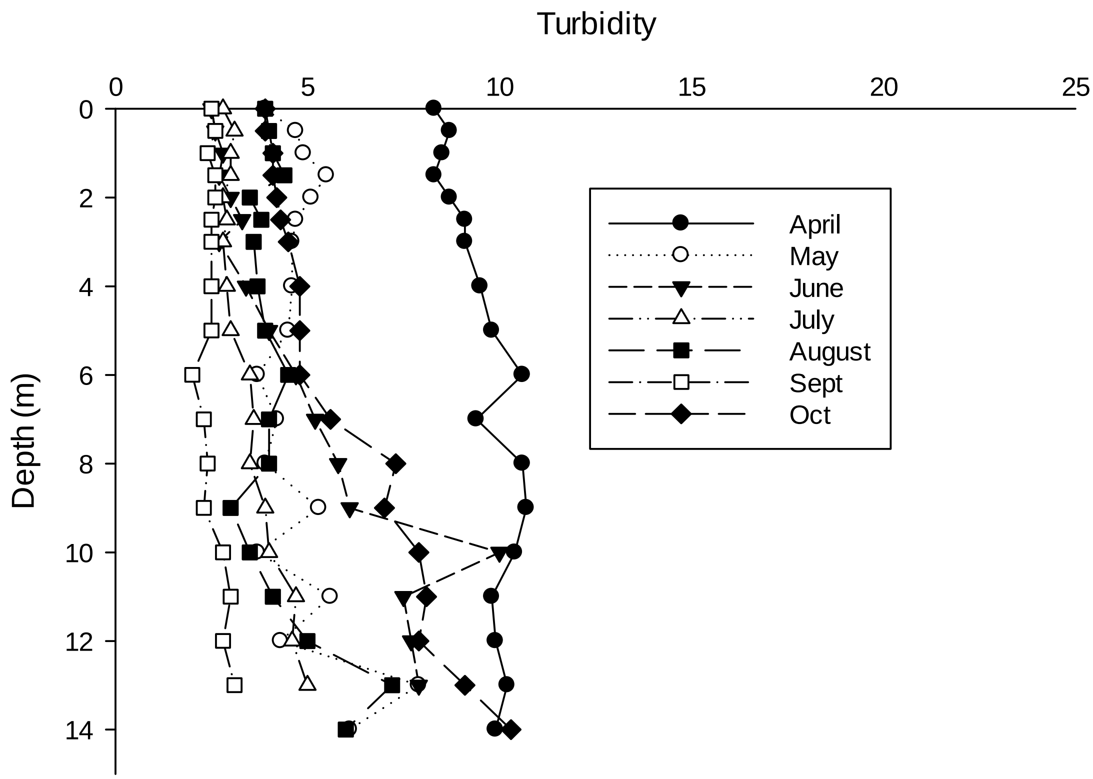


Figure 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2019)

Seasonal Analysis

Turbidity in the reservoir is strongly linked to hydrology from sediment loading and the growth of phytoplankton in the reservoir. Overall at this station and in comparison with the high levels of sedimentation entering at Pigg River turbidity is quite low. The April measures were the greatest for the season and when observed in conjunction with Chlorophyll *a* this was likely due to sediment and not phytoplankton productivity. Turbidity appears to be a mixture of both sediment and phytoplankton as August readings were not the greatest observed while recording very high Chlorophyll *a* observations.

Comparisons Across Years

When turbidity is elevated it will increase with depth but only minimally. 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. By comparison, the wet summer of 2018 and dry summer of 2019 were hardly different in terms of observed turbidity. This strongly suggests that conditions at the dam are mitigated by upper portions of the reservoir. Limnological and hydrological processes occurring in the upper portions of the reservoir (above MM6) seem inconsequential to the lower portions of the reservoir (at the dam).

Other Parameters Measured

Table 1.8. Other parameters measured over study period (2019). Dates represent sampling of both the volunteers and Lynchburg College. First Column represents each parameter measured along with units of measure.

Date	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	2:05 PM	9:45 AM		10:45 AM		11:25 AM		10:20 AM	9:01 AM	3:25 PM	
Secchi (M)	1.20	2.30	0.5	2.30	1.60	2.00	1.50	1.70	1.80	1.80	1.67
TP Surface	0.091	0.080	0.084	0.030	0.052	0.027	0.062	0.095	0.075	0.079	0.07
TP 8 Meters	0.104	0.149		0.039		0.027			0.078	0.101	0.08
NO3	2.737	1.476		2.036				1.220	2.458	1.165	1.85
Integrate Chl	6.71	19.00		10.78		13.47		37.41	22.32	14.81	17.79
TSI S	57	48	70	48	53	50	54	52	52	52	53.62
TSI TP	66	64	65	51	58	50	60	66	63	64	60.63
TSI CHL	49	59		54		56		66	61	57	57.58
TSI AVG	57	57	67	51	56	52	57	62	59	57	57.52

Table 1.9. Zooplankton and *E. coli* measured over study period (2019). Dates represent sampling of both the volunteers and Lynchburg College. Zooplankton numbers are organisms per liter.

Date	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	2:05 PM	9:45 AM		10:45 AM		11:25 AM		10:20 AM	9:01 AM	3:25 PM	
Daphnia	0.2	12.1		4.4		0.2		0.2	0.0	0.4	2.51
Bosmina	24.3	2.8		3.6		1.4		7.5	1.0	1.2	5.98
Diaptomus	2.0	1.6		2.0		2.8		0.4	1.0	0.0	1.42
Cyclops	3.6	0.8		0.4		8.3		1.2	8.9	1.6	3.55
Nauplii	8.1	0.0		4.9		12.5		5.3	4.0	4.9	5.66
Cerodaphnia	0.0	0.0		0.4		0.0		0.0	0.0	0.0	0.06
Diaphanosom	0.0	3.6		0.8		5.9		0.6	0.2	0.0	1.59
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.0	0.00
E. coli MPN	14.60	7.50	135.4	3.00	8.50	99.30	24.60	1.70	4.10	3.00	30.17

Observations of the other parameters in the reservoir yield some additional insights. E. coli was elevated above the 126 counts/100ml on June 13. Certainly, storms were strong enough at this period of time to drive sediment laden water throughout the entire reservoir. *Daphnia* peaked in May but at lower levels than the previous year. Dry conditions appear to improve water quality measured through TSI although levels of Chlorophyll *a* tend to increase.

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 (2019)

Date	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	2:40 PM	10:12 AM		11:15 AM		12:06 PM		10:50 AM	9:33	3:48 PM	
Secchi (M)	1.3	2.0	0.5	0.6	1.4	1.6	1.4	1.6	1.7	1.6	1.4
TP Surface (PPM)	0.167	0.076		0.043		0.039		0.007	0.08	0.105	0.07
NO3	2.5			2.0		0.7		0.1	0.1	0.7	1.0
E. coli MPN	28.8	8.6	78.0	15.8	7.3	113.4	12.0	5.2	1.0	9.0	27.9
Turb		2.4		1.9		0.7		1.8	1.0	1.7	1.6

Water quality measured at the mouth of Old Womens Creek is generally good. None of the measured *E. coli* concentrations were beyond the 126 counts/100ml benchmark. This is a bit surprising due to historical problems associated with Old Womens Creek. It appears that the problems associated with input of the Pigg River into Leesville Lake are not replicated here. All other parameters look excellent thus suggesting water quality here is primarily influenced by conditions at the dam and its isolation from the upper portion of the reservoirs.

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 (2019)

	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	2:50 PM	10:22 AM		11:23 AM		12:15 PM		11:02 AM	9:42	3:58 PM	
Secchi (M)	1.2	1.6	0.5	1.6	1.4	1.5	1.4	1.5	1.7	1.4	1.4
TP Surface (PPM)	0.116	0.088		0.034		0.039		0.028	0.089	0.111	0.07
NO3	2.5	1.6		2.1		0.8		0.1	0.2	0.8	1.1
E. coli MPN	128.1	5.2	98.8	11.0	7.3	99.3	5.2	1.0	1.0	6.0	36.3
Turb		1.8		2.1		1.3		2.0	2.0	3.1	2.1

Water quality at this station is of good quality as well. Factors influencing the dam station appear to be the primary driver of water quality here. April *E. coli* was only slightly elevated above 126 counts / 100ml. All other measures at this station were below this level. Only April and October TP values were elevated above 100 ug/L. Secchi depths are lower than the dam station but as we move from the dam up the reservoir this tends to occur. Any problems due to leaking septic systems or input from streams entering this area are not apparent at this site.

1.3.1.4 Mile Marker 6 (Transition)[1]

Background

In discussing water quality at the transition station (MM6), comparisons are made back to Lacustrine and Riverine portions of the lake. 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.

Conductivity

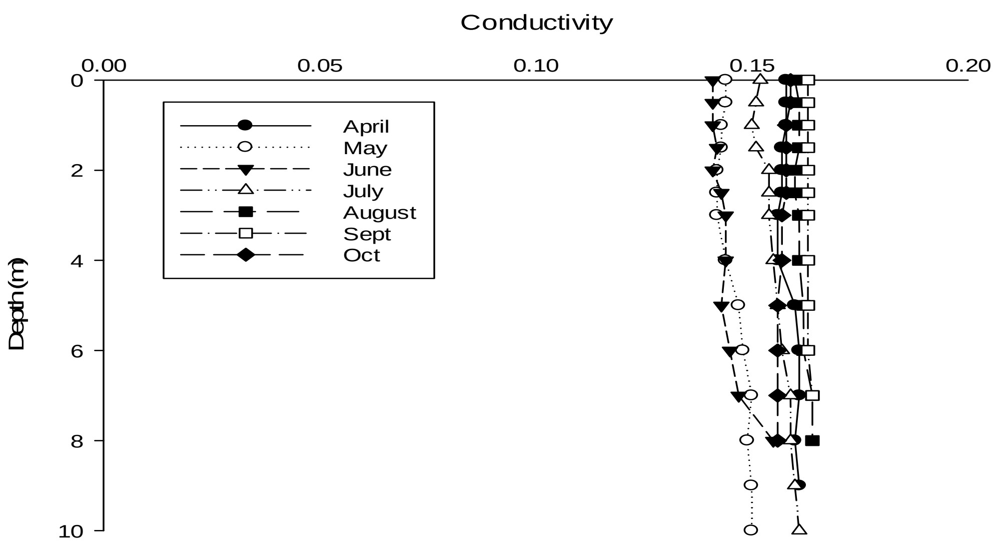


Figure 1.8. Mile Marker 6 (Transition) Conductivity (ms/cm) measures over study period (2019)

Seasonal Analysis

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

Conductivity patterns at the transition region were similar to those observed at the dam (between 0.14 and 0.17 ms/cm). Conductivity in this range and the absence of lower values suggest very limited influence from Pigg River inputs at this site.

Comparisons Across Years

Comparisons among years reveal a similar trend with a majority of the samples collected having conductivities between 0.14 and 0.2 us/cm.

Dissolved Oxygen

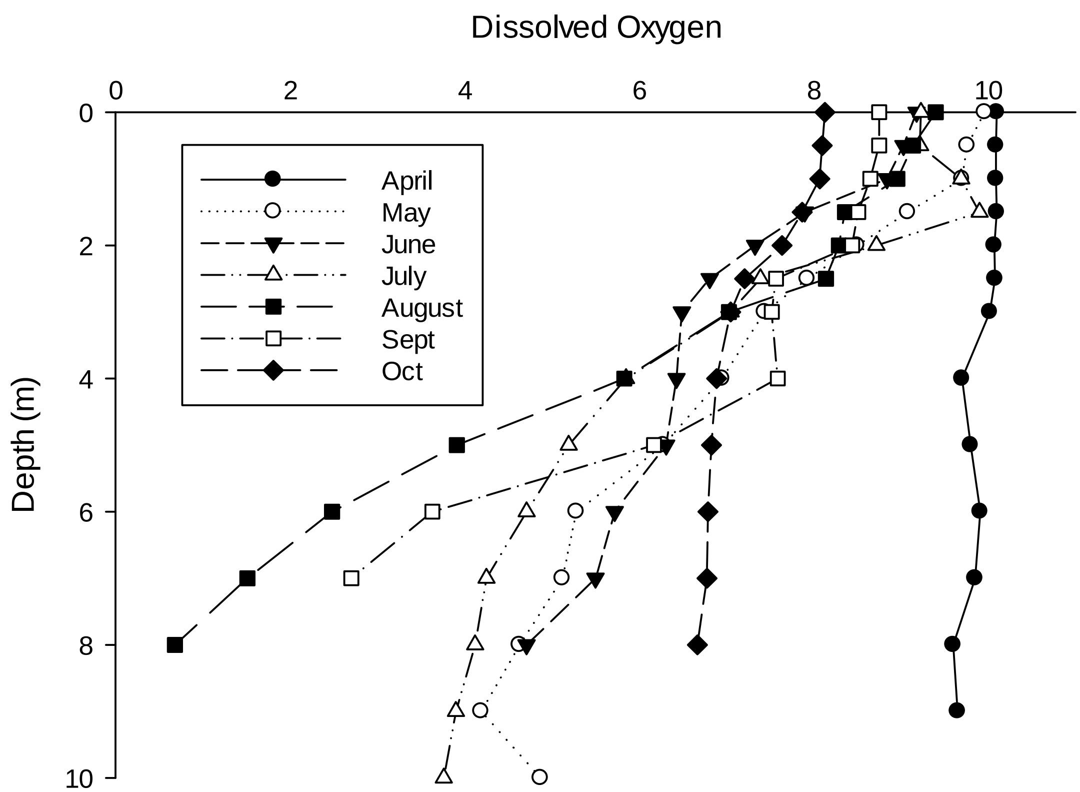


Figure 1.9. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2019)

Seasonal Analysis

The reservoir is both stratified at this station and more shallow when compared to the dam station. This alters the pattern of dissolved oxygen in the transition area and is dissimilar from the dam in the following ways. During summer months, a strong stratification pattern is observed beginning at 2 meters. Only in August and September did oxygen dip below 4 mg/L at depth, unlike the station at the dam. This suggests mixing to lower depths occurs at this station with greater frequency than at the dam. Overall, the pattern of stratification is not as pronounced at this station.

Comparisons Across Years

The lower levels of oxygen that we observed throughout the water column toward the end of the 2018 season did not occur this year. In fact, turnover was delayed until October and when oxygen levels were within acceptable range. This year's trends looked similar to earlier trends (before 2014) and most likely a result of dry conditions. Certainly, weather patterns have a profound impact on the trends we are observing.

Temperature

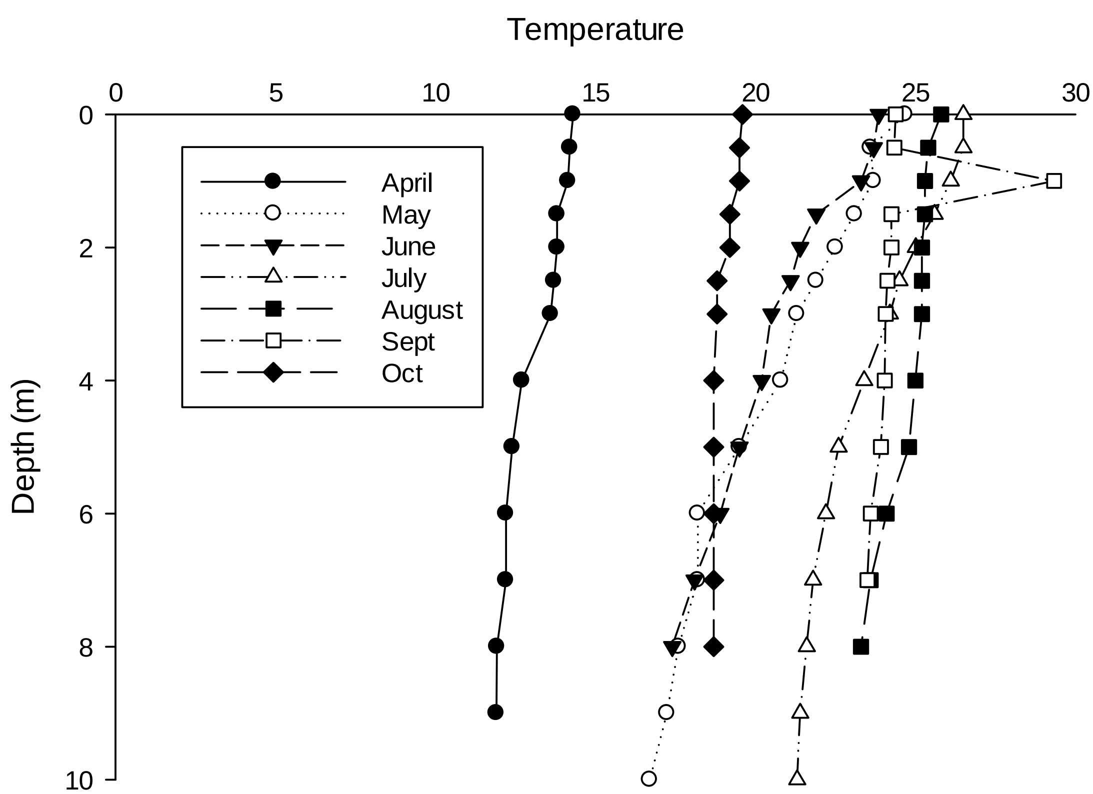


Figure 1.10. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2019)

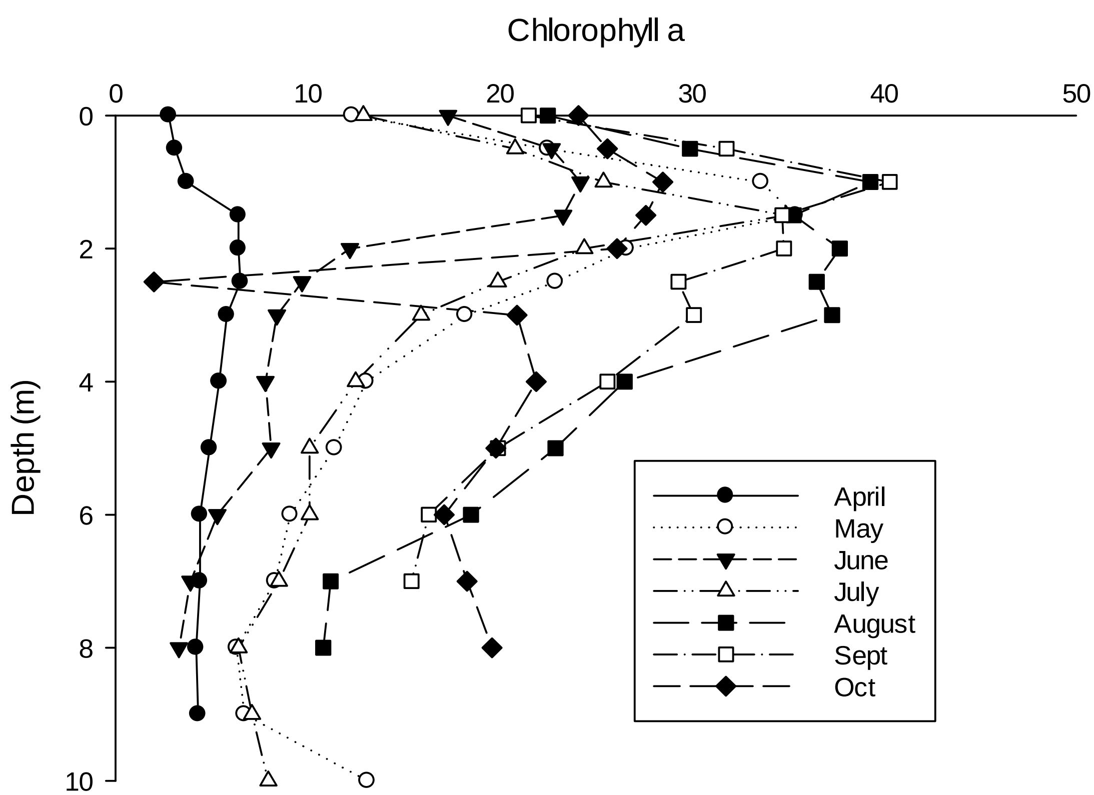
Seasonal Analysis

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*



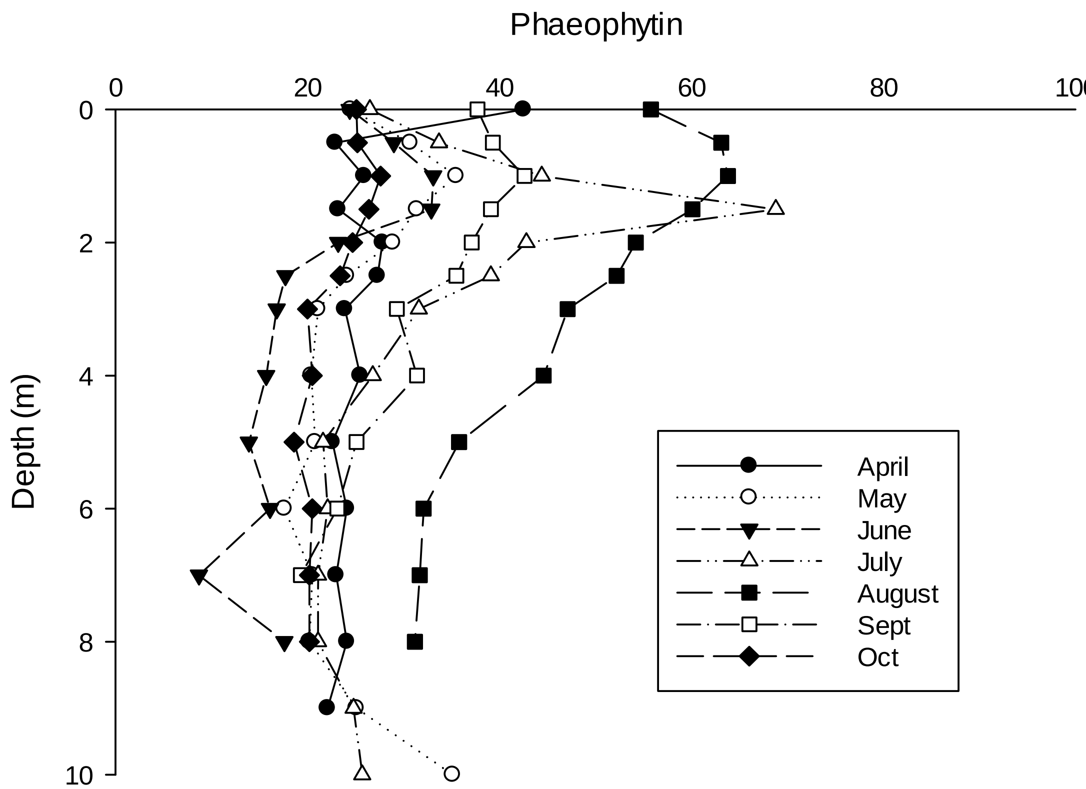


Figure 1.11. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) and Pheophytin (ppb) concentrations over study period (2019)

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. Yet, the dam area exhibited the greatest concentrations of Chlorophyll a, up to 80*u*g/L in August. July and August measures were high but there is not as much phytoplankton mass here at this station. This is most likely due to periodic mixing. The high phytoplankton measures may also be an extension from the dam station.

Comparisons Across Years

The return to higher phytoplankton concentrations last season (2018) from the very low concentrations measured in 2017 continued in 2019 and actually increased substantially. If we simply examine the last 3 years, chlorophyll *a* in the reservoir has increased substantially. This may be a manifestation of conditions created during the spring when conditions will still very wet. Or sedimentation from Pigg River and availability of light are creating conditions where the productivity in the reservoir increases during the dry periods we experienced this year. Whatever the mechanism, dry conditions appear to create optimal times for phytoplankton growth. The discovery of *Microspora* in samples during this fall may have exasperated this problem.

pH

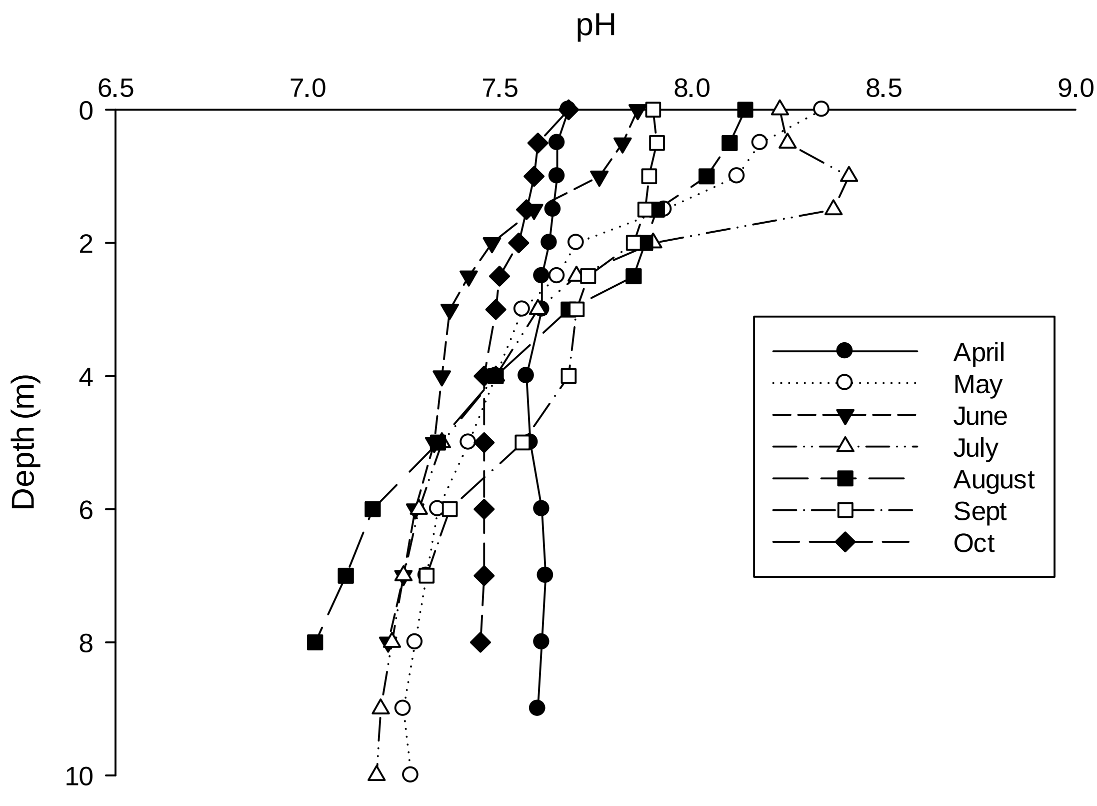


Figure 1.12. Mile Marker 6 (Transition) pH measures over study period (2019)

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 2019 are similar to patterns observed throughout the years of study.

ORP

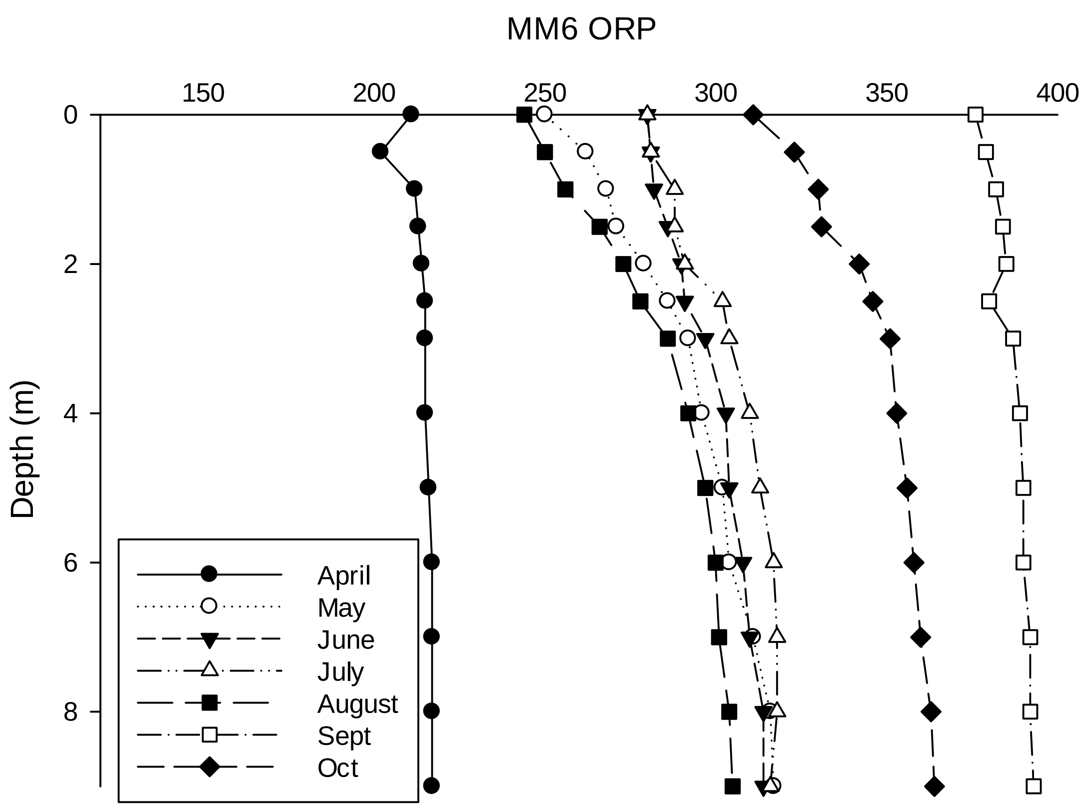


Figure 1.13. Mile Marker 6 (Transition) ORP (mV) measures over study period (2019)

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

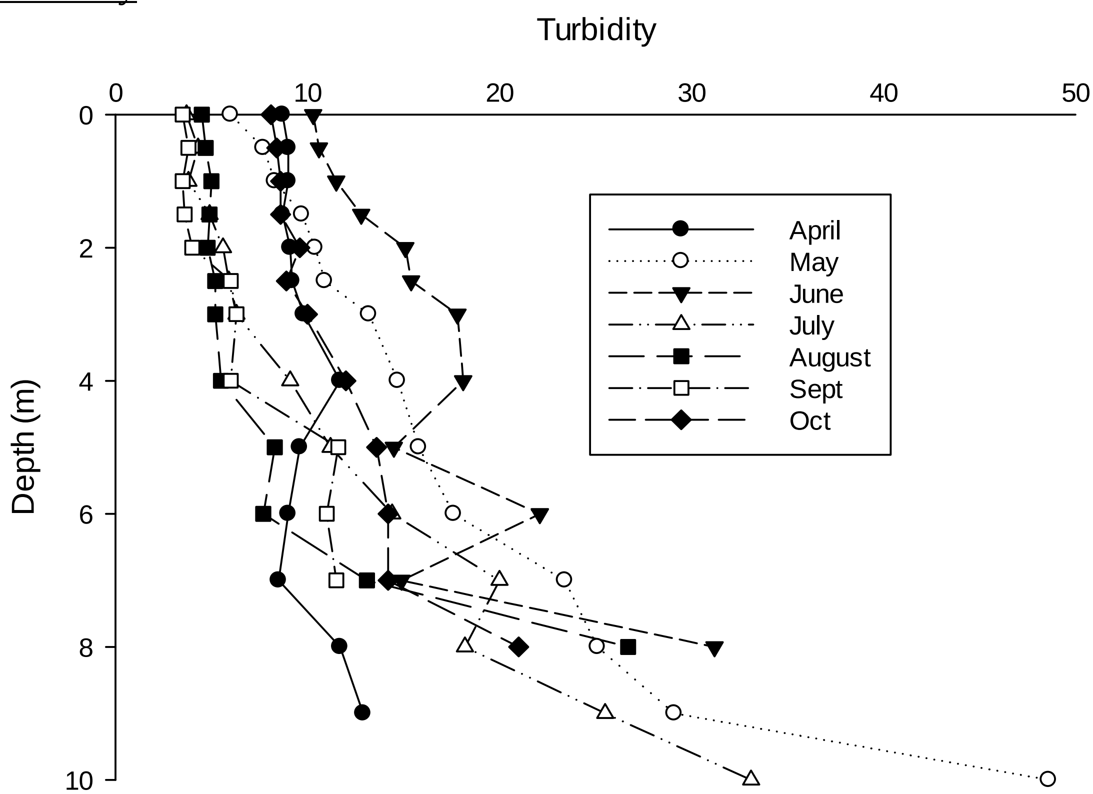


Figure 1.14. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2019)

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, with increased turbidity along the lower portion of the epilimnion and into the hypolimnion being 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 (2019). Dates represent sampling of both the volunteers and university. First Column represents each parameter measured along with units of measure.

Date	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	2:55 PM	10:30 AM		11:38 AM		12:24 PM		11:10 AM	9:50 AM	4:05 PM	
Secchi (M)	1.25	1.40	0.5	1.25	1.20	2.00	1.4	1.35	1.80	1.10	1.33
TP Surface (PPM)	0.116	0.098	0.104	0.065	0.03	0.030	0.04	0.013	0.097	0.090	0.07
TP 6 Meters (PPM)	0.098	0.120		0.068		0.063		0.107	0.115	0.115	0.10
NO3	2.659	2.680		2.262		0.987		1.310	2.150	1.121	1.88
Integrate Chl a	4.79	17.10		12.18		15.49		27.37	27.25	20.96	17.88
TSI S	57	55	70	57	57	50	55	56	52	59	56.71
TSI TP	69	67	68	61	51	51	55	41	67	66	59.39
TSI CHL	46	58		55		57		63	63	60	57.65
TSI AVG	57	60	69	58	54	53	55	53	60	62	58.08

Table 1.20. Zooplankton and *E. coli* measured over study period (2019). Dates represent sampling of both the volunteers and university. Zooplankton numbers are organisms per liter.

Date	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	2:55 PM	10:30 AM		11:38 AM		12:24 PM		11:10 AM	9:50 AM	4:05 PM	
Daphnia	0.0	0.5		2.6		0.6		0.2	0.0	0.2	0.59
Bosmina	22.2	0.9		1.7		0.4		0.9	1.4	6.1	4.81
Diaptomus	0.9	0.0		0.7		0.8		0.0	0.2	0.9	0.52
Cyclops	1.9	0.0		2.8		0.6		2.1	2.6	1.4	1.64
Nauplii	1.7	0.0		2.8		1.4		1.2	4.2	6.6	2.56
Cerodaphnia	0.0	0.0		0.0		0.0		0.0	0.0	0.0	0.00
Diaphanosoma	0.0	2.8		2.6		2.8		1.2	0.7	1.4	1.65
Chydorus	0.0	1.2		0.2		0.0		0.0	0.0	0.0	0.21
E. coli MPN	131.40	5.20	127.4	23.80	3.00	6.30	5.2	0.00	3.10	4.00	30.94

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 (2019)

	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	3:20 PM	11:00 AM		11:56 AM		12:50 PM		11:40 AM	10:17	4:30 PM	
Secchi (M)	1.8	1.1	0.5	0.6	0.8	1.3	1.2	1.0	1.3	0.5	1.01
TP Surface (PPM)	0.091	0.097		0.078		0.051		0.006	0.093	0.229	0.09
NO3	2.8	2.1		2.5		1.3		0.5	1.8	1.2	1.73
E. coli MPN	47.3	6.3	313.0	55.4	21.1	80.5	3.1	0.0	2.0	5231.0	575.97
Turb		9.3		6.7		1.4		3.8	1.9	9.3	5.41

1.3.1.6 Toler Bridge (Riverine)[2]

Background

Riverine conditions as well as influx of tail waters of Smith Mountain Lake and influx of Pigg River water heavily influence 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.

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

Conductivity

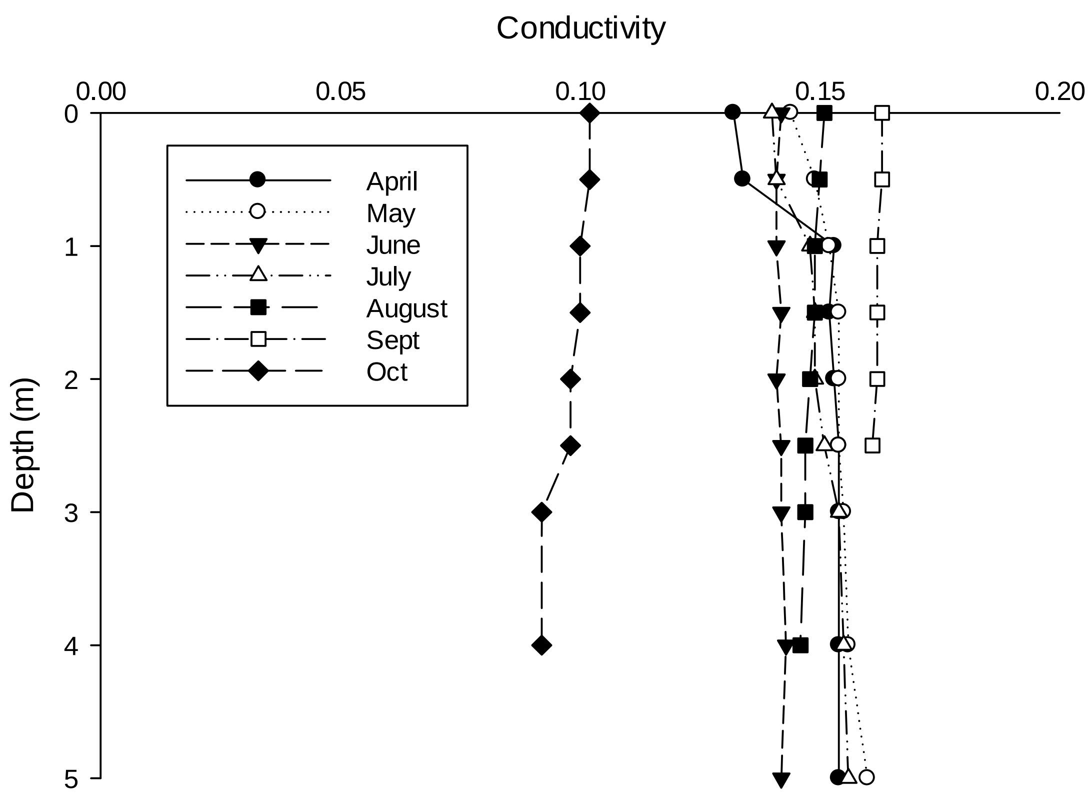


Figure 1.15. Toler Bridge (Riverine) Conductivity (ms/cm) measures over study period (2019).

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 ms/cm average) is generally lower than SML dam release (0.2 ms/cm average) (Tables 1.31 and 1.32). Thus, readings on the lower end of the scale reflect greater Pigg River influence such as in October, Interestingly, in April it seems that warmer Pigg River water was released as a layer above cooler SML tail water release. Thus the April stratification observed in temperature (Figure 1.17) was a result of Pigg input rather than solar heating. Other observations suggest the water is well mixed and dominated by SML release over the remainder of the sampling period.

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. This is a very dynamic station with changing conditions due to the proximity to SML dam and Pigg River.

Dissolved Oxygen

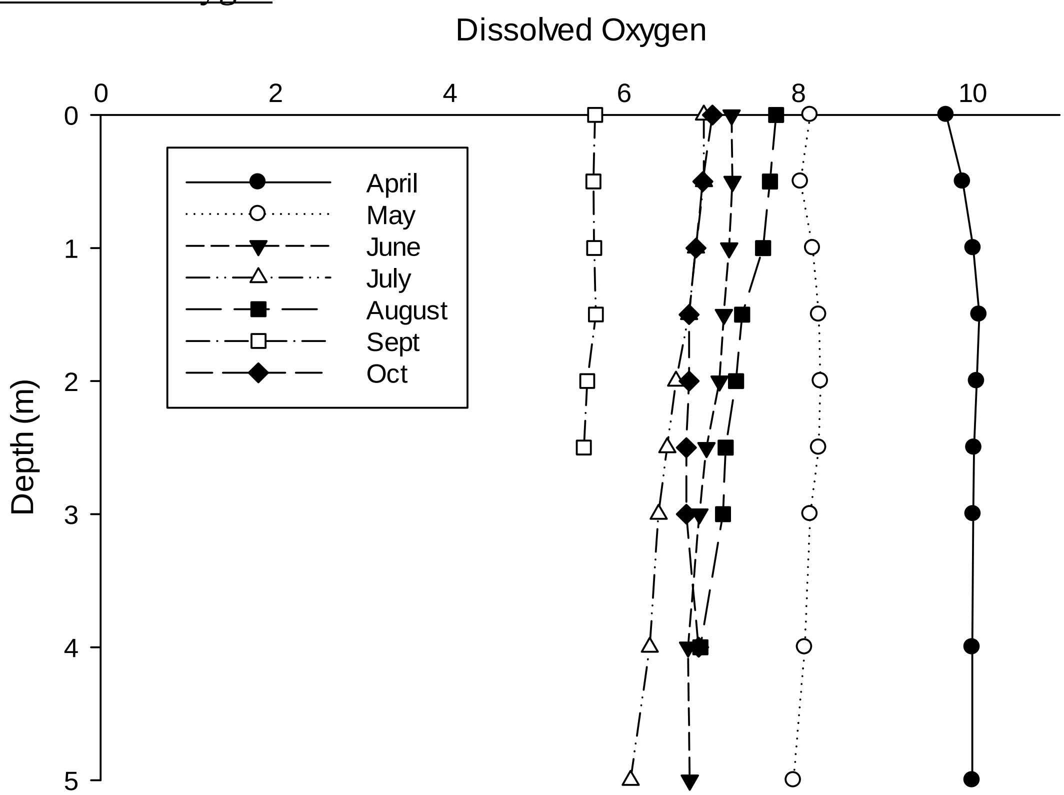


Figure 1.16. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2019)

Seasonal Analysis

Oxygen dynamics in this portion of the reservoir are driven through Pigg River – SML dam movement. 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 may reflect the combination of oxygen depletion in the hypolimnion of Smith Mountain Lake and thus tail water release into Leesville combined with Pigg River. 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

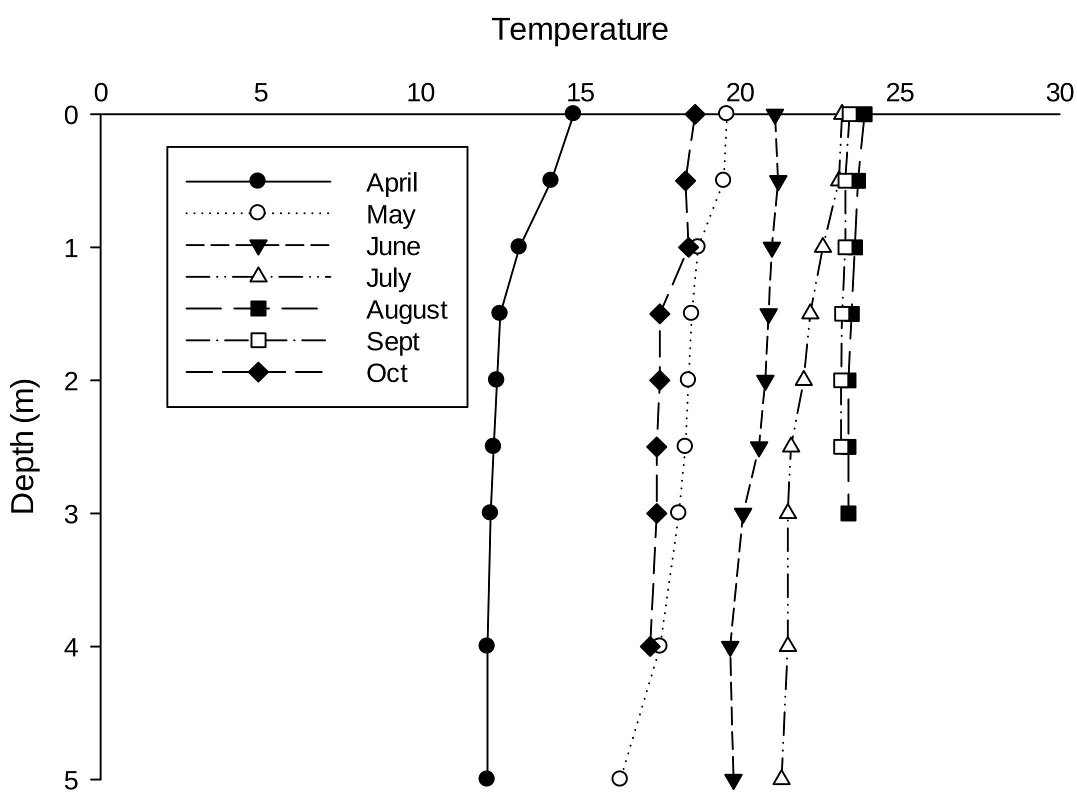


Figure 1.17. Toler Bridge (Riverine) Temperature (°C) measures over study period (2019)

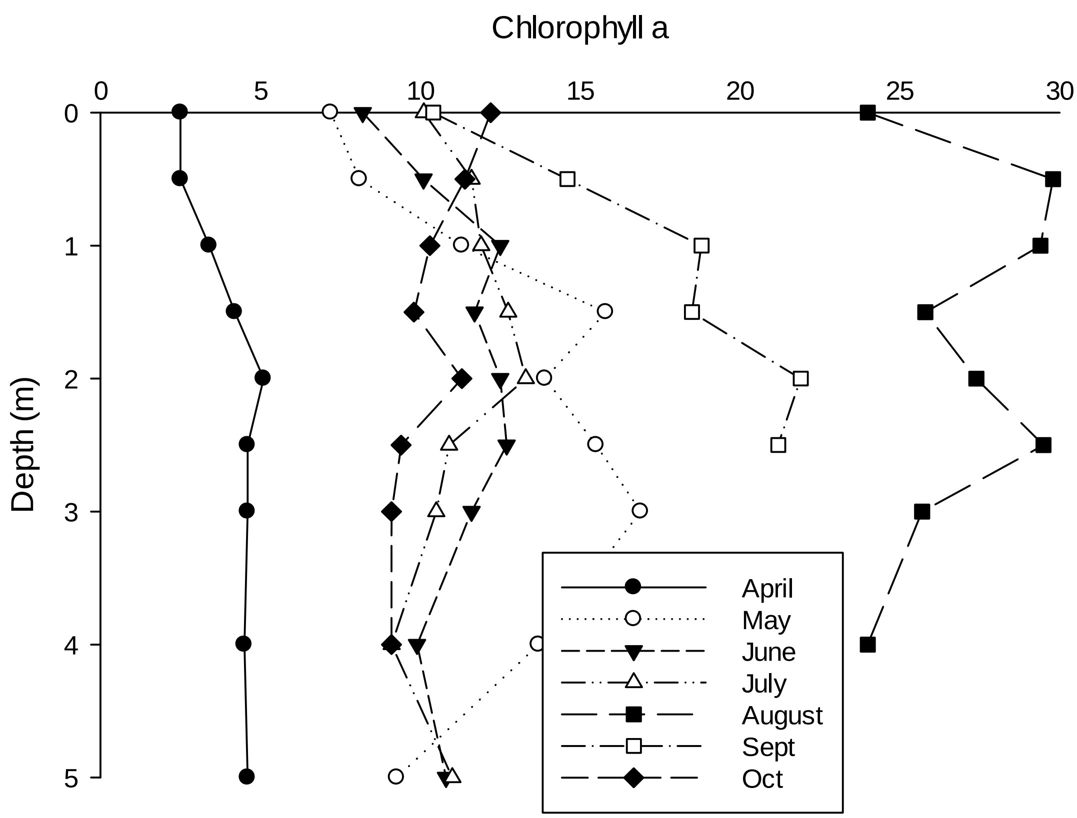
Seasonal Analysis

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. Consistent with previous seasons, August - September are the warmest months with considerable cooling into October.

Chlorophyll *a*



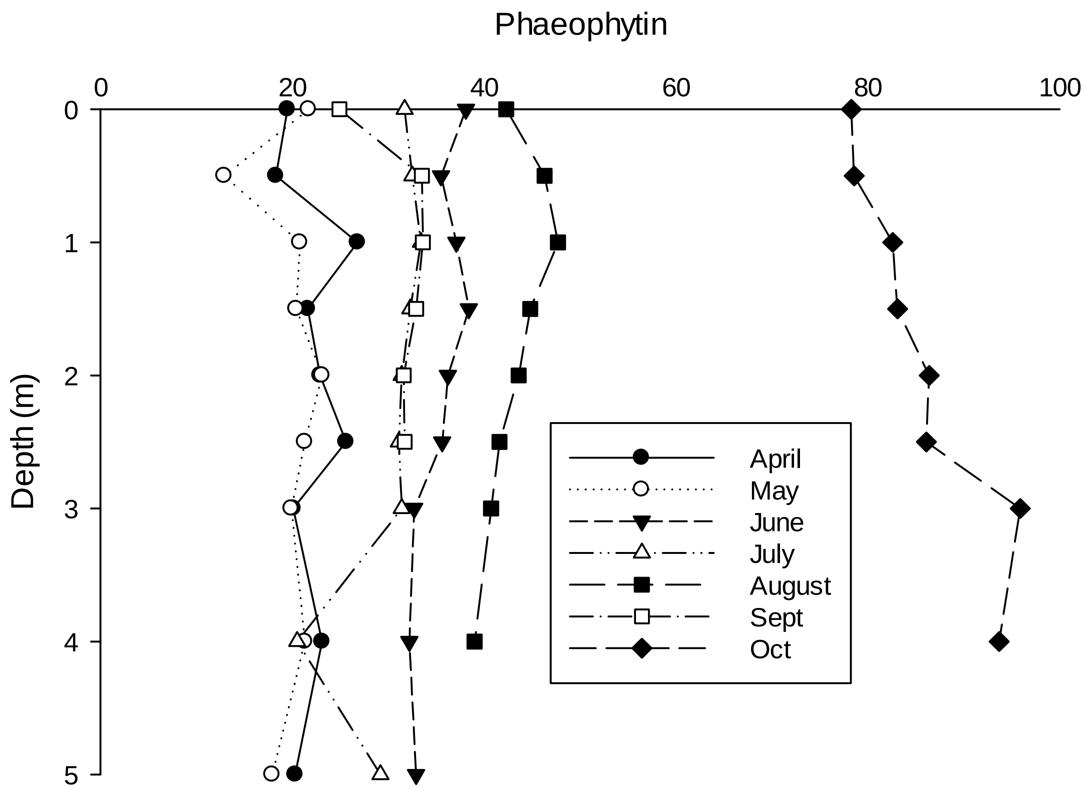


Figure 1.18. Toler Bridge (Riverine) Chlorophyll *a* (ppb) and Pheophytin (ppb) concentrations over study period (2019)

Seasonal Analysis

This station contains the lowest readings of phytoplankton biomass in the reservoir and measures of pheophytin may help to interpret these findings. Pheophytin measures are higher than measured Chlorophyll *a*. Pheophytin is a measure of chlorophyll breakdown suggesting sediment influences the observations. And this is confirmed directly by the turbidity observations (Figure 1.21). Thus, October Pheophytin measures are correspondingly high as well with a much smaller portion of the overall turbidity a product of Chlorophyll *a*. Thus, productivity here is most likely influenced by water movement, Pigg River flow and high turbidity create the lower overall values.

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

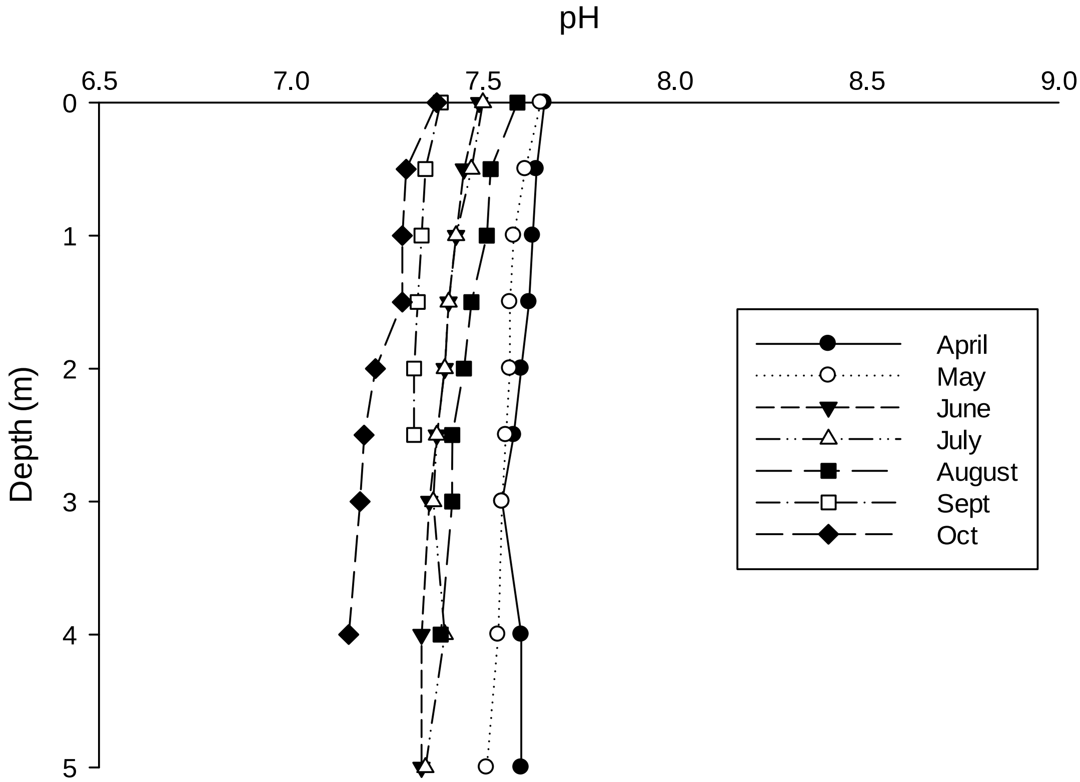


Figure 1.19. Toler Bridge (Riverine) pH measures over study period (2019)

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. 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 2019 or in previous years.. It is likely that pH is traceable to flow and phytoplankton growth throughout the years.

ORP

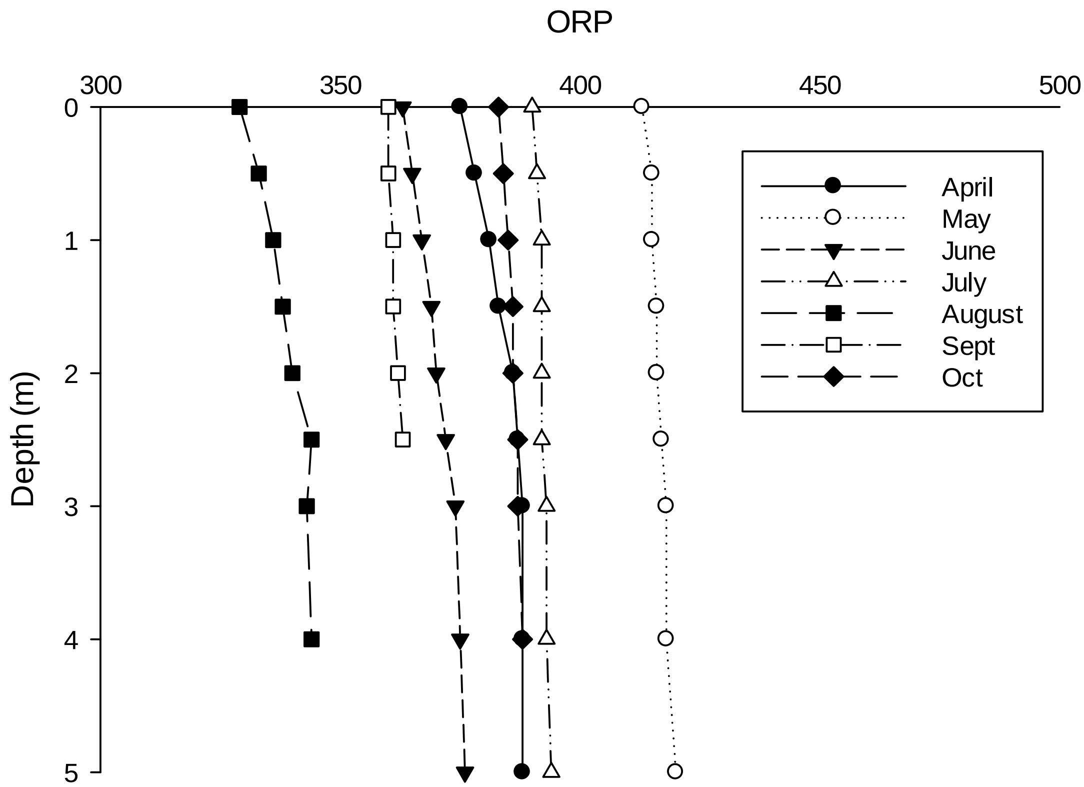


Figure 1.20. Toler Bridge (Riverine) ORP (mV) measures over study period (2019)

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

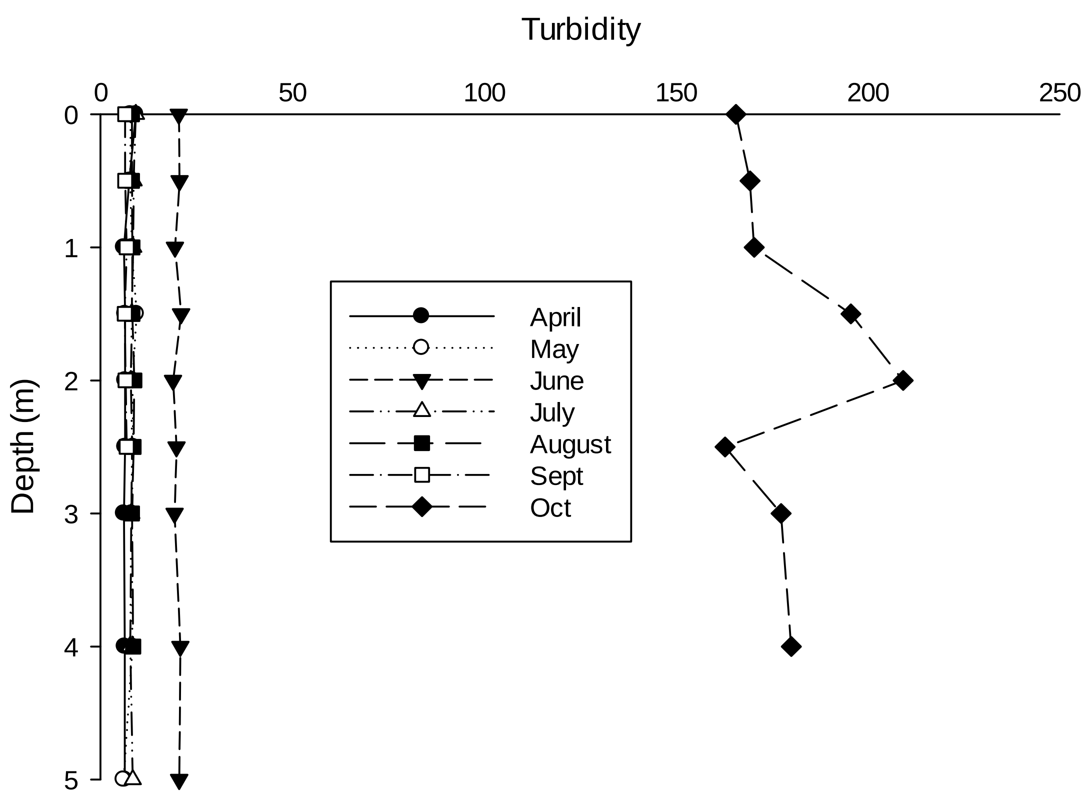


Figure 1.21. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2019)

Seasonal Analysis

Turbidity pattern in this portion of the is heavily dependent on flow from Pigg River. As a good portion of time this season was dry until the sampling in October, the results demonstrate how turbidity is important driver of water quality at Toler Bridge.

Comparisons Across Years

Turbidity consistently ranged between 15-50 NTU through previous years of study. October reading in 2019 were very high and well beyond what is typical. 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 (2019). Dates represent sampling of both the volunteers and university. First Column represents each parameter measured along with units of measure.

	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	3:30 PM	11:10 AM		12:11 PM		12:58 PM		11:55 AM	10:31 AM	4:40 PM	
Secchi (M)	1.20	1.30	0.4	0.70	0.90	1.25	1.10	1.20	1.35	0.20	0.96
TP Surface (PPM)	0.140	0.111	0.189	0.065	0.058	0.047	0.011	0.106	0.076	0.456	0.13
NO3	2.780	2.598		2.738		2.148		0.946	1.305	2.963	2.21
Integrate Chl a	4.00	12.41		11.11		11.24		26.95	17.57	10.33	13.37
TSI S	57	56	73	65	62	57	59	57	56	83	62.51
TSI TP	72	68	76	61	60	57	39	68	63	88	65.20
TSI CHL	44	55		54		54		63	59	54	54.74
TSI AVG	58	60	75	60	61	56	49	63	59	75	61.48

Of note this season were the readings associated with the October inflow of water from Pigg River and other measures in the earlier part of the sampling season. During wet weather, TP inflow is high. From April-June, TP exceeded 100 ug/L. This continues to be concerning and this level of TP moves either into SML or down Leesville will cause problems. Poor TSI readings and lower Secchi depths are associated with this. Finally, October readings were as high as ever observed entering the reservoir. If Pigg River empties waters as high as 456 ug/L of TP this is a very HIGH loading rate. This needs serious consideration and management in the watershed.

Table 1.30. Zooplankton and *E. coli* measured over study period (2019). Dates represent sampling of both the volunteers and university. Zooplankton numbers are organisms per liter.

	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	3:30 PM	11:10 AM		12:11 PM		12:58 PM		11:55 AM	10:31 AM	4:40 PM	
Daphnia	0.0	1.4		2.8		0.6		0.0	0.0	0.3	0.73
Bosmina	13.0	1.1		0.0		3.1		1.4	1.4	2.8	3.28
Diaptomus	0.0	0.0		1.7		0.6		0.6	0.3	0.6	0.53
Cyclops	0.0	0.0		1.4		7.6		5.7	3.4	1.7	2.83
Nauplii	0.8	0.0		0.8		5.1		1.4	0.0	0.6	1.25
Cerodaphnia	0.0	0.3		1.1		0.0		0.3	0.0	0.0	0.24
Diaphanosoma	0.0	0.3		0.0		0.0		0.8	1.1	0.0	0.32
Chydorus	0.0	0.0		0.0		0.0		0.0	0.0	0.0	0.00
E. coli MPN	209.80	78.00	2419.6	68.90	8.60	48.00	6.3	4.10	1.00	8664.50	1150.88

Zooplankton is never of note at this station primarily because of the high turbidity that interferes with zooplankton feeding and the movement of water that is not ideal habitat for these organisms. *E. coli* concentration is concerning. October readings were extremely high and I cannot find similar readings ever at this station. In fact, the June 13 readings were the second highest we have ever observed at this station. We have a strong concern conditions are worsening in the watershed and must be properly investigated and measures developed to control these problems.

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 (2019). Measures are integrative throughout the entire water column. Profile data located in the appendix.

	24-Apr	29-May	13-Jun	25-Jun	16-Jul	25-Jul	13-Aug	28-Aug	25-Sept	28-Oct	Average
Time	3:47 PM	11:24 AM		12:25 PM		1:13 PM		12:05 PM	10:48 AM	4:58 PM	
Secchi (M)	0.80	1.00	0.15	0.6	0.5	0.75		0.70	0.70	0.10	0.59
TP Surface (PPM)	0.092	0.105		0.115	0.149	0.123		0.085	0.108	1.182	0.24
NO3	1.8	2.8		2.7		2.7		1.7	1.3	5.3	2.61
Integrate CHL	5.5	6.9		4.5		6.5		7.6	16.6	10.8	8.36
TSI S	63	60		67		64		65	65	93	68.31
TSI TP	66	68		69		70		65	68	102	72.46
TSI CHL	47	50		45		49		50	58	54	50.57
TSI AVG	59	59		61		61		60	64	83	63.78
E. coli cfu/100ml	387	205	9678	579	214	73	72	167	86	24196	3565.87
Temp C	17.9	23.9		24.4		23.8		22.6	21.4	17.07	21.58
DO mg/L	9.15	7.26		7.63		7.98		8.3	8.14	8.5	8.14
DO %	99.1	88.9		93.7		96		98.5	94.2	88.4	94.11
Turbidity NTU	17.2	12.5		33.8		21.8		27.6	24.6	495	90.36
Cond ms/cm	0.064	0.094		0.073		0.074		0.076	0.079	0.058	0.07
pH	7.48	7.47		0.32		7.45		7.32	7.32	7.23	6.37
ORP	475	424		396		403		419	368	457	420.29
CHL ug/L	3.7	5.4		4.4		6.54		7.6	16.1	11.2	7.85
Pheophytin ug/L	28.1	19.6		19		19.9		34.1	36.9	157	44.94

It has become apparent that water in the Pigg River is very impaired when impacted by stormwater flow and delivered to Leesville Lake. Two measures this season, June 13 and Oct 28 are very concerning. *E. coli* is extremely high with the October reading of 24196 counts/100ml hard to analyze. This reading is so high it should cause alarm to anyone responsible for water management in the area. Further, the associated TP of 1182 ug/L is tremendous. This level of pollution entering Leesville Lake and SML forebay through pumpback will create problems in these reservoirs that will be very difficult to manage. It is extremely high.

1.3.1.8 Smith Mountain Lake Tail Waters

Table 1.32. Smith Mountain Lake Tail Waters other parameters measured over study period (2019). Measures are at the surface.

	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct	Average
Time	4:03 PM	11:44 AM	12:40 PM	1:30 PM	12:20 PM	10:48 AM	5.17 PM	
Temp	11.7	15.7	19.8	21.02	22.6	23.39	19.9	19.16
Cond	0.168	0.164	0.139	0.158	0.136	0.152	0.161	0.15
DO	10.07	8.11	6.99	6	6.7	6.57	6.7	7.31
pH	7.59	7.52	7.34	7.4	7.37	7.45	7.35	7.43
DO %	95.6	84.2	78.5	68.5	80.3	78.8	74.9	80.11
ORP	467	493	437	462	476	42.7	493	410.10
Turbidity	1.8	4.1	15.6	5	8	7	27.1	9.80
Secchi (M)	4.20	2.54	0.70	1.75	1.30	1.200	0.750	1.78
CHL	2.4	3.75	4.91	3.15	10.1	13.9	11.1	7.04
PHy	20.4	15.9	26.7	20.1	26.3	33.6	20.6	23.37
Turb	1.8	7.117	6.901	5	8	7	27.1	8.99
TP	0.092	0.105	0.056	0.019	0.026	0.098	0.148	0.08
NO3	1.78	2.77	2.69	2.18	1.85	1.00	0.94	1.89
TSI S	39	47	65	52	56	57	64	54.38
TSI TP	66	68	59	45	49	67	72	60.88
TSI CHL	39	44	46	42	53	56	54	47.82
TSI AVG	48	53	57	46	53	60	64	54.36
E. coli MPN	6	24	127	41	8	10	980	171

Observations at the Tail water station reveal interesting trends that occur in the reservoir at this starting point. Summer oxygen levels are generally concerning. Our measures this summer did not find a date where levels dipped below the 5 mg/L threshold. Additionally, water at the tail waters seemed to be a mix between Pigg River and SML hypolimnion release. April and May Secchi depths were the deepest of the season very unlike readings at the Leesville Lake dam. Readings for the rest of the season suggest pumpback influenced water quality at this station. The October *E. coli* was extremely high for this station along with the June sampling. Thus there may be a trade off in at this station between higher levels of oxygen with *E. coli* depending on pump back rates from Pigg River.

Section 2: Lake-Wide Trends

The purpose of this section is to look at the functioning of the reservoir and establish trends using each new year of data. 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[3]

In this analysis, trends of all the measurable trophic state indices (TSI) are evaluated for 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

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

provides a predictor based on differing influences within the reservoir. Secchi depth is influenced by both sediment input and phytoplankton growth, whereas total phosphorus (TP) simply reflects the concentrations of this limiting nutrient but also dynamics within the reservoir. Additionally, Chlorophyll *a* concentrations reflect conversion of TP into 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, with municipal input from Rocky Mount). This unique combination has a very profound impact on water quality. This trophic state analysis (Section 2.1), hydrological 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.

<u>Secchi Depth TSI</u>

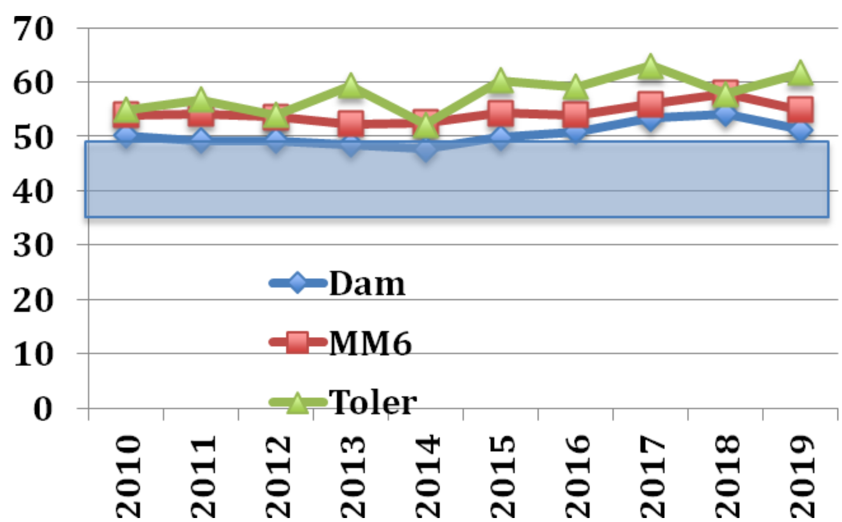


Figure 2.1. Trophic State Index (TSI) based upon Secchi disk (meters) measurements in Leesville Lake from 2010-2019. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Analysis

Predictions of trophic state using Secchi depth clearly suggest the reservoir has become more turbid. Since departure from the mesotrophic classification in 2015, the dam station has not returned. Examining precipitation data from the last two seasons (Figure 2.2), 2018 was a very wet year while 2019 somewhat dry. Total precipitation in this chart is somewhat misleading as the very wet weather during 2018 continued into the spring of 2019 followed by very dry and drought conditions. The calendar year 2019 ended with a return of wet weather (our sampling captured this in the October sampling) giving a clear picture of hydrology impact in the reservoir.

Thus, dry summer conditions appear to have the impact of improving water quality based on Secchi down the reservoir while decreasing water quality in the upper portions. Most likely a product of reduced inflow from SML while greater frequency of pump back is likely to entrain more water from Pigg River in the upper portions of the reservoir.

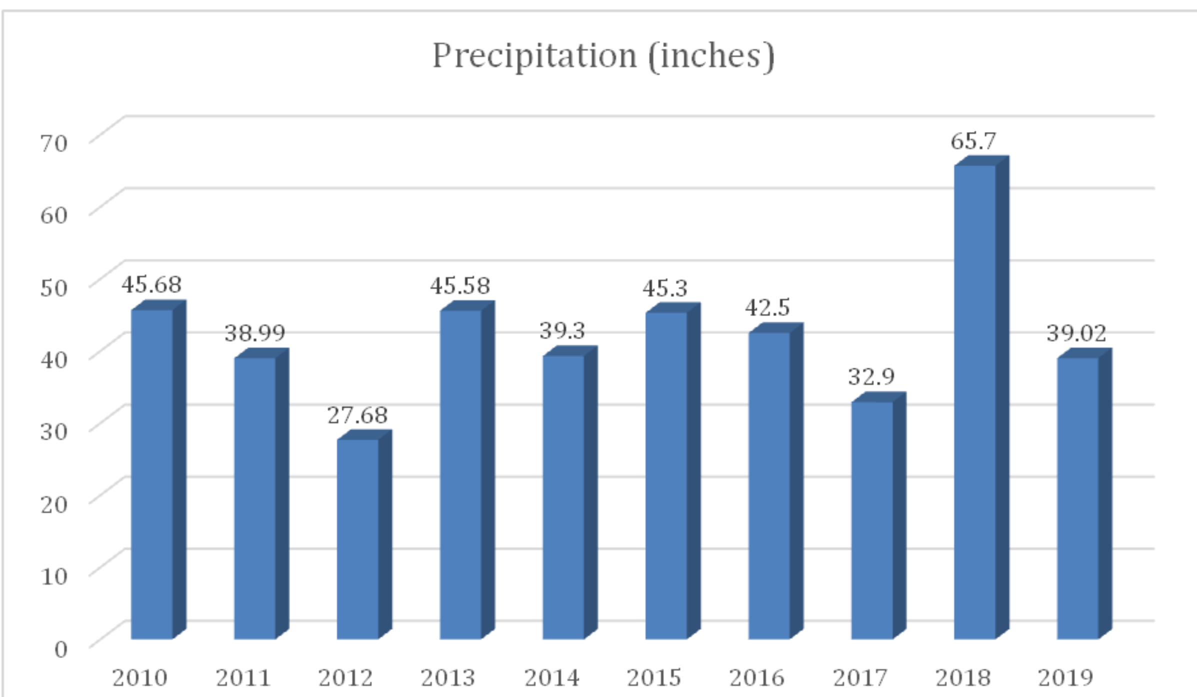


Figure 2.2. Annual precipitation in the Central Virginia area measured by National Weather Service reported in inches. Hashed line represents tend line over the period of study.

Total Phosphorous TSI

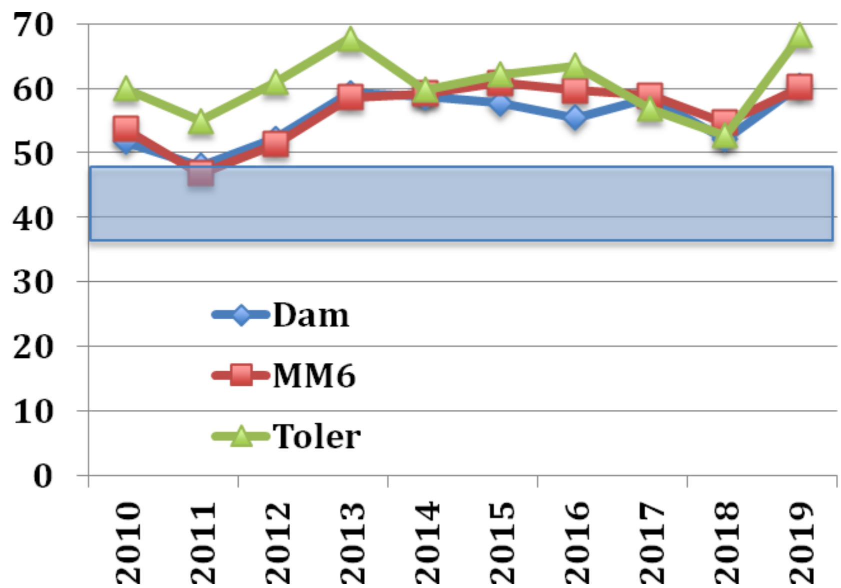


Figure 2.3. Same as Figure 2.1 but TSI based on Total Phosphorus (TP).

Analysis

Trophic state based on total phosphorus suggests the reservoir is eutrophic (Figure 2.3). Yet trending provides a somewhat different interpretation from TSI Secchi data. Since the mid-point of 2014, TSI phosphorus was trending lower. Yet in 2019 all stations throughout the entire lake trending toward increase. And TP at Toler station was as poor as we have ever measured. 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. Because of dry conditions and absence of dilution from SML higher than expected TP conditions were recorded. The interesting trend was throughout the entire lake. Seems lack of dilution from SML and the worsening conditions in the Pigg river are observed throughout the entirety of Leesville Lake.

Chlorophyll *a* TSI

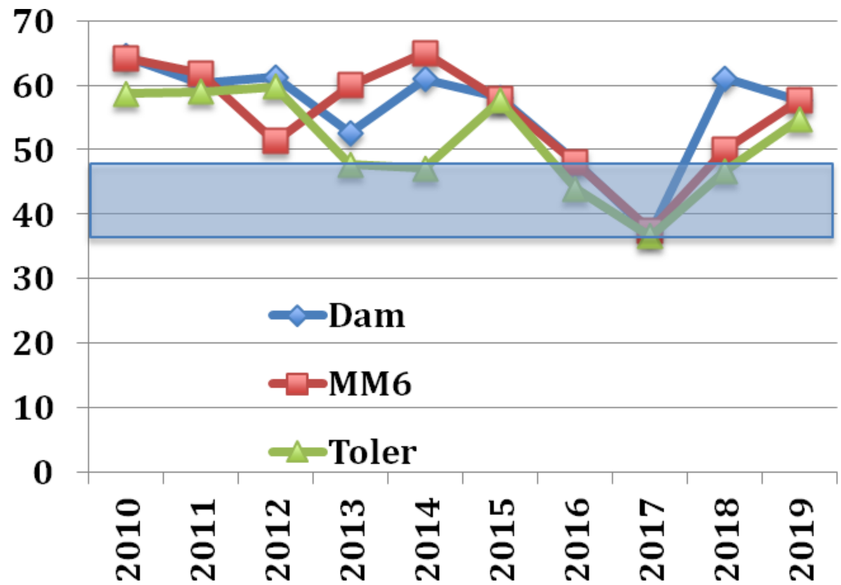


Figure 2.4. Same as Figure 2.1 but TSI is based on Chlorophyll *a*.

Analysis

Trophic state based upon Chlorophyll *a* is more difficult to interpret. TSI based both on Secchi depth (Figure 2.1) and phosphorus (Figure 2.3) are now trending upward. The exception is mid to lower stations where TSI Secchi did improve in 2019. So typical arguments suggest increased TSI Chlorophyll *a* (Figure 2.4) should naturally occur with elevated TP. This type of thinking is supported at Toler and MM6 but not at the Dam. Characterizing this as bottom up control of productivity the argument can be made the upper portions of the reservoir are influenced in this manner.

As discussed in previous reports, Pigg River turbidity and sediment inputs appear to drive the reservoir. What also is suggested here is that pump back operations influence this bottom up control. Because water is moving back and forth it is the upper part of the reservoir that is most heavily influenced. Thus, pump back almost creates water quality conditions in the upper portion of the reservoir isolating it from the lower portion.

Therefore, the lower portion of the reservoir may be controlled by top down forces. Looking at zooplankton data (Figure 2.8), it is clear the dam station is consistently the most productive station for *Daphnia*. In a typical reservoir, it may be assumed that MM6 or the middle transition zone would harbor the greatest productivity of zooplankton, Thus even with increasing levels of phosphorus loading from the Pigg River, the dam station Chlorophyll *a* may be controlled by *Daphnia* productivity or top down forces.

TSI Average

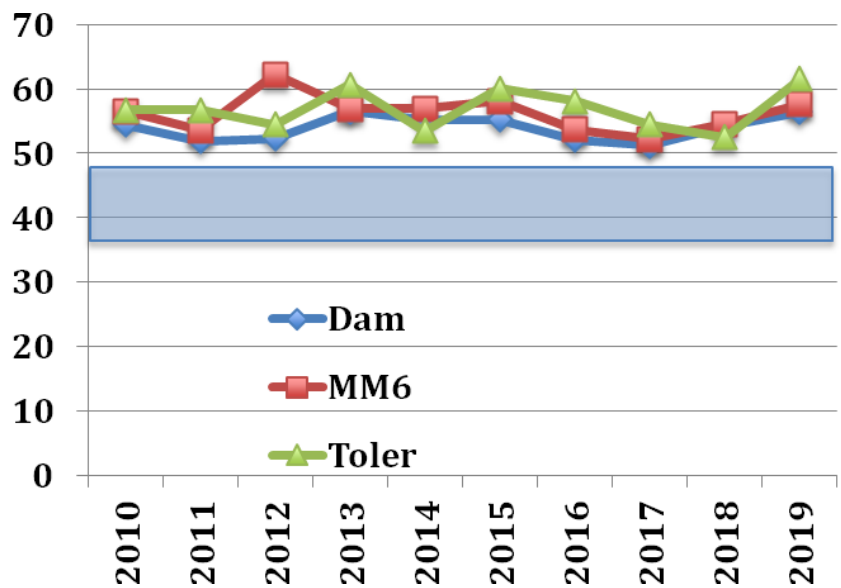


Figure 2.5. Same as Figure 2.1 but TSI presented is the average of TSI for all parameters evaluated (Secchi Depth, Total Phosphorous, Chlorophyll *a*).

Analysis

Averaging trophic state indices based upon multiple parameters leads to the conclusion that the trophic state in the reservoir has remained somewhat consistent throughout the study period and that the reservoir is mildly eutrophic. These trends have moved up and down through the years but remains in the range between 50-60. While during other periods of time we have observed trends declining in this range we are currently experiencing a period of increasing trophic state.

Daphnia Productivity

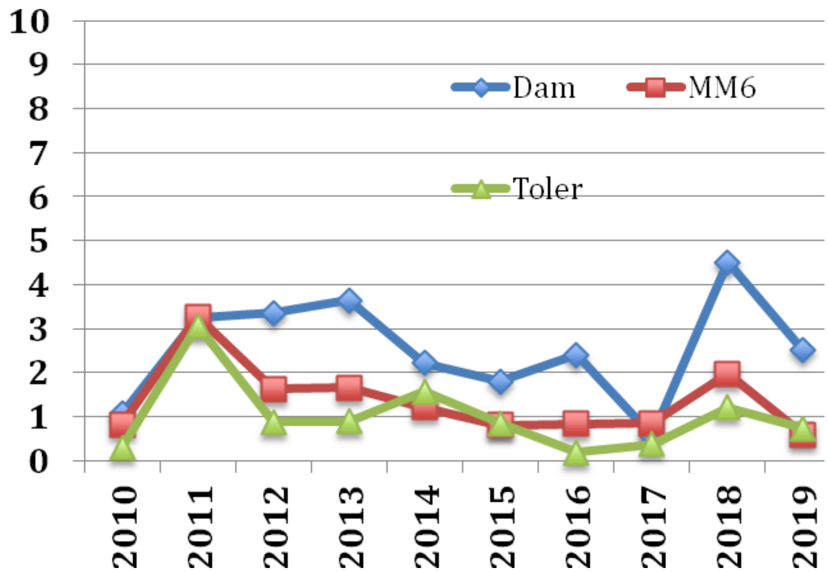


Figure 2.6. Average *Daphnia* concentrations in Leesville Lake from 2010-2019. Numbers on y-axis represent *Daphnia*/ liter.

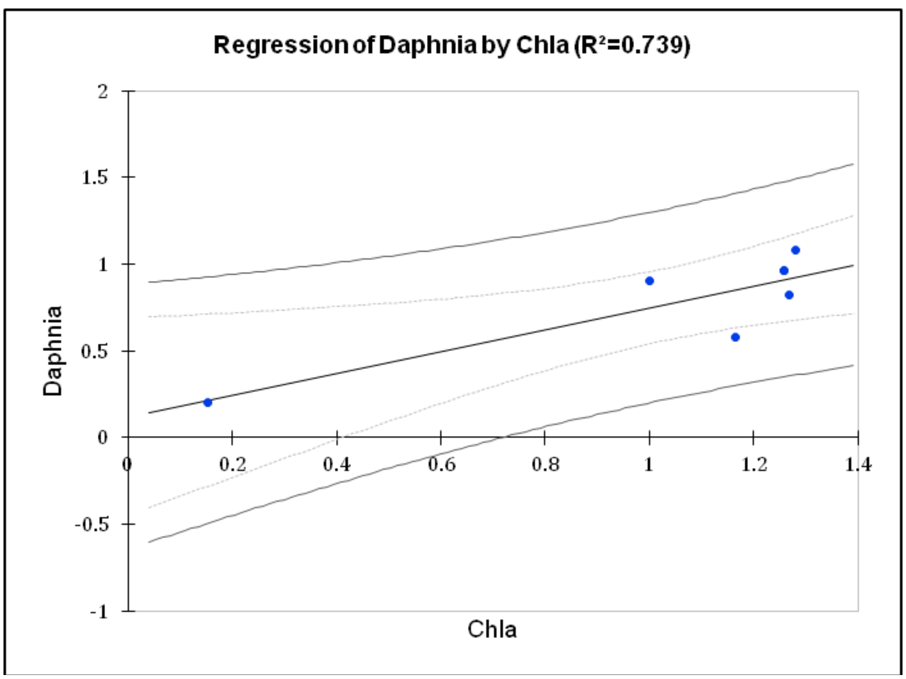


Figure 2.7. Regression of *Daphnia* with Chlorophyll *a* values in the reservoir from 2013-2019 at Dam station. Values are log transformed and the relationship is significant (p=0.026).

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 while in 2018 we measured the highest. In 2019, this trend once again normalized back to abundances observed between 2011-2016. It is now becoming clear that in Leesville Lake, *Daphnia* populations respond to phytoplankton abundance at MM6 and Toler Bridge while potentially responding to fish predation at the Dam station.

These relationships may be very temporal. 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. Another

2.2 Hydrological Analysis

In an effort to understand the relationship between Pigg River input, pump back operations at SML dam, hydrological flow from SML to Leesville Lake and overall water quality we undertook a study of pump storage patterns during the 2019 season. Ethan Bachelor, an Undergraduate Environmental Science Major collected data on pump back operations at the SML dam using data available on the AEP website (AEP 2019). Data collected included the forebay of LVL that is the water height at LVL dam and tail water height that is the height of LVL at base of SML dam. To determine the intensity and direction of flow from pump-storage, we subtracted tail water height from forebay height. Thus, a positive difference reflected pump back because forebay height was greater than tail water height. A negative difference reflects release from SML to LVL. The intensity (amount of water) of the release or pump back was determined by size of number. The results were separated between morning (defined as 12:00am- 11:59am) and evening (defined as 12pm-11:59pm).

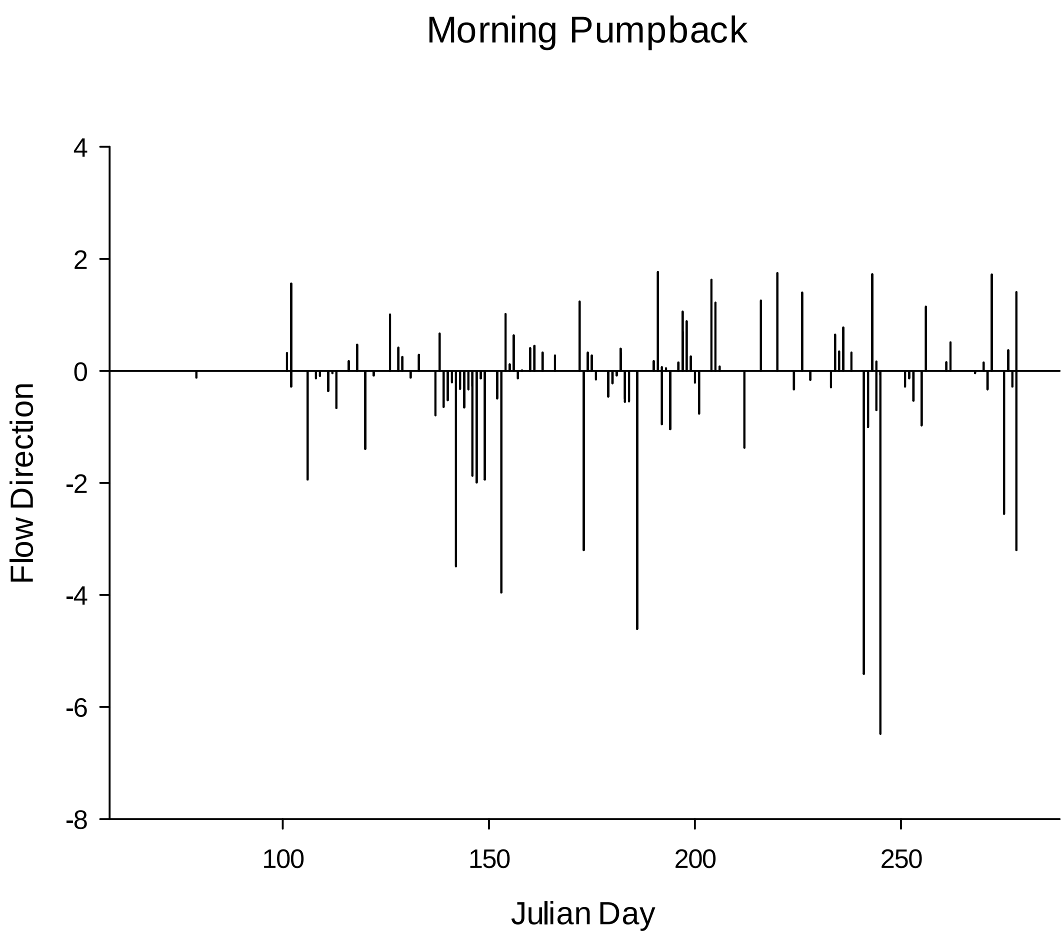


Figure 2.8 - The difference in elevation between the LVL forebay and SML tail water in feet plotted over the period of time collected. This figure represents only pump back/release rates in feet during the morning which is defined as 12:00am to 11:59am. Positive values on the y-axis represent water being pumped back into SML and negative values represent water being released into LVL to generate electricity. The greater the values deviate from 0 feet, the greater the intensity of water movement.

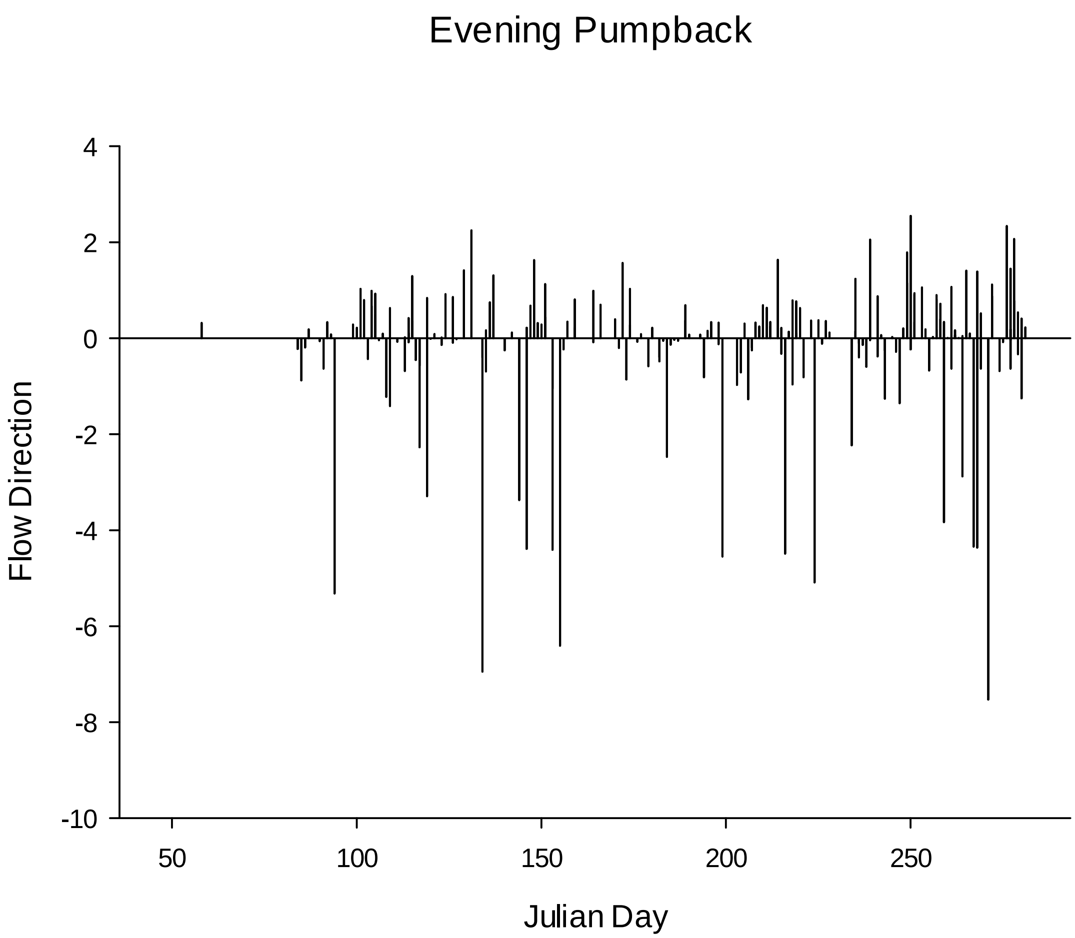


Figure 2.9 - The difference in elevation between the LVL forebay and SML tail water elevation in feet plotted over the period of time collected. This figure represents only pump back/release rates in feet during the evening which is defined as 12:00 pm to 11:59 pm. Positive values on the y-axis represent water being pumped back into SML and negative values represent water being released into LVL to generate electricity. The greater distance the rate of pump back/release is from a difference of 0 feet, the greater the intensity of water movement.
There is no discernable pattern in when American Electric Power pumps or releases water between SML and LVL (Figures 1 and 2). Figures 1 and 2 confirm that AEP is capable of releasing far greater quantities of water to the storage reservoir than it pumps to the upper reservoir.

Pump storage data did not discern a detectable pattern (Figures 2.8 and 2.9). Electricity demand and other factors appear to drive how SML is operated. Some generalizations are apparent. Pump back does occur more frequently during the evening. This seems rather intuitive however pump back occurs often during the morning hours as well (Figure 2.8). SML release into LVL is quite intensive at times. It can occur over multitude of days but often is an isolated event followed by pump back. Did not appear morning or evening impacted the intensity of release.

From this data we took two approaches to determine the impact of these pump storage patterns on water quality in Leesville Lake at the tail water release. Using Principal Component Analysis (PCA), all data collected at the tail water station in 2019 was analyzed. Thus, a 24hr, 48hr, 72hr and 168hr compilation of SML dam operation was created to compare to this collected data. The value calculated was a culmination of all of our data collected in the time allotment prior to the sampling date.

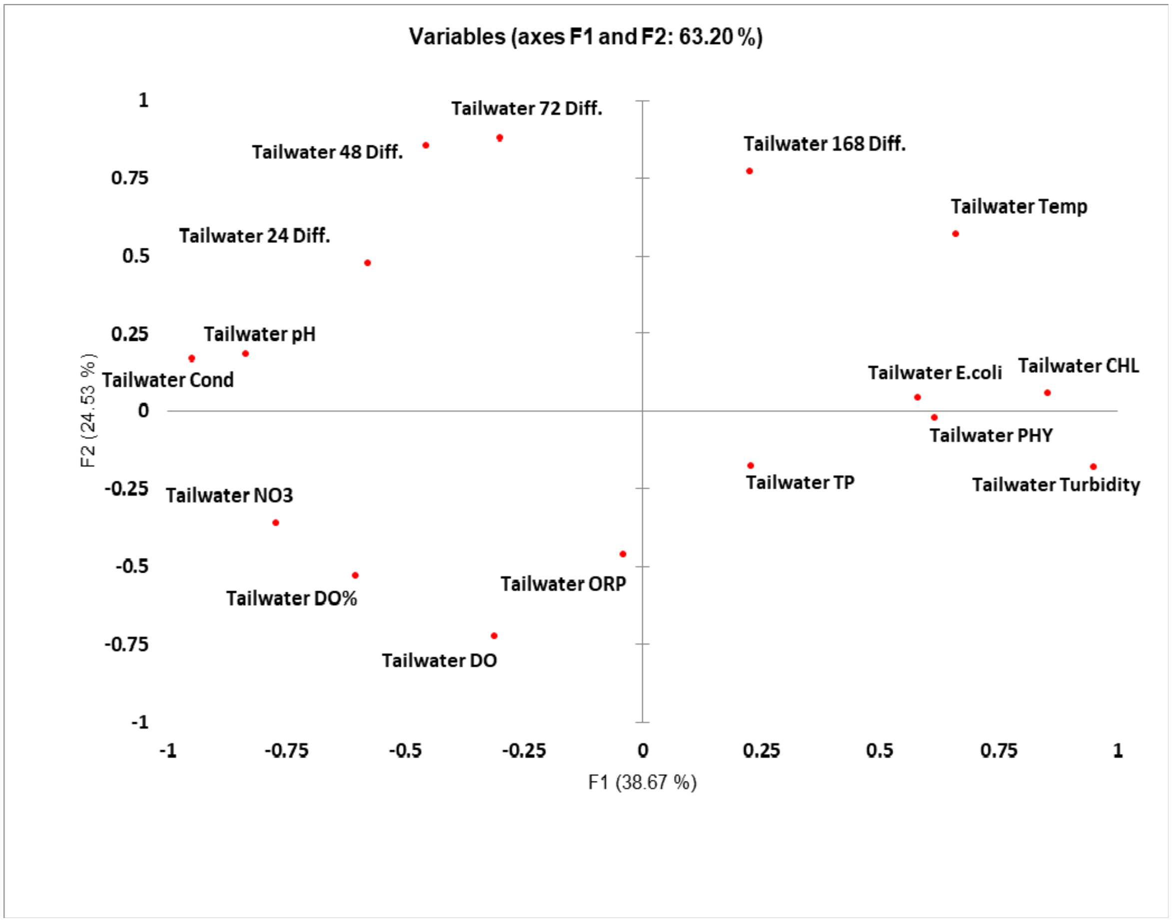


Figure 2.10— Principal Component Analysis of Tail water quality parameters. F1 on the y-axis represents factor 1., or principal component 1. The greater the distance the data deviates from the y-axis, the greater influence that individual water quality parameter has affecting all other water quality parameters. The greater the data deviates from the x-axis for Factor 2, the greater the influence that individual water quality parameter has on affecting all other water quality parameters.

The findings of the PCA analysis reveal interesting patterns between SML dam operation and water quality (Figure 2.10). Tail water conductivity very strongly negatively correlated along the F1 axis. This suggests that declines in conductivity are correlated along the F1 axis. We know that conductivity is much lower in the Pigg River thus declining conductivity suggest an influx of Pigg River water into the tail water station. The other parameters follow in this analysis (Figure 3). *E. coli*, turbidity and Chlorophyll *a* show increasing trends followed by a decrease if oxygen in this analysis. Thus, the influx of low conductivity water (Pigg River) corresponds with increasing *E. coli*, turbidity and Chlorophyll *a*. These findings suggested by this analysis are rather intuitive and thus confirmed by the PCA. What is novel is the correlation to water movement.

Time differential moves along the F1 axis from a negative association at 24hrs to a positive association at 168hrs. This suggests the immediate impact of pump storage is a reduction in conductivity at the 24hr pump back and an increase of other parameters at the 168 hour interval. Thus, the following implications can be inferred. Short term changes in water quality from pump back include a decrease in conductivity. In situations where 168hrs cumulative impact is a pump back from LVL to SML, E. coli, turbidity and Chlorophyll *a* increase while oxygen decreases.

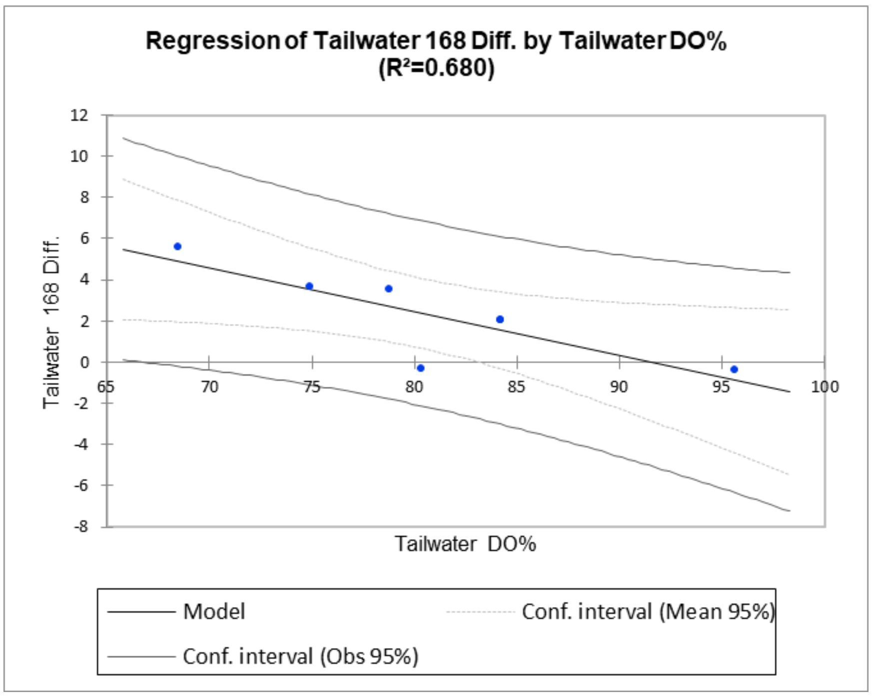


Figure 2.11— Relationship between tail water DO% and calculated net tail water difference for pumping 168 hours before sampling time and date.

Plotting oxygen data with the 168hr differential (Figure 5), the relationship between pump back intensity and oxygen is further identified. Greater pumpback intensity was associated with lower saturation levels of oxygen. This further supports the idea that pumpback is the cause of low oxygen levels at the tail water release.

2.3 Pigg River Study

Introduction and Background

The investigation initiated in the summer of 2018 to investigate water quality conditions in the Pigg River Watershed was continued in 2019 to determine the exact origins of *E. coli* contaminations at certain stations and during various stormwater flows in the river. Background of the study including sampling methodology, stations investigated, rational and findings during 2018 are included in Appendix D for reference and explanations. Here, we report on the additional findings during the more intensive sampling and bacterial source tracking initiated in 2019.

Based upon areas identified in 2018 as potential “hot spots” we initiated sampling in 2019 to monitor these sites using both the conventional sampling that included water chemistries and Colilert E. coli testing with the addition of Bacterial Source Tracking (BST). A hot spot was considered a sampling station where excessive concentrations of E. coli were measured in 2018 using the Colilert methodology. Excessive was considered over 1000 counts/100ml during low flow conditions and in excess of 2400 counts/100ml during flood conditions. The excessive classification for hot spots was determined through observations of the data collected in 2018 along with statistical analysis looking at clusters in the data.

A two tiered approach was selected for this study. Initially, we sampled above (Figure 1), below (Figure 2) and directly in the hot spot during low flow conditions in the river (Figure 3). Low flow was during periods of time where stormwater was flowing in the river. Stormwater could be identified by high turbidity (>50 NTU) in the river and appreciable rain (> 0.5 inches) in the watershed during the week preceding a sampling. Low flow sampling was designed to pinpoint exact location of bacterial contamination. The second sampling was designed to identified contamination during a stormwater event. Several additional sampling sites along Pigg River were sampled to track the flow of contamination along the river into Leesville Lake.

Figure 2.12. Sampling the Pigg River at Chestnut Hill Road crossing during the dry period for Bacterial Source Tracking.

Three sampling dates were selected. September 18 2019 was our initial sampling around the hot spot and conditions were very dry without any appreciable precipitation in the area for well over 3 months. On October 10, 2019, we followed-up on this study under dry conditions once again including sites further down the Pigg River (Toshes and Truevine) to determine if the high readings from Rocky Mount flowed into

The bacterial source tracking was conducted by a commercial firm (SourceMolecular, Miami Lakes, FL) on water samples that were aseptically collected and shipped overnight. The host species was determined using quantitiatve polymerase chain reaction (qPCR). Marker sequenes were for various bacteriodes species were identified and, using appropriate primers, the sequences were amplified sequences and quantified. A single human marker sequence was targeted, two bovine sequences (bovine 1 and 2) and a more encompassing ruminant sequence was also targeted. A sequence for geese was also targeted in the September sampling, but was eliminated subsequently because geese were not a contributing factor. The qPCR for the ruminant marker is more sensitive than the bovine markers, however revealed the same pattern. Most likely indicating that amont ruminants, cattle are the primary hosts for contamination.

Results and Discussion

It is clear from the collected data that the Pigg River is impaired (Table 1). Our bacteriological results clearly suggest the river is constantly impaired for *E. coli* whether dry or wet conditions prevail. The Furnace Creek area in Rocky Mount is very concerning and very contaminated with human source bacteria. We found extremely high bacteria counts in our initial dry period sampling (September 18) and the following date (October 10) while much lower was still all human source. This is an area of concern that needs immediate attention. Following this contamination down Pigg River on Oct 10 to Toshes Road we found the contamination was lower and only a fraction of the human source remained. Yet, the water remained contaminated with primarily ruminant marker. Looking at the other parameters, nutrient pollution is concerning as well (Table 1). This likely results from agricultural activity in the watershed. The area at Chestnut Hill Road crossing is the most concerning.

Wet period data was very concerning (October 23). We found extremely high E. coli counts at Chestnut Hill Road, Furnace Creek and Toshes Road (near entrance to Leesville Lake. The Toshes Road sample was over 12000 E. coli/100ml which is extremely high for water entering the lake. The identification patterns were somewhat similar to the dry period with all bacteria identified with human marker in Furnace Creek, mixed but primarily ruminant in the other samples. While Chestnut Hill Road *E. coli* concentrations were lower than Toshes Road, bacteria source tracking suggested greater amounts of contamination. Regardless, the levels of contamination were very, very elevated. Nutrient pollution was also concerning during the wet period sampling with Chestnut Hill Road and Waid Park the greatest concern.

Table 2.1– All collected data during the study.

Pigg River Sampling			18-Sep-19												
Station	Temp C	Cond	DO %	DO mg/l	pH	ORP	Turbidity	TP mg/l	NO3 mg/l	E. coli	Human	Bovine	Ruminant	Geese	Total
Waid Park	17.9	55	103	9.76	7.4	25.2	2.9	0.041	2.499	365	375	0	8100	0	8475
S. Main St.	18.2	64	101.3	9.57	7.51	17.2	3.2	0.058	2.438	2420	223000	0	1030	0	224030
Furnace Creek	17.5	129	98.2	9.41	7.5	21.2	2.2	0.114	3.282	2430					
Power Dam Road	18.7	65	102.8	9.6	7.5	19.2	5.2	0.082	2.676	326	15000	0	2170	0	17170
Chestnut Hill Roa	18.7	69	104.3	9.73	7.6	24.7	4.5	0.145	2.897	548	6400	0	1890	0	8290
			10-Oct-19								Human	Bovine I	Bovine II	Ruminant	Total
Waid Park	14.23	40	100.2	10.26	7.71	19.7	1.84	0.098	2.45	276	8	0	0	2210	2218
Memorial Park	14.42	49	100.9	10.31	7.52	35.7	1.22	0.084	2.179	687					
Furnace Creek	14.52	112	104	10.6	7.79	25.6	0.91	0.08	2.862	407	427	0	0	0	427
South Main	14.52	61	103.9	10.59	7.78	25.7	1.74	0.114	2.56	484	85.3	0	0	1530	1615
Avalon Road	13.72	109	84.1	8.87	7.67	35.6	2.48	0.097	2.779	977					
Chestnut hill	15.69	61	109.7	10.87	7.16	38.3	4.7	0.254	2.616	488	34.9	0	339	6170	6544
Truvine	14.41	52	92.1	9.44	7.49	37.2	2.29	0.121	1.031	236	8	0	0	681	689
Toshes	15.97	55	94.5	9.33	7.78	48.9	4.78	0.108	0.778	132	2.13	0	0	944	946
			23-Oct-19								Human	Bovine I	Bovine II	Ruminant	Total
Waid Park	10.65	44	90.3	10.05	7	28	8.95	0.352	2.707	1986	240	766	1040	87400	89446
Furnace Creek	11.25	98	89.6	9.77	7.32	29.6	3.91	0.096	2.588	1151	36000	0	0	0	36000
South Main	11.15	66	112.8	12.4	7.12	35	4.52	0.13	1.995	2897	17900	780	2000	79500	100180
Avalon Road	10.77	95	78.5	8.61	7.31	25.6	2.38	0.101	2.421	1538					
Chestnut hill	11.48	54	100.8	10.97	6.93	35.8	10.41	0.292	4.372	9932	920	21000	37100	1290000	1349020
Truvine	11.32	45	102.5	11.19	6.88	41	7.72	0.22	1.54	3024	284	803	1110	53800	55997
Toshes	11.9	42	80.2	8.63	6.62	72	12.95	0.262	2.681	12098	196	2110	2900	154000	159206

One additional task was to determine if our conventional sampling could be used to detect the contamination we documented from the Bacterial Source Tracking. Using Principle Component

Analysis (PCA), we examined all data first from the Oct 10 dry period (Figure 2.13). Interestingly, *E. coli* did not closely correlate to any of the BST data. The only parameter closely correlated with *E. coli* was NO3. Conversely, TP provided a close match to the ruminant and bovine data. Thus, in the river we can track TP in the basin along with E. coli to help track down even further where these contaminants are originating. Unfortunately, none of the conventional pollutants monitored were well correlated with the human bacteriological markers.

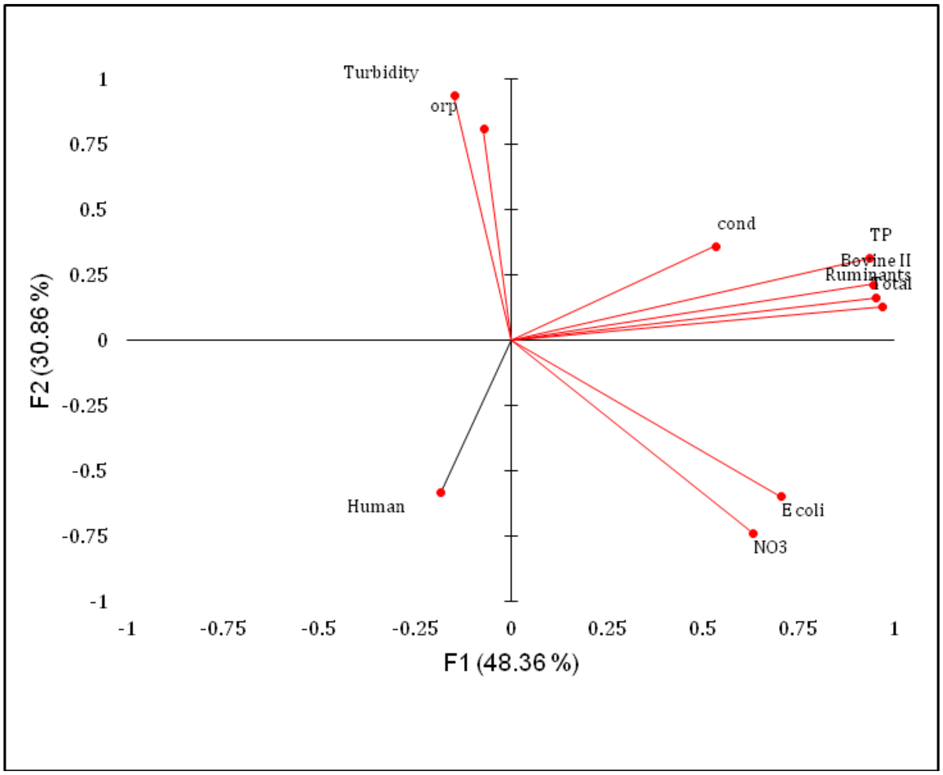


Figure 2.13 – PCA analysis for water quality parameters collected during the October 10 sampling.

Results from the wet period gave some promising results (Figure 2.14). In this instance, conductivity associated with the human contamination. Thus, in conjunction with *E. coli* sampling to determine the extent of Human bacteriological contamination we can look at conductivity. And then using NO_3, we can approximate ruminant and bovine. These approximations would be useful in future studies to pinpoint exact hotspots in the river that would later be confirmed with the BST. We can use regression analysis to approximate.

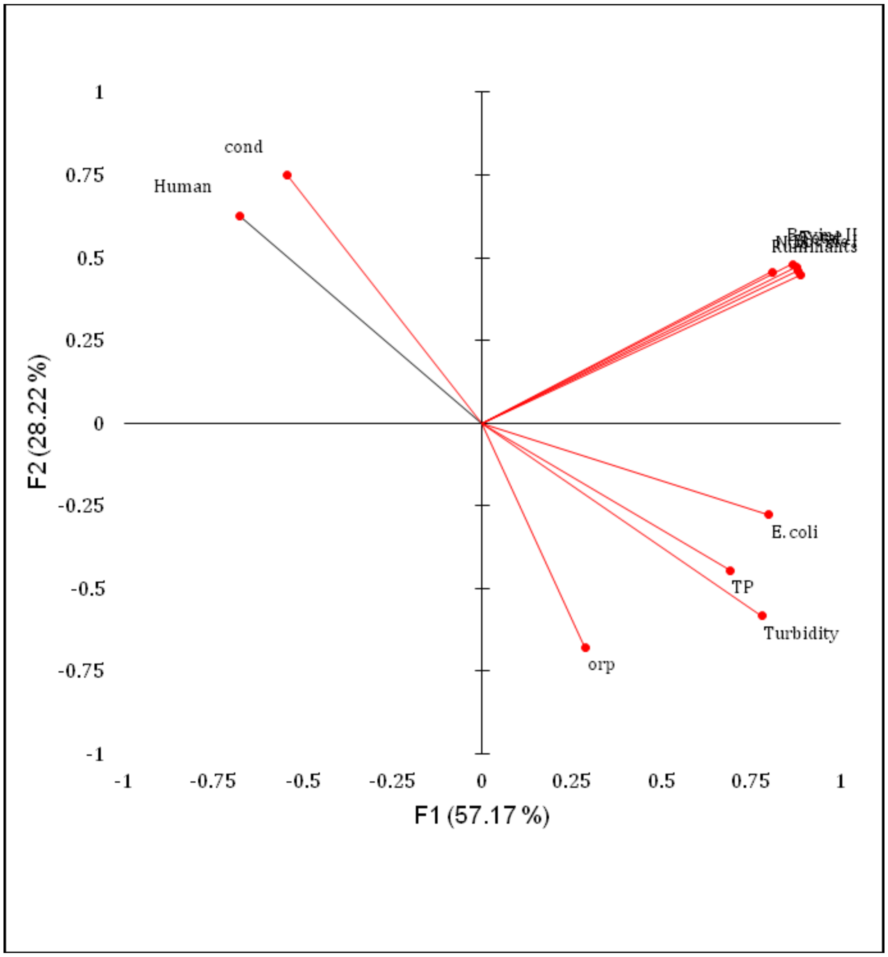


Figure 2.14 – PCA analysis during the wet period.

Section 3: Conclusions and Management Implications

Water quality indicators suggest Leesville Lake is mildly eutrophic. Current trends suggest this is a consistent pattern. While 2019 was very dry through the summer, the greatest impact on trophic state and worsening of water quality was in the upper portions of the reservoir. It is hypothesized this was due to constant pump back of Pigg River water in this area. Interestingly, water quality at the Dam Station improved as a result. Again, the implication is a lessening of Pigg River input into this area accounted for the improvement. Thus, water quality in Leesville Lake as we study it seems very dependent on movement of Pigg River water through the reservoir and dilution with SML tail water.

Because of these observations, we have begun more intensive study on both the Pigg River and pumping operations at the dam. Both need to be better understood to truly decipher how water quality is driven in this reservoir. Both of these factors are addressed in this report.

First, we have established in two seasons of sampling throughout the Pigg River and concluded that it is a very contaminated river system. Contamination is both from human and agricultural sources. Areas in Rocky Mount VA have now been identified as polluters to the system with human sourced bacteria and nutrients. This is very concerning as disease is generated from these inputs along with the potential for this contamination to travel great distances and into Leesville Lake.

Secondly, ruminant pollution is very significant during rain events. These sources originate at various locations throughout the watershed then appear to culminate at Toshes Road at the headwaters of Leesville Lake. Thus, the collection and input of this contamination is disproportionately impacting the lake as the contamination is greatest as it enters the headwaters. This water is later pumped into both Leesville Lake and SML depending on electrical demand.

Third, all trending suggests the contamination we have documented in the Pigg River is certainly worsening. Consider the following trends below. The turbidity (Figure 3.1) at the Pigg River Station in the Lake continues to increase. Since 2015, it is clear that turbidities have elevated and continue to do so. Turbidity is associated with both an abundance of *E. coli* and TP as both adhere to the surface of the clay particles. Clay provides an excellent transport mechanism for both of these pollutants and actually competes with phytoplankton for TP potentially impacting fish production. In all instances, it is not good for the reservoir

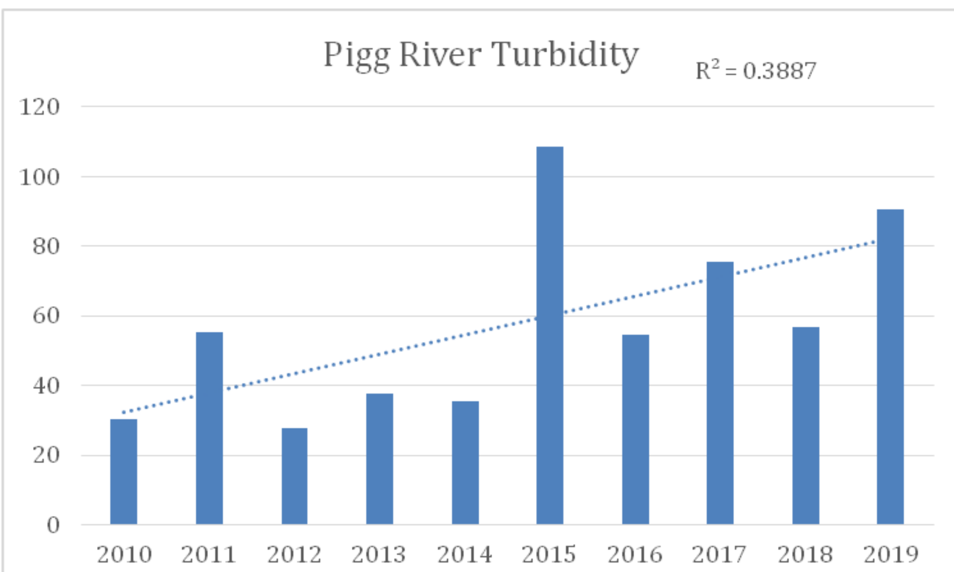


Figure 3.1 – Turbidity trends at Pigg River station 2010-2019.

Further, storm events are discharging very high concentrations of pollutants into the reservoir. Figures 3.2 – 3.4 represent the final sampling of 2019 where the Pigg River discharged flood waters into Leesville Lake for a 10 day period. Turbidity was 495 NTU at the Pigg River Station (Figure 3.2). Considering the average is 85 NTU, this is somewhat alarming. Additionally, this turbidity concentrates in the upper portions of the reservoir causing water quality problems.

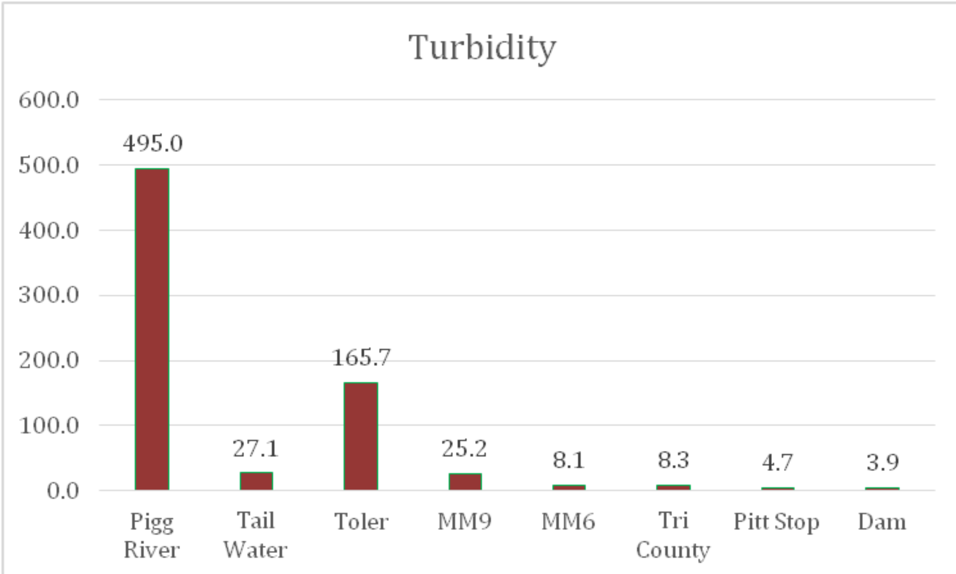


Figure 3.2 – Turbidity throughout Leesville Lake during the October 2019 sampling.

Additionally, both E. coli (Figure 3.3) and TP (Figure 3.4) follow as similar pattern. The measured *E. coli* of 24196 confirms the culmination and extremely high measures for this parameter in the reservoir. This ripples down to MM9 creating concerning recreational safety issues as these values are well in violation of safe levels. And measured TP is very concerning from this sampling event for the future trophic condition of the lake. A TP of 1182 ppb is extremely high. And in a similar fashion elevates levels throughout the reservoir down to MM9. The eventual fate of this nutrient loading will increase the trophic state and lead to greater problems with eutrophication in the future. Steps to control this problem must be undertaken immediately.

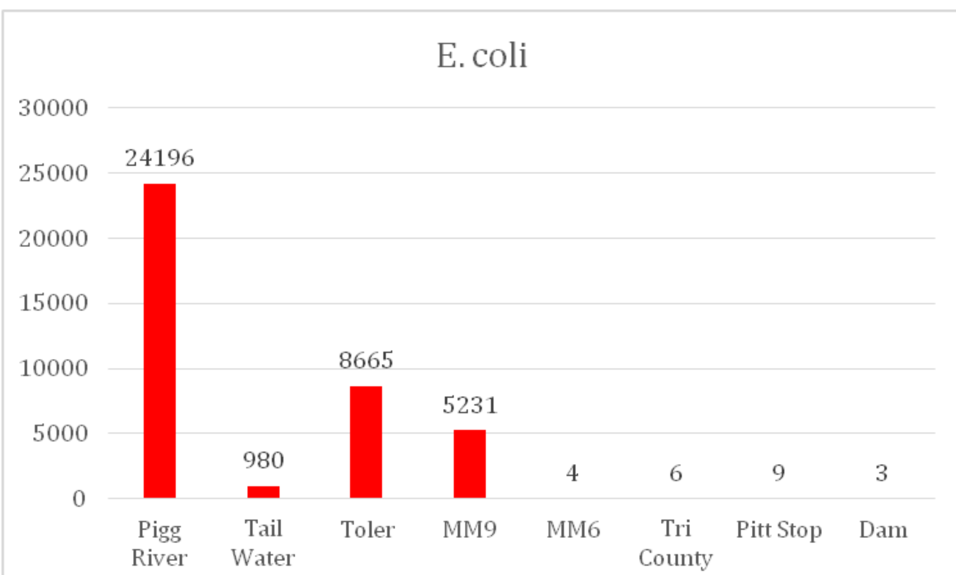


Figure 3.3 – *E. coli* throughout Leesville Lake during the October 2019 sampling.

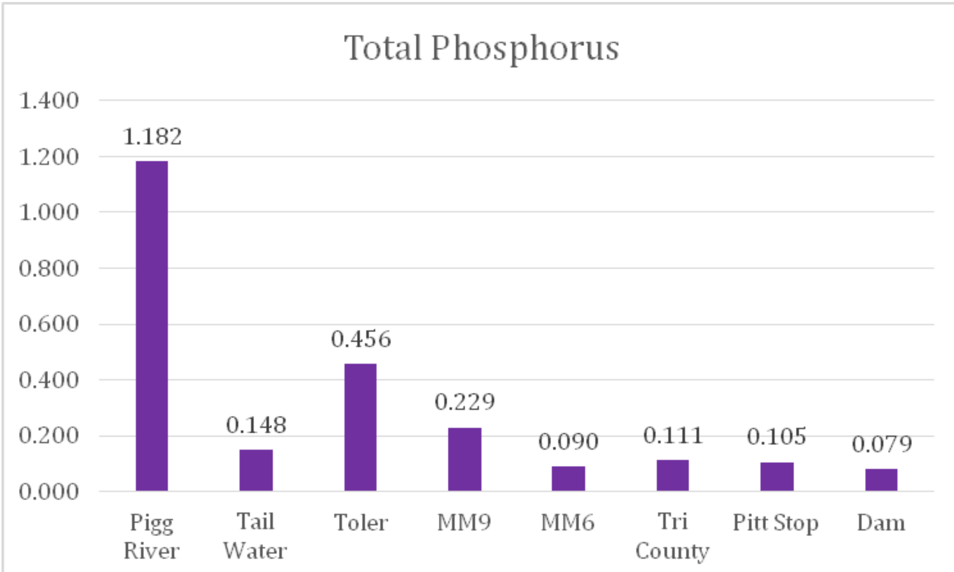


Figure 3.4 – Total Phosphorus throughout Leesville Lake during the October 2019 sampling.

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

1. Precipitation patterns have a significant impact on water quality in the lake. The upper portions (MM6 and above) water quality is driven by these patterns and the movement of water between SML and Leesville lake in conjunction with these weather patterns.
2. The Pigg River clearly degrades the water quality in Leesville Lake. The pattern and intensity of degradation is influenced by SML operations.
3. The idea that hypolemnetic release from SML is creating the oxygen problems at the SML tail water station is not currently supported by the collection of data in 2019. Rather, it is the cumulative direction and duration (intensity) of pumping operation that influences oxygen. Thus, intensive periods of SML operation where the cumulative impact is a net pump back to SML is more influential on DO loss than release of SML tail water. It is likely the contamination of Pigg River is responsible.
4. Other parameters such as increasing Chlorophyll a, turbidity and E. coli follow this pumping operation trend. Thus, overall water quality degrades in the top section of Leesville Lake (above the Pigg River confluence) with cumulative pump back duration and intensity.
5. Chlorophyll *a* is again increasing in the reservoir and reached a concentration of 80 ug/L in August of 2019. This level of algal productivity is considered hypereutrophic. The green algae *Microspora* was discovered in September and was in bloom stage during the October monitoring.
6. It is now becoming clear that in Leesville Lake, *Daphnia* populations respond to phytoplankton abundance *rather than* graze and control phytoplankton populations. Yet in 2019, some data suggested that at the Dam Station *Daphnia* may exert some control on

Chlorophyll *a*. This is suggested due to the higher TP concentrations and lack of Chlorophyll *a* response to these elevated TP levels. Other factors may be important as well.

7. Investigations on the Pigg River suggest that both human and agricultural waste pollute the river. During low flow or dry conditions contamination by human waste at alarming levels was evident with input from Furnace Creek in Rocky Mount and agricultural waste at Chestnut Hill Road. During high flow or wet conditions the contamination by agricultural waste resulted in extraordinarily high quantities of bacteria entering Leesville Lake.. The human waste contamination may not have been related to rainfall, but to other temporal issues.
8. Pigg River is not only degraded it is worsening. Our identification of "hot spots" and the ability to track sources of contamination confirms this.

Management recommendations suggested here are intended to improve or preserve the overall condition of the reservoir. **A reservoir is a direct reflection of its watershed**. Thus, any management plan must start and end in the watershed. Because Leesville Lake is the storage reservoir for the SML project, tail water release and pumping operation influence water quality as well. But, it is the Pigg River that is the key ingredient for management of the reservoir.

1. Continue to research links between hydrology, Pigg River input and water quality. Further study and research how Smith Mountain Lake operations influence water quality in the reservoir and loss of oxygen at the tail waters. Look at scenarios for pump operations that can influence and improve water quality.
2. Continue to monitor and research all aspects of the Pigg River. The isolation and determination of contamination inputs needs to be identified and quantified to begin the process of control and clean-up of this river. Additional funding for bacterial sources tracking, pollutant monitoring and land use identification needs to be pursued.
3. Develop a watershed management plan for the Pigg River. We need to seek funding from Virginia Environmental Endowment or DEQ or other entity to create the management plan.
4. Quantify the influence of the Pigg River during base flow and contrast this with storm flow on water quality.
5. 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.

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

Preparation of Reagents and Standards:

Stock Standards:

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

Reagents:

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

Standards used in the digestion process:

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

Standards:

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

Dissolved Phosphorus

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

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

Dissolved phosphorus testing was completed for all test sites by 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.

Appendix D

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

<u>Collection of samples for Chlorophyll a using syringe filtration p. 21</u>

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

<u>Field Quality Control Samples</u>

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

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

pH/mV/Ion meter

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

Dissolved oxygen and temperature meter

- Calibrate daily when in use, air calibration is the easiest
- Record the % saturated DO in the log sheet
- A DO% saturation confirmation needs to be performed in the middle of run
- Field probe maintenance: average life of membrane is 2-4 weeks, but may vary
- Some gases can contaminate the sensor, evidenced by discoloration of gold cathode
- Check probe performance every month when probe is in daily use

- For the DO meter, make calibration checks daily. Check calibration during sampling and at conclusion of day's sampling. Record onto log sheet; if check is off ±5%, flag data
- Monthly, place probe into a clean bucket full of analyte free or uncontaminated water, rinse BOD bottle 1 or 2 times with water, determine DO by Winkler method
- If the oxygen concentration of the air calibration disagrees with average results of Winkler value by more than 0.5 mg/l, have the electrode or meter serviced or replaced
- Check temperature probe against another multiprobe instrument's temp. probe semi-annually

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 E – Initial Pigg River Water Quality Study

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

Figure 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 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 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 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.

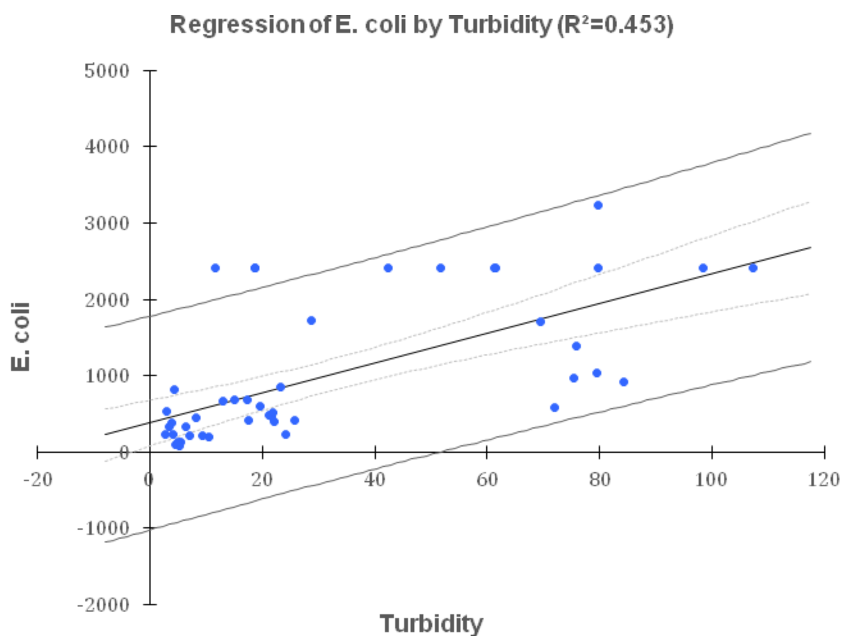

Figure 5 – regression of turbidity and *E. coli*. The relationship is highly significant ($p<0.001$). Lines represent 95% confidence interval.

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.

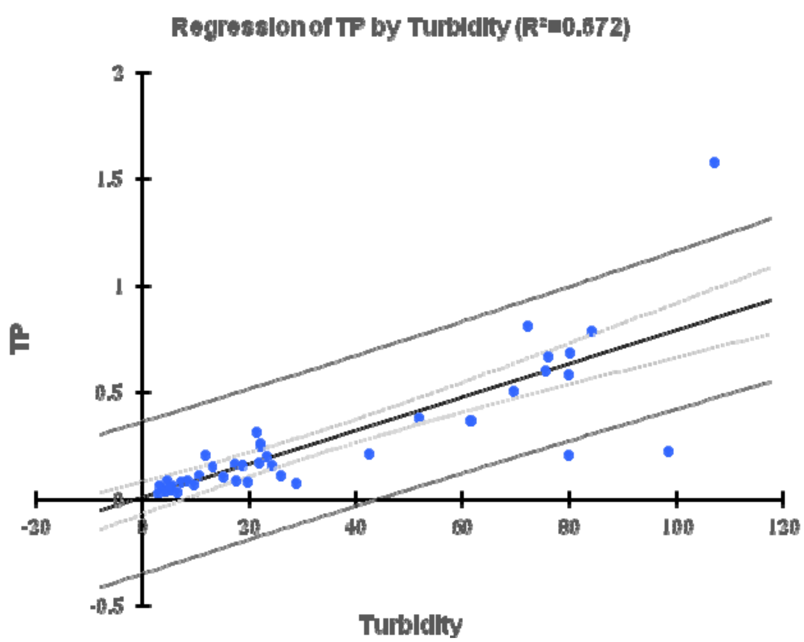

Figure 6 – regression of turbidity and TP. The relationship is highly significant (p<0.001). Lines represent 95% confidence interval.

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 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.

Appendix F – Collected Data

Table 1.1. Dam (Lacustrine) Conductivity (µs/cm) measures over study period (2019)

Conductivity							
Depth:	**24-Apr**	**29-May**	**25-Jun**	**25-Jul**	**28-Aug**	**25-Sept**	**28-Oct**
0	0.146	0.143	0.135	0.147	0.159	0.16	0.161
0.5	0.146	0.142	0.135	0.147	0.159	0.161	0.16
1	0.147	0.142	0.135	0.147	0.158	0.161	0.16
1.5	0.146	0.142	0.135	0.147	0.158	0.161	0.16
2	0.145	0.141	0.135	0.146	0.158	0.16	0.16
2.5	0.146	0.141	0.135	0.148	0.158	0.16	0.16
3	0.149	0.141	0.135	0.151	0.158	0.16	0.159
4	0.149	0.14	0.139	0.153	0.159	0.16	0.159
5	0.149	0.14	0.14	0.153	0.159	0.159	0.159
6	0.15	0.14	0.141	0.152	0.159	0.159	0.159
7	0.151	0.14	0.141	0.152	0.161	0.16	0.159
8	0.15	0.14	0.14	0.151	0.161	0.16	0.158
9	0.151	0.14	0.143	0.151	0.162	0.16	0.156
10	0.152	0.141	0.144	0.153	0.161	0.16	0.156
11	0.152	0.141	0.147	0.153	0.163	0.164	0.156
12	0.154	0.143	0.151	0.153	0.164	0.164	0.155
13	0.154	0.143	0.152	0.153	0.167	0.164	0.155
14	0.154	0.144			0.167		0.155

Table 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2019)

DO Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	11	9.42	9.43	8.69	9.78	9.1	8.26
0.5	10.6	9.47	9.4	8.8	9.91	9.19	8.19
1	10.4	9.76	9.37	8.7	9.92	9.16	8.17
1.5	10.1	10.12	9.38	8.78	9.64	9.18	8.19
2	9.75	10.24	9.3	8.91	9.55	9.23	7.8
2.5	9.46	10.2	9.21	7.51	9.36	9.34	7.15
3	9.37	10.23	9.13	5.6	9.4	9.31	6.8
4	9.23	10.46	7.82	4.5	8.01	8.1	6.6
5	9.27	10.02	7.04	3.28	6.81	6.63	6.06
6	9.27	7.17	6.43	2.4	6.1	3.47	5.73
7	9.16	6.81	6.08	2.27	3.38	1.98	5.42
8	9.11	6.33	5.4	0.196	1.05	0.71	5.18
9	9.08	6.18	5.3	1.6	0.5	0.63	5.32
10	9.19	5.79	4.9	1.48	0.31	0.32	5.25
11	8.9	5.6	5.13	1.08	0.26	0.29	5.18
12	9	5.38	5.2	0.9	0.24	0.3	5.52
13	8.97	5.11	5.37	0.7	0.24	0.3	5.32
14	8.92	4.9			0.29		4.98

Table 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2019)

Temperature C							
Depth:	**24-Apr**	**29-May**	**25-Jun**	**25-Jul**	**28-Aug**	**25-Sept**	**28-Oct**
0	16.49	27.14	25.97	26.75	25.44	24.4	20.4
0.5	15.8	27.14	25.5	26.56	25.3	24.49	20.21
1	15.6	26.7	25.3	26.4	25.2	24.5	20.17
1.5	14.7	26.2	25.1	26.35	25.1	24.49	19.7
2	14.2	25.9	24.5	26.3	25.1	24.49	19.6
2.5	13.3	25.6	24	26.2	25.1	24.48	19.3
3	13.2	25.2	23.7	25.6	25.1	24.48	19.2
4	13.04	24.1	21.1	24.9	24.9	24.39	19.17
5	12.9	20.8	19.7	24.2	24.8	24.1	19.12
6	12.7	19.27	19.3	23.4	24.7	23.8	19.08
7	12.7	19.01	18.9	22.9	24.3	23.7	19.05
8	12.6	18.5	18.4	22.4	23.7	23.4	18.8
9	12.5	18.4	17.9	21.9	23.5	23.4	18.7
10	12.4	17.88	17.3	21.6	22.8	23.28	18.6
11	12.3	17.7	17	21.1	22.6	22.8	18.6
12	12.2	17.2	16.6	20.9	22.2	22.5	18.5
13	12.2	16.6	16.5	20.6	22.1	22.4	18.5
14	12.2	16.4			21.8		18.3
15							

Table 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	7.55	5.37	10.8	17.8	36.3	28.3	11.6
0.5	16.8	7.21	12.4	14.6	44.4	30.1	16.6
1	16.3	11.7	14.6	20.2	62.9	28.7	18.4
1.5	12.1	22.61	17.9	24.2	67.4	32.5	20.3
2	9.6	32.1	19.5	25.7	65.2	24.7	25.3
2.5	5.1	34.9	19.7	30.2	67.1	40.7	24.2
3	5.7	33.3	23.5	26.9	67.3	35.8	23
4	4.7	35.5	16.5	19.7	73.2	34.5	18.9
5	4.1	38.9	10.5	12.7	56.9	34.9	16.9
6	4.5	26.4	10.1	7.1	48.6	23.2	11.3
7	4.7	18.9	6.4	5.6	33.1	16.3	11.8
8	4.9	17.4	5.44	5.3	19.9	14.1	9.5
9	4.8	15.8	4.1	4.5	9.2	13.9	11.1
10	4.3	11.9	3.4	4.02	5.8	9.6	10.9
11	4.8	11.7	2.7	4.1	4.2	4.3	8.5
12	3.6	6.4	2.9	3.5	3.8	3.9	9.8
13	3.6	6.1	2.9	2.9	4.7	4	8.6
14	3.6	5.8			3.4		9.8

Table 1.5. Dam (Lacustrine) pH measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	7.85	8.4	8.26	8.21	8.43	8.04	7.86
0.5	7.8	8.48	8.22	8.28	8.46	8.12	7.78
1	7.77	8.48	8.2	8.23	8.46	8.12	7.77
1.5	7.68	8.5	8.16	8.27	8.39	8.12	7.75
2	7.61	8.49	8.07	8.33	8.36	8.14	7.72
2.5	7.5	8.47	7.96	7.8	8.36	8.16	7.65
3	7.5	8.45	7.89	7.56	8.31	8.16	7.62
4	7.49	8.41	7.64	7.38	7.98	7.89	7.57
5	7.49	8.13	7.51	7.27	7.79	7.72	7.53
6	7.48	7.55	7.43	7.18	7.61	7.43	7.5
7	7.48	7.5	7.36	7.13	7.41	7.33	7.48
8	7.47	7.45	7.3	7.1	7.22	7.22	7.45
9	7.47	7.42	7.27	7.05	7.17	7.2	7.46
10	7.47	7.38	7.23	7.02	7.11	7.15	7.44
11	7.47	7.36	7.2	6.99	7.09	7.14	7.44
12	7.48	7.33	7.23	6.97	7.08	7.13	7.44
13	7.48	7.31	7.24	6.96	7.07	7.12	7.44
14	7.5	7.29			7.07		7.43
15							

Table 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	397	429	352	353	353	417	368
0.5	401	426	355	355	354	419	368
1	403	425	358	358	354	420	367
1.5	405	425	360	357	356	421	368
2	408	424	363	357	358	422	369
2.5	410	424	367	368	359	422	370
3	412	425	369	377	360	423	371
4	413	426	378	383	367	428	372
5	413	434	382	386	373	433	374
6	415	446	384	388	375	439	374
7	416	447	386	390	382	442	375

8	416	448	388	391	385	444	376
9	417	448	389	392	387	445	376
10	417	449	391	393	388	446	376
11	418	449	391	394	387	446	377
12	418	450	391	394	386	444	377
13	418	450	391	395	340	444	377
14	418	450			295		377

Table 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	8.3	3.9	2.5	2.8	3.9	2.5	3.9
0.5	8.7	4.7	2.6	3.1	4	2.6	3.9
1	8.5	4.9	2.8	3	4.1	2.4	4.1
1.5	8.3	5.5	2.7	3	4.4	2.6	4.1
2	8.7	5.1	3	2.8	3.5	2.6	4.2
2.5	9.1	4.7	3.3	2.9	3.8	2.5	4.3
3	9.1	4.6	2.7	2.8	3.6	2.5	4.5
4	9.5	4.6	3.4	2.9	3.7	2.5	4.8
5	9.8	4.5	4	3	3.9	2.5	4.8
6	10.6	3.7	4.7	3.5	4.5	2	4.8
7	9.4	4.2	5.2	3.6	4	2.3	5.6
8	10.6	3.9	5.8	3.5	4	2.4	7.3
9	10.7	5.3	6.1	3.9	3	2.3	7
10	10.4	3.7	10	4	3.5	2.8	7.9
11	9.8	5.6	7.5	4.7	4.1	3	8.1
12	9.9	4.3	7.7	4.6	5	2.8	7.9
13	10.2	7.9	7.9	5	7.2	3.1	9.1
14	9.9	6.1			6		10.3

Table 1.8. Dam (lacustrine) Phycocyanin (ppb) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	31.3	5.32	17.5	46.2	59.7	37.8	15.4
0.5	32.6	7.38	16.3	23.8	62.9	37.8	18.4
1	27.9	9.8	16.1	28.8	62.1	37.9	17.7
1.5	29.8	14.4	18.1	26.1	61.6	36.7	18.1
2	23.7	17.6	19.9	26.7	57.4	35.4	19.7
2.5	18.4	15.8	20.9	27.7	54.2	35.4	17.2
3	20.1	17.2	21.4	29.1	56.2	35.17	18.5

4	16.6	19.5	20.3	19.9	64.5	39.3	15.8
5	17.7	16.8	13.5	13.2	58.3	47.5	12.2
6	18.8	17.7	13.6	7.9	51.2	29.3	12.1
7	15.5	13.5	10.2	6.1	36.5	18.1	11.1
8	18.5	13.1	9.5	5.7	31.5	16.1	12.1
9	19.1	12.6	5.8	7.3	21.6	13.4	11.7
10	19.3	12.6	9.9	5.58	22.8	12.3	11.6
11	19	9.09	9.7	4.6	22.9	8.07	9.6
12	16.5	9.3	9.14	3.7	18.5	7.5	11
13	16.9	6.5	8.7	4.1	21.9	5.8	12.9
14	16.3	6.8			21.4		12.7

Mile Marker 6

Table 1.9. Mile Marker 6 (Transition) Conductivity (µs/cm) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	0.158	0.144	0.141	0.152	0.16	0.163	0.159
0.5	0.158	0.144	0.141	0.151	0.161	0.163	0.159
1	0.158	0.143	0.141	0.15	0.161	0.163	0.158
1.5	0.157	0.143	0.142	0.151	0.161	0.163	0.158
2	0.157	0.142	0.141	0.154	0.16	0.163	0.158
2.5	0.157	0.142	0.143	0.154	0.16	0.163	0.158
3	0.156	0.142	0.144	0.154	0.161	0.163	0.157
4	0.156	0.144	0.144	0.155	0.161	0.163	0.157
5	0.16	0.147	0.143	0.156	0.162	0.163	0.156
6	0.161	0.148	0.145	0.157	0.162	0.163	0.156
7	0.161	0.15	0.147	0.159	0.164	0.164	0.156
8	0.16	0.149	0.155	0.159	0.164		0.156
9	0.161	0.15		0.16			
10		0.15		0.161			

Table 1.10. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	10.1	9.96	9.18	9.23	9.4	8.75	8.13
0.5	10.09	9.76	9.03	9.22	9.14	8.75	8.1
1	10.09	9.7	8.84	9.69	8.96	8.65	8.07

1.5	10.1	9.08	7.9	9.9	8.36	8.51	7.87
2	10.07	8.5	7.33	8.72	8.29	8.44	7.64
2.5	10.08	7.93	6.81	7.39	8.14	7.57	7.21
3	10.02	7.44	6.49	7.05	7.03	7.52	7.05
4	9.7	6.95	6.43	5.85	5.83	7.59	6.89
5	9.8	6.28	6.31	5.19	3.91	6.17	6.83
6	9.91	5.28	5.72	4.71	2.48	3.63	6.79
7	9.85	5.12	5.5	4.25	1.51	2.7	6.78
8	9.6	4.63	4.71	4.12	0.68		6.67
9	9.65	4.19		3.9			
10		4.87		3.76			

Table 1.11. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	14.3	24.68	23.85	26.5	25.8	24.38	19.6
0.5	14.2	23.6	23.7	26.5	25.4	24.34	19.5
1	14.14	23.7	23.3	26.1	25.3	29.33	19.5
1.5	13.8	23.1	21.9	25.6	25.3	24.25	19.2
2	13.8	22.5	21.4	25.01	25.2	24.25	19.2
2.5	13.7	21.9	21.1	24.5	25.2	24.12	18.8
3	13.6	21.3	20.5	24.2	25.2	24.07	18.8
4	12.7	20.8	20.2	23.4	25	24.04	18.7
5	12.4	19.5	19.5	22.6	24.8	23.92	18.7
6	12.2	18.2	18.9	22.2	24.1	23.6	18.7
7	12.2	18.2	18.1	21.8	23.6	23.5	18.7
8	11.92	17.6	17.4	21.6	23.3		18.7
9	11.9	17.24		21.4			
10		16.7		21.3			

Table 1.12. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	2.77	12.3	17.3	12.9	22.5	21.5	24.1
0.5	3.1	22.5	22.7	20.8	29.9	31.8	25.6
1	3.7	33.6	24.2	25.4	39.3	40.3	28.5

1.5	6.4	35.4	23.3	34.9	35.3	34.7	27.6
2	6.4	26.6	12.2	24.4	37.7	34.8	26.1
2.5	6.5	22.9	9.71	19.9	36.5	29.3	2
3	5.8	18.2	8.4	15.9	37.3	30.1	20.9
4	5.4	13.05	7.8	12.5	26.5	25.6	21.9
5	4.9	11.4	8.1	10.1	22.9	19.9	19.8
6	4.4	9.1	5.3	10.1	18.5	16.3	17.1
7	4.4	8.3	3.9	8.5	11.2	15.4	18.3
8	4.2	6.3	3.3	6.4	10.8		19.6
9	4.3	6.7		7.1			
10		13.1		7.95			

Table 1.13. Mile Marker 6 (Transition) pH measures over study period (2019)

Depth:	**24-Apr**	**29-May**	**25-Jun**	**25-Jul**	**28-Aug**	**25-Sept**	**28-Oct**
0	**7.68**	**8.34**	**7.86**	**8.23**	**8.14**	**7.9**	**7.68**
0.5	**7.65**	**8.18**	**7.82**	**8.25**	**8.1**	**7.91**	**7.6**
1	**7.65**	**8.12**	**7.76**	**8.41**	**8.04**	**7.89**	**7.59**
1.5	**7.64**	**7.93**	**7.59**	**8.37**	**7.91**	**7.88**	**7.57**
2	**7.63**	**7.7**	**7.48**	**7.9**	**7.88**	**7.85**	**7.55**
2.5	**7.61**	**7.65**	**7.42**	**7.7**	**7.85**	**7.73**	**7.5**
3	**7.61**	**7.56**	**7.37**	**7.6**	**7.68**	**7.7**	**7.49**
4	**7.57**	**7.49**	**7.35**	**7.49**	**7.49**	**7.68**	**7.46**
5	**7.58**	**7.42**	**7.33**	**7.35**	**7.34**	**7.56**	**7.46**
6	**7.61**	**7.34**	**7.28**	**7.29**	**7.17**	**7.37**	**7.46**
7	**7.62**	**7.31**	**7.25**	**7.25**	**7.1**	**7.31**	**7.46**
8	**7.61**	**7.28**	**7.21**	**7.22**	**7.02**		**7.45**
9	**7.6**	**7.25**		**7.19**			
10		**7.27**		**7.18**			

Table 1.14. Mile Marker 6 (Transition) ORP (mV) measures over study period (2019)

Depth:	**24-Apr**	**29-May**	**25-Jun**	**25-Jul**	**28-Aug**	**25-Sept**	**28-Oct**
0	**378**	**394**	**349**	**377**	**339**	**364**	**383**
0.5	**383**	**401**	**352**	**377**	**338**	**365**	**382**
1	**386**	**404**	**355**	**375**	**340**	**366**	**381**

1.5	388	410	362	377	343	367	381
2	390	415	365	387	344	368	381
2.5	393	418	368	390	345	371	382
3	394	421	371	392	350	372	383
4	396	423	372	396	354	373	383
5	396	427	373	399	359	377	383
6	395	429	376	401	363	381	383
7	395	430	377	403	367	383	383
8	395	431	380	404	363		382
9	395	431		405			
10		430		405			

Table 1.15. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	8.7	6	10.3	3.7	4.5	3.5	8.1
0.5	9	7.7	10.6	4.3	4.7	3.8	8.4
1	9	8.3	11.5	3.8	5	3.5	8.6
1.5	8.7	9.7	12.8	4.9	4.9	3.6	8.6
2	9.1	10.4	15.1	5.6	4.8	4	9.6
2.5	9.2	10.9	15.4	5.9	5.2	6	8.9
3	9.8	13.2	17.8	6.3	5.2	6.3	10
4	11.7	14.7	18.1	9.1	5.5	6	12
5	9.6	15.8	14.5	11.2	8.3	11.6	13.6
6	9	17.6	22.1	14.4	7.7	11	14.2
7	8.5	23.4	14.9	20	13.1	11.5	14.2
8	11.7	25.1	31.2	18.2	26.7		21
9	12.9	29.1		25.5			
10		48.6		33.1			

Table 1.15. Mile Marker 6 (Transition) Pheophytin (ppb) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	42.5	24.5	24.4	26.5	55.8	37.7	25.1
0.5	22.9	30.7	29	33.7	63.1	39.3	25.2
1	25.9	35.5	33.1	44.4	63.8	42.6	27.6

1.5	**23.2**	**31.4**	**32.9**	**68.8**	**60.1**	**39.1**	**26.4**
2	**27.8**	**28.9**	**23.2**	**42.8**	**54.2**	**37.1**	**24.7**
2.5	**27.3**	**24.1**	**17.7**	**39.1**	**52.2**	**35.5**	**23.4**
3	**23.9**	**21.1**	**16.8**	**31.6**	**47.1**	**29.3**	**20**
4	**25.5**	**20.4**	**15.7**	**26.8**	**44.6**	**31.4**	**20.5**
5	**22.6**	**20.8**	**13.9**	**21.6**	**35.8**	**25.1**	**18.6**
6	**24.1**	**17.6**	**16.1**	**22.1**	**32.1**	**23.1**	**20.5**
7	**23**	**20.5**	**8.7**	**21.1**	**31.7**	**19.3**	**20.2**
8	**24.1**	**20.2**	**17.6**	**21.1**	**31.2**		**20.2**
9	**22.1**	**25.1**		**24.8**			
10		**35.1**		**25.7**			

Toler Bridge

Table 1.16. Toler Bridge (Riverine) Conductivity (ms/cm) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	0.132	0.144	0.142	0.14	0.151	0.163	0.102
0.5	0.134	0.149	0.141	0.141	0.15	0.163	0.102
1	0.153	0.152	0.141	0.148	0.149	0.162	0.1
1.5	0.152	0.154	0.142	0.149	0.149	0.162	0.1
2	0.153	0.154	0.141	0.149	0.148	0.162	0.098
2.5	0.154	0.154	0.142	0.151	0.147	0.161	0.098
3	0.154	0.155	0.142	0.154	0.147		0.092
4	0.154	0.156	0.143	0.155	0.146		0.092
5	0.154	0.16	0.142	0.156			

Table 1.17. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	9.7	8.14	7.24	6.92	7.75	5.67	7.02
0.5	9.89	8.03	7.25	6.92	7.68	5.65	6.91
1	10.01	8.17	7.21	6.83	7.6	5.66	6.83

1.5	**10.08**	**8.24**	**7.15**	**6.75**	**7.36**	**5.68**	**6.75**
2	**10.05**	**8.26**	**7.1**	**6.6**	**7.29**	**5.58**	**6.75**
2.5	**10.02**	**8.24**	**6.95**	**6.5**	**7.17**	**5.54**	**6.72**
3	**10.01**	**8.14**	**6.87**	**6.4**	**7.14**		**6.72**
4	**10**	**8.08**	**6.74**	**6.3**	**6.88**		**6.86**
5	**10**	**7.95**	**6.76**	**6.08**			

Table 1.18. Toler Bridge (Riverine) Temperature (°C) measures over study period (2019)

Depth:	**24-Apr**	**29-May**	**25-Jun**	**25-Jul**	**28-Aug**	**25-Sept**	**28-Oct**
0	**14.8**	**19.6**	**21.1**	**23.2**	**23.9**	**23.43**	**18.6**
0.5	**14.1**	**19.5**	**21.2**	**23.1**	**23.7**	**23.3**	**18.3**
1	**13.1**	**18.7**	**21**	**22.6**	**23.6**	**23.3**	**18.4**
1.5	**12.5**	**18.5**	**20.9**	**22.2**	**23.5**	**23.2**	**17.5**
2	**12.4**	**18.4**	**20.8**	**22**	**23.4**	**23.17**	**17.5**
2.5	**12.3**	**18.3**	**20.6**	**21.6**	**23.4**	**23.17**	**17.4**
3	**12.2**	**18.1**	**20.1**	**21.5**	**23.4**		**17.4**
4	**12.1**	**17.51**	**19.7**	**21.5**			**17.2**
5	**12.1**	**16.27**	**19.8**	**21.3**			

Table 1.19. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2019)

Depth:	**24-Apr**	**29-May**	**25-Jun**	**25-Jul**	**28-Aug**	**25-Sept**	**28-Oct**
0	**2.5**	**7.2**	**8.2**	**10.11**	**24**	**10.4**	**12.2**
0.5	**2.5**	**8.1**	**10.1**	**11.6**	**29.8**	**14.6**	**11.4**
1	**3.4**	**11.3**	**12.5**	**11.9**	**29.4**	**18.8**	**10.3**
1.5	**4.2**	**15.8**	**11.7**	**12.75**	**25.8**	**18.5**	**9.8**
2	**5.1**	**13.9**	**12.5**	**13.3**	**27.4**	**21.9**	**11.3**
2.5	**4.6**	**15.5**	**12.7**	**10.9**	**29.5**	**21.2**	**9.4**
3	**4.6**	**16.9**	**11.6**	**10.5**	**25.7**		**9.1**
4	**4.5**	**13.7**	**9.9**	**9.1**	**24**		**9.1**
5	**4.6**	**9.27**	**10.8**	**11**			

Table 1.20. Toler Bridge (Riverine) pH measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	7.66	7.65	7.49	7.5	7.59	7.39	7.38
0.5	7.64	7.61	7.45	7.47	7.52	7.35	7.3
1	7.63	7.58	7.43	7.43	7.51	7.34	7.29
1.5	7.62	7.57	7.41	7.41	7.47	7.33	7.29
2	7.6	7.57	7.4	7.4	7.45	7.32	7.22
2.5	7.58	7.56	7.38	7.38	7.42	7.32	7.19
3	7.55	7.55	7.36	7.37	7.42		7.18
4	7.6	7.54	7.34	7.4	7.39		7.15
5	7.6	7.51	7.34	7.35			

Table 1.21. Toler Bridge (Riverine) ORP (mV) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	375	413	363	390	329	360	383
0.5	378	415	365	391	333	360	384
1	381	415	367	392	336	361	385
1.5	383	416	369	392	338	361	386
2	386	416	370	392	340	362	386
2.5	387	417	372	392	344	363	387
3	388	418	374	393	343		387
4	388	418	375	393	344		388
5	388	420	376	394			

Table 1.22. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2019)

Depth:	24-Apr	29-May	25-Jun	25-Jul	28-Aug	25-Sept	28-Oct
0	9.2	7.8	20.4	9.2	8.2	6.4	165.7
0.5	7.5	7.7	20.6	8.6	8.2	6.4	169.3
1	6.1	8.1	19.4	8.5	8.3	6.8	170.4
1.5	6.4	9.4	21	8.1	8.3	6.3	195.6
2	6.4	8.3	18.9	7.9	8.8	6.5	209.2
2.5	6.4	8.5	19.8	8.2	8.6	6.8	162.8

3	6.1	8.1	19.3	8	8.2		177.4
4	6.3	8.3	20.8	7.7	8.5		180.1
5	6.3	6	20.5	8.4			

Table 1.23. Toler Bridge (Riverine) Pheophytin (ppb) measures over study period (2019)

Depth:	**24-Apr**	**29-May**	**25-Jun**	**25-Jul**	**28-Aug**	**25-Sept**	**28-Oct**
0	**19.5**	**21.7**	**38.1**	**31.7**	**42.3**	**24.9**	**78.3**
0.5	**18.3**	**12.9**	**35.5**	**32.5**	**46.3**	**33.5**	**78.6**
1	**26.8**	**20.8**	**37.1**	**33.4**	**47.7**	**33.6**	**82.6**
1.5	**21.6**	**20.4**	**38.4**	**32.3**	**44.8**	**32.9**	**83.1**
2	**22.9**	**23.1**	**36.2**	**31.4**	**43.6**	**31.6**	**86.4**
2.5	**25.6**	**21.3**	**35.6**	**31.1**	**41.6**	**31.7**	**86.1**
3	**20.1**	**19.9**	**32.7**	**31.4**	**40.7**		**95.9**
4	**23.1**	**21.3**	**32.2**	**20.5**	**39**		**93.7**
5	**20.3**	**17.9**	**32.9**	**29.18**			

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