Leesville Lake 2017
Water Quality Monitoring

Prepared for:
Leesville Lake Association

Prepared by:
Dr. Thomas Shahady Lynchburg College
Wrenn Cleary Lynchburg College

February 2018

Funds Supplied by: American Electric Power & Leesville Lake Association

(Page Left Intentionally Blank)

Table of Contents Page

List of Acronyms and Abbreviations

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

Executive Summary

The Leesville Lake Association and Lynchburg College, in partnership with the American Electric Power Company, monitored water quality of Leesville Lake between April and October 2017. The lake was monitored mid-month from April – October by Lynchburg College. Additional samples were collected by the Leesville Lake Water Quality Committee during June, July and August, at the beginning of each month. Results of the 2017 yearly results are reported here with additional analysis of lake trends and current research pursuits. The current project was initiated in 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.

Leesville Lake continues to meet prescribed water quality parameters measured in the main stem of the reservoir and *E. coli* violations continue to occur periodically in the upper portions of the reservoir near Pigg River. During the initial sampling period (sampling dates in April, May and June) extensive portions of the reservoir were in violation of *E. coli* standards. Concerns were raised over removal of a dam on Pigg River. The Pigg River violated state *E. coli* standards in 5 of 10 samples, with concentrations for the year averaging 379 MPN CFU/100ml. Chlorophyll *a* was noticeably lower this season, enough to classify the lake as mesotrophic for this parameter. The continued bloom of phytoplankton, as detected by Chlorophyll *a* at a depth of 2-4 meters below the lake surface, was minimal this season. It is hypothesized that increased turbidity contributed to minimization of this bloom. The source of increased sediment turbidity was likely the dam removal project on the Pigg River, which impacted the water quality dynamics of the entire reservoir throughout the 2017 sampling year.

Classification of Leesville Lake remains mildly eutrophic. Overall Trophic State Index values were again lower in 2017 demonstrating inter-annual variation but remaining in the eutrophic range. Monitoring should continue in the reservoir at the intervals and stations currently in place. Recommendations need to be implemented and studied for water quality improvements.

These recommendations include:

1. Continue to research links between hydrology, Pigg River input and water quality. Pinpoint how Smith Mountain Lake operations influence these relationships.
2. Sample areas of Pigg River to better quantify potential increases in sedimentation, nutrient inputs and changes in productivity.
3. Considerable debris in the channel and elevated *E. coli* both pose hazards for users of the lake. Although efforts have been made to implement a better alert system for Association members, information may need to be posted in public areas.
4. Examine inputs from other tributaries to the lake such as Old Womens Creek and any others that may influence water quality. Build maps and database to document these inputs to serve as baselines for future work.
5. Conduct more intensive research on the Pigg River. Understand the influence this river has during base flow and storm inputs on water quality.

Section 1: Current Conditions (2017)

1.1 General:

This is the seventh year of water quality monitoring of Leesville Lake by Lynchburg College in partnership with Leesville Lake Association (LLA). Seven 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 by Lynchburg College and Leesville Lake volunteers. Data are reported in graphical form with interpretations of current water quality. In **Appendix D**, these 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. Events of this season emphasize the need for continued study of the lake.

A full background of the study and its rationale are located in **Appendix A**.

1.2 Methods:

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

Table 1.0. Leesville Lake 2016 Sampling Sites

LC Station	LLA Station	Site ID	DEQ Station ID	Latitude	Longitude
Leesville Lake Dam	11	2636	LVLAROA140.66	37.0916	-79.4039
Leesville Lake Marina	5	1275	LLAOQC000.58	37.05939	-79.39574
Tri County Marina	3	1273	LLATER000.33	37.05942	-79.44489
Mile Marker 6	8	1373	LLAROA146.87	37.06320	-79.47110
Mile Marker 9	2	1272	LLAROA149.94	37.03993	-79.48233
Toler Bridge	1	1271	LLLAROA153.47	37.01090	-79.47530
Pigg River	9	1374	LLAPGG000.47	37.00430	-79.48590
SML Tail Waters	12	2637	LVLAROA157.92	37.0382	-79.531306

Detailed methodologies used by Lynchburg College 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 (2017)

1.3.1 Temporal Analysis by Station

Background

Leesville Lake is a reservoir by definition. It is a river course with a dam constructed and filled to form this reservoir. Leesville Lake is an interesting reservoir because it serves as a source of water (pump back operations) and a recipient of water for the generation of electricity by the Smith Mountain Lake Hydroelectric Plant. The reservoir receives water input primarily from Smith Mountain Lake and secondarily from several other stream systems. Therefore, Leesville Lake is subject to a unique hydrology that impacts the water quality of the reservoir.

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

Leesville Lake is very unique is these qualities. First, the headwaters are fed by release of tail water from Smith Mountain Lake. This release is of very good quality water because of the aforementioned typical water quality in a reservoir. Thus one source of incoming water to Leesville Lake is excellent. A secondary source of water into Leesville Lake is the Pigg River. This is an impaired river delivering high concentrations of nutrients, sediment and bacteria to Leesville Lake. The fate of this polluted water depends on hydroelectric operations. During energy production, Pigg River water is diluted and pushed through the reservoir. During pump back operations, Pigg River water is drawn 4 miles to the dam and the lacustrine areas of Smith Mountain Lake. And depending upon electric demand, a mix of both of these conditions is possible.

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

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

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

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

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

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

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

Trophic State – this is a convienent 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 tannis in the water. Tannis are created when leaf litter degrades. Dystrophic water is often tea colored and found more often in coastal systems.

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

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

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

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

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

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

1.3.1.1 Dam (Lacustrine)[1]

Background

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

---

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

Conductivity

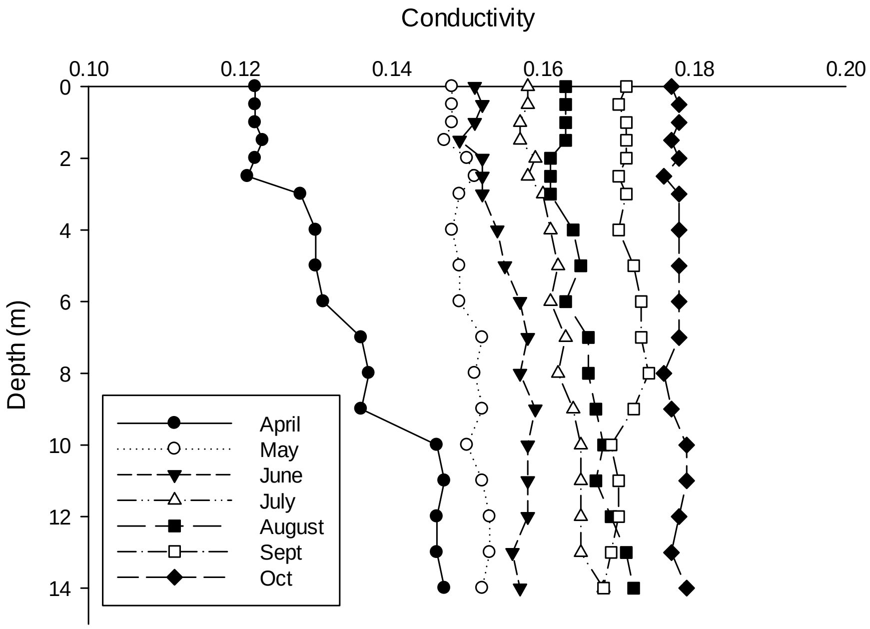


Figure 1.1. Dam (Lacustrine) Conductivity (ms/cm) measures over study period (2017)

Spatial 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. Typically, there is not a strong vertical (depth) pattern in conductivity, making it more useful along a spatial or temporal scale than along a vertical scale. Water conductivity at the dam is generally between 0.14 and 0.18 ms/cm. Higher conductivity in the spring is reflective of excessive runoff from surrounding areas and conductivity decreases throughout the summer due to phytoplankton uptake of material and settling. This is a typical pattern for the reservoir.

Temporal Analysis

Pattern for conductivity is typically between 0.14-0.18 ms/cm in most years at the dam. In 2012 and 2015, conductivity ranges were much broader extending up to 0.25. The changing water patterns and flow regime likely are responsible for these variations in the reservoir during the 2017 season.

Dissolved Oxygen

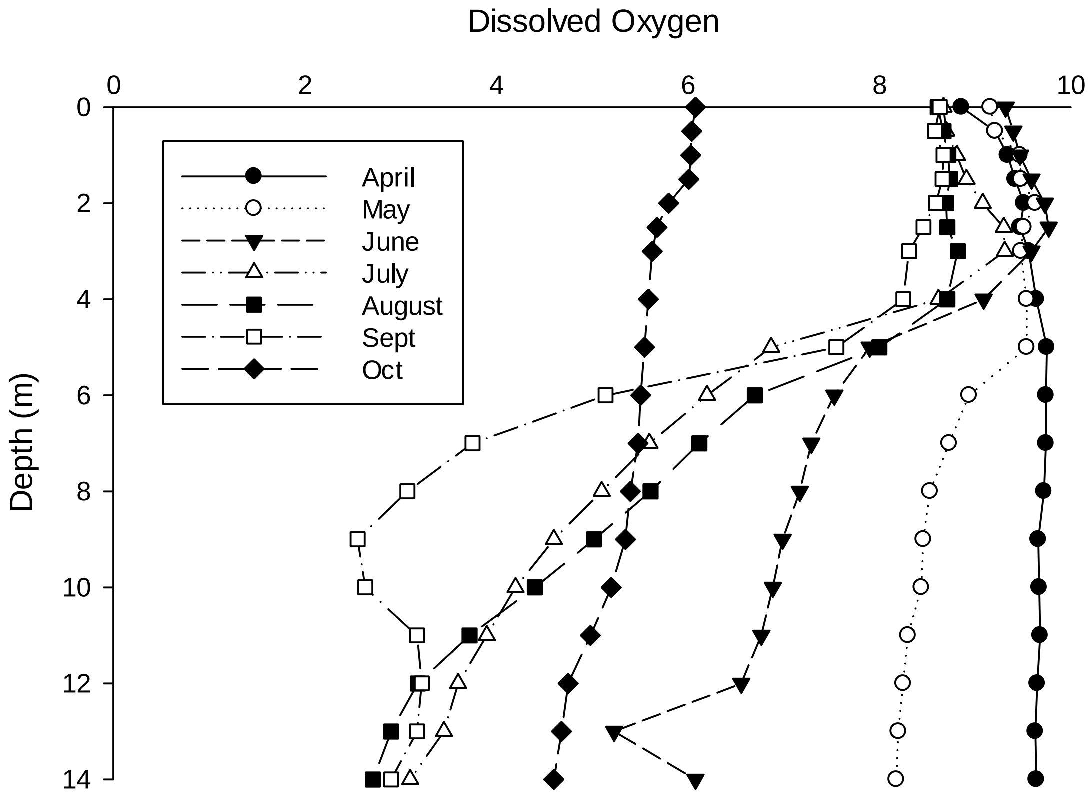


Figure 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2017)

Spatial Analysis

Dissolved oxygen patterns in the reservoir continue to suggest that it is eutrophic.
At the start of the sampling season in April, water was well oxygenated throughout the entire water column. In May, a positive heterograde began to develop below the surface as productivity increases. Water remained well oxygenated at depth through this month. In June, and throughout the summer months, the hypolimnion was depleted of oxygen. This phenomenon suggests the reservoir is eutrophic. In 2017, this condition extended into September. In October, as water cooled and turned over, oxygen returned to the hypolimnion. This pattern seems relatively consistent in the reservoir. In April and in October the reservoir was well mixed. April was very different from October as the entire water column was highly oxygenated. In October, low oxygen levels observed in the hypolimnion were reflected in lower oxygen levels throughout the reservoir due to turnover. Only the timing of this event has changed throughout the years. Sometimes, this event occurs in September. It is important for residents and AEP to recognize this problem during the fall months. Lower oxygen levels influences fisheries, chemical composisiton of the lake and water quality.

Temporal Analysis

The observed 2017 pattern of oxygen in the reservoir is quite typical. April displays high oxygen content throughout throughout the water column, with development of positive heterograde in May. Oxygen depletion occurs in the hypolimnion throughout the summer months. Depending on weather conditions, turnover occurs in September or October. Concentration of oxygen throughout the lake during turnover is dependent on movement of water at this time of year. The amount of oxygen loss in the hypolimnion during the summer months is always concerning. If the reservoir becomes more eutrophic, levels of oxygen loss will increase. This will lead to lower overall oxygen levels in the reservoir during fall turnover. Coupled with influx of Pigg River pollutants and discharge from Smith Mountain Lake – water quality could degrade considerably. Tracking eutrophication on Leesville Lake should be given a very high priority.

Temperature

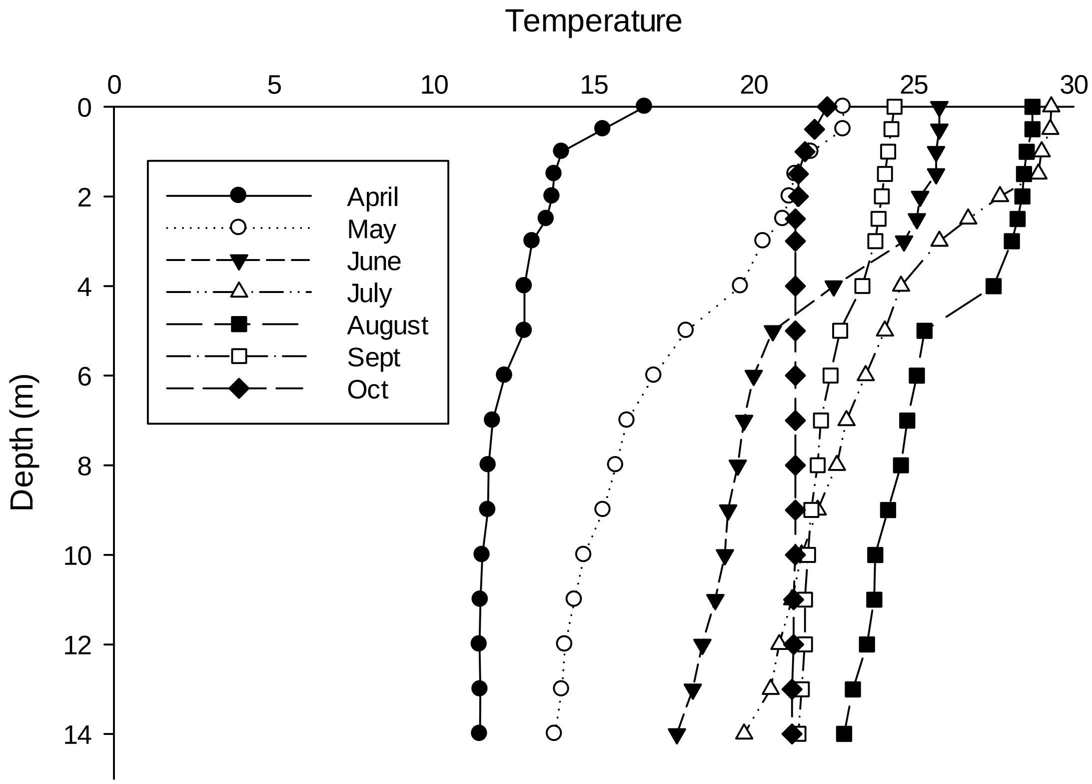


Figure 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2017)

Spatial Analysis

This year’s temperature profiles suggest that the lake is stratified throughout the year but not strongly. Consistent with previous years, June and July had the strongest stratification, with measured temperature differences between 8-10 degrees from top to bottom. Spring and fall months demonstrated less stratification, with a weaker stratification in September. This suggests the lake is polymictic, mixing many times throughout the season. This is likely driven by precipitation events and movement of water during operation of both Leesville and Smith Mountain Lake Dam.

Temporal Analysis

This pattern is very typical for the reservoir. In some years the overall temperatures vary and during heavy precipitation periods the polymictic nature of the reservoir is demonstrated. Yet overall, the lake consistently stratifies throughout the summer months with strength of stratification (temperature differential) inversely related to water movement.

Chlorophyll *a*

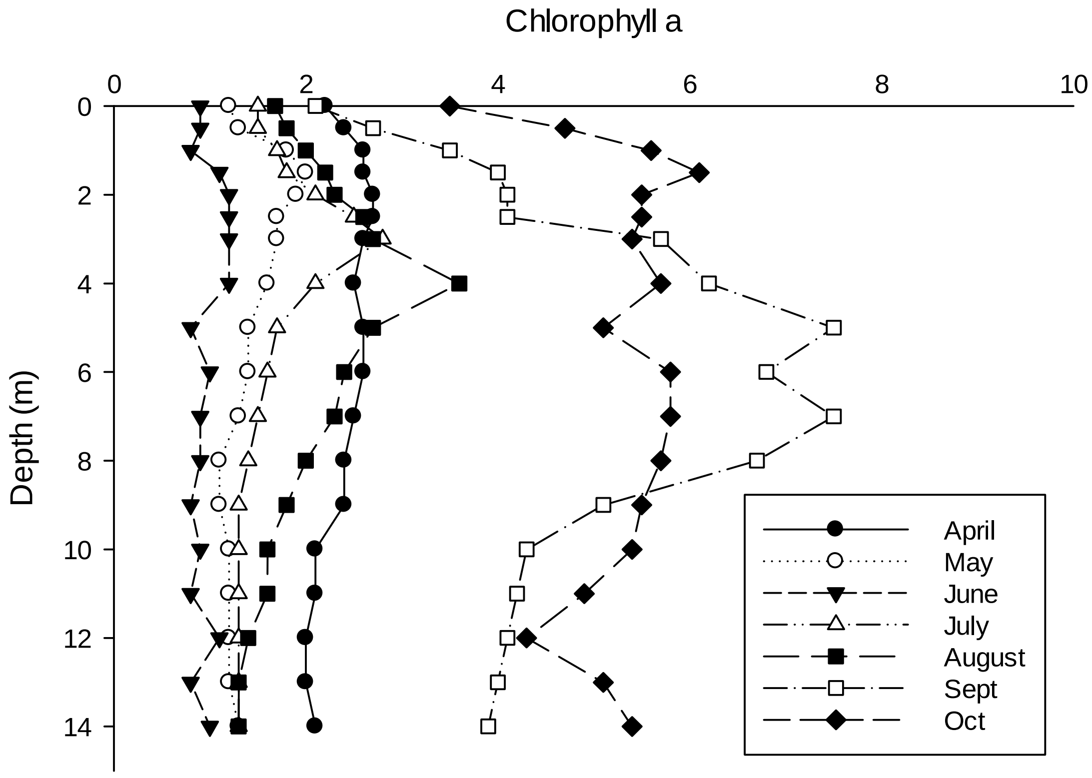


Figure 1.4. Dam (Lacustrine) Chlorophyll a (ppb) concentrations over study period (2017)

Spatial Analysis

The reservoir continues to demonstrate a pattern of greater phytoplankton growth along the thermocline however this pattern was greatly reduced in 2017. This coincides with stratification, pH elevation and oxygen observations. This is a typical pattern for eutrophic reservoirs where phytoplankton growth is photo-inhibited at the surface and blooms along the thermocline as nutrients are more available and temperatures very conducive for growth. Photoplankton growth was lower in 2017 than years prior.

Temporal Analysis

The pattern of increased phytoplankton along the 2-4 meter thermocline in the reservoir is a well-established phenomenon in eutrophic lakes. In most seasons, this pattern is more pronounced in the summer months. Spikes of phytoplankton observed in previous seasons did not occur again this year. These spikes had occurred in June of previous seasons, but water movement from heavy spring rain may have pushed this phytoplankton growth out of the reservoir early in the season. Additionally, heavy inputs of sediment occurred during the first portion of the monitoring season. Clay often photo-inhibits phytoplankton growth and competes for available phosphorus. This may account for the lower phytoplankton biomass measures in 2017.

pH

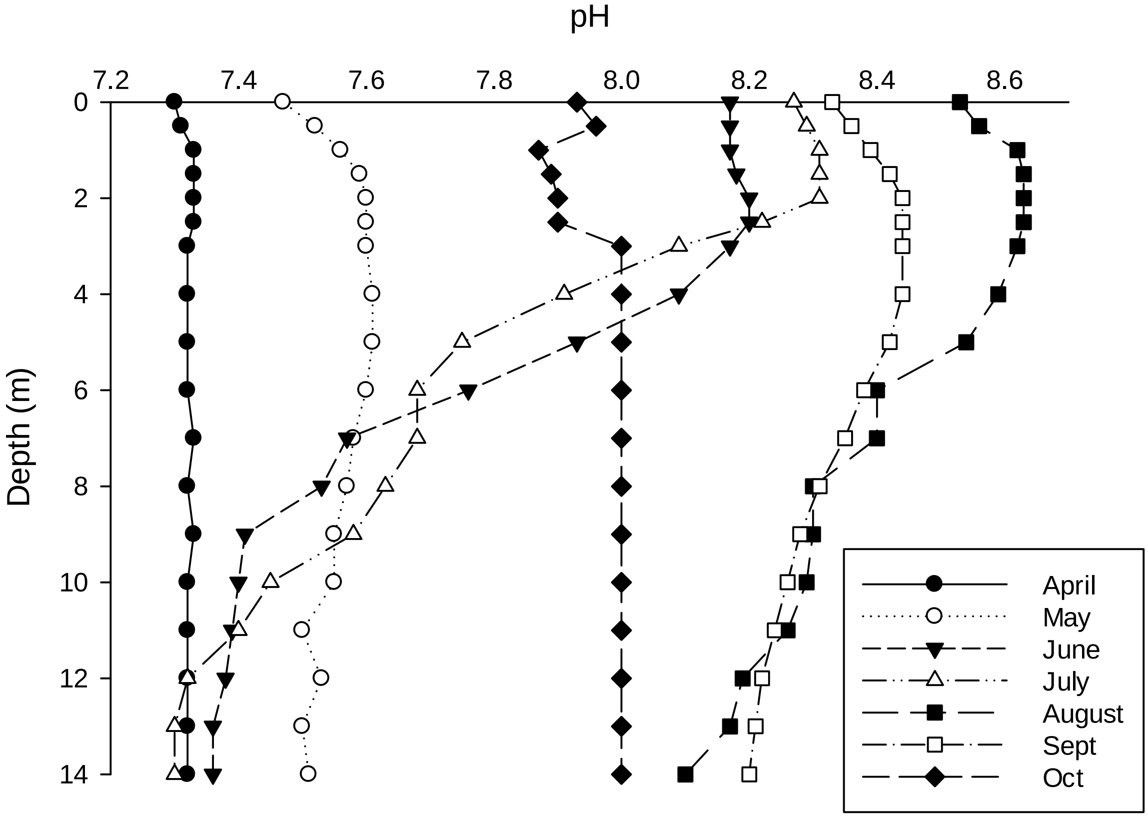


Figure 1.5. Dam (Lacustrine) pH measures over study period (2017)

Spatial analysis

The pH in the reservoir varied between 7.3 and 8.7 throughout the season, providing further evidence that the reservoir is eutrophic because high pH levels correlate with increased eutrophication. As the lake stratifies, the epilimnion becomes concentrated with phytoplankton and, through photosynthetic removal of CO_2, the pH increases. In 2017, August was the most productive month as indicated by pH, with values near 8.7 at depths below the surface. This corresponds with the idea that photo-inhibition of phytoplankton (due to suspended sediment) occurred early in the year and productivity later in the summer with increased water clarity, peaking in August.

Temporal Analysis

The observed pattern in pH is somewhat different than previous years. Typically, summer months of June, July and August are the most productive months and produce the elevated pH previously observed. In 2017, these peaks were delayed. This further strengthens the idea that water movement drives water quality conditions in the reservoir, in this case influx of poor water quality from the Pigg River.

ORP

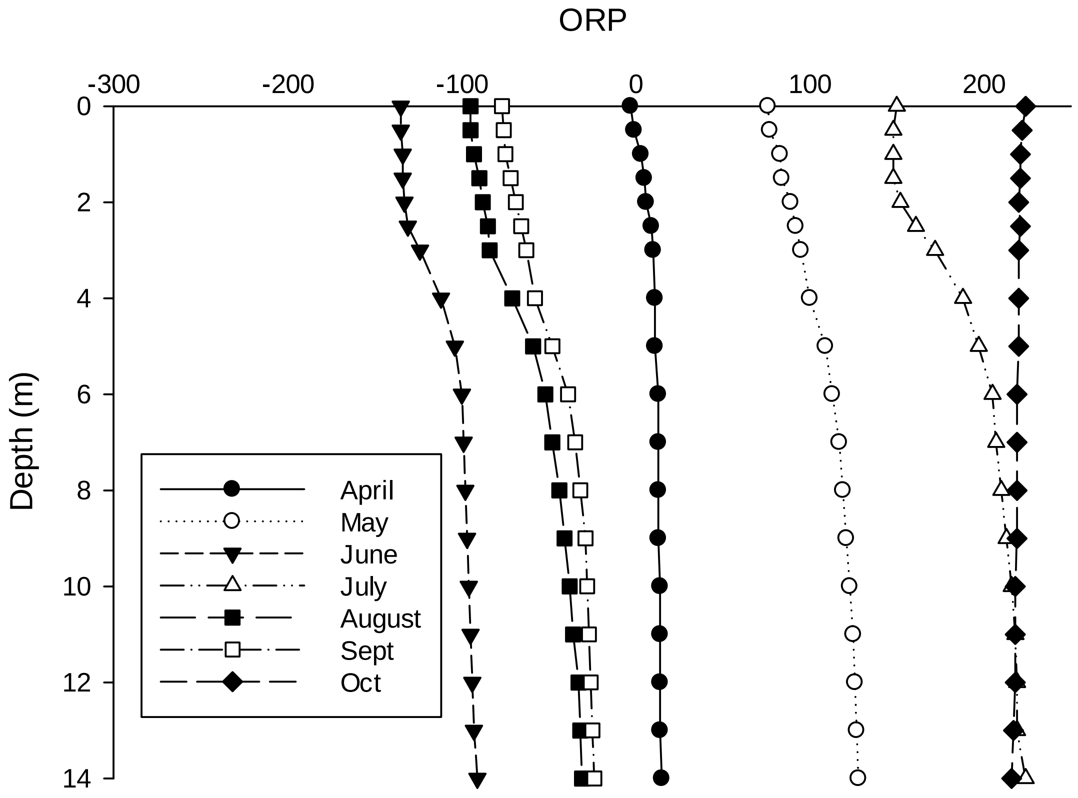


Figure 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2017)

Spatial Analysis

It is often difficult to discern patterns in ORP in this reservoir. There is a pattern of slightly increased ORP with depth. July produced the greatest contrast from epilimnion to hypolimnion. In 2017, ORP varied month to month, with the lowest levels of ORP occurring during summer sampling. Although this pattern is descernable, it is difficult to make broad interpretations from redox potential measurements. Typically, ORP measures are confounded by pH, with increasing pH lowering ORP. This accounts for the increasing ORP with depth. If a correction is applied (58 mv per unit of pH) the epilimnion is more oxidized than the hypolimnion, as suggested by the dissolved oxygen results.

Temporal Analysis

On a temporal scale, ORP measures differ from year to year. This variability is likely a result of the quality of water inputs and the influence of water flow. However, the reservoir is consistently oxidized, and this is the important interpretation of this result.

Turbidity

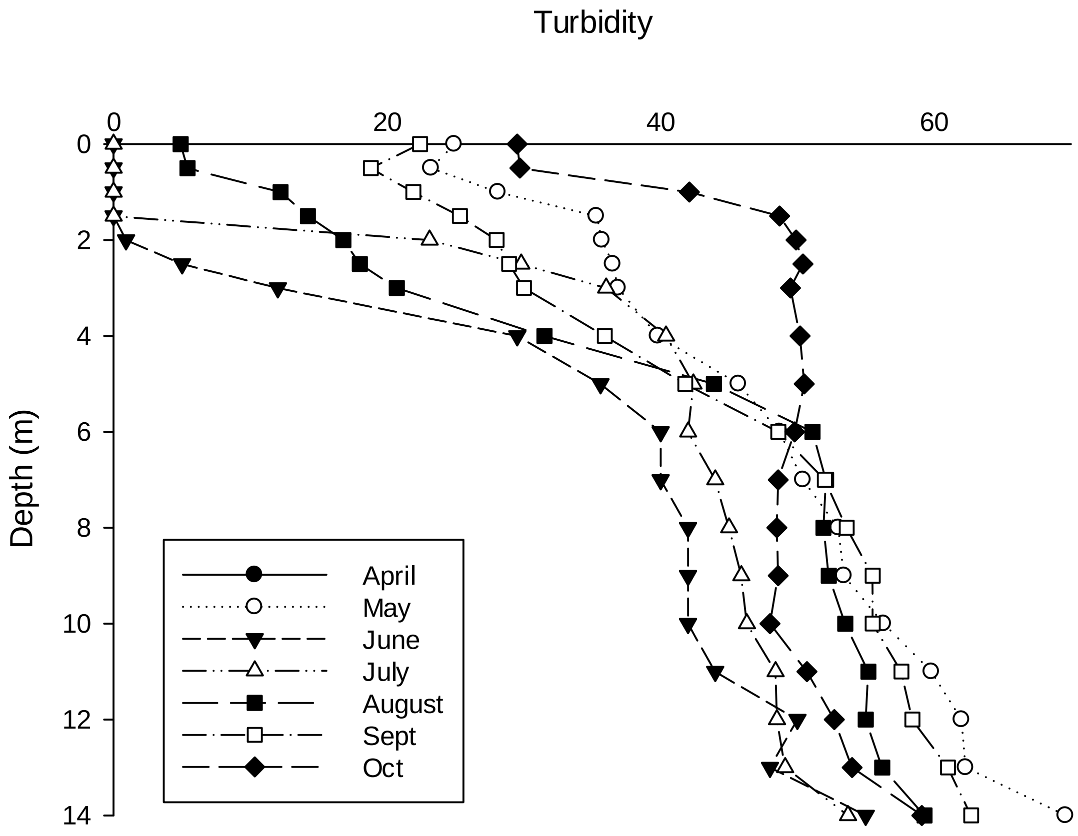


Figure 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2017)

Spatial Analysis

Turbidity in 2017 consistently increased with depth. Turbidity measures are reflect both algal and non-algal particles present in the water. Turbidity data at this station increased sharply just below the surface, mirroring the chlorophyll *a* data. But turbidity did not decline again past the thermocline as did Chlorophll *a*. . This likely reflected increased growth of phytoplankton during summer months and prevalence of solids in the water column.

Temporal Analysis

The turbidity pattern observed in 2017 was relatively consistent with that observed in previous years. Low and variable turbidity in the epilimnion increased with depth. Variation in the observations throughout the epilimnion from year to year are hard to interpret. However, summer months contain low turbidity in the epilimnion and increases in turbidity with depth while other months are more susceptibility to storm water inputs and sediment turbidity. In 2017, it appears that non-algal turbidity became more important than in previous years. Although the source of this turbidity is unknown, we suspect that it reflected release of sedmiment following demolition of the Pigg River dam.

Other Parameters Measured

Table 1.8. Other parameters measured over study period (2017). Dates represent sampling of both the volunteers and Lynchburg College. First Column represents each parameter measured along with units of measure.

Date	28-Apr	19-May	6-Jun	20-Jun	5-Jul	21-Jul	2-Aug	23-Aug	20-Sep	20-Oct
Time	10:02 AM	9:41 AM	8:55 AM	11:31 AM	9:30 AM	10:35 AM	10:45 AM	10:15 AM	9:50 AM	12:32 PM
Secchi (M)	0.4	1.2	1.6	2	1.5	2.6	1.8	2	3	1.5
TP Surface (PPM)	0.090	0.154	0.031	0.012	0.032	0.063	0.029	0.109	0.075	0.071
TP 8 Meters (PPM)	2.265	1.954		2.018		0.038		0.026	0.073	0.103
Integrate Chl a (PPB)	2.39	1.42		0.97		0.97		1.37	4.81	5.28
TSI S	73	57	53	50	54	46	52	50	44	54
TSI TP	66	73	51	40	52	61	50	68	63	62
TSI CHL	39	34		30		30		34	46	47
TSI AVG	59	55	52	40	53	46	51	51	51	54

Table 1.9. Zooplankton and *E. coli* measured over study period (2017). Dates represent sampling of both the volunteers and Lynchburg College. Zooplankton numbers are organisms per liter.

Date	**28-Apr**	**19-May**	**6-Jun**	**20-Jun**	**5-Jul**	**21-Jul**	**2-Aug**	**23-Aug**	**20-Sep**	**20-Oct**
Daphnia	0.20	1.62		0.40		0.61		0.00	1.21	0.00
Bosmina	1.21	17.79		0.40		0.20		4.45	0.81	0.28
Diaptomus	1.42	2.02		2.43		1.21		3.03	0.40	2.55
Cyclops	1.01	2.83		0.81		2.83		16.99	3.03	3.40
Nauplii	0.81	8.90		2.02		5.46		10.31	3.03	5.66
Cerodaphnia	0.00	0.81		0.00		0.00		0.00	1.01	0.85
Diaphanosoma	0.00	0.00		3.64		0.61		2.02	1.42	0.28
Chydorus	0.00	0.00		0.00		0.20		0.00	0.00	0.57
E. coli MPN	687	5	16	2	127	4	4	5	1	3

1.3.1.2 Leesville Lake Marina

Photograph of Leesville Lake Marina taken by Jade Woll.

Table 1.10. Leesville Lake Marina other parameters measured over study period (2017)

Date	**28-Apr**	**19-May**	**6-Jun**	**20-Jun**	**5-Jul**	**21-Jul**	**2-Aug**	**23-Aug**	**20-Sep**	**20-Oct**
Time	9:50 AM	10:20 AM	19:20 AM	12:05 PM	9:52 AM	10:50 AM	10:55 AM	10:28 AM	10:15 AM	12:54 PM
Secchi (M)	0.4	1.3	1.5	1.7	1.7	2.4	1.4	1.6	2.2	1.5
TP Surface (PPM)	0.009	0.085		0.011		0.248		0.080	0.052	0.085
TSI S	73	56		52		47		53	49	54
TSI TP	37	65		39		80		64	58	65
TSI AVG	55	60		46		64		59	53	59
***E. coli* MPN**	686	13.5	14	6.3	25	10.9	138	6.3	2	2

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 (2017)

Date	28-Apr	19-May	6-Jun	20-Jun	5-Jul	21-Jul	2-Aug	23-Aug	20-Sep	20-Oct
Time	10:42 AM	10:32 AM	9:35 AM	12:15 PM	10:10 AM	11:01 AM	11:10 AM	10:50 AM	10:30 AM	1:02 PM
Secchi (M)	0.5	0.8	1.75	1.25	1.6	2.1	1.5	1.55	2.2	1.25
TP Surface (PPM)	0.018	0.033		0.101		0.065		0.080	0.080	0.100
TSI S	70	63		57		49		54	49	57
TSI TP	45	52		67		61		64	64	67
TSI AVG	57	58		62		55		59	56	62
***E. coli* MPN**	325	34	8	10	6	4	8	6	0	5

1.3.1.4 Mile Marker 6 (Transition)[2]

Background

In discussing water quality at the transition station (MM6), comparisons are made back to Lacustrine and Riverine portions of the lake. The purpose of this section is not to further discuss the patterns observed at the Dam (Lacustrine) or Toler Bridge

---

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

(Riverine), but to discern any trends the data provide on a spatial scale moving up or down the lake.

Conductivity

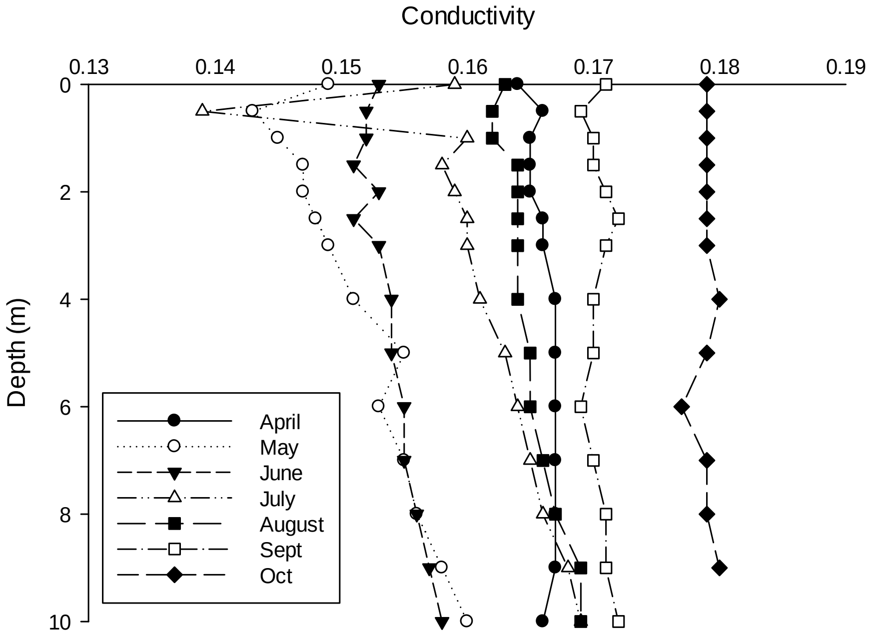


Figure 1.8. Mile Marker 6 (Transition) Conductivity (ms/cm) measures over study period (2017)

Spatial Analysis

Conductivity measures were similar to those observed at the dam (between 0.14 and 0.18 ms/cm), except that measures in April fell in the middle of the collected data pattern, and were considerably greater than expected. Higher conductivity in April suggests greater volumes of water flowing into Leesville from SML as tail water conductivity is often greater than conductivity of Pigg River water.

Temporal Analysis

Comparisons among years reveal a similar trend, with a majority of the samples collected having conductivities between 0.14 and 0.18 us/cm. Unlike previous years, the April data in 2016 and 2017 differed from those during the remainder of the year.

Dissolved Oxygen

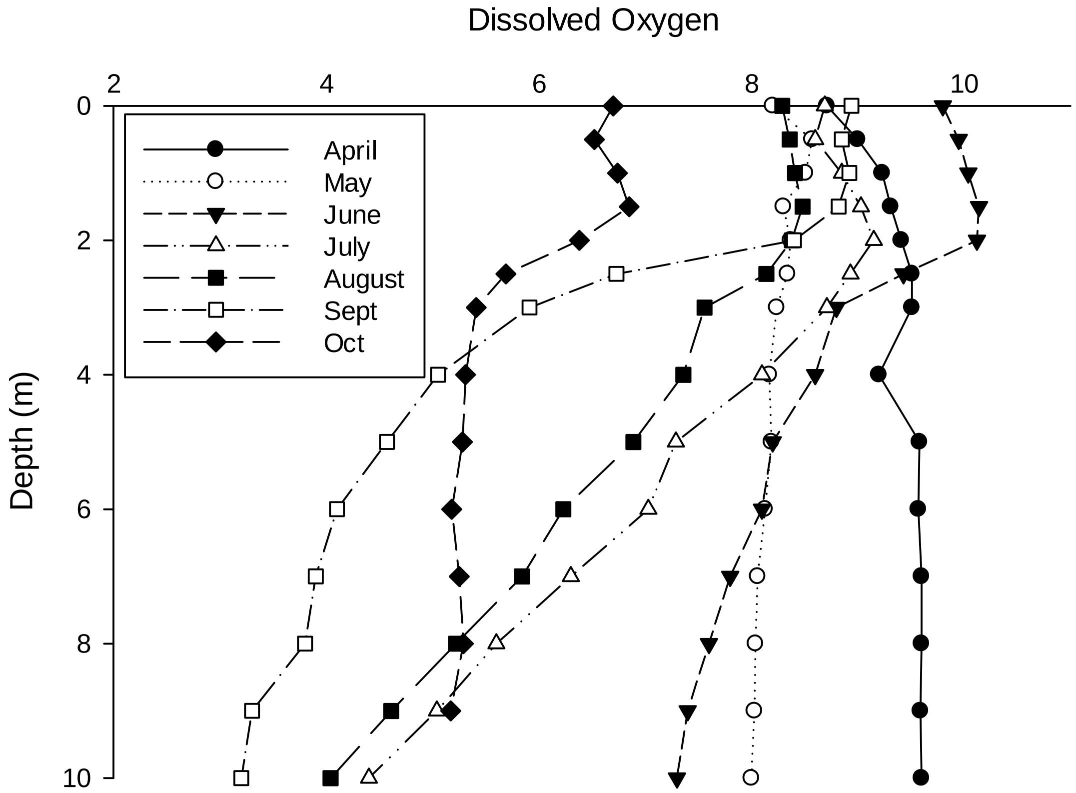


Figure 1.9. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2017)

Spatial Analysis

The pattern of dissolved oxygen in the transition area was similar to that observed at the dam with a few notable exceptions. Some of the surface readings were lower than measured at the dam, particularity late in the season. This is an interesting result that is hard to interpret. Perhaps water movement throughout the reservoir accounts for this result, with mixing lowering overall levels of oxygen (i.e., mixing is more prominent in the riverine and transition regions of the lake than in the lacustrine, dam region). This was very concerning in October, as the entire reservoir in this area has very low concentrations of oxygen. If water movement creates this problem, this needs to be addressed.

Temporal Analysis

The lower levels of oxygen toward the end of the season is a phenomenon observed only recently at this station. Earlier trends did not exhibit as large a spread of oxygen concentrations, including very high levels of observed oxygen in the summer. You see a similar pattern beginning in 2015 and 2016. This is an area of concern in the reservoir as it is a source of impairment.

Temperature

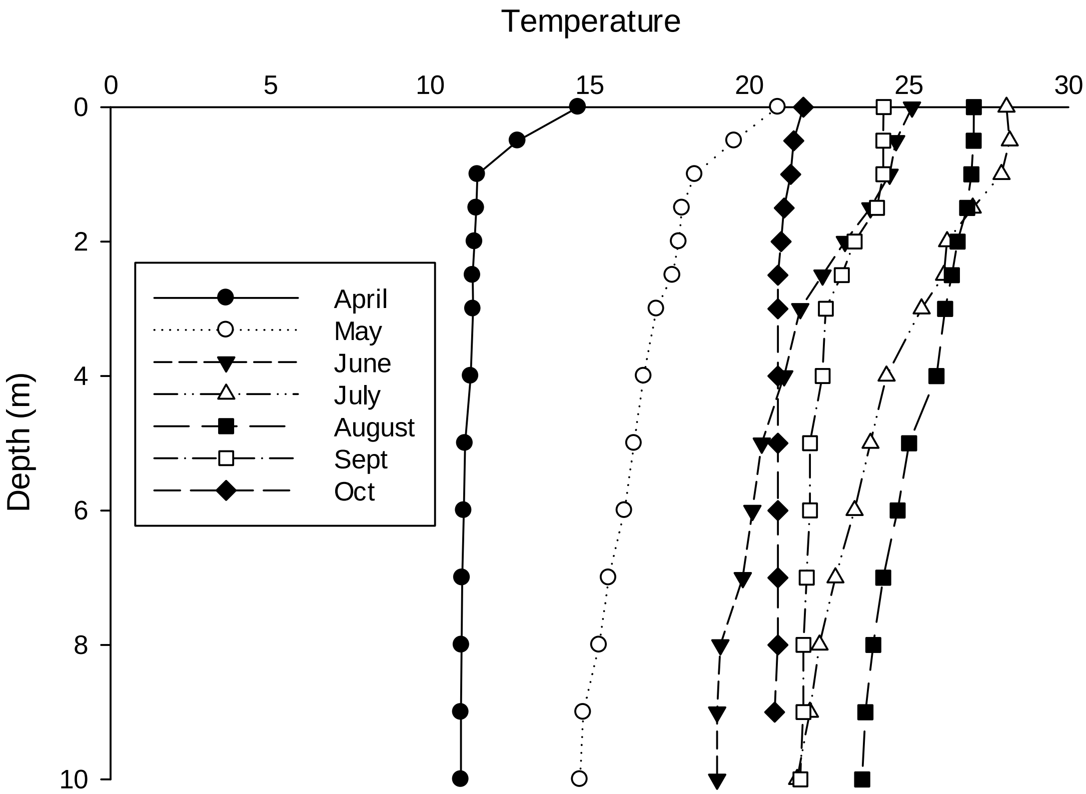


Figure 1.10. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2017)

Spatial Analysis

The range of water temperatures was very similar to that observed at the dam throughout the season. The greatest difference was a lack of stratification, which may account for many of the observations in other parameters we see at this station.

Temporal Analysis

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. Changes observed in oxygen depth profiles consistently suggest more significant stratification than did water temperature profiles.

Chlorophyll *a*

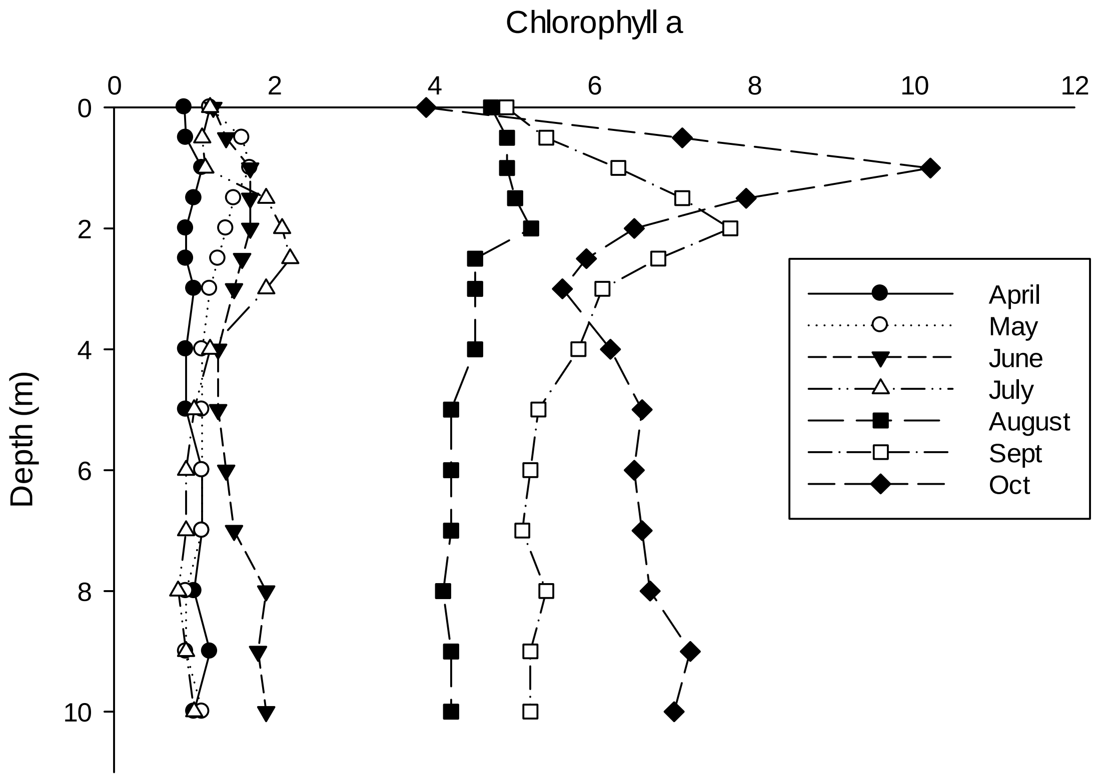


Figure 1.11. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2017)

Spatial Analysis

Phytoplankton abundance measured by Chlorophyll *a* at this station strongly supports the pattern of low phytoplankton growth during the early part of the season (April-July) with substantial growth during the final 3 months of monitoring. This station often reflects conditions of growth similar to the dam but the influence of hydrology and nutrient concentrations result in greater Chlorophyll *a* maximums at this site. This suggests that movement of water from the SML dam and sediment inputs from the Pigg River influence this portion of the reservoir on a regular basis.

The clear separation between the first portion of sampling (first four months) and later sampling are very stark. This provides the strongest data suggesting the limitation of sedimentation and water movement on phytoplankton growth. Low Chlorophyll *a* with minimal stratification impacts during the portion of sampling with high flow rates. Much higher concentrations with increases along the thermocline occurred later into the season when rainfall was limited.

Temporal Analysis

The pattern of moderate increases in the phytoplankton population along the thermocline is consistent with historical data at this station during rainy periods. When the reservoir does not experience significant rain events (sediment inputs are minimal), we see high growth of phytoplankton particularly at MM6. Conversely, this station is often impacted by sedimentation and thus limited growth of phytoplankton. These processes are the most important factors regulating productivity in Leesville Lake.

pH

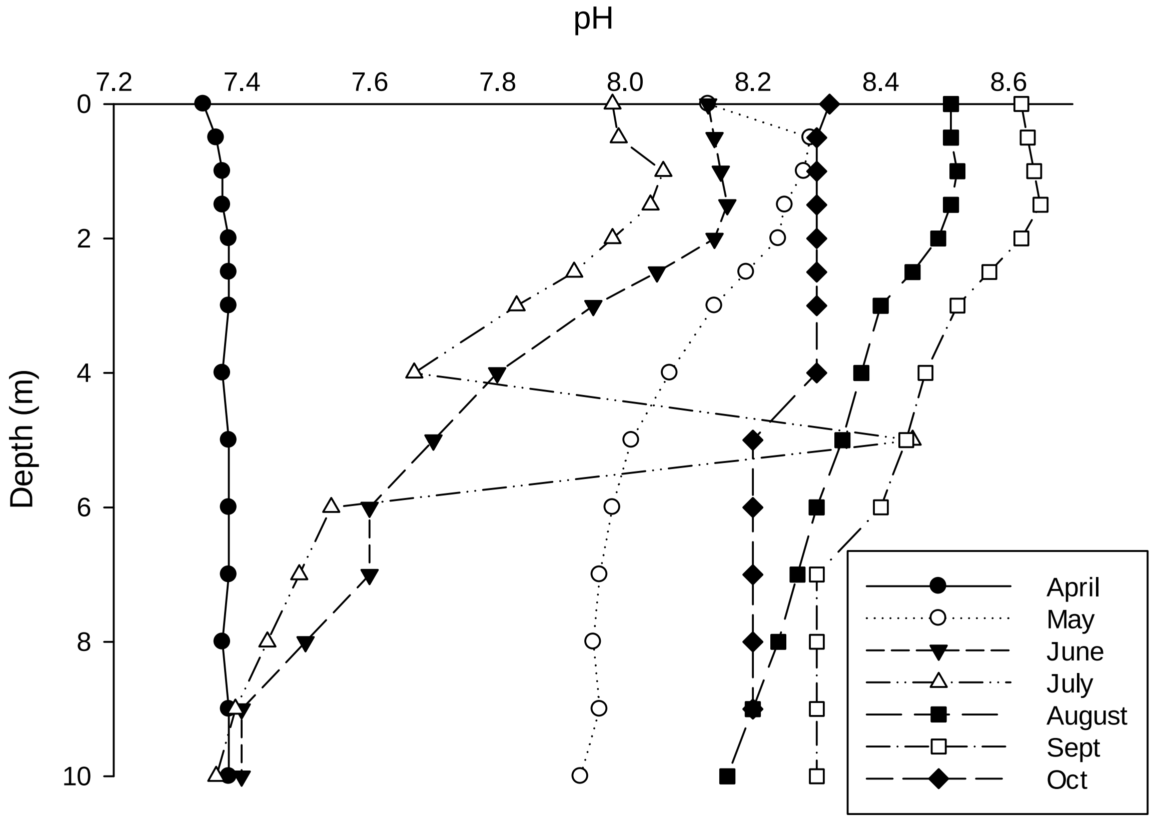


Figure 1.12. Mile Marker 6 (Transition) pH measures over study period (2017)

Spatial Analysis

The pH pattern is similar to that observed at the dam with some exceptions. Unlike the pattern at the dam, September pH measures were greater at this station. As this station is influenced by riverine processes, the ability of phytoplankton to reduce the water pH is lessened.

Temporal Analysis

Patterns of pH values observed in 2017 are similar to patterns observed throughout the years of study. Higher pH values in the epilimnion during summer is a typical pattern that develops each year. The lower pH particularly in October is a pattern that has become more pronounced in the last three seasons. Processes that are driving pH to lower levels and turbidity to higher levels must be evaluated.

ORP

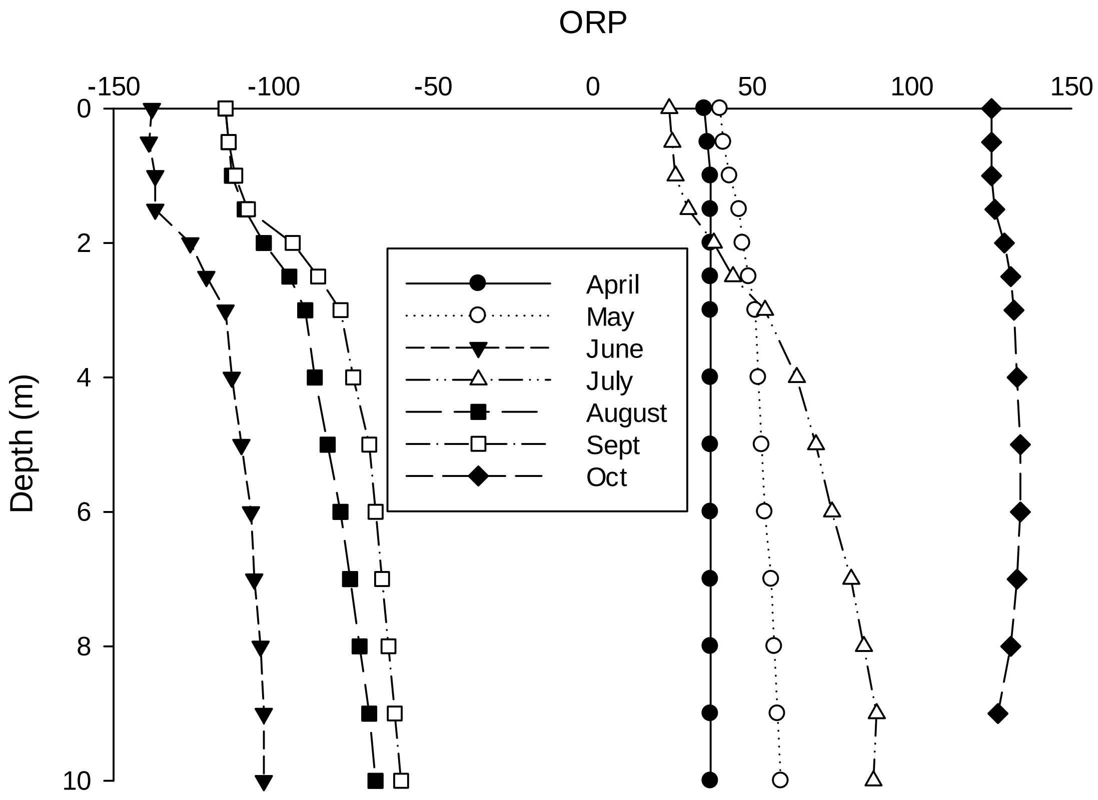


Figure 1.13. Mile Marker 6 (Transition) ORP (mV) measures over study period (2017)

Spatial 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.

Temporal Analysis

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

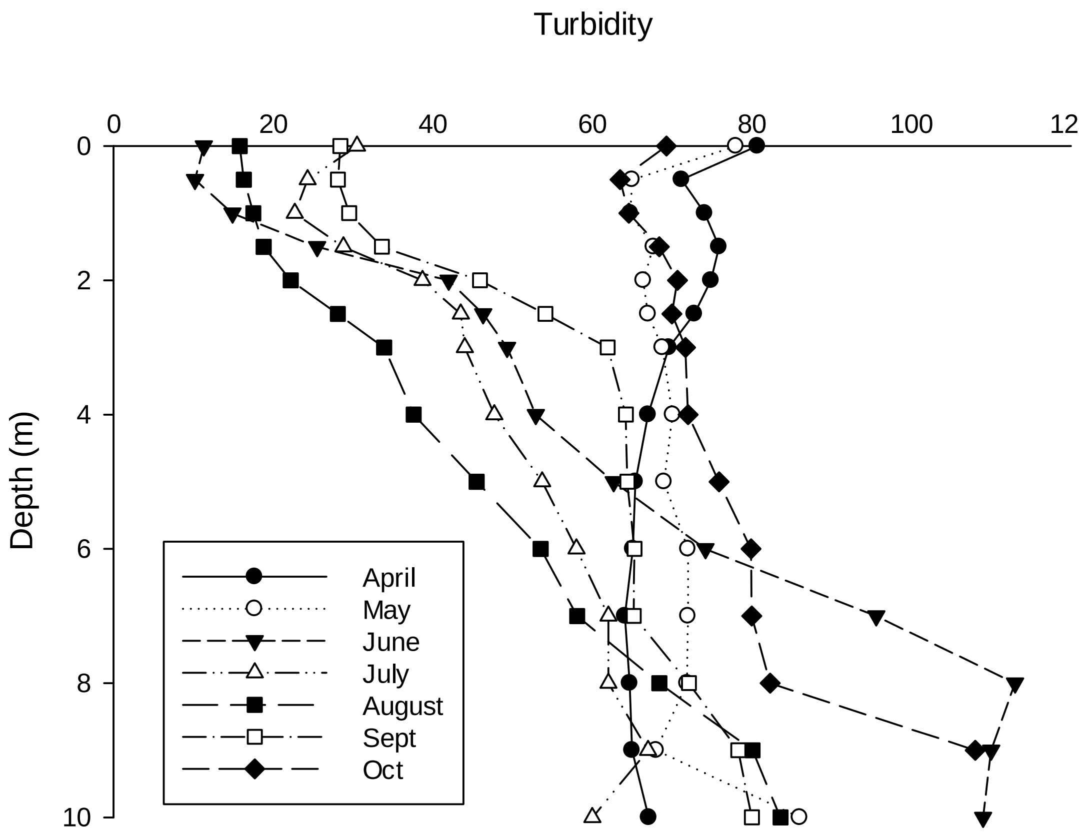


Figure 1.14. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2017)

Spatial Analysis

Similarities between dam and MM6 include increasing turbidities with depth. This is expected as phytoplankton production influences turbidity. Yet differences between sites give insight into the hydrology and other processes functioning in the reservoir. April, May and Oct provide the highest turbidity readings at MM6 while turbidity readings in October were very elevated at the dam.

Temporal Analysis

Turbidities appear to be increasing in the reservoir. Historically, overall levels of turbidity have been lower in past years, and the increased turbidity along the lower portion of the epilimnion and into the hypolimnion is a more recent development. Processes that are occurring to create this pattern need to be investigated.

Other Parameters Measured

Table 1.19. Other parameters measured over study period (2017). Dates represent sampling of both the volunteers and Lynchburg College. First Column represents each parameter measured along with units of measure.

Date	28-Apr	19-May	6-Jun	20-Jun	5-Jul	21-Jul	2-Aug	23-Aug	20-Sep	20-Oct
Time	10:52 AM	10:50 AM	9:48 AM	12:20 PM	10:50 AM	11:07 AM	11:02 AM	10:56 AM	10:40 AM	1:09 PM
Secchi (M)	0.7	0.7	1.75	1.4	1.55	1.75	1.5	1.6	1.8	1.1
TP Surface (PPM)	0.035	0.055	0.016	0.016	0.004	0.097	0.167	0.193	0.139	0.144
TP 6 Meters (PPM)	0.01	2.13				0.10		0.04	0.145	0.108
Integrate Chl a (PPB)	0.99	1.23		1.57		1.30		1.42	5.82	6.68
TSI S	65	65	52	55	54	52	54	53	52	59
TSI TP	53	59	43	43	30	67	74	76	72	72
TSI CHL	31	33		35		33		34	48	49
TSI AVG	50	52	48	44	42	51	64	54	57	60

Table 1.20. Zooplankton and *E. coli* measured over study period (2017). Dates represent sampling of both the volunteers and Lynchburg College. Zooplankton numbers are organisms per liter.

Date	28-Apr	19-May	6-Jun	20-Jun	5-Jul	21-Jul	2-Aug	23-Aug	20-Sep	20-Oct
Daphnia	0.00	0.00		1.21		0.00		0.20	0.81	3.68
Bosmina	1.01	10.38		0.20		1.18		1.42	6.87	3.11
Diaptomus	0.20	1.42		0.61		0.71		0.20	1.42	3.11

Cyclops	**0.20**	**4.25**		**3.84**		**2.59**		**1.82**	**1.62**	**10.76**
Nauplii	**0.20**	**1.42**		**0.81**		**2.12**		**2.43**	**1.21**	**11.89**
Cerodaphnia	**0.00**	**4.25**		**0.40**		**0.00**		**0.00**	**0.00**	**0.00**
Diaphanosoma	**0.00**	**0.00**		**3.24**		**2.12**		**3.24**	**3.24**	**0.85**
Chydorus	**0.00**	**0.00**		**0.00**		**0.00**		**0.00**	**0.20**	**1.13**
***E. coli* MPN**	**224**	**50**	**2**	**5**	**3**	**2**	**2**	**1**	**0**	**8**

1.3.1.5 Mile Marker 9

Photograph of Leesville Lake taken by Jade Woll.

Table 1.21. Mile Marker 9 other parameters measured over study period (2017)

Date	28-Apr	19-May	6-Jun	20-Jun	5-Jul	21-Jul	2-Aug	23-Aug	20-Sep	20-Oct
Time	11:17 AM	11:10 AM	10:04 AM	1:05 PM	10:40 AM	11:38 AM	11:35 AM	11:25 AM	11:15 AM	1:34 PM
Secchi (M)	1.00	0.90	1.25	0.9	1.1	1.45	1.2	1.40	1.40	1.00

TP Surface (PPM)	0.038	0.015		0.14		0.036		0.067	0.101	0.132
TSI S	60	62		62		55		55	55	60
TSI TP	54	42		72		53		61	67	71
TSI AVG	57	52		67		54		58	61	65
***E. coli* MPN**	70	62	21	40	7	4	4	3	3	5

1.3.1.6 Toler Bridge (Riverine)[3]

Background

Riverine conditions as well as influx of tail waters of Smith Mountain Lake 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.

---

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

Conductivity

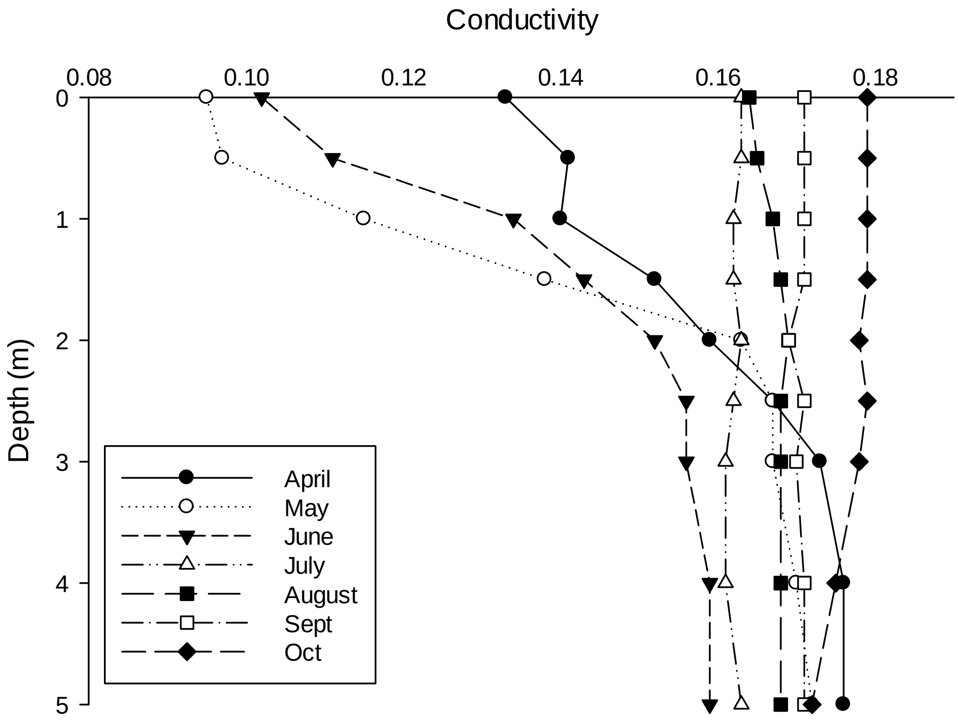


Figure 1.15. Toler Bridge (Riverine) Conductivity (ms/cm) measures over study period (2017).

Spatial 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 is generally lower than the lake (Table 1.31). Readings are consistently below 0.1 ms/cm. Dynamics in the early portion of the year (April-June) suggest Pigg River water predominates water quality conditions at Toler Bridge. Warmer river water enters and flows over top of the cooler reservoir water as indicated by the conductivity curves. Later in the year, this pattern is not obvious most likely due to hydropower operations and lower flows from the Pigg River.

Temporal Analysis

Trends for conductivity in the reservoir suggest that overall it was lower in 2017. As Pigg River conductivity is generally lower than that measured in the main stem of the reservoir, and conductivity of water from the tail race is higher, greater influence on limnology of the reservoir from river inputs is inferred.

Dissolved Oxygen

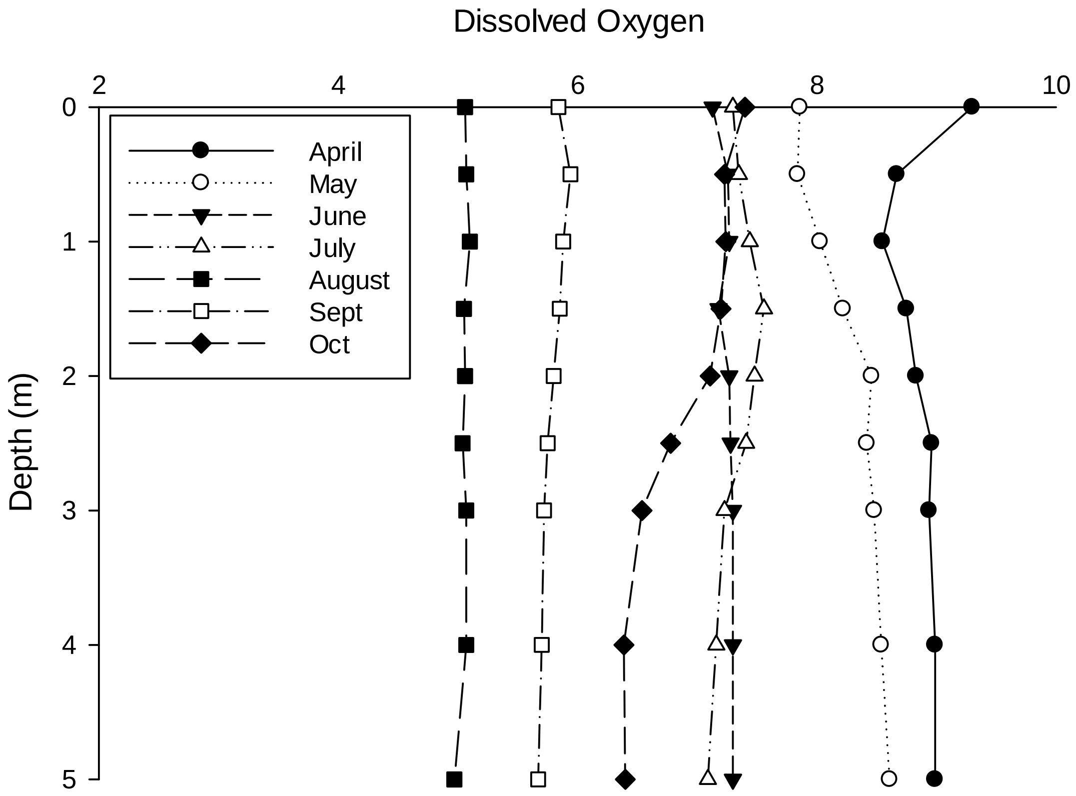


Figure 1.16. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2017)

Spatial Analysis

Oxygen dynamics in this portion of the reservoir reflect constant water movement unlike other portions studied. Oxygen concentrations are consistent top to bottom suggesting hydropower operations prevent stratification. This station has the strong influence of hypolimnion withdrawal from SML. Higher flow from Pigg River additionally creates impacts on this station. Readings in August and September are lower than the remainder of the reservoir at both the surface and at depth. August readings are very concerning as these concentrations are close to regulated minimums throughout the water column.

Temporal Analysis

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

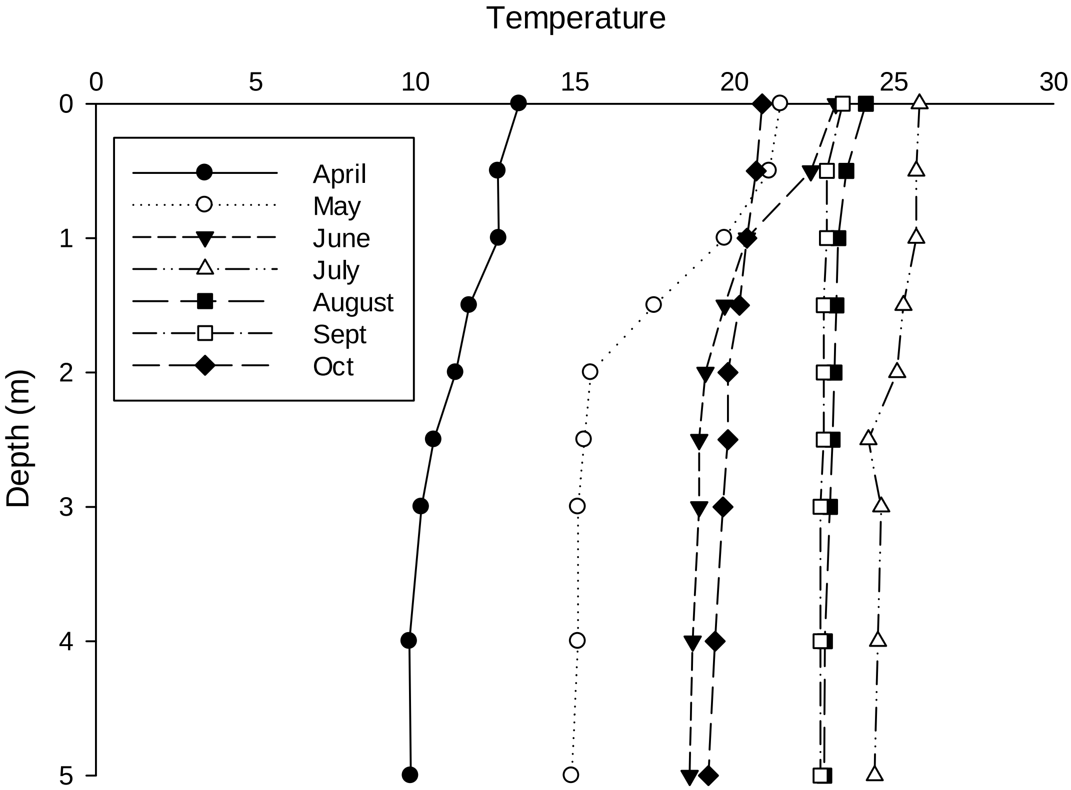


Figure 1.17. Toler Bridge (Riverine) Temperature (°C) measures over study period (2017)

Spatial Analysis

The most significant difference observed at this station is minimalization 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.

Temporal Analysis

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

Chlorophyll *a*

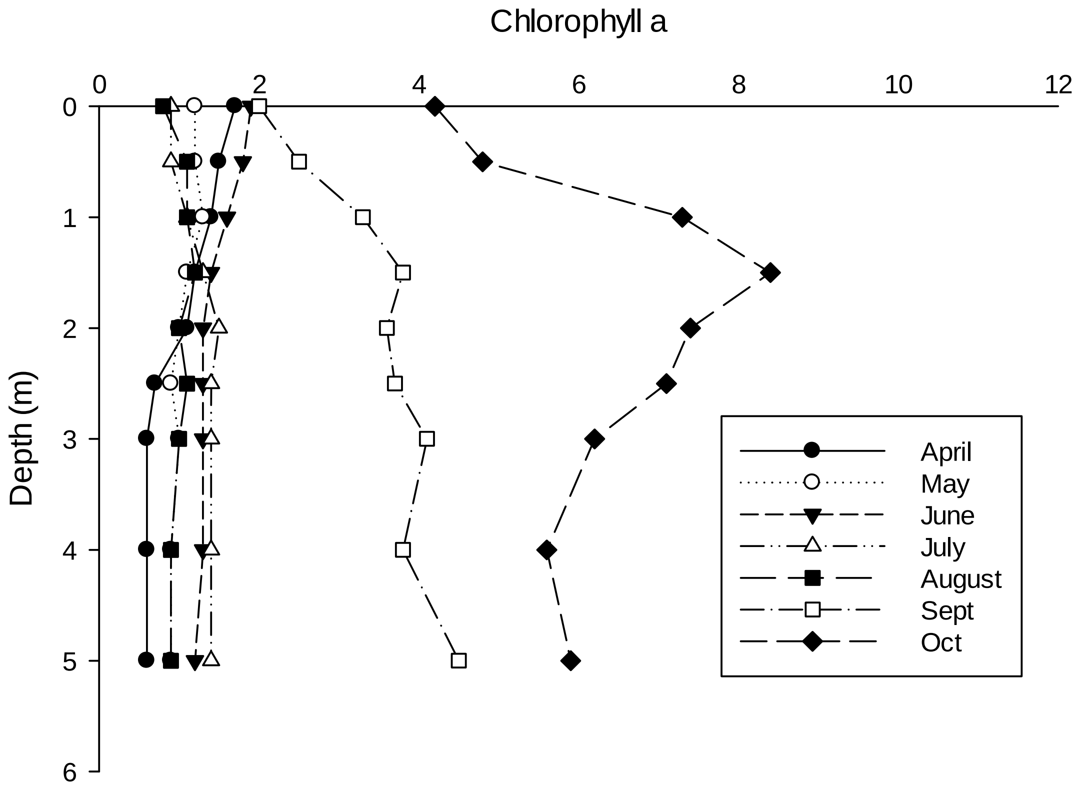


Figure 1.18. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2017)

Spatial Analysis

This station contains the lowest readings of phytoplankton biomass throughout the entire reservoir. The observed 2017 pattern suggests, similar to MM6 and other portions of the reservoir in 2017, that limited sedimentation and water movement allow for growth of phytoplankton at this station. Thus, pumpback operations highly influence the ability of phytoplankton to grow and develop at this station. Movement of water tends to flush the phytoplankton from this portion of the reservoir.

Temporal Analysis

The low readings from this year's water samples are not typical for the reservoir. In some past years, readings were much higher than observed during this sampling season. 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. Depending on flow from Pigg River, various conditions could develop where growth of phytoplankton increases at this station. Greater knowledge of both generation of power by AEP, conditions that contribute to this trend in the hypolimnion of SML and flow from the Pigg River are needed to understand the contribution of factors that contribute and impair this growth.

pH

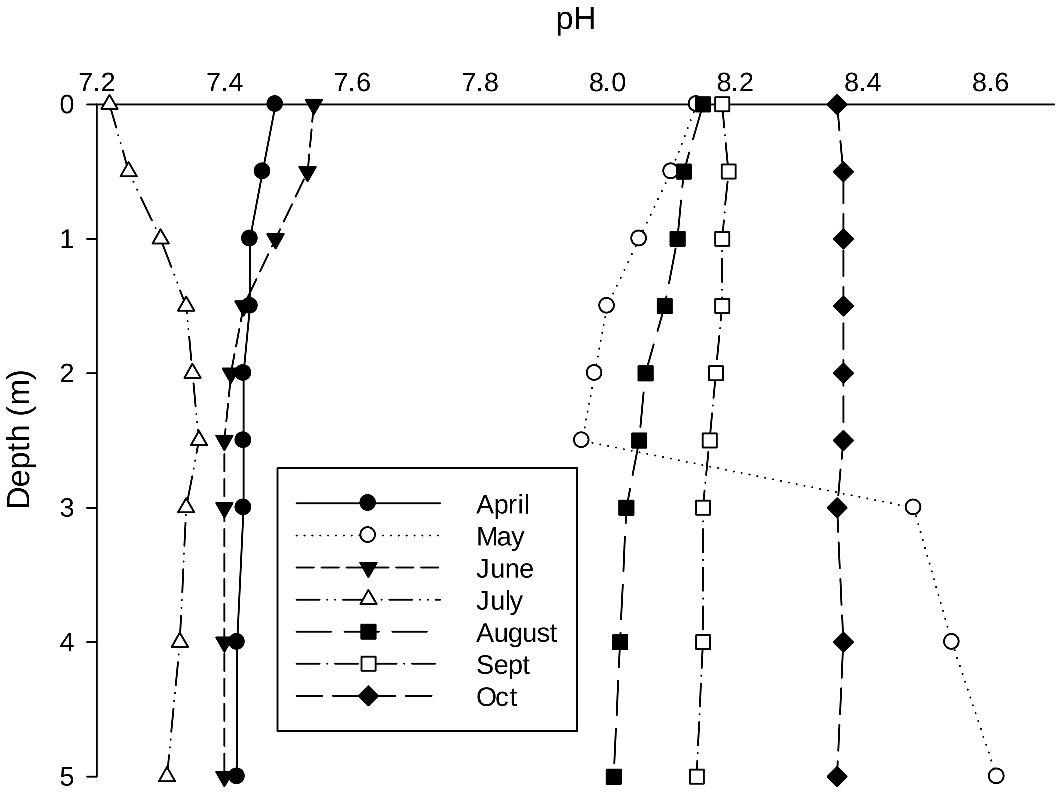


Figure 1.19. Toler Bridge (Riverine) pH measures over study period (2017)

Spatial Analysis

The pH readings in this portion are lower than at stations further down the lake, as expected. Processes at this locale are driven more by water inputs than productivity. The rise in pH with depth in May is clearly a result of Pigg River vs. SML hypolimnion and demonstrates this dynamic. Unsure why May pH results cluster with measures of pH during the second half of sampling season as increased phytoplankton activity is the likely the driver of high pH.

Temporal Analysis

No discernable patterns patterns of pH distribution through the water column, as occur with stratification, were evident in 2017 or in previous years.. It is likely that pH is traceable to flow and phytoplankton growth throughout the years.

ORP

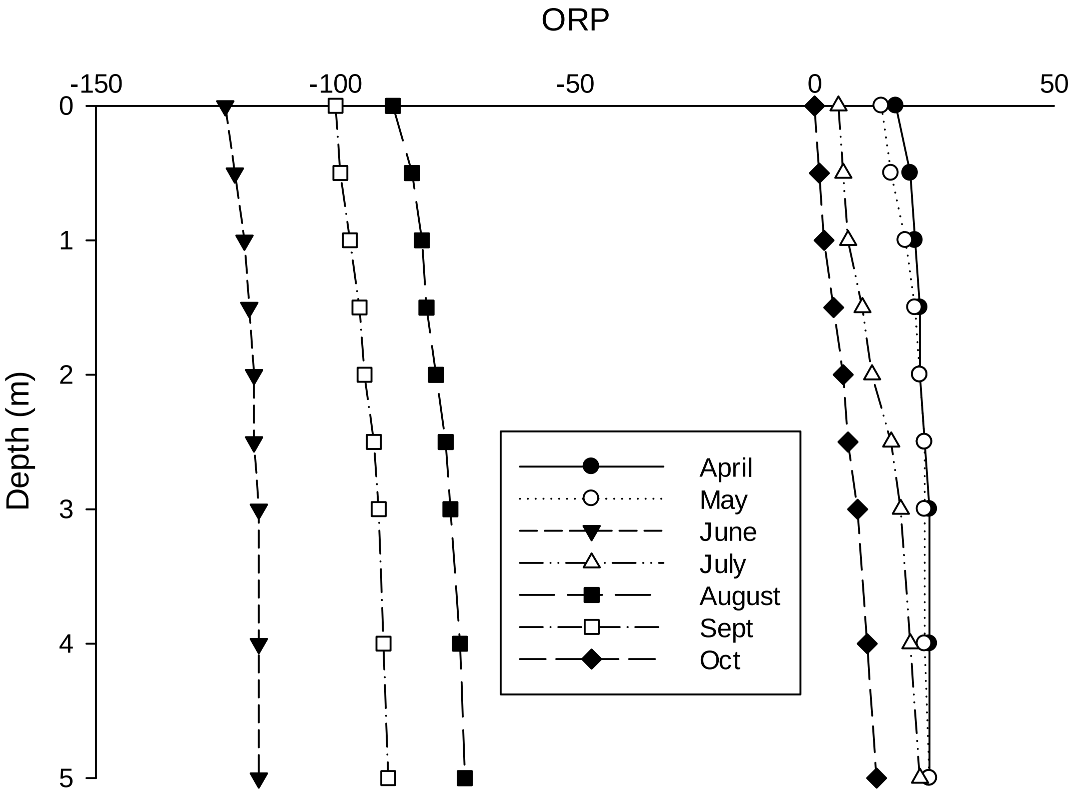


Figure 1.20. Toler Bridge (Riverine) ORP (mV) measures over study period (2017)

Spatial 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.

Temporal Analysis

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 among the years.

Turbidity

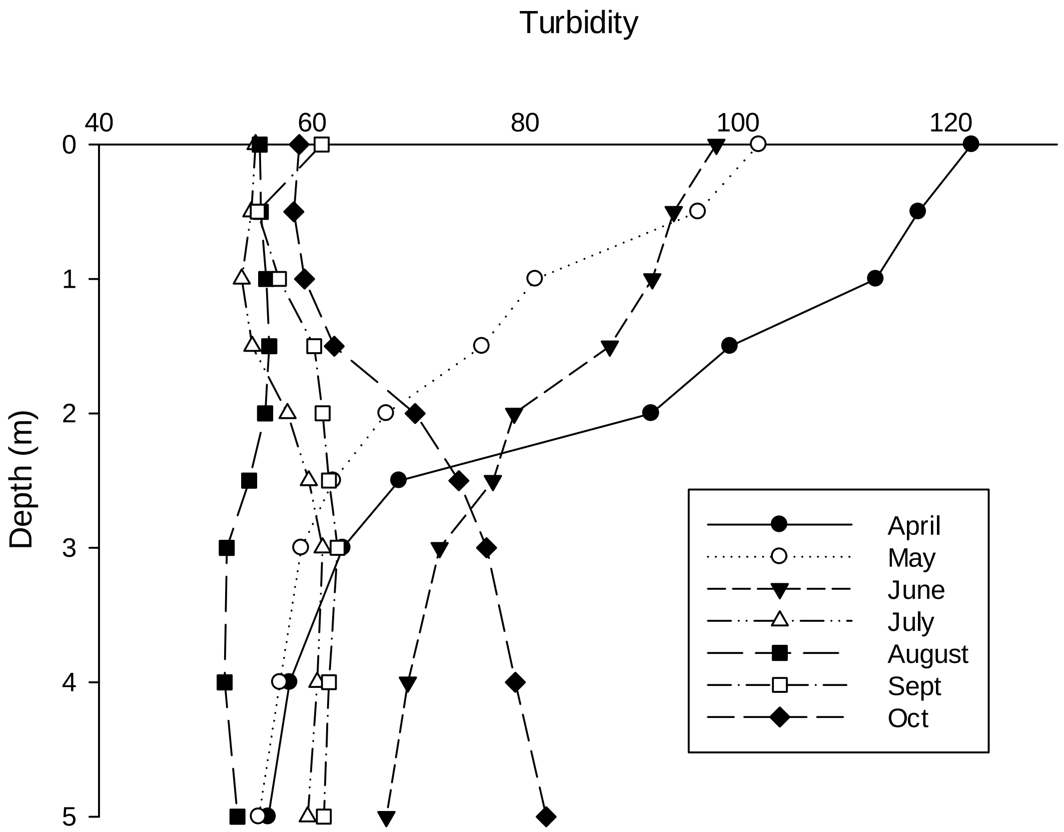


Figure 1.21. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2017)

Spatial Analysis

Turbidity in this portion of the reservoir is quite different than other portions of the reservoir. Early season measures (April-June) reflect the high levels of turbidity driven by sedimentation from storm inputs. Additionally, high turbidity readings occur in upper waters (Pigg River input) with lower readings below (presumably SML release). These data support trends throughout the reservoir suggesting that high sediment inputs drove water quality during the early portion of the season, with lower turbidity and sediment inputs during the later part of the sampling year.

Temporal Analysis

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

Other Parameters Measured

Table 1.29 Other parameters measured over study period (2017). Dates represent sampling of both the volunteers and Lynchburg College. First Column represents each parameter measured along with units of measure.

Date	**28-Apr**	**19-May**	**6-Jun**	**20-Jun**	**5-Jul**	**21-Jul**	**2-Aug**	**23-Aug**	**20-Sep**	**20-Oct**
Time	**11:28 AM**	**11:24 AM**	**10:35 AM**	**1:20 PM**	**10:55 AM**	**11:55 AM**	**11:50 AM**	**11:39AM**	**11:45AM**	**1:45PM**
Secchi (M)	**0.40**	**0.50**	**0.60**	**0.30**	**1.00**	**1.25**	**1.15**	**1.40**	**1.40**	**1.25**
TP Surface (PPM)	**0.010**	**0.029**	**0.045**	**0.081**	**0.078**	**0.006**	**0.052**	**0.109**	**0.081**	**0.140**
TP 4 Meters (PPM)									**0.168**	**0.127**
Integrate Chl a (PPB)	**1.04**	**1.06**		**1.46**		**1.26**		**1.01**	**5.48**	**6.32**
TSI S	**73**	**70**	**67**	**77**	**60**	**57**	**58**	**55**	**55**	**57**
TSI TP	**38**	**50**	**56**	**64**	**64**	**33**	**58**	**68**	**64**	**72**
TSI CHL	**31**	**31**		**34**		**33**		**31**	**47**	**49**
TSI AVG	**47**	**51**	**62**	**59**	**62**	**41**	**58**	**51**	**56**	**59**

Table 1.30. Zooplankton and *E. coli* measured over study period (2017). Dates represent sampling of both the volunteers and Lynchburg College. Zooplankton numbers are organisms per liter.

Date	**28-Apr**	**19-May**	**6-Jun**	**20-Jun**	**5-Jul**	**21-Jul**	**2-Aug**	**23-Aug**	**20-Sep**	**20-Oct**
Daphnia	0.0	1.1		0.3		0.9		0.0	0.2	0.0
Bosmina	2.4	9.6		0.3		2.6		5.9	4.0	2.3
Diaptomus	0.2	1.1		0.0		0.2		0.6	1.2	0.6

Cyclops	0.4	7.9		1.7		4.0		5.7	1.8	4.2
Nauplii	0.2	6.5		1.7		3.3		4.5	0.8	3.7
Cerodaphnia	0.0	2.3		0.0		0.0		0.0	0.0	0.0
Diaphanosoma	0.0	0.0		0.0		2.8		2.8	0.6	0.0
Chydorus	0.2	0.0		0.0		0.0		0.3	0.2	0.6
E. coli MPN	548	326	145	238	9	5	6	6	3	3

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 (2017)

pH	8.4	7.3		7.22		7.34		7.98	8.31	8.4
DO%	7.39	83.3		93.5		95.3		78.6	93.3	101.3
ORP (mV)	93.8	23		-111		12		-89	-98	93.8
Turbidity (NTU)	29	118		116		40.3		39.6	64.0	94.6
Secchi (m)	0.20	0.40	0.4	0.3	0.4	0.80	0.4	0.75	0.90	1.75
TP (mg/L)	0.084	0.053		0.104		0.066		0.006	0.113	0.145

Date	**28-Apr**	**19-May**	**6-Jun**	**20-Jun**	**5-Jul**	**21-Jul**	**2-Aug**	**23-Aug**	**20-Sep**	**20-Oct**
Time	11:44 AM	11:46 AM	10:42 AM	1:40 PM	11:48 AM	12:07 PM	12:00 PM	12:00PM	11:45AM	2:02PM
Temp. (°C)	19.68	22.2		25.6		27.5		27.59	23.8	16.9
Cond. (µs/cm)	0.055	0.07		0.065		0.079		0.106	0.08	0.055
DO Surface (mg/L)	DNM	DNM		7.5		7.37		6.05	7.8	9.51

(PPM)										
TSI S	83	73		77		63		64	62	52
TSI TP	65	58		68		61		33	69	72
TSI AVG	74	66		72		62		49	65	62
E.coli MPN	579	387	547	488	1553	98	71	35	20	14

1.3.1.8 Smith Mountain Lake Tail Waters

Table 1.32. Smith Mountain Lake Tail Waters other parameters measured over study period (2017)

Date	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
Time	12:19 PM	11:46 AM	2:00 PM	12:25PM	12:19PM	12:02PM	2:18PM
Temp. (°C)	9.72	16.04	22.7	24.3	22.31	22.5	20.29
Cond. (ms/cm)	0.178	0.173	0.156	0.157	0.172	0.163	0.186
DO (mg/L)	8.81	7.88	7.1	6.2	4.72	5.77	6.626
pH	7.35	7.25	7.2	6.52	7.97	8.15	8.28
DO%	79.2	80.6	84	75.9	55.3	62.6	69.8
ORP (mV)	6.6	-10	-109	-8	-76	-105	29
Turbidity (NTU)	43.2	53.8	68	57.6	59	75.3	35.6
Secchi (m)	2.75	2.25	0.75	0.80	1.800	1.600	1.750
TP Surface (PPM)	0.200	0.050	0.009	0.067	0.014	0.117	0.125
TSI S	38	48	64	63	52	53	52
TSI TP	77	58	34	61	42	69	70
TSI AVG	57	53	42	62	47	61	61
E.coli MPN	1.00	38.30	55.40	7.40	2.000	17.500	5.100

Section 2: Lake-Wide Trends

The purpose of this section is to look at the functioning of the reservoir and establish trends. These trends are important to give a trajectory of lake health and allow us to manage the lake for optimum water quality. These trends are based on collected water quality parameters over the course 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 the 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 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 than in eutrophic lakes due to the lower nutrient levels. However, excessive eutrophication is to be avoided. This is classified as TSI > 61.

2.1 Analysis of Trophic State[4]

In this analysis, trends of all the measurable trophic state indices (TSI) are evaluated for all of the sampling data collected during this project. The usefulness of this is many-fold. First, we can examine several parameters that are used to predict TSI or lake health. The use of multiple parameters always strengthens any scientific investigation. Second, each parameter measured provides a predictor based on differing influences within the reservoir. Secchi depth is influenced by both sediment input and phytoplankton growth, whereas total phosphorus (TP) simply reflects the concentrations of this limiting nutrient but also reflects dynamics within the reservoir. Additionally, chlorophyll *a* concentrations reflect use of TP for phytoplankton growth

---

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

within the limitations of shading (sediment inputs) and grazing by zooplankton (*Daphnia* concentrations). While each TSI predictor is based upon a differing parameter for prediction, often the predictions are within similar ranges.

We are also interested in trends over time. What are the trends we are observing in the reservoir? How is the reservoir changing over time? These observations will guide our management decisions and conclusions as well as future work.

Secchi Depth TSI

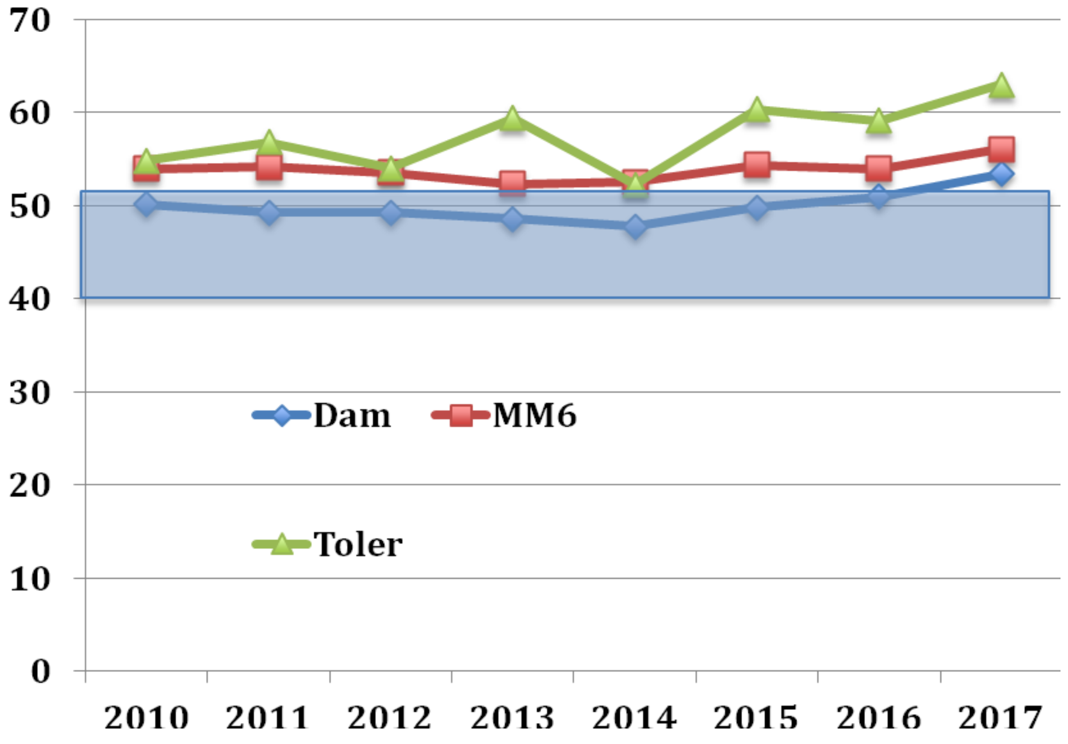


Figure 2.1. Trophic State Index (TSI) based upon Secchi disk measurements in Leesville Lake from 2010-2017. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Analysis

Predictions of trophic state using Secchi depth provides consistent results in the reservoir. It shows relative consistency throughout the seven-year study period, but more recently a trend toward increasing trophic state. Throughout the previous six years, the Dam remained in the upper mesotrophic range. In 2017, for the first time in the study, Dam was in the eutrophic range for Secchi depth. MM6 remains mildly eutrophic with an increasing trend as well as Toler. This trend suggests the lake is either receiving greater concentrations of sediment or increases in growth of phytoplankton contributing to increases in trophic state due to reduced transparency. These trends are analyzed further with the other graphs.

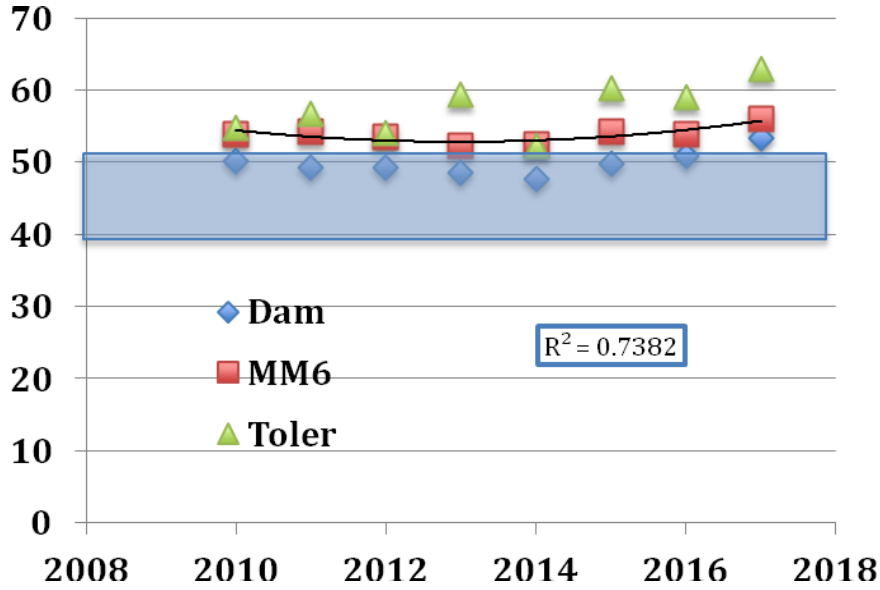


Figure 2.2. Polynomial trend line applied to the same data from Fig 2.1. Strength of relationship reflected by R2. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Regression analysis (Fig 2.2) suggests that while Leesville Lake trophic state was in decline during the study period through 2014, the last three sampling seasons document an increasing trophic state based on Secchi depth trophic indices. The sharpest increases occurred at the Dam and Toler Bridge stations. Increases in TSI at the Dam have been consistent and progressive over that period while the trajectory at other stations has been more variable. This recent increase in TSI is a concerning trend and will be analyzed further.

Total Phosphorous TSI

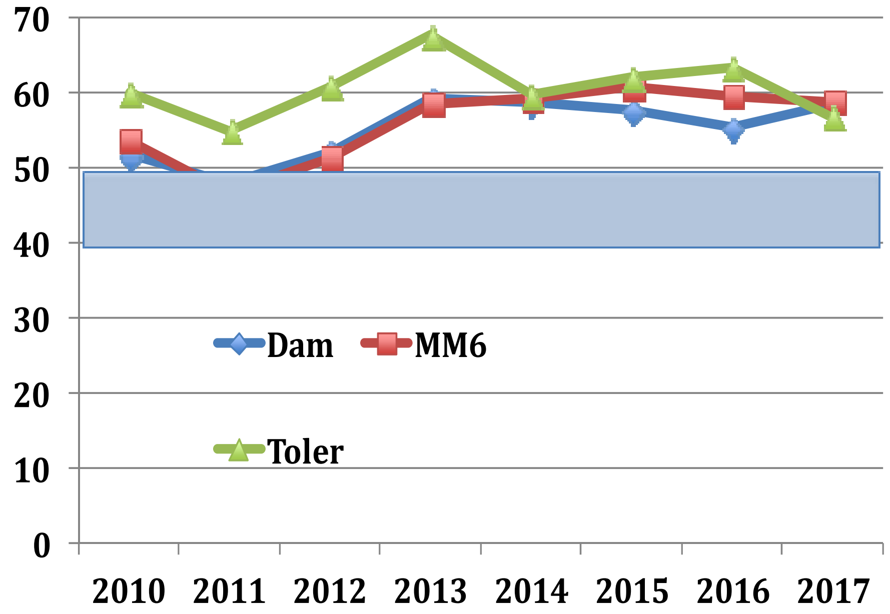


Figure 2.3. Same as Figure 2.1 but TSI based on Total Phosphorus (TP).

Analysis

Trophic state based on total phosphorus suggests that the reservoir is eutrophic. These data are consistent with predictions based on Secchi disk reading, but, unlike Secchi this trend has stabilized over the last three sampling seasons. Most interesting is the decline in trophic state at Toler Bridge station and, for the first time, observed a trophic state that was numerically lower than values for the remainder of the lake. This observation is very counter intuitive. First, upper portions of a reservoir are usually the most eutrophic. Leesville Lake is a pump storage reservoir so some easing of the eutrophic condition is expected but inputs of TP from the Pigg River are high and the expected result is an increased trophic condition. Only increased dilution from the hypolimnion of Smith Mountain Lake can create this observation. But why in 2017? Was the volume of water released in 2017 considerably greater than in past years? Answers are unclear. Certainly over the years of study TSI based on TP at Toler Bridge station has been below 60. But the remainder of the lake remained equal or lower than measures at Toler Bridge. This result suggests inputs from Smith Mountain lake are lower than previously recorded and resultant in lower measures at Leesville. Or pumping operations are creating a differential impact on Leesville Lake or greater impacts are occurring below the station at Toler Bridge in the reservoir.

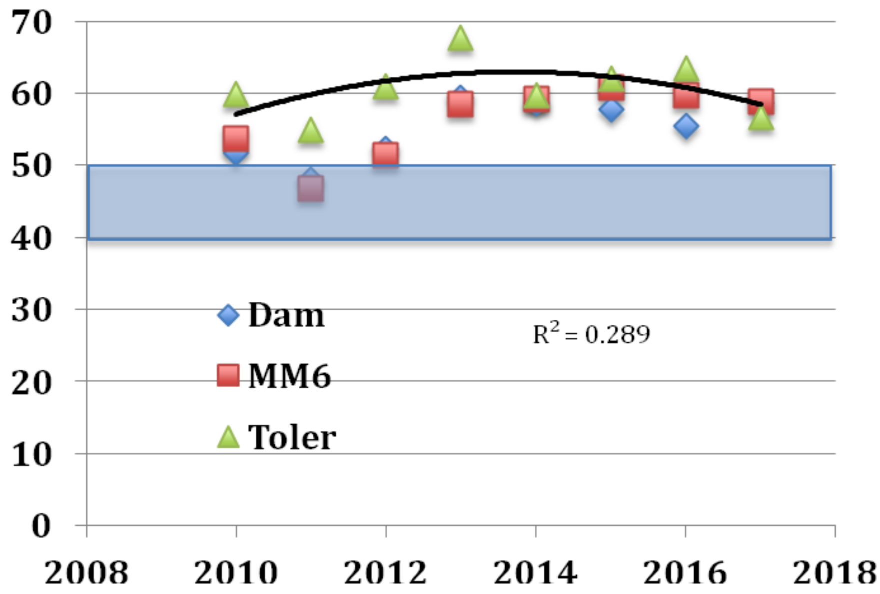


Figure 2.4. Polynomial trend line applied to the same data from Fig 2.3.

This is the weakest of the relationships based upon strength of correlation (0.289) but nevertheless suggests that trophic state that was increasing due to nutrient enrichment is now declining. Again, the last three seasons (2014-2017) now create the decreasing trend. Coupled with the increase in trophic state over the same time period based on Secchi depth the best plausible explanation is differential mixing with SML. Pigg River input of sediment is increasing while tail water release from SML is diluting. Certainly possible that processes below Pigg River confluence are confounding this trend. Upper portions of Leesville Lake have a very strong relationship with Pigg River and SML tailrace. In fact, this relationship is considered the primary driver of lake water quality. But perhaps this thinking needs revision. Old Womens Creek is known to be impaired listed by DEQ. Water quality of other tributaries not part of Pigg River Watershed is unknown. Decreasing trophic state driven by Toler Bridge may not be realized throughout the entire lake. Other tributaries may increase TSI in lower portion of the lake while operations at SML dam lower TSI by mitigating Pigg River input.

Chlorophyll *a* TSI

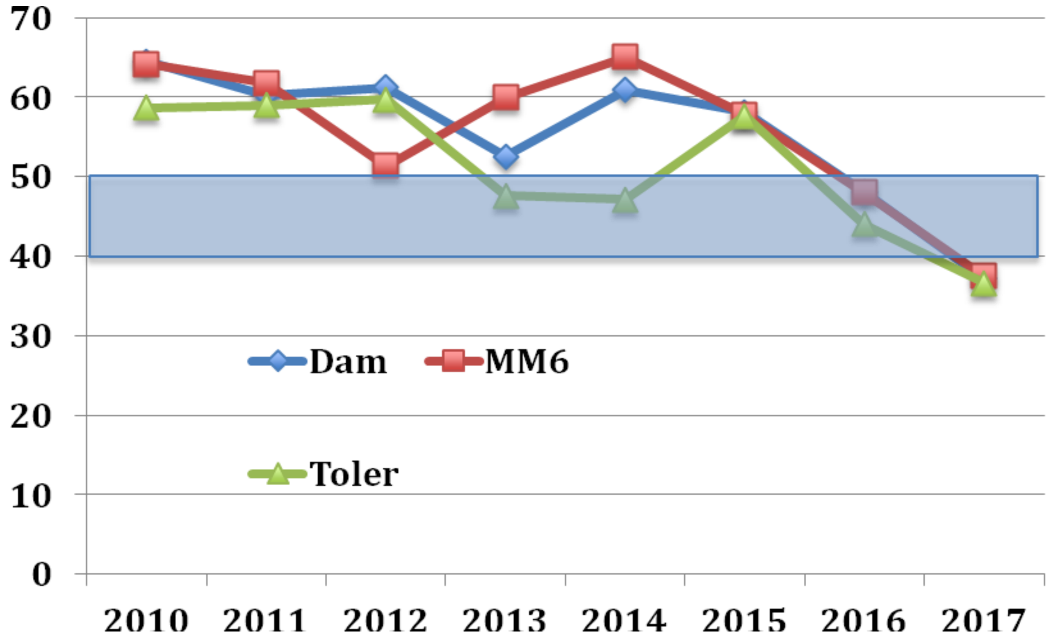


Figure 2.5. Same as figure 2.1 but TSI is based on Chlorophyll *a*.

Analysis

Trophic state based upon Chlorophyll *a* is more difficult to interpret. The last two sampling season (2016 and 2017) measures are considerably lower than previous 5 years of sampling. The most obvious interpretation suggests increased turbidity and sediment drove phytoplankton productivity down. First, sediment associates with high levels of bacteria and forces increased observations in *E. coli*. Certainly, the violation of state standards at Pigg River during 2017 season supports the idea that sediment loading to the reservoir is increasing. Secondly, trophic state based upon Secchi depth is increasing suggesting the lake is becoming more turbid and reductions in phosphorus are likely a result of sorption to clay particles. And not only sorption of phosphorus but also phytoplankton reductions are associated with sorption and sinking due to turbidity. So, all three trends observed in the lake are suggestive of increasing lake turbidity due to sediment increases. Reduction in phytoplankton due to sediment and turbidity issues is concerning. It remains to be determined if this situation returns to previous levels after the impact of removing the Pigg River dam has run its course.

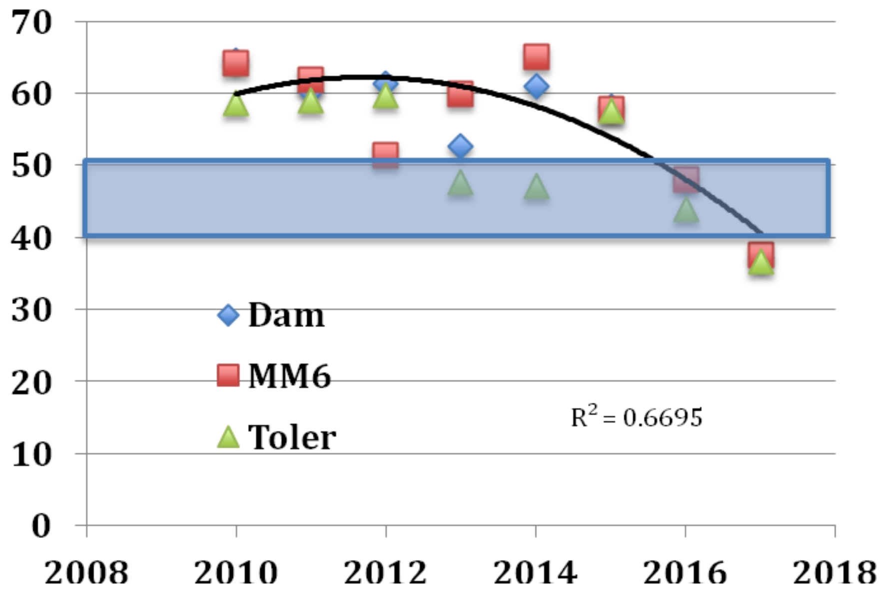


Figure 2.6. Polynomial trend line applied to the same data from Fig 2.5.

The trend suggesting reducing concentrations of chlorophll *a* is strong. Levels with the exception of Toler have continually dropped over the last four years. While collectively the analysis suggests this is a result of sedimentation the idea that phytoplankton populations are dropping does have positive water quality benefits. It is important to find the underlying cause for this drop and whether it is an anomaly of lake-wide changes.

TSI Average

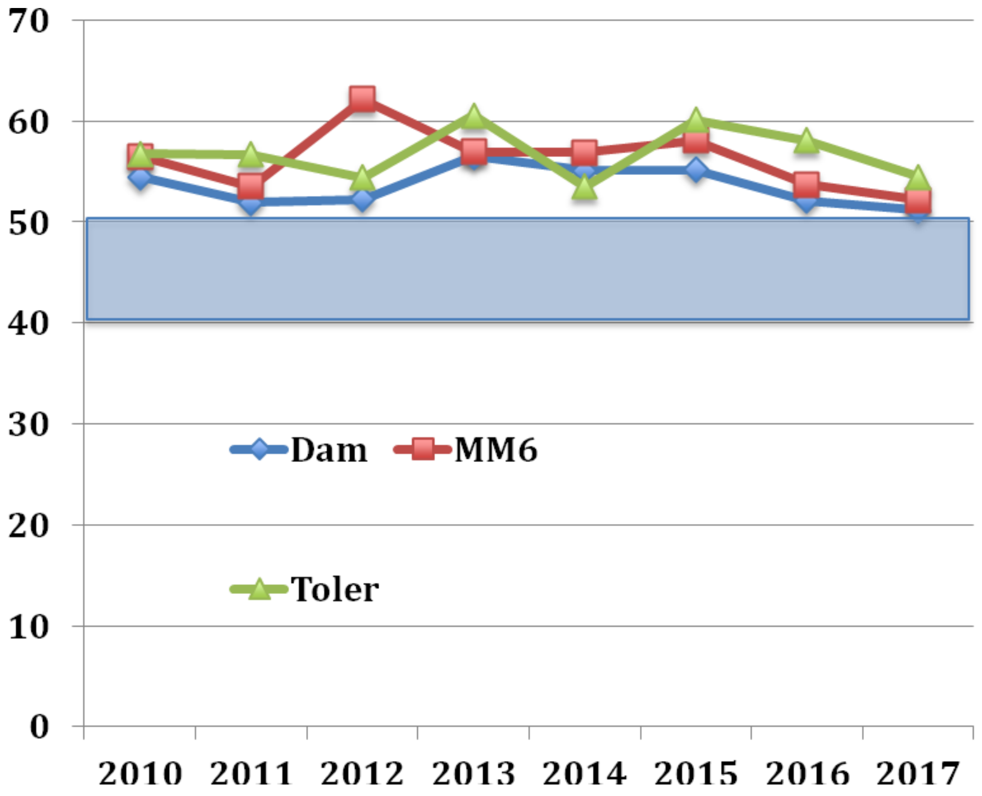


Figure 2.7. Same as Figure 2.1 but TSI presented is the average of TSI for all parameters evaluated (Secchi Depth, Total Phosphorous, Chlorophyll *a*).

Analysis

Averaging trophic state indices based upon multiple parameters leads to the conclusion that the trophic state in the reservoir has remained very consistent throughout the seven years of study. Lower Chlorophyll *a* in 2016 was counteracted by the higher levels of TP. These data suggest that the lake is mildly eutrophic. Data do not suggest any discernable trend in the trophic state of the reservoir and it remains eutrophic.

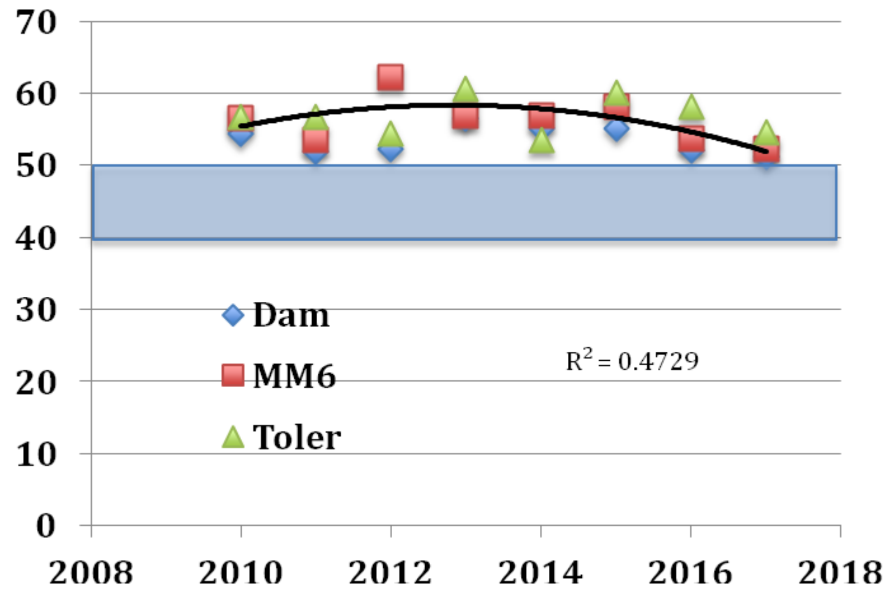


Figure 2.8. Polynomial trend line applied to the same data from Fig 2.7. Strength of relationship reflected by R^2.

Daphnia Productivity

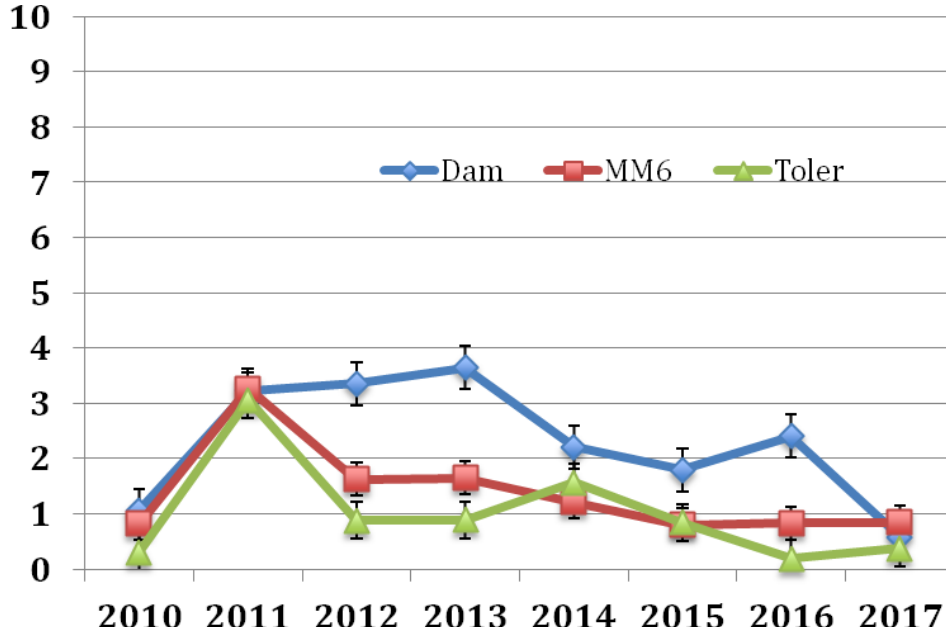


Figure 2.9. Average *Daphnia* concentrations in Leesville Lake from 2010-2017. Numbers on y-axis represent *Daphnia/* liter.

Analysis

The abundance of *Daphnia* in the reservoir not only impacts the population of phytoplankton through grazing, but also impacts the influence of fisheries on water quality. Implications of this are two-fold. First, lower populations reduce the grazing pressure on phytoplankton. For 2017, we recorded the lowest concentrations of *Daphnia* on record in this study. While *Daphnia* provide beneficial grazing reductions on Chlorophyll *a*, the lower concentrations of phytoplankton in the reservoir may be responsible for the decreases observed. While sediment in the reservoir contribute to the other problems discussed, sediment also reduces nutrition for a grazing animal such as *Daphnia* and has been shown to reduce *Daphina* populations.

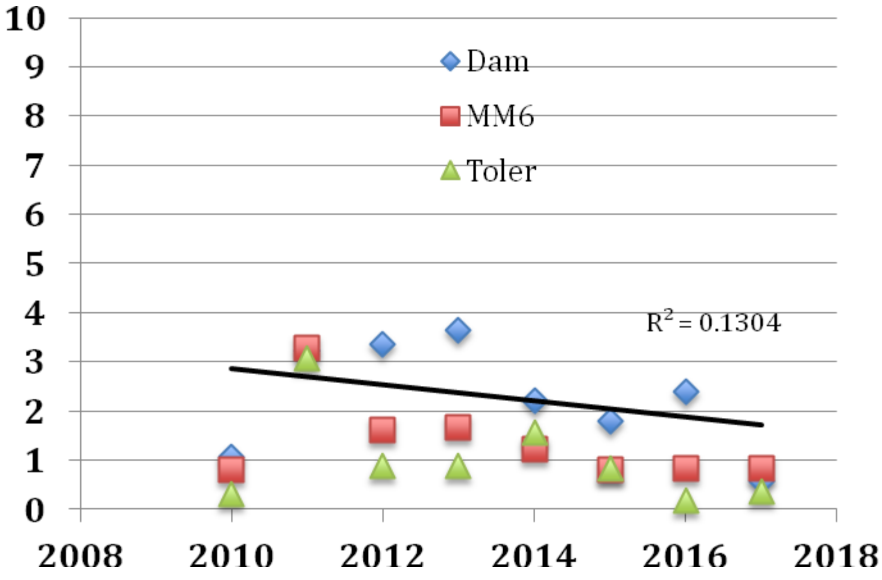


Figure 2.10. Linear trend line applied to the same data from Fig 2.9. Strength of relationship reflected by R^2.

Trending of *Daphnia* populations in the reservoir continues to decline. Current observations of sedimentation and lower Chlorophyll *a* concentrations are the likely contributor to continued loss in *Daphnia* productivity. Also a factor for consideration are the population dynamics of fisheries in the reservoir.

2.2 Water Quality and Fisheries Analysis

The status of fisheries on Leesville Lake was summarized in a report written by DGIF and available online. https://www.dgif.virginia.gov/wp-content/uploads/Leesville-Lake-Report-2016.pdf

In summary, the lake has a diversity of fish species of varying success to anglers

- The headwaters of Leesville Lake are a very harsh environment for most fish species due to the cold water temperatures, fast water currents, and poor forage. Consequently, fishing is generally poor from Smith Mountain dam to mile marker 6.
- Largemouth bass are the most sought after species by anglers at Leesville Lake. Smallmouth bass are also present at Leesville Lake but do not contribute significantly to the black bass fishery due to their very low abundance.
- Leesville Lake is stocked with additional predators, striped bass and walleye.
- Striped bass populations are currently declining after a record year in 2010.
- Walleye populations are increasing after introduction of the hybrid Saugeye.
- White bass at Leesville Reservoir have historically produced a good fishery. However, the increasing white perch population in recent years has severely limited the white bass population to the extent there is no longer a viable white bass fishery.
- Catfish are abundant at this reservoir with the most common species being channel and white catfish.
- Additional species of interest include black crappie, yellow perch, bluegill, and redbreast sunfish. The crappie fishery is fair, the best crappie fishing months are April through August and the average size harvested is 10 inches. Leesville Lake has traditionally been one of the few good yellow perch fisheries in Virginia but has recently declined to very low numbers but there are still decent numbers in the upper end near the Smith Mountain Lake dam.

While it is difficult to correlate fisheries populations and water quality in reservoirs, it is naïve to think fisheries and water quality are unrelated. Zooplankton are often representative of the link between fisheries and water quality and may provide some evidence to possible links.

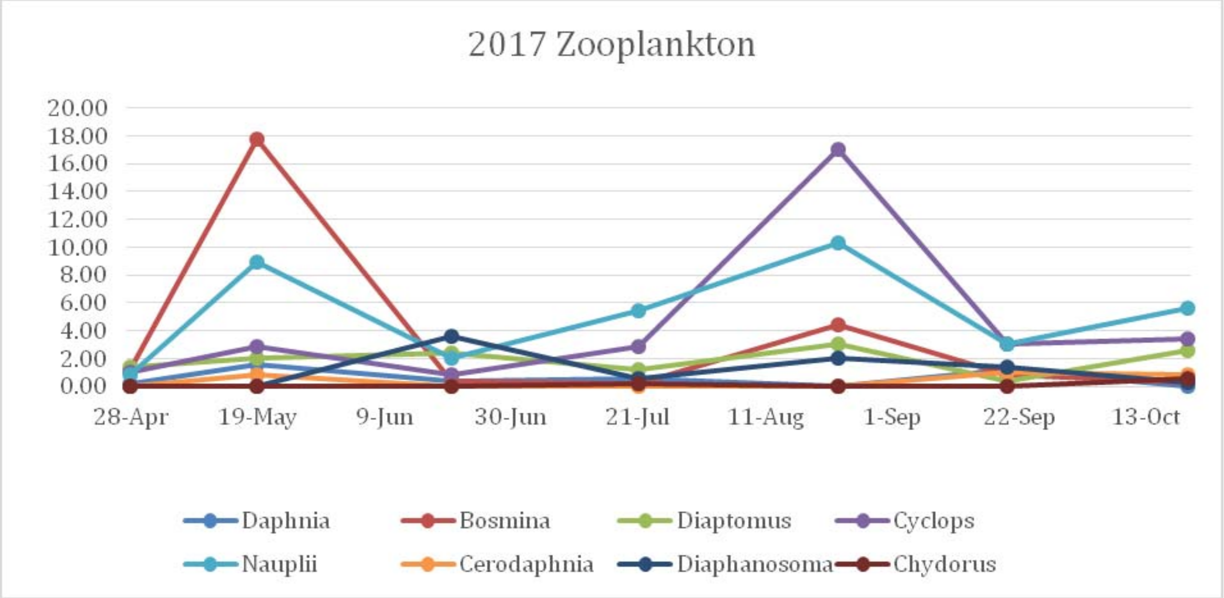


Figure 2.11. Zooplankton in Leesville Lake. Abundance is in number per liter and one sample taken at the Dam.

Zooplankton populations in Leesville Lake are representative of intensive fish and zooplankton predation. The predominance of *Bosmina*, *Cyclops* and nauplii suggest intensive fish predation is occurring. These small sized and evasive species are typical when planktivorous fish predation is intense. Additionally, *Leptodora*, a zooplankton predator, is common in some of the sampling particularly in the upper reaches of the reservoir. This predator consumes larger *Daphnia* and *Ceriodaphnia* and may account for some of the low abundances. This predator is susceptible to fish predators if it cannot find a refuge during the day. By migrating to the thermocline or the heavy input of sediment can provide that refuge. Thus sedimentation also appears to impact zooplankton composition through fish predation. Combined it appears these factors are keeping zooplankton abundance low.

Concerning water quality low abundances of zooplankton reduce the overall filtering capacity and removal of particulates and phytoplankton. While other factors appear to control phytoplankton at this time, abundant populations of zooplankton and in particular species easily consumed by forage fish are an important part of the food chain. Low abundances and the observed community composition is not ideal for fish populations in the reservoir.

Section 3: Management Implications

Current water quality indicators suggest Leesville Lake is mildly eutrophic. Current trends suggest some improvement in trophic state and movement toward a mesotrophic condition. This is a very positive trend. Of concern is the increasing sediment loading. This increased sediment load may be confounding some of the other trophic state measures. Management recommendations suggested here are intended to improve the overall condition of the reservoir and potentially bring the trophic state into a mesotrophic classification.

1. Continue to research links between hydrology, Pigg River input and water quality. Pinpoint how Smith Mountain Lake operations influence these relationships.
2. Sample areas of Pigg River to better quantify potential increases in sedimentation, nutrient inputs and changes in productivity.
3. Derive a system for hazard identification on the lake. Considerable debris in the channel and elevated *E. coli* both pose hazards for users of the lake. A better alert system needs to be established or guidelines clearly posted for lake users. Information may be posted at the annual picnic or in public areas.
4. Examine closely inputs from other tributaries to the lake such as Old Womens Creek and any others that may influence water quality. Build maps and database to document these inputs to serve as baselines for future work.
5. Conduct more intensive research on the Pigg River. Understand the influence this river has during base flow and storm inputs on water quality.

Section 4: Future Directions

Section 4.1 - Hydrological Analysis including Impacts of Upstream Dam Remov

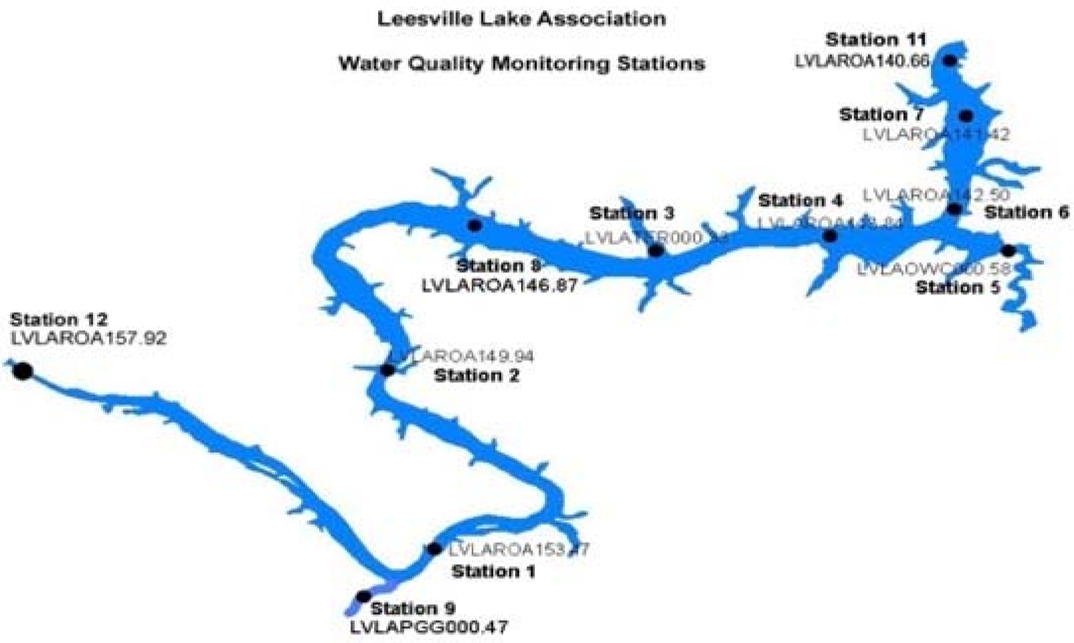
Currently we are engaged in the development of a hydrological model of Leesville Lake to examine the impacts of pump – storage operation on water quality. Unique to this situation is the Pigg River and the entrance of this impaired water near intake of Smith Mountain Lake. This creates water movement throughout the reservoir exchanging hypolimnetic discharge with river inputs into the headwater for Leesville Lake. This area of research is ongoing and will be published separately from the annual report in 2018.

Additional studies of the Pigg River are warranted. TMDL studies pinpointed agricultural inputs as a concern and potential for impairment with *E. coli*. This sampling year (2017) the mouth of the Pigg River entering Leesville Lake violated both instantaneous and mean average state standards for *E. coli*. The removal of the dam contributed to elevated sediment turbidity and apparent influence on primary productivity throughout the lake until mid-summer. This is a very important change in water quality and needs further investigation. Better quantification of the sources of turbidity, nutrients and bacteria from the Pigg River and their locations in the Pigg River watershed need to be determined. A preliminary study addessing these questions is planned for summer of 2018.

Section 4.2 Water Sources including Summaries of Historical Data

Pigg River Watershed - The annual reports of the Leesville Lake Association’s Citizen Water Monitoring Project and the Virginia DEQ data are the two primary sources of historical data.

DEQ compiled the data with the assistance of the Department of Conservation and Recreation (DCR) for its Virginia Water Quality Assessment Reports. Data were collected by the agencies’ quality control citizen monitoring data. DEQ used Water Quality Management Plans (WQMPs), required by section 303(e) of the Clean Water Act, to establish the link between the required water quality assessment and water quality based controls.



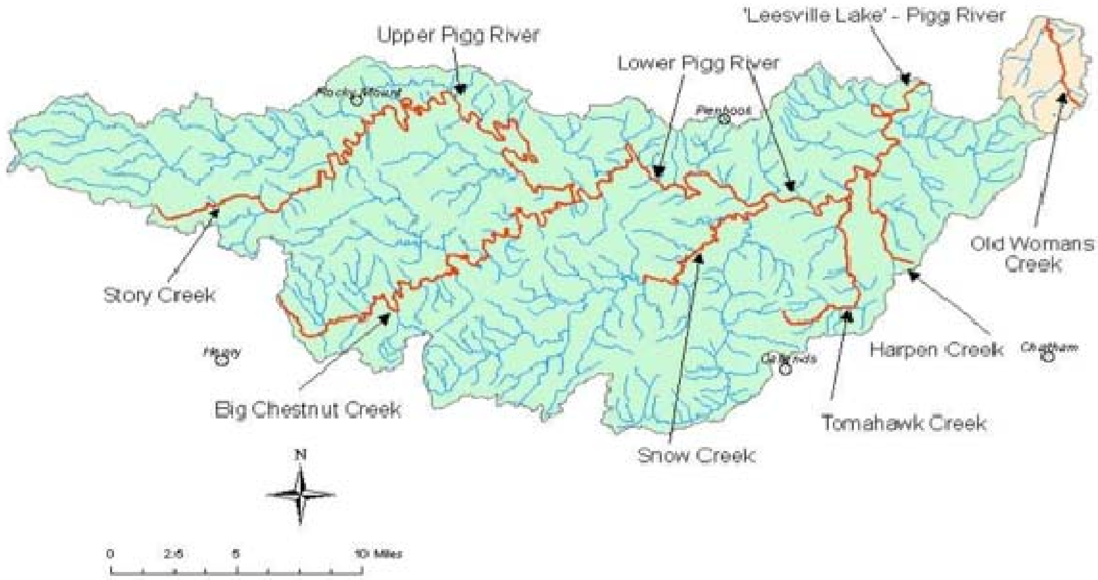
Map 4.1. Leesville Lake Water Quality Monitoring Stations with DEQ Identification (Lobue 2011)

From June through November 2010, Lynchburg College and volunteers from LLA collected Leesville Lake water quality data. Lynchburg College sampled eight sites while LLA sampled seven. Data on water quality parameters included temperature, oxygen (dissolved oxygen and percent saturation dissolved oxygen percentage), conductivity, pH, oxidation-reduction potential, turbidity and more. Lynchburg College and LLA volunteers also monitored water quality in 2011, 2012, 2013 and 2014.

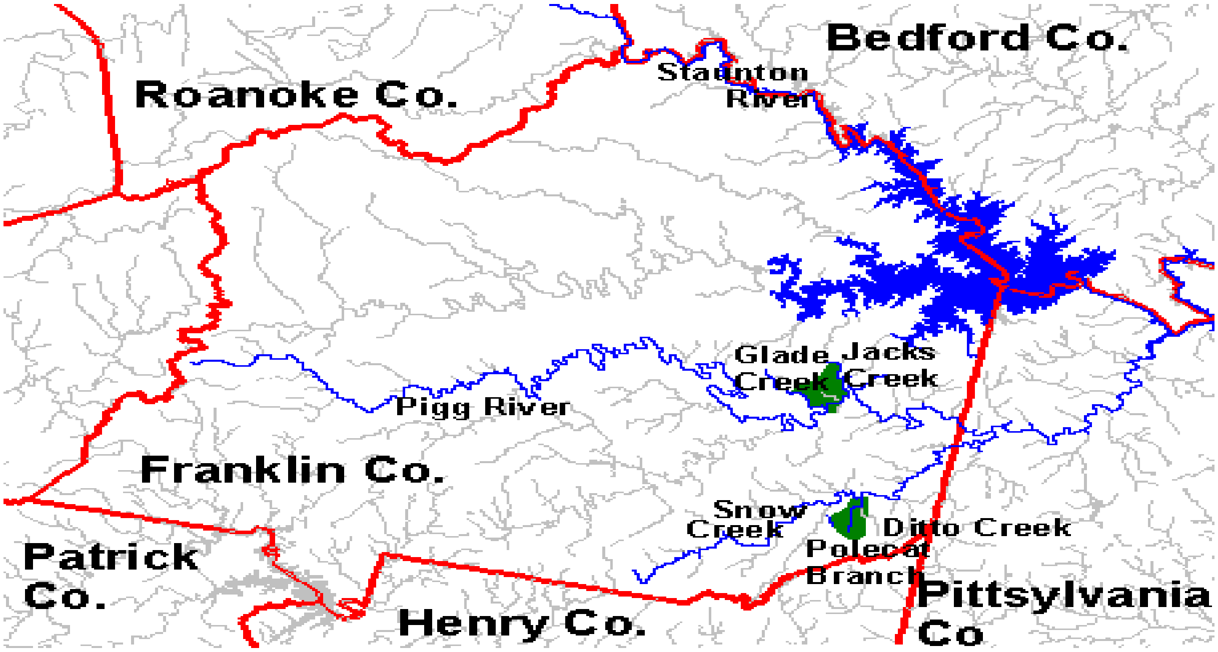
Total Maximum Daily Load (TMDL):

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 are 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).



Map 4.2. Pigg River and Old Womans Creek Watersheds from TMDL studies (Virginia Tech, 2006).



Map 4.3 – Franklin County Virginia showing Pigg River flowing under Smith Mountain Lake and into Leesville Lake along the border of Franklin and Pittsylvania counties. For reference, Snow Creek And Pigg River are shown in greater detail in Map 4.2.

Pigg River and Old Woman's Creek TMDL Implementation Plan published 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 consistently in the creek at the Leesville site. The Leesville 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.

References

Federal Energy Regulatory Commission. Office of Energy Projects. (2009, August). *Final Environmental Impact Statement for Hydropower License, Smith Mountain Pumped Storage Project, FERC Project Number 2210 Virginia*. Retrieved from http://www.smithmtn.com/Project%20Relicensing/FinalEISAugust2009.pdf

Federal Energy Regulatory Commission. (2009, December 15). United States of America 129 FERC ¶ 62,201, Federal Energy Regulatory Commission, Appalachian Power Company Project No. 2210-169, Order Issuing New License. Retrieved from http://www.smithmtn.com/

Leesville Lake Association. *About the Lake*. Retrieved from http://www.leesvillelake.org/AboutLake.htm

Leesville Lake Association. (2009, July 11). *Minutes, Leesville Lake Association, July 11, 2009, Annual General Membership Meeting.* Retrieved from http://www.leesvillelake.org/Minutes.htm

Leesville Lake Association. (2008, April 10). *Minutes, Leesville Lake Association, April 10, 2008, Quarterly General Meeting.* Retrieved from http://www.leesvillelake.org/Minutes.htm

Leesville Lake Association. (2003, September 25). *Minutes, Leesville Lake Association, September 25, 2003.* Retrieved from http://www.leesvillelake.org/Minutes.htm

Leesville Lake Association. *Articles of Incorporation of Leesville Lake Association, Inc*. Retrieved from http://www.leesvillelake.org/Documents/ArticlesOfInc.htm

Lobue, Michael A. (2010, January). *Leesville Lake Water Quality Monitoring Program 2009 Report*. Leesville Lake Association.

The Louis Berger Group, Inc. (2009, February). *Smith Mountain Project Socioeconomics Study Phase II Report*. Retrieved from http://www.smithmtn.com/

The Louis Berger Group, Inc. (2003, August 29). *Smith Mountain Pumped Storage Project FERC No. 2210 Shoreline Management Plan.* Retrieved from http://www.smithmtn.com/shorelinemanagement/Plan/pdf/Final/FinalSMP.pdf

Virginia Department of Environmental Quality (2007). *DEQ's 2007 Water Quality Monitoring Strategy*. Retrieved from http://www.deq.state.va.us/watermonitoring/monstrat.html
Virginia Department of Game and Inland Fisheries. (2002). *Leesville Reservoir 2002 Management Report*. Retrieved from http://www.dgif.virginia.gov/fishing/waterbodies/reports/2002%20Leesville%20Reservoir.pdf

Virginia Department of Game and Inland Fisheries. (2008). *Leesville Reservoir 2008*. Retrieved from http://www.dgif.virginia.gov/fishing/waterbodies/reports/2008%20Leesville%20Biologist%20Report.pdf

Virginia Tech. Department of Biological Systems Engineering. (2006, April). Bacteria Total Maximum Daily Load Development for Pigg River, Snow Creek, Story Creek, and Old Womans Creek. Retrieved from http://www.deq.virginia.gov/tmdl/apptmdls/roankrvr/piggec.pdf

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^oC. The solution was stable for approximately 4 weeks.

Reagents:

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

Standards used in the digestion process:

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

Standards:

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

Dissolved Phosphorus

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

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

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

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

Nitrogen

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

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

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

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

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

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

Stock Standard contained:

- Potassium Nitrate, KNO_3

Preparation of Reagents and Standards:

Reagents:

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

Standards:

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

Summary of Run:

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

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

3. The optical density of the samples was measured. By comparing the O.D. values to the standard curve set in Step 1, the concentration of nitrate in the lake samples was determined.

4. For every 10 samples, a check standard, spike, and a duplicate were included. Thus, for 40 cups of samples, there were 4 check standards of a known 10ppm nitrate solution, 4 spikes from different samples, and 4 different duplicates of lake samples. The check standards, serving as the Quality Control Samples (QCS), fell within 10% of the QCS true value.
5. The analysis ended with a blank to check the validity of the instrument's readings.

Fluorescence

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

Integrated Chlorophyll *a*

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

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

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

Secchi Depth

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

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

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

Trophic State

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

E. coli

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

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

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

Prior to 2011, Leesville Lake Association citizen volunteers used Coliscan Easygel® test kits for *E. coli* testing. Beginning in 2011 water samples collected by both LLA volunteers and Lynchburg College were tested for *E. coli* with the Colilert™ test method. Samples were collected in sterile 125 ml polypropylene bottles and stored according to standard methods. A Colilert™ media packet was added to each water sample; the mixture was poured into a sterile

Quanti-Tray, sealed and incubated. A color change from clear to yellow indicates a positive result for total coliform and fluorescence indicates a positive result for *E. coli*. The number of yellow and fluorescent wells are counted and the values are evaluated using a Most Probable Number (MPN) chart developed by the IDEXX Company, which developed the test method. MPN is used instead of colony forming units (cfus) and is generally considered an equivalent measure of the microbial and bacterial populations. The Colilert™ method has been rated as the "best" in agreement with a reference lab, has the lowest detection limit and the method is EPA approved for ambient water.

Zooplankton

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

Appendix C

Quality Assurance (QA) / Quality Control (QC)

Sample Collection, Preservation, and Storage:

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

Samples were refrigerated.

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

Hydrolab Calibration and Sampling post Calibration:

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

The sensors were cleaned and prepared for the following parameters:

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

Dissolved Oxygen %Saturation and mg/L:

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

pH and ORP (Redox):

1. Cleaning and Preparation: The pH sensor was clean with a soft cloth wet with rubbing alcohol and then rinsed with DI water. The platinum band at the tip of the ORP sensor was checked for any discoloration or contamination. Then the reference sleeve was pulled away from the Transmitter and the old electrolyte from the reference sleeve was discarded. Then two KCl salt pellets (or KCl rings) were dropped into the reference sleeve and the sleeve was refilled with reference electrolyte. With the Transmitter

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

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

Turbidity:

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

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

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

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

Post Calibration

Pre Sampling at Leesville Lake

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

The Hydrolab was calibrated and the information was recorded.

An ice chest was half-filled with ice.

Batteries in the Hydrolab were checked.

At the lake, the following parameters were recorded:

- Smith Mountain Lake tailwaters: whole water for TP
- Pigg River near its mouth: Secchi depth, TP, Hydrolab data
- Toler Bridge (after confluence with Pigg River/riverine zone): Secchi depth, TP, no Hydrolab data was taken because the flow of water was too quick
- Mile Mark 9 (mixing zone): Secchi depth, TP?

- Mile Mark 6 (end of mixing zone/beginning of lacustrine): Secchi depth, TP, hydrolab data
- Tri-County Marina: Secchi depth, TP
- Leesville Lake Marina: Secchi depth, TP
- Near dam (end point of lacustrine): Secchi depth, TP, Hydrolab data

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

Nitrate Method

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

Summary of Run:

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

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

The instrument read the optical density of the calibrants. O.D. readings of a 0ppm standard and of two blanks (composed of DI water) were taken.
A standard curve was set. The linear correlation coefficient (r^2) was always greater than 0.995.

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

Total Phosphate Method

Summary of Method:
Under this method for the determination of total phosphate, the aqueous sample was mixed with sulfuric acid, ammonium molybdate and antimony potassium tartrate to form antimony-1, 2-phosphorous molybdenum acid. The resulting complex was then reduced by ascorbic acid to get

a blue heteropoly acid (molybdenum blue). To determine the concentration of ortho-phosphate, the absorbance of the formed blue complex, was measured at 880nm.
Since only orthophosphate formed a blue color in this test, polyphosphates (and some organic phosphorus compounds) were converted to the orthophosphate form by manual sulfuric acid hydrolysis. Organic phosphorus compounds were converted to the orthophosphate form by manual persulfate digestion. The developed color was then measured automatically.

Summary of Run:

1. The lake samples were chilled to about 4^0C and analyzed within 48 hours
2. Standards and reagents were prepared by the above steps and then placed in the EasyChem instrument.
3. A standard curve for a range of 0-5mg/L (check) was created by the following steps:
   A 5ppm total phosphate standard was placed in the instrument.

   Standards were prepared through dilutions at 5, 2, 1, 0.5, 0.1, and 0ppm

   The instrument read the optical density of the calibrants. O.D. readings of a 0ppm standard and of two blanks (composed of DI water) were taken.
   A standard curve was set. The linear correlation coefficient (r^2) was always greater than 0.995.
4. The optical density of the samples was measured. By comparing the O.D. values to the standard curve set in Step 1, the concentration of nitrate in the lake samples was determined.
5. For every 5 samples, a blank and a duplicate were included. Halfway through the run and at the end of the run there were 2 check standards. Thus, for 40 cups of samples, there were 2 check standards of a known 1ppm phosphate solution and 2 check standards of a known 0.5ppm phosphate solution, and 8 different duplicates of lake samples. The check standards, serving as the Quality Control Samples (QCS), fell within 10% of the QCS true value.
6. The analysis ended with a blank to check the validity of the instruments readings.

Quality Assurance/Quality Control

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

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

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

Ammonia	0.04 mg/L

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

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

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

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

$$P = [100(A – B)]/T$$

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

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

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

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

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

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

General Procedures:

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

Sampling Requirements:

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

Sampling Equipment Preparation and Cleaning:

- Water Sampling Equipment:
- Daily: Rinse buckets at the end of the day with analyte free water and allow to dry; if a pump/hose was used, pump 5 gallons of analyte free water through system and allow to drain; if using Kemmerer or Alpha Bottle sampling devices, follow manufacturer's instructions using analyte free water
- Weekly: Wash buckets with lab grade soap (Liquinox or Alconox) using a brush to remove particulate matter or surface film; rinse with tap water and then analyte free water, allow to dry
- Monthly: pump 5 gallons of a 5% solution (consists of 1 quart of vinegar mixed with 4 ¾ gallons of water) through hose and pump apparatus; pump 5 gallons of anaylte free water through hose and pump apparatus and completely drain
- Annually: replace hoses of pump and hose sampling devices
- Sample container handling and preservation:
- Refer to the DCLS laboratory catalog in CEDS for the appropriate preservation procedures. Samples not preserved properly may be rejected by DCLS.
- make sure the lids were on tight
- Sample containers should be stored with the tops fastened.
- Samples should be iced to 4°C in a cooler immediately after collection. In the cooler, samples shall be placed upright and if possible, covered with ice in such a manner that the container openings are above the level of ice. Chlorophyll a filter pad samples will be placed in appropriately sized Ziploc bags and placed on top of the layer of ice. Ziploc bags containing filters should be oriented so that the sealed opening of the Ziploc bag hangs outside the cooler lid when the lid is closed. Bacteria sample bottles should be stored in mesh bags, placed in coolers and surrounded with wet ice.
- Package glass sample containers in bubble wrap or other waterproof protective materials
- Make sure that every cooler used to ship samples to DCLS contains one temperature bottle to determine sample temp upon arrival at DCLS.
- Regional office should date boxed or packaged sample containers upon receipt and stock on shelves with the oldest dated box/packages used first.

Sample identification:

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

Field Sampling Procedures:

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

Sampling from a boat:

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

Secchi disk:

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

Vacuum Filtering Method (In-Line Filtering)

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

Preparation:

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

Filtration of samples:

- Rinse acid washed and DI washed container with sample water, then fill container with enough sample water to filter more than one sample
- Rinse filtration towers and base with DI water, connect vacuum power pump to battery
- Place filters on bases, place clean NTNP bottles under PP bases, rinse graduated cylinders

with sample, and transfer sample to towers
- Turn pump on
- Add $MgCO_3$ to last 25 ml of Chla sample
- Close valves or turn off pump to remove filtration vacuum
- Bleed excess pressure off and then open vacuum valves of stacks slowly
- Rinse forceps with DI water
- Remove filters from base
- Record volume filtered
- Remove NTNP bottle from PP cylinder and cap tightly
- Label- station, date, time depth, unit code, collector's initials, group code, container #, volume of sample filtered
- Place samples on ice

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

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

Field Quality Control Samples

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

Field Testing Procedures (p. 69)

pH/mV/Ion meter

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

Dissolved oxygen and temperature meter

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

annually

DO and conductivity meter calibration checks

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

Thermistor Verification

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

Sample Identification and Corrective Action

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

Appendix D

Table 1.1. Dam (Lacustrine) Conductivity (µs/cm) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	0.122	0.148	0.151	0.158	0.163	0.171	0.177
0.5	0.122	0.148	0.152	0.158	0.163	0.170	0.178
1	0.122	0.148	0.151	0.157	0.163	0.171	0.178
1.5	0.123	0.147	0.149	0.157	0.163	0.171	0.177
2	0.122	0.150	0.152	0.159	0.161	0.171	0.178
2.5	0.121	0.151	0.152	0.158	0.161	0.170	0.176
3	0.128	0.149	0.152	0.160	0.161	0.171	0.178
4	0.130	0.148	0.154	0.161	0.164	0.170	0.178
5	0.130	0.149	0.155	0.162	0.165	0.172	0.178
6	0.131	0.149	0.157	0.161	0.163	0.173	0.178
7	0.136	0.152	0.158	0.163	0.166	0.173	0.178
8	0.137	0.151	0.157	0.162	0.166	0.174	0.176
9	0.136	0.152	0.159	0.164	0.167	0.172	0.177
10	0.146	0.150	0.158	0.165	0.168	0.169	0.179
11	0.147	0.152	0.158	0.165	0.167	0.170	0.179
12	0.146	0.153	0.158	0.165	0.169	0.170	0.178
13	0.146	0.153	0.156	0.165	0.171	0.169	0.177
14	0.147	0.152	0.157	0.168	0.172	0.168	0.179

Table 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	8.86	9.16	9.32	8.67	8.61	8.63	6.08
0.5	9.21	9.21	9.4	8.7	8.67	8.58	6.04
1	9.34	9.47	9.47	8.81	8.72	8.67	6.03
1.5	9.42	9.48	9.59	8.91	8.74	8.66	6.01
2	9.51	9.63	9.73	9.08	8.7	8.59	5.8
2.5	9.47	951	9.77	9.3	8.71	8.46	5.68
3	9.56	9.48	9.59	9.31	8.82	8.31	5.63
4	9.64	9.54	9.09	8.62	8.71	8.25	5.59
5	9.75	9.54	7.9	6.87	8	7.55	5.55
6	9.74	8.94	7.53	6.2	6.7	5.14	5.51
7	9.74	8.73	7.29	5.6	6.12	3.75	5.48
8	9.72	8.53	7.17	5.1	5.61	3.07	5.4
9	9.66	8.46	6.99	4.6	5.02	2.55	5.35

10	9.67	8.44	6.89	4.2	4.4	2.63	5.2
11	9.68	8.3	6.77	3.9	3.72	3.17	4.98
12	9.65	8.25	6.56	3.6	3.18	3.22	4.75
13	9.63	8.2	5.23	3.45	2.9	3.17	4.68
14	9.64	8.18	6.08	3.1	2.71	2.9	4.6

Table 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	16.6	22.8	25.8	29.3	28.71	24.4	22.3
0.5	15.29	22.8	25.8	29.27	28.71	24.3	21.9
1	14	21.8	25.7	29	28.53	24.2	21.6
1.5	13.77	21.3	25.7	28.9	28.45	24.1	21.4
2	13.7	21.12	25.2	27.7	28.4	24	21.4
2.5	13.52	20.92	25.1	26.7	28.25	23.9	21.3
3	13.08	20.3	24.7	25.8	28.07	23.8	21.3
4	12.83	19.6	22.5	24.6	27.5	23.4	21.3
5	12.83	17.9	20.6	24.1	25.34	22.7	21.3
6	12.22	16.89	20	23.5	25.1	22.4	21.3
7	11.84	16.05	19.7	22.9	24.8	22.1	21.3
8	11.71	15.7	19.5	22.6	24.6	22	21.3
9	11.69	15.3	19.2	22	24.2	21.8	21.3
10	11.52	14.7	19.1	21.5	23.8	21.7	21.3
11	11.46	14.4	18.8	21.2	23.77	21.6	21.25
12	11.43	14.1	18.4	20.8	23.54	21.6	21.25
13	11.45	14	18.1	20.53	23.1	21.5	21.2
14	11.44	13.78	17.6	19.7	22.83	21.4	21.2

Table 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	2.2	1.2	0.9	0.8	0.98	2.1	3.5
0.5	2.4	1.3	0.9	0.8	1.1	2.7	4.7
1	2.6	1.8	0.8	1	1.3	3.5	5.6
1.5	2.6	2	1.1	1.1	1.5	4	6.1
2	2.7	1.9	1.2	1.4	1.6	4.1	5.5
2.5	2.7	1.7	1.2	1.8	1.9	4.1	5.5
3	2.6	1.7	1.2	2.1	2	5.7	5.4
4	2.5	1.6	1.2	1.4	2.9	6.2	5.7
5	2.6	1.4	0.8	1	2	7.5	5.1
6	2.6	1.4	1	0.9	1.7	6.8	5.8
7	2.5	1.3	0.9	0.8	1.6	7.5	5.8
8	2.4	1.1	0.9	0.7	1.3	6.7	5.7
9	2.4	1.1	0.8	0.6	1.1	5.1	5.5

10	2.1	1.2	0.9	0.6	0.9	4.3	5.4
11	2.1	1.2	0.8	0.6	0.9	4.2	4.9
12	2	1.2	1.1	0.6	0.7	4.1	4.3
13	2	1.2	0.8	0.6	0.6	4	5.1
14	2.1	1.3	1	0.6	0.6	3.9	5.4

Table 1.5. Dam (Lacustrine) pH measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	7.3	7.47	8.17	8.27	8.53	8.33	7.93
0.5	7.31	7.52	8.17	8.29	8.56	8.36	7.96
1	7.33	7.56	8.17	8.31	8.62	8.39	7.87
1.5	7.33	7.59	8.18	8.31	8.63	8.42	7.89
2	7.33	7.6	8.2	8.31	8.63	8.44	7.9
2.5	7.33	7.6	8.2	8.22	8.63	8.44	7.9
3	7.32	7.6	8.17	8.09	8.62	8.44	8
4	7.32	7.61	8.09	7.91	8.59	8.44	8
5	7.32	7.61	7.93	7.75	8.54	8.42	8
6	7.32	7.6	7.76	7.68	8.4	8.38	8
7	7.33	7.58	7.57	7.68	8.4	8.35	8
8	7.32	7.57	7.53	7.63	8.3	8.31	8
9	7.33	7.55	7.41	7.58	8.3	8.28	8
10	7.32	7.55	7.4	7.45	8.29	8.26	8
11	7.32	7.5	7.39	7.4	8.26	8.24	8
12	7.32	7.53	7.38	7.32	8.19	8.22	8
13	7.32	7.5	7.36	7.3	8.17	8.21	8
14	7.32	7.51	7.36	7.3	8.1	8.2	8

Table 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	-3	76	-135	150	-95	-77	224
0.5	-1	77	-135	148	-95	-76	222
1	3	83	-134	148	-93	-75	221
1.5	5	84	-134	148	-90	-72	221
2	6	89	-133	152	-88	-69	220
2.5	9	92	-131	161	-85	-66	221
3	10	95	-124	172	-84	-63	220
4	11	100	-112	188	-71	-58	220
5	11	109	-104	197	-59	-48	220
6	13	113	-100	205	-52	-39	219
7	13	117	-99	207	-48	-35	219
8	13	119	-98	210	-44	-32	219
9	13	121	-97	213	-41	-29	219
10	14	123	-96	216	-38	-28	218

11	14	125	-95	218	-36	-27	218
12	14	126	-94	219	-33	-26	218
13	14	127	-93	219	-32	-25	217
14	15	128	-91	224	-31	-24	216

Table 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	112	24.9	0	0	4.9	22.4	29.5
0.5	104	23.2	0	0	5.4	18.8	29.7
1	128	28.1	0	0	12.2	21.9	42.1
1.5	129	35.3	0	0	14.2	25.3	48.7
2	131	35.7	0.9	23.1	16.8	28	49.9
2.5	127	36.5	5	29.8	18	28.9	50.4
3	128	36.9	12	36	20.7	30	49.5
4	130	39.8	29.5	40.4	31.5	35.9	50.2
5	135	45.7	35.6	42.4	43.9	41.8	50.5
6	137	48.7	40	42	51.1	48.6	49.8
7	136	50.4	40	44	52.1	52	48.6
8	136	53	42	45	51.9	53.6	48.5
9	133	53.4	42	45.9	52.3	55.5	48.6
10	125	56.3	42	46.3	53.5	55.5	48
11	121	59.8	44	48.4	55.2	57.6	50.7
12	121	62	50	48.5	55	58.4	52.7
13	119	62.3	48	49.1	56.2	61	54
14	119	69.6	55	53.7	59.3	62.7	59.1

Table 1.12. Mile Marker 6 (Transition) Conductivity (µs/cm) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	0.164	0.149	0.153	0.159	0.163	0.171	0.179
0.5	0.166	0.143	0.152	0.139	0.162	0.169	0.179
1	0.165	0.145	0.152	0.16	0.162	0.17	0.179
1.5	0.165	0.147	0.151	0.158	0.164	0.17	0.179
2	0.165	0.147	0.153	0.159	0.164	0.171	0.179
2.5	0.166	0.148	0.151	0.16	0.164	0.172	0.179
3	0.166	0.149	0.153	0.16	0.164	0.171	0.179
4	0.167	0.151	0.154	0.161	0.164	0.17	0.18
5	0.167	0.155	0.154	0.163	0.165	0.17	0.179
6	0.167	0.153	0.155	0.164	0.165	0.169	0.177
7	0.167	0.155	0.155	0.165	0.166	0.17	0.179
8	0.167	0.156	0.156	0.166	0.167	0.171	0.179

9	0.167	0.158	0.157	0.168	0.169	0.171	0.18
10	0.166	0.16	0.158	0.169	0.169	0.172	

Table 1.13. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	8.71	8.2	9.8	8.69	8.29	8.94	6.7
0.5	9	8.57	9.95	8.6	8.36	8.85	6.52
1	9.23	8.51	10.04	8.85	8.41	8.92	6.74
1.5	9.31	8.3	10.14	9.03	8.48	8.82	6.85
2	9.41	8.37	10.12	9.15	8.38	8.4	6.38
2.5	9.51	8.34	9.43	8.93	8.14	6.73	5.69
3	9.51	8.24	8.8	8.71	7.56	5.91	5.41
4	9.2	8.17	8.6	8.1	7.36	5.05	5.31
5	9.58	8.19	8.2	7.29	6.89	4.57	5.28
6	9.57	8.13	8.1	7.03	6.23	4.1	5.18
7	9.6	8.06	7.8	6.3	5.84	3.9	5.25
8	9.6	8.04	7.6	5.6	5.22	3.8	5.29
9	9.59	8.03	7.4	5.04	4.61	3.3	5.17
10	9.6	8	7.3	4.4	4.04	3.2	

Table 1.14. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	14.64	20.9	25.1	28.06	27.04	24.21	21.7
0.5	12.75	19.53	24.6	28.16	27.03	24.2	21.4
1	11.49	18.3	24.4	27.9	26.96	24.2	21.3
1.5	11.45	17.9	23.8	27	26.83	24	21.1
2	11.4	17.8	23	26.2	26.53	23.3	21
2.5	11.34	17.6	22.3	26.1	26.35	22.9	20.9
3	11.35	17.1	21.6	25.4	26.14	22.4	20.9
4	11.28	16.7	21.1	24.3	25.87	22.3	20.9
5	11.1	16.4	20.4	23.8	25.01	21.9	20.9
6	11.06	16.1	20.1	23.3	24.65	21.9	20.9
7	11.01	15.6	19.8	22.7	24.2	21.8	20.9
8	10.99	15.3	19.1	22.2	23.89	21.7	20.9
9	10.97	14.8	19	21.9	23.64	21.7	20.8
10	10.97	14.7	19	21.5	23.54	21.6	

Table 1.15. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct

0	0.88	1.2	1.24	1.2	1.6	4.9	3.9
0.5	0.9	1.6	1.4	1.1	1.8	5.4	7.1
1	1.1	1.7	1.7	1.14	1.8	6.3	10.2
1.5	1	1.5	1.7	1.9	1.9	7.1	7.9
2	0.9	1.4	1.7	2.1	2.1	7.7	6.5
2.5	0.9	1.3	1.6	2.2	1.4	6.8	5.9
3	1	1.2	1.5	1.9	1.4	6.1	5.6
4	0.9	1.1	1.3	1.2	1.4	5.8	6.2
5	0.9	1.1	1.3	1	1.1	5.3	6.6
6	1.1	1.1	1.4	0.9	1.1	5.2	6.5
7	1.1	1.1	1.5	0.9	1.1	5.1	6.6
8	1	0.9	1.9	0.8	1	5.4	6.7
9	1.2	0.9	1.8	0.9	1.1	5.2	7.2
10	1	1.1	1.9	1	1.1	5.2	

Table 1.16. Mile Marker 6 (Transition) pH measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	7.34	8.13	8.13	2.98	8.51	8.62	8.32
0.5	7.36	8.29	8.14	7.99	8.51	8.63	8.3
1	7.37	8.28	8.15	8.06	8.52	8.64	8.3
1.5	7.37	8.25	8.16	8.04	8.51	8.65	8.3
2	7.38	8.24	8.14	7.98	8.49	8.62	8.3
2.5	7.38	8.19	8.05	7.92	8.45	8.57	8.3
3	7.38	8.14	7.95	7.83	8.4	8.52	8.3
4	7.37	8.07	7.8	7.67	8.37	8.47	8.3
5	7.38	8.01	7.7	8.45	8.34	8.44	8.2
6	7.38	7.98	7.6	7.54	8.3	8.4	8.2
7	7.38	7.96	7.6	7.49	8.27	8.3	8.2
8	7.37	7.95	7.5	7.44	8.24	8.3	8.2
9	7.38	7.96	7.4	7.39	8.2	8.3	8.2
10	7.38	7.93	7.4	7.36	8.16	8.3	

Table 1.17. Mile Marker 6 (Transition) ORP (mV) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	35	40	-138	24	-115	-115	125
0.5	36	41	-139	25	-114	-114	125
1	37	43	-137	26	-113	-112	125
1.5	37	46	-137	30	-109	-108	126
2	37	47	-126	38	-103	-94	129
2.5	37	49	-121	44	-95	-86	131
3	37	51	-115	54	-90	-79	132
4	37	52	-113	64	-87	-75	133

5	37	53	-110	70	-83	-70	134
6	37	54	-107	75	-79	-68	134
7	37	56	-106	81	-76	-66	133
8	37	57	-104	85	-73	-64	131
9	37	58	-103	89	-70	-62	127
10	37	59	-103	88	-68	-60	

Table 1.18. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	80.7	78	11.3	30.5	15.8	28.4	69.3
0.5	71.2	65	10.2	24.3	16.3	28.1	63.5
1	74.1	64.8	14.9	22.7	17.5	29.5	64.6
1.5	75.9	67.7	25.5	28.8	18.8	33.6	68.4
2	74.9	66.4	42	38.7	22.2	45.9	70.7
2.5	72.8	67	46.3	43.5	28.1	54.1	70
3	69.6	68.8	49.3	44	33.9	61.9	71.7
4	67	70.1	52.9	47.7	37.6	64.2	72
5	65.4	69	62.7	53.7	45.5	64.4	75.9
6	65.1	72	74.2	58	53.5	65.3	79.9
7	64.1	72	95.6	62	58.1	65.2	80
8	64.7	71.9	113	62	68.4	72.1	82.3
9	65	68	110	67	80.1	78.3	108
10	67.1	86	109	60	83.6	80	

Table 1.22. Toler Bridge (Riverine) Conductivity (µs/cm) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	0.133	0.095	0.102	0.163	0.164	0.171	0.179
0.5	0.141	0.097	0.111	0.163	0.165	0.171	0.179
1	0.14	0.115	0.134	0.162	0.167	0.171	0.179
1.5	0.152	0.138	0.143	0.162	0.168	0.171	0.179
2	0.159	0.163	0.152	0.163	0.169	0.169	0.178
2.5	0.167	0.167	0.156	0.162	0.168	0.171	0.179
3	0.173	0.167	0.156	0.161	0.168	0.17	0.178
4	0.176	0.17	0.159	0.161	0.168	0.171	0.175
5	0.176	0.172	0.159	0.163	0.168	0.171	0.172

Table 1.23. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	9.3	7.86	7.13	7.3	5.06	5.84	7.4
0.5	8.67	7.84	7.26	7.35	5.07	5.94	7.23
1	8.55	8.03	7.27	7.44	5.1	5.88	7.24

1.5	8.75	8.22	7.18	7.56	5.05	5.85	7.2
2	8.83	8.46	7.27	7.48	5.06	5.8	7.11
2.5	8.96	8.42	7.28	7.41	5.04	5.75	6.78
3	8.94	8.48	7.3	7.23	5.07	5.72	6.54
4	8.99	8.54	7.3	7.16	5.07	5.7	6.39
5	8.99	8.61	7.3	7.09	4.97	5.67	6.4

Table 1.24. Toler Bridge (Riverine) Temperature (°C) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	13.26	21.45	23.18	25.8	24.12	23.4	20.88
0.5	12.59	21.1	22.4	25.7	23.51	22.9	20.69
1	12.62	19.7	20.4	25.7	23.26	22.9	20.4
1.5	11.7	17.5	19.7	25.3	23.2	22.8	20.16
2	11.27	15.5	19.1	25.1	23.14	22.8	19.8
2.5	10.59	15.3	18.9	24.2	23.08	22.8	19.8
3	10.2	15.1	18.9	24.6	23	22.7	19.65
4	9.82	15.1	18.7	24.5	22.84	22.7	19.4
5	9.86	14.9	18.6	24.4	22.82	22.7	19.19

Table 1.25. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	1.7	1.2	1.9	0.9	0.8	4	4.2
0.5	1.5	1.2	1.8	0.9	1,1	4.5	4.8
1	1.4	1.3	1.6	1.1	1.1	5.3	7.3
1.5	1.2	1.1	1.4	1.3	1.2	5.8	8.4
2	1.1	1	1.3	1.5	1	5.6	7.4
2.5	0.7	0.9	1.3	1.4	1.1	5.7	7.1
3	0.6	1	1.3	1.4	1	6.1	6.2
4	0.6	0.9	1.3	1.4	0.9	5.8	5.6
5	0.6	0.9	1.2	1.4	0.9	6.5	5.9

Table 1.26. Toler Bridge (Riverine) pH measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	7.48	8.14	7.54	7.22	8.15	8.18	8.36
0.5	7.46	8.1	7.53	7.25	8.12	8.19	8.37
1	7.44	8.05	7.48	7.3	8.11	8.18	8.37
1.5	7.44	8	7.43	7.34	8.09	8.18	8.37
2	7.43	7.98	7.41	7.35	8.06	8.17	8.37
2.5	7.43	7.96	7.4	7.36	8.05	8.16	8.37
3	7.43	8.48	7.4	7.34	8.03	8.15	8.36
4	7.42	8.54	7.4	7.33	8.02	8.15	8.37
5	7.42	8.61	7.4	7.31	8.01	8.14	8.36

Table 1.27. Toler Bridge (Riverine) ORP (mV) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	23-Aug	20-Sep	20-Oct
0	17	14	-123	5	-88	-100	0
0.5	20	16	-121	6	-84	-99	1
1	21	19	-119	7	-82	-97	2
1.5	22	21	-118	10	-81	-95	4
2	22	22	-117	12	-79	-94	6
2.5	23	23	-117	16	-77	-92	7
3	24	23	-116	18	-76	-91	9
4	24	23	-116	20	-74	-90	11
5	24	24	-116	22	-73	-89	13

Table 1.28. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2017)

Depth:	28-Apr	19-May	20-Jun	21-Jul	20-Sep	20-Sep	20-Oct
0	122	102	98	54.7	55.1	60.9	58.8
0.5	117	96.3	94	54.3	55.2	54.9	58.3
1	113	81	92	53.4	55.7	56.9	59.3
1.5	99.3	76	88	54.4	56	60.2	62.1
2	91.9	67	79	57.7	55.6	61	69.7
2.5	68.2	62	77	59.7	54.1	61.6	73.8
3	62.9	59	72	61	52	62.4	76.4
4	57.9	57	69	60.5	51.8	61.6	79.1
5	55.9	55	67	59.6	53	61.1	82