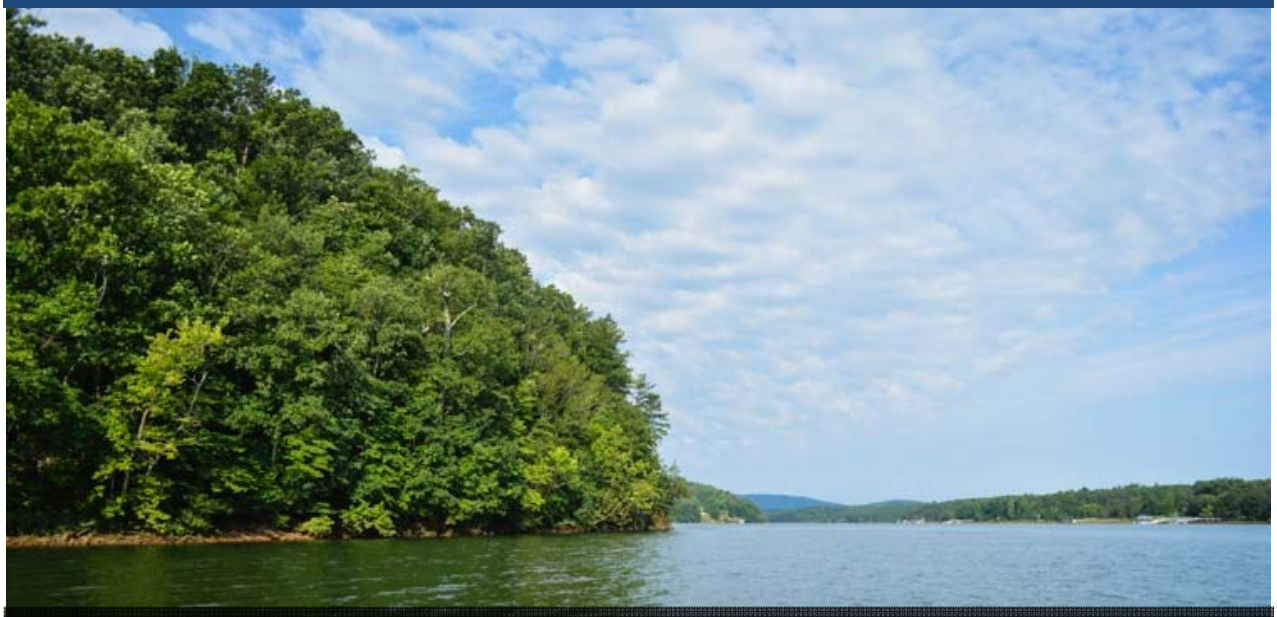

Leesville Lake 2016
Water Quality Monitoring

Prepared for:
Leesville Lake Association

Prepared by:
Dr. Thomas Shahady Lynchburg College
Jade Woll Lynchburg College

February 2016

Funds Supplied by: American Electric Power & Leesville Lake Association

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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 2016. The lake was monitored monthly in the months of April, May, September and October. Bi-monthly monitoring occurred in June, July and August. Results of the 2016 yearly results are reported here with additional analysis of lake trends based on previous sampling years. The current project was initiated in 2010. The intent of this report is to provide a technical and scientific foundation that can be used 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 the prescribed water quality parameters measured in the main stem of the reservoir. *E. coli* violations continue to occur particularly in the upper portions of the reservoir near Pigg River. During this sampling year, elevated *E. coli* occurred at stations otherwise very low in bacterial levels. Chlorophyll *a* was noticeably lower this season but in line with other measures of eutrophication. The continued bloom of phytoplankton as detected by Chlorophyll *a* below the surface at a depth of 2-4 meters again occurred in the reservoir.

Classification of Leesville Lake remains mildly eutrophic. Trophic State Index values were lower in 2016 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:

Compartmentalization and characterization of reservoir hydrology. It is the suggestion that an early empirical model is developed reflecting this condition in the reservoir.

Initiation of a detailed study of Pigg River Watershed. It is recommended the engagement process occurs in sample year 2017, as the model and sample station data is developed into a manuscript for publication.

Fisheries dynamics in Leesville Lake continue to remain an under studied portion of this investigation. It is currently recommended that the independent study outline be created including DFIF and Leesville Lake Association and presented to local colleges for potential involvement by interested students.

Section 1: Current Conditions (2016)

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. Datum is reported in graphical form with interpretations of current water quality. In the appendix, the similar data is reported in tabular form to facilitate future analysis and use for other projects. These data are located in **Appendix D**. This project continues to provide essential baseline results for the condition of the lake. We look forward to the continued study of the lake.

A full background of the study and rationalization is 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	12	2637	LVLAROA157.92	37.0382	-79.531306

Waters					

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 (2016)

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 (pumpback 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 contains 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 tailwater 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 pumpback 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 suggests management recommendations.

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

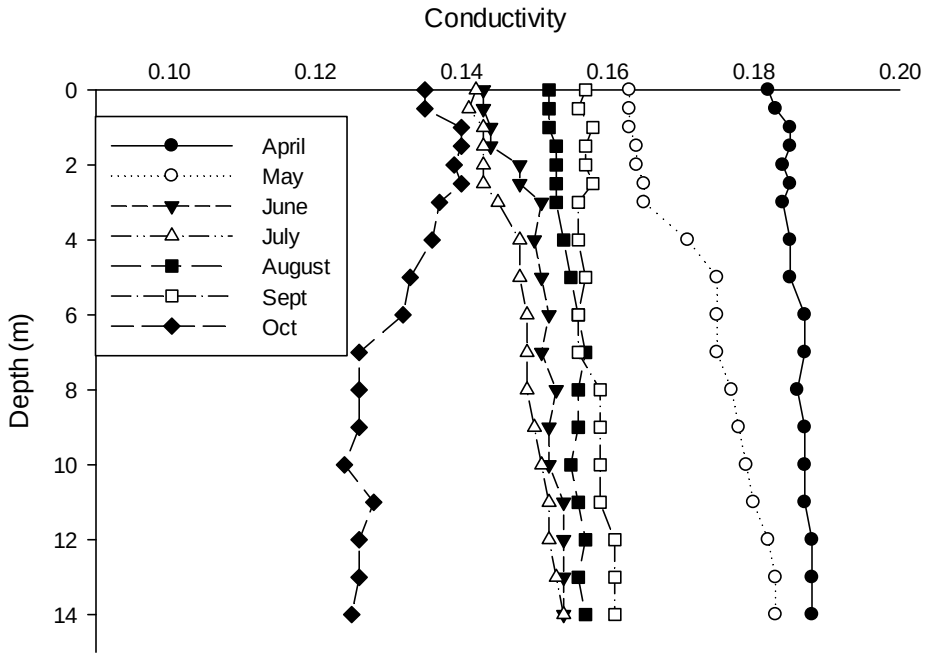


Figure 1.1. Dam (Lacustrine) Conductivity (µs/cm) measures over study period (2016)

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 pattern in conductivity, making it more useful along a spatial scale than along a vertical scale. Water conductivity at the dam is generally between 0.14 and 0.18 µs/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 0.14-0.18 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.

Dissolved Oxygen

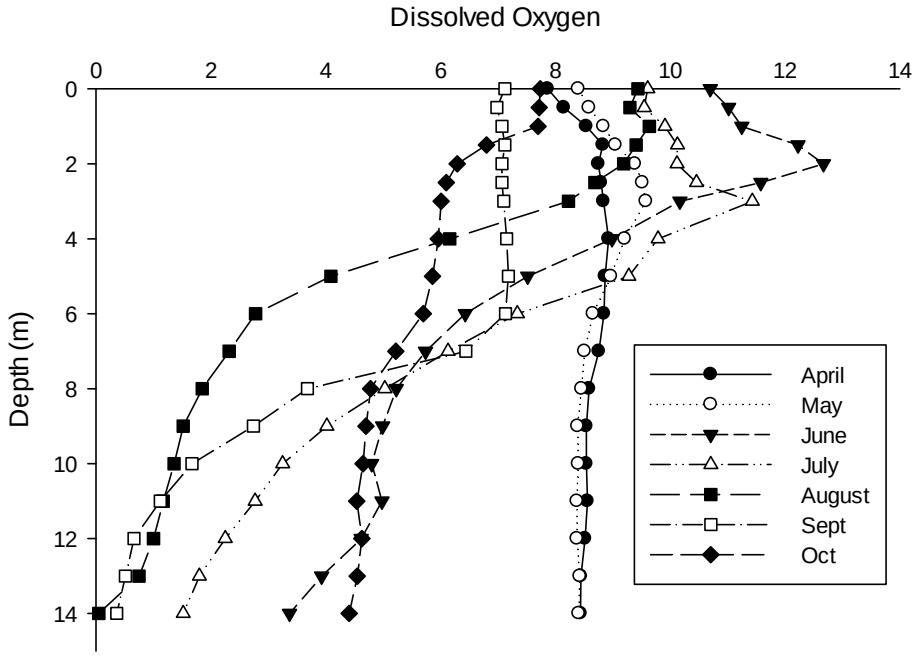


Figure 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2016)

Spatial Analysis

Dissolved oxygen patterns in the reservoir continue to suggest it is eutrophic.
At the start of the sampling season in April, water is well oxygenated throughout the entire water column. In May, a positive heterograde begins to develop below the surface as productivity increases. Water remains well oxygenated at depth through this month. In June, and throughout the summer months, the hypolimnion is depleted of oxygen. This phenomenon suggests the reservoir is eutrophic. In 2016, this condition extended into September. In October, as water cools and turns over, oxygen returns to the hypolimnion. In 2016, overall oxygen levels in the reservoir were low throughout the water column. Because of dry conditions, mixing forced the low oxygenated water into epilimnion lowering overall levels of oxygen in the reservoir. This is a concern during dry years. Siltation may have contributed to this condition as well. Siltation limits light, thus limiting phytoplankton production and producing less oxygen.

Temporal Analysis

The observed 2016 pattern of oxygen in the reservoir is quite typical. April displays high oxygen content throughout 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.

Temperature

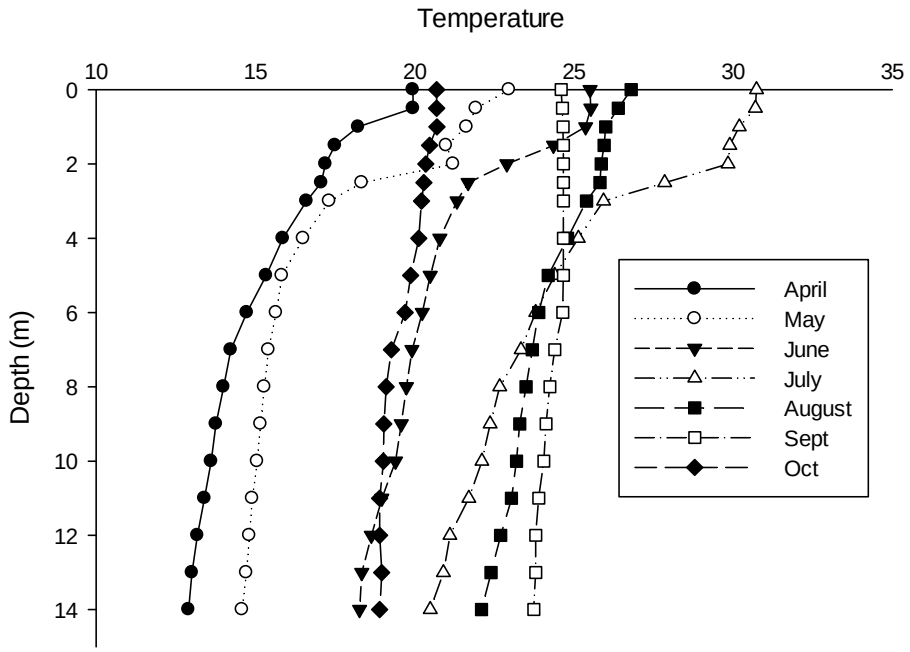


Figure 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2016)

Spatial Analysis

Temperature profiles suggest the lake stratifies throughout the year but not strongly. In June and July the strongest stratification occurred, with measured temperature differences between 8-10 degrees from top to bottom. Spring and fall months demonstrated less stratification, with weakest stratification in September. This suggests the lake is polymictic, mixing many times throughout the season. This appears to be 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) relative to water movement.

Chlorophyll *a*

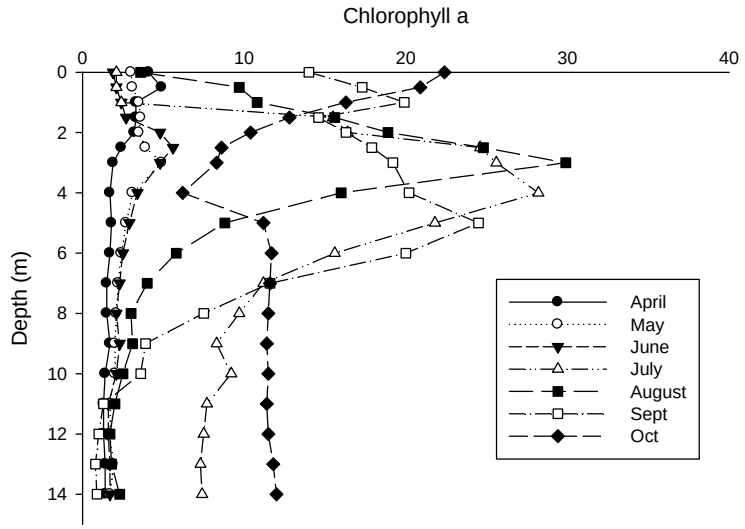


Figure 1.4. Dam (Lacustrine) Chlorophyll a (ppb) concentrations over study period (2016)

Spatial Analysis

The reservoir continues to demonstrate a pattern of high phytoplankton growth along the thermocline. This coincides with the pattern of stratification, pH elevation and oxygen elevation in this area. 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. This section of the reservoir set up with this distinctive pattern due to the stability of the water and less influence from water movement.

Temporal Analysis

The pattern of increased phytoplankton along the 2-4 meter thermocline in the reservoir is a well established pattern. In most seasons, this pattern occurs through the summer months. The very high spikes of phytoplankton of past seasons did not occur this year. These spikes had occurred in June of previous seasons, but water movement from heavy rain during the first part of the year may have pushed this phytoplankton growth out of the reservoir early in the season.

pH

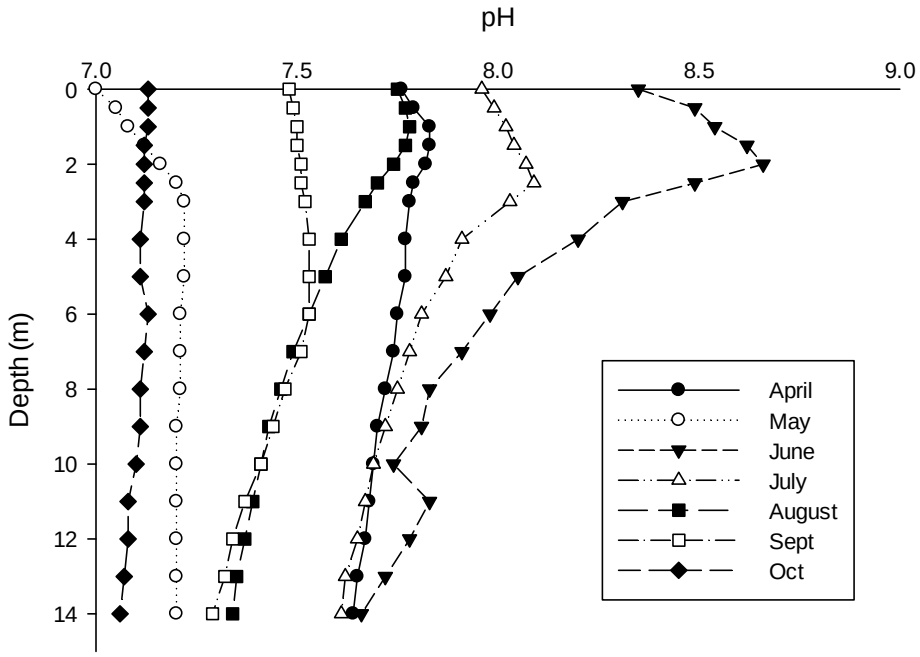


Figure 1.5. Dam (Lacustrine) pH measures over study period (2016)

Spatial analysis

The pH in the reservoir varies between 7 and 8.5 throughout the season. This is further evidence the reservoir is eutrophic. High pH levels correlate well with eutrophication. As the lake stratifies, the epilimnion becomes concentrated with phytoplankton and through the removal of CO_2 increases pH. In 2016, June was the most productive month as measured by pH, with values near 8.5 at depths below the surface. The pattern of higher pH at depths between 2-5 meters is typical as phytoplankton concentrate in this zone. The highest levels of the water column are subject to photoinhibition and lower levels are light-limited. The lower pH observations in July and August suggest the reservoir was not as productive during these critical summer months.

Temporal Analysis

The observed pattern in pH is a typical pattern in the reservoir. Summer months of June, July and August are the most productive months and produce the elevated pH observed, although this is not always the case. Often July is the most productive month with highest observed pH.

Other months do produce elevated pH readings. This suggests the importance of water movement in the reservoir dictating water quality conditions.

ORP

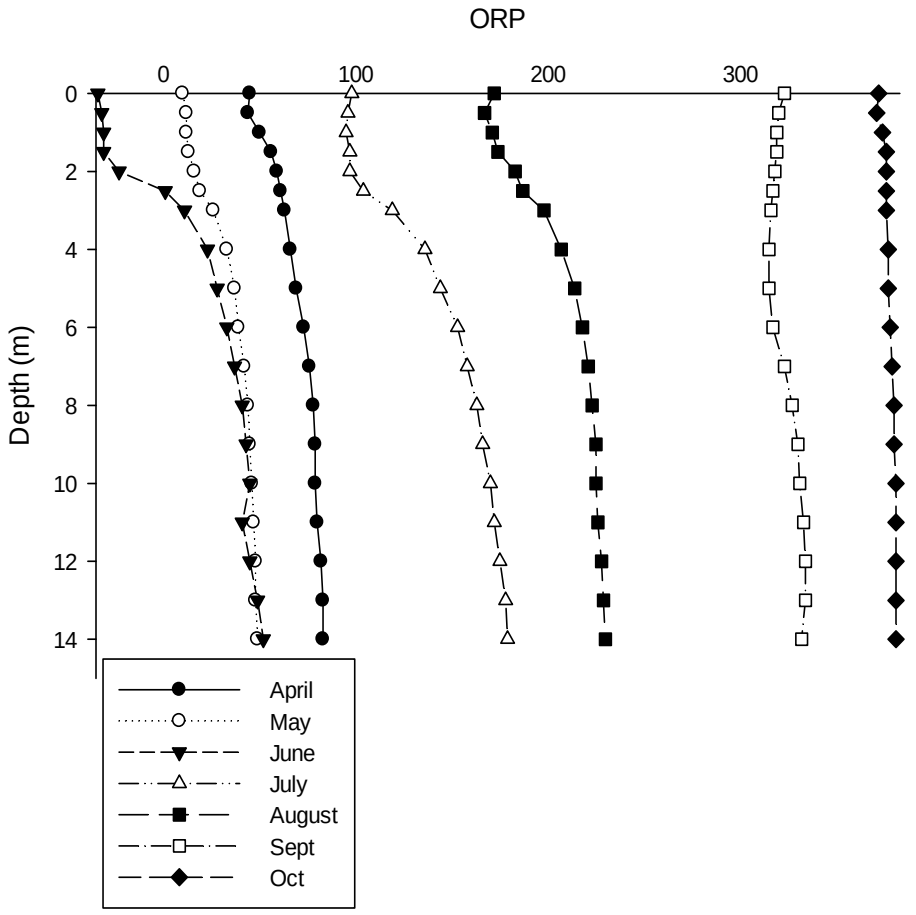


Figure 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2016)

Spatial Analysis

Discernable patterns in ORP suggest the reservoir in 2016 was oxidized throughout the water column. The level of oxidation varied throughout the season with the lowest levels of ORP in spring sampling increasing through the fall months. It is interesting to note this pattern but it is difficult to make broad interpretations from redox potential measurements. Typically, ORP measures are influenced by pH with increasing values in 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 results are variable among years.. Variability from year to year is likely a result of water inputs and influence of water flow. However, the reservoir is consistently oxidized, and this is the important interpretation of this result

Turbidity

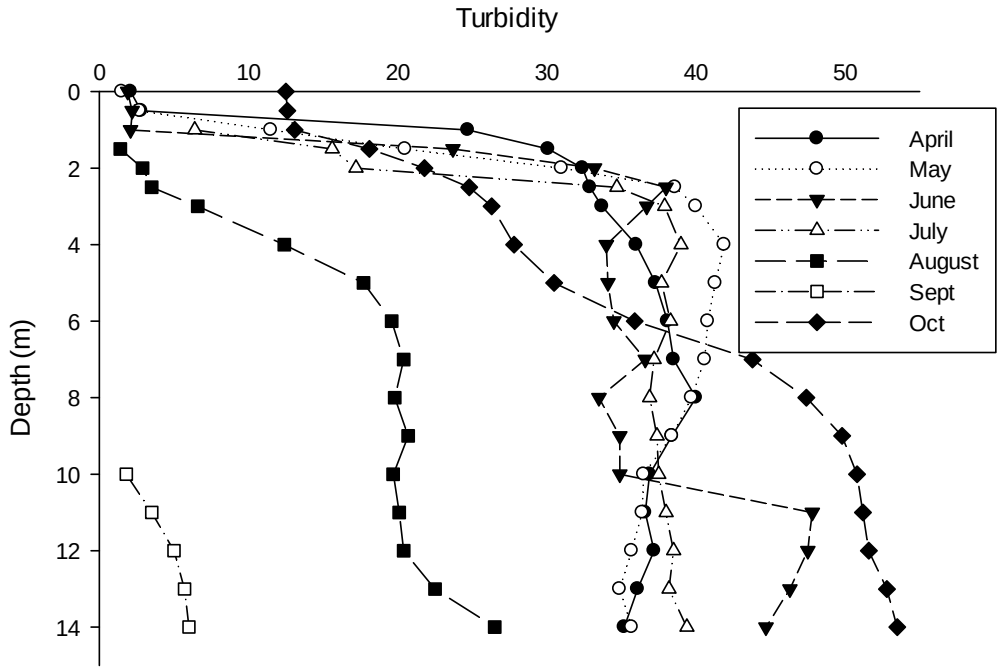


Figure 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2016)

Spatial Analysis

Turbidity in 2016 ranged from 0-55 NTU with lowest measures at the surface of the reservoir increasing with depth. The importance of turbidity measures includes both algal and non algal particles that are present in the water. Turbidity data at this station follow Chlorophyll data, increasing sharply just below the surface. This is likely resultant from the increased growth of phytoplankton during summer months but also dissolved organics in the water column. Similarity in turbidity pattern through much of the 2016 season reflects entrainment in this portion of the reservoir.

Temporal Analysis

The turbidity pattern observed in 2016 is unique to this season. The pattern is typically low at the surface with increasing turbidity through depth only in the summer months. This pattern is easily interpreted to follow algal turbidity with minimal inputs from non algal sources in this portion of the reservoir. However, in 2016, it appears that non-algal turbidity became more important than in other years. Source of this turbidity is unknown.

Other Parameters Measured

Table 1.8. Other parameters measured over study period (2016). Dates represent sampling of both the volunteers and Lynchburg College. First Column represents each parameter measured along with units of measure.

Date	28-Apr	27-May	15-Jun	30-Jun	18-Jul	28-Jul	11-Aug	29-Aug	26-Sep	19-Oct
Time	**10:48**	**10:53**	**8:55**	**11:25**	**7:50**		**9:00**		**8:25**	**8:32**
Secchi (m)	**2.7**	**2.0**	**2.0**	**2.5**	**2.2**	**2.0**	**1.7**	**1.6**	**2.5**	**0.7**
TP Surface (PPM)	**0.029**	**0.072**	**0.029**	**0.033**	**0.024**	**0.024**	**0.044**	**0.064**	**0.041**	**0.130**
TP 8 M (PPM)	**0.128**	**0.039**		**0.008**		**0.056**		**0.067**	**0.025**	**0.129**
Integrate Chl a (PPB)	2.21	2.72		2.69		12.37		9.13	11.92	12.31
TSI S	46	50	50	47	49	50	52	53	47	65
TSI TP	50	62	50	52	48	48	56	61	55	71
TSI CHL	38	40		40		55		52	55	55
TSI AVG	45	51		46		51		55	52	64

Table 1.9. Phytoplankton and Zooplankton parameters measured over study period (2016). Dates represent sampling of both the volunteers and Lynchburg College. Zooplankton numbers are organisms per liter.

Date	28-Apr	27-May	15-Jun	30-Jun	18-Jul	28-Jul	11-Aug	29-Aug	26-Sep	19-Oct
Daphnia	2.83	3.64		8.49		0.40		0.61	0.00	0.81

Bosmina	10.51	17.39		0.81		2.02		9.30	0.61	3.44
Diaptomus	3.24	3.64		0.40		0.81		2.22	0.40	2.43
Cyclops	6.47	6.07		1.62		7.48		11.53	3.03	5.26
Nauplii	7.28	3.24		8.09		9.10		4.45	7.48	4.65
Cerodaphnia	0.40	1.21		0.00		0.00		0.00	0.00	0.00
Diaphanosoma	0.00	0.40		0.81		1.62		1.01	0.00	1.01
Chydorus	0.40	0.00		0.00		0.20		0.00	0.00	0.20
E. coli MPN	1	9	**4**	4	1	7	14	5	9	53

1.3.1.1 Leesville Lake Marina

Photograph of Leesville Lake Marina taken by Jade Woll.

Table 1.10. Leesville Lake Marina other parameters measured over study period (2016)

Date	**28-Apr**	**27-May**	**15-Jun**	**30-Jun**	**18-Jul**	**28-Jul**	**11-Aug**	**29-Aug**	**26-Sep**	**19-Oct**
Time	11:19	11:13	9:50	8:30	8:07	1:10	9:22	11:00	8:56	8:57
Secchi (m)	1.75	1.5	1.5	2	1.3	2	1.6	1.6	2.5	0.6
TP Surface (PPM)	0.026	0.068		0.052		0.043		0.032	0.019	0.088

E.coli MPN	124	19	4	4	4	4	81	1	5	DNM

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 (2016)

Date	**28-Apr**	**27-May**	**15-Jun**	**30-Jun**	**18-Jul**	**28-Jul**	**11-Aug**	**29-Aug**	**26-Sep**	**19-Oct**
Time	11:28	11:26	10:05	8:30	8:25	1:20	9:40	11:07	9:07	9:06
Secchi (m)	2.3	1.3	1.8	2.0	1.6	1.8	1.2	1.6	2.3	0.6
TP Surface (PPM)	0.054	0.058		0.02	0.032	0.055		0.179	0.061	0.067
E.coli MPN	5	41	4	4	4	21	53	1	5	DNM

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

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

Conductivity

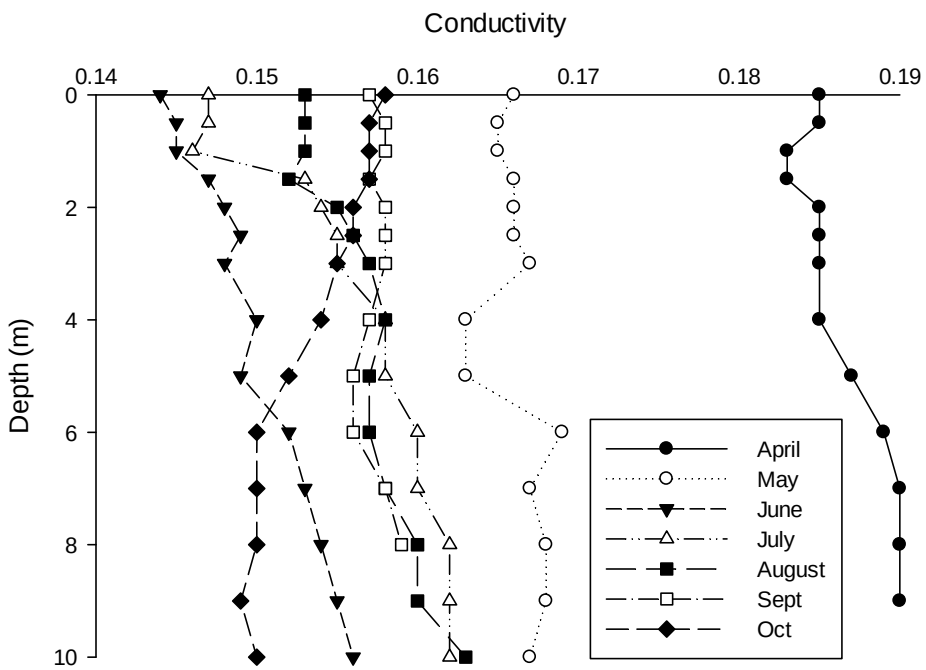


Figure 1.8. Mile Marker 6 (Transition) Conductivity (µs/cm) measures over study period (2016)

Spatial Analysis

Similar results were similar to those observed at the dam (concentrations between 0.14 and 0.18), with the exception of a greater differential between collected months and April. This strongly suggests the influence of river and external input to the reservoir during early part of the season.

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 differed from those during the remainder of the year.

Dissolved Oxygen

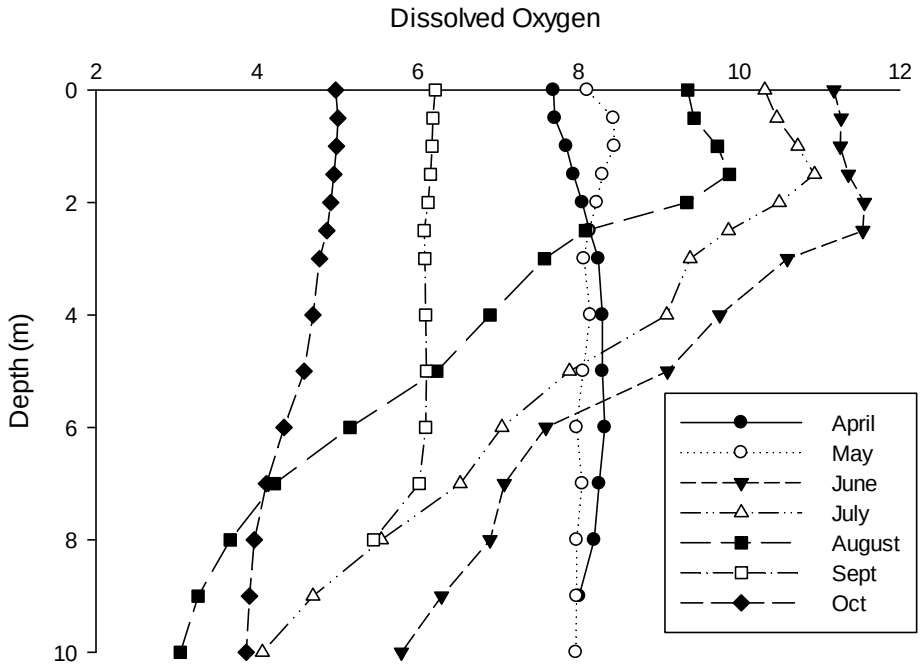


Figure 1.9. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2016)

Spatial Analysis

The pattern 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. 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 do not have as large a spread of observations including very high levels of observed oxygen in the summer. You see a similar pattern beginning in 2015 and in 2016 more defined and relevant. This is an area of concern in the reservoir.

Temperature

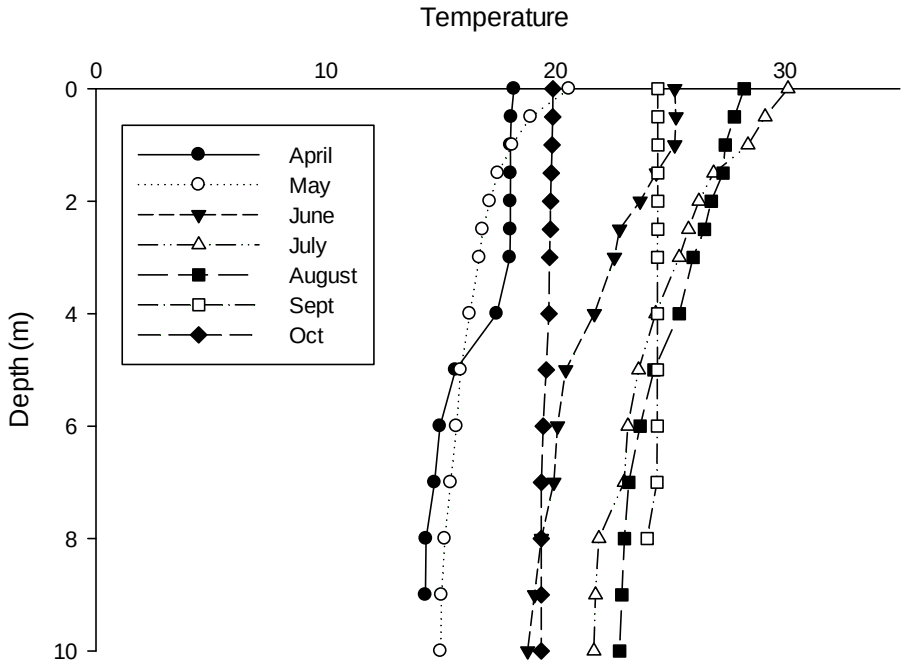


Figure 1.10. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2016)

Spatial Analysis

Temperature range is very similar to that observed at the dam throughout the season. Greatest difference is lack of stratification, which may account for many of the observations we see at this station. Greater mixing and destabilization creates some of the patterns observed.

Temporal Analysis

There was not much variation in temperature and there was a lack of discernable stratification at this station throughout the years. It is interesting that the more recent changes observed in oxygen did not parallel changes in temperature and stratification.

Chlorophyll *a*

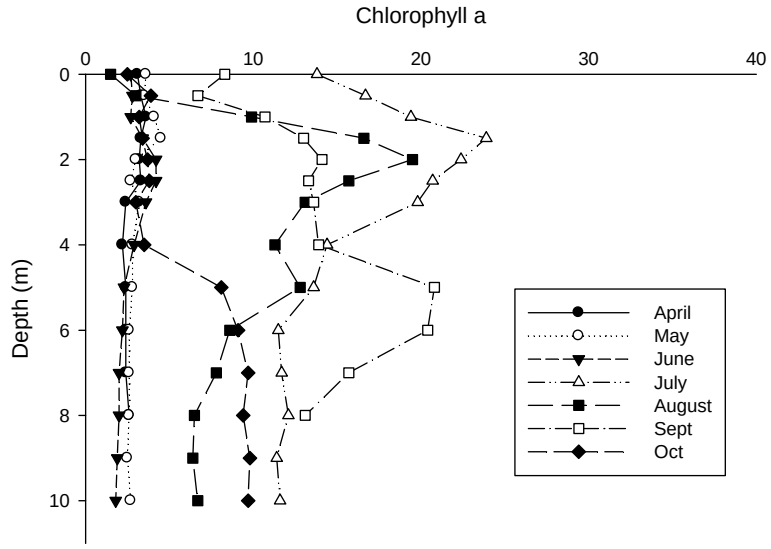


Figure 1.11. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2016)

Spatial Analysis

Growth of phytoplankton at this station is not as defined as at the dam. Population increases were noted at the thermocline (2-4 meters) but were not as pronounced as those at the dam. Summer growth was not as dense as observed at the dam, suggesting more water movement disrupting this pattern of development. These concentrations were lower than at the dam site suggesting the transition area of the reservoir is controlled more through riverine than lacustrine processes.

Temporal Analysis

The pattern of less pronounced growth of the phytoplankton population along the thermocline is consistent with historical data at this station. Population densities are usually lower at this station and only occasionally was there a high spike of growth. Densities are lower in 2016 than previous years.

pH

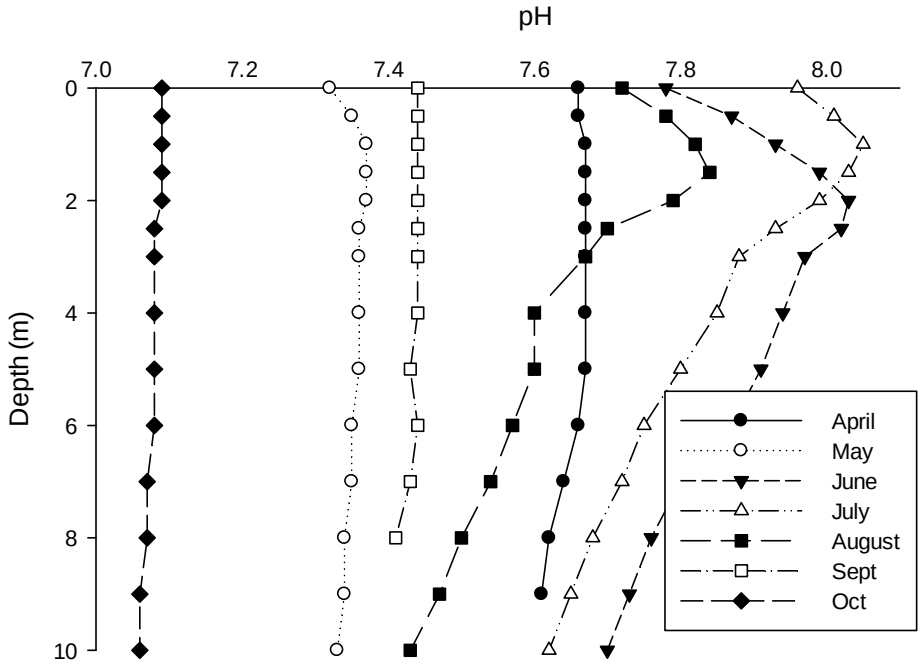


Figure 1.12. Mile Marker 6 (Transition) pH measures over study period (2016)

Spatial Analysis

The pH pattern is similar to the dam with some exceptions. Unlike the pattern at the dam, July pH measures were highest observed for the season. This suggests influence of phytoplankton production in the reservoir and particularly at this station. As this station is influenced by riverine processes, changes in measured pH occur thus a lowering of pH as phytoplankton impact is lessened.

Temporal Analysis

The pattern of pH values observed in 2016 is similar to patterns observed throughout the years of study. Higher pH observations 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 two seasons. Processes that are driving pH to lower levels and turbidity to higher levels must be evaluated.

ORP

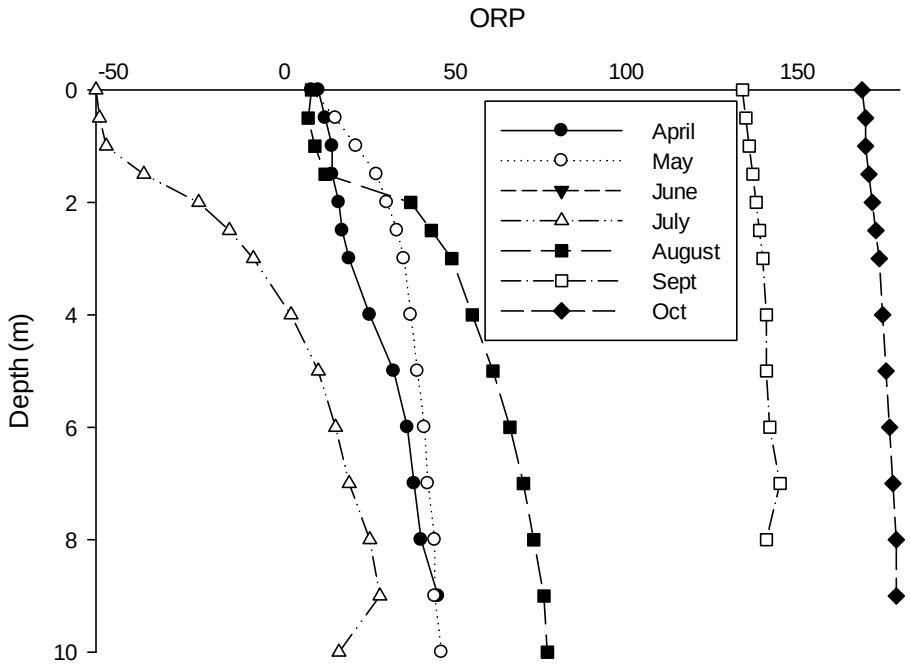


Figure 1.13. Mile Marker 6 (Transition) ORP (mV) measures over study period (2016)

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

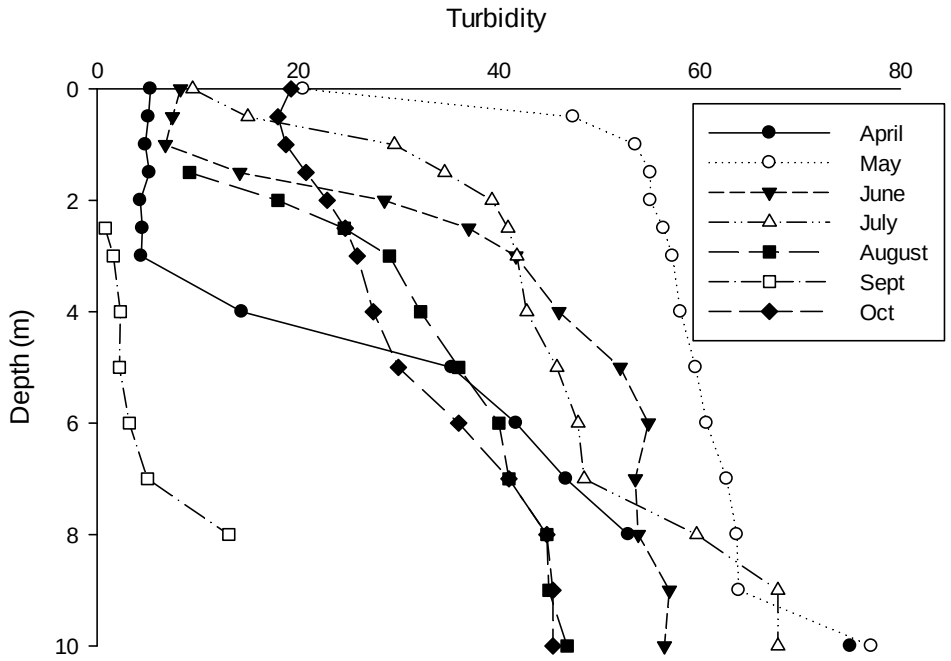


Figure 1.14. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2016)

Spatial Analysis

Similarities between dam and mm6 include the increasing turbidities with depth. This is expected as phytoplankton production influences turbidity. Yet differences between the sites give insight into the hydrology and other processes functioning in the reservoir. May and July provide the highest readings at MM6 while the October readings were very elevated at the dam. The movement of water throughout the reservoir is very important to measured water quality. In this instance, water quality at the dam was of the poorest quality in the reservoir at the October sampling in comparison to all other stations in October. While there are concerns over water quality in some portions of the reservoir, it is not always predictable the locations of these concerns.

Temporal Analysis

Turbidities appear to be increasing in the reservoir. Historically, turbidity levels have been lower in the past and the increase along the lower portion of the epilimnion and into the hypolimnion is a more resent 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 (2016). Dates represent sampling of both the volunteers and Lynchburg College. First Column represents each parameter measured along with units of measure.

Date	28-Apr	27-May	15-Jun	30-Jun	18-Jul	28-Jul	11-Aug	29-Aug	26-Sep	19-Oct
Time	**11:34**	**11:33**	**10:17**		**8:40**	**1:40**	**9:53**	**11:25**	**9:20**	**9:16**
Secchi (m)	**2.0**	**0.9**	**1.8**	**2.3**	**1.8**	**1.8**	**1.5**	**1.4**	**2.3**	**0.6**
TP Surface (PPM)	**0.038**	**0.093**		**0.043**		**0.021**	**0.03**	**0.354**	**0.044**	**0.080**
TP 6 M (PPM)	**0.149**	**0.103**		**0.050**		**0.026**		**0.156**	**0.163**	**0.112**
Integrate Chl a (PPB)	2.85	3.09		2.76		15.93		9.96	10.89	5.91
TSI S	50	62	52	48	52	52	54	55	48	67
TSI TP	54	66		56		47	51	85	56	64
TSI CHL	41	42		41		58		53	54	48
TSI AVG	48	56	52	48	52	52	53	64	53	60

Table 1.20. Zooplankton parameters measured over study period (2016). Dates represent sampling of both the volunteers and Lynchburg College. Zooplankton numbers are organisms per liter.

Date	28-Apr	27-May	15-Jun	30-Jun	18-Jul	28-Jul	11-Aug	29-Aug	26-Sep	19-Oct
Daphnia	2.36	2.36		0.00		0.40		0.00	0.71	0.00
Bosmina	4.72	18.40		0.24		1.21		0.71	2.36	5.19
Diaptomus	2.36	2.36		0.71		0.00		0.47	1.18	0.94
Cyclops	3.30	18.87		0.00		0.40		1.42	6.84	8.96
Nauplii	11.32	2.83		0.47		1.21		1.89	5.90	2.36
Cerodaphnia	0.94	4.25		0.24		0.00		0.00	0.24	0.00
Diaphanosoma	0.00	1.62		7.08		0.81		0.47	1.89	0.47
Chydorus	0.00	0.00		0.24		0.00		0.00	0.00	0.00
E. coli MPN	3.1	93	**3**	2	DNM	13	33	0	9	DNM

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 (2016)

Date	**28-Apr**	**27-May**	**15-Jun**	**30-Jun**	**18-Jul**	**28-Jul**	**11-Aug**	**29-Aug**	**26-Sep**	**19-Oct**
Time	12:11	12:07	10:33	9:20	8:55	1:55	10:05	11:50	9:36	9:40
Secchi (m)	1.5	0.75	1.2	1.5	1.4	1.5	1.2	1.25	1.7	0.6
TP Surface (PPM)	0.034	0.113		0.046		0.029		0.058	0.051	0.066
E.coli MPN	8	236	3	2	6	13	47	0	9	DNM

1.3.1.6 Toler Bridge (Riverine)[3]

Background

Riverine conditions as well as the tail waters of Smith Mountain Lake heavily influence the Toler Bridge station. We see a combination of the water qualities of Pigg River discharge with hypolimnion release from SML. The resulting water quality is completely driven by hydrological dynamics of the 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

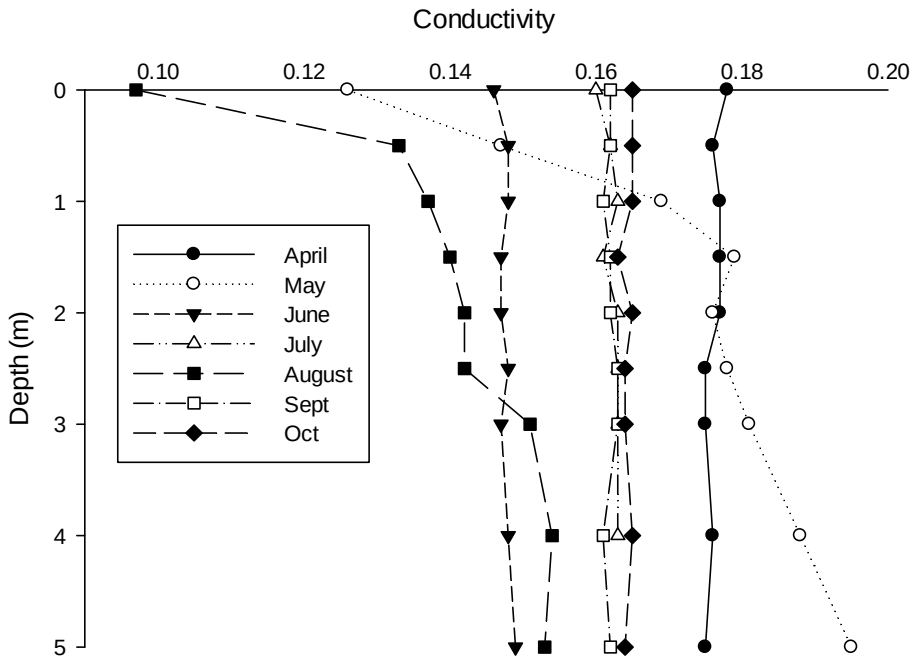


Figure 1.15. Toler Bridge (Riverine) Conductivity (µs/cm) measures over study period (2016).

Spatial Analysis

Conductivity in this portion of the reservoir is very similar to that at MM6, suggesting a strong connection between the sites and influence of riverine conditions.

Temporal Analysis

Trends for conductivity in the reservoir suggest that overall it was lower in 2016. 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. This suggests that movement of water from the Pigg River had the greatest influence on overall productivity in 2016. Productivity is often a balance between water movement, nutrient influx and sediment turbidity. This trend suggests all three of these factors were increased for 2016.

Dissolved Oxygen

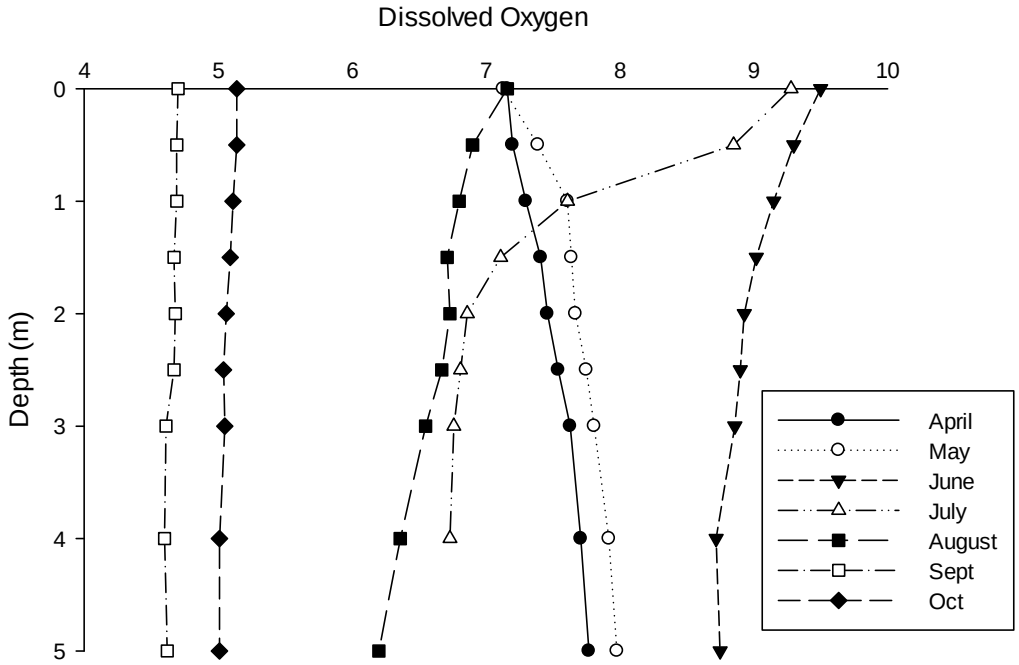


Figure 1.16. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2016)

Spatial Analysis

Oxygen concentrations in this part of the reservoir were similar to the rest of the reservoir, with the exception of the lack of oxygen loss in the hypolimnion, due to the shallow depth and mixing. It is nteresting to note that low oxygen concentrations observed in September and October persisted throughout all portions of the reservoir. Readings in September were very low. This is a concern as there was no observable refuge from low oxygen levels in the reservoir.

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 is 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.

Temperature

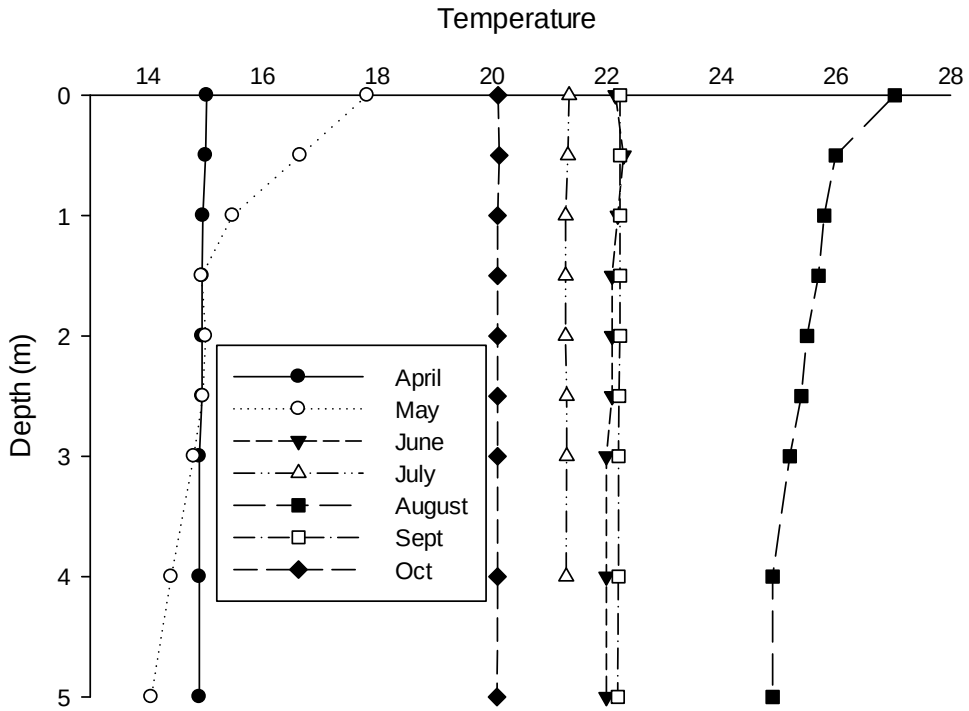


Figure 1.17. Toler Bridge (Riverine) Temperature (°C) measures over study period (2016)

Spatial Analysis

The most significant difference observed at this station is lack 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 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 August of this year was the warmest recorded during the years of study. This may be suggest that environmental warming is impacting the reservoir or that there is an impact by other undetermined processes. Increased temperatures will increase the metabolism of aquatic organisms and lead to increased productivity and eutrophication.

Chlorophyll *a*

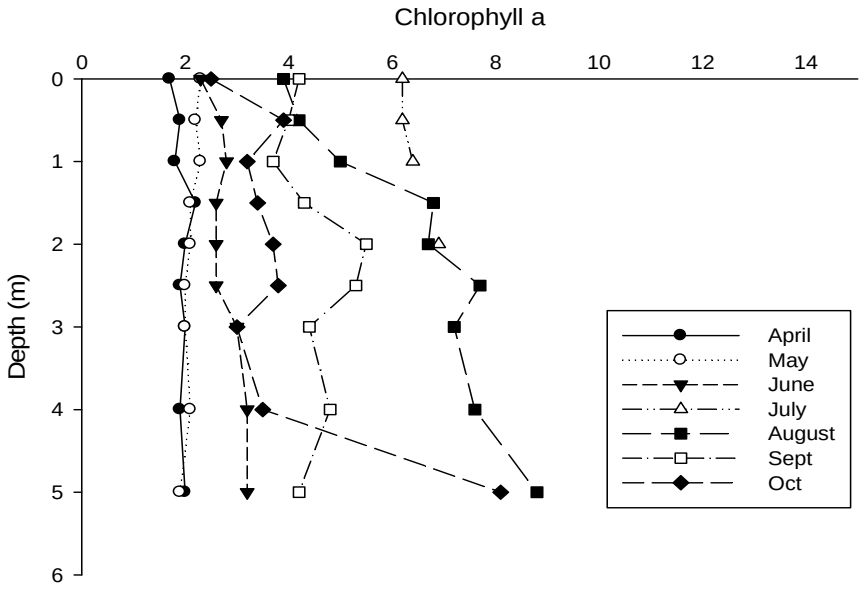


Figure 1.18. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2016)

Spatial Analysis

This station contains the lowest readings of phytoplankton biomass throughout the entire reservoir. This is likely from a combination of factors. Primary is the release of hypolimnion water from Smith Mountain Lake. This water is very clear and contains minimal concentrations of phytoplankton. Secondary, water from the Pigg River is very high in turbidity. Even when river water containing high nutrient concentration is released, the turbidity prevents increased growth of phytoplankton. Typically in reservoirs, very high growth of phytoplankton is expected in this portion of the reservoir. Leesville Lake operates in the reverse.

Temporal Analysis

The low readings from this year's analysis are not typical for the reservoir. In some past years, readings were much higher than observed during this sampling season. Operationally, drawing water from the transition portion of the reservoir would increase phytoplankton at this station. 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 and flow from the Pigg River are needed to understand the contribution of factors that contribute and impair this growth.

pH

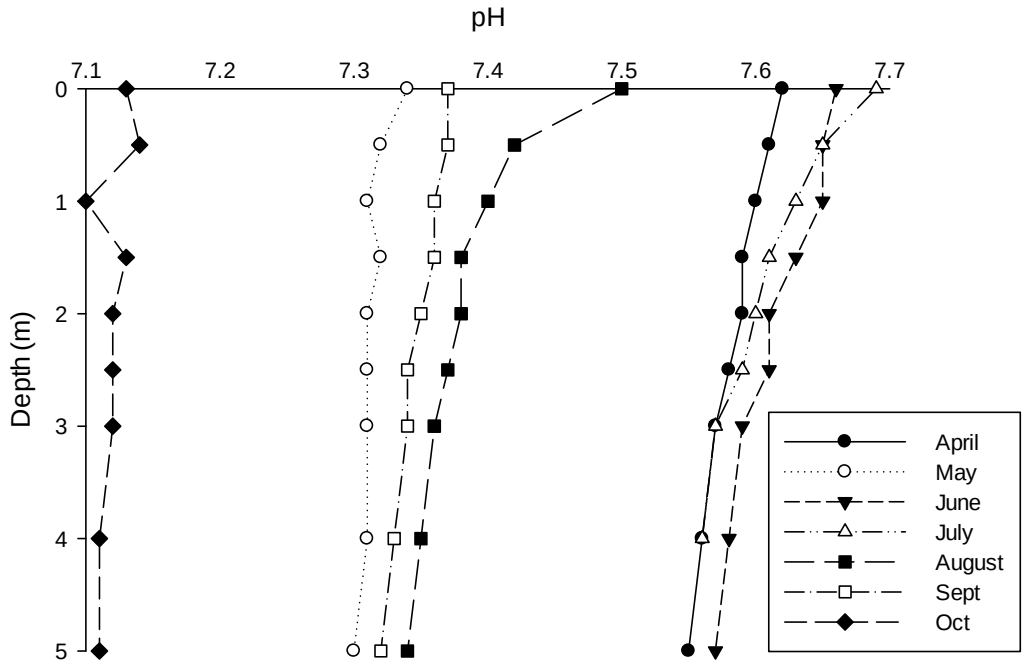


Figure 1.19. Toler Bridge (Riverine) pH measures over study period (2016)

Spatial Analysis

The pH readings in this portion were lower than down lake as is expected. Processes at this locale are driven more by water inputs than productivity. The higher pH readings in April were confined to this portion of the lake, possibly driven by Smith Mountain release and Pigg River input. August readings showed some productivity in the epilimnion where other months' readings were consistent through the water column.

Temporal Analysis

Patterns of pH distribution through the water column were consistent throughout the years of study. No discernable patterns driven by stratification. The low pH during October is only noticeable during this sampling season and 2015. This trend only occurs in 2015 and 2016. This may be a trend suggesting changes in the reservoir water quality.

ORP

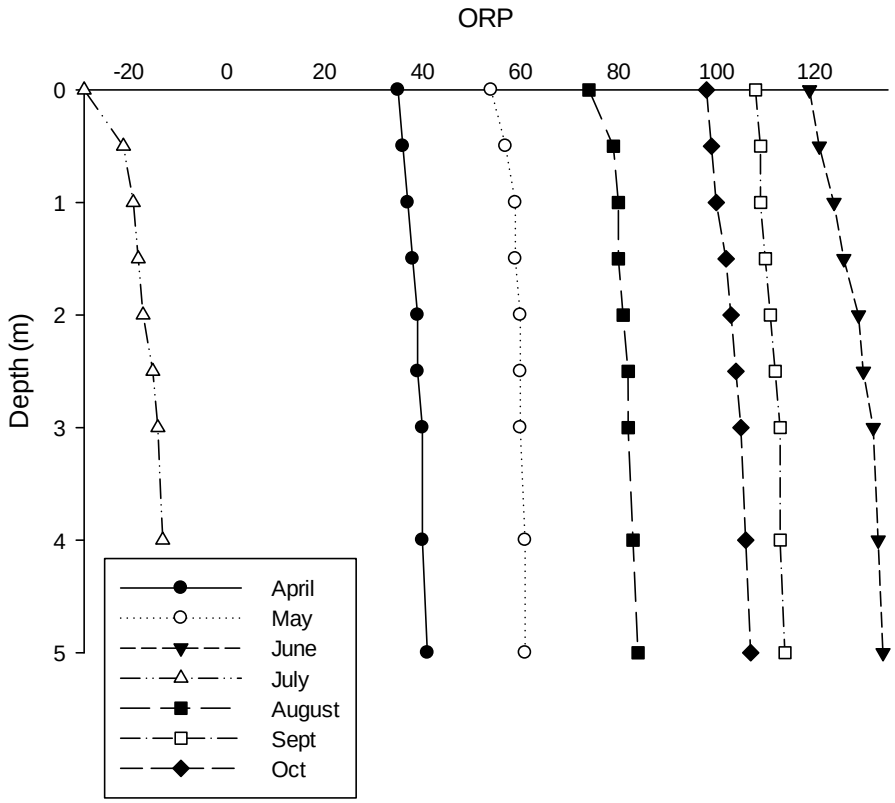


Figure 1.20. Toler Bridge (Riverine) ORP (mV) measures over study period (2016)

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

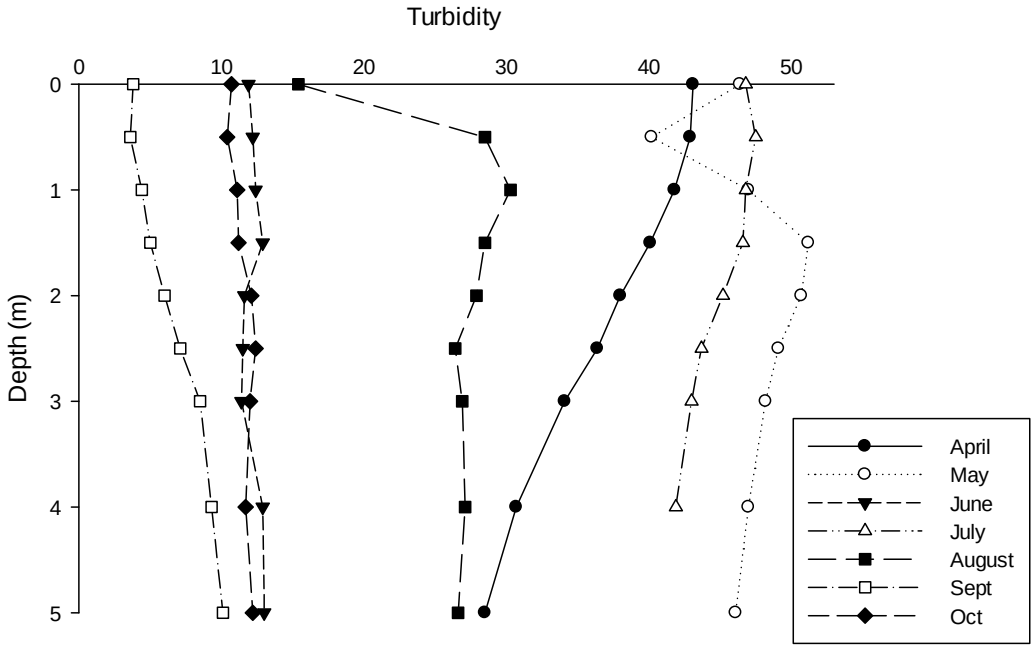


Figure 1.21. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2016)

Spatial Analysis

Turbidity at this portion of the reservoir was independent of turbidity in the lower portions. September was a very good example with high turbidity readings here and much lower readings from MM6 to the dam. This year the lake became very segmented, with Pigg River inputs creating high turbidity that remained in this portion of the reservoir. These readings were further complicated by the predominance of sediment turbidity here and algal turbidity near the dam. Because these readings are not homogenous throughout the reservoir, we suggest pockets of water move throughout the reservoir, impacting various parameters depending on Pigg River flow and Smith Mountain release and drawback.

Temporal Analysis

Turbidity consistently ranged between 15-50 NTU through the years of study. Some months a significant storm increased turbidity, which was most evident at this station. Trends consistently show decreasing turbidity with depth, unlike further down lake.

Other Parameters Measured

Table 1.29 Other parameters measured over study period (2016). Dates represent sampling of both the volunteers and Lynchburg College. First Column represents each parameter measured along with units of measure.

Date	28-Apr	27-May	15-Jun	30-Jun	18-Jul	28-Jul	11-Aug	29-Aug	26-Sep	19-Oct
Time	12:24	12:15	10:50	9:38	9:15	2:15	10:22	12:00	9:46	9:51
Secchi (m)	2.0	0.6	1.1	1.5	0.7	2.0	0.5	1.0	1.5	0.9
TP Surface (PPM)	0.037	0.287	0.146	0.114		0.057		0.059	0.025	0.079
TP 4 M (PPM)	0.038	0.053		0.06				0.097	0.100	0.057
Integrate Chl a (PPB)	1.93	2.11		2.78		6.43		6.43	4.49	6.60
TSI S	50	67	59	54	65	50	70	60	54	62
TSI TP	54	82	72	69		59		60	49	64
TSI CHL	37	38		41		49		49	45	49
TSI AVG	47	62	65	55	65	53	70	56	49	58

Table 1.30. Phytoplankton and Zooplankton parameters measured over study period (2016). Dates represent sampling of both the volunteers and Lynchburg College. Zooplankton numbers are organisms per liter.

Date	28-Apr	27-May	15-Jun	30-Jun	18-Jul	28-Jul	11-Aug	29-Aug	26-Sep	19-Oct
Daphnia	0.28	0.28		DNM		0.57		0.00	0.00	0.00
Bosmina	3.68	10.47		DNM		0.85		2.26	5.66	2.26
Diaptomus	0.28	1.13		DNM		2.55		2.26	0.00	1.70
Cyclops	0.85	6.23		DNM		4.25		0.85	3.68	7.36
Nauplii	3.40	3.40		DNM		0.28		2.26	0.57	1.70
Cerodaphnia	0.00	5.66		DNM		0.00		0.00	0.28	0.00
Diaphanosoma	0.00	0.00		DNM		5.94		0.28	0.57	0.28
Chydorus	0.00	0.00		DNM		0.00		0.00	0.00	0.00

E. coli MPN	10	457	**15**	2	39	60	727	19	23	DNM

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 (2016)

Surface (PPM)	**28-Apr**	**27-May**	**15-Jun**	**30-Jun**	**18-Jul**	**28-Jul**	**11-Aug**	**29-Aug**	**26-Sep**	**19-Oct**
TSI LS	56	63	65	63	65	50	83	63	65	83
Time	12:40	12:40	**11:05**	9:50	9:25	2:30	10:35	12:23	10:03	10:10
TSI TP	57	64	72	76		72		64	73	65
Temp. (C)	20.74	22.24	69	23.9	65	27.85	83	26.09	22.62	17.54
TSI AVG	56	64	69	70	65	61	83	64	69	74
Cond. (us/cm)	22.5	751	40	163	96	122	1732	28	547	261
E. coli MPN	0.079	0.077		0.069		0.156		0.129	0.084	0.075
DO (mg/L)	6.61	7.04		8.23		7.42		6.99	6.65	8.28
pH	7.57	7.32		7.56		7.53		7.35	7.38	7.39
DO%										
ORP (mV)	44	52		117		-31		75	94	57
Turbidity (NTU)	18.9	64.3		33		42.8		27	36.6	131
Secchi (m)	1.3	0.8	0.7	0.8	0.7	2.0	0.2	0.8	0.7	0.2

1.3.1.8 Smith Mountain Lake Tail Waters

Table 1.32. Smith Mountain Lake Tail Waters other parameters measured over study period (2016)

Date	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
Time	12:40	12:40	10:10	2:40	12:40	10:19	10:24
Temp. (°C)	11.75	15.36	21.6	19.08	21.1	12.18	19.99
Cond. (µs/cm)	0.211	0.195	0.138	0.169	0.166	0.167	0.163
DO (mg/L)	7.88	7.41	8.62	6.15	5.61	4.38	5.8
pH	7.53	7.27	7.46	7.58	7.37	7.23	7.12
DO%	73.7	75.5	98.9	67.2	61.2	50.1	64.8
ORP (mV)	65	80	73	-26	94	84	58
Turbidity (NTU)	46.5	50.8	25.3	43.7	0	4	14.7
Secchi (m)	3.0	1.5	1.0	3.0	2.0	1.6	0.7
TP Surface (PPM)	0.036	0.093	0.195	0.045	0.015	0.133	0.159
TSI S	44	54	60	44	50	53	64
TSI TP	53	66	76	56	43	71	73
TSI AVG	49	60	68	50	46	62	69
E.coli MPN	1	148	25	8	31	13	16

Section 2: Lake-Wide Trending

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 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. Conversely, 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 looked at over a five-year period. 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. Additionally, chlorophyll *a* concentrations reflect use of TP for phytoplankton growth within the limitations of shading (sediment inputs) and grazing by zooplankton (*Daphnia*

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

concentrations). While each TSI predictor is based upon a differing parameter for prediction, often the predictions are within similar ranges.

Secchi Depth TSI

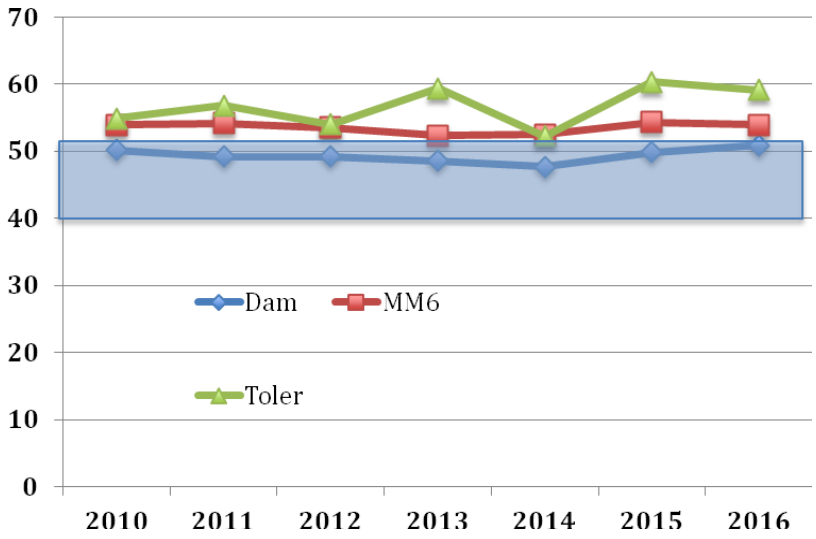


Figure 2.1. Trophic State Index (TSI) based upon Secchi disk measurements in Leesville Lake from 2010-2016. Y-axis reflects the calculated TSI for each of the three primary sampling stations throughout the reservoir. The shaded box represents the mesotrophic range for TSI where below this range is oligotrophic conditions and above represents eutrophic conditions.

Analysis

Predictions of trophic state using Secchi Depth provide the most consistent results on the reservoir. It shows relative consistency throughout the seven-year study period with the Dam in the upper mesotrophic range, MM6 very mildly eutrophic and Toler somewhat more eutrophic than MM6 but still in the mild range. This also verifies the strong influence of sediment from the Pigg River, as other indicators suggest the reservoir is structured in the other direction with Toler in the upper mesotrophic range and the Dam in the mild eutrophic range. An important note from these data is the consistency throughout the years, suggesting that processes contributing to Secchi Depth are well established and working. This is a good range of data for comparison and prediction of this trend.

Total Phosphorous TSI

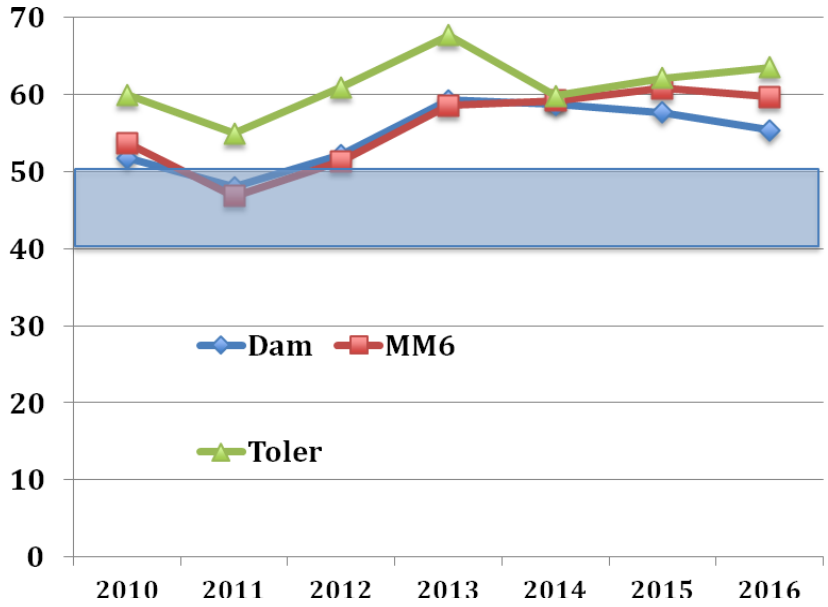


Figure 2.2. Same as Figure 2.1 but TSI is based on Total Phosphorus (TP).

Analysis

Trophic state based on total phosphorus suggests that the reservoir is eutrophic. These data are consistent with predictions based on Secchi Disk reading, suggesting some correlation in impact between sediment and nutrients. This is an obvious connection as sediment often carries a nutrient load with it. The Dam is furthest from this source and as a result contains lower concentrations of nutrients and a better trophic state. The nutrient data suggesting a greater level of eutrophication than Secchi Disk can be concerning. Primary mechanisms causing this disparity are likely movement of water and hydrology and the potential of zooplankton grazing improving the clarity of the water. In the case of hydrology, Smith Mountain Lake operations not only control Leesville Lake water levels but also trophic state to a limited degree.

Chlorophyll *a* TSI

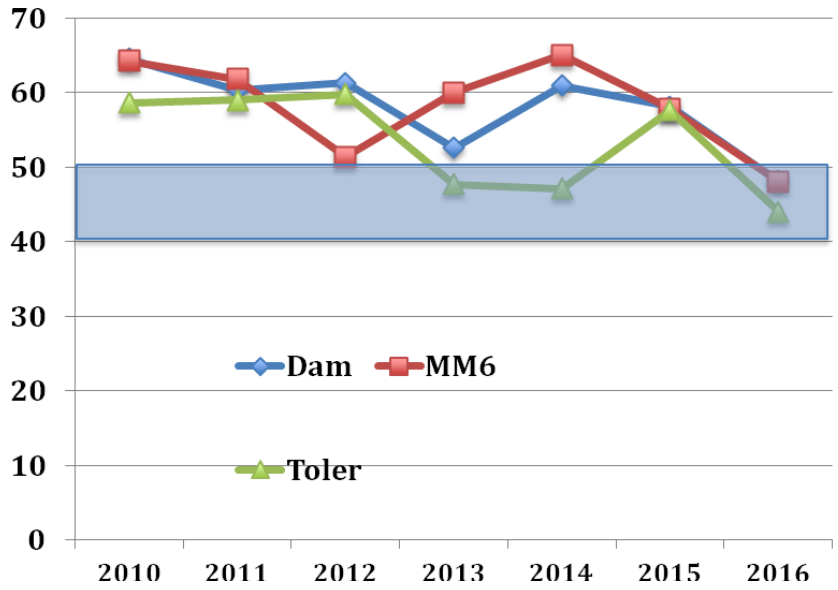


Figure 2.3. Same as figure 2.1 but TSI is based on Chlorophyll *a*.

Analysis

Trophic state based upon Chlorophyll *a* is more difficult to interpret. Current year's data suggest that the lake is completely mesotrophic based on the levels of Chlorophyll a or phytoplankton growth. This is a good result, as in previous years Chlorophyll data suggested the reservoir was eutrophic. In this year's data, sedimentation my have been very important to limiting the growth of phytoplankton. Sediment that entered the reservoir during the wet spring months may have persisted throughout the summer limiting growth. Some of the large spikes of growth observed in years past were not observed in 2016. It is important to continue to monitor this trend to determine if the reservoir is entering a lower level of phytoplankton growth. We can also not rule out the importance of water movement as this has been shown to reduce the development of large areas of phytoplankton growth.

TSI Average

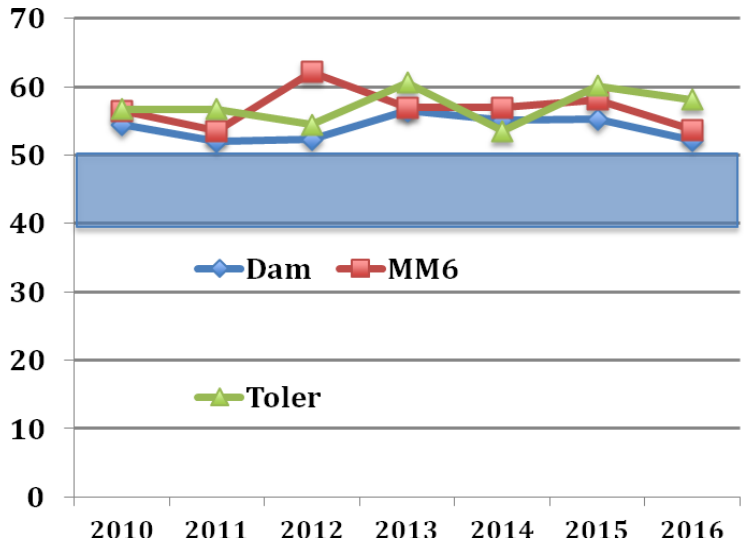


Figure 2.4. Same as Figure 2.1 but TSI presented is the average of TSI for all parameters evaluated (Secchi Depth, Total Phosphorous, Chlorophyll *a*).

Analysis

Averaging trophic state indices 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 trend in the trophic state of the reservoir.

Daphnia Productivity

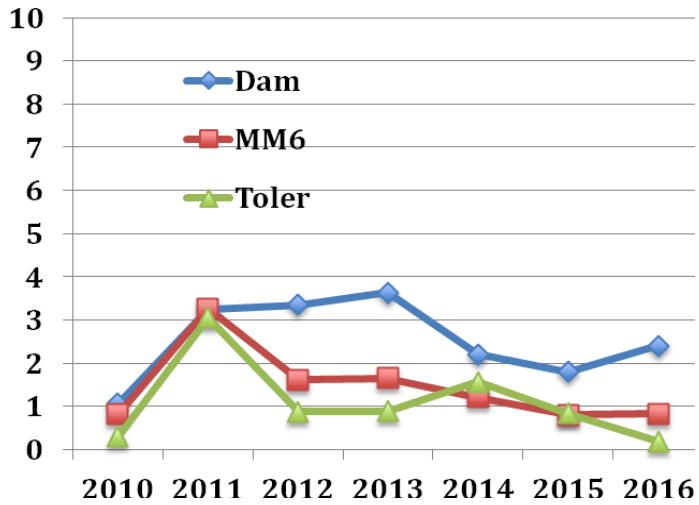


Figure 2.5. Average *Daphnia* concentrations in Leesville Lake from 2010-2015. Numbers on y-axis represent *Daphnia/* liter.

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 2016, this suggests hydrology is a much more important factor in producing the lower Chlorophyll observations. The beneficial impact of *Daphnia* grazing reductions on Chlorophyll is increased water clarity. While Chlorophyll was reduced in 2016, water clarity did not increase. Secondly, reduced *Daphnia* abundance decreases the quality of forage available for Shad and other forage fish in the reservoir. Healthy populations of *Daphnia* provide better zooplankton forage.

2.2 Sources and Fate of Mn and Fe in Flow-Regulated River

The first publication from some of our work on the reservoir was accepted to the Journal of Hydrological Processes. Munger et. al. 2017. Effects of reservoir stratification and watershed hydrology on manganese and iron in a dam-regulated river Hydrological Processes (*In Press*)

This work is based on source tracking of metals and demonstrated the reductive processes occurring in the hypolimnion of Leesville Lake and release downstream. This work was initiated by Geology Professor Madeline Schreiber and graduate student Zach Munger of Virginia Tech. Our data collections, boat, sampling, knowledge of the lake and processes occurring all contributed to this publication. Below is the abstract for this work. Entire paper will be published this year.

Abstract

The presence of metals, including manganese (Mn) and iron (Fe), adversely impacts water quality. In seasonally stratified reservoirs, Mn and Fe can accumulate in the water column due to reducing conditions in sediments released to downstream rivers through dam discharge. In addition to reservoir stratification influences, the release of metals downstream is influenced by hydrologic conditions in the river. We examined the seasonal and spatial variability of Mn and Fe concentrations in a eutrophic, hydropower reservoir and the downstream river over a two-year period. Overall, we found that reservoir stratification was a strong predictor of tailrace Mn and Fe concentrations but that tailrace Fe concentrations were also influenced by dam discharge. Downgradient of the tailrace, river discharge and suspended sediment were the dominant predictors of both Mn and Fe concentrations. Using our data, we develop a conceptual model of seasonal and hydrologic drivers of metal concentrations. The model can be modified for other systems aiding drinking water utilities and other water users in forecasting under what seasonal and hydrologic conditions Mn and Fe concentrations in river systems are likely to be elevated.

Section 3: Management Implications

Current water quality indicators suggest Leesville Lake is mildly eutrophic. Eutrophication indicators for 2016 did show some improvement yet long-term trends suggest this condition is not changing. Management recommendations are suggested to improve the overall eutrophic condition of the reservoir and potentially bring the trophic state into a mesotrophic classification. Several characteristics of the reservoir suggest this is possible.

1. Leesville Lake shows tends of improved water quality in the headwater regions during times of predominant flow from Smith Mountain Lake. The hypolimnetic release from Smith Mountain Lake is mesotrophic – oligotrophic. Understanding how to maximize this flow for improvement in the reservoir is very beneficial.

2. Leesville Lake is a typical run of the river reservoir in that it is controlled by hydrology. The very unique hydrology consists of a combination between natural river inputs and movement of water from Smith Mountain operations. This provides the critical link for management.

3. Entire lake stratification, concentration of phytoplankton blooms and nutrient dynamics are easily controlled through water movements and can be manipulated.

4. Predominantly one river system, the Pigg River, is the impaired water flowing into the reservoir. This study suggests that improvements to this watershed will directly improve water quality in Leesville Lake.

Recommendations:

- Compartmentalization and characterization of reservoir hydrology is warranted. Detailed understanding of physical water exchange is not as important as understanding critical exchange points (Pigg River flow and movement down or up reservoir). Examining how this water exchange influences water quality. It is the suggestion that a early empirical model is developed reflecting this condition in the reservoir. It is further suggested that this model along with data point comparisons along the reservoir be

developed into a manuscript for publication during the 2017 sampling season. Lynchburg College will begin to model this condition.

- Findings from this model study will be disseminated to Leesville Lake Association and allowing discussion among the appropriate agencies.
- Initiation of a detailed study of Pigg River Watershed. It is recommended that Lynchburg College in partnership with Leesville Lake Association begin to study current TMDL and other appropriate water quality documents associated with the Pigg River Watershed. Additional, both entities begin the process of engagement with DEQ and SWCD in the area to seek funding for comprehensive study of the impact watershed water quality on Leesville Lake. It is recommended the engagement process occurs in sample year 2017 as the model and sample station data is developed into a manuscript for publication. This will allow launch of a Pigg River Study to occur in 2018.
- Fisheries dynamics in Leesville Lake continue to remain an under studied portion of this investigation. Forage fish dynamics are important to water quality as evidenced in the fluctuating compositions of zooplankton particularly *Daphnia*. While this is not in the forefront of the suggested management recommendations it continues to be needed. It is suggested that if a interested student presents themselves for this study the investigation should occur. It is currently recommended that the independent study outline be created including DFIF and Leesville Lake Association and presented to local colleges for potential interested students.

Section 4: Hydrological Analysis

4.1 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)

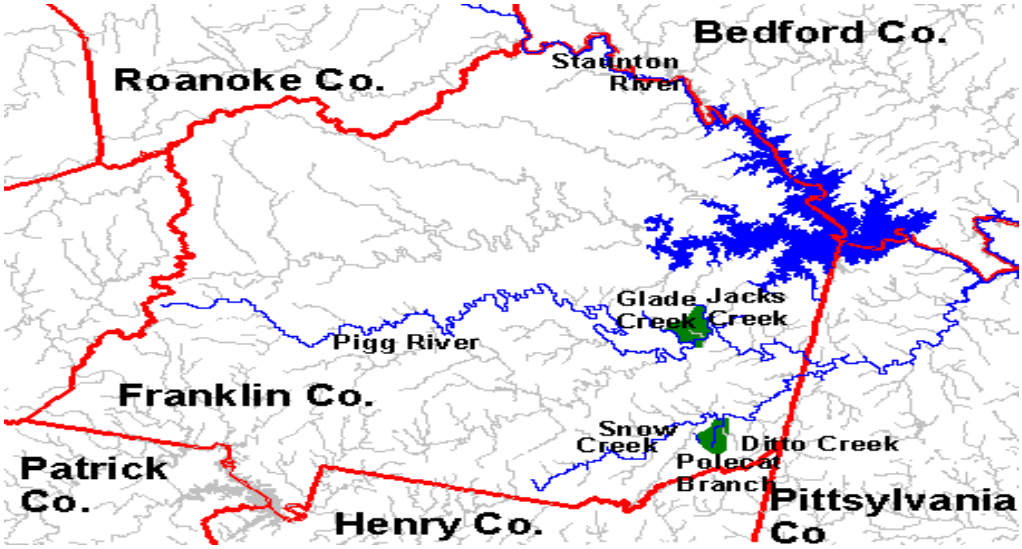
From June through November 2010, Lynchburg College and volunteers from LLA collected Leesville Lake water quality data. Lynchburg College sampled eight sites while LLA sampled seven. Data on water quality parameters included temperature, oxygen (dissolved oxygen and percent saturation dissolved oxygen 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.

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Appendix A

Background of Water Quality Program

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

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

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

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

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

To renew their license, Appalachian Power Company (Appalachian Power), a unit of American Electric Power (AEP), submitted an application for a new license in March 2008. In August 2009, the Federal Energy Regulatory Commission issued a Final Environmental Impact Statement for the Smith Mountain Project relicensing. While reissuing, the Commission reviewed AEP's methods and proposals for "the protection, mitigation of damage to, and

enhancement of fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality." (FERC, 2009, p. 1). In the final Environmental Impact Statement (EIS), FERC endorsed Appalachian Power's proposed $25,000 annually to the LLA to support the on-going water quality monitoring program (FERC, 2009, p. 25). The Commission approved the new license, effective April 1, 2010.

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

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

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

Participants:

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

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

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

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

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

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

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

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

- Educate to individuals, organizations, and the general public information concerning:
  a. Water quality monitoring results
  b. Management techniques and practices to preserve the environmental quality of Leesville Lake and its watersheds
  c. Safe recreational activities
  d. Commercial and government activities that could harm geographic area of Leesville Lake
  e. How to maintain optimum water levels in Leesville Lake

Appendix B

Water Parameter Testing Details

Oxygen

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

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

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

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

Temperature

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

and resulting density difference of the thermocline disrupts nutrient and gas circulation, resulting in lake stratification (Kaulff, 2002, p. 154).

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

pH

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

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

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

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

Conductivity

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

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

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

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

Turbidity

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

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

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

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

Oxidation-Reduction Potential

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

measurement of ORP in the final proposal to further understand chemical activity and developing eutrophication.

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

Total Phosphorus

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

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

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

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

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

phosphate, the absorbance of the formed blue complex, was measured at 880nm.

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

List of Chemicals:

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

Preparation of Reagents and Standards:

Stock Standards:

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

Reagents:

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

Standards used in the digestion process:

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

Standards:

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

Dissolved Phosphorus

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

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

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

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

Nitrogen

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

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

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

the following method.

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

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

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

Stock Standard contained:

- Potassium Nitrate, KNO_3

Preparation of Reagents and Standards:

Reagents:

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

Standards:

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

Summary of Run:

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

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

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

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

Fluorescence

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

Integrated Chlorophyll *a*

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

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

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

Secchi Depth

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

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

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

Deleted: Scchi

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 SysteaÕs 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) $C_{12}H_{14}N_2$⟨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. 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.

⟨ 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.

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.

Ortho-Phosphate Method

Summary of Method:
The solution containing phosphate was mixed with sulfuric acid, ammonium molybdate and antimony potassium tartrate to form antimony-1, 2-phosphorous molybdenum acid. To create a blue heteropoly acid (molybdenum blue), the complex was reduced by ascorbic acid. The absorbance of the blue complex was measured at 880nm to determine the concentration of phosphorus.

List of Chemicals:
Ammonium Molybdate, (NH4)6Mo7O24 4H2O
Antimony Potassium Tartrate, K(SbO)C4H4O6⟨3H2O
Ascorbic Acid, C6H8O6
Potassium Dihydrogen Phosphate, KH2PO4
Sulfuric Acid conc., H2SO4

Preparation of Reagents and Standards:
Stock Solutions:
⟨ 4.0g of ammonium molybdate were dissolved in 100mL of water, then transferred to a light-resistant polyethylene container.
⟨ 14mL of sulfuric acid were added to 70mL of DI water. The solution was cooled, and diluted to 100mL with DI water.
⟨ 0.3g of antimony potassium tartrate were dissolved in 100mL water and the solution was transferred to a light-resistant container.
Reagents:
⟨ The first phosphate reagent depended on the concentration range. For a range of up to 20mg/L, 50mL of (5N) sulfuric acid were mixed with 5mL of antimony stock. 15mL of molybdate stock and 50mL of DI water were added.
⟨ For the second reagent, 0.9g of ascorbic acid were dissolved in 100mL of DI water.
Standards:
⟨ A phosphate stock standard of 1000mg/L was made by dissolving 4.395g of potassium dihydrogen phosphate in 1000mL of DI water.
⟨ The 100 ppm and 10 ppm nitrite stock standard were prepared by subsequently diluting the 1000 ppm standard

Nitrite Method

Summary of Method:

Under this automated procedure, the nitrite ion reacted with sulfanilamide under acidic conditions to form a diazo compound. This compound then combined with N-1-napthylethylenediamine dihydrochloride to form a reddish-purple azo dye. To determine nitrite concentration, the colored complex was measured at 546nm.

List of Chemicals:
N-1-naptylethylenediamine dihydrochloride, C12H14N2⟨2HCl
Phosphoric Acid, H3PO4
Sodium Nitrite, NaNO2
Sulfanilamide, C6H8N2O2S

Preparation of Reagents and Standards:
Reagents:
⟨ 10mL of concentrate phosphoric acid, 1.0g of sulfanilamide, and 0.1g of N-1-napthylethlyenediamine dihydrochloride were dissolved in approximately 40mL of DI water in a 100mL volumetric flask. The solution was diluted to 100mL with DI water and transferred to a polyethylene bottle.
Standards:
⟨ A nitrite stock standard of 1000 mg/L was made by dissolving 4.9242g of sodium nitrite in one liter of DI water.
⟨ The 100 ppm and 10 ppm nitrite stock standard were prepared by subsequently diluting the 1000 ppm standard.

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.

List of Chemicals:
Ammonium Molybdate, (NH4)6Mo7O24⟨4H2O
Ammonium Persulfate, (NH4)2S2O8
Antimony Potassium Tartrate, K(SbO)C4H4O6⟨3H2O
Ascorbic Acid, C6H8O6
Isopropyl Alcohol, (CH3)2CHOH
Phenolphthalein, C20H14O4
Potassium Dihydrogen Phosphate, KH2PO4
Sulfuric Acid conc., H2SO4

Preparation of Reagents and Standards:

Stock Standards:

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

Reagents:

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

Standards used in the digestion process:

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

Standards:

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

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 (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	0.182	0.163	0.143	0.142	0.152	0.157	0.135
0.5	0.183	0.163	0.143	0.141	0.152	0.156	0.135
1	0.185	0.163	0.144	0.143	0.152	0.158	0.14
1.5	0.185	0.164	0.144	0.143	0.153	0.157	0.14
2	0.184	0.164	0.148	0.143	0.153	0.157	0.139
2.5	0.185	0.165	0.148	0.143	0.153	0.158	0.14
3	0.184	0.165	0.151	0.145	0.153	0.156	0.137
4	0.185	0.171	0.15	0.148	0.154	0.156	0.136
5	0.185	0.175	0.151	0.148	0.155	0.157	0.133
6	0.187	0.175	0.152	0.149	0.156	0.156	0.132
7	0.187	0.175	0.151	0.149	0.157	0.156	0.126
8	0.186	0.177	0.153	0.149	0.156	0.159	0.126
9	0.187	0.178	0.152	0.15	0.156	0.159	0.126
10	0.187	0.179	0.152	0.151	0.155	0.159	0.124
11	0.187	0.18	0.154	0.152	0.156	0.159	0.128
12	0.188	0.182	0.154	0.152	0.157	0.161	0.126
13	0.188	0.183	0.154	0.153	0.156	0.161	0.126
14	0.188	0.183	0.154	0.154	0.157	0.161	0.125

Table 1.2. Dam (Lacustrine) Dissolved Oxygen (mg/L) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	7.87	8.4	10.7	9.61	9.44	7.12	7.74
0.5	8.15	8.59	11.02	9.55	9.3	6.98	7.72
1	8.54	8.84	11.25	9.91	9.64	7.07	7.7
1.5	8.83	9.05	12.23	10.13	9.41	7.12	6.8
2	8.75	9.39	12.67	10.12	9.19	7.07	6.29
2.5	8.8	9.52	11.58	10.46	8.69	7.07	6.1
3	8.84	9.58	10.17	11.43	8.23	7.1	6.01
4	8.93	9.21	8.99	9.79	6.16	7.15	5.96
5	8.87	8.97	7.52	9.28	4.09	7.18	5.86
6	8.85	8.66	6.43	7.34	2.78	7.13	5.7
7	8.76	8.51	5.74	6.13	2.32	6.44	5.22
8	8.59	8.46	5.23	5.03	1.85	3.68	4.78
9	8.54	8.39	4.99	4.02	1.52	2.74	4.7

10	8.54	8.4	4.8	3.25	1.36	1.67	4.65
11	8.56	8.38	4.98	2.77	1.17	1.12	4.54
12	8.52	8.38	4.62	2.25	1	0.66	4.63
13	8.45	8.43	3.93	1.8	0.75	0.51	4.55
14	8.44	8.41	3.37	1.52	0.05	0.36	4.41

Table 1.3. Dam (Lacustrine) Temperature (°C) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	19.94	22.96	25.51	30.74	26.8	24.6	20.69
0.5	19.95	21.92	25.54	30.7	26.4	24.64	20.69
1	18.23	21.63	25.37	30.2	26	24.66	20.7
1.5	17.5	20.99	24.36	29.9	25.95	24.67	20.47
2	17.2	21.21	22.89	29.84	25.86	24.67	20.35
2.5	17.07	18.34	21.68	27.85	25.82	24.67	20.29
3	16.6	17.32	21.33	25.93	25.4	24.67	20.21
4	15.86	16.5	20.79	25.14	24.8	24.67	20.13
5	15.34	15.83	20.49	24.4	24.2	24.67	19.87
6	14.73	15.65	20.24	23.8	23.9	24.65	19.7
7	14.23	15.41	19.91	23.34	23.7	24.4	19.27
8	14	15.28	19.74	22.67	23.5	24.25	19.1
9	13.76	15.16	19.58	22.37	23.3	24.13	19.03
10	13.61	15.05	19.4	22.11	23.2	24.06	19.01
11	13.4	14.9	18.97	21.7	23.04	23.9	18.9
12	13.18	14.81	18.64	21.1	22.7	23.8	18.9
13	13.01	14.71	18.34	20.9	22.4	23.8	18.96
14	12.9	14.58	18.27	20.49	22.1	23.74	18.9

Table 1.4. Dam (Lacustrine) Chlorophyll *a* (ppb) concentrations over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	4.1	3	1.9	2.1	3.6	14	22.4
0.5	4.9	3.1	2.1	2.1	9.7	17.3	20.9
1	3.3	3.5	2.4	2.4	10.8	19.9	16.3
1.5	3.3	3.6	2.7	15.5	15.6	14.6	12.8
2	3.2	3.5	4.8	16.4	18.9	16.3	10.4
2.5	2.4	3.9	5.6	24.6	24.8	17.9	8.6
3	1.9	4.9	4.8	25.6	29.9	19.2	8.3
4	1.7	3.1	3.4	28.2	16	20.2	6.2
5	1.8	2.7	2.9	21.8	8.8	24.5	11.2
6	1.7	2.4	2.5	15.6	5.8	20	11.7
7	1.5	2.2	2.3	11.2	4	11.6	11.6
8	1.5	2.1	2.1	9.7	3	7.5	11.5
9	1.7	2	2.3	8.3	3.1	3.9	11.4

10	1.4	2	2.1	9.2	2.5	3.6	11.5
11	1.3	1.7	1.6	7.7	2	1.3	11.4
12	1.3	1.7	1.6	7.5	1.7	1	11.5
13	1.4	1.9	1.7	7.3	1.8	0.8	11.8
14	1.4	1.7	1.7	7.4	2.3	0.9	12

Table 1.5. Dam (Lacustrine) pH measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	7.76	7	8.35	7.96	7.75	7.48	7.13
0.5	7.79	7.05	8.49	7.99	7.77	7.49	7.13
1	7.83	7.08	8.54	8.02	7.78	7.5	7.13
1.5	7.83	7.12	8.62	8.04	7.77	7.5	7.12
2	7.82	7.16	8.66	8.07	7.74	7.51	7.12
2.5	7.79	7.2	8.49	8.09	7.7	7.51	7.12
3	7.78	7.22	8.31	8.03	7.67	7.52	7.12
4	7.77	7.22	8.2	7.91	7.61	7.53	7.11
5	7.77	7.22	8.05	7.87	7.57	7.53	7.11
6	7.75	7.21	7.98	7.81	7.53	7.53	7.13
7	7.74	7.21	7.91	7.78	7.49	7.51	7.12
8	7.72	7.21	7.83	7.75	7.46	7.47	7.11
9	7.7	7.2	7.81	7.72	7.43	7.44	7.11
10	7.69	7.2	7.74	7.69	7.41	7.41	7.1
11	7.68	7.2	7.83	7.67	7.39	7.37	7.08
12	7.67	7.2	7.78	7.65	7.37	7.34	7.08
13	7.65	7.2	7.72	7.62	7.35	7.32	7.07
14	7.64	7.2	7.66	7.61	7.34	7.29	7.06

Table 1.6. Dam (Lacustrine) ORP (mV) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	45	10	-34	98	172	323	372
0.5	44	12	-32	96	167	320	371
1	50	12	-31	95	171	319	374
1.5	56	13	-31	97	174	319	376
2	59	16	-23	97	183	318	376
2.5	61	19	1	104	187	317	376
3	63	26	11	119	198	316	376
4	66	33	23	136	207	315	377
5	69	37	28	144	214	315	377
6	73	39	33	153	218	317	378
7	76	42	37	158	221	323	379
8	78	44	41	163	223	327	380
9	79	45	43	166	225	330	380
10	79	46	45	170	225	331	381

11	80	47	41	172	226	333	381
12	82	48	45	175	228	334	381
13	83	48	49	178	229	334	381
14	83	49	52	179	230	332	381

Table 1.7. Dam (lacustrine) Turbidity (NTU) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	2.1	1.5	1.9	0	0	0	12.5
0.5	2.8	2.7	2.2	0	0	0	12.6
1	24.7	11.5	2.1	6.4	0	0	13.1
1.5	30.1	20.5	23.7	15.6	1.4	0	18.1
2	32.4	31	33.2	17.2	2.9	0	21.8
2.5	32.9	38.6	38	34.7	3.5	0	24.8
3	33.7	40	36.7	37.9	6.6	0	26.3
4	36	41.9	34	39	12.4	0	27.8
5	37.3	41.3	34.1	37.7	17.7	0	30.5
6	38.1	40.8	34.5	38.3	19.6	0	35.9
7	38.5	40.6	36.6	37.2	20.4	0	43.8
8	40	39.7	33.5	36.9	19.8	0	47.4
9	38.4	38.4	34.9	37.4	20.7	0	49.8
10	36.9	36.5	34.9	37.5	19.7	1.8	50.8
11	36.6	36.4	47.8	38	20.1	3.5	51.2
12	37.2	35.7	47.5	38.5	20.4	5	51.6
13	36.1	34.9	46.3	38.2	22.5	5.7	52.8
14	35.2	35.7	44.7	39.4	26.5	6	53.5

Table 1.12. Mile Marker 6 (Transition) Conductivity (µs/cm) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	0.185	0.166	0.144	0.147	0.153	0.157	0.158
0.5	0.185	0.165	0.145	0.147	0.153	0.158	0.157
1	0.183	0.165	0.145	0.146	0.153	0.158	0.157
1.5	0.183	0.166	0.147	0.153	0.152	0.157	0.157
2	0.185	0.166	0.148	0.154	0.155	0.158	0.156
2.5	0.185	0.166	0.149	0.155	0.156	0.158	0.156
3	0.185	0.167	0.148	0.155	0.157	0.158	0.155
4	0.185	0.163	0.15	0.158	0.158	0.157	0.154
5	0.187	0.163	0.149	0.158	0.157	0.156	0.152
6	0.189	0.169	0.152	0.16	0.157	0.156	0.15
7	0.19	0.167	0.153	0.16	0.158	0.158	0.15
8	0.19	0.168	0.154	0.162	0.16	0.159	0.15

9	0.19	0.168	0.155	0.162	0.16	0.149
10		0.167	0.156	0.162	0.163	0.15

Table 1.13. Mile Marker 6 (Transition) Dissolved Oxygen (mg/L) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	7.69	8.11	11.18	10.32	9.36	6.22	4.98
0.5	7.71	8.44	11.27	10.47	9.44	6.19	5.01
1	7.85	8.45	11.26	10.73	9.73	6.18	4.99
1.5	7.94	8.3	11.36	10.94	9.88	6.16	4.96
2	8.05	8.23	11.56	10.5	9.35	6.13	4.92
2.5	8.14	8.13	11.54	9.87	8.09	6.08	4.87
3	8.25	8.07	10.6	9.39	7.58	6.09	4.78
4	8.3	8.15	9.76	9.1	6.9	6.1	4.7
5	8.3	8.06	9.11	7.89	6.24	6.11	4.59
6	8.33	7.98	7.6	7.05	5.16	6.1	4.34
7	8.26	8.05	7.08	6.53	4.22	6.02	4.12
8	8.2	7.98	6.9	5.55	3.67	5.45	3.97
9	8.01	7.98	6.3	4.7	3.27		3.91
10		7.97	5.8	4.07	3.05		3.87

Table 1.14. Mile Marker 6 (Transition) Temperature (°C) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	18.2	20.6	25.2	30.13	28.23	24.46	19.9
0.5	18.08	18.93	25.26	29.14	27.8	24.46	19.89
1	18.04	18.12	25.2	28.39	27.4	24.47	19.86
1.5	18.05	17.5	24.4	26.9	27.3	24.46	19.83
2	18.04	17.15	23.7	26.25	26.79	24.46	19.8
2.5	18.04	16.83	22.8	25.8	26.5	24.46	19.79
3	18.02	16.69	22.58	25.4	26	24.45	19.76
4	17.45	16.27	21.7	24.37	25.4	24.45	19.73
5	15.65	15.87	20.46	23.63	24.3	24.45	19.61
6	14.98	15.69	20.1	23.16	23.7	24.44	19.48
7	14.74	15.44	19.94	23	23.2	24.43	19.4
8	14.37	15.19	19.4	21.9	23.01	24	19.39
9	14.34	15.04	19.1	21.75	22.9		19.39
10		15	18.8	21.68	22.8		19.39

Table 1.15. Mile Marker 6 (Transition) Chlorophyll *a* (ppb) concentrations over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	3.1	3.6	2.7	13.8	1.5	8.3	2.5

0.5	3.3	3.5	2.8	16.7	3	6.7	3.9
1	3.6	4.1	2.7	19.4	9.9	10.7	3.2
1.5	3.3	4.5	3.4	23.9	16.6	13	3.4
2	3.2	3	4.2	22.4	19.5	14.1	3.7
2.5	3.3	2.7	4.2	20.7	15.7	13.3	3.8
3	2.4	3.2	3.6	19.8	13.1	13.6	3
4	2.2	2.8	2.9	14.4	11.3	13.9	3.5
5	2.4	2.8	2.3	13.6	12.8	20.8	8.1
6	2.4	2.6	2.2	11.5	8.6	20.4	9.1
7	2.4	2.6	2	11.7	7.8	15.7	9.7
8	2.6	2.6	2	12.1	6.5	13.1	9.4
9		2.5	1.9	11.4	6.4	-5.6	9.8
10		2.7	1.8	11.6	6.7	-5.6	9.7

Table 1.16. Mile Marker 6 (Transition) pH measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	7.66	7.32	7.78	7.96	7.72	7.44	7.09
0.5	7.66	7.35	7.87	8.01	7.78	7.44	7.09
1	7.67	7.37	7.93	8.05	7.82	7.44	7.09
1.5	7.67	7.37	7.99	8.03	7.84	7.44	7.09
2	7.67	7.37	8.03	7.99	7.79	7.44	7.09
2.5	7.67	7.36	8.02	7.93	7.7	7.44	7.08
3	7.67	7.36	7.97	7.88	7.67	7.44	7.08
4	7.67	7.36	7.94	7.85	7.6	7.44	7.08
5	7.67	7.36	7.91	7.8	7.6	7.43	7.08
6	7.66	7.35	7.87	7.75	7.57	7.44	7.08
7	7.64	7.35	7.8	7.72	7.54	7.43	7.07
8	7.62	7.34	7.76	7.68	7.5	7.41	7.07
9	7.61	7.34	7.73	7.65	7.47		7.06
10		7.33	7.7	7.62	7.43		7.06

Table 1.17. Mile Marker 6 (Transition) ORP (mV) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	10	8	253	-55	8	134	169
0.5	12	15	250	-54	7	135	170
1	14	21	250	-52	9	136	170
1.5	14	27	250	-41	12	137	171
2	16	30	252	-25	37	138	172
2.5	17	33	261	-16	43	139	173
3	19	35	268	-9	49	140	174
4	25	37	274	2	55	141	175
5	32	39	280	10	61	141	176

6	36	41	283	15	66	142	177
7	38	42	286	19	70	145	178
8	40	44	288	25	73	141	179
9	45	44	290	28	76		179
10		46	290	16	77		

Table 1.18. Mile Marker 6 (Transition) Turbidity (NTU) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	5.3	20.5	8.3	9.5	0	0	19.3
0.5	5.1	47.4	7.5	15	0	0	18
1	4.8	53.6	6.8	29.6	0	0	18.8
1.5	5.2	55.1	14.2	34.6	9.2	0	20.8
2	4.3	55.1	28.6	39.3	18	0	22.9
2.5	4.5	56.4	37	40.9	24.6	0.8	24.7
3	4.4	57.3	41.7	41.8	29.1	1.6	25.9
4	14.4	58.1	46	42.8	32.2	2.3	27.5
5	35.3	59.6	52.1	45.8	36	2.2	30
6	41.7	60.7	54.9	47.9	40	3.2	36
7	46.7	62.7	53.6	48.5	41	5	41
8	52.9	63.7	53.9	59.7	44.8	13.1	44.8
9	bottom	63.9	57	67.8	45		45.4
10	75	77.1	56.5	67.8	46.8		45.4

Table 1.22. Toler Bridge (Riverine) Conductivity (µs/cm) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	0.178	0.126	0.146	0.16	0.097	0.162	0.165
0.5	0.176	0.147	0.148	0.162	0.133	0.162	0.165
1	0.177	0.169	0.148	0.163	0.137	0.161	0.165
1.5	0.177	0.179	0.147	0.161	0.14	0.162	0.163
2	0.177	0.176	0.147	0.163	0.142	0.162	0.165
2.5	0.175	0.178	0.148	0.163	0.142	0.163	0.164
3	0.175	0.181	0.147	0.163	0.151	0.163	0.164
4	0.176	0.188	0.148	0.163	0.154	0.161	0.165
5	0.175	0.195	0.149		0.153	0.162	0.164

Table 1.23. Toler Bridge (Riverine) Dissolved Oxygen (mg/L) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	7.16	7.13	9.5	9.28	7.16	4.7	5.14
0.5	7.2	7.39	9.3	8.85	6.9	4.69	5.14
1	7.3	7.61	9.15	7.61	6.8	4.69	5.11
1.5	7.41	7.64	9.02	7.11	6.71	4.67	5.09

2	7.46	7.67	8.93	6.86	6.73	4.68	5.06
2.5	7.54	7.75	8.9	6.81	6.67	4.67	5.04
3	7.63	7.81	8.86	6.76	6.55	4.61	5.05
4	7.71	7.92	8.72	6.73	6.36	4.6	5.01
5	7.77	7.98	8.75		6.2	4.62	5.01

Table 1.24. Toler Bridge (Riverine) Temperature (°C) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	15.03	17.83	22.16	21.35	27.03	22.24	20.11
0.5	15.01	16.66	22.3	21.33	26	22.24	20.13
1	14.96	15.48	22.2	21.29	25.8	22.24	20.1
1.5	14.95	14.94	22.1	21.29	25.7	22.24	20.1
2	14.95	15.01	22.1	21.29	25.5	22.24	20.1
2.5	14.95	14.96	22.1	21.31	25.4	22.22	20.1
3	14.9	14.8	22	21.31	25.2	22.21	20.1
4	14.9	14.41	22	21.3	24.9	22.21	20.1
5	14.9	14.06	22		24.9	22.2	20.09

Table 1.25. Toler Bridge (Riverine) Chlorophyll *a* (ppb) concentrations over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	1.7	2.3	2.3	6.2	3.9	4.2	4.5
0.5	1.9	2.2	2.7	6.2	4.2	4	6.1
1	1.8	2.3	2.8	6.4	5	3.7	6.1
1.5	2.2	2.1	2.6		6.8	4.3	6.7
2	2	2.1	2.6	6.9	6.7	5.5	6.5
2.5	1.9	2	2.6		7.7	5.3	6.6
3	2	2	3		7.2	4.4	7.8
4	1.9	2.1	3.2		7.6	4.8	7.3
5	2	1.9	3.2		8.8	4.2	7.8

Table 1.26. Toler Bridge (Riverine) pH measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	7.62	7.34	7.66	7.69	7.5	7.37	7.13
0.5	7.61	7.32	7.65	7.65	7.42	7.37	7.14
1	7.6	7.31	7.65	7.63	7.4	7.36	7.1
1.5	7.59	7.32	7.63	7.61	7.38	7.36	7.13
2	7.59	7.31	7.61	7.6	7.38	7.35	7.12
2.5	7.58	7.31	7.61	7.59	7.37	7.34	7.12
3	7.57	7.31	7.59	7.57	7.36	7.34	7.12
4	7.56	7.31	7.58	7.56	7.35	7.33	7.11
5	7.55	7.3	7.57		7.34	7.32	7.11

Table 1.27. Toler Bridge (Riverine) ORP (mV) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	35	54	119	-29	74	108	98
0.5	36	57	121	-21	79	109	99
1	37	59	124	-19	80	109	100
1.5	38	59	126	-18	80	110	102
2	39	60	129	-17	81	111	103
2.5	39	60	130	-15	82	112	104
3	40	60	132	-14	82	113	105
4	40	61	133	-13	83	113	106
5	41	61	134		84	114	107

Table 1.28. Toler Bridge (Riverine) Turbidity (NTU) measures over study period (2016)

Depth:	28-Apr	27-May	30-Jun	28-Jul	29-Aug	26-Sep	19-Oct
0	43.1	46.4	11.9	46.8	15.4	3.8	10.7
0.5	42.9	40.2	12.2	47.5	28.5	3.6	10.4
1	41.8	47	12.4	46.8	30.3	4.4	11.1
1.5	40.1	51.2	12.9	46.6	28.5	5	11.2
2	38	50.7	11.6	45.2	27.9	6	12.1
2.5	36.4	49.1	11.5	43.7	26.4	7.1	12.4
3	34.1	48.2	11.4	43	26.9	8.5	12
4	30.7	47	12.9	41.9	27.1	9.3	11.7
5	28.5	46.1	13		26.6	10.1	12.2