Lac La Biche County
welcoming by nature.

2019
Beaver Lake Water Quality Report
Lac La Biche County, Alberta

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Executive Summary

Beaver lake is a large and attractive recreational lake located in Lac La Biche County, Alberta ("County") and is popular for a variety of recreational activities. However, there is a concern that declining water quality in the lake is limiting the opportunities of recreational activities like swimming, boating and fishing.

The County follows a regular program to monitor water quality of lakes located within its jurisdiction. The water sampling events were conducted during the early spring and summer of 2019. The data collected includes water temperature, pH, specific conductivity, and dissolved oxygen which was collected in-situ through a multi-probe and Kemmerer sampling device. Analytical data of nitrogenous compounds, heavy metals, and other inorganic parameters was provided from ALS laboratory. Water samples for microbial parameters were analyzed by PROVLAB of Alberta Health Services.

Collected water samples were analyzed by ALS laboratory. The laboratory results obtained were compared to the CCME's Canadian Environmental Quality Guidelines for Protection of Aquatic Life and Protection of Agricultural Water, and Alberta Environment and Parks' Environmental Quality Guidelines for Alberta Surface Waters 2018.

Trophic State Index (TSI) is a classification system designed to rate lakes based on the amount of biological activity they sustain. The concentrations of nutrients (nitrogen and phosphorous) are the primary determinants of TSI. Increased concentrations of nutrients tend to result in increased plant growth, followed by an increase in subsequent trophic level. Nurnberg (1996) used parameters including Secchi depth, chlorophyll, total nitrogen and total phosphorus concentrations in lake waters to determine the trophic state of the lakes, which is provided as Table 1 in Appendix A. TSI is a useful tool for evaluation and management of lake health and setting objectives including sport and recreational activities related to the lake. Trophic classification of Beaver Lake based on Secchi depth and nutrients is presented in Table 2 in Appendix A.

For the purpose of this report, the parameters used to determine the trophic state will only include Secchi depth, total nitrogen and total phosphorus. Chlorophyll will not be used to determine the trophic state. Chlorophyll is a green pigment present in all green plants and is responsible for the absorption of light to provide energy for photosynthesis. It is associated with algae growth in a waterbody and affects the trophic status of a lake. Chlorophyll concentration is measured as part of the County's monitoring program. However, the measurement can be an underestimate of algae biomass when blue-green algae are present. It is also difficult to have consistent measurements of Chlorophyll as there can be large variances in concentrations due to anomalies such as temperature and weather conditions. Therefore, it is difficult to report Chlorophyll concentrations and make recommendations based on the results. Based on this information, Chlorophyll is not reported in this document.

There are four classes of trophic states which include: Oligotrophic which would be the highest quality of water with low productivity, nutrients and algae; Mesotrophic which is fair quality water with some productivity, nutrients and algae; Eutrophic which is relatively poor quality water with high productivity, nutrients and algae; and Hypereutrophic which is the poorest quality water with excessive productivity, nutrients, and algae.

Beaver Lake would be considered Eutrophic based on the average of the three water parameters Secchi depth, total nitrogen and total phosphorus. The trophic status would be Eutrophic based on Secchi depth, Hypereutrophic based on total nitrogen, and Eutrophic based on total phosphorus.

Results and Discussion

In 2019, Secchi depths in Beaver Lake were measured on March 13, July 23, August 7, and August 20, 2019. The average seasonal Secchi depth was observed to be 2.4 m, which is slightly higher with historical results. The low average Secchi depth means that Beaver lake water has poor transparency due to suspended materials. Based on the Secchi depths and in accordance with the classification provided in Table 1 (Appendix A), Beaver Lake is classified as Eutrophic (high productivity, nutrients, and algae growth).

Sampling events in 2019 showed an average water temperature of 14.8 ^{O}C. Uniform temperature profiles were observed during the summer as there were no significant variation in temperatures with depth. Based on the data provided, thermal stratification was not observed in any of the summer sampling events between July 23 and August 20, 2019.

Dissolved oxygen data collected in 2019 shows that the average dissolved oxygen levels ranged from 0.15 mg/L to 11.63 mg/L. These concentrations were higher in proximity to the regulatory criteria for dissolved oxygen in cold water lakes for early life stages (9.5 mg/L) and for all other life stages (6.5 mg/L).

In 2019, two types of lake water samples for analyses of nutrients were collected from Beaver Lake; composite samples and Kemmerer samples (obtained from different depths using a Kemmerer device). These samples were analyzed for total nitrogen and total phosphorous.

Total nitrogen concentrations in the composite samples collected from the lake in 2019 had an average of 1.57 mg/L of total nitrogen, while the Kemmerer samples collected had an average of 1.96 mg/L of total nitrogen; both of which exceeded the applicable regulatory guidelines and were consistent with historical results. Total nitrogen concentrations from both sampling methods classify Beaver Lake as Hypereutrophic (excessive productivity, nutrients, and algae growth).

Total phosphorus concentrations in the composite samples collected during the summer of 2019 had an average of 0.043 mg/L of total phosphorus, while the Kemmerer samples collected had an average of 0.042 mg/L; both of which do not exceed the applicable regulatory guidelines of 0.05 mg/L and were consistent with historical results. Total phosphorus concentrations from both sampling methods classify Beaver Lake as Eutrophic (high productivity, nutrients, and algae growth).

The average N:P ratios for composite and Kemmerer sampling events were 46:1 and 59:1 which is higher than the Redfield Ratio of 16:1. Therefore, the total phosphorus concentrations are considered low enough for phosphorus to be considered the main nutrient limiting growth in Beaver Lake.

Routine water chemistry showed that Beaver Lake has an average pH of 8.76 in 2019 which is consistent with historical results.

Concentrations of metals analyzed from the composite and Kemmerer samples taken at a depth of 6 m were generally below detection limits and/or below the applicable regulatory guidelines.

Beaver Lake would be considered Eutrophic based on the average of the three water parameters Secchi depth, total nitrogen and total phosphorus. The trophic status would be Eutrophic based on Secchi depth, Hypereutrophic based on total nitrogen, and Eutrophic based on total phosphorus.

Recommendations:

It is recommended that Lac La Biche County continues to monitor the water quality of Beaver Lake on a regular basis. Continuous monitoring will help the County to determine how the lake management strategies and policies such as the Riparian Setback Matrix Model are impacting the lake water quality, and what the net effect on human and environmental health is.

Monitoring and sampling should be conducted under a strategic plan and in a uniform manner to ensure that results produced are meaningful and are useful for establishing a correlation with the past results. This may include sampling at same period of the year each time, recording the same parameters critical to lake health, obtaining samples from the same depths, and implementing a quality assurance program for reliability of analytical results.

Nutrient loading is the main source of eutrophication in Beaver Lake which is degrading the water quality; leading to algae growth, foul smells and a reduction in water recreation. Therefore, action must be taken to slow down the eutrophication process and improve water quality. Best management practices would include education of the public on appropriate land use including watershed protection and waste and recycling management; restoration and protection of riparian areas (water buffers); and strengthening laws and regulations governing land use such as municipal sewer hookups and protection of environmental reserves.

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Abbreviations/Acronyms Used

CCME: Canadian Council of Ministers of the Environment
County: Lac La Biche County
EQGASW-AGW: Environmental Quality Guidelines for Alberta Surface Waters 2018 for protection of Agricultural Water
EQGASW-FAL: Environmental Quality Guidelines for Alberta Surface Waters 2018 for protection of Fresh Water Aquatic Life
LLB Lake: Lac La Biche Lake
QA/QC: Quality Assurance and Quality Control
Total N: Total Nitrogen
Total P: Total Phosphorous
TSI: Trophic State Index

1. INTRODUCTION

Beaver lake is a large recreational lake popular for boating and fishing. It is located approximately 210 km northeast of the city of Edmonton. The closest population center is the hamlet of Lac La Biche which is located 5 km to the northwest of Beaver Lake. A location map of Beaver Lake is provided in Figure 1.

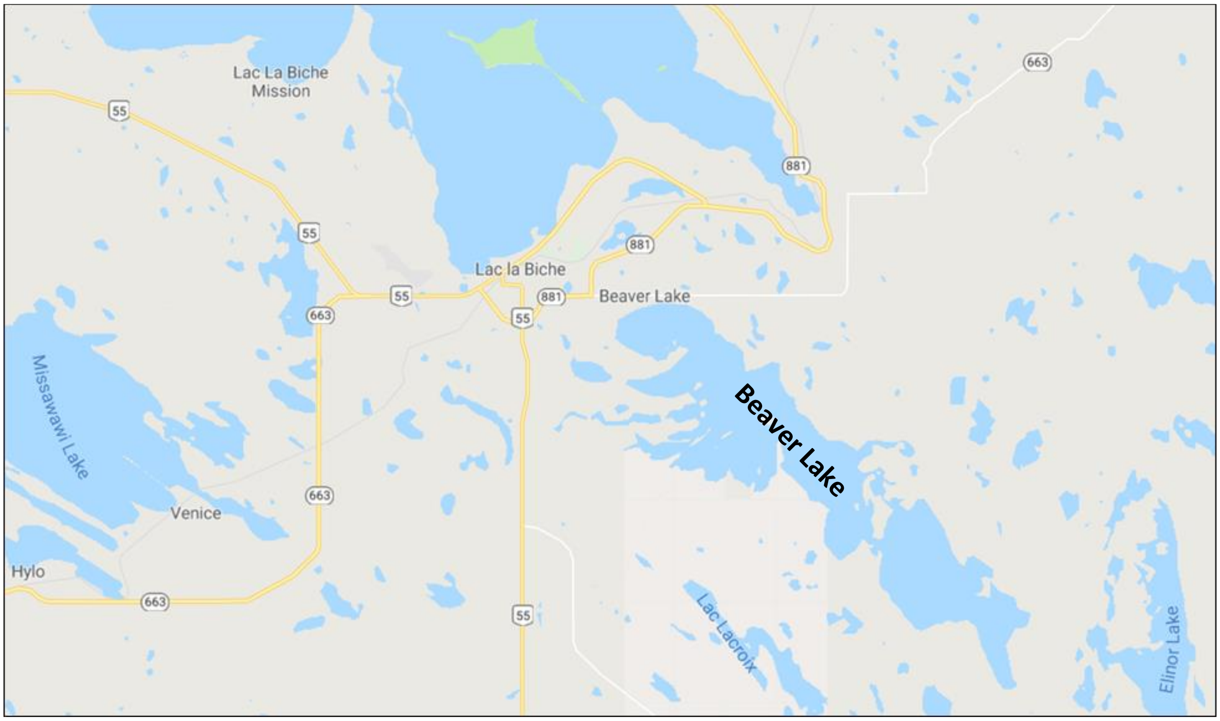

Figure 1: Location map of Beaver Lake

Beaver lake has an irregular shaped surface area of 33.1 Km^2 and is comprised of two distinct basins. The two basins are connected by a shallow and a narrow channel. The maximum depth of the lake is 15.2 m in the northwest basin and 10.7 m in the southeast basin. Beaver Lake is the headwater of the Beaver River and lies in the Beaver River Drainage Basin. The drainage basin for Beaver Lake is 290 km^2, which is roughly nine times the surface area of the lake itself. Beaver Lake receives water from two other lakes within the watershed; Elinor Lake which drains into the Southeast basin and Lac La Croix which drains into the Northwest Basin. In years of significantly high-water levels, Beaver Lake also receives water from Roseland and Normandeau Lakes. The lake's outlet creek, which is located on the west side of the north basin, flows into Outlet Lake, which further drains into the Beaver River and eventually into the Churchill River.

The main agricultural activities are livestock production, production of pasture and forage crops such as hay, oats and barley. A large number of natural gas and oil wells are found within the County.

The main sport fish species found in the lake include: Walleye (*Sander vitreus*), Yellow Perch (*Perca flavescens*), Northern Pike (*Esox lucius*) and Lake Whitefish (*Coregonus clupeaformis*).

2. WATER QUALITY SAMPLING PROGRAM

Lac La Biche County has sampled Beaver Lake from 2003 to 2005, 2010 to 2015, 2017, 2018 and most recently in 2019. Beaver Lake is sampled for various parameters using different techniques. Vertical profiles were taken using a multi-probe testing different depths (zones) of the lake for dissolved oxygen, pH, conductivity, and temperature. Composite samples are taken from 10 different locations throughout the lake, while Kemmerer sampling is used for discrete depth sampling; both the composite and Kemmerer samples are tested for nutrients such as, phosphorus, nitrogen, ammonia, nitrates, nitrites, and metals. Beaver Lake sampling program for 2019 was completed as follows:

a) Secchi Depths were measured on March 13, July 23, August 7 and August 20, 2019;
b) Composite samples from the Beaver Lake were collected on July 23, August 7 and August 20, 2019. Lake water samples were analyzed for nutrients, metals and basic water chemistry parameters by ALS laboratories;
c) Kemmerer water samples using the Kemmerer device were collected on March 13 and August 21, 2019 from depths of 3 m, 6 m, and 9 m; and were analyzed for nutrients, metals and basic water chemistry parameters by ALS laboratories;
d) Lake profiles were recorded to a maximum depth of 11.0 m using a multi-probe on March 13, July 23, August 7, and August 20, 2019;

2.1 Water Quality Parameters

Water samples collected for each of the sampling locations were analyzed for a variety of parameters used to characterize the chemical composition of the lake and further identify any potential concerns. The water quality parameters measured and analyzed during the 2019 program along with a brief description of each parameter and reason for monitoring are provided in the table below:

Parameters Affecting Lake Water Quality

Water Quality Parameter	Description and Reason for Measuring
Secchi Depth	Secchi depth is a measure of the transparency of water and trophic state of a lake. A Secchi disk is generally a disk of 20 cm diameter with alternating black and white quadrants. It is lowered into the lake water until it can no longer be seen. This depth of disappearance is called the Secchi depth. A low Secchi depth (<4m) is characteristic of a mesotrophic to hypereutrophic lake with turbid water. Whereas a high Secchi depth (>4m) is characteristic of an oligotrophic lake with clear water.
Dissolved Oxygen	Dissolved oxygen is required by aquatic plants and animals for respiration. Survival of aquatic life such as fish, generally depends on an adequate amount of dissolved oxygen for respiration. As dissolved oxygen levels in the water drop below 5.0 mg/L, aquatic life is subjected to stress. Oxygen levels that consistently remain below 1-2 mg/L can result in the loss of large populations of fish.
Temperature	Temperature of water affects different physical, biological and chemical characteristics of a lake and determines the behavior of many parameters responsible for water quality. The solubility of oxygen and other gases decrease as temperature increases. An increase in water temperature decreases the concentration of dissolved oxygen required for the survival of aquatic organisms.
Nutrients	Total nitrogen (N) and phosphorus (P) are principal nutrients in lake water and are representative of all forms of N and P present in the water. There are various sources of N and P both natural and anthropogenic. These nutrients are a major cause of eutrophication, decreasing dissolved oxygen concentrations and are detrimental to lake water quality.

Metals	Metals enter the lake waters through natural (geological) and anthropogenic point and non-point sources. Certain metals such as lead and mercury, are toxic to aquatic life and can bio-accumulate in the tissues and organs of aquatic organisms, becoming a part of the food chain. This may lead to loss of aquatic life and further affect human health.

3. REGULATORY FRAMEWORK

The protection of water quality in Canadian lakes is a federal, provincial and territorial responsibility. Therefore, lake waters in Alberta are regulated by federal and provincial guidelines and fall under the jurisdiction of Canadian Council of Ministers of the Environment (CCME), Alberta Environment and Parks (AEP), and Health Canada.

The regulatory criteria selection for lake waters in Alberta are subjected to CCME's Canadian Environmental Quality Guidelines (CEQG) and AEP's Environmental Quality Guidelines for Alberta Surface Waters 2018 (EQGASW). Protection of lake water is covered under CCME's CEQG and AEP's EQGASW chapters of water quality guidelines for Protection of Aquatic Life, Protection of Agricultural Water, and protection of Recreation and Aesthetics. In addition, Health Canada's Guidelines for Canadian Recreational Water Quality for protection of lake waters have also been considered.

The analytical and monitoring results obtained for this report were compared to the above-mentioned regulations and are hereinafter referred to as regulatory guidelines or regulatory criteria.

4. SAMPLING ANALYSIS AND MONITORING RESULTS

4.1 Secchi Depth

The Secchi disk is a common method used to measure water clarity. Water clarity of a lake can be influenced by the amount of suspended materials such as phytoplankton, zooplankton, pollen, sediments and dissolved compounds. The Secchi depth multiplied by 2 provides us with the euphotic depth of the lake. The euphotic depth is the maximum depth to which light can penetrate within a lake to facilitate growth.

In 2019, Secchi depths in Beaver Lake were measured on March 13, July 23, August 7, and August 20, 2019. The average seasonal Secchi depth was observed to be 2.4 m. A maximum Secchi depth of 4.1m was recorded on March 13, 2019 while a minimum Secchi depth of 1.3m was recorded on August 7, 2019. Overall, a decreasing temporal trend was observed in Secchi depth (Figure 2).

The low average Secchi depth of 2.4 m means that the lake water has poor transparency due to suspended materials. Based on the Secchi depths and in accordance with the classification provided in Table 1 (Appendix A), Beaver Lake is classified as Eutrophic (high productivity, nutrients, and algae growth).

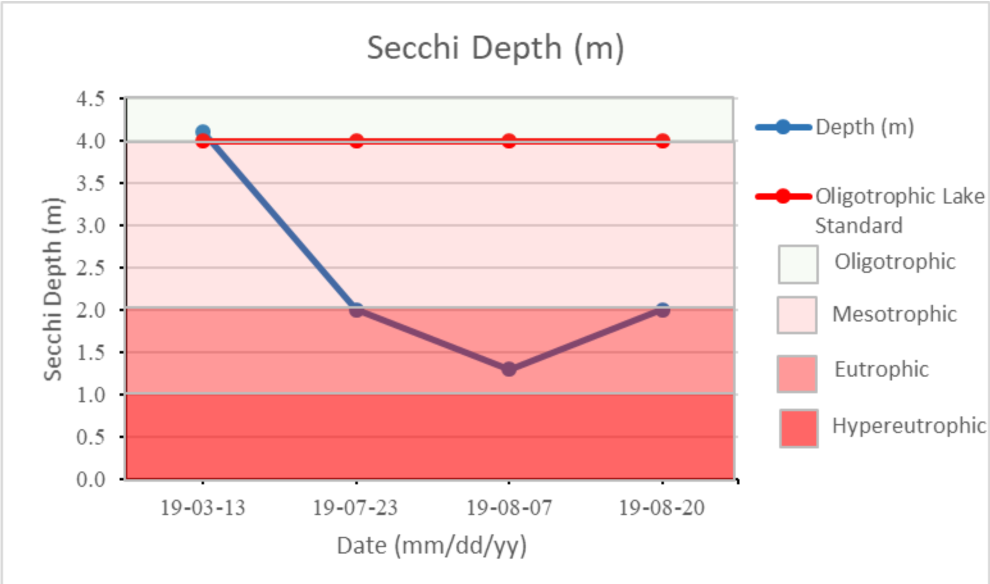

Figure 2: Secchi depths measured in Beaver Lake - 2019

4.2 Temperature

Water temperature in a lake determines the behavior of many parameters responsible for water quality. Thermal stratification occurs within a lake with a distinct difference in temperature between the surface water (epilimnion layer) and the deeper water (hypolimnion layer) separated by a thermocline. The thermocline is identified when the water changes by more than one degree Celsius per meter. Under winter conditions, ice covers the surface water and a thermocline is formed with the colder water at the surface and the warmer water at the bottom of the lake. Lakes without thermal stratification mix from top to bottom and this mixing allows oxygen to distribute throughout the water column preventing hypolimnetic anoxia (lack of oxygen). In the summer time, warmer surface water can facilitate cyanobacteria blooms at the lake surface (Wetzel, R. 2001).

The temperatures in Beaver Lake were recorded to a maximum depth of 11 m on March 13, July 23, August 7, and August 20, 2019. A minimum average temperature of 2.85 ˚C was observed on March 13, 2019 with a spatial increasing trend with depth, starting from 0.729 ˚C at 1 m and 3.831 ˚C at an 8 m depth.

Sampling events in 2019 showed an average water temperature of 14.8 ˚C. Uniform temperature profiles were observed during the summer as there were no significant variation in temperatures with depth. Based on the data provided, thermal stratification was not observed in any of the summer sampling events between March 13, July 23, August 7, and August 20, 2019. Results of temperatures observed at varying depths at the sampling dates are illustrated in Figure 3.

Similar trends in temperature profiles have been reported for Beaver Lake previously (ALMS 2010). Historical sampling also suggests that Beaver Lake is likely polymictic, indicating that the water from various depths of the lake mixes several times per year.

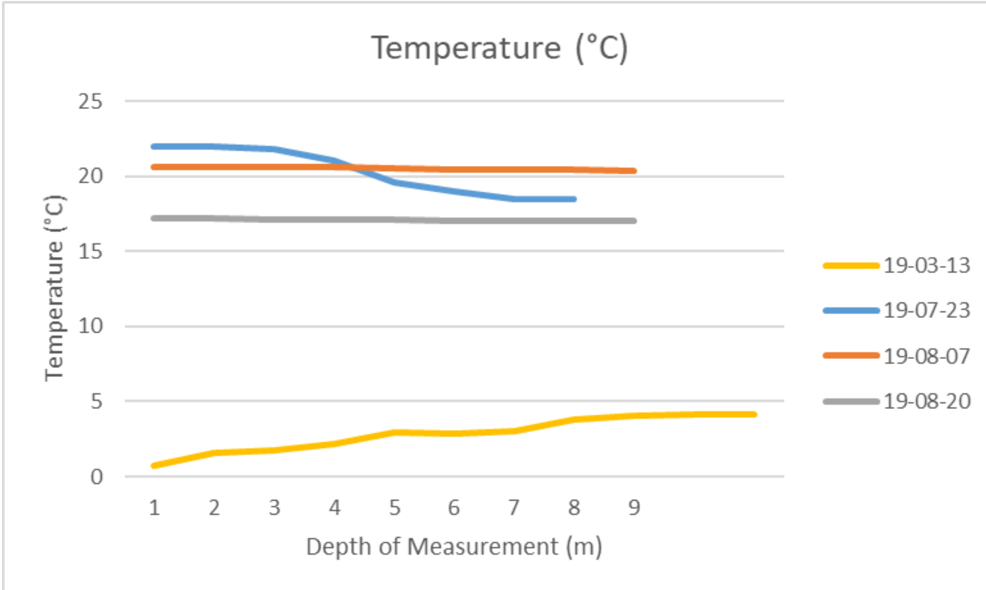

Figure 3: Temperature in Beaver Lake – 2019

4.3 Dissolved Oxygen

Dissolved oxygen is the amount of gaseous oxygen dissolved in the water and is necessary for respiration and survival of aquatic life (e.g. fish, invertebrates, bacteria, and underwater plants). Dissolved oxygen is also needed for the decomposition of organic matter in the lakes. Oxygen enters the lake water by direct absorption from the atmosphere through rapid movement of water or as a product of plant photosynthesis. Therefore, the epilimnion zone (shallow layer of water) is relatively richer in oxygen than the hypolimnion zone (deeper layer of water) which is low in oxygen due to consumption by respiration.

There are several conditions necessary for fish survival in a lake including adequate water temperatures and available dissolved oxygen for respiration. The regulatory guidelines for dissolved oxygen in cold water lakes are 9.5 mg/L for early life stages and 6.5 mg/L for all other life stages (CCME, 1999). If dissolved oxygen levels are too low, fish will move to other depths in the water column, often where temperatures are conducive to sustain aquatic life.

The amount of dissolved oxygen in lakes usually decreases under winter ice-cover primarily due to respiration by organisms (particularly bacteria) and decomposition of organic matter. In shallow lakes, oxygen depletion can proceed rapidly under ice during the winter. If dissolved oxygen drops below 3.0 mg/L during the winter, many fish and invertebrate species will not survive.

Dissolved oxygen levels in Beaver Lake were recorded to a maximum depth of 11.0 m using a multi-probe on March 13, July 23, August 7, and August 20, 2019. A maximum concentration of dissolved oxygen (11.63 mg/L) was observed on July 23, 2019 at a depth of 1 m depth. This concentration declined gradually to (1.25 mg/L) at a depth of 9 m.

A decrease in dissolved oxygen was noted in the late summer measurements with a decreasing gradual spatial trend with depth. The lowest level of dissolved oxygen was recorded on March 13, 2019 (0.15 mg/L) at 11 m.

Dissolved oxygen data collected in 2019 shows that average dissolved oxygen levels ranged from 0.15 mg/L to 11.63 mg/L. These concentrations were in proximity to the regulatory criteria for dissolved oxygen in cold water lakes for early life stages (9.5 mg/L) and for all other life stages (6.5 mg/L).

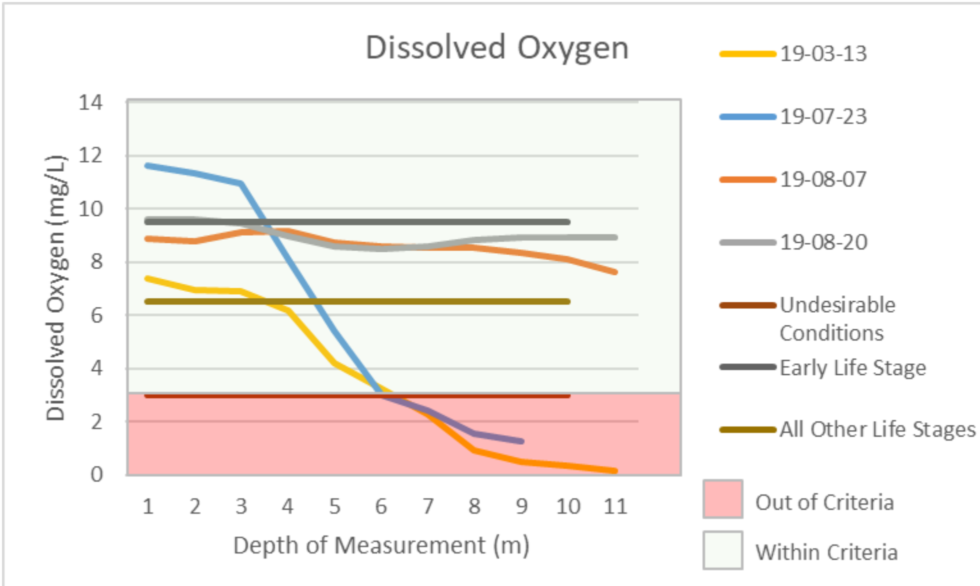

Figure 4: Dissolved oxygen in Beaver Lake – 2019

4.4 Nutrients

Excessive levels of nitrogen and phosphorus are found in many lakes across Alberta leading to excessive growth of algae and aquatic plants. Decay of aquatic vegetation causes oxygen depletion in the water column and contributes to eutrophication. Consequently, the decreased levels of oxygen can suffocate fish and other aquatic organisms. High nutrient conditions foster algal blooms and can result in the proliferation of toxin-producing blue-green algae (e.g. cyanobacteria). The input of nutrients into aquatic systems can occur naturally, but large amounts of nutrients typically originate from indirect, non-point anthropogenic sources, including improperly treated sewage, residential use of fertilizers and agricultural operations.

In 2019, two types of lake water samples for analyses of nutrients were collected from Beaver Lake; composite samples and Kemmerer samples (obtained from different depths using a Kemmerer device). These samples were analyzed for total nitrogen and total phosphorous.

Total Nitrogen

Total nitrogen is an essential nutrient for plants and animals; however, excessive amounts of nitrogen in lake water may lead to low levels of dissolved oxygen and negatively affect water quality and health of aquatic life within the lake. Nitrogen concentrations in the water are typically measured in three forms: ammonia, nitrates and nitrites. Total nitrogen is the sum of total Kjeldahl nitrogen (ammonia, organic and reduced nitrogen), nitrate and nitrite. Nitrogen levels in lakes are also affected by atmospheric deposition, which refers to nitrogen in the air being deposited into the water system. Nitrogen oxides (NOx) are added to atmosphere due to the burning of fossil fuels, so emissions from motor vehicles and industrial facilities can also affect nitrogen levels in aquatic environments.

Composite Samples

Composite lake water samples for analyses of total nitrogen were collected on July 23, August 7, and August 20, 2019. The total nitrogen concentrations ranged from 1.3 mg/L to 1.95 mg/L during 2019. The analytical results are displayed in Figure 6.

Nitrogen concentrations in the composite samples collected from the lake in 2019 had an average of 1.57 mg/L of total nitrogen which exceeded the applicable regulatory guidelines. The average total nitrogen indicates that Beaver Lake is Hypereutrophic (excessive productivity, nutrients, and algae growth) based on total nitrogen from composite samples.

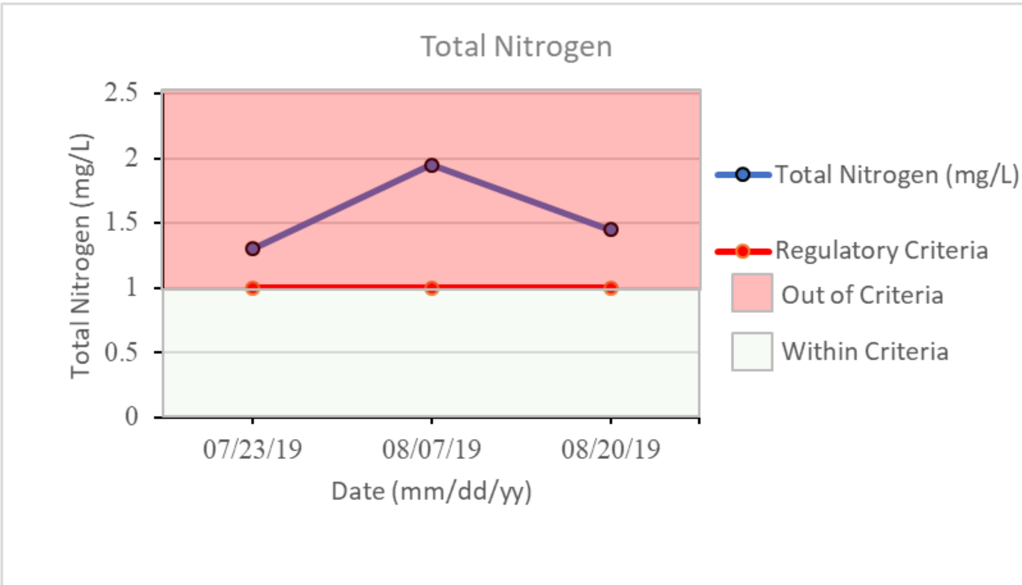

Figure 5: Total nitrogen from composite samples of Beaver Lake – 2019

Kemmerer Sampling

Kemmerer water samples are collected from different depths of the lake by using a Kemmerer device which makes it possible to obtain a sample of water from specific depths. Kemmerer samples were collected on March 13 and August 21, 2019, from 3 m, 6 m, and 9 m depths and were analyzed for total nitrogen by ALS laboratories. Results of total nitrogen in Kemmerer samples collected from Beaver Lake on two different dates are illustrated in Figure 6. On March 13, 2019 a total nitrogen concentration of 1.93 mg/L was recorded at a depth of 3 m, which increased to a concentration of 2.18 mg/L at a depth of 9 m. On August 21, 2019 a total nitrogen concentration of 1.87 mg/L was recorded at a depth of 3 m, which increased to a concentration of 2.05 mg/L at a depth of 9 m.

The concentrations of total nitrogen in samples collected during March 13 and August 20, 2019 sampling events exceeded the applicable regulatory guidelines. The results from the Kemmerer sampling resulted in the same trophic state classification as the composite samples which is Hypereutrophic (excessive productivity, nutrients, and algae growth) based on total nitrogen.

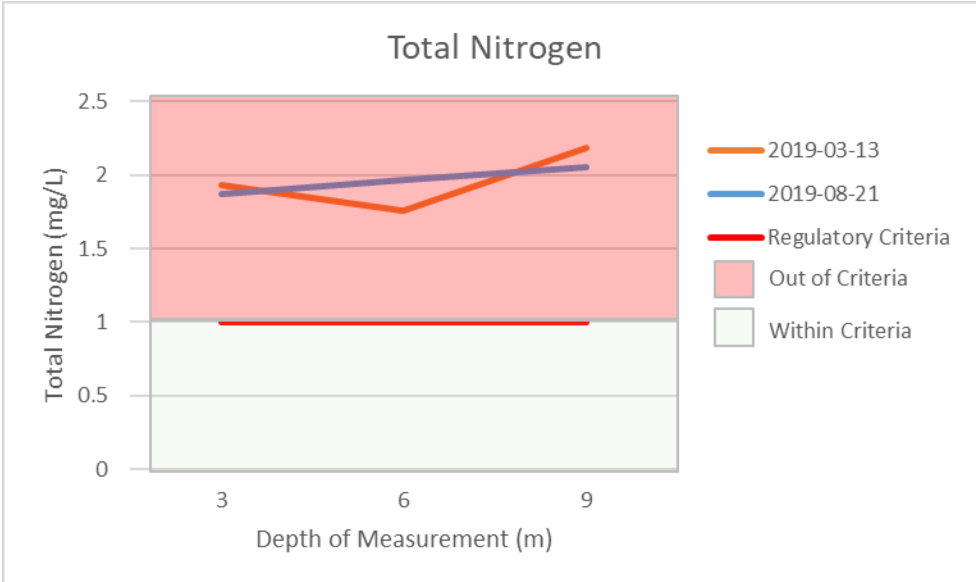

Figure 6: Total nitrogen from Kemmerer samples of Beaver Lake - 2019

Total Phosphorus

Increased phosphorus concentrations are the largest cause of degradation in water quality within lakes, causing 'dead zones', toxic algal blooms, a loss of biodiversity and increased health risks for plants, animals and humans that encounter polluted lake waters. Run-off from agriculture, human sewage and industrial practices results in increased phosphorus concentrations in lake water and lake bed sediments (Wetzel, 2001). Long-term monitoring activities following the control of phosphorus sources to lakes indicates that plants and animals do not recover from the effects of excessive phosphorous for several years.

Composite Sampling

Composite lake water samples for total phosphorus were collected on July 23, August 7, and August 20, 2019 from Beaver Lake. A minimum total phosphorus concentration of 0.031 mg/L was measured in a sample obtained on July 23, 2019 which increased over time to a maximum of 0.0.050 mg/L on August 20, 2019. The analytical results are illustrated below in Figure 7.

Total phosphorus concentrations in the samples collected during the summer of 2019 had an average of 0.043 mg/L of total phosphorus which does not exceed the applicable regulatory guidelines of 0.05 mg/L. This average total phosphorus concentration classifies Beaver Lake as Eutrophic (high productivity, nutrients, and algae growth) based on total phosphorus from composite samples.

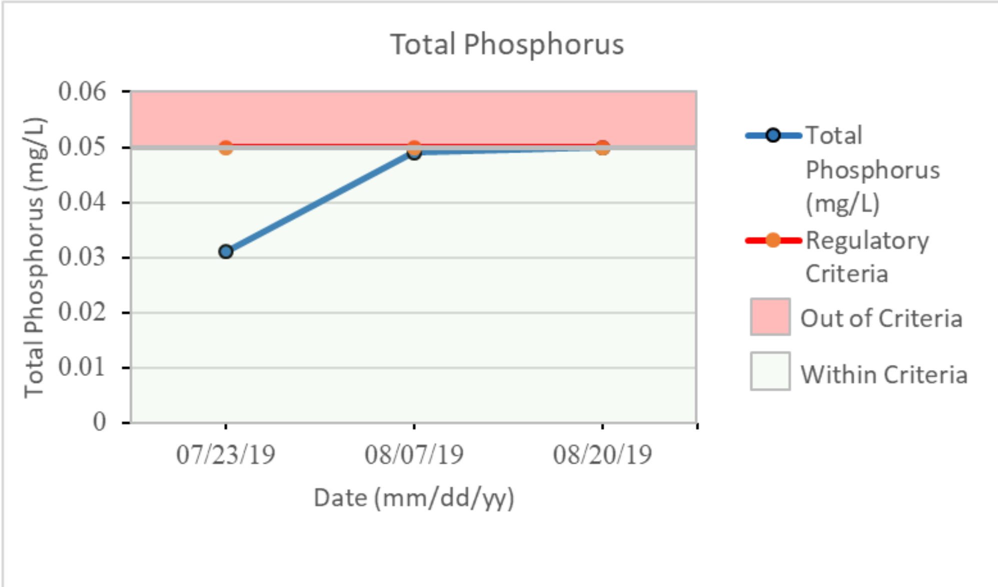

Figure 7: Total phosphorous from composite samples of Beaver Lake - 2019

Kemmerer Sampling

Kemmerer water samples using a Kemmerer sampling device were collected on March 13 and August 21, 2019 from depths of 3 m, 6 m, and 9 m. Both samples were analyzed for total phosphorous by ALS laboratories. Total phosphorus concentrations in lake water samples collected on March 13, 2019 (0.020 mg/L – 0.045 mg/L) were slightly lower in comparison to the samples collected on August 21, 2019 (0.045 mg/L – 0.048 mg/L). The laboratory results are presented below in Figure 8.

Total phosphorus concentrations from the Kemmerer sampling in 2019 did not exceed the regulatory criteria. The results from the Kemmerer sampling resulted in the same trophic state classification as the composite samples which is Eutrophic (high productivity, nutrients, and algae growth) based on total phosphorus.

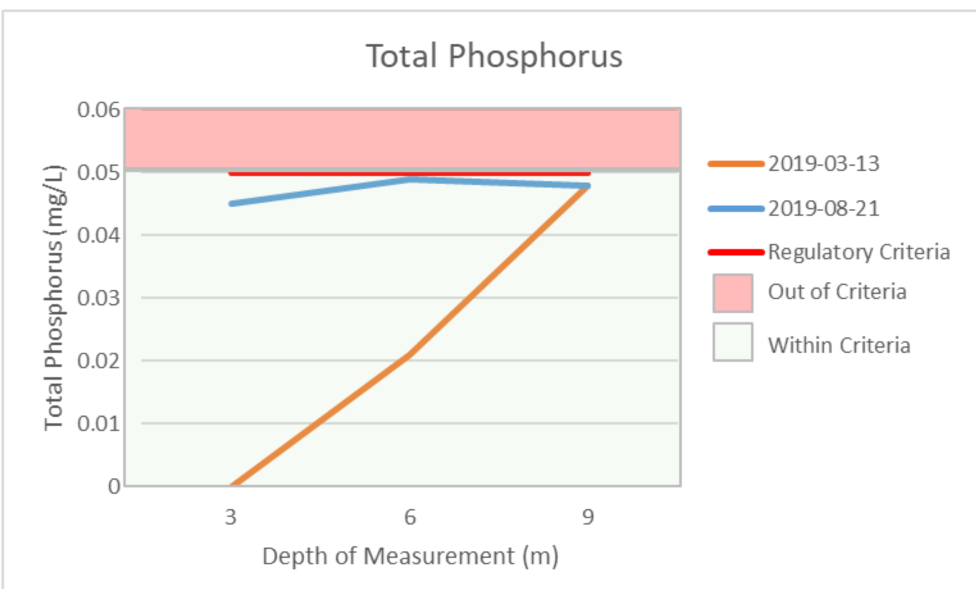

Figure 8: Total phosphorus from Kemmerer samples of Beaver Lake - 2019

N:P Ratio

The Redfield Ratio describes the optimal balance of total nitrogen to total phosphorous for aquatic plant growth, which is an optimal value of 16:1 (Teubner and Dokulil 2002). If the ratio is lower than 16:1, phosphorus is no longer considered a limiting nutrient and aquatic vegetation and cyanobacteria can use the dissolved and atmospheric nitrogen for growth by using the high amounts of phosphorus available in lake waters. If the ratio is higher than 16:1, it indicates that the phosphorus concentrations are occurring at levels much less than nitrogen and hence limit the growth within lakes.

The average N:P ratios for composite and Kemmerer sampling events in Beaver Lake were 46:1 and 59:1 respectively, which is higher than the Redfield Ratio of 16:1. Therefore, the total phosphorus concentrations are considered low enough for phosphorous to be considered the main nutrient limiting growth in the Beaver Lake.

4.5 Routine Water Chemistry

Results of routine water chemistry of composite and Kemmerer samples collected from Beaver Lake are presented in Table 4.

The average measured pH of 8.76 in 2019 was consistent with historical results. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals. The ability of a lake to neutralize these hydrogen ions is referred to as a buffering capacity. Any lake with a total alkalinity of more than 100 mg/L is considered to have high buffering capacity (Mitchell and Prepas 1990). The pH in Beaver Lake is likely buffered against change by its high alkalinity. The high alkalinity in Alberta lakes is derived from the rich calcareous glacial till over which the lakes have formed.

4.6 Metals

Metals enter the water naturally through the weathering of rocks and soil. These metals are generally non-toxic and in low concentrations. However, metals can also come from a wide variety of anthropogenic and non-point pollution sources including runoff from urban areas, wastewater discharge, improperly managed sewage treatment, industrial activities and agricultural runoff. The analytical results of total dissolved metals in the Kemmerer and composite water samples collected from Beaver Lake are presented in Table 5.

Concentrations of all metals analyzed from the composite and Kemmerer samples taken at a depth of 6 m were generally below detection limits and/or below the applicable regulatory guidelines.

5. HISTORICAL TREND ANALYSIS

The objective of the historical trend analysis is to provide an overview of water quality conditions in a lake with time and to evaluate the impact of watershed management practices on lake water quality.

Three parameters are significant in trend analyses for lake water quality: Secchi depth, total nitrogen and total phosphorus; all of which are also used for trophic classification of lakes.

5.1 Secchi Depth

Historical data indicates that the Secchi depth in Beaver Lake was always less than the standard Oligotrophic (low productivity, nutrients and algae growth) standard for Secchi depth (4.0 m) with the exception of 2010 when Secchi depth (4.2 m) was slightly higher than the standard (Figure 9). A temporal decreasing trend in Secchi depth was observed for Beaver Lake following 2012. The low average Secchi depth means that the lake water has poor transparency due to suspended materials. However, the Secchi depth readings may not provide an exact measure of the water transparency due to various errors such as time of the day, sun's glare on the water, and eyesight of the observer.

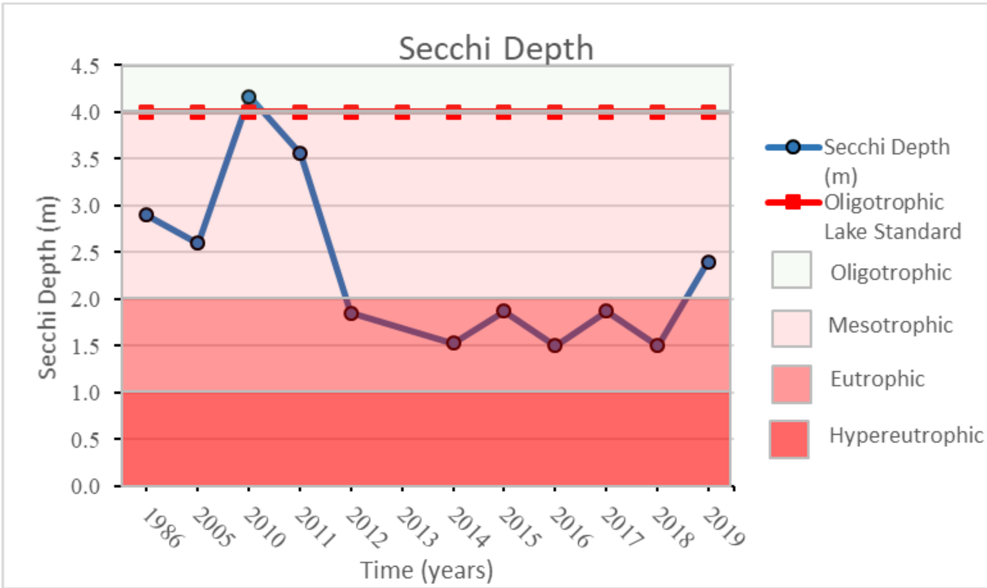

Figure 9: Historical trend for Secchi depth in Beaver Lake

5.2 Total Nitrogen

Historical data shows that total nitrogen concentrations in Beaver Lake were historically higher than the regulatory guideline of 1.0 mg/L. An increasing trend in total nitrogen was observed from 1986 to 2019 and a sharp increase was measured in 2013. Total nitrogen concentrations after 2014 were relatively stable with a small annual fluctuation (Figure 10). Total nitrogen concentrations have historically been classified as Hypereutrophic (excessive productivity, nutrients, and algae growth).

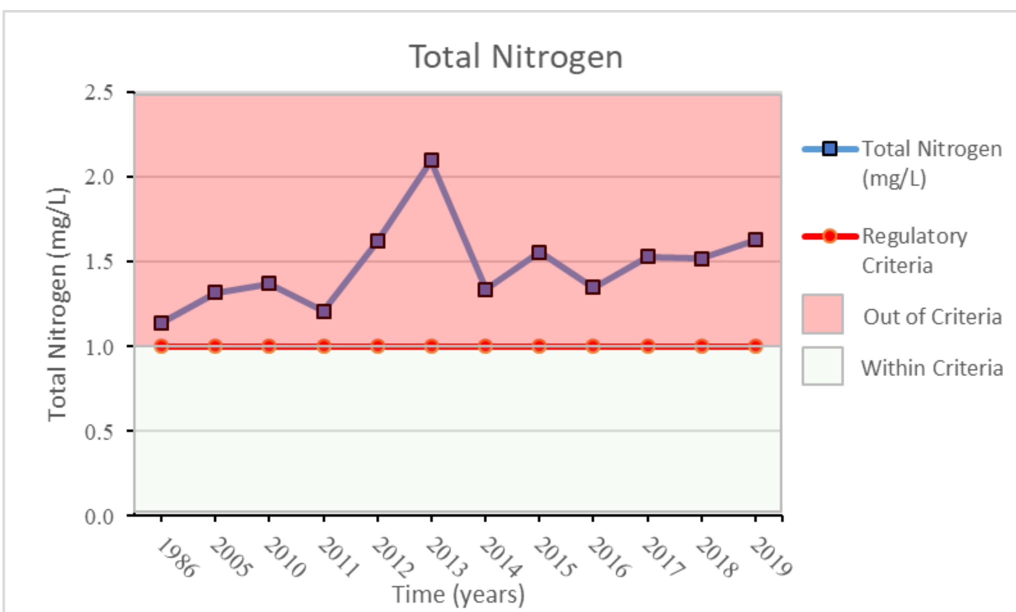

Figure 10: Historical trend for total nitrogen in Beaver Lake

5.3 Total Phosphorus

Historical data shows that total phosphorus concentrations in Beaver Lake were less than the regulatory guidelines (0.05 mg/L), with the exception of 2012 (0.07 mg/L). A temporal decreasing trend in total phosphorus concentrations was observed following 2012 and total phosphorus concentrations were below the applicable guideline (Figure 11). A continuous decrease in total phosphorus concentrations was noted from 2012 until 2017 at which time the total phosphorus concentration began increasing. . Total phosphorus concentrations have historically been classified as Eutrophic (high productivity, nutrients, and algae growth).

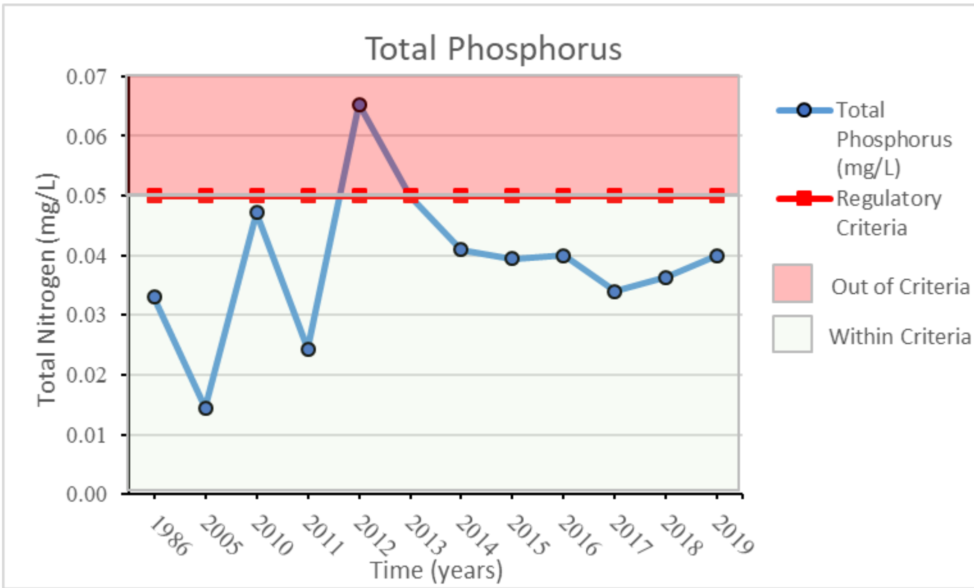

Figure 11: Historical trend for total phosphorus in Beaver Lake

6. DISCUSSION

Trophic State Index (TSI) is a classification system designed to rate lakes based on the amount of biological activity they sustain. The concentrations of nutrients (nitrogen and phosphorous) are the primary determinants of TSI. Increased concentrations of nutrients tend to result in increased plant growth, followed by an increase in subsequent trophic level. Nurnberg (1996) used parameters including Secchi depth, chlorophyll, total nitrogen and total phosphorus concentrations in lake waters to determine the trophic state of the lakes, which is provided as Table 1 in Appendix A. TSI is a useful tool for evaluation and management of lake health and setting objectives including sport and recreational activities related to the lake. Trophic classification of Beaver Lake based on Secchi depth and nutrients is presented in Table 2.

For the purpose of this report, the parameters used to determine the trophic state will only include Secchi depth, total nitrogen and total phosphorus. Chlorophyll will not be used to determine the trophic state. Chlorophyll is a green pigment present in all green plants and is responsible for the absorption of light to provide energy for photosynthesis. It is associated with algae growth in a waterbody and affects the trophic status of a lake. Chlorophyll concentration is measured as part of the County's monitoring program. However, the measurement can be an underestimate of algae biomass when blue-green algae are present. It is also difficult to have consistent measurements of Chlorophyll as there can be large variances in concentrations due to anomalies such as temperature and weather conditions such as precipitation and wind. Therefore, it is difficult to report Chlorophyll concentrations and make recommendations based on the results. Based on this information, Chlorophyll is not reported in this document.

There are four classes of trophic states which include: Oligotrophic which would be the highest quality of water with low productivity, nutrients and algae; Mesotrophic which is fair quality water with some productivity, nutrients and algae; Eutrophic which is relatively poor quality water with high productivity, nutrients and algae; and Hypereutrophic which is the poorest quality water with excessive productivity, nutrients, and algae.

Beaver Lake would be considered Eutrophic based on the average of the three water parameters Secchi depth, total nitrogen and total phosphorus. The trophic status would be Eutrophic based on Secchi depth, Hypereutrophic based on total nitrogen, and Eutrophic based on total phosphorus.

7. RECOMMENDATIONS

It is recommended that Lac La Biche County continues to monitor the water quality of Beaver Lake on a regular basis. Continuous monitoring will help the County to determine how the lake management strategies and policies such as the Riparian Setback Matrix Model are impacting the lake water quality, and what the net effect is on human and environmental health.

A strategic monitoring plan should be developed by the County to ensure that sampling is carried out in a consistent manner for all lakes that are sampled each year. This would include sampling each lake the same number of times per year with a uniform sampling procedure; and implementing a quality assurance program for both the multi-probe and water chemistry analysis to ensure that the data used to evaluate the lake water quality is accurate and reliable. By maintaining consistency in sampling programs, the County will be able to monitor changes occurring in lake water quality, and hence assist the County in developing policies and management practices to ensure the optimum health of the lake.

Nutrient loading is the main source of eutrophication in Beaver Lake which is degrading the water quality; leading to algae growth, foul smells and a reduction in water recreation. Therefore, action must be taken to slow down the eutrophication process and improve water quality. Best management practices would include education of the public on appropriate land use including watershed protection and waste management; restoration and protection of riparian areas (water buffers); and strengthening laws and regulations governing land use such as municipal sewer hookups and protection of environmental reserves.

8. REFERENCES

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APPENDIX A

Table 1: Trophic status classification based on lake water parameters (Nurnberg 1996)

Trophic State	**Total Phosphorus** (mg/L)	**Total Nitrogen** (mg/L)	**Secchi Depth** (m)
Oligotrophic	<0.01	<0.35	>4
Mesotrophic	0.01 – 0.03	0.35 – 0.65	4 - 2
Eutrophic	0.03 – 0.10	0.65 – 1.20	2 - 1
Hypereutrophic	>0.1	>1.20	<1

Table 2: Trophic status of Beaver Lake based on lake water parameters – 2019

Trophic State	**Secchi Depth**	**Total Nitrogen**	**Total Phosphorus**
	(m)	-------------(mg/L) ---------------	
Oligotrophic	>4	<0.35	<0.01
Mesotrophic	4 – 2	0.35 – 0.65	0.01 – 0.03
Eutrophic	2 – 1	0.65 – 1.00	0.0310 – 0.1
Hypereutrophic	<1	>1.2	>0.1
Beaver Lake	1.5	1.68	0.034
Trophic State of Beaver Lake 2019	Eutrophic	Hypereutrophic	Eutrophic
Trophic State of Beaver Lake 2018	Eutrophic	Hypereutrophic	Eutrophic

Table 3: Average N:P ratios for Beaver Lake water samples in - 2019

Sampling Event	**Total Nitrogen (mg/L)**	**Total Phosphorus (mg/L)**	**N:P**
Composite Sampling	1.57	0.043	36:1
Kemmerer Sampling	1.96	0.042	59:1

Table 4: Routine water chemistry parameters in Beaver Lake composite samples – 2019

Date of Sampling	**23-Jul-19**	**07-Aug-19**	**20-Aug-19**
	mg/L		
pH	8.40	8.76	8.59
Temperature (°C)	20.28	20.18	17.09
Ammonia, Total (as N)	<0.05	<0.05	<0.05
Nitrate (as N)	0.02	<0.020	<0.020
Nitrite (as N)	<0.010	<0.010	<0.010
Nitrate and Nitrite (as N)	0.02	<0.022	<0.022

* Based on average pH and temperature of 8.76 and 19.18 °C of Beaver Lake in 2019

1: CCME C Guidelines, de-minimis criteria for Protection of Aquatic Life and Agricultural Water Uses

2 - Environmental Quality Guidelines for Alberta Surface Waters 2018

a: CCME Canadian Environmental Quality Guidelines for water for the Protection of Aquatic Life

b: CCME Guidelines for Protection of Agricultural Water Uses (Irrigation and Livestock pathways included)

Table 5: Total dissolved metals in Kemmerer samples from Beaver Lake – 2019

Date of Sampling	**Kemmerer Sampling (6 m depth) March 13, 2019**	**Kemmerer Sampling (6 m depth) August 21, 2019**	**Criteria[1]**	**Criteria[2]**
Parameters	-------------(mg/L)--------------			
Aluminum (Al)-Total	<0.0030	0.0094	0.1[a]	0.1
Antimony (Sb)-Total	<0.00010	0.00011	NS	NS
Arsenic (As)-Total	0.00195	0.00207	0.005[a]	0.005
Barium (Ba)-Total	0.0605	0.0597	NS	NS
Beryllium (Be)-Total	<0.00010	<0.00010	100[b]	NS
Boron (B)-Total	0.089	0.086	1.5[a]	1.5
Cadmium (Cd)-Total	<0.0000050	<0.0000050	0.00009[a]	0.00033
Chromium (Cr)-Total	<0.00010	<0.00010	NS	NS
Cobalt (Co)-Total	<0.00010	<0.00010	0.05[a]	0.0012
Copper (Cu)-Total	<0.00050	<0.00050	0.0040[a]	0.022
Iron (Fe)-Total	0.013	0.016	0.3[a]	0.3
Lead (Pb)-Total	<0.000050	0.000060	0.007[a]	0.007
Lithium (Li)-Total	0.0477	0.0403	2.5[b]	NS
Manganese (Mn)-Total	0.161	0.0768	0.2[b]	NS
Mercury (Hg)-Total	<0.0000050	<0.0000050	0.000026[a]	NS
Molybdenum (Mo)-Total	0.000138	0.000109	0.073[a]	0.073
Nickel (Ni)-Total	<0.00050	<0.00050	0.150[a]	0.11
Selenium (Se)-Total	<0.000050	<0.000050	0.001[a]	NS
Silver (Ag)-Total	<0.000010	<0.000010	0.00025[a]	0.00025
Thallium (Tl)-Total	<0.000010	<0.000010	0.0008[a]	0.0008
Tin (Sn)-Total	<0.00010	0.00010	NS	NS
Titanium (Ti)-Total	<0.00030	0.00033	NS	NS
Uranium (U)-Total	0.000181	0.000162	0.01[b]	0.015
Vanadium (V)-Total	<0.00050	0.00113	0.1[b]	NS
Zinc (Zn)-Total	<0.0030	<0.0030	0.007[a]	0.03

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Table 6: Historical data of routine water chemistry in for Beaver Lake

	Year											
Parameter	**1986**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
pH	8.50	8.50	8.66	8.47	8.92	6.92	8.66	9.10	8.65	8.77	8.56	8.30
Secchi Depth (m)	2.90	2.60	4.17	3.56	1.85		1.53	1.88	1.50	1.88	1.50	2.40
Total Nitrogen (mg/L)	1.14	1.32	1.37	1.21	1.62	2.1	1.337	1.558	1.35	1.53	1.52	1.63
Total Phosphorus (mg/L)	0.033	0.145	0.047	0.024	0.065	0.050	0.041	0.039	0.040	0.034	0.036	0.040
Nitrate/Nitrite (mg/L)	0.0056	0.0018	0.0810	<0.071	<0.071		0.0	<0.022	<0.022	<0.022	<0.022	<0.022
Ammonia (mg/L)	0.0030	0.0331	0.0270	<0.050	<0.050	0.196	0.095	0.099	0.070	0.070	0.064	<0.050
Specific Conductivity (µS/cm)	409	462	508	500	529	600	554	491	559	493	757	526

Table 7: Historical data of total dissolved metals in Beaver Lake

Dissolved Metals	2017	2018	2019	Criteria[1]	Criteria[2]
Aluminum (Al)	<0.015	0.0043	0.0094	0.1[a]	0.1
Antimony (Sb)	<0.00050	<0.00050	0.00011	NS	NS
Arsenic (As)	0.00161	0.00208	0.00207	0.005[a]	0.005
Barium (Ba)	0.0603	0.0602	0.0597	NS	NS
Beryllium (Be)-Total	<0.00050	<0.00010	<0.00010	100[b]	NS
Boron (B)	0.125	0.094	0.086	1.5[a]	1.5
Cadmium (Cd)	<0.000025	0.0000055	<0.0000050	0.00009[a]	0.00033
Chromium (Cr)	0.001	0.00183	<0.00010	NS	NS
Cobalt (Co)-Total	<0.00050	<0.00010	<0.00010	0.05[a]	0.0012
Copper (Cu)	<0.0025	0.016	<0.00050	0.0040[a]	0.022
Iron (Fe)	<0.050	<0.050	0.016	0.3[a]	0.3
Lead (Pb)	<0.00025	0.000052	0.000060	0.007[a]	0.007
Lithium (Li)-Total	0.0434	0.0395	0.0403	2.5[b]	NS
Manganese (Mn)	0.0258	0.0998	0.0768	0.2[b]	NS
Mercury (Hg)	<0.0000050	<0.0000050	<0.0000050	0.000026[a]	NS
Molybdenum (Mo)-Total	<0.00025	0.000177	0.000109	0.073[a]	0.073
Nickel (Ni)	<0.0025	0.00072	<0.00050	0.150[a]	0.11
Selenium (Se)	<0.00025	<0.000050	<0.000050	0.001[a]	NS
Silver (Ag)	<0.000050	<0.000010	<0.000010	0.00025[a]	0.00025
Thallium (Tl)-Total	<0.000050	<0.000010	<0.000010	0.0008[a]	0.0008
Tin (Sn)-Total	<0.00050	0.0001	0.00010	0.0[a]	NS
Titanium (Ti)-Total	<0.0015	<0.00030	0.00033	0.0[a]	NS
Uranium (U)	0.0002	0.000184	0.000162	0.01[b]	0.015
Vanadium (V)-Total	<0.0025	<0.00054	0.00113	0.1[b]	NS
Zinc (Zn)	<0.015	0.0092	<0.0030	0.007[a]	0.03

*Analysis for total dissolved metals began in 2016

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