Lac La Biche County
welcoming by nature.

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

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Executive Summary

Fork Lake is relatively smaller, but a scenic fork-shaped lake located within Lac La Biche County, Alberta ("County"), and is known for a variety of recreational activities such as swimming and boating. However, there is a concern that declining water quality in the lake is limiting the opportunities of recreational activities. Therefore, it is important that the lake water quality be monitored.

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 2018. 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.

The water sampling events were conducted during spring and summer of 2019. Collected water samples were analyzed by ALS laboratory. The laboratory results obtained were compared to the CCME 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 Fork 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.

Fork 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 Mesotrophic based on Secchi depth, Hypereutrophic based on total nitrogen, and Eutrophic based on total phosphorus.

Results and Discussion

In 2019, Secchi depths in Fork Lake were measured on March 14, July 30, and August 15, 2019. The average seasonal Secchi depth was observed to be 2.4 m which is slightly higher than historical results. The low average Secchi depth means that Fork 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), Fork Lake is classified as Mesotrophic (some productivity, nutrients, and algae growth).

Sampling events in 2019 showed an average water temperature of 13.7 ^{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 sampling events between March 14 to August 15, 2019.

Dissolved oxygen data collected in 2019 shows that the average dissolved oxygen levels were 5.4 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).

In 2019, two types of lake water samples for analyses of nutrients were collected from Fork 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 2.1 mg/L of total nitrogen, while the Kemmerer samples collected had an average of 2.34 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 Fork 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 0.05 mg/L of total phosphorus, while the Kemmerer samples collected had an average of 0.05 mg/L. The average of both sampling methods is 0.05 mg/L of total phosphorus which does exceed the applicable regulatory guidelines of 0.05 mg/L and is consistent with historical results. Total phosphorus concentrations from both sampling methods classify Fork Lake as Eutrophic (high productivity, nutrients, and algae growth).

The average N:P ratios for composite and Kemmerer sampling events were 44:1 and 49:1 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 Fork Lake.

Routine water chemistry showed that Fork Lake has an average pH of 8.00 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.

Fork 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 Mesotrophic based on Secchi depth, Hypereutrophic based on total nitrogen, and Eutrophic based on total phosphorus.

Recommendations:

It is recommended that County continues to monitor the water quality of Fork Lake to achieve to continue to long term representation of the average water quality in the lake. Continuous monitoring will help in evaluating if the existing lake management policies need to be changed to ensure the lake's health. To ensure that data received is consistent and comparable year to year, consistency in spatial and temporal data collection needs to be maintained in a consistent manner.

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 Fork 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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List of Abbreviations 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
EQGASW-RA: Environmental Quality Guidelines for Alberta Surface Waters 2018 for Recreation and Aesthetics
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

Fork Lake is located in east central Alberta, approximately 185 km northeast of Edmonton and approximately 40 km southeast of town of Lac La Biche. It covers a surface area of 12 km^2 within the Beaver River Basin. Popular game fish of this lake include Yellow Perch (*Perca flavescens*), Northern Pike (*Esox lucius*), and Lake Whitefish (*Coregonus clupeaformis*).

Figure 1: Location map of Fork Lake

2. FORK LAKE WATER QUALITY SAMPLING PROGRAM

Fork Lake has been sampled since 2005 first by the Alberta Lake Management Society, and then by Lac La Biche County. Fork 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. Fork Lake sampling program for 2019 was completed as follows:

a) Secchi depths were measured on March 14, July 30, and August 15, 2019 using a Secchi Disc;
b) Composite samples from the lake were collected on July 30 and August 15, 2019. Lake water samples were analyzed for nutrients, metals and basic water chemistry parameters by ALS laboratories;
c) Kemmerer water samples using a Kemmerer device were collected on March 14 and August 15, 2019 from depths of 3 m, 6 m, and 9 m; and these samples were analyzed for nutrients, metals and basic water chemistry parameters by ALS laboratories.
d) Fork Lake profiles were recorded for various parameters (pH, temperature, dissolved oxygen) to a maximum depth of 11 m using a multi-probe on March 14, July 30 and August 15, 2019.

2.1 Water Quality Parameters

Water samples collected during 2019 sampling events of Fork Lake were analyzed for a variety of parameters to characterize the lake water and identify potential issues associated with lake water quality. The water quality parameters measured/analyzed during 2019 are provided in the table below with a brief description.

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 Depths

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 Fork Lake were measured on March 14, July 30, and August 15, 2019. The average seasonal Secchi depth was observed to be 2.4 m which is slightly higher than historical results. The low average Secchi depth means that Fork 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), Fork Lake is classified as Mesotrophic (some productivity, nutrients, and algae growth).

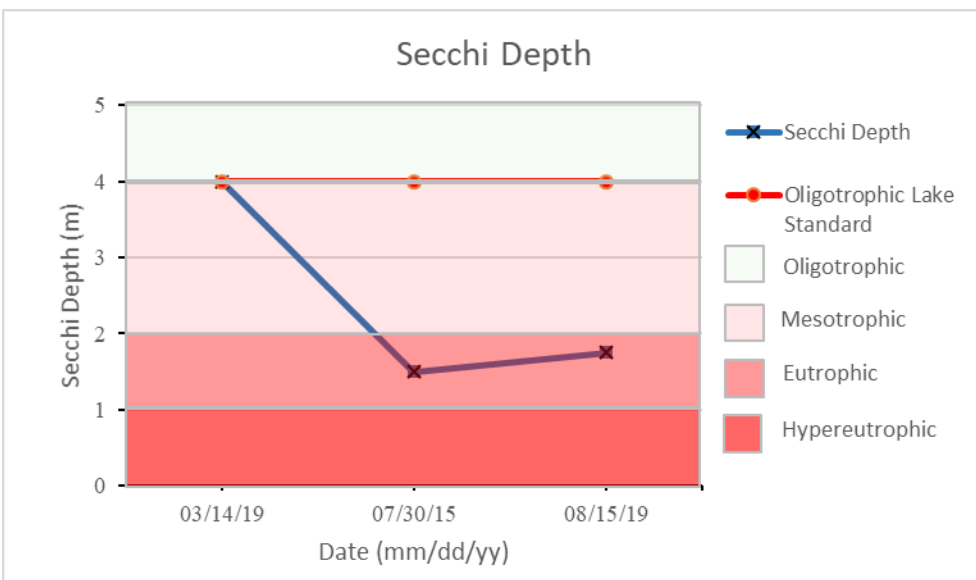

Figure 2: Secchi depths measured in Fork Lake – 2019

4.2 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.

In 2019, dissolved oxygen levels in Fork Lake were recorded to a maximum depth of 9 m using a multi-probe on March 14, July 30, and August 15, 2019. Maximum dissolved oxygen (9.37 mg/L) was observed on July 30, 2019 at 1m depth which declined gradually to 5 mg/L at the lake bed (Figure 3).

A gradual downward temporal trend was observed in all dissolved oxygen measurements. The average dissolved oxygen levels was 4.58 mg/L and was below the range of applicable regulatory guidelines for dissolved oxygen in cold water lakes (9.5 mg/L for early life stages and 6.5 mg/L for all other life stages). This low dissolved oxygen at the lake bed means that it is not an ideal environment for most life stages.

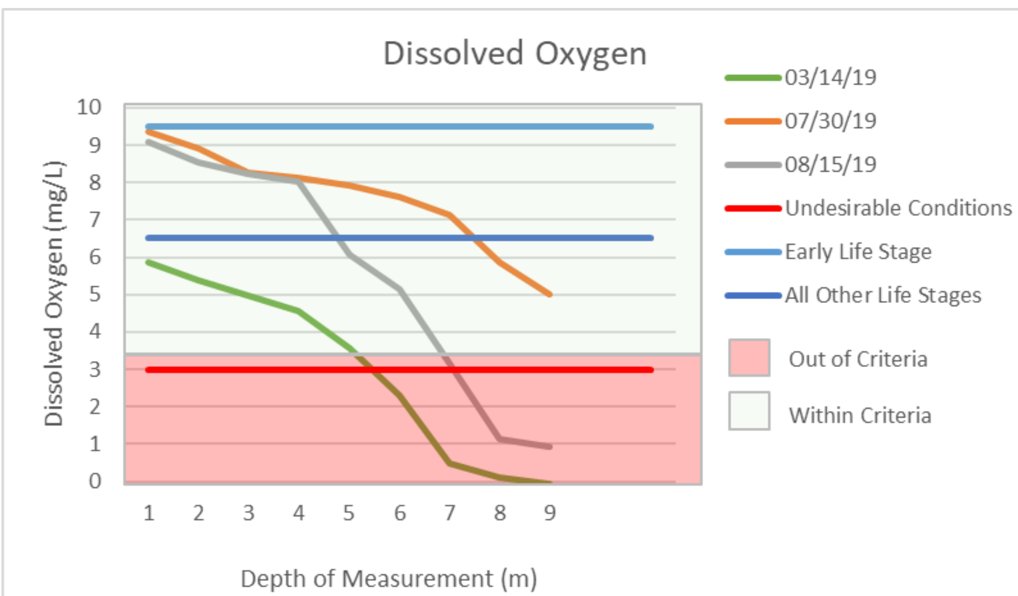

Figure 3: Dissolved oxygen in Fork Lake – 2019

4.3 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 summer time, warmer surface water can facilitate cyanobacteria blooms at the lake surface (Wetzel, R. 2001).

Fork Lake temperatures were recorded to a maximum depth of 9 m. Minimum temperature of 0.632 ˚C was observed on March 14, 2019 and maximum temperature of 19.92 ˚C was noted on July 30, 2019 at 1 m depth. Results of temperatures observed on different dates and depth are illustrated in Figure 4. Fork Lake temperature sampling data showed a fairly uniform temperature profile. Thermal stratification was not observed on any of the sampling events.

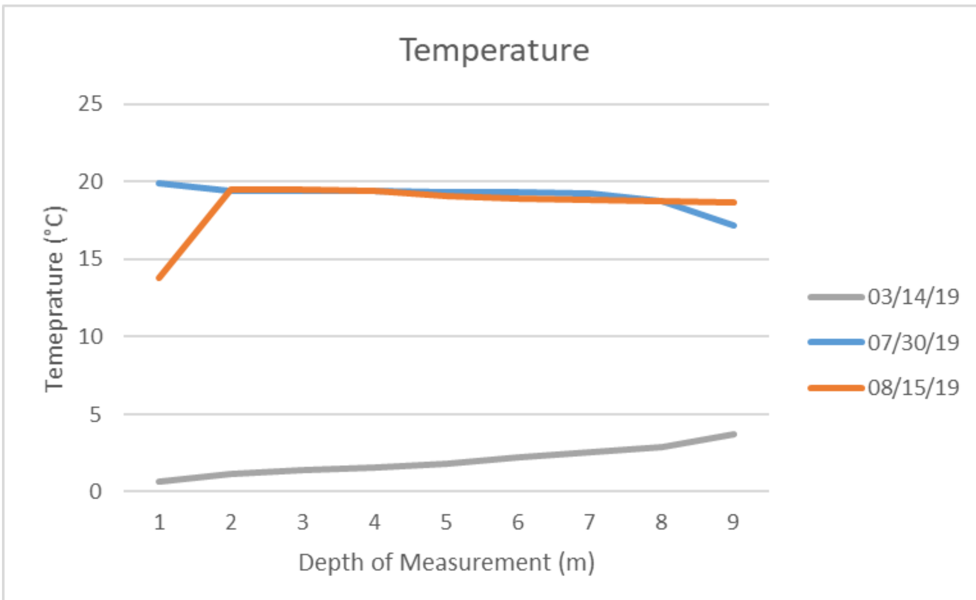

Figure 4: Temperature profile in Fork Lake – 2019

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 Fork 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 and this 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 30, and August 15, 2019. The results indicated that total nitrogen concentration in composite samples ranged from 1.92 mg/L to 2.27 mg/L. The analytical results are presented in Figure 5.

Nitrogen concentrations in the composite samples collected from the lake in 2019 had an average of 2.10 mg/L of total nitrogen which exceeded the applicable regulatory guidelines. The average total nitrogen indicates that Fork Lake is Hypereutrophic (excessive productivity, nutrients, and algae growth) based on total nitrogen from composite samples.

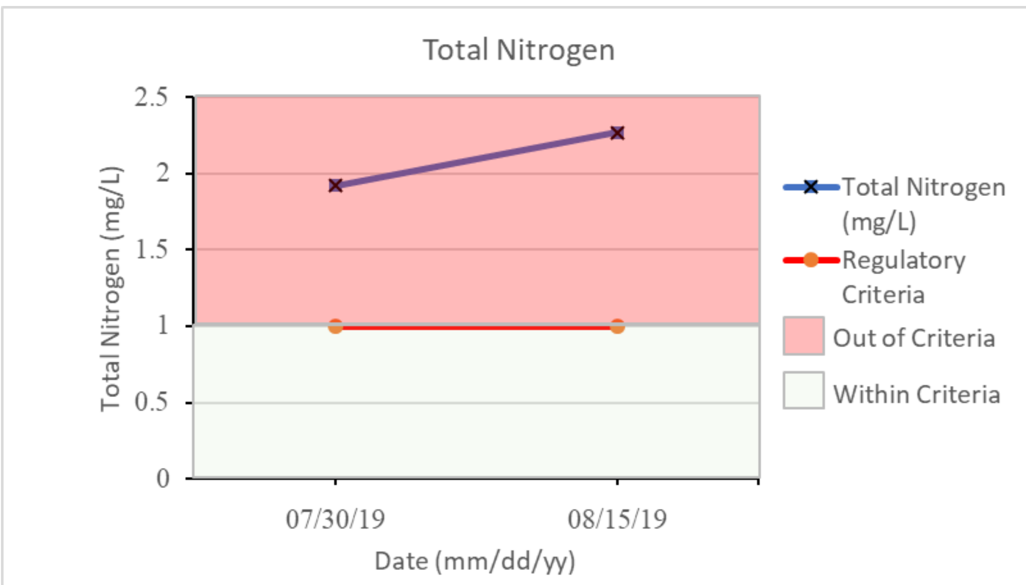

Figure 5: Total nitrogen from composite samples of Fork Lake - 2019

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 014, and August 15, 2019 at various depths (3, 6, and 9 m) and were analyzed for total nitrogen by ALS laboratories. Total nitrogen concentrations ranged from 2.0mg/L to 2.78 mg/L with an average of 2.34 mg/L. Analytical results of total nitrogen are presented in Figure 6.

Total nitrogen concentrations in all samples from all depths exceeded the applicable regulatory guideline of 1.0 mg/L. 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.

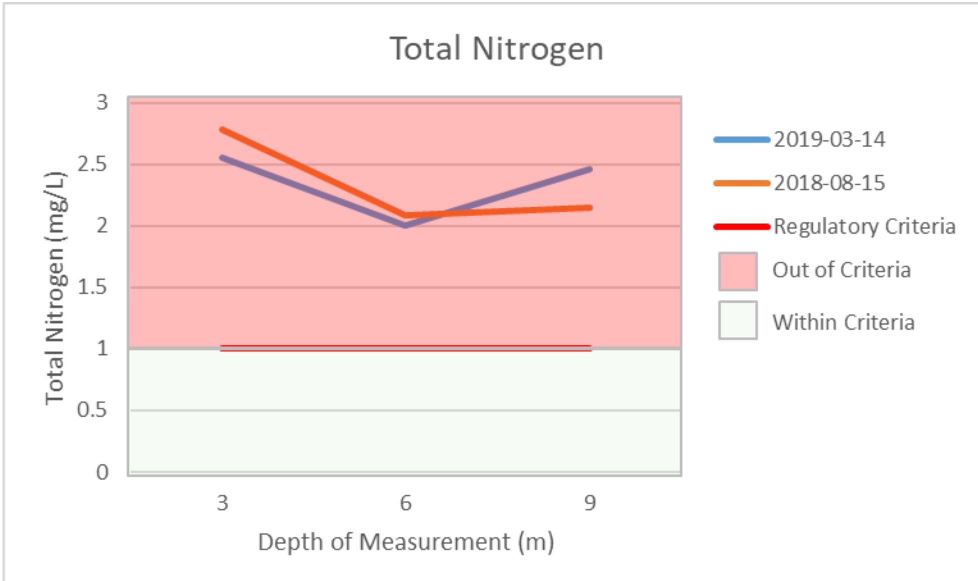

Figure 6: Total nitrogen from Kemmerer samples of Fork Lake - 2019

Total Phosphorous

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 analyses of total phosphorus were collected on July 30, and August 15, 2019 and the total phosphorus concentrations were 0.067 mg/L and 0.029 mg/L. The analytical results are presented in Figure 7.

Total phosphorus concentrations in the composite samples had an average of 0.048 mg/L of total phosphorus which does not exceed the applicable regulatory guideline of 0.05 mg/L. This average total phosphorus concentration classifies Fork Lake as Eutrophic (high productivity, nutrients, and algae growth) based on total phosphorus from composite samples.

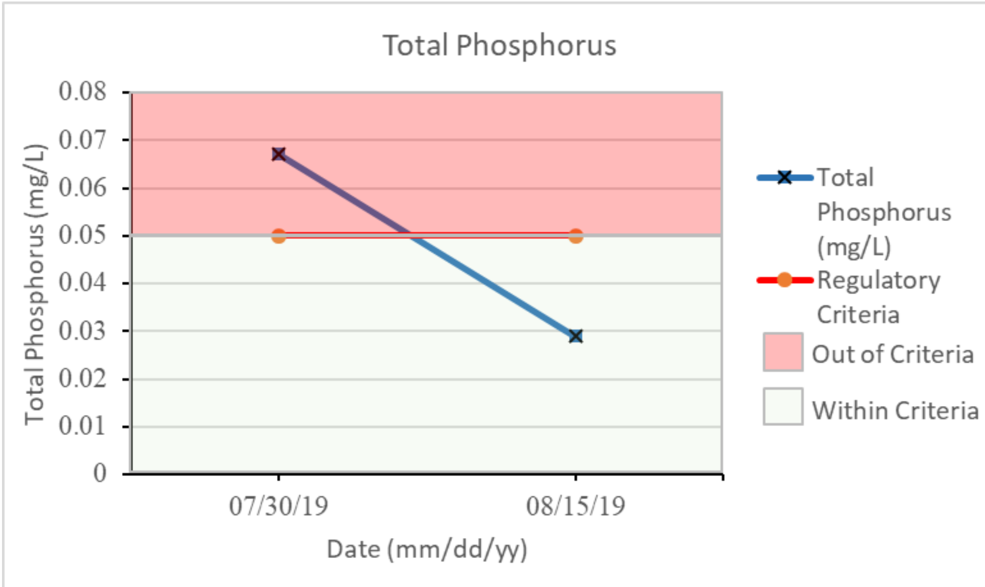

Figure 7: Total phosphorus in composite samples of Fork Lake - 2019

Kemmerer Sampling

Kemmerer water samples using Kemmerer device were collected on March 14 and August 15, 2019 from depths of 3 m, 6 m, and 9 m, and were analyzed for total phosphorus by ALS laboratories. The total phosphorus concentration in lake water samples collected on March 14 and August 15, 2019 at 3 m, 6 m, and 9 m depths ranged from 0.031 mg/L to 0.086 mg/L respectively. The Kemmerer samples had an average of 0.048 mg/L of total phosphorus. An increasing trend in total phosphorus concentrations was observed with an increase in lake depth. The results of total phosphorus concentrations for Fork Lake at different lake depths are presented in Figure 8.

Total phosphorus concentrations in all samples does not exceed the applicable regulatory guideline of 0.05 mg/L. The results from the Kemmerer sampling resulted in the same trophic state classification as the composite samples for total phosphorus which is Eutrophic (high productivity, nutrients, and algae growth) based on total phosphorus.

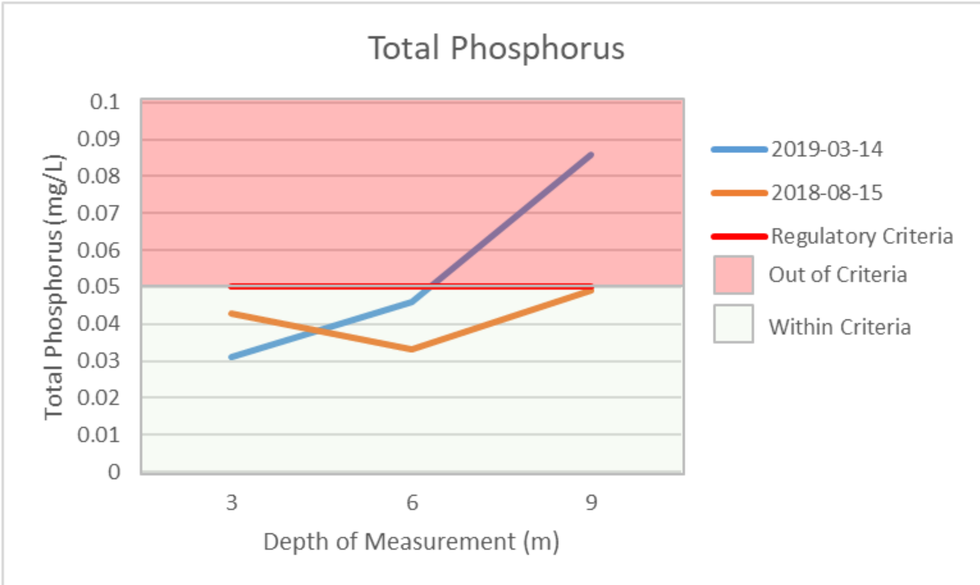

Figure 8: Total phosphorus from Kemmerer samples of Fork Lake – 2019

N:P Ratio

The Redfield Ratio describes the optimal balance of total nitrogen to total phosphorous for aquatic plant growth and has 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 limits the growth within lakes.

Average N:P ratios in the Fork Lake were 44:1 and 49:1 for composite and Kemmerer samples, respectively. These ratios are higher than the Redfield Ratio of 16:1, indicating that total phosphorus concentration is considered low enough for phosphorous to be considered the main nutrient limiting growth in the Fork Lake.

4.5 Routine Water Chemistry

Results of routine water chemistry of samples collected from Fork Lake are presented in Table 4, Appendix A.

The average measured pH for Fork Lake was 8.00 which was consistent with the average of past years. 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 Fork 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 and 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 Fork 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.

The total dissolved metals in the composite and Kemmerer lake water samples collected from Fork Lake 2019 were below detection limits and therefore were below the applicable regulatory guidelines (Table 5).

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 shows that Secchi Depth in Fork Lake was always less than the standard Oligotrophic Secchi depth of 4 m. Results of these samples are presented in Figure 9. A Secchi Depth of 2 m was measured in 2005 but gradually decreased to 2.5 m in 2018, then decreased in 2019 to 2.4 m. The low 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.

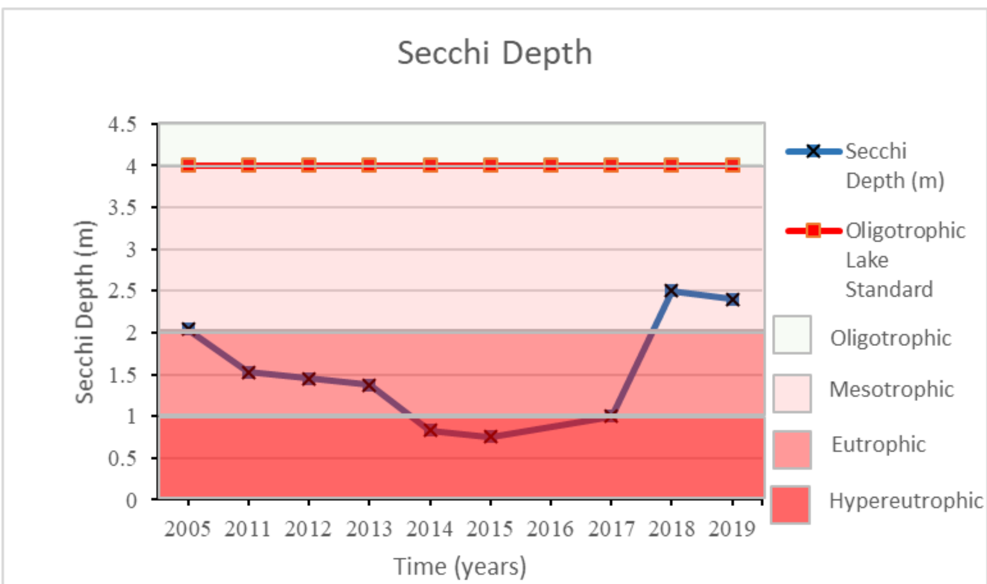

Figure 9: Historical trend for Secchi Depth in Fork Lake

5.2 Total Nitrogen

Historical data shows that total nitrogen in Fork Lake ranged from 1.20 mg/L to 2.03 mg/L and consistently exceeded the regulatory guideline of 1.0 mg/L (Figure 11). Total nitrogen concentrations of 1.70 mg/L measured in 2005 decreased to 1.25 mg/L in 2011; however, a temporal increasing trend in total nitrogen concentrations was observed since after 2011. Total nitrogen concentrations have historically been classified as Hypereutrophic (excessive productivity, nutrients, and algae growth).

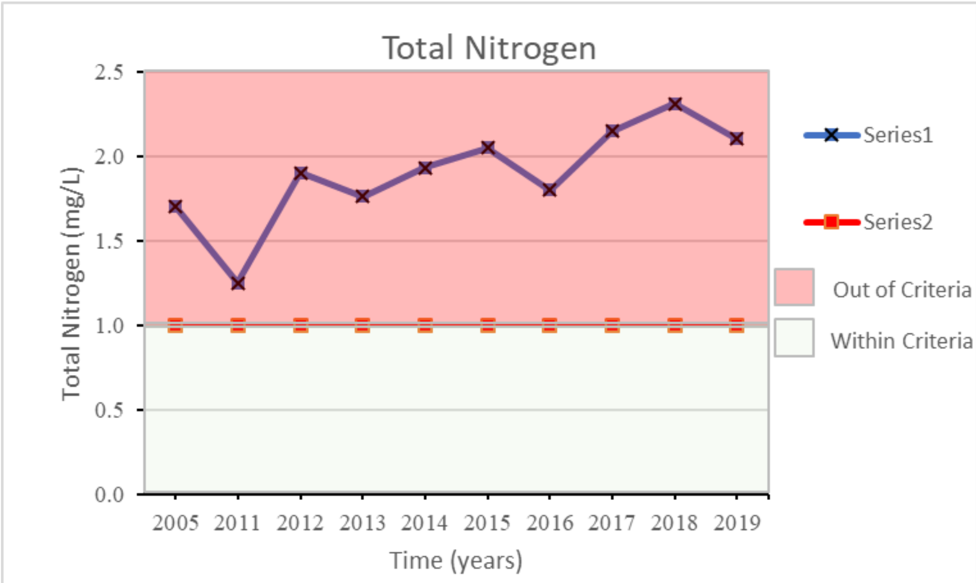

Figure 10: Historical trend of total nitrogen concentrations in in Fork Lake

5.3 Total Phosphorus

Historical data shows that total phosphorus concentrations in Fork Lake ranged from a minimum of 0.036 mg/L in 2017 to a maximum of 0.070 mg/L in 2018 as presented in Figure 12. However, total phosphorus concentrations fluctuated over time, and the values recorded in 2011, 2014, 2015, 2016, 2017, 2018 and 2019 exceeded the applicable regulatory guideline of 0.05 mg/L. No representative trend of change for total phosphorus concentrations in Fork Lake was observed. Total phosphorus concentrations have historically been classified as Eutrophic (high productivity, nutrients, and algae growth).

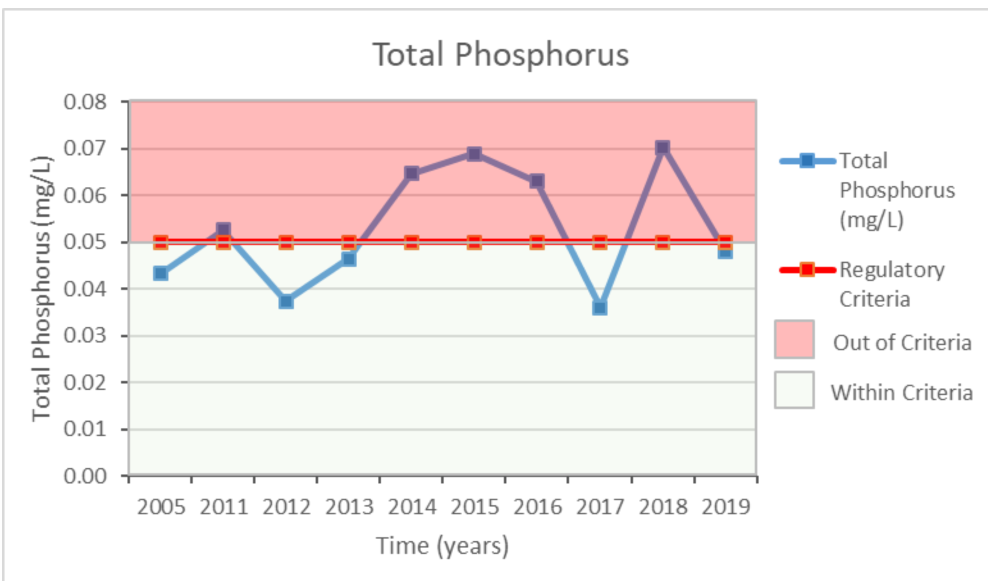

Figure 11: Historical trend of total phosphorus concentrations in Fork Lake

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 Fork 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.

Fork 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 Mesotrophic based on Secchi depth, Hypereutrophic based on total nitrogen, and Eutrophic based on total phosphorus.

7 RECOMMENDATIONS

It is recommended that County continues to monitor the water quality of Fork Lake to achieve to continue to long term representation of the average water quality in the lake. Continuous monitoring will help in evaluating if the existing lake management policies need to be changed to ensure the lake's health. To ensure that data received is consistent and comparable year to year, consistency in spatial and temporal data collection needs to be maintained in a consistent manner.

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 Fork 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.

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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	>0.10	>1.20	<1

Table 2: Trophic status of Fork Lake in 2019 based on lake water parameters (Nurnberg 1996)

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
Fork Lake Data	2.5	2.31	0.070
Trophic State of Fork Lake in 2019	Mesotrophic	Hypereutrophic	Eutrophic
Trophic State of Fork Lake in 2018	Mesotrophic	Hypereutrophic	Eutrophic

Table 3: Average lake water N:P ratios for composite and Kemmerer samples from Fork Lake – 2019

Sampling Event	**Total Nitrogen (mg/L)**	**Total Phosphorus (mg/L)**	**N:P**
Composite Sampling	2.10	0.048	44:1
Kemmerer Sampling	2.34	0.048	49:1

Table 4: Routine water chemistry analysis from composite samples of Fork Lake – 2018

Date of Sampling	**30-Jul-19**	**15-Aug-19**
	mg/l	
pH	8.04	8.37
Temperature (°C)	17.888	13.2
Ammonia, Total (as N)	<0.05	<0.05
Nitrate (as N)	<0.020	<0.020
Nitrite (as N)	<0.010	<0.010
Nitrate and Nitrite (as N)	<0.022	<0.022

* Based on average pH and temperature of 8.0 and 13.72 °C of Fork Lake in 2019

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Table 5: Dissolved metals from Kemmerer samples in Fork Lake – 2019

Fork Lake Metal Analysis		
Analyte (periodic)	19 03 14 Concentration (mg/L)	19 08 15 Concentration (mg/L)
Aluminum (Al)-Total	<0.0030	0.0056
Arsenic (As)-Total	0.0014	0.00141
Calcium (Ca)-Total	38.8	33.9
Copper (Cu)-Total	<0.00050	<0.00050
Iron (Fe)-Total	<0.010	0.017
Lead (Pb)-Total	<0.000050	<0.000050
Lithium (Li)-Total	0.0375	0.0284
Magnesium (Mg)-Total	39.5	34.6
Manganese (Mn)-Total	0.04230	0.10100
Mercury (Hg)-Total	<0.0000050	<0.0000050
Potassium (K)-Total	29.3	26.3
Sodium (Na)-Total	20.9	18.2
Sulfur (S)-Total	42.4	37.5
Zinc (Zn)-Total	0.0071	0.0112

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Table 6: Historical data of routine chemistry and other parameters for Fork Lake

	Year									
Parameter	**2005**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
pH	8.62	8.53	8.60	8.40	8.20	8.80	8.30	8.73	7.94	8.260
Secchi Depth (m)	2.04	1.53	1.45	1.38	0.83	0.75		1.00	2.50	2.40
Total Nitrogen (mg/L)	1.70	1.25	1.90	1.76	1.93	2.05	1.80	2.03	2.31	2.10
Total Phosphorus (mg/L)	0.010	0.020	0.020	0.020	0.020	0.030	0.020	0.044	0.070	0.048
Nitrate/Nitrite (mg/L)	0.01	0.05	0.10	0.09	0.41	-	0.06	0.01	<0.02	<0.022
Ammonia (mg/L)	0.04	<0.05	<0.05	<0.05	0.07	0.02	<0.022	<0.036	0.125	<0.050
Specific Conductivity (µS/cm)	496	522	545	537	549	479	573	493	766	822

Table 7: Historical trend of total dissolved metals in Fork Lake

Dissolved Metals	2016	2017	2018	2019	Criteria[1]	Criteria[2]
	-------------------------------(mg/L ------------------------------					
Aluminum (Al)	0.031	0.0086	0.0035	0.0056	0.1[a]	0.1
Antimony (Sb)	<0.00010	0.00022	<0.00010	<0.00010	NS	NS
Arsenic (As)	0.0115	0.00122	0.00144	0.00141	0.005[a]	0.005
Barium (Ba)	0.0688	0.0587	0.0587	0.0634	NS	NS
Beryllium (Be)-Total	-	<0.00010	<0.00010	<0.00010	100[b]	NS
Boron (B)	0.083	0.075	0.0667	0.075	1.5[a]	1.5
Cadmium (Cd)	<0.0000005	<0.0000050	<0.0000050	<0.0000050	0.00034[a]	0.00034
Chromium (Cr)	<0.0001	0.00011	0.00177	<0.00010	NS	NS
Cobalt (Co)-Total	-	<0.00010	<0.00010	<0.00010	0.05[a]	NS
Copper (Cu)	<0.0005	0.00057	<0.0005	<0.00050	0.0040[a]	0.04
Iron (Fe)	<0.010	0.01	0.015	0.017	0.3[a]	0.3
Lead (Pb)	<0.00005	<0.000050	0.000256	<0.000050	0.007[a]	0.007
Lithium (Li)-Total	-	0.0302	0.0360	0.0284	2.5[b]	NS
Manganese (Mn)	0.0676	0.0192	0.0571	0.101	0.2[b]	NS
Mercury (Hg)	<0.000005	<0.0000050	<0.0000050	<0.0000050	0.000026[a]	NS
Molybdenum (Mo)-Total	-	0.000203	<.000050	0.000051	0.073[a]	0.073
Nickel (Ni)	<0.0005	<0.00050	<0.00050	<0.00050	0.150[a]	0.12
Selenium (Se)	<0.00005	<0.000050	<0.000050	<0.000050	0.001[a]	NS
Silver (Ag)	<0.00001	<0.000010	<0.000010	<0.000010	0.00025[a]	0.00025
Thallium (Tl)-Total	-	<0.000010	<0.000010	<0.000010	0.0008[a]	0.0008
Tin (Sn)-Total	-	<0.00010	<0.00010	<0.00010	NS	NS
Titanium (Ti)-Total	-	<0.00030	<0.00030	<0.00030	NS	NS
Uranium (U)	0.000074	0.000079	0.000079	0.000068	0.01[b]	0.015
Vanadium (V)-Total	-	<0.00050	<0.00050	0.00086	0.1[b]	NS
Zinc (Zn)	<0.003	0.0043	0.0033	0.0112	0.007[a]	0.03

*Analysis for total dissolved metals began in 2016

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