Elk Lake Centre
Water Quality Trends
from 1986-2022

Coastal Collaborative Sciences

A Division of World Fisheries Trust

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Prepared by: Rebecca Nielsen, BSc, EPt

Executive Summary

Water quality in Elk Lake has been declining for decades and in recent years algal blooms and eutrophication have increased. Phosphorus loading has been identified as the main driver for these issues, and the majority of the phosphorus is being released from lake sediments. The Capital Regional District is installing an oxygenation system at the bottom of Elk Lake in 2023 to reduce internal loading of phosphorus from the sediment. This report provides a summary of water quality trends recorded by the British Columbia Ministry of the Environment and Climate Change, and the Capital Regional District from 1986 to 2022. Trends in this report will be compared to water quality measurements after the oxygenation system is installed to monitor changes in water quality within Elk Lake.

Acknowledgements

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Coastal Collaborative Sciences acknowledges that we work and live on the traditional territories of the Lək̓ʷəŋən speaking people, including the WSÁNEĆ, Songhees, Esquimalt, T'Sou-ke, and other First Nations whose historical relationships with the land continue to this day

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Introduction

This report was commissioned by the Victoria Golden Rods and Reels and sponsored by the British Columbia Wildlife Federation (BCWF) to understand water quality trends in Elk Lake up to 2022. These trends will be used to compare water quality after an oxygenation system is installed in the lake in 2023.

Data for this report were sourced from the British Columbia Ministry of Environment and Climate Change Strategy (BC ENV) Lake Monitoring Network and various Capital Regional District (CRD) monitoring initiatives. The sample site for the data in this report is shown in *Figure 1* below, and the BC ENV sample ID is 1100844 Elk Lake Centre (BC ENV, 2023). This sampling site is also known as the Elk Lake Deep Site, or Elk-02 in CRD databases.

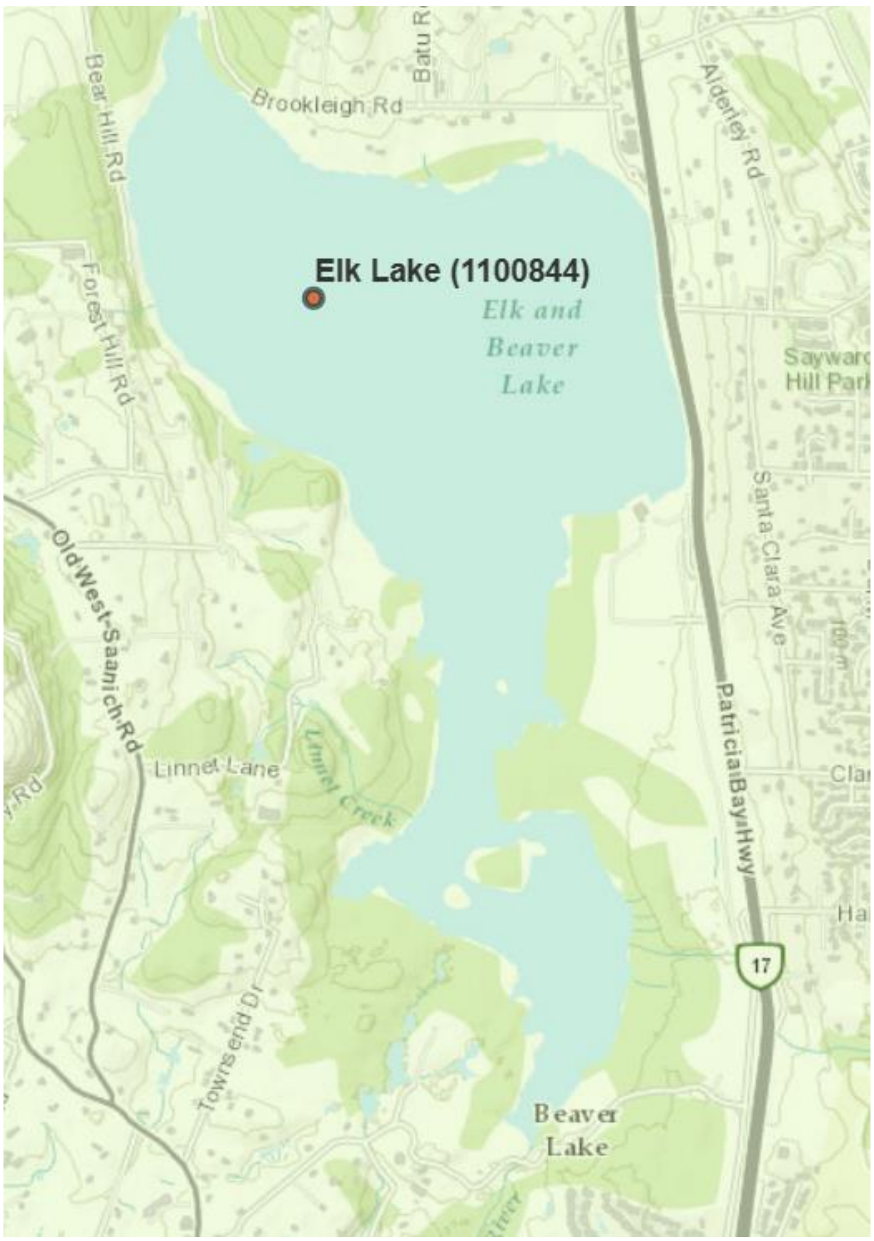

Figure 1: Elk Lake Centre Sample Site

Background

Elk Lake is a popular recreational lake and was historically used as a drinking water source up until the 1970's (Mckean, 1992). Declining water quality issues have reduced water clarity and increased potentially toxic blue-green algal blooms in the lake. Studies by various consultants in the last decade have concluded that the majority of the lake's water quality issues stem from internal phosphorus loading from the sediment at lake bottom. External phosphorus loading from the surrounding watershed is also contributing to the problem (CRD, 2020).

Elk Lake is connected to Beaver Lake by a shallow channel, and water drains both lakes through a weir at the South end of Beaver Lake. Water residence time within Elk/Beaver Lake is around 7 years which means that nutrients and contaminants remain in the lake for a long time (CRD, 2018). Elk Lake mixes completely in the winter months and stratifies from approximately March to November each year.

In response to deteriorating water quality in Elk Lake for both aquatic life and recreational uses, an Elk Beaver Lake Watershed Management Plan was created by the CRD in 2020. Water quality objectives and an in-lake water sampling plan were developed and are shown in *Table 1* and *Table 2* below.

Table 1: Water Quality Objectives for Elk Lake (CRD, 2020)

	Objectives	**Source**
I.	Maintain Chlorophyll-A mean summer range of 1.5-2.5 µg/L	McKean 1992
II.	Reduce year-round total phosphorus concentrations 5-15 µg/L to support aquatic life and lake recreation	Water Quality Objectives (BC ENV)
III.	Maintain deep water temperatures below 15°C in the hypolimnion to support aquatic life	McKean 1992
IV.	Improve year-round dissolved oxygen concentrations >5 mg/L at 1m above lake bottom	McKean 1992
V.	Improve water clarity to no less than 1.9 m Secchi depth year-round	McKean 1992
VI.	Shift the phytoplankton community composition such that blue-green algae make up no more than 50% of the cells/mL	Nordin 2015

Table 2: In-Lake Water Sample Plan (CRD, 2020)

In-Lake Water Sampling Plan		
Physical Parameters	Chemical Samples	Biological Samples
Dissolved Oxygen	Total Phosphorus	Chlorophyl-A
Temperature	Ortho-phosphate	Phytoplankton Tow
pH	Total Nitrogen (NO_2, NO_3, NH_3)	Zooplankton Tow
Conductivity	Dissolved Organic Carbon	
Water Clarity		

This report focuses on water quality trends at the Elk Lake deep site because this is where the oxygenation system is to be installed to increase oxygen levels at lake bottom and decrease phosphorus loading from the sediment.

Water quality guidelines are based on requirements for the protection of aquatic life and come from both the BC ENV and the Canadian Council of Ministers for the Environment (CCME). Additional information on each parameter and its importance to water quality and aquatic life is discussed below.

Physical Parameters

Dissolved Oxygen

Oxygen in water is measured as dissolved oxygen, usually in mg/L or % oxygen, and is essential for aquatic life. Dissolved oxygen comes from aquatic plants, turbulence, and the atmosphere, and changes with water temperature and turbidity. When the lake stratifies in the warmer months, oxygen levels at the lake bottom get depleted and the remaining oxygen is consumed (Nordin, 2014). The deep-water environment becomes unsupportive of aquatic life. Water quality guidelines for dissolved oxygen are based on the minimum requirements for aquatic life, and there are both short term (instant) and long term (chronic) guidelines. The BC ENV dissolved oxygen guidelines for aquatic life are a minimum of 5mg/L short term and 8mg/L long term (BC MOE, 1981).

Temperature

Water temperature in lakes changes seasonally and with depth. In Elk Lake the water temperature remains cool at the lake bottom year-round but the surface warms significantly during summer months. This is called stratification, which happens when the warmer surface waters maintain a distinct layer above the cooler hypolimnion (deep-water) temperatures. In late fall the surface temperatures cool and the lake mixes, resulting in consistent temperatures from surface to lake bottom. The lake remains mixed during the winter months until around February when the surface temperatures begin to rise. Temperature depth profiles provide a graphic of this phenomenon and are shown in the results section of this report.

Temperature guidelines for the protection of aquatic life vary based on the type of water body and the aquatic species present. For Elk Lake the temperature guideline for aquatic life is below 15°C in the hypolimnion, which is the cooler deep water in the stratified lake.

pH

The measure of acidity or alkalinity in water is referred to as pH, which ranges from 1.0 to 14.0. Neutral pH is measured at 7.0 and anything below 7.0 is acidic, while anything above 7.0 is alkaline.

Figure 2: pH Scale (Atlas Scientific, 2023)

The pH requirements for aquatic life depend on the organism and its life stage, as well as the ambient normal pH concentrations. An abrupt change in pH can negatively impact aquatic life. The BC ENV water quality guidelines for the protection of aquatic life is a pH range of 6.5 to 9.0 (BC ENV, 2021).

Specific Conductivity

Conductivity in water refers to the number of ions in solution that allow an electric charge to pass through them. Salt water generally has a much higher conductivity than fresh water, and distilled water is void of ions and therefor has no conductivity. Specific conductivity is an indirect measure of the concentration of dissolved ions in 1 cubic centimeter of water corrected to 25°C and is represented in µS/cm (USGS, 1998). There are no BC ENV water quality guidelines for specific conductivity, however, understanding background conductivity in a freshwater system can help identify inputs when conductivity increases. Land disturbance is a common source of increased specific conductivity in freshwater systems due to increased sedimentation. In lakes, increased specific conductivity at the lake bottom is likely from sediment disturbance or release of ions from sediment during anoxic periods.

Water Clarity

The depth at which an observer can see down into the water is measured with a secchi disk and reported as water clarity. Clarity in Elk Lake is impacted by algae within the upper water column and fluctuates throughout the year in response to temperatures and available nutrients near the surface. The objective for Elk Lake clarity is greater than 1.7 m, which means the secchi disk should be visible at depths below 1.7 m.

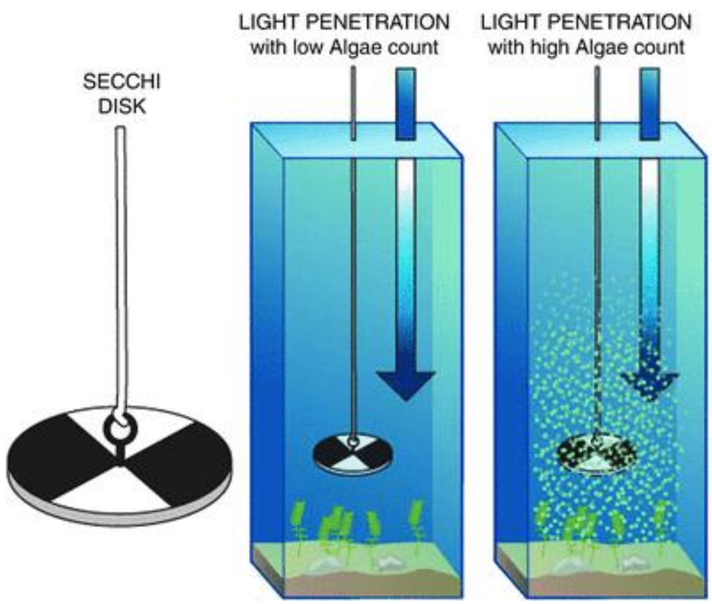

Figure 3: Secchi Disk and Lake Clarity (Harrison, 2016)

Chemical Samples

Phosphorus

Phosphorus is an essential nutrient required for all living things, and it is usually the limiting nutrient in freshwater ecosystems. This means that in healthy systems there is very little phosphorus available so plant and algae growth is limited. In a eutrophic system like Elk Lake, the phosphorus concentrations are well above that of a natural system, and therefor growth has become unlimited. High phosphorus and uncontrolled growth of plants and algae can lead to poor water quality and eutrophication.

Figure 4 below shows how phosphorus enters the lake and cycles through inorganic and organic forms, including sediment cycling. Please note: *Figure 4* shows phosphorus cycling in a lake containing Zebra Mussels which Elk Lake does not have, however; Elk Lake's benthic invertebrate populations play a similar role to the phosphorus locking represented by Zebra Mussels in this diagram.

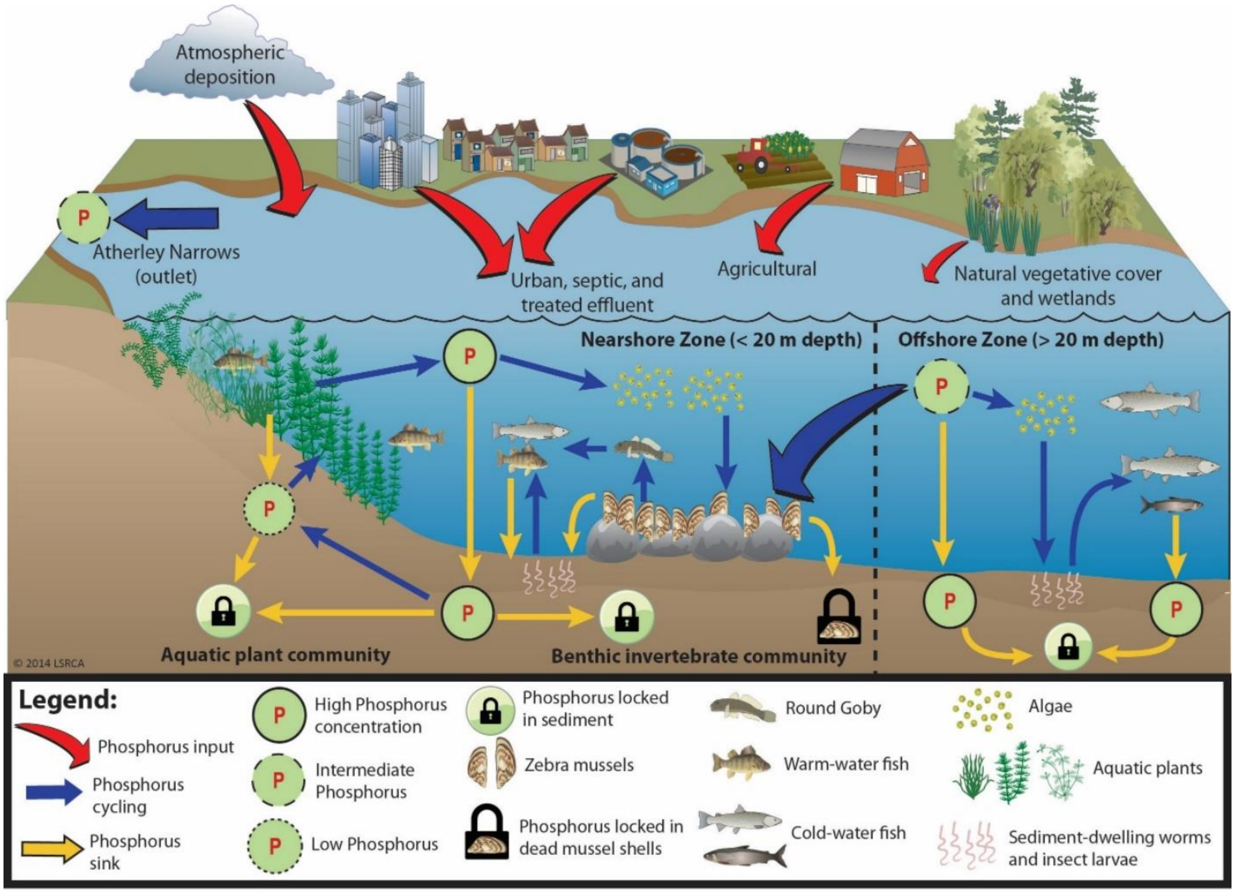

Figure 4: Phosphorus Cycle in Lakes (LSRCA, 2014)

Forms of phosphorus include: inorganic phosphate (ortho-phosphate), organic particulate phosphate, and organic dissolved phosphate, as well as total phosphorus (TP) which includes all of the different forms. TP is the only form of phosphorus with a BC ENV water quality objective, however; measurements of ortho-phosphorus can indicate levels of biologically available phosphorus within the water column. The BC ENV objective for total phosphorus suggests an acceptable range of 5-15 µg/L TP. The Canadian Council of Ministers for the Environment (CCME) shows how different phosphorus concentrations impact lake water quality in the list below:

Oligotrophic 4-10 ug/L phosphorus (low nutrients, good water quality)
Mesotrophic 10-20 ug/L phosphorus (some nutrients, fair water quality)
Meso-eutrophic 20-35 ug/L phosphorus (nutrients available, fair water quality)
Eutrophic 35-100 ug/L phosphorus (high nutrients, poor water quality) (CCME, 2021)

Nitrogen

Nitrogen is another essential nutrient that supports all life and contributes to plant and algae growth. There are several forms of nitrogen that changes as it cycles, including: ammonia, nitrite and nitrate. These three compounds can be toxic to aquatic life at high concentrations so monitoring is important, particularly in eutrophic systems. *Figure 5* below shows how nitrogen cycles in aquatic systems.

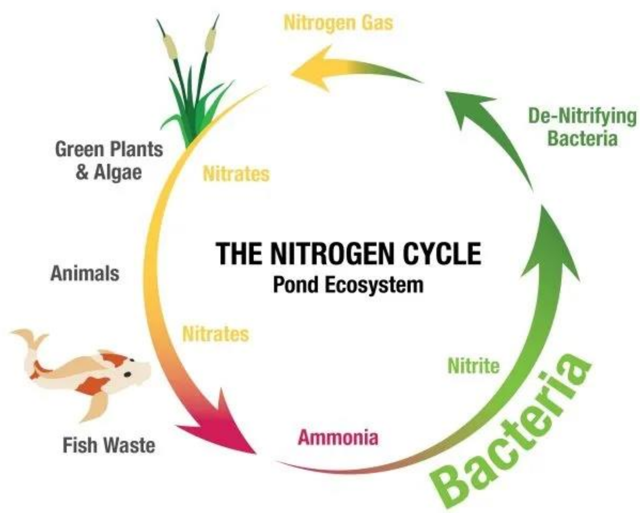

Figure 5: The Nitrogen Cycle (Aquascape)

Water quality objectives for nitrogenous compounds are based on their toxicity to aquatic life. The BC ENV objective for nitrate is: maximum short-term (acute) concentration of 32.8 mg/L N, and long-term (chronic) concentration of 3.0 mg/L N (BC ENV, 2019). For nitrite, the objectives are: a maximum short-term (acute) nitrite concentration of 0.06 mg/L N, and a maximum long-term (chronic) concentration of 0.02 mg/L N (BC ENV, 2019). Ammonia concentrations for the protection of aquatic life fluctuate based on the temperature and pH of the water, as these parameters impact toxicity. The BC ENV provides a table for ammonia guidelines based on pH and temperature at the time of sampling, see BC ENV, 2019.

Dissolved Organic Carbon

Dissolved organic carbon (DOC) is the concentration of organic carbon dissolved in water and is made up of humic substances and non-humic substances (BC ENV, 1998). Humic substances make up most of the DOC found in aquatic systems, and non-humic substances includes molecules such as carbohydrates, fats and proteins (BC ENV, 1998). The concentration and type of DOC in aquatic systems can help identify sources of pollution and indicate whether DOC is natural or anthropogenic. Low DOC concentrations are natural and provide nutrients and buffering for aquatic life, but high DOC concentrations can impact pH and toxicity of certain metal complexes, as well as increase microbial growth which can decrease available oxygen (BC ENV, 1998). The BC ENV water quality objective for DOC is for the 30-day average to be within 20% of the background concentrations (BC ENV, 1998).

Biological Samples

Phytoplankton are naturally occurring microbial algae that are an important part of aquatic ecosystems, however; high concentrations of algae can contain toxic cyanobacteria and can deplete oxygen within the water column. In Elk Lake algal blooms are a result of high nutrients within the lake and generally occur when the lake is well mixed in winter months. The availability of phosphorus in the mixed lake increases algae production and leads to these large blooms.

Chlorophyll A

Chlorophyll A is a type of algal pigment whose measurement can indicate phytoplankton concentrations within water, and can also indicate water clarity (Nordin, 2015). Chlorophyll A concentrations are generally lowest in summer months when the Elk Lake is stratified, and highest in winter months when the mixed lake increases nutrients at the surface resulting in algae blooms. The objective for Chlorophyll A in Elk Lake is a mean summer range of 1.5-2.5 µg/L (CRD, 2020).

Methods

BC ENV data were sourced from the B.C. Lake Monitoring Network, Elk Lake Center (EMS ID 1100844) file name EMSWR_Rus_092537 (BC ENV, 2023). Data were sorted by parameter, depth and date, and then relevant parameters were copied to a master excel file used to create the tables and graphs in this report. Historic data from the BC ENV were inconsistent between years, months, and sample depths, and were a challenge to compare. Where appropriate, data were averaged across depths, or graphed separately to show data across consecutive years. The main objective of displaying these historic data was to compare water quality trends from previous decades with more recent data and future data to monitor effectiveness of the oxygenation system being installed.

CRD data were provided in three separate files, then amalgamated into the master excel file. CRD data files were labelled CRD Elk Lake Data (7319), Lisa Rodgers Elk Beaver Lake Data, and CRD2019-2021ElkBeaverLakeData. CRD data from 2019 to 2022 were fairly consistent between depths and were sampled in most months during this time frame. Most of the CRD data were uploaded and included in the BC ENV database, but were presented separately in this report to maximize available data and compare to historic data.

Where duplicate samples were taken, an average was used as the measurement unless otherwise stated. Unit conversions were carried out through excel to reduce error (ie: µg to mg). Parameter specific data analysis methods are explained in the results section for ease of reading.

All data were compared to the BC ENV water quality guidelines (WQG) or water quality objectives (WQO) for the protection of aquatic life or for recreation use. Specific objectives for water quality in Elk Beaver Lake from the CRD Elk Beaver Lake Watershed Management Plan were also used.

Results

Water quality results are organized by physical parameters, chemical samples, and biological samples to match how they are presented in the CRD Elk Beaver Environmental Management Plan.

Physical Parameters

Dissolved Oxygen

Available BC ENV dissolved oxygen (DO) data began in 1993 and were sampled at 2m intervals from depths of 0-12m in May to September. DO data at 17 m (1 m off the bottom) were unavailable until 2014. DO data from other years were limited to one or two sample dates and were difficult to compare as a time series. DO/depth profiles were created for February/March (mixed lake) and August (stratified lake) to show trends for years where those data were available. DO data were graphed as a time series at 17m from 2019-2021 to show monthly fluctuations at the bottom of the lake. Data provided by the CRD were within the BC ENV database, so only one dataset was used. DO data were compared to the BC WQO of >5mg/L for the protection of aquatic life (BC MOE, 1981). Recorded methods for measurement of dissolved oxygen included meter, hydrolab, and DO meter.

Figure 6 below shows a dissolved oxygen depth profile from 2003-2021 for February and March. Data from both months were used to maximize comparisons across years, as some years spring sampling was conducted in February, and other years in March. DO data from 2018 and 2020 were removed from the graph because they were very similar to other years and complicated the graph.

Surface DO ranged from 10.95 mg/L in Feb 2014, to 14.28 in Feb 2017. From 2003-2021 DO did not seem to increase or decrease over time, and instead fluctuated from year to year. At all depths in February and March the DO was above the WQO of >5mg/L and therefor protective of aquatic life.

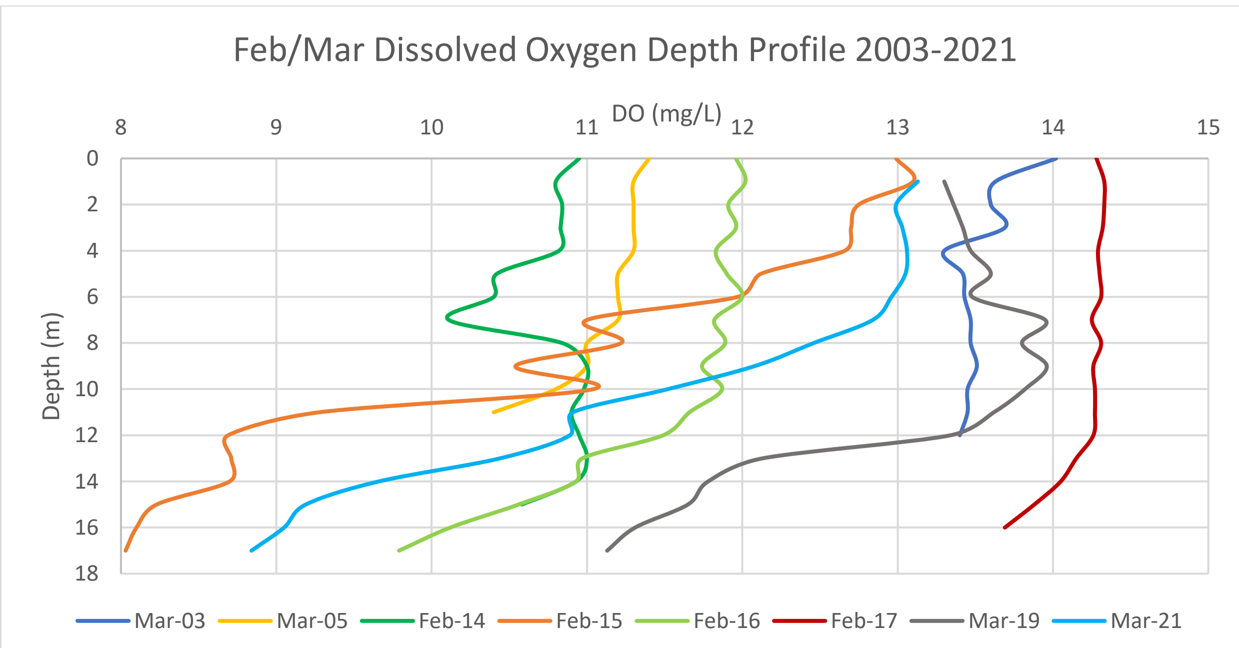

Figure 6: Feb/Mar Dissolved Oxygen Depth Profile 2003-2021

Key Finding: Spring DO was supportive of aquatic life at all depths from 2003-2021

Figure 7 below compares August DO measures across depths from 1993-2021 for years where August data were available. DO data from 2015, 2016, 2018 and 2020 showed duplicate trends to other years and were removed from the graph for ease of viewing. The WQO of >5 mg/L is shown with a red dotted line. Some years did not include all depths, and recent years sampled at 1m, while previous years had sampled at 0 or 0.5 m.

August DO data ranged from 8.66 mg/L in 2019 at 1m, to 9.72 mg/L in 2021 at 1m. DO dropped below the WQO in all years between 7m and 9m, and was unsupportive of aquatic life below these depths. DO trends in August from 1993 to 2021 do not show increasing or decreasing DO over time, and instead fluctuate between years. For example; 2016 and 2019 had the lowest August DO levels at the surface and 1994 and 2021 had the highest DO levels at the surface.

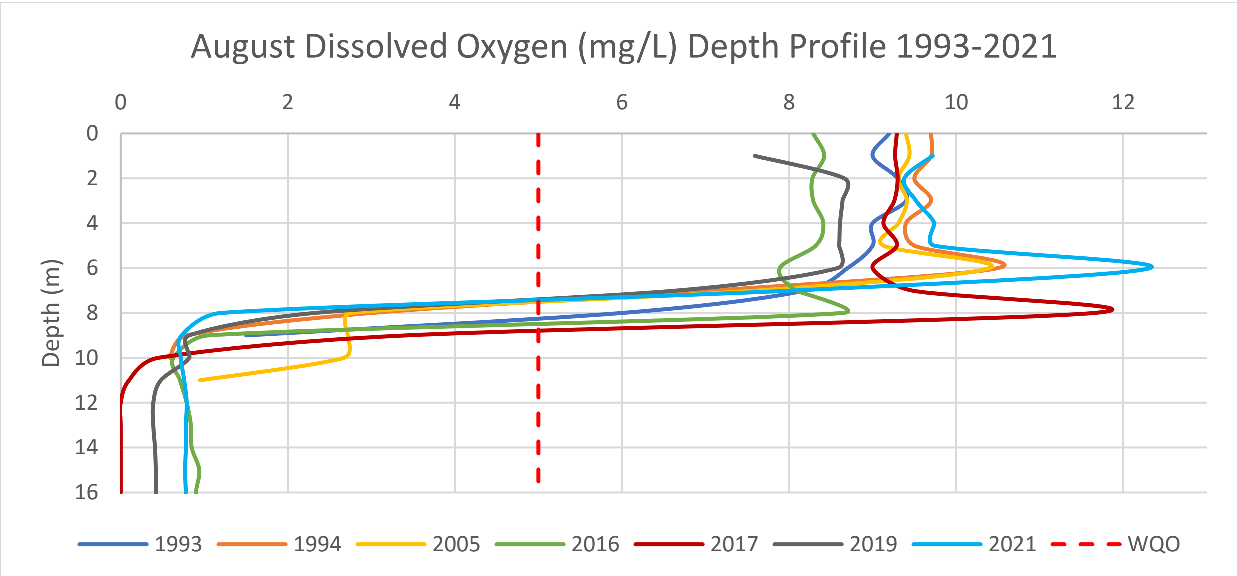

Figure 7: August Dissolved Oxygen Depth Profile 1993-2021

Key Finding: August DO was unsupportive of aquatic life below depths of 8-9m from 1993-2021

Figure 8 below shows monthly DO concentrations at 17m from March 2019 to November 2021. DO concentrations were below the minimum WQO of 5 mg/L from approximately May to November of each year, and above the 5mg/L objective by November or December of each year. This means that DO at the lake bottom was unsupportive of aquatic life from May to November.

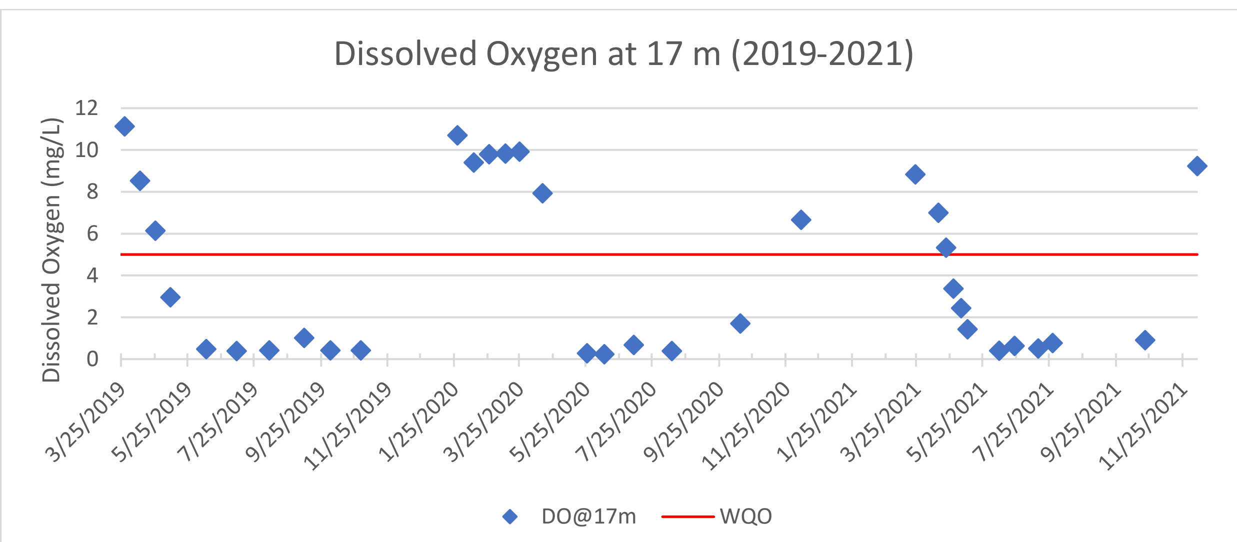

Figure 8: Dissolved Oxygen at 17m 2019-2021

Key Finding: DO at lake bottom was unsupportive of aquatic life from May to November

Temperature

BC ENV had inconsistent temperature data from 1993 to 2018. To best represent these data, August measurements were compared in a temperature depth profile for years when those data were available. BC ENV deep water temperature data were not available until after 2014. CRD temperature data from 2019 to 2021 were available for most months measured at 1m intervals from the lake surface down to 16-18m depending on year. CRD data were graphed in temperature depth profiles for 2019, 2020 and 2021. All available BC ENV and CRD temperature data were combined and graphed to show deep water trends from 2014 to 2021 and surface trends from 1993 to 2021. The Elk Beaver WMP has a WQO of 15°C maximum in the hypolimnion for protection of aquatic life.

Figure 9 shows available BC ENV August temperatures by depth for 1993, 1994, 1995, 2005, 2016, 2017 and 2018. The coolest summer during these years was in 1995 with surface temperatures reaching 19.8°C. Surface temperatures in 1994 and 2005 were the warmest during this time frame at 23.9°C and 24.3°C respectively. The thermocline in 1994 and 2005 shows a temperature drop of 12°C between 5m and 8m. Hypolimnion data were not available for most years in this timeframe, but thermocline temperatures dropped below 15°C which would indicate that deep water temperatures were within the WQO for Elk Lake.

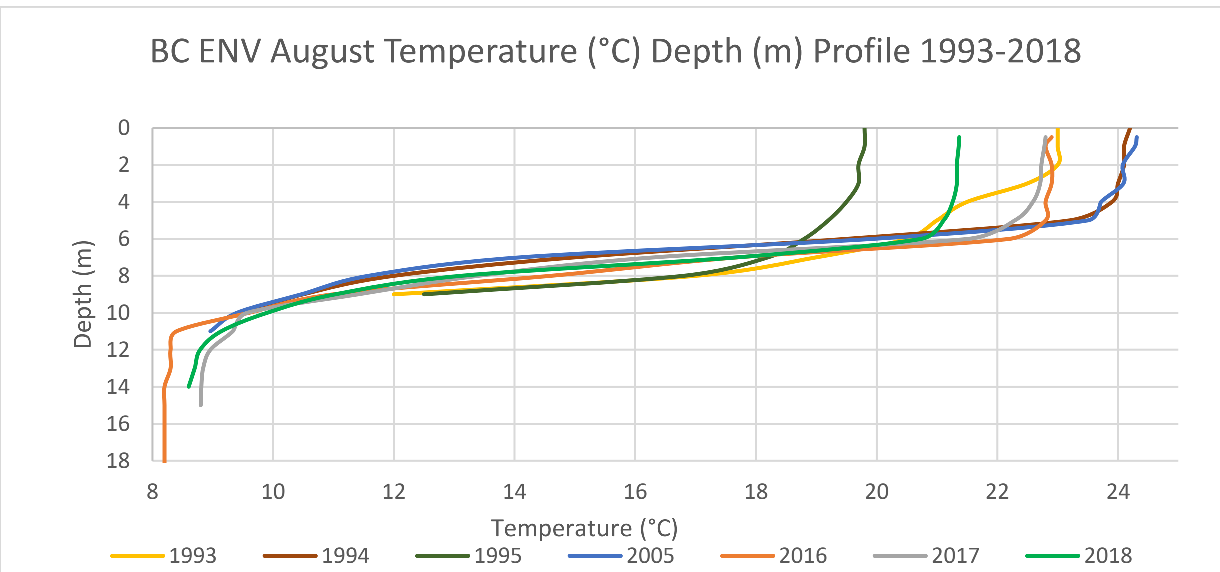

Figure 9: BC ENV August Temperature Depth Profile 1993-2018

Key Finding: August temperatures at 17m were protective of aquatic life from 1993-2018 where data were available

Surface temperature trends of available BC ENV and CRD data are shown in *Figure 10* from 1993 to 2021. Sampling depth varied by year and data from 0m, 0.5m, and 1m are shown to maximize available dates. From 1993 to 1995 only summer months were sampled, which explains why lower temperatures are not observed during that time frame. From 2002 to 2016 most data represent winter temperatures except for one summer temperature in 2005. After 2016 temperatures were recorded regularly throughout all the seasons which best shows the temperature fluctuations between winter and summer months. Surface temperatures ranged from 2.72°C in 2017 to 27.7°C in 2021.

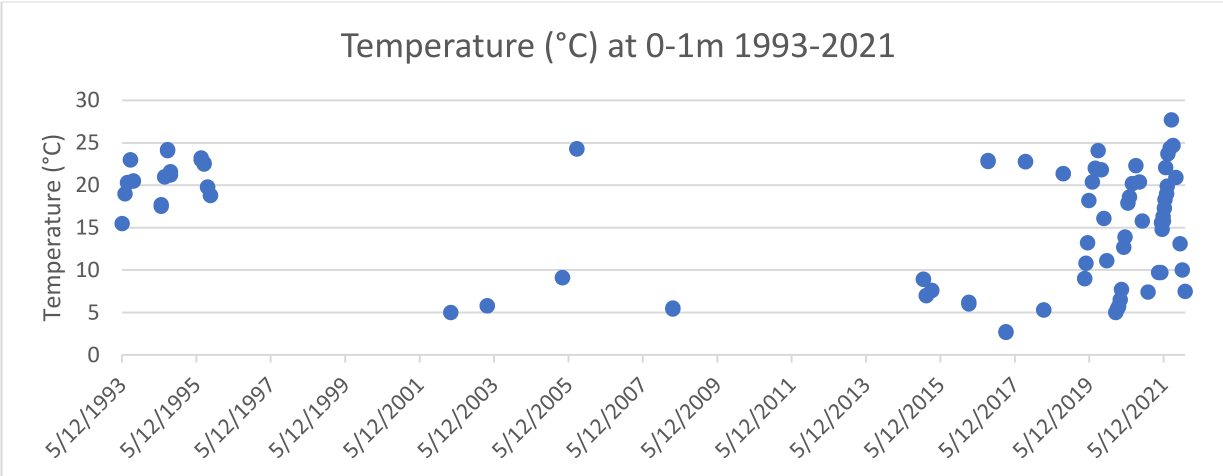

Figure 10: Temperature at 0-1m 1993-2021

Key Findings: available temperatures were below 25°C from 1993-2020 but spiked to 27.7°C in 2021

Figure 11 below shows averaged temperatures at 12-18m deep throughout the year from November 2014 through to November 2021. Temperature readings were taken bi-annually from 2014 to 2018, and monthly from 2018 to 2021. No earlier hypolimnion data were available. During this time frame all temperatures at the hypolimnion remained below the WQO of 15°C. Hypolimnion temperatures ranged from 2.64°C in February 2017 to 9.8°C in November 2021.

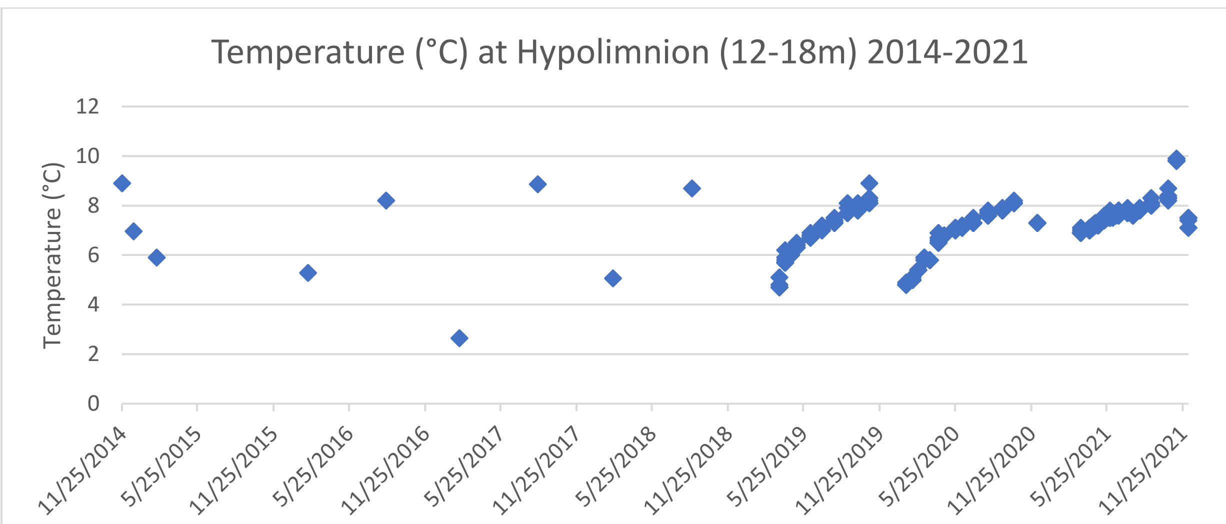

Figure 11: Temperature at Hypolimnion 2014-2021

Key Finding: Hypolimnion temperatures remained within the WQO for protection of aquatic life

CRD data were used to create a temperature depth profile for 2021 shown in *Figure 12* below. No data were available for January or February, but March shows the start of a thermocline with the surface temperature of 9.9°C and a deep-water temperature of 7.1°C. By April the lake appears to be fully stratified. In July the effects of a local heat dome can be observed with an extreme temperature of 27.7°C at the lake surface, though the deep water remained at 7.6°C. By October the surface temperature dropped to 13.1°C and the hypolimnion warmed slightly to 8.3°C. November and December show a well-mixed lake where the temperature is the same at all depths. Hypolimnion temperatures in all months remained below the WQO for Elk Lake for the protection of aquatic life.

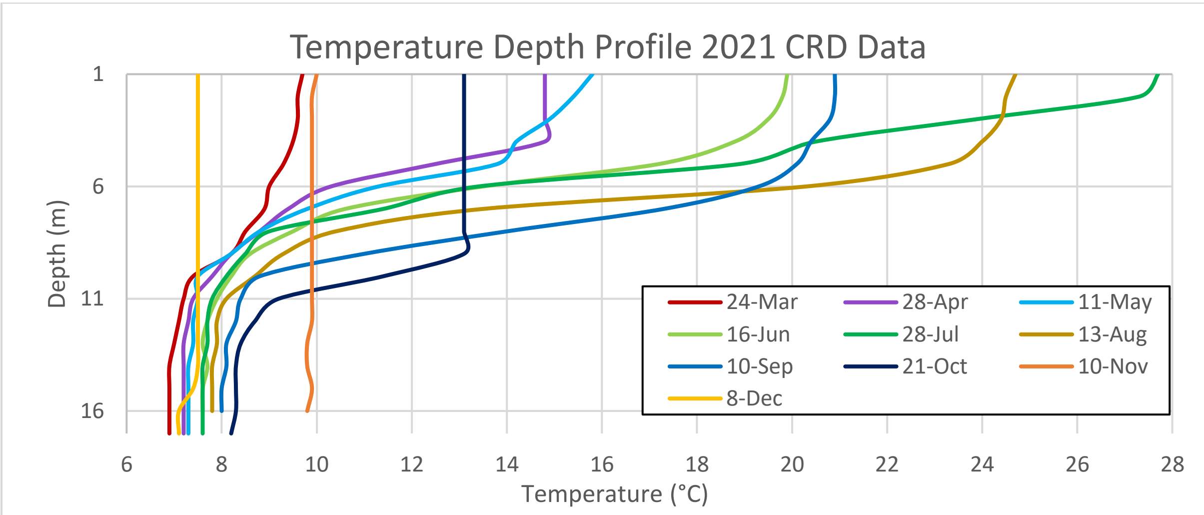

Figure 12: Temperature Depth Profile 2021 CRD Data

Key Findings: Stratification occurred from March to November and surface temperatures were unsupportive of aquatic life in summer months.

pH

BC ENV pH data were limited to one or two samples per year, with most data collected in spring, and some data collected in summer. pH samples were taken at different depths, with some at discrete depths and others at composite depths. To maximize available data from 1988 to 2021, pH data were graphed at 0-1m, 10-12m, and 15-17m depths, but not averaged if more than one depth was measured. BC guidelines for the protection of aquatic life are 6.5-9.0 for pH (BC ENV, 2021).

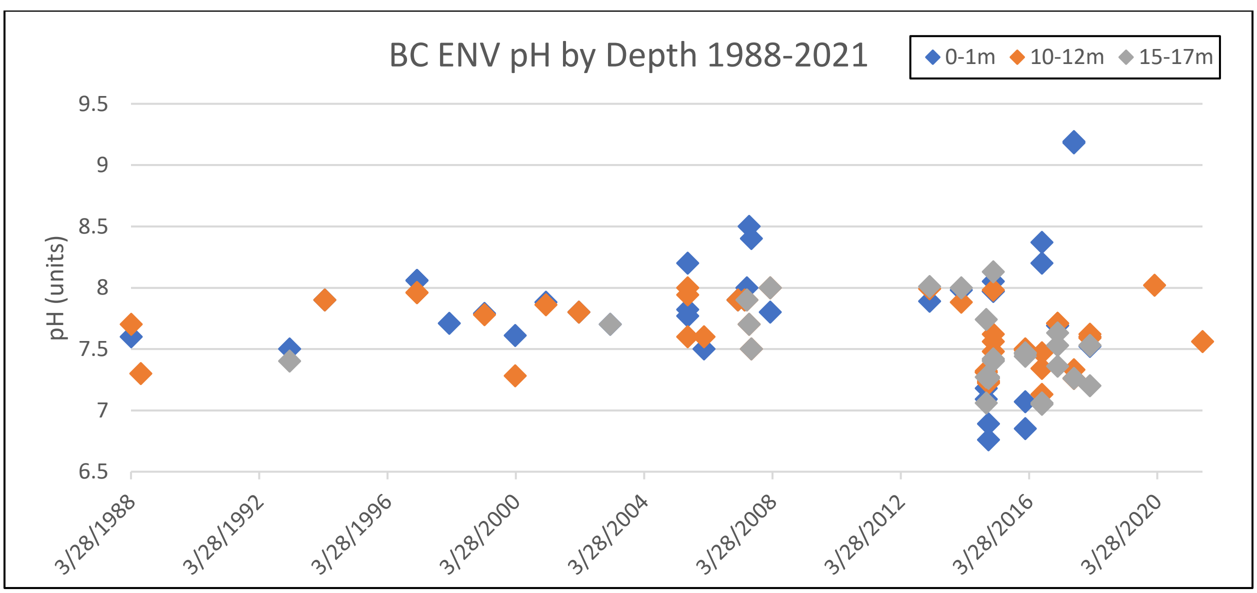

Figure 13: BC ENV pH by Depth 1988-2021

Key Finding: pH remained within guidelines for all samples except on Aug 23, 2017 surface pH was 9.2

CRD pH data included discrete measurements at each meter depth for most months from 2019 to 2021. Data were graphed at discrete depths of 1m, 9m, and 16m to best compare to BC ENV data. CRD pH measurements were also graphed in a depth profile by month for 2019. CRD pH data from 2020 and 2021 were not shown graphically due to their complexity which made the graphs too busy for easy viewing.

Figure 14 below shows that pH was generally higher at the surface and lower at lake bottom. Surface pH increased and became more basic from May to August in 2019, and again in September 2021. In March 2020 a temporary acidification can be observed at all depths with pH ranging from 5.8 at 16m to 6.5 at the surface, this is likely due to a calibration error (Rick Nordin, personal communication, 2023). All pH measurements were within guidelines except the low measurements assumed to be caused by calibration error on March 12, 2020.

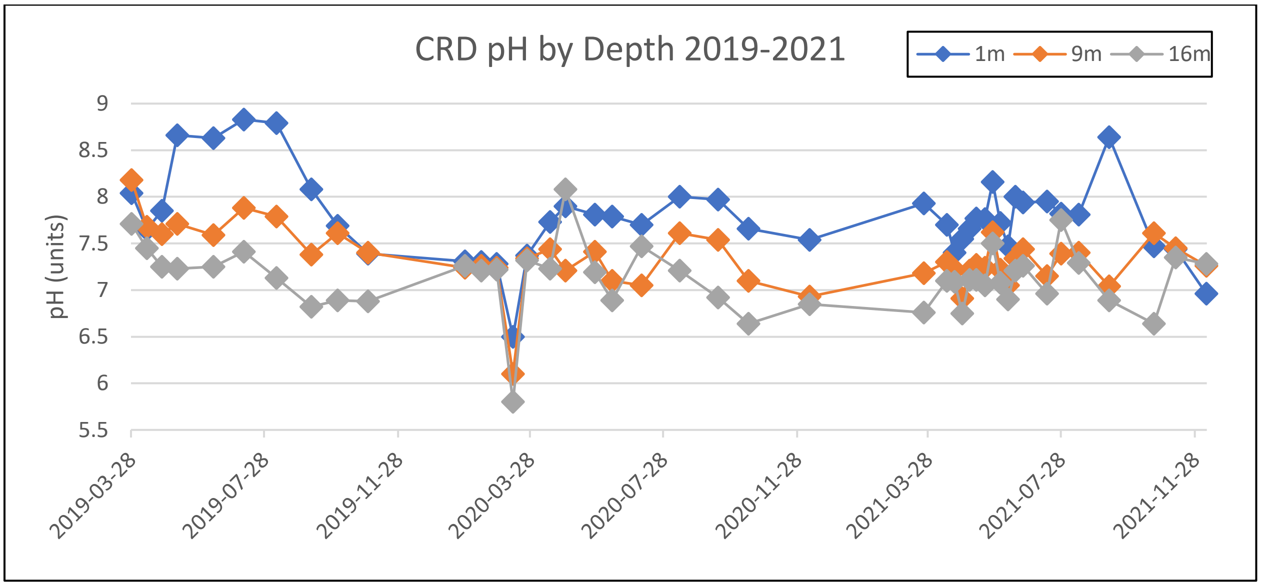

Figure 14: CRD pH by Depth 2019-2021

Key Findings: pH levels remained within guidelines and generally decreased with depth; a calibration error likely resulted in low readings at all depths on March 12, 2020

Figure 15 below shows a pH depth profile from CRD data in 2019. PH remained within guidelines in 2019, and fluctuated between months, with highest surface pH levels in summer months. PH dropped with depth, and the lowest pH values in deep water also occurred during summer months.

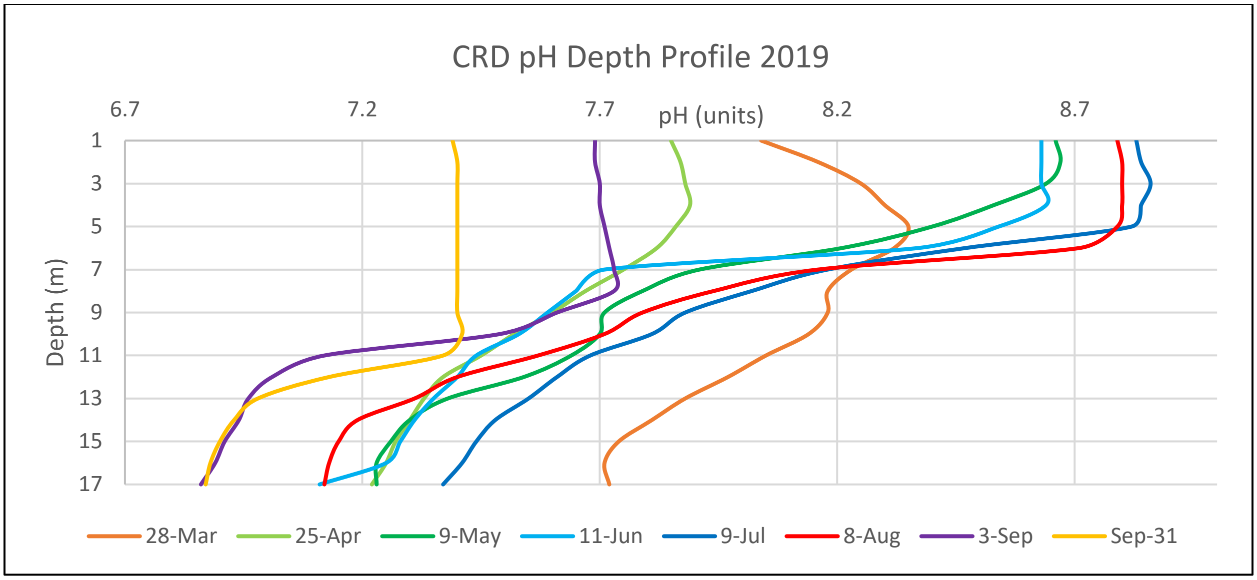

Figure 15: CRD pH Depth Profile 2019

Key Findings: pH levels decreased with depth, summer pH was high at the surface and lower at depth

Specific Conductivity

BC ENV specific conductivity data were presented graphically from 1988 to 2022 from composite samples. Surface samples were measured from 0-6m and deep samples were measured from 9-16m. Very few samples were measured at 7 or 8 m therefore these were excluded from the graph.

Figure 16 below shows that surface and deep-water conductivity were similar during winter months but increased with depth during summer months. Trends show a general increase in specific conductivity at both surface and deep water from 1988 to 2022.

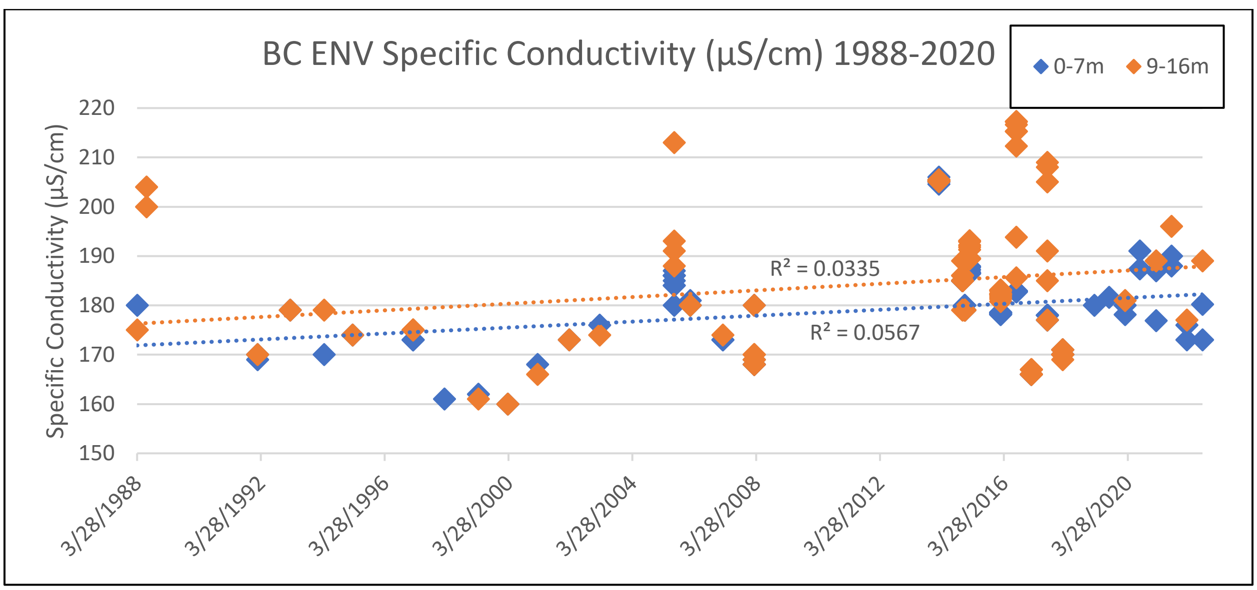

Figure 16: BC ENV Specific Conductivity 1988-2020

Key Finding: Specific Conductivity showed a slight increase over time from 1988 to 2021 at all depths

Specific conductivity depth profiles were created with CRD conductivity data for 2019, 2020 and 2021, but only the 2019 profile was presented in this report as the other two years were difficult to view. Conductivity increased dramatically at depths below 11m from June through October during stratification.

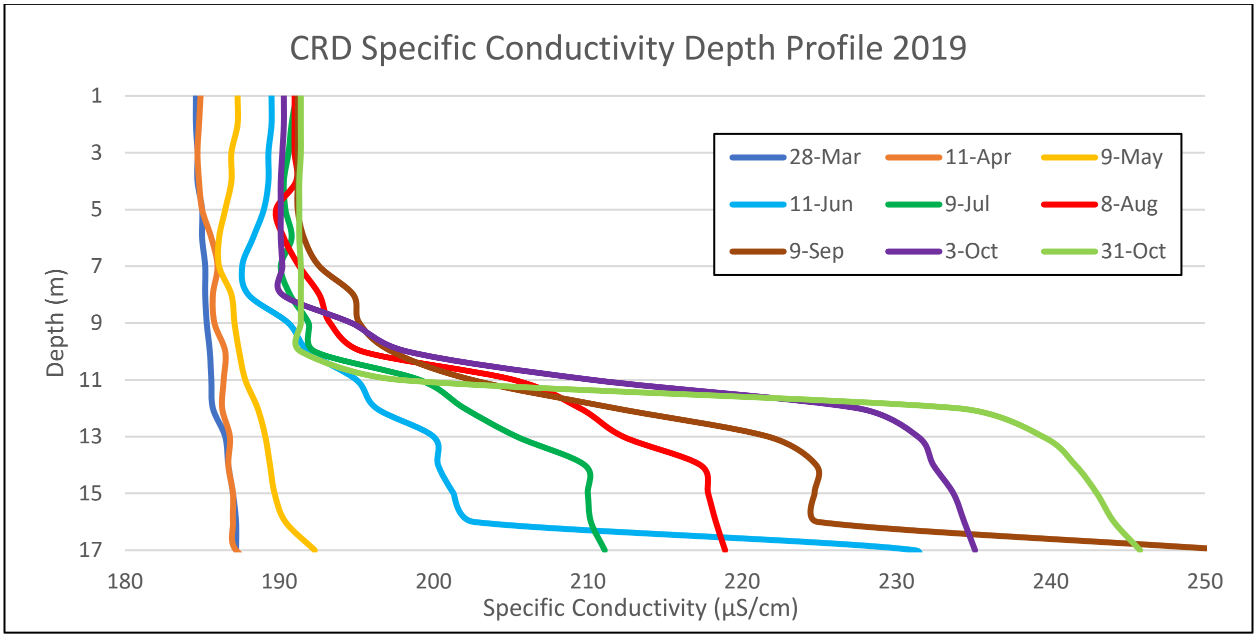

Figure 17: CRD Specific Conductivity Depth Profile 2019

Key Finding: Specific conductivity increased during summer months at depths below 11m

Water Clarity

Water clarity was measured with a secchi disk from the lake surface. BC ENV water clarity data were presented in four graphs each with 3–4-year time frames and the same y-axis for ease of comparison. The data were presented this way because there were gaps in the data which made a continuous timeline from 1993 to 2021 difficult to view in a single graph.

From 1993 to 1995 water clarity was sampled during summer months in each year. Generally, clarity improved as the summer progressed except in 1995 when clarity remained around 5m throughout the summer. From 2002 to 2008 samples were taken in March except in 2005 an additional sample was taken in August showing a similar clarity to the March sample. From 2014 to 2022 water clarity was sampled in winter and summer, with winter clarity generally worse than summer clarity. Over time water clarity shows a general decline with summer visibility decreasing by approximately 3m in summer months from 2003 and 2022.

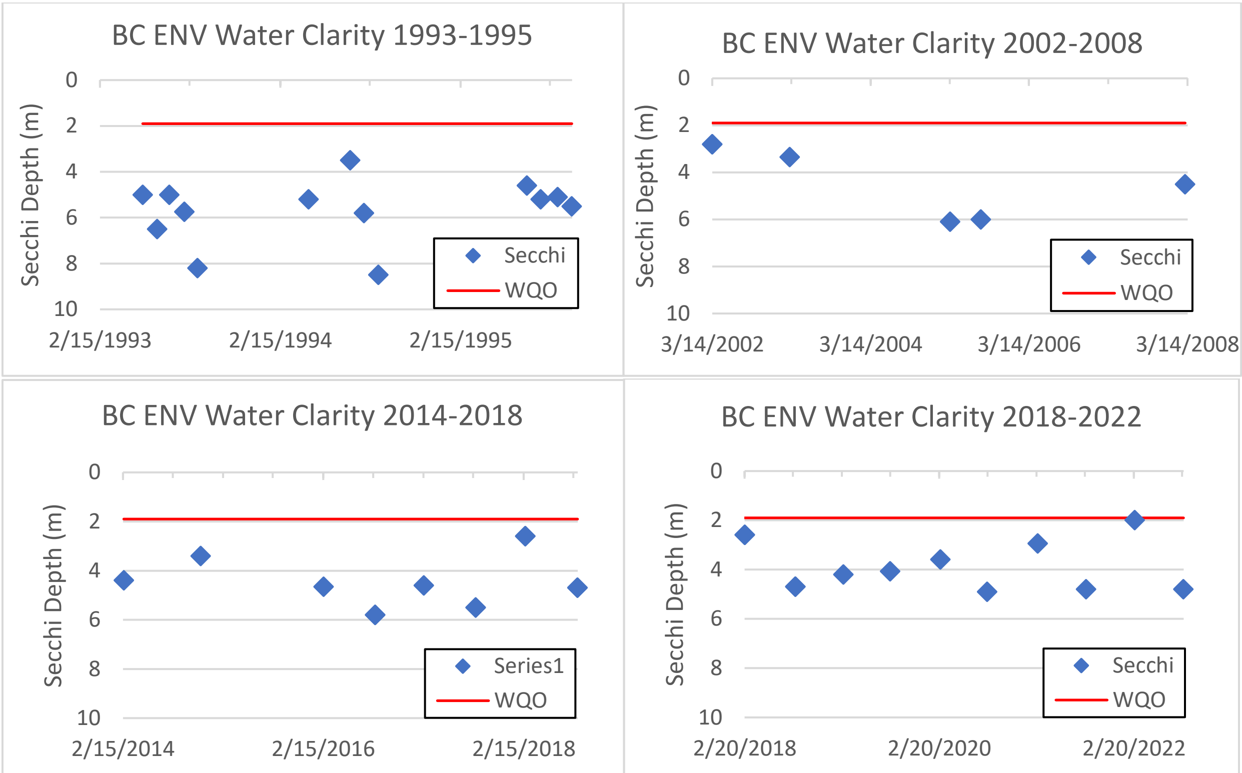

Figure 18: BC ENV Water Clarity 1993-2022

Key Finding: Water clarity decreased by 3m in summer months between 1993 to 2022

CRD water clarity data were presented in a single timeline from 2019 to 2021 and compared to the water quality objective of secchi disc observations greater than 1.9 m deep (CRD, 2020).

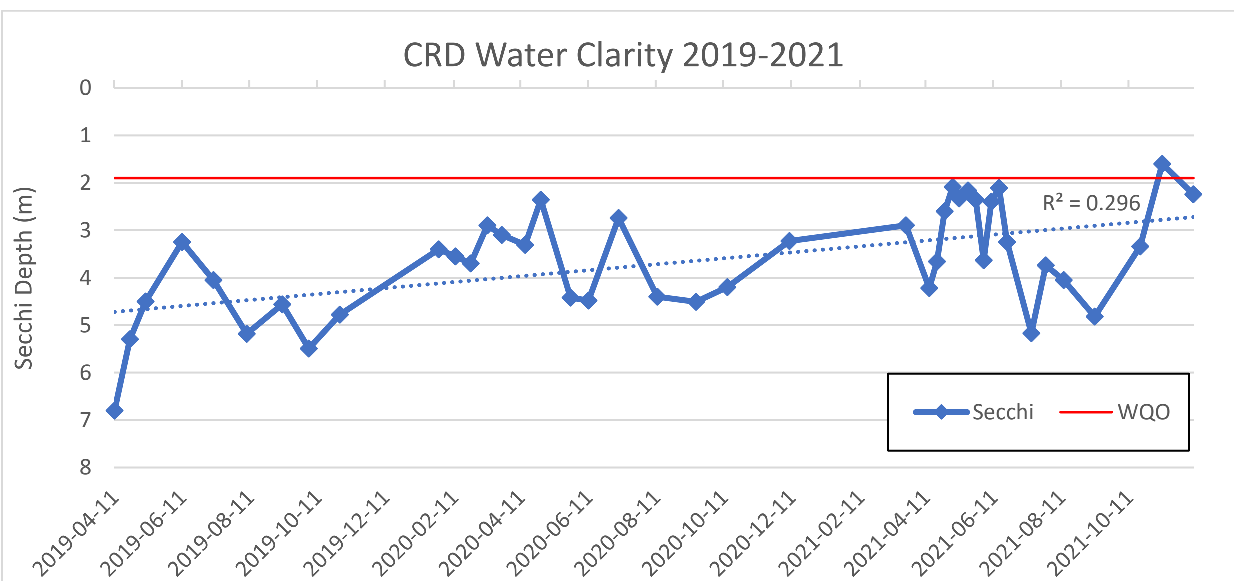

Figure 19: CRD Water Clarity 2019-2021

Key Finding: Water clarity generally decreased over time from 2019 to 2021

Chemical Samples

Phosphorus

The BC ENV phosphorus dataset included total phosphorus (T--P), ortho-phosphate dissolved, and phosphorus total dissolved. The CRD dataset for 2019-2022 included total phosphate (PO4-T) and ortho phosphate (PO4-O), and the Lisa Rodgers CRD dataset included total phosphorus (T-P) and ortho-phosphate. BC ENV T--P data from 2019 to 2021 matched the dates and values for the CRD PO4-T data, but there was a discrepancy in the parameter label (P--T vs PO4-T). CRD has confirmed that their data was labelled incorrectly, and what is labelled as PO4-T in the CRD database is in fact P-T.

Total Phosphorus

Spring overturn data were used to compare total phosphorus when the lake was expected to be well mixed. Spring overturn measurements can be used to evaluate phosphorus supply for summer algal growth (Nordin, 2022). Most of the historic spring overturn data from BC ENV was sampled in March or April each year. Due to gaps in data and variability in depths measured, and to maximize data presented, averages of surface depths and hypolimnion depths were calculated. The depth at which surface data and hypolimnion data could be combined were determined by three temperature depth profiles from CRD data in 2019-2021. Based on these profiles, the surface data used for spring turnover were calculated from depths of 0m-6m. A total phosphorus depth profile was also created from March to October in 2021 to visualize the phosphorus concentrations at various depths throughout the season. Not enough data were available to include winter months.

Some data points could not be included in the surface or hypolimnion graphs because they did not have sample depth specified in the data set. Only discrete samples were used to determine averages, as the composite samples appeared to be much higher than the corresponding discrete samples at the same depths. Further analysis to determine if contamination or other errors occurred during composite grab samples is needed, but not carried out in this report.

The BC ENV dataset specified the analytical method used for total phosphorus analysis in water, and these included: Dig Auto Ascorbic Acid, Colorimetric, Pursulf/H2SO4 Dig: Colm. The majority of the data were analyzed using the Dig Auto Ascorbic Acid method, so only data from that method was used in this report. Further analysis could be carried out to compare data from other methods used.

Surface spring turnover measurements of total phosphorus were taken every year from 1986 through to 2022, except for 1996, and from 2009-2013. The results are shown in *Figure 20* below. The BC objective for total phosphorus in lakes for the protection of aquatic life cannot be specified by a single concentration, and is instead suggested as a range of 5-15 µg/L, and the upper limit of 15 µg/L is depicted in *Figure 20* by a red line (BC ENV, 2023). The BC objective for total phosphorus in lakes for recreational use is 10 µg/L, and is shown in *Figure 20* with an orange line (BC ENV, 2023). The trend line of the data is shown in blue dashes with an R^2 value of 0.3093. Every year after shows that surface spring total phosphorus exceeded both guidelines.

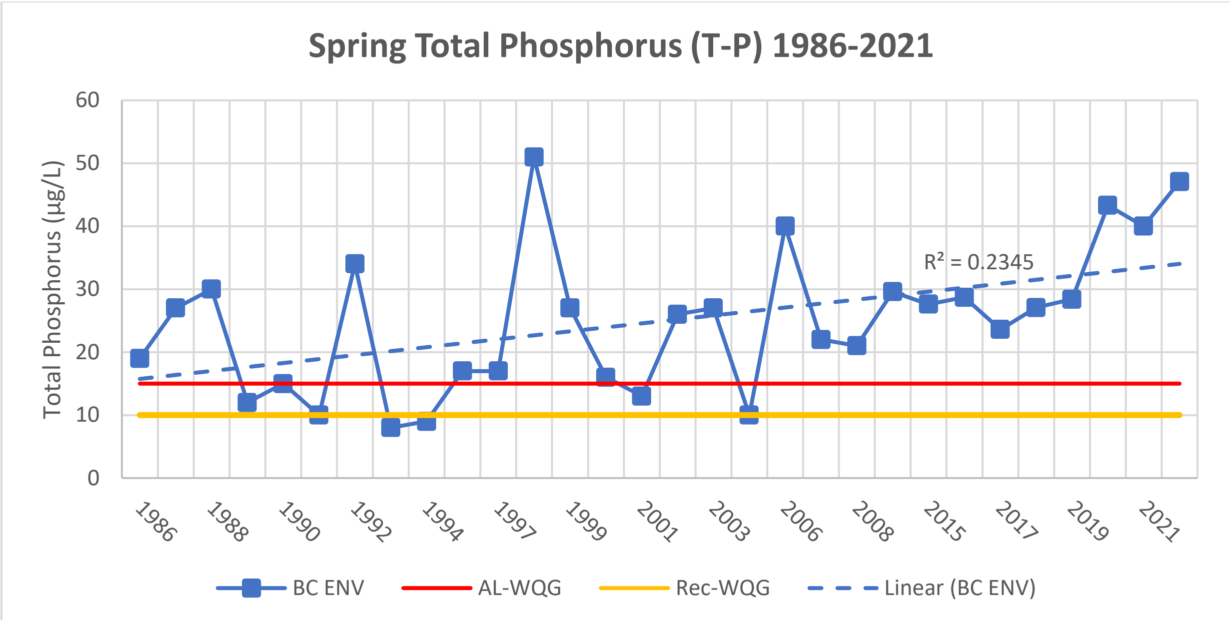

Figure 20: Spring Total Phosphorus 1986-2021

Key Finding: total phosphorus at spring turnover has increased between 1986 and 2021

Ortho-phosphate

BC ENV data for ortho-phosphate (ortho-P) were very limited and inconsistent between discrete depths and composite samples, as well as months, so were therefore not shown graphically. CRD ortho-P data were more robust from 2019 to 2021 and were measured at 1m and 16m depths. These data are shown below in *Figure 21* as a time series by depth.

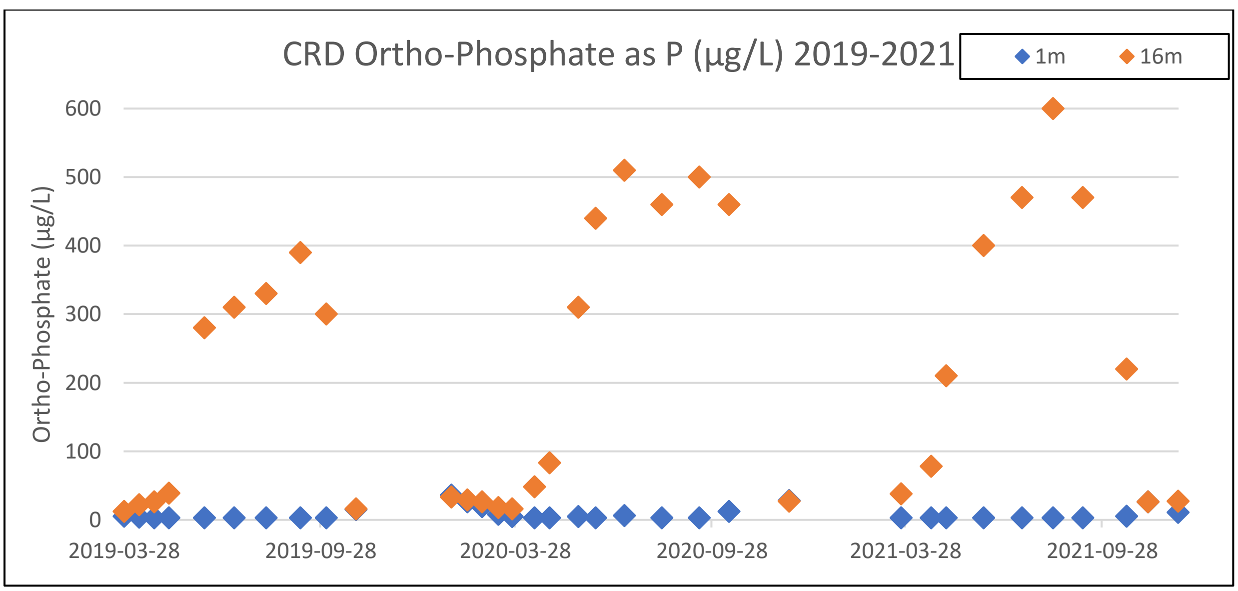

Figure 21: CRD Ortho-Phosphate 2019-2021

Key Finding: Ortho-P remained low at the surface but increased greatly in summer months at 16m

An ortho-P depth profile was created for 2021 and compared to a total phosphorus depth profile for 2021 in *Figure 22* below. Ortho-P and total P show very similar trends for most months with low measures at the surface and increasing concentrations with decreasing depth.

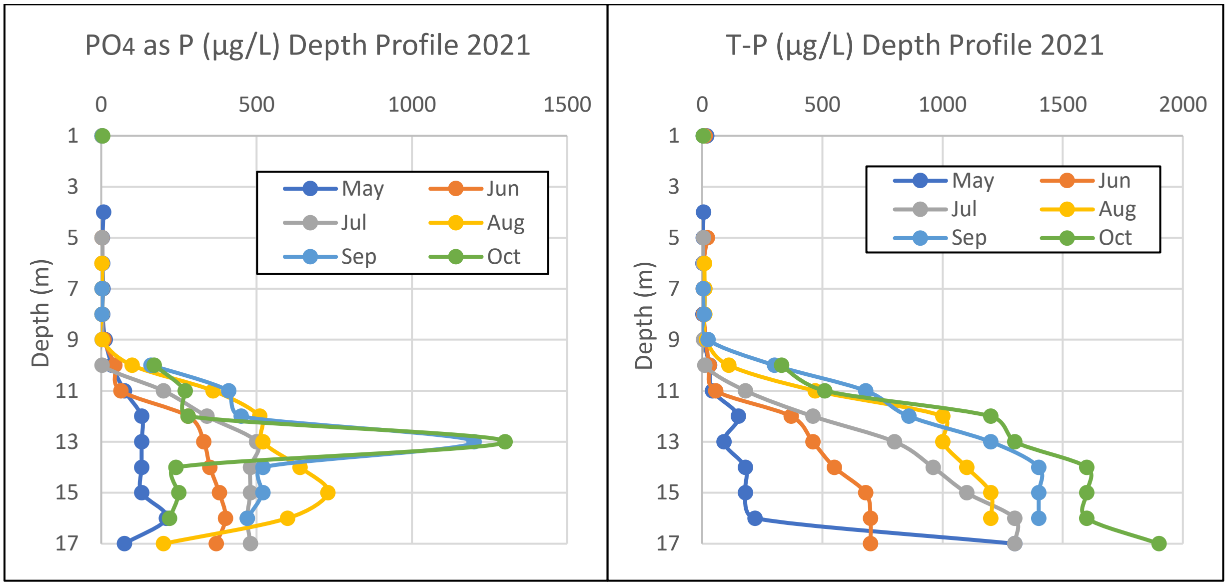

Figure 22: Ortho Phosphate and Total Phosphorus Depth Profiles 2021

Key Finding: ortho-P and total P show similar trends and increase with depth in summer months

Nitrogen

Nitrogen data were presented in separate graphs for ammonia, nitrate + nitrite, and total nitrogen. Ammonia represents reduced organic nitrogen and nitrate/nitrite are the oxidized inorganic form of nitrogen (Nordin, 2015).

BC ENV ammonia, nitrate + nitrite, and total nitrogen data were presented graphically by depth ranges of 0-6m, 10-17m. There were very limited data points for 7-8m depths so these were excluded for ease of comparison. Data points were not averaged for these depths, and were instead all represented to show any major discrepancies between depths. Date ranges with available data varied between parameters, and all available BC ENV data were graphed up to 2019.

CRD ammonia, nitrate + nitrite, and total nitrogen data were graphed at 1m and 16m, as these were the only depths measured from 2019 to 2021.

Ammonia

Figure 23 shows BC ENV ammonia data from 1986 to 2014 at 0-6m and 10-17m depths. Ammonia remained below 0.2 mg/L on almost all dates except on October 8 1987 and August 1 2007 ammonia levels spiked to 1.19 mg/L and 0.85 mg/L respectively. Higher ammonia measures were observed at lower lake depths in September 1987 and August 2007.

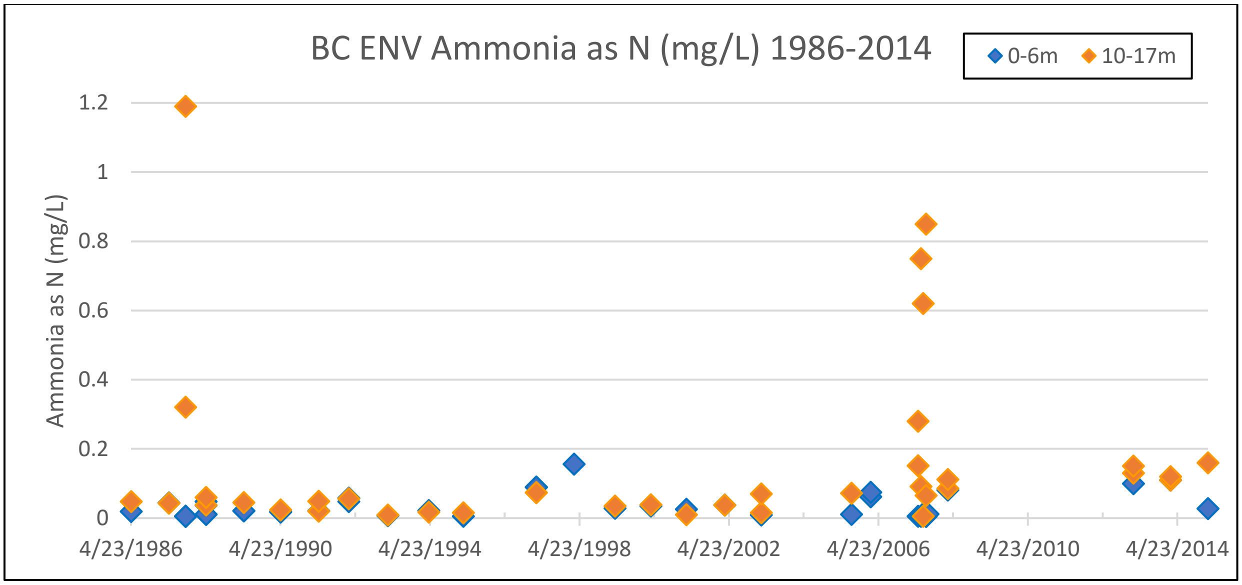

Figure 23: BC ENV Ammonia 1986-2014

Key Finding: Ammonia remained low except in Oct 1987 and Aug 2007 deep water ammonia spiked

CRD ammonia is shown below in *Figure 24* from 2019 to 2021 at 1 m and 16 m depths. Surface ammonia remained below 0.2 mg/L, but at 16 m ammonia levels ranged from 0.46 to 1.9 mg/L and increased monthly from March through October, with highest levels observed in October of each year.

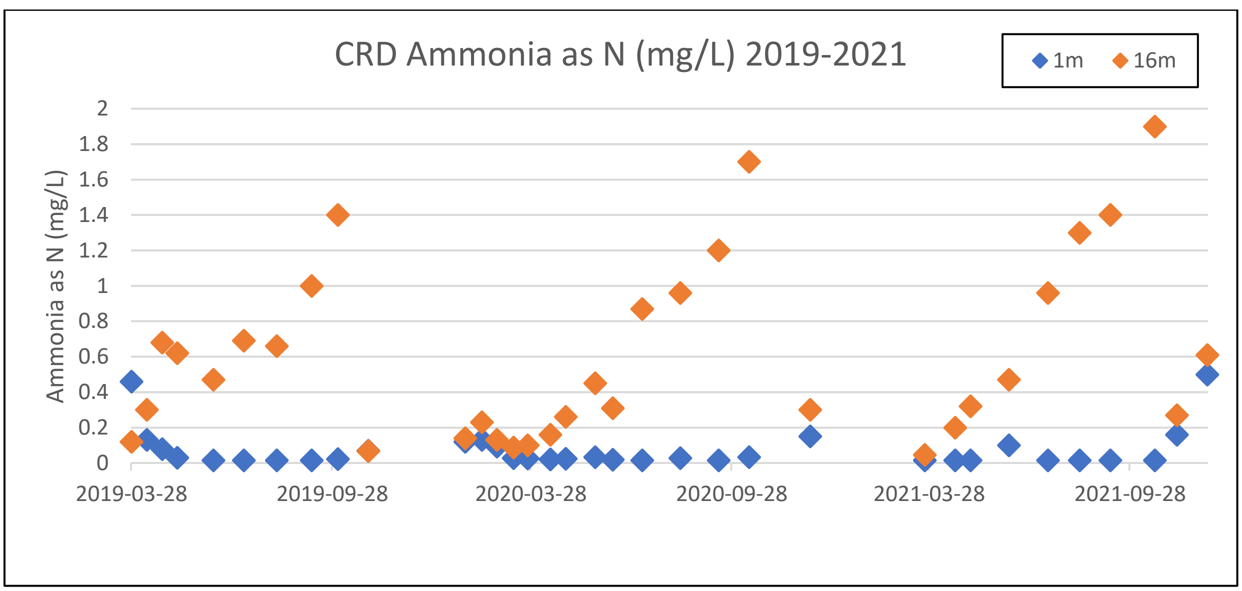

Figure 24: CRD Ammonia 2019-2021

Key Finding: Ammonia at 16 m deep increased monthly from March to October

Both BC ENV and CRD ammonia data show increased levels at the lake bottom during stratification when oxygen was depleted at the hypolimnion.

Nitrate + Nitrite

BC ENV nitrate + nitrite measurements were graphed at surface (0-6m) and hypolimnion (9-17m) from 1986 to 2018. Most samples were taken in April or May, with one occurring in July 2007. Overall nitrate + nitrite levels remained fairly consistent in years they were sampled from 1986 to 2019.

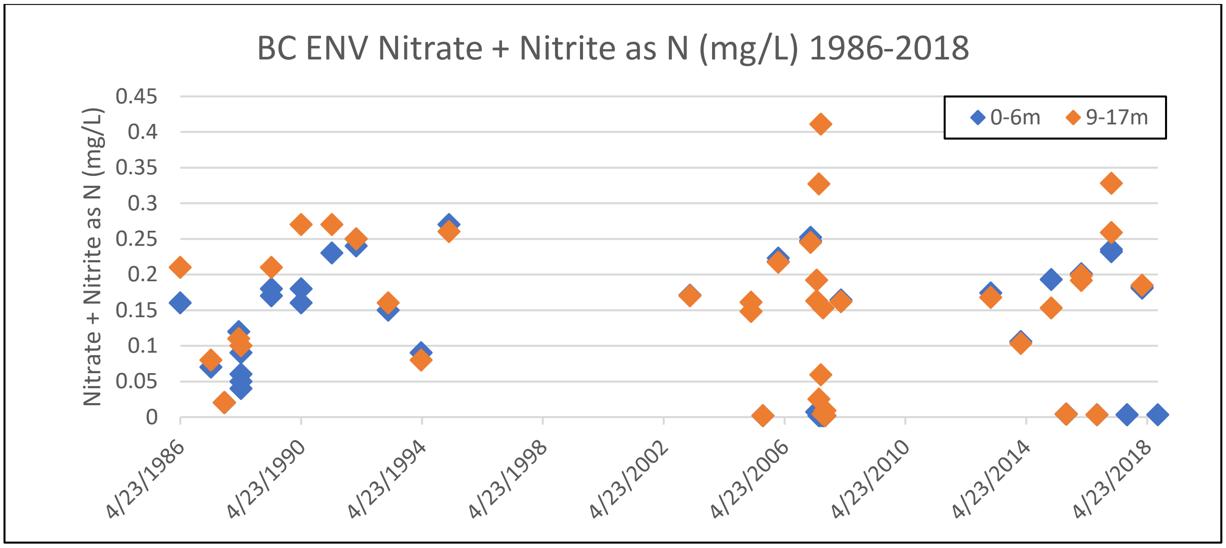

Figure 25:BC ENV Nitrate + Nitrite 1986-2018

Key Finding: Nitrate + Nitrite remained similar for sample years from 1986 to 2018

CRD nitrate + nitrite data were measured during spring overturn and in summer months from 2019 to 2022. Data were presented graphically in *Figure 26* below at depths of 1m and 16m showing discrete measurements. Trends show that both surface and deep-water nitrate + nitrite were below detectable levels in summer months consistently, and increased during winter months. Deep water samples show slightly higher nitrate + nitrite than surface samples during the winter, but by February of each year surface and deep-water levels matched and remained the same until the following winter.

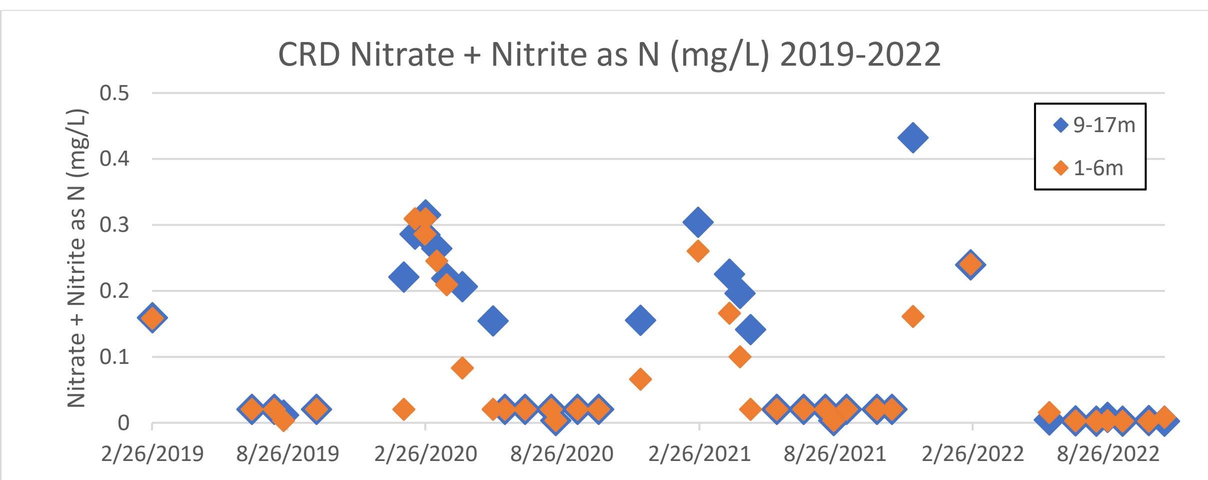

Figure 26: CRD Nitrate + Nitrite 2019-2022

Key Finding: Nitrite + Nitrite remained low during summer months and increased in the winter

Total Nitrogen

The BC ENV database contained total nitrogen measurements from 1997 to 2018 at surface and below 9m, however, most data were taken in 2007 and 2014. Due to inconsistent data the total nitrogen graphed below in *Figure* 27 appears to increase over time but there were not enough to data to confirm this. Total nitrogen data were graphed discretely per sample and were not averaged. Surface total nitrogen remained low throughout the time series, but total nitrogen below 9 m depths appeared to increase with depth.

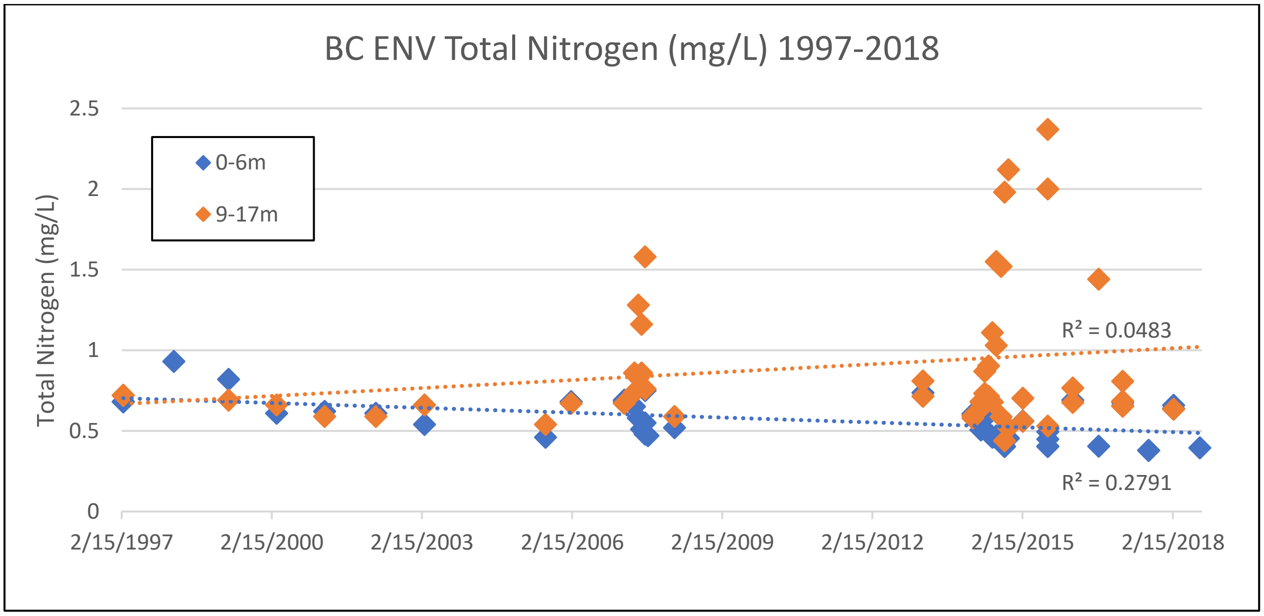

Figure 27: BC ENV Total Nitrogen 1997-2018

Key Finding: There were not enough BC ENV data to confidently assess long-term Total N trends

CRD total nitrogen data was measured almost every month from 2019 to 2022 at 1m and 16m. These data were graphed in *Figure 28* below, and show a more robust picture of total nitrogen than the BC ENV data. Surface total nitrogen remained relatively low, but total nitrogen increased with depth. Deep water total nitrogen was lowest in late winter and increased throughout the year with highest measurements occurring in October and November annually.

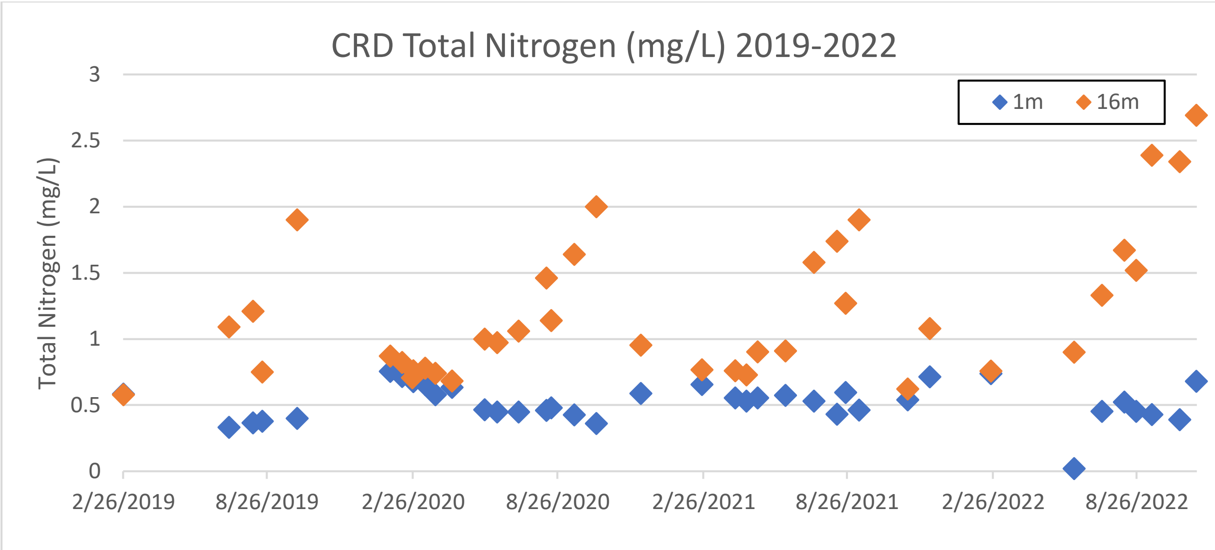

Figure 28: CRD Total Nitrogen 2019-2022

Key Finding: total nitrogen was highest at 16 m depth and showed annual cyclical patterns

Dissolved Organic Carbon

The BC ENV database only contained a few dissolved organic carbon (DOC) measurements in 2006 and 2007 and one DOC measurement in 2014 so data were not shown graphically. During this time frame surface DOC ranged from 5.0 to 6.8 mg/L and hypolmnion DOC ranged from 4.2 to 5.8 mg/L.

The CRD measured DOC almost monthly from 2019 to 2022, and these data are shown graphically in *Figure 29* below. Surface and deep water DOC were similar on most dates, and a severe spike was measured in February 2020 at both depths.

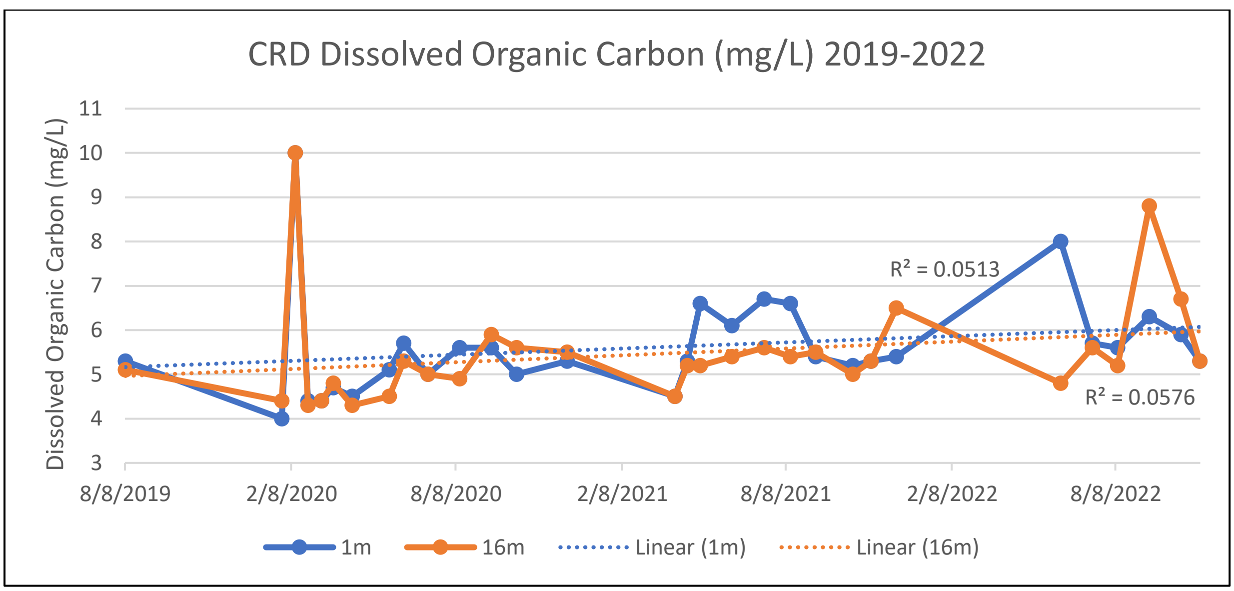

Figure 29: CRD Dissolved Organic Carbon 2019-2022

Key Finding: Surface and deep-water DOC increased slightly between 2019 to 2022

Biological Samples

Chlorophyll A

Chlorophyll A data were presented graphically by date from 1988 to 2022 at surface depths of 0.2m-1.0m to maximize available data. Summer mean Chlorophyll A data were also presented graphically as annual averages from 0m-6m depths and from July, August and September of each year. Summer means were compared to the water quality objective range of 1.5-2.5 µg/L (CRD, 2020).

Figure 30 below shows Chlorophyll A surface measurements from 0.2m-1.0m from 1988 to 2022. This graph appears to show Chlorophyll A increasing over time, however; the first two groups of Chlorophyll A data were measured in summer months, and the rest were measured in winter which show higher results. Since Chlorophyll A measurements were taken at different times of the year, *Figure 30* does not show timeline trends very well.

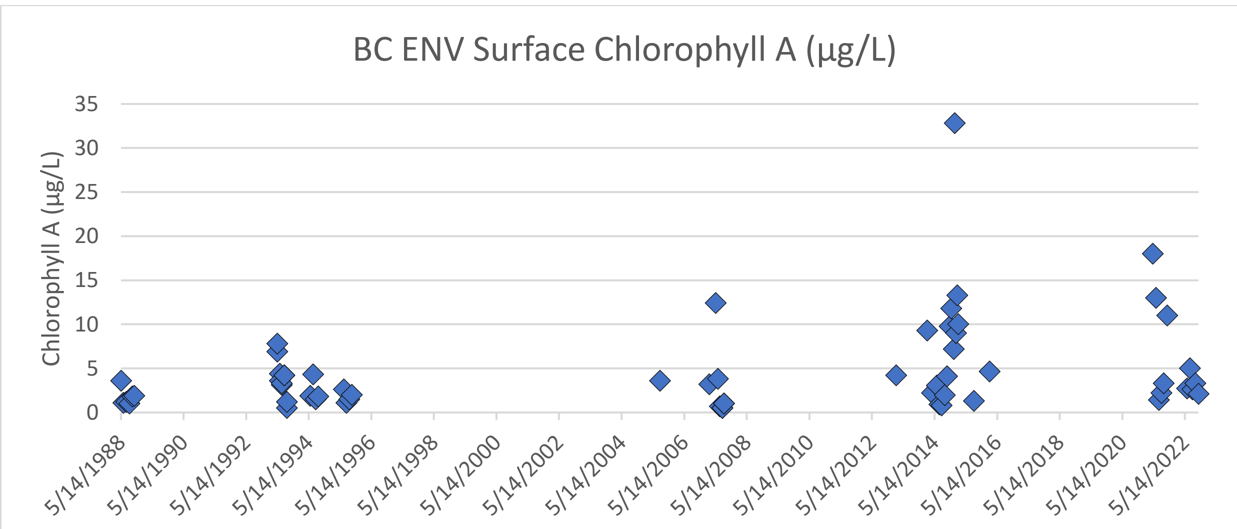

Figure 30: BC ENV Surface Chlorophyll A 1988-2022

Key Finding: Data were too inconsistent to draw conclusions about surface Chlorophyl A

Summer mean Chlorophyll A is shown below in *Figure 31*. Measurements were not taken consecutively until 2014, but six historic years are included to compare levels. In 1988 Chlorophyll A summer mean levels were below guidelines, but rose above the maximum guideline in 1993 and 1994, and spiked considerably in 2005. Summer mean Chlorophyll A dropped to within guidelines for years it was sampled from 2007 t0 2015, but many years are missing. In 2019 and 2022 Chlorophyll A spiked again and matched concentrations seen in 2005.

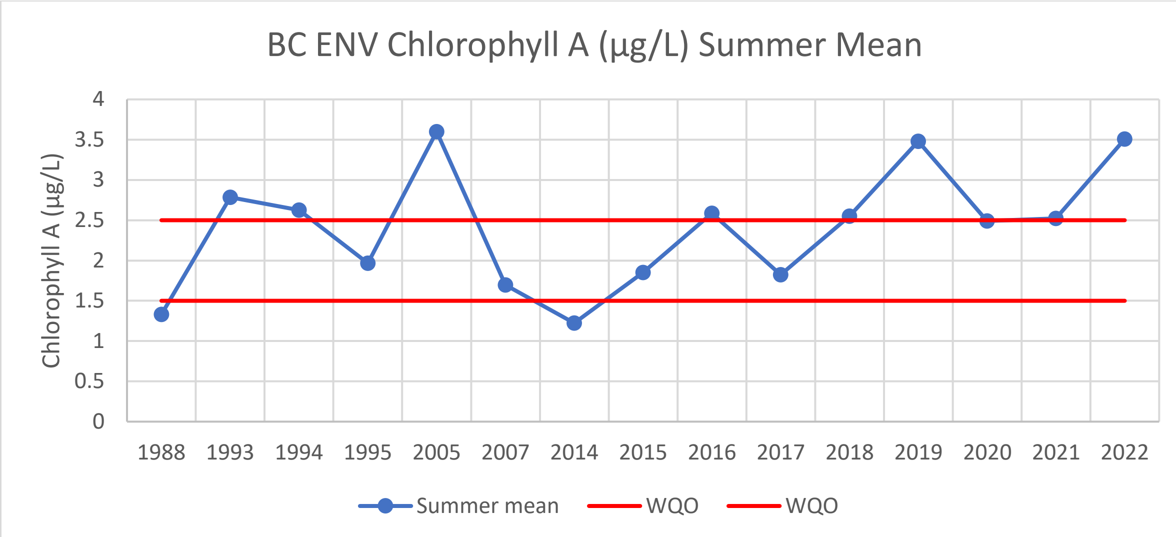

Figure 31: BC ENV Chlorophyll A Summer Mean 1988-2022

Key Finding: Summer mean Chlorophyll A was well above guidelines in 2005, 2019 and 2022

Discussion

Available data before 2019 were inconsistent and therefor challenging to compare over time. While some of the graphical comparisons appear to imply changes over time in water quality parameters, lack of available data makes this difficult to conclude. Interestingly, some of the data available in other reports were not within the BC ENV database, and were therefor not included in this report.

Physical Parameters

Water quality in Elk Lake becomes unsustainable for many aquatic species during summer months as surface temperatures rise above aquatic guidelines and deep water dissolved oxygen drops below aquatic guidelines.

Temperature depth profile data showed that Elk Lake mixes around November or December, and only stays mixed until the end of February or early March. This data was only available for recent years, and may indicate that samples taken during March and April in historic BC ENV data may not have represented a completely mixed lake.

The temperature guidelines for Elk Lake require lake bottom temperatures to remain below 15°C during summer months for the protection of aquatic life, and all historic data shows that deep water temperatures have remained within guidelines. Despite temperatures being within guidelines for aquatic life, the dissolved oxygen drops below the minimum guideline and therefor the lake bottom remains unsupportive of aquatic life in summer months.

Chemical Parameters

Surface spring total phosphorus exceeded both objectives for aquatic life and recreation on almost all sample dates from 1986 to 2021. Phosphorus has been identified by many experts as being the nutrient of concern in Elk Lake, and this analysis shows that to be true. Reducing nutrients flowing into the lake may help over time to reduce the phosphorus load, however, hypolimnion phosphorus shows significant internal loading from the bottom of the lake. Ammonia and dissolved organic carbon also increase at the lake bottom during summer months, and are likely released in anoxic conditions in tandem with phosphorus.

An observation made during this data analysis is based on the temperature depth profiles for the lake. According to 2019, 2020 and 2021 temperature data, spring over turn appears to occur in December, January and February, and starts to stratify by March. There does not appear to be corresponding temperature data for most of the historic total phosphorus data, so historic lake mixing cannot be confirmed with the available data. If stratification in 1988 through to 2016 was similar to the stratification observed in 2019 through 2021, then the spring overturn data sampled in April of many years may be lower than if the lake had been sampled in January or February.

Biological Samples

Chlorophyll A is the only biological sample shown in this report because most of the available historic data focuses on this algal species. While data is limited, general trends show that Chlorophyll A was historically relatively low and below the objective more often than not, however, more recently Chlorophyll A has exceeded the objective every year for the past 5 years. This is likely due to the increased available nutrients from both internal and external loading. Increased Chlorophyll A also coincides with decreased water clarity which was also been observed in recent years.

Climate Change

Impacts of climate change may further exacerbate declining water quality in Elk Lake on several fronts; temperature fluctuations, increased flood events, and decreased annual precipitation. In 2021 a "heat dome" increased surface temperatures in Elk Lake higher than they had been previously recorded. Increased temperatures result in decreased oxygen levels which caused increased internal phosphorus loading from sediment. With more weather extremes expected, flooding events will also negatively impact Elk Lake water quality by increasing external nutrient loading from the watershed and erosion of tributaries feeding the lake. Greater nutrient and sediment inputs will amplify the existing nutrient loading issue, leading to more algae blooms and faster eutrophication. To further amplify these problems, decreased annual precipitation will result in increased water retention within the lake, which will allow nutrients to remain in the lake rather than being washed downstream.

Recommendations

BC ENV data would be more robust if all available data from various sources were added to the dataset. For example, Rick Nordin's work with the CRD in 2014-2015 does not appear within the BC ENV dataset. There may be other data from various consultants that could also be added to the BC ENV lake monitoring program to improve data trend analysis.

Spring overturn measurements for total phosphorus may need to take place earlier in the year to properly represent a mixed lake. Historic spring overturn samples were taken in March and April but depth profiles show that the lake had begun stratifying when these samples were taken. It is recommended that sampling take place in January or February to properly represent a mixed lake.

The Elk Beaver Watershed Management Plan contains an incorrect unit for the water quality objective for Chlorophyll A. The WMP suggests a WQO of 2.5 **g/L** when in fact the WQO is 2.5 **μg/L**. CRD staff have been consulted and have corrected this typo.

Another error discovered during this data review was the incorrect labelling of total phosphorus (T-P) as total phosphate (T-PO_4) in the CRD database, with identical numbers in the BC ENV database under total phosphorus. The CRD has confirmed this was a typo, and the data labelled total phosphate was in fact total phosphorus.

The CRDs latest sampling plan for Elk Lake has been fairly robust since 2019, and it is recommended that this sampling plan continue after the oxygenation system has been installed to monitor ongoing water quality trends over the next decade.

Conclusion

Data trends from available BC ENV and CRD data from the 1980s to 2022 show that phosphorus and chlorophyll A levels have increased over time, and resulting water quality has diminished so that during summer months much of Elk Lake is uninhabitable for aquatic life. This analysis was limited by inconsistent historic data, and the more recent and robust CRD sampling program should continue to monitor trends before and after installation of the oxygenation system on Elk Lake.

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