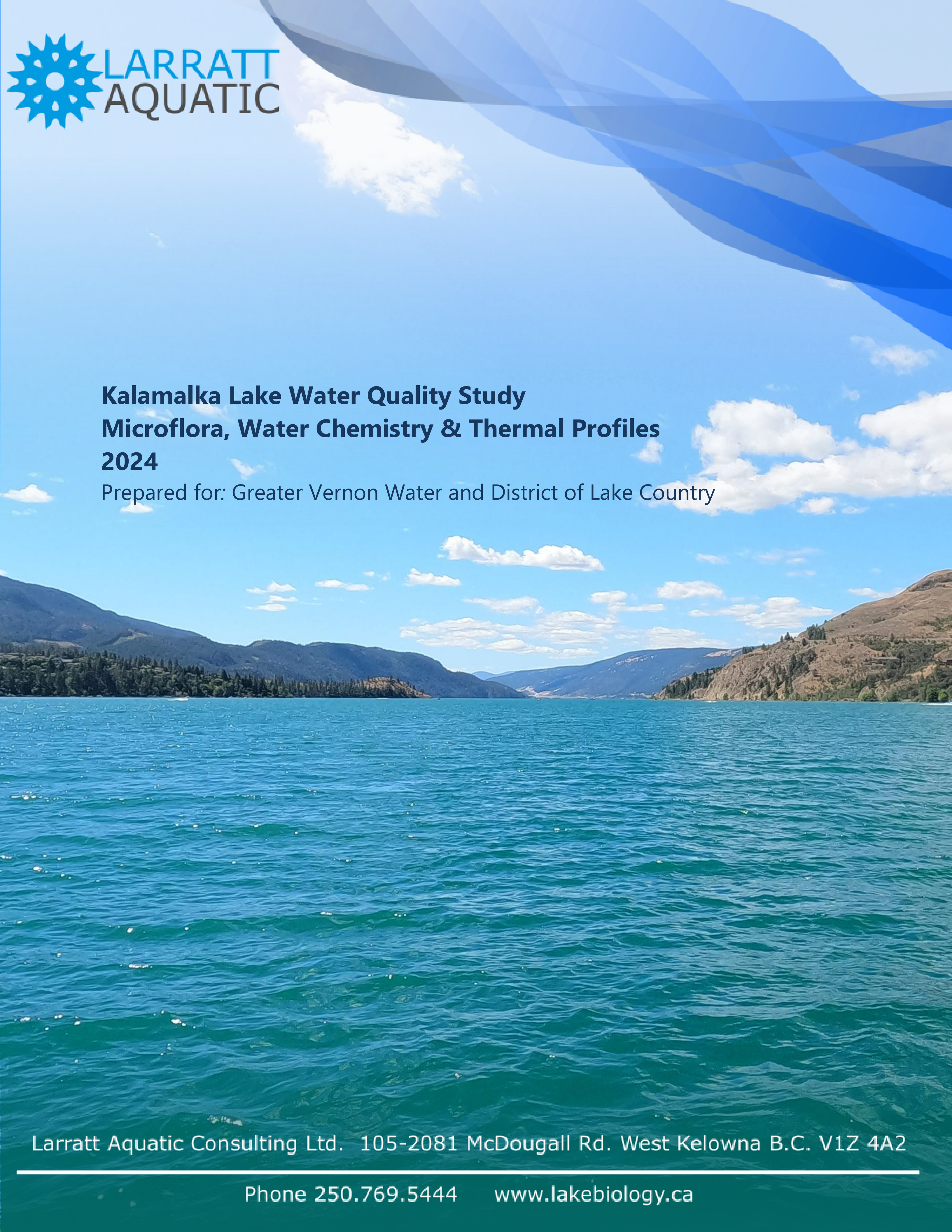

Kalamalka Lake Water Quality Study
Microflora, Water Chemistry & Thermal Profiles
2024

Prepared for: Greater Vernon Water and District of Lake Country

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2024 Kalamalka Lake Report – Key Findings

The purpose of this report is to summarize the 2024 results and compare them to trends found over the course of this study (2000-present). The recommendations in this report are based on all results to date.

Kalamalka Lake experienced extreme weather the past six years with intense freshets, flooding, droughts, heatwaves, and major forest fire activity throughout the province. Weather during 2024 included an below average and brief freshet followed by a hot dry summer with drought conditions extending into the winter. The Kalamalka Lake water level was record low throughout the year and reached nearly 40 cm below the normal lake level.

Key Findings of 2024 Study

Coldstream Creek Coldstream Creek always contained far more bacteria than any site in the North Arm and this was again true during 2024. Freshet *E.coli* counts were regularly very high indicating fecal contamination within the watershed. Coldstream Creek total annual inflows into Kalamalka Lake during 2024 were below the long-term average. Turbidity in the creek was also below the historic average including the brief freshet. Completely evading the creek plume is not possible within the North Arm, particularly during a strong freshet pulse. In all results to date, the *E. coli* counts from the south end of Kalamalka Lake were lower than those from the north end, confirming the impact of Coldstream Creek on water quality within the north arm. Nutrient contributions from Coldstream Creek were substantial with annual average TP greatly exceeding the lake concentration.

Wood Lake Wood Lake avoided a lake squeeze event in 2024 but remained strongly anoxic below the thermocline that extended down to the sediment. Cyanobacteria densities were record high in 2024, and reached a maximum concentration of 101,035 cells/mL on May 31, dominated by *Planktothrix sp*. Interior Health Authority completed cyanotoxin testing and revealed no detectable microcystin on June 24, 2024.

Wood Lake experienced a strong marl event in July. TN and TP were elevated in Wood Lake in recent years. There was also a trend towards larger and more intense anoxic zones in Wood Lake in recent years. The combination of higher nutrients, algae blooms, and greater anoxic nutrient recycling fuel a positive feedback loop that results in larger blooms and poorer water quality. It is unclear how long this cycle will continue or if Wood Lake is transitioning into a more permanent eutrophic condition.

Kalamalka Lake Thermal stratification was established by mid-May in 2024. Oxygen super-saturation was seen in all 2024 profiles as occurred in most years. Dissolved oxygen concentrations remained excellent throughout the Kalamalka Lake water column in all 2024 profiles, consistent with historic norms. The 2024 marl was strong began in late June.

Oscillations in Kalamalka Lake pH data since 1970 were not statistically significant and appear to be induced by climate patterns; Kalamalka Lake pH is currently in a declining phase of the cycle. Marl settling usually increases turbidity at the intakes in late summer. As in most years, UV transmissivity was excellent throughout the year at all sites.

Trend analysis of Kalamalka Lake data showed stable TN but elevated TP concentrations in recent years. Elevated TP is concerning, particularly given a corresponding increasing trend in algae densities. Despite significant nutrient loading from Coldstream Creek that has increased in recent decades, most phosphorus values met the 0.008 mg/L TP Objective set for Kalamalka Lake in the past decade, including 2024.

Chloride concentrations have more than doubled over the course of this study, with no indication of stabilizing through the 2024 data. This is concerning, as it indicates ongoing urban and road impacts.

2024 chlorophyll-a (chl-a) concentrations were near the historic average. Despite wide annual variations driven by weather, a statistically significant pattern emerged where chl-a was lowest at the 40 m sites and highest at the 20 m sites over 1999 – 2024.

Cyanobacteria concentrations were above average during 2024. Most sites were lower than the record highs from 2020 while the north 0 m site set a new record maximum for algae densities. In the study data from 2000 to 2024, the best depths for low algae densities were the 40 m sites.

Turbidity data collected to date indicate a strong connection between increased turbidity at the DLC S-Kal intake and boating activity in Kalamalka Lake, particularly across the S-Kal shallows. Dredging of the Oyama canal occurred in 2024 and may lead to greater boat traffic across the S-Kal shallows and therefore increased turbidity and sediment resuspension at the S-Kal intake in 2025. District of Lake Country is currently engaged in a study to refine the estimate for best depth to extend the intake.

Combined impacts from multiple consecutive years of extreme weather were felt in Kalamalka Lake during 2024 were again unusual with record low water levels in Kalamalka Lake, a strong and early marl event, and algae blooms at the intake depths. Recent years indicate a clear benefit for extending the intakes because of focused algae blooms near the current intake depths. Climate change predictions indicate that extreme weather events will become more frequent. The effects of these on Kalamalka Lake will be exacerbated by increasing nutrient trends and a watershed that is significantly impacted by human activities, reducing its resilience.

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Glossary and Abbreviations

Glossary: The following terms are defined as they are used in this report.

Term	Definition
Algae bloom	A superabundant growth of algae, a marked increase to >2000 cells/mL
Anaerobic/anoxic	Devoid of oxygen
Benthic	Organisms that dwell in or are associated with the sediments
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment
Diatoms	Algae that have hard, silica-based "shells" called frustules
Fall overturn	Surface waters cool and sink, until a fall storm mixes the water column
Eutrophic	Nutrient-rich, biologically productive water body
Green algae	A large family of algae with chlorophyll as the main photosynthetic pigment
Inflow plume	A creek inflow seeks the layer of matching density in a receiving lake, mixing and diffusing as it travels; cold, TSS, and TDS increase water density
Limitation, nutrient	A nutrient that limits or controls the potential growth of organisms e.g. P or N
Mesotrophic	A water body having a moderate amount of dissolved nutrients
Microflora	Sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Oligotrophic	A water body having low dissolved nutrient concentrations that restrict microflora growth
Periphyton	Algae that are attached to aquatic plants or solid substrates
pH	A numeric value that expresses acidity/alkalinity of water. pH affects solubility of dissolved substances such as metals and nutrients
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
Plankton	Those organisms that float or swim in water
Redox	Reduction (-ve) or oxidation (+ve) potential of a solution
Reducing envi	Devoid of oxygen with reducing conditions (-ve redox) e.g. swamp sediments
Residence time	Time for a parcel of water to pass through a reservoir or lake (flushing time)
Riparian	Interface between land and a stream or lake
Secchi depth	Depth where a 20 cm secchi disk can be seen; measures water transparency
Seiche	Wind-driven tipping of lake water layers in the summer, causes oscillations
Thermocline	Lake zone of greatest change in water temperature with depth (> 1^{o}C/m); it separates the surface water (epilimnion) from the cold hypolimnion below
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

Nutrient Balance Definitions for Microflora (Dissolved Inorganic N : Dissolved Inorganic P)

Phosphorus Limitation	Co-Limitation of N and P	Nitrogen Limitation
> 15 : 1	15 : 1 – 5 : 1	< 5 : 1

After Nordin,1985

Lake Classification by Trophic Status Indicators

Trophic Status	Chlorophyll-a (µg/L)	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Secchi Depth (m)	Primary Production (mg C/m^2/day)	TSI Index
Ultra-oligotrophic	< 0.95	< 4	< 75	> 10	> 50	< 30
Oligotrophic	1 - 2	4 – 10	< 100	6 - 12	50 – 300	30 – 40
Mesotrophic	2 - 5	10 – 20	100 – 500	3 – 6	250 - 1000	40 – 50
Meso-eutrophic	5 – 7	20 – 35	500 - 900	2 – 3		50 – 60
Eutrophic	7 – 25	35 – 100	900 – 1500	1 – 2.5	> 1000	60 – 70
Hyper-eutrophic	> 25	> 100	> 1500	< 1		> 70

(after Ashley 1996, Carlson 1983, Wetzel 2001, Carlson and Simpson 1996,Vollenweider and Kerekes, 1982, Kasprzac et al. 2008)

Report Abbreviations

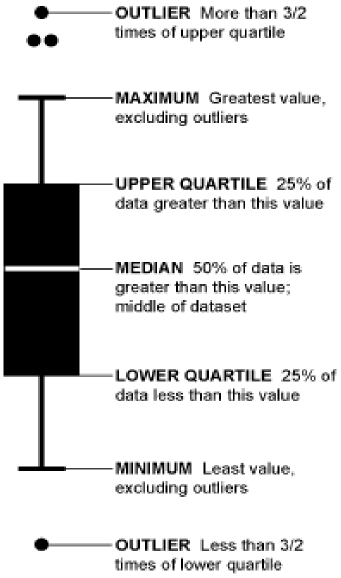
Entities:		**Parameters:**	
DLC	*District of Lake Country*	TOC	total organic carbon
GVW	*RDNO – Greater Vernon Water*	Chl-a	chlorophyll-a
RDNO	*Regional District of North Okanagan*	DO	dissolved oxygen
ENV	*Ministry of Environment*	DGT	detection greater than
IHA	*Interior Health Authority*	UVT	ultraviolet transmissivity
LAC	*Larratt Aquatic Consulting*	TDS	total dissolved solids

Sample Site GPS Coordinates

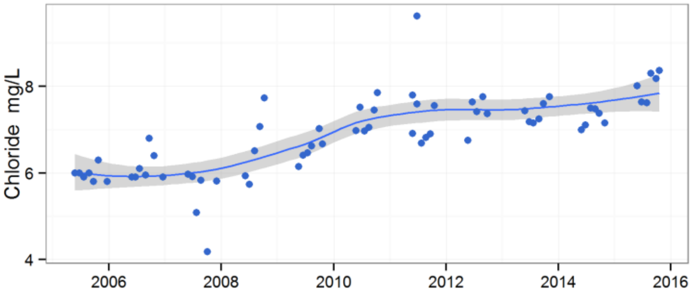
Kal N 47 m	N 50 12.740	W 119 17.222	Kal S 20 m	N 50 07.005	W 119 22.350
Kal N 40 m	N 50 12.977	W 119 16.896	Kal S 30 m	N 50 07.110	W 119 22.463
Kal N 35 m	N 50.21929	W 119.2788	Kal S 40 m	N 50.127	W 119.374
Kal N 30 m	N 50 13.421	W 119 16.459			
Kal N 20 m	N 50.13.628	W 119 16.499	Coldstream Ck	N 50.22427	W 119.261962
Kal N 10 m	N 50 13.454	W 119 15.899	Wood Lk	N 50.1045	W 119.382
ENV Kal N	N 50.2224	W 119.2727	ENV Kal M	N 50.1589	W 119.3538
ENV Kal S	N 50.1347	W 119.3688	ENV Wood Lk	N 50.0749	W 119.3917

Note: surface samples are collected at the 20 m sites

Box Plot Legend



Trend Graph Legend



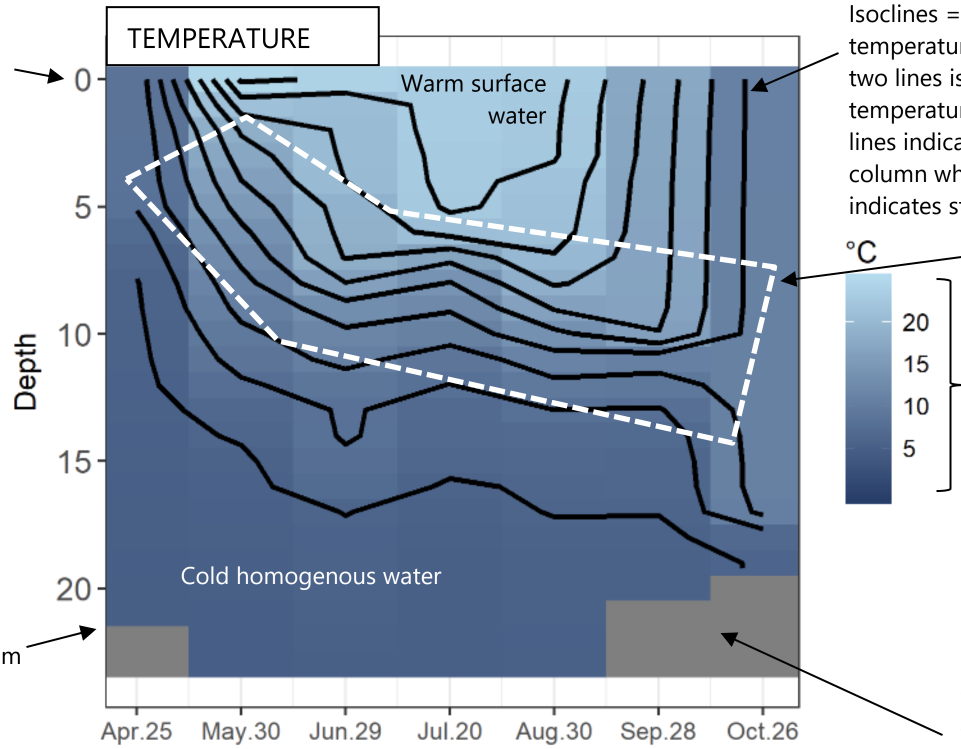
— Data trend line calculated with LOWESS polynomial regression

▨ Range of Standard Error of trend line

● data points

How to Read Temperature/DO Profile Plot

Temperature and dissolved oxygen profiles were routinely collected as part of this study. They are displayed in several locations throughout this report. An example of a temperature graph and a dissolved oxygen graph, their descriptions of key features and how to read them are presented here.



Surface

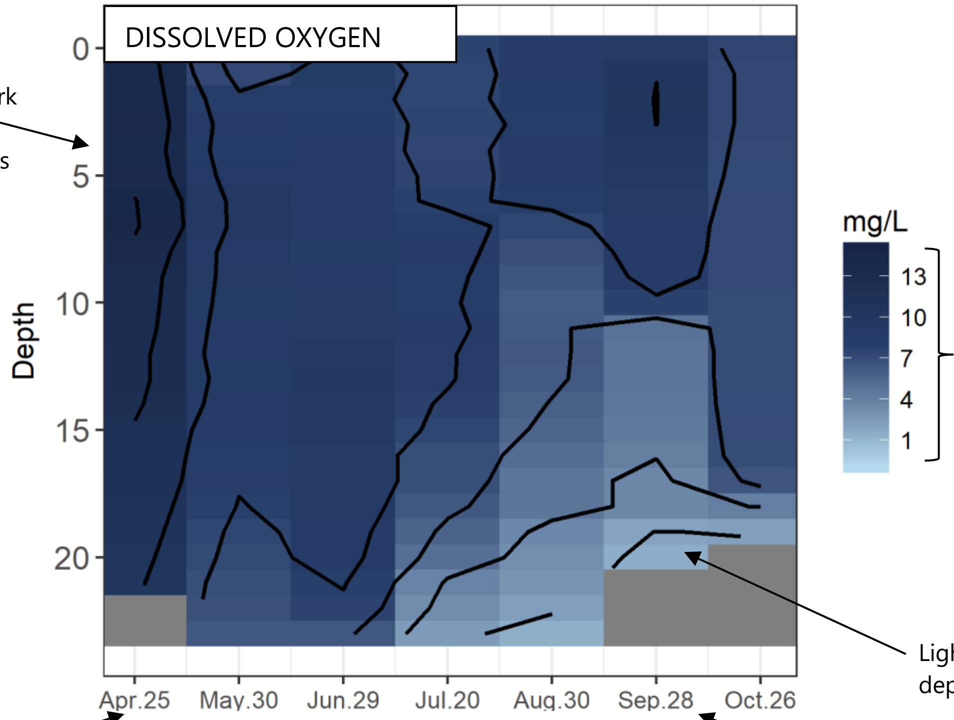
Isoclines = areas of equivalent temperature. That is, the space between two lines is approximately the same temperature. Large spaces between lines indicate homogenous water column while many lines close together indicates stratified conditions

Tight concentration of lines = rapid change in temperature over short depth (i.e. thermocline)

Scale: Lighter shading = warmer water

Lake bottom

Gray or white area indicates lake bottom. This appears on the plot when profiles were taken at sites with different depths on different dates. For example, on Jul 20, the profile was at a site 24 m deep but on Oct 26, the profile was done only at a site 19 m deep. This can occur when weather conditions move the sampling boat into a slightly different location on the lake.



Very dark area indicates spring algae bloom

Scale: Lighter shading = Low DO (anaerobic conditions)
Darker shading = High DO (algae blooms)

Light area indicates oxygen depletion along sediments

Each vertical column in graph represents conditions within a column of the lake on given date. E.g. on Apr 25, DO was very high through entire water column but on Sept 28, there was significant oxygen depletion in the deep water

1.0 Introduction

Project History:

An offensive taste and odor event occurred throughout Kalamalka Lake in summer 1999 that was apparently caused by an algae bloom. The taste and odor event, and changes detected in water quality, resulted in a jointly funded study between the Regional District of North Okanagan (now known as RDNO-Greater Vernon Water), City of Vernon water department (up until 2003), and the District of Lake Country (DLC). The Ministry of Environment (ENV) also partnered with this group through in-kind support and nutrient data monitoring[1]. Larratt Aquatic has studied the impact of Kalamalka Lake water chemistry and microflora production as they pertain to drinking water quality since 1999. The annual Kalamalka Lake study is now in its 25th year.

Over the years of study, many trends and influences on intake water quality have been identified and clarified. On an annual basis, this research is evaluated and re-directed by the participants. Other groups including BC Ministry of Environment, Agriculture Canada, and UBCO are conducting valuable research within the Kalamalka and Wood Lake watersheds. Their work is referenced in this study.

Goals of 2024 study:

1) Define the physical and biological impacts on drinking water quality at the existing RDNO and DLC intakes
2) Provide baseline water chemistry for future additional water treatment
3) Study fluctuations in water chemistry and algae production in Kalamalka Lake
4) Evaluate water quality at different depths in the lake to determine if there would be benefits if intakes were extended to greater depths for DLC
5) Evaluate source water quality fluctuations in Coldstream Creek and Wood Lake, and their impacts on Kalamalka Lake
6) Co-operate with ENV in tracking long-term water quality and productivity changes in Kalamalka Lake and the implications of those changes for water resources
7) Evaluate impacts on water quality from flooding and large freshets during 2017-2018, 2020, and 2022
8) Determine if major algae blooms of 2020 would repeat during 2024

This report's purpose is to summarize the findings of the 2024 study and compare them to trends over past years. This report offers recommendations based on the results to date and suggests a direction for subsequent years.

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[1] All nutrients data displayed in this report are from ENV monitoring.

Sampling Overview:
Field water quality measurements, water chemistry samples, and biological samples were taken monthly through the 2024 growing season from Kalamalka Lake and a portion of the contributing watershed (Table 1, Figure 1). Since the primary focus of this water quality study is drinking water, the sample sites were located around the RDNO intake at the north end of the lake and the DLC intake at the south end of the lake. Additional samples were examined at each of the drinking water intakes for algae density and taxonomy.

While most sample sites were on Kalamalka Lake, the contributing watershed was also sampled. Inflows into Kalamalka Lake are primarily from Coldstream Creek, Wood Lake, and groundwater. Coldstream Creek supplies approximately 80% of the annual surface inflow into Kalamalka Lake (Bryan, 1990). Water usually moves from Wood Lake into Kalamalka Lake through Oyama Canal, although lake water levels and winds can reverse the flow. During late summer and in very dry years, a net southerly flow occurs (MoE, 1975). At most other times, a net northerly flow occurs.

Sampled water quality parameters included the following in 2024:
<u>Field Meter Depth Profiles</u>: temperature, pH, dissolved oxygen, TDS, conductivity
<u>On-line Analyzers:</u> temperature, turbidity, conductivity, water level
<u>Lab Samples:</u> alkalinity, chloride, sulphate, UVT, TOC, DOC[2], turbidity, pH, chlorophyll-a, conductivity, hardness, total metals, total coliforms, *E. coli*

Table 1: List of Kalamalka Lake sample sites in 2024

	North Sites	**South Sites**
Watershed sites	Coldstream Creek*	Wood Lake
Kalamalka Lake sites	0, 20, 30, and 40 m	0, 20, 30, and 40** m
Intake samples (collected by water suppliers)	20 m RDNO intake (3.5 m clearance)	20 m DLC intake (2.0 m clearance)

* Coldstream creek sampling performed by RDNO, sampling frequency increased compared to lake samples. RDNO operates multiple sample locations and samples from the Kirkland Road sample site are used in this report.
** 40 m south sample site was moved in 2017 because of new bathymetry data (Figure 23)

All deep, near-bottom samples were collected with 2-3m clearance from the substrate. Details of sampling methods and procedures used in 2024 can be found in Appendix 2: Methods and Water Quality Guidelines.

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[2] DOC sampling began in 2024

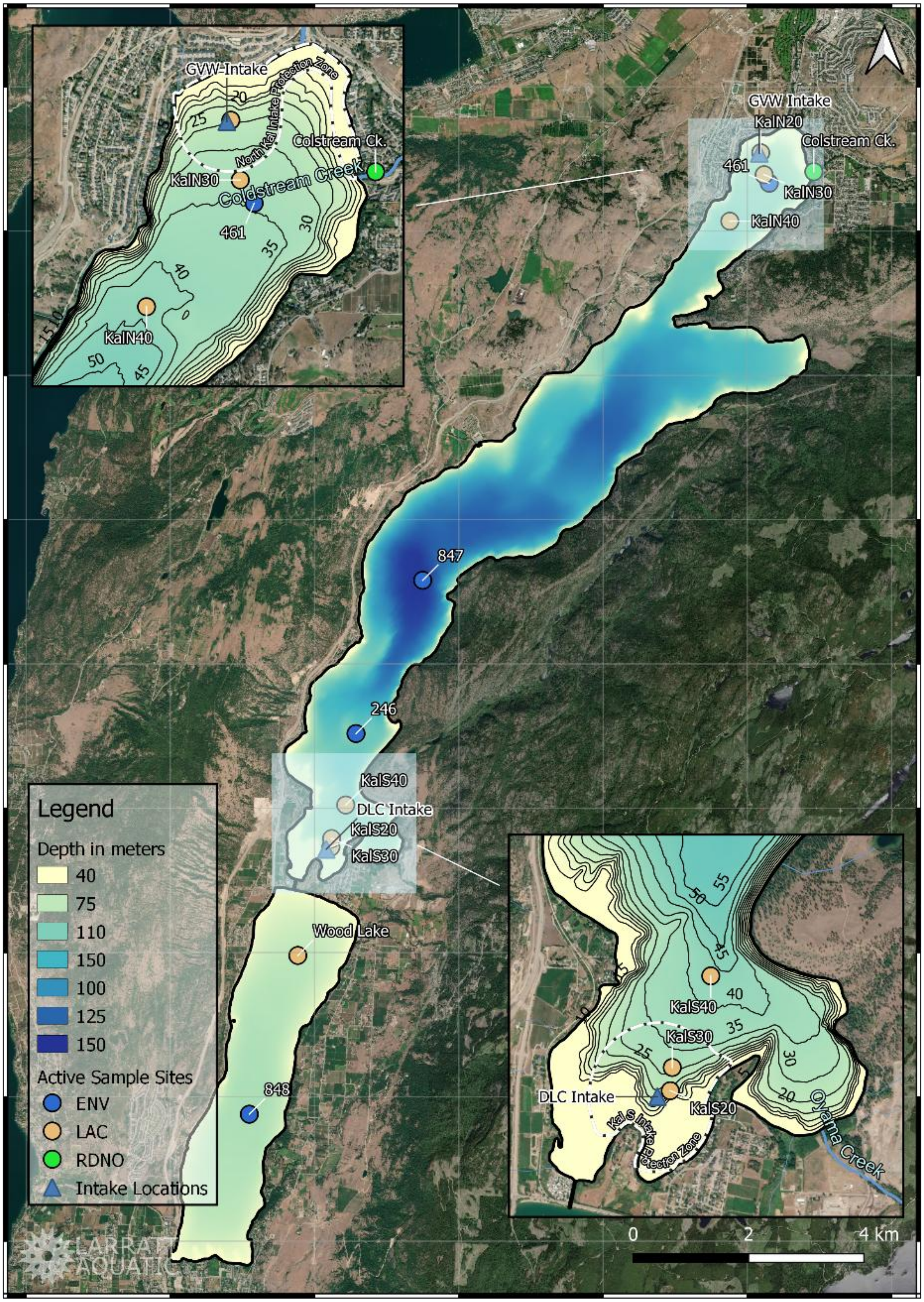


Figure 1: Location of Kalamalka Lake Study Sample Sites

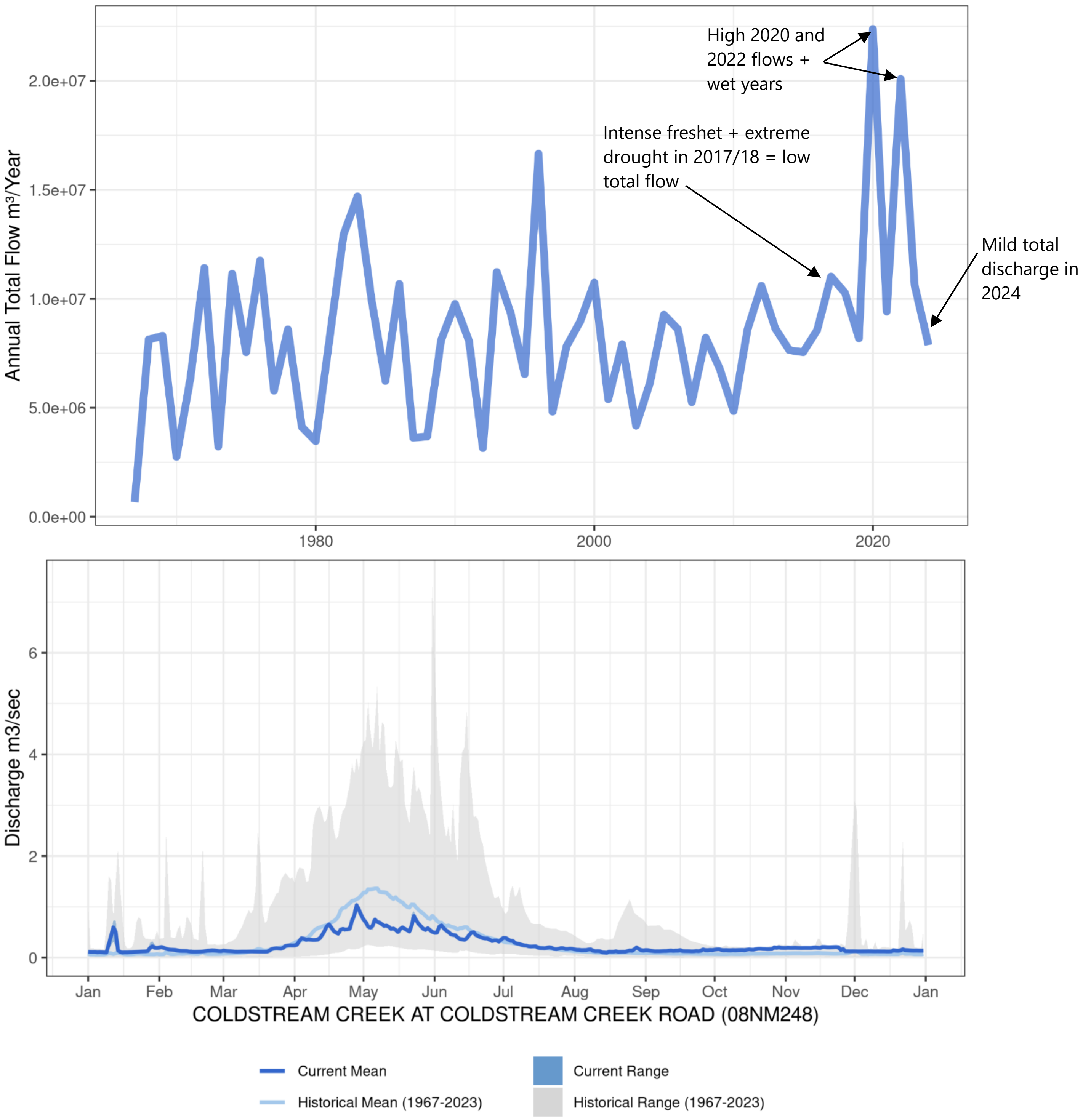
2.0 Results & Discussion

2.1 Contributing Watershed

2.1.1 Coldstream Creek

Weather, Flow, and Field Data

Weather during winter 2024 began cool followed by a below average freshet. The summer was dry and hot with drought conditions extending into winter. Coldstream Creek had a small spike in flow during the last week of April up to 1.1 m^3/sec (Figure 2; Water Office, 2024). The annual total discharge into Kalamalka Lake was 7.9 million m^3; this was close to the 1967-2023 average of 9.1 ± 4.7 million m^3.



High 2020 and 2022 flows + wet years

Intense freshet + extreme drought in 2017/18 = low total flow

Mild total discharge in 2024

Figure 2: Annual cumulative flow (top) and daily flow (bottom) in Coldstream Creek from 1967-2024

Source: Combined data of Water Office 08NM142[3] and 08NM248 Coldstream Creek Above Municipal Intake

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[3] This site is now discontinued. Future years will shift to the newer site 08NM248

During freshet snowmelt water contributes to most of Coldstream Creek's flow rather than groundwater. Freshet dilutes high conductivity base flow, causing conductivity to decrease (Figure 3). TDS and conductivity in the Coldstream Creek freshet flows were far below the ambient levels in Kalamalka Lake and resulted in a buoyant plume entering the lake, despite the cold temperature of the creek water. During the times of the year when the TDS and conductivity were similar to Kalamalka Lake, Coldstream Creek inflows sank to the depth in the lake with equal temperature. In most years, the plume enters the surface water during the spring and flows progressively deeper into the summer and fall. It is expected that during the summer and fall the plume descends to the depth of the intake (refer to 2020 report for more detail on this process). The lake is not typically well stratified during freshet allowing mixing of some turbid plume water down to the intake depth. Suspended material will also settle out of the plume as it spreads across the lake, increasing turbidity.

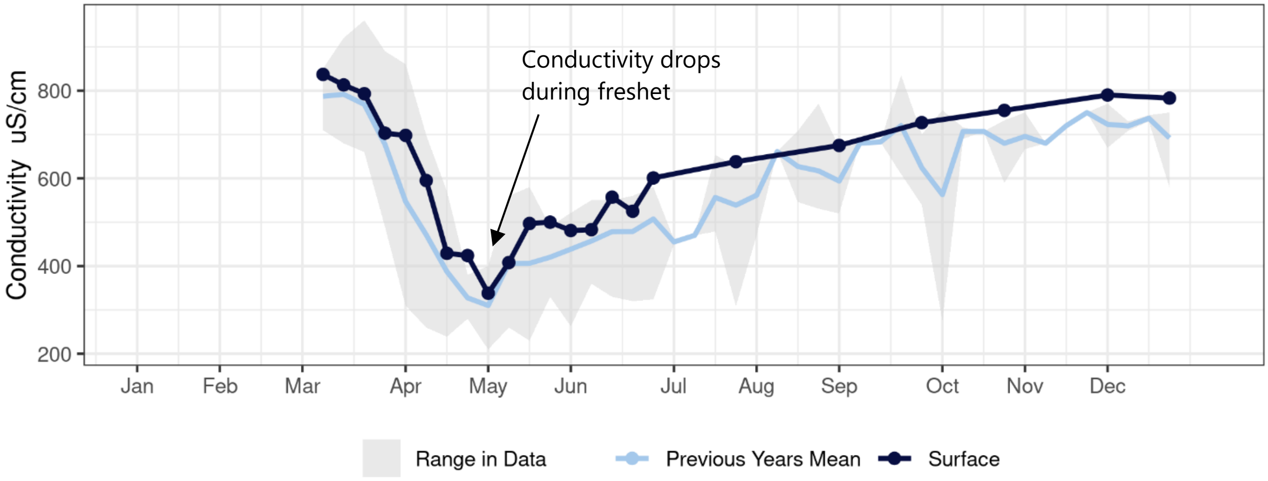

Figure 3: Coldstream Creek conductivity during 2024 compared to previous years (2007-2023)

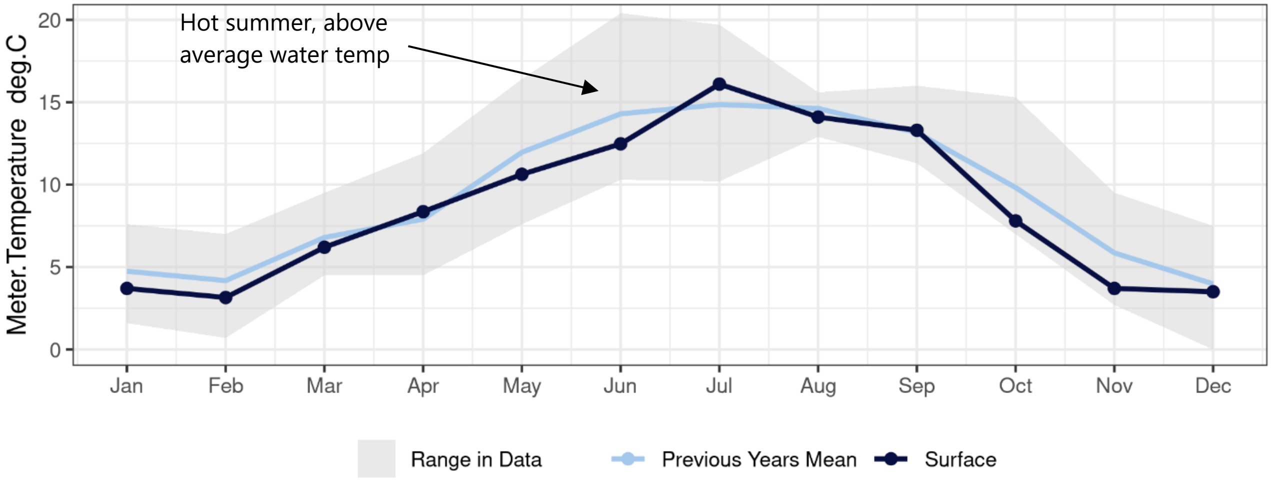

Figure 4: Coldstream Creek temperature during 2024 compared to previous years (2007-2023)

Turbidity

Turbidity in Coldstream Creek upstream of Kalamalka Lake averaged 6.15 ± 6.44 NTU during 2024 (18.6 ± 39.1 NTU from 2007-2024), with a freshet maximum of only 28.3 NTU on April 15 during the peak of freshet (Figure 2; Figure 5). The freshet peak flows on April 15 resulted in the lowest freshet turbidity spike in the 2007-2024 record (Figure 5; Figure 40).

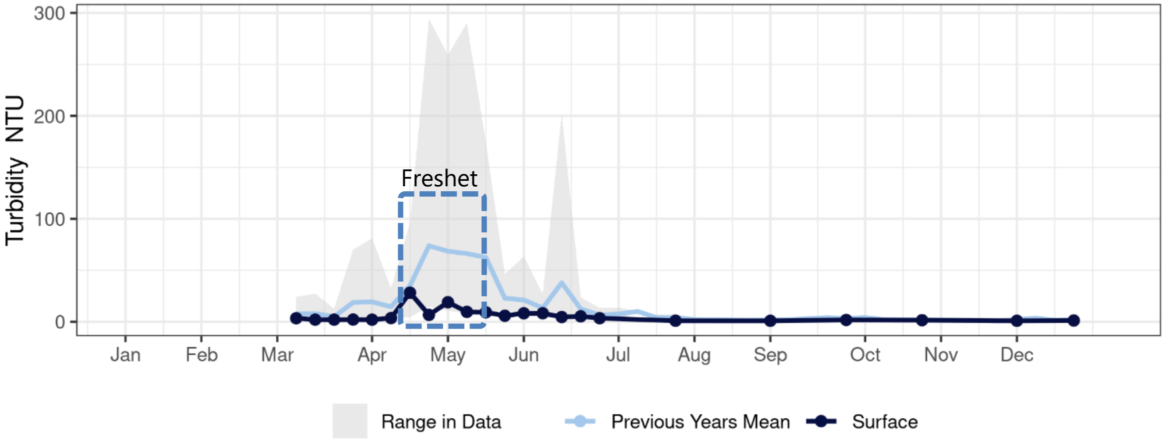

Figure 5: Turbidity in Coldstream Creek during 2024 compared to previous years (2007-2023)
Note: N-Kal intake shut off during peak of freshet

Chemistry

Coldstream Creek (measured at Kirkland Drive throughout this section) averaged 21.4 ± 4.9 mg/L chloride in 2024 compared to 10.6 ± 0.4 mg/L at 0 m N in Kalamalka Lake. There was also a long-term increasing trend in chloride in Coldstream Creek from 2007-2024 (Mann-Kendall, $p < 0.001$). Chloride is used as a marker for human impacts and typically originates from road de-icing and agriculture.

Coldstream Creek is a major source of nutrients to Kalamalka Lake and has a well-documented effect on the water quality of the North Arm (Figure 6). Dissolved inorganic nutrients including ammonia and nitrate averaged 0.049 ± 0.052 mg/L as N and 1.96 ± 0.48 mg/L as N, respectively in 2024. While nitrate concentrations were stable from 2016-2024, they still contributed a significant nutrient load to Kalamalka Lake. Meanwhile, there was a significant declining trend in ammonia in Coldstream Creek from 2016-2024 (Mann-Kendall, $p < 0.002$). No samples exceeded relevant aquatic life or drinking water guidelines during 2024; a maximum nitrate concentration of 2.54 mg/L as N was recorded on March 27. Nitrate concentrations in Coldstream Creek are the highest during low flow periods because nutrient-enriched groundwater is supplying the base of the flow without dilution from precipitation.

Sources of nitrate probably include manure or fertilizer applications that elevate nitrate in groundwater and ultimately creek flow, but no recent research exists (Sokal, 2010). Many studies dating as far back as the 1970’s identified serious issues with agricultural practises in the Coldstream watershed and the need for better riparian protection (MoE, 1978; Ecoscape, 2009; Sokal, 2010). There was a distinct increase in nitrate once the creek entered the agricultural areas at Lavington (Figure 6). Average nitrate concentrations in Coldstream Creek at Kirkland Dr. were 47 times higher than the epilimnion of Kalamalka Lake during 2024 (ENV Site 0500461, average of 0.0418 ± 0.0569 mg/L as N; Figure 6). While Coldstream Creek nutrient concentrations decrease during freshet, total nutrient load into Kalamalka Lake is largest during freshet because of increased volumes of creek flow reporting to the lake.

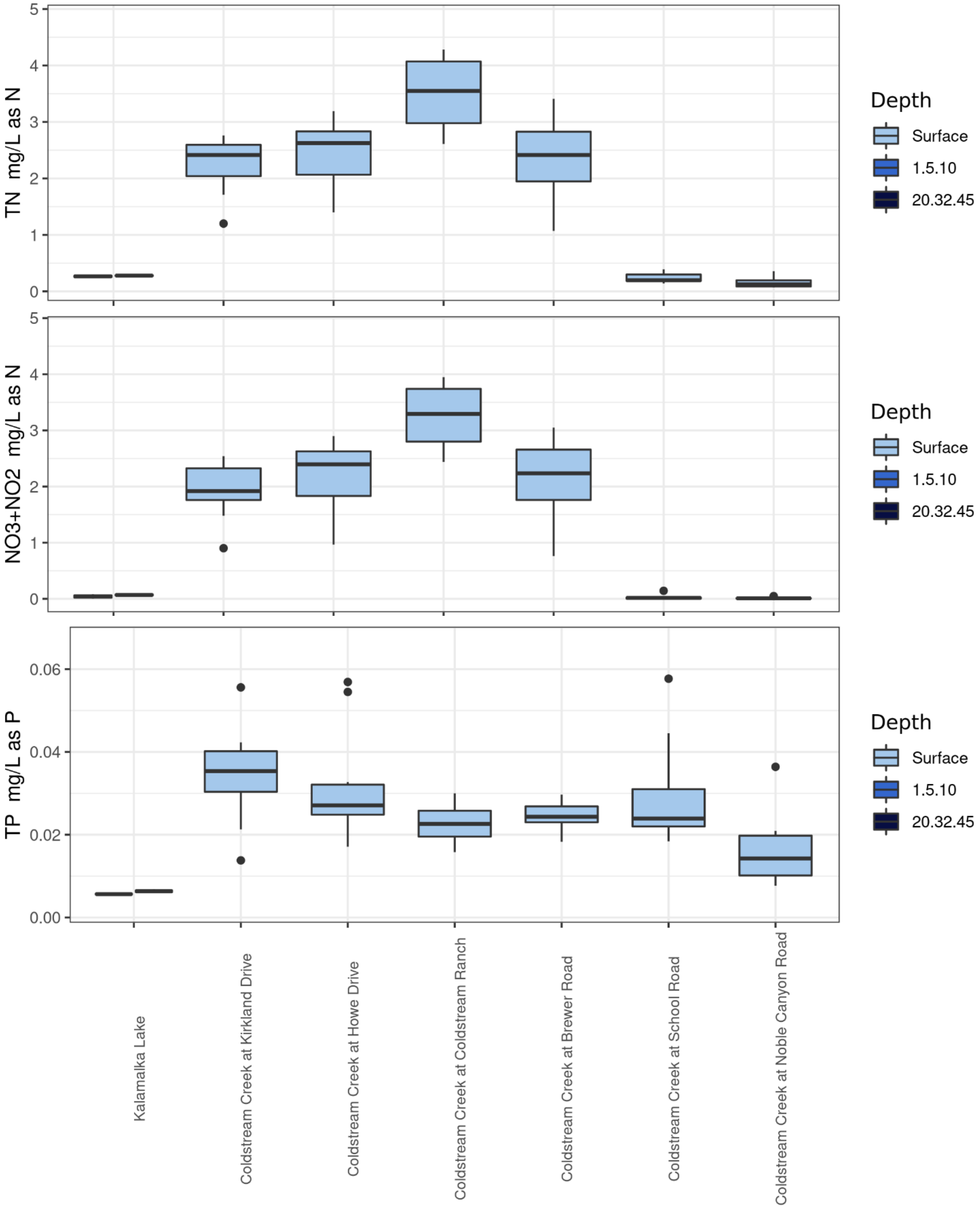

Figure 6: Comparison of TN, NO3+NO2, and TP from Kalamalka Lake (left) to upstream (right) on Coldstream Creek during 2024

In Coldstream Creek, the BC water quality objective of 0.015 mg/L TP has not been met since it was set in 1985 (Sokal, 2010). TP averaged 0.035 ± 0.011 mg/L as P in 2024, lower than the very high 2017-2018 averages but still 6 times higher than Kalamalka Lake in the North Arm (ENV Site 0500461, average of 0.0057 ± 0.0004 mg/L as P). TP increased moving from upstream to downstream during 2024 (Figure 6).

Bacteria

Coldstream Creek is a major source of bacteria and specifically fecal bacteria to Kalamalka Lake. During 2024, total coliforms measured as high as 8600 CFU/100mL and *E. coli* reached a maximum of 1200 CFU/100mL just upstream of the lake. These numbers are high and indicate that Coldstream Creek remains a highly compromised creek system (Figure 7).

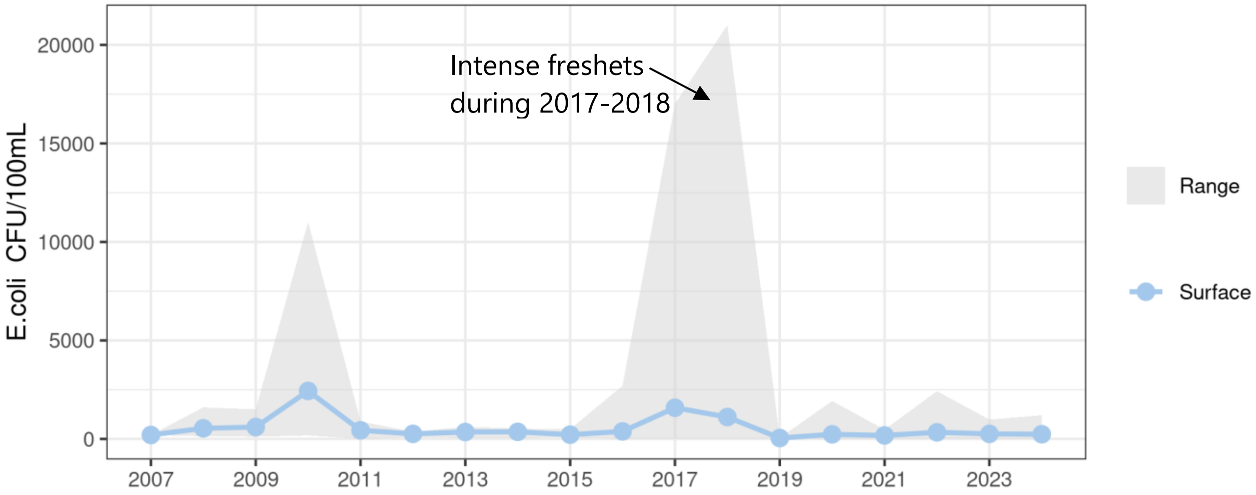

Figure 7: Annual average *E.coli* counts in Coldstream Creek, 2007-2024

Note: shaded area provides range of data

2.1.2 Wood Lake

Wood Lake is the other main source of water entering Kalamalka Lake. Water quality in Wood Lake has a greater impact on the south end of Kalamalka Lake than the north. Wood Lake's high nutrient status is maintained primarily by internal phosphorus recycling during the summer and to a much lesser extent, by high nutrient inflows from the Wood Lake watershed, particularly Middle Vernon Creek (Self, 2016; M. Sokal. pers. comm). A reduction in any nutrient loading is important to maintaining a healthy balance within the system (Epp and Neumann, 2014).

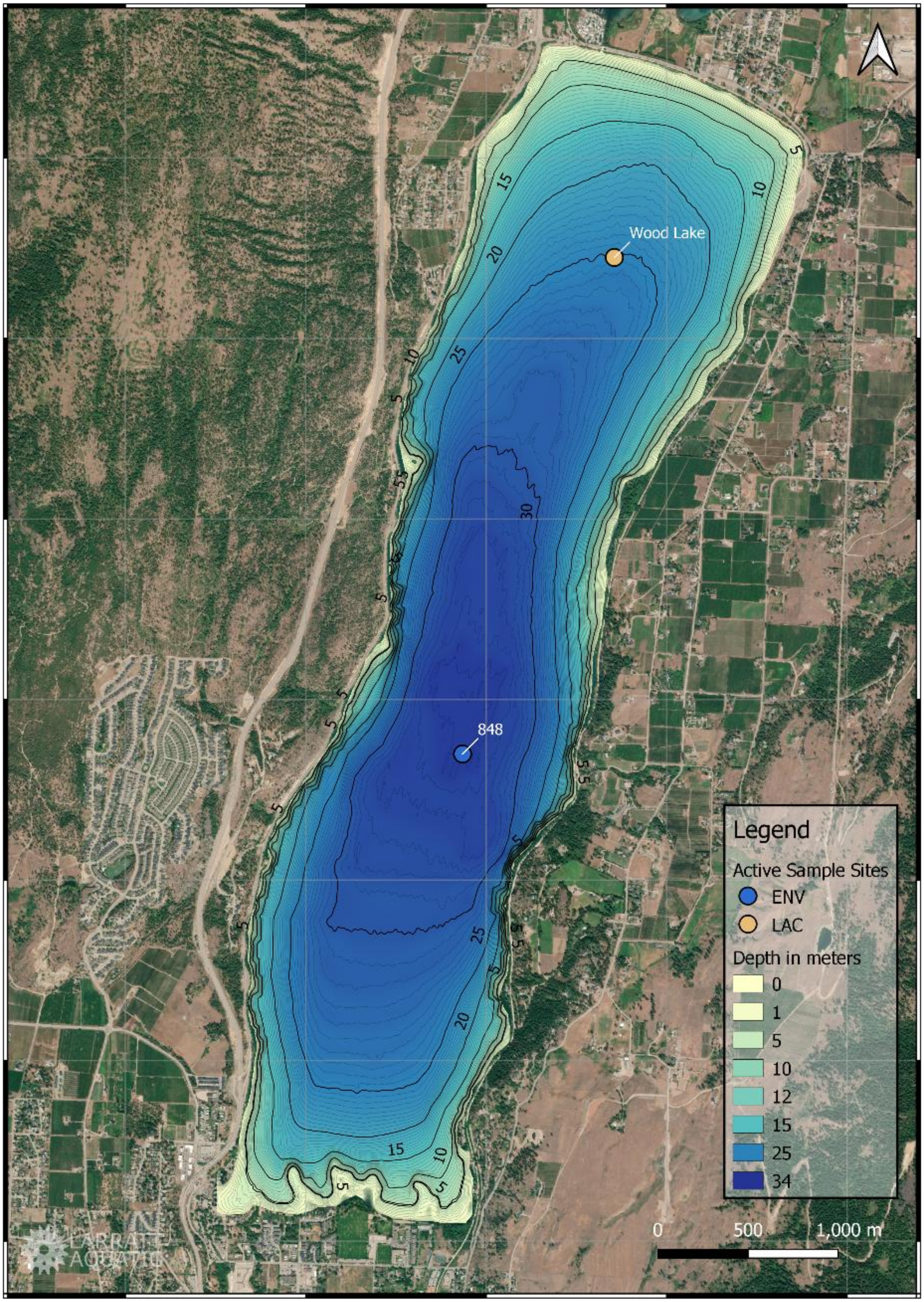

Figure 8: Wood Lake Bathymetric Map

Thermal Structure

Wood Lake is smaller and shallower than Kalamalka Lake, resulting in higher temperatures throughout the water column during the growing season. During the summer, Wood Lake reached a recorded maximum surface temperature of 22.7 °C on July 31, 2024 (Figure 9). Water temperatures of > 20 °C usually extend to the 7 m depth in Wood Lake by mid-summer (> 20°C at 7 m in August 2024). During 2024, Wood Lake was thermally stratified by end of May and remained stratified until at least October (mixed water column during November 29 sampling). Wood Lake usually destratifies in late November or early December.

A lake squeeze occurred during 2022 and 2023 with water up to 21 °C extending down to 7 m depth and hypoxic water extending from the sediments up to the thermocline at 7 m (Figure 10). Wood Lake appeared to have avoided a lake squeeze during 2024 with 2-3 m of oxygenated water that was < 20 °C. Fisheries monitoring by BC ENV indicates that Wood Lake kokanee populations have suffered a significant decline from the two consecutive summers with major lake squeeze events (2022 and 2023; pers comm. Kristen King, BC ENV).

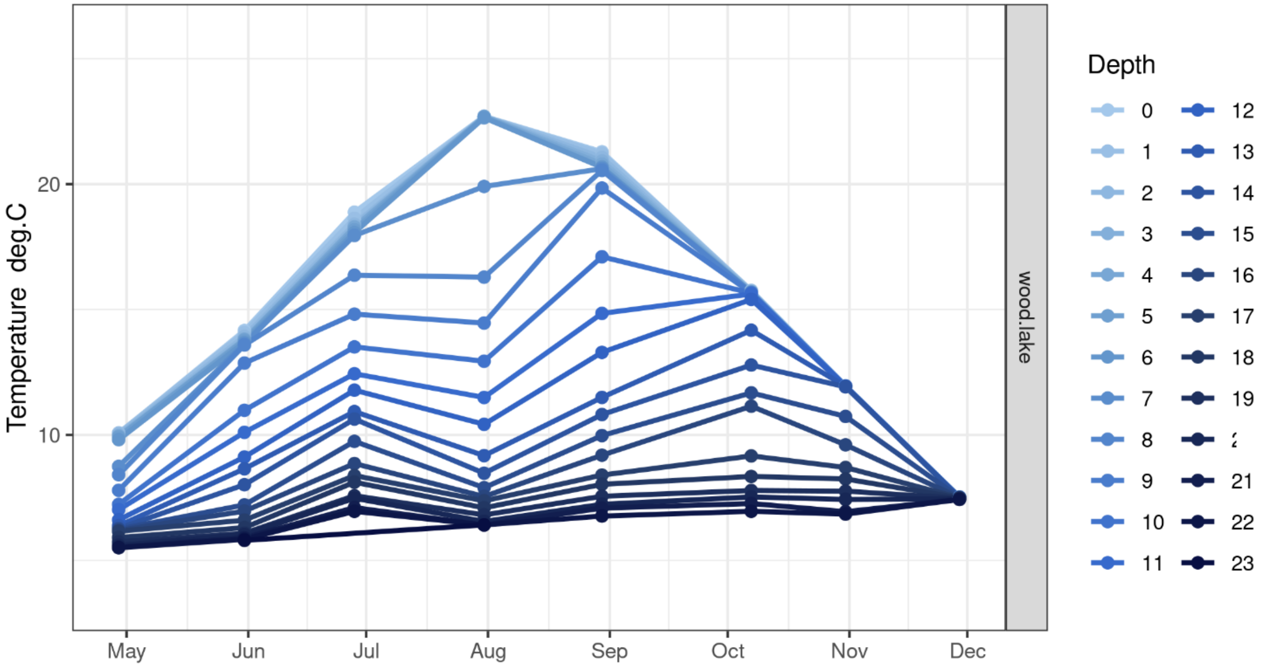

Figure 9: Thermal profiles of Wood Lake, 2024

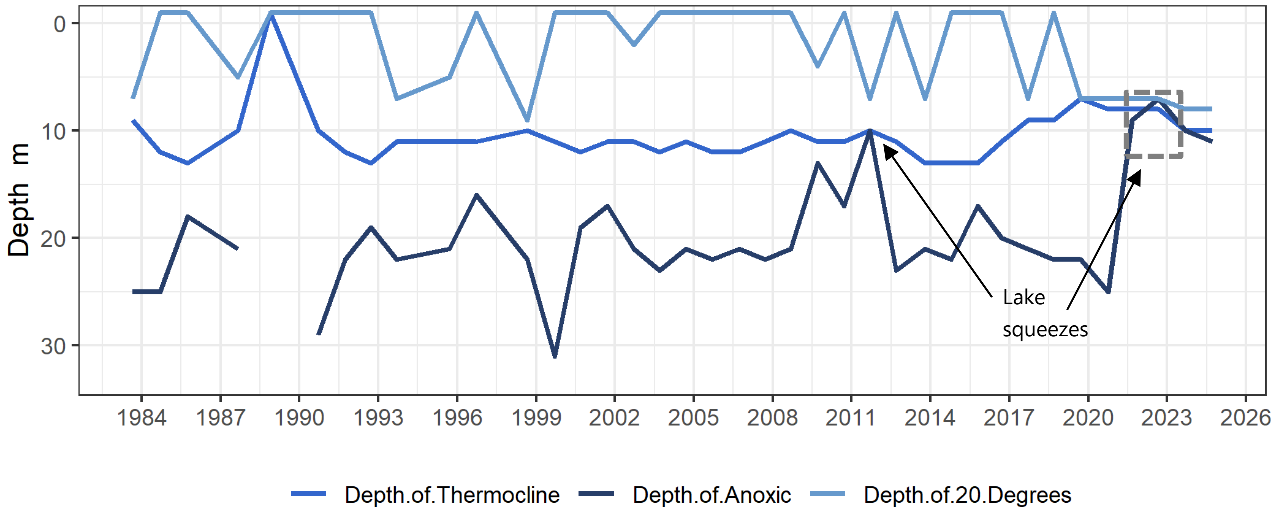

Figure 10: Thermocline vs anoxic zone position in Wood Lake, 1983-2024

Unlike Kalamalka Lake, a low dissolved oxygen (DO) zone forms above the Wood Lake sediments during late summer each year (Figure 11; Figure 12). This anoxic zone is typically thickest in the deep central area of the lake, located to the south of the sample site. Overall, the extent of the 2024 low DO zone was average compared to previous years (Figure 11; Figure 12). Wood Lake has also exhibited a pattern of anoxic water at the thermocline during the early-summer that eventually merges with the anoxic zone extending upwards from the sediment. The cause of this mid-water column anoxic zone is believed to be from decomposition of the spring algae bloom by bacteria that use the density differential of the thermocline for buoyancy. A trend towards larger and more intense anoxic zones at the same time as higher surface dissolved oxygen has developed in recent years; the pattern in DO closely matches algae densities (Figure 21). Anoxic conditions affect the redox potential of the lake water, and this dramatically affects water chemistry by mobilizing nutrients, iron, and manganese (Figure 16).

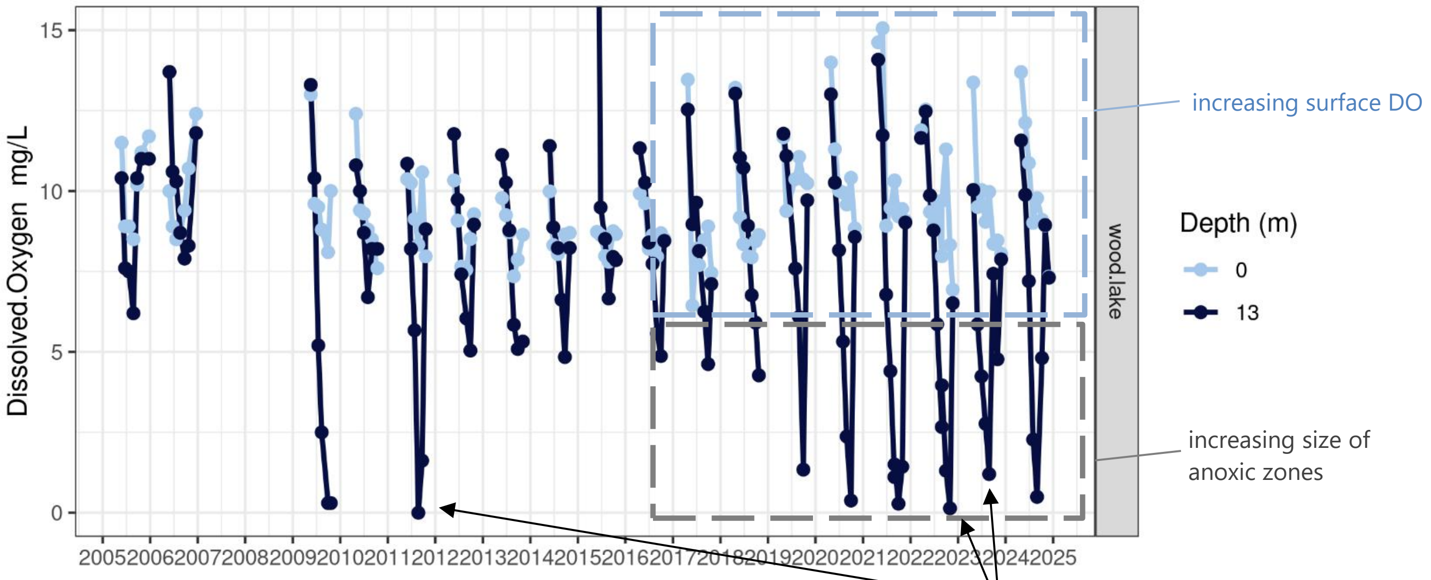

Figure 11: Dissolved oxygen in Wood Lake, 2005-2024

lake squeezes
(2011, 2022, and 2023)

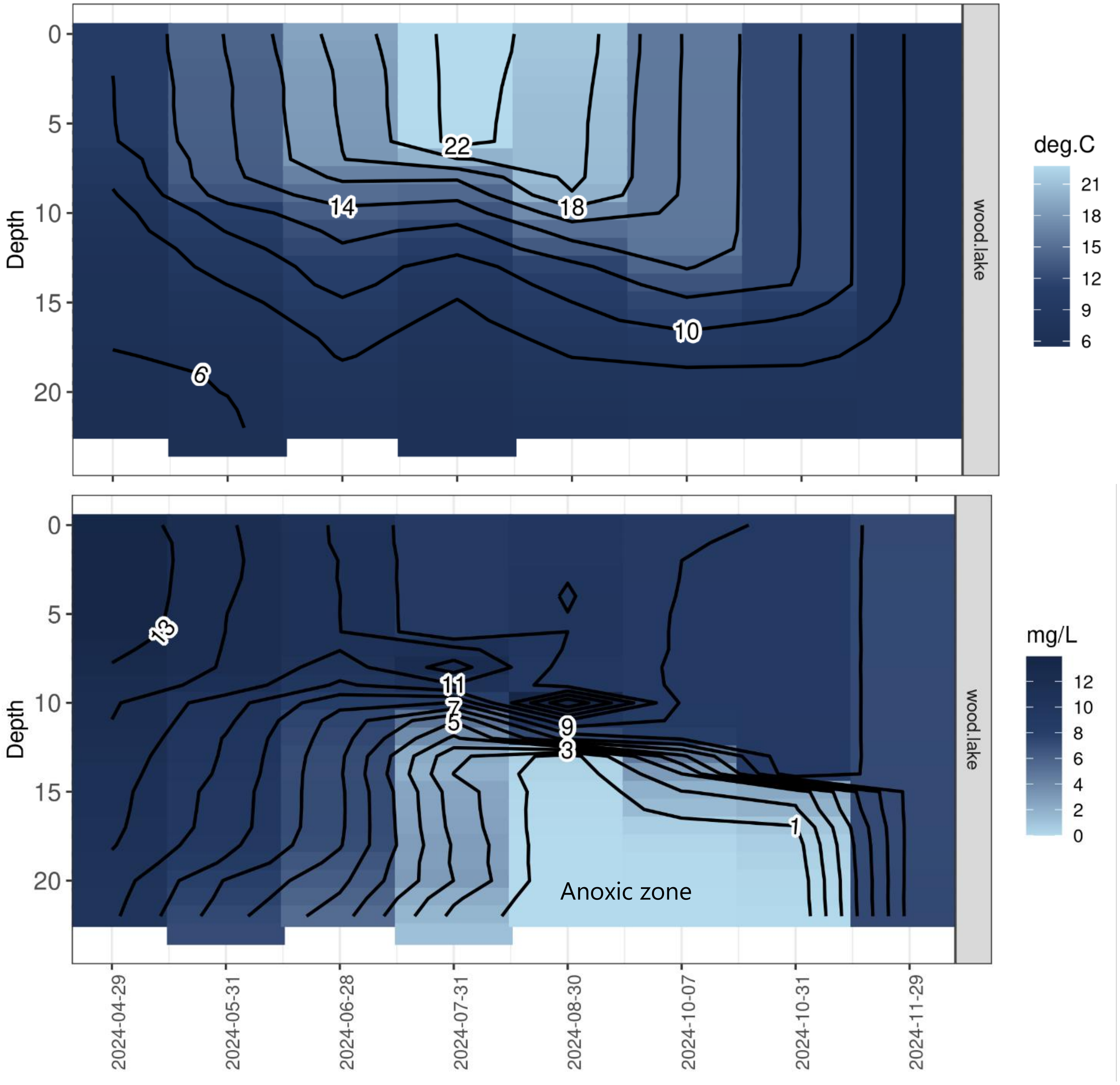

Figure 12: Temperature and dissolved oxygen profiles for Wood Lake in 2024

Note: White blocks represent the lake bottom which is variable depending on the lake elevation relative to high water

General Water Chemistry

High productivity in Wood Lake exerts a strong influence on pH. pH was elevated by photosynthesis in the surface water and was depressed by decomposition in the bottom water when anoxic conditions were present (Figure 13). Surface pH exceeded 9 from May to July, and in September 2024 because of high algae production (Figure 13).

pH and hardness showed an oscillating trend over the years of study with no long-term increases or decreases (Figure 13). Hardness measures mainly calcium carbonate, a constituent of marl events. High hardness increases the likelihood of marl events while drops in hardness is related to weak marl events (Figure 13).

Anecdotal evidence suggests that the increased inflow of lower hardness water from Okanagan Lake while the Hiram-Walker plant was in operation (1971-1993) reduced the frequency of marl events. More frequent marl events would have a range of influences on water quality, notably increased phosphorus removal from the upper water column.

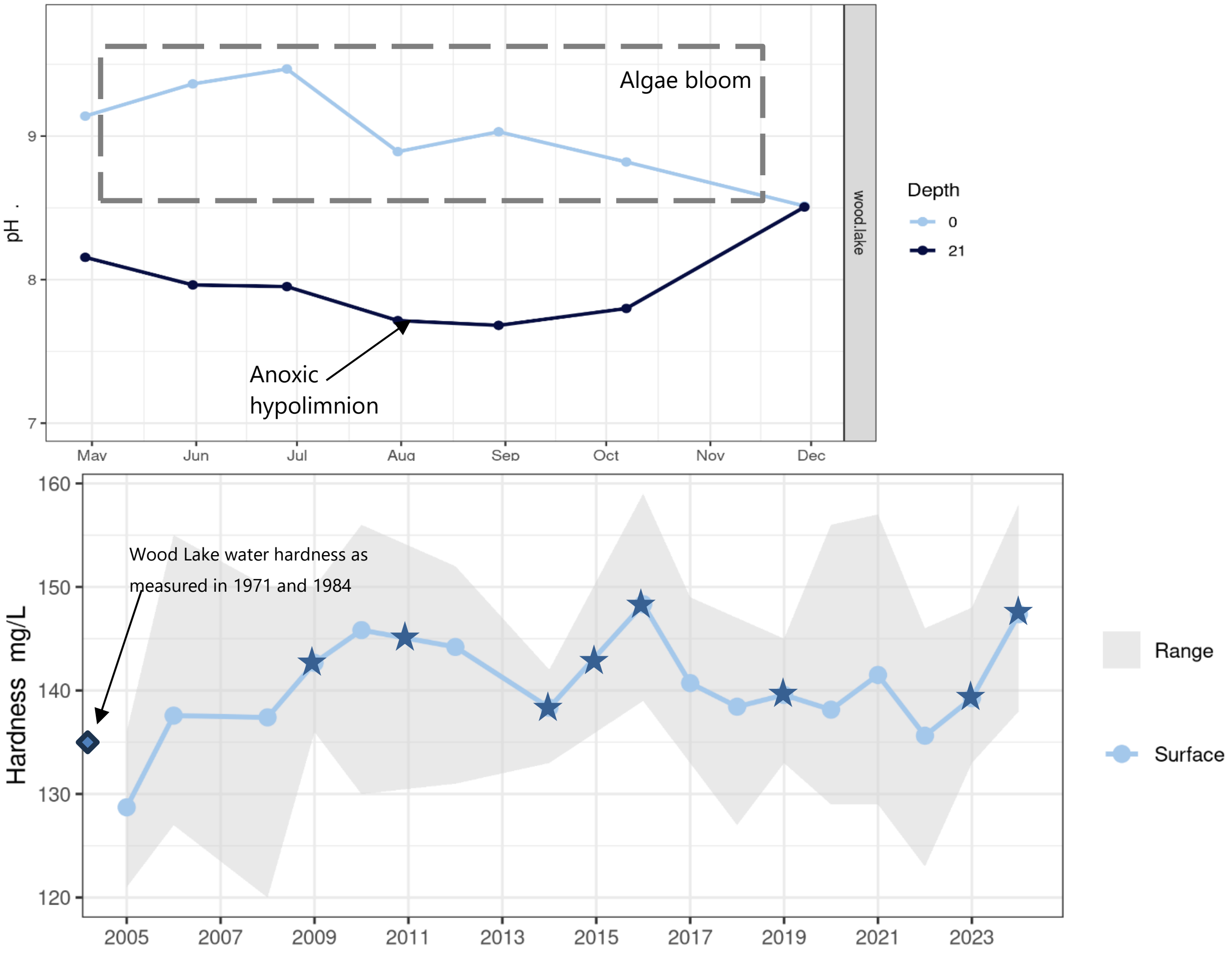

Figure 13: Wood Lake surface and bottom pH during 2024 (top) and hardness (bottom) from 2005-2024

Note: Hardness data from LAC; stars mark marl years; Source for 1971 and 1984 data: Jensen & Bryan, 2001

Chloride and sodium concentrations in Wood Lake both showed strong increasing trends to 2010 but both parameters decreased from 2011-2014 (Figure 14). Chloride and sodium resumed increasing again after 2015 (Mann-Kendall, $p < 0.001$). The 2011-2014 decreases were potentially from dilution through extra inflows during wet years. Large freshets and subsequent flooding that occurred in 2017, 2020, and 2022 created temporary dips in chloride concentration but were not sufficient to overcome the increasing trend with 2024 having the highest average chloride to date (Figure 14). Since the main sources of salt include road salt and treated sewage, the increase will continue as Wood Lake's watershed becomes more urbanized. Ratios of sodium to chloride has decreased from 1.5 to 0.9 from 2005 to 2024. Increasing chloride relative to sodium (decreasing ratio value) is consistent with road impacts because it is transported more readily than sodium (Kelting et al. 2012; Stromberg, 2014). Chloride and sodium averaged 21.6 ± 0.71 mg/L and 19.9 ± 1.23 mg/L respectively during 2024. Chloride concentrations were significantly higher in Wood Lake compared to Kalamalka Lake in every year of this study (Kal S 0m 2024 average of 10.6 ± 0.50 mg/L).

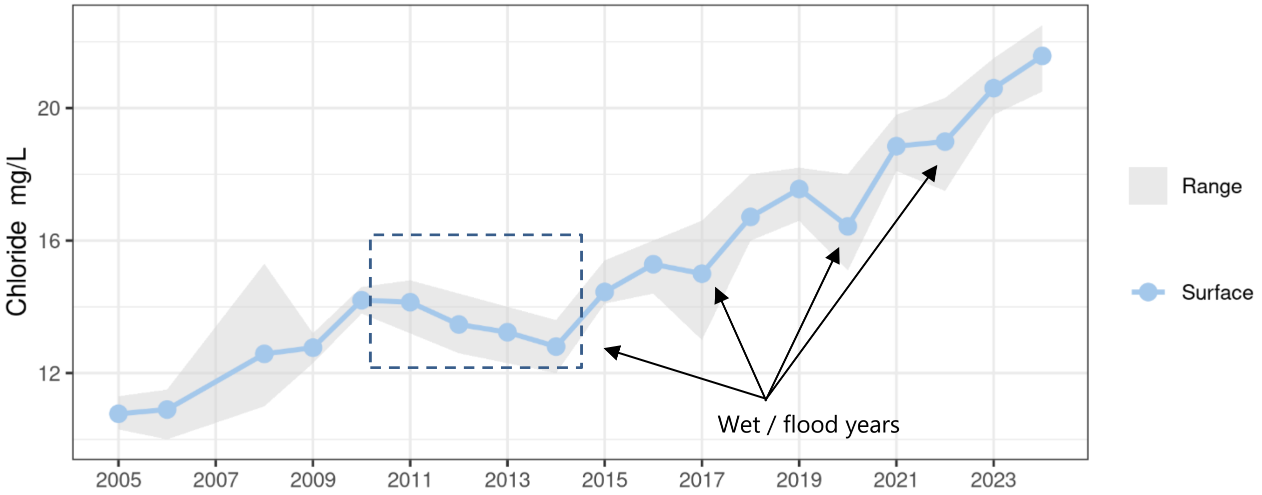

Figure 14: Chloride in Wood Lake surface water from 2005-2024

Total calcium averaged 32 ± 2.8 mg/L in Wood Lake during 2024 and was stable over the course of this study (Mann-Kendall, $p = 0.13$; Figure 15).

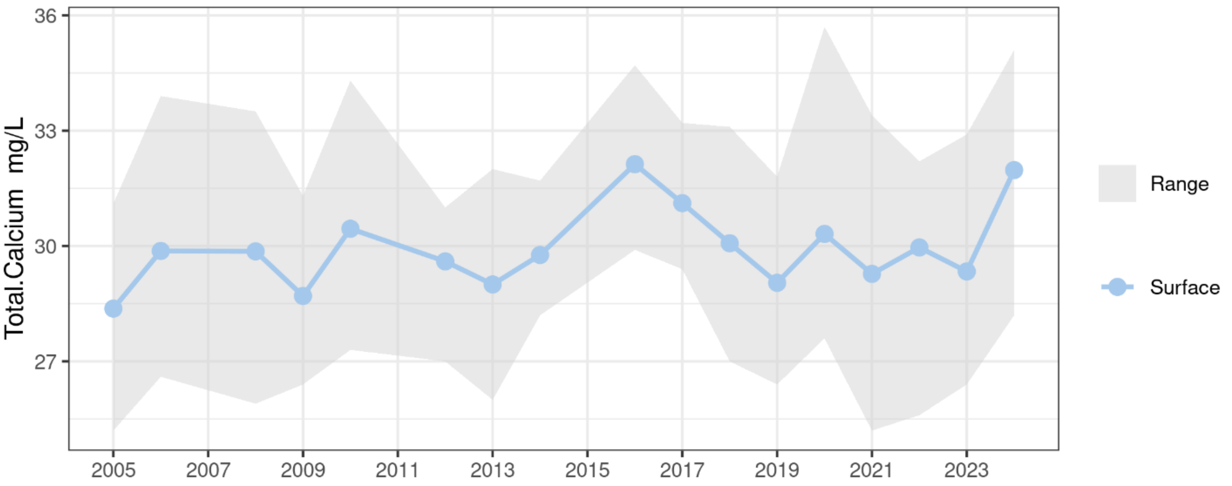

Figure 15: Total calcium trends in Wood Lake surface water from 2005-2024

Marl

Occasionally Wood Lake experiences a late summer marl precipitation as in 2010, 2011, 2014-2016, a strong marl in July 2019, 2023, and 2024. Marl events were more frequent during the 2010s than the preceding two decades. Marl events have a beneficial effect on lake productivity by typically causing cyanobacteria numbers to drop dramatically because marling strips phosphorus and small algae cells from the water column. For example, the July 2015 marl event induced a decrease of 0.0415 mg/L TDP (89%) in the epilimnion between the spring peak and the August low[4]. The 2024 marl event did not stop a significant cyanobacteria bloom, but it is possible that a more serious bloom was avoided (Figure 21).

Nutrients

Wood Lake has more water column interaction with its nutrient-rich sediments than Kalamalka Lake does, making it consistently more productive than Kalamalka Lake. Wood Lake provides nutrients and often algae to Kalamalka Lake every year via the Oyama Canal.

Nutrients in the sediment can re-dissolve into the low dissolved oxygen zone in response to negative redox (Figure 16). Released nutrients from the sediment fertilize the entire lake after fall overturn, when the anoxic zone mixes upwards. Blue-green algae (cyanobacteria) blooms mark the Wood Lake overturn every year despite cool, dark November/December conditions (refer to algae section). Increased flows from nutrient-rich Lower Vernon Creek for fish flows also provide an additional late season nutrient source. Internal loading is responsible for supplying up to 99% of the ortho-phosphate in Wood Lake and more than 66% of the dissolved inorganic nitrogen (DIN = NO_3 + NH_3, Self, 2016).

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[4] ENV decreased monitoring frequency to March and September in recent years preventing an update to this percentage.

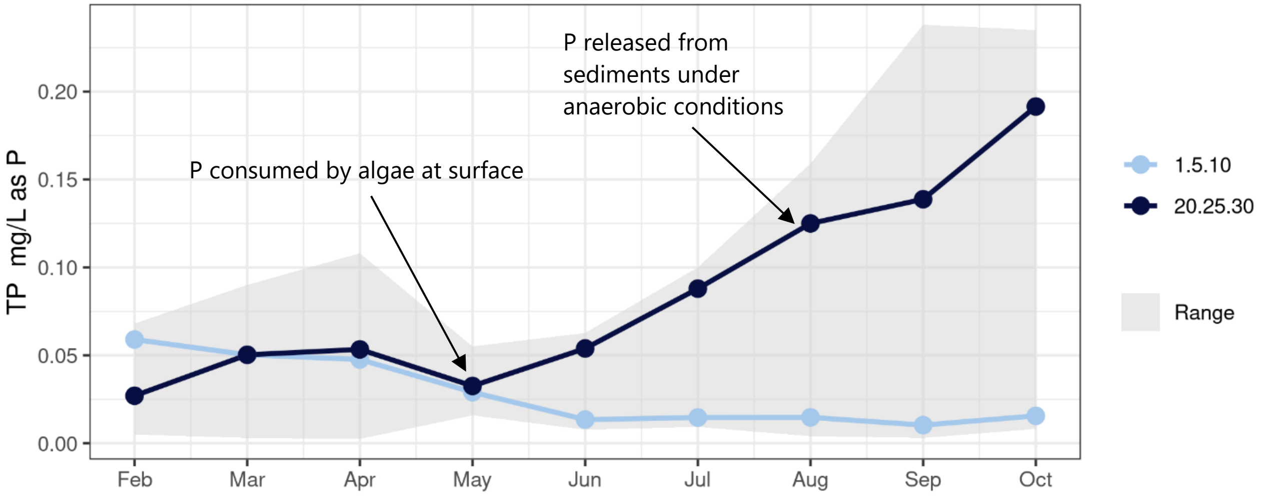


Figure 16: Total phosphorus concentration in Wood Lake by month, 1970-2024

Note: Data for March and Aug/Sep exist for all years while other months were from 2013-2015 only | Site = ENV 0500848

Wood Lake's total nitrogen concentrations showed a significant declining trend from 1970 to the early 1990's (Mann-Kendall, $p \leq 0.002$, 1970-1990). TN increased from 2009-2024 in both the epilimnion and hypolimnion (Mann-Kendall, $p < 0.01$). Although there was an extended period of stability from 2012-2018. The four highest surface TN averages since 1981 occurred annually from 2020-2023 (increasing averages year-after-year). 2024 had above average surface TN of 0.584 ± 0.146 mg/L (1970-2024 average = 0.464 ± 0.156 mg/L). Hypolimnion TN was the second highest since 1981 in 2024 (after 2021; 2024 average = 0.777 ± 0.132 mg/L). Wood Lake TN surface averages were 1.9 times higher than Kalamalka Lake during 2024 (compared to Kalamalka ENV deep basin site 0500847).

In most years, dissolved nitrogen is rapidly consumed by algae in Wood Lake, resulting in nitrate concentrations that were lower than those of Kalamalka Lake during the summer months. Despite this, across the entire 1970 - 2024 data set, surface NO_2 + NO_3 averaged 0.051 ± 0.068 mg/L as N in Wood Lake and 0.049 ± 0.046 mg/L as N in the south end of Kalamalka Lake (ENV 0500246). During the 2024 fall sampling when the anoxic zone was well-established, Wood Lake surface water measured 0.48 mg/L TN, while the anoxic zone measured a much higher 0.87 mg/L TN caused by nitrogen release from sediments overlain by anoxic water (September 2024 ENV data). Nitrogen concentrations remain far below the level of concern for drinking water, but annual shifts in the N:P ratio of Wood Lake affect its algae production.

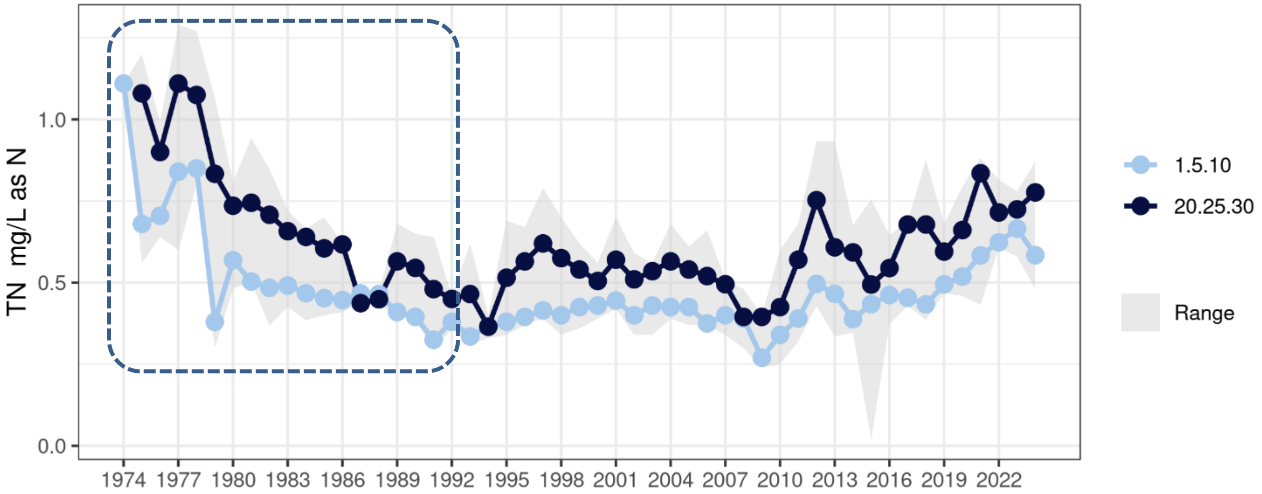


Figure 17: Total nitrogen in Wood Lake from 1974-2024

Note: Deep = 20-25-30 m composite and shallow = 1-5-10 m composite collected by MoE | Site = ENV 0500848
Blue box (1970s-1992) is years with Hiram Walker input

Wood Lake phosphorus concentrations improved during the late 1980's to early 1990's compared to the 1970's and early 1980's (before the Lake Country sewer system, Figure 18). Total phosphorus (TP) concentrations were higher during the past 10 years than the early 1990s and the fall 2024 deep water TP was the highest recording since the 1980s, when concentrations were much higher (Figure 18). TP concentrations averaged 0.041 ± 0.040 mg/L as P in the epilimnion and 0.124 ± 0.086 mg/L as P in the hypolimnion during 2024. TP exceeded the ENV objective of < 0.015 mg/L as P in the spring epilimnion sample during every year since 1998.

Dissolved phosphorus (TDP) had a similar pattern with a decline from very high concentrations during the 1970s to low concentrations in the early 1990s and then moderate concentrations during the past 10 years. This pattern was most pronounced when comparing only the fall data indicating that internal loading may be intensifying, although again, the trend was not statistically significant over the past 20 years. Higher concentrations of total and dissolved phosphorus in Wood Lake during recent years may trigger more intense algae blooms in future years and may be related to the recent increasing trend in algae densities (Figure 21).

Phosphorus loading to mainstem Okanagan lakes is affected by precipitation patterns, with wetter years having greater phosphorus inputs than drier years. Further, there may be an influence exerted by the duration of Wood Lake ice cover, where longer periods between ice-on and ice-off may permit winter anoxic conditions in the bottom water and greater nutrient release.

Wood Lake was classified as eutrophic in the 1980s (Nordin et al, 1988; table on page 9) and would be classified as meso-eutrophic based on recent nutrient concentrations, including those of 2024. The dissolved nitrogen to total phosphorus ratio in Wood Lake during 2024 was 3:1 at the surface indicating strong nitrogen limitation. Under these conditions, cyanobacteria are expected and did dominate at Wood Lake in every year of this study (Figure 21).

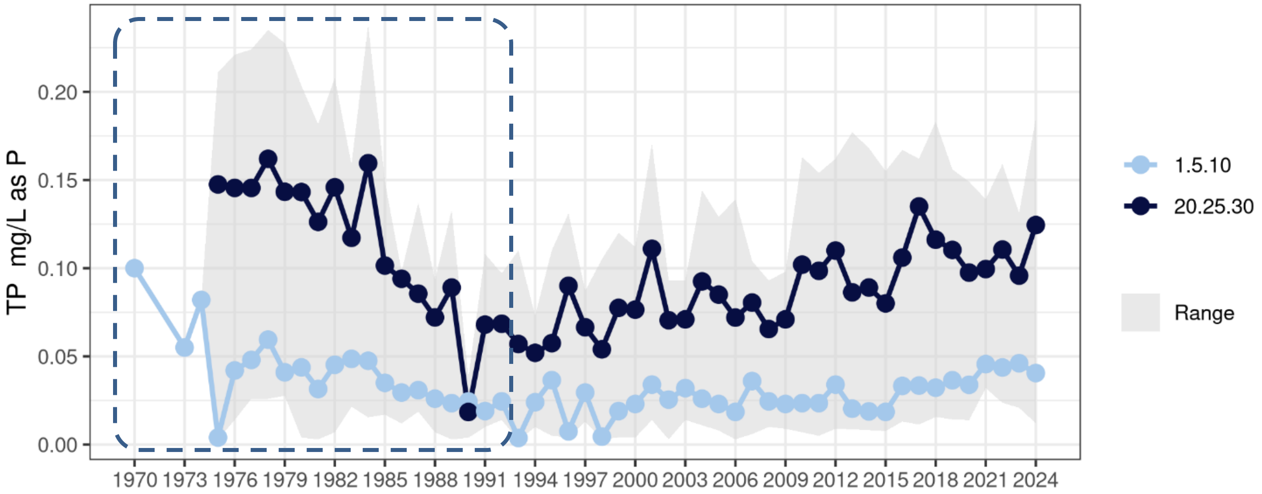


Figure 18: Total phosphorus in Wood Lake, 1973-2024

Note: Deep = 20-25-30 m composite and shallow = 1-5-10 m composite collected by ENV | Site = ENV 0500848
Blue box indicates years with Hiram Walker pumping (1970s-1992)
Dashed red line represents 0.015 mg/L ENV objective

Algae Productivity

Secchi depths in Wood Lake are affected by the nutrient-driven algae production and by marl precipitation. A declining trend in Secchi depth was detected from 2012-2024 in Wood Lake with the annual average decreasing from 7.7 m in 2012 to 2.8 m in 2024 (Mann-Kendall, $p < 0.001$; Figure 19). This trend was noted in both the LAC collected and ENV collected data. Water clarity is now similar to what it was in the 1970s (Figure 19). The decreasing trend in Secchi corresponds to an increasing trend in cyanobacteria over the same time frame (Mann-Kendall, $p < 0.001$, 2012-2024; Figure 21).

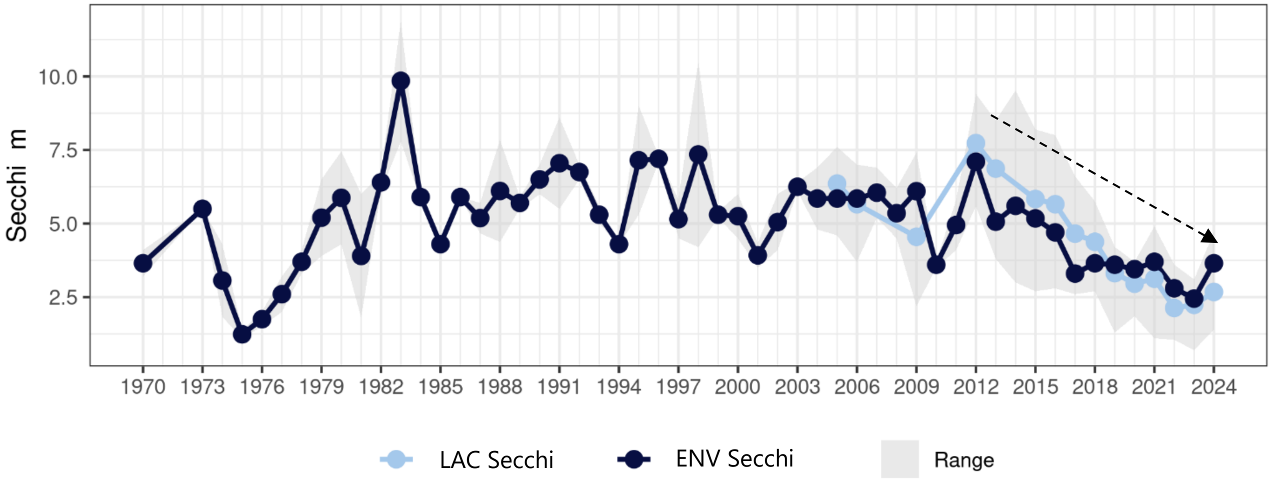


Figure 19: Secchi depth in Wood Lake from 1970-2024

Wood Lake experienced extremely high algal counts in 2024 with a major cyanobacteria bloom during April and May (Figure 21). Chlorophyll-a (chl-a) is a major photosynthetic pigment common in many algae types and therefore excessive algal growth leads to high chl-a. Chl-a surface concentrations decreased in 2024 relative to 2021 and 2022 but were still high for Wood Lake; the composite depth samples collected by ENV were similar to LAC surface samples indicating that peak bloom production was near the surface. A 2024 spring bloom increased chlorophyll-a to 19.9 µg/L on April 30, while 2021 and 2022 chl-a highs were 49.2 µg/L and 21.8 µg/L respectively. Recorded chlorophyll-a concentrations in Wood Lake have always been higher than Kalamalka Lake with an annual average of 8.40 ± 6.80 µg/L chl-a compared to 0.83 ± 0.48 µg/L in S-Kal and 1.13 ± 0.55 µg/L in N-Kal surface samples during 2024 (Figure 20, Figure 21).

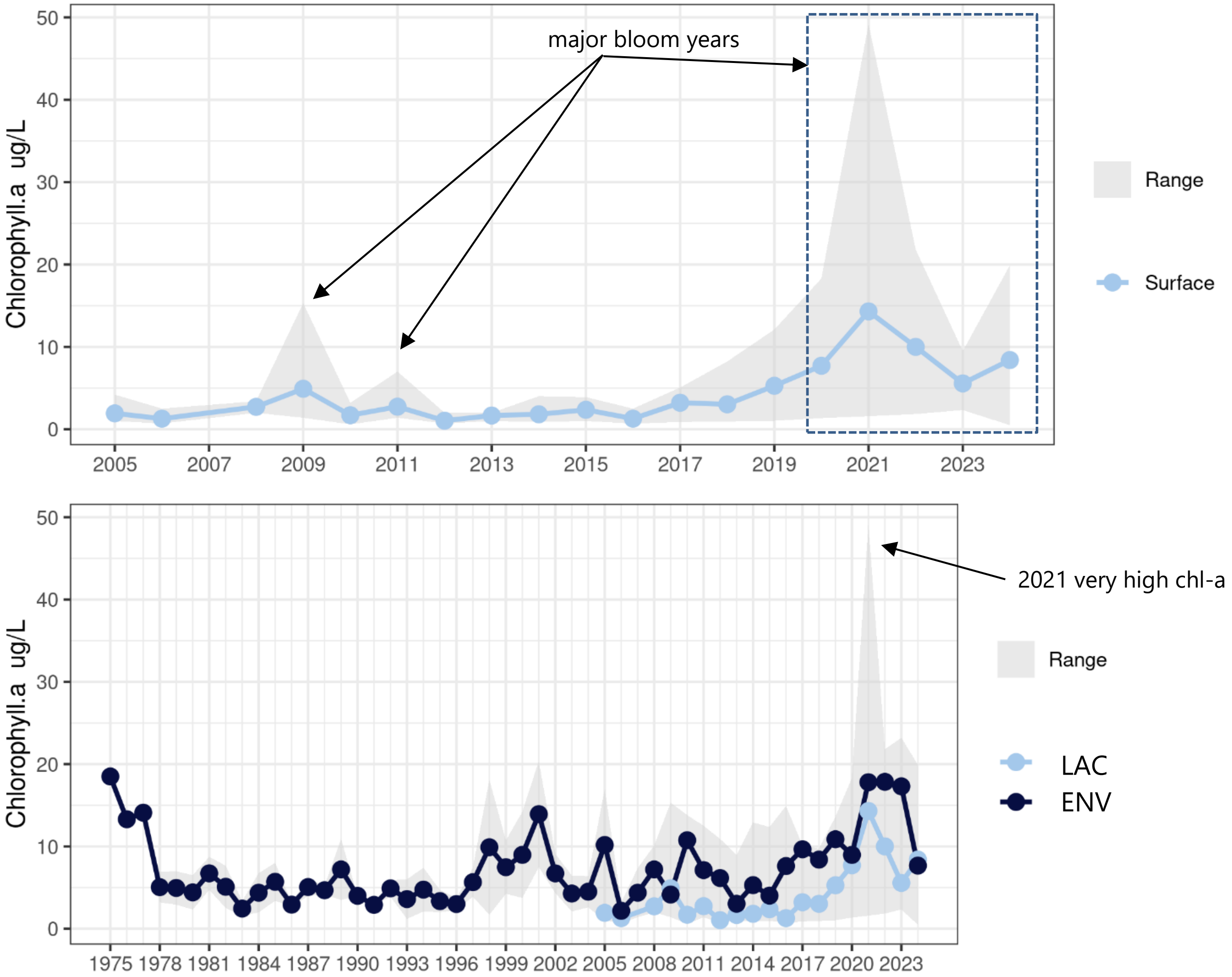


Figure 20: Chlorophyll-a concentration in Wood Lake, 2005-2024 (top) and combined with ENV data from 1975-2024 (bottom)

Overall, excess algae production in Wood Lake declined from the 1970's to 2010's but recent years indicate a troubling reversal with increasing densities. While lower algae production helps water purveyors, it may also slow down the prized Wood Lake kokanee fishery because algae are the base of the food chain. Although algae benefit kokanee by increasing the base of the food chain, large blooms generate copious amounts of organic material that consumes dissolved oxygen. As the organic material decomposes on the sediment, it generates large anoxic zones each year that can cause stress to kokanee (Figure 10). An increasing trend in anoxic zone size and intensity was noted that closely matched the increasing trend in algae (Figure 11). Wood Lake has weak, sporadic marl precipitation and therefore does not have the reliable summer lull in algae production that Kalamalka Lake has.

Wood Lake algae density and diversity exceeded that of Kalamalka Lake on most sample dates. Algal density and diversity can be affected by inflows from Ellison Lake but most of Wood Lake's algae blooms develop locally.

Wood Lake did not experience a major cyanobacteria bloom during 2012-2017, but there were spring and fall blooms each year during 2018 to 2024. Cyanobacteria densities were extremely high during 2024 with a maximum of 101,035 cells/mL and was dominated by *Planktothrix sp.* (May 31). While *Planktothrix sp.* is not a surface bloom forming type of cyanobacteria, it is well documented to be capable of producing cyanotoxins and these densities are therefore concerning (Table A 4). Canadian Recreational Water Quality Guideline for cyanobacteria cells is 50,000 cells/mL; cyanobacteria concentrations in Wood Lake surface water on May 31 were double the guideline value. Cyanotoxin testing completed by IHA on June 24, 2024, following the high densities measured on May 30, revealed no detectable microcystins. Although the time delay meant that cyanobacteria densities at the time of sampling were less than ¼ of the peak in May.

During five of eight 2024 sampling events, cyanobacteria concentrations exceeded the low cyanotoxicity risk threshold of 2,000 cells/mL; two of the eight events passed the moderate cyanotoxicity risk level boundary of 15,000 cells/mL and the highest cyanobacteria count to date exceeded the high risk level of 50,00 cells/mL (May 31, 2024; Figure 21; Appendix 7: Cyanotoxicity Risk Levels).

Cyanobacteria concentrations have increased since sampling began, with 2005-2015 averaging 1,720 ± 2,755 cyanobacteria cells/mL and 2016-2024 averaging 5,870 ± 13,300 cyanobacteria cells/mL (Mann-Kendall, $p < 0.001$). During 2024, cyanobacteria averaged 17,150 ± 34,440 cells/mL (Figure 21).

Cyanobacteria common to Wood Lake include the bloom-forming genera *Anabaena*, *Anacystis, Aphanizomenon, Gomphosphaeria, Planktolyngbya*, and *Planktothrix* and they can produce a range of cyanotoxins (see Appendix 4: Toxin forming Cyanobacteria in Kalamalka Lake). Risk of cyanobacterial toxicity in Wood Lake is dependent upon the species present and cell density. 2024 productivity included all six of the problematic taxa, with *Planktothrix* dominating cyanobacterial counts. Wood Lake cyanobacterial species involved in the annual blooms vary by year and by season in response to factors including nutrient balances, weather, and zooplankton grazing.

Years with algae blooms in Wood Lake have increased algae densities in South Kalamalka Lake, with donations of cyanobacteria being of greatest concern.

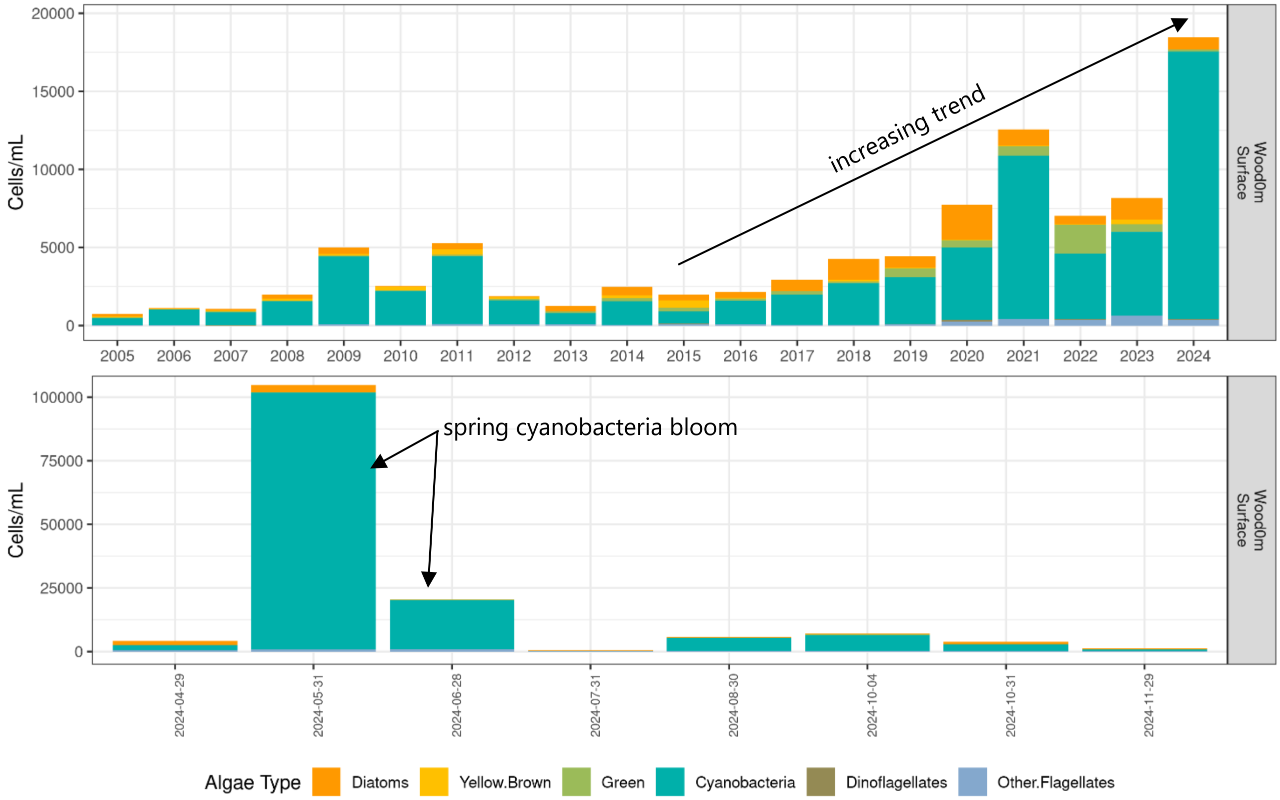


Figure 21: Wood Lake annual average surface algae counts from 2005-2024 (top) and 2024 only counts (bottom)

Bacteria

Wood Lake samples had consistently low *E. coli* counts and were below detection in all samples during most years (Figure 22). To date, there have been only nine detectable *E. coli* results out of 113 samples, most recently 1 CFU/100 mL on June 30, 2023. All 2024 samples were below the detection limit (Figure 22).

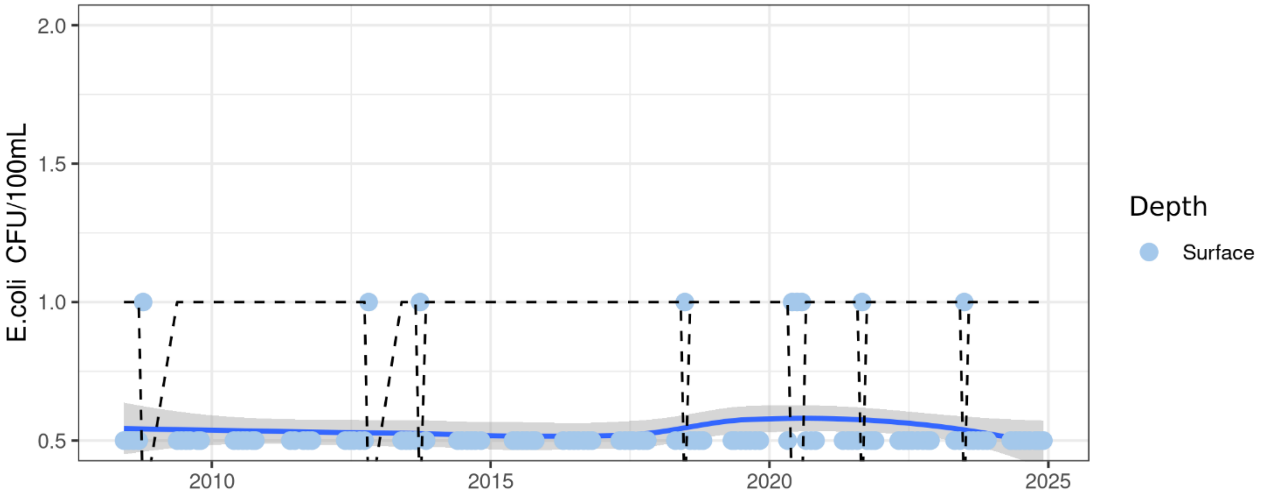


Figure 22: E.coli counts in Wood Lake, 2008-2024

Note: Lab detection limit of 1 CFU/100mL indicated with dashed line

2.2 Kalamalka Lake

Sampling in Kalamalka Lake focuses on the current intake locations and additional sites that may serve as future intake extension depths. Data collected at the deeper sites remains valuable to the current intakes even if they are not extended because seiches within Kalamalka Lake alternately bring deeper and shallower water to the intake depths and the accumulated knowledge informs management decisions at those times.

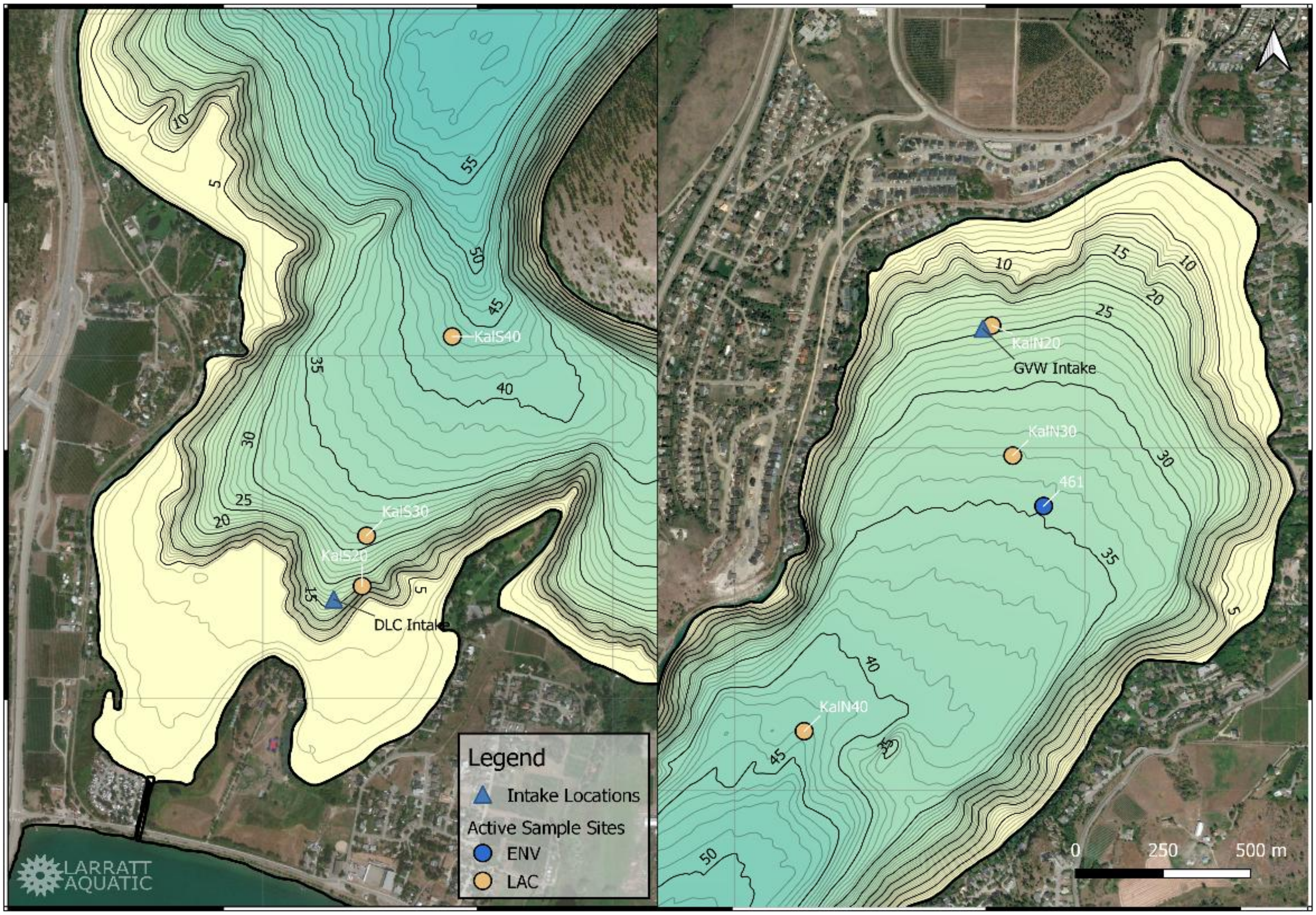


Figure 23: Bathymetric maps of Kalamalka Lake north and south regions with intakes marked

2.2.1 Water Level

The water level of Kalamalka Lake was below average and at or below the record low water level throughout 2024 because of drought conditions (Figure 24). Vernon Creek outflows were also below normal at 5.5 million m^3 compared to the 1927-2023 average of 27.3 ± 22.9 million m^3. It is likely that the hot dry weather and low water level affected algae production leading to higher-than-normal algae densities (Figure 46).

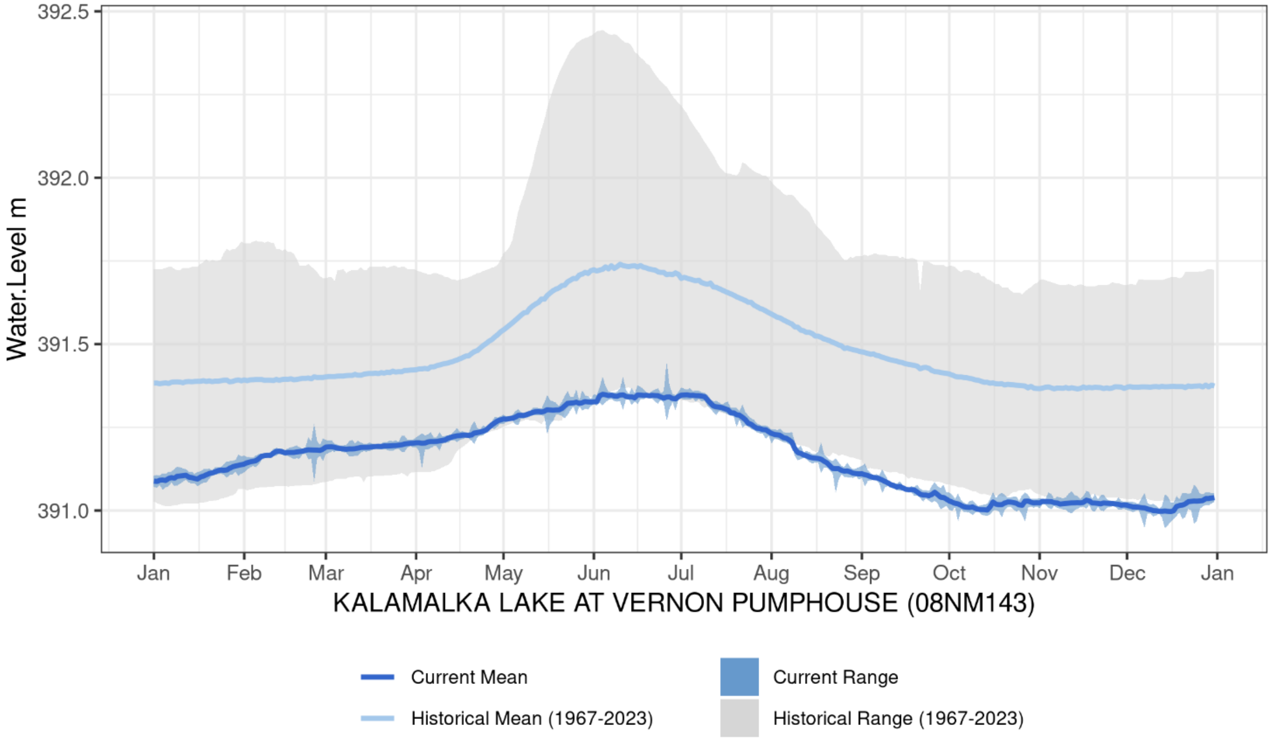
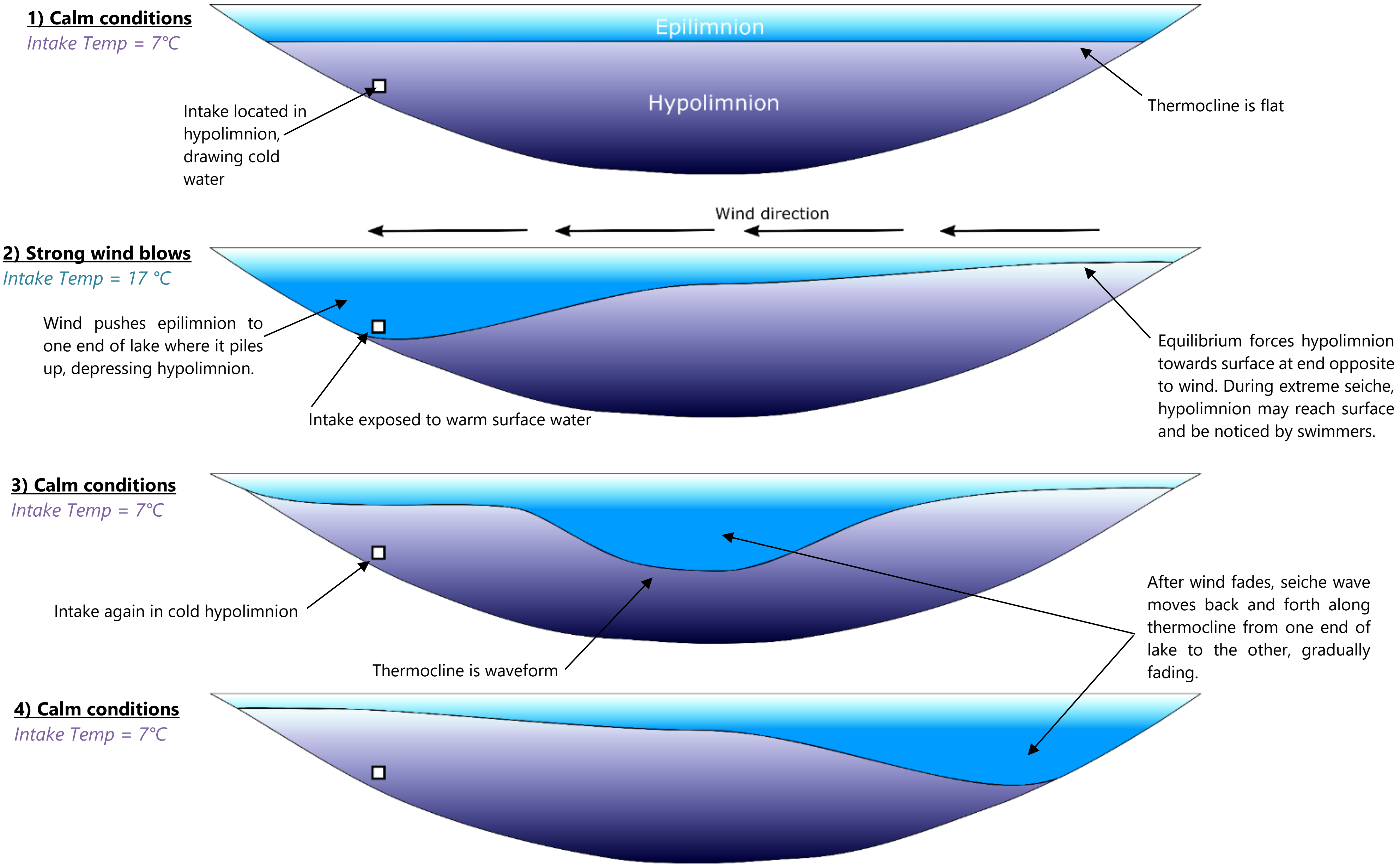


Figure 24: Water level in Kalamalka Lake during 2024 compared to historical average (1967-2023)
Source: Water Office, 2024

2.2.2 Thermal Structure

Thermal structure of Kalamalka Lake is typical for a large temperate lake. It is a warm monomictic lake, where the entire water column mixes from the fall to the spring but is thermally stratified from May to November each year. A thermocline defines the boundary between the warm surface layer and the deep cooler layer in the summer. Windstorms tip the water layers and deflect the thermocline in a process called seiching (Figure 25); the shape of the south end of Kalamalka Lake makes the south intake more susceptible to seiches than the north intake. Thermal stratification influences water chemistry and the water quality withdrawn by Kalamalka Lake intakes.



1) Calm conditions

Intake Temp = 7°C

Intake located in hypolimnion, drawing cold water

Thermocline is flat

2) Strong wind blows

Intake Temp = 17 °C

Wind pushes epilimnion to one end of lake where it piles up, depressing hypolimnion.

Intake exposed to warm surface water

Equilibrium forces hypolimnion towards surface at end opposite to wind. During extreme seiche, hypolimnion may reach surface and be noticed by swimmers.

3) Calm conditions

Intake Temp = 7°C

Intake again in cold hypolimnion

Thermocline is waveform

After wind fades, seiche wave moves back and forth along thermocline from one end of lake to the other, gradually fading.

4) Calm conditions

Intake Temp = 7°C

Figure 25: Anatomy of a seiche

Depending on weather, thermal stratification can develop in Kalamalka Lake anytime between late April and late June. Thermal stratification was recorded in Kalamalka Lake by the end of April in 2024. Summer 2024 was hot and the maximum surface temperatures measured between 21.7 and 23.1 °C at both ends of the lake in late July. Surface water maximum temperatures were near historic averages for maximum summer surface temperatures.

2.2.3 Kalamalka Lake Dissolved Oxygen

Every summer, dissolved oxygen (DO) concentrations were near saturation throughout the Kalamalka Lake water column. As in most years, summer 2024 profiles showed zones of oxygen super-saturation from May to September because of algae photosynthesis in the mid water column. The super-saturated zone extended down to 23 m and raised DO saturation to 126%. In every year to date, DO concentrations remained very high, often greater than 11 mg/L throughout the water column (>12 mg/L during April 2024).

Surface DO concentrations declined over the 2024 summer as they do every year, a function of water temperature. Minimum dissolved oxygen concentrations occurred in a very narrow band (0.1 – 0.4 m) near the sediments and within the warmest 2-3 m of the upper water column. The lowest DO level recorded during 2024 was 9.01 mg/L in the surface at the N-20 m site on July 31. Anoxic conditions (<1 mg/L DO) have not occurred at any of the Kalamalka sites to date. These results are consistent with the sediment trap and sediment sample data collected over the course of this study. The oxygen demand of the Kalamalka Lake sediments never depleted the hypolimnion as happens each year in Wood Lake.

2.2.4 General Water Quality & Nutrients

From 1999-2024, monthly water quality samples were collected during the growing season – the period with the highest frequency of water quality fluctuations. Every year, the greatest impact on water quality in Kalamalka Lake is the size of the freshet, affecting turbidity, nitrogen, phosphorus, pH, calcium, sulphate, and organic/inorganic particulate inputs.

pH

pH in lakes affects every aspect of water quality, including the concentrations of nutrients and metals. Kalamalka Lake's high alkalinity maintains pH between 7.6 and 8.8 during most years. During 2024, pH varied from 7.2 – 8.5 (lab data), with pH exceeding 9 units in May, June, and September (field data). Both ends of the lake showed matching trends in pH, indicating whole-lake influences (Figure 26). Since 2000, pH at most sampled sites has oscillated without a long-term increasing or decreasing trend, although wet years have often lowered pH during the next year. Surface pH indicates Kalamalka Lake is currently declining at N-Kal 0 m, S-Kal 0 m, and S-Kal 40 m sites (Mann-Kendall, $p < 0.01$; Figure 26). Surface pH averaged 8.13 ± 0.31 in the North Arm and 8.12 ± 0.17 in the South during 2024 (Figure 26).

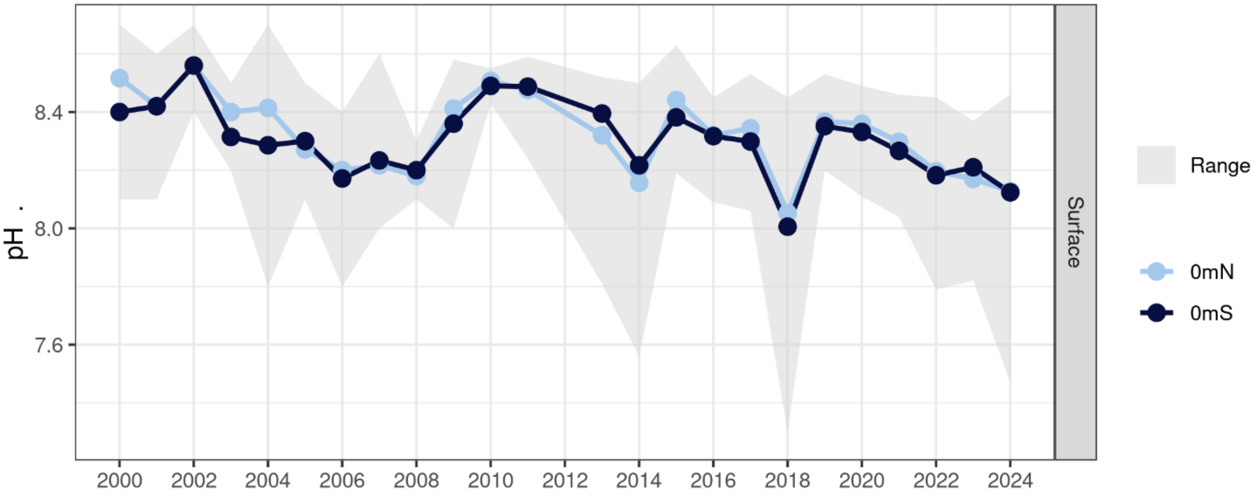


Figure 26: pH for Kalamalka Lake at intake depths, 2000-2024

Parameters that Affect Marl Precipitation

When calcium concentrations exceed 30 mg/L in lakes and other conditions allow, calcite (calcium carbonate) and gypsum (calcium sulphate) can precipitate and form what is collectively known as marl (Wetzel, 2000). Kalamalka Lake experiences an annual marl event that commences abruptly sometime in July or August and it tapers off into October. Kalamalka Lake experienced a strong marl event in 2024 that began during late June, an unusually early start that was likely related to the hotter than normal June weather (Figure 27). Kalamalka Lake also marled in late June during 2023. Flooding and large freshets dilute the lake reducing the intensity of marl events; this was noted during the 2017-2018 and 2020 flood years as well. Each year, the marl process is initiated in mid-summer by phytoplankton photosynthesis because it shifts the inorganic carbon balance and results in higher pH (Wetzel, 2001). Precipitated marl drops slowly through the water column to create a turbid layer near the sediments. Marl settling usually increases turbidity at the intakes in late summer (Figure 40).

Total calcium concentrations averaged 38.5 ± 2.4 mg/L in Kalamalka Lake across all years of study (40.5 ± 0.85 mg/L in 2024, N-Kal 20 m site; Figure 28). Hardness, alkalinity, and calcium increased significantly from 2000-2015 at both intake depths but were stable over the past ten years (Figure 28).

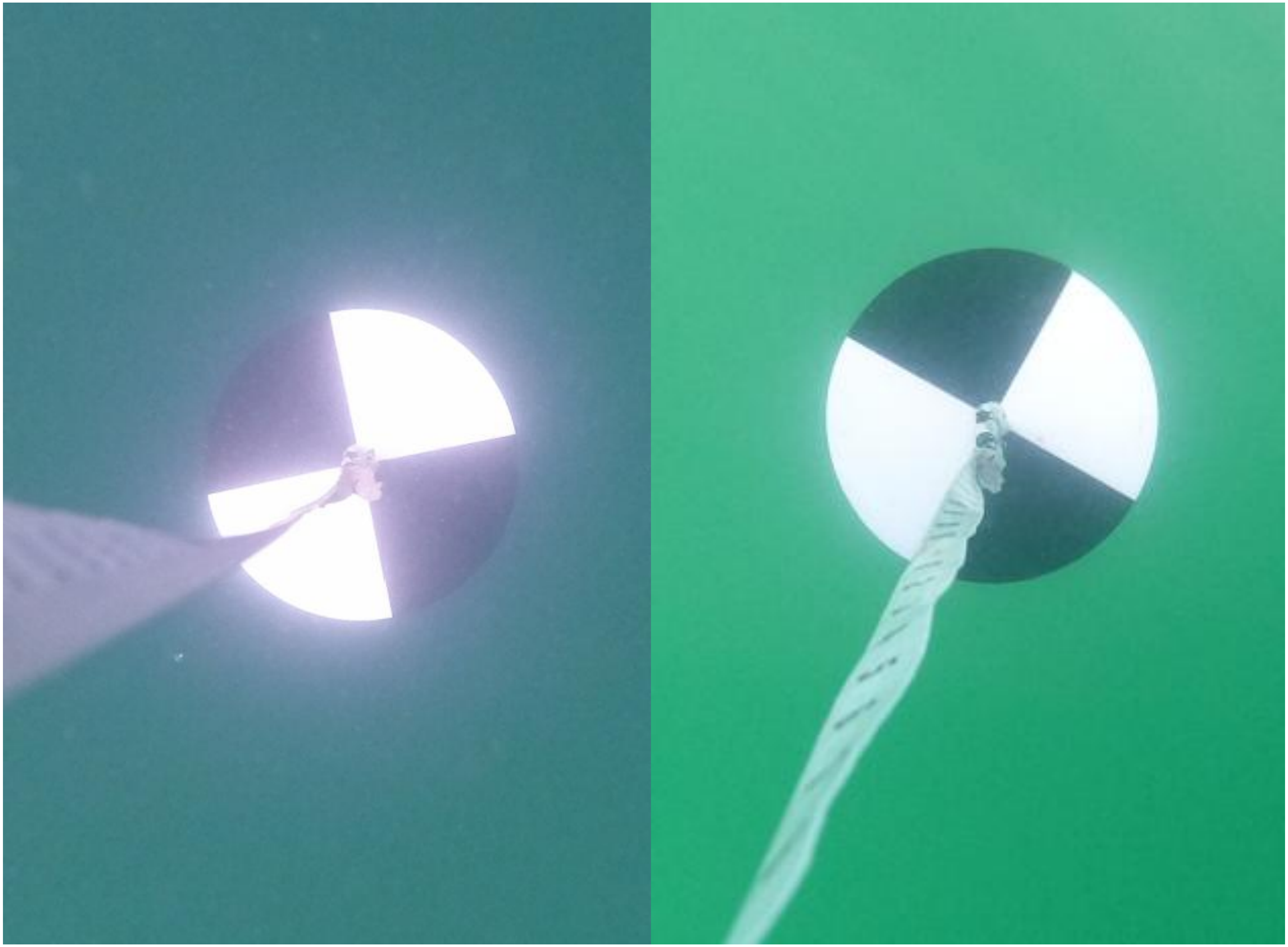


Figure 27: Photographs of secchi disk in Kalamalka Lake before and after marl event during 2024

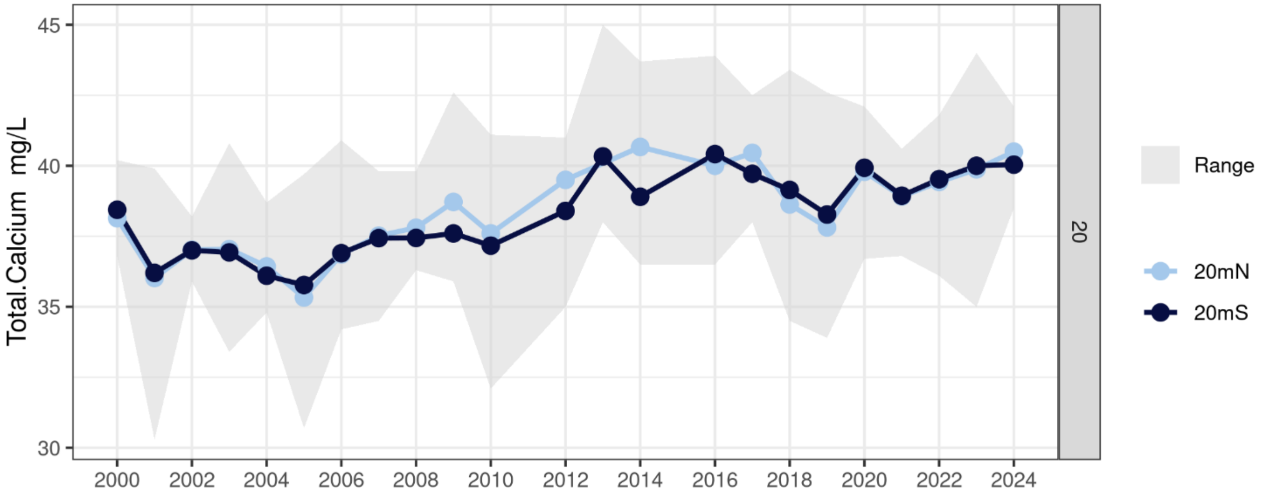


Figure 28: Total calcium at north and south intake sites in Kalamalka Lake, 2000-2024

Average sulphate concentrations in Kalamalka Lake (50.1 ± 2.47 mg/L in 2024; S-Kal 20 m) were more than double the concentrations in Wood Lake (20 ± 0.5 mg/L in 2024; Wood Lake 0 m) because of unique local groundwater contributions and Coldstream Creek. Coldstream Creek sulphate were higher than Kalamalka Lake, particularly during times of lower flow when groundwater represents a larger fraction of the flow volume, averaging 77.0 ± 18.4 mg/L in 2024.

High sulphate concentrations contribute to the formation of calcium sulphate, a component of marl. Since 2003, sulphate concentrations in Kalamalka Lake have been cyclically oscillating around a long-term mean. From 2011-2020 there was a downward swing in the cycle and from 2020-2023 there was an upward swing, but 2024 showed the cycle trending back to decreased values (Figure 29). Sulphate cycling in Kalamalka Lake is probably related to the wet-dry climate cycles. There is also seasonal variation in sulphate with lower concentrations during freshet; freshet flows are naturally low in dissolved ions because they are fed by melting snow.

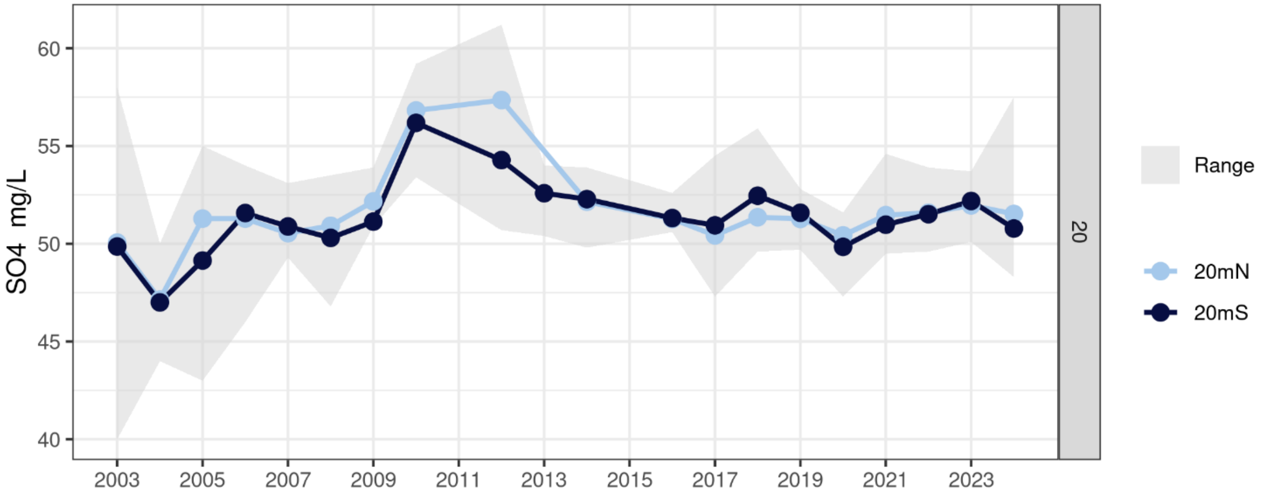


Figure 29: Sulphate at north and south intake sites in Kalamalka Lake, 2000-2024

Seasonal delivery of sulphate in lake water depends on the types of minerals found in the watershed (Shaw et al., N.D.), fall rains, and groundwater inflows. High sulphate concentrations have been documented in groundwater supplying the Kalamalka Lake drainage (Newmann et al, ND). Using the generalized Okanagan Basin water balance, about one quarter of the inflow to Kalamalka Lake would be supplied by ground water (Self, 2024).

Sodium, Chloride and Conductivity

Sodium (Na) and chloride (Cl) concentrations are naturally low in the Okanagan mainstem lakes. Increasing concentrations are indicative of anthropogenic inputs to Kalamalka Lake. These ions can come from road salt, urban stormwater, agriculture, and natural groundwater sources. Na and particularly Cl are conservative ions that are removed from Kalamalka Lake primarily through simple hydraulic flushing.

Chloride concentrations increased significantly at both ends of Kalamalka Lake from 2005 to 2024 (Mann-Kendall, $p < 0.001$; Figure 30). Maximum chloride concentrations increased dramatically from 6.0 mg/L in 2005 to 11.2 mg/L in 2024 (S-Kal 20 m). This represents a dramatic example of human impacts on Kalamalka Lake (Figure 30). Despite the long-term increasing trend in chloride, sodium concentrations were stable or declining over the past 10 years at all sampled sites (Mann-Kendall, $p = 0.003$); sodium interacts with soil slowing its movement through groundwater compared to chloride.

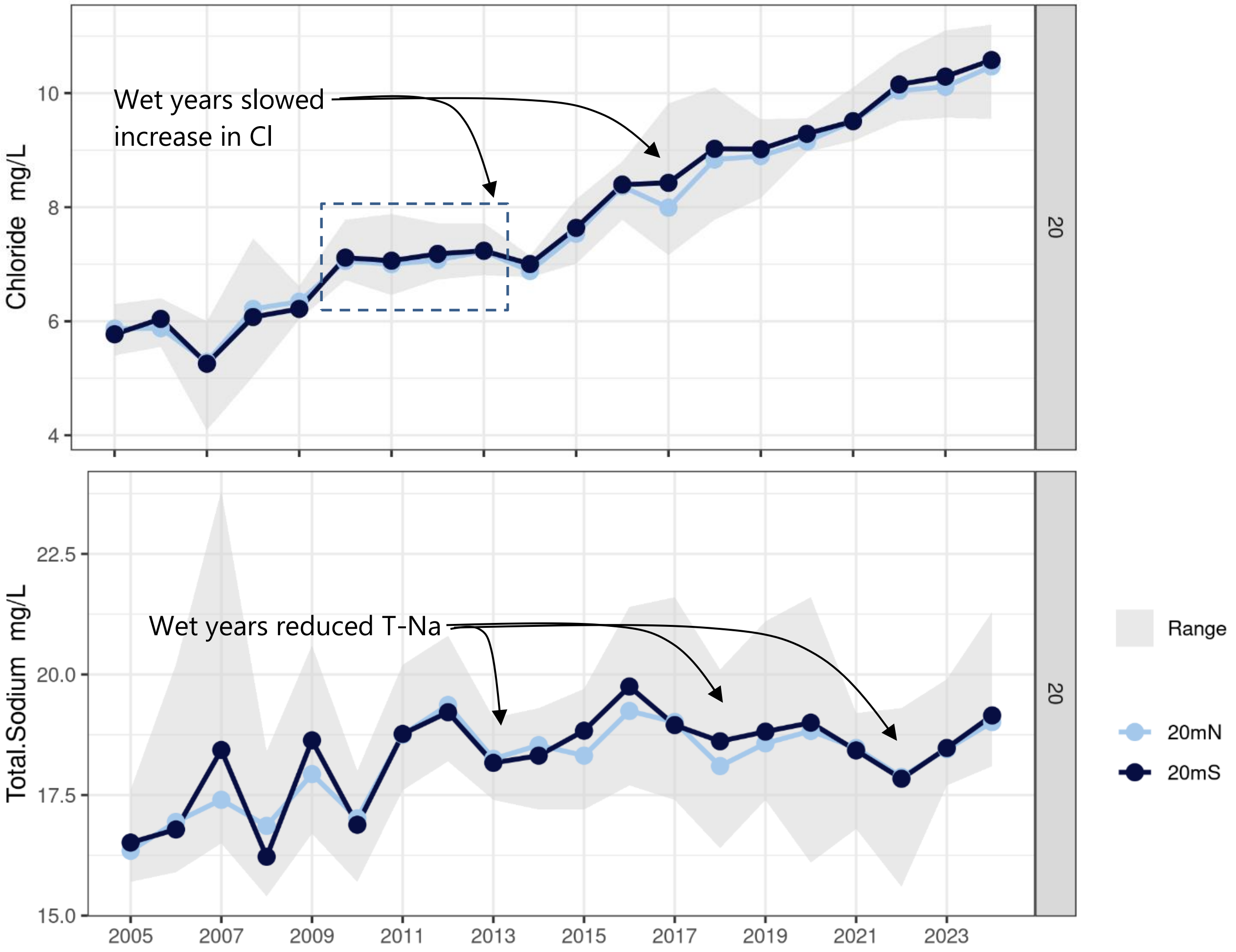


Figure 30: Growing season chloride and sodium in Kalamalka Lake from 2005-2024

Both Wood Lake and Coldstream Creek can act as chloride sources to Kalamalka Lake (Figure 31). Wood Lake averaged 21.6 ± 0.71 mg/L and Coldstream Creek averaged 21.4 ± 4.9 mg/L in 2024. With a flushing time for Kalamalka Lake of 55 to 65 years, salt inputs accumulate in the lake.

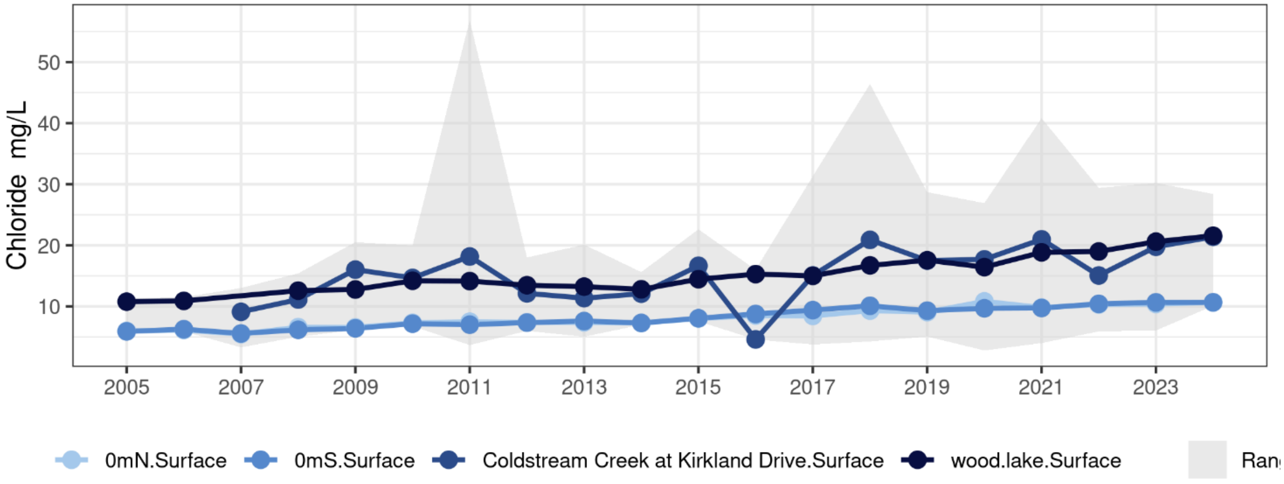


Figure 31: Chloride concentrations in Kalamalka Lake, Coldstream Creek, and Wood Lake: 2005-2024

Note: Coldstream Creek had only one chloride sample in 2016

Like sodium and chloride, conductivity was lower in Kalamalka surface water and higher in the hypolimnion during the stratified growing season in all years of study. Surface conductivity averaged 419 µS/cm in Kalamalka Lake during 2024, the highest annual average since 2000 when this study began. The increase is related to evaporative concentration during the past two very dry years.

2.2.5 Nutrients

Nitrogen and phosphorus are the two most important nutrients controlling Kalamalka Lake productivity, as they are in most lakes. Spring nutrient concentrations measured when the water columns were freely mixing provide an important predictor for productivity in the coming growing season. Spring 2024 epilimnion TN in Kalamalka Lake averaged 0.311 ± 0.038 mg/L as N while TP averaged 0.007 ± 0.001 mg/L as P (March ENV data for 3 Kalamalka sites combined). Kalamalka Lake does not experience anoxic conditions, as Wood Lake does, and therefore nutrients do not increase seasonally in the hypolimnion (Table 2). Nutrient data are not collected by LAC as part of this study to avoid duplication of work done by ENV.

Table 2: Total nitrogen and total phosphorus, 2024 (ENV Site Kal 0500847 and Wood 0500484)

	Kalamalka Lake		Wood Lake	
Total Nitrogen (mg/L)	Shallow 0-5-10 m	Deep 20-32-45 m	Shallow 0-5-10 m	Deep 20-32-45 m
Spring	0.355	0.361	0.687	0.683
Fall	0.254	0.290	0.481	0.870
Total Phosphorus (mg/L)				
Spring	0.0071	0.0060	0.0690	0.0639
Fall	0.0083	0.0060	0.0121	0.1850

Note: Spring = March, Fall = September
Source: ENV EMS, 2024

Trend analysis of Kalamalka Lake showed stable TN from over the past 30 years (Figure 32). There was a weak declining trend in annual average TP from 1975-2003 (Mann-Kendall, $p < 0.01$). This trend reversed in the early 2000s and TP has significantly increased from 2003-2016 (Mann-Kendall, $p < 0.001$; Figure 32). TP was stable but elevated over the past 8 years. The 0.008 mg/L TP objective for Kalamalka Lake was met in most years over the past decade including 2024 (Table 2; Figure 32; Nordin et al, 1988). Epilimnion TP reached 0.0059 mg/L on March 20, 2024, at site Kal 0500461 below the TP objective. Fortunately, the annual marl precipitation helps maintain low phosphorus concentrations in Kalamalka Lake.

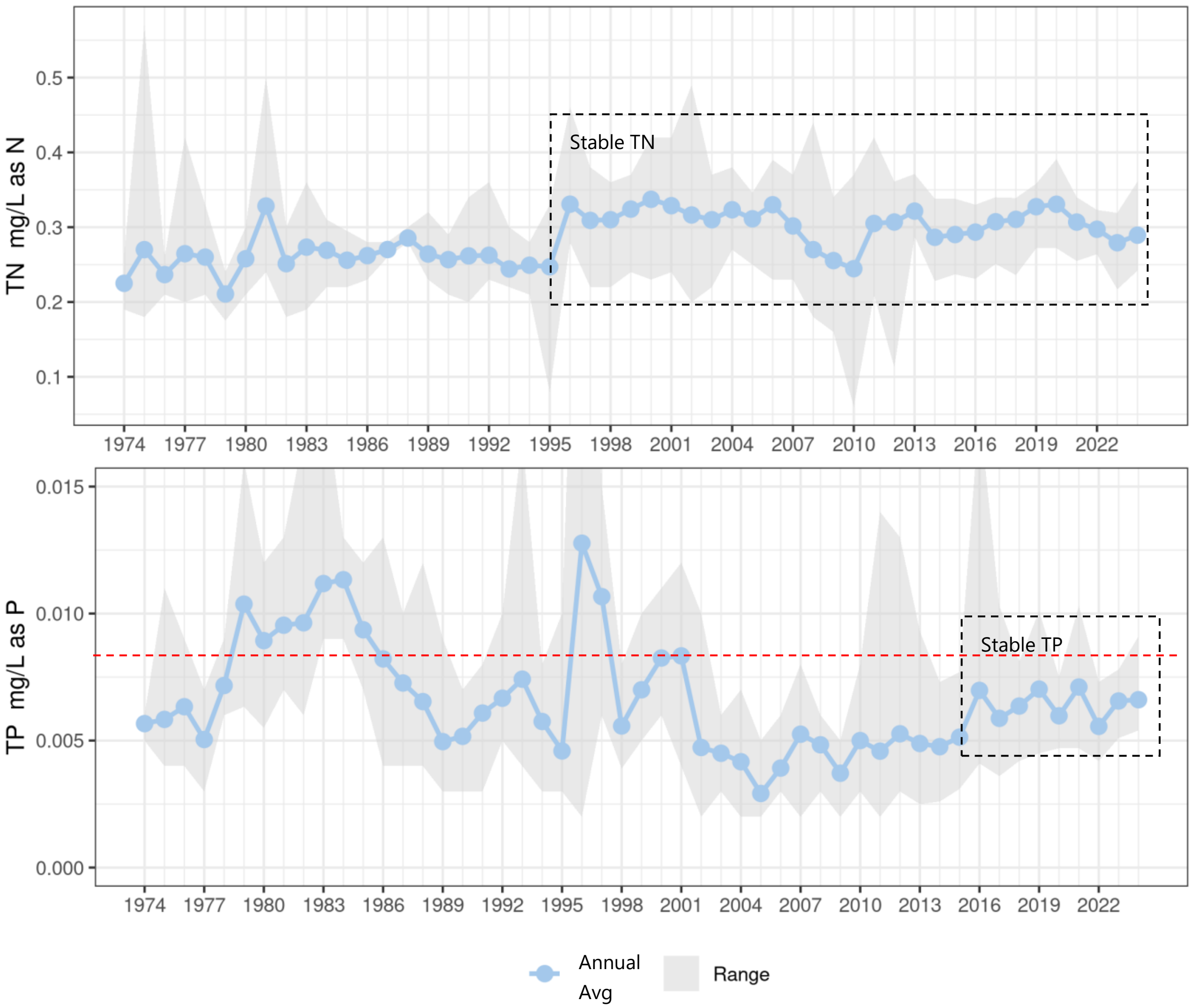


Figure 32: Nitrogen and phosphorus in Kalamalka Lake north arm from shallow 1-5-10 m and deep 20-24-29 m composites 1974 – 2024

Note: Dashed red line = the ENV Objective of 0.008 mg/L TP | Sites = ENV 0500246, 0500461, 0500847

Spring nutrient concentrations set the tone for productivity in Kalamalka Lake in the subsequent summer. Large nutrient concentrations in the spring can lead to larger algae production, dependent on other factors such as weather and marl intensity. March ENV measurements in 2009 through 2023 showed relatively high nitrate concentrations in Kalamalka Lake, ranging from 0.0745 to 0.114 mg/L as N. Epilimnion nitrate averaged 0.088 ± 0.005 mg/L as N during 2024. There was a significant decreasing trend in hypolimnetic nitrate from 1997-2013 throughout the lake although the trend appears to have stabilized in recent years (Figure 33). With lake mixing in the fall, nitrate concentrations were restored to Kalamalka Lake surface water by winter.

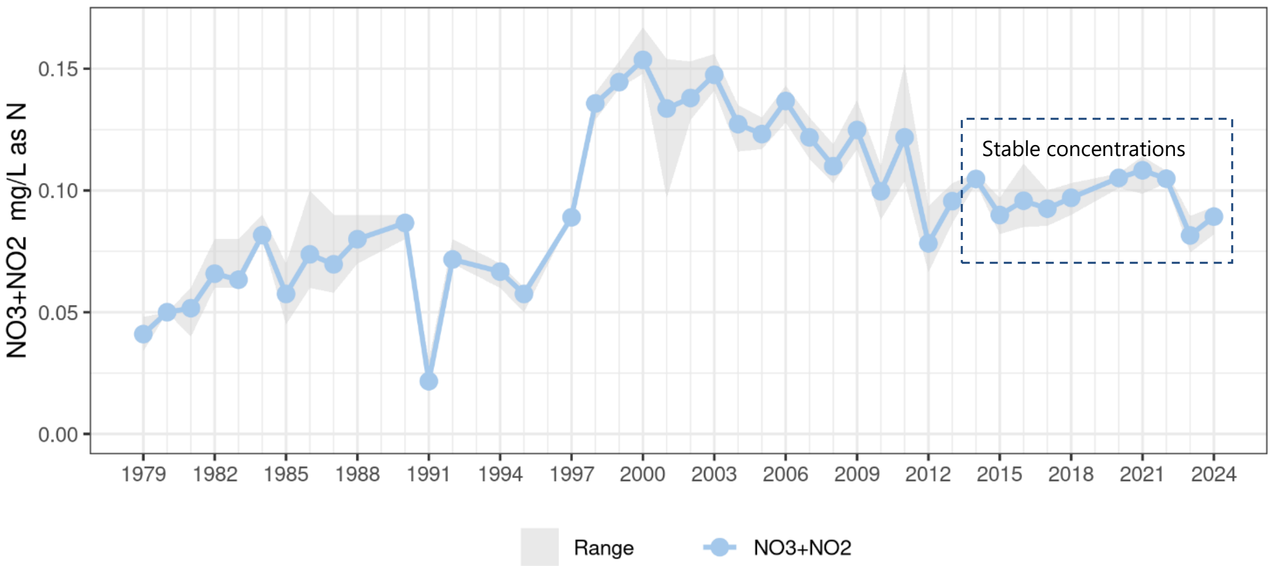


Figure 33: Spring nitrate + nitrite concentrations in Kalamalka Lake, 1975-2024

Note: This graph combines epilimnion and hypolimnion data from the north, central, and south basins for March to highlight the lake-wide nature of the trend | Sites = ENV 0500246, 0500461, 0500847

Nutrient data accumulated from all sources over the years shows several important trends in Kalamalka Lake:

- Within Kalamalka Lake, the shallow ends were more productive than the main body of the lake
- Nutrient trends at the north and south sites on Kalamalka Lake moved together (Figure 32, Figure 33), indicating whole-lake influences, including:
    - freshet nutrient inflow via Coldstream Creek
    - inflows from Wood Lake
    - normal or nutrient-enriched groundwater seepage
    - possible episodic overland flow from land use applications like the spray effluent program, agriculture and/or stormwater outfalls. (Bailey Creek averaged 1.58 ± 1.13 mg/L as N from 2017-2019 in recent RDNO study).
- Wetter years usually had greater nutrient loading from larger springtime inflows. Small peaks in south Kalamalka nutrients or in north Kalamalka nutrients in Figure 32 probably relate to greater inflow from Wood Lake or Coldstream Creek, respectively.
- Surface dissolved nitrogen and phosphorus concentrations dropped gradually over every growing season through microflora consumption
- Total phosphorus concentrations dropped during the summer marl events through co-precipitation and settling of small algae cells (see Appendix 1: Kalamalka Lake and Wood Lake Water Quality Data - 2023).
- The statistical correlation between algae production in 2003 – 2024 and lake-wide annual average TP was very weak (Pearson's R=0) throughout the lake. The weak relationship and high variability in correlation between nearby sites is because other factors, including weather and marl intensity, also affect Kalamalka Lake production.
- Coldstream Creek influences Kalamalka Lake nutrient concentrations because it supplies an approximately half of the annual surface inflow to Kalamalka Lake (Self, 2024). Coldstream Creek total nitrogen concentrations from recent years reached higher maximum values than in the 70's and 80's, (Sokal, 2010).

Nutrient balance of all additions and consumptions in Kalamalka Lake provides the N:P balance that determines the type and intensity of algae growth. In spring 2024, the average Kalamalka Lake surface DIN:TDP ratio (DIN = Dissolved inorganic N **:** TDP = Total dissolved P) was 22**:**1 for the north arm and 24**:**1 in the south basin. The 2024 ratios indicate phosphorous limitation. This is expected in Kalamalka Lake because the marl removes phosphorus from solution. However inorganic nitrogen is rapidly removed from the surface water by algae activity and by the fall the DIN**:**TDP was only 1.4**:**1 in the south and 2.3**:**1 in the north of the lake in 2024. Kalamalka Lake is therefore limited by phosphorus in the spring and nitrogen in the summer and fall. Certain species of cyanobacteria present in Kal Lake can fix atmospheric nitrogen and will excel under nitrogen limiting conditions and are regularly observed in Kalamalka Lake in the late summer (Figure 45, Figure 46). Both N and P will co-direct algae growth in Kalamalka Lake through the annual productivity cycles.

2.2.6 Chlorophyll-a and Total Organic Carbon

Chlorophyll-a is a photosynthetic pigment found in most aquatic microflora. It provides a measurement of algae and photosynthetic bacteria production. Epilimnion chlorophyll-a averaged 1.8 ± 1.1 µg/L at the south end of Kalamalka Lake, and 2.2 ± 1.1 µg/L in the North end from 1975-2024 (ENV data only). The range in chl-a currently found in Kalamalka Lake would classify it as oligo-mesotrophic.

Figure 34 shows the annual spring peak in chl-a when increased nutrients and day length coincide and facilitate diatom blooms. Monthly chl-a data showed decreased chl-a through the balance of the growing season at all depths. Minimum algae production usually occurred in August to October after marl precipitation removed phosphorus from solution and before overturn during most years. There is considerable year-to-year variation in response to weather and watershed activities (Figure 34; Figure 35).

Peak chl-a occurred in May 2024 at 3.6 µg/L in the S-Kal 30 m sample, a typical result for Kalamalka Lake (Figure 35). Samples from 20 m contained more chlorophyll-a than the surface samples over the course of this study (KW-Test, $p < 0.001$; Figure 35) because of several factors including: deep-water cyanobacteria, dying algae settling towards the bottom, and because storms and seiches create turbulence that re-suspend low-light tolerant microflora from the sediments. Overall, chl-a was lowest at the 40 m sites from 2000 – 2024 (KW-Test, $p < 0.001$; Figure 35). Within this study, surface and 20 m chl-a has remained relatively stable with annual averages between 1 and 2 µg/L during most years. However, there was a weak declining trend from 2000-2024 for the 30 m and 40 m sites (Man-Kendall, $p < 0.001$; Figure 35).

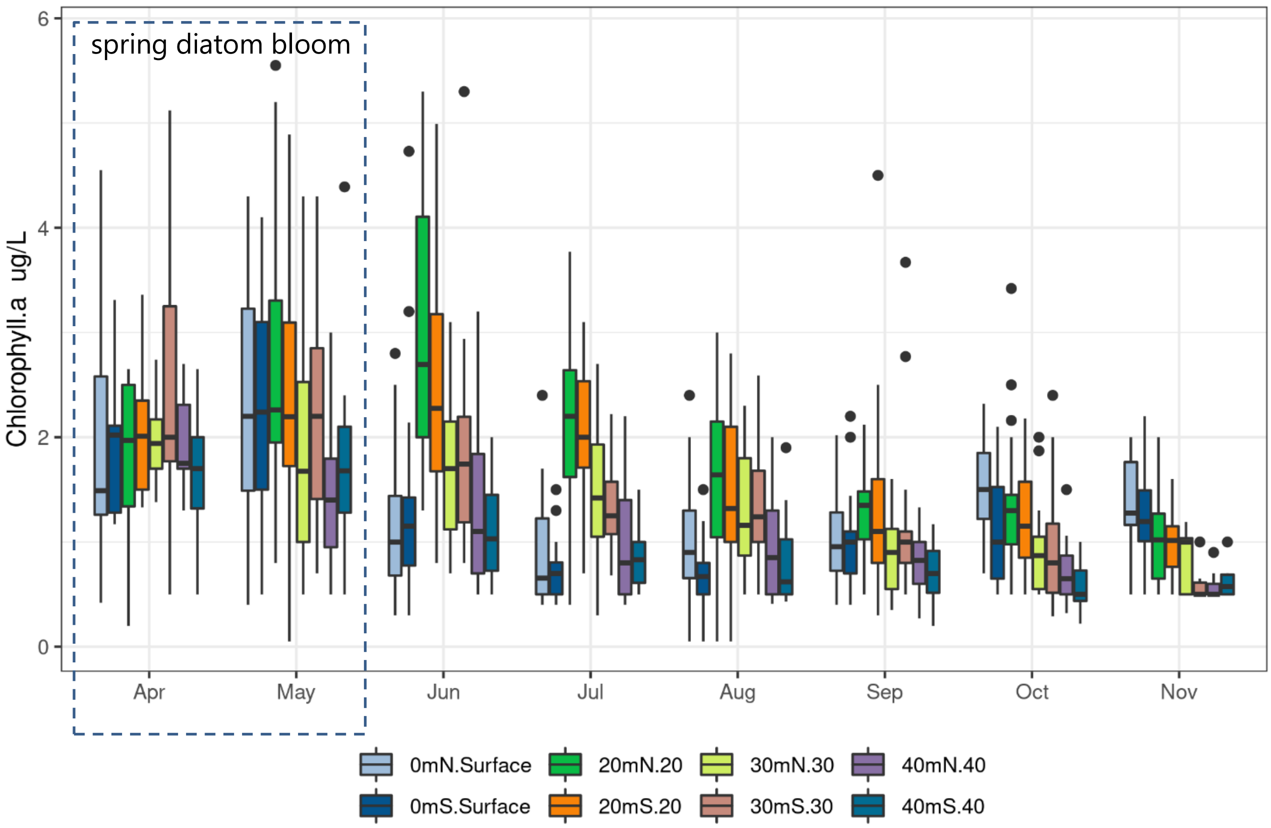


Figure 34: Chlorophyll-a by depth during the growing season in Kalamalka Lake from 2000 - 2024
Note: peak in 0m chl-a occurs in May while 20 m chl-a peaks in June because bloom sinks slowly
Note: extreme chl-a concentrations between July and Sept 2020 are cut off to emphasize general trends

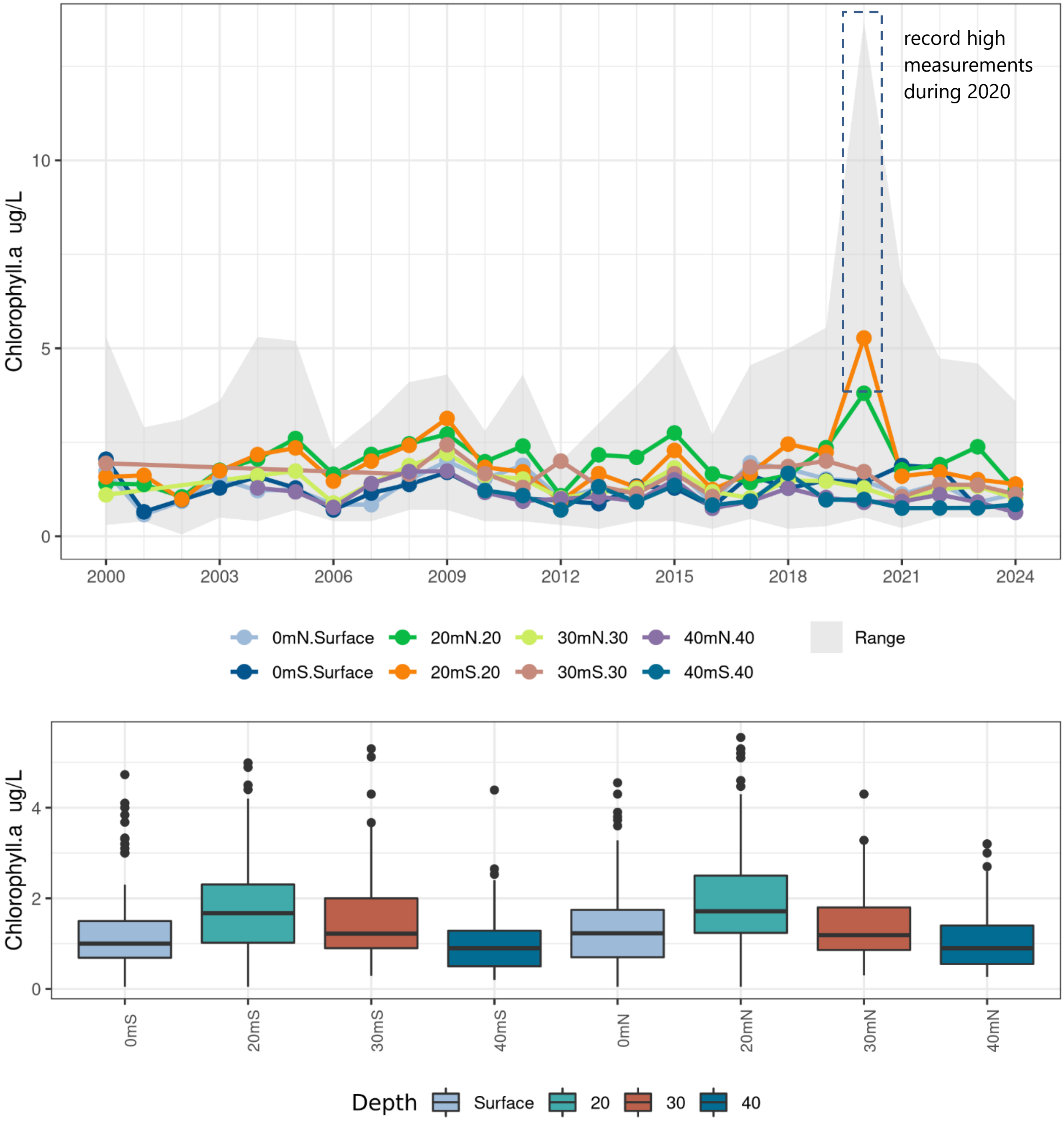


Figure 35: Chlorophyll-a concentrations in Kalamalka Lake, 2000-2024
Note: Record high 2020 chlorophyll-a measurements above the scale on this graph to highlight broader patterns

Total Organic Carbon (TOC) measures dissolved and suspended carbon bound in organic molecules and organisms. Both Coldstream Creek (only during freshet) and Wood Lake TOC exceeded that of Kalamalka Lake every year (Figure 36). TOC averaged 4.40 ± 0.40 mg/L and 4.44 ± 0.16 mg/L at the north and south intake depths respectively during 2024. All sites exceeded the BC guideline for drinking water of 4.0 mg/L of TOC at some point during 2024 (BC MoE, 2001). The S-Kal 40 m site had the lowest growing season TOC during most years (2024 lowest TOC sites = S-Kal 40 m and N-Kal 40 m; Figure 37).

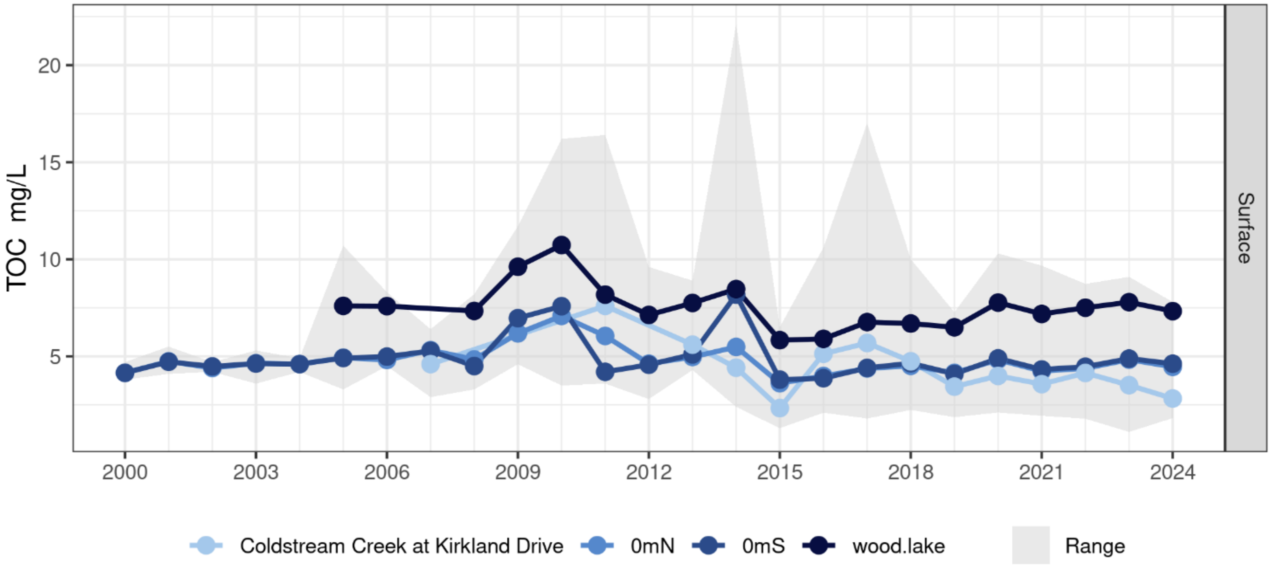


Figure 36: Total organic carbon in Coldstream Ck., Kalamalka Lake, and Wood Lake, 2000-2024

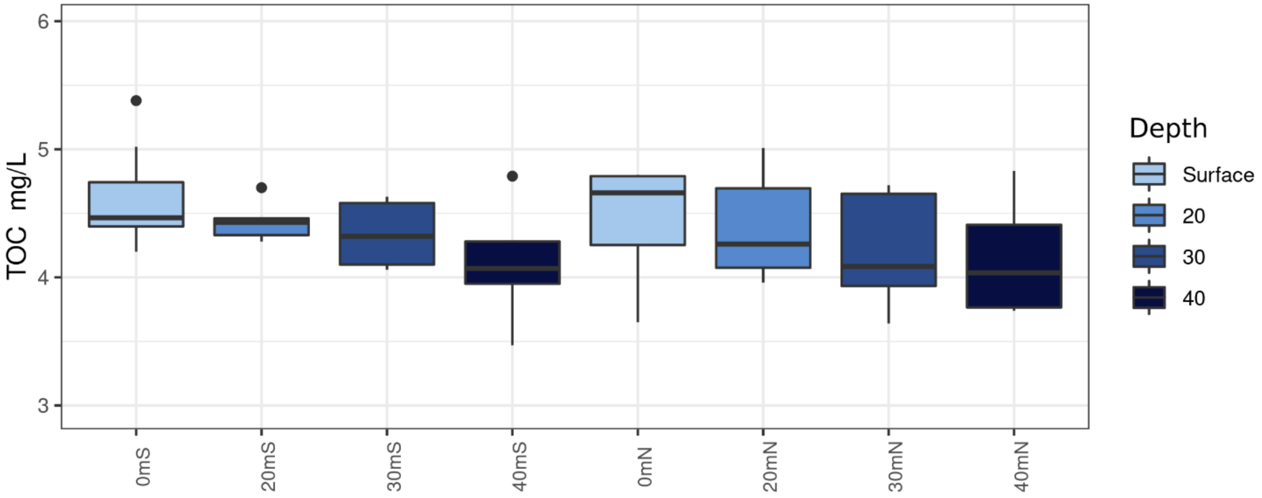


Figure 37: Total organic carbon in Kalamalka Lake during 2024

Large whole-lake effects and weather influences TOC because all Kalamalka sites and Wood Lake showed the same long-term pattern (Figure 36). Kalamalka Lake's TOC concentrations peaked in 2009 and 2010, followed by lower but increasing concentrations from 2015 - 2024 (Mann-Kendall, $p < 0.001$; Figure 36).

2.2.7 Water Transparency

Secchi Depth

Based only on Secchi depth, Kalamalka Lake was historically classified as oligotrophic (6-12 m) with clear, transparent water (see Glossary for more information on trophic levels). However, annual average secchi depths over the past 10 years would place it within the mesotrophic range (3-6 m). Lower secchi depths were caused by turbid freshets or intense algae growth and these effects were lake wide. Historic secchi depths from Kalamalka Lake measured 6 – 7 m in 1935 (Clemens et al., 1939) and 6.0 ± 2.4 m (1971-2024 average for ENV + LAC sampled sites). Secchi depth at the intake sites averaged 5.1 ± 2.2 m in the north and 6.0 ± 2.4 m in south Kalamalka Lake during 2024. Secchi depths decreased from 2003-2017 but have stabilized over the past 7 years (Mann-Kendall, $p < 0.001$ for all Kalamalka samples combined; Figure 38).

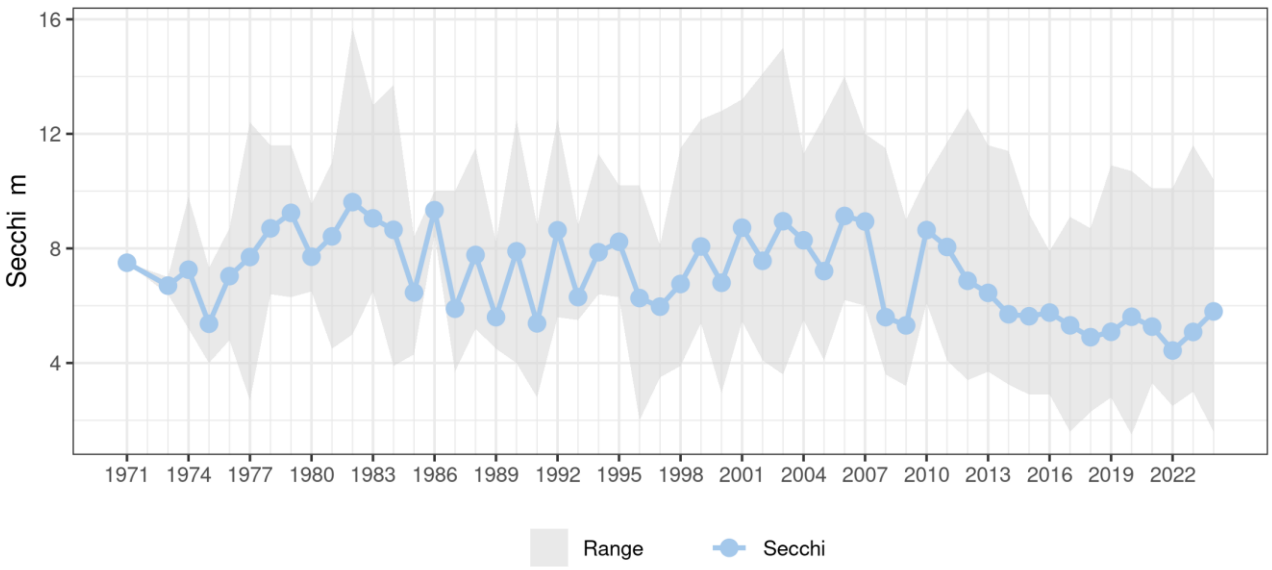


Figure 38: Annual secchi depths from all Kalamalka Lake sample sites, 1971-2024
Note: The above figure combines data from LAC and ENV monitored sites

Ultraviolet Transmissivity (UVT)

Both turbidity and UVT are affected by suspended materials. Measurements of turbidity and transmissivity are related but do not always show matched patterns over time because dissolved organic molecules lower transmissivity but do not affect turbidity. Similarly, marl and re-suspended sediments affect turbidity but UVT to a lesser extent. UVT remained above 85 % at all sites in 2024, varying from 88.8 – 91.8% in the north and from 88.9 – 91.2% in the south (Figure 39). Average %UVT exceeding 90% occurred at both 30 m and 40 m sample sites in 2024, a typical result. Overall, %UVT is decreasing at all LAC sample sites except S-Kal 20 m where %UVT is stable (Mann-Kendall, $p < 0.05$). The UVT advantage of an intake at 40 m versus 20 m was present during the 2024 growing season (KW-Test, $p < 0.001$, Figure 39).

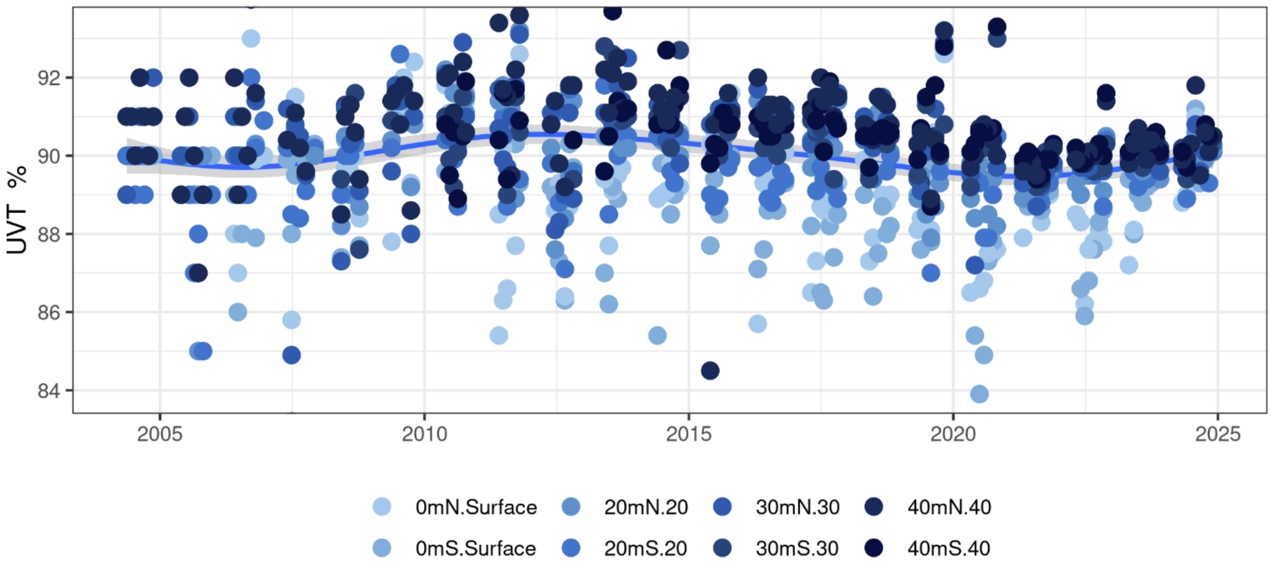


Figure 39: UVT in Kalamalka Lake, 2004-2024

Turbidity

Turbidity and taste and odor events often coincide in Kalamalka Lake and occurred most recently during 2020. These events are particularly related when the cause is algae-driven. To solve this, the intake was extended to allow 3.5 m clearance while maintaining a depth of 20 m during 2016. Outside of freshet, the increased clearance has reduced turbidity in the new N-Kal intake (Figure 40). Turbidity averaged 0.53 ± 0.19 NTU at the north intake and 0.47 ± 0.20 NTU at the south intake during 2024 (20 m lake samples).

Boating activity during the summer of 2021 was greatly reduced because of COVID travel restrictions and the intense smoke. Increases in raw water turbidity were routinely observed at the DLC intake during long weekends and other periods of intense boating activity (Figure 41). However, these increases in turbidity did not occur during 2021 because of the reduced boating activity, a clear indication that boat traffic in the south basin of Kalamalka Lake is affecting the DLC intake. A number of unusually high turbidity readings were observed during summer weekends in 2024.

Oyama canal was dredged in September 2024. Increasing the depth of the canal may likely lead to both an increase in number and size of boats crossing the S-Kal shallows; however, the extent of the dredging was much smaller than originally expected. Given the established connection between boating activity and turbidity in the S-Kal raw water, it is likely that any increase in boat traffic across the shallows would lead to an increase in turbidity at the S-Kal intake.

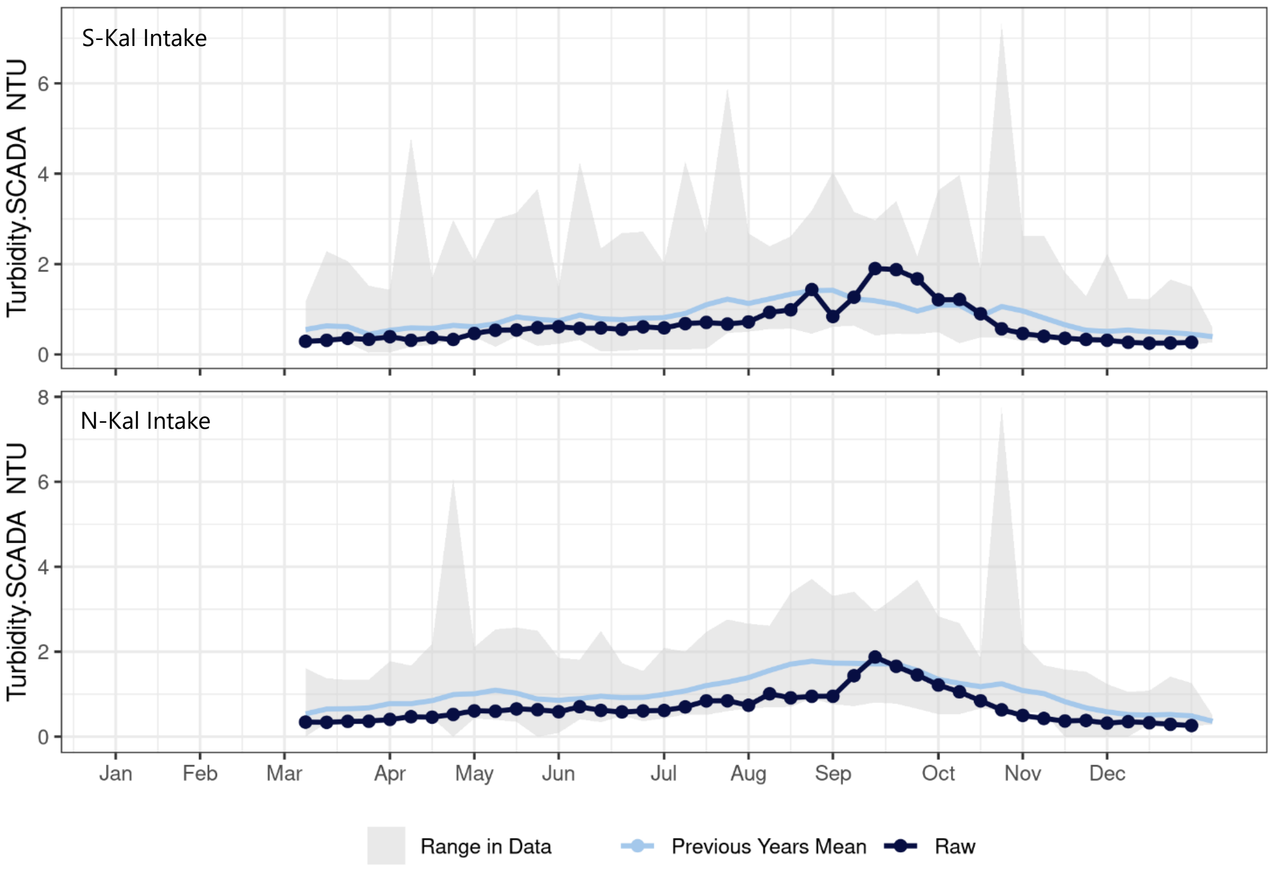


Figure 40: Turbidity at Kalamalka intakes from 2009-2024

Note: only 2015-2024 intake data available for south intake

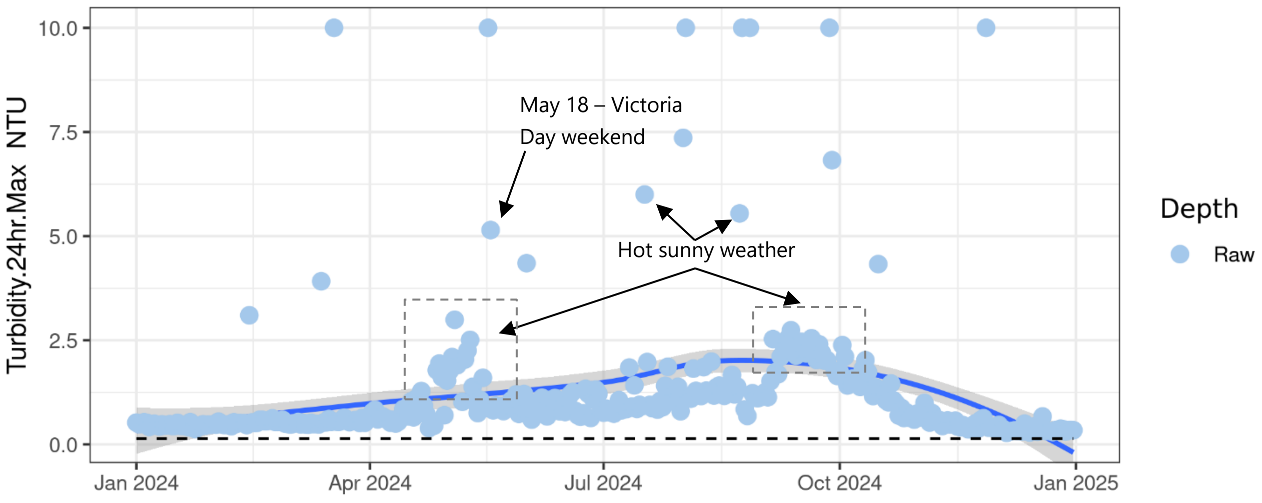


Figure 41: Turbidity at DLC intake with suspected boating induced turbidity spikes marked

Since 2004, this study found that S-Kal 40 m samples had the lowest turbidity and averaged about half of the surface or 20 m turbidity values (Figure 42). North sites had higher turbidities because of the influence of Coldstream Creek across all years. Turbidity values at all south sites and N-Kal 0 m were stable during the past 10 years (Mann-Kendal, $p = 0.02$). N-Kal 20, 30, and 40 m sites have decreased in turbidity from 2014-2024 (Mann-Kendal, $p < 0.001$) and both 20 m sites have decreased in turbidity since 2004 (Mann-Kendal, $p < 0.001$; Figure 43).

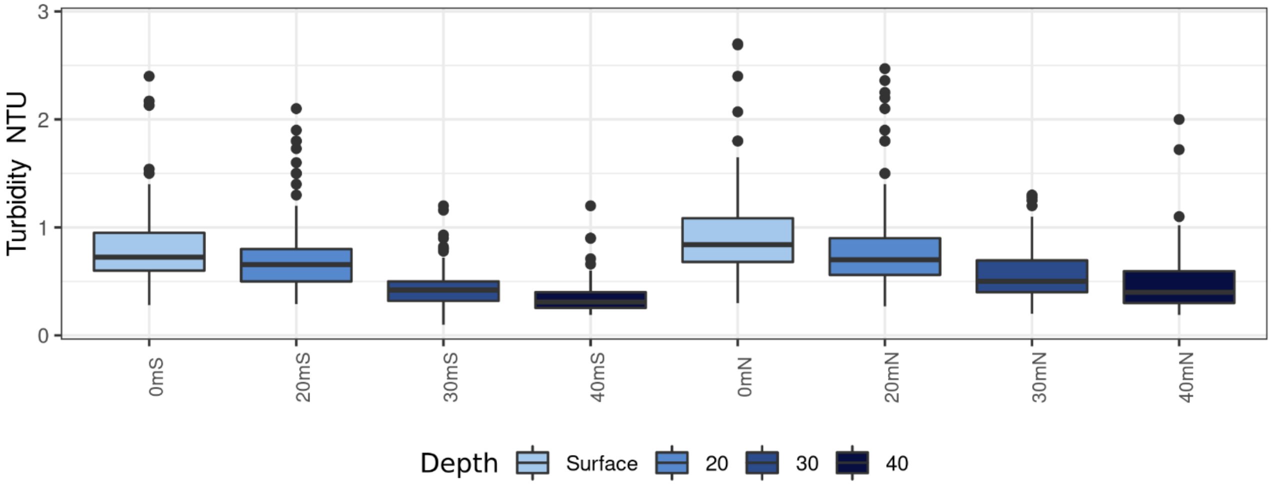


Figure 42: Comparison of turbidity at different sample sites during 2000-2024

Note: outliers at N-Kal 0 m site were excluded for visual purposes

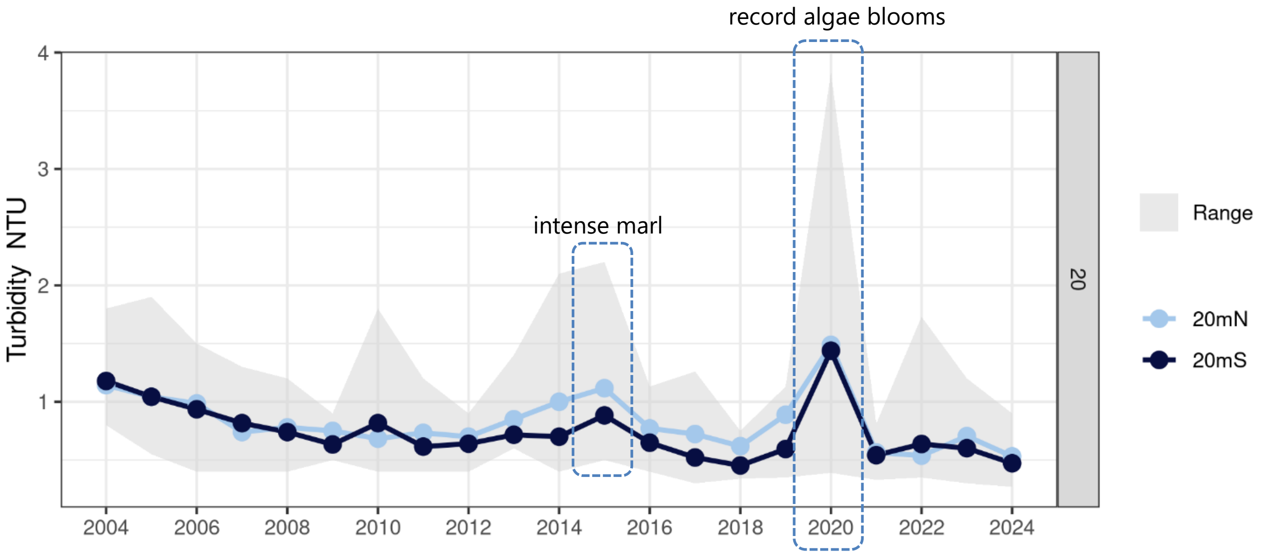


Figure 43: Annual turbidity in Kalamalka Lake with trends highlighted, 2004-2024

2.2.8 Algae

Algae Populations

Algae community composition and numbers are variable from year to year in Kalamalka Lake. These variations help explain the transient water quality problems with taste, odor, and turbidity experienced by GVW and DLC. Within whole-lake algae patterns, the shallow ends where intakes are located have distinct algae communities. For example, the North Arm is affected by nutrient loads introduced by large freshets that in turn control algae production, while in the south end, Wood Lake contributes cyanobacteria from blooms when water flows north through the Oyama Canal.

General Trends

After the spring diatom bloom, algae numbers usually remain strong until the marl precipitation removes phosphorus from Kalamalka Lake's water column. This creates a summer lull, followed by a smaller rise in algae densities during the fall, dominated by cyanobacteria (Figure 45). This is consistent with a reduction in lake nutrients following marl precipitation and is normal for the Okanagan region (Bryan, 1990).

In most years, both intake and 20 m samples contained more algae than either the surface or the deep samples (Figure 46). While diatoms dominated by cell volume, the blue-green cyanobacteria dominated numerically in most fall samples collected in this study. This is a function of the large difference in cell size between the two types of algae.

2024 Results

All sampled sites had above average algae densities during 2024 (Figure 45; Table 3). N-Kal 0 m sample site recorded new maximum observed density during 2024, exceeding the previous records set during the 2023 bloom (Table 3). Very high algae counts have occurred at most Kalamalka Lake sample sites since 2020 (Figure 44).

Table 3: Total cell count averages in Kalamalka Lake, 2001-2024

Site	2001-2024 average (cells/mL)	2024 average (cells/mL)	Total cell count: record high samples collected during 2024
S-Kal 0 m	2,265 ± 3,210	5,868 ± 6,170	
S-Kal 20 m	3,197 ± 5,767	6,126 ± 9,633	
S-Kal 30 m	2,901 ± 3,120	4,208 ± 4,168	
S-Kal 40 m	2,379 ± 2,643	3,529 ± 4,097	
N-Kal 0 m	2,623 ± 3,930	7,492 ± 9,597	May 31 – 27,030 cells/mL
N-Kal 20 m	2,940 ± 4,900	5,526 ± 6,491	
N-Kal 30 m	2,071 ± 2,240	3,156 ± 1,699	
N-Kal 40 m	1,839 ± 2,320	2,747 ± 2,338	

Note: Orange filled cells indicate values above 2001-2024 average

There was a spring diatom bloom throughout the lake with several dominant taxa including *Fragilaria* and *Lindavia*. The diatom bloom was most intense in the raw intake sample in the north arm where densities reached 7760 cells/mL on May 31 (Figure 45). Cyanobacteria counts were high in the spring and late summer/early-fall with a distinct mid-summer decrease throughout Kalamalka Lake during 2024 (Figure 45).

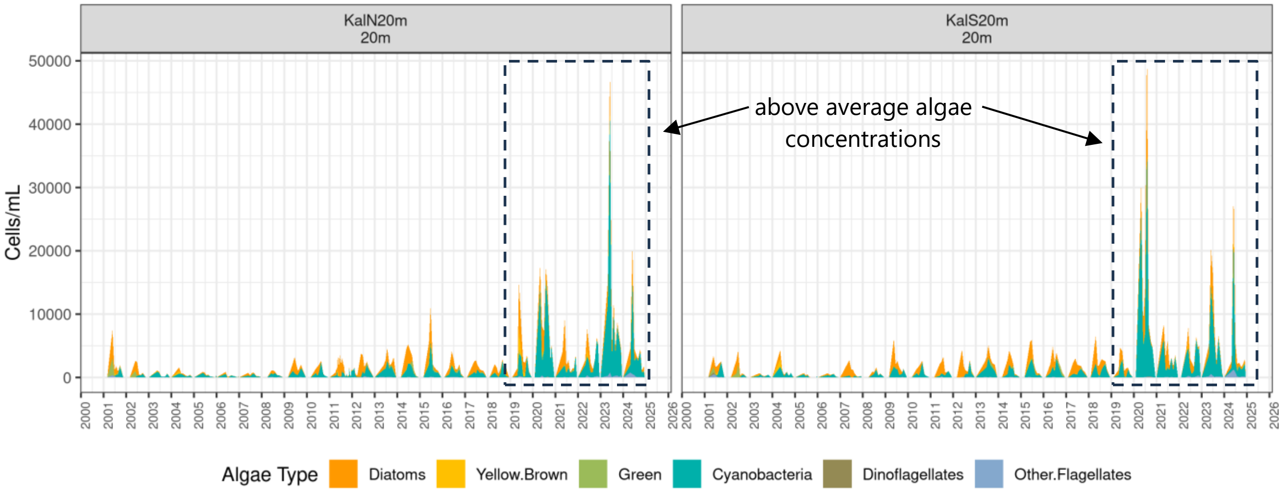


Figure 44: Algae cell densities at the north (left) and south (right) Kalamalka 20 m site, 2001-2024

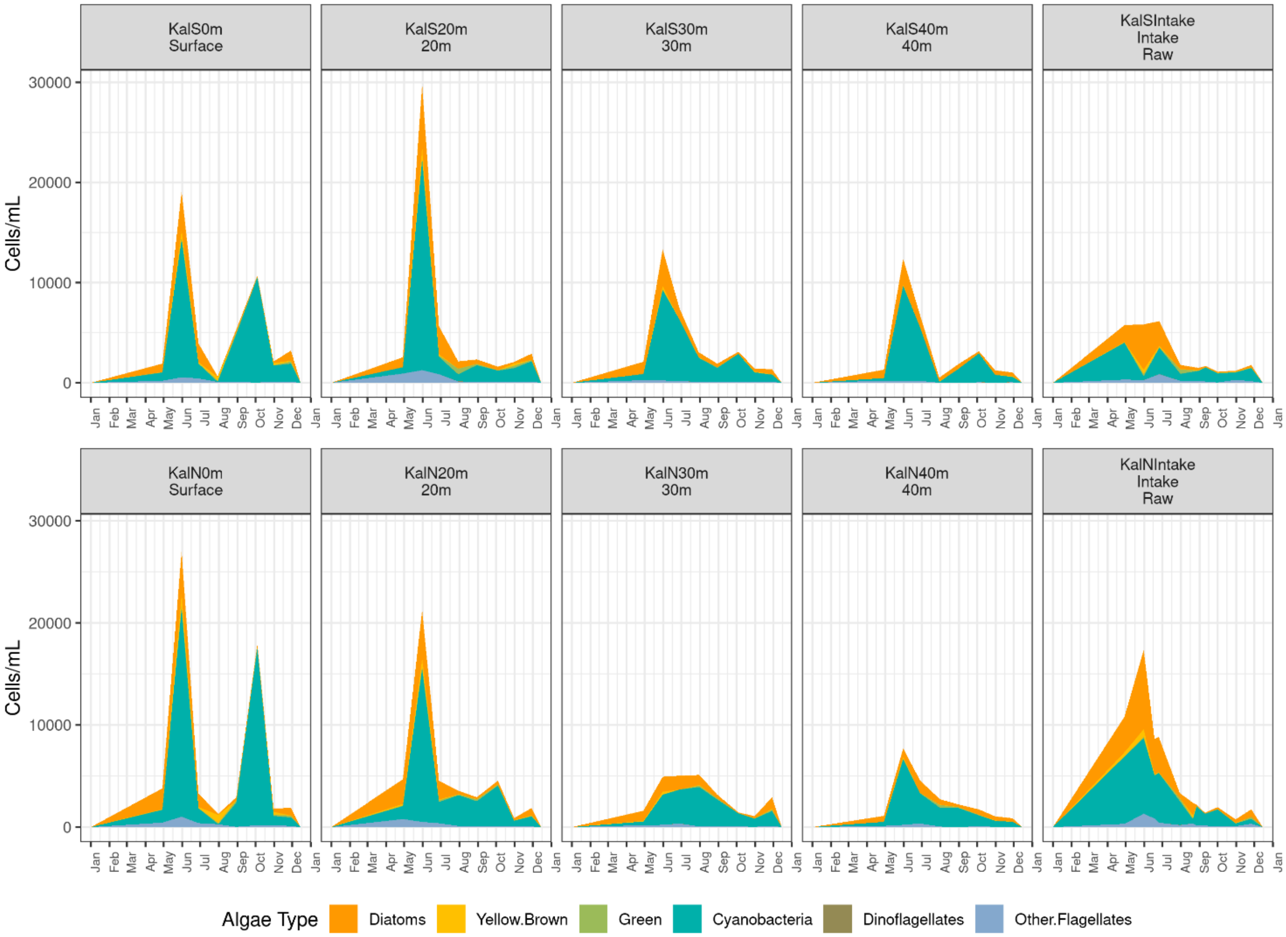


Figure 45: 2024 algae counts for Kalamalka Lake by month

Figure 46: Annual average algae densities in Kalamalka Lake, 2001-2024

Cyanobacteria

Cyanobacteria (blue-green algae) are a natural component of the Kalamalka Lake algae densities. Every year, 5-10 cyanobacterial species are counted in Kalamalka Lake and typically samples are dominated by *Lyngbya* and *Anacystis* in the surface water as well as *Oscillatoria* and *Planktothrix* in deeper water. Samples collected in 2024 were dominated by *Anacystis, Aphanocapsa, Aphanothece, Planktothrix,* and *Planktolyngbya.*

Despite year-to-year variation, ENV data shows a gradual increase in the cyanobacteria component since the 1970s, a trend that continues through the 2001-2024 data collected for this study (Mann-Kendall, $p < 0.001$; Figure 47). All sites sampled by LAC increased in cyanobacteria concentrations from 2001-2024 (Mann-Kendall, $p < 0.001$). Cyanobacteria concentrations were very high at all LAC sampled sites during 2024 (Table 4). All S-Kal sample sites and N-Kal 0 and 20 m sites contained elevated cyanobacteria concentrations (Table 4).

Elevated cyanobacteria became prevalent at all sites starting in 2020. The highest recorded concentrations of cyanobacteria at all sampled sites have occurred in the past five years (Table 4). Average cyanobacterial densities from 2001-2018 are lower than the 2019-2024 cyanobacterial averages (Table 5). Recent elevated cyanobacteria may be related to recent exceptional climate conditions.

Table 4: Record-breaking cyanobacteria concentrations in Kalamalka Lake, 2001-2024

Site	Highest concentration in 2024	Highest concentration to date (year)
S-Kal 0 m	13,810 cells/mL	--
S-Kal 20 m	21,030 cells/mL	36,285 cells/mL (2020)
S-Kal 30 m	9,040 cells/mL	16,440 cells/mL (2020)
S-Kal 40 m	9,470 cells/mL	--
N-Kal 0 m	20,400 cells/mL	--
N-Kal 20 m	15,010 cells/mL	42,250 cells/mL (2023)
N-Kal 30 m	3,845 cells/mL	10,425 cells/mL (2023)
N-Kal 40 m	6,450 cells/mL	12,410 cells/mL (2023)

Note: -- = highest concentration to date set in 2024
light red = highest concentration to date
orange = 2nd highest concentration to date
yellow = 3rd highest concentration to date

Table 5: Cyanobacteria averages in Kalamalka Lake, 2001-2024

Site	2001-2018 average (cells/mL)	2019-2024 average (cells/mL)
S-Kal 0 m	431 ± 642	2,868 ± 3,081
S-Kal 20 m	738 ± 731	4,641 ± 6,983
S-Kal 30 m	847 ± 830	3,046 ± 3,308
S-Kal 40 m	566 ± 527	2,441 ± 2,565
N-Kal 0 m	421 ± 609	3,726 ± 4,500
N-Kal 20 m	670 ± 697	4,642 ± 6,824
N-Kal 30 m	650 ± 751	2,696 ± 2,247
N-Kal 40 m	510 ± 575	2,592 ± 2,791

The 40 m sites had the lowest average cyanobacteria densities during most years while the 20 m sites were dominated by the fall cyanobacteria bloom and had the highest growing season averages during most years (Table 5). Cyanobacteria densities in raw water from the north intake averaged 2836 ± 2537 cells/mL while the south intake averaged 1417 ± 1067 cells/m during 2024.

Several cyanobacteria taxa found in Kalamalka Lake are known to produce toxins (*Anacystis, Lyngbya, Anabaena, Limnothrix, Oscillatoria, Planktothrix,* etc.; see Appendix 4: Toxin forming Cyanobacteria in Kalamalka Lake). The microcystin group of toxins produced by these algae can be broken down by chlorine while other cyanobacteria toxins are less vulnerable to chlorine (Larratt, 2009). From 2001-2019, intake samples occasionally exceed the 2,000 cyanobacteria cells/mL threshold of concern. 2020 was the first year on record to regularly exceed this threshold and approach cyanobacteria densities where toxicity becomes possible (Figure 47, Appendix 7: Cyanotoxicity Risk Levels). Cyanobacteria densities remained above the long-term average during 2021-2024 with 39% of samples above the 2,000 cells/mL threshold during 2024 (Figure 47). Most sites were higher than the record 2020 concentrations except for S-Kal 20 and 30 m sites (Table 4).

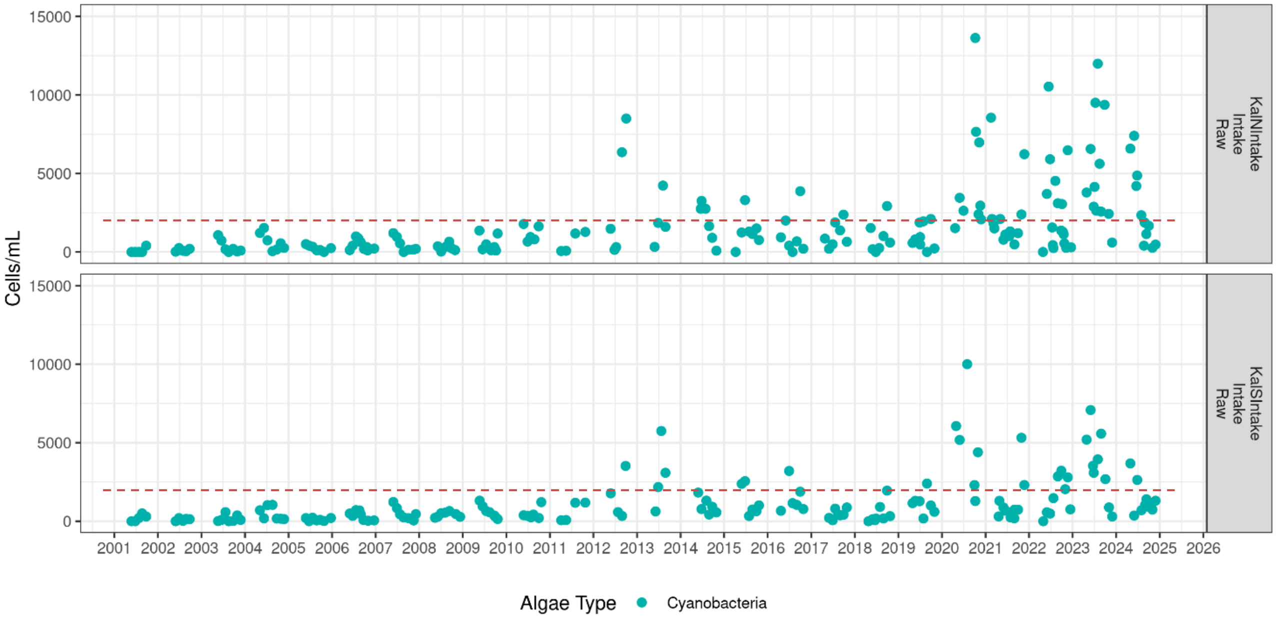


Figure 47: Cyanobacteria densities in raw water from north and south Kalamalka Lake intakes, 2001-2024

Note: red line indicates 2000 cells/mL threshold of concern, record 2020 algae densities above scale of graph

Algae and Taste and Odor Events

Kalamalka Lake periodically experiences taste and odor issues, most recently in 2020. These are primarily caused by high cyanobacteria counts because these algae can generate the compounds that are responsible for musty odors (Methyl-Isoborneol [MIB] and geosmin). Elevated cyanobacteria counts are correlated with taste and odor complaints but there is not a clear cell density threshold. Cyanobacteria counts routinely exceed the density observed during the major 1999 taste and odor event without similar complaints, indicating that several factors must occur simultaneously to generate taste and odor complaints (elevated cyanobacteria counts, a decomposing algae bloom, and *Actinomycetes* decomposers).

This exact combination of effects was documented during the winter of 2020/2021 following the prolific cyanobacteria bloom at fall overturn during 2020 that led to a taste and odor event (Figure 48). There was another taste and odor event during the spring/summer of 2020 that affected both ends of the lake and is attributed to the intense algae blooms, probably in conjunction with decomposer fungi (Figure 48).

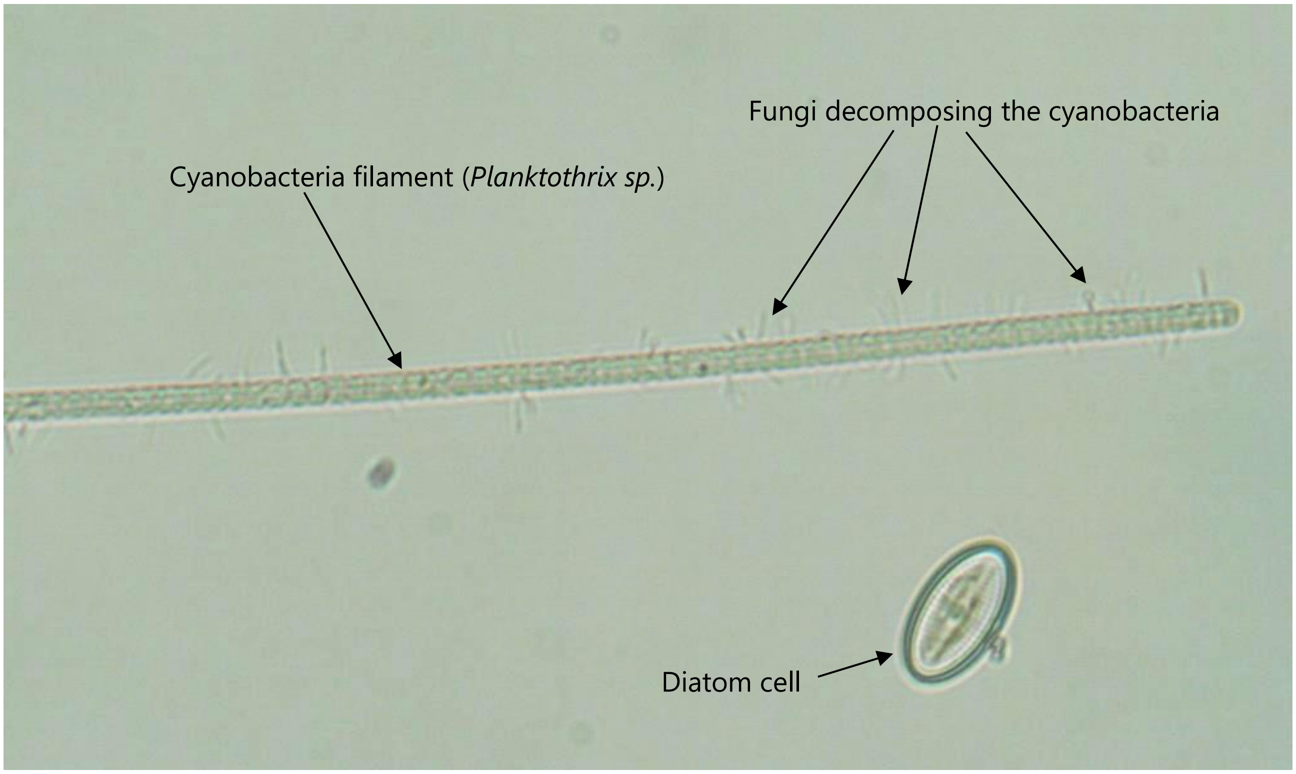


Figure 48: Cyanobacterial filament colonized by fungi in N-Kal raw water

2.2.9 Bacteria

Total coliforms are a broad category of bacteria that indicate the amount of bacterial loading in the water. *Escherichia coli* (*E. coli*) are found in mammal or bird wastes and they serve as an indicator of fecal contamination. Only a few of the thousands of *E. coli* strains are disease-causing, however if *E. coli* are present, fecal contamination that may contain other harmful pathogens can be inferred.

E. coli

2024 growing season bacterial counts were very low in S-Kal samples and ranged from < 1 – 5 CFU/100mL (Figure 49). North Kalamalka samples contained higher *E. coli* counts than the south end of the lake each year (< 1 – 5 CFU/100mL in 2024; Figure 49) potentially from the influence of Coldstream Creek (Figure 7; Figure 50). Lake sediments from beneath the S-Kal Intake contained < 1 CFU/100mL while the N-Kal sediments contained 5 CFU/100mL of *E. coli* in the most recent samples (2024).

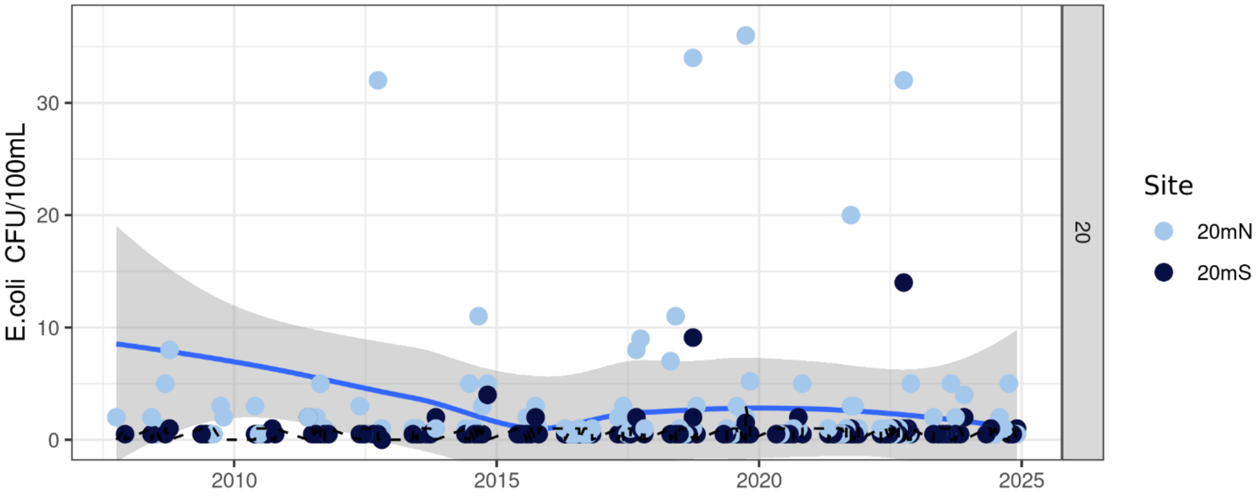


Figure 49: *E. coli* counts at intake depths in north and south Kalamalka Lake, 2007-2024

Note: Dashed line indicates lab reportable detection limit of 1 CFU/100mL

Samples on 2010-10-13 (270 CFU/100ml) and 2007-12-04 (45 CFU/100mL) were removed from this plot for viewing purposes

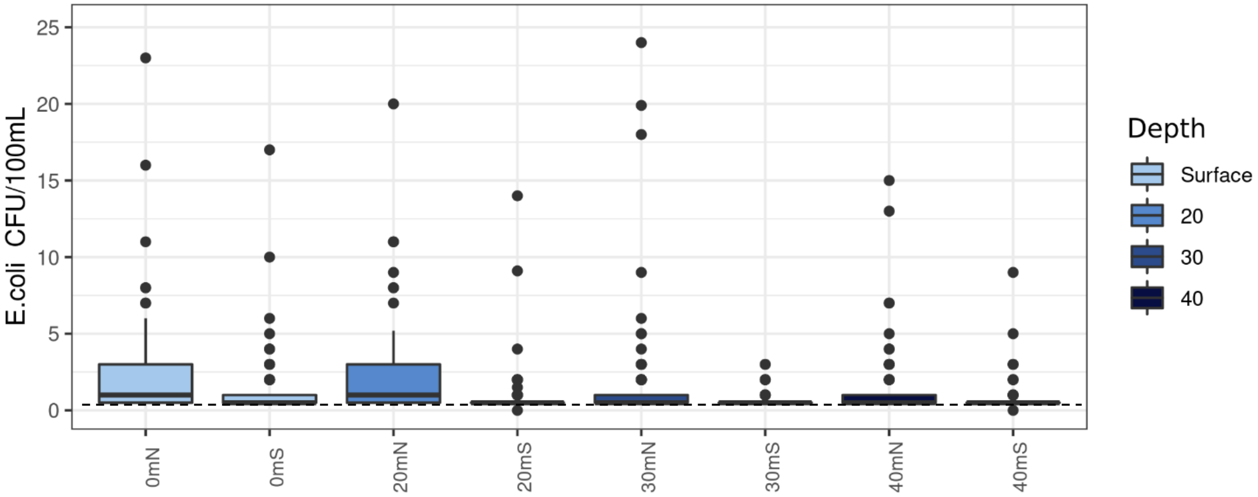


Figure 50: *E.coli* in Kalamalka Lake samples compare by depth, 2007-2024

Note: Dashed line indicates lab reportable detection limit of 1 CFU/100mL

Data points above 23 CFU/100 mL are excluded for viewing purposes

Total Coliforms

Total coliform data from 2007- 2024 showed no clear benefit with increasing depth (Figure 51). Since 2007, total coliforms were significantly higher in the north than the south of Kalamalka Lake (KW-Test, $p < 0.001$; Figure 51). However, in 2024 total coliforms ranged from < 1 – 105 CFU/100mL in north and < 1 – 261 CFU/100 mL south arm. Very high total coliforms were noted in raw water samples collected by DLC during June/July of 2021 and 2022 but this did not repeat during 2023 or 2024.

Total coliform criteria for filtration deferral states that no more than 10% of samples should exceed 100 CFU/100mL in a six-month period, and the *E. coli* criteria states not more than 10% of samples should exceed 20 CFU/100 mL in a six-month period. Both the monthly data and the growing season averages during most years indicate that the 20m, 30m, and 40m sites at both ends of the lake would meet these criteria.

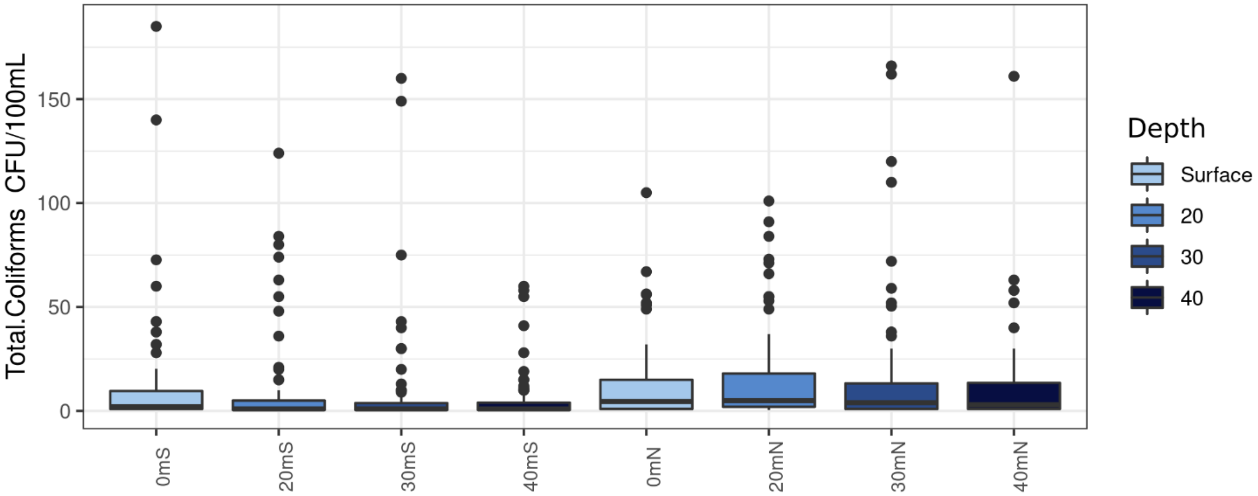


Figure 51: Total coliform in Kalamalka Lake samples compared by depth, 2007-2024

Note: Data points above 200 CFU/100 mL are excluded for viewing purposes

Lake sediments from beneath the S-Kal Intake contained 8 CFU/100mL while the N-Kal sediments contained 28 CFU/100mL of total coliforms in the most recent samples (2024). Increased total coliforms in the north arm are potentially influenced by Coldstream Creek.

3.0 Summary of Extended, Deeper Intake Benefits

3.1 Overview

Extending drinking water intakes deeper into Kalamalka Lake theoretically reduces the risk of contaminants from land-based activities, bacterial loading, and algae numbers. The biggest disadvantage to extending the intakes is the cost of installation and the cost of maintenance (Cotsworth, pers comm 2009). The imminent threat of invasive mussels will also add cost for additional maintenance or refitting intakes with chlorine injection to discourage their growth. GVW installed a chlorine injection line as part of their recent intake extension in anticipation of this threat.

Over the years of study of deeper potential intake sites, TOC, conductivity, and TDS did not vary with depth sufficiently to impact water quality, treatment, or aesthetics (Figure 52). Other parameters including pH and UV transmissivity demonstrated slight improvement at deeper sites, but all monitored depths were well within desirable ranges for domestic water. A few parameters showed significant change with depth that could affect water quality and they include chl-a, algae density, turbidity, and bacteria concentrations.

The importance of algae densities increases when filtration is used; GVW operated a pilot filtration plant for the N-Kal intake from 2020-2021. Diatom blooms adversely affect filtration and may require an additional treatment before filtration. Diatom blooms are regular occurrences in the spring each year.

Differences in water quality described in this section are based on the growing season: the time of greatest frequency of water quality problems and the highest demands. During the fully mixing winter season, the differences in water quality between the depths would be much smaller.

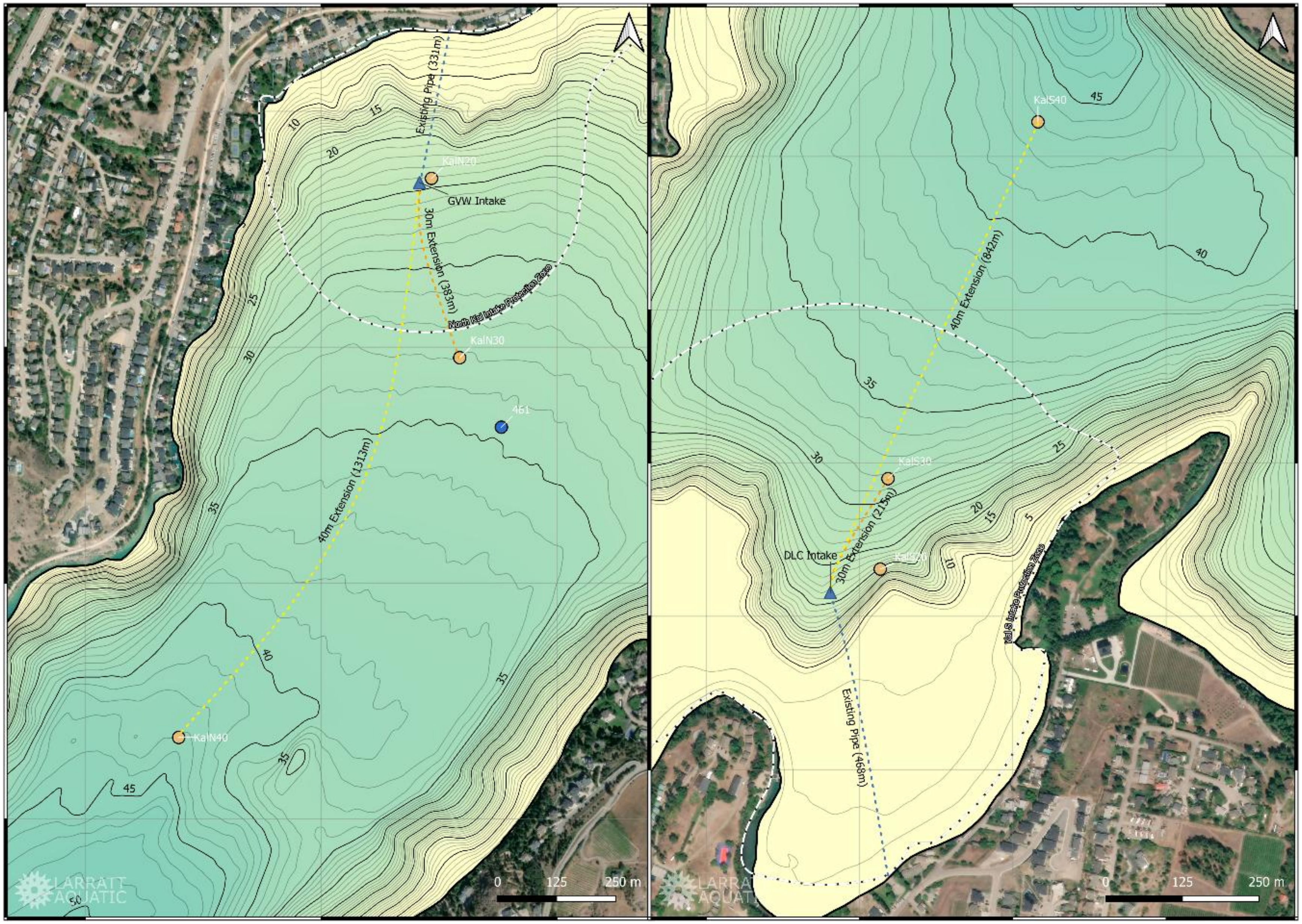


Figure 52: Proposed intake extension routes

3.2 North Kalamalka Intake Extension

The N-40 m position consistently has the highest water quality but the distance to the existing pumphouse is a significant disadvantage (1.7 km; Figure 52). The cost benefit of deepening the intake must also consider that the Coldstream Creek plume can negatively impact the entire North Arm of Kalamalka Lake regardless of water depth.

To date, this study identifies the N-30 m site as the best option due its stable, high-water quality and reasonable distance to the existing pumphouse (see Appendix 6: Summary of Intake Extension Water Quality). In 2016, GVW extended their N-Kal intake 72 m to maintain 20 m intake depth and increase intake clearance from 0.6 m to 3.5 m.

Based on all years of study, the advantages of extended intakes with 3 m clearance in north Kalamalka Lake over the current GVW 20 m intake site are detailed by site, below. Many of these benefits were realized by the 2016 extension but algae densities remained significantly higher at 20 m than either of the deeper sites.

As of May 2022, GVW had completed their filtration pilot trial, secured funding, and had begun the design and build phase for a future filtration plant on their Kalamalka Lake intake. The design/build phase is expected to take 7 years.

North 30 m (380 m extension[5])

- N-30 m would have a mean annual temperature of 5.05 ± 0.79 °C with a range of 3.3 – 8.5 °C under normal conditions (2011-2024 growing season field data)
- Fewer seiches (4/year) and they would have smaller maximum temperature deviation of 1.5 – 10 °C
- Lower turbidity, averaging 0.56 ± 0.23 NTU (2004-2024)
- Negligible change in UV transmissivity in most years
- *E. coli* lower than 20 m averaging 2.2 ± 5.5 CFU/100mL (2008-2024)
- Fewer incidents of high background bacteria counts
- Typically, fewer cyanobacteria than 20 m, averaging 1,224 ± 1,627 cells/mL from 2003-2024 (maximum of 3,845 cells/mL in 2024; 20 m maximum = 15,010 cells/mL) in the growing season, with annual average chl-a 1.01 ± 0.45 µg/L (2000-2024)

North 40 m (1310 m extension[5])

- N-40 m would have a mean annual temperature of 4.55 ± 0.43 °C with a range of 3.4 – 6.5 °C under normal conditions (2011 – 2024 growing season field data)
- N-40 m would evade most seiches, with a maximum temperature deviation of 1.5 – 4 °C
- Lowest turbidity, averaging 0.48 ± 0.25 NTU (2004-2024 growing season average)
- Smallest effect from Coldstream Creek plume of North Arm sample sites
- *E. coli* usually non-detectable and averaged 1 ± 2 CFU/100mL from 2008-2024 with a 2024 maximum of 3 CFU/100mL
- Low cyanobacteria averaging 1,094 ± 1,808 cells/mL from 2003-2024 (maximum of 6,450 cells/mL in 2024) with a growing season average chl-a of 1.08 ± 0.63 µg/L (2004-2024 growing season average)

3.3 South Kalamalka Intake Extension

Possible intake extension sites at 30 m and 40 m depths have been studied in South Kalamalka Lake. As noted throughout this report, 40 m sites are on average, the best sites for an intake from a water quality perspective. The distance required for a 40 m intake may be cost-prohibitive. Data to date suggests that the 30 m site would provide the biggest benefit because of lower turbidity and chl-a, cooler temperatures and fewer seiche events with smaller temperature deviations compared to the existing intake. DLC is currently engaged in a study to re-evaluate intake extension options.

Based on all years of study, the advantages of extended intakes with 3 m clearance in south Kalamalka Lake over the existing DLC 20 m intake site are detailed by site, below:

South 30 m (215 m extension[5])

- S-30 m would have a mean growing season temperature of 5.10 ± 0.65 °C with a range of 3.9 – 6.8 °C under normal conditions (2012-2024 growing seasons average)
- 8 – 10 seiches reach 30 m annually, with a maximum temperature deviation of 3.2 – 6 °C and a typical range of 2-3 °C fluctuation
- Lower turbidity than 20 m, averaging 0.46 ± 0.19 NTU (2008-2024)
- Negligible change in UV transmissivity except during marl events and fall overturn, growing season average of 90.5 ± 1.2 % (2008-2024)
- < 1 CFU/100 mL average *E. coli* (2008-2024)
- Lower algae production; chl-a average of 1.53 ± 0.97 µg/L (2000-2024) with 2024 maximum of 3.59 µg/L
- Average cyanobacteria density here were slightly lower to those at the existing intake (growing season average cyanobacteria counts of 1,735 ± 2,437 cells/mL, 2008-2024; maximum of 9,040 cells/mL in 2024)

South 40 m (840 m extension[5])

- S-40 m would have a growing season average temperature of 4.6 ± 0.4 °C with a range of 3.7 – 5.5 °C under normal conditions (2011-2024 growing seasons average)
- 4 – 5 seiches reach 40 m annually, with a maximum temperature deviation of 3 °C
- Lowest turbidity, averaging 0.36 ± 0.16 NTU (2010-2024)
- Negligible change in UV transmissivity (except during fall overturn), averaging 91 ± 1 % (2010-2024)
- Non-detectable *E. coli* in most samples, average < 1 CFU/100mL from 2010-2024
- Lower algae production, growing season average chl-a of 1.01 ± 0.65 µg/L (2010-2024) with a maximum of 2.24 µg/L in 2024
- Average deep-water cyanobacteria density at S-40 m was lower than the existing intake site in several years (2010-2024 growing seasons average of 1403 ± 1983 cells/mL; 9470 cells/mL max in 2024)

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[5] Extension distances assume an extension from the existing intake location, alternate land start points may be considered that would shorten these distances at the expense of burying new pipe.

4.0 Recommendations

4.1 Coldstream Creek Protection

Long-term results from this Kalamalka Lake study results have provided ample evidence to link the poor water quality from Coldstream Creek to a direct negative impact on water quality in the GVW Kalamalka intake, particularly during heavy freshet years. Any improvements to water quality of Coldstream Creek would benefit the water quality at the north intake.

4.2 Intake Modifications

The data to date supports extending intakes to ≥30 m with 3 m of clearance above the sediments. A 30 m intake would provide cooler water with improved and more stable water quality including significantly lower algae densities than the existing intakes.

4.3 Invasive Mussels

Continue to work with OBWB on initiatives to request senior government to install boat inspection/disinfection stations and to convince BC boat owners to Clean Drain Dry their boats when moving between lakes. DLC should install chlorine injection to the mouth of the intake if they move or upgrade their intake.

4.4 Database Maintenance

2024 data was added to the extensive database on Kalamalka Lake compiled for this project in 2013. Beginning in 2019, all data collected for this project is made available through the new OBWB Okanagan Basin Water Quality Database (www.obwb.ca/wqdb).

5.0 Proposed Sampling Program for 2025

As in all years, the proposed schedule covers the growing season when most water quality issues occur. We propose to monitor water quality, plankton algae, thermal structure and bacterial samples monthly, April – November 2025. Sample locations should include raw intake water, surface water, and the intake depths (20 m), including any proposed depths for extended intakes. Any sites that are no longer under consideration can be removed from the sampling schedule, though continuing to sample deeper sites even if extension is not considered is still valuable because seiches cause deeper water to oscillate up and down in the water column passing over the intakes regularly.

Water quality parameters recommended as part of this study are needed for the benefit of current and future water treatment and to track long-term trends in Kalamalka Lake that can impact domestic water quality (Table 6).

Table 6: Recommended 2025 monitoring parameters

CARO Lab Parameters:	LAC Lab Parameters	Field Parameters
• Chlorophyll-a • pH, chloride, conductivity, hardness, SO_4, alkalinity • UVT, Turbidity • Total coliform and *E. coli* • TOC + DOC • Total metals	• Algae taxonomy	• Conductivity • Dissolved Oxygen • Secchi • TDS • Temperature • Turbidity • Salinity

ENV will conduct March and September sampling for nutrients, temperature and dissolved oxygen profiles and general water chemistry in Kalamalka and Wood lakes. These results are provided to this study courtesy of Dr. Mike Sokal.

RDNO took over responsibility from LAC for sampling Coldstream Creek in 2016. This worked very well with more sample dates than previous years. We recommend continuing this program in 2025 unchanged from 2016-2024 with one exception; LAC recommends that ammonia analysis for Coldstream Creek be changed from the default 0.05 mg/L detection limit to a lower limit.

Additional emergency sampling or algae taxonomy can be conducted by LAC on an as-needed basis at the request of RDNO or DLC. This could include additional dates if another fall/winter algae bloom develops causing taste and odor problems.

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7.0 Appendices

Appendix 1: Kalamalka Lake and Wood Lake Water Quality Data - 2024

Data available through the OBWB Water quality database (www.obwb.ca/wqdb)

Table A 1: Spring and fall nitrate/nitrite and TDP concentrations in Kalamalka Lake (0-5-10m)

	Nitrate and nitrite		Total dissolved phosphorus	
(mg/L)	**South**	**North**	**South**	**North**
Spring 2003	0.016 – 0.024	0.044 – 0.065	0.003-0.004	0.003
Fall 2003	<0.002	<0.002	0.004-0.008	<0.002
Spring 2004	0.022 – 0.057	0.002	<0.002-0.003	<0.002-0.002
Fall 2004	0.025 – 0.072	0.002	<0.002-0.003	<0.002-0.005
Spring 2005	0.010	0.009 – 0.015	<0.002	<0.002
Fall 2005	<0.002 – 0.013	0.003	<0.002	0.002-0.003
Winter 2005	0.104	0.106	0.003	0.006
Spring 2006	0.008 – 0.057	0.018 – 0.029	0.003	0.003
Fall 2006	0.003	0.008	0.003	0.003
Winter 2006	0.127	0.124	0.003	0.003
Spring 2007	0.002 – 0.003	0.004 – 0.035	<0.002-0.008	<0.002
Fall 2007	0.002	0.003	0.004-0.008	<0.002
Winter 2007	0.069	0.084	0.007	0.006
Spring 2008	0.040	0.038	0.003	0.004
Fall 2008	0.005	<0.002	0.004-0.005	0.005-0.006
Spring 2009	0.127	0.137	0.003	0.002
Fall 2009	<0.002	0.035	0.002	0.002
Spring 2010	0.09	0.100	0.003	0.004
Fall 2010	<0.002	<0.002	0.005	0.002
Spring 2011	0.104	0.119	0.002	0.002
Fall 2011	<0 .002	<0.002	0.003	0.003
Spring 2012	0.0710	0.092	0.003	0.006
Fall 2012	<0 .002	<0.002	0.0035	0.0032
Spring 2013	0.0974	0.0865	0.0026	0.0025
Fall 2013	<0.002	0.0579	0.0035	0.0022
Spring 2014	0.103	-	0.0051	-
Fall 2014	<0.002	<0.002	0.0029	-
Spring 2015	0.083	0.0852	0.0055	0.0062
Fall 2015	<0.003	<0.0032	0.0029	0.003
Spring 2016	0.097	0.092	0.0026	0.0032
Fall 2016	0.051	0.056	0.0022	0.0022
Spring 2017	0.090	0.0855	0.0057	0.0071
Fall 2017	0.0032	0.0032	0.0036	0.0047
Spring 2018	0.0951	0.0895	0.0043	0.004
Fall 2018	0.0032	0.0102	0.0023	0.0022
Spring 2019	0.109	0.111	0.00795	0.0099

	Nitrate and nitrite		Total dissolved phosphorus	
(mg/L)	**South**	**North**	**South**	**North**
Fall 2019	0.0475	0.0409	0.0056	0.0056
Spring 2020	0.1010	0.1030	<0.002	0.0032
Fall 2020	<0.0032	0.0074	0.0037	0.0042
Spring 2021	0.0987	0.1060	<0.002	0.0029
Fall 2021	<0.0032	<0.0032	0.0025	0.0032
Spring 2022	0.103	0.104	0.0022	0.0033
Fall 2022	<0.0032	<0.0032	0.0030	0.0035
Spring 2023	0.0796	0.0761	0.0039	0.0041
Fall 2023	<0.0032	<0.0032	0.0031	0.0033
Spring 2024	0.0888	0.082	0.0039	0.0038
Fall 2024	<0.0015	<0.0015	0.0033	0.0032

Table A 2: Variations in Wood Lake algae blooms by year and season, 2007-2024

Year	Season	Bloom taxa
2007	Spring	Anacystis Gomphosphaeria
	Summer	Anacystis
	Fall	Anabaena Aphanizomenon
	Early winter	Aphanizomenon
2008	Spring	Gomphosphaeria Anacystis
	Summer	Anacystis
	Fall	Anabaena Anacystis Aphanizomenon
	Early winter	Aphanizomenon
2009	Spring	Anacystis Aphanizomenon
	Summer	Anacystis
	Fall	Anacystis Gomphosphaeria
	Early winter	Aphanizomenon Gomphosphaeria
2010	Spring	Anacystis (light)
	Summer	Anacystis (moderate)
	Fall	None – Wood Lake marled
	Early winter	None – Wood Lake marled
2011	Spring	Aphanizomenon Anabaena (light)
	Summer	Aphanizomenon (moderate)
	Fall	None – Wood Lake marled
	Early winter	None – Wood Lake marled
2012	Spring	Dinobryon spp. (chrysophyte)
	Summer	Tabellaria (diatom)
	Fall	Aphanizomenon
	Early winter	Aphanizomenon
2013	Spring	*Anacystis cyanea, Lyngbya* (large species)
	Summer	*Anacystis circinalis, Aphanizomenon elachista*
	Fall	*Lyngbya lrg sp, Aphanizomenon flos-aquae*
	Early winter	*Anacystis cyanea, Aphanizomenon elachista Lyngbya lrg sp*
2014	Spring	*Anacystis cyanea*
	Summer	*Anacystis cyanea, Aphanizomenon, Anabaena circinalis*
	Fall	*Anacystis cyanea, Gomphosphaeria lacustris*

Year	Season	Bloom taxa
2015	Spring	*Anacystis cyanea, Aphanizomenon, Anabaena circinalis* (all light)
	Summer	*Anacystis cyanea* (mod); *Aphanizomenon, Anabaena circinalis* (light)
	Fall	*Lyngbya* (moderate), *Gomphosphaeria lacustris* (light)
2016	Spring	*Aphanizomenon* (moderate)
	Summer	*Anabaena, Anacystis, Lygnbya* (all light)
	Fall	*Lyngbya* (moderate), *Aphanizomenon*
2017	Spring	*Anabaena spp.* (moderate)
	Summer	-
	Fall	*Lyngbya spp. Aphanothece.* (moderate)
2018	Spring	*Tabellaria, Fragilaria*
	Summer	-
	Fall	*Lyngbya, Gleothricia, Aphanothecae, Aphanocapsa, anabaena, anacystis*
2019	Spring	*Tabellaria*
	Summer	*Fragilaria, Anacystis*
	Fall	*Lyngbya, Aphanizomenon, Planktothrix*
2020	Spring	*Asterionella, Tabellaria* (largest diatom bloom to date), *Lyngbya,*
	Summer	*Anacystis, Aphanizomenon, Lyngbya, Microcystis*
	Fall	*Lyngbya,*
2021	Spring	*Anabaena*
	Summer	*Aphanothece, Anacystis, Fragilaria*
	Fall	*Aphanothece, Aphanocapsa, Planktolyngbya, Pseudanabaena, Aulacoseira*
2022	Spring	*Anacystis, Aphanizomenon, Tabellaria*
	Summer	*Anacystis, Planktolyngbya*
	Fall	*Anacystis, Planktolyngbya, Pseudanabaena*
2023	Spring	*Planktolyngbya, Asterionella, Fragillaria*
	Summer	*Anacystis, Planktolyngbya, Planktothrix, Pseudanabaena*
	Fall	*Aphanothece, Anacystis, Planktolyngbya*
2024	Spring	*Planktothrix, Aphanizomenon, Fragilaria*
	Summer	*Planktothrix, Aphanizomenon, Anabaena*
	Fall	*Planktolyngbya, Gomphosphaeria, Fragilaria*

Table A 3: Marl Dates in Kalamalka Lake

Year	Marl Date	Comment
2024	July 31	Strong on Kal and Wood Lake
2023	June 25	Strong on Kal and Wood Lake
2022	July 28	Moderate/Strong
2021	17-Jul	Moderate
2020	late-july	Weak
2019	24-Jul	Strong
2018	19-Jul	Moderate
2017	12-Jul	Weak
2016	30-Jul	Weak
2015	01-Jul	Very intense
2014		Strong

Appendix 2: Methods and Water Quality Guidelines

At each site, field water quality measurements, water chemistry samples and biological samples were taken by LAC monthly through the growing season from Kalamalka Lake and a portion of the contributing watershed.

Sampled water quality parameters included:
Field Meter Depth Profiles: Temperature, pH, dissolved oxygen, TDS, conductivity
Lab Samples: Alkalinity, hardness, Total chloride, calcium sodium sulphate, magnesium, and turbidity, UVT, TOC, DOC, chl-a, conductivity, Total coliform, and *E. coli*

Algae Samples Algae samples were taken from the surface, 20 meters, and from the intake water before chlorination. Additional samples were collected from 30m - 40m and from Wood Lake. An 80-micron mesh plankton net was used to concentrate algae and zooplankton from the surface waters in a one-minute diagonal tow of the upper 10 meters.

Algae samples were identified using 200x and 400x magnification on an inverted light microscope. Samples were refrigerated and allowed to settle for 24 hours. One mL was removed from the bottom of each sample and put in a Sedgewick-Rafter counting cell. Algae density, diversity and condition were recorded. Notes on the presence of zooplankton, bacteria and fungi were made.

Water Chemistry A YSI multi-meter or an In-Situ AquaTroll 500 multi-parameter sonde with a 50 m cable was used for dissolved oxygen, temperature, TDS, and conductivity profiles. Readings were taken at one-meter intervals through the water column at every site.

Water transparency was measured with a standard 20 cm Secchi disk.

Water quality samples were collected using a low-metals bottle Van Dorn sampler. Samples were delivered on the same day, on ice, using filed filtration and preservation as prescribed by Caro Labs, Kelowna. They analyzed the samples according to Standard Methods.

Summary of Selected Water Quality Guidelines and Limits of Concern

	Aquatic Life			
	Mean CCME	***Concern Level*** B.C. ENV, Kamloops	30 day average B.C. ENV CCREM CWQG	Maximum B.C. ENV CCREM CWQG
pH			6.5 - 9.0	
Dissolved Oxygen			8.0 minimum	
Suspended solids (TSS)				max increase = 10
Dissolved Solids (TDS)				
Ammonia - as N		1.0 mg/L	1.15 mg/L at 8°C pH 8	1.57 - 13.4 mg/L
Nitrate - as N	13 mg/L		3 mg/L	31.1 mg/L
Nitrite - as N (Cl > 10 mg/L)	0.06 mg/L		0.2 mg/L	0.6 mg/L
Phosphorus total - as P			5 – 15 µg/L	
Chloride	640 mg/L			
Sodium				
Sulphate				100 mg/L
Aluminum, dissolved	0.1 mg/L if pH>6.5		0.05 mg/L	0.10 mg/L
Arsenic, total	5 µg/L			5 µg/L
Cadmium, total (hardness dependent)	Equation: at HVC 0.021 – 0.141 mg/L			0.2 - 0.8 mg/L
Copper, total (see Table 8.2)	Equation: at HVC 2 – 4 µg/L	3 µg/L	3 – 22 µg/L hardness>50mg/L	Equation; at HVC 2 – 8 µg/L
Iron, total	0.3 mg/L			1.0 mg/L (D-Fe 0.035)
Lead, total (hardness >300 mg/L)	Equation at HVC 1.8 – 7 µg/L		16 µg/L	330 µg/L
Manganese, total (hardness >300mg/L)		1.0 mg/L	1.9 mg/L	3.8 mg/L
Molybdenum, total (see Table 8.3)	0.073 mg/L (interim)	0.30 mg/L	1.0 mg/L	2.0 mg/L
Mercury (methyl Hg)	0.026 (0.004) µg/L			
Zinc, total (hardness >300 mg/L)	0.03 mg/L		0.24 mg/L	0.265 mg/L

Note: ug/L /1000 = mg/L
(Updated Mar 2013)

Water Quality Guidelines and Limits of Concern, Continued

	Drinking Water	Irrigation	
	Maximum for drinking water B.C. ENV CDWG	CCME	Maximum for irrigation B.C. Environment
pH	6.5 - 8.5	6.5 – 9.0	4.5 - 9.0
Dissolved Oxygen			
Suspended solids (TSS)			
Dissolved Solids (TDS)	500 mg/L		500 – 3500 mg/L
Ammonia - as N		0.019 mg/L	
Nitrate - as N	10 mg/L	100 mg/L	
Nitrite - as N	1.0 mg/L	10 mg/L	
Phosphorus - as P	10 ug/L		
Chloride	250 mg/L		100-700 mg/L crop dependent
Sodium	270 mg/L		30-40 mg/L maintain SAR <2
Sulphate	500 mg/L		
Aluminum, diss	0.20 mg/L		5.0 total Al
Arsenic, total	10 ug/L	0.1 mg/L	0.1-2.0 mg/L soil / crop dependent
Cadmium, total (hardness dependent)	5 ug/L	5.1 ug/L	10 ug/L
Copper, total (see Table 8.2)	0.5 mg/L	0.2-1.0 mg/L crop-dependent	0.2 mg/L
Iron, total	0.3 mg/L	5.0 mg/L	5.0 mg/L
Lead, total (hardness dependent)	0.050 mg/L	0.2 mg/L	0.2-0.4 mg/L soil/pH dependent
Manganese, total		0.2 mg/L	
Mercury ug/L			
Molybdenum, total (see Table 8.3)	0.25 mg/L	0.01 mg/L continuous use	0.01-0.03 mg/L avg 0.05 mg/L max
Zinc, total	5.0 mg/L	5.0 mg/L if soil pH>6.5	1.0-5.0 mg/L soil/pH dependent

Note: ug/L /1000 = mg/L

* = aesthetic objective value

**** =** Canadian Guidance Framework for Phosphorus is for developing phosphorus guidelines (does not provide guidance on other freshwater nutrients). It provides Trigger Ranges for Total Phosphorus (see Guidance Framework for Phosphorus factsheet):

Trophic Status	**Phosphorus**	**Nitrogen**
ultra-oligotrophic	< 4 µg/L	
oligotrophic	4 – 10 µg/L	< 100 µg/L
mesotrophic	10 – 20 µg/L	100 – 500 µg/L
meso-eutrophic	20 – 35 µg/L	
eutrophic	35 – 100 µg/L	500-1000 µg/L
hyper-eutrophic	> 100 µg/L	> 1000 µg/L

(Updated Jan 2025)

Appendix 3: Sources of Taste and Odour Problems in Kalamalka Lake

An offensive earthy/musty taste and odour problem triggered complaints commencing in late June 1999. Several residents said that their Britta™ type filter (activated carbon + ion exchange resin) was not effective, although filter performance depends on how it is used. Other clients offered that boiling and chilling the water eliminated or reduced the problem. Increasing the chlorine dose was helpful, either by oxidizing the offensive compound(s) or by masking it.

Algae are the most common cause of off-tastes and odours in surface waters. Living algae excrete organic substances and some of these cause tastes and odours. Decomposition of these compounds and the algae cells themselves constitutes yet another potential source of taste and odour-causing compounds in water supplies.

Another possible source for the Kal Lake episode is humic materials washed from thawing soils and brought in by freshet flows. Freshet flows are also responsible for importing actinomycetes bacteria. They are adapted to but not entirely an aquatic organism. Heavy rains and freshet greatly increase their presence in lakes by washing them in along with more organic matter and nutrients to support their growth (Mallevaille & Suffet, 1987).

Decomposition of algae by actinomycetes bacteria increases the earthy/musty odours by their production of organic compounds called geosmin -earthy and 2-methylisoborneol (MIB) - musty.

Taste thresholds vary with pH, thus the marl precipitation event seen in mid-summer at Kal Lake may affect a taste and odour problem.

Taste and odour compounds may also react with chlorine, including the chlorinated degradation products of humic and fulvic acid (e.g. 2,2-dichloroacetic acid is detectable at 0.2 mg/m3 air, Van Gemert and Nettenbreijer, 1977).

Summer 1999 Taste and Odour Problem

Thermal Considerations

Kalamalka Lake maintained good oxygen concentrations throughout the water column, therefore anaerobic decomposition is probably not a contributing factor to the taste and odour problem.

The 20 meter intakes draw bottom (hypolimnion) water until the fall overturn. While the taste and odour problem diminished after August in both water systems, it was no longer detectable after the overturn.

Unlike Wood Lake where algae produce a fishy smell in the surface water, Kal Lake surface water had no smell. The problem in Kal Lake was confined to the bottom water during the summer.

The 1999 freshet was large and lasted into July. The influx of relatively nutrient-rich cold water to the hypolimnion may have encouraged biological growth or it may have imported sufficient humic compounds from thawing soils to directly increase the taste and odour problem (Mallevialle & Suffet, 1987). The freshet may also have imported actinomycete bacteria, a flora noted for its earthy/musty odour.

Microflora Considerations

The sum of the data in 1999 indicates that microflora (algae, bacteria) played a part in the taste and odour problem. For example:

- During August, chlorophyll-a levels increased with depth, probably from an accumulation of decaying algae near the bottom since most of the algae found there are normally surface forms
- Larger algae counts usually coincided with increased taste and odour in the water
- Types of algae that were prevalent in August can produce a taste problem when abundant
- Many more algae produce a musty, decaying taste and odour when they are decomposed by filamentous bacteria, *Actinomycetes* and the large freshet may have imported more bacteria than normal

A combination of cyanobacteria and *Actinomycetes* is the most probable cause of the taste and odour event. Of all the compounds produced by either living or dead algae, those of blue-green algae and actinomycetes are the most durable, often defying treatment plant procedures and surviving chlorination.

There is no appropriate treatment to curtail algae growth in Kalamalka Lake, however fore warning of an algae problem will allow a faster response to increase the chlorine dose. Chlorine either masked or partially destroyed the odour-causing compounds in the water and improved the aesthetic quality of the finished water. Boiling was also found effective while Britta™ filters were reported to be ineffective.

Algae known to produce objectionable taste and odour that are found in Kalamalka Lake include:

Cyanobacteria **(musty/earthy)**
Anabaena sp. and *Lyngbya sp*.

Blue-green algae **(grassy, septic, fishy)**
Anacystis cyanea, and *Oscillatoria sp*.

Flagellated golden algae **(violets, cucumber, fishy)**
Dinobryon sp. and *Peridinium sp*.

Diatoms **(geranium, grassy, musty)**
Fragilaria
(Palmer, 1980)

During the lake-wide 1999 taste and odor event that prompted this study, cyanobacteria counts exceeded 1700 cells/mL at the N-Kal intake. 2005, 2006 and 2009 also had mild odor events caused by algae. In 2017, the highest count from the North intake was 2925 cyanobacteria cells/mL and the South intake was 1950 cells/mL during September and yet there were no unusual complaints (Appendix 3). Presence of A*ctinomycetes* decomposers and re-suspended detritus may also be required to induce a taste and odor event.

Water Quality Considerations
Total dissolved solids concentrations (130 - 203 mg/L) were well below the 500 mg/L TDS concentration where concentrations may affect taste and odour of the water.

Similarly, ammonia and nitrate concentrations were low and unlikely to cause odours via inadvertent chloramination or other nitrogen compound formation.

Nutrient concentrations support microfloral growth. Increasing concentrations of nitrogen (forms = nitrate + nitrite, ammonia, organic nitrogen) and phosphorus (forms = ortho-phosphate, total dissolved phosphorus, organic phosphorus) cause increased algae growth. The ratio of these two nutrients is crucial to algae growth. Where the ratio of nitrogen : phosphorus falls below 15 : 1 (by wt), phosphorus no longer limits plankton growth (Nordin, 1985). In Kal Lake, phosphorus is limiting for most of the growing season. Years with higher runoff also had higher total and dissolved phosphorus levels (Ashley et al., 1999).

Spring nitrate nitrogen concentrations trend gradually upward over the past 25 years in Kal Lake (Ashley et al., 1999).

Available water quality data indicates that Kalamalka Lake water quality and algae production fluctuates, but overall trends indicate deterioration. Continued study of nutrient trends is vital to understanding how the resumption of Kal Lakes natural flushing time will affect nutrient concentrations.

Distribution System Considerations
No other organisms (iron bacteria, SRB bacteria, etc.) were found in the 1999 – 2000 RDNO or DLC hydrant samples that could have caused the taste and odour problem within the distribution system itself.

Summary
Study to date has allowed the range of potential sources of the summer, 1999 taste and odour episode to be focused. Potential sources that were ruled out include;

- anaerobic bottom water
- inadvertent chloramination
- dissolved minerals (TDS)
- biological growth or regrowth in the distribution system

Based on current information, probable sources of the problem, in descending order of importance include;

- enhanced growth of blue-green algae especially *Lyngbya, Anacystis*
- large freshet importing more nutrients, actinomycetes and humic acids
- larger than normal growths of actinomycetes in Kal Lake
- changing nutrient status in Kal Lake
- accumulation of algae debris in the distribution systems

Appendix 4: Toxin forming Cyanobacteria in Kalamalka Lake

Cyanobacteria species number in the thousands. Toxic cyanobacteria have been found on every continent except Antarctica (Hoehn and Long, 2002). They can occur as surface scum, benthic growths on substrates or along a thermocline. Their cyanotoxins occur widely in drinking water sources. The toxins include a diverse range of chemical compounds, with equally diverse toxic effects (Table A 4). These toxins are not limited to individual cyanobacterial species or genera; as the research improves, toxins are found in an ever-increasing array of cyanobacterial species (Hudnell 2008). Twenty-four potentially toxic cyanobacteria species were identified in Kalamalka Lake samples during this study (Table A 4). Ultimately, most if not all, cyanobacteria will be identified as capable of producing toxins.

Not all strains within a given cyanobacteria species are toxic, or at least, not all the time (Shirai et al., 1991). Toxin content in potentially toxic strains tend to be highest when:

- Water temperature is within the 18 – 25 °C range (water < 10 °C or > 30 °C had lower cyanotoxin contents)
- Toxin concentration increased with increased pH, possibly because intense photosynthesis in a bloom raises pH
- In high phosphorus waters, the cyanobacteria produced more toxins (D. Stone, 2009)

Most cyanotoxins have an LD_{50} of 50 – 300 µg/kg acute toxicity range, meaning water containing cyanotoxins can be assessed for acute risk as follows (Chorus and Bartram, 1999):

- < 10 µg/L low risk
- 10 – 20 µg/L moderate risk
- 20 - 2000 µg/L high risk
- > 2000 µg/L very high risk

Cyanotoxins include a wide array of organic molecules but they fall into three broad chemical categories; cyclic peptides that impact the liver; alkaloids that attack the nervous system (other examples include caffeine and cocaine) and lipopolysaccharides that are skin irritants (Sivonen and Jones, 1999).

For clarity regarding this section, please allow the following definitions to stand while discussing chronic low dose exposure:

- Chronic: Any period longer than 28 days
- Low Dose: Any dose less than lethal with minimal immediate symptoms
- Exposure: Contact with cyanotoxins through ingestion, inhalation and/or skin contact

The probability of high-level cyanotoxin exposures through drinking water from Kalamalka Lake is far less than that for repeated, low-level exposures through recreational or drinking water contact (e.g., ingestion, absorption through the skin, inhalation). The prevalent cyanobacteria and the toxins they produce are summarized in Table A 4.

Exposure to an acute dose of cyanotoxins are more probable to involve direct effects of the toxins, whereas very low dose chronic effects may result from secondary toxin actions, including triggering an inflammatory response in the immune system. Unlike acute effects, much less is known about the health risks posed by repeated, low-level exposures to cyanotoxins. This is unfortunate, since most human poisonings are classified as chronic, developing over long periods of exposure and often resulting in liver damage and cancer (Hoehn & Long, 2002). Human deaths rarely occur because water containing cyanotoxins also frequently has a vile taste and odor. Animal deaths from cyanotoxin poisoning are far more common because they do not reject water with an odor, taste, or scum.

Whereas acute-phase cyanotoxin illness is characterized by rapid onset gastrointestinal and respiratory distress, the chronic phase is characterized by sustained fatigue, muscle and joint pains, and severe neurologic symptoms that persist indefinitely. Lower-level exposures also may cause chronic illness in some individuals (Palafox and Buenconsejo-Lum 2005). Most vulnerable are the young (low body weight), the elderly, and the immune-compromised (particularly those battling cancer, liver or kidney disease or nervous disorders). There is evidence that nutritional status, sex, age, and strain of laboratory animals can influence the severity of cyanotoxicity in laboratory tests. These variables ought to be considered when examining adverse effects of cyanobacteria in humans (Hudnell, 2008).

The following Table A 4 contains a summary of the plankton (free-floating) and benthic (bottom-dwelling) cyanobacteria common in North America, and the toxins that have been reported for them. Not all authors report all the toxins. The list of toxins produced by a given cyanobacteria is increasing as the research expands and methodologies improve.

Table A 4: Toxins Produced by Blue-green Algae (Cyanobacteria)

Cyanobacteria	LYN	APL	ApopTX	LPS	CYN	MC	NOD	ATX	SAX NEO	GNT	BMAA	CPL	APT
Type of toxin	Dermal	Dermal		Dermal	Liver	Liver carcinogenic	Liver carcinogenic	Nerve	Nerve		Nerve carcinogenic	Nerve	Nerve
LD50 (ug/kg)					300	50–1000		20-5000					
Guideline						<1 ug/L		<1 ug/L					
Anabaena	Yes-?		Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
Anabaenopsis				Yes		Yes					Yes		
Anacystis	Yes-?			Yes		Yes	Yes-?	Yes			Yes	Yes	Yes
Aphanizomenon	Yes-?			Yes	Yes	Yes	Yes	Yes	Yes		Yes		Yes
Aphanocapsa	Yes-?			Yes		Yes					Yes		
Aphanothece						Yes-?							
Cylindrospermopsis	Yes-?			Yes	Yes	Yes		Yes-?	Yes		Yes		
Gloeotrichia	Yes-?					Yes					Yes		
Gomphosperia						Yes							
Haplosiphon				Yes		Yes					Yes		
Lyngbya	Yes	Yes		Yes	Yes	Yes		Yes	Yes		Yes		Yes
Microcystis	Yes-?			Yes		Yes	Yes-?	Yes			Yes	Yes	Yes
Nostoc	Yes-?		Yes	Yes		Yes	Yes	Yes-?			Yes		
Nodularia	Yes-?			Yes		Yes-?	Yes				Yes		Yes
Oscillatoria	Yes	Yes		Yes	Yes-?	Yes		Yes	Yes		Yes		Yes
Phormidium	Yes			Yes		Yes	Yes-?	Yes	Yes		Yes		
Planktolyngbya	Yes					Yes					Yes		
Planktothrix	Yes	Yes		Yes		Yes		Yes	Yes		Yes	Yes	Yes
Pleactonema	Yes	Yes		Yes	Yes	Yes		Yes-?	Yes		Yes		
Pseudanabaena	Yes-?			Yes		Yes		Yes-?			Yes		
Raphidiopsis				Yes	Yes	Yes-?		Yes	Yes		Yes		
Schizothrix	Yes	Yes		Yes		Yes-?					Yes		Yes
Synechococcus				Yes		Yes		Yes-?			Yes		
Synechocystis				Yes		Yes-?					Yes		

NOTE: Yes-? = Not all authors list this toxin for the cyanobacteria species

Legend: LYN = Lyngbyatoxin, APL = Aplysiatoxins, ApopTX = Apoptogen Toxin, LPS = Lipopolysaccharide, CYN = Cylindospermopsin, MC = Microcystin, NOD = Nodularins, ATX = Anatoxins (-a), SAX NEO = Saxitoxins SAX, neosaxitoxin NEO, GNT = Guanitoxin, BMAA = β-Methylamino-L-alanine, CPL = Cyanopeptolins, APT = Anabaenopeptins

Appendix 5: Causes of Turbidity at Kalamalka Lake Intakes

- **Marl:** Turbidity is naturally high in Kalamalka Lake during the marl precipitation. Turbidity was consistently better in the surface water than at either the N-Kal intake (old intake was 0.6 m above substrate) or the S-Kal intake (2.0 m above substrate), respectively, during a summer turbidity event. After the marl precipitation, turbidity rose in the deep water throughout the lake. The marl event was weak in 2018 and increased turbidity to 1.9 NTU in the North Arm and 1.0 NTU in the south of the lake (SCADA daily averages). Historically, August had the highest turbidity, with a pronounced spike at 20 m corresponding to the marl precipitation and occasionally with higher concentrations of cyanobacteria and detritus as well (Figure 40). By September, marl cleared from the upper 20 m and increased turbidity in deeper water in most years.
- **Coldstream Creek plume:** During the freshet, turbidity in Coldstream Creek reached 174 NTU Coldstream Creek (grab sample on May 14, 2018). This affects the intake and the entire North Arm and forced RDNO to shut-off the Kalamalka intake for several weeks during 2018 (Figure 40). Mid-winter melting events have occurred multiple times over the years and these events will also trigger surges of turbidity in the Coldstream Creek plume. During high freshet years, turbidity from the Coldstream Creek plume raised turbidity in the entire North Arm. Even the 40 m site was occasionally affected because most of the plume travels through the deeper trough in the center of the North Arm (Figure 23).
- **Seiches:** Severe windstorms cause large seiches that can raise turbidity at the intake through sediment resuspension. The new N-Kal intake is less susceptible to seiches because it now has 3.5 m of clearance while the S-Kal has good protection with 2 m of clearance (Figure 40).
- **Fall Overturn:** Turbulence generated by the fall overturn increases turbidity briefly at both intakes. This was most pronounced at the N-Kal intake before it was raised but the increased clearance now protects the intake from sediment resuspension associated with fall overturn; intake turbidity decreased through fall overturn in 2017 and 2018. The S-Kal intake is well protected from sediment resuspension at fall overturn (Figure 40).
- **Bottom disturbance:** Very fine marl substrates in Kalamalka Lake are easily re-suspended by turbulence because they have a finer grain size than clay and have very slow settling rates. Their resuspension contributes to turbidity. Shallow sediment traps collected more material than their deep counterparts at both ends of the lake, indicating greater sediment resuspension from a combination of boat wakes and waves especially when boats travel in water shallower than 3 m, as well as sediment introduction from onshore sources (Schleppe et al. 2017). Both intakes are now well protected from sediment resuspension with clearances of 3.5 m (N-Kal) and 2 m (S-Kal).
- **Rototilling:** A final cause of high turbidity (> 5 NTU in 2007) was rototilling near the N-Kal intake that resulted in a plume containing very high organic detritus and fine silt counts (Figure A 1; Figure A 2). It travelled with prevailing water currents to the intake. Rototilling should be deferred to the freshet months or to November so additional turbidity notifications can be avoided. Accordingly, OBWB and GVW coordinate to ensure rototilling impacts on the intake are minimized by moving the rototilling window from spring to Nov 1– Mar 31.
- **Algae blooms:** Large algae blooms in Kalamalka Lake can trigger turbidity events as they did in 2020.

Figure A 1: Turbidity plume from milfoil rototilling machine

Figure A 2: Turbidity plume from milfoil rototilling machine in south end of Kalamalka Lake during 2022

Appendix 6: Summary of Intake Extension Water Quality

Table A 4: Average water quality change with current and potential intake depths, using 2024 only and combining all data to date

Kalamalka Lake 2024	South 20 m	South 30 m	South 40 m	North 20 m	North 30 m	North 40 m
Distance to pumphouse*, m	550	715	1700	330	700	1600
Average temperature, °C	9.1	6.1	5.1	8.1	5.7	4.8
pH	8.04	7.98	7.94	7.99	7.87	7.82
Hardness, mg/L	182	182	183	182	181	181
Total calcium, mg/L	40.0	40.5	40.7	40.5	40.3	40.5
Total organic carbon, mg/L	4.4	4.3	4.1	4.4	4.2	4.1
Chlorophyll-a, µg/L	1.4	1.1	0.8	1.2	1.0	0.6
Turbidity, NTU	0.47	0.39	0.35	0.53	0.43	0.31
UV Transmissivity, %	89.7	90.1	90.3	90.0	90.1	90.3
Avg algae counts, cells/mL	6126	4208	3529	5526	3156	2747
E. coli, CFU/100 mL	<1	<1	1.5	1.3	1.4	1.1
Total coliforms, CFU/100mL	4	2	4	13	13	10
Kalamalka Lake 2000-2024	South 20 m	South 30 m	South 40 m	North 20 m	North 30 m	North 40 m
Distance to pumphouse*, m	550	715	1700	330	700	1600
Average temperature, °C	7.0	5.2	4.6	6.7	5.0	4.6
# of seiches over 2 °C/yr	20	8	5	10	4	1
Max seiche temperature fluctuation, °C	14	3.2	3	11.7	9.9	4
pH	8.12	8.05	8.07	8.09	8.02	7.99
Hardness, mg/L	175	178	178	175	176	175
Total calcium, mg/L	38.4	39.2	39.7	38.5	38.7	38.5
Total organic carbon, mg/L	4.4	4.2	4.1	4.4	4.3	4.2
Chlorophyll-a, ug/L	1.9	1.5	1.0	2.0	1.4	1.1
Turbidity, NTU	0.75	0.46	0.36	0.82	0.56	0.48
UV Transmissivity, %	89.8	90.5	90.7	90.1	90.4	90.7
Avg algae counts, cells/mL	3197	2901	2379	2940	2071	1839
E. coli, CFU/100 mL	<1	<1	<1	5.7	2.2	1.3
Total coliforms, CFU/100mL	44	46	53	79	40	45

Note: Average temperature based on field profiles from 2011-2024 only

***** = Minimum possible distance from pumphouse to sample site assuming pipe extended from existing intake location, actual engineered intake locations and pipe runs may vary

Appendix 7: Cyanotoxicity Risk Levels

Risk Levels used throughout this report were created by Heather Larratt, the senior biologist of LAC (Figure 53). H. Larratt has more than 40 years' experience in aquatic research and microbiology. The table was created by harmonizing at least 30 sources, including the following references:

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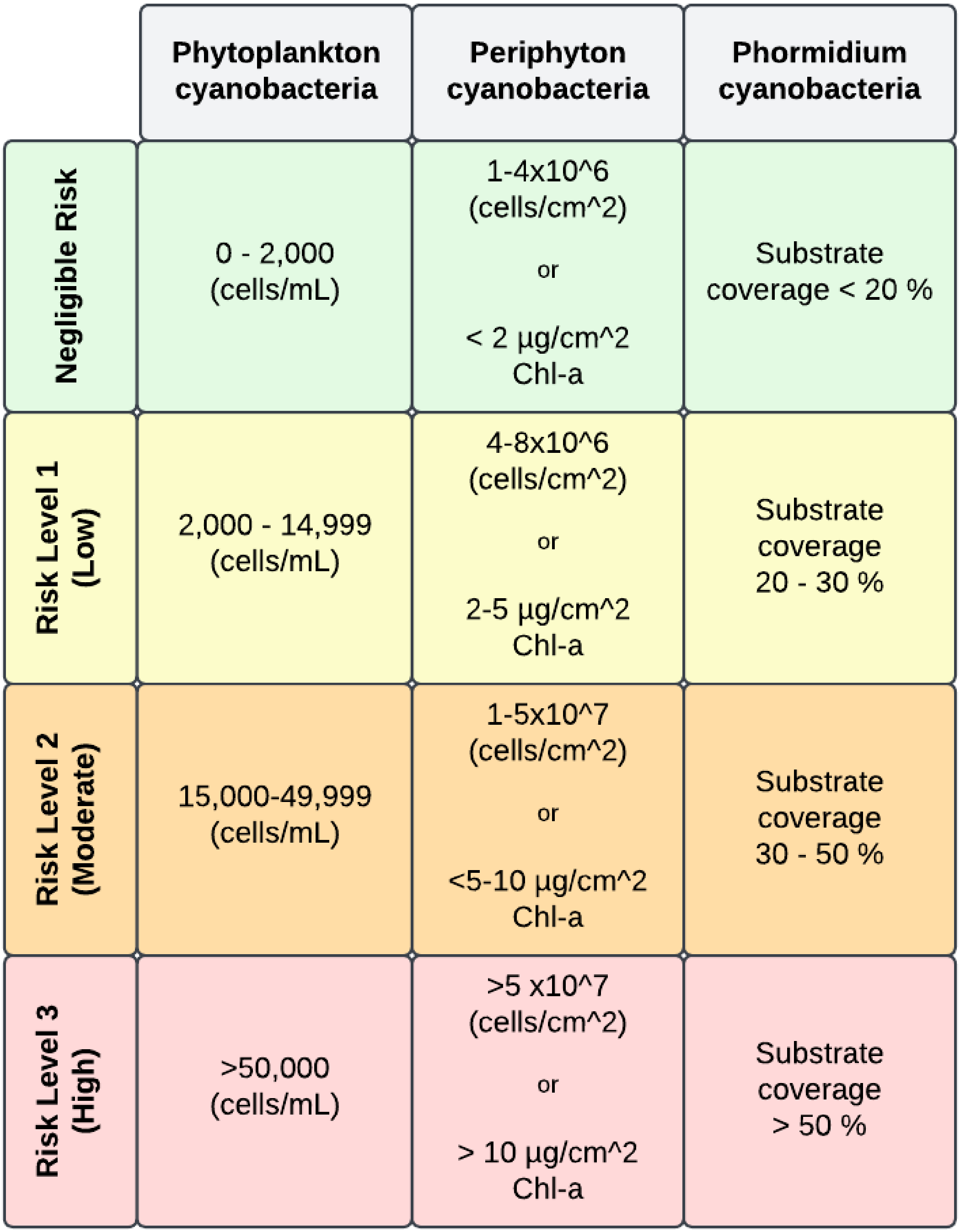

	Phytoplankton cyanobacteria	**Periphyton cyanobacteria**	**Phormidium cyanobacteria**
Negligible Risk	0 - 2,000 (cells/mL)	1-4x10^6 (cells/cm^2) or < 2 µg/cm^2 Chl-a	Substrate coverage < 20 %
Risk Level 1 (Low)	2,000 - 14,999 (cells/mL)	4-8x10^6 (cells/cm^2) or 2-5 µg/cm^2 Chl-a	Substrate coverage 20 - 30 %
Risk Level 2 (Moderate)	15,000-49,999 (cells/mL)	1-5x10^7 (cells/cm^2) or <5-10 µg/cm^2 Chl-a	Substrate coverage 30 - 50 %
Risk Level 3 (High)	>50,000 (cells/mL)	>5 x10^7 (cells/cm^2) or > 10 µg/cm^2 Chl-a	Substrate coverage > 50 %

Figure 53: Cyanotoxicity Risk Level Boundaries

------------------------End of Report-----------------------