Wood Lake British Columbia
A Review of Historical Conditions, Current Trends, and Recommendations for a Sustainable Future

Prepared for the District of Lake Country

Larratt Aquatic Consulting Ltd. 105-2081 McDougall Rd. West Kelowna B.C. V1Z 4A2
Phone: 250.769.5444 www.lakebiology.ca

Executive summary

Wood Lake is the first and smallest of five mainstem lakes in the Okanagan Valley BC, fed upstream by Middle Vernon Creek and Duck Lake and emptying into Kalamalka Lake. European settlement of the Wood Lake watershed began around 1860 leading to numerous changes in the watershed including orchards, ranches, roads, and other resource extraction. The Oyama canal was created in 1908, permanently linking Kalamalka Lake and Wood Lake water levels.

The goal of this study was to summarize the state of knowledge of Wood Lake and determine if Wood Lake is deteriorating and if so, what practical steps can be taken to restore it. All available data and reports were reviewed and compiled to build a comprehensive database upon which statistical analyses could be performed to address the study's primary questions. This review identified that new sediment cores should be collected and were analyzed for metals and diatoms to build a picture of Wood Lake since European settlement began.

The historical data reveals that Wood Lake has experienced multiple distinct phases depending on the activity within its watershed. The water sampling record goes back to 1970 and captures the high nutrient, high productivity, low water clarity phase that dominated the middle of the twentieth century. Increased flushing from water released by the Hiram-Walker distillery (1971-1992) combined with the introduction of nutrient removal to wastewater treatment (late-1990s) led to a 30-year span of improving water quality in Wood Lake. Conditions appear to have reversed over the past 10 years with declining trends in water clarity and increasing trends in nutrients and productivity.

Sediment cores extend the time frame to the start of European settlement and show that Wood Lake water quality changed significantly around 1940, coinciding with the widespread use of fertilizers and chemical pesticides in agriculture. Sediment chemistry data aligns with water chemistry showing the second shift in water quality around 1970. Diatom community composition within the sediment cores also aligns well with the chemistry data showing three primary phases with large shifts in diatom populations around 1940 and again around 1970. Once again, matching the historical activities within the watershed.

This report sought to address, in detail, the following questions:

Is Wood Lake significantly different from the Indigenous era (pre-1850) in terms of water chemistry and primary productivity?

Yes. Wood Lake has undergone three major phases since European settlement began with the start of a fourth potentially occurring presently.

1) Pre-1940s early settlement
2) 1940s-1970s agriculture dominated activities with effects of fertilizers and pesticides visible in the sediment record
3) Post-1970s was urban dominated with improvements in water quality
4) Post 2010s appears to be a regression caused by climate change and continued disruption of the watershed

Is Wood Lake deteriorating today and why?

Yes. Data from 2010-present catalogue a decline in water clarity, increase in nutrients, increase in the size and intensity of the summer anoxic zones, and increase in productivity. However, current conditions remain better than those from the 1940-1970s period. The current decline is attributed to several factors such as:

- Decline in watershed resiliency
- Nutrient enrichment from the watershed and in-lake activities
- Climate Change
- Accelerating internal nutrient recycling

Are Wood Lake fish safe to eat?

Latest research says that muscle tissue is probably safe for human consumption but that there will still be some cyanotoxins in it. All research is clear that internal organs, particularly the liver, are to be avoided as they can contain potentially harmful concentrations of cyanotoxins. The effect of cyanotoxin exposure to piscivorous birds is not well established. Cyanotoxins are known to persist in fish tissues for weeks after a bloom has ended but there is no strong evidence for biomagnification of cyanotoxins.

What is at stake if Wood Lake deteriorates – an economic analysis

Wood Lake is a very important feature in the region. Wood Lake provides a variety of economic benefits to the community. These include increased property values for lakeside and lake-view residents, tax revenue from real estate and tourism, and support for local businesses like restaurants and shops. The lake is also used for irrigation by agricultural and private landowners, reducing their water treatment costs. Further deterioration of Wood Lake could cost the region millions/year in lost revenue and economic value.

What feasible steps can be taken to lower the scale and frequency of cyanobacteria blooms in Wood Lake?

The issues afflicting Wood Lake are not new and several previous studies made recommendations about potential solutions. A comprehensive list of these proposals was complied and assessed according to several criteria including cost, effectiveness, and the strengths and weaknesses of each approach. The restoration proposals focused on two major categories: improving Wood Lake directly and changing the watershed such that the downstream effects improve Wood Lake. The most achievable options include:

Wood Lake Watershed Options:

- Riparian setbacks and revegetation of tributaries and shoreline
- Educate residents and guests on Wood Lake condition to encourage stewardship
- Greywater reuse programs to reduce pressure on WWTP
- Prescribed burning in watershed to limit wildfire risk

Wood Lake Options

- Engage with Syilx water declaration and processes such as the kɬúsx̌nítk (Okanagan Lake) Watershed Responsibility Planning Initiative

- Boating education programs to encourage responsible boating near shore and around Oyama Canal, wake surfing in 8+ m water depth, Clean Drain Dry, I'm a Wake. Etc.

All these options should be considered in addition to the excellent initiatives by DLC, OKIB, and others to the health of Wood Lake.

Acknowledgements

The LAC team would like to gratefully acknowledge funding from Okanagan Basin Water Board and from District of Lake Country. The assistance District staff including Sarah Graham, Greg Buchholz, and Patti Meger was vital. Concerned long-time resident Jack Allingham helped instigate this study. We are indebted to the previous researchers who have written extensively about Wood Lake for over 100 years. We would also like to acknowledge collaboration with Okanagan Indian Band (OKIB) in whose traditional lands Duck and Wood lakes function.

Preferred Citation

Self, J., Viita, C., Knezevic, S., and Larratt, H. (2024). *Wood Lake British Columbia: A Review of Historical Conditions, Current Trends, and Recommendations for a Sustainable Future*. Prepared by Larratt Aquatic Consulting Ltd. Prepared for the District of Lake Country.

Report prepared by LAC:

Jamie Self: Senior Aquatic Biologist, H BSc, RP Bio

Cierra Viita: Aquatic Biologist, BSc, BIT

Sara Knezevic: Aquatic Biologist, BSc, RP Bio

Reviewed by:

Heather Larratt: Principal Aquatic Biologist, H BSc, RP Bio

Table of Contents

Figures

Tables

Definitions

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
Epilimnion	Surface layer of lake during stratified periods above the thermocline
Eutrophic	Nutrient-rich, biologically productive water body
Green algae	A large family of algae with chlorophyll as the main photosynthetic pigment
Hypolimnion	Deep layer of lake below the thermocline
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
Stratification	Physical process where lake becomes divided into 2 or more vertical layers
Thermocline	Lake zone of greatest change in water temperature with depth (> 1°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

Acronym	**Definition**
Chl-a	Chlorophyll-a
DLC	District of Lake Country
DO	Dissolved Oxygen
IHA	Interior Health Authority
LAC	Larratt Aquatic Consulting Ltd.
MVC	Middle Vernon Creek
OBWB	Okanagan Basin Water Board
OCCP	Okanagan Collaborative Conservation Program
OKIB	Okanagan Indian Band
ONA	Okanagan Nation Alliance
TEK	Traditional Ecological Knowledge

Lake Classification by Trophic Status Indicators

Trophic Status	Chlorophyll-a ug/L	Total P ug/L	Total N ug/L	Secchi disc m	Primary production mg C/m^2/day
Oligotrophic	0 – 2	1 – 10	<100	> 6	50- 300
Mesotrophic	2 – 5	10 – 20	100 – 500	3 – 6	250 – 1000
Eutrophic	>5	> 20	500-1000	< 3	>1000

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 or less

(Nordin, 1985)

Wood Lake Background and History

Wood Lake is the first and smallest of five mainstem lakes in the Okanagan Valley BC, located in the headwaters of the Columbia River. Wood Lake has a catchment area of 190 km^2, holds 193 million cubic meters of water, averages 22 m in depth, and has an estimated residence time of 30 years (Jensen & Bryan, 2001; ILEC, n.d.; Self & Larratt, 2016; Figure 1). Water flows from Duck Lake through Middle Vernon Creek (MVC) into Wood Lake (average = 15.1 ± 9.1 Mm^3 per year from 2012-2023[1]; BC Gov't data, 2024). Outflows from Wood Lake travel to Kalamalka Lake through the man-made Oyama Canal (Figure 1). Groundwater likely contributes a significant water and nutrient load to Wood and Kalamalka lakes (British Columbia Water Resources Service, 1974).

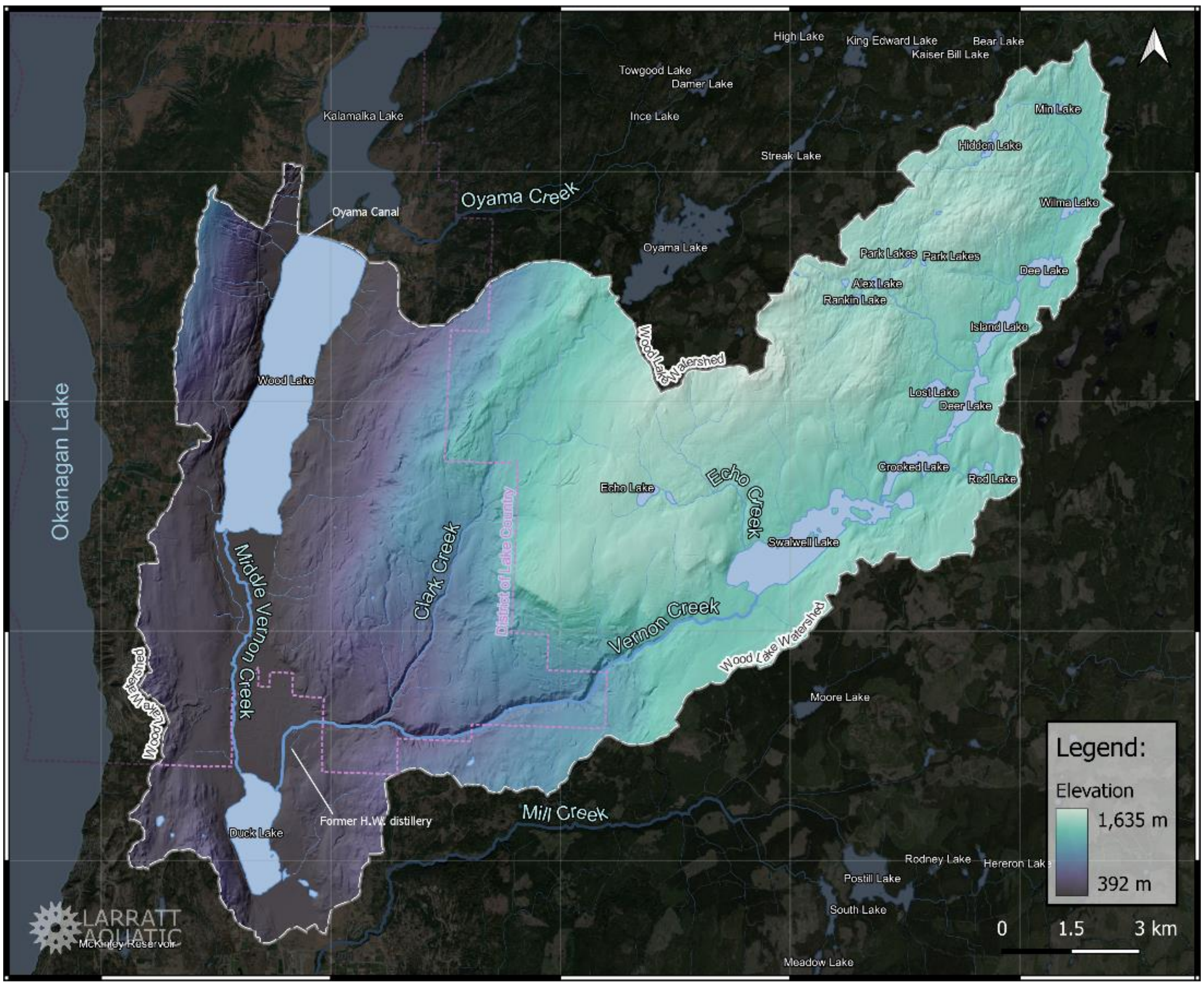

Figure 1: Map of Wood Lake and its watershed

---

[1] The hydrometric station was damaged during the 2017 freshet flooding and did not operate for most of 2017 and all of 2018

Before colonization, Syilx Okanagan people had little impact on the surrounding watershed and on Wood Lake itself (Stockner & Northcote, 1974). Around the 1860's, European settlers established large ranches, orchards, and built roads along Wood Lake (Figure 4). As of 2021, the Wood Lake watershed, which encompasses most of the District of Lake Country, had a permanent population of approximately 15,000 (Statistics Canada, 2023). Most of the population was focused around the lowland area between Duck and Wood lakes with low population density in the upper elevation areas (Figure 2).

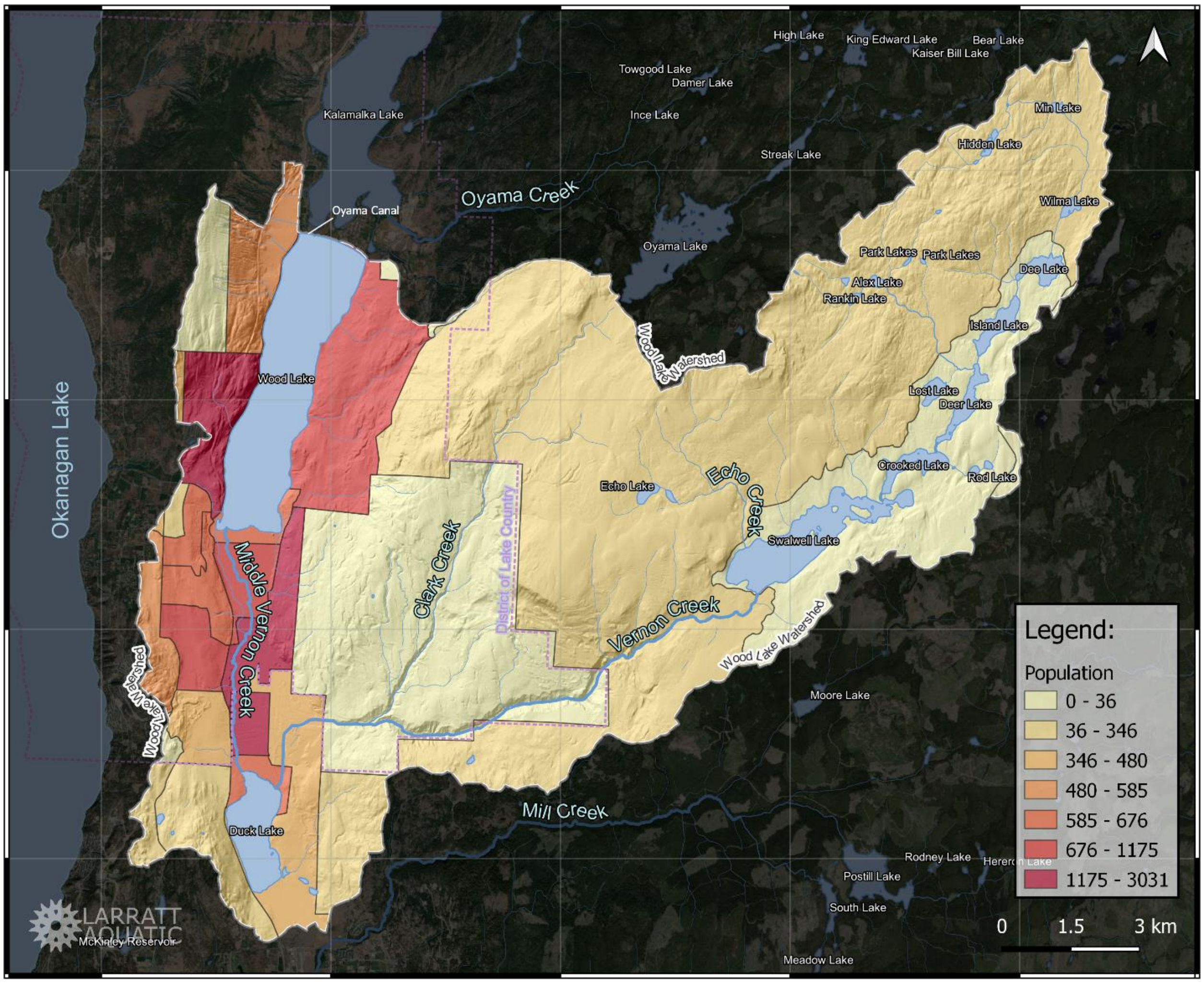

Figure 2: Population density in Wood Lake watershed by 2021 census dissemination area
Source: (Statistics Canada, 2022)

In 1908, settlers excavated the Oyama Canal between Wood and Kalamalka lakes to allow navigation between the two (Jensen & Bryan, 2001; Figure 3). The canal excavation lowered Wood Lake by 0.60 m and raised Kalamalka Lake by 0.25 m. During the 1900's, dam construction in the upper watershed reservoirs altered inflows to Duck and Wood lakes. This increased water residence time and decreased water quality in Wood Lake (Jensen & Bryan, 2001; Bryan, 1990). Vernon Creek was diverted around Duck Lake in 1930 until 1971 when flows were restored to Duck Lake by the Hiram-Walker distillery. Logging also altered the basin hydrology and increased nutrient loads to Wood Lake (Jensen & Bryan, 2001).

Figure 3: Image of Oyama Canal with Wood Lake in the foreground and Kalamalka Lake in the background

As early as the 1930's, Wood Lake had hypolimnetic oxygen depletion, cyanobacteria blooms and black organic substrates (Clemens et al. 1939). More detailed reporting occurred in the 1970's and particularly in the 1980's by the National Water Research Institute (Stein and Couthard 1971; Okanagan Basin Study 1969-1971; Pinsent and Stockner (1974; Gray and Jasper 1982; 1986; Jasper and Gray 1982; Weigand 1984; Weigand and Chamberlain 1987)).

The presence of an unusual, massive cyanobacteria bloom in 1971 prompted detailed limnological studies of Wood Lake (Anon., 1974; Jensen & Bryan, 2001; Figure 4). From 1971 – 1992, Okanagan Lake water was used in the Hiram Walker Distillery (Winfield BC). The distillery discharged 13,600 m^3/day of cooling water from Okanagan Lake into Vernon Creek upstream of Duck Lake while it was operating (Jensen & Bryan, 2001; Figure 1). There remains uncertainty over whether this flushed additional nutrients from Duck Lake into Wood Lake or if the water quality in Wood Lake improved (B.C. Research, 1974; Bryan, 1990; Jensen & Bryan, 2001). Discharges from Hiram Walker Distillery changed Wood Lake's residence time from 30 years to 17 years and transferred nutrient rich Wood Lake water into Kalamalka Lake (Nordin, 1987). Residence time has decreased back to 30 years since the Hiram Walker Distillery closed in 1995 (ILEC, n.d.).

In the decades that followed, the influences on Wood Lake became increasingly complex (Figure 4). Wood Lake may be approaching tipping point that teeters between acceptable and unacceptable water quality for recreational and fishery use. Larratt Aquatic Consulting Ltd. (LAC) was contracted by the District of Lake Country (DLC) to analyze long term changes of water quality.

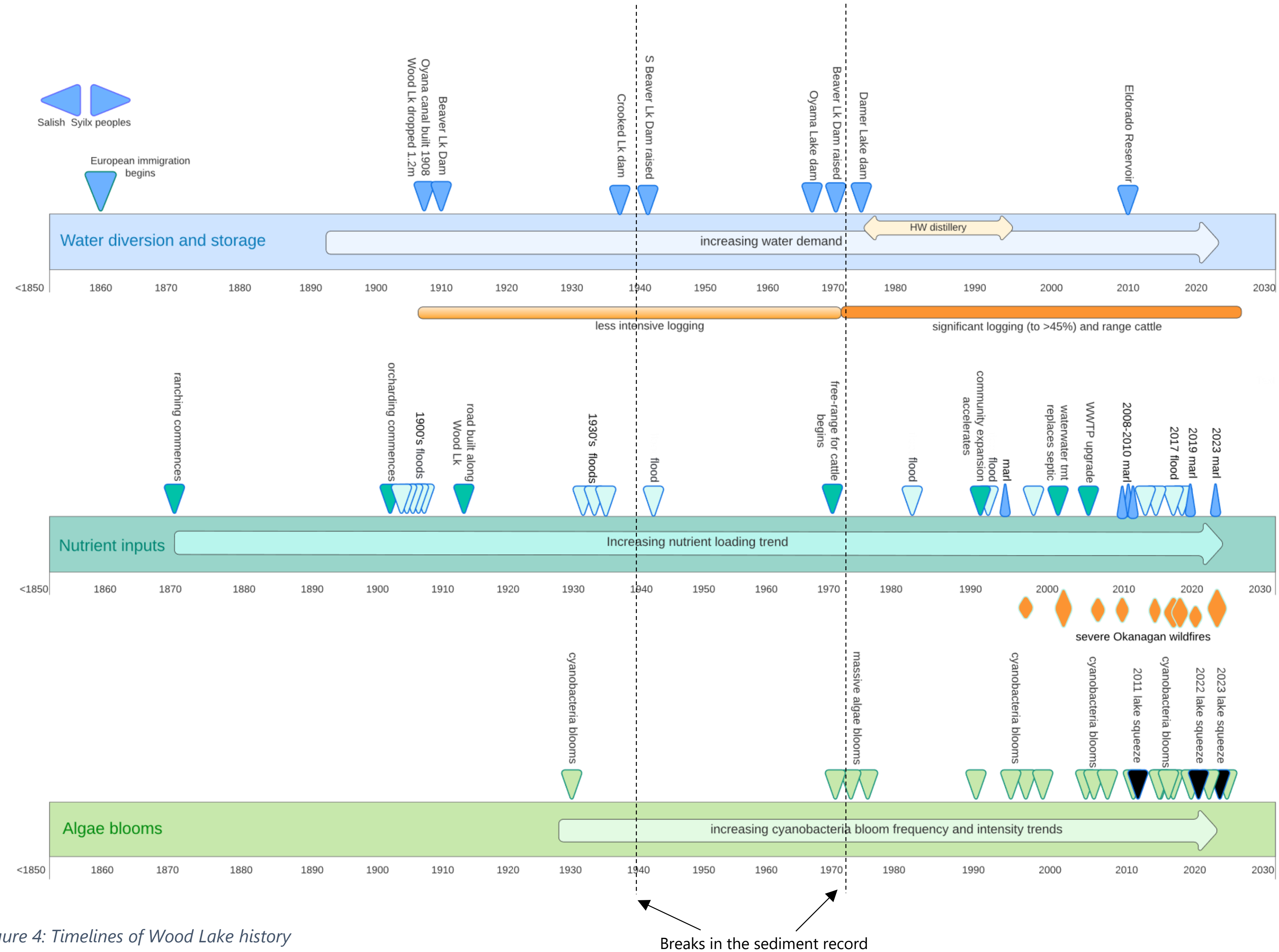

Figure 4: Timelines of Wood Lake history

Methods

Physical, chemical, and biological metrics were analyzed to understand the current and historical state of water quality in Wood Lake. All water-based parameters and algal data used in this study are from ongoing research performed on Kalamalka and Wood lakes by LAC on behalf of RDNO and DLC (Appendix 3: Water Parameters Collected by LAC). Publicly available literature on Wood Lake was also used to supplement historical baselines. Only sediment sampling was performed specifically for this study.

Sediment Cores

Sediment samples were collected using an Ogeechee™ corer with an attached drive hammer. Wood Lake T1 sampling site was 9.6 m deep from the surface and located in the north end of the lake (Figure 6). Sediment corers are designed to collect a vertical profile of sediment. Core length was 0.38 m long and was separated every 2 cm for the first 16 cm and then separated every 4 cm for the remaining core length (13 samples, Figure 5). Nine sediment cores were collected on June 28, 2023, and were combined to create thirteen individual samples (Table 1). The separation of cores into segments (cm intervals) provides insight into Wood Lake's history.

Table 1: Sediment core horizons sampled

Core Increments	Sample Name
0-2 cm	T1 0-2
2-4 cm	T1 2-4
4-6 cm	T1 4-6
6-8 cm	T1 6-8
8-10 cm	T1 8-10
10-12 cm	T1 10-12
12-14 cm	T1 12-14
14-16 cm	T1 14-16
16-20 cm	T1 16-20
20-24 cm	T1 20-24
24-28 cm	T1 24-28
28-32 cm	T1 28-32
32-36 cm	T1 32-36

Samples were analyzed at CARO Analytical Services – Kelowna Office. Analyses included total volatile solids, total metals, and hydrocarbons (PAHS/EPHS/HEPHS).

Figure 5: Photo of sediment core from Wood Lake with deepest (oldest) sediment on the left and shallowest (newest) sediment on the right.

Sediment Traps

Sediment traps were installed May 4 and removed October 31, 2023. One trap was placed in a deep site and the other in a shallow site of Wood Lake (Figure 6). Sediment traps measured sediment accumulation rates over six months. Traps were installed 1 m above the sediment at each site (11 m for shallow, 22.5 m for deep). Samples were analyzed at CARO Analytical Services – Kelowna Office. Analyses included dry weight and total volatile solids. Each trap consisted of two catch basins to allow for replicate comparison.

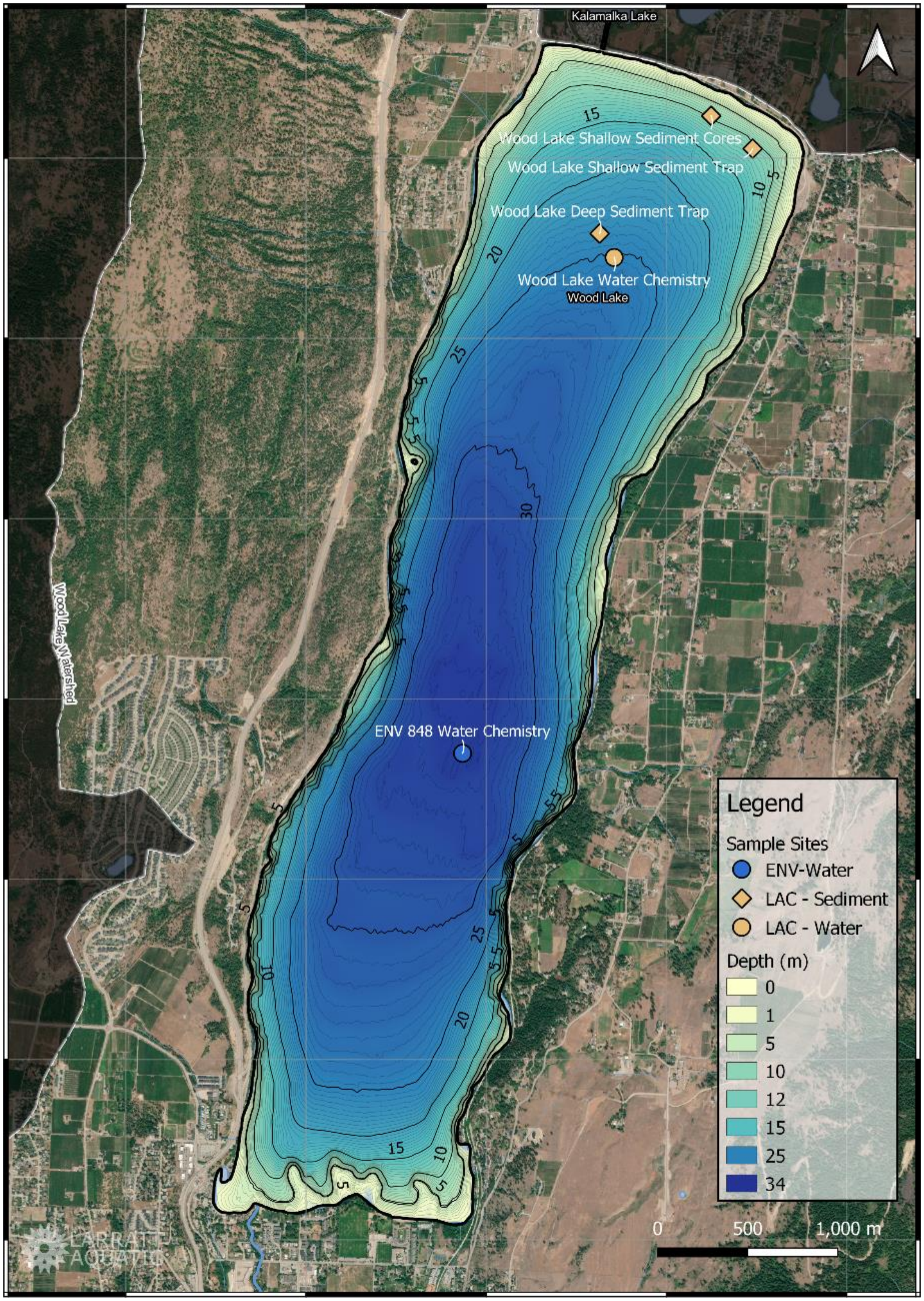

Figure 6: Map of Wood Lake bathymetry with sample sites highlighted

Results

Physical Conditions

Wood Lake has an average depth of 22.6 m with a maximum depth of 34 m in the center (Stockner & Northcote, 1974); Figure 6).

Water Clarity

Water clarity in Wood Lake is poor with an average Secchi depth of 4.8 ± 2.0 m from 1970-2023 (Figure 7). There was a significant declining trend in water clarity over the past ten years that led to the lowest Secchi on record during freshet 2023 (0.7 m on April 28, Mann-Kendall, $p < 0.001$; Figure 7). Current water clarity is similar to what it was back in the 1970's. The oldest secchi depth measurement from Wood Lake was collected during an *Aphanizomenon sp*. cyanobacteria bloom in August 1935, measuring just 2.25 m (Clemens et al. 1939).

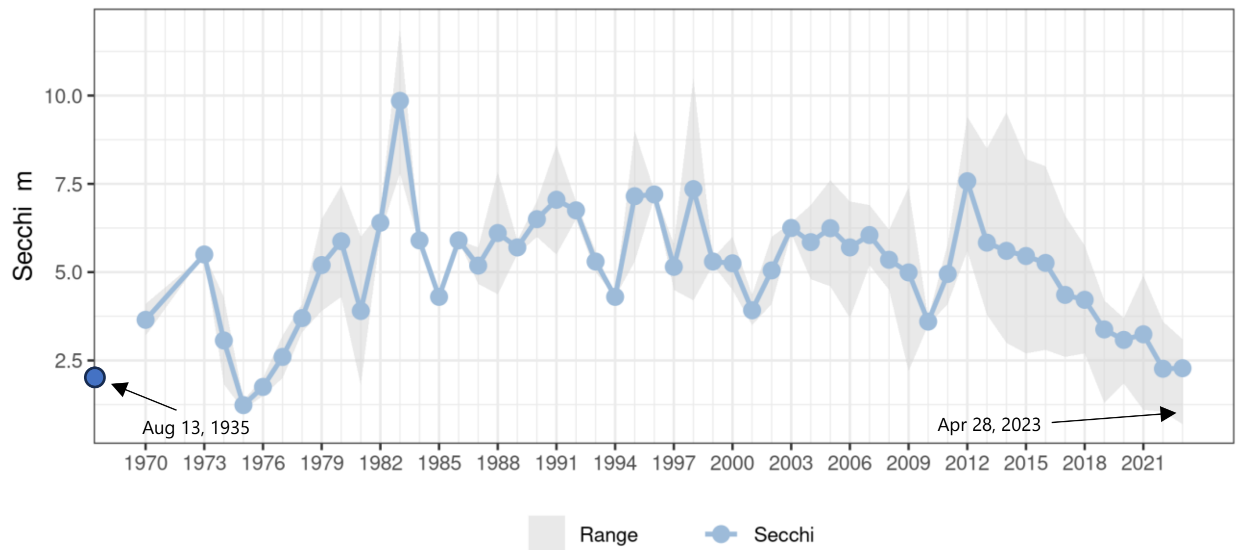

Figure 7: Secchi depth in Wood Lake from 1970-2023, ENV and LAC data

Turbidity in Wood Lake was moderate and often exceeded 1 NTU in the water column (1.53 ± 1.90 NTU from 2005-2023; Figure 8). The BC Recreational Water Quality Guideline for turbidity is 50 NTU based on aesthetics. Wood Lake average results were far below this value but far exceeded the 1 NTU drinking water guideline established by IHA. Turbidity data shows a significant increasing trend in Wood Lake, driven by recent cyanobacteria blooms (2005-2023; Mann-Kendall, $p < 0.001$, Figure 29).

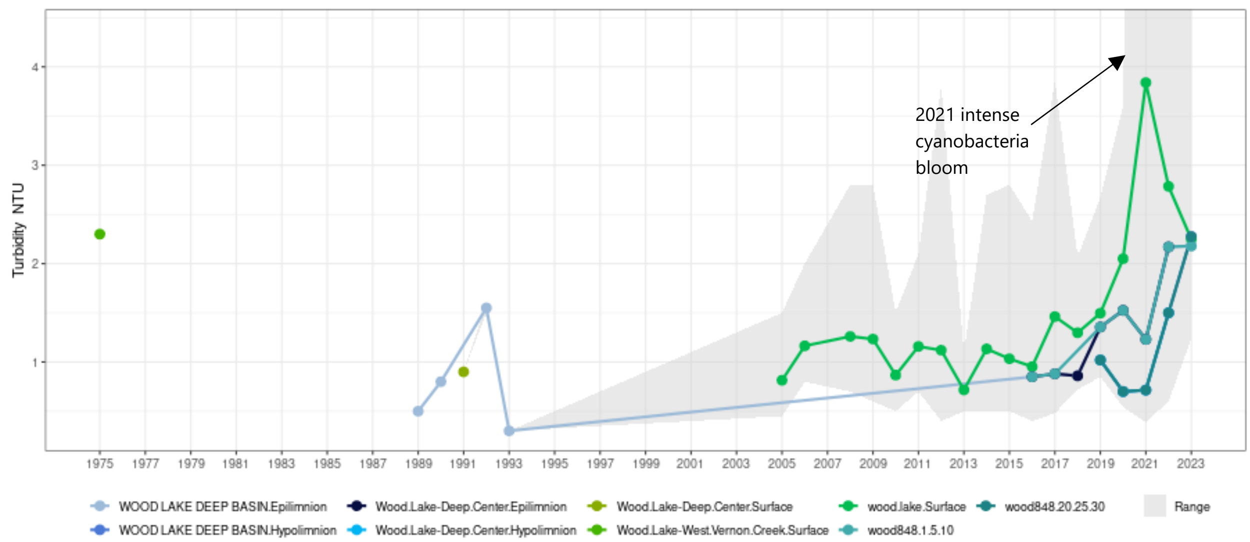

Figure 8: Turbidity in Wood Lake from 1975-2023

Note: During spring freshet, turbidity to spike to 18.2 NTU in April 2021 accounting for the large spike

Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek)

Water Temperature and Dissolved Oxygen

Wood Lake fits the warm monomictic lake category; it thermally stratifies from May to October and mixes completely from November to April (Figure 11). During mixed periods, the water column becomes uniform from the surface to the bottom sediments. During stratified periods, the deep bottom waters (hypolimnion) become isolated from the surface leading to dramatic changes in water conditions.

During the summer, Wood Lake reaches a maximum average surface temperature of 22.9 ± 1.4 °C during July and August (2005-2023, Figure 9). No significant trend in surface maximum water temperatures was detected from 2005-2023.

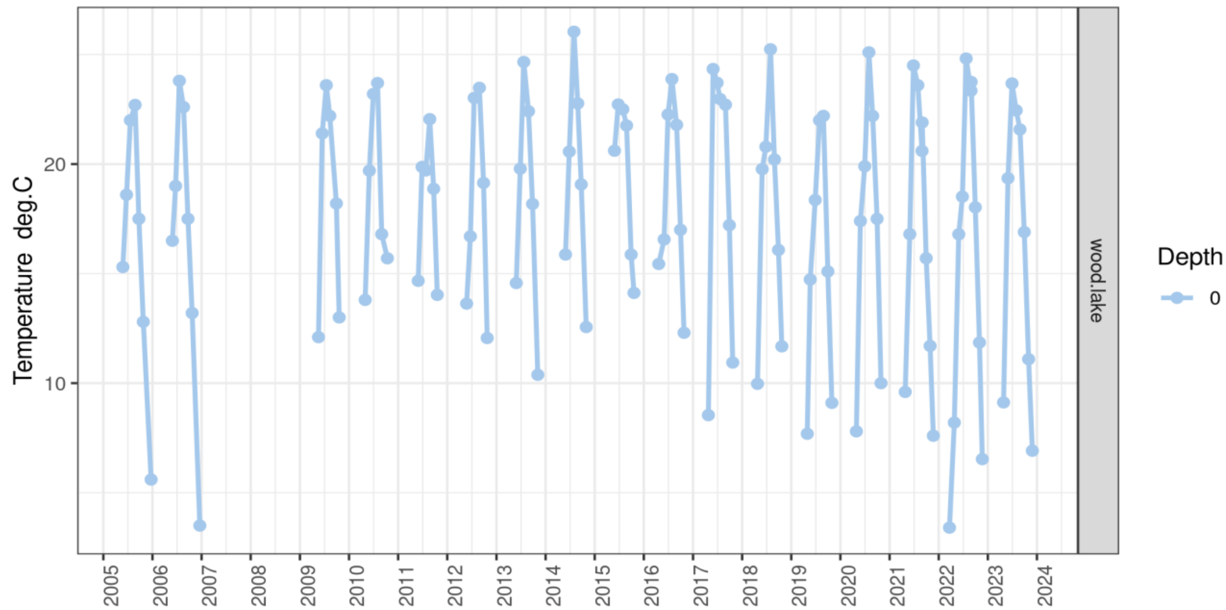

Figure 9: Surface temperature measurements in Wood Lake, 2005-2023

Late ice-off combined with early stratification in spring can lead to incomplete water column mixing and the increased risk of a temperature – dissolved oxygen squeeze. In 2011, the first documented die-off of Kokanee occurred which was attributed to a temperature-DO squeeze (lake-squeeze) in the late summer (Self & Larratt, 2016; Figure 10). Lake-squeezes occurred again during 2021 (minor), 2022, and 2023 that cumulatively led to Kokanee population declines (Figure 10; pers comm, Kristen King).

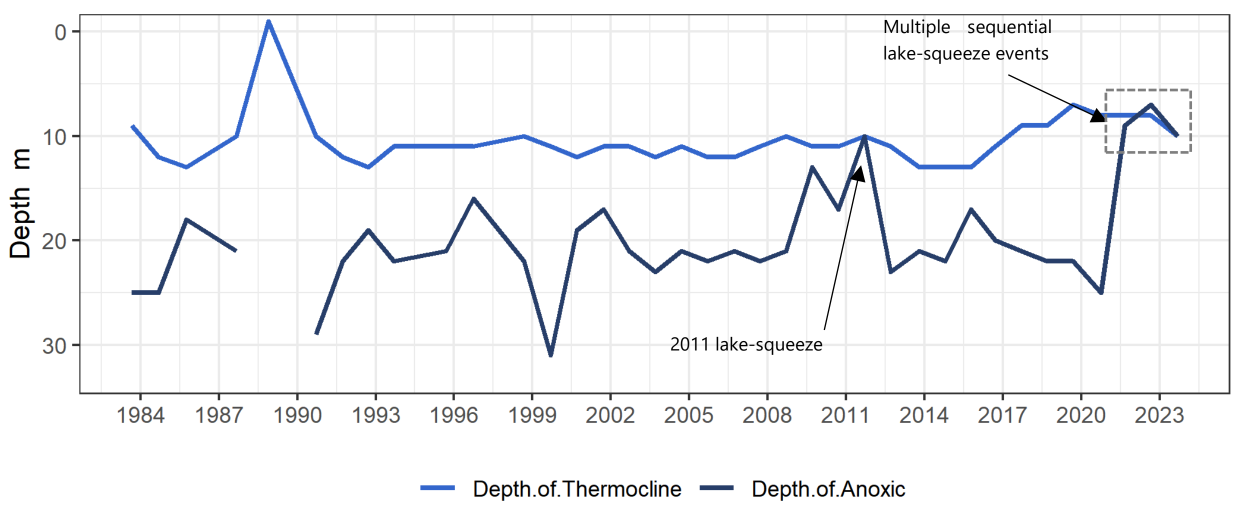

Figure 10: Thermocline vs. anoxic zone position in Wood Lake, 1983-2023

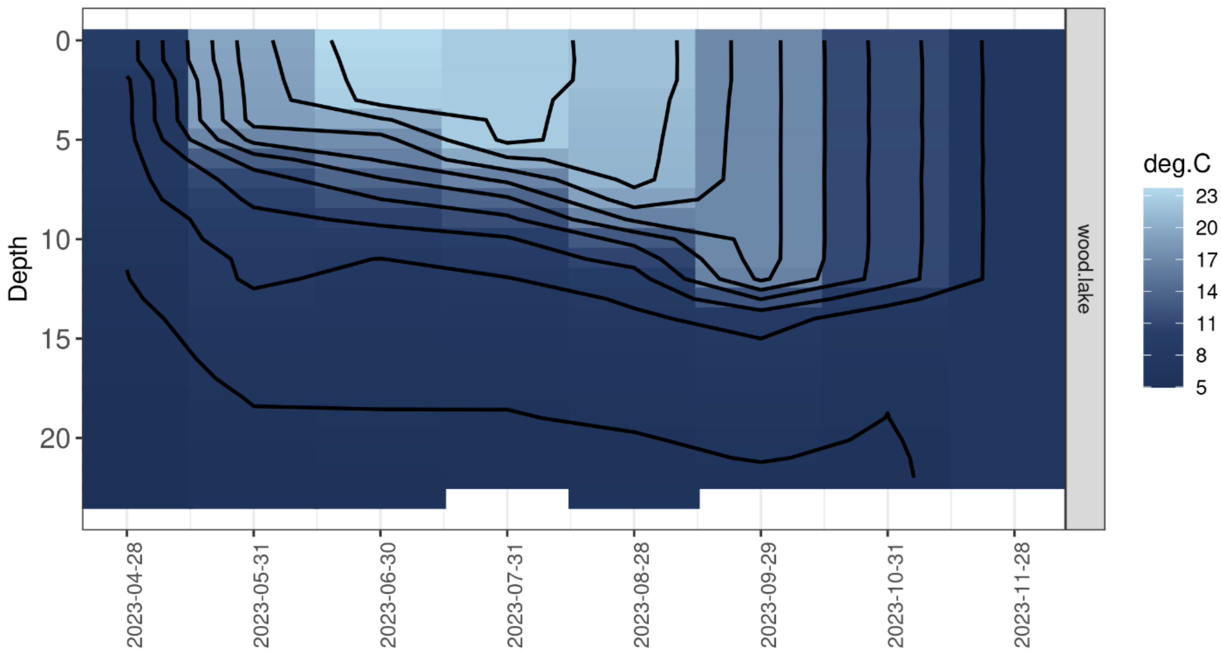

Figure 11: Temperature profile for Wood Lake during 2023

A low dissolved oxygen (DO) zone forms above the sediments in Wood Lake during late summer each year (Figure 12). Wood Lake's productivity creates considerable organic matter (algae and bacteria) that settle into the bottom waters as they decompose. The decomposition of organic material consumes dissolved oxygen from the surrounding water column, generating anoxic conditions in the hypolimnion (Figure 12). Bacteria often congregate along the density differential at the thermocline and, in recent years, this has also led to an unusual situation where the water at the thermocline was profoundly anoxic while dissolved oxygen was available above and below it (Figure 12).

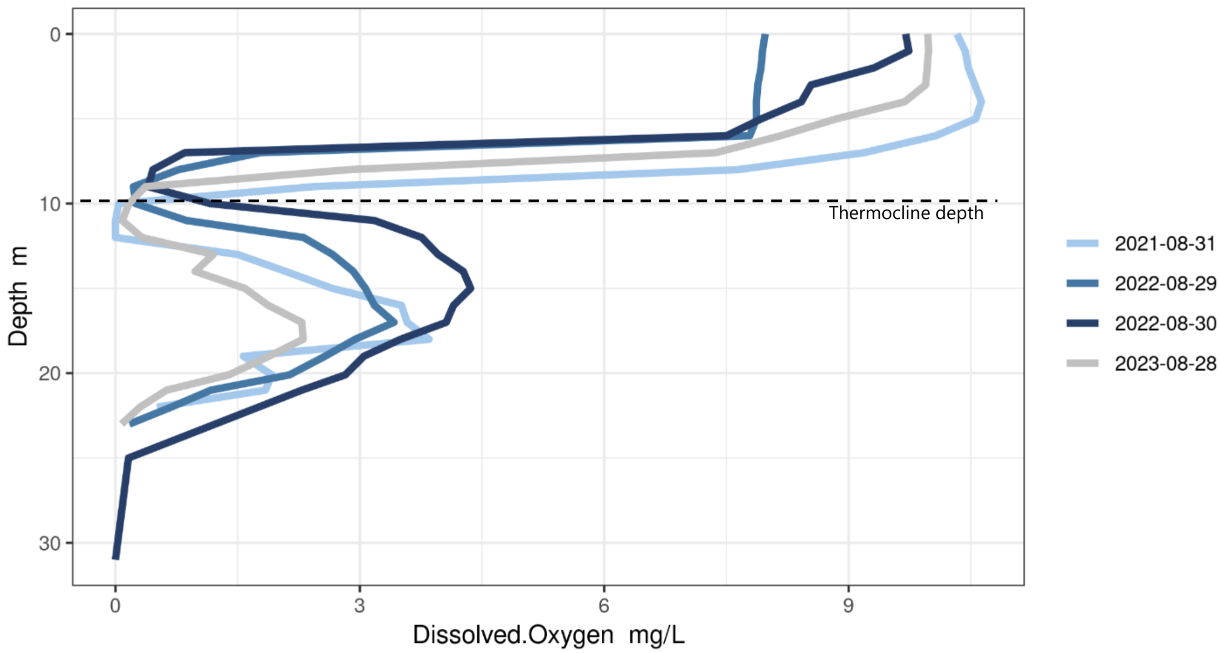

Figure 12: Dissolved oxygen profiles from Wood Lake during August, 2021-2023

Wood Lake has, in recent years, trended towards larger and more intense anoxic zones and higher surface DO, closely matching algae densities (Figure 13). Anoxic conditions in the bottom water layer affect water chemistry by mobilizing nutrients and metals out of the sediments (Figure 22, Figure 21).

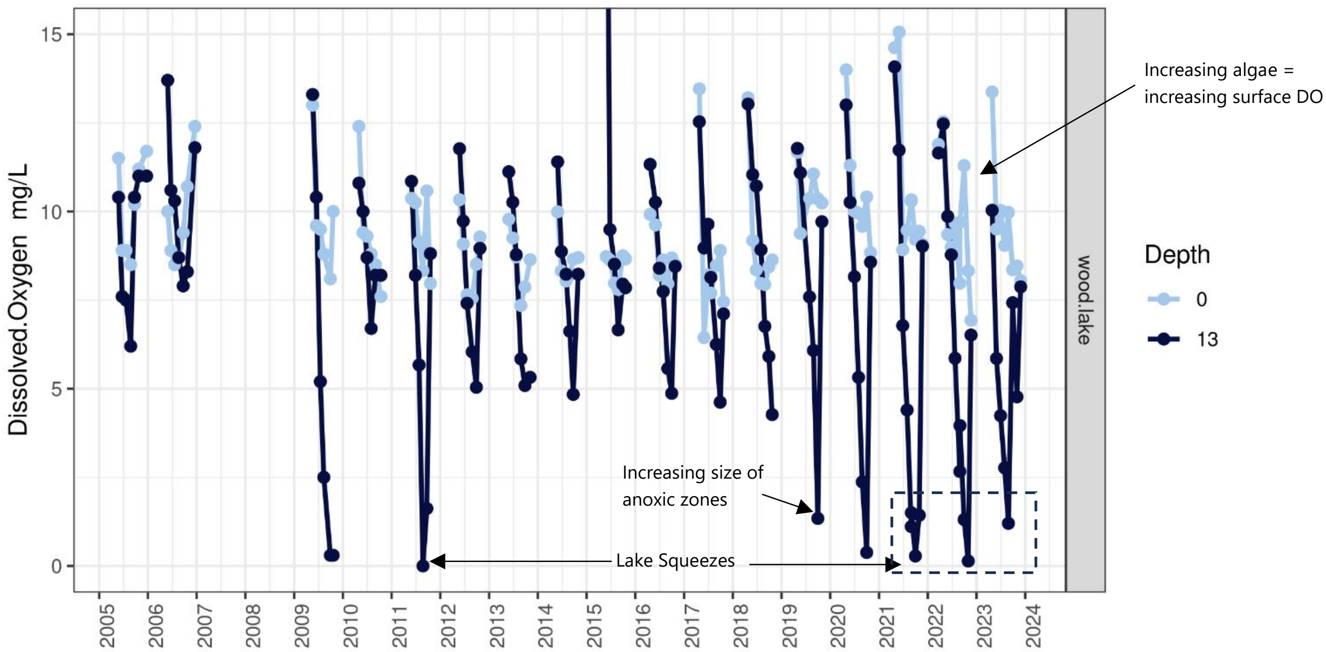

Figure 13: Dissolved oxygen in Wood Lake. 2005-2023

Inflows

Middle Vernon Creek (MVC) is the dominant surface inflow into Wood Lake, averaging 15.1 ± 9.1 Mm^3/year from 2012-2023. Discharge was measured at the inflow to Wood Lake from 1919-1921, 1969-1987, and from 2012-present. When comparing decadal time spans, the influence of the Hiram-Walker plant is clear with a dramatic increase in inflows beginning in the 1970s (Table 2, Figure 14). During those years, flows remained much higher in MVC during the summer and fall (Figure 14). A pattern of increasing maximum inflows during freshet also occurred (Table 2, Figure 14). The low number of years with data in each decade prior to 1970 reduces the strength of this pattern as it is possible that only dry years were captured but the data since 1970 still shows an increase in freshet peak consistent with a watershed that is experiencing ongoing degradation.

Table 2: Annual average inflow (m^3/year) by decade from Middle Vernon Creek into Wood Lake

Decade	# Years from decade captured	Avg Annual Inflow (m^3/year)	SD Annual Inflow (m^3/year)	Min Annual Inflow (m^3/year)	Max Annual Inflow (m^3/year)	Freshet Maximum Flow (m^3/sec)
1910	1	3,252,344	-	3,252,344	3,252,344	1.5
1920	2	5,503,896	523,881	5,133,456	5,874,336	2.1
1960	1	2,989,180	-	2,989,180	2,989,180	1.0
1970	10	13,298,903	7,721,652	1,928,867	26,561,267	7.3
1980	8	16,973,188	10,301,158	4,298,748	31,593,197	8.2
2010	7	12,542,793	5,413,938	3,770,524	18,033,399	15.9
2020	5	14,951,925	13,332,894	2,844,468	34,886,563	15.4

Note: blue shading = HW pumping

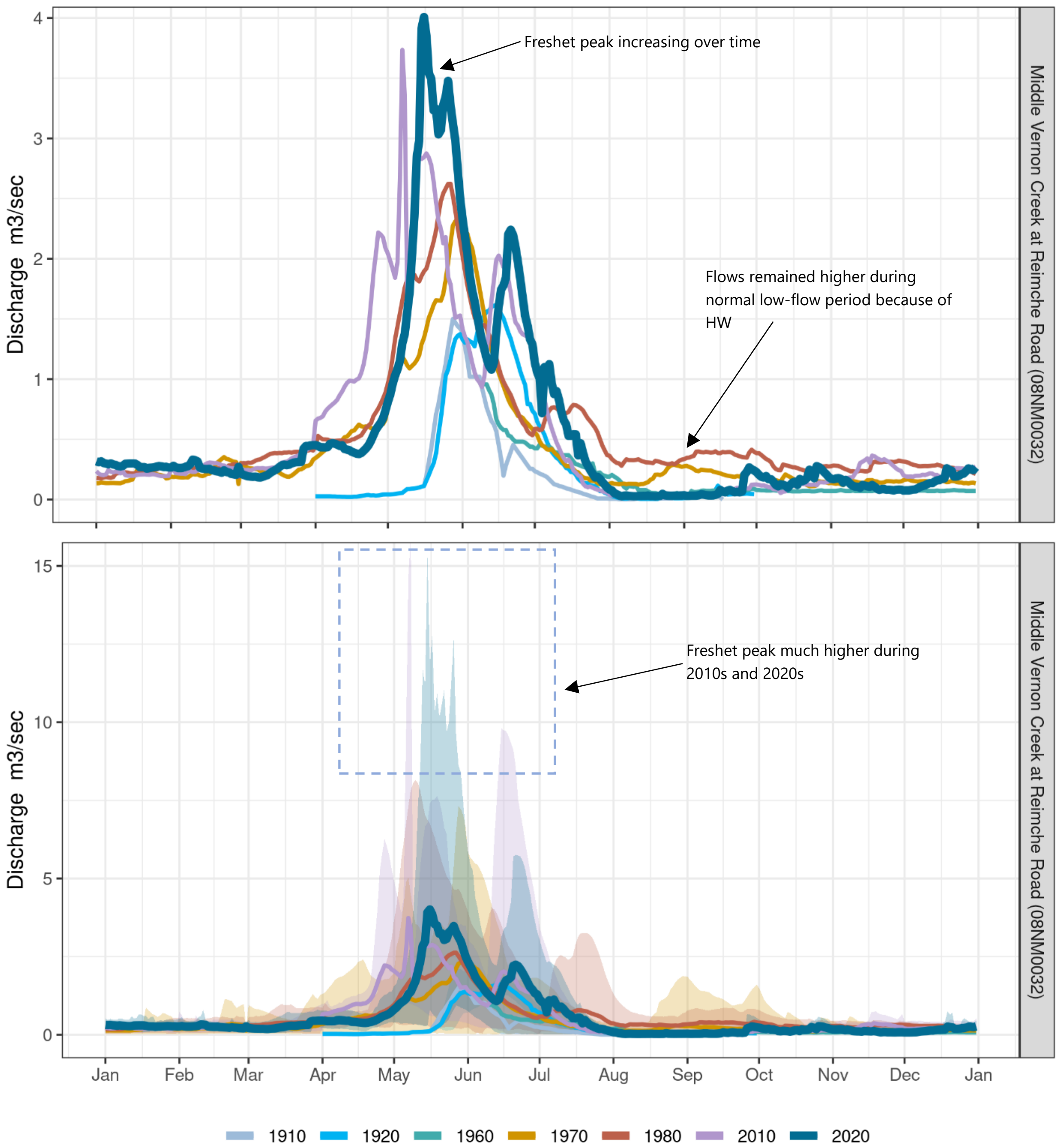

Figure 14: Average daily flow by decade in Middle Vernon Creek upstream of Wood Lake, 1919-2024

Note: Top and bottom figure show the same data with top figure zoomed in focusing on average lines while bottom figure includes ranges for each day by decade to visualize the variability

Water Chemistry

Major influences on water quality in the Okanagan Valley mainstem lakes are attributed to land clearance/logging, agriculture, and waste discharge from settlements in the areas (Canada-British Columbia Consultative Board, 1974; Stockner & Northcote, 1974)

General Water Chemistry

Chloride is naturally low in the Okanagan and its concentration can be used as a marker for human effects on a watershed. The earliest chloride data found for Wood Lake was from July 1971 at 2.8 mg/L (Jensen & Bryan, 2001). A significant increasing trend occurred across all combined data sets leading to an annual average of 20.6 mg/L during 2023 (Kalamalka Lake study data), a greater than 7x increase in 50 years (Mann-Kendall, $p<0.001$; Figure 15). Chloride accumulates in Wood Lake because of its relatively slow residency time of approximately 30 years (ILEC, n.d.). The rate of chloride increase appears to be accelerating in recent years, indicating that the total load from human effects is also increasing.

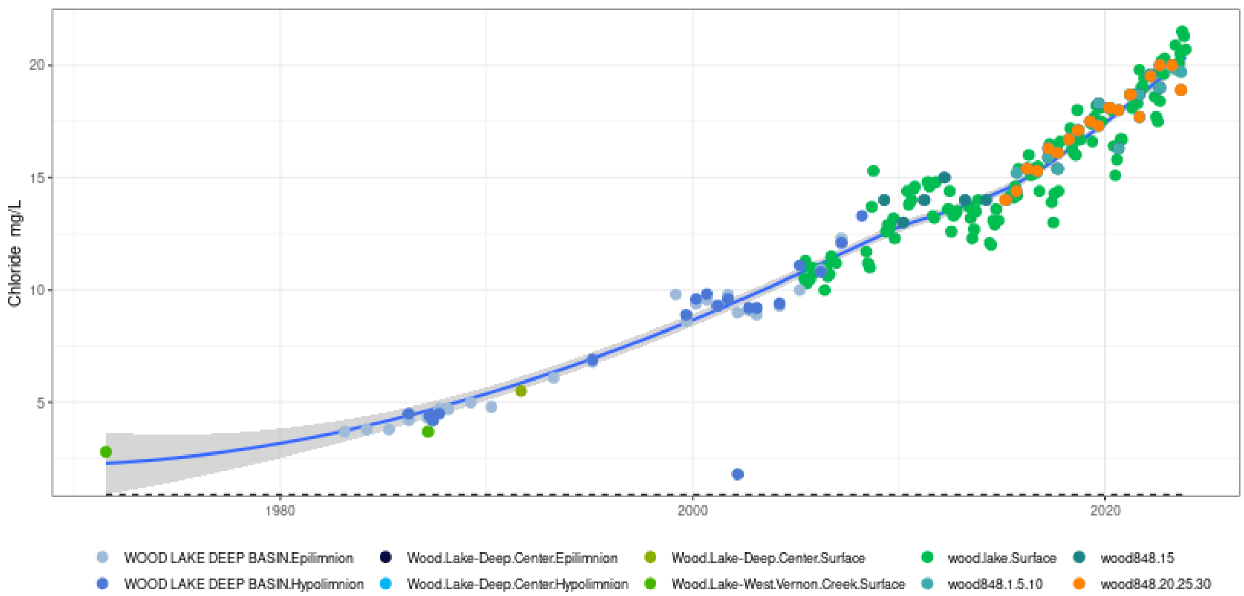

Figure 15: Chloride concentration in Wood Lake, 1971 to 2023
Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek)

Sulphate is an important parameter because of its involvement in marl precipitation. Sulphate decreased significantly over the range of available data declining from 21.9 mg/L in 1983 to 18.7 mg/L during 2023 (Mann-Kendall, $p<0.001$; Figure 16). A distinct increase in sulphate was noted during the late 2000s into 2010. This rise may relate to a corresponding increase in hardness during the same time (Figure 19).

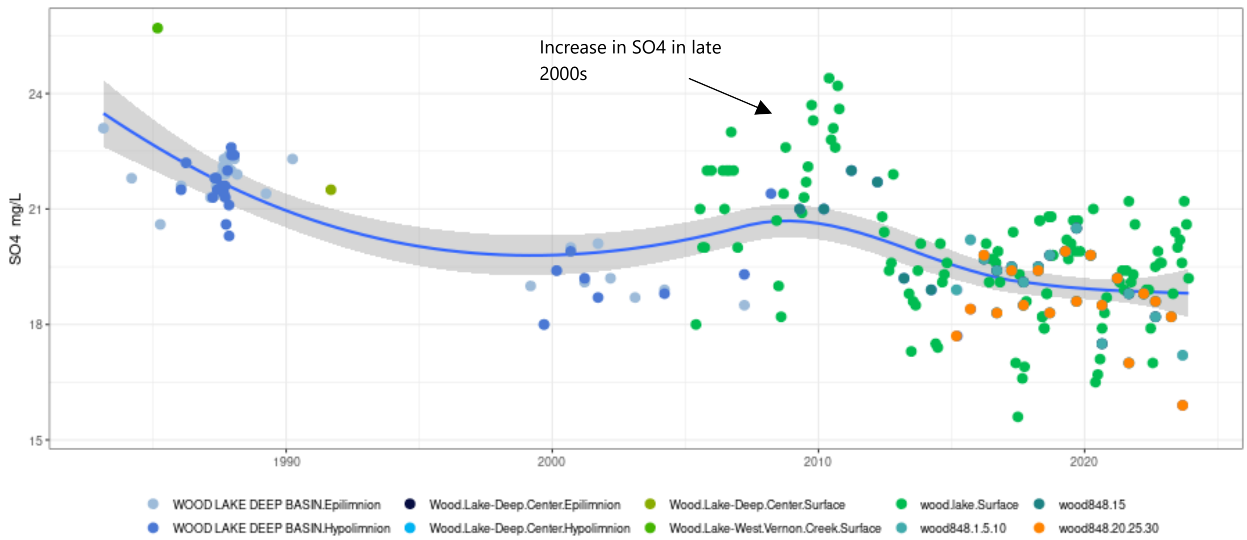

Figure 16: Sulphate concentration in Wood Lake, 1983 to 2023

Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek)

Marl

Hardwater lakes such as Kalamalka (hardness =175 ± 8 mg/L $CaCO_3$ during 2023) and Wood Lakes (hardness = 139 ± 6 mg/L $CaCO_3$ during 2023) exhibit the aquatic phenomenon called marling. Marling occurs in summer when calcium carbonate and, to a lesser degree, calcium sulphate spontaneously precipitate forming microscopic crystals (Wiik et al., 2013). These crystals scatter sunlight giving marl lakes a characteristic teal-blue color, like rock flour in glacial lakes (Figure 18). Marl is induced by a combination of factors including water temperature above 20 °C and pH above 8.5 that reduces calcium carbonate solubility.

Marling occurs sometime during July and August in Kalamalka and Wood lakes and while Kalamalka Lake marls every year, Wood Lake marls only occasionally. Wood Lake marled most recently during 2023, likely induced by increased pH from a large algae bloom that occurred at the same time. Previously recorded marl events are listed in Table 3. There was an unusual abundance of marl events during the 2010s (6 events) compared to previous decades (1 event per decade in 1980s and 1990s). The cause of this high marl frequency is not firmly established but may relate to higher water hardness observed during the 2010s (Figure 19). Previous research identified a marked increase in the accumulation of marl in sediment cores in the 1940s (I.R. Walker, E.D. Reavie, S. Palmer, 1993). This trend was attributed to increased evaporation because of water diversion from irrigation.

A significant increasing trend in calcium concentration in Wood Lake occurred from 1972-2023 (Mann-Kendall, $p<0.001$; Figure 17). This study identified a data gap in the historical data with missing long-term hardness data and a lack of recorded marl events prior to 1987. While it is impossible to look back without sample data, it is important to ensure these events are recorded moving forward (see Table 3).

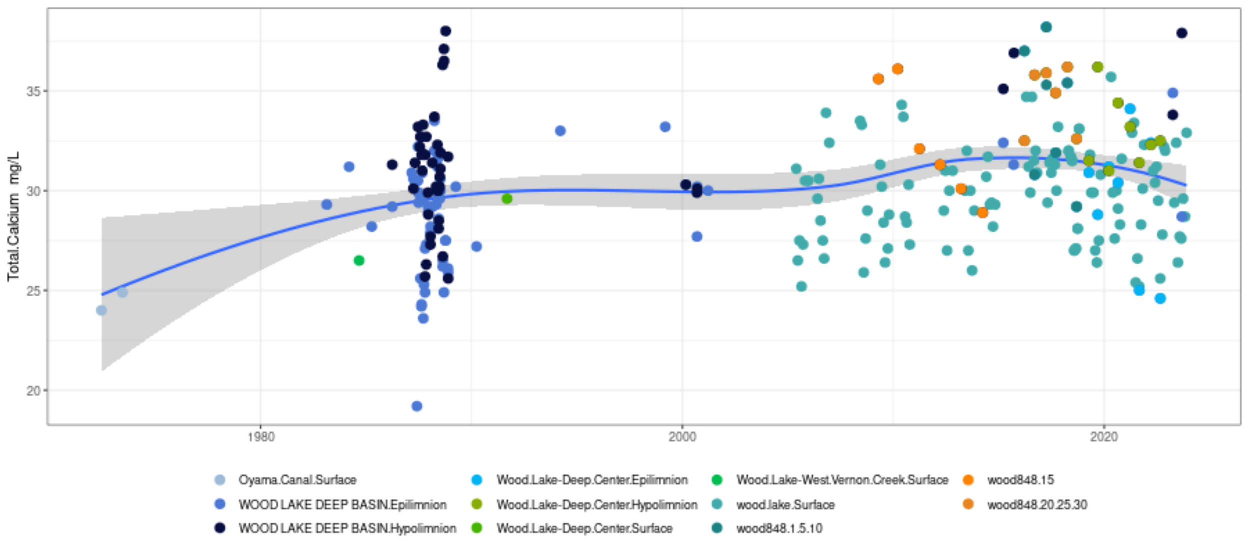

Figure 17: Total calcium concentration in Wood Lake, 1972-2023

Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848, Wood Lake Deep Basin); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek);

Figure 18: Wood Lake experiencing marl during 2023 (top) compared to without marl during 2022 (bottom)

Table 3: Years with recorded marl events in Wood Lake

Year	Researchers
1980	(Gray & Jasper, 1982)
1987?	Anecdotal
1994?	Anecdotal
2010	LAC
2011	LAC
2014	LAC
2015	LAC: Chris Young 2016
2016	LAC
2019	LAC
2023	LAC

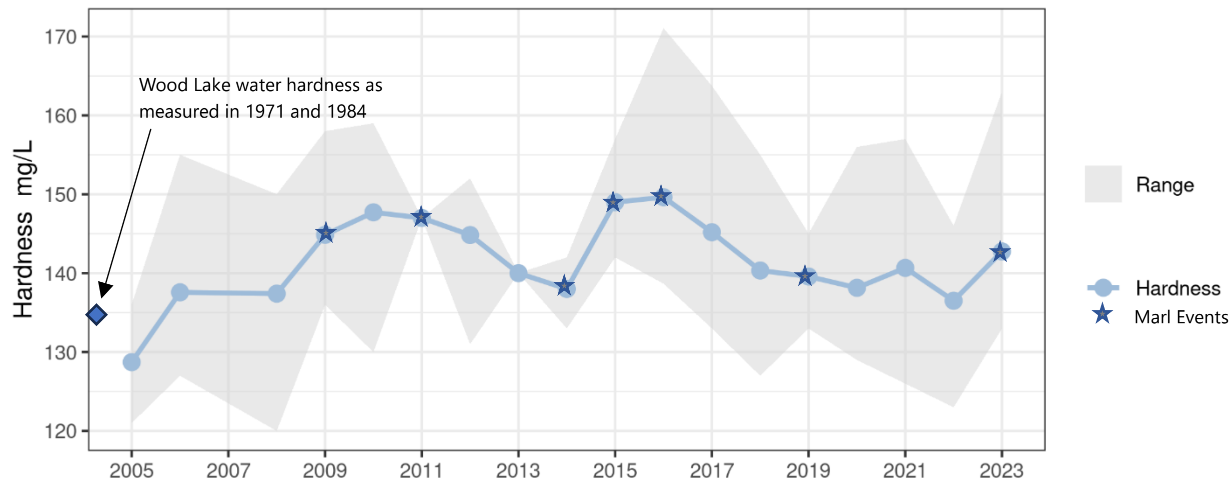

Figure 19: Water hardness in Wood Lake from 2005-2023

Note: Data from LAC and ENV sample sites combined in this figure; Source for 1971 and 1984 data: Jensen & Bryan, 2001

Nutrients

Wood Lake is classified as a meso-eutrophic lake based on the current levels of nutrients, productivity, and water clarity (Table 4, Figure 20). Historically, Wood Lake's nutrient regime was classified as oligo-mesotrophic (Walker et al., 1993). Since regular sampling began in the 1970s, Wood Lake has shifted between mesotrophic, meso-eutrophic, and rarely, eutrophic (Figure 20). A declining trend in eutrophication (improved water quality) occurred from the 1970s through the 1990s that led to a decade of mesotrophic conditions. This aligned with pumping by the Hiram-Walker Distillery (1971-1992) and the introduction of improved wastewater treatment for District of Lake Country (late 1990s). However, there was an increasing trend towards greater eutrophication in Wood Lake since the mid-2000s and 2022 was the first year rated eutrophic since the 1970s. High phosphorus concentrations, a consequence of internal nutrient loading, push Wood Lake towards eutrophication but overall productivity is limited by other factors such as available nitrogen. Nutrient loading during the 1970s was higher for phosphorus than the 2010s (B.C. Research, 1974; Self & Larratt, 2016, Table 5)

Table 4: Lake Classification by Trophic Status Indicators

Trophic Status (score)	Total P µg/L	Total N µg/L	Chlorophyll-a µg/L	Secchi m
Ultra-oligotrophic (0)	<4	<75	<0.95	>10
Oligotrophic (1)	4 –10	75 –100	1 – 2	6 – 10
Mesotrophic (2)	10 – 20	100 – 500	2 – 5	3 – 6
Meso-eutrophic (3)	20 – 35	500 – 900	5 – 7	2 – 3
Eutrophic (4)	35 – 100	900 – 1500	7 –25	1 – 2
Hyper-eutrophic (5)	>100	>1500	>25	<1

Source: (Self & Larratt, 2020b); green shading marks median range for each parameter in Wood Lake, 1970-2023

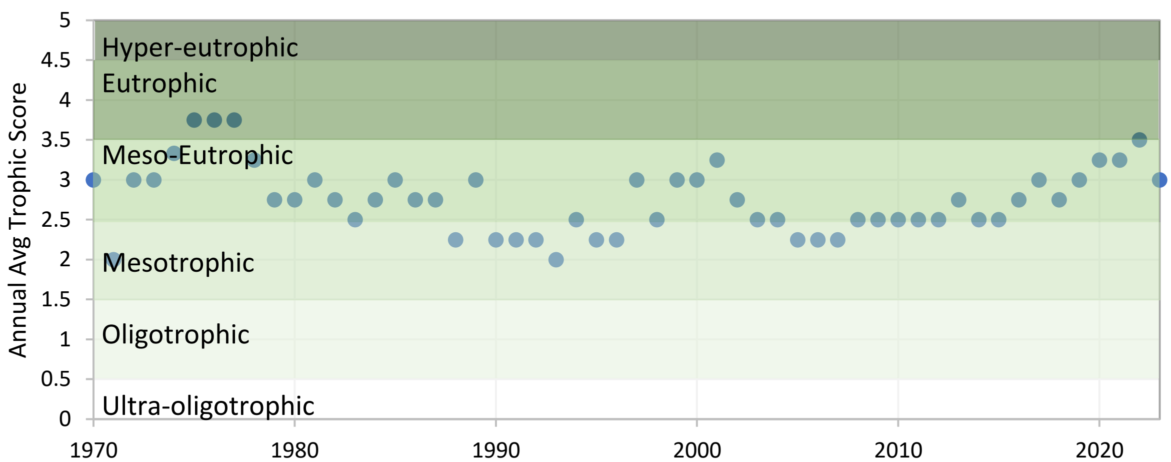

Figure 20: Annual average trophic score for Wood Lake, 1970-2023

Note: Ranks displayed represent mean of each parameter's rank per year using the scores in Table 4

Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848, Wood Lake Deep Basin); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek);

Table 5: Nutrient loading estimates from Vernon Creek into Wood Lake

Param	1972	1973	2013	2014	2015
TN	16,103	8,346	20,357	15,422	6,499
TP	3,706	898	1,747	1,435	277
TDP	558	331	728	527	82

Sources: (British Columbia Water Resources Service, 1974; Self & Larratt, 2016)

All lakes accumulate nutrients from watershed activities in continuously accumulating sediment layers. Wood Lake experiences intense internal nutrient loading, or recycling of nutrients within the lake that originated in the watershed. Internal loading of nutrients accelerates when anoxic water overlays the sediment. Redox conditions shift and some phosphorus becomes mobilized out of the sediments into the water column. During the stratified periods in Wood Lake, phosphorus accumulates in the hypolimnion leading to very high concentrations by the end of the summer (Figure 21). Nutrients mix upwards during fall overturn, routinely triggering late summer or even winter algae blooms (Figure 28). Most recently, a winter cyanobacteria bloom occurred during December 2023-January 2024 (Figure 31). Internal loading is the primary source of orthophosphate in Wood Lake; orthophosphate is a highly bioavailable form of phosphorus that fuels surface algae blooms (Self & Larratt, 2016).

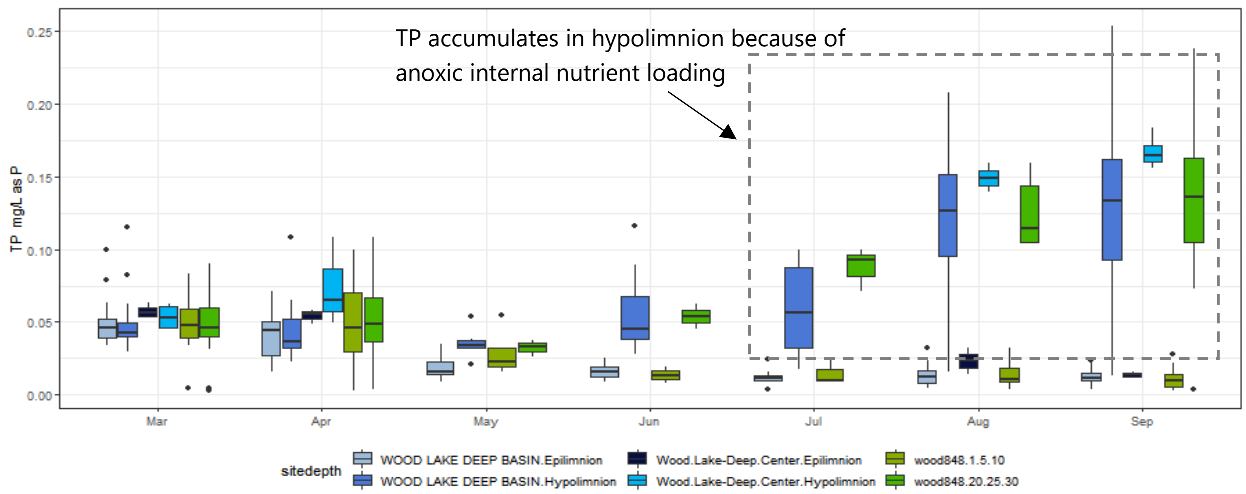

Figure 21: Total phosphorus concentration in Wood Lake by month, 1970-2023

Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848, Wood Lake Deep Basin); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek);

A declining trend in total phosphorus (TP) occurred from the 1970s through the 1990s that aligned with the increased flushing caused by the Hiram Walker discharge upstream and improved wastewater treatment for District of Lake Country (Mann-Kendall, $p<0.001$; Figure 22). The trend reversed in the early 2000s with an increasing TP trend through 2023 (Mann-Kendall, $p<0.001$; Figure 22). TP averaged 0.046 ± 0.029 mg/L as P during 2023 in the epilimnion, the highest annual average since 1983 (Figure 22). Total dissolved phosphorus (TDP) behaved like TP in the hypolimnion but consumption by algae affected the epilimnion TDP values and masked the trends. TDP is rapidly consumed by algae in Wood Lake and an increase in TDP loading is therefore likely to manifest as increased algae production; this relationship was observed through increasing chlorophyll-a and algae densities (Figure 27, Figure 27, Figure 29).

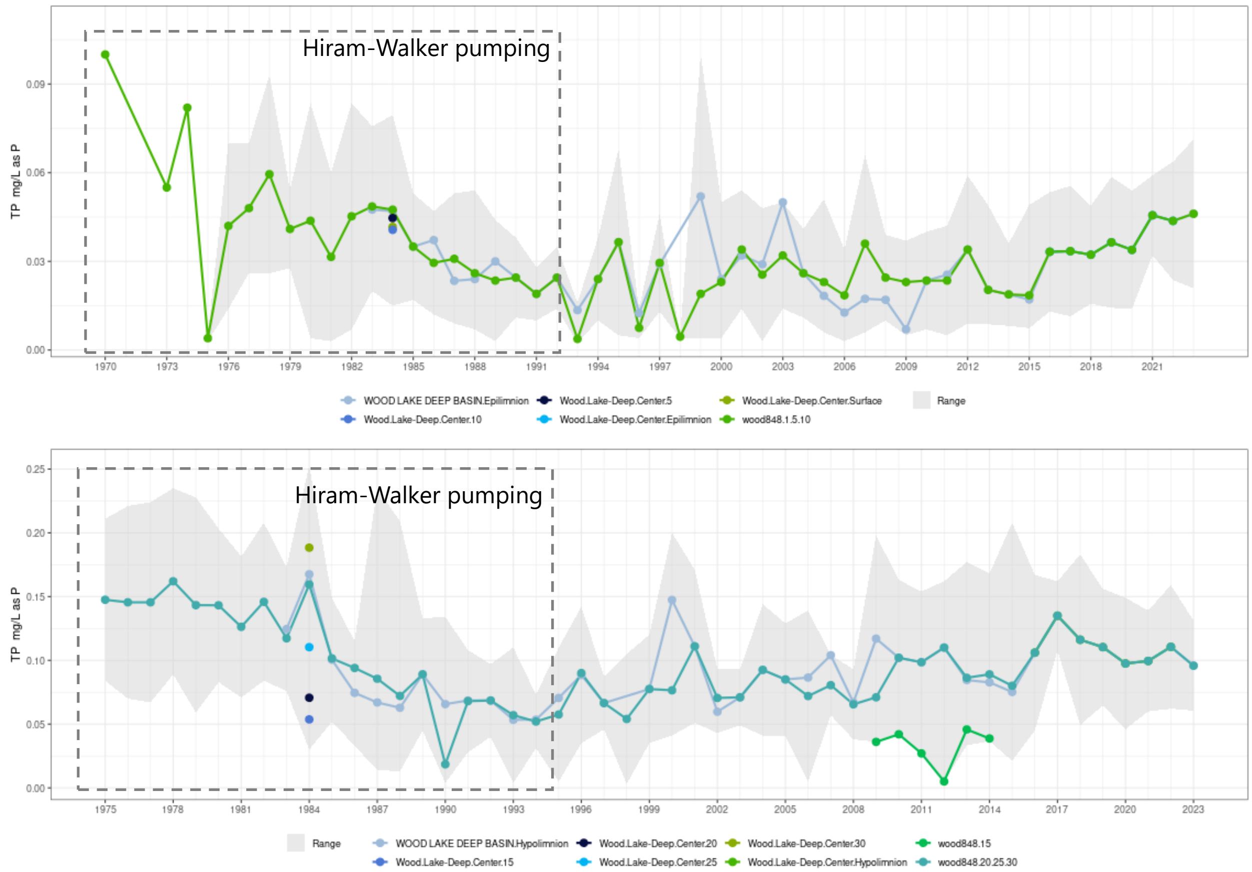

Figure 22: Total Phosphorus (TP) in Wood Lake epilimnion (top) and hypolimnion (bottom), 1975-2023

Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848, Wood Lake Deep Basin); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek);

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 2009-2023 in both the epilimnion and hypolimnion (Mann-Kendall, $p \leq 0.01$). Although there was an period of stability from 2012-2018, 2023 had the highest annual average surface TN since 1978 (2023 = 0.665 ± 0.120 mg/L). The four highest surface TN averages since 1981 occurred annually from 2020-2023 (increasing averages year-after-year). Hypolimnion TN was the third highest since 1981 in 2023 (after 2021 and 2012; 2023 average = 0.725 ± 0.077 mg/L). The oldest available TN measurement was from the 1935 study and measured only 0.223 mg/L, 3 times lower than current concentrations.

In most years, dissolved inorganic nitrogen was rapidly consumed by algae in Wood Lake, resulting in inorganic nitrogen limitation in the surface water (Figure 24). As with phosphorus, nitrogen accumulates in the bottom water during the stratified period because of anoxic nutrient recycling. Ammonia becomes the dominant form of inorganic nitrogen each summer in the hypolimnion of Wood Lake. Surface nitrogen limitation favours the proliferation of cyanobacteria because some species can utilize atmospheric nitrogen leading to Wood Lakes common cyanobacteria blooms (Figure 29).

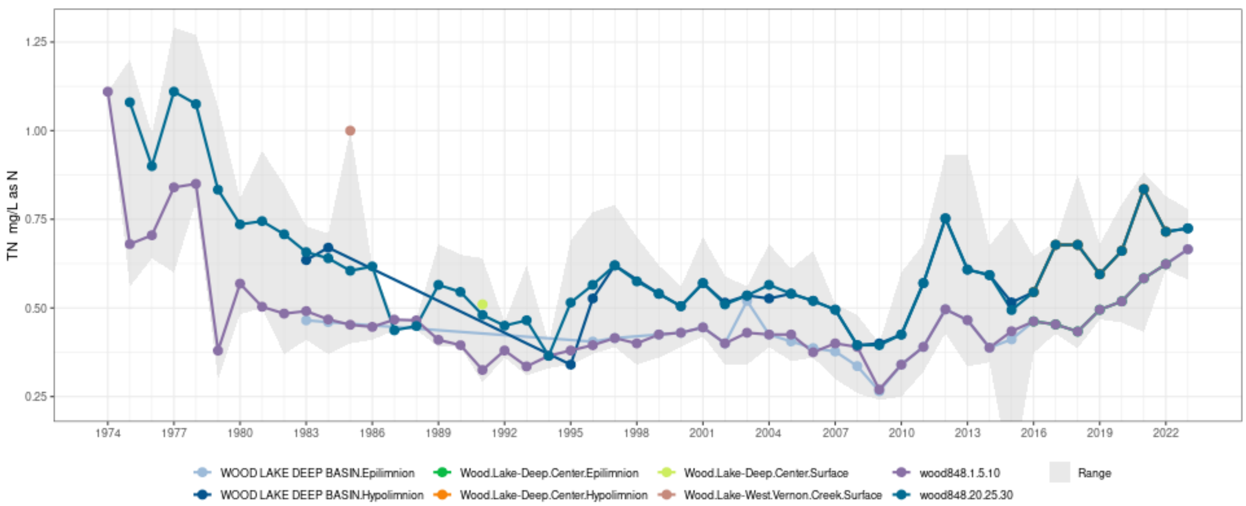

Figure 23: Total nitrogen in Wood Lake, 1974-2023

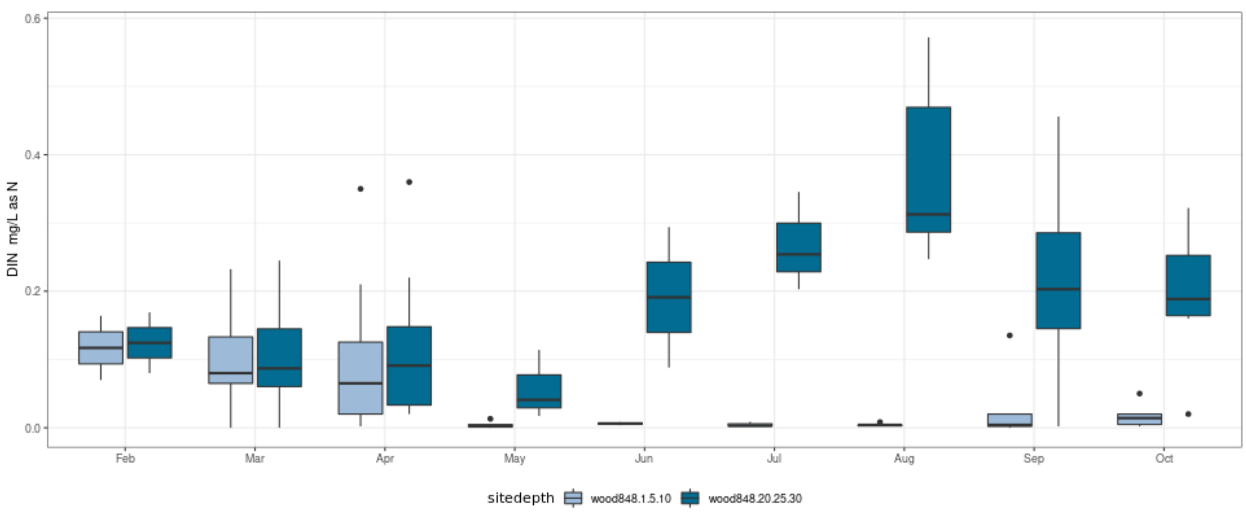

Figure 24: Dissolved inorganic nitrogen in Wood Lake by month, 1970-2023

Duck (Ellison) Lake Comparison

Duck Lake (called Ellison Lake in BC EMS database), is a small, shallow, and very productive lake located upstream of Wood Lake and it feeds Middle Vernon Creek (MVC). The condition of Duck Lake affects Wood Lake directly. The Hiram-Walker distillery discharged its used cooling water into Vernon Creek upstream of Duck Lake, greatly increasing the theoretical flushing rate through Duck Lake while it operated (1971-1992). However, research conducted at the time on the behavior of the Vernon Creek plume showed that it routinely short-circuited Duck Lake and flowed along the north shore directly into MVC (British Columbia Water Resources Service, 1974). This would have reduced flushing of nutrients from Duck Lake into Wood Lake.

TN and TP were 27% and 50% higher, respectively, in Duck Lake compared to the epilimnion samples of Wood Lake across the historical dataset (1969-2023; KW-Tests, $p<0.001$, Figure 25). However, nutrient recycling within the anoxic zone of Wood Lake leads to significantly higher TP in the hypolimnion of Wood Lake than Duck Lake (63% higher in Wood Lake). Nutrients from Duck Lake that reach Wood Lake fuel algae growth which transports those nutrients to the sediment where they can then be recycle within Wood Lake. TN conditions were stable with strong interannual variation in Duck Lake over the past 20 years while TP showed a significant increasing trend since 2008 (Mann-Kendall, $p=0.002$).

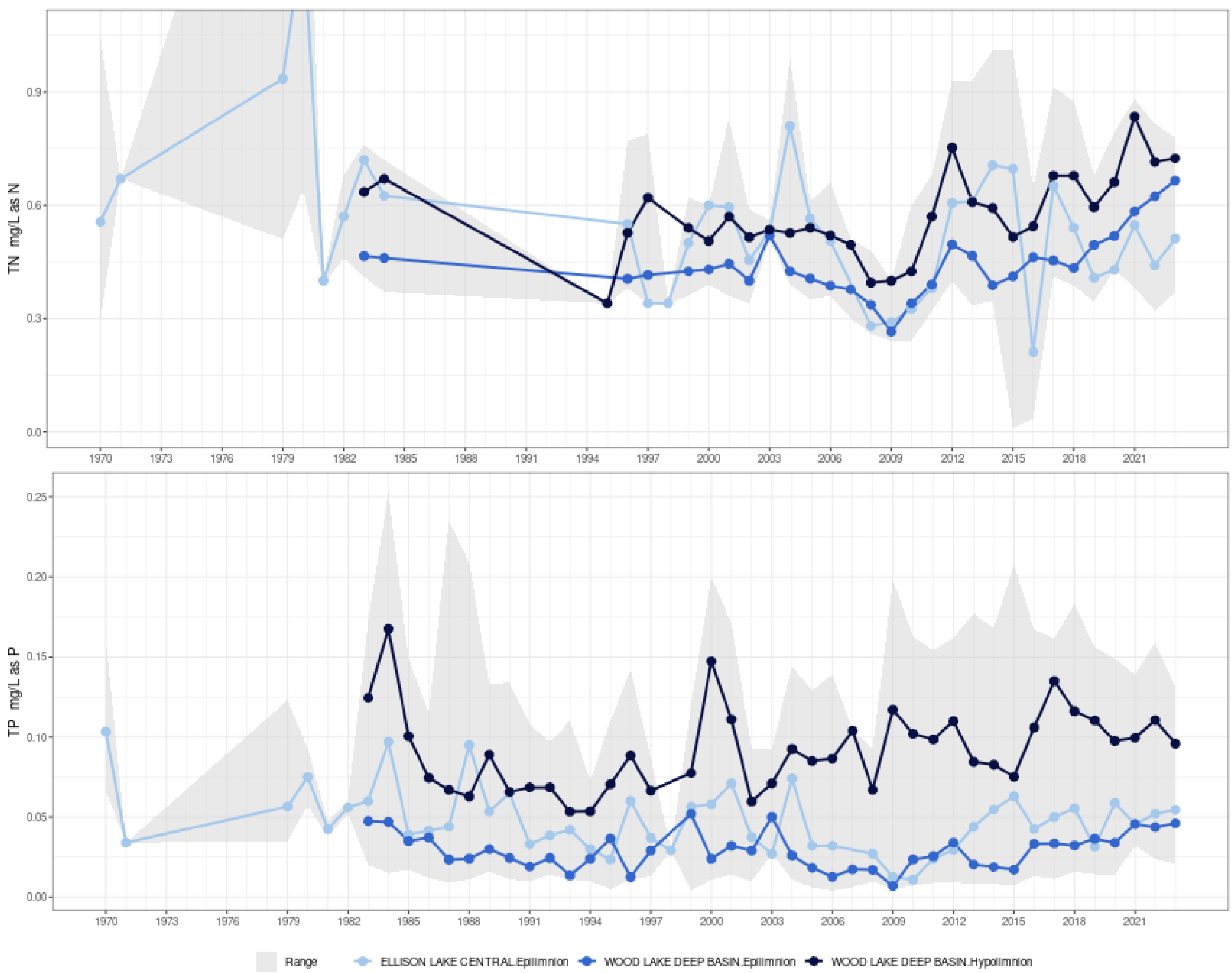

Figure 25: Total nitrogen (top) and total phosphorus (bottom) in Duck and Wood Lakes, 1970-2023

Total nutrients were significantly higher in Duck Lake but, dissolved inorganic nitrogen (DIN = nitrate + ammonia) was higher in Wood Lake surface waters (KW-Test, $p<0.001$; Figure 26). A declining trend in ammonia occurred in Duck Lake with the highest concentrations observed during the 1980s followed a clear decline into the late- 1990s (Mann-Kendall, $p=0.006$). TDP was quite similar between the two lakes and was stable from 1979-2023 (Figure 26).

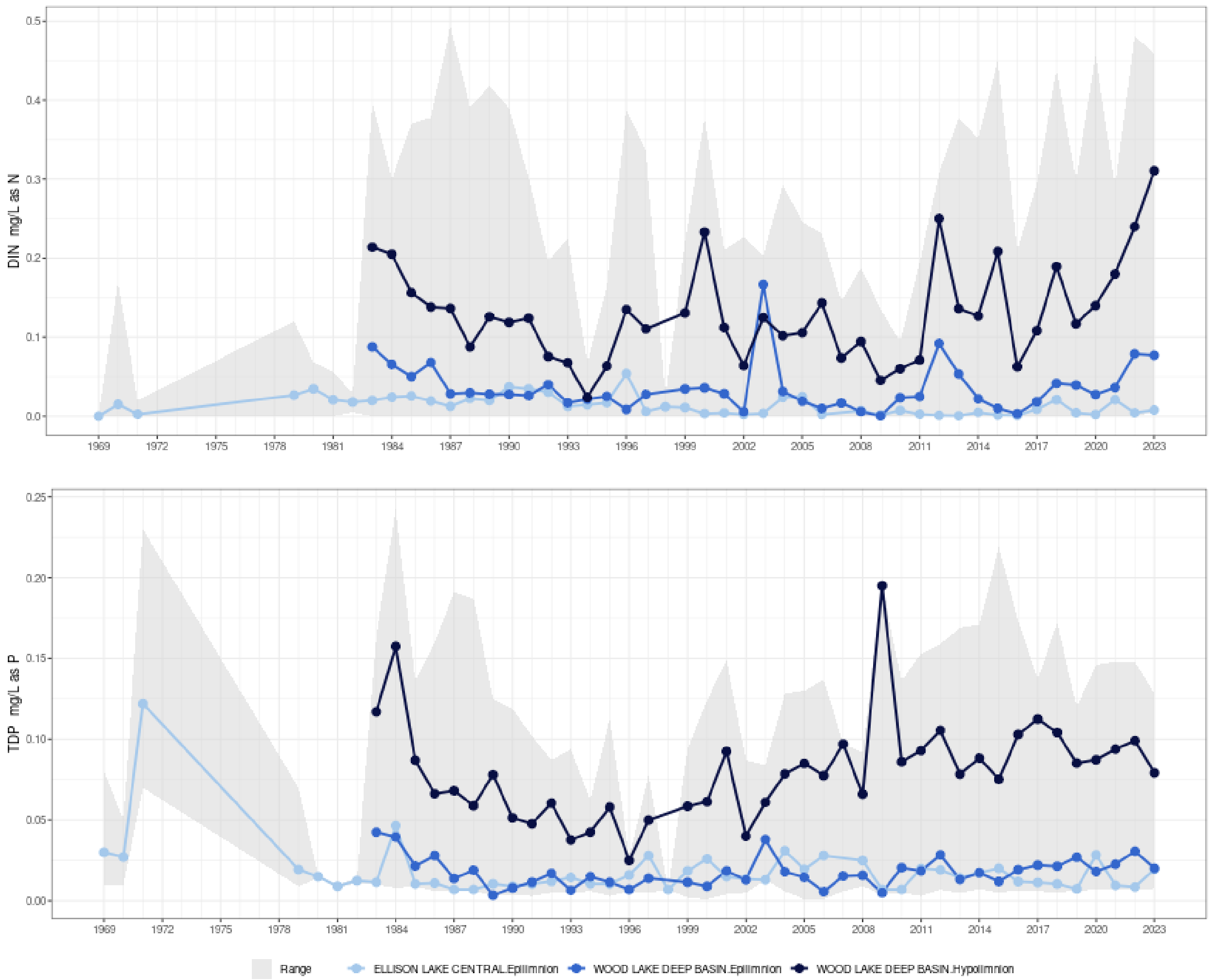

Figure 26: Dissolved inorganic nitrogen (DIN) and total dissolved phosphorus (TDP) in Duck and Wood lakes, 1969-2023

Algae & Bacteria

Since the mid-2000's algae blooms frequency has increased (Pearson's R = 0.52 for annual average TP vs chlorophyll-a at the Wood848 sample site since 2000; Figure 27). This led to large nuisance blooms during some years and a positive feedback loop where decomposition of large algae blooms leads to larger anoxic zones and greater nutrient recycling that fuels larger blooms the following year, repeating the cycle.

Chlorophyll-a

Chlorophyll-a (chl-a) is a major photosynthetic pigment common in many algal types and excessive algal growth leads to higher chl-a concentrations. Wood Lakes surface water averaged 5.7 ± 6.1 µg/L in chl-a from 2005-2023 (7.9 ± 6.0 µg/L in 2023). Chl-a concentrations significantly increased in the surface water of Wood Lake over the past 10 years (Mann-Kendall, p <0.001; Figure 27).

Spikes in chl-a are associated with major bloom events (Figure 27, Figure 29). Climatic variation also affects chl-a; for example, the wet years of the late 1990s led to several years of very high chl-a. A cyanobacteria bloom with >50 µg/L chlorophyll-a can have a cell count approaching 100,000 cells/mL and toxicity to animals drinking the water would be probable (World Health Organization, 1999).

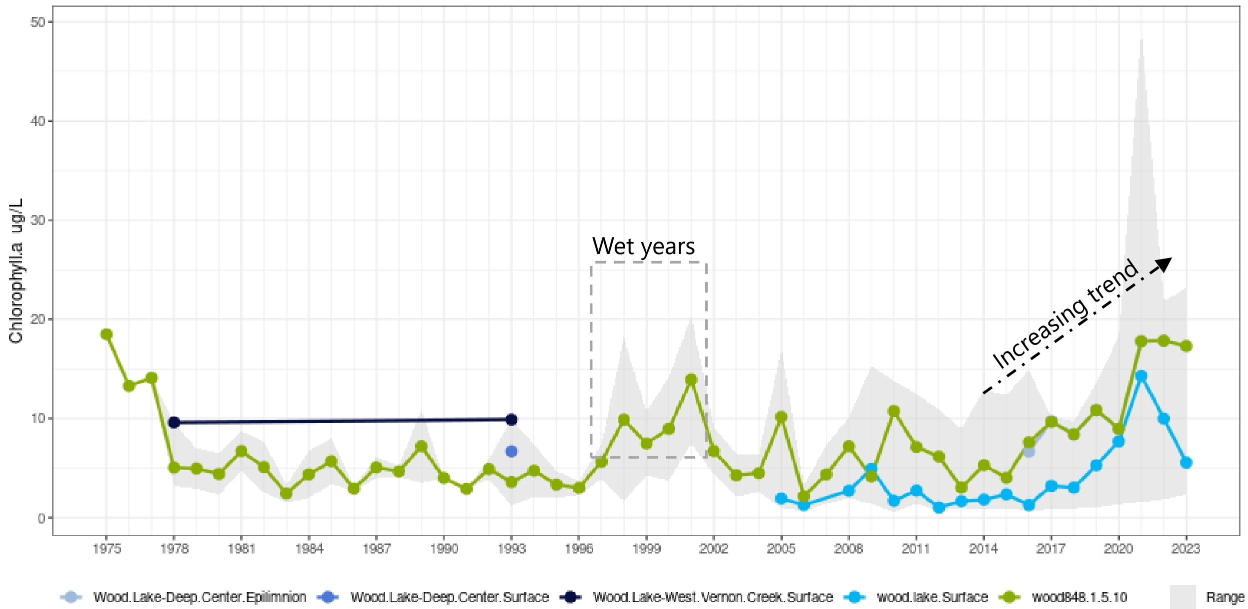

Figure 27: Chlorophyll-a concentrations in Wood Lake, 1975-2023

Chlorophyll-a concentrations demonstrate seasonality in Wood Lake. Each spring algae production increases as day length and water temperature increase, leading to a spring bloom. This bloom is typically dominated by diatoms (Figure 29). Diatom cells are orders of magnitude larger than cyanobacteria cells and produce much more chl-a per cell. This leads to an apparent mismatch highlighted in Figure 28 and Figure 29 where chl-a is very high in the spring, but cell densities appear relatively low. Despite the apparent mismatch, the spring biomass produced is considerable and diatoms will compete against cyanobacteria for nutrients, restricting what is available later in the summer. Cyanobacteria proliferate in Wood Lake during the late summer leading to very high cell densities and a second peak in the chl-a distribution (Figure 28, Figure 29). Nutrient accumulation in the hypolimnion during years with intense anoxic zones, such as 2023, can trigger winter cyanobacteria blooms after the lake mixes in November and those nutrients become available to algae (Figure 31).

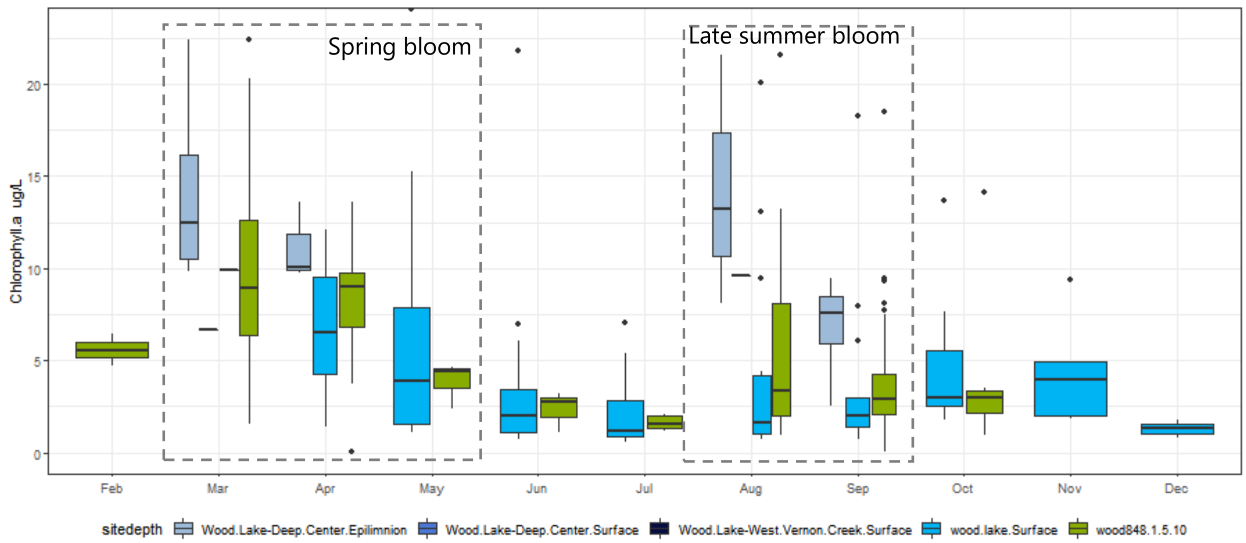

Figure 28: Chlorophyll-a concentration in Wood Lake by month, 1975-2023

Sources: Kalamalka Lake study (wood.lake); BC EMS (wood848, Wood Lake Deep Basin); Jensen & Bryan, 2001 (Wood.Lake Deep, Wood.Lake West Vernon Creek);

Algae Abundance

Wood Lake total cell densities increased significantly since 2005 (Mann-Kendall, $p < 0.001$). This trend is because of increasing trends in diatoms, green algae, cyanobacteria, and flagellate concentrations over the same time frame (Mann-Kendall trend tests), although the increase in cyanobacteria abundance was the largest contributor (Figure 29).

In 2023, the average total cell density for Wood Lake was 8,161 ± 7,328 cells/mL with 5,370 ± 5,643 cell/mL of cyanobacteria. The highest count recorded was 14,930 cells on September 29, 2023. During six of the eight 2023 sampling events, cyanobacteria concentrations exceeded the WHO alert threshold of 2000 cells/mL (Figure 29). Only during the blooms of 2011 and 2021 did cyanobacteria densities exceed the Alert Level 2 threshold (>15,000 cells/mL, Appendix 5: Cyanobacteria Alert Level Boundaries, Figure 30).

Cyanobacteria common to Wood Lake include the bloom-forming genera *Anabaena, Anacystis, and Aphanizomenon* and they can produce a range of cyanotoxins (Appendix 4: Common cyanobacteria in Wood Lake). The other common cyanobacteria taxa, *Planktolyngbya* and *Gomphosphaeria,* while capable of producing cyanotoxins, are not noted for toxicity. The oldest algae taxonomy results reported that *Aphanizomenon sp.* was dominant and forming a nuisance surface bloom on August 13, 1935 (Clemens et al. 1939). Risk of cyanobacterial toxicity in Wood Lake is therefore dependent upon the species present and cell density (Figure 30); 2023 productivity included all three of the problematic taxa: *Anabaena, Anacystis, and Aphanizomenon*. 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.

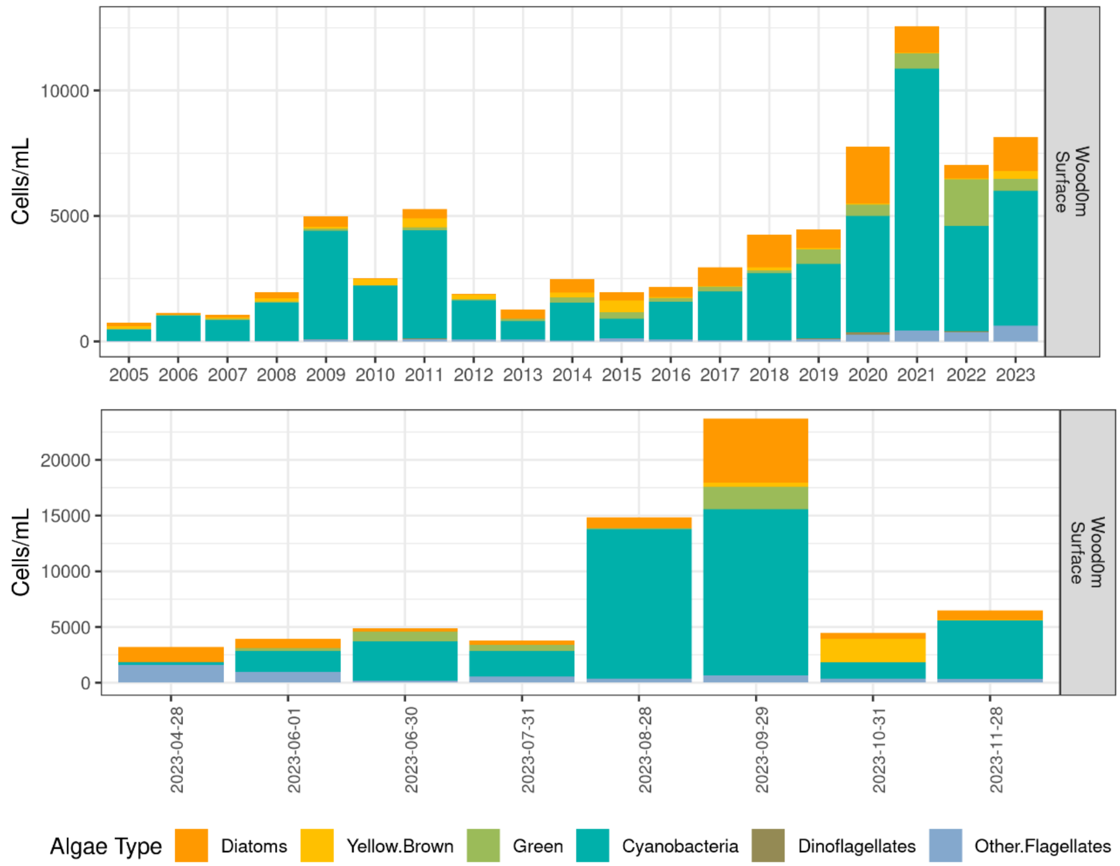

Figure 29: Wood Lake annual average surface algae counts from 2005-2023 (top) and 2023 counts only (bottom)

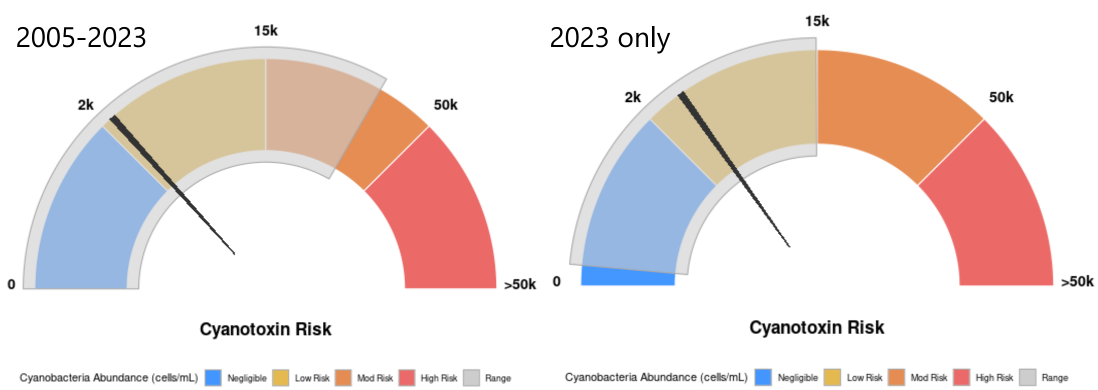

Figure 30: Cyanotoxin production risk scale for Wood Lake

Graph Interpretation:

- Black line indicates mean cyanobacteria abundance within the selected date range
- Gray shaded region indicates range of cyanobacteria abundance values within the selected date range
- Coloured zones mark cyanobacteria abundance ranges that correspond to certain risk levels associated with cyanotoxin production (see Appendix 5: Cyanobacteria Alert Level Boundaries for details on the sources used to define categories)

Figure 31: Cyanobacteria bloom in Wood Lake, January 2, 2024
Source: Mike Soloshy

Bacteria

E. coli is a metric of fecal contamination; Wood Lake surface samples had consistently low *E. coli* counts and were below detection limits in 91% of samples from 2008-2023 with a maximum of only 1 CFU/100mL (Figure 32).

Total coliforms are a group of soil bacteria used for testing water treatment efficacy. They can also serve as a marker for watershed disruption. Concentrations in Wood Lake increased significantly from 2008 to 2023 with the largest increase occurring from 2020 to 2023 (Mann-Kendall, $p < 0.001$). The highest concentration to date measured 1730 CFU/100 mL on August 28, 2023 (Figure 32). These results closely match the total algae densities and indicate a shift in Wood Lake's microbiota in recent years (Figure 29).

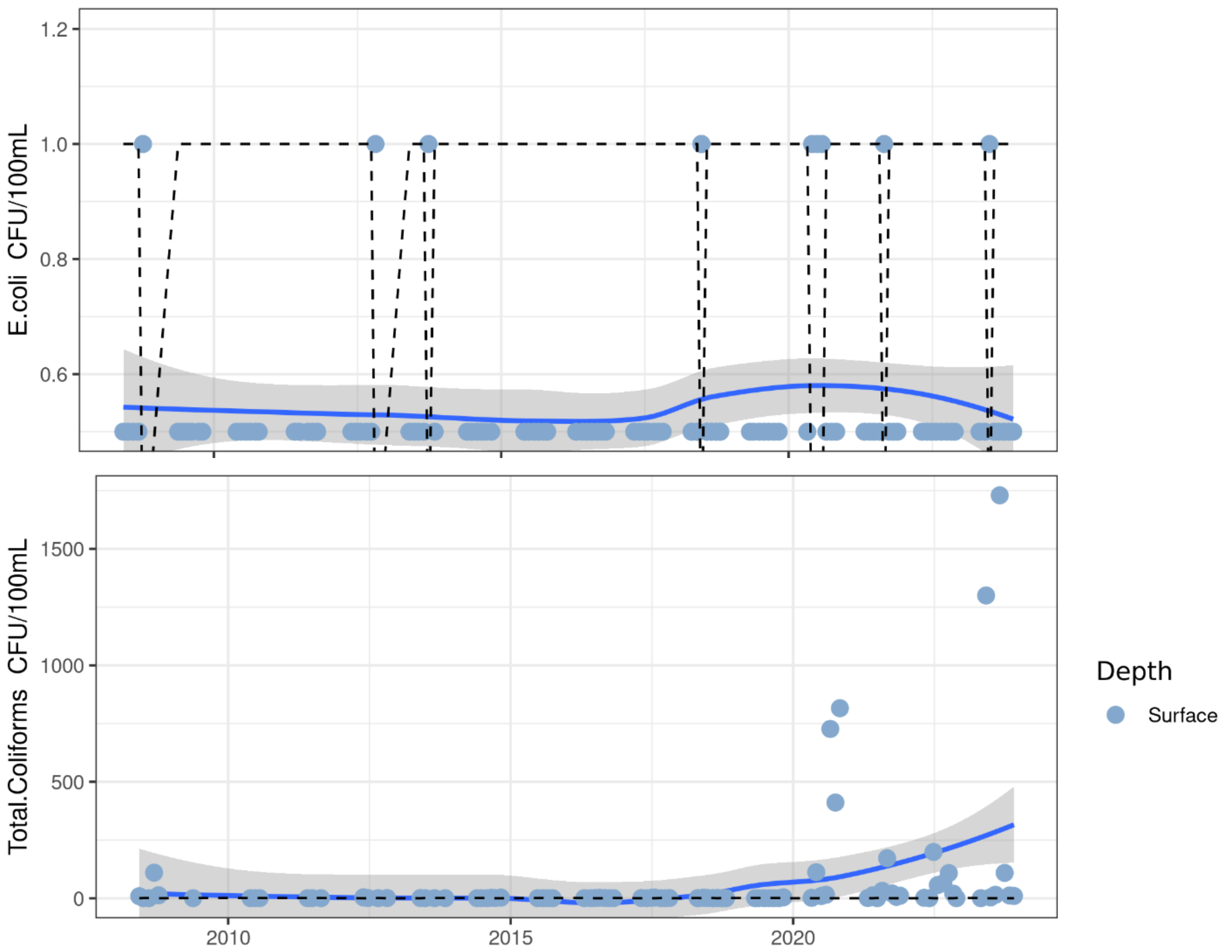

Figure 32: E. coli (top) and Total coliform bacteria (bottom) concentrations in Wood Lake, 2008-2023

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

Sediment

Sediments continuously accumulate in all lakes. Surface sediments were recently deposited while deep sediments were laid down long ago. Sediments lining the bottom of Wood Lake are fine organic silts: 3.3% sand, 61.7% silt, 35.0% clay, with the most common size averaging 12 microns (St John, 1973a).

Composite sediment cores were taken at one site near the north end of Wood Lake (Figure 6). The maximum depth that could be sampled was limited to 10 m below the surface because of the sediment corer mechanism. Sediment in Wood Lake was soft and dark grey to black in colour. Arsenic concentrations in the core were used as a timestamp based on the method employed by Walker and collaborators (I.R. Walker, E.D. Reavie, S. Palmer, 1993). This method cross references the timing of peak lead-arsenate use in orchards to a distinct peak in sediment arsenic concentrations. This peak was measured at approximately 24 cm deep during the 1993 study while it was observed at 14-20 cm deep in our cores (Figure 33). These depths indicate the expected result that the sediment accumulation rate is higher at the deepest point in Wood Lake compared to the north-end shallows.

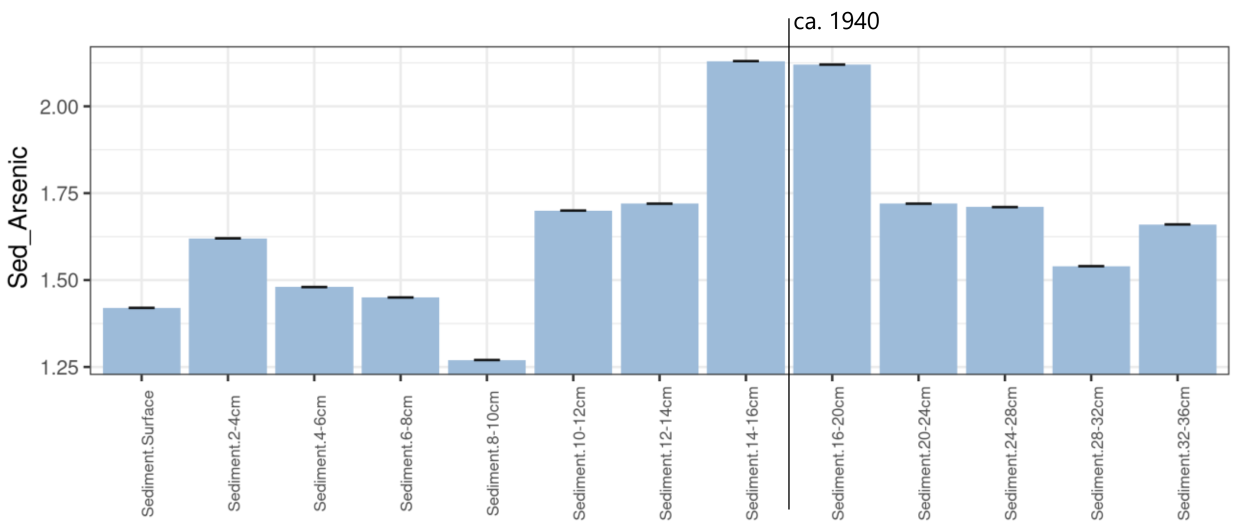

Figure 33: Arsenic concentration (mg/kg) in Wood Lake sediment by depth, illustrating the distinctive arsenic peak that marks the year 1940

Sediment Accumulation Rates

Sediment accumulation rates can vary significantly between lakes and even within the same lake depending on proximity to inflows, sediment disturbances, and position within the lake. Sediment naturally focuses into the deepest point of the lake but this can still be variable (I.R. Walker, E.D. Reavie, S. Palmer, 1993). For example, Walker and collaborators measured accumulation rates as high as 10 mm/year in Wood Lake at the deepest point in 1993 based on sediment core metals. LAC deployed a pair of sediment traps near the north end of the lake that measured average accumulation rates of 0.09 ± 0.03 mm/yr in the shallows (12 m deep) and 0.12 ± 0.04 mm/yr at a deeper location (23 m deep). Using the sediment core approach, based on the arsenic spike, LAC estimated a sediment accumulation rate of 1.9 mm/yr. This closely matches the estimated accumulation rate of 2.0 mm/yr from the 1973 study of the Okanagan Lakes limnogeology (St John, 1973b) but was less than the rate measured in 1993 (I.R. Walker, E.D. Reavie, S. Palmer, 1993). This sediment core dating approach produced a significantly higher sediment accumulation rate than what was measured by the sediment traps method and suggests that method is either missing a significant fraction of accumulated sediment, or, that the accumulation rate was uncommonly low during 2023. Assuming the sedimentation rate of ~2mm/yr according to the sediment arsenic marker, the 2023 sediment core extends back to the mid-1800s, therefore capturing most the time since European settlement began, but does not include pre-settlement sediment.

Sediment Hydrocarbons

EPHs, HEPHs, LEPHs, and PAHs are hydrocarbons and represent contaminants from petroleum and incomplete combustion. Hydrocarbons are found in and around industrial areas and in road runoff. These compounds can be washed into lakes and contribute hydrocarbons concentrations in sediment. Sediment core samples from 2023 Wood Lake were undetectable for all hydrocarbons, an encouraging result. Other sediment samples taken in a Wood Lake marina reflected hydrocarbon use in power boating (Schleppe et al., 2016; Self & Larratt, 2020a).

Sediment Total Volatile Solids

Volatile solids measure the organic compounds in sediment. Volatiles are materials from both natural and anthropogenic origins including plants, bacteria, and algae (Lu et al., 2021). Wood Lake sediment averaged 3.3 ± 0.53 % with T1 0-2 containing the lowest and T1 4-6 containing the highest concentration of total volatile solids (1.9 % and 4.1 % respectfully, Figure 34). Cores collected in 1973 showed a similar pattern with higher organic carbon content in surface sediments that were recently laid down (St John, 1973b). The arsenic dating timeline indicates that the peak in organic carbon sedimentation was in the late 1990s to early 2000s, aligning to a climatic wet period with high algae production (Figure 28). The current high production period (2020-2023) does not appear to have affected organic sedimentation at the north shallows site.

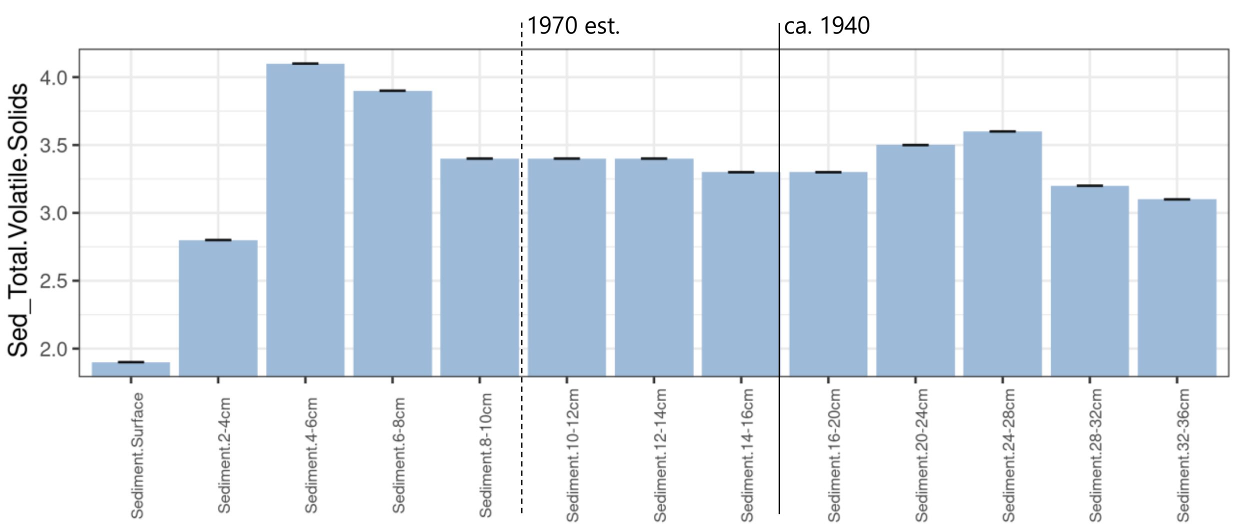

Figure 34: Total volatile solids (%) in Wood Lake sediment, 2023

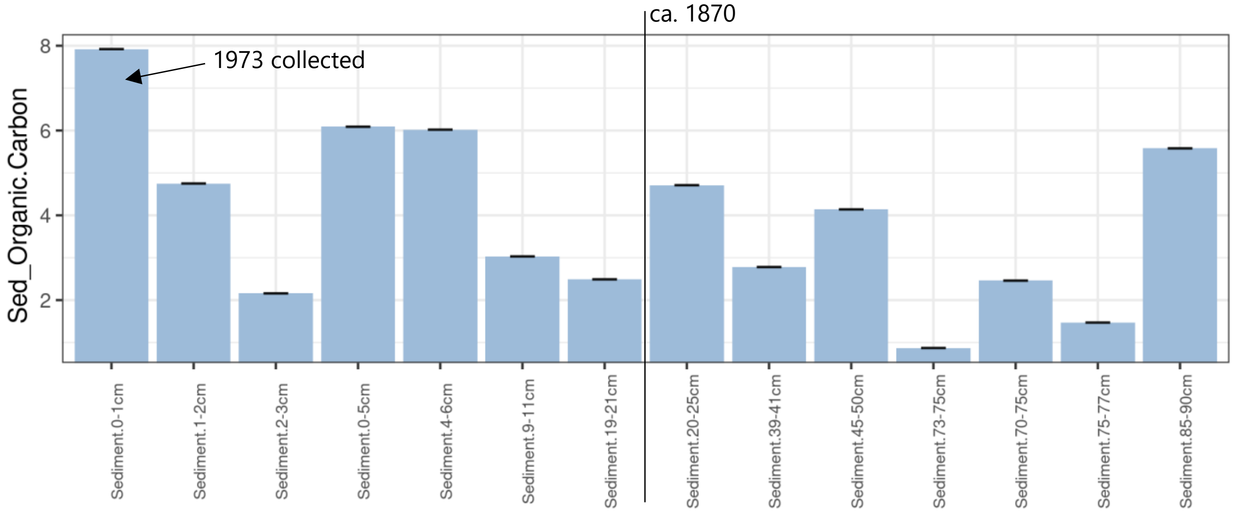

Figure 35: Sediment carbon concentrations at deepest point in Wood Lake as measured in 1973
Note: circa 1870 line is from St John, 1973 | Source: St John, 1973

Sediment Total Metals

Total metals were screened against British Columbia Interim Sediment Quality Guidelines (BC ISQG). All core segments from Wood Lake exceeded two guidelines, manganese (<460 mg/kg) and nickel (<16 mg/kg; Table 6).

Manganese concentrations averaged 996 ± 129 mg/kg in the Wood Lake 2023 sediment core samples. The lowest concentration was 608 mg/kg in T1 0-2 core segment, and the highest concentrations were 1090 mg/kg in segments T1 4-6 and T1 16-20 (Table 6).

Nickel averaged 20.2 ± 2.43 mg/kg with T1 0-2 containing the lowest concentration at 16.1 mg/kg and T1 12-14 measuring the highest nickel concentration of 25.1 mg/kg (Table 6).

Several metal concentrations were correlated, forming distinct clusters in the dendrogram (Figure 36). A group containing calcium, sulfur, and magnesium clustered because of their common relationship in marl and hard water. Moisture and manganese correlated strongly because highly organic sediment retains more water (higher moisture) and is more strongly anoxic which is associated with the movement of manganese in and out of the sediment. Another distinct group included metals commonly associated with historic agricultural activities such as copper, arsenic, and lead (Figure 36).

Non-parametric multidimensional scaling (NMDS) was also performed on the metals results to determine how the different depths grouped across all parameters. The results grouped similarly to the diatom NMDS results with three distinct groupings corresponding to pre-1940s, mid-twentieth century, and the most recent sediments (Figure 37, Figure 43).

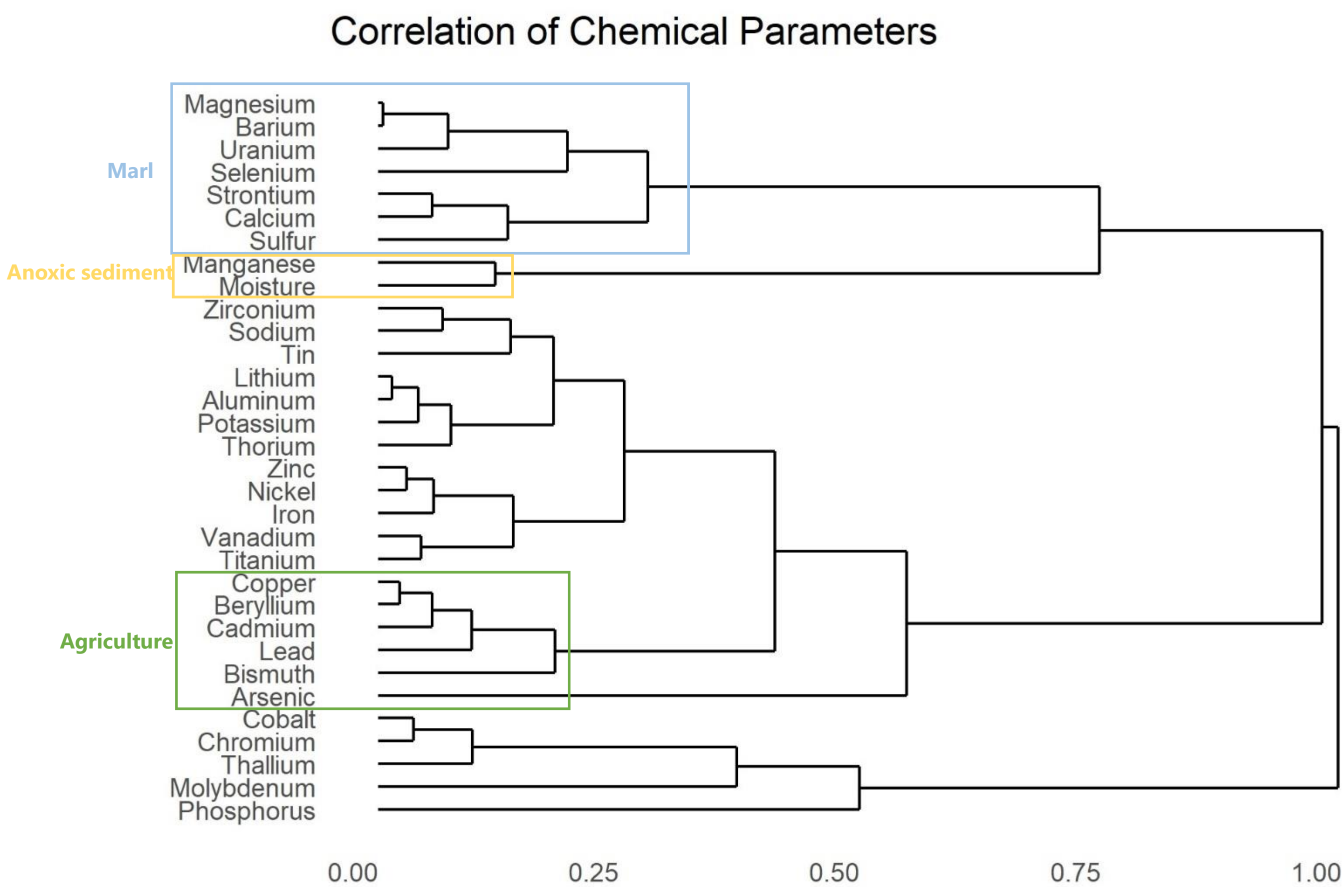

Figure 36: Dissimilarity dendrogram for sediment core metals

Note: dissimilarity matrix calculated Pearson's correlation coefficient

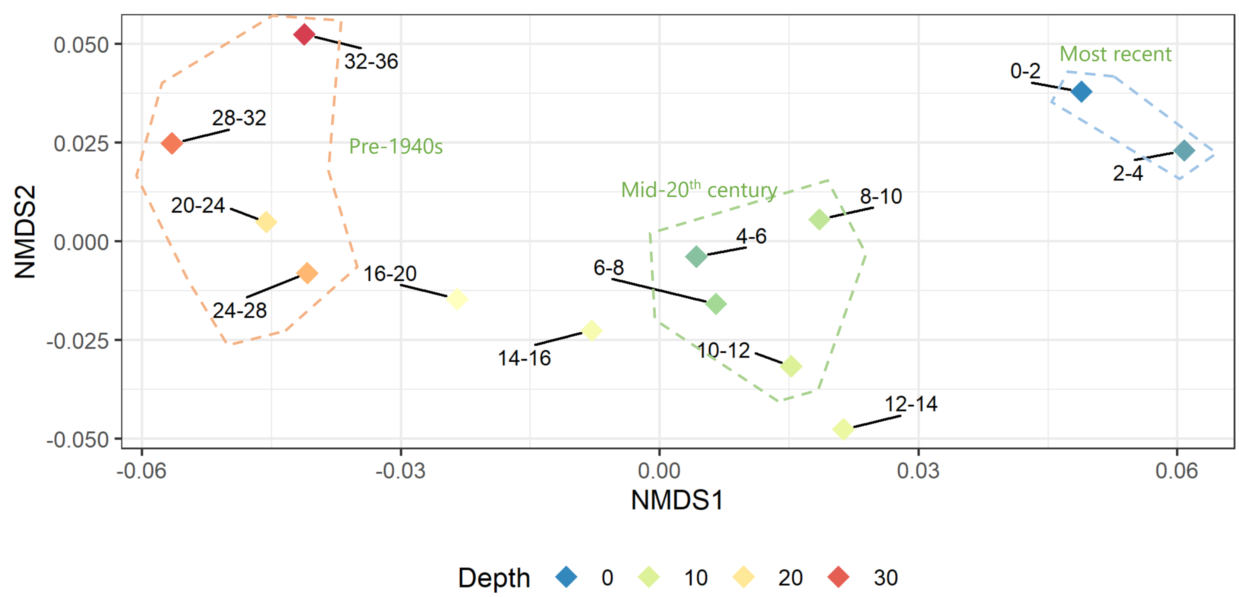

Figure 37: NMDS analysis of sediment core metals

Table 6: Metal exceedances in Wood Lake sediment

Core segment	Metal	Result (mg/kg)	BC ISQG (mg/kg)
T1 0-2 cm	Manganese	608	460
	Nickel	16.1	16
T1 2-4 cm	Manganese	987	460
	Nickel	18.3	16
T1 4-6 cm	Manganese	1090	460
	Nickel	21.1	16
T1 6-8 cm	Manganese	1080	460
	Nickel	21.1	16
T1 8-10 cm	Manganese	1020	460
	Nickel	19.6	16
T1 10-12 cm	Manganese	1070	460
	Nickel	22.6	16
T1 12-14 cm	Manganese	1030	460
	Nickel	25.1	16
T1 14-16 cm	Manganese	1050	460
	Nickel	21.9	16
T1 16-20 cm	Manganese	1090	460
	Nickel	22.1	16
T1 20-24 cm	Manganese	1030	460
	Nickel	19.4	16
T1 24-28 cm	Manganese	1050	460
	Nickel	20.1	16
T1 28-32 cm	Manganese	937	460
	Nickel	17.4	16
T1 32-36 cm	Manganese	906	460
	Nickel	18.2	16

Source: for BC ISQG https://bcgov-env.shinyapps.io/bc_wqg/

Sediment Diatoms

Diatoms are a diverse group of unicellular microscopic photosynthetic organisms with silica cell walls that can be preserved indefinitely in sediments (Burge et al., 2018). They are useful as biological indicators of change in aquatic systems because individual diatom species have specific ecological requirements. Examining diatom abundance and distribution in sediment allows reconstruction of entire lake histories.

The Wood Lake sediment cores were therefore analyzed for diatom abundance from each horizon (1-2 cm thick slices). We used the relative abundance of diatoms in each horizon to track changes in water quality over time using diatom habitat preferences such as high or low nutrient concentrations. The date of the horizons was cross-referenced using the metals dating discussed previously. The results were lumped into several groups depending on the change observed. Across a broad range of taxa, the 1940-1970 period was an inflection point and is marked on the graphs.

Taxa That Show Temporary Changes

The first group of sediment diatom taxa showed temporary changes in abundance. A pattern of relatively high abundance in the oldest sediments followed with a distinct drop and then a reappearance in more recent sediments emerged. The sediment core horizons between 8 and 16 cm deep had markedly lower relative abundances for several common taxa (Figure 38). These five taxa are all generalist algae types that can tolerate mesotrophic and eutrophic conditions; the direct cause of their population shift is not clear. The 1993 sediment diatom study also identified shifts in *Aulacoseira, Fragilaria,* and *Navicula*. This pattern was also observed in *Fragilaria* and *Navicula* during the 1993 study (Walker et al., 1993; Figure 40).

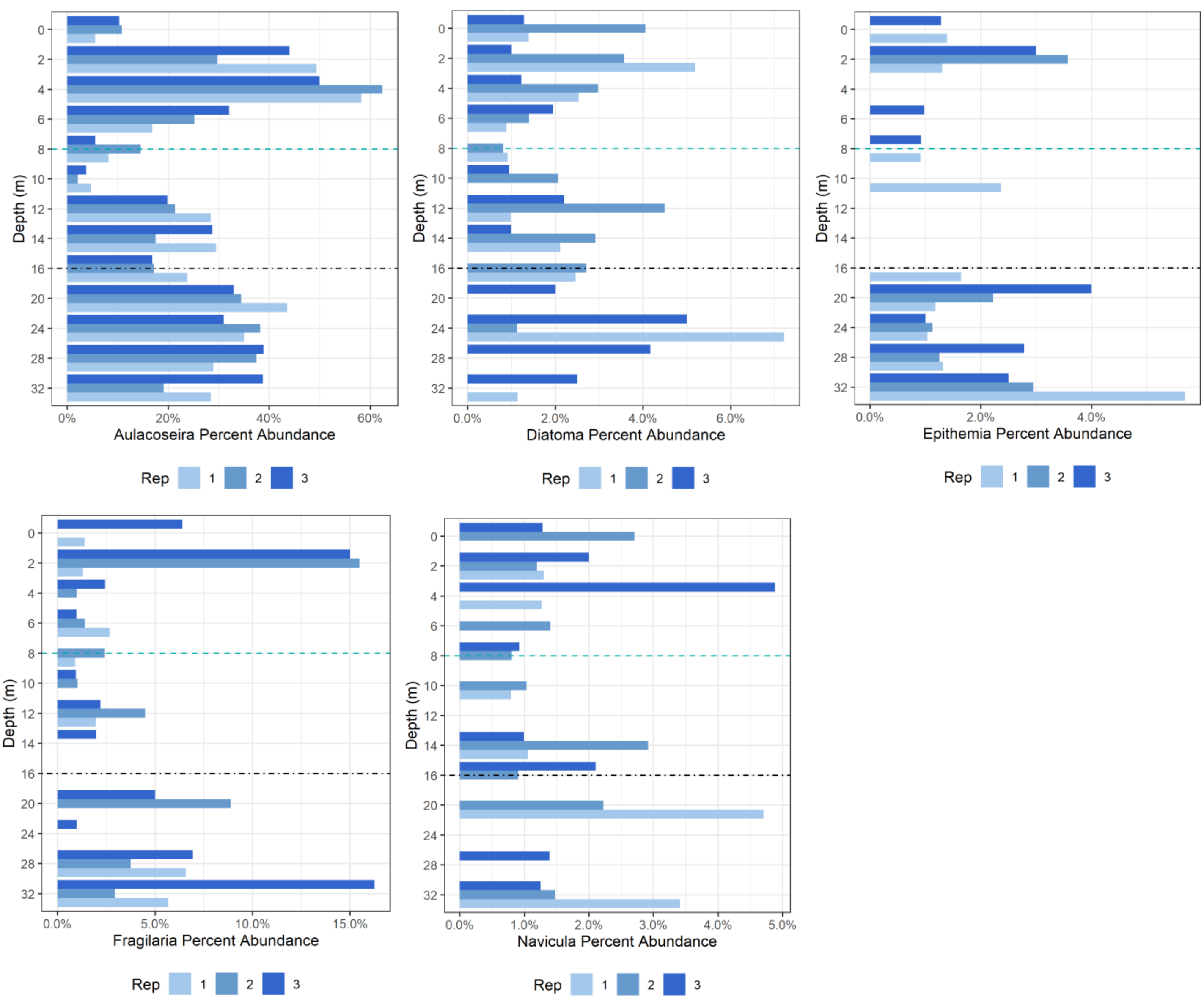

Figure 38: Diatom genera in the taxonomic record that declined temporarily before returning

Note: Teal dashed line =~1970 while black dashed line =~1940 based on metals analysis | 2023 sediment core

Taxa That Decreased or Disappeared

Several taxa were observed that either declined in abundance over time, or suddenly disappeared from the taxonomic record (Figure 39). Of these, *Achnanthidium* is considered sensitive to poor water quality and its decline over the past 100+ years may indicate a long-term decline in Wood Lake water quality. *Discostella*, a close relative and sometimes cross-identified as the common genus *Cyclotella*, was common in the oldest sediments before largely disappearing. The 1993[2] study also noted a shift from *Cyclotella to Stephanodiscus* (I.R. Walker, E.D. Reavie, S. Palmer, 1993; Figure 40, Figure 41). *Platessa* is a type of algae that grows in periphyton of rivers and its disappearance may be linked changes to the upstream watershed such as the Hiram-Walker inflows, urbanization, agricultural pesticide use, etc. *Rhopalodia* is a low-nutrient indicator taxa that was present in only the oldest sediments in both the 1992 and 2023 sediment cores, indicating that nutrients have increased since European settlement began (Figure 40).

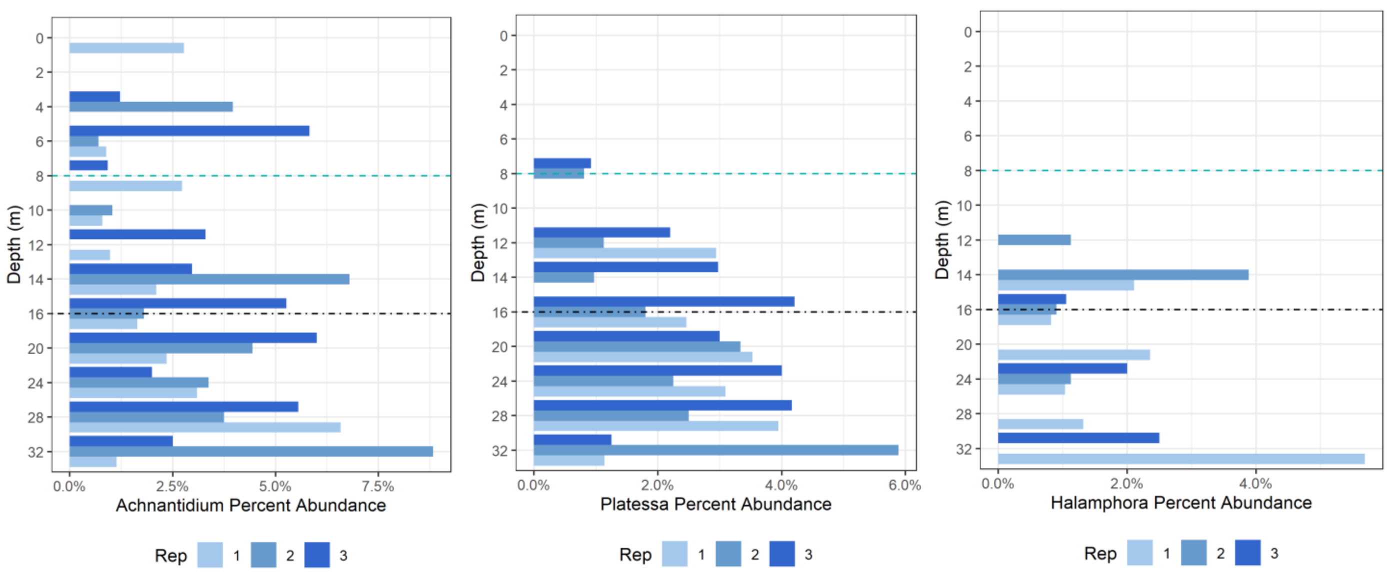

Figure 39: Diatom genera that declined or disappeared from the taxonomic record

Note: Teal dashed line =~1970 while black dashed line =~1940 based on metals analysis | 2023 sediment core

[2] The 1993 Walker study used a sediment core collected in May of 1992 for diatom comparison. Both years are used in this report to refer to this document depending on the context.

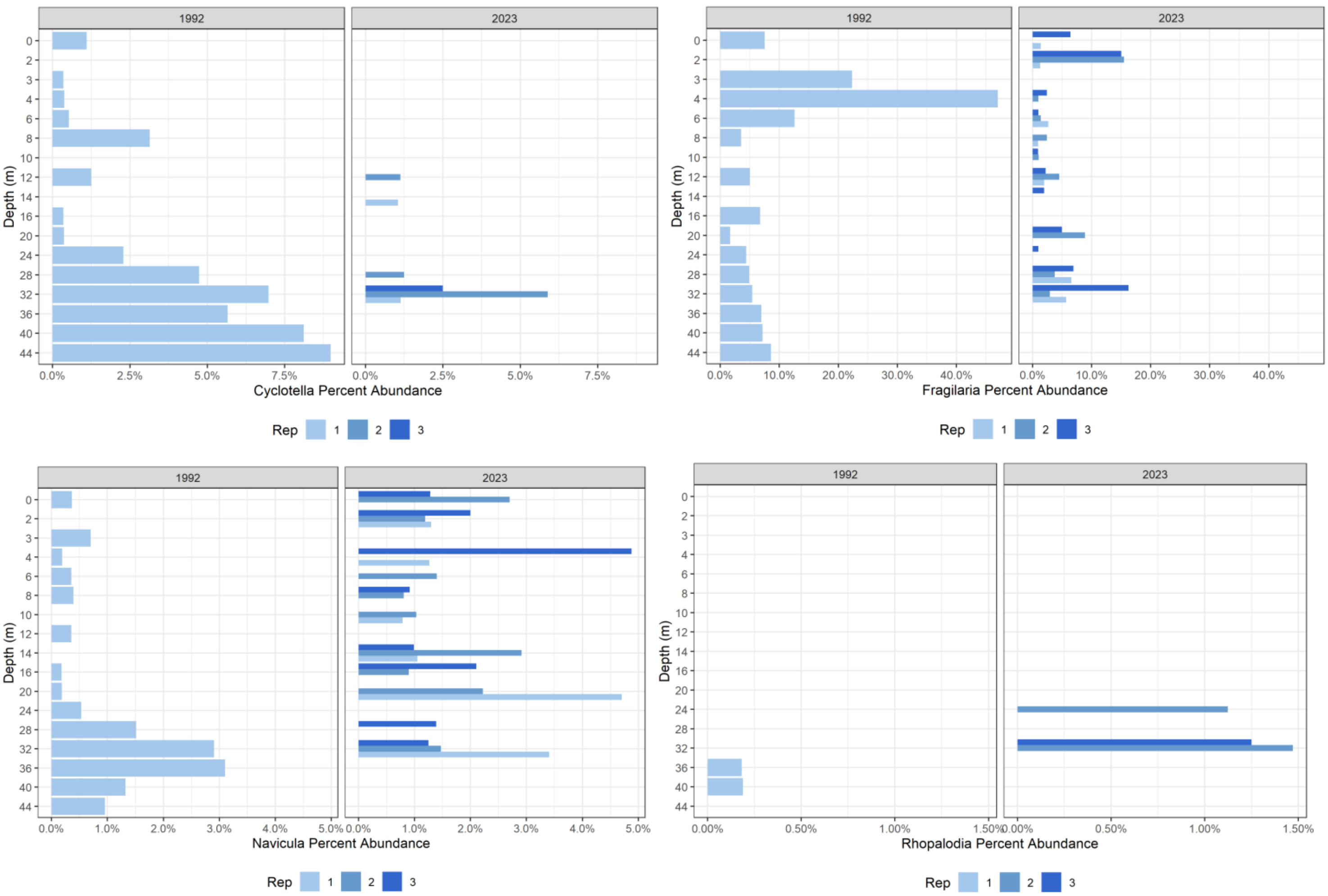

Figure 40: Comparison of Cyclotella, Fragilaria, Navicula, and Rhopalodia percent abundance in 1992 and 2023 sediment cores

Taxa That Increased or Appeared

Some taxa increased in abundance over time or appeared suddenly in the taxonomic record (Figure 41). *Cavinula* is a recently identified split from the very large genus *Navicula*[3,4]and was common throughout the taxonomic record but became the dominant species present in the most recent sediments. *Cavinula* contains several species that range in habitat preferences from generalist to alpine oligotrophic specialists and the cause its surge in the taxonomic record is unclear (Cvetkoska et al., 2014). Two taxa that appeared suddenly in Wood Lake's taxonomic record were *Stephanodiscus* and *Ulnaria*; both genera that include pollution tolerant species. The sudden appearance of *Stephanodiscus* was also noted in the 1993 Wood Lake study as a marker of nutrient enrichment, although the

[3] Fun taxonomy fact: these two taxa are spelled the same except that the n and c are swapped.
[4] The genus *Navicula* currently has over 1000 accepted species according to ITIS.

abundances observed in that study were much higher than was found in the 2023 core and the cause of this disparity is not clear (I.R. Walker, E.D. Reavie, S. Palmer, 1993).

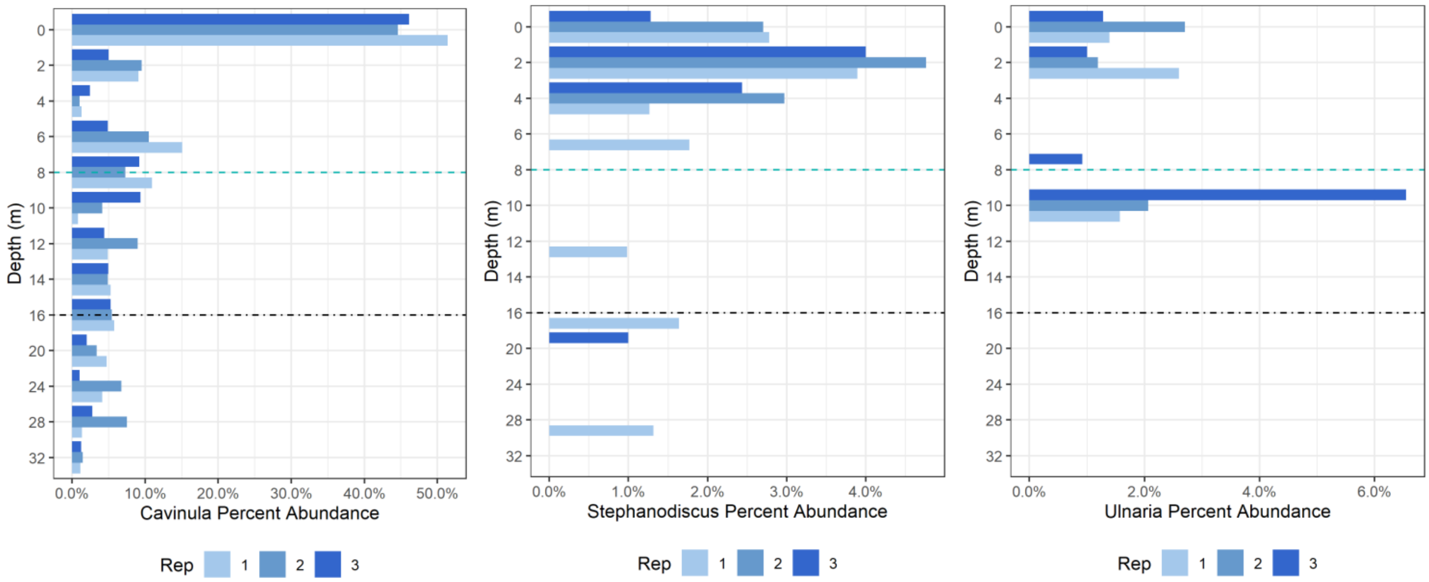

Figure 41: Diatom genera that increased or appeared suddenly in the taxonomic record
Note: Teal dashed line =~1970 while black dashed line =~1940 based on metals analysis | 2023 sediment core

In addition to diatoms, two types of green algae were common in the 2023 sediment cores[5]. *Phacotus* was among the most common taxa in Wood Lake prior to the 1970s based on the 2023 sediment core (Figure 42). It is a marker of warm, high calcite water and may be a marker for the introduction of Okanagan Lake water into Middle Vernon Creek by Hiram-Walker (Schlegel et al., 1998). *Phacotus* abundance was weakly correlated with sediment calcium concentration (Pearson's R=0.38) with both parameters showing a decline in recent years. One of the most common features in the 2023 core were the remnants of filamentous green algae, of the genus *Mougeotia* (Figure 42). This is a very common species in Wood Lake today and is routinely found in water samples collected for the ongoing Kalamalka Lake Study. Interestingly, this taxa is absent in the oldest sediment, and then suddenly becomes a top 3 most abundant taxa in every horizon since around 1940.

[5] The 1993 study focused only on diatoms, preventing a comparison of these algae types.

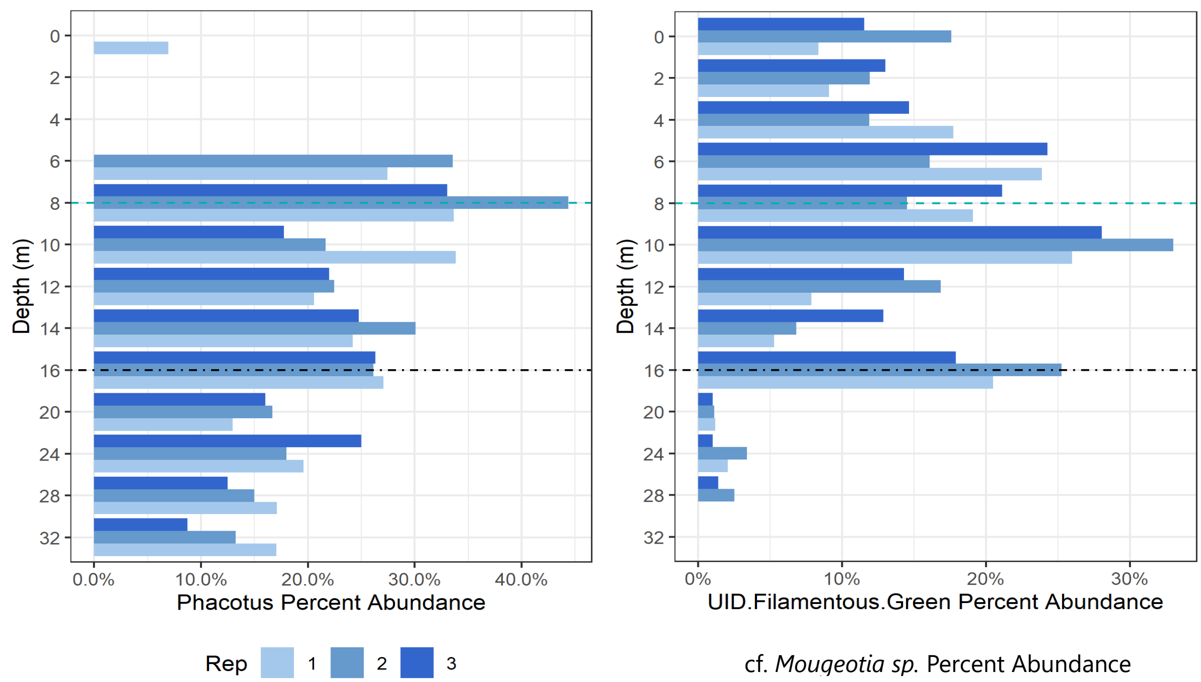

Figure 42: Green algae identified in sediment horizons collected during 2023
Note: Teal dashed line =~1970 while black dashed line =~1940 based on metals analysis

Community Composition

In addition to comparing individual species across time through the sediment cores, it is also possible to compare the community composition across time using non-parametric multidimensional scaling analysis (NMDS). This approach collapses multiple dimensions into 2-dimensions for plotting and visual comparison. The NMDS results indicated that the diatom community compositions were distinct between the 1992 and 2023 sediment cores (Figure 43). The relationship between the depth horizons in the cores is plotted in Figure 43. While there is no overlap between the 1992 and 2023 cores, the same patterns come through as marked by the coloured groupings in Figure 43. Differences in taxonomic approach and re-naming of species could explain some of the differences between the two datasets. The results indicate that Wood Lake has experienced three distinct phases as captured in both the 1992 and 2023 cores that can be summarized by their time-frames and the type of activity in the watershed (I.R. Walker, E.D. Reavie, S. Palmer, 1993); these groupings also aligned with NMDS analysis of the sediment metals (Figure 37).

1. Pre-1940s = Early European settlement, basic agriculture
2. 1940s to 1970s = Intense agriculture with heavy chemical use
3. Post-1970s[6] = Urbanization of the watershed

[6] Water chemistry results indicate that this third group may be splitting into a fourth group post-2010, but these changes have not affected the sediment core.

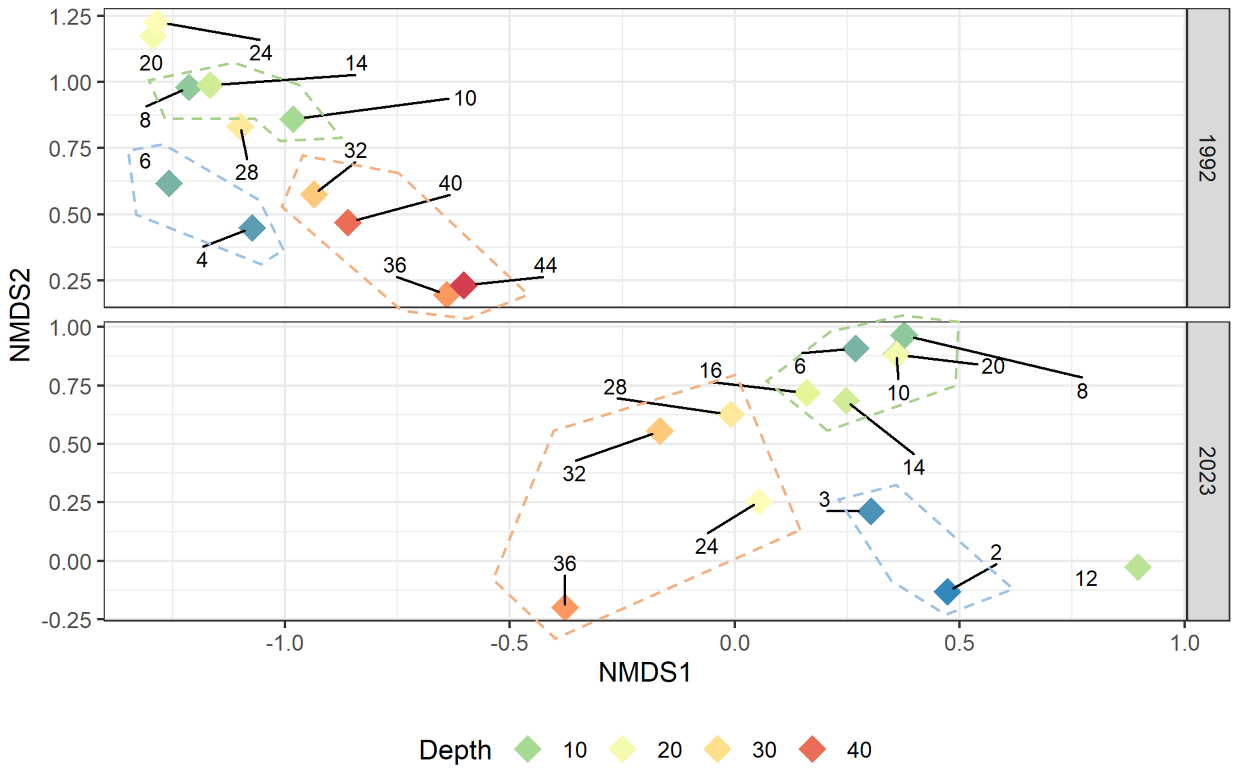

Figure 43: NMDS results comparing 1992 and 2023 sediment core diatom communities

Legend for Groupings:

Oldest Sediments	Mid-twentieth century sediments	Most recent sediments

Discussion

Is Wood Lake significantly different from pre-1850 in terms of water chemistry and primary productivity?

Water Chemistry Data

Water quality data for Wood Lake is limited to 1970-present that indicates a significant improvement from the 1970s through the 2000s followed by a period of regression since 2010 (Figure 7, Figure 20, Figure 27). Higher nutrient levels, frequent algal blooms, reduced water clarity, and expanding anoxic zones characterized periods of poorer water quality (Figure 7, Figure 10, Figure 20, Figure 22, Figure 23). Notably, the intensity and size of anoxic zones have increased in recent years, leading to Kokanee die-offs in 2011, 2022, and 2023 (Figure 10).

Sediment Core Data

Sediment core analysis provides a longer historical record, extending back to the mid-1800s, capturing most of the period following European settlement (Figure 33). A core collected in 1973 potentially reached even further back, but due to limited parameter analysis, it offers little insight into that earlier period (St John, 1973a, Figure 35).

The sediment core data reveals a significant shift in lake chemistry and diatom composition around 1940 and again in the 1970s (Figure 33, Figure 37 - Figure 42). Analysis of diatoms, a type of algae, indicates that the period between 1940 and the 1970s was the most detrimental for the lake's ecosystem, with a decline or disappearance of numerous species. While some species recovered, others did not, and new species emerged, with some filamentous green algae becoming dominant (Figure 38 - Figure 43).

Marling

Marling frequency has increased unusually in the past decade, possibly linked to higher water hardness (Figure 19, Table 3). Previous research suggests that marl accumulation in the sediment intensified after the 1940s, potentially due to water diversion for irrigation (I.R. Walker, E.D. Reavie, S. Palmer, 1993).

Wood Lake Nutrient Budget

A 2016 study by LAC and ENV identified internal loading as the primary source of bioavailable phosphorus in the lake while external loading was more important to the nitrogen balance within the lake (Table 5; Self & Larratt, 2016). Earlier data from the 1970s by MVC suggests higher total phosphorus (TP) levels compared to today, while total nitrogen (TN) remained similar (Table 5; (British Columbia Water Resources Service, 1974).

Changes to Duck Lake

Duck Lake is a small, shallow, and very productive lake located upstream of Wood Lake and it feeds Middle Vernon Creek (MVC). While not the focus of this study, the condition of Duck Lake affects Wood Lake directly. Duck Lake contained significantly higher nutrient concentrations than Wood Lake’s surface waters, that is to say that Duck Lake is a nutrient source to Wood Lake. There was also a significant increasing trend in TP in Duck Lake.

Is Wood Lake deteriorating today and why?

The analysis of water chemistry data and sediment cores reveals a period of significant decline in Wood Lake's health between the 1940s and 1970s. Fortunately, water quality improvements followed, likely due to upgrades in wastewater treatment plants and the flushing effects of Hiram-Walker operations (Figure 20, Figure 22, Figure 23, Figure 27, Figure 33, Figure 37, Figure 43). However, over the past 10 years Wood Lake has exhibited:

- Higher nutrients (Figure 20, Figure 22, Figure 23)
- Higher algae production with more frequent and intense blooms (Figure 27, Figure 29, Figure 31)
- Larger and more intense anoxic zones (Figure 10, Figure 12, Figure 13)
- Multiple kokanee die-offs (pers comm w Kristen King)
- Water quality markers such as chloride[7] show accelerating cumulative effect of human activity on Wood Lake (Figure 15)

These changes in water quality are attributed to several factors including:

- Decline in watershed resiliency: Wood Lake's watershed has experienced decades of logging and resource extraction, agriculture with fertilizer and pesticide application, urbanization and population growth, and wastewater disposal. These lead to a reduction in the capacity of the watershed to buffer against further changes, lowering its resiliency. This can be clearly seen in the hydrometric graph of Middle Vernon Creek where peak freshet flows and total water yield from the watershed have increased dramatically (Figure 14). There is more runoff from the watershed that reports to Wood Lake more quickly because of loss of forest cover and increase increased impermeable surface area.
- Nutrient enrichment from dramatic changes in the watershed. The introduction of advanced nutrient removal technology to the WWTP[8] was part of a decades long period of improved water quality but continued population growth and associated impacts have reversed the trend leading to significant increasing trends for both of the major aquatic nutrients (nitrogen and phosphorus) during the past 10 years.

---

[7] This is a benign parameter at the concentrations found in Wood Lake, but if it is accumulating from human activity, so are other things that are not quite obvious. For example, nutrients don't stay in solution and may not show up as clearly in chemistry trends (although they still do for Wood Lake, Figure 22, Figure 23), they are consumed by algae and then decomposed at the sediment. This leads to other changes that can be tracked such as phytoplankton production (Figure 27, Figure 29).

[8] DLC WWTP discharges to ground with some portion of the nutrients ultimately reporting to Wood Lake via groundwater.

- Changes to in-lake usage through introduction and widespread use of wake-surf boats. These boats create large wakes that cause shoreline erosion and sediment resuspension, both of which increase nutrient loading to the lake and damage sensitive riparian habitats (Francis et al., 2023; Schleppe et al., 2016, 2017; Sébastien Raymond & Galvez-Cloutier, 2015).
- Climate Change: Overlain upon the increasing nutrient concentrations are the effects of climate change. These include: longer, hotter, and drier summers (Figure 44). These conditions prime Wood Lake for longer stratified periods that lead to greater anoxic nutrient recycling, and warmer, calmer surface water ideal for cyanobacteria blooms (Figure 10, Figure 21, Figure 29).
- Nutrient recycling positive feedback: Nutrients that return to the water column within the anoxic zone fuel algae blooms that, when the die, sink to the sediment and decompose, consuming oxygen. Larger blooms lead to larger and more intense anoxic zones that lead to greater nutrient recycling that fuel larger blooms.

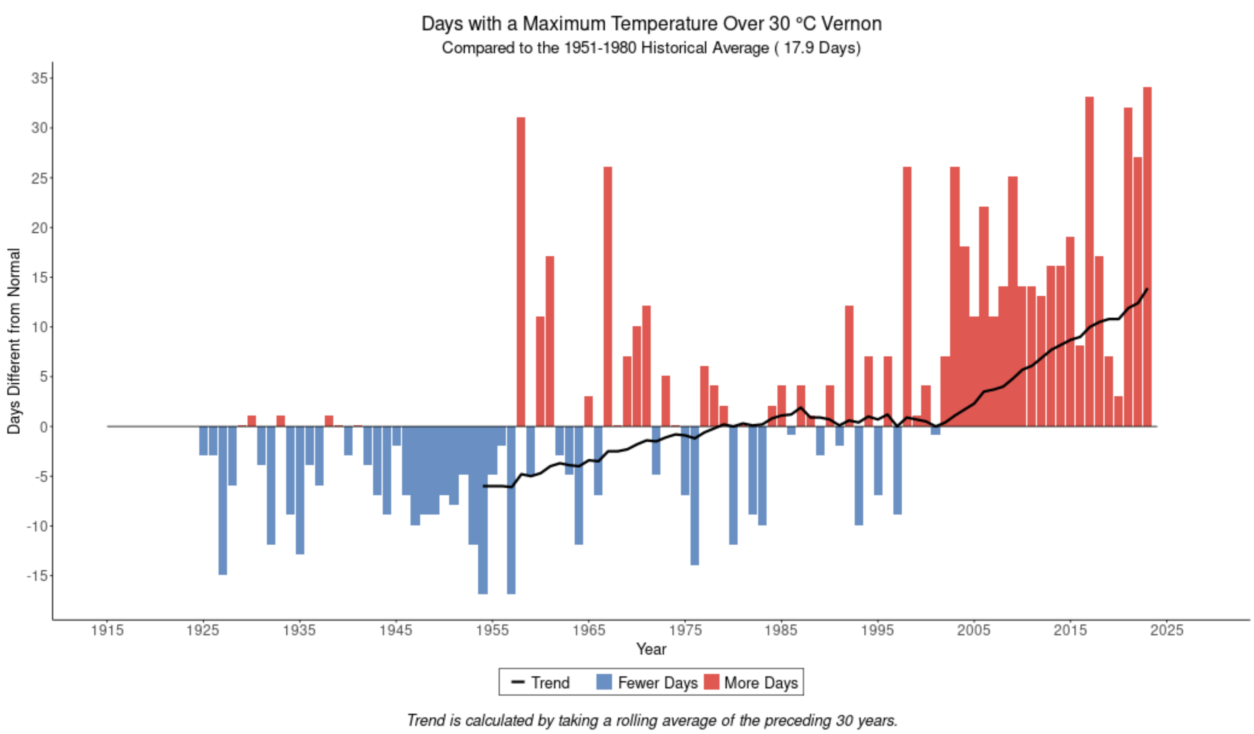

Figure 44: Days with maximum temperature over 30 °C at Vernon (1925-2024)
Source: (Okanagan Basin Water Board, 2024)

Are Wood Lake fish safe to eat?

Wood Lake is prone to harmful algae blooms (HABs) dominated by a few cyanobacteria such as *Anabaena, Anacysits, Aphanizomenon,* and *Microcystis*. These species will, when conditions such as abundant phosphorus and warm stable water columns exist, create surface scums. While the precise trigger conditions remain poorly understood, these taxa of cyanobacteria are all known to produce a range of toxins (Appendix 4: Common cyanobacteria in Wood Lake). The risk to wildlife and people from these toxins is proportional to the abundance of cyanobacteria in the water (Figure 30).

Acute cyanotoxin exposure has long been associated with respiratory and skin irritation (Berry, 2013). Today, chronic cyanotoxins exposure is now also associated with a number of negative health conditions including neurodegenerative diseases (Mutoti et al., 2022) and liver cancer (Drobac et al., 2017).

The risk of cyanotoxins in the cyanobacteria cells and the surrounding water during blooms is well established but recent research has focused on the potential for biomagnification of these up the food chain, potentially affecting the consumption and use of fish from bloom prone lakes, such as Wood Lake.

Studies within the past few years have confirmed that cyanotoxins do travel through the food chain and have been routinely observed in zooplankton, invertebrates, and fish[9]. Cyanotoxin concentrations within fish were found to be highest in the liver while muscles contained up to 20x lower concentrations[10]. The high liver concentrations suggest that fish are physiologically stressed by blooms, potentially increasing their vulnerability to lake-squeezes that can follow large blooms[11]. Other studies have found that fish tissue cyanotoxin concentrations vary significantly between different individuals and between different species[12]. The risk to piscivorous birds is not well established at this time.

In addition to organisms that live in bloom prone lakes, plants that are irrigated by water from such lakes are also documented to accumulated cyanotoxins within their tissues, up to 27% of the cyanotoxin load from the original water body[13].

Despite the clear evidence for the presence of cyanotoxins within fish, there remains no firm support for the risk of biomagnification. Instead, biodilution is considered to be the mechanism involved (Berry, 2013; Kozlowsky-Suzuki et al., 2012). Biomagnification would see concentrations of cyanotoxins increase with each trophic level up the food chain and is typically observed with fat soluble compounds such as methyl-mercury, and “forever chemicals” (PFAS). Cyanotoxins, conversely, are water soluble and are gradually excreted by exposed organisms. However, through repeated and prolonged exposure, cyanotoxins will build up in the tissues of all animals within a lake.

---

[9] (Berry, 2013; Chia et al., 2021; Christensen & Khan, 2020; de Almeida et al., 2024; Drobac Backović & Tokodi, 2024; Garita-Alvarado et al., 2023; Kozlowsky-Suzuki et al., 2012; Mutoti et al., 2022; Shahmohamadloo, Bhavsar, Ortiz Almirall, C, et al., 2023; Shahmohamadloo, Bhavsar, Ortiz Almirall, Marklevitz, et al., 2023; Shahmohamadloo et al., 2022; Sundaravadivelu et al., 2022)

[10] (Garita-Alvarado et al., 2023; Mutoti et al., 2022; Shahmohamadloo, Bhavsar, Ortiz Almirall, C, et al., 2023)

[11] (Shahmohamadloo, Bhavsar, Ortiz Almirall, C, et al., 2023; Shahmohamadloo, Bhavsar, Ortiz Almirall, Marklevitz, et al., 2023)

[12] (Shahmohamadloo et al., 2022)

[13] (Drobac Backović & Tokodi, 2024; Mutoti et al., 2022)

Studies of fish tissues from the Great Lakes region have found that fish fillets from lakes prone to blooms can still be safely consumed by people as long as the internal organs are not consumed.

What is at stake if Wood Lake deteriorates – an economic analysis

Wood Lake is an important feature for the District of Lake Country and Central Okanagan for a number of reasons. These include: economic, cultural, recreational, aesthetic, etc. A detailed description of the values Wood Lake provides is given below in Table 7.

Table 7: Economic values provided by Wood Lake

	Item	Estimated Valuation ($)	Description	Change if Wood Lake improves from eutrophic to mesotrophic	Emerging Threats	References
	fishery	0.5 million	cultural benefits far outweigh the fishery revenues | 9471 angler days/yr 2018-2023 @ $50/day on fuel/food/equipment	healthier fish; fewer fish-kills	lake squeeze (fish kills) | low hot creek flows | invasive mussels	Pers comm. Kristen King (BC Fisheries); (Okanagan Basin Water Boa, 2024)
Real Estate	real estate DLC views of Wood Lake	1.8 billion	visual aesthetic of the lakes plays a big role in why people want to live in Lake Country Figure 45	improved value	development pressures on water/sewer	(District of Lake Country, 2023a, 2023b)
Real Estate	real estate taxation (DLC)	20 million	critical to DLC revenues	increased revenue	deteriorating lake decreases tax revenue	(District of Lake Country, 2022)
Wood Lake Tourism	Local boating	60 million	Est. 3000 boats registered in DLC @20K (wake surf boats 200K)	improved value	may exceed safe carrying capacity of Wood Lk	(BoatDriving.org, n.d.; Schleppe et al., 2016)
Wood Lake Tourism	tourism out-of-town boats	unknown	highest risk category for aquatic invasives	improved value	increased invasive mussel risk shore erosion	(InterVistas, 2023)
Wood Lake Tourism	tourism-accomodations/shoreline amenities/food/retail	<15 million	tourism is Okanagan's 4th largest industry 2.1 billion 2022 | Wood Lk watershed = 7% of RDCO = $150M if 10% DLC =$15M	increased revenue	relies on lake health, affected by wildfires over-tourism diminishes lake health	(Tourism Kelowna, 2022)
Wood Lake Tourism	tourism tax revenue (estimate)	~23 million	Vital industry to DLC	increased revenue		(District of Lake Country, 2022)
Water Supply	agri/private water intakes	~0.5 million	Vital industry to DLC: direct production, fruit stands, wineries, restaurants, etc.	safer water and crops	invasive mussels clog intakes-maintenance	(British Columbia Government, 2024)
Water Supply	cost of water intake /treatment	3.8 million	400,000 m^3/yr | 96% to agriculture (vital) 4% domestic Figure 46	safer, decreased cost of treatment	invasive mussels clog intakes-maintenance	(British Columbia Government, 2024)
Water Supply	sewer operations	-2.4 million	critical to lake health with population/tourist pressures	---	DLC must export nutrients out of District	(District of Lake Country, 2022, 2023a; Graham, 2023)

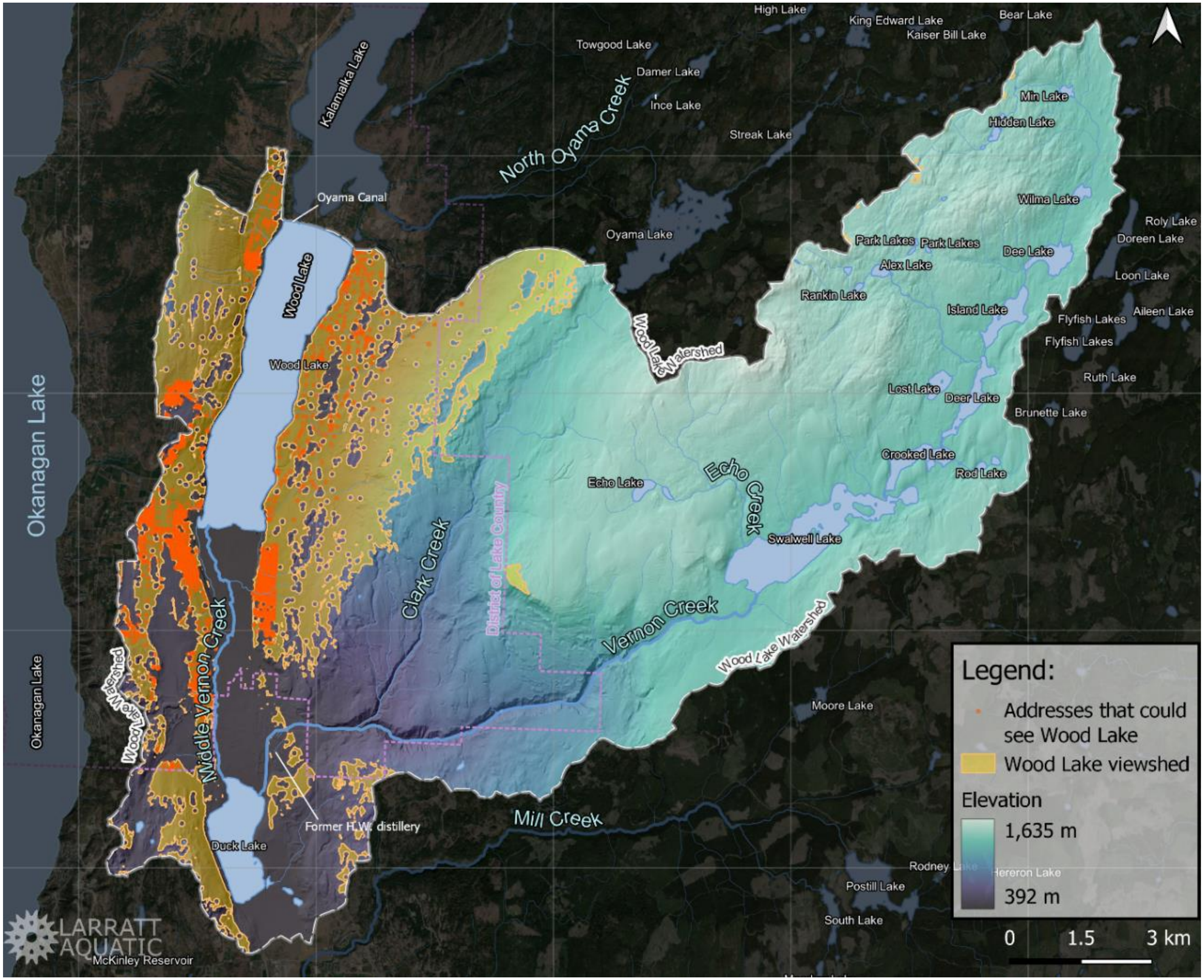

Figure 45: Map of Wood Lake watershed with viewshed of lake highlighted including properties with lake views

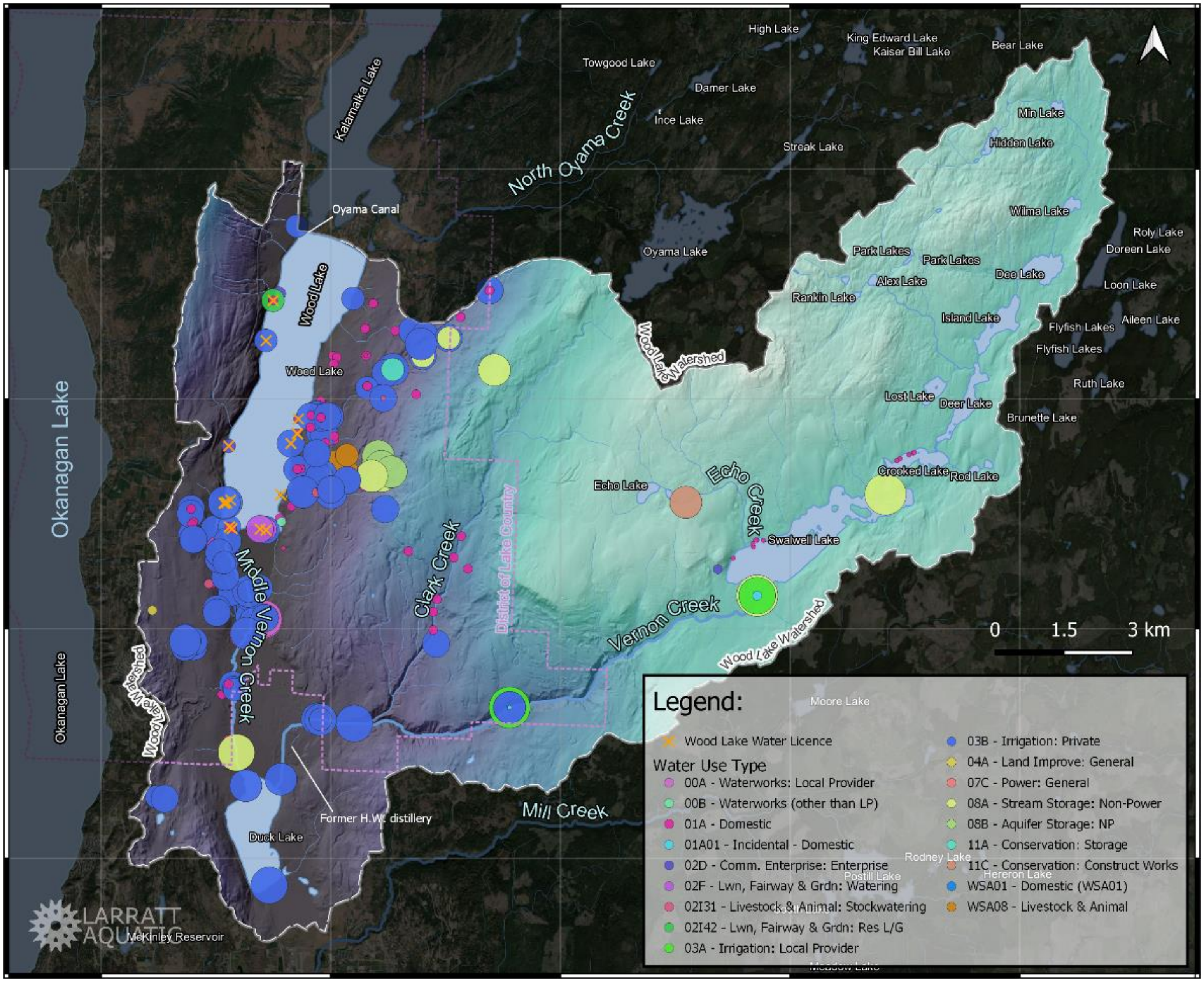

Figure 46: Map of water licences within Wood Lake watershed, coloured by use

Source: (British Columbia Government, 2024)

What feasible steps can be taken to lower the scale and frequency of cyanobacteria blooms in Wood Lake?

Table 8: Techniques that have been proposed or considered for improving water quality in Wood Lake

	Technique	Date	Source	Cost	Premise	Strengths	Weaknesses	Update as of 2024?	Action
aeration /sonic	destratification aeration (spring to fall only)	1974	(British Columbia Water Resources Service, 1974)	$$$	use compressed air to lift bottom water to surface for aeration	low cost localized fish refugia application	• increases heat budget • off gassing • can increase algae by surfacing nutrients from hypolimnion • must operate immediately after ice-off • ideal for localized disruption, would be too energy intensive and costly to destratify the entire lake	water-lifting aerators are large subsurface structures that draw in deep water and lift it to the surface with compressed air - limits sediment lift	**consider further**
	pumping deep water to MV Ck	2023	Novel proposal by LAC	$$$	augments flows with cool water that will quickly aerate	• low cost, fish spawning support • does not require releases from storage	• Wood Lake hypolimnion is profoundly anoxic and aeration baffles/structure would be needed at discharge point and infrastructure required • Potential of harmful off-gassing at the aeration point • recirculating high nutrient hypolimnion water back into photic zone of MVC/Wood Lake during peak growing season = prodigious algae growth • hypolimnion of Wood Lake contains elevated iron and manganese that would precipitate out in MVC • failure of aeration would lead to mortality event of fish in MVC, including juvenile Kokanee • During low-flow period. This could become primary source of flow in MVC	• now commercially available • could be trialled as a fish refugia and then expanded to lake restoration	**consider further**
	oxygen injection	1999	(Ashley & Nordin, 1999)	$$$$$	provides dissolved oxygen nanobubbles to deep water	• proven fish refugia capacity • ideal for localized refugia vs whole lake re-oxygenation • reduces sediment N, P release by 50% in unit's region • keeps stratification	• requires power, intake and discharge lines, etc. • expensive to build and operate • prone to equipment failure • pure oxygen tanks required are a fire/explosion hazard • likely multiple structures would be required throughout the lake to provide adequate refugia • structures could be targets for vandalism	• line diffuser systems are suitable for Wood Lake ~150 m dispersal area in deep water • fish refugia application	**consider further**
	hypolimnetic aeration	1974	(British Columbia Water Resources Service, 1974)	$$$$$($)	aerate the hypolimnion only with ~10 designed units	• increase fish habitat • lower sediment P release	• nitrogen super-saturation can occur • expensive to build and operate • cyanobacteria blooms can persist when high nutrient water is brough up to photic zone • to be effective it would require coverage of the whole lake which would be enormously expensive	numerous full or partial air-lift infrastructure designs available to release air microbubbles - expensive for entire lake so discrete area(s)	**consider further**
	sonic water treatment	2024	King, K.	$$$$$$	sonic waves disrupt the vacuoles of cyanobacteria causing them to sink and lowers bloom intensity	• no disruption of zooplankton or fish • no chemicals	• for a lake the size of Wood Lake, LGSONIC uses 50+ units - a navigation hazard • does not address nutrients, DO etc. • structures could be targets for vandalism	synchronized communication sonic units increases effectiveness but very expensive (>55,000 USD/unit + annual operating fees/repairs)	**X**
land use	riparian set-backs & greenbelts	1974	(British Columbia Water Resources Service, 1974)	$ -$$$	• riparian zones filter nutrients along creeks and lakeshores • a ban on fertilizer use within set-back helps	• aesthetic and habitat gains • lower nutrient loads N~75% P~66% • lower stream shoreline water temp	• none other than potential cost to purchase lands 15-30m on either side of streams • cliffs on east and west side of Wood Lake restrict width of riparian to very narrow band • lakeshore properties along south end of Wood Lake would likely resist to preserve their views • public beaches and road at north end of Wood Lake restrict riparian expansion there	recent research confirms need for >30 -50 m green belts to control nutrients but any interception helps	**implement**
	curtail development	1974	(British Columbia Water Resources Service, 1974)	$$	exceeding the residence carrying capacity of the Wood Lake watershed will damage the lake	less development would lessen the pressure on Wood Lake	• very unpopular politically unless part of a region-wide initiative • could exacerbate housing costs	contradicts BC's 2024 housing initiative	**consider further**

	Technique	Date	Source	Cost	Premise	Strengths	Weaknesses	Update as of 2024?	Action
	land use zoning lakeshore	1974	(British Columbia Water Resources Service, 1974)	$$	restrict shoreline development and preserve natural shoreline function	functioning shorelines benefit shorebirds, spawners, Wood Lake health	difficult to enforce	aerial drone imagery and mapping can help with monitoring of shoreline modification	underway
	public education	Ongoing	LAC	$	educating local and tourist population on risks to Wood Lake and how they can operate within its watershed to preserver and improve water quality	public education underpins most other proposed solutions because an informed and engaged public is essential for the acceptance of other solutions	• time consuming for busy staff		implement
	marina mooring buoy moratorium	2023	DLC	$	restricts damage to critical littoral sediments	prevents unrestricted use of ecologically important lake shallows	• pressure from developers and boating lobby • complicated jurisdictional issue to enforce this	more municipalities (e.g., DLC, Osoyoos) recognize the need for restrictions on boat proliferation and ad-hoc buoy placement	consider further
	agriculture/garden fertilizer use	1974	(British Columbia Water Resources Service, 1974)	$$	lowering fertilizer use on orchards, near-lake gardens, will lower the non-point source load to Wood Lake	fertilizer nutrients can be conserved - not wasted by leaching to Wood Lake; improves lake health	• need to educate land owners • fertilizer/pesticide use is difficult to enforce	sap analysis can determine plant needs for fertilizer - usually lowers the amount applied and improves plant health	consider further
	spray irrigation	1980>	(British Columbia Water Resources Service, 1974) | Others	$$$$$($)	use 2nd treated water to irrigate forage or other harvested crops to export nutrients		• more expensive than conventional disposal of treated effluent • nutrients can still report to Wood Lake via groundwater	long-term use of Vernon spray irrigation resulted in increased nutrients reporting to Kalamalka Lake	X
	grey water re-use	2017	(British Columbia Ministry of Health, 2017)	$	household/farm re-use of grey water recycles nutrients and lowers water demand	inexpensive, conserves nutrients and water at the household level	• small risk of contaminants from cleaning products, detergents • cannot be allowed to run off property • cannot be stored without treatment	avoid grey-water use if a household member is ill; avoid kitchen grey water with oils and fats	implement
	watershed protection	ongoing	TEK OBWB OCCP	$$-$$$$	preserves natural water condition and hydrograph	provides multiple ecological, habitat and economic benefits, including lake health	• Complicated multi-jurisdictional issue with many stakeholders pursuing their own agendas that may be incompatible with each other	Kalamalka Lake study group developing permanent TAC for Wood and Kalamalka Lakes	consider further
boating	restrict out of province power boats	2023	OBWB	$$$	large power boats are the primary carrier of aquatic invasives, so a ban slows aquatic invasive species (AIS) spread	a ban would slow or halt the spread of AIS	• will require enforcement • enforcement agency is unclear	as popularity of ever-bigger wake boats increases, so does the risk of introducing invasive mussels	consider further
boating	clean drain dry campaign	2000>	OBWB	$	limits the spread of AIS	educates public of risks to moving boats from lake to lake	needs occasional rebranding to maintain interest	proven effective at slowing the spread of AIS	underway
boating	wake control	2020>	DLC RDNO Nordin others	$	nutrients are readily released from boat wakes suspending Wood Lake sediments	fewer wakes mean less eutrophication, less habitat and shoreline erosion damage	will require boater buy-in and/or enforcement	education programs are underway, but the number of boats is increasing and may exceed carrying capacity of Wood Lake	underway
boating	reconsider canal dredging	1974	(British Columbia Water Resources Service, 1974)	$$	Boat traffic between Kalamalka and Wood Lakes is very high and already causes water quality issues at DLC intake in S-Kal. More and larger boats facilitated by deeper channel would likely lead to greater water quality impacts	• reduces presence of Eurasian milfoil in canal • lowers spread of invasive species	• dredging canal increases cyanobacteria and phosphorus donations from Wood Lake • increases boat traffic • decreases spawning habitat • dredging produces major sediment disturbance that could affect drinking water quality	• potential impact to South Kalamalka Lake from Wood Lake nutrients, algae and increased boating sediment disturbance • dredging has been approved by the province as of May 2024	consider further
water management	TEK - Siwlk	ongoing	ONA, OKIB	$$	Syilx siwlk water Declaration and Strategy lay out respectful conservation	• strategy lays out protections for water that are confirmed by Western science • focus on working together	• concerns about water scarcity and water rights need to be worked out • some impacts are almost impossible to reverse	awareness of and implementation of the strategy is ongoing	implement
water management	supplementing MV Ck inflow from Okanagan Lake	1974	(British Columbia Water Resources Service, 1974)	$$$$	return volumetric fluxes to pre-industrial rates	increasing flushing rate can lower nutrient concentrations in Wood Lake	will cause increased nutrient enrichment of Kalamalka Lake	South Kalamalka Lake has measurable deterioration from Wood Lake inflows and canal dredging may make this worse	X
water management	bypassing Duck Lake	1974	(British Columbia Water Resources Service, 1974)	$$$$$	Duck Lake is a key nutrient source to Wood Lake so bypass should lower Wood Lake nutrients	nutrients and cyanobacteria blooms should decrease in Wood Lake	• Duck Lake will deteriorate to an evaporative lake • fine sediments that currently deposit in Duck Lake will deposit in Wood Lake	• Duck Lake is currently under study by OKIB • Numerous stake holders would need to approve any changes to Duck Lake hydrology	consider further
water management	daylight Upper Vernon Ck	2023	King, K	$$$$$	return creek function to Upper Vernon Ck through DLC	• creek function could benefit kokanee spawning • improved aesthetics • moves towards Syilx water values	• would require displacing part of the DLC industrial area • contaminant cleanup possible • functionally similar to bypassing Duck-Lake	some interest by BC ENV but practical barriers	consider further
water management	mixing Kal and Wood lakes	1974; 2016	(British Columbia Water Resources Service, 1974); Young, 2016	$$$$	pump hypolimnetic water from Wood Lake to Kal hypolimnion for precipitation	this concept would export Wood Lake nutrients during stratified conditions and would represent a major nutrient injection into Kalamalka Lake	• this concept could exceed marl capacity & increase nutrient regime of South Kal Lake expensive • anoxic hypolimnion would create dead zone around plume	Kalamalka Lake is already showing increasing signs of excess nutrients	X

	Technique	Date	Source	Cost	Premise	Strengths	Weaknesses	Update as of 2024?	Action
	tunnel from Okanagan Lk	1974	(British Columbia Water Resources Service, 1974)	$$$$$$$	gravity feed high nutrient Wood water into low-nutrient cold Okanagan Lake deep water and pump back clean replacement water	reduce Wood nutrient condition, possibly aid with flood control	• tunnel construction cost-prohibitive • return pumping up 50m very expensive • massive nutrient contribution to Okanagan Lake • anoxic hypolimnion would create dead zone around plume • approvals of this from environmental regulators almost certainly rejected outright	still prohibitively expensive in 2024	X
Phosphorus control	stop-log Oyama Canal	1974	(British Columbia Water Resources Service, 1974)	$$$	restrict importing algae & nutrients (30% of Kal nutrients) from Wood to Kal during cyanobacteria blooms	would lower the measured impact of Wood Lake on South Kal Lake in summer	• prevents boat passage and blooms are now annual • possible fish obstruction	no longer workable due to increased cyanobacteria bloom frequency and duration	X
	alum (aluminum sulfate)	1976	BC Research	$$$$$	~50+% removal and immobilization of water column P with an ice-off application	lower pH and P removal should halt cyanobacteria blooms, intensity of anoxic zone	1100 tons of alum required for Wood Lake (2-5 mg/cm2 dose) must be re-applied every 5-10 years	alum applications have proven more expensive than aeration systems in the long term	X
	hypolimnion iron application	1987	(Nordin, 1987)	$$$$	Fe restricts anoxic P regeneration from low Fe Wood Lake sediments	• Fe from steel treatment injected to anoxic hypolimnion (50 tons Fe binds 5 tons P) • FeCl 50 tons at ~$7000/ton	• needs to be applied every 5 - 10 years initially until Fe accumulates in sediments • H2S inhibits Fe-P removal • public concern	• needs field trial to verify favorable 1987 bench results before full scale treatment • reported field trials had variable results	**consider further**
	ammonium nitrate	1982	(Gray & Jasper, 1982)	$$$$	fertilize hypolimnion in spring with N to disadvantage cyanobacteria, sediment diatoms, accelerate denitrification	can oxidize sediments, lowering net nutrient load returned to the water column	• not widely used so research is sparse • Wood Lake is not N limited in the spring, but rather in the summer after N has been consumed by spring bloom.	not widely used; research is sparse and research results are often negative	X
	Liming CaCO3 addition (marl)	1974	(British Columbia Water Resources Service, 1974)		increasing marl events, phosphorus precipitates down to the bottom and coats sediments	enhances natural processes for marl -P precipitation, could increase the frequency of attractive marl events	• ~ 5000 - 8000 tons required (>500 dumptruck loads) • most of the applications are on acidified lakes which Wood Lake is not	• the amount of lime is prohibitive • effectiveness can be poor in hard water lakes	X
	aeration	see top section of this table							
	TEK prescribed burning	ongoing	Polis Wildfire Project 2024	$$$	TEK prescribed burns limit ashfall P from major wildfires	TEK prescribed burns limit ecological damage while lowering fuel loads	there are narrow weather windows for TEK prescribed burns to manage risks	Polis research strongly concurs with TEK	**underway**
	convert septic fields to secondary treatment	1974	(British Columbia Water Resources Service, 1974)		septic tanks were formerly estimated to contribute 45% N and 62% P of Wood Lake external nutrient budget (Winfield area)	lowers nutrient effluent concentrations and non-point source loading to Wood Lake	• expensive • facilitates developments in Wood Lake watershed - increases total nutrient load	• thoroughly proven to lower non-point source nutrient loading to water bodies. • all urban areas within Lake Country that are within Wood Lake watershed are currently on sewer. • rural east bench of Wood Lake does not have sewer	**Done**
	Deep lake WWTP discharge	Ongoing	many researchers | Urban Systems	$$$$$$	WWTP > ground injection + pipe to Kelowna WWTP or Okanagan Lake	• far lower nutrients to lakes compared to septic field use • exports nutrients away from Wood Lake	facilitates development in Wood Lake watershed - increases pressure	• Environmental impact assessment for deep lake outfall is under consideration by BC ENV • DLC currently pumps excess treated wastewater to City of Kelowna	**underway**

Cost	Legend
$	negligible
$$	< 100,000
$$$	< 500,000
$$$$	< million
$$$$$	few million
$$$$$$	many millions
$$$$$$$	prohibitive

Next Steps

This study identifies a number of next steps for works on and around Wood Lake such as

- Begin to pursue realistically achievable options listed in Table 8 such as:
  Wood Lake Watershed Options:
  - Riparian setbacks and revegetation of tributaries and shoreline
  - Educate residents and guests on Wood Lake condition to encourage stewardship
  - Greywater reuse programs to reduce pressure on WWTP
  - Prescribed burning in watershed to limit wildfire risk

  Wood Lake Options
  - Engage with Syilx water declaration and processes such as the kɬúsx̌nítk (Okanagan Lake) Watershed Responsibility Planning Initiative
  - Boating education programs to encourage responsible boating near shore and around Oyama Canal, wake surfing in 8+ m water depth, Clean Drain Dry, I'm a Wake. Etc.
- Pursue further investigations on viability of other treatment options
  - Localized aeration for fish refugia
  - Trial FeCl removal of P from Wood Lake using bench trials
- Continue to monitor condition of Wood Lake to track further changes
- Repeat sediment coring assessment every 5 years
- Patch data gaps:
  - Wood Lake marl history: publish and maintain archive of marl years

References

Ashley, K., & Nordin, R. (1999). Lake aeration in British Columbia: Applications and experiences. In T. Murphy & Munawar M (Eds.), *Aquatic Restoration in Canada* (pp. 87–108).

B.C. Research. (1974). *Water Quality of the Kalamalka-Wood Lake Basin*.

Berry, J. (2013). Cyanobacterial Toxins in Food-Webs: Implications for Human and Environmental Health. *Current Topics in Public Health*. https://doi.org/10.5772/55111

BoatDriving.org. (n.d.). *How Much Does A Boat Cost?* Retrieved May 21, 2024, from https://www.boatdriving.org/average-boat-price/#:~:text=Research%20shows%20that%20the%20average,than%20an%20average%20American%20vehicle!

British Columbia Government. (2024). *Water Rights Licences - Public*. https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights

British Columbia Ministry of Health. (2017). *HEALTH INFORMATION: GREY WATER RE-USE HEALTH PROTECTION BRANCH MINISTRY OF HEALTH*.

British Columbia Water Resources Service. (1974). *Kalamalka-Wood Lake Basin Water Resource Management Study*.

Bryan, J. E. (1990). *Water Quality of Okanagan, Kalamalka, and Wood Lake*.

Burge, D. R. L., Edlund, M. B., & Frisch, D. (2018). Paleolimnology and resurrection ecology: The future of reconstructing the past. *Evolutionary Applications*, *11*(1), 42. https://doi.org/10.1111/EVA.12556

Canada-British Columbia Consultative Board. (1974). *1974 Okanagan Basin Study Summary Report*. https://www.obwb.ca/fileadmin/docs/1974_Basin_Study_Summary_Report.pdf

Chia, M. A., Abdulwahab, R., Ameh, I., Balogun, J. K., & Auta, J. (2021). Farmed tilapia as an exposure route to microcystins in Zaria-Nigeria: A seasonal investigation. *Environmental Pollution*, *271*. https://doi.org/10.1016/j.envpol.2020.116366

Christensen, V. G., & Khan, E. (2020). Freshwater neurotoxins and concerns for human, animal, and ecosystem health: A review of anatoxin-a and saxitoxin. *Science of the Total Environment*, *736*. https://doi.org/10.1016/j.scitotenv.2020.139515

Clemens, W. A., Rawson, D. S., & McHugh, J. L. (1939). *Biological Survey of Okanagan Lake B.C.* http://a100.gov.bc.ca/appsdata/acat/documents/r1954/oklkstudy_1362690263031_964b8eb84253194546e8eed7b6cea9606f70d159938f36e216459469b9d7bcce.pdf

Cvetkoska, A., Levkov, Z., Hamilton, P. B., & Potapova, M. (2014). The biogeographic distribution of Cavinula (Bacillariophyceae) in North America with the descriptions of two new species. *Phytotaxa*, *184*(4), 181. https://doi.org/10.11646/phytotaxa.184.4.1

de Almeida, É. C., Passos, L. S., de Freitas, P. N. N., de Souza, A. O., & Pinto, E. (2024). Impacts of cyanobacterial metabolites on fish: Socioeconomic and environmental considerations. In *Reviews in Aquaculture*. John Wiley and Sons Inc. https://doi.org/10.1111/raq.12891

District of Lake Country. (2022). *Lake Country, British Columbia, 2021 Annual Report*. https://issuu.com/lakecountry/docs/annual_report_2021_draft

District of Lake Country. (2023a). *2023 Financial Plan*. https://pub-lakecountry.escribemeetings.com/filestream.ashx?DocumentId=3283

District of Lake Country. (2023b). *2023-Tax-Rates-Bylaw-1206-2023*. https://www.lakecountry.bc.ca/en/business-information/resources/Document-Manager/Bylaws/2023-Tax-Rates-Bylaw-1206-2023.pdf

Drobac Backović, D., & Tokodi, N. (2024). Cyanotoxins in food: Exposure assessment and health impact. *Food Research International*, *184*. https://doi.org/10.1016/j.foodres.2024.114271

Drobac, D., Tokodi, N., Kiprovski, B., Malenčić, D., Važić, T., Nybom, S., Meriluoto, J., & Svirčev, Z. (2017). Microcystin accumulation and potential effects on antioxidant capacity of leaves and fruits of Capsicum annuum. *Journal of Toxicology and Environmental Health - Part A: Current Issues*, *80*(3), 145–154. https://doi.org/10.1080/15287394.2016.1259527

Francis, J., Nohner, J., Bauman, J., & Gunderman, B. (2023). *FISHERIES DIVISION STATE OF MICHIGAN DEPARTMENT OF NATURAL RESOURCES M IC HIGA N FISHERIES REPORT 37 A Literature Review of Wake Boat Effects on Aquatic Habitat*. www.michigan.gov/dnr/

Garita-Alvarado, C. A., Bojorge-García, M. G., & Cantoral Uriza, E. A. (2023). Cyanotoxins bioaccumulation in freshwater ecosystems in Latin America: a review. *Hidrobiologica*, *33*(3), 353–365. https://doi.org/10.24275/CSUP3520

Graham, S. (2023). *WASTEWATER TREATMENT PLANT 2022 ANNUAL REPORT DISTRICT OF LAKE COUNTRY*.

Gray, C. B. J., & Jasper, S. (1982). *Limnological Trends in Wood Lake B.C. (1971 – 1981) With Some Implications for Lake Management*.

ILEC. (n.d.). *Wood Lake Database*. International Lake Environmental Committee Foundation (ILEC). Retrieved January 23, 2024, from https://wldb.ilec.or.jp/Display/html/3453

InterVistas. (2023). *2022 Economic Impact of Tourism in the Greater Kelowna Area Prepared for Tourism Kelowna*.

I.R. Walker, E.D. Reavie, S. Palmer, R. N. N. (1993). A Palaeoenvironmental Assessment of Human Impact on Wood Lake, Okanagan Valley, British Columbia. *Quaternary International*, *20*, 51–70. https://www.researchgate.net/profile/Euan_Reavie/publication/223514412_A_palaeoenvironmental_assessment_of_human_impact_on_Wood_Lake_okanagan_valley_British_Columbia_Canada/links/59e4da5d458515250246e697/A-palaeoenvironmental-assessment-of-human-impact-on

Jensen, E. V, & Bryan, J. E. (2001). *Water Quality Trends In Kalamalka, Wood, and Ellison Lakes 1969 To 1999*.

Kozlowsky-Suzuki, B., Wilson, A. E., Da, A., & Ferrão-Filho, S. (2012). Biomagnification or biodilution of microcystins in aquatic foodwebs? Meta-analyses of laboratory and field studies. *Harmful Algae*, *18*, 47–55. https://doi.org/10.1016/j.hal.2012.04.002

Lu, X., Ma, Z., Yi, L., Zhang, G., Chen, F., & Han, F. (2021). The Composition and Distribution of Volatile Organic Compounds in Sediments of the East Taijinar Salt Lake in Northern Qinghai-Tibet Plateau. *Frontiers in Environmental Chemistry*, *2*, 11. https://doi.org/10.3389/FENVC.2021.653867

Mutoti, M., Gumbo, J., & Jideani, A. I. O. (2022). Occurrence of cyanobacteria in water used for food production: A review. In *Physics and Chemistry of the Earth* (Vol. 125). Elsevier Ltd. https://doi.org/10.1016/j.pce.2021.103101

Nordin, R. (1985). *Water Quality Criteria for Nutrients and Algae. Overview Report.*

Nordin, R. (1987). *Wood Lake: A Proposal For A Demonstration Project For Water Quality Improvement*.

Okanagan Basin Water Boa. (2024). *Preparing for Invasive Mussels: Vulnerability Assessment Guide for Raw Water Infrastructure*.

Okanagan Basin Water Board. (2024). *Okanagan Basin Water Quality and Climate Indicators Dashboard*.

Schlegel, I., Koschel, R., & Krienitz, L. (1998). On the occurrence of Phacotus lenticularis (Chlorophyta) in lakes of different trophic state. *Hydrobiologia*, *369–370*, 353–361. https://doi.org/10.1023/A:1017019925927

Schleppe, J., Larratt, H., & Plewes, R. (2016). *Kalamalka and Wood Lake Boat Capacity Study on Source Waters*.

Schleppe, J., Larratt, H., & Plewes, R. (2017). *Kalamalka and Wood Lake Boat Capacity Study on Water Sources*. http://a100.gov.bc.ca/appsdata/acat/documents/r52567/16-1796-BoatCapacityReport-FINAL-Mar.14.2017_1499805760065_9804505186.pdf

Sébastien Raymond, P., & Galvez-Cloutier, R. (2015). *IMPACT DE LA NAVIGATION EN MILIEU LACUSTRE - ÉTUDE SUR LA REMISE EN SUSPENSION DES SÉDIMENTS : CAS DU LAC MASSON ET DU LAC DES SABLES (Impact of lake navigation—sediment suspension study: Lake Masson and Sand Lake cases)* [Ph.D, Université Laval]. https://www.lacdessablesapels.com/wp-content/uploads/2019/10/U-Laval-wake-boats-Rapport_final-02-12-15.pdf

Self, J., & Larratt, H. (2016). *Long-term Water Quality Trends, Nutrient Budgets, and Cyanobacteria Blooms as they Affect the Kokanee Fishery of Wood Lake*.

Self, J., & Larratt, H. (2020a). *2019 Kalamalka Lake Boating Impact Study*.

Self, J., & Larratt, H. (2020b). *Kalamalka Lake Water Quality Study - Microflora, Water Chemistry & Thermal Profiles - 2019*.

Shahmohamadloo, R. S., Bhavsar, S. P., Ortiz Almirall, X., C, S. A., Rudman, S. M., & Sibley, P. K. (2023). Lake Erie fish safe to eat yet afflicted by algal hepatotoxins. *Science of the Total Environment*, *561*. https://doi.org/10.1101/2022.06.07.495188

Shahmohamadloo, R. S., Bhavsar, S. P., Ortiz Almirall, X., Marklevitz, S. A. C., Rudman, S. M., & Sibley, P. K. (2023). Cyanotoxins accumulate in Lake St. Clair fish yet their fillets are safe to eat. *Science of the Total Environment*, *874*. https://doi.org/10.1016/j.scitotenv.2023.162381

Shahmohamadloo, R. S., Ortiz Almirall, X., Simmons, D. B. D., Poirier, D. G., Bhavsar, S. P., & Sibley, P. K. (2022). Fish tissue accumulation and proteomic response to microcystins is species-dependent. *Chemosphere*, *287*, 132028. https://doi.org/10.1016/j.chemosphere.2021.132028

St John, B. E. (1973a). *PRELIMINARY REPORT N0.18 The Limnogeology of the Okanagan Mainstem Lakes PREPARED FOR THE OKANAGAN STUDY COMMITTEE CANADA-BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT TASK 121 The Limnogeology of the Okanagan Mainstem Lakes*.

St John, B. E. (1973b). *The Limnogeology of the Okanagan Mainstem Lakes, Preliminary Report No. 18*. *18*.

Statistics Canada. (2022, February 9). *Population and dwelling counts: Canada and aggregate dissemination areas*. 2021 Canadian Census.

Statistics Canada. (2023). *Census Profile, 2021 Census of Population* . https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=Lake%20Country&DGUIDlist=2021A00055935016&GENDERlist=1,2,3&STATISTIClist=1&HEADERlist=0

Stockner, J. G., & Northcote, T. G. (1974). *RECENT LIMNOLOGICAL STUDIES OF OKANAGAN BASIN LAKES CONTRIBUTION TO COMPREHENSIVE WATER RESOURCE PLANNING*.

Sundaravadivelu, D., Sanan, T. T., Venkatapathy, R., Mash, H., Tettenhorst, D., Danglada, L., Frey, S., Tatters, A. O., & Lazorchak, J. (2022). Determination of Cyanotoxins and Prymnesins in Water, Fish Tissue, and Other Matrices: A Review. In *Toxins* (Vol. 14, Issue 3). MDPI. https://doi.org/10.3390/toxins14030213

Tourism Kelowna. (2022, January 31). *The Value of Tourism: Lake Country Spotlight*.

Walker, I. R., Reavie, E. D., Palmer, S., & Nordin, R. N. (1993). A palaeoenvironmental assessment of human impact on Wood Lake, okanagan valley, British Columbia, Canada. *Quaternary International*, *20*(C), 51–70. https://doi.org/10.1016/1040-6182(93)90036-F

Wiik, E., Bennion, H., Sayer, C. D., & Willby, N. J. (2013). Chemical and Biological Responses of Marl Lakes to Eutrophication. *Freshwater Reviews*, *6*(2), 35–62. https://doi.org/10.1608/FRJ-6.2.630

Appendices

Appendix 1: Sampling Data

See companion document "Appendix 1 - Wood Lake Report 2023 Sampling Data.pdf"

Appendix 2: Water Quality Guidelines

Table A 1: Canadian and British Columbia Drinking Water Guidelines and Aesthetic Objectives

Parameter	CDWG	CDWG Aesthetic Objective	BC Drinking Water	BC Aesthetic Objective
Chloride		250		250
Colour		15		15
E. coli	0/100 mL		< 10 / 100 mL (minimum of 5 samples)	
Enterococci			< 3 / 100 mL	
Enteric Protozoa	Minimum 3 log removal and/or inactivation of cysts and oocysts			
Enteric Viruses	4 log reduction (removal and or inactivation)			
Fluoride	1.5		1.5	
Nitrate	10 Reported as N 45 Reported as Nitrate		10 Reported as N 45 Reported as Nitrate	
Nitrite	1 Reported as N 3 Reported as Nitrite		1 Reported as N 3 Reported as Nitrite	
pH		7-10.5		
SO4		500		500
TDS		500		
Temperature		15		15
TOC			4	
Total Aluminum	2.9		9.5	
Total Antimony*	0.006		0.006	
Total Arsenic*	0.01		0.01	
Total Atrazine*	0.005			
Total Barium	2			
Total Benzene	0.005		0.005	
Total Boron*	5		5	
Total Bromate	0.01			
Total Cadmium	0.007		0.005	
Total Chromium	0.05		0.05	
Total Cobalt			0.001	
Total Coliforms	0/100 mL in water leaving a treatment plant and in			

Parameter	CDWG	CDWG Aesthetic Objective	BC Drinking Water	BC Aesthetic Objective
	non-disinfected groundwater leaving well			
Total Copper	2	1	2	1
Total Cyanide	0.2		0.2	
Total Haloacetic Acids*	0.08 ALARA			
Total Iron*		0.3		0.3
Total Lead	0.005 ALARA		0.005	
Total Manganese	0.12	0.02	0.12	0.02
Total Malathion*	0.19			
Total Mercury	0.001		0.001	
Total Molybdenum			0.088	
Total Nickel			0.08	
Total Phosphorous				0.01
Total Selenium	0.05		0.01	
Total Sodium		200		
Total Strontium	7		7	
Total Sulphide		0.05		
Total Uranium	0.02		0.02	
Total Xylenes	0.09	0.02	0.09	0.02
Total Zinc		5	3	5

Note: * = Health Canada is developing or updating guidelines and guidance over the new few years

Note: Updated 2023

Table A 2: BC water quality guidelines for primary contact recreational uses

Parameter	Recreational Water Quality Guidelines	Guideline Source
Monochlorophenol	0.0001 mg/L	ENV 1997a
Total Dichlorophenols	0.0003 mg/L	ENV 1997a
Total Trichlorophenols	0.002 mg/L	ENV 1997a
Total Tetrachlorophenols	0.001 mg/L	ENV 1997a
Pentachlorophenol	0.03 mg/L	ENV 1997a
Chlorophyll-a	50 mg/m^2 (streams)	ENV 1985
Colour, True	15 TCU (aesthetic Objective); mean (minimum of 5 samples in 30 days)	ENV 1997b
Cyanobacterial toxins: Total cyanobacteria or total microcystins	100 000 cells/mL OR 0.02 mg/L (expressed as microcystin-LR)	Health Canada 2012
Methyl Tertiary Butyl Ether (MTBE)	0.02 mg/L	ENV 2001
Microbial Indicators		
Escherichia Coli	≤ 200 *E. coli* /100 mL; geometric mean concentration (minimum of 5 samples*) or, ≤ 400 *E. coli* /100 mL; single sample maximum concentration (units will depend on whether the multiple-tube fermentation method (MPN/100 mL) or the membrane filtration method (*E. coli*/100 mL) is used).	Health Canada 2012
Enterococci	≤ 35 Enterococci /100 mL; geometric mean concentration (minimum of 5 samples*), or, ≤ 70 Enterococci /100 mL; single sample maximum concentration (units will depend on whether the multiple-tube fermentation method or the membrane filtration method is used).	Health Canada 2012
Nitrate	45 mg/L (nitrate) 10 mg/L (nitrate-N)	ENV 2009
Nitrite	3.0 mg/L (nitrite) 1.0 mg/L (nitrite-N)	ENV 2009
pH	5.0 – 9.0	Health Canada 2012
Phosphorous	0.01 mg/L (lakes)	ENV 1985
Temperature	Should not cause an appreciable increase or decrease in the deep body temperature of swimmers.	Health Canada 2012
Turbidity	50 NTU (aesthetic objective)	Health Canada 2012

Source: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/drinking-water-and-recreation/recreational_water_quality_guidelines_bcenv.pdf

Appendix 3: Water Parameters Collected by LAC

Table A 3: Water parameters collected by LAC

Parameter	Units	Date Range
Algae	cells/mL	2005-2023
Alkalinity	mg/L	2005-2006, 2008-2010, 2012, 2014, 2016-2023
Background Colonies	CFU/100mL	2010, 2012-2019
Chloride	mg/L	2005-2006, 2008-2023
Chlorophyll-a	µg/L	2005-2006, 2008-2023
Conductivity	µS/cm	2005-2006, 2008-2023
Conductivity Adjusted	µS/cm	2011-2023
Density	g/cmÂ³	2022-2023
Dissolved Oxygen	mg/L	2005-2006, 2009-2023
Dissolved Oxygen Percent	%	2011-2023
E. coli	CFU/100mL	2008-2023
Hardness	mg/L	2005-2006, 2008-2010, 2012, 2014, 2016-2023
ORP	mV	2011-2018, 2022-2023
pH	--	2005-2006, 2008-2023
Salinity	PSU	2001, 2013-2023
Secchi	m	2005-2006, 2009-2010, 2012-2023
SO4	mg/L	2005-2006, 2008-2010, 2012-2014, 2016-2023
Temperature	°C	2005-2006, 2009-2023
TDS	mg/L	2011-2023
TOC	mg/L	2005-2006, 2008-2023
Total Aluminum	mg/L	2018-2023
Total Antimony	mg/L	2018-2023
Total Arsenic	mg/L	2018-2023
Total Barium	mg/L	2018-2023
Total Beryllium	mg/L	2018-2023
Total Bismuth	mg/L	2018-2023
Total Boron	mg/L	2018-2023
Total Cadmium	mg/L	2018-2023
Total Calcium	mg/L	2005-2006, 2008-2010, 2012-2014, 2016-2023
Total Chromium	mg/L	2018-2023
Total Cobalt	mg/L	2018-2023
Total Coliforms	CFU/100mL	2008-2023
Total Copper	mg/L	2018-2023
Total Iron	mg/L	2005, 2015-2023
Total Lead	mg/L	2018-2023
Total Lithium	mg/L	2018-2023
Total Magnesium	mg/L	2008-2010, 2012, 2014-2023
Total Manganese	mg/L	2018-2023
Total Molybdenum	mg/L	2018-2023
Total Nickel	mg/L	2018-2023

Parameter	Units	Date Range
Total Potassium	mg/L	2018-2023
Total Selenium	mg/L	2018-2023
Total Silicon	mg/L	2018-2023
Total Silver	mg/L	2005-2006, 2008-2023
Total Sodium	mg/L	2018-2023
Total Strontium	mg/L	2018-2023
Total Sulfur	mg/L	2018-2023
Total Tellurium	mg/L	2018-2023
Total Thallium	mg/L	2018-2023
Total Thorium	mg/L	2018-2023
Total Tin	mg/L	2018-2023
Total Titanium	mg/L	2018-2023
Total Tungsten	mg/L	2018-2023
Total Uranium	mg/L	2018-2023
Total Vanadium	mg/L	2018-2023
Total Zinc	mg/L	2018-2023
Total Zirconium	mg/L	2018-2023
Total Phosphorus	mg/L	2018-2023
TSS	mg/L	2005-2006
Turbidity	NTU	2005-2006, 2008-2023
UVT	%	2005-2006, 2008-2023

Appendix 4: Common cyanobacteria in Wood Lake

Table A 4: Common cyanobacteria found in Wood Lake and associated known toxins

Cyanobacteria	Toxin(s)	Type of toxin(s)
Anabaena sp.	LYN*, LPS, CYN, MC, ATX, STX, and BMAA	Dermal, liver, and nerve toxins
Anacystis sp.	LYN*, LPS, MC, NOD*, ATX, and BMAA	Dermal, liver, and nerve toxins
Aphanizomenon sp.	LYN*, LPS, CYN, MC, NOD, ATX, STX, and BMAA	Dermal, liver, and nerve toxins
Aphanocapsa sp.	LYN*, LPS, MC, and BMAA	Dermal, liver, and nerve toxins
Aphanothece sp.	MC*	Liver toxins
Chroococcus sp.	MC* and BMAA	Liver and nerve toxins
Gloeotrichia sp.	LYN*, MC, and BMAA	Dermal, liver, and nerve toxins
Gomphosphaeria sp.	MC	Liver toxins
Limnothrix sp.	MC, STX, and BMAA	Liver and nerve toxins
Lyngbya sp.	LYN, APL, LPS, CYN, MC, ATX, STX, and BMAA	Dermal, liver, and nerve toxins
Merismopedia sp.	MC and BMAA	Liver and nerve toxins
Microcystis sp.	LYN*, LPS, MC, NOD*, ATX, and BMAA	Dermal, liver, and nerve toxins
Oscillatoria sp.	LYN, APL, LPS, CYN*, MC, ATX, STX, and BMAA	Dermal, liver, and nerve toxins
Phormidium sp.	LYN, LPS, MC, NOD*, ATX, STX, and BMAA	Dermal, liver, and nerve toxins
Planktothrix sp.	LYN, APL, LPS, MC, ATX, STX, and BMAA	Dermal, liver, and nerve toxins
Planktolyngbya sp.	LYN, MC, and BMAA	Dermal, liver, and nerve toxins
Pseudanabaena sp.	LYN*, LPS, MC, ATX*, and BMAA	Dermal, liver, and nerve toxins
Spirulina sp.	MC, ATX*, and BMAA	Liver and nerve toxins
Snowella sp.	LPS, MC, and NOD*	Dermal and liver toxins
Synechococcus sp.	LPS, MC, ATX* and BMAA	Dermal, liver, and nerve toxins

Notes:

LYN = Lyngbyatoxin-a (dermal toxin)
APL = Aplysiatoxin (dermal toxin)
LPS = Lipopolysaccharide(s) (dermal toxin)
CYN = Cylindrospermopsin (liver toxin)
MC = Microcystin (liver toxin, carcinogenic)
NOD = Nodularins (liver toxin, carcinogenic)
ATX = Anatoxin-a (nerve toxin)
STX = Saxitoxin (nerve toxin)
BMAA = β-Methylamino-L-alanine (nerve toxin, carcinogenic)
* = Not all authors list this toxin for the cyanobacteria species

Appendix 5: Cyanobacteria Alert Level Boundaries

Alert Level Boundaries used throughout this report were created by Heather Larratt, the senior biologist of LAC (Figure 47). 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:

- Anderson-Abbs, B., Howard, M., Taberski K., and Worcester, K. 2016. California Freshwater Harmful Algal Blooms Assessment and Support Strategy. Prepared for California State Water Resources Control Board. SWAMP-SP-SB-2016-0001 39 p
- Chorus, I. and J. Bartram. 1999. Toxic Cyanobacteria in Waters: a Guide to Public Health. Significance, Monitoring and Management, London: The World Health Organization E and FN Spon.
- Berg M and Sutula M. 2015. Factors affecting the growth of cyanobacteria with special emphasis on the Sacramento-San Joaquin Delta. Southern California Coastal Water Research Project Technical Report 869 August 2015.
- O'Neil, J.M., T.W. Davis, M.A. Burford, C.J. Gobler, 2012. The rise of harmful cyanobacteria blooms: the potential roles of eutrophication and climate change. Harmful Algae 14, 313-334.
- Quiblier, C., Wood, S.A., Echenique, I., Heath, M., Humbert, J.F., 2013. A review of current knowledge on toxic benthic freshwater cyanobacteria – Ecology, toxin productions and risk management. Water Research. 47(15), 5464-5479.
- Wood, S.A., Wagenhoff, A., Young, R.G., Roygard, J., 2014. The effect of river flow and nutrients on Phormidium abundance and toxin production in rivers in the ManawatuWhanganui Region. Prepared for Horizon Regional Council. Cawthron Report No. 2575. 46 p.
- Paerl, H.W., Gardner W., Havens K., Joyner A., McCarthy M., Newell S., Qin B., and Scott T. (2016). Mitigating cyanobacterial harmful algal blooms in aquatic ecosystems impacted by climate change and anthropogenic nutrients. Harmful Algae. 54: 213-222.
- Paerl, H.W. and T.G. Otten. 2013. Harmful Cyanobacterial Blooms: Causes, Consequences, and Controls. Microbial Ecology. 65: 995-1010.
- Carmichael, W., 2008. A world overview – One-hundred-twenty-seven years of research on toxic cyanobacteria – Where do we go from here? In Hudnell, H.K., (ed.), Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs, Springer, New York, pp. 105-125.
- Global Water Research Coalition. (2009). *International Guidance Manual for The Management of Toxic Cyanobacteria*.
- Bureau of Environmental and Occupational Health. (2019). *HARMFUL ALGAL BLOOMS TOOLKIT A planning guide for public health and emergency response professionals*.
- Chorus, I., & Welker, M. (2021). Toxic Cyanobacteria in Water - Second Edition. *World Health Organization*. https://doi.org/10.1201/9781003081449
- Joab, C., Chetelat, G., Geologist, E., Newsom, G., Longley, K., Ramirez, C., Bradford, V.-C. M., Brar, R., Kadara, D., Marcum, D., & Pulupa, P. (2019). *Regional Water Quality Control Board Central Valley Region Nonpoint Source 319(H) Program Cyanobacteria and Harmful Algal Blooms Evaluation Project Harmful Algal Bloom Primer Report Prepared By: Regional Water Quality Control Board Central Valley Region*.

- Wyoming Department of Environmental Quality. (2021). *Harmful Cyanobacterial Bloom (HCB) Action Plan for Publicly Accessible Waterbodies in Wyoming in cooperation with: Wyoming Department of Health Wyoming Livestock Board*.

	Phytoplankton cyanobacteria	Periphyton cyanobacteria	Phormidium cyanobacteria	Didymosphenia geminata
All Good Risk is negligible to nil	Harmful cyanobacteria <500 cells/mL	Harmful cyanobacteria < 1-4x10^6 cells/cm^2 (<2 ug/cm^2 chl-a)	Phormidium substrate coverage <20%	Didymo coverage of substrate is 0 - 15%
Alert level 1 Risk is low	Harmful cyanobacteria >500 but <2000 cells /mL (~1-5 ug/L chl-a)	Harmful cyanobacteria ~ 4-8x10^6 cells/cm^2 (~2-5 ug/cm^2 chl-a)	Phormidium substrate coverage ~20-30%	Didymo substrate coverage 16-25%
Alert level 2 Risk is significant	Harmful cyanobacteria >15,000 cells/mL (>5-20 ug/L chl-a)	Harmful cyanobacteria 1-5x10^7 cells/cm^2 (>5 -10 ug/cm^2)	Phormidium substrate coverage ~30-50%	Didymo substrate coverage ~26-50%
Alert level 3 Risk is high	Harmful cyanobacteria >50,000-100,000 cells/mL (20-50 ug/l chl-a)	Harmful cyanobacteria >5x10^7 cells/cm^2 (>10-30+ ug/cm^2 chl-a)	Phormidium substrate coverage >50%	Didymo substrate coverage >50 -75 %

Figure 47: Alert Level Boundaries

Appendix 6: Report Revision History

Revision History				
Version	Date	Prepared By	Reviewed By	Notes/Revisions
Draft	May 23 2024	JS/CV/SK	HL	Draft for DLC review
Draft	June 18 2024	S Graham	JS	Draft returned to LAC
Final	June 21 2024	JS		Final Supplied to DLC

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