LARRATT AQUATIC

Okanagan Lake Collaborative Monitoring Agreement
2022 Summary Report

Prepared for:
Okanagan Basin Water Board
BC Ministry of Environment and Climate Change Strategy

Larratt Aquatic Consulting Ltd. 2605 Campbell Rd. West Kelowna B.C. V1Z 1T1
Phone: 250.769.5444 www.lakebiology.ca

Executive Summary

The British Columbia Ministry of Environment and Climate Change Strategy (BC ENV) in partnership with local municipalities, commissioned an annual collaborative monitoring program to sample water quality in Okanagan Lake every year since 2011. Now operated by the Okanagan Basin Water Board (OBWB), sampling occurred monthly from March to September at four locations in 2022.

A primary function of the monitoring was to determine attainment of Okanagan Lake water quality objectives, along with increasing the temporal resolution of water quality data for Okanagan Lake, specifically with the goal of determining trends in nutrient and biological data. Similar to previous years, parameters such as temperature and dissolved oxygen were measured throughout the water column as well as several chemical parameters including silica, nitrogen, and phosphorus at discrete depths. Biological data including phytoplankton and zooplankton biomass with taxonomic identification were also collected. This report summarizes the 2022 findings and sets these recent data within the context of this program (2011-2022).

The results to date indicate that the Armstrong Arm is the most impacted by human activities and watershed degradation. These impacts include including agriculture, cattle range, logging, septic systems adjacent to the shoreline, and now the White Rock Lake wildfire. This site had the most exceedances and the most parameters trending towards greater exceedances. Weather was the dominant factor on water quality at Okanagan Centre, Kelowna, and Summerland but long-term data still demonstrates human impacts.

Physical

Okanagan Lake is usually stratified from May to November, it mixes in mid-November and then freely mixes over the winter. Secchi depth was highest in late winter and decreased each spring in response to increased phytoplankton activity. Water clarity was typical for Okanagan Lake in 2022. Armstrong Arm and Summerland failed to meet the Secchi depth objective in 2022.

Chemical

Dissolved oxygen (DO) is essential for all aquatic animals and is high throughout Okanagan Lake at all times except in the hypolimnion of the Armstrong Arm where DO fell below the water quality objective each summer including 2022. Silica, an important micronutrient, had stable concentrations in Okanagan Lake over the past 20 years.

Total nitrogen (TN) exceeded the objective at all sites during 2022 as it did in most years. There were significant increasing trends in TN from 2011-2022 at Kelowna, Okanagan Centre, and Armstrong Arm, driven in part by a decades-long increasing trend in nitrate in the deep water of Okanagan Lake. This increasing nitrate trend has continued through multiple wet-dry climate cycles and is likely caused by increasing human impacts within the Okanagan region and possibly also climate change.

Total phosphorus (TP) had a year-over-year increasing trend at all sites from 2011-2022, and forms part of a longer-term trend since the mid-2000s. TP includes phosphorus associated with suspended sediment carried into the lake. It increased in Okanagan Lake during wet years such as 2017-2018 and decreased during dry years such as 2019 and 2021. Dissolved phosphorus is less affected by freshets than TP and was stable or declining at the three main basin sites while it also increased in the Armstrong Arm.

The ratio of total nitrogen to total phosphorus (N:P) available to phytoplankton will play a major role in which types of phytoplankton proliferate in a lake. A lower N:P ratio (abundant phosphorus relative to nitrogen) will favour the growth of cyanobacteria. The N:P ratio failed to meet the objective in the Armstrong Arm in 2022 with a downwards trend at all sites (farther from meeting objective).

Biological

Chlorophyll-a was used as a measure of photosynthetic activity in Okanagan Lake. A decreasing north to south trend in the chlorophyll-a data occurred over the course of this study. All sites met the chlorophyll-a objectives during 2022. However, a significant increasing trend occurred at Kelowna, Okanagan Centre, and Armstrong Arm from 2011-2022, part of a trend since the mid-2000s.

Phytoplankton abundance during 2022 was high compared to 2011-2021 because of elevated cyanobacteria densities. All sites met the phytoplankton biovolume objective but failed to meet the phytoplankton taxonomy objective during 2022 because of elevated cyanobacteria densities, particularly the Armstrong Arm.

Zooplankton biomass met the objective at Okanagan Centre in 2022. All sites failed to meet the objective of >5% cladocerans in some samples during 2022. A decline in cladoceran abundance was noted at Armstrong Arm from 2018-2022.

The following areas of concern have been identified that may require further investigation on the part of the Ministry:

- Chronically low Secchi depth in the Armstrong Arm
- Increasing nitrate in hypolimnion of Okanagan Lake since 1970s
- Increasing total phosphorus at all sites except Summerland since early 2000s
- Decreasing N:P ratio in the Armstrong Arm
- High densities of potentially toxic cyanobacteria in Armstrong Arm during 2018-2021
- Role of Climate Change in water quality changes in Okanagan Lake
- Phosphorus loading to the Armstrong Arm and north basin of Okanagan Lake from the White Rock Lake wildfire

Water Quality Objectives, 2011-2022 Values, and Trends for Okanagan Lake

Table 1: Okanagan Lake water quality objectives

Parameter (Nordin, 2005)	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth (growing season average: Apr-Sep)	>7m	>6m	>6m	>5m
Dissolved Oxygen (minimum in bottom waters)	-	-	-	>5 mg/L
TP (mg/L as P) (maximum at spring overturn)	<0.007	<0.008	<0.008	<0.01
Chlorophyll-a (µg/L) (maximum seasonal average)	<4.5	<4.5	<4	<5
TN (mg/L as N) (maximum at spring overturn)	<0.230	<0.230	<0.230	<0.250
N:P Ratio (spring weighted ratio)	>25:1	>25:1	>25:1	>25:1
Algae Taxonomy (% heterocystous cyanobacteria)	<5%	<5%	<5%	<5%
Algae Biomass (µL/L) (growing season average)	<0.75	<0.75	<0.75	<0.75
Zooplankton Biomass (µg/L) (growing season average)	>50	>50	>50	>50
Zooplankton Taxonomy (% cladocerans)	>5%	>5%	>5%	>5%

Table 2: Attainment of Okanagan Lake water quality objectives compared to growing season averages during 2022

Objective	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth	6.4 (did not achieve)	6.4 (achieved)	7 (achieved)	3.3 (did not achieve)
Dissolved Oxygen	7.96	8.25	8.20	1.84 (did not achieve)
TP (mg/L) 0:10m:	0.006 (achieved)	0.007 (achieved)	0.009 (achieved)	0.011 (did not achieve)
20-45m:	0.004 (achieved)	0.008 (achieved)	0.006 (achieved)	0.027 (did not achieve)
Chlorophyll-a (µg/L)	1.99 (achieved)	2.33 (achieved)	2.46 (achieved)	3.62 (achieved)
TN (mg/L) 0-10m:	0.224 (did not achieve)	0.227 (did not achieve)	0.225 (did not achieve)	0.253 (did not achieve)
20-45m:	0.246 (did not achieve)	0.251 (did not achieve)	0.245 (did not achieve)	0.323 (did not achieve)
N:P Ratio 0-10m:	45:1 (achieved)	43:1 (achieved)	34:1 (achieved)	18:1 (did not achieve)
20-45m:	52:1 (achieved)	49:1 (achieved)	32:1 (achieved)	18:1 (did not achieve)
Algae Taxonomy (% heterocystous cyanobacteria)	15.6% (some samples)	14.0% (did not achieve)	15.7% (some samples)	29.9% (some samples)
Algae Biovolume (µL/L)	0.164 (achieved)	0.229 (achieved)	0.273 (achieved)	0.269 (achieved)
Zooplankton Biomass (µg/L)	18.8 (did not achieve)	37.9 (did not achieve)	58.1 (achieved)	39.8 (did not achieve)
Zooplankton Taxonomy (% cladocerans)	2.4% (did not achieve)	3.3% (did not achieve)	6.3% (did not achieve)	7.9% (some samples)

Legend:

Achieved objective	Achieve objective in some but not all samples	Did not achieve objective

Table 3: Summary of trends compared to attainment of water quality objectives in Okanagan Lake during 2011-2022

Objective	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth	- (did not achieve)	- (achieved)	- (achieved)	- (did not achieve)
Dissolved Oxygen	-	-	-	- (did not achieve)
TP (mg/L) 0:10m:	↑ (achieved)	↑ (achieved)	↑ (achieved)	↑ (did not achieve)
Chlorophyll-a (µg/L)	- (achieved)	↑ (achieved)	↑ (achieved)	↑ (achieved)
TN (mg/L) 0-10m:	- (did not achieve)	↑ (did not achieve)	↑ (did not achieve)	↑ (did not achieve)
N:P Ratio 0-10m:	↓ (achieved)	↓ (achieved)	↓ (achieved)	↓ (did not achieve)
Algae Taxonomy (% heterocystous cyanobacteria)	- (some samples)	- (did not achieve)	- (some samples)	- (some samples)
Algae Biovolume (µL/L)	↑ (achieved)	↑ (achieved)	- (achieved)	- (achieved)
Zooplankton Biomass (µg/L)	- (did not achieve)	- (did not achieve)	- (achieved)	- (did not achieve)
Zooplankton Taxonomy (% cladocerans)	- (did not achieve)	- (did not achieve)	- (did not achieve)	↓ (some samples)

Legend:

Achieved objective	Achieve objective in some but not all samples	Did not achieve objective

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Report prepared by: Larratt Aquatic Consulting Ltd.

Jamie Self: BSc, RPBio
Senior Aquatic Biologist

Table of Contents

Table of Figures and Tables

Definitions

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

Term	Definition
Algae bloom	A superabundant growth of algae that may result in surface scum depending on type of algae that is blooming
Anoxic	Devoid of oxygen
Bioavailable	Available for use by plants or animals
Chlorophyll-a	Primary photosynthetic pigment in algae; used as a measure of photosynthetic activity
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment
Diatoms	Algae that have hard, silica-based "shells" frustules
Fall overturn	Surface waters cool and sink, until a fall storm mixes the water column
Eutrophic	Nutrient-rich, biologically productive water body
Hypoxic	Very low dissolved oxygen
Macronutrient	The major constituents of cells: nitrogen, phosphorus, carbon, sulphate, H
Micronutrient	Small amounts are required for growth; Si, Mn, Fe, Co, Zn, Cu, Mo etc.
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Monomictic	“One Mixing”: describes lakes that are thermally stratified in summer and mixed in winter
Nutrient limitation	A nutrient will limit or control the potential growth of organisms e.g. P or N
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
Plankton	Those organisms that float or swim in water
Riparian	The interface between land and a stream or lake
Secchi depth	Depth where a 20 cm Secchi disk can be seen; measures water transparency
Thermocline	The 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

Term	Definition
AFDM	Ash-free dry mass
Chl-a	Chlorophyll-a units µg/L
DO	Dissolved oxygen units mg/L
N	Nitrogen units mg/L as N
Ortho-P	Orthophosphate ≈ SRP monomeric inorganic phosphorus units mg/L as N
P	Phosphorus units mg/L as P
DIN	Dissolved inorganic nitrogen = ammonia + nitrate + nitrite units mg/L as N
TDN	Total dissolved nitrogen = ammonia + nitrate + nitrite + dissolved organic N units mg/L as N
TDP/DP	Total dissolved phosphorus units mg/L as P
TN	Total nitrogen: organic + dissolved units mg/L as N
TP	Total phosphorus: organic + dissolved units mg/L as P

Lake Classification by Trophic Status Indicators (Nordin, 1985)

Trophic Status	chlorophyll-a ug/L	Total P ug/L	Total N ug/L	Secchi disc m	Phytoplankton density (cells/mL)	Phytoplankton biomass (mg/m^3)
Oligotrophic	0 – 2	1 – 10	<100	> 6	<1000	0-500
Mesotrophic	2 – 5	10 – 20	100 – 500	3 – 6	1000-5000	500-2000
Eutrophic	>5	> 20	500-1000	< 3	>5000	>2000

Nutrient Balance Definitions for Microflora (Dissolved Inorganic N : Dissolved Inorganic P) (Nordin,1985)

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

1.0 Introduction

1.1 Overview

The British Columbia Ministry of Environment and Climate Change Strategy (ENV) in partnership with the City of Kelowna, the Regional District of Central Okanagan, and the District of Summerland began a seasonal sampling program of Okanagan Lake in 2011 to increase the temporal resolution of water quality data being gathered. This program was performed collaboratively between ENV staff, Okanagan Nation Alliance (ONA; 2011), and Larratt Aquatic Consulting (2012-2022). The current program is overseen by the Okanagan Basin Water Board (OBWB). Okanagan Lake was sampled monthly from March to September from 2011-2021 at four key sites (Figure 1, Table 4).

Table 4: GPS coordinates of sampling sites

Site Name	EMS ID	Latitude	Longitude
Summerland	0500454	49.600550°	-119.628030°
Kelowna	0500236	49.861350°	-119.513420°
Ok Centre	0500730	50.089900°	-119.478270°
Armstrong Arm	0500239	50.315450°	-119.357180°

Note: EMS = Environmental Monitoring System and serves as ENV's database of water quality

Sampling focused on three broad subjects at each site: physical parameters, water chemistry, and biological activity.

Physical parameters including temperature profiles were taken at each site on each date to build a composite image of conditions in Okanagan Lake over time (Figure 4). Secchi depth, a measure of water clarity, was also recorded for each site.

In addition, dissolved oxygen profiles were taken and a range of parameters were chemically analyzed from samples taken in the epilimnion (1-5-10 m composite) and the hypolimnion (20-32-45 m composite). Chemistry focused on the major nutrients in their various forms. Chemistry results were analyzed by ALS Environmental throughout this study.

Biological sampling included generic parameters such as chlorophyll-a concentration and biomass, as well as detailed taxonomic classification of phytoplankton (algae) and zooplankton.

The 2022 data were added to the existing 2011 – 2021 database upon which all the analyses in this report were performed. Water quality objectives were based upon Nordin (2005) (Appendix 1).

Figure 1: Okanagan Basin Watershed with four sampling locations identified and 2021 wildfires marked

1.2 Weather and Climate Conditions in 2022

The weather during any given year will have a major impact on physical conditions, water chemistry, and biological activity in Okanagan Lake during that and subsequent years. The weather during 2022 was another unusual year for the Okanagan climate (Figure 2). Spring was cooler than normal for the Okanagan with a large freshet in the Mission Creek watershed followed by a shift to hot dry weather that extended into October. The water level of Okanagan Lake was near record low throughout the first half of 2022, but the large freshet led to high water levels during the summer. Both the peak water level and inflows as measured at Mission Creek (08NM116) were amongst the top 10 for Okanagan Lake since record keeping began in the 1940s. Hot dry weather led to a rapid drawdown of Okanagan Lake that led to below average water levels by the end of the year (Figure 3). This type of extreme weather is expected to become more frequent and more intense because of Climate Change.

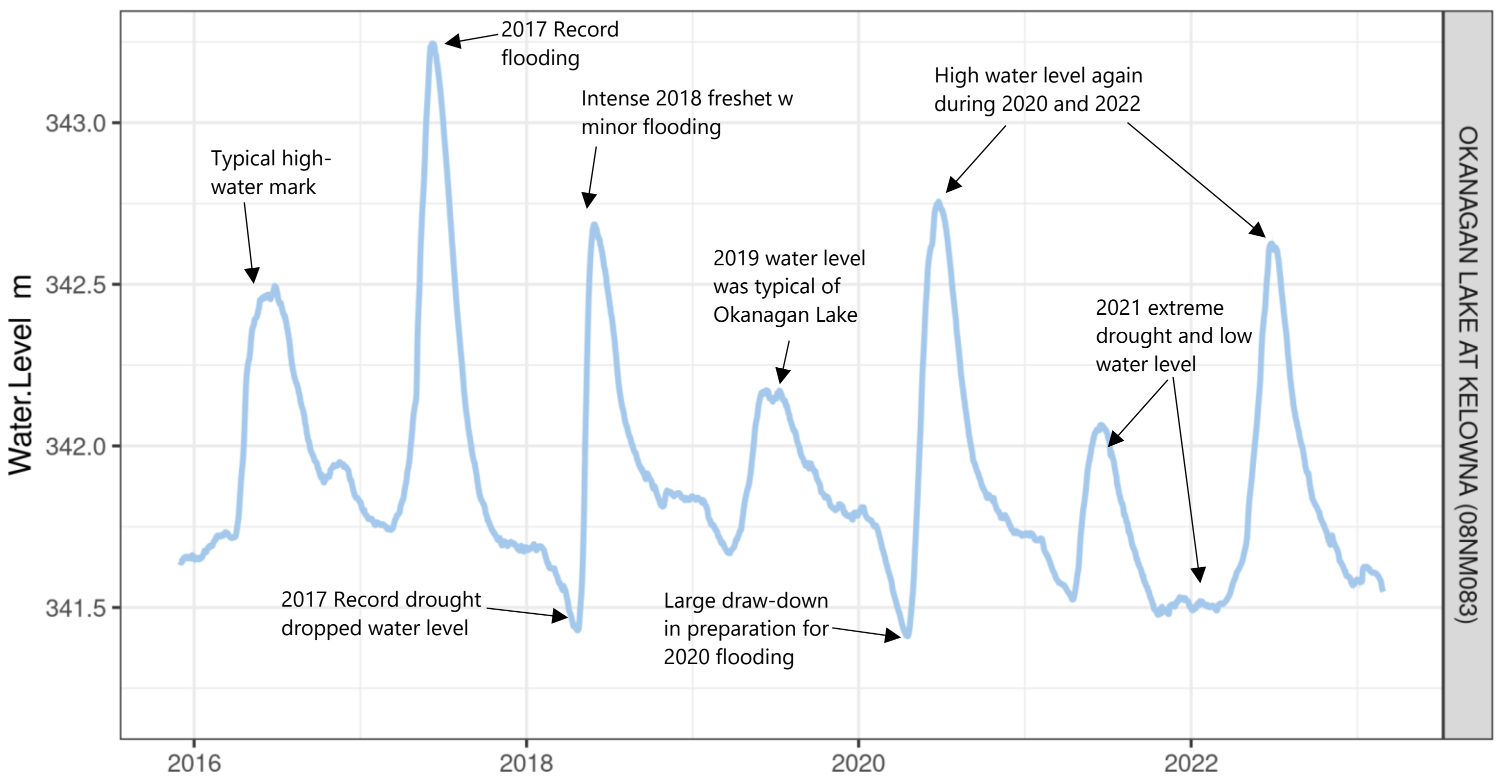

Figure 2: Water level in Okanagan Lake at Kelowna from 2016-2022

Source: (Water Office, 2022)

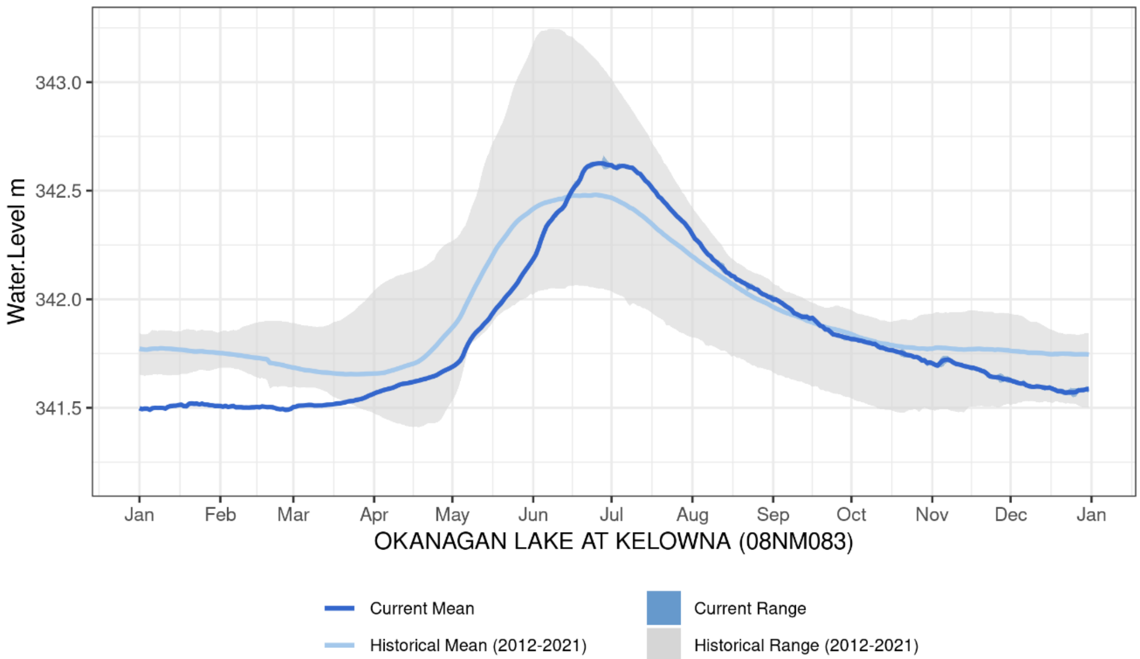

Figure 3: Water level in Okanagan Lake during 2022 compared to 2012-2021

Source: (Water Office, 2022)

2.0 Results & Discussion

2.1 Physical

2.1.1 Temperature

Okanagan Lake is a deep monomictic lake. From May to November each year, the surface water (epilimnion) is thermally isolated from the deep water (hypolimnion) by a thermocline. The sun warms the epilimnion to over 20 °C each summer while water below 20 m changes temperature by less than 4 °C annually (Figure 4).

The three main basin sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal behavior while the northern Armstrong Arm site is shallower and reaches a higher surface temperature each summer (Figure 4). Thermal stratification in Okanagan Lake breaks down each November and the water column freely circulates through the winter. There were no statistically significant trends in the 2011–2022 temperature data either annually, seasonally (Mann-Kendall trend tests).

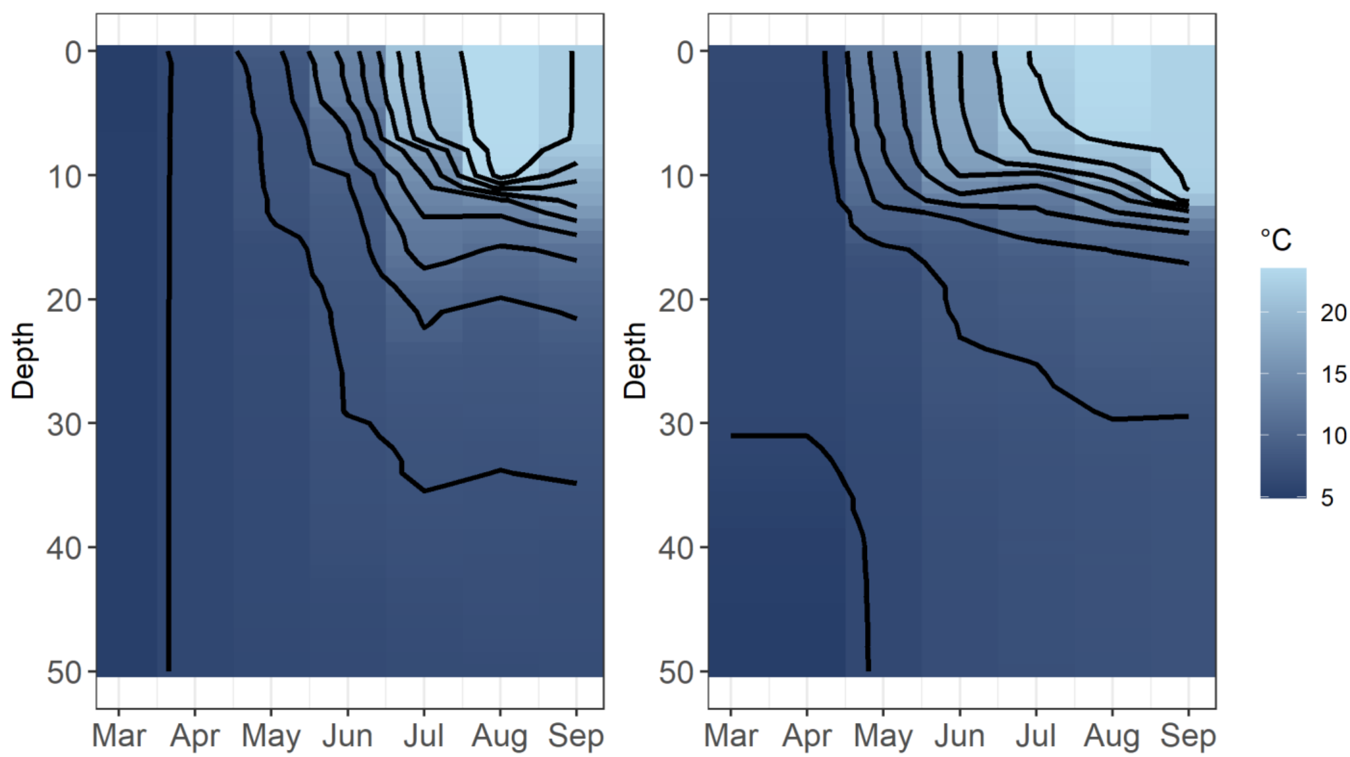

Figure 4: Temperature profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right), 2022

Notes: Lines represent contours of same temperature or dissolved oxygen within the water column through time. Samples not collected during March 2020 at Armstrong Arm because of ice-cover

Surface water temperatures of Okanagan Lake at all four sites were below average throughout the cool, wet spring before transitioning to above average during the late summer into fall months (Figure 5).

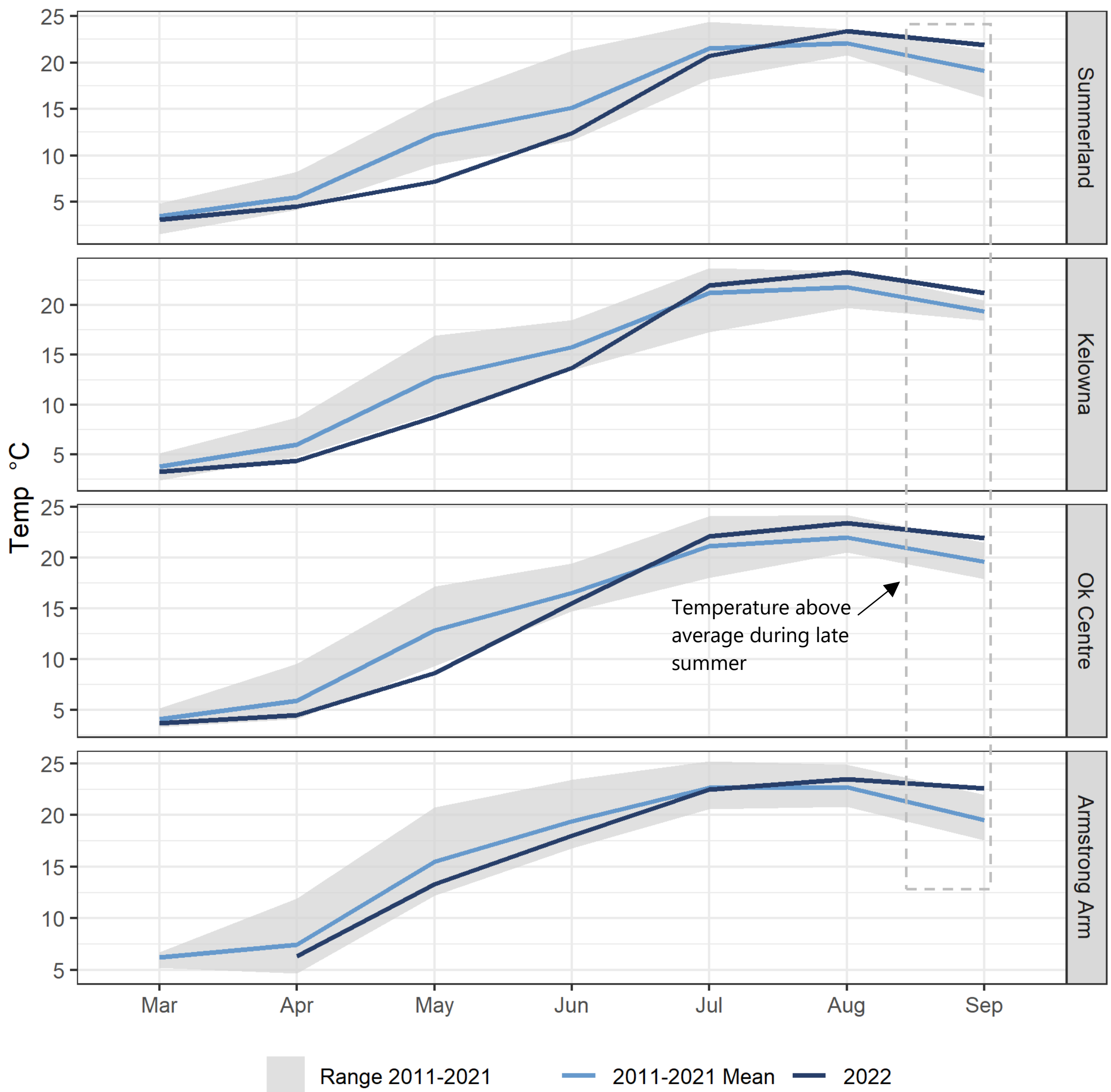

Figure 5: Temperature at Okanagan Lake sampling sites during 2022 compared to 2011-2021

2.1.2 Water Clarity and Secchi Depth

Water clarity, as measured by Secchi depth, ranged from a minimum of only 1.8 m at Armstrong Arm in June to a maximum of 15.9 m at Okanagan Centre in March during 2022 (Table 5). Secchi depth averages were near the 2011-2022 average during 2022 (Figure 6, Figure 7). Armstrong Arm and Summerland failed to meet their respective objectives during 2022 (Table 5). The overall average for Okanagan Lake historically has been 6.5-6.6 m but averaged 5.8 ± 2.4 m in 2022 (Andrusak et al., 2006; Nordin, 2005). The relatively low water clarity during 2022 may relate to an increasing trend in chlorophyll-a observed throughout the lake during the past 10 years (Figure 17).

Secchi depth followed a consistent pattern each year. Maximum Secchi depths occurred in the late winter when biological activity was the lowest. During increased spring algal growth and freshet, the Secchi depth dropped dramatically to the lowest of the year at all sites. As nutrients were used up, algae concentrations diminished, and water clarity increased through the summer and into the fall (Figure 6).

The Secchi depth in the Armstrong Arm was much lower than at the other sites in Okanagan Lake during all years. This is clearly illustrated in Figure 7. Secchi depth was stable from 2011-2022 and there were no statistically significant year-over-year trends in the Secchi depth data from 2011-2021 but there was a significant drop when the 1973-2022 historical data was considered (Mann-Kendall tests, Figure 7). This long-term trend is related to a period of high water-clarity in the years following the installation of nutrient removal systems at wastewater treatment plants; the current lower water clarity likely relates to the cumulative effects of increased population and human activities within the Okanagan watershed over the past 30 years.

Table 5: Growing Season (Apr-Sep) Secchi depth in meters at Okanagan Lake sampling sites, 2022

Site	Objective	Average	StdDev	Max	Min
Summerland	7.0	6.4	1.8	8.5	3.5
Kelowna	6.0	6.4	2.7	8.8	1.8
Ok Centre	6.0	7.0	2.4	10.8	4.4
Armstrong Arm	5.0	3.3	0.5	3.9	2.6

Note: Objective refers to growing season average (Apr-Sep); Coloured shading indicates status of objective during that year with green meaning met objective and red meaning failed to meet objective

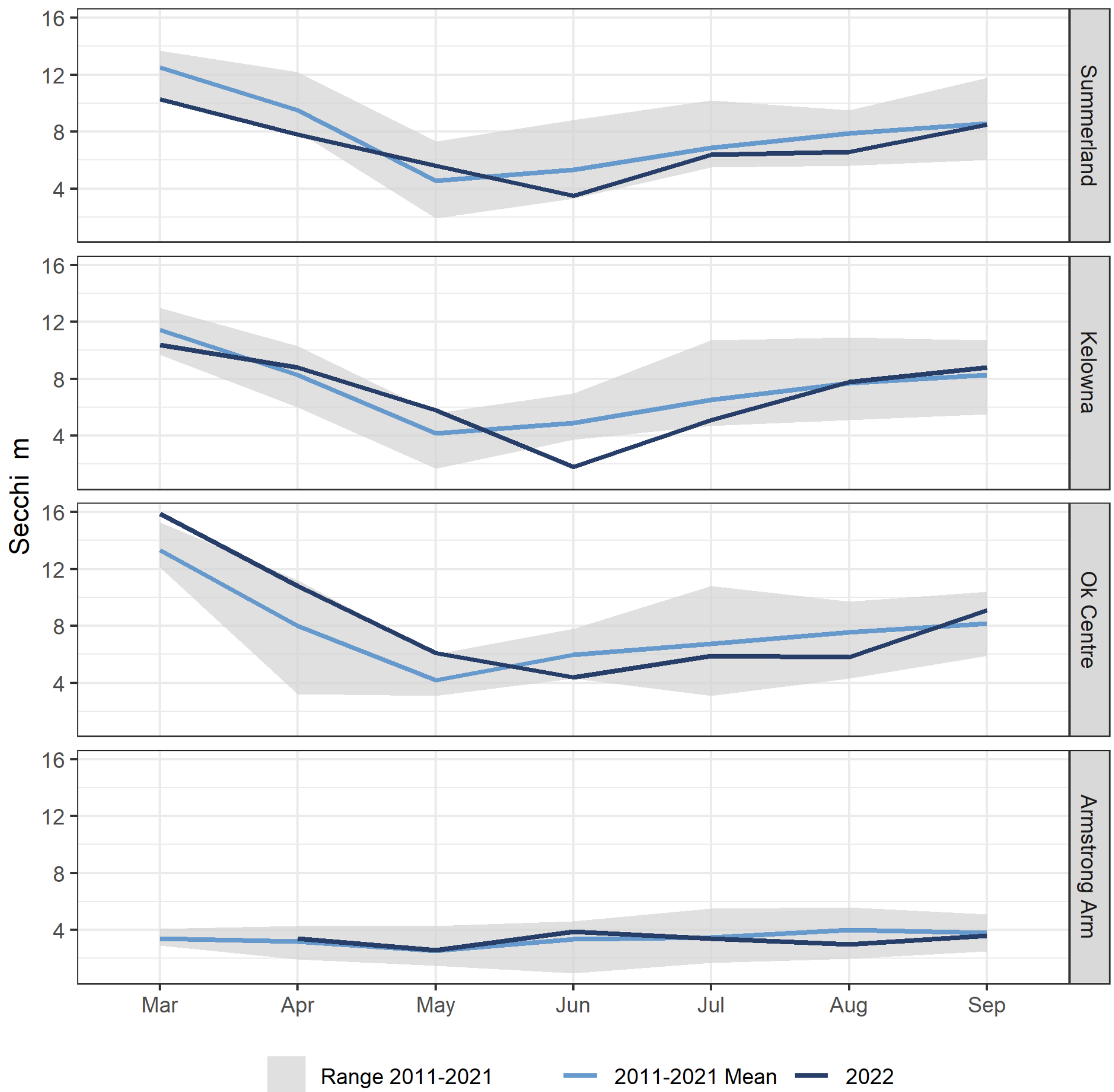

Figure 6: Secchi depth at Okanagan Lake sampling sites during 2022 compared to 2011-2021

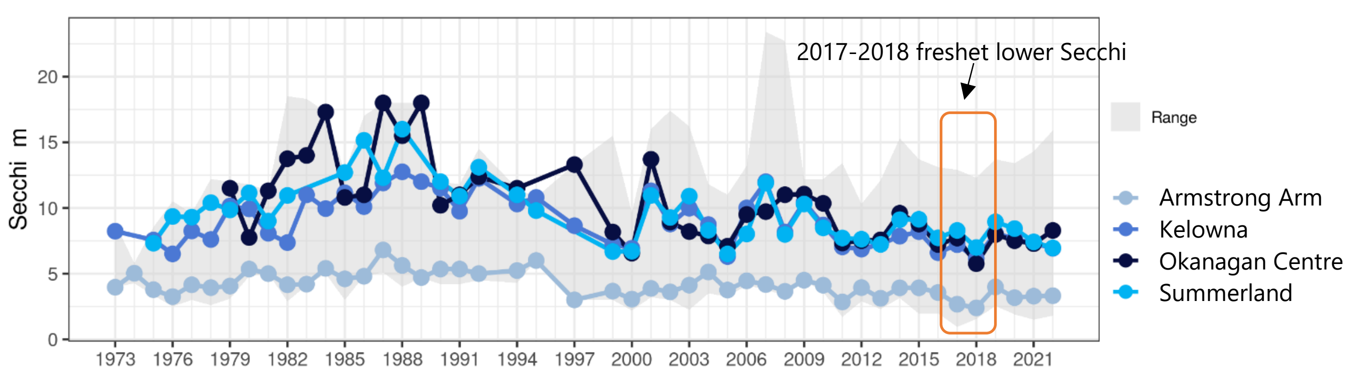

Figure 7: Annual average secchi depth in Okanagan Lake from 1973-2022

2.2 Chemistry

Chemistry sampling focused on dissolved oxygen, nitrogen and phosphorus (the most important aquatic nutrients), and silica, a key micronutrient. Increasing nutrient trends frequently result from human activities such as wastewater effluent disposal, riparian degradation, agriculture, fertilizer use, storm water, etc. These human-caused impacts are gradual and are easiest to detect as year-over-year trends. As the database grows, it will become easier to separate climatic impacts from human impacts.

2.2.1 Dissolved Oxygen

Dissolved oxygen (DO) is essential for all aquatic animals. Low DO will stress fish and possibly preclude them from certain portions of the water column. Hypoxic conditions occur when DO is very low (<2 mg/L) and this has a profound impact on water chemistry through the mobilization of nutrients and metals from the sediment. The three major basin sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal and high dissolved oxygen behavior while the northern Armstrong Arm site is shallower and behaves differently. The later reaches a higher surface temperature and experiences a reduction in dissolved oxygen in the deep water each summer (Figure 8). The reduction in dissolved oxygen is caused by decomposition of organic material in the sediment and deep water and can lead to internal nutrient loading if oxygen becomes depleted. The Armstrong Arm is the only site with a dissolved oxygen objective (>5 mg/L in bottom water), a threshold that it fails to meet every year. By September 2022, the low dissolved oxygen zone (depth below red line in Figure 8) had expanded to 35 m thick with a minimum concentration of only 1.84 mg/L.

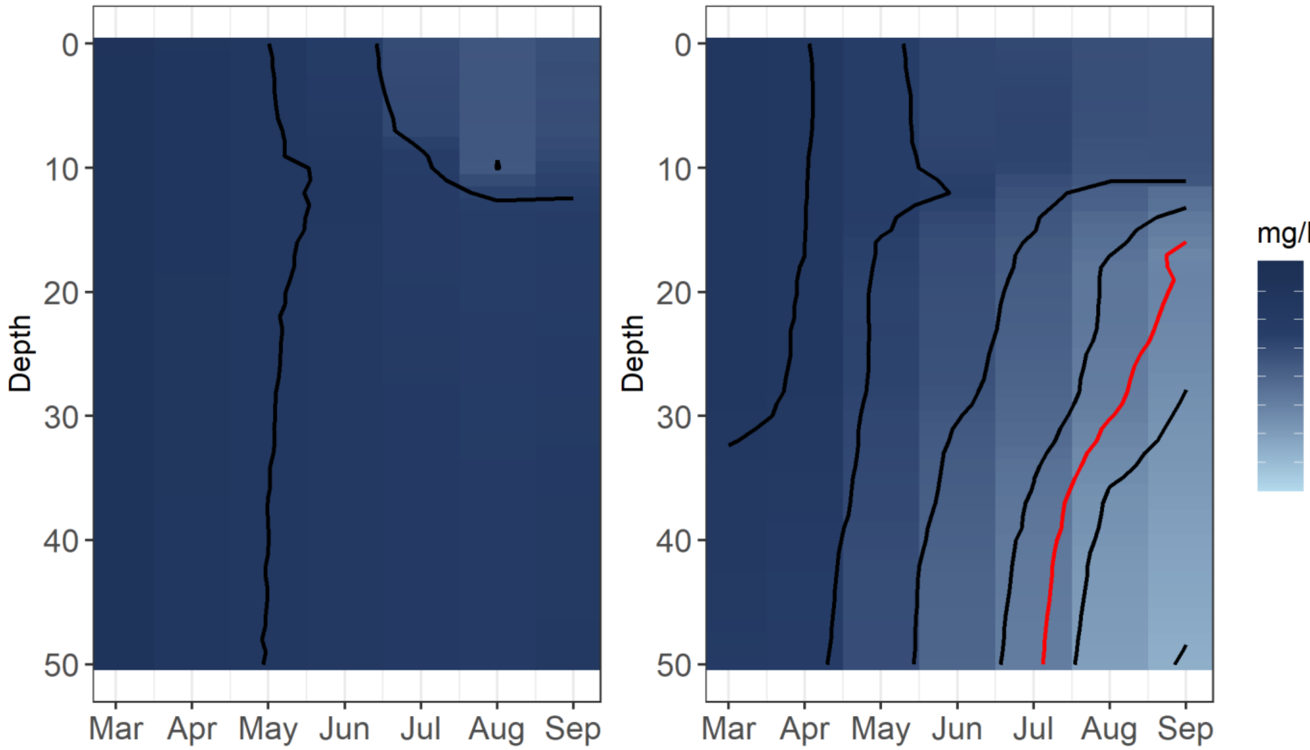

Figure 8: Dissolved oxygen profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right) during 2022

Dissolved oxygen profile illustrates high dissolved oxygen concentrations at Summerland and characteristic oxygen depletion in deep waters of the Armstrong Arm. Lines represent contours of same dissolved oxygen within the water column through time. Note: The red line on dissolved oxygen plot represents Water Quality Objective; all water below this line does not meet the objective.

2.2.2 Silica

Diatoms, a major group of algae in Okanagan Lake, use silica (measured as dissolved silica) as a structural building block for their cell walls. While no objectives for silica concentrations in Okanagan Lake have been set, monitoring continues as silica is a key micronutrient for this important group of algae. Silica sampling shifted to only March and September beginning in 2015 because it did not change significantly over the course of the growing season from 2011-2014. Silica was higher during 2017-2018, likely an effect of the flooding and intense freshets during those years, but when looking at the long-term data, there was an increasing trend from the 1970s to 2000 followed by a period of stability since 2000 (Table 6, Figure 9). There was unusually low silica at the Kelowna sample point on Aug 16, 2022 but the cause was unclear. The cause of the change in silica from increasing to stable is not known.

Table 6: Silica concentration in mg/L at Okanagan Lake sampling sites, 2022

Site	Average	StdDev	Max	Min
Armstrong Arm	7.91	1.20	9.97	6.15
Kelowna	6.07	2.45	7.72	1.26
Ok Centre	7.32	0.49	7.82	6.52
Summerland	7.31	0.24	7.62	6.83

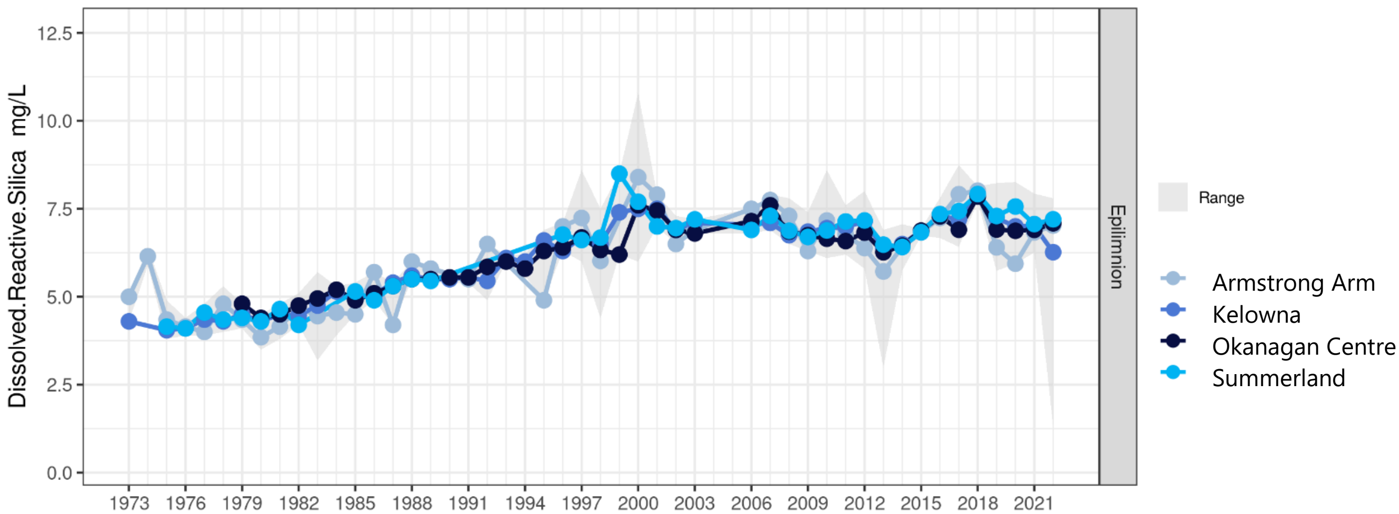

Figure 9: Annual average silica concentration in Okanagan Lake at each sampling site by year with trends highlighted, 1973-2022

2.2.3 Nitrogen and Phosphorus

Nitrogen and phosphorus are the most important nutrients in most aquatic environments. Nutrient limitation occurs when an essential element (typically nitrogen or phosphorus) is in relatively short supply. Algae production is limited by the availability of that nutrient despite potential abundance of other nutrients. In the Okanagan, phosphorus is the main limiting nutrient while dissolved inorganic nitrogen also limits productivity during the summer. Their concentrations are directly linked to the amount of algae that the lake produces (Nordin, 2005).

Nitrogen

Total nitrogen (TN) averaged 0.248 ± 0.041 mg/L as N in the epilimnion of Okanagan Lake during 2022. The objective for Okanagan Lake was set as a spring value (March sample date[1]) of 0.230 mg/L for the main basins and 0.250 mg/L for the Armstrong Arm. The objective was exceeded at all sites during 2022 as it has in most years (Table 7). TN increased in the hypolimnion at all sites except Summerland from 2011-2022 (Mann-Kendall, p≤0.02; Table 7). Average TN values were comparable to those found in the literature for Okanagan Lake (0.17-0.23 mg/L as N; Andrusak et al.,2000).

[1] The Armstrong Arm sample is typically collected in early April because of ice-cover in that part of the lake

Table 7: Total nitrogen in mg/L as N concentration at Okanagan Lake sampling sites, 2022

Site	Depth	Objective	Trend	Avg	SD	Max	Min
Summerland	<10m	0.230	-	0.224	0.030	0.265	0.184
	>20m		-	0.246	0.014	0.265	0.225
Kelowna	<10m	0.230	-	0.227	0.031	0.271	0.187
	>20m		↑	0.251	0.035	0.299	0.186
Ok Centre	<10m	0.230	-	0.225	0.020	0.250	0.200
	>20m		↑	0.245	0.016	0.277	0.228
Armstrong	<10m	0.250	-	0.253	0.017	0.276	0.232
Arm	>20m		↑	0.323	0.061	0.4	0.26

Note: Red shaded cells indicate that the Spring value exceeded the objective while green indicates that the value met the objective. Statistical significance of general trends derived from all data for a site may disappear when depths are split apart due to smaller sample size

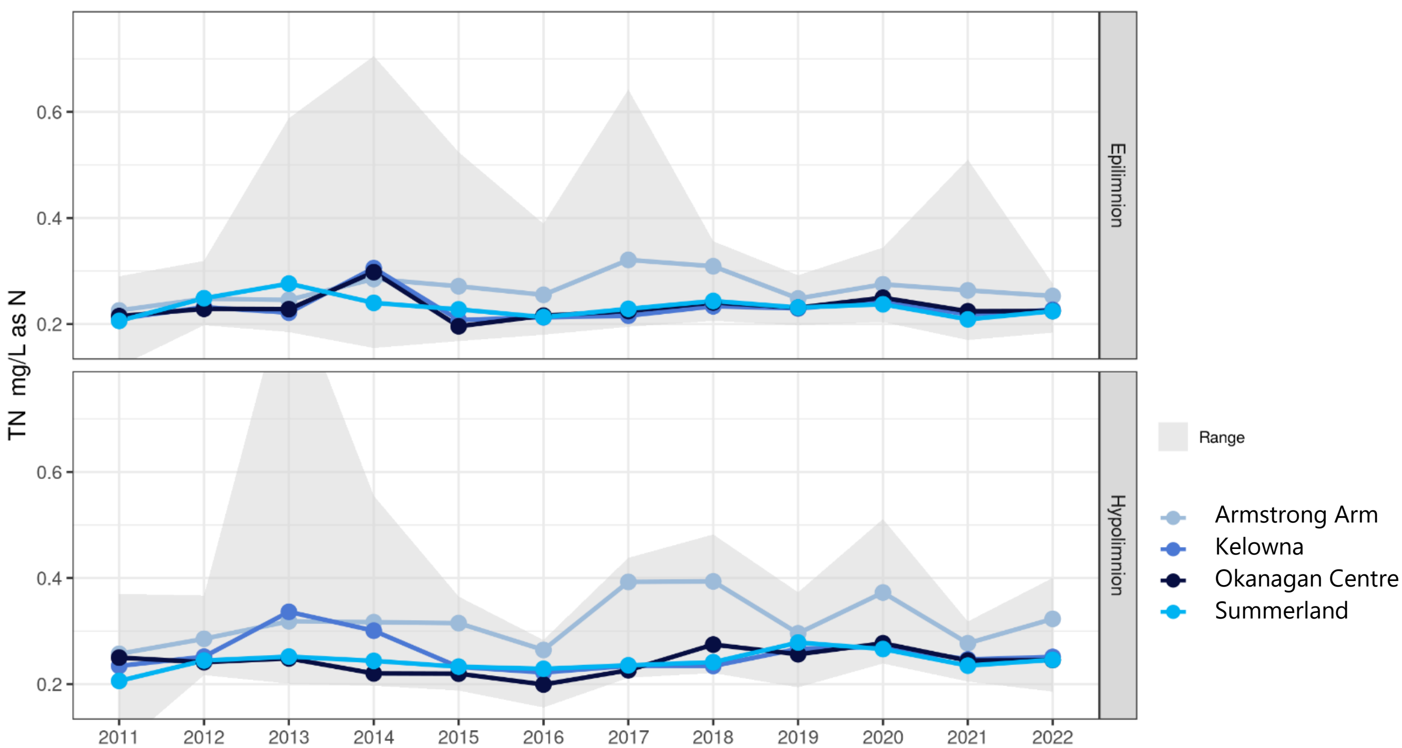

Figure 10: Annual average total nitrogen in Okanagan Lake, 2011-2022

Hypolimnetic nitrate increased at all sites from 2011-2022 (Mann-Kendall, $p<0.001$; Figure 11). Analysis of the entire Okanagan Lake water chemistry database indicates that this trend has been ongoing for decades (1973-2022 dataset; Mann-Kendall, $p<0.001$; Figure 11). This suggests a connection to human activities in the region because the trend has continued through several wet-dry climate cycles. There is also recent research noting that changes in nitrate concentration are a marker of climate change (Mas-Pla & Menció, 2019; Stuart et al., 2011). Layered on top of this trend are short-term increases in nitrate during and after wet years such as 2017-2018, 2020, and 2022.

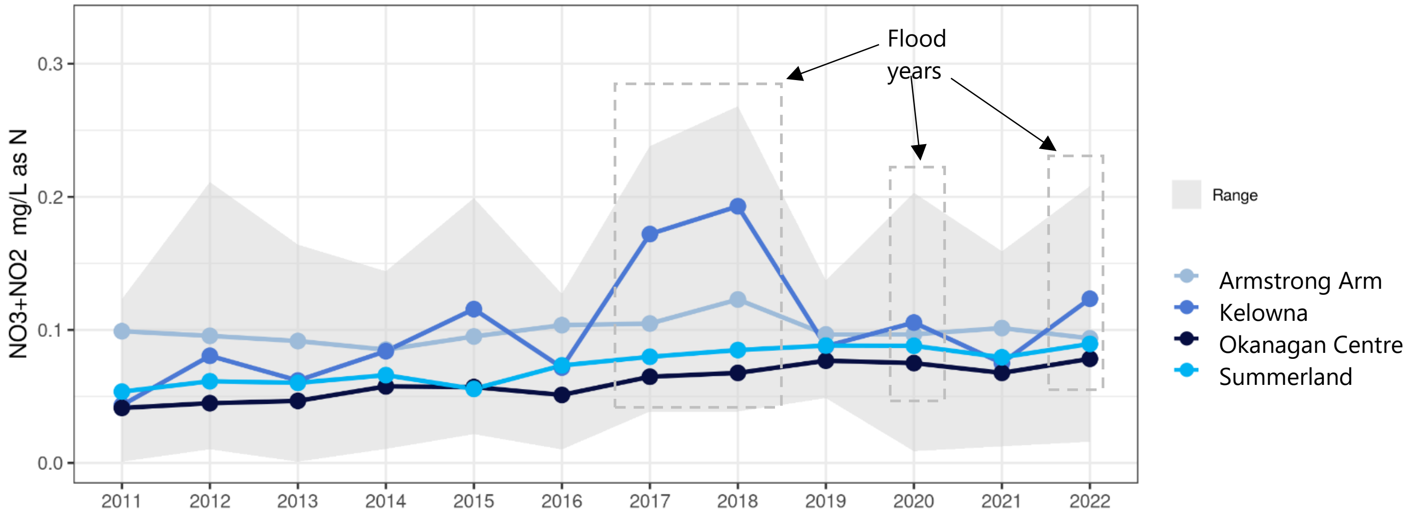

Figure 11: Annual average nitrite (NO_2) + nitrate (NO_3) in mg/L as N in the deep water of Okanagan Lake, 2011-2022

Nitrate is rapidly consumed by algae in the epilimnion each spring and thermal stratification prevents replenishment from the deeper water during the summer (Figure 11). Nitrate increased dramatically each summer in the hypolimnion of the Armstrong Arm because of chemistry associated with the low-DO conditions (Figure 12). For example, nitrate increased from <0.0032 mg/L as N in the epilimnion to 0.208 mg/L as N in the hypolimnion by Sept 2022.

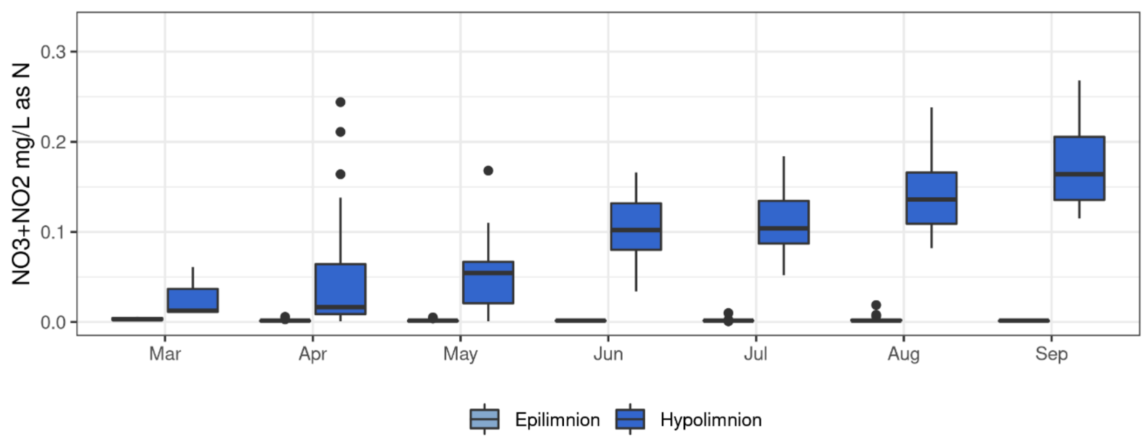

Figure 12: Nitrate + nitrite in Okanagan Lake at Armstrong Arm by month illustrating seasonal accumulation of nitrate in low oxygen hypolimnion, 2011-2022

Phosphorus

Total phosphorus (TP) measures all forms of phosphorus including those that may not be bioavailable. Total phosphorus averaged 0.009 ± 0.008 mg/L as P across Okanagan Lake during 2022 (Table 8). The TP objective for Okanagan Lake applies to the maximum phosphorus concentration at the spring overturn (Nordin, 2005; taken as March[2]). The objectives range from 0.007 mg/L in the south basin to 0.010 mg/L in the Armstrong Arm.

The TP objective was exceeded in the epilimnion and hypolimnion of Armstrong Arm in 2022, as it was in most years from 2011-2022 (Table 8). Increasing trends in TP occurred at all sites from 2011-2022 (Mann-Kendall, p≤0.02; Table 8, Figure 13). This trend was driven, in part, by large increases in TP during wet years such as 2012-2013 and 2017-2018, 2020, and 2022. TP includes phosphorus associated with suspended sediment carried into the lake and it increases in Okanagan Lake during wet years and decreases during dry years (Figure 13).

Table 8: Total phosphorus (mg/L as P) at Okanagan Lake sampling sites during 2022

Site	Depth	Objective	Trend	Avg	SD	Max	Min
Summerland	<10m	0.007	-	0.006	0.001	0.007	0.004
	>20m		↑	0.004	0.001	0.006	0.003
Kelowna	<10m	0.008	↑	0.007	0.003	0.011	0.003
	>20m		↑	0.008	0.007	0.024	0.003
Ok Centre	<10m	0.008	↑	0.009	0.006	0.022	0.004
	>20m		↑	0.006	0.001	0.008	0.005
Armstrong	<10m	0.010	↑	0.011	0.004	0.016	0.006
Arm	>20m		↑	0.027	0.012	0.045	0.016

Note: Red shaded cells indicate that spring overturn value exceeded the objective while green shaded cells met the objective during 2022. Trends are based upon 2011-2022 data only

[2] The Armstrong Arm spring sample is typically collected in early April because of ice-cover in March

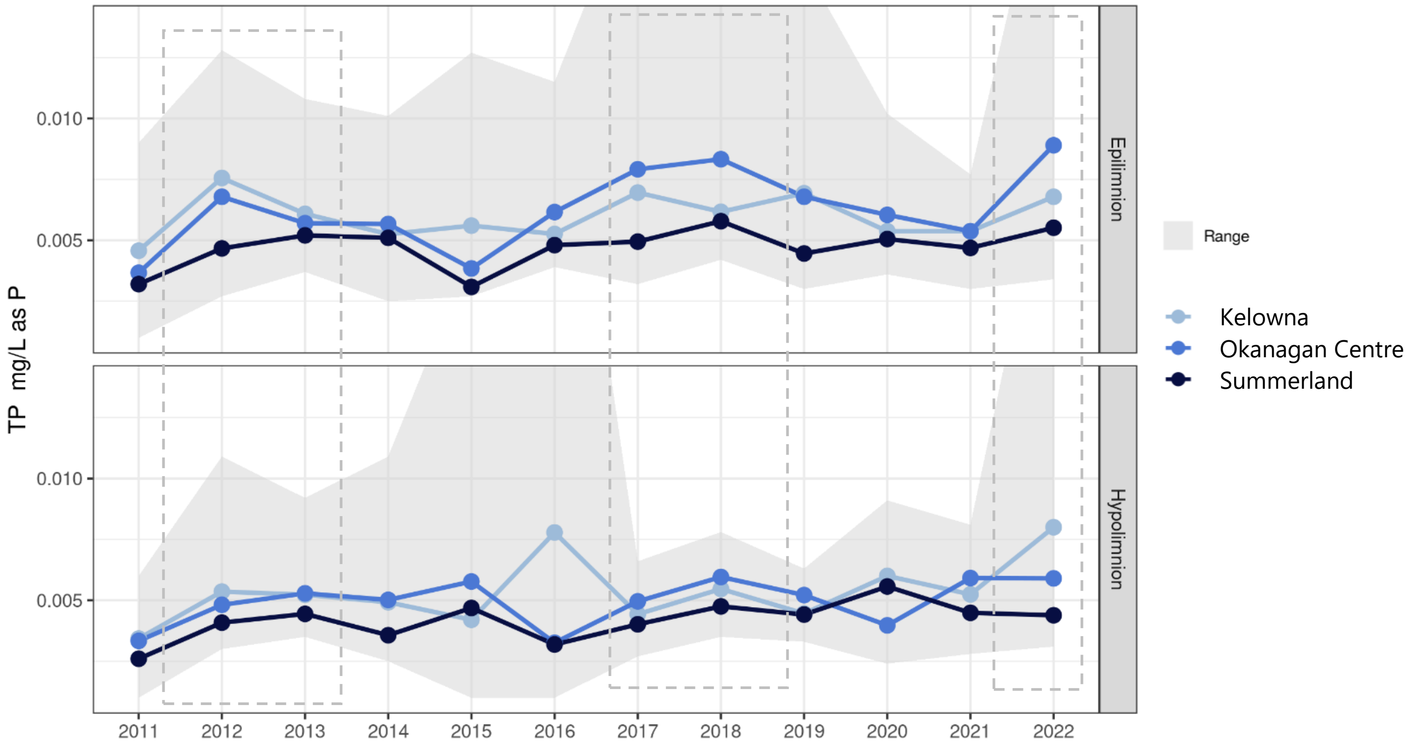

Figure 13: Annual average total phosphorus in Okanagan Lake at the three major basin sampling sites by year from 2011-2022

Notes: Grey boxes indicate wet years, decreasing trend from 1973-2005 and increasing trend from 2005-2022

TP experienced minor seasonal variation with a slight increase during freshet in some years at Summerland, Kelowna and Okanagan Centre while there was dramatic variation in the Armstrong Arm over the course of each growing season. TP increased in the hypolimnion during the summer, possibly from phosphorus released from the sediment under low-oxygen conditions while algae productivity reduced surface concentrations over the growing season (Figure 14).

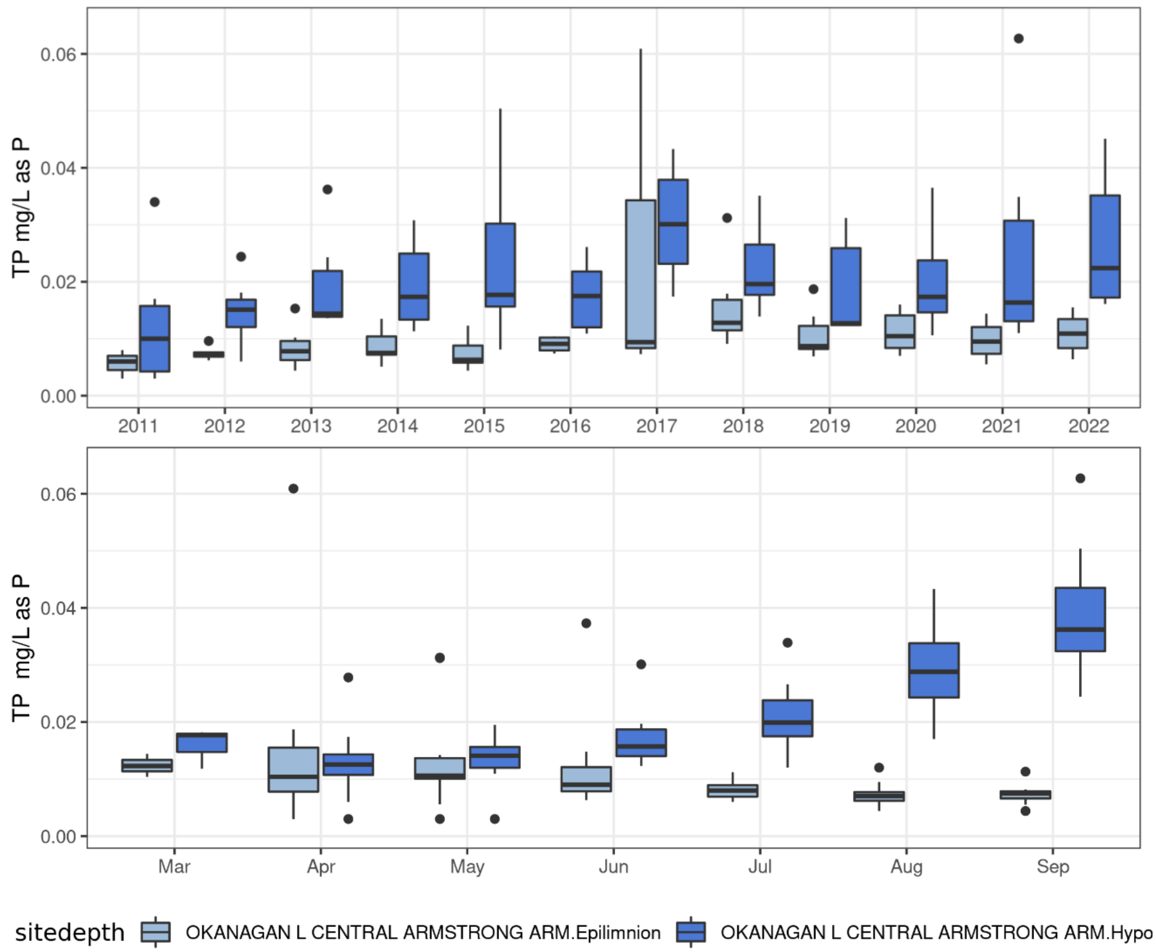

Figure 14: Total phosphorus in the Armstrong Arm, 2011-2022
Note: small reduction in eplimnetic TP over the growing season but it does not drop below detection as nitrate does

Dissolved phosphorus (TDP) measures the more bioavailable forms of phosphorus and is a good indicator of potential impacts to biota. TDP in the epilimnion of the Armstrong Arm increased from 2011-2015 but was stable over the past 5 years while the hypolimnion continued to increase (Mann-Kendall for 2011-2021 in the hypolimnion, $p<0.001$). TDP was stable at Kelowna and Okanagan Centre but decreased at Summerland from 2011-2021 (Mann-Kendall, $p\leq0.02$). Despite the stable long-term trend, TDP was noticeably higher in the Okanagan Centre epilimnion samples following the White Rock Lake Fire (Figure 15). Ortho-phosphate measures only the soluble reactive phosphorus fraction of the TDP and there were no significant trends in ortho-phosphate data at any of the sites from 2011-2022 with 79% of samples from the major basin sample sites having undetectable concentrations during 2022. Anoxic conditions in the Armstrong Arm increase hypolimnetic orthophosphate each summer.

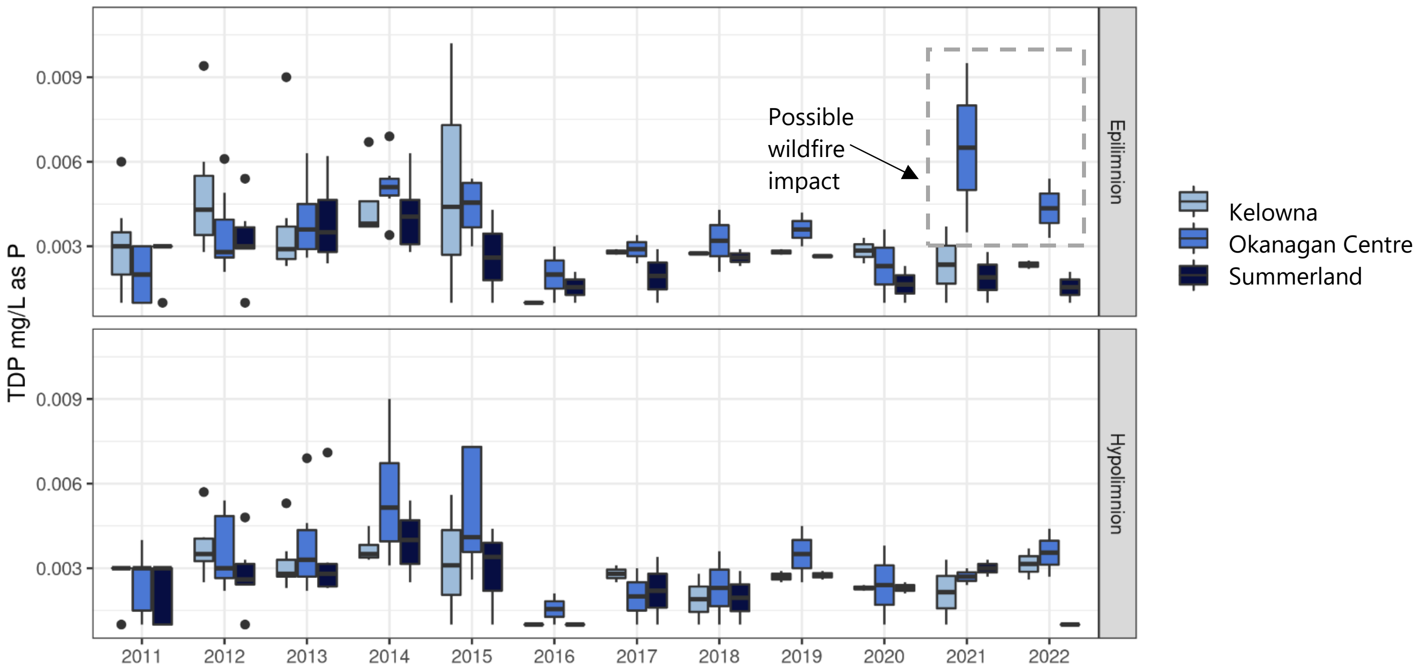

Figure 15: Annual average dissolved phosphorus in Okanagan Lake illustrating declining long-term trend at Okanagan Centre, Kelowna, and Summerland from 2011-2022

N:P Ratio

The ratio of nitrogen to phosphorus is a key factor in determining which types of phytoplankton will proliferate. Many species of cyanobacteria can fix atmospheric nitrogen and are therefore limited primarily by available phosphorus. These algae are more likely to bloom when phosphorus is abundant relative to nitrogen. The Okanagan Lake objective for the spring ratio of total nitrogen to total phosphorus is >25:1 in March samples. The objective was met at Summerland, Kelowna, and Okanagan Centre during 2022 while the Armstrong Arm had higher phosphorus concentrations than the rest of Okanagan Lake and did not meet the objective in 2022 (Figure 13, Table 9). The TN:TP ratio decreased in the at all sites from 2011-2022 (Mann-Kendall, p≤0.02) (Figure 13). The declining TN:TP trend is related to corresponding increasing trends in TP in the hypolimnion of Okanagan Lake at Kelowna and Armstrong Arm, a trend that is related to the recent series of flood years (2017-2018, 2020, and 2022; Table 8).

Table 9: Ratio of average TN to average TP during spring at Okanagan Lake sampling locations, 2011-2022

Site	Depth	TN	TP	2021 Ratio	Objective	Trend
Summerland	<10m	0.224	0.0055	45:1	>25:1	↓
	>20m	0.246	0.0044	52:1	>25:1	-
Kelowna	<10m	0.227	0.0068	43:1	>25:1	-
	>20m	0.251	0.0080	49:1	>25:1	↓
Ok Centre	<10m	0.225	0.0089	34:1	>25:1	↓
	>20m	0.245	0.0059	32:1	>25:1	↓
Armstrong Arm	<10m	0.253	0.0109	18:1	>25:1	↓
	>20m	0.323	0.0268	18:1	>25:1	↓

Note: red shaded cells indicate that the value did not meet the objective while green shaded cells met the objective during 2022

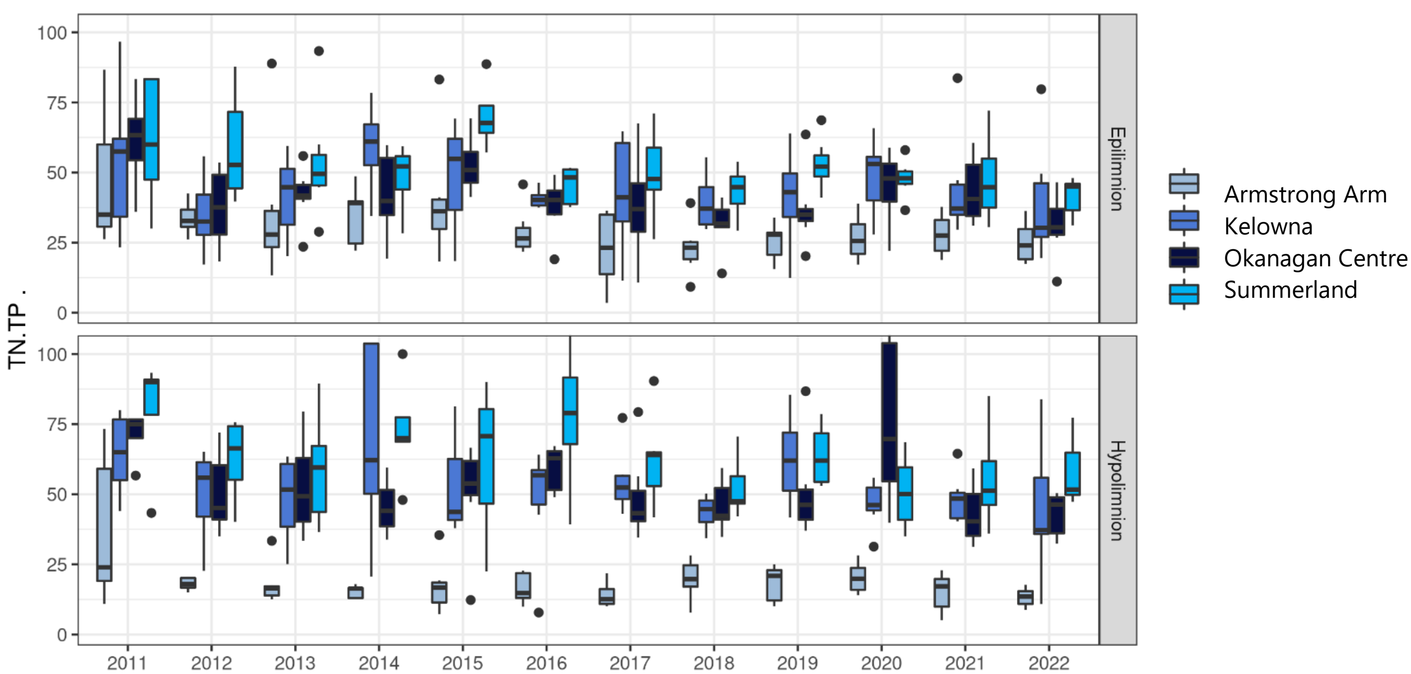

Figure 16: Nitrogen to phosphorus ratio at Okanagan Lake sampling sites 2011-2022

2.3 Biology

2.3.1 Phytoplankton

The Armstrong Arm of Okanagan Lake is shallower and has the potential to produce more phytoplankton and zooplankton than the deep basins of Okanagan Lake regardless of human activity. Phytoplankton and zooplankton samples were taken from all four sites were analyzed during 2022. Biomass analysis and taxonomic identification were performed on the taxonomy samples while chlorophyll-a concentrations were monitored as a productivity metric for phytoplankton abundance.

Chlorophyll-a

Chlorophyll-a (chl-a) is a photosynthetic pigment found in most freshwater algae species. As expected, chl-a followed an inverse trend to Secchi depth (Figure 6, Figure 17). Chl-a was lowest in the late winter and peaked in April-May during the increased spring algal growth before decreasing through the summer. During 2022, chl-a concentrations met the objectives at all sites (Table 10). Spring chl-a concentrations were high with a maximum of 5.5 µg/L in the Armstrong Arm (Table 10). Average chl-a concentrations in the Armstrong Arm have declined significantly since 2017 and averaged the lowest since 2014 (Mann-Kendall, p=0.04), an encouraging result after the dramatic increase from the 2017-2018 flooding (Figure 17). Chl-a concentration at the three major basin sites was stable from 2011-2016 and then again from 2018-2022 but there was a large increase during 2017-2018 because of the flooding during those years. While not yet statistically significant, there was a small apparent decrease in annual averages from 2017-2022 at Okanagan Centre (Figure 17).

In most years, including 2022, there was a north to south decreasing trend in the chlorophyll-a data with the Armstrong Arm having the highest and Summerland having lowest average concentrations (Table 10).

Table 10: Chlorophyll-a in µg/L at Okanagan Lake sampling sites, 2011-2022

Site	Objective	Trend	Average	StdDev	Max	Min
Summerland	4	-	1.99	0.96	3.28	0.82
Kelowna	4.5	↑	2.33	1.29	4.59	1.03
Ok Centre	4.5	↑	2.46	1.34	4.87	1.34
Armstrong Arm	5	↑	3.62	1.06	5.53	2.37

Note: Green shading indicates met objective during 2022

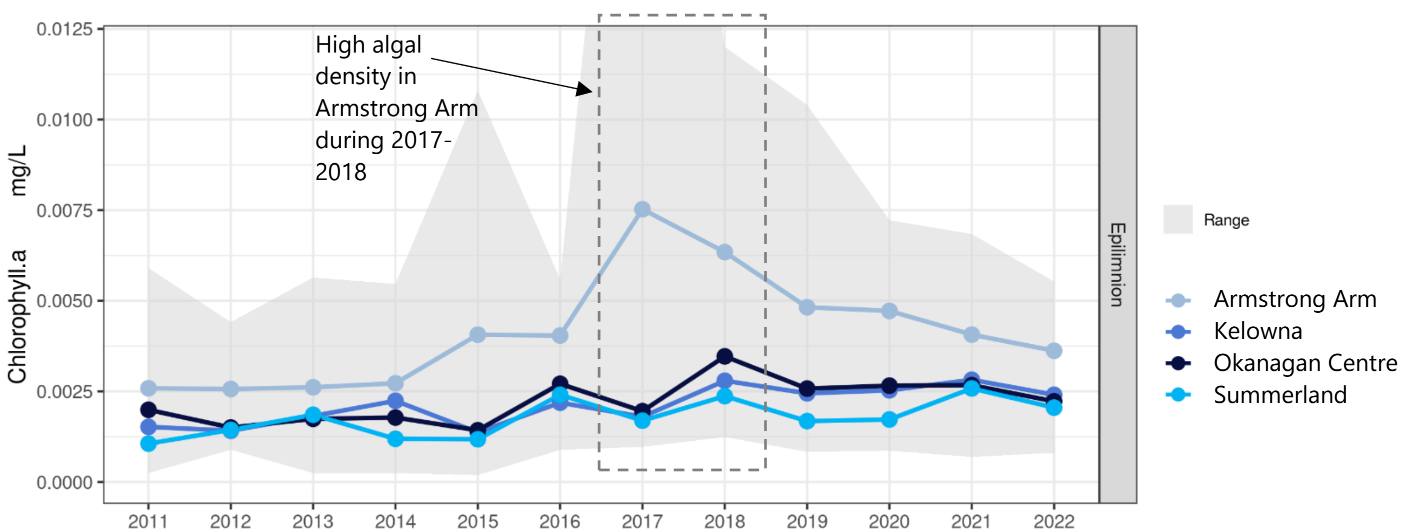

Figure 17: Annual chlorophyll-a concentration at the four Okanagan Lake sampling sites, 2011-2022

Phytoplankton Biovolume

Phytoplankton biovolume samples were collected as one litre composites from 1-10 m and the biovolumes were determined taxonomically. From 2011-2014, biomass was determined using ash-free dry mass (AFDM). It is not possible to directly compare the results from the two methodologies and only the 2015-2022 results are considered here.

The objective is that the growing season average should be <0.75 µL/L (Table 11). Samples from all sites met the objective during 2022.

Phytoplankton biovolume increased significantly from 2015-2021 at Summerland and at Kelowna (MK tests, $p=0.001$) - a trend that matches chlorophyll-a and is related to increased nutrient delivery from the recent large freshets (Figure 18). Productivity was lower during 2022 than 2021. A one-year lag has been observed between wet years and elevated productivity in Okanagan Lake and this effect helps explain why 2019 and 2021 production was very high despite the much smaller freshets (Figure 18). This may lead to higher productivity in 2023 because of the large 2022 freshet.

Table 11: Phytoplankton biovolume in µL/L at Okanagan Lake sampling sites, 2022

Site	Objective	Trend	Average	StdDev	Max	Min
Summerland	<0.75	↑	0.164	0.113	0.353	0.016
Kelowna	<0.75	↑	0.229	0.165	0.495	0.008
Ok Centre	<0.75	-	0.273	0.127	0.499	0.107
Armstrong Arm	<0.75	-	0.269	0.254	0.763	0.061

Notes: Green shading = met objective while red shading = did not meet objective.

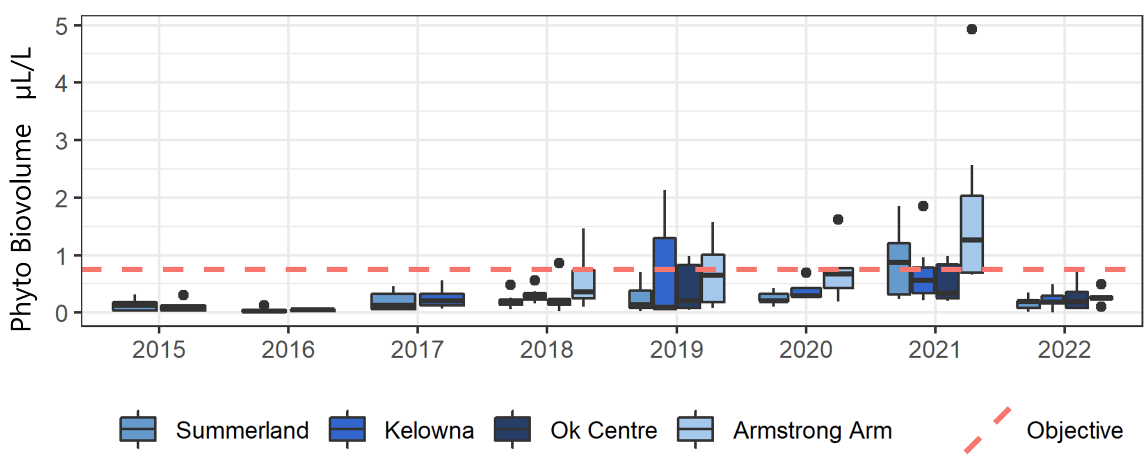

Figure 18: Phytoplankton Biovolume at Summerland and Kelowna, 2015-2022

Phytoplankton Taxonomy

Algae samples were identified to the species level and then grouped into broad algae types for analysis in this report. Diatoms tend to proliferate in the spring and their numbers decrease through the summer. Cyanobacteria were always numerous throughout the growing season in Okanagan Lake, but typically peaked in the late summer (Figure 19, Table 12). Algae counts were highest in the Armstrong Arm throughout the year but all sites experienced high densities of cyanobacteria during 2022 (Figure 20). The Armstrong Arm experienced particularly high cyanobacteria densities during the late summer (maximum of 42,526 cells/mL during April) led by Planktolyngbya sp., *Anacystis sp.*, and *Aphanizomenon sp.*, all potentially toxic species. Very high cyanobacteria densities in the Armstrong Arm may be a marker for nutrients delivered to Okanagan Lake from the areas burned in the White Rock Lake wildfire.

Table 12: Average phytoplankton counts by major algae groups in cells/mL, 2022

	2022 Averages			
Algae Type	Summerland	Kelowna	Okanagan Centre	Armstrong Arm
Diatoms	440	286	392	323
Greens	139	67	139	541
Yellow-Brown	270	437	565	526
Cyanobacteria	5916	4900	6659	16600
Dinoflagellates	0	12	16	61
Other.Flagellates	6727	5711	7781	18044
Total Algae	440	286	392	323

Figure 19: Taxonomic breakdown of algae by major types during 2022

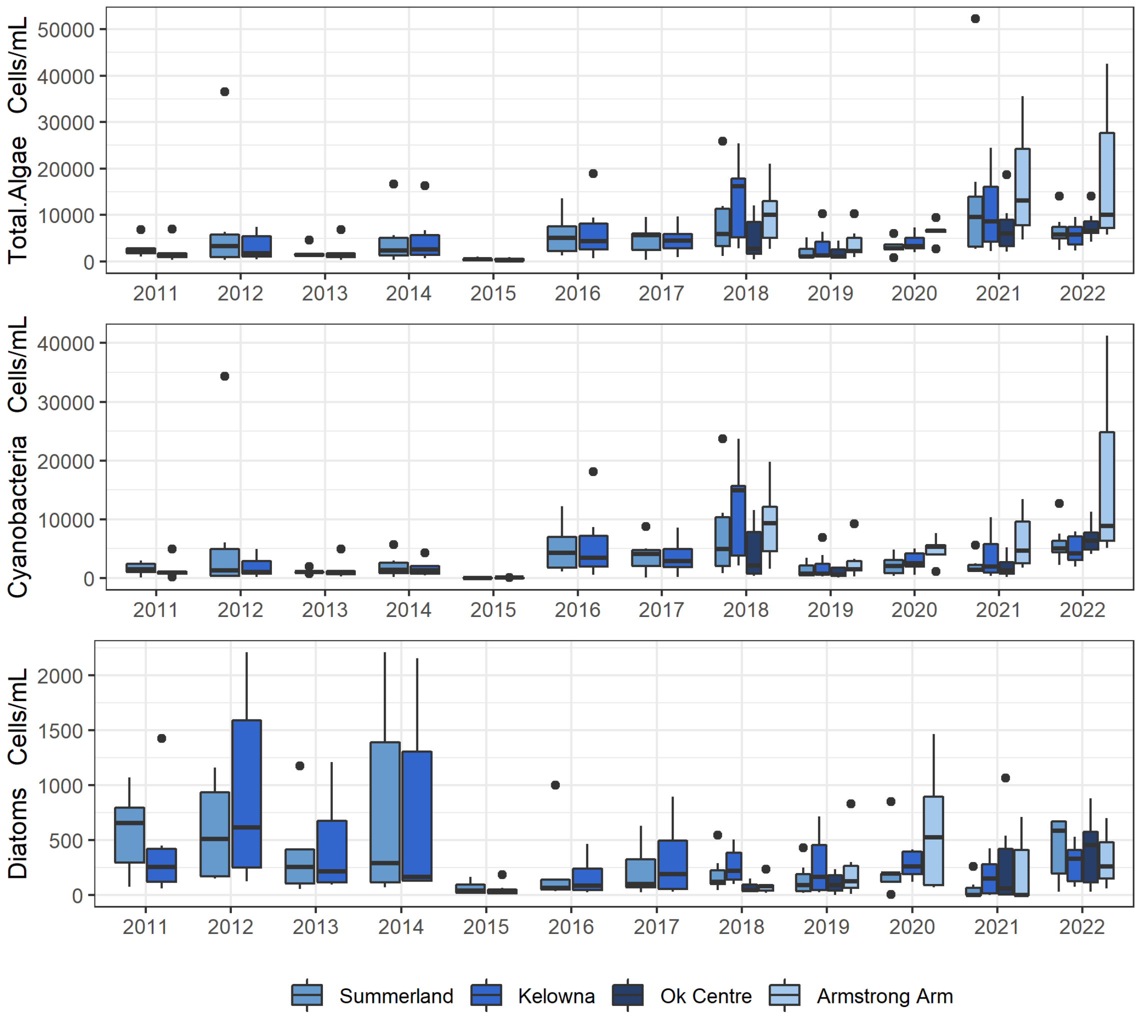

Figure 20: Total algae, cyanobacteria, and diatom counts in Okanagan Lake, 2011-2022

The Okanagan Lake objective for phytoplankton taxonomy states that no more than 5% of total cell counts should be heterocystous cyanobacteria in a given sample. These and other cyanobacteria can produce toxins that are harmful to human health when they are present in high concentrations. The heterocystous cyanobacteria objective was exceeded during most years including 2022 (93% of samples from 2022 exceeded this objective; Table 13). While problematic, the cyanobacteria densities observed at during 2022 were not high enough to cause acute health concerns at any of the sites. While densities were elevated during 2022, no significant year-over-year trends were detected in the heterocystous cyanobacteria counts from 2011-2022.

Table 13: Percent of total algae counts that were heterocystous cyanobacteria from 2022

Site	Objective	Trend	# Exceeding	Average	StdDev	Max	Min
Summerland	<5%	-	6/7	15.6%	12%	34%	0%
Kelowna	<5%	-	7/7	14.0%	7%	23%	5%
Ok Centre	<5%	-	6/7	15.7%	14%	42%	2%
Armstrong Arm	<5%	-	6/7	29.9%	14%	55%	17%

Note: Yellow shading indicates that the site did not meet the objective in some but not all samples

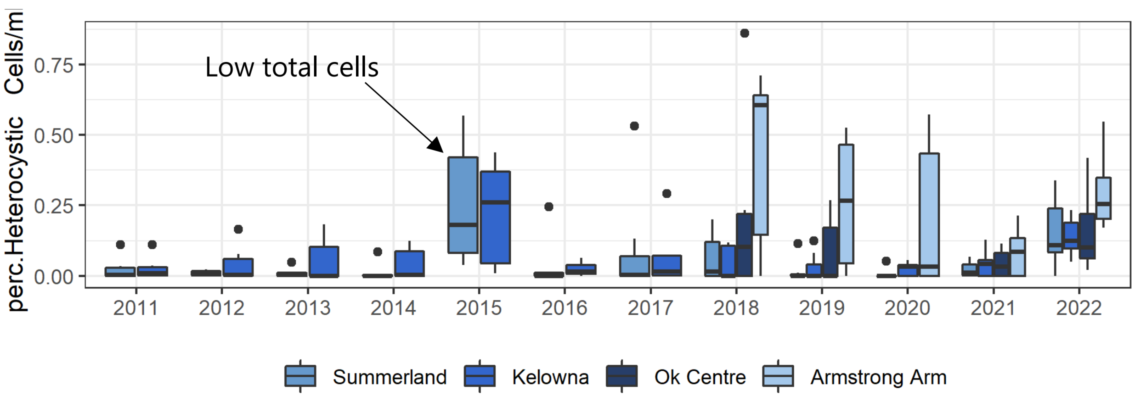

Figure 21: Percent of total algae counts that were heterocystous cyanobacteria, 2011-2022

2.3.2 Zooplankton

Biomass

Zooplankton biomass samples were obtained using a 150 µm net lowered to 45 m and raised vertically at a rate of approximately 0.5 m/second. The 150 µm net mesh size lets most phytoplankton pass through, while collecting most zooplankton. Samples were identified taxonomically and the biomass was calculated from the abundance.

The Okanagan Lake objective is a growing season average of >50 µg/L (Nordin, 2005). This objective was met at Okanagan Centre during 2022 with all sites near the 2015-2022 average (Table 14, Figure 22). While biomass during 2021 was unusually high, skewing trend results, there were no significant trends were detected in zooplankton biomass from 2015-2022 beyond the interannual variation. The cause of the elevated 2021 zooplankton density remains uncertain and was not repeated during 2022.

Table 14: Zooplankton biomass in µg/L at Okanagan Lake sampling sites, 2022

Site	Objective	Trend	Average	StdDev	Max	Min
Summerland	>50 µ/L	-	18.8	16.8	37.9	3.8
Kelowna		-	37.9	19.0	65.7	16.4
Okanagan Centre		-	58.1	16.1	75.7	32.4
Armstrong Arm		-	39.8	23.4	74.2	9.5

Note: Data includes only Apr-Aug results, Mar and Sep results not released by lab at time of writing.

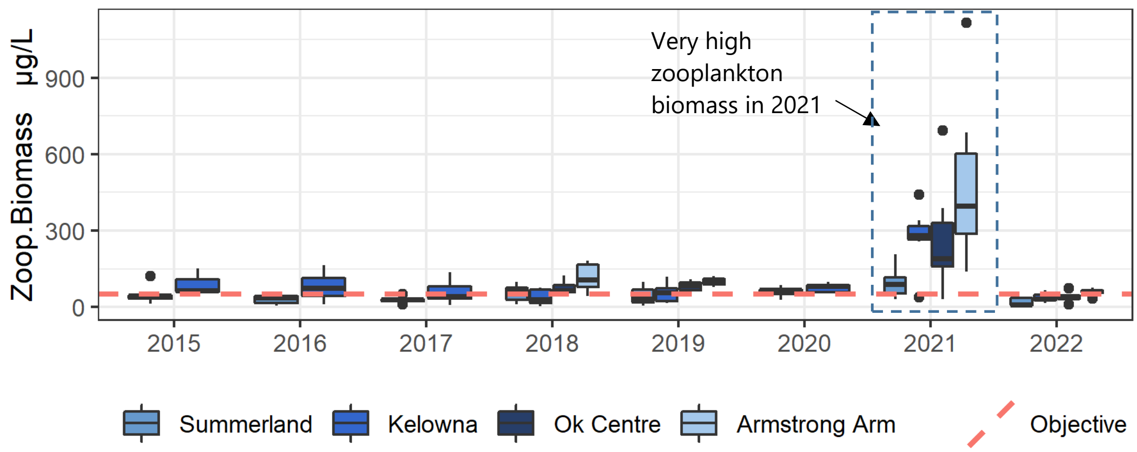

Figure 22: Zooplankton Biomass at the Kelowna and Summerland sampling locations by year, 2015-2022

Notes: There was a change in lab methodology in 2015, preventing comparison with previous years' data; 2022 data includes only Apr-Aug results, Mar and Sep results not released by lab at time of writing.

Zooplankton Taxonomy

Zooplankton samples were taxonomically identified to the species level and then grouped for analysis in this report. Copepods were the most numerous during every year of the study and averaged between 76% at Armstrong Arm and 94% at Summerland in 2022 (Table 15).

The objective for Okanagan Lake is a minimum of 5% of the sample counts be cladocerans. Approximately half of the samples met this objective at Okanagan Centre, an improvement compared to 2021 while Armstrong Arm, Kelowna, and Summerland had poorer objective achievement during 2022.

The average zooplankton abundances were consistent with values found in the literature (Andrusak et al., 2000; Rae and Andrusak, 2006; Andrusak et al., 2006). There was a decreasing trend in total zooplankton abundance in the Armstrong Arm from 2018-2022 (Table 15).

Table 15: Growing Season average percent cladocerans zooplankton, 2022

Site	Objective	# of samples exceeding	Trend	Average	StdDev	Max	Min
Summerland		1/5	-	2.4%	3.5%	7.5%	0.0%
Kelowna	>5% / sample	1/5	-	3.3%	4.6%	11.1%	0.3%
Okanagan Centre		3/5	-	6.3%	6.2%	14.9%	0.1%
Armstrong Arm		2/5	↓	7.9%	8.3%	18.9%	0.7%

Notes: Yellow shading = met objective in approximately half of samples, red shading = rarely met objective; Data includes only Apr-Aug results, Mar and Sep results not released by lab at time of writing.

3.0 Conclusions

This report summarizes the 2022 findings within the context of the 2011-2022 dataset. This report also extracts trends from the data accumulated by the Okanagan Lake Collaborative Sampling program to date (2011-2022) and compares those to the long-term historical database (1973-2022). The effects of Climate Change are already being felt in the Okanagan in recent years with repeated swings between large freshets and intensely dry summers; Fall was unusually hot and dry throughout the southern interior during 2022. While the results to date indicate that Okanagan Lake exhibits evidence of human activities, the Armstrong Arm is most impacted by continued human activities and watershed degradation, a situation likely to get worse because of the White Rock Lake wildfire. This site had the most exceedances and the most problematic trends, that is, trends moving parameters towards greater exceedances and poorer water quality.

Dissolved Oxygen Each year the temperature of Okanagan Lake increases seasonally in the surface waters until the lake becomes thermally stratified, usually in May. This physical dynamic isolates the deep water from the atmosphere and leads to oxygen depletion below the thermocline in Armstrong Arm. The Armstrong Arm therefore failed to meet the dissolved oxygen objective in 2022, as it has in each year of this study.

Nutrients
Silica analysis of water samples revealed a long period of stable conditions over the past 20 years.

Total nitrogen increased in the Armstrong Arm from 2011-2022 while increasing trends were noted in the hypolimnion at Kelowna. Total nitrogen exceeded the water quality objectives at all sites during 2022. Nitrate increased significantly in the Armstrong Arm and in the hypolimnion at all sites from 2011-2022. This is part of a decades long increasing trend in hypolimnetic nitrate in Okanagan Lake that has continued through multiple wet-dry climate cycles and is likely caused by increasing human impacts within the Okanagan region.

Phosphorus concentrations were highest in the Armstrong Arm where they exceeded the objective during 2022. There were increasing trends in TP from 2011-2022 at all four sites driven in part by increases during wet years such as 2017-2018. The Armstrong Arm is more heavily impacted by human activities and has numerous phosphorus sources such as nutrient enrichment of the Deep Creek watershed from over 100 years of agriculture, and the rise may become exacerbated by nutrients shed from the areas burned during the 2021 White Rock Lake fire. Dissolved phosphorus (TDP) and ortho-P represent the more bioavailable forms of phosphorus and were stable or declining at Summerland, Kelowna, Okanagan Centre while DP increased at the Armstrong Arm. Samples from the Armstrong Arm exceeded the nitrogen-phosphorus ratio objective in 2022, with a decreasing trend in that ratio from 2011-2022 at all sites.

Phytoplankton Productivity Chlorophyll-a (chl-a) concentrations increased each spring during the annual spring high algal growth period and then decreased over the summer and into the fall. Peak chl-a was moderate at all sites during 2022. Previous research by ENV has identified a one-year lag between major nutrient inputs and increases in phytoplankton productivity so it was expected that 2022 productivity would be lower after the small 2021 freshet. The chl-a and phytoplankton biovolume objectives were met at all sites during 2022.

The taxonomic data indicated that cyanobacteria numerically dominated the phytoplankton samples in 2022, as in every year studied. Samples from all sites exceeded the <5% heterocystous cyanobacteria objective in at least some samples during 2022 and Kelowna exceeded the objective in all samples.

Zooplankton Productivity Zooplankton biomass was stable from 2015-2022 with an unusually high result during 2021. Zooplankton biomass met the objective of >50 µg/L at at Okanagan Centre during 2022, the only site to do so. Copepods numerically dominated most samples. The water quality objective of >5% of zooplankton as cladocerans was achieved in 1/3 of samples from 2022.

Table 16 to Table 18 summarize the findings of this report for 2011-2022 by pairing trends to objective exceedances. Special focus should be paid to parameters that did not meet the objective and for which the data trended in the adverse direction over the course of the sampling program.

Similar to the 2011-2021 report, the following areas of concern have been identified that may require further investigation on the part of the Ministry:

- Chronically low Secchi depth in the Armstrong Arm
- Increasing nitrate in hypolimnion of Okanagan Lake since 1970s
- Increasing total phosphorus at all sites except Summerland since early 2000s
- Decreasing N:P ratio in the Armstrong Arm
- High densities of potentially toxic cyanobacteria in Armstrong Arm during 2018-2022
- Phosphorus loading to the Armstrong Arm and north basin of Okanagan Lake from the White Rock Lake wildfire

Armstrong Arm frequently exceeds most objectives and is the site most at risk of water quality degradation including harmful algae blooms, poor drinking water quality, anoxic conditions, and further eutrophication. There is also high likelihood of further degradation as a consequence of the White Rock Lake wildfire. It must be acknowledged that Armstrong Arm is shallower and therefore would be more productive than the deep basins of Okanagan Lake regardless of human activity. However, human activities in the watershed have impacted this northern-most basin of the lake.

The period of 2016-2022 was marked by multiple extreme weather events that have left a distinct mark on the water quality record of Okanagan Lake. Climate Change and is expected to increase the frequency and intensity of extreme weather events in the future. Climate Change also compounds the loss of resilience in Okanagan watersheds leading to greater water quality changes from those extreme weather events.

Table 16: Okanagan Lake Water Quality Objectives

Objectives (Nordin, 2005)	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth (growing season average)	7m	6m	6m	5m
Dissolved Oxygen (minimum in bottom waters)	-	-	-	>5 mg/L
TP (mg/L as P) (maximum at spring overturn)	0.007	0.008	0.008	0.01
Chlorophyll-a (µg/L) (maximum seasonal average)	<4.5	<4.5	<4	<5
TN (mg/L as N) (maximum at spring overturn)	0.230	0.230	0.230	0.250
N:P Ratio (spring weighted ratio)	>25:1	>25:1	>25:1	>25:1
Algae Taxonomy (% heterocystous cyanobacteria)	<5%	<5%	<5%	<5%
Algae Biomass (µL/L) (growing season average)	<0.75	<0.75	<0.75	<0.75
Zooplankton Biomass (µg/L) (growing season average)	>50	>50	>50	>50
Zooplankton Taxonomy (% cladocerans)	>5%	>5%	>5%	>5%

Table 17: Attainment of Okanagan Lake water quality objectives compared to growing season averages during 2022

Objective		Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth		6.4	6.4	7	3.3
Dissolved Oxygen		7.96	8.25	8.20	1.84
TP (mg/L)	0:10m:	0.006	0.007	0.009	0.011
	20-45m:	0.004	0.008	0.006	0.027
Chlorophyll-a (µg/L)		1.99	2.33	2.46	3.62
TN (mg/L)	0-10m:	0.224	0.227	0.225	0.253
	20-45m:	0.246	0.251	0.245	0.323
N:P Ratio	0-10m:	45:1	43:1	34:1	18:1
	20-45m:	52:1	49:1	32:1	18:1
Algae Taxonomy (% heterocystous cyanobacteria)		15.6%	14.0%	15.7%	29.9%
Algae Biovolume (µL/L)		0.164	0.229	0.273	0.269
Zooplankton Biomass (µg/L)		18.8	37.9	58.1	39.8
Zooplankton Taxonomy (% cladocerans)		2.4%	3.3%	6.3%	7.9%

Legend:

Achieved objective	Achieve objective in some but not all samples	Did not achieve objective

Table 18: Summary of trends (2011-2022) and the water quality objectives for Okanagan Lake collaborative sampling program during 2022

Objective		Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth		-	-	-	-
Dissolved Oxygen		-	-	-	-
TP (mg/L)	0:10m:	↑	↑	↑	↑
Chlorophyll-a (µg/L)		-	↑	↑	↑
TN (mg/L)	0-10m:	-	↑	↑	↑
N:P Ratio	0-10m:	↓	↓	↓	↓
Algae Taxonomy (% heterocystous cyanobacteria)		-	-	-	-
Algae Biovolume (µL/L)		↑	↑	-	-
Zooplankton Biomass (µg/L)		-	-	-	-
Zooplankton Taxonomy (% cladocerans)		-	-	-	↓

Legend:

Achieved objective	Achieve objective in some but not all samples	Did not achieve objective

↑ = Increasing Trend ↓ = Decreasing Trend - = No Trend

4.0 Recommendations

The following recommendations are made for the program moving forward:

- Continue the monitoring program, unchanged in 2023
- Complete another summary report at the end of the next three-year cycle (next in 2024)
- Continue to analyze taxonomy samples in Okanagan Centre and Armstrong Arm
- Incorporate invasive mussels risk criteria in future editions of this report

5.0 References

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6.0 Appendices

6.1 Appendix 1: 2011-2022 Sampling Data

All data used in this report can be found in the data transfer file
MoE-Synth-DB.xlsx

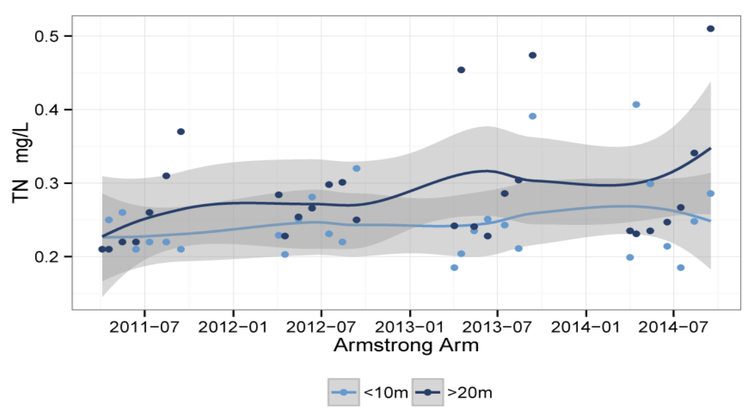
6.2 Appendix 2: Statistics and Graphing Overview

Statistical analyses were performed on data to support interpretations made throughout this report. The use of the word 'significantly' within this report is understood to signify that the claim being made has stood up under statistical analysis. Unless otherwise stated, all statistical analyses were performed to a confidence of greater than or equal to 95% ($p \leq 0.05$). The ± symbol indicates plus or minus the standard deviation throughout this report.

Trends were determined through Mann-Kendall linear regression. Mann-Kendall is a non-parametric test for linearity in data. The test produces a Tau-value and a p-value. The Tau value gives the direction of the data and the p-value indicates whether the trend is statistically significant.

Throughout this report the monthly sampling data was grouped seasonally for additional analyses. March, April, and May data were combined as "Spring"; June, July, and August as "Summer"; and September as "Fall".

Correlations were performed using the Pearson's Correlation method and all R values reported at Pearson's Correlation Coefficients.



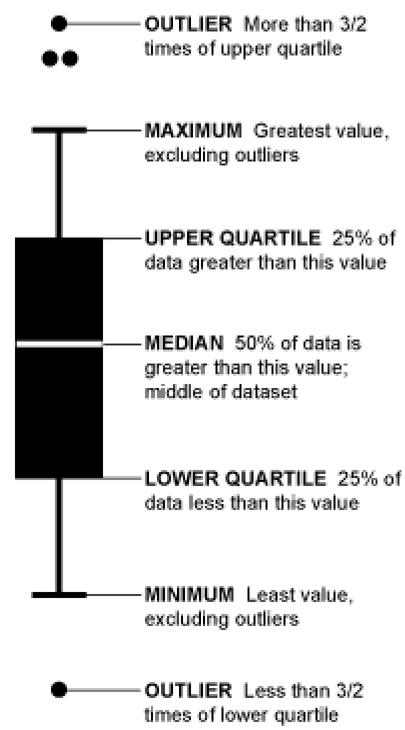
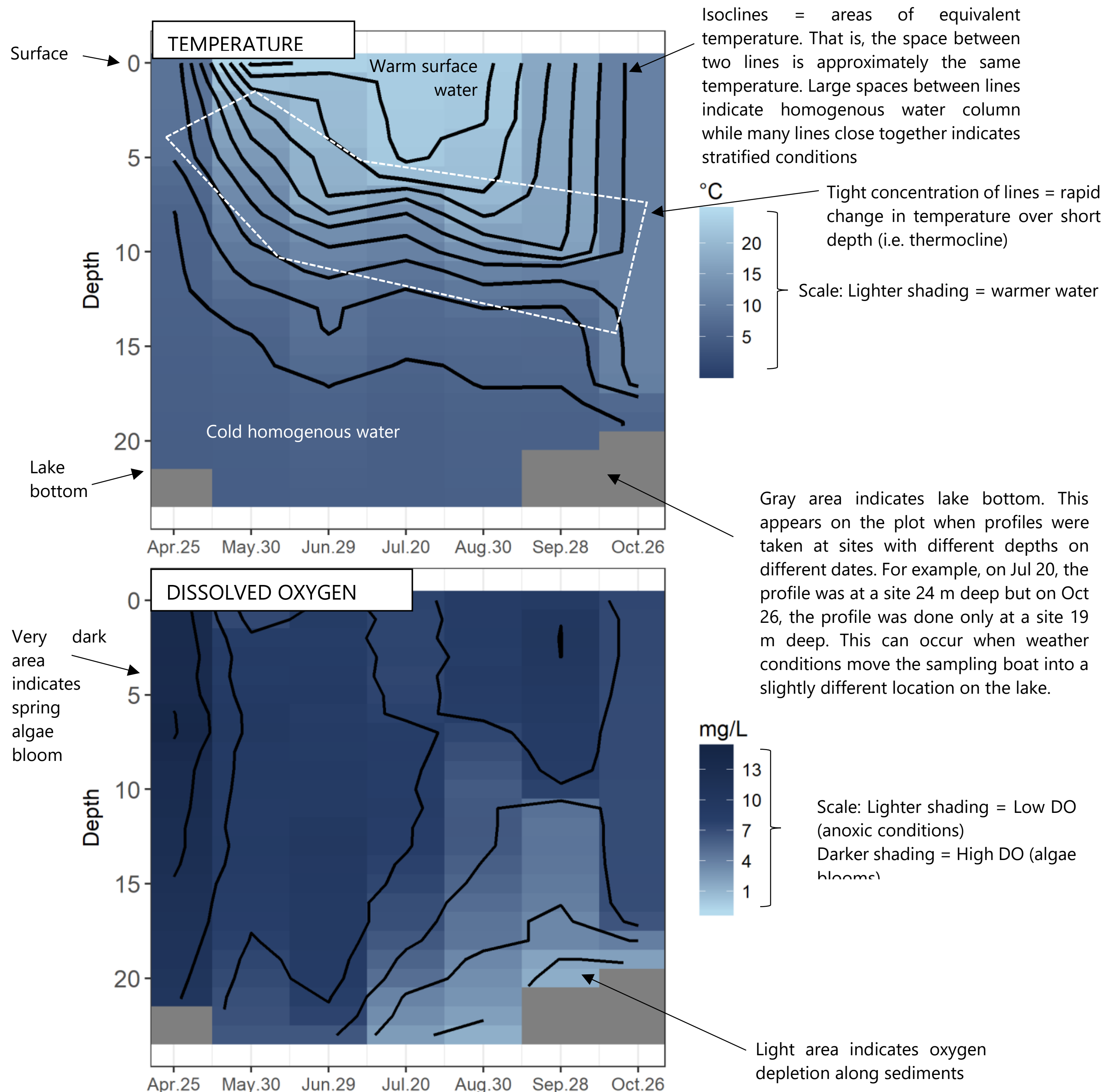


Figure i: Example scatterplot and boxplot
Includes all data for a parameter sorted by depth, LOESS polynomial trendlines and the standard errors of those trendlines are also included. Example boxplot is labeled with key information. Whiskers represent the distance to the highest or lowest point within 1.5 * IQR where IQR represents the range between the upper and lower quartiles.

How to Read Temperature/DO Profile Plot

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



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

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