LARRATT AQUATIC

Okanagan Lake Collaborative Monitoring Agreement 2018 Summary Report

Prepared for BC Ministry of Environment and Climate Change Strategy, Environmental Protection Division

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 (ENV) in partnership with local municipalities, commissioned a multi-year collaborative monitoring program to sample long-term water quality in Okanagan Lake, monthly (March to September) at four locations from 2011 to 2018. A primary function of the monitoring is 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. In 2018, 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 ranging from phytoplankton and zooplankton biomass to specific taxonomic identification, were also collected. This report summarizes the 2018 findings and analyzes data from 2011-2018 for trends.

2018 was the second year in a wet phase in the natural wet-dry climate cycle and experienced an intense freshet and minor flooding that significantly impacted water quality throughout the lake. The results to date indicate that the Armstrong Arm is impacted by human activities and watershed degradation including but not limited to agriculture, cattle range, logging and shoreline septic. This site had the most exceedances and the most parameters trending towards greater exceedances.

Physical

Okanagan Lake experienced thermal stratification during May-November in 2018 as it did in each year of study. Secchi depth was highest in late winter and decreased each spring in response to increased phytoplankton activity. Water clarity was low throughout the lake in 2018 because of the intense freshet and associated effects including suspended sediment and increased phytoplankton growth. All sites failed to meet the Secchi depth objective in 2018.

Chemical

Dissolved oxygen (DO) is essential for all aquatic animals and is high throughout Okanagan Lake at all times except in the Armstrong Arm. DO in the deep water of the Armstrong Arm fell below the water quality objective each summer including 2018. Silica concentrations were higher in the Armstrong Arm than the rest of Okanagan Lake averaging compared to the southern sites during 2018. Silica increased significantly at all sites from 2013-2018 and may relate to lower diatom concentrations over that time period.

Total nitrogen averaged 0.268 ± 0.065 mg/L as N in Okanagan Lake and exceeded the objective at all sites during 2018. Total nitrogen increased at the Armstrong Arm but was stable at the three southern sites from 2011-2018.

Nitrate increased significantly in the Armstrong Arm and in the hypolimnion at all sites from 2011-2018. 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.

Total phosphorus (TP) averaged 0.010 ± 0.008 mg/L as P in Okanagan Lake during 2018 and increased at all sites in 2018 because of P imported by the intense freshet flows. TP had a year-over-year increasing trend in the Armstrong Arm, where it also exceeded the objective in 2018. TP includes phosphorus associated with suspended sediment carried into the lake and it increased in Okanagan Lake during wet years and decreased during dry years (see 2017 comprehensive report). This is supported by the absence of comparable trends in dissolved phosphorus which is not as affected by freshet inflows. Dissolved phosphorus was stable at the three southern sites but increased dramatically in the Armstrong Arm from 2011-2018.

The ratio of nitrogen to phosphorus (N:P) available to phytoplankton will play a major role in which types of phytoplankton proliferate in a given lake. A lower N:P ratio (abundant phosphorus relative to nitrogen) will favour the growth of less desirable cyanobacteria. The N:P ratio failed to meet the objective in the Armstrong Arm surface samples in 2018 with a downwards trend (farther from meeting objective).

Biological

Chlorophyll-a was used as a measure of photosynthetic activity in Okanagan Lake. An increasing south to north trend in the chlorophyll-a data occurred over the course of this study. Increased chlorophyll-a occurred at all sites in 2018 because of greater phytoplankton productivity associated with nutrients carried into Okanagan Lake during the intense 2017 and 2018 freshets. Previous research by ENV has identified a one-year lag between major nutrient inputs and increases in phytoplankton productivity so 2019 productivity is expected to be high even if there is a normal freshet that year. Armstrong Arm had a significant year-over-year increasing trend and failed to meet the chlorophyll-a objective for the second year in a row.

Phytoplankton abundance and biovolume were both elevated in 2018 compared to previous years because of increased nutrient concentrations associated with the 2017 and 2018 freshets. Cyanobacteria numerically dominated phytoplankton counts and all samples exceeded the phytoplankton taxonomy objective in 2018.

Zooplankton biomass met the objective in Summerland but not in Kelowna during 2018, which is the first year Kelowna failed to meet the objective since the current sampling program began in 2015. Kelowna and Summerland both failed to meet the objective of >5% cladocerans in 2018 and this was likely related to predation by fish and mysid shrimp. There were no significant trends in zooplankton data to date.

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 and dissolved phosphorus in the Armstrong Arm
- Decreasing N:P ratio in the Armstrong Arm
- Lingering effects of the 2017-2018 freshets on 2019 productivity

The following areas had been previously identified as concerns but were no longer considered issues as of 2018:

- Decreasing dissolved oxygen concentrations throughout the lake (data have been stable for 5 years)

Water Quality Objectives, 2018 Values, and Trends for Okanagan Lake

Objectives (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)	<0.008	<0.008	<0.007	<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%

Objective		**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth		5.4	4.6	4.7	2.4
Dissolved Oxygen		9.21 (Aug)	9.63 (Jul)	9.4 (Aug)	1.39 (Sep)
TP (mg/L)	0:10m:	0.007	0.011	0.008	0.016
	20-45m:	0.005	0.009	0.006	0.022
Chlorophyll-a (µg/L)		2.5	2.81	3.82	6.26
TN (mg/L)	0-10m:	0.241	0.235	0.241	0.309
	20-45m:	0.240	0.236	0.275	0.394
N:P Ratio	0-10m:	40:1	35:1	32:1	23:1
	20-45m:	51:1	38:1	46:1	20:1
Algae Taxonomy (% heterocystous cyanobacteria)		20%	12%		
Algae Biomass (µg/L)		0.196	0.326		
Zooplankton Biomass (µg/L)		70.2	45.5		
Zooplankton Taxonomy (% cladocerans)		1.2%	4.5%		

Legend:

Met objective in 2018	Did not meet objective in 2018	No Data/ No Objective

Summary of trends and the water quality objectives for Okanagan Lake collaborative sampling program (2011-2018). Modified from Nordin 2005.

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

Legend:

Met objective in 2018	Did not meet objective in 2018	No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend

Cell colours in the table: Summerland — Secchi Depth, TN, Algae Taxonomy, Zooplankton Taxonomy did not meet objective; Dissolved Oxygen no data; others met. Kelowna — Secchi Depth, Algae Taxonomy, Zooplankton Biomass, Zooplankton Taxonomy did not meet; Dissolved Oxygen no data; others met. Ok Centre — Secchi Depth did not meet; Dissolved Oxygen and the algae/zooplankton rows no data; others met. Armstrong Arm — TN met; algae/zooplankton rows no data; others did not meet.

Preferred Citation

Self, J. and H. Larratt, 2019. Okanagan Collaborative 2086 Update Report. Prepared by Larratt Aquatic Consulting Ltd. Prepared for British Columbia Ministry of Environment and Climate Change Strategy.

Report prepared by: Larratt Aquatic Consulting Ltd.

Jamie Self: BSc, RPBio
Aquatic Biologist

Heather Larratt: BSc. RPBio
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
Anaerobic/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
Littoral	Shoreline between high and low water; the most productive area of a lake
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
Peak biomass	The highest density, biovolume or chl-a attained in a set time on a substrate
Periphyton	Algae that are attached to aquatic plants or solid substrates
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
Plankton	Those organisms that float or swim in water
Residence time	Time for a parcel of water to pass through a reservoir or lake (flushing time)
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
Seiche	Wind-driven tipping of lake water layers in the summer, causes oscillations
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	primary production mg C/m²/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) (Nordin,1985)

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

Statistics Overview

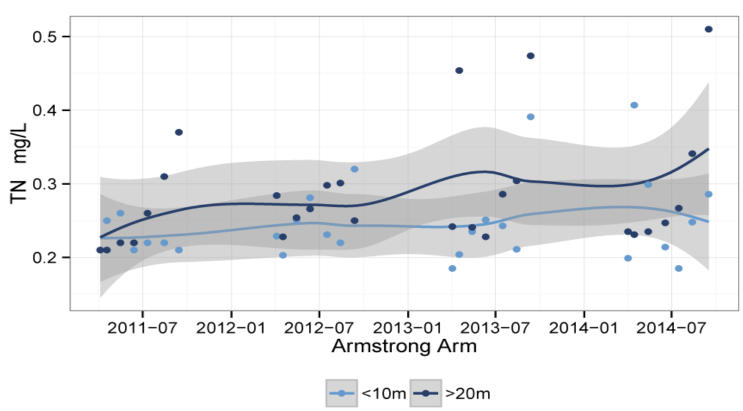
Statistical analyses were performed on data to support interpretations made throughout this report. The use of the word 'significantly' within this report is understood to signify that the claim being made has stood up under statistical analysis. Unless otherwise stated, all statistical analyses were 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.

Water quality data often contains non-detect values for many parameters. Non-detect values were converted to ½ detection limit for all calculations.

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.



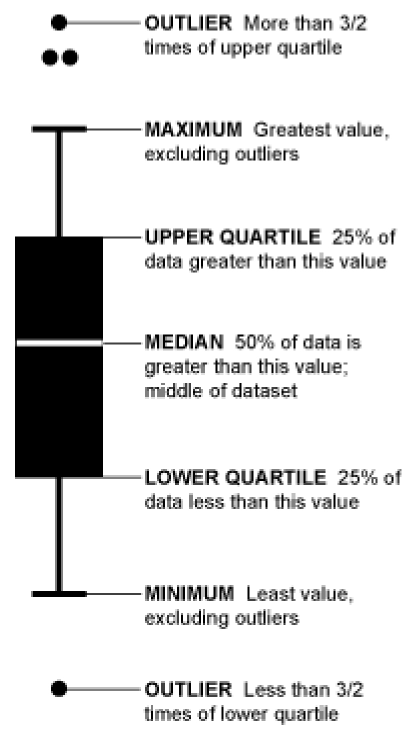
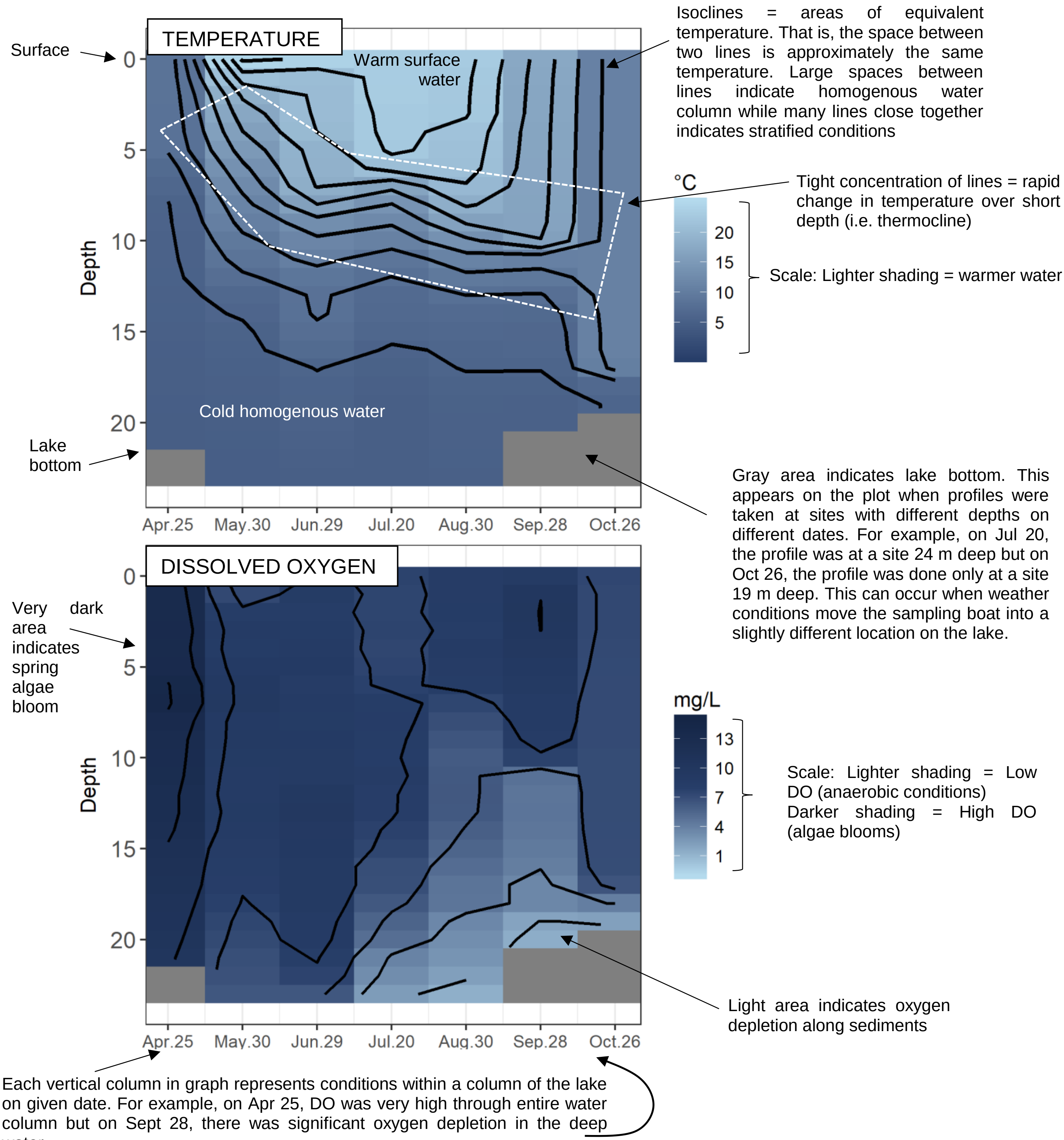


Figure i: Example scatterplot and boxplot
Includes all data for a parameter sorted by depth, LOESS polynomial trendlines and the standard errors of those trendlines are also included. Example boxplot is labeled with key information. Whiskers represent the distance to the highest or lowest point within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



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 on 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 (2012-2018). Okanagan Lake was sampled monthly from March to September from 2011-2018 at four key sites (Figure 1.1-1, Table 1.1-1).

Table 1.1-1: GPS coordinates of sampling sites

Site Name	Site Number	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°

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 2.1-1). 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.

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

The 2018 data were added to the existing 2011 – 2017 database upon which all the analyses in this report were performed. Water quality objectives were based upon Nordin (2005) (Appendix 1).

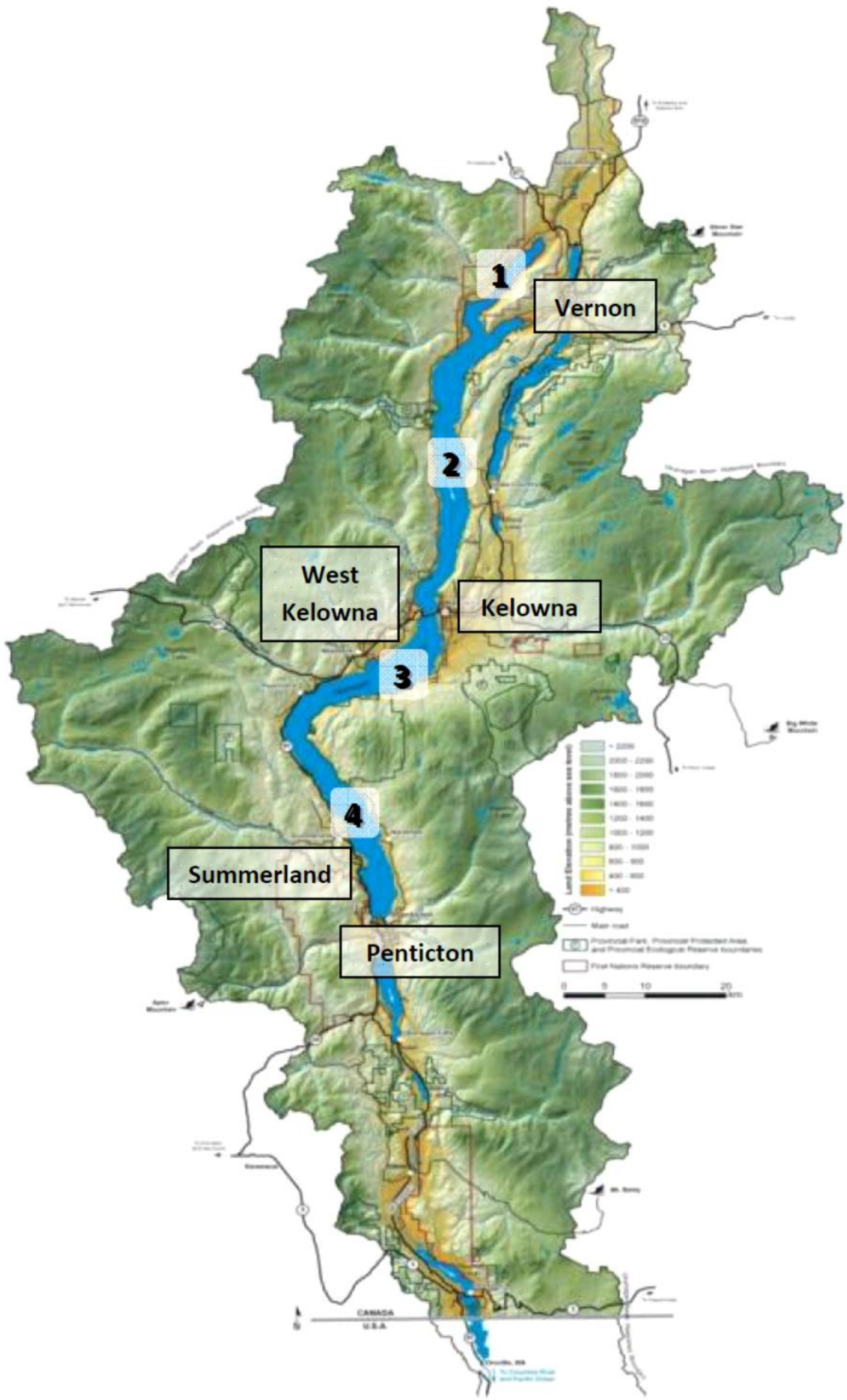


Figure 1.1-1: Okanagan Basin Watershed with four sampling locations identified. 1=Armstrong Arm, 2=Ok Centre, 3=Kelowna, 4=Summerland
(Sokal, 2013)

1.2 Weather and Climate Conditions in 2018

The weather during any given year will have a major impact on physical conditions, water chemistry, and biological activity in Okanagan Lake during that year. The weather during 2017 and 2018 was very unusual for the Okanagan region. 2017 had the record highest flooding of Okanagan Lake followed immediately by the driest summer recorded. 2018 had a long, cold, and snowy winter followed by a wet spring, that combined to create a very intense freshet and minor flooding throughout the valley (Figure 1.2-1, Figure 1.2-2). The 2018 spring flooding was followed by a very hot and dry summer in which the Okanagan experienced weeks of intense smoke and ash from wildfires (Figure 1.2-3). The net result was 2018 had lower water quality, across a variety of parameters, than is typical for Okanagan Lake.

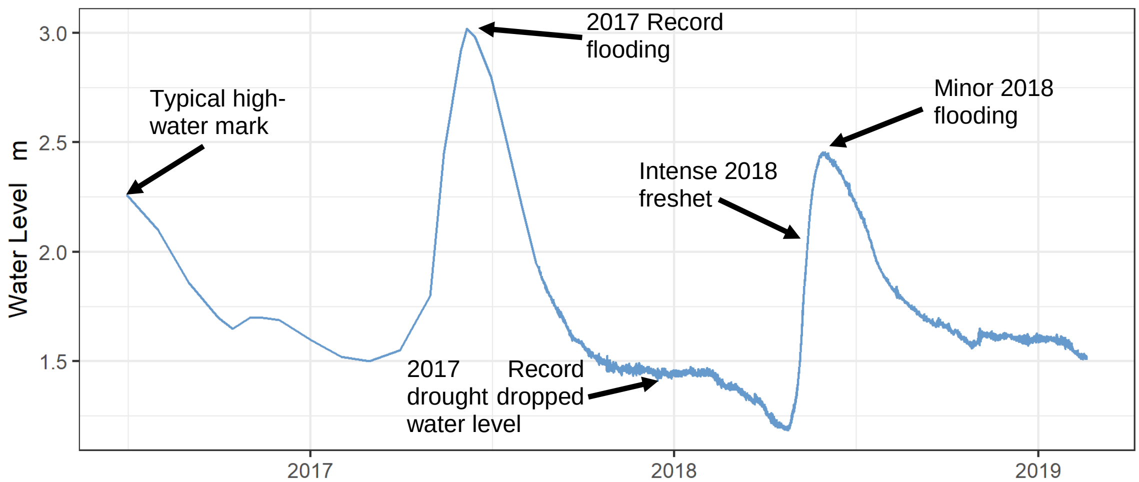


Figure 1.2-1: **Water level in Okanagan Lake at Kelowna from Jun 2016 – Feb 2019**
Source: (Water Office, 2019)


Figure 1.2-2: Bear Creek plume into Okanagan Lake in May 2018


Figure 1.2-3: Smoky skies in the Okanagan during 2018

2.0 Results & Discussion

2.1 Physical

2.1.1 Temperature

Okanagan Lake is a deep monomictic lake. This means 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 2.1-1).

The three southern sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal behavior while the northern Armstrong Arm site is shallower and behaves differently. The later reaches a higher surface temperature and experiences oxygen depletion in the deep water each summer (Figure 2.1-1). 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 2011–2018 temperature data either annually, seasonally, or monthly (Mann-Kendall trend tests).

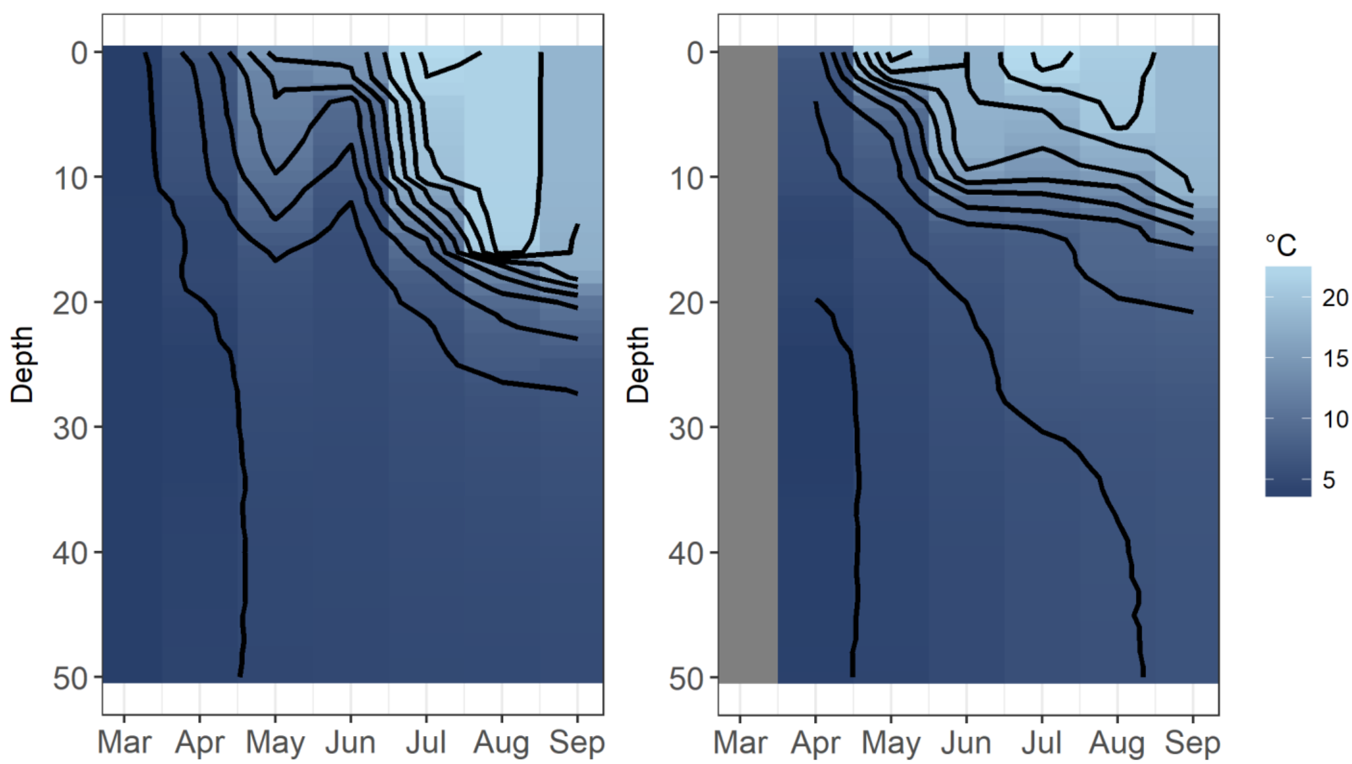


Figure 2.1-1: Temperature and dissolved oxygen profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right), 2018

Lines represent contours of same temperature or dissolved oxygen within the water column through time.

Surface water temperatures of Okanagan Lake at all four sites were above average during May 2018 because of the hot spring. Temperatures declined to the average in June and remained close to average despite the hot dry summer, possibly because of the intense smoke reducing the amount of sunlight that reached the lake (Figure 2.1-2).

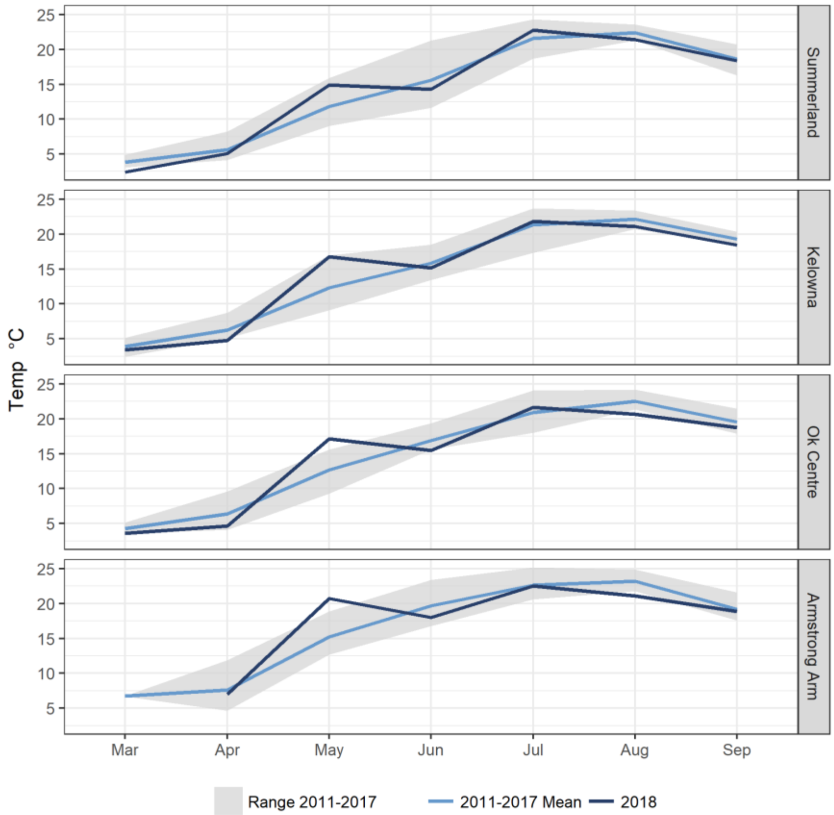


Figure 2.1-2: Temperature at Okanagan Lake sampling sites during 2018 compared to 2011-2017

2.1.2 Water Clarity and Secchi Depth

Secchi depth during 2018 ranged from a minimum of only 1.55 m at Armstrong Arm in August to a maximum of 12.3 m at Okanagan Centre in March (Table 2.1-1). Secchi depth averages were low during 2018 because of sediment carried into Okanagan Lake during the intense freshet (Figure 1.2-2, Figure 2.1-3). All four sites failed to meet the objective during 2018, and the Armstrong Arm growing season average was less than half of the objective. The overall average for Okanagan Lake historically has been 6.5-6.6 m and averaged 4.3 ± 1.9 m in 2018 (Andrusak et al., 2006; Nordin, 2005).

Secchi depth followed a consistent pattern each year. Maximum Secchi depths occurred in the late-winter when biological activity was the lowest. During the spring algae bloom 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 2.1-3).

The Secchi depth in the Armstrong Arm was much lower throughout 2018 than at the other sites in Okanagan Lake. This is clearly illustrated in Figure 2.1-3. There were no statistically significant year-over-year trends in the Secchi depth data from 2011-2018 but the 2017 and 2018 Secchi results lowered the averages (Figure 2.1-4).

Table 2.1-1: Growing Season (Apr-Sep) Secchi depth in meters at Okanagan Lake sampling sites, 2018

Site	Objective	Average	StdDev	Max	Min
Summerland	7.0	5.4	2.1	8.0	1.9
Kelowna	6.0	4.6	1.7	6.8	1.7
Ok Centre	6.0	4.7	1.4	6.8	3.1
Armstrong Arm	5.0	2.4	0.6	3.2	1.6

Note: Objective refers to growing season average (Apr-Sep)

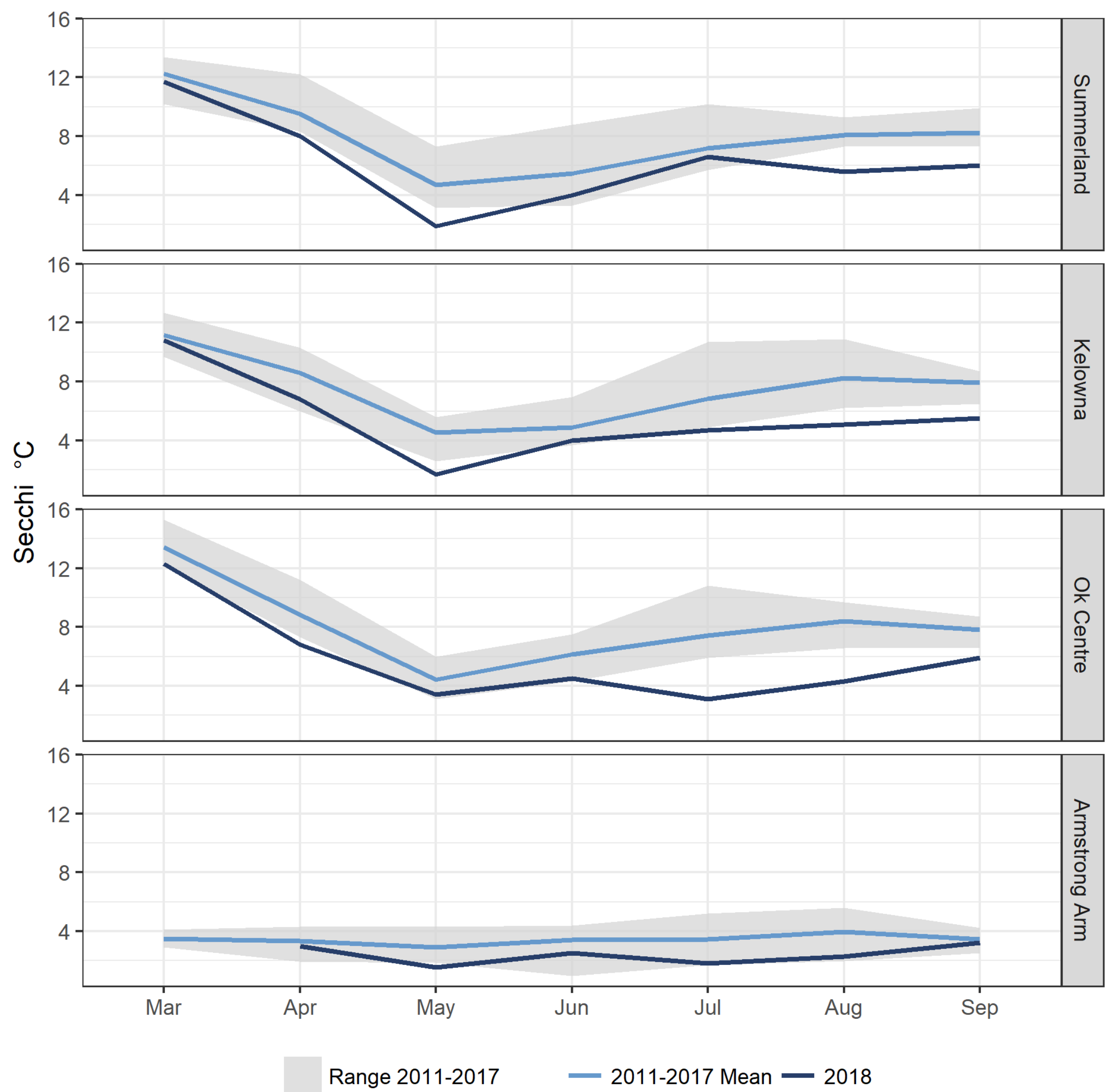


Figure 2.1-3: Secchi depth at Okanagan Lake sampling sites during 2018 compared to 2011-2017

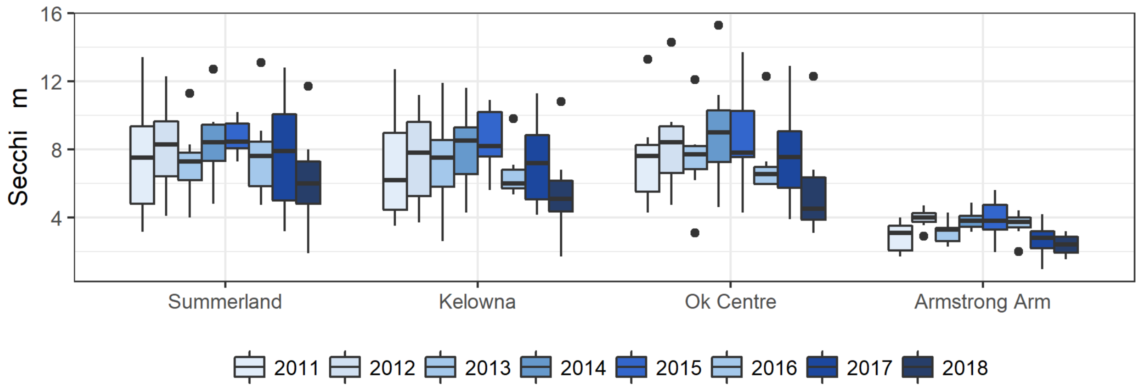


Figure 2.1-4: Secchi Depth at Kelowna during Summer (June-Aug) from 2011-2018

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 are frequently the result of 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. Anaerobic 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 southern sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal and dissolved oxygen behavior while the northern Armstrong Arm site is shallower and behaves differently. The later reaches a higher surface temperature and experiences oxygen depletion in the deep water each summer (Figure 2.2-1). Oxygen depletion is caused by decomposition of organic material in the sediment and deep water. 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 August 2018, the low dissolved oxygen zone (volume below red line in Figure 2.2-1) had expanded to fill the entire hypolimnion and was 41 m thick. The bottom 9 m were fully anaerobic by September (≤2 mg/L).

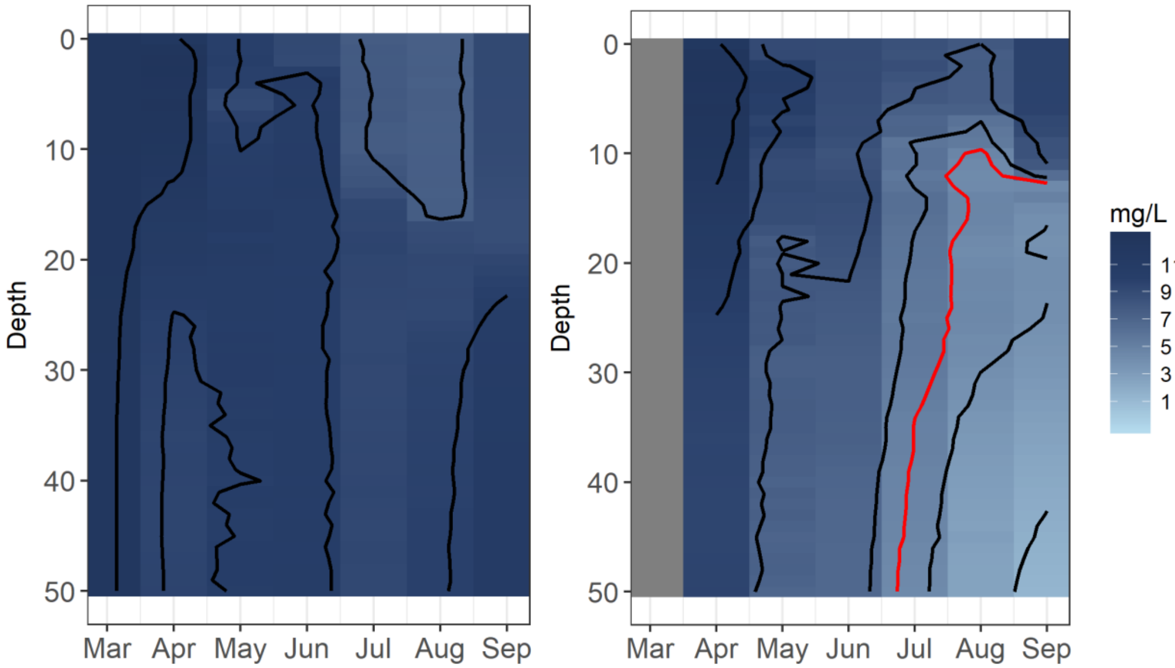


Figure 2.2-1: Dissolved oxygen profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right) during 2018

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.

Surface dissolved oxygen concentrations vary throughout the year and have been stable throughout the lake from 2012-2018[1] (Figure 2.2-2).

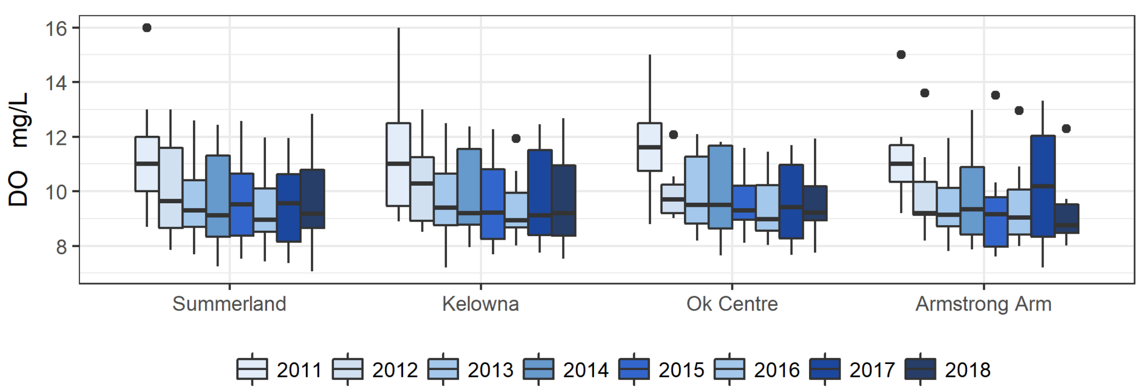


Figure 2.2-2: Surface dissolved oxygen concentrations at Okanagan Lake sampling sites grouped by year, 2011-2018

[1] DO concentrations in 2011 were above average and including this year in the trend analysis generates artificial decreasing trends. Previous reports identified these decreasing trends as an area of concern but additional years of data have revealed that DO is stable in Okanagan Lake.

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 it 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 in the Armstrong Arm than the three southern sites which were similar to each other (Table 2.2-1, Figure 2.2-3). Silica increased significantly from 2011-2018 in the Armstrong Arm (Mann-Kendall, $p=0.001$) and from 2013-2018 at the southern sites (Mann-Kendall, $p<0.05$). The increase in silica may relate to lower diatom concentrations observed at Kelowna and Summerland over the past 4 years (Figure 2.3-6); diatoms take-up dissolved silica reducing its concentration (Schelske, 1988).

Table 2.2-1: Silica concentration in mg/L at Okanagan Lake sampling sites, 2018

Site	Average	StdDev	Max	Min
Armstrong Arm	9.36	1.80	11.80	7.89
Kelowna	7.87	0.08	7.97	7.80
Ok Centre	8.00	0.25	8.32	7.71
Summerland	8.03	0.26	8.41	7.85

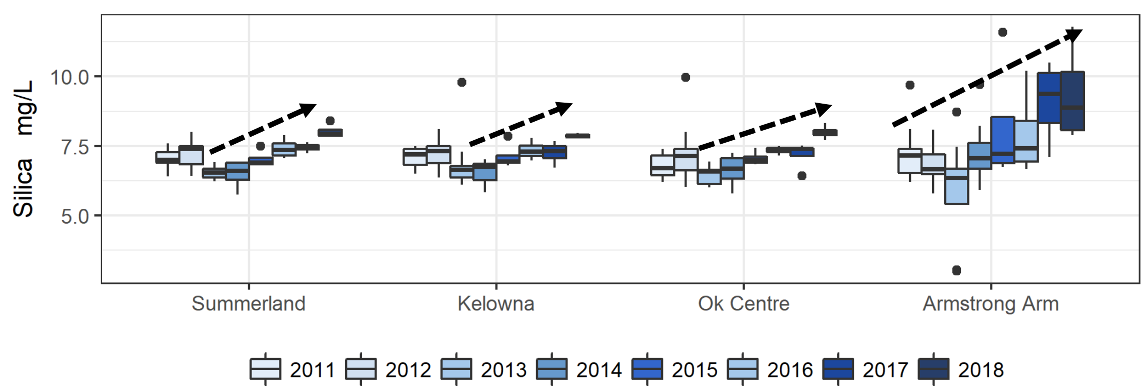


Figure 2.2-3: Silica concentration in Okanagan Lake at each sampling site by year with trends highlighted, 2011-2018

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 and its concentration is directly linked to the amount of algae that the lake produces (Nordin, 2005).

Nitrogen

Total nitrogen (TN) averaged 0.268 ± 0.065 mg/L as N in Okanagan Lake during 2018 (Table 2.2-2). The objective for Okanagan Lake was set as a spring value (March sample date) of 0.230 mg/L for the main basins and 0.250 mg/L for the Armstrong Arm. The objectives were exceeded at all sites during 2018. TN increased in the Armstrong Arm from 2011-2018 (Mann-Kendall, $p \leq 0.007$) and was stable at the three southern sites (Table 2.2-2).

Table 2.2-2: Total nitrogen in mg/L as N concentration at Okanagan Lake sampling sites, 2018

Site	Depth	Objective	Exceeded in 2018?	Trend	Avg	SD	Max	Min
Summerland	<10m	0.230	Yes	-	0.241	0.021	0.276	0.214
	>20m		Yes	-	0.240	0.007	0.249	0.231
Kelowna	<10m	0.230	Yes	-	0.235	0.017	0.262	0.215
	>20m		Yes	-	0.236	0.010	0.25	0.221
Ok Centre	<10m	0.230	Yes	-	0.241	0.032	0.308	0.206
	>20m		Yes	-	0.275	0.085	0.463	0.223
Armstrong	<10m	0.250	Yes	↑	0.309	0.039	0.356	0.265
Arm	>20m		Yes	↑	0.394	0.077	0.482	0.273

Note: Statistical significance of general trends derived from all data for a site may disappear when depths are split apart due to smaller sample size

Nitrate increased in the Armstrong Arm at both depths (Mann-Kendall, $p<0.001$; Figure 2.2-4) and in the hypolimnion throughout the lake from 2011-2018 (Mann-Kendall, $p<0.001$). Analysis of the entire Okanagan Lake water chemistry database indicates that this trend has been ongoing for decades (Figure 2.2-5). That this trend has continued through several wet-dry climate cycles suggests a connection with human activities in the region.

Nitrate is rapidly consumed by algae in the epilimnion each spring and thermal stratification prevents replenishment from the deeper water during the summer (Figure 2.2-4). Nitrate increases dramatically each summer in the hypolimnion of the Armstrong Arm because of chemistry associated with the low-DO conditions, rising from 0.0032 mg/L as N in the epilimnion to 0.268 mg/L as N in the hypolimnion by Sept 11, 2018. 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).

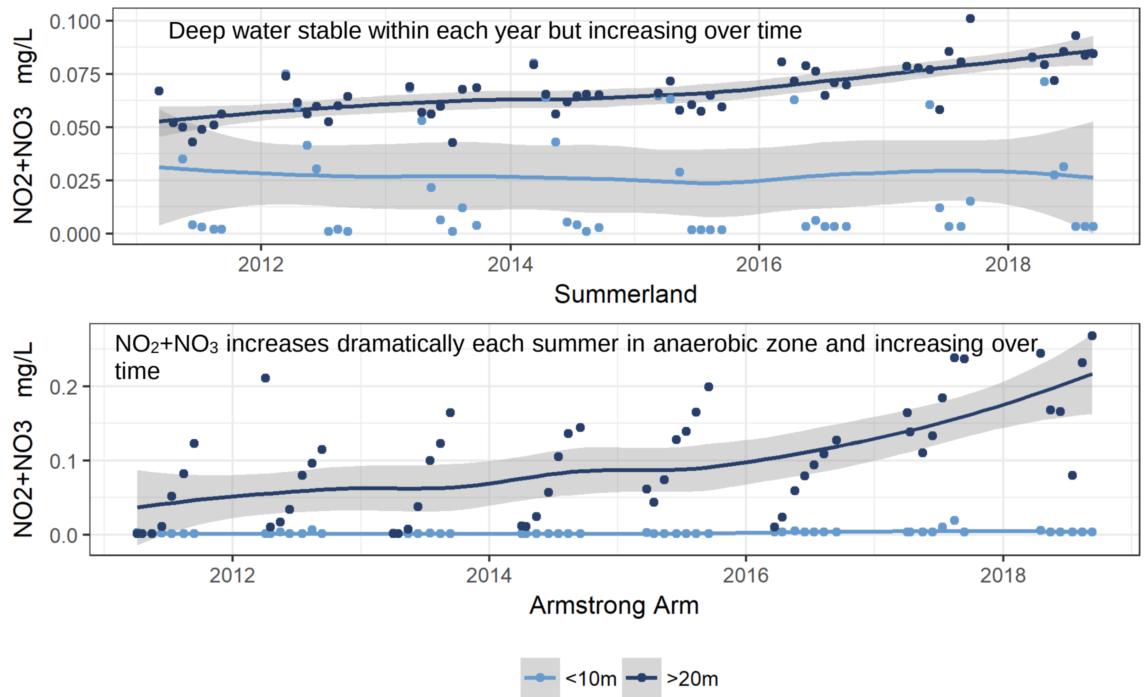


Figure 2.2-4: Nitrite (NO_2) + nitrate (NO_3) in mg/L as N in the surface and deep water of Okanagan Lake at Summerland and in the Armstrong Arm, 2011-2018
Note: Different scales between Summerland and Armstrong Arm

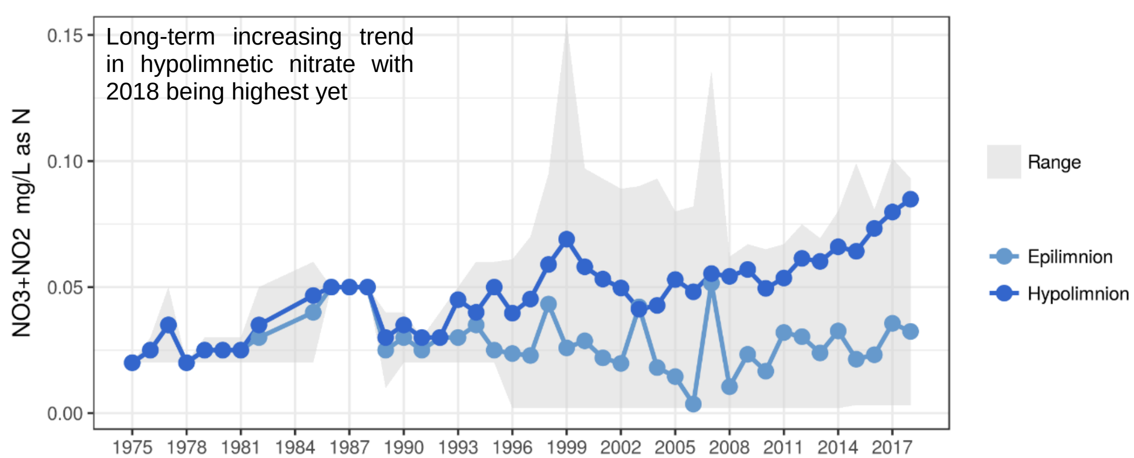


Figure 2.2-5: Nitrate + nitrite in Okanagan Lake at Summerland from 1975-2018 illustrating clear increasing trend in hypolimnetic nitrate

Phosphorus

TP measures all forms of phosphorus including those that may not be bioavailable. Total phosphorus (TP) averaged 0.010 ± 0.008 mg/L as P across Okanagan Lake during 2018 (Table 2.2-3). The TP objective for Okanagan Lake applies to the maximum phosphorus concentration at the spring overturn (Nordin, 2005; taken as March). 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 2018.

There were increasing trends in TP at both depths in the Armstrong Arm (MK test, $p<0.001$), Summerland (Epilimnion; MK test, $p=0.02$), Kelowna (Hypolimnion; MK test, $p=0.03$), and Okanagan Centre (Epilimnion; MK test, $p=0.007$) from 2011-2018 (Table 2.2-3, Figure 2.2-6). The trends at the three southern sites were weak and only became significant with the inclusion of the 2018 data. These increasing trends were likely related to the wet weather in 2017 and 2018. 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 (see 2017 comprehensive report). This is supported by the absence of comparable trends in dissolved phosphorus which is not as affected by freshet inflows.

Table 2.2-3: Total phosphorus (mg/L as P) at Okanagan Lake sampling sites, 2018

Site	Depth	Objective	Exceeded in 2018?	Trend	Avg	SD	Max	Min
Summerland	<10m	0.007	No	↑	0.007	0.002	0.011	0.005
	>20m		No	-	0.005	0.001	0.006	0.004
Kelowna	<10m	0.008	No	-	0.011	0.012	0.038	0.004
	>20m		No	↑	0.009	0.010	0.031	0.005
Ok Centre	<10m	0.008	No	↑	0.008	0.003	0.015	0.006
	>20m		No	-	0.006	0.001	0.008	0.004
Armstrong	<10m	0.010	Yes	↑	0.016	0.008	0.031	0.009
Arm	>20m		Yes	↑	0.022	0.008	0.035	0.014

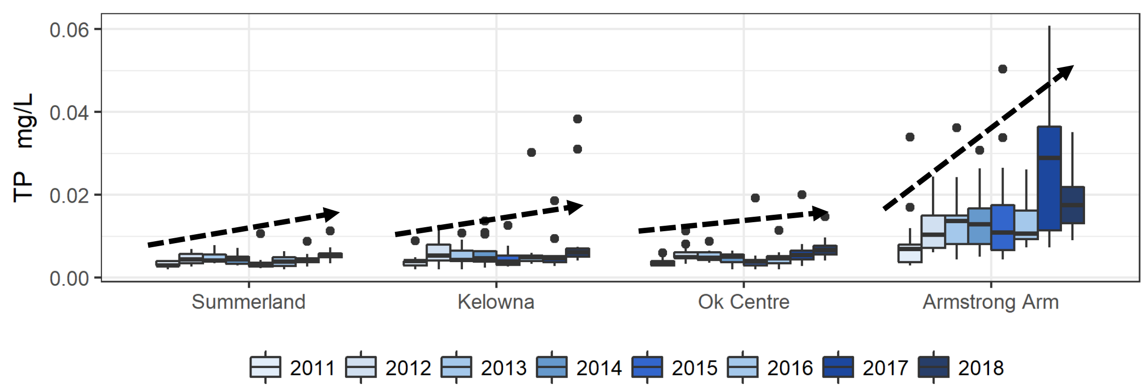


Figure 2.2-6: Total phosphorus in Okanagan Lake at the four sampling sites by year with trends highlighted, 2011-2018
Note: increasing trends related to wet-dry climate cycle, 2017-2018 = wet years

Dissolved phosphorus (DP) measures the more bioavailable forms of phosphorus and is a good indicator of potential anthropogenic impacts to biota. Dissolved phosphorus increased dramatically from 2011-2018 in the Armstrong Arm (Mann-Kendall $p\leq0.005$). Ortho-phosphate measures only the soluble reactive phosphorus fraction of the DP. No significant trends in ortho-phosphate data occurred at the three southern sites but a significant increasing trend was detected in the Armstrong Arm hypolimnion (Mann-Kendall, $p<0.001$). The increasing trend DP and ortho-P in the Armstrong Arm indicates anthropogenic sources.

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 nitrogen to phosphorus is >25:1 in March samples. All three southern sites met the objective in 2018 while the Armstrong Arm had higher phosphorus concentrations than the rest of Okanagan Lake and did not meet the objective in 2018 (Figure 2.2-6, Table 2.2-4). The N:P ratio decreased in the Armstrong Arm from 2011-2018 (Mann-Kendall, $p=0.003$). There were also significant declining trends in the N:P ratio at the three southern sites from 2011-2018 (Mann-Kendall, $p<0.05$). The declining trends at all four sites was related to the increase in TP during the 2017-2018 wet phase (Figure 2.2-6).

Table 2.2-4: Ratio of average TN to average TP during spring at Okanagan Lake sampling locations, 2018

Site	Depth	TN	TP	Avg Ratio	Objective	Exceeded in 2018?	Trend*
Summerland	<10m	0.241	0.007	40:1	>25:1	No	↓
	>20m	0.240	0.005	51:1	>25:1	No	-
Kelowna	<10m	0.235	0.011	35:1	>25:1	No	-
	>20m	0.236	0.009	38:1	>25:1	No	↓
Ok Centre	<10m	0.241	0.008	32:1	>25:1	No	↓
	>20m	0.275	0.006	46:1	>25:1	No	↓
Armstrong Arm	<10m	0.309	0.016	23:1	>25:1	Yes	↓
	>20m	0.394	0.022	20:1	>25:1	No	↓

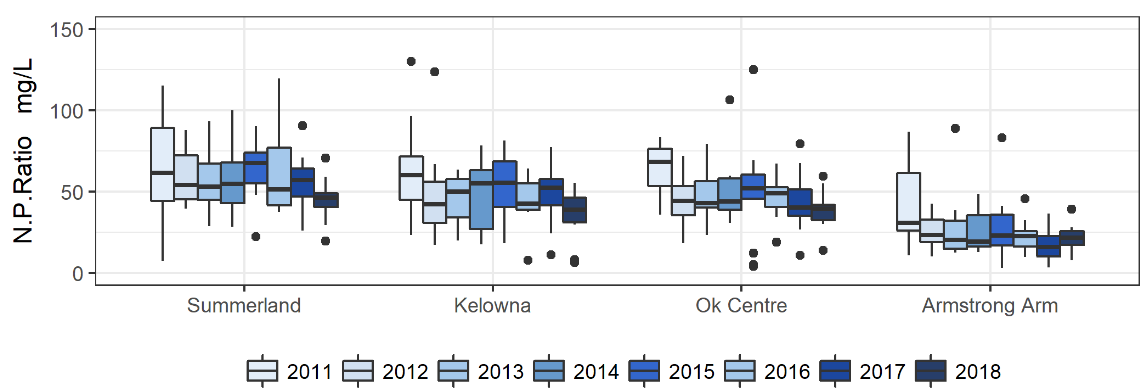


Figure 2.2-7: Nitrogen to phosphorus ratio at Okanagan Lake sampling sites 2011-2018

2.3 Biology

2.3.1 Phytoplankton

Phytoplankton and zooplankton samples were taken at the Summerland and Kelowna sites. Biomass analysis and taxonomic identification were performed on samples from both sites. Chlorophyll-a concentrations were monitored at all sites as a productivity metric for phytoplankton abundance. 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.

Chlorophyll-a

Chlorophyll-a is the primary photosynthetic pigment in most freshwater algae species (Felip and Catalan, 2000), and in many photosynthetic bacteria. As expected, chlorophyll-a followed an inverse trend to Secchi depth (Figure 2.1-3, Figure 2.3-1). Chlorophyll-a was lowest in the late winter and peaked in April-May during the spring algae bloom before decreasing through the summer (Figure 2.3-3). During 2018, chlorophyll-a concentrations met the objectives at the three southern sites but failed to meet the objective in the Armstrong Arm. This was the second year in a row that the Armstrong Arm has exceeded the chlorophyll-a objective. Spring chlorophyll-a concentrations were high in June in the Armstrong Arm, at up to 11.9 µg/L chl-a and were sufficient to colour the entire Arm green (Table 2.3-1, Figure 2.3-2).

In most years, including 2018, 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. The elevated nutrient concentrations in 2018 (Figure 2.2-6) led to higher overall algae production and higher chlorophyll-a concentrations throughout Okanagan Lake (Figure 2.3-1). A significant increasing trend for chlorophyll-a occurred at all four sites from 2011-2018 (Mann-Kendall, $p \leq 0.01$). The increasing trends at the three southern sites was related to the high chlorophyll-a concentrations during 2018 while in the Armstrong Arm, there has been a significant year-over-year increase from 2011-2018 (Figure 2.3-1).

Table 2.3-1: Chlorophyll-a in µg/L at Okanagan Lake sampling sites, 2018

Site	Objective	Exceeded in 2018?	Trend	Average	StdDev	Max	Min
Summerland	4	N	↑	2.50	0.76	3.78	1.57
Kelowna	4.5	N	↑	2.81	0.57	3.51	1.89
Ok Centre	4.5	N	↑	3.82	1.33	6.08	2.71
Armstrong Arm	5	Y	↑	6.26	2.92	11.90	4.05

Note: Based on growing season only (Apr-Sep)
Note: Increase at Ok Centre based on increase between 2015 and 2016

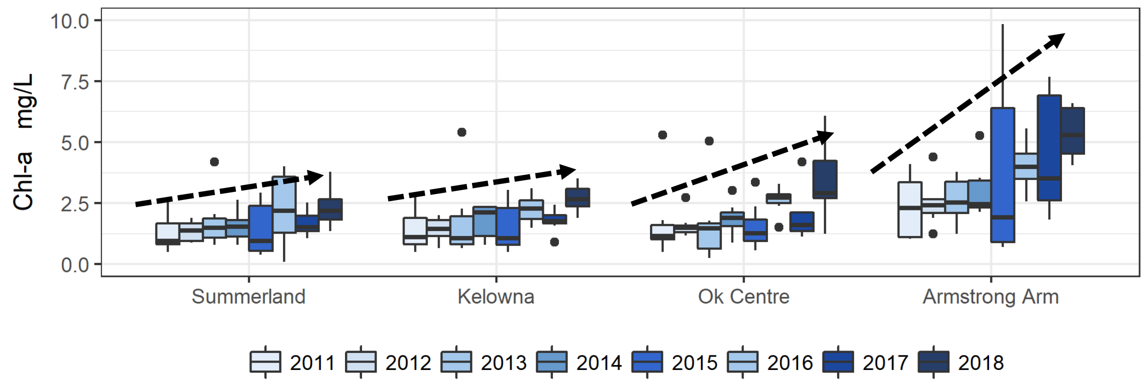


Figure 2.3-1: Annual chlorophyll-a concentration at the four Okanagan Lake sampling sites, 2011-2018

Figure 2.3-2: Water coloured green with algae at Armstrong Arm in July 2018

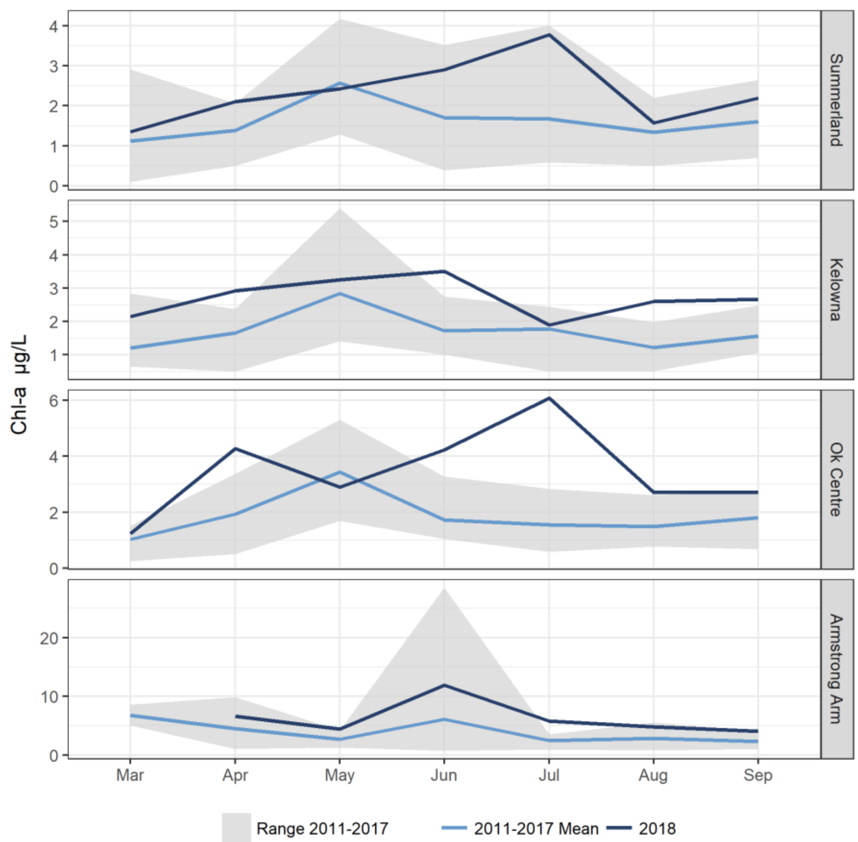


Figure 2.3-3: Chlorophyll-a at Okanagan Lake sample sites during 2018 compared to 2011-2017

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 2015-2018 results are considered here.

All samples were well below the objective of 0.75 µL/L during 2018 (Table 2.3-2). Phytoplankton biomass increased significantly from 2015-2018 at Summerland (MK test, $p=0.02$) and Kelowna (MK test, $p<0.001$), a trend that matches chlorophyll-a and is related to the increase in nutrients during the large 2017 and 2018 freshets (Figure 2.3-4).

Table 2.3-2: Phytoplankton biovolume in µL/L at Okanagan Lake sampling sites, 2018

Site	Obj	Apr	May	Jun	Jul	Aug	Sep	Avg	SD
Kel.	<0.75	0.1600	0.2905	0.3084	0.3720	0.2635	0.5617	0.3260	0.1347
Sum.	<0.75	0.1721	0.1629	0.2165	0.2774	0.0946	0.2745	0.1964	0.1670

Note: Growing season average based on Apr-Sep only

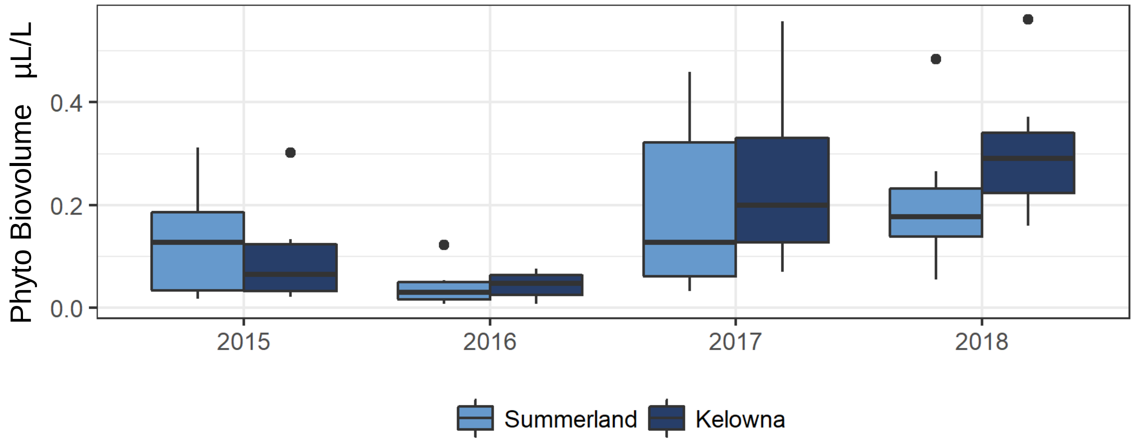


Figure 2.3-4: Phytoplankton Biovolume at Summerland and Kelowna, 2015-2018

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 bloom in the spring and their numbers decrease through the summer. Diatom densities were lower in 2015-2018 than in 2011-2014 although the cause is not clear but may relate to the decreasing trend in the N:P ratio that would favour cyanobacteria. Cyanobacteria were always numerous throughout the growing season in Okanagan Lake, but peaked in the late-summer. Cyanobacteria dominated the algae counts at 23,000 cells/mL in Kelowna and Summerland September 2018 samples (Figure 2.3-5, Table 2.3-3).

Algae counts, led by cyanobacteria counts, were high in 2018 (Figure 2.3-6). The higher algae counts match the higher chlorophyll-a concentrations from 2018 and were caused by nutrients carried into Okanagan Lake during the intense 2017 and 2018 freshets. Okanagan Lake phytoplankton production often lags behind nutrient inputs by one year and so it is expected that 2019 counts will be high even if there is a normal freshet.

Table 2.3-3: Average phytoplankton counts by major algae groups in cells/mL, 2018

	2018 Averages	
Algae Type	**Kelowna**	**Summerland**
Diatoms	266	193
Greens	163	192
Yellow-Brown	1014	670
Cyanobacteria	11377	7743
Dinoflagellates	32	29
Euglenoids	55	44
Total Algae	12908	8872

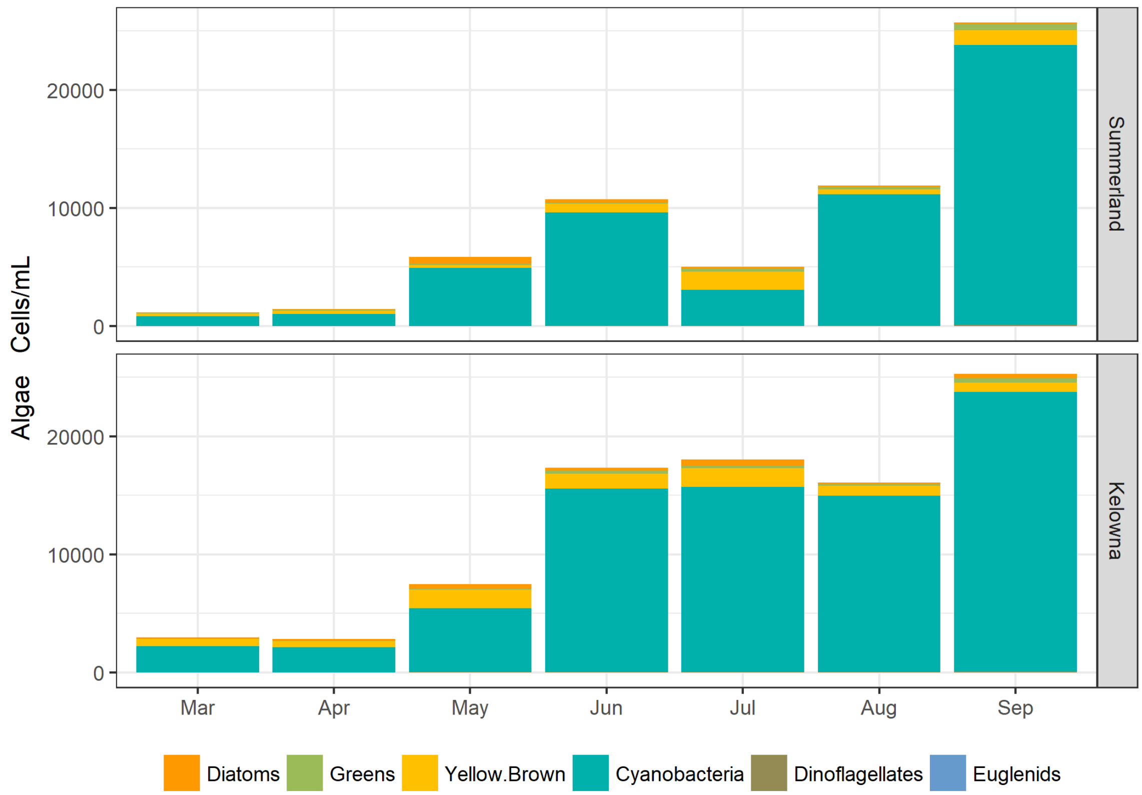
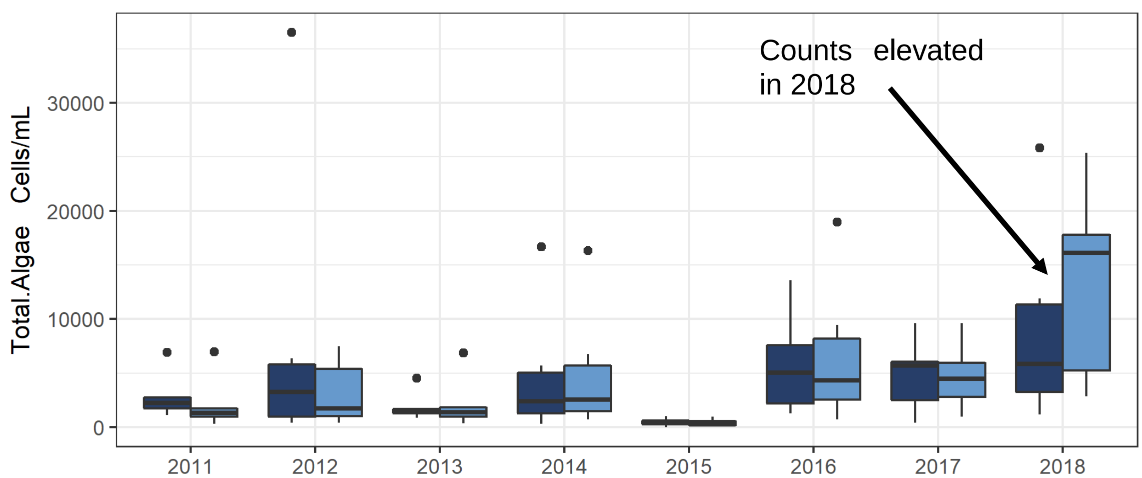


Figure 2.3-5: Taxonomic breakdown of algae by major types at Summerland (top) and Kelowna (bottom), 2018



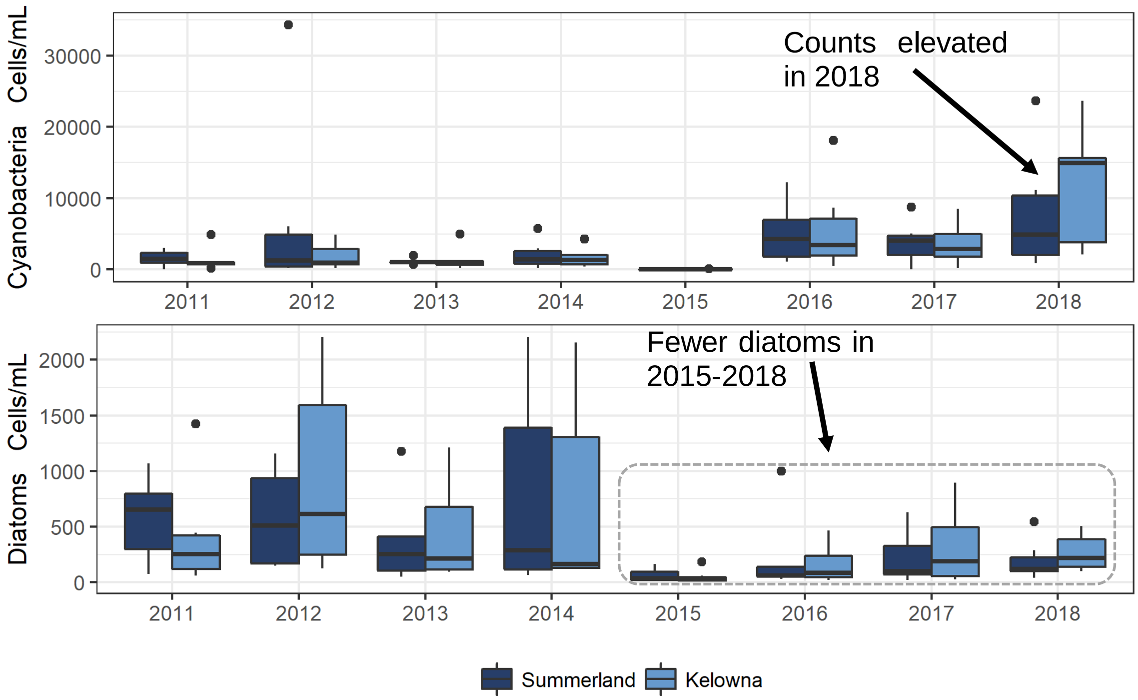


Figure 2.3-6: Total algae, cyanobacteria, and diatom counts at Summerland and Kelowna, 2011-2018

The Okanagan Lake objective for phytoplankton taxonomy states that no more than 5% of total cell counts should be heterocystous cyanobacteria. These phytoplankton can fix atmospheric nitrogen but also may produce toxins that are harmful to human health when they are present in high concentrations. During 2018, 3/7 samples exceeded this objective at both Kelowna and Summerland. The maximum heterocystous cyanobacteria percentages occurred during July 2018 with 12% at Kelowna and 20% at Summerland (Figure 2.3-7). There were no significant year-over-year trends in the heterocystous cyanobacteria counts from 2011-2018.

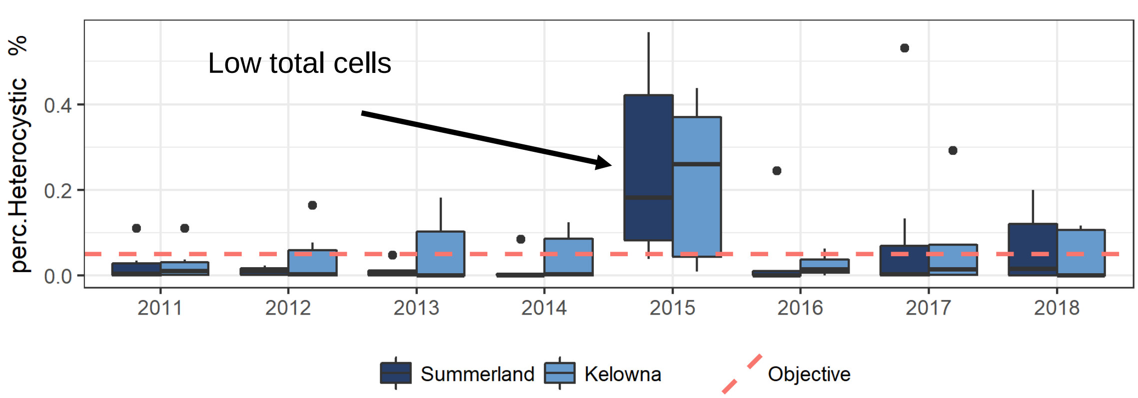


Figure 2.3-7: Percent of total algae counts that were heterocystous cyanobacteria, 2011-2018

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 Summerland but not at Kelowna in 2018, the first year Kelowna did not meet the objective since 2015 (Table 2.3-4). There were no significant trends in zooplankton biomass from 2015-2018 beyond the interannual variation.

Table 2.3-4: Zooplankton biomass in µg/L at Okanagan Lake sampling sites, 2018

Site	Objective	Avg	SD	Max	Min	Trend
Kelowna	>50	45.5	29.8	76.8	12.9	45.5
Summerland	>50	70.2	40.1	164.1	12.9	70.2

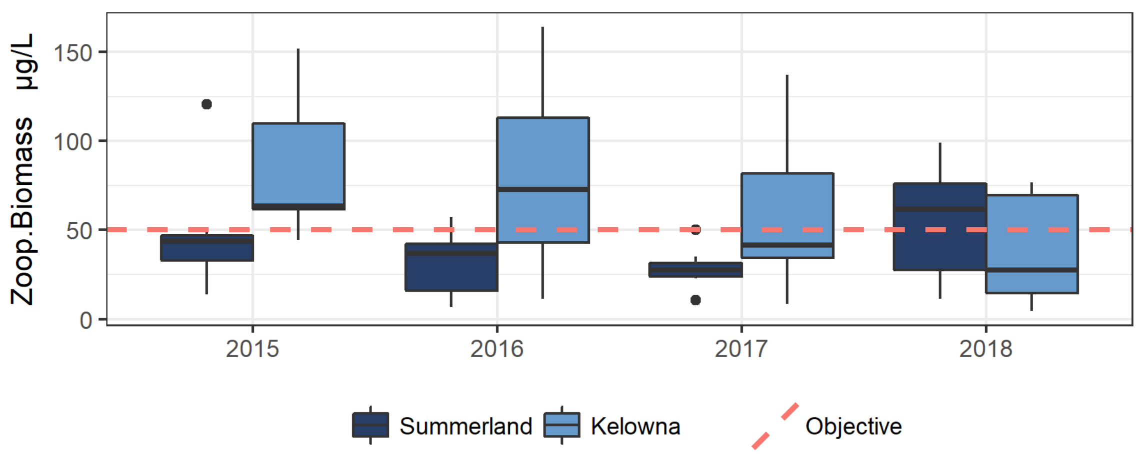


Figure 2.3-8: Zooplankton Biomass at the Kelowna and Summerland sampling locations by year, 2015-2018

Note: There was a change in lab methodology in 2015, preventing comparison with previous years' data

Zooplankton Taxonomy

Zooplankton samples were taxonomically identified to the species level and then grouped for analysis in this report. Copepods were the most numerous and averaged 35 ± 25% at Kelowna and 67 ± 59% at Summerland in 2018 (Table 2.3-5).

The objective for Okanagan Lake is a minimum of 5% of the sample counts be cladocerans. 33% of samples at Summerland and 22% of samples at Kelowna met the objective during 2018. The Okanagan Lake average was 2.4 ± 3.6 % of zooplankton counts were cladocerans during 2018. Mysid shrimp and kokanee salmon prefer to eat cladocerans and their predation may be holding populations below the objective (Andrusak et al., 2000).

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 were no longer term year-over-year trends in the zooplankton taxonomic data.

Table 2.3-5: Average zooplankton by major taxonomic groups, 2018

Zooplankton Type	Kelowna	Summerland
Copepods	35%	67%
Cladocerans	1%	4%
Rotifers	17%	19%
Mysids	0%	0%
Chironomids	0%	0%
Total Zooplankton	57%	99%

3.0 Conclusions

3.1

This report summarizes the 2018 results and extracts trends from the data accumulated by the Okanagan Lake Collaborative Sampling program to date (2011-2018). 2018 was the second year in a wet phase in the natural wet-dry climate cycle and experienced a very intense freshet and minor flooding that significantly impacted water quality throughout the lake. The results to date indicate that the Armstrong Arm is impacted by human activities and watershed degradation. This site had the most exceedances and the most problematic trends, that is, trends moving parameters towards greater exceedances.

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 isolated 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 2018, as it has in each year of this study.

Nutrients Silica analysis of water samples revealed increasing trends in silica concentrations. Total nitrogen has been stable at the southern sites but increased in the Armstrong Arm from 2011-2018. Total nitrogen exceeded the water quality objectives at all sites during 2018. Nitrate increased significantly in the Armstrong Arm and in the hypolimnion at all sites from 2011-2018. 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 2018. There were increasing trends in TP at all sites from 2011-2018, particularly in the Armstrong Arm where the increase was greatest. The current wet phase in the climate cycle is the probable cause of the increasing trend at the southern sites while the Armstrong Arm is more heavily impacted by human activities and has numerous phosphorus sources. Dissolved phosphorus and ortho-P represent the more bioavailable forms of phosphorus and were stable at the southern sites while they increased at the Armstrong Arm. Samples from the Armstrong Arm exceeded the nitrogen-phosphorus ratio objective in 2018, with a decreasing trend in that ratio from 2011-2018 because of increased TP over the same time.

Phytoplankton Productivity Chlorophyll-a concentrations increased each spring during the annual spring bloom and then decreased over the summer and into the fall. Chlorophyll-a was above average at all sites during 2018 because of the increase in nutrients from the large 2017 and 2018 freshets. Previous research by ENV has identified a one-year lag between major nutrient inputs and increases in phytoplankton productivity so it is expected that 2019 productivity will be high even if there is a normal freshet in that year. There was an increasing year-over-year trend detected for chl-a at the Armstrong Arm from 2011-2018. Chlorophyll-a concentrations in the Armstrong Arm exceeded the objective of 5 µg/L but the objective was met at the three southern sites during 2018. Phytoplankton biovolume met the objective in 2018 and increased from 2015-2018 at Kelowna and Summerland. The increase in biovolume is related to the increase in chlorophyll-a and TP from the 2017 and 2018 freshets.

The taxonomic data indicated that cyanobacteria numerically dominated the phytoplankton samples in 2018, as in every year studied, while overall counts were higher than previous years because of the nutrients carried into the lake during the large 2017 and 2018 freshets. Samples from Kelowna and from Summerland exceeded the phytoplankton objective of <5% of algae as heterocystous cyanobacteria during 2018 and is related to elevated cyanobacteria concentrations at both sites.

Zooplankton Productivity Zooplankton biomass was stable from 2015-2018. Zooplankton biomass met the objective of >50 µg/L at Summerland but not at Kelowna during 2016. Copepods numerically dominated most samples. The water quality objective of >5% of zooplankton as cladocerans was achieved in less than half of the samples from Summerland and Kelowna in 2018.

Table 3.1-1 and Table 3.1-2 summarize the findings of this report for 2018 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.

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 and dissolved phosphorus in the Armstrong Arm
- Decreasing N:P ratio in the Armstrong Arm
- Lingering effects of the 2017-2018 freshets on 2019 productivity

The following areas had been previously identified as concerns but were no longer considered issues as of 2018:

- Decreasing dissolved oxygen concentrations throughout the lake (data have been stable for past 5 years)

Armstrong Arm frequently exceeds most objectives and is the site most at risk of water quality degradation including nuisance algae blooms, poor drinking water quality, anaerobic conditions, and further eutrophication. 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 North Okanagan watershed have impacted this northern-most basin of the lake.

Table 3.1-1: Okanagan Lake Water Quality Objectives and 2018 values with exceedances

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)	0.008	0.008	0.007	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%

Objective	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth	5.4	4.6	4.7	2.4
Dissolved Oxygen	9.21 (Aug)	9.63 (Jul)	9.4 (Aug)	1.39 (Sep)
TP (mg/L) 0:10m:	0.007	0.011	0.008	0.016
20-45m:	0.005	0.009	0.006	0.022
Chlorophyll-a (µg/L)	2.5	2.81	3.82	6.26
TN (mg/L) 0-10m:	0.241	0.235	0.241	0.309
20-45m:	0.240	0.236	0.275	0.394
N:P Ratio 0-10m:	40:1	35:1	32:1	23:1
20-45m:	51:1	38:1	46:1	20:1
Algae Taxonomy (% heterocystous cyanobacteria)	20%	12%		
Algae Biomass (µg/L)	0.196	0.326		
Zooplankton Biomass (µg/L)	70.2	45.5		
Zooplankton Taxonomy (% cladocerans)	1.2%	4.5%		

Legend:

Met objective in 2018	Did not meet objective in 2018	No Data/ No Objective

Table 3.1-2: Summary of trends and the water quality objectives for Okanagan Lake collaborative sampling program. Modified from Nordin 2005.

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

Legend:

Met objective in 2018	Did not meet objective in 2018	No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend

4.0 Recommendations

The Okanagan Collaborative Program is currently in a three-year (2018-2020) term. No changes to the sampling program are recommended at this time. However, if additional funding is available, adding phytoplankton taxonomy to the Armstrong Arm samples would be useful, given the impacts at that site.

5.0 References

Andrusak, H., Matthews, S., Wilson, A., Andrusak, G., Webster, J., Sebastian, D., … Branch, E. (2006). *Okanagan Lake Action Plan Year 10 (2005) Report - Introduction* (Vol. 10).

Andrusak, H., Sebastian, D., Mcgregor, I., Matthews, S., Smith, D., Ashley, K., … Yassien, H. (2000). Okanagan Lake Action Plan Year 4 (1999) Report, *4*(1999).

Bergman, B., Gallon, J. R., Rai, A. N., & Stal, L. J. (1997). N2 fixation by non-heterocystous cyanobacteria. *FEMS Microbiology Reviews*. https://doi.org/10.1016/S0168-6445(96)00028-9

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

Felip, M., & Catalan, J. (2000). The relationship between phytoplankton biovolume and chlorophyll in a deep oligotrophic lake: decoupling in their spatial and temporal maxima. *Journal of Plankton Research*, *22*(1), 91–106. https://doi.org/10.1093/plankt/22.1.91

Larratt, H. (2009). *Deep Okanagan Lake Biology Report. For: Okanagan Basin Water Board, grant-funded publication.*

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

Nordin, R. N. (2005). *Water Quality Objectives for Okanagan Lake*. North Saanich BC.

Rae, R., & Andrusak, H. (2006). *Ten- Ten - Year summary of the Okanagan Lake Action Plan*. Penticton BC.

Schelske, C. L. (1988). Historic Trends in Lake Michigan Silica Concentrations. *Internationale Revue Der Gesamten Hydrobiologie Und Hydrographie*, *73*(5), 559–591. https://doi.org/10.1002/iroh.19880730506

Sokal, M. (2013). *Okanagan Lake Collaborative Monitoring Agreement 2013 Summary Report*. Penticton BC.

Water Office. (2017). Real-Time Hydrometric Data Graph for Okanagan Lake At Kelowna (08nm083) [Bc]. Retrieved December 21, 2017, from https://wateroffice.ec.gc.ca/report/real_time_e.html?mode=Graph&type=&stn=08NM083&startDate=2016-06-21&endDate=2017-12-21&prm1=46&y1Max=&y1Min=&prm2=-1&y2Max=&y2Min=

Wehr, J. (2002). *Freshwater algae of North America: ecology and classification*. Retrieved from http://books.google.ca/books?hl=en&lr=&id=IikPwCt1ioEC&oi=fnd&pg=PP2&dq=Freshwater+Algae+of+North+America:+Ecology+and+Classification+&ots=hL32vxVcVg&sig=wMq94pq1DoQb6FBYBpZWg8_QayU

6.0 Appendices

6.1 Appendix 1: 2018 Sampling Data

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