Okanagan Lake Collaborative Monitoring Agreement
2011-2017 Summary Report

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

Executive Summary

The British Columbia Ministry of Environment & Climate Change Strategy (ENV) together 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 2017. A primary function of the monitoring is to determine attainment of Okanagan Lake water quality objectives. This study also provides increased temporal resolution of water quality data for Okanagan Lake, to enable trend analyses in nutrient and biological data. This report summarizes the 2017 findings, compares it with the 2011-2017 record, and compares the 2011-2017 dataset to the 1973-2017 historic database for trends.

Physical

In each year of study, Okanagan Lake experienced thermal stratification that lasted from May to November. Secchi depth was highest in late winter and decreased each spring in response to increased phytoplankton activity. The Secchi depth averaged from 3.4 ± 1.0 m in the Armstrong Arm to 7.2 ± 2.1 m at Summerland during 2011-2017, and both failed to meet their objectives in 2017 of >5 m and >7.0 m, respectively. Kelowna and Okanagan Centre met the Secchi depth objective of >6.0 m in 2017 as they did in every year of this study. Water clarity was highest at Summerland in 2017 which is typical for Okanagan Lake.

Chemical

Dissolved oxygen in the deep water of the Armstrong Arm fell below the water quality objective each summer including 2017. Silica concentrations were similar throughout Okanagan Lake averaging between 6.83 and 7.09 mg/L at the four sample sites from 2011-2017. There have been several short-term trends in silica but no long-term trends over the entire 2011-2017 sampling period. Total nitrogen averaged 0.243 ± 0.078 mg/L as N in Okanagan Lake and exceeded the objective at Summerland and Okanagan Centre in the epilimnion sample. Total nitrogen decreased at Okanagan Centre and increased in the Armstrong Arm hypolimnion from 2011-2017. Nitrate decreased from spring to fall in response to algae activity at the three southern sites but increased year-over-year at Summerland (hypolimnion) and in the Armstrong Arm from 2011-2017. Total phosphorus (TP) averaged 0.007 ± 0.007 mg/L as P in Okanagan Lake from 2011-2017. TP increased in the Armstrong Arm from 2011-2017, where it also exceeded the objective in 2017. TP in the Armstrong Arm also correlated well with climate and indicates that it is vulnerable to watershed disturbances. Dissolved phosphorus was stable at the three southern sites while dissolved phosphorus increased dramatically in the Armstrong Arm from 2011-2017. The N:P ratio objective was exceeded in the Armstrong Arm in 2017, and is trending downwards (away from objective).

Biological

Chlorophyll-a is used as a measure of photosynthetic activity in Okanagan Lake. There was an increasing south to north trend in the chlorophyll-a data over the course of this study. Chlorophyll-a averaged 1.72 ± 0.94 µg/L at Summerland in the south end of the lake, and increased to 3.58 ± 4.10 µg/L at the north end of the lake in the Armstrong Arm during 2011-2017. The three southern sites achieved the objective for chlorophyll-a in all years, but the flooding in 2017 triggered a large algae bloom in the Armstrong Arm that caused the objective to be exceeded. There were no year-over-year trends in chl-a data at any site from 2011-2017.

Biomass and taxonomy of phytoplankton and zooplankton were sampled at the Kelowna and Summerland sites only. Phytoplankton biovolume averaged 0.142 ± 0.139 µL/L at Summerland and 0.151 ± 0.155 µL/L at Kelowna from 2015-2017. Cyanobacteria numerically dominated phytoplankton counts in all years. A total of 3/14 samples exceeded the phytoplankton taxonomy objective with up to 53 % and 29 % of counted cells being heterocystous cyanobacteria at Summerland and Kelowna, respectively. Zooplankton biomass met the objective in Kelowna (78.4 ± 40.3 µg/L) but not in Summerland (40.0 ± 23.5 µg/L) during 2015-2017. The zooplankton taxonomic objective was not met in 2017 at either Summerland or Kelowna with only 3% and 4% of zooplankton being cladocerans, respectively.

Areas of concern

Throughout this report, we have identified several areas or concern where ENV may wish to pursue further action. These include:

- Chronically low Secchi depth in the Armstrong Arm
- Increasing nitrate in the hypolimnion at Summerland and Armstrong Arm
- Increasing total phosphorus and dissolved phosphorus in the Armstrong Arm
- Decreasing N:P ratio in the Armstrong Arm
- Flooding in Armstrong Arm during 2017 triggered a major algae bloom and impaired water quality

Recommendations

The Okanagan Collaborative Program is currently at the end of a three-year (2015-2017) term. We therefore recommend that the program be renewed in its current form for another three years. No additional changes need to be made to the program at this time.

Water Quality Objectives, 2011-2017 average 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	🟨 7.2 ± 2.1	🟩 6.8 ± 2.1	🟩 7.2 ± 1.9	🟥 3.4 ± 1.0
Dissolved Oxygen	⬜ 9.5 (Jul)	⬜ 9.6 (Aug)	⬜ 9.4 (Jul)	🟥 1.7 (Sep)
TP (mg/L) 0:10m:	🟩 0.005 ± 0.001	🟩 0.006 ± 0.003	🟩 0.006 ± 0.003	🟨 0.010 ± 0.009
20-45m:	🟩 0.004 ± 0.001	🟩 0.005 ± 0.004	🟩 0.005 ± 0.002	🟥 0.020 ± 0.010
Chlorophyll-a (µg/L)	🟩 1.72 ± 0.94	🟩 1.80 ± 0.90	🟩 1.99 ± 1.10	🟩 3.58 ± 4.10
TN (mg/L) 0-10m:	🟥 0.231 ± 0.066	🟨 0.227 ± 0.050	🟨 0.224 ± 0.079	🟨 0.261 ± 0.086
20-45m:	🟨 0.232 ± 0.049	🟨 0.254 ± 0.118	🟨 0.224 ± 0.048	🟥 0.295 ± 0.075
N:P Ratio 0-10m:	🟩 55:1	🟩 45:1	🟩 49:1	🟨 34:1
20-45m:	🟩 65:1	🟩 67:1	🟩 56:1	🟨 19:1
Algae Taxonomy (% heterocystous cyanobacteria)	🟨 7 ± 14%	🟨 6 ± 11%	⬜	⬜
Algae Biovolume (µL/L)	🟩 0.142 ± 0.139	🟩 0.151 ± 0.155	⬜	⬜
Zooplankton Biomass (µg/L)	🟨 40.0 ± 23.5	🟩 78.4 ± 40.3	⬜	⬜
Zooplankton Taxonomy (% cladocerans)	🟨 4 ± 5 %	🟨 4 ± 4 %	⬜	⬜

Legend:

🟩 Achieve objective in >70% of samples	🟨 Achieve objective in >25% and <70% of samples	🟥 Achieve objective in <25% of samples	⬜ No Data/ No Objective

Summary of trends and the water quality objectives for Okanagan Lake collaborative sampling program, 2011-2017.

Objective		Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth		🟨 -	🟩 -	🟩 -	🟥 -
Dissolved Oxygen		⬜ -	⬜ -	⬜ -	🟥 -
TP (mg/L)	0:10m:	🟩 -	🟩 -	🟩 -	🟨 ↑
	20-45m:	🟩 -	🟩 -	🟩 -	🟥 ↑
Chlorophyll-a (µg/L)		🟩 -	🟩 -	🟩 ↑	🟩 ↑
TN (mg/L)	0-10m:	🟥 -	🟨 -	🟨 -	🟩 -
	20-45m:	🟩 -	🟨 -	🟨 ↓	🟥 ↑
N:P Ratio	0-10m:	🟩 -	🟩 -	🟩 -	🟨 -
	20-45m:	🟩 -	🟩 -	🟩 -	🟨 ↓
Algae Taxonomy (% heterocystous cyanobacteria)		🟨 -	🟨 -	⬜	⬜
Algae Biovolume (µL/L)		🟩 -	🟩 -	⬜	⬜
Zooplankton Biomass (µg/L)		🟨 -	🟩 -	⬜	⬜
Zooplankton Taxonomy (% cladocerans)		🟨 -	🟨 -	⬜	⬜

Legend:

🟩 Achieve objective in >70% of samples	🟨 Achieve objective in >25% and <70% of samples	🟥 Achieve objective in <25% of samples	⬜ No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend	

Preferred Citation

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Disclaimer: This report is based on research on complex lake systems. Larratt Aquatic Consulting Ltd and its associates have striven to ensure accuracy of the information contained within it. No liability is incurred by LAC or the Ministry of Environment & Climate Change Strategy for accidental omissions or errors made in the preparation of this report.

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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
Benthic	Organisms that dwell in or are associated with the sediments
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
Green algae	A large family of algae with chlorophyll as the main photosynthetic pigment
Light attenuation	Reduction of sunlight strength during transmission through water
Limnology	The study of the physical, chemical, and biological aspects of freshwater
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
Photic Zone	The zone in a water body that receives sufficient sunlight for photosynthesis
Plankton	Those organisms that float or swim in water
Reclamation	A restoration to productivity and usefulness
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^{o}C/m); it separates the surface water (epilimnion) from the cold hypolimnion below
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

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
MoE	British Columbia Ministry of Environment
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/m^2/day
Oligotrophic	0 – 2	1 – 10	<100	> 6	50- 300
Mesotrophic	2 – 5	10 – 20	100 – 500	3 – 6	250 – 1000
Eutrophic	>5	> 20	500-1000	< 3	>1000

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

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

Statistics Overview

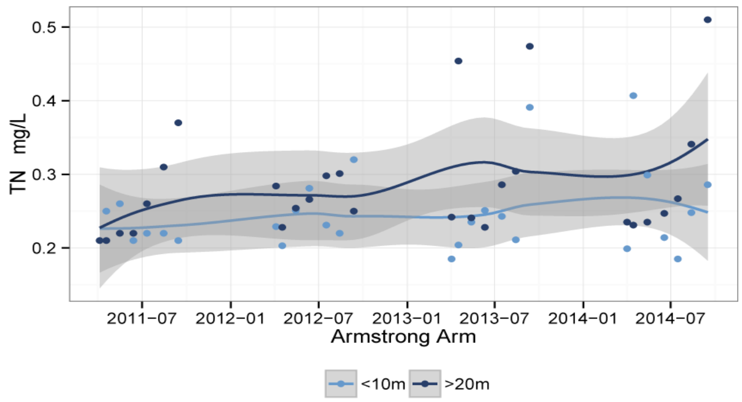
Statistical analyses were performed on data to support claims made throughout this report. The use of the word 'significantly' within this report is understood to signify that the claim being made has stood up under statistical analysis. Unless otherwise stated, all statistical analyses were performed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



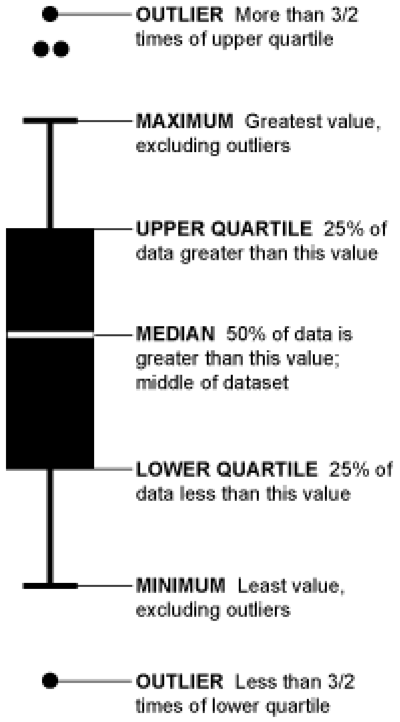


Figure i: Example scatterplot and boxplot
Includes all data for a parameter sorted by depth, LOESS polynomial trendlines and the standard errors of those trendlines are also included. Example boxplot is labeled with key information. Whiskers represent the distance to the highest or lowest point within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

1.0 Introduction

1.1 Overview

The British Columbia Ministry of Environment & 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 (2012-2017). Okanagan Lake was sampled monthly from March to September from 2011-2017 at four key sites (Figure 1.1, Table 1.1).

Table 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 2017 data were added to the existing 2011 – 2016 database upon which all the analyses in this report were performed. Water quality objectives were based upon Nordin 2005 (Appendix 1). Additional trend analyses were performed on the historical database as well (1973-2017) for comparison.

Figure 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 2017

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 was very unusual for the Okanagan region. There was an abnormally long, cold, and snowy winter followed by a very wet spring, that combined to create a very intense freshet and record flooding throughout the valley (Figures 1.2 and 1.3). Following the spring flooding, there was a record hot and dry summer in which Kelowna experienced nearly 4 consecutive months without significant rainfall. The net result for this study is that across a variety of parameters, 2017 had lower water quality than is typical for Okanagan Lake.

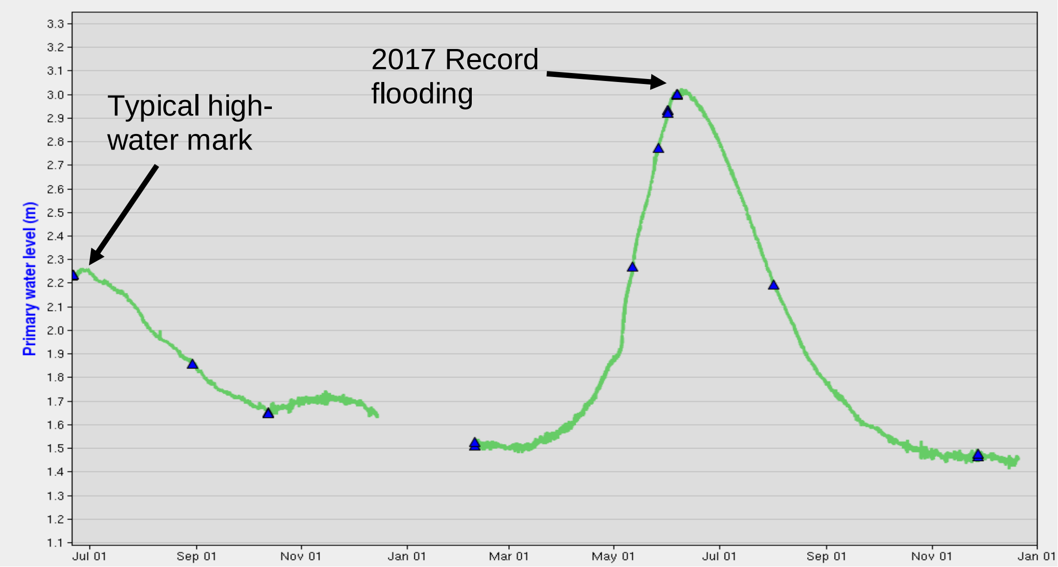


Figure 1.2: Water level in Okanagan Lake at Kelowna from Jun 2016 – Dec 2017 (Water Office, 2017)

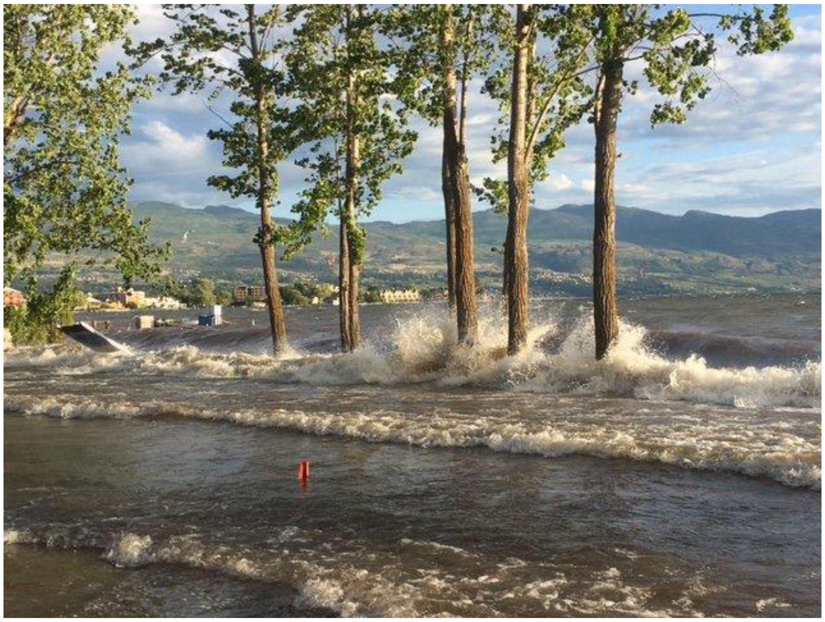


Figure 1.3: Flooding at Kelowna's Gyro Beach on June 13, 2017, Photo credit: Denise Egan

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 (Figures 2.1.1 and 2.1.2), while water below 20 m only changes temperature by less than 4 °C annually (Figure 2.1.1). In 2017, seasonal surface water temperatures of Okanagan Lake at all four sites, were within the observed range from 2011-2016 (Figure 2.1.2).

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 (Figures 2.1.1 and 2.2.1). 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 2011–2017 temperature data either annually, seasonally, or monthly. Temperature readings were not performed in a consistent manner historically and extracting trends out of the long-term database for field temperature did not yield results.

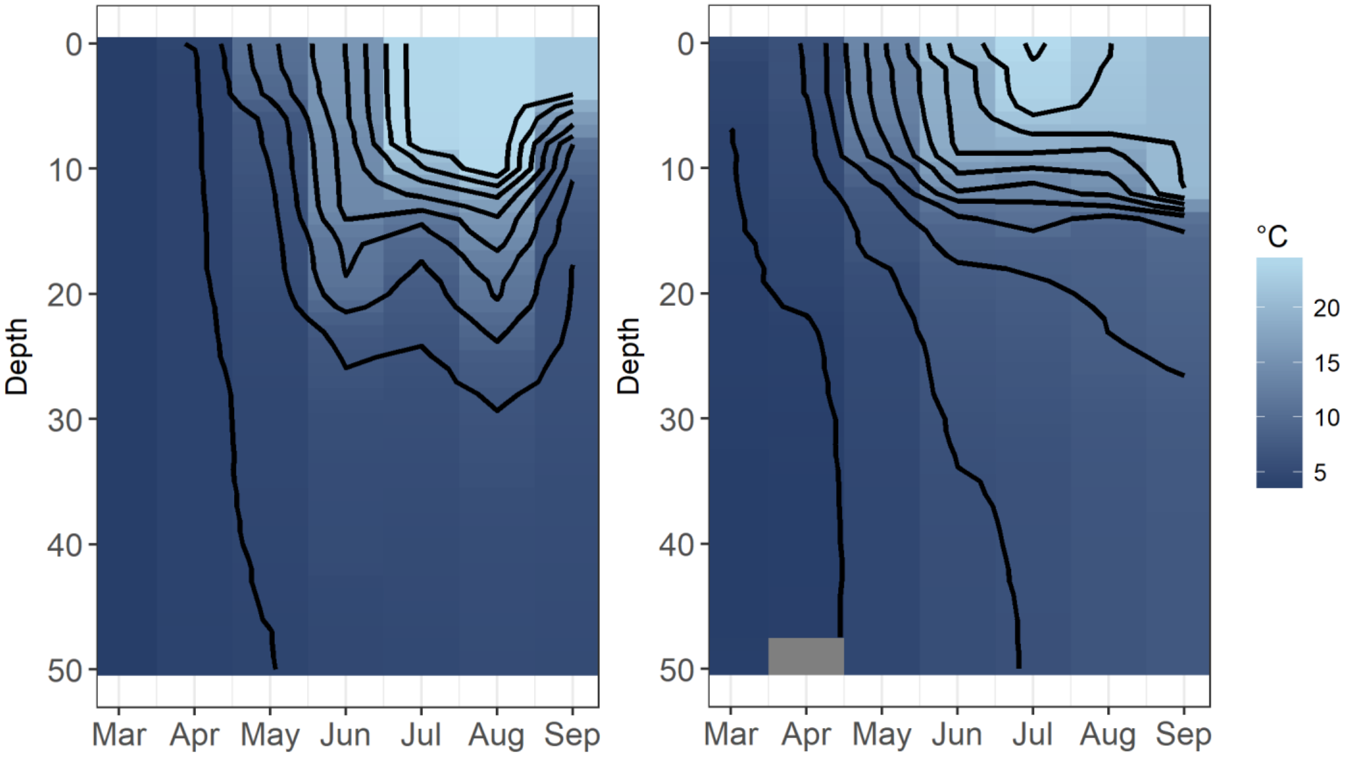


Figure 2.1.1: Temperature profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right), 2017. Lines represent contours of same temperature within the water column through time.

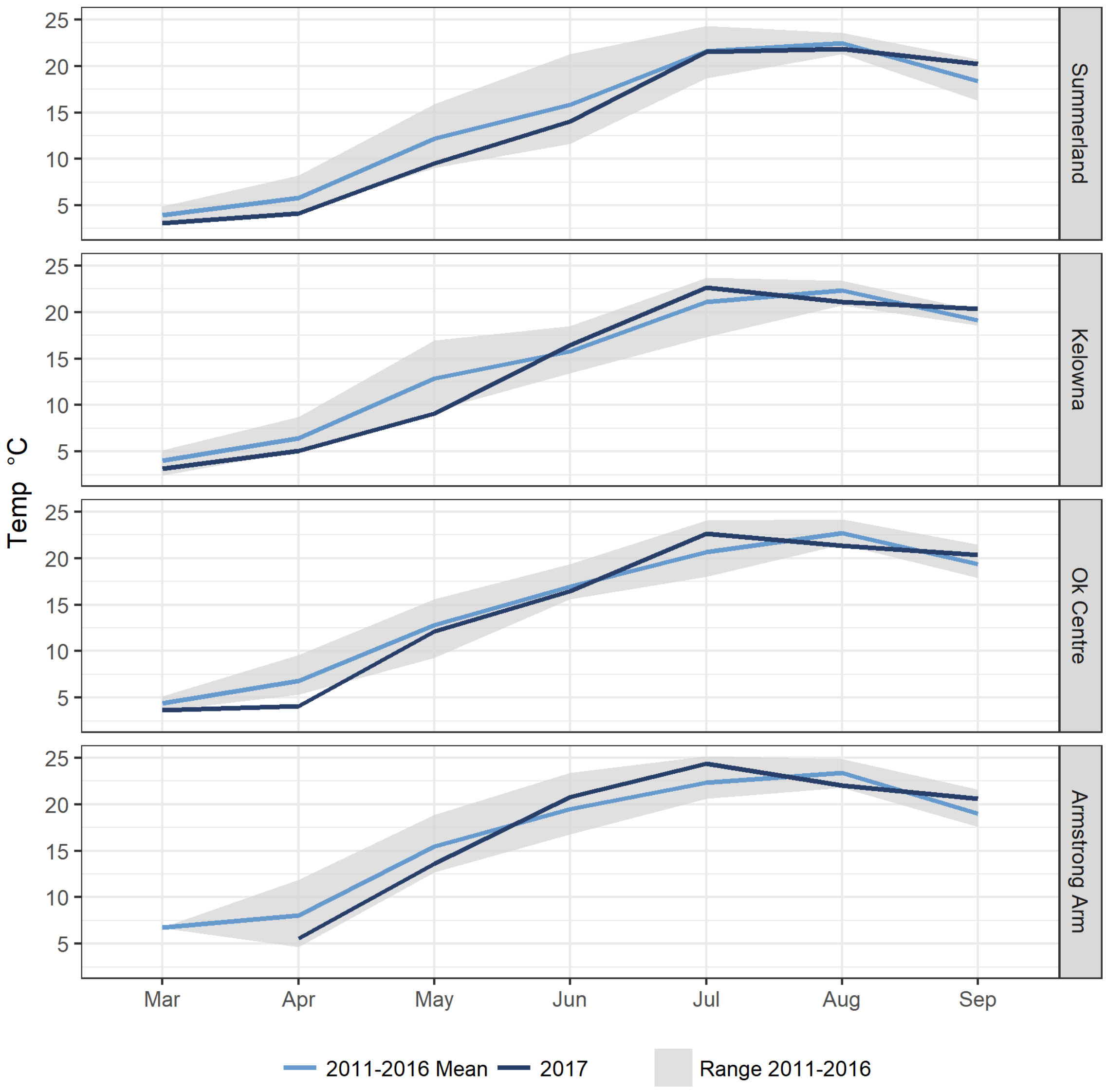


Figure 2.1.2: Surface temperature at Okanagan Lake sample sites by month, 2011-2017

2.1.2 Water Clarity and Secchi Depth

Secchi depth is a standard measure of water clarity where a 30 cm black and white disk is lowered through the water column until it can no longer be seen from the surface and then that depth is recorded. Secchi depth during 2017 ranged from a minimum of 0.95 m at Armstrong Arm in June to a maximum of 12.9 m at Ok Centre in March (Table 2.1.1). Secchi depth averages were lower at all sites during 2017 because of the intense freshet and flooding. From 1973-2017, average Secchi depth ranged from 4.2 ± 1.8 m in the Armstrong Arm to 8.9 ± 3.2 m at Summerland.

Secchi depth followed a consistent pattern each year from 2011-2017. 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). This pattern is confirmed by seasonal cycles in the nutrients data (Figure 2.2.5) and algae data (Figures 2.3.1).

The Secchi depth in the Armstrong Arm was much lower throughout the year than at the other sites in Okanagan Lake (2011-2017). This is clearly illustrated in Figure 2.1.3. The Secchi depth of Summerland and the Armstrong Arm did not meet their respective objectives (>7 m, >5 m) while the Secchi did meet the objective (>6 m) at Kelowna and Ok Centre during 2017 (Table 2.1.1). Over the 2011-2017 sampling program, the Armstrong Arm has never achieved the Secchi depth objective while at Summerland the objective was not met in four of seven years (2011, 2013, 2016, and 2017). The Secchi depth objective was always met at Kelowna and Ok Centre from 2011-2017. There were no statistically significant increasing or decreasing trends in the Secchi depth data either annually, or monthly from 2011-2017. A significant decreasing trend exists in the historical dataset (1973-2017) at all sites, however when 2000-2017 (increased sampling frequency since 2000) is analyzed, the trend only persists for Kelowna (Mann-Kendall, p=0.01). This indicates that throughout Okanagan Lake, Secchi depths were higher in the 1980s, declined through the 1990s, and have been relatively stable since 2000 (Figure 2.1.4). This appeared to be related to shifts in chlorophyll-a and phytoplankton densities (Figure 2.3.3).

Table 2.1.1: Growing Season (Apr-Sep) Secchi depth in meters at Okanagan Lake sampling sites

2017

Site	Objective	Average	StdDev	Max	Min
Summerland	7.0	6.9	3.2	12.2	3.2
Kelowna	6.0	6.5	2.3	10.2	4.2
Ok Centre	6.0	6.8	2.2	10.4	3.9
Armstrong Arm	5.0	2.7	1.0	4.2	1.0

2011-2017

Site	Objective	Average	StdDev	Max	Min	Trend
Summerland	7.0	7.2	2.1	12.2	3.2	-
Kelowna	6.0	6.8	2.1	10.9	2.6	-
Ok Centre	6.0	7.2	1.9	11.2	3.1	-
Armstrong Arm	5.0	3.4	1.0	5.6	1.0	-

Note: Objective refers to growing season average (Apr-Sep)
Note: Red cell shading = rarely or never achieves objective, yellow shading = occasionally fails to achieve objective

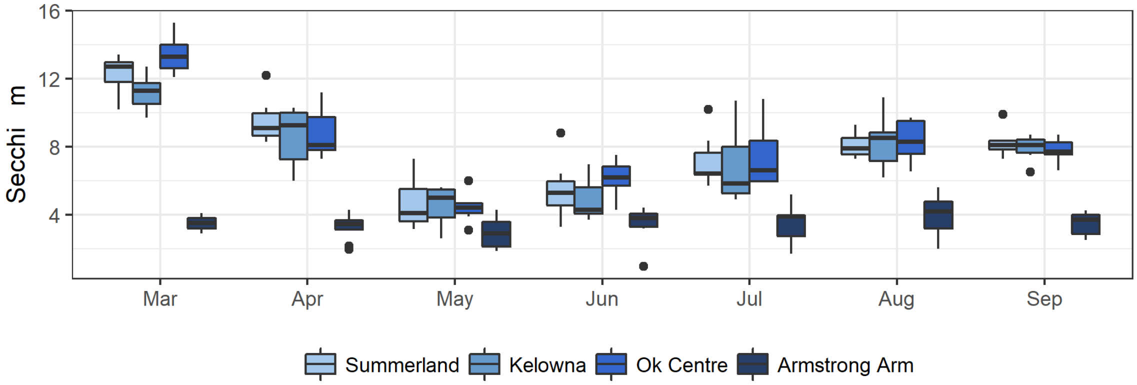


Figure 2.1.3: Monthly Secchi depth at each of the sampling sites, 2011-2017

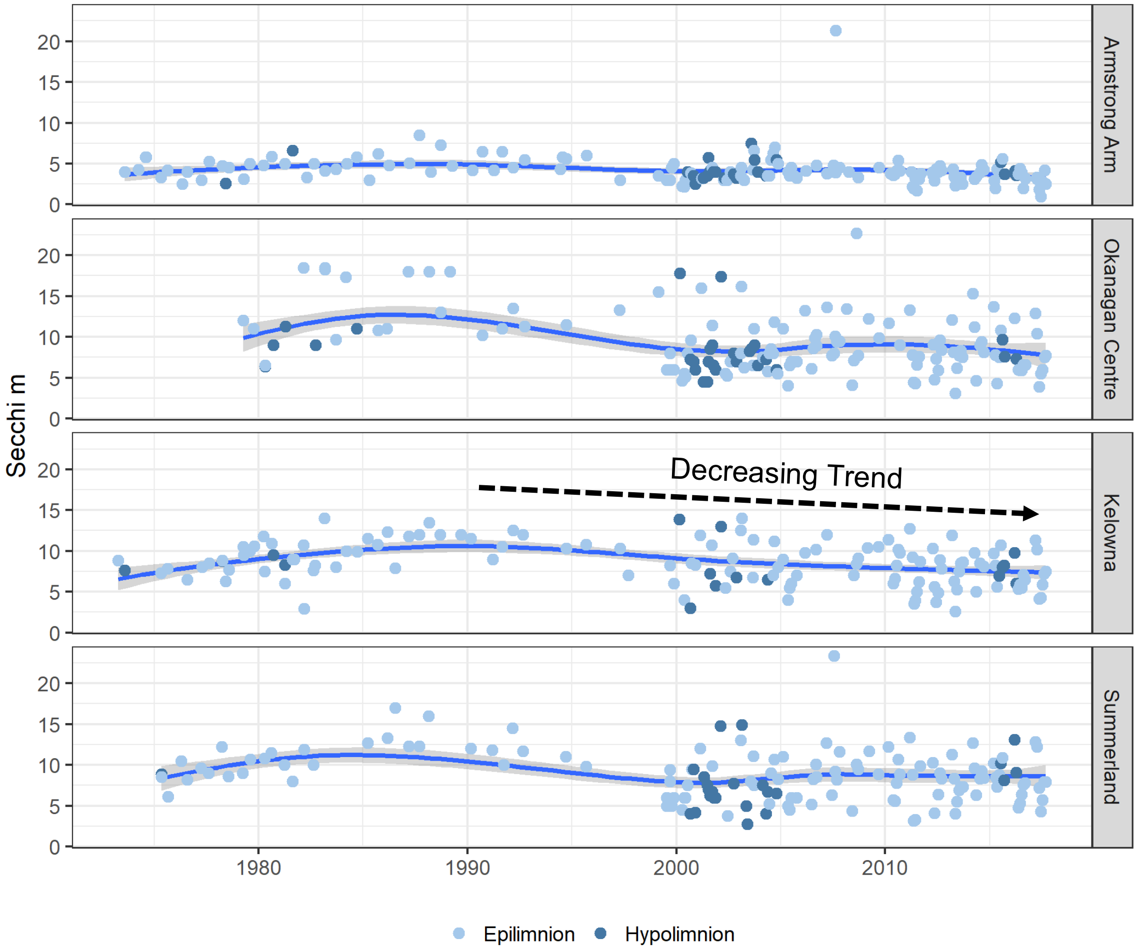


Figure 2.1.4: Historical Secchi depth at all sites from 1973-2017

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 and foreshore development, agriculture, fertilizer use, storm water runoff, 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 signals from human impacts. Inclusion of the historical dataset in this report provides additional context for the 2011-2017 collaborative data.

2.2.1 Dissolved Oxygen

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 quite differently. The later site reaches a higher surface temperature and experiences annual summer oxygen depletion in the hypolimnion (Figure 2.2.1). Oxygen depletion is caused by decomposition of organic material in the sediment and deep water. Dissolved oxygen concentrations below 5 mg/L will stress fish and can lead to fish kills under certain circumstances. The Armstrong Arm did not meet the dissolved oxygen concentration objective (>5 mg/L in the hypolimnion) during any year from 2011-2017.

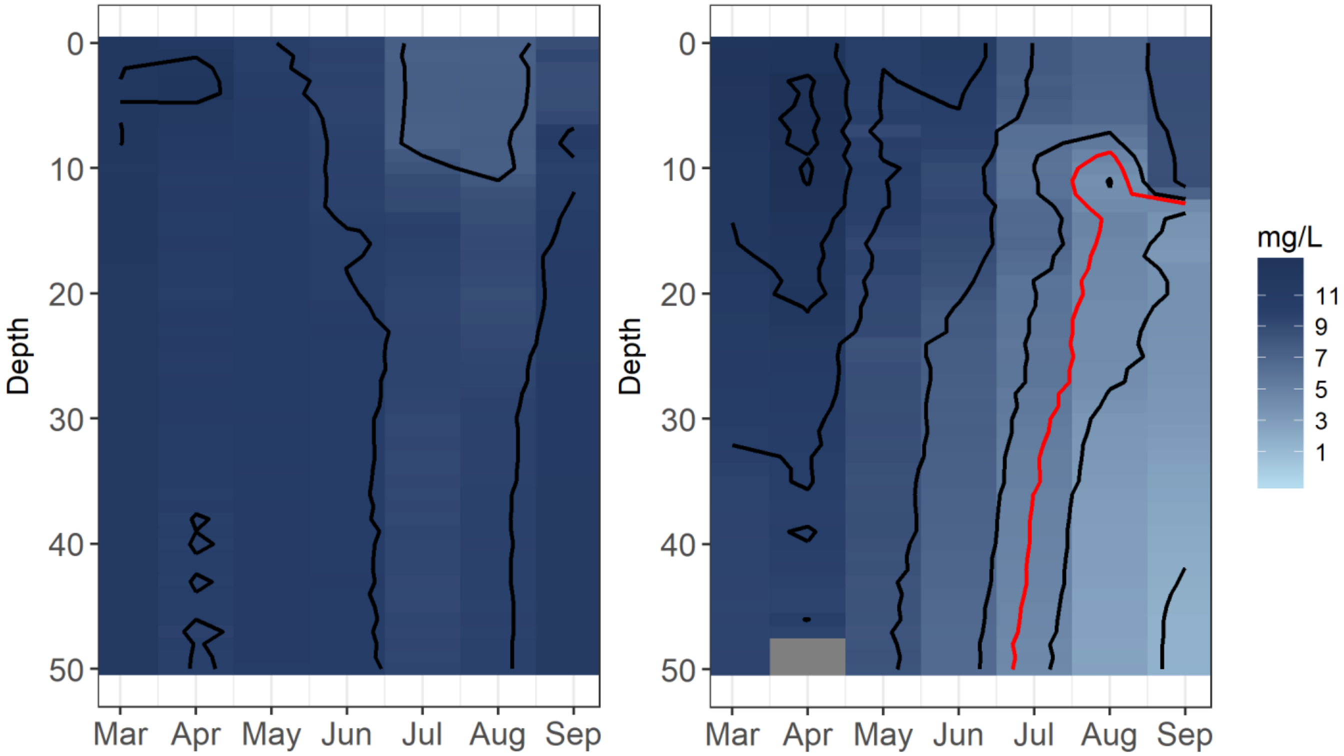


Figure 2.2.1: Dissolved oxygen profiles for Okanagan Lake at Summerland (left) and at Armstrong Arm (right) in 2017.

Dissolved oxygen profiles illustrate high dissolved oxygen concentrations at Summerland, and typical 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 the Armstrong Arm plot represents the water quality objective; all water below this line does not meet the objective.

Surface concentrations of dissolved oxygen vary throughout the year, but trend downwards at all sites over the course of the collaborative monitoring sampling program (2011-2017; Figure 2.2.2; Mann-Kendall p≤0.01). However, these trends were no longer statistically significant when the unusually high 2011 data were removed. This indicates that 2011 was biasing the results and masking the overall lack of trend. Dissolved oxygen depletion is not a concern at the three southern sites where it remained high throughout the water column on all dates from 2011-2017. Fish stress from low dissolved oxygen is not a concern outside of the Armstrong Arm.

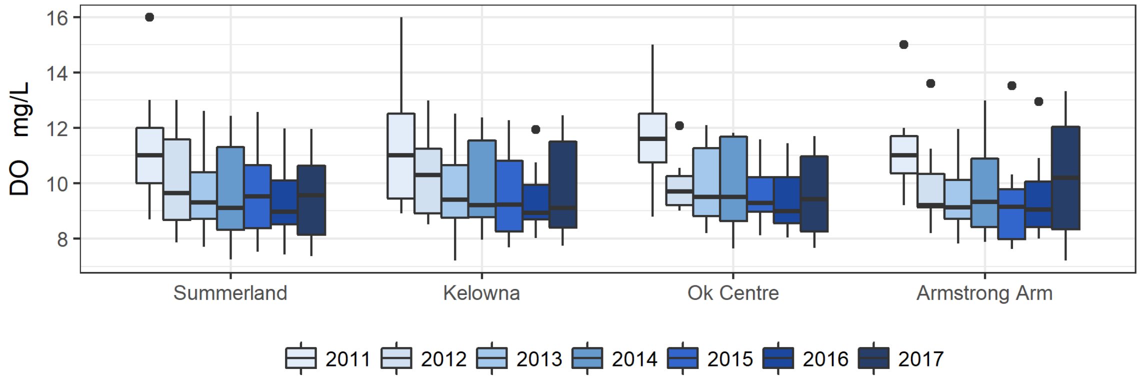


Figure 2.2.2: Surface dissolved oxygen concentrations at Okanagan Lake sampling sites grouped by year with trends highlighted, 2011-2017

2.2.1 Silica

Diatoms, a major group of phytoplankton algae in Okanagan Lake, use silica as a structural building block for their cell walls (Wehr, 2002). 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 was not significantly different between the four sites in most years (Table 2.2.1, Figure 2.2.3). Silica concentrations have been stable at the three southern sites from 2011-2017, but there was a significant increase in the Armstrong Arm over the same period (Mann-Kendall, p=0.018). Silica sampling shifted to only March and September beginning in 2015, because it did not change significantly over the course of the growing season. Silica concentrations have increased over time in the historical dataset (1973-2017) at all four sites (Mann-Kendall, p<0.001; Figure 2.2.4). However, the long-term trend indicates a stabilizing of silica throughout the lake since 2000. This may relate to the increasing trend in chlorophyll-a (a measure of phytoplankton) at all sites from 1973-2000 (Figure 2.3.3).

Table 2.2.1: Silica concentration in mg/L at Okanagan Lake sampling sites, 2011-2017

Site	Average	StdDev	Max	Min
Armstrong Arm	7.09	1.41	11.60	2.99
Kelowna	6.98	0.61	9.79	5.83
Ok Centre	6.83	0.63	9.96	5.79
Summerland	6.93	0.49	8.00	5.75

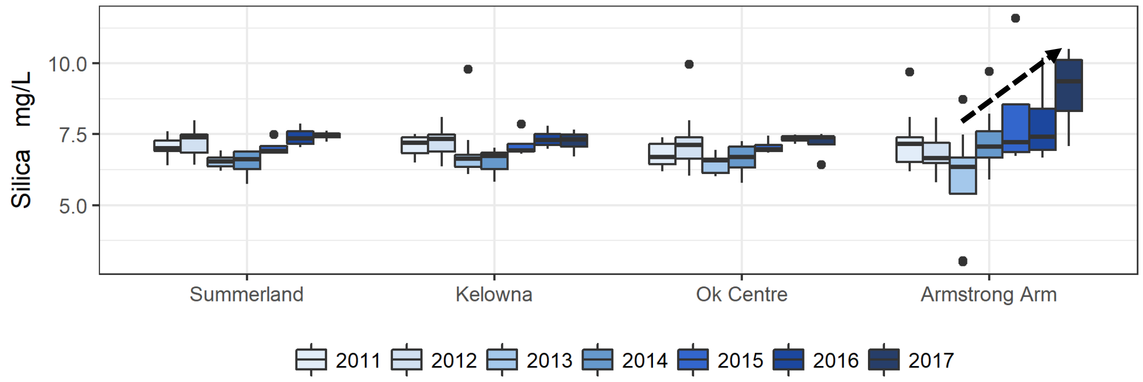


Figure 2.2.3: Silica concentration in Okanagan Lake at each sampling site by year with trends highlighted, 2011-2017

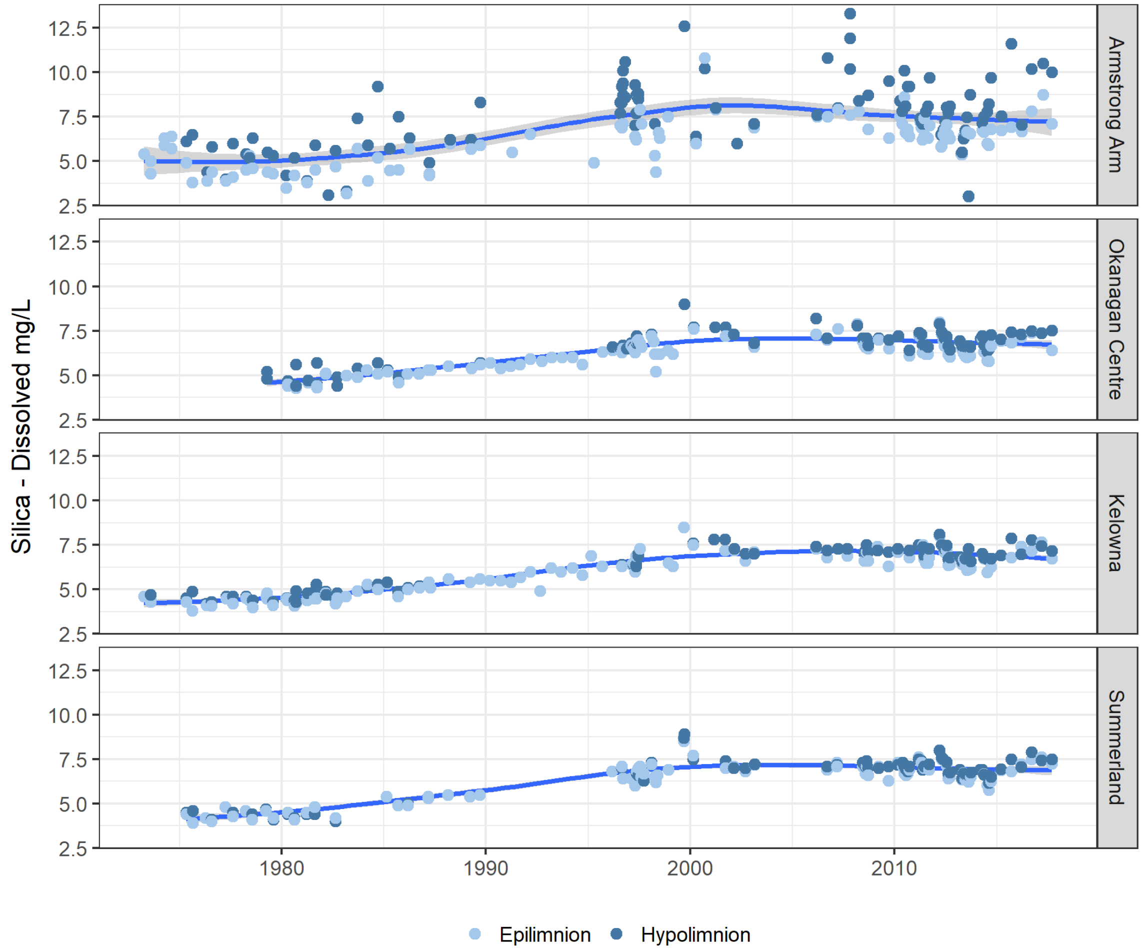


Figure 2.2.4: Historical silica concentrations in Okanagan Lake from 1973-2017

2.2.2 Nitrogen and Phosphorus

Nitrogen and phosphorus are the most important nutrients in most aquatic environments. Phosphorus is the main limiting nutrient in Okanagan Lake and its concentration is directly linked to the amount of algae that the lake produces (Nordin, 2005).

Nitrogen

Total nitrogen (TN) averaged 0.257 ± 0.077 mg/L as N in Okanagan Lake during 2017 (Table 2.2.2). The objective for Okanagan Lake was set as a spring value (March date or April if Armstrong Arm is still iced over in March) of 0.230 mg/L for the main basins, and 0.250 mg/L for the Armstrong Arm. The objectives were exceeded at the Summerland and Okanagan Centre sites in the epilimnion during 2017, but this is not surprising, as the TN objectives were regularly exceeded at all sites from 2011-2017. TN increased in the hypolimnion samples from Armstrong Arm (Mann-Kendall, $p=0.004$), but decreased at Okanagan Centre (Mann-Kendall, $p=0.03$) from 2011-2017 (Table 2.2.2). There were no trends in TN from 2011-2017 at either Summerland or Kelowna.

Nitrite+nitrate increased in the Armstrong Arm throughout the water column (Mann-Kendall, $p<0.001$), and at all sites in the hypolimnion from 2011-2017 (Mann-Kendall, $p\leq 0.01$; Figure 2.2.5). Nitrate in surface water is rapidly consumed by algae in the spring, and thermal stratification prevents replenishment from the deeper water during the summer (Figure 2.2.5). 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). There were no clear long-term trends in TN within the historical dataset (1973-2017). However, there were significant increasing trends at all sites for hypolimnetic nitrite+nitrate (Mann-Kendall, $p<0.001$).

Table 2.2.2: Total nitrogen in mg/L as N concentration at Okanagan Lake sampling sites, 2011-2017

Site	Depth	Objective	Exceeded in 2017?	% Years Exceeding	Trend	Avg	SD	Max	Min
Summerland	<10m	0.230	Yes	71%	-	0.231	0.066	0.588	0.120
	>20m		No	29%	-	0.232	0.049	0.340	0.030
Kelowna	<10m	0.230	No	43%	-	0.227	0.050	0.502	0.130
	>20m		No	57%	-	0.254	0.118	0.968	0.100
Ok Centre	<10m	0.230	Yes	57%	-	0.224	0.079	0.705	0.022
	>20m		No	43%	↓	0.224	0.048	0.342	0.022
Armstrong	<10m	0.250	No	29%	-	0.261	0.086	0.642	0.181
Arm	>20m		No	71%	↑	0.295	0.075	0.510	0.165

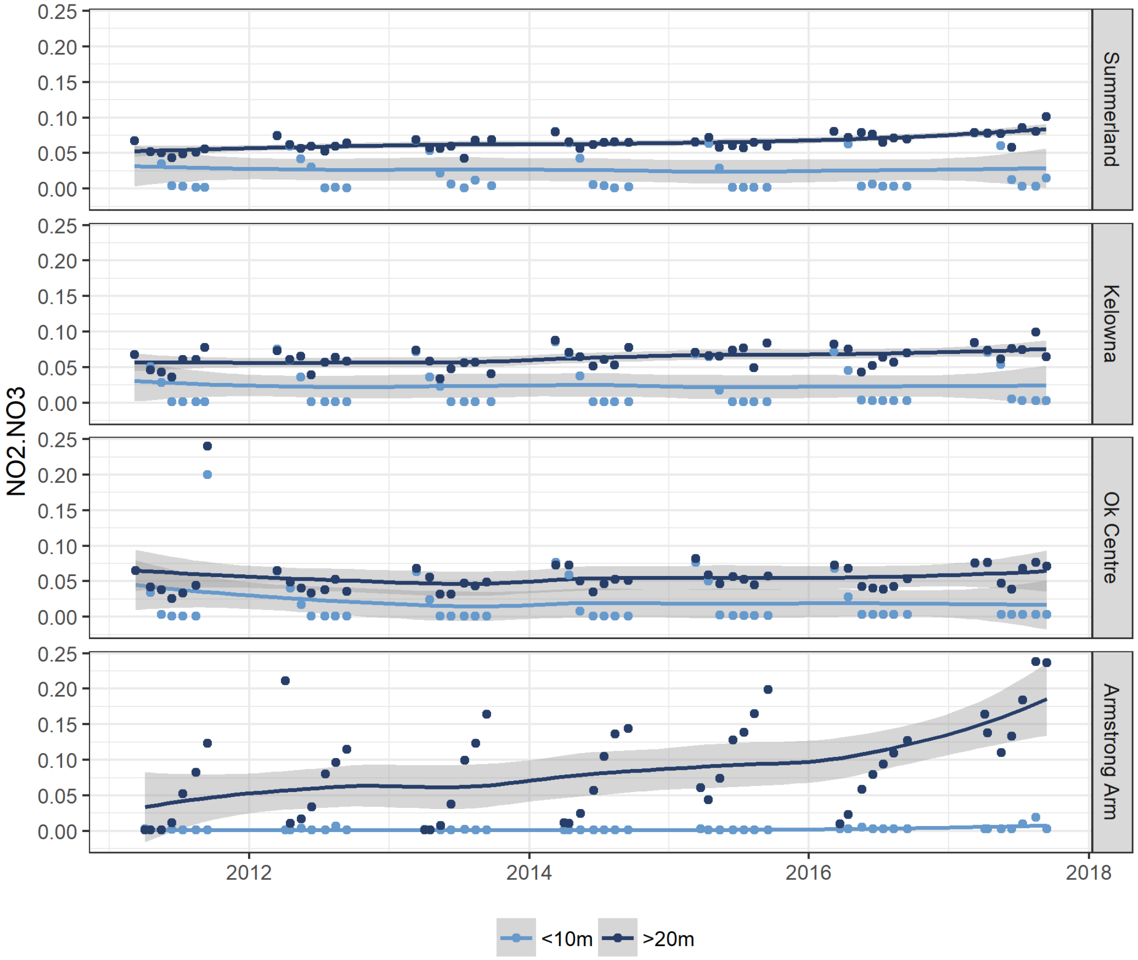


Figure 2.2.5: Nitrite+nitrate in mg/L as N in the surface and deep water of Okanagan Lake, 2011-2017

Phosphorus

Total phosphorus (TP) measures all forms of phosphorus including those that may not be bioavailable. In 2017, TP concentrations averaged 0.011 ± 0.013 mg/L as P across Okanagan Lake. The TP objective for Okanagan Lake applies to the maximum phosphorus concentration at spring overturn (Nordin, 2005; samples taken in March, or sometimes April in the Armstrong Arm if it is still frozen in March). The objective varies 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 hypolimnion of Armstrong Arm in 2017, but has regularly been exceeded in in this lake basin over the past 7 years. In contrast, the TP objective was met at the three southern sites in 2017, and in most years. Also, there was an increasing TP trend in the Armstrong Arm from 2011 to 2017 (Mann-Kendall, p≤0.005), while the other basins remained stable (Table 2.2.3).

Table 2.2.3: Total phosphorus in mg/L as P concentration at Okanagan Lake sampling sites, 2011-2017

Site	Depth	Objective	Exceeded in 2017?	% Years Exceeding	Trend	Avg	SD	Max	Min
Summerland	<10m	0.007	No	0%	-	0.005	0.001	0.009	0.002
	>20m		No	14%	-	0.004	0.001	0.011	0.002
Kelowna	<10m	0.008	No	14%	-	0.006	0.003	0.019	0.003
	>20m		No	14%	-	0.005	0.004	0.030	0.002
Ok Centre	<10m	0.008	No	0%	-	0.006	0.003	0.020	0.003
	>20m		No	0%	-	0.005	0.002	0.019	0.002
Armstrong	<10m	0.010	No	43%	↑	0.010	0.009	0.061	0.003
Arm	>20m		Yes	86%	↑	0.020	0.010	0.050	0.003

Dissolved phosphorus (DP) measures the more bioavailable forms of phosphorus and is a good indicator of potential anthropogenic impacts to biota. From 2011-2017, DP was stable at the three southern sites but increased significantly in the Armstrong Arm (Mann-Kendall, p≤0.001; see arrows in Figure 2.2.6).

Ortho-phosphate measures only the soluble reactive phosphorus fraction of the DP. There was also a significant increase in ortho-phosphate in the hypolimnion of the Armstrong Arm from 2011-2017 (Figure 2.2.6; Mann-Kendall, p<0.001). Ortho-phosphate averaged from 0.001 ± 0.001 mg/L as P at Summerland to 0.007 ± 0.010 mg/L as P in the Armstrong Arm from 2011-2017. Throughout the lake from 2011-2017, ortho-phosphate composed 60 ± 33 % of the dissolved phosphorus.

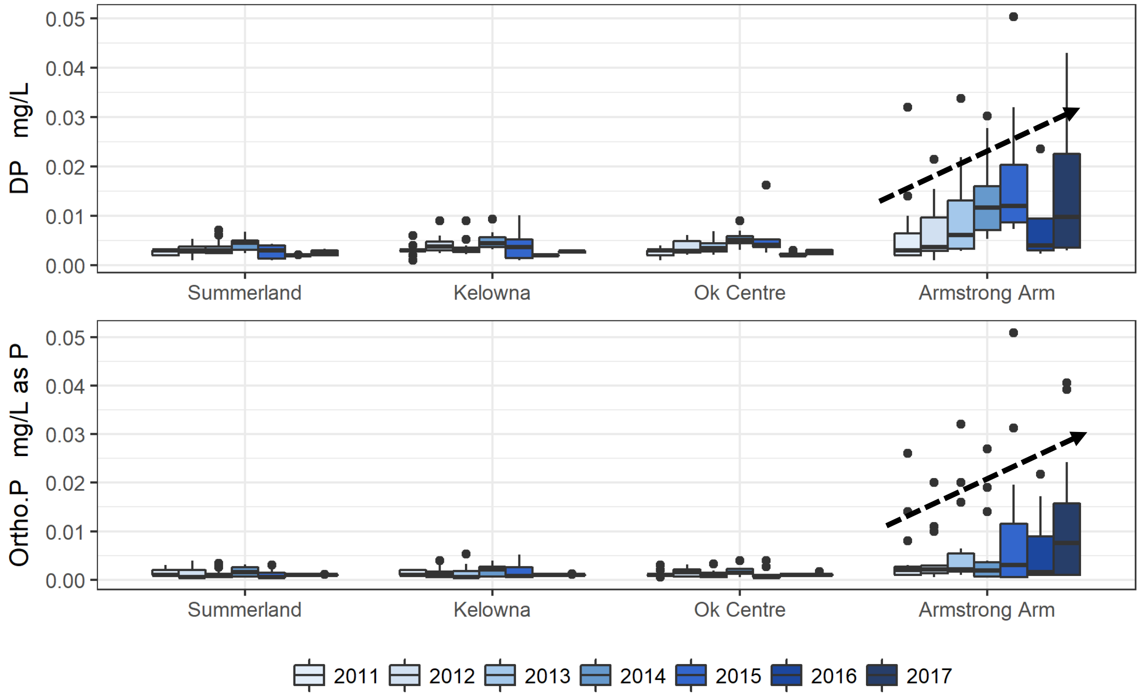


Figure 2.2.6: Dissolved phosphorus (top) and ortho-phosphate (bottom) in Okanagan Lake at the four sampling sites by year with trends highlighted, 2011-2017

Over the historical dataset (1973-2017), TP and DP declined throughout the lake but not in the Armstrong Arm (Figure 2.2.7; Mann-Kendall, p≤0.003). Comparing only the spring overturn dates, we see a clear declining trend in TP in Okanagan Lake (Figure 2.2.8) and a correlation between phosphorus concentration and wet/dry years. Wet years contribute more TP to Okanagan Lake than dry years because phosphorus is part of soil particles that are flushed in during freshet. The effect of wet years was greater on the shallow Armstrong Arm which is vulnerable to impacts in its watershed. Spring sample TP in the Armstrong Arm correlated well with the discharge at Penticton (Pearson's R=0.57).

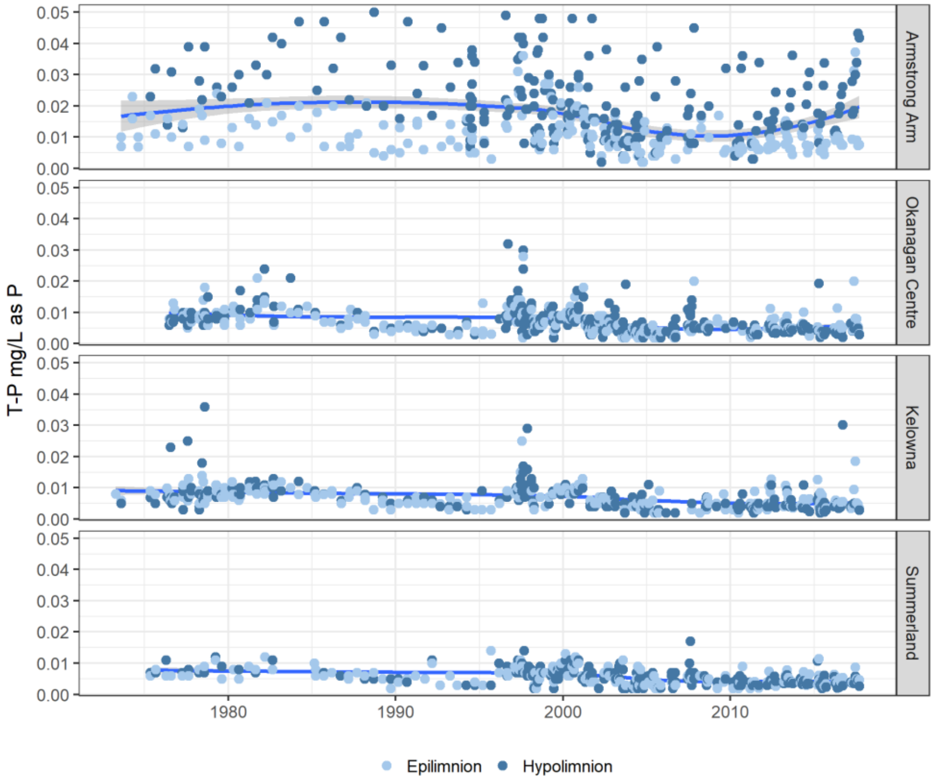


Figure 2.2.7: Historic total phosphorus in Okanagan Lake, 1973-2017

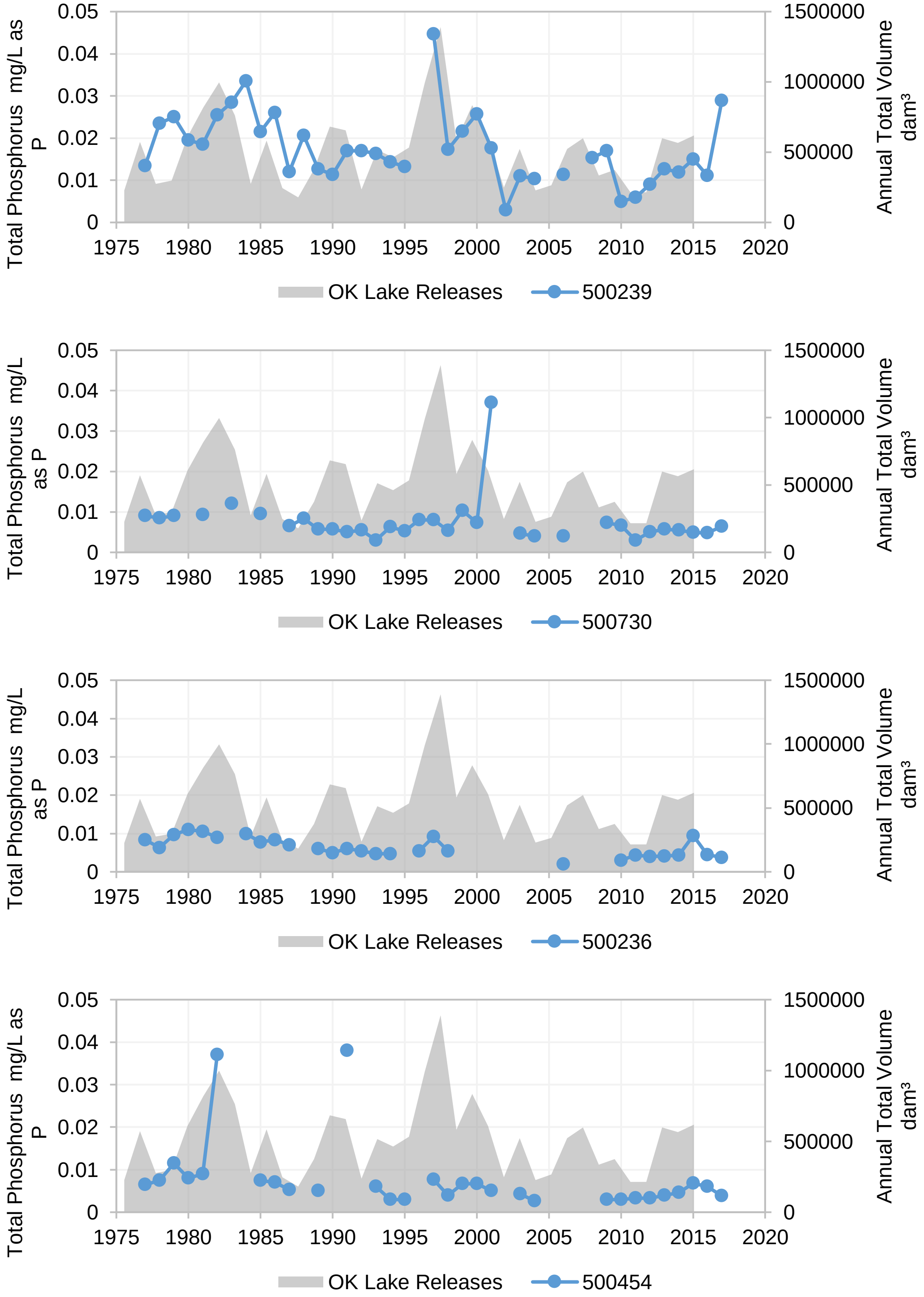


Figure 2.2.8: Total phosphorus at spring sample date compared to annual total discharge in Okanagan River at Penticton, 1977-2017

Note: Discharge volume is a proxy for climate. Years with large discharges were wet years while low discharge years were dry years. March sample dates for TP were used when present and supplemented with April dates in years when March was not sampled but April was.

Nitrogen to Phosphorus Ratio

The ratio of nitrogen to phosphorus (N:P) is a key factor in determining which types of phytoplankton algae will proliferate. Many species of cyanobacteria can fix atmospheric nitrogen, and are therefore limited primarily by the availability of phosphorus. These algae are more likely to bloom when phosphorus is abundant relative to nitrogen. The Okanagan Lake objective for the spring N:P ratio is >25:1 in March samples (or April in the Armstrong Arm if it is still frozen over in March). All three southern sites met this objective in 2017. The Armstrong Arm had much higher phosphorus concentrations than the rest of Okanagan Lake, and as a result, did not meet the N:P ratio objective in 2017 (Figure 2.2.7, Table 2.2.4). During 2011-2017, the objective was met in most years at the three southern sites, but was rarely met in the Armstrong Arm. The N:P ratio decreased in the Armstrong Arm from 2011-2017, which means it trended farther away from the objective (Mann-Kendall, p=0.002).

Table 2.2.4: Ratio of average TN to average TP during spring at Okanagan Lake sampling locations, 2011-2017

Site	Depth	TN	TP	Avg Ratio	Objective	Exceeded in 2017?	% Years Exceeding	Trend
Summerland	<10m	0.231	0.0045	55:1	>25:1	No	0%	-
	>20m	0.232	0.0039	65:1		No	14%	-
Kelowna	<10m	0.227	0.0060	45:1	>25:1	No	7%	-
	>20m	0.254	0.0051	67:1		No	7%	-
Ok Centre	<10m	0.224	0.0056	49:1	>25:1	No	7%	-
	>20m	0.224	0.0046	56:1		No	7%	-
Armstrong Arm	<10m	0.261	0.0100	34:1	>25:1	No	36%	-
	>20m	0.295	0.0198	19:1		Yes	43%	↓

2.3 Biology

2.3.1 Phytoplankton

Phytoplankton and zooplankton samples were only 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 most photosynthetic bacteria (e.g., cyanobacteria). As expected, chlorophyll-a concentrations in Okanagan Lake followed an inverse relationship with Secchi depth (Figures 2.3.1). In most years, chlorophyll-a was lowest in the late-winter and peaked in April-May during the spring algae bloom before decreasing through the summer (Figures 2.3.1 and 2.3.2). Chlorophyll-a concentrations met the objectives at the three southern sites in all years, and in the Armstrong Arm in all years except 2017 (Table 2.3.1).

Flooding during May-July 2017 triggered a large algae bloom in the Armstrong Arm, with chlorophyll-a concentrations peaking at a record high of 28.5 µg/L.

In most years, including 2017, there was a north to south trend in the chlorophyll-a data with the Armstrong Arm having the highest and Summerland having the lowest average concentrations. There was a weak increasing trend calculated for chlorophyll-a at Ok Centre because of a 74% increase in chl-a between 2015 and 2016. There was also an increasing trend in the Armstrong Arm but this appeared to be biased from the record high sample in June 2017. No other statistically significant year-over-year trends in the 2011-2017 chlorophyll-a data were observed.

Table 2.3.1: Chlorophyll-a in µg/L at Okanagan Lake sampling sites, 2011-2017

Site	Objective	Exceeded in 2017?	# of Years Exceeding	Trend	Average	StdDev	Max	Min
Summerland	4	N	0	-	1.72	0.94	4.18	0.38
Kelowna	4.5	N	0	-	1.80	0.90	5.40	0.50
Ok Centre	4.5	N	0	↑	1.99	1.10	5.30	0.50
Armstrong Arm	5	Yes	1 (2017)	↑	3.58	4.10	28.50	0.71

Note: Based on growing season only (Apr-Sep)

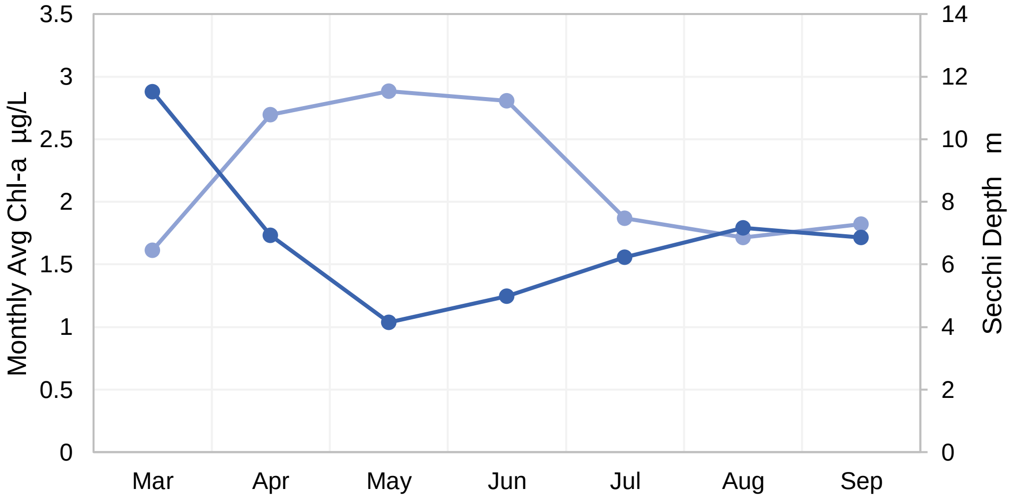


Figure 2.3.1: Seasonal inverse relationship between chlorophyll-a and Secchi depth

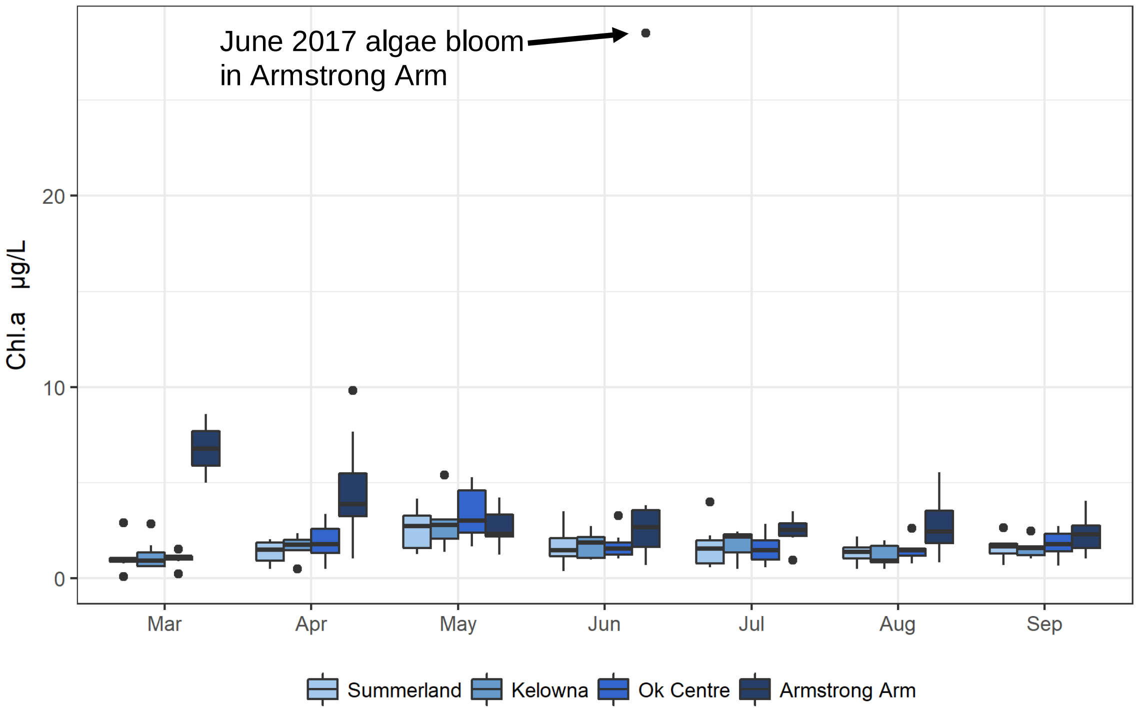


Figure 2.3.2: Monthly chlorophyll-a concentration at the four Okanagan Lake sampling sites, 2011-2017

In the historical dataset (1973-2017), there were several significant trends. Chlorophyll-a declined significantly from 1973-2017 at Summerland and Kelowna (Mann-Kendall, p≤0.03) driven by the high chl-a during the 1996-2000 wet years. Other trends included increases from 1973-2000 at all sites (Mann-Kendall, p≤0.002; Figure 2.3.3).

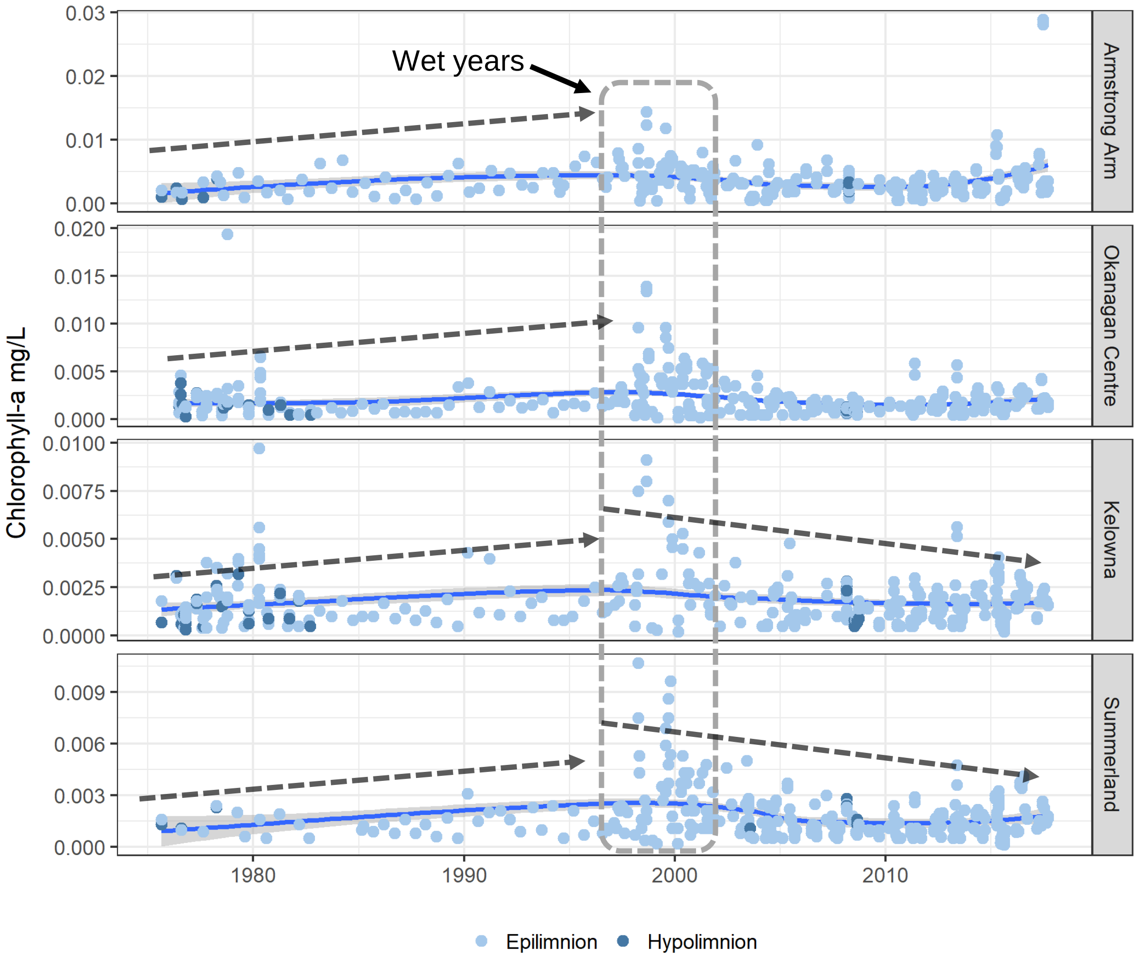


Figure 2.3.3: Historic chlorophyll-a in Okanagan Lake with trends highlighted, 1973-2017

Biovolume

Phytoplankton biovolume samples were collected as a one litre composite from 1-10 m. 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 2015-2017 results are considered here. All samples were far below the objective of 0.75 µL/L during 2015-2017 (Table 2.3.2). After three years of data, there were no statistically significant trends in phytoplankton biovolume at either Kelowna or Summerland (Figure 2.3.2).

Table 2.3.2: Phytoplankton biovolume in µL/L at Okanagan Lake sampling sites, 2015-2017

Site	Obj	Mar	Apr	May	Jun	Jul	Aug	Sep	Avg	SD
Kel.	<0.75	0.0363	0.1761	0.1204	0.1858	0.2459	0.0383	0.1309	0.1507	0.1554
Sum.	<0.75	0.0192	0.0880	0.1798	0.2571	0.1941	0.0338	0.0792	0.1422	0.1388

Note: Growing season average based on Apr-Sep only

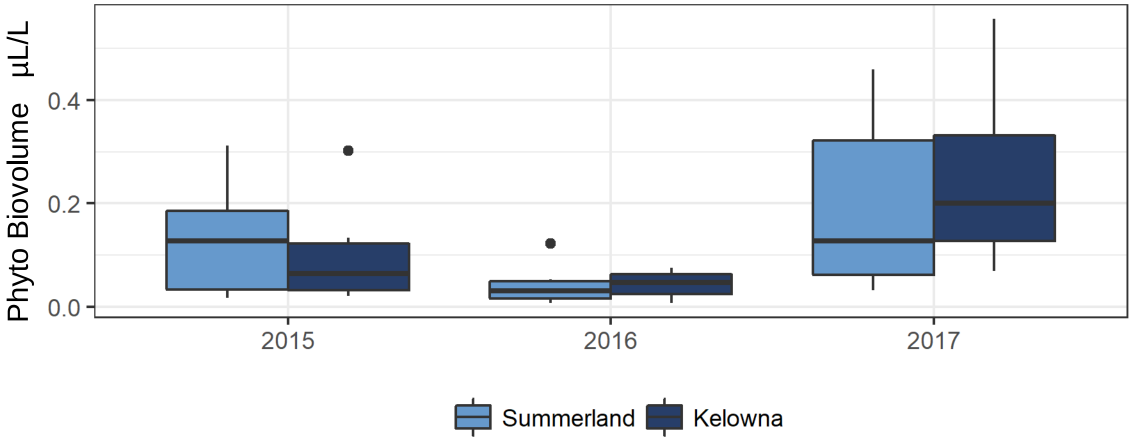


Figure 2.3.2: Phytoplankton biovolume at Summerland and Kelowna, 2015-2017

Phytoplankton Taxonomy

Algae samples were identified to the species level and then grouped into broad algae types for analysis in this report. Diatoms tended to bloom in the spring and then their numbers decreased as the summer progressed. Cyanobacteria were always numerous and typically dominate counts in Okanagan Lake. They peaked in the late-summer at approximately 8500 cells/mL at both Kelowna and Summerland during 2017 (Figure 2.3.3, Table 2.3.3). There was a statistically significant increasing trend in yellow-brown algae at Kelowna (Mann-Kendall, $p<0.001$) and a significant decreasing trend in diatom algae at both sites (Mann-Kendall, $p\leq0.03$) over the course of the sampling program (Figure 2.3.4). There were no trends in either cyanobacteria counts or total algae counts at either Kelowna or Summerland from 2011-2017.

Table 2.3.3: Average phytoplankton counts by major algae groups in cells/mL, 2011-2017

	2017 Averages		2011-2017 Averages	
Algae Type	**Kelowna**	**Summerland**	**Kelowna**	**Summerland**
Diatoms	315	219	5312	3307
Greens	111	106	164	145
Yellow-Brown	629	575	378	269
Cyanobacteria	3590	3776	5635	5185
Dinoflagellates	7	5	12	10
Euglenoids	0	0	7	1
Total Algae	**4652**	**4682**	**11507**	**8917**

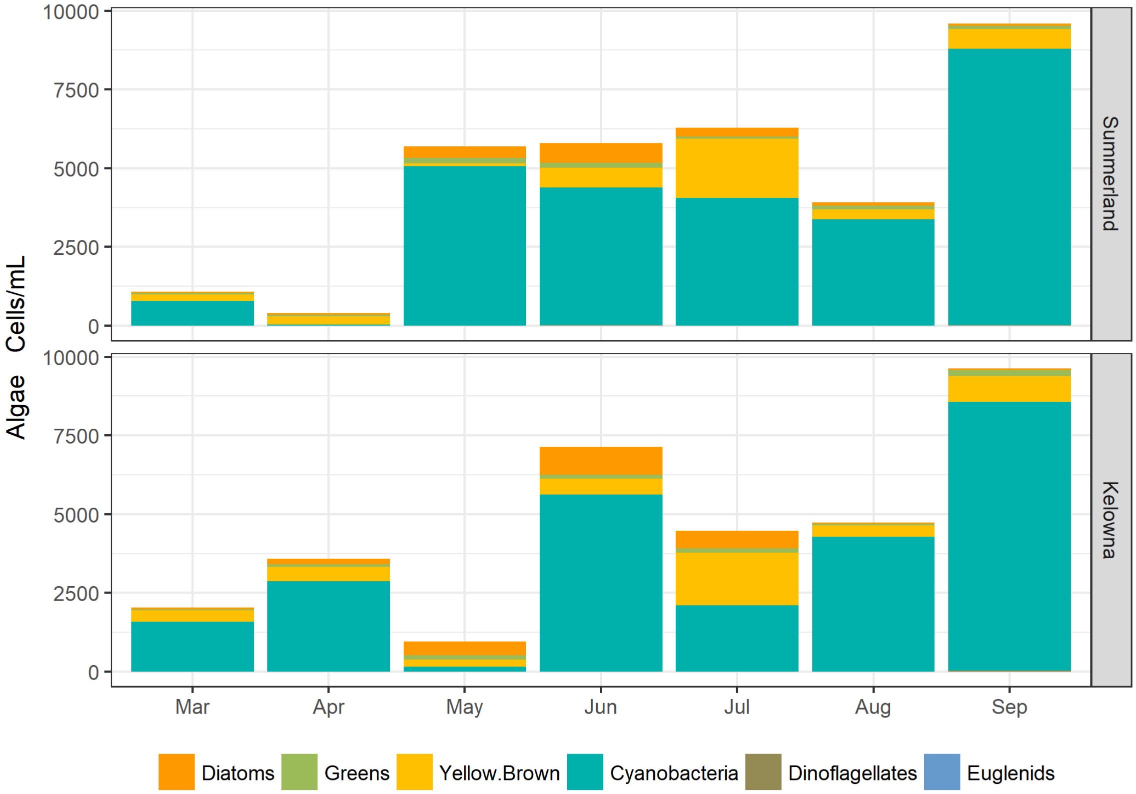


Figure 2.3.3: Taxonomic breakdown of algae by major types at Summerland (top) and Kelowna (bottom), 2017

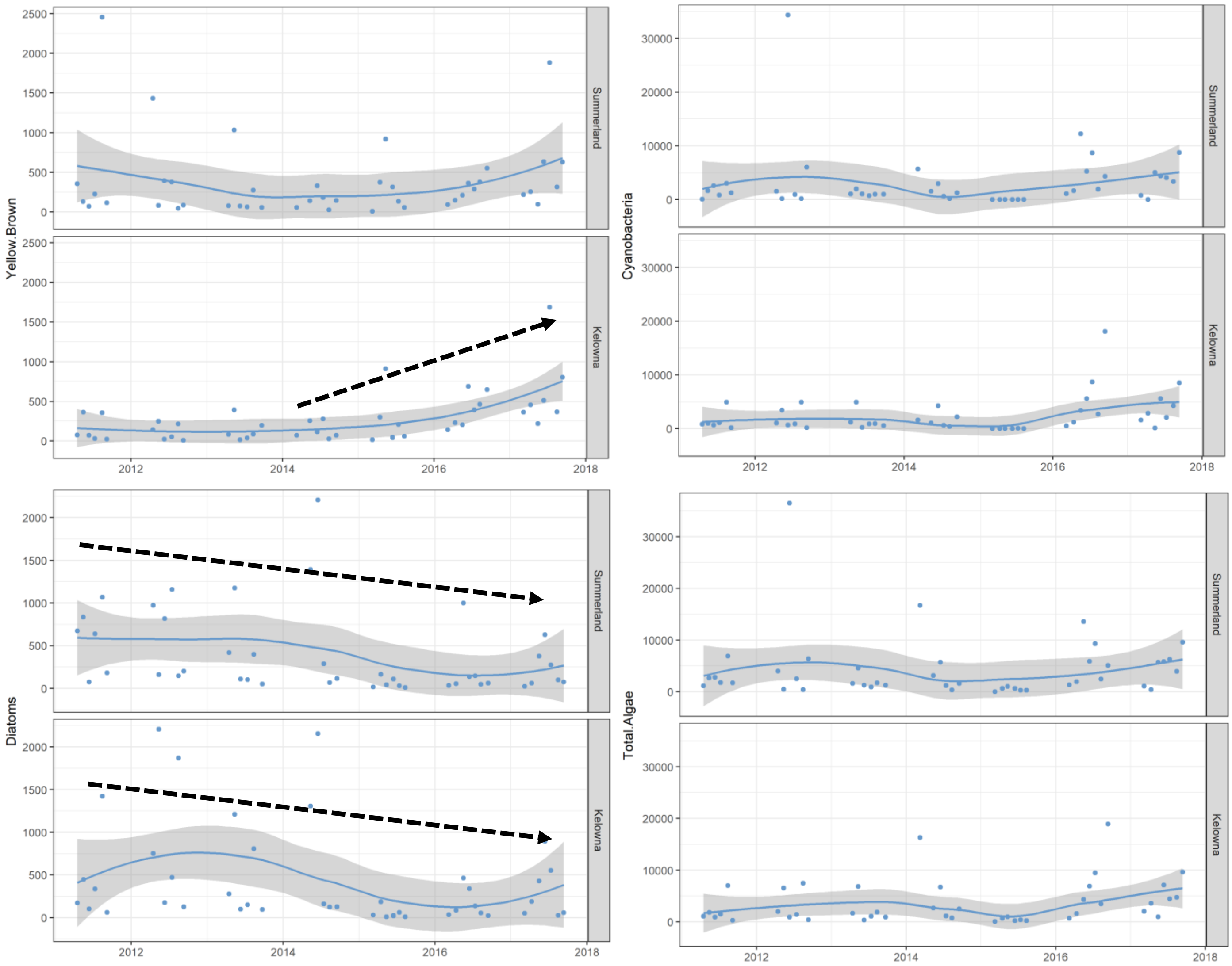


Figure 2.3.4: Algae counts at Summerland and Kelowna with significant trends highlighted, 2011-2017

The Okanagan Lake objective for phytoplankton taxonomy states that no more than 5% of total cell counts should be heterocystous cyanobacteria (Order Nostocales). These phytoplankton can produce toxins that are harmful to human health when they are present in high concentrations. Okanagan Lake is naturally predisposed to this type of phytoplankton and achieving the Objective is difficult in most years (Nordin, 2005). To date, 30% of samples collected have exceeded this objective[1] (28/93 samples) (Figure 2.3.5, Table 2.3.4). There were 3 exceedances at Kelowna (max of 29% heterocystous) and 2 exceedances at Summerland (max of 53% heterocystous) during 2017. Cyanobacteria counts of the scale observed in Okanagan Lake were too low to pose an immediate health risk to people, pets, or wildlife. However, the effect of chronic low dose cyanotoxins remains unresolved (Larratt, 2009). There were no year-over-year trends in the

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[1] In the 2016 report, it was erroneously reported that nearly all samples that year exceeded this objective. This was caused by a taxonomic misclassification in which a relatively common species of cyanobacteria was incorrectly included with the heterocystous cyanobacteria.

heterocystous cyanobacteria counts from 2011-2017. The 2015 results appear unusually high compared to other years because the total algae counts were very low in that year and cyanobacteria composed a larger than usual percentage even though the cyanobacteria counts were also very low numerically. A taxonomic error in 2016 resulted in erroneous exceedances

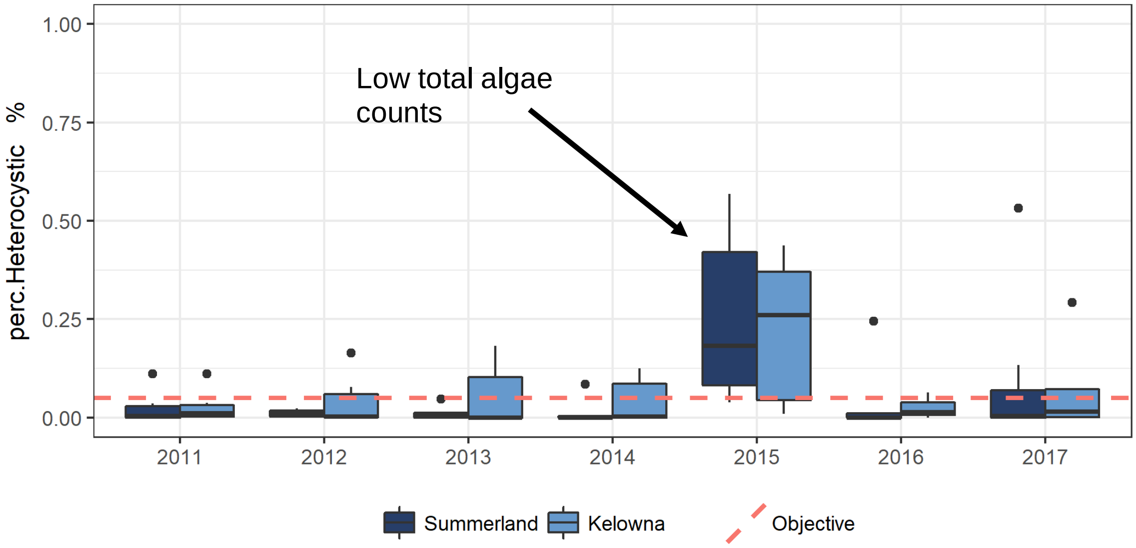

Figure 2.3.5: Percent of total algae counts that were heterocystous cyanobacteria, 2011-2017

Table 2.3.4: Percent of total algae counts that were heterocystous cyanobacteria from 2011-2017

Kelowna		**Average**	**SD**	**# Exceedances**	**# Samples**	**% Exceeding**
	2011	3%	4%	1	6	17%
	2012	3%	4%	1	6	17%
	2013	3%	6%	1	6	17%
	2014	4%	5%	3	7	43%
	2015	22%	19%	4	7	57%
	2016	2%	3%	2	7	29%
	2017	6%	11%	3	7	43%
Summerland						
	2011	4%	7%	1	6	17%
	2012	3%	5%	1	6	17%
	2013	2%	3%	1	6	17%
	2014	1%	3%	1	7	14%
	2015	25%	22%	5	6	83%
	2016	4%	9%	1	7	14%
	2017	10%	20%	2	7	29%

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 to genus and zooplankton biomass was calculated from the abundance data. In previous years (2011-2014), AFDM was used to calculate the zooplankton biomass. The change in methodology may be responsible for the apparent change in zooplankton between 2014 and 2015 and prevents comparisons between 2002-2014 and 2015-2017. The Okanagan Lake objective is a growing season average of >50 µg/L (Nordin, 2005). The objective has been met at Kelowna each year from 2015-2017 but at Summerland, the growing season average was below the objective during the past two years (Table 2.3.5). There were no year-over-year trends in zooplankton biomass from 2015-2017 (Figure 2.3.6).

Table 2.3.5: Zooplankton biomass in µg/L at Okanagan Lake sampling sites, 2015-2017

Site	Objective	Avg	SD	Max	Min	Trend	Met Objective in 2017?	# Years >50 µg/L
Kelowna	>50	78.4	40.3	164.1	16.6	-	Y	3/3
Summerland	>50	40.0	23.5	120.6	6.7	-	N	1/3

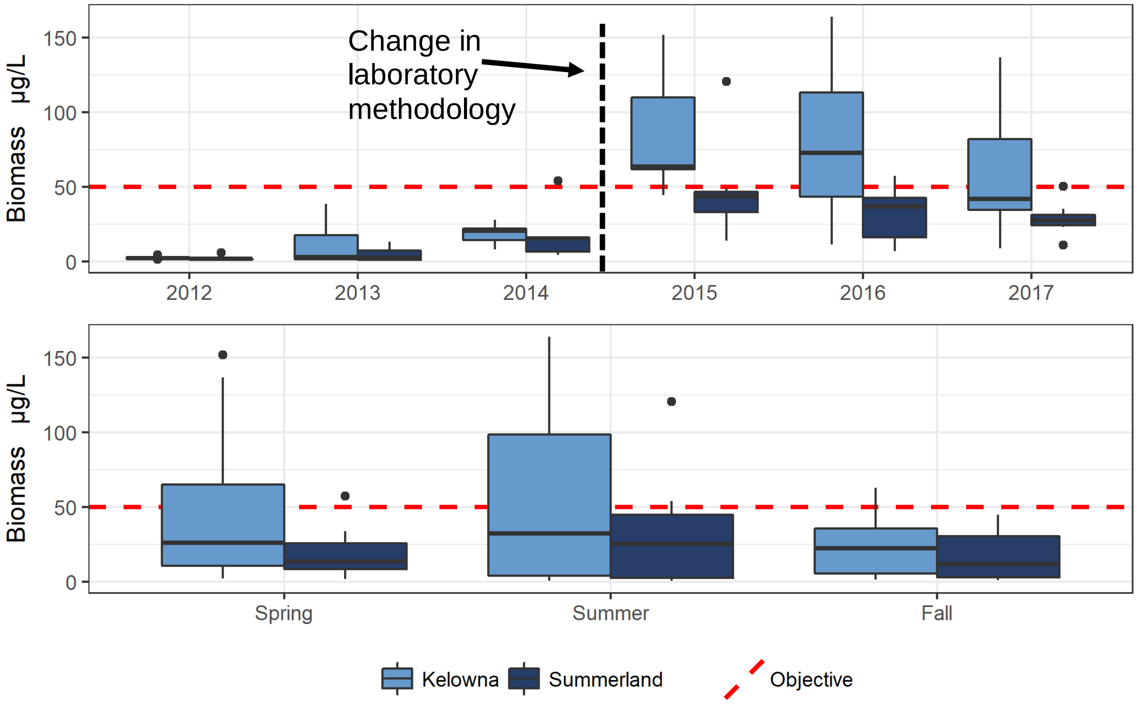

Figure 2.3.6: Zooplankton biomass at the Kelowna and Summerland sampling locations by year (top) and season (bottom), 2012-2017

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 71 ± 41% at Kelowna and 74 ± 42% at Summerland from 2011-2017 (Table 2.3.6, Figure 2.3.7). The Objective for Okanagan Lake is a minimum of 5% of the sample counts be cladocerans. 35 % of samples at Summerland met this objective and 33 % of samples at Kelowna met the objective from 2011-2017. Mysid shrimp and kokanee salmon prefer to eat cladocerans and their consumption 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 was a large increase in rotifers at Kelowna in 2016 but no year-over-year trends in the zooplankton taxonomic data were detected (Figure 2.3.8).

Table 2.3.6: Average annual total zooplankton by major taxonomic groups as percent, 2011-2017

Zooplankton Type	2017		2011-2017	
	Kelowna	Summerland	Kelowna	Summerland
Copepods	56%	71%	71%	74%
Cladocerans	4%	3%	4%	6%
Rotifers	40%	26%	26%	20%
Mysids	0%	0%	0%	0%
Chironomids	0%	0%	0%	0%
Total Zooplankton	100%	100%	100%	100%
# Samples >5% Cladocerans	2/9	1/9	16/48	17/49

Note: Red shading = did not achieve objective, yellow shading = often did not achieve objective

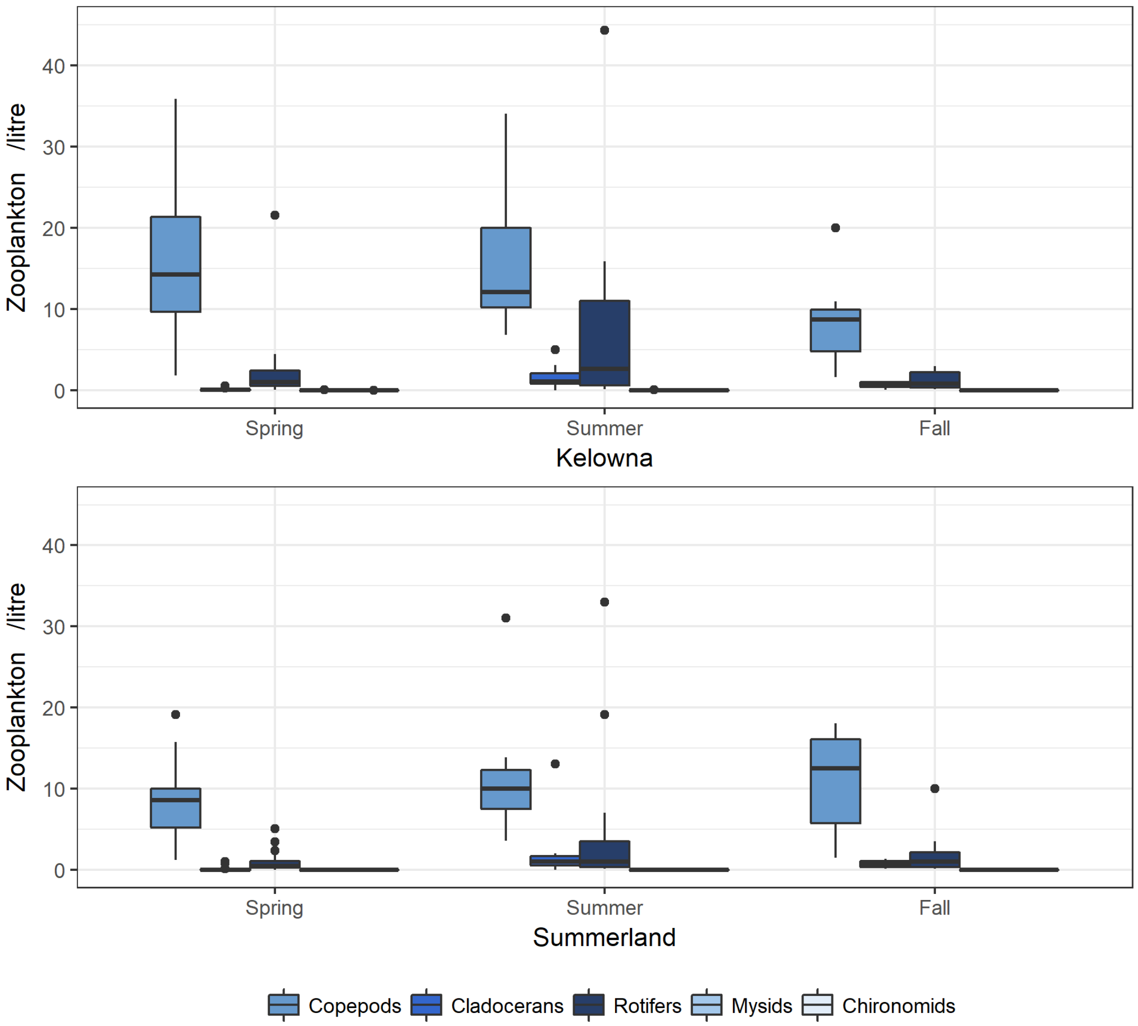

Figure 2.3.7: Breakdown of seasonal zooplankton counts by major taxonomic types at Kelowna (top) and Summerland (bottom), 2011-2017

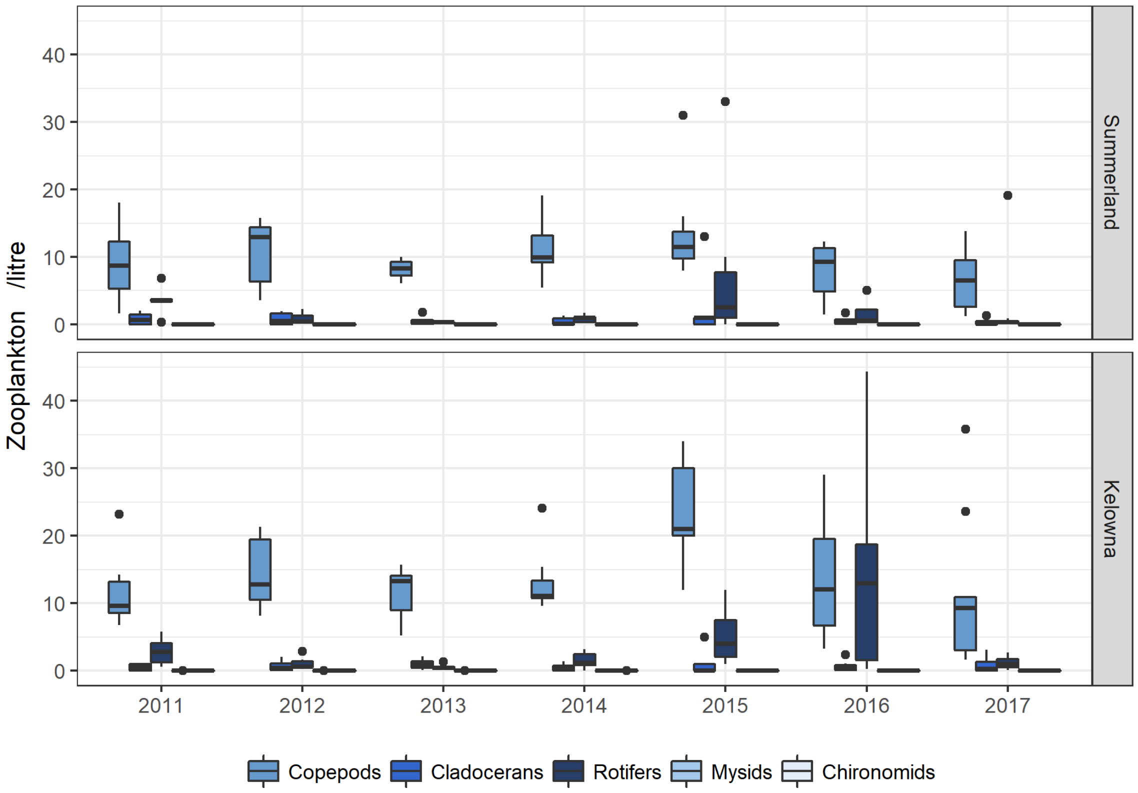

Figure 2.3.8: Zooplankton counts at Kelowna and Summerland, 2011-2017

3.0 Conclusions

This report summarizes the 2017 results and extracts trends from the data accumulated by the Okanagan Lake Collaborative sampling program to date (2011-2017). It is important to note that Okanagan Lake had an extreme freshet peaking in May 2017, resulting in record flooding, followed by a record hot dry summer. The impact of this unusual weather was detected in the data provided by this study.

Each year, the temperature of Okanagan Lake increased in the surface waters until the lake became thermally stratified, usually in May. This physical dynamic isolated the deep water from the atmosphere and led to oxygen depletion below the thermocline in Armstrong Arm. Therefore, the Armstrong Arm failed to meet the dissolved oxygen objective again in 2017, as it has in each year of this study. Dissolved oxygen was excellent at the other three sites throughout the entire study period.

Chemical analysis of water samples revealed no long-term trends in silica concentrations at the three southern sites, while it significantly increased in the Armstrong Arm from 2011-2017. Within the historical dataset, silica increased significantly from the 1973-2000, and has been relatively stable for the past 17 years. Total nitrogen has been stable at Kelowna and Summerland, but there was a small decreasing trend in the hypolimnion at Ok Centre and an increasing trend in the hypolimnion of the Armstrong Arm from 2011-2017. Nitrite+nitrate increased significantly in the Armstrong Arm and in the hypolimnion at Summerland over the same period. There were no significant trends in total nitrogen at any site from 1973-2017. Total nitrogen regularly exceeded the water quality objectives at all sites from 2011-2017, including Summerland and Ok Centre in 2017. Phosphorus concentrations were highest in the Armstrong Arm, where concentrations exceeded the objective during 2017, but only in the hypolimnion. Total phosphorus decreased from 1974-2017 at the three southern sites, but there was no statistically significant trend in total phosphorus in the Armstrong Arm. Dissolved phosphorus increased slightly from 2011-2014 and then leveled off or decreased at the three southern sites, but it increased steadily in the Armstrong Arm from 2011-2017. Samples from the Armstrong Arm frequently exceeded the nitrogen-phosphorus ratio objective, including 2017 and there was a decreasing trend in that ratio in the Armstrong Arm from 2011-2017.

Chlorophyll-a concentrations increased each spring during the annual diatom bloom and then decreased over the summer and into the fall. There were weak increasing trends detected for chlorophyll-a at Ok Centre between 2015 and 2016, and also in the Armstrong Arm which had an intense algae bloom in June 2017. This algae bloom was likely triggered by nutrients washed in from shoreline flooding. The three southern sites met the chlorophyll-a objective in all years, while the Armstrong Arm failed to meet the objective for the first time in 2017. Phytoplankton biovolume met the objective at Kelowna and Summerland from 2015-2017 but a change in methodology in 2015 prevented comparison to previous years. There were no statistically significant trends in phytoplankton biovolume from 2015-2017 at either site.

The taxonomic data indicated that cyanobacteria numerically dominated the phytoplankton samples from 2011-2017. There were several trends from 2011-2017, including an increase in yellow-brown algae at Kelowna, and a decrease in diatom algae at Kelowna and Summerland. Three out of seven samples from Kelowna, and two out of seven from Summerland exceeded the phytoplankton objective of <5% of algae as

heterocystous cyanobacteria during 2017. There were no trends in heterocystous cyanobacteria detected from 2011-2017.
Zooplankton biomass was stable from 2015-2017. Zooplankton biomass met the objective of >50 µg/L at Kelowna, but not at Summerland during 2016 or 2017. Copepods numerically dominated most samples. The water quality objective of >5% of zooplankton as cladocerans was achieved in only 1/9 samples at Summerland and in 2/9 samples at Kelowna in 2017.

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 at Summerland and Armstrong Arm
- Increasing total phosphorus and dissolved phosphorus in the Armstrong Arm
- Decreasing N**:**P ration in the Armstrong Arm
- Flooding in Armstrong Arm during 2017 triggered major algae bloom and impaired water quality

Tables 3.1 and 3.2 summarize the findings of this report for 2011-2017 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. 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 likely 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.

Table 3.1 Summary of 2011-2017 averages and objective exceedances for Okanagan Lake collaborative sampling program.

Objective	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth	🟨 7.2 ± 2.1	🟩 6.8 ± 2.1	🟩 7.2 ± 1.9	🟥 3.4 ± 1.0
Dissolved Oxygen	⬜ 9.5 (Jul)	⬜ 9.6 (Aug)	⬜ 9.4 (Jul)	🟥 1.7 (Sep)
TP (mg/L) 0:10m:	🟩 0.005 ± 0.001	🟩 0.006 ± 0.003	🟩 0.006 ± 0.003	🟨 0.010 ± 0.009
20-45m:	🟩 0.004 ± 0.001	🟩 0.005 ± 0.004	🟩 0.005 ± 0.002	🟥 0.020 ± 0.010
Chlorophyll-a (µg/L)	🟩 1.72 ± 0.94	🟩 1.80 ± 0.90	🟩 1.99 ± 1.10	🟩 3.58 ± 4.10
TN (mg/L) 0-10m:	🟥 0.231 ± 0.066	🟨 0.227 ± 0.050	🟨 0.224 ± 0.079	🟨 0.261 ± 0.086
20-45m:	🟨 0.232 ± 0.049	🟨 0.254 ± 0.118	🟨 0.224 ± 0.048	🟥 0.295 ± 0.075
N:P Ratio 0-10m:	🟩 55:1	🟩 45:1	🟩 49:1	🟨 34:1
20-45m:	🟩 65:1	🟩 67:1	🟩 56:1	🟨 19:1
Algae Taxonomy (% heterocystous cyanobacteria)	🟨 7 ± 14%	🟨 6 ± 11%	⬜	⬜
Algae Biovolume (µL/L)	🟩 0.142 ± 0.139	🟩 0.151 ± 0.155	⬜	⬜
Zooplankton Biomass (µg/L)	🟨 40.0 ± 23.5	🟩 78.4 ± 40.3	⬜	⬜
Zooplankton Taxonomy (% cladocerans)	🟨 4 ± 5 %	🟨 4 ± 4 %	⬜	⬜

Legend:

🟩	🟨	🟥	⬜
Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Table 3.2: Summary of 2011-2017 trends and objective exceedances for Okanagan Lake collaborative sampling program.

Objective		Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth		🟨 -	🟩 -	🟩 -	🟥 -
Dissolved Oxygen		▨ -	▨ -	▨ -	🟥 -
TP (mg/L)	0:10m:	🟩 -	🟩 -	🟩 -	🟨 ↑
	20-45m:	🟩 -	🟩 -	🟩 -	🟥 ↑
Chlorophyll-a (µg/L)		🟩 -	🟩 -	🟩 ↑	🟩 ↑
TN (mg/L)	0-10m:	🟥 -	🟨 -	🟨 -	🟩 -
	20-45m:	🟩 -	🟨 -	🟨 ↓	🟥 ↑
N:P Ratio	0-10m:	🟩 -	🟩 -	🟩 -	🟨 -
	20-45m:	🟩 -	🟩 -	🟩 -	🟨 ↓
Algae Taxonomy (% heterocystous cyanobacteria)		🟨 -	🟨 -	▨	▨
Algae Biovolume (µL/L)		🟩 -	🟩 -	▨	▨
Zooplankton Biomass (µg/L)		🟨 -	🟩 -	▨	▨
Zooplankton Taxonomy (% cladocerans)		🟨 -	🟨 -	▨	▨

Legend:

🟩	🟨	🟥	▨
Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

↑ = Increasing Trend

↓ = Decreasing Trend

- = No Trend

4.0 Recommendations

The Okanagan Collaborative Program is currently at the end of a three-year (2015-2017) term. We therefore recommend that the program be renewed in its current form for another three years. No additional changes need to be made to the program at this time.

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Appendices

Appendix 1 2011-2017 Sampling Data

All data used in this report can be found in the data transfer file
MoE-Synth-DB (2017).xlsx