Okanagan Lake Collaborative Monitoring Agreement
2015 Summary Report

June 2016

Prepared for BC Ministry of Environment, Environmental Protection Division

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Executive Summary

The British Columbia Ministry of Environment commissioned a collaborative monitoring program to sample Okanagan Lake monthly (March to September) at four locations from 2011 to 2015. 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. Physical metrics such as temperature and dissolved oxygen throughout the water column were measured as well as several chemical parameters including silica, nitrogen, and phosphorus. Biological data ranging from biomass to specific taxonomic identification was also collected. This report summarizes the 2015 findings and analyzes the 2011-2015 database for trends.

Physical

Okanagan Lake experienced thermal stratification in 2015 as it did in each year of study. Dissolved oxygen in the deep water of the Armstrong Arm fell below the water quality objective each summer including 2015. Surface dissolved oxygen concentrations decreased from 2011-2015 at all four sample sites on Okanagan Lake, probably as a function of summer water temperature. Secchi depth was highest in late winter and decreased each spring in response to increased phytoplankton activity. The Armstrong Arm Secchi depth averaged only 3.9 ± 1.3 m in 2015 and failed to meet the objective of >5 m averaged over the growing season. Water clarity was highest at Okanagan Centre averaging 8.8 ± 3.0 m.

Chemical

Silica concentrations were similar throughout the lake averaging between 7.03 and 8.20 mg/L at the four sample sites. Silica appeared to increase from spring to fall at all sites during 2015. Silica also decreased year-over-year at Kelowna and Summerland. Total nitrogen averaged 0.224 ± 0.069 mg/L as N in Okanagan Lake and exceeded the objective at all sites except Okanagan Centre during 2015. Total nitrogen increased in the Armstrong Arm and decreased at Okanagan Centre from 2011-2015. Nitrate decreased from spring to fall in response to algae activity at the three southern sites. Total phosphorus averaged 0.007 ± 0.008 mg/L as P in Okanagan Lake during 2015 and increased in the Armstrong Arm from 2011-2015. Dissolved phosphorus increased at all sites from 2011-2015. The objective was exceeded at Kelowna and Summerland in 2015. All sites did not meet the N:P objective during 2015.

Biological

Chlorophyll-a was used as a measure of photosynthetic activity in Okanagan Lake. There was an increasing south to north trend in the chlorophyll-a data. Chlorophyll-a averaged

from 1.44 ± 1.12 µg/L at Summerland in the south end of the lake to 3.87 ± 3.86 µg/L at the north end of the lake in the Armstrong Arm during 2015. All samples achieved the objective for chlorophyll-a. There were no noticeable year-over-year trends in the chlorophyll-a data. The rest of the biological data (biomass and taxonomy of phytoplankton and zooplankton) was sampled at the Kelowna and Summerland sites only. Phytoplankton biovolume averaged 0.103 ± 0.107 µg/L at Kelowna and 0.132 ± 0.116 µg/L at Summerland during 2015. Diatoms and yellow-brown algae numerically dominated phytoplankton counts with a small bloom of *Dinobryon sp.* in May at both sites during 2015. 1/7 samples from Kelowna and 0/6 samples from Summerland exceeded the phytoplankton taxonomic objective. Zooplankton biomass met the objective in Kelowna (0.086 ± 0.039 g/m³) but not in Summerland (0.048 ± 0.034 g/m³) during 2015. Zooplankton biomass also increased year-over-year at both sites from 2012-2015. 27% of samples met the zooplankton taxonomic objective.

Areas of concern

Through this report, we have identified several areas or concern where the Ministry of Environment may wish to pursue further action. These include:

- The Secchi depth in the Armstrong Arm was below the objective on most dates from 2011-2015.
- Dissolved oxygen concentrations decreased at all sites from 2011-2015.
- Total nitrogen concentrations frequently exceeded the objective at all sites.
- Total nitrogen and total phosphorus increased in the Armstrong Arm from 2011-2015.
- Dissolved phosphorus increased at all sites from 2011-2015.

Recommendations

We recommend that the existing collaborative monitoring program be continued as is, through the remainder of the current term and a second detailed synthesis report be compiled at the end of the term in 2017.

Water Quality Objectives, 2015 Values, and Trends for Okanagan Lake

Objectives (Nordin, 2005)	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth (growing season average)	6m	6m	7m	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)	<750	<750	<750	<750
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	8.7 ± 1.1	8.6 ± 2.0	8.8 ± 3.0	3.9 ± 1.3
Dissolved Oxygen	7.97 (Aug)	7.85 (Aug)	8.8 (Aug)	0.05 (Sept)
TP (mg/L)	0-10m: 0.003 20-45m: 0.0107	0-10m: 0.0127 20-45m: 0.0062	0-10m: 0.0054 20-45m: 0.0043	0-10m: 0.0096 20-45m: 0.0081
Chlorophyll-a (µg/L)	1.44 ± 1.12	1.54 ± 1.05	1.53 ± 0.99	3.87 ± 3.86
TN (mg/L)	0-10m: 0.266 20-45m: 0.241	0-10m: 0.234 20-45m: 0.235	0-10m: 0.0223 20-45m: 0.0224	0-10m: 0.313 20-45m: 0.287
N:P Ratio	0-10m: 89:1 20-45m: 23:1	0-10m: 18:1 20-45m: 38:1	0-10m: 4:1 20-45m: 5:1	0-10m: 33:1 20-45m: 35:1
Algae Taxonomy (% heterocystous cyanobacteria)	Max: 3% (Aug)	Max: 21 % (Jul)		
Algae Biomass (µL/L)	0.103 ± 0.107	0.132 ± 0.116		
Zooplankton Biomass (µg/L)	86.0 ± 38.5	48.2 ± 33.9		
Zooplankton Taxonomy (% cladocerans)	2/7 samples >5%	2/8 samples >5%		

Legend:

Met objective in 2015	Did not meet objective in 2015	No Data/ No Objective

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 2015	Did not meet objective in 2015	No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend

Preferred Citation

Self, J. and H. Larratt, 2016. Okanagan Collaborative 2015 Update Report. Prepared by Larratt Aquatic Consulting Ltd. Prepared for British Columbia Ministry of Environment.

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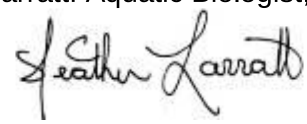

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Definitions

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
Limitation,nutrient	A nutrient will limit or control the potential growth of organisms e.g. P or N
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
Myxotrophic	Organisms that can be photosynthetic or can absorb organic materials directly from the environment as needed
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
Redox	The reduction (-ve) or oxidation (+ve) potential of a solution
Reducing env.	Devoid of oxygen with reducing conditions (-ve redox) eg. swamp sediments
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 (> $1^oC/m$); 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.

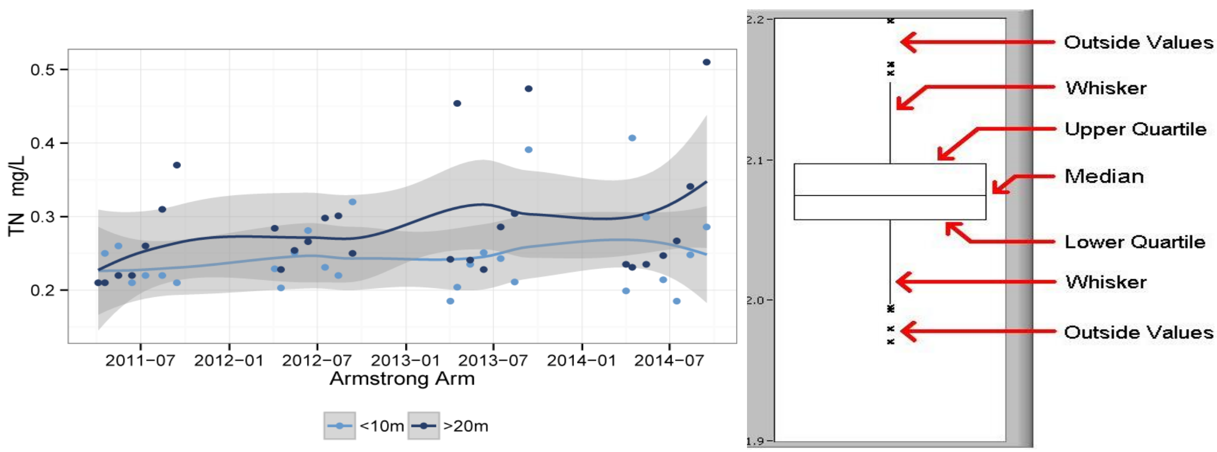

Figure i: Example scatterplot includes all data for a parameter sorted by depth, LOESS polynomial trendlines and the standard errors of those trendlines are also included. Example boxplot is labeled with key information. Whiskers represent the distance to the highest or lowest point within 1.5 * IQR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

1.0 Introduction

1.1 Overview

The British Columbia Ministry of Environment (MoE) 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 data being gathered. This program was performed collaboratively between MoE staff, Okanagan Nation Alliance (ONA; 2011), and Larratt Aquatic Consulting (2012-2015). Okanagan Lake was sampled monthly from March to September from 2011-2015 at four 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 areas at each site: physical parameters, water chemistry, and biological activity. Temperature and dissolved oxygen profiles were taken at each site on each date to build a composite image of temperature and oxygen in Okanagan Lake over time (Figure 2.1.1). Secchi depth, a measure of water clarity, was also recorded for each site.

In addition, 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 Maxxam Analytics and ALS Environmental.

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

The 2015 data were added to the existing 2011 – 2014 database upon which all the analyses in this report were performed. Water quality objectives were based upon Nordin 2005 (Appendix 1).

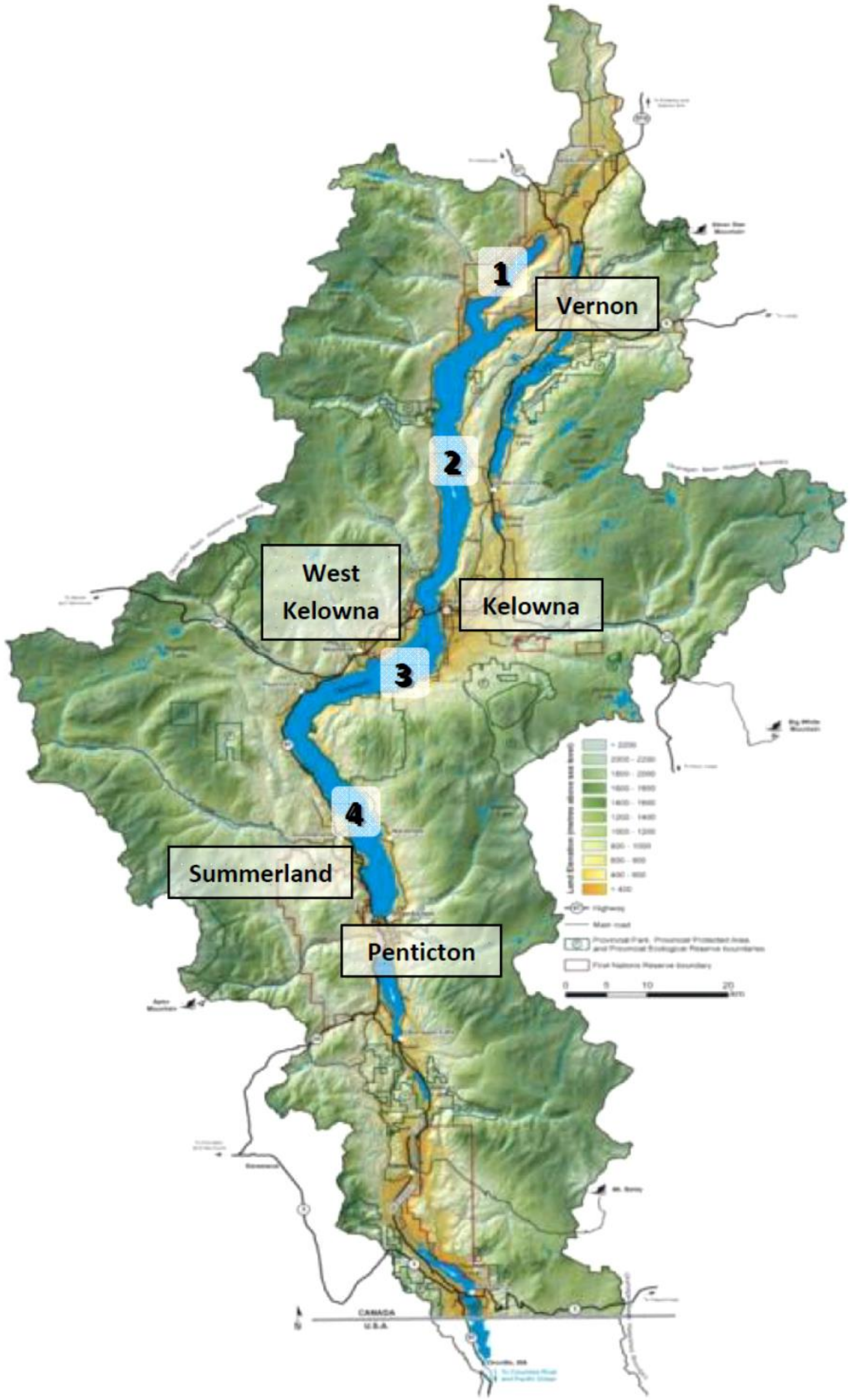

Figure 1.1: Okanagan Basin Watershed with four sampling locations identified. 1=Armstrong Arm, 2=Ok Centre, 3=Kelowna, 4=Summerland (Sokal, 2013).

2.0 Results & Discussion

2.1 Physical

2.1.1 Temperature and Dissolved Oxygen

Okanagan Lake is a deep monomictic lake. This means from May to November each year, the surface water (epilimnion) is 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 only changes temperature by less than 4 °C (Figure 2.1.1).

The three southern sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal and dissolved oxygen behavior while the 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 2.1.2). Oxygen depletion is caused by decomposition of organic material in the sediment of the lake. The Armstrong Arm did not meet the dissolved oxygen concentration guideline during 2015. Thermal stratification breaks down each November and water column freely circulates through the winter. There were no statistically significant trends in the 2011–2015 temperature data either annually, seasonally, or monthly.

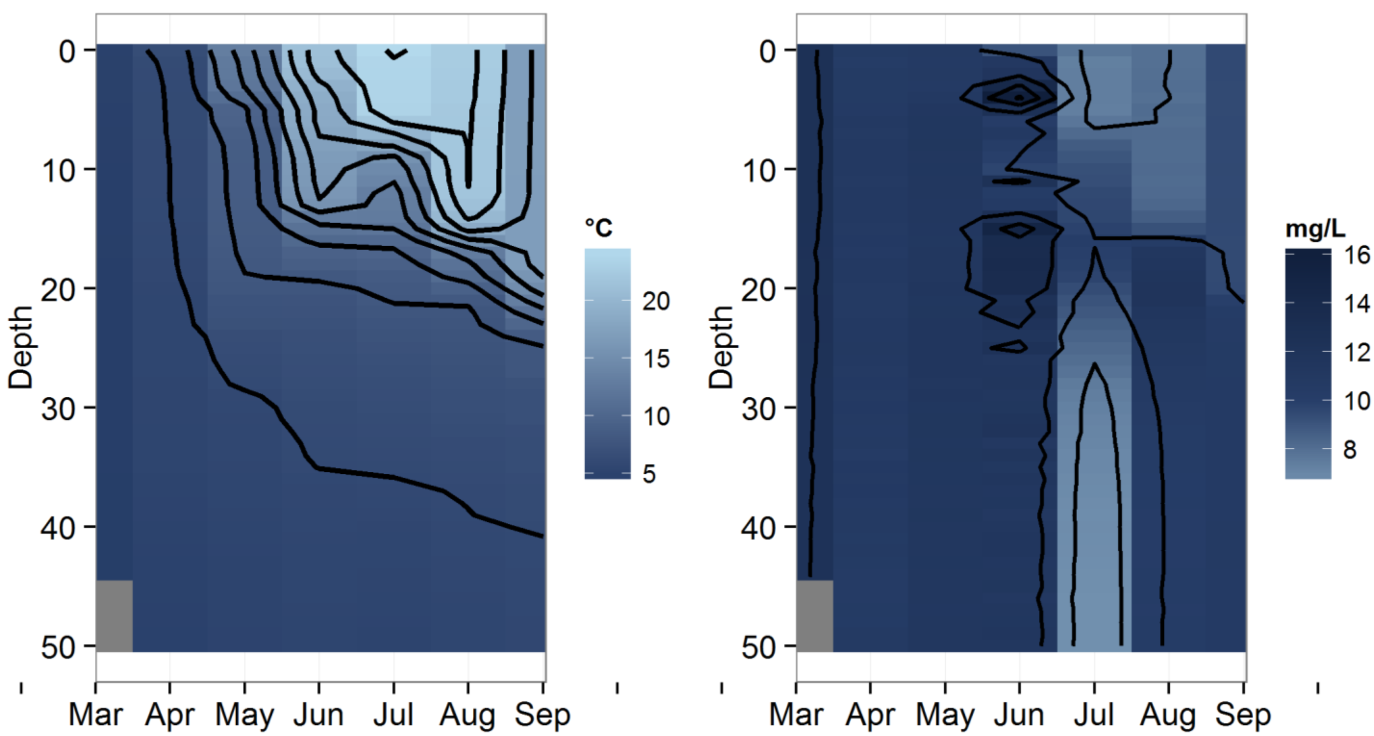

Figure 2.1.1: Temperature and dissolved oxygen profiles for Okanagan Lake at Summerland, 2015. Dissolved oxygen was high throughout the year in the deep water. Lines represent contours of same temperature within the water column through time.

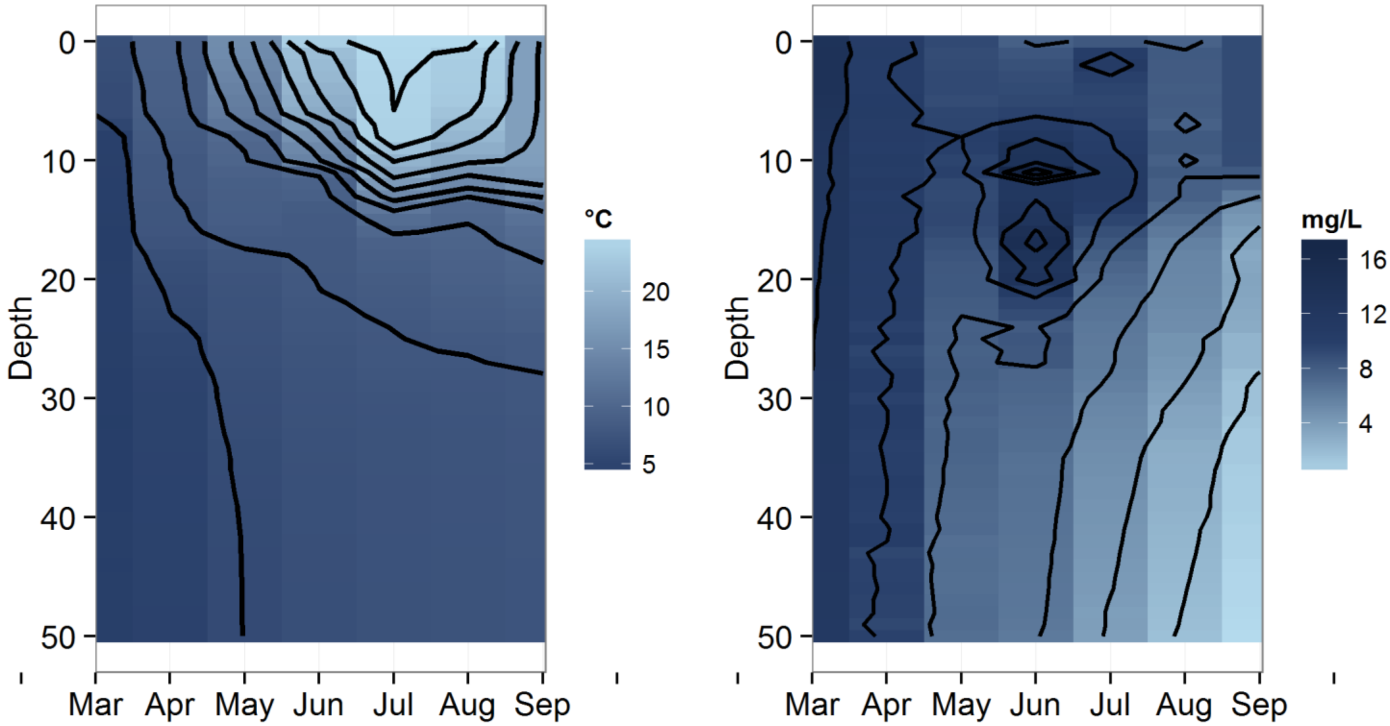

Figure 2.1.2: Temperature and dissolved oxygen profiles for Okanagan Lake at Armstrong Arm in 2015. Dissolved oxygen profile illustrates characteristic oxygen depletion in deep waters of the Armstrong Arm. Lines represent contours of same dissolved oxygen within the water column through time.

Surface dissolved oxygen concentrations vary throughout the year but have been trending downwards at all sites over the course of the collaborative sampling program (2011-2015; Figure 2.1.3; Mann-Kendall p averaged 0.008±0.006). Colder water has a greater capacity to carry dissolved oxygen than warmer water does, however, there were no significant trends in the temperature data. The shift in dissolved oxygen was probably connected to increased water temperature but the high variability in the temperature data masked any trends.

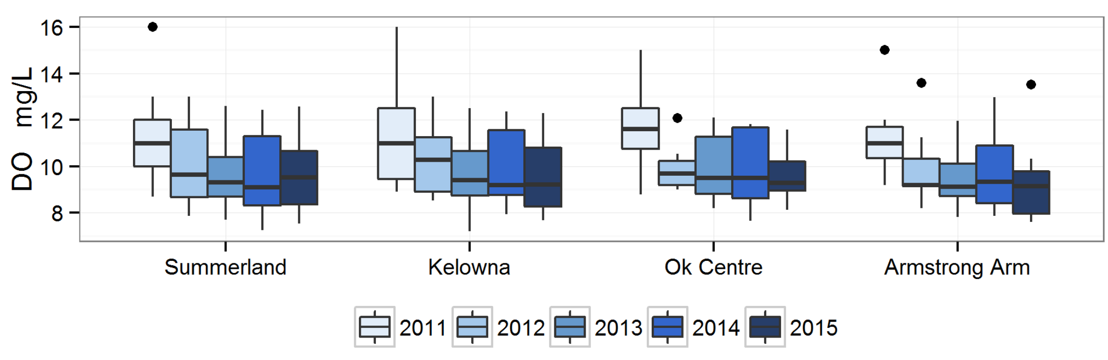

Figure 2.1.3: Surface dissolved oxygen concentrations at Okanagan Lake sampling sites grouped by year, 2011-2015

Surface water temperatures of Okanagan Lake at all four sites were not outside of the range seen in previous years over the course of 2015 except for June in spite of the year being warmer than normal (Figure 2.1.4).

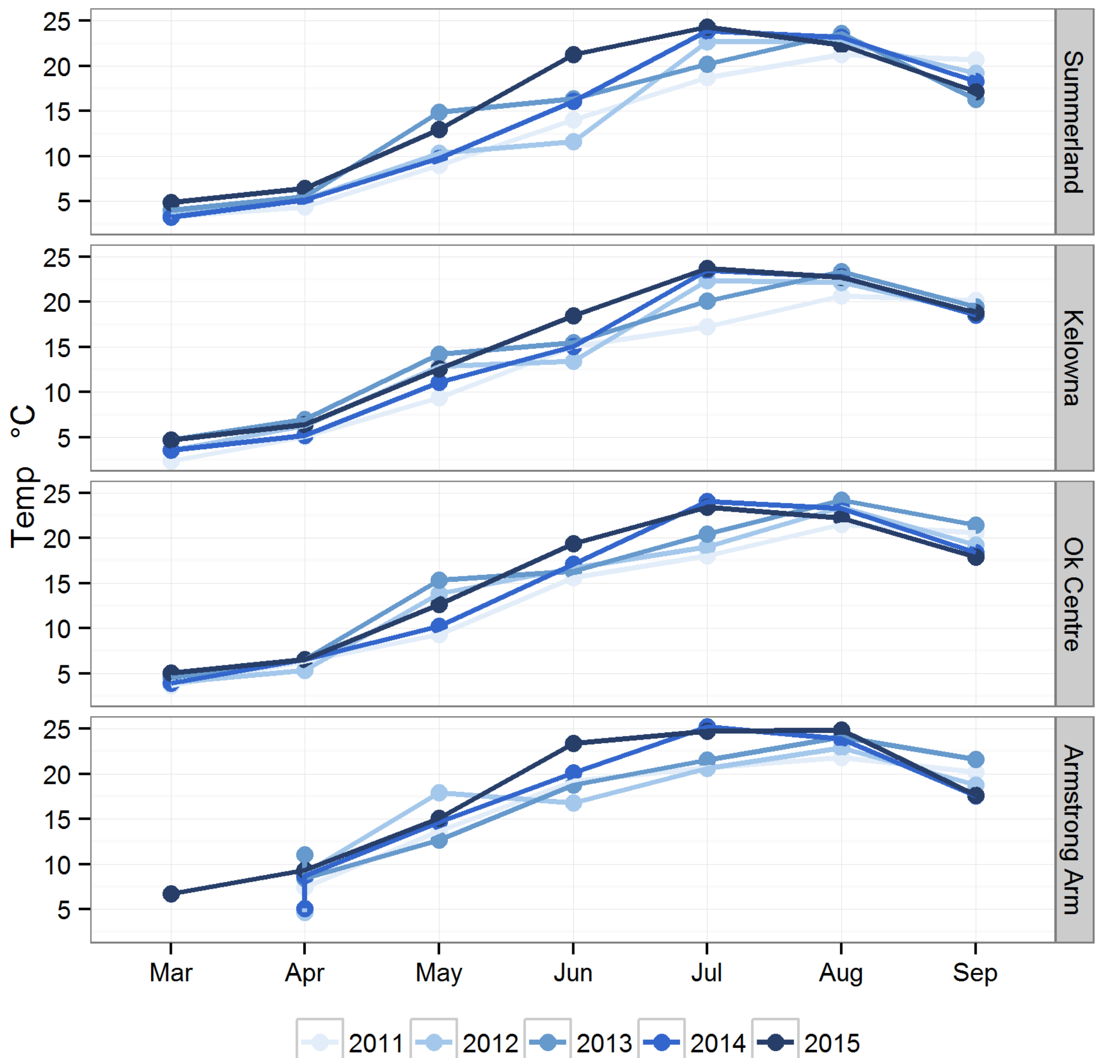

Figure 2.1.4: Surface temperature at Okanagan Lake sample sites by month, 2011-2015

2.1.2 Water Clarity and Secchi Depth

Secchi depth during 2015 ranged from a minimum of 1.9 m at Armstrong Arm in April to a maximum of 13.7 m at Okanagan Centre in March (Table 2.1.1). The average for Okanagan Lake historically has been 6.5-6.6 m (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, 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 2.1.4). The Secchi depth in the Armstrong Arm was much lower throughout the year than at the other sites. This is clearly illustrated in Figure 2.1.4. The Secchi depth in Armstrong Arm did not meet the objective (>5 m) while the Secchi did meet the objective (>6-7 m) at the other sites during 2015 (Table 2.1.1). There were no statistically significant trends in the Secchi depth data either annually, seasonally, or monthly.

Table 2.1.1: Secchi depth in meters at Okanagan Lake sampling sites, 2015

Site	Objective	Average	StdDev	Max	Min
Summerland	7.0	8.7	1.1	10.2	7.3
Kelowna	6.0	8.6	1.9	10.9	5.6
Ok Centre	6.0	8.8	3.0	13.7	1.9
Armstrong Arm	5.0	3.9	1.3	5.6	4.3

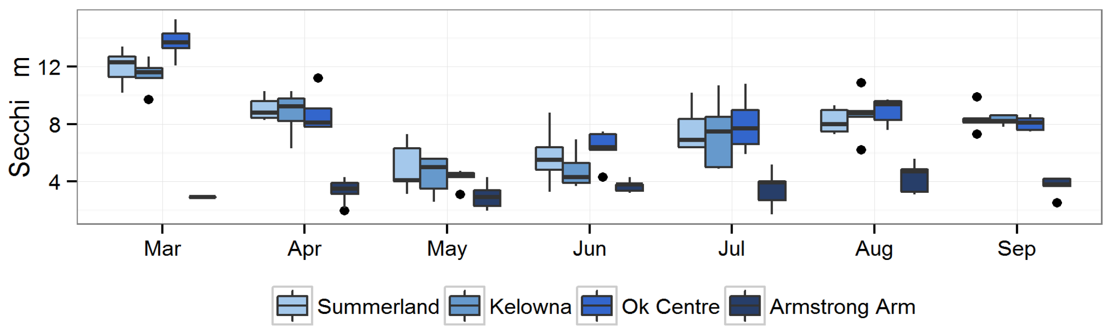

Figure 2.1.5: Monthly Secchi depth at each of the sampling sites, 2011-2015.

2.2 Chemistry

Chemistry sampling focused on 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 sewage 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 weather impacts from human impacts.

2.2.1 Silica

Diatoms, a major group of algae in Okanagan Lake, use silica as a structural building block. Silica was not significantly different between the four sites but decreased year-over-year at the two southern sites from 2011-2015 (Table 2.2.1; Figure 2.2.1; Mann-Kendall p averaged <0.001). Silica concentration appeared to increase at all sites from March to September during 2015 but the sample size was too small to analyze statistically.

Table 2.2.1: Silica concentration in mg/L at Okanagan Lake sampling sites, 2015

Site	Average	StdDev	Max	Min
Armstrong Arm	7.03	0.31	7.49	6.81
Kelowna	7.13	0.49	7.86	6.81
Ok Centre	7.06	0.27	7.44	6.84
Summerland	8.20	2.29	11.60	6.74

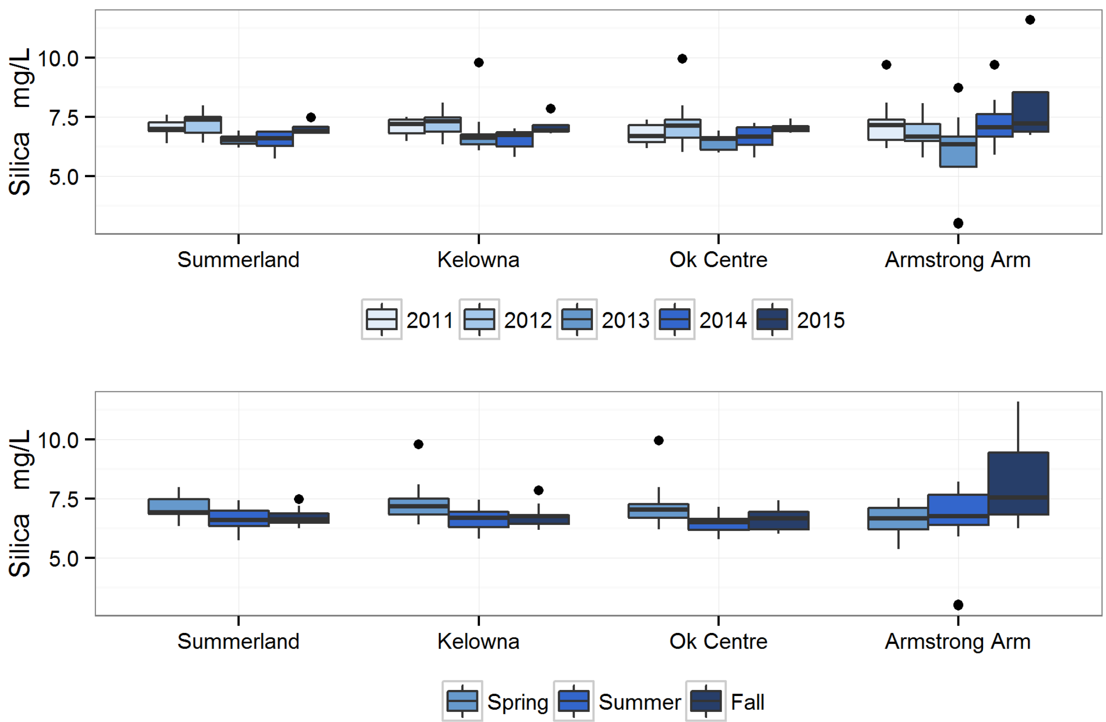

Figure 2.2.1: Silica concentration in Okanagan Lake at each sampling site group by year (top) and season (bottom), 2011-2015

2.2.2 Nitrogen and Phosphorus

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

Nitrogen

Total nitrogen (TN) averaged 0.224 ± 0.069 mg/L as N in Okanagan Lake during 2015 (Table 2.2.1). The objective for Okanagan Lake was set as a spring value (March for three southern sites and April for the Armstrong Arm) 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 except Okanagan Centre in 2015. TN increased in the Armstrong Arm (Mann-Kendall, p=0.035) but decreased at Okanagan Centre (Mann-Kendall, p=0.036) from 2011-2015. Nitrate+nitrite also increased in the Armstrong Arm from 2011-2015 (Mann-Kendall, p=0.01). Nitrate is rapidly consumed by algae in the spring and thermal stratification prevents replenishment with the deeper water during the summer (Figure 2.2.2). Average TN values were comparable to those found in the literature (0.17-0.23 mg/L as N; Andrusak et al.,2000).

Table 2.2.1: Total nitrogen in mg/L as N concentration at Okanagan Lake sampling sites, 2015

Site	Depth	Objective	Exceeded in 2015?	Trend	Avg	SD	Max	Min
Summerland	<10m	0.23	Yes	-	0.207	0.031	0.266	0.183
	>20m		Yes	-	0.222	0.013	0.241	0.206
Kelowna	<10m	0.23	Yes	-	0.213	0.037	0.285	0.176
	>20m		Yes	-	0.233	0.032	0.301	0.205
Ok Centre	<10m	0.23	No	-	0.167	0.066	0.224	0.022
	>20m		No	-	0.191	0.079	0.262	0.022
Armstrong	<10m	0.25	Yes	-	0.271	0.118	0.524	0.181
Arm	>20m		Yes	↑	0.286	0.059	0.342	0.165

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

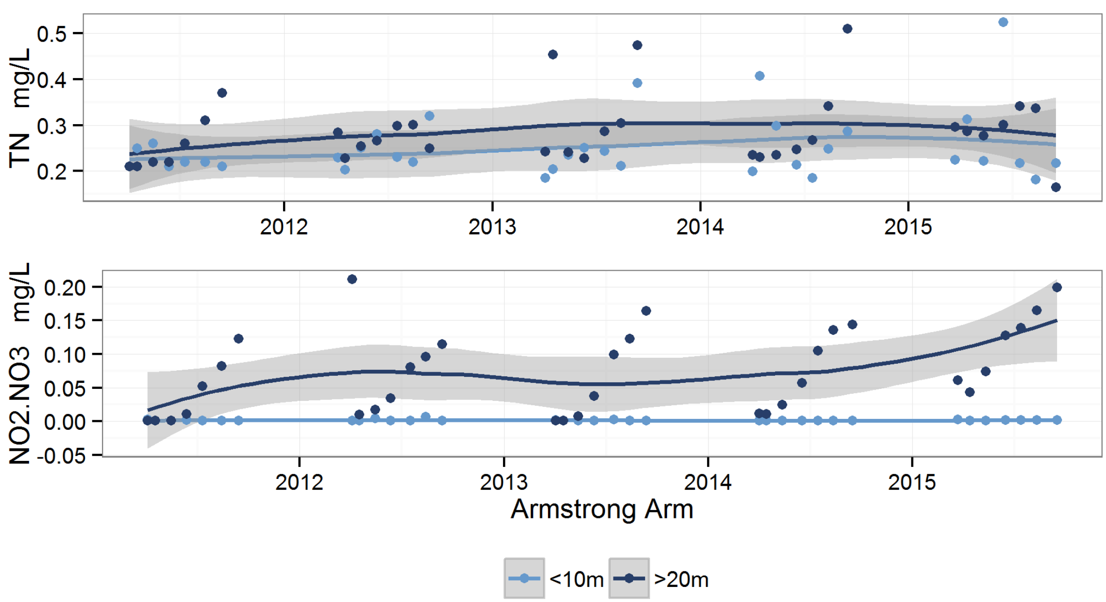

Figure 2.2.2: Total nitrogen and nitrite+nitrate in mg/L as N in the surface and deep water of Okanagan Lake in the Armstrong Arm, 2011-2015

Phosphorus

TP measures all forms of phosphorus including those that may not be bioavailable. Total phosphorus (TP) averaged 0.007 ± 0.008 mg/L as P across Okanagan Lake during 2015 (Table 2.2.2). These data were similar to previous years. The TP objective for Okanagan Lake applies to the maximum phosphorus concentration at the spring overturn (Nordin, 2005; taken as March for the three southern sites and April for the Armstrong Arm). It ranged from 0.007 mg/L in the south basin to 0.010 mg/L in the Armstrong Arm. The TP objectives were exceeded in the deep sample at Summerland and the shallow sample at Kelowna in 2015. TP increased in the Armstrong Arm from 2011 to 2015 (Mann-Kendall, p=0.009).

Table 2.2.2: Total phosphorus in mg/L as P concentration at Okanagan Lake sampling sites, 2015

Site	Depth	Objective	Exceeded in 2015?	Trend	Avg	SD	Max	Min
Summerland	<10m	0.007	No	-	0.003	0.000	0.004	0.003
	>20m		Yes	-	0.004	0.003	0.011	0.002
Kelowna	<10m	0.008	Yes	-	0.005	0.003	0.013	0.003
	>20m		No	-	0.004	0.002	0.008	0.003
Ok Centre	<10m	0.008	No	-	0.004	0.001	0.005	0.003
	>20m		No	-	0.006	0.006	0.019	0.002
Armstrong Arm	<10m	0.010	No	-	0.007	0.003	0.012	0.004
	>20m		No	↑	0.024	0.014	0.050	0.008

Dissolved phosphorus (DP) measures the more bioavailable forms of phosphorus and is a good indicator of potential anthropogenic impacts to biota. Dissolved phosphorus increased from 2011-2015 across all sites, particularly in the Armstrong Arm (Figure 2.2.3; Mann-Kendall p averaged 0.016 ± 0.018). Ortho-P measures only the soluble reactive phosphorus fraction of the DP. There were no statistically significant trends in ortho-phosphate data.

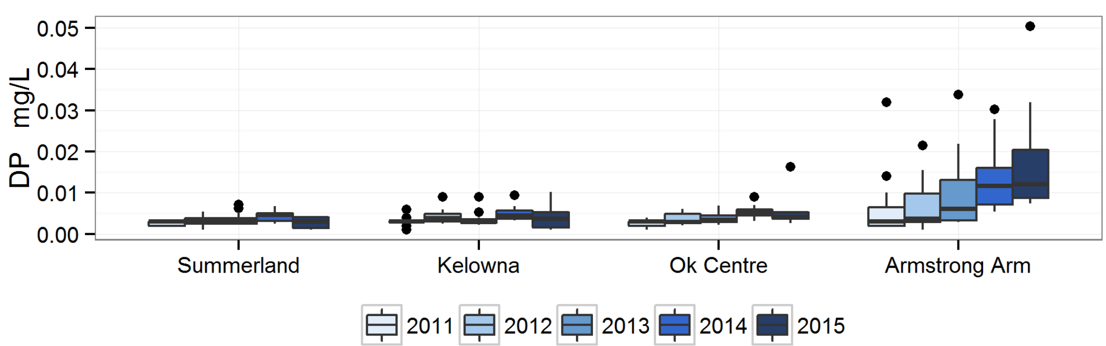

Figure 2.2.3: Dissolved phosphorus in Okanagan Lake at the four sampling sites by year, 2011-2015

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 (Samples from March for the three southern sites and April for the Armstrong Arm). All three southern sites exceeded the objective in some samples with Summerland and Kelowna only exceeding the objective in half of the spring samples. The Armstrong Arm had higher phosphorus concentrations than the rest of Okanagan Lake but did not exceed the objective during April 2015 (Figure 2.2.3, Table 2.2.3). The N:P ratio decreased in the Armstrong Arm from 2011-2014 (Mann-Kendall, p=0.02).

Table 2.2.3: Ratio of average TN to average TP during spring at Okanagan Lake sampling locations, 2015

Site	TN	TP	Avg Ratio	Objective	Exceeded in 2015?	Trend
Summerland	0.215	0.0037	65:1	25:1	Yes (at >20m)	-
Kelowna	0.223	0.0048	54:1	25:1	Yes (at <10m)	-
Ok Centre	0.179	0.0048	49:1	25:1	Yes	-
Armstrong Arm	0.279	0.0157	28:1	25:1	No	↓

2.3 Biology

2.3.1 Phytoplankton

Phytoplankton and zooplankton samples were taken only 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 therefore would 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. As expected, chlorophyll-a followed an inverse trend to Secchi depth (Figures 2.1.4 and 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 2.3.1). During 2015, chlorophyll-a concentrations met the objectives at all sites. Spring chlorophyll-a concentrations were high at 9.8 µg/L in April but the seasonal average remained below the objective (Table 2.3.1). There was a north to south trend in the chlorophyll-a data with the Armstrong Arm having the highest and Summerland having lowest average concentrations. There were no statistically significant trends year-over-year in the chlorophyll-a data at any site.

Table 2.3.1: Chlorophyll-a in µg/L at Okanagan Lake sampling sites, 2015

Site	Objective	Exceeded in 2015?	Trend	Average	StdDev	Max	Min
Summerland	4	N	-	1.44	1.12	2.93	0.38
Kelowna	4.5	N	-	1.54	1.05	3.04	0.50
Ok Centre	4.5	N	-	1.53	0.99	3.37	0.58
Armstrong Arm	5	N	-	3.87	3.86	9.83	0.71

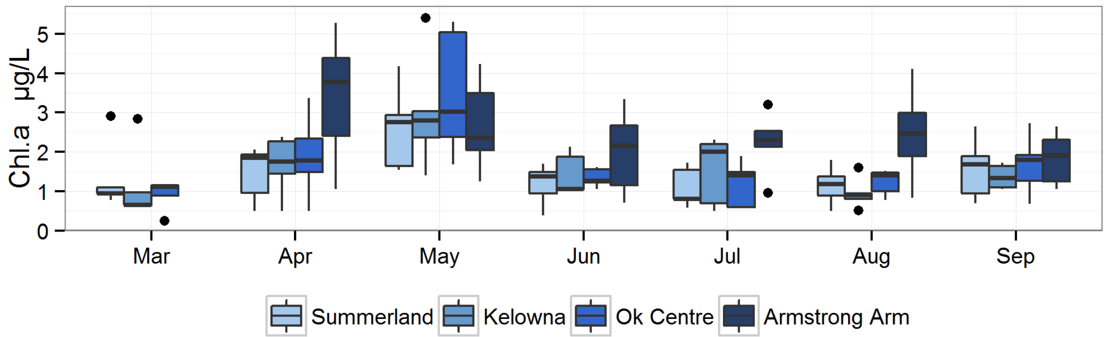

Figure 2.3.1: Monthly chlorophyll-a concentration at the four Okanagan Lake sampling sites, 2011-2015

Biomass

Phytoplankton biovolume samples were collected in a one litre composite of 0-10 m. The biovolumes were determined taxonomically. In previous years, 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 results are shown here. All samples were well below the objective of 750 µL/L during 2015. Phytoplankton biomass averaged 0.103 ± 0.107 µL/L at Kelowna and 0.132 ± 0.116 µL/L at Summerland in 2015 (Table 2.3.2).

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

Site	Obj	Mar	Apr	May	Jun	Jul	Aug	Avg	SD
Kel	<750	0.0314	0.3024	0.0920	0.0372	0.1334	0.0211	0.1029	0.1067
Sum	<750	0.0174	0.1865	0.1858	0.3117	0.0698	0.0221	0.1322	0.1160

Phytoplankton Taxonomy

Algae samples were identified to the species level and then grouped into broad algae types for analysis in this report. Figure 2.3.2 illustrates the major trends in phytoplankton taxonomy in Okanagan Lake. Diatoms bloomed in the spring and then faded as the summer progressed. Cyanobacteria were always numerous in Okanagan Lake but became most intense in the late summer and fall. A small bloom of *Dinobryon sp.* during May in 2015 dominated the algae counts for 2015 (Figure 2.3.2, Table 2.3.3).

Algae counts were very low in 2015 while chlorophyll-a was in line with previous years. The lab used to identify algae species changed between 2014 and 2015 and may be a factor in the apparent drop in algae counts relative to previous years.

Table 2.3.3: Average phytoplankton counts by major algae groups in cells/mL, 2015

	2015 Averages	
Algae Type	**Kelowna**	**Summerland**
Diatoms	50	62
Greens	50	43
Yellow-Brown	226	301
Cyanobacteria	39	14
Dinoflagellates	15	20
Euglenoids	3	0
Total Algae	**408**	**475**

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. One sample from Kelowna (1/7 samples) and zero samples from Summerland exceeded this objective (0/6 samples). There were no year-over-year trends in the heterocystous cyanobacteria counts from 2011-2015.

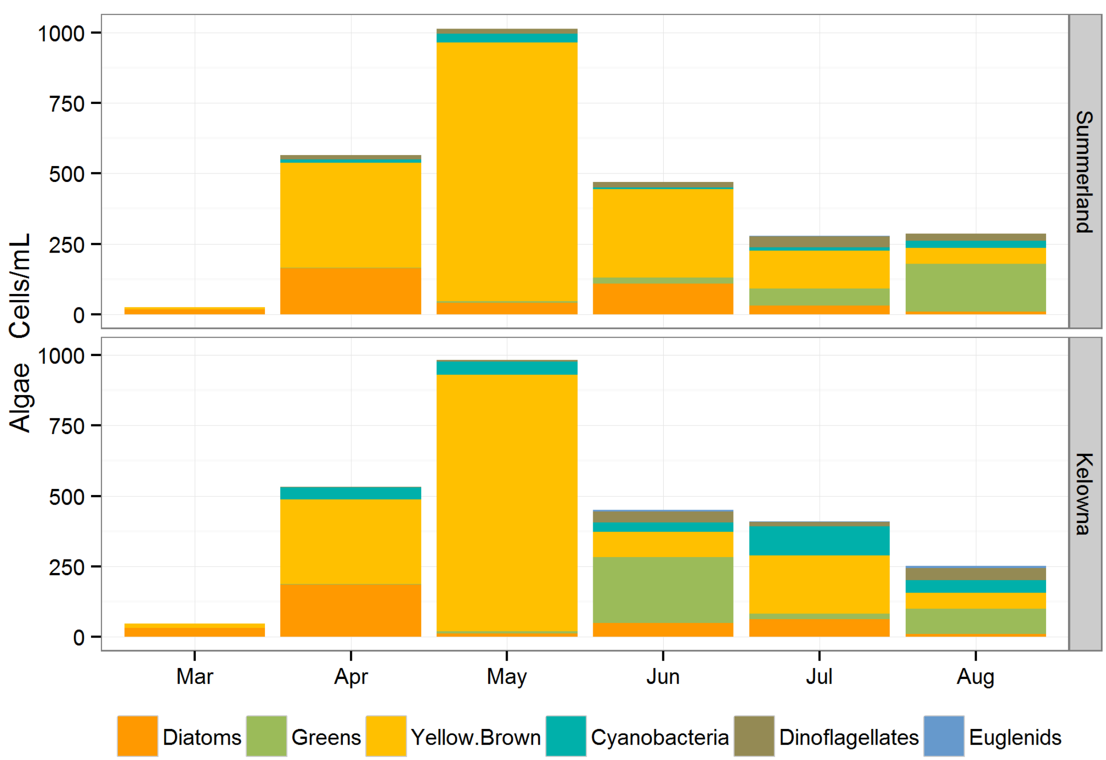

Figure 2.3.2: Taxonomic breakdown of algae by major types at Summerland (top) and Kelowna (bottom), 2015.

2.3.2 Zooplankton

Biomass

Zooplankton biomass samples were obtained using a 150 µm net lowered to 45 m and raised vertically. The 150 µm net mesh size lets most phytoplankton pass through. Samples were identified taxonomically and the biomass was calculated from the abundance. In previous years AFDM was used to calculate the zooplankton biomass. The change in methodology may be responsible for the apparent drop in zooplankton between 2014 and 2015. The Okanagan Lake objective is a growing season average of >0.05 g/m³. This objective was met at Kelowna but not at Summerland in 2015 (Table 2.3.4). There were no statistically significant trends in zooplankton biomass from 2012-2015 (Mann-Kendall; Table 2.3.4; Figure 2.3.3).

Table 2.3.4: Zooplankton biomass in µg/L at Okanagan Lake sampling sites, 2015

Site	Objective	Avg	SD	Max	Min	Trend	P-Value
Kelowna	>50	86.0	38.5	151.7	44.3	-	0.18
Summerland	>50	48.2	33.9	120.6	14.0	-	0.32

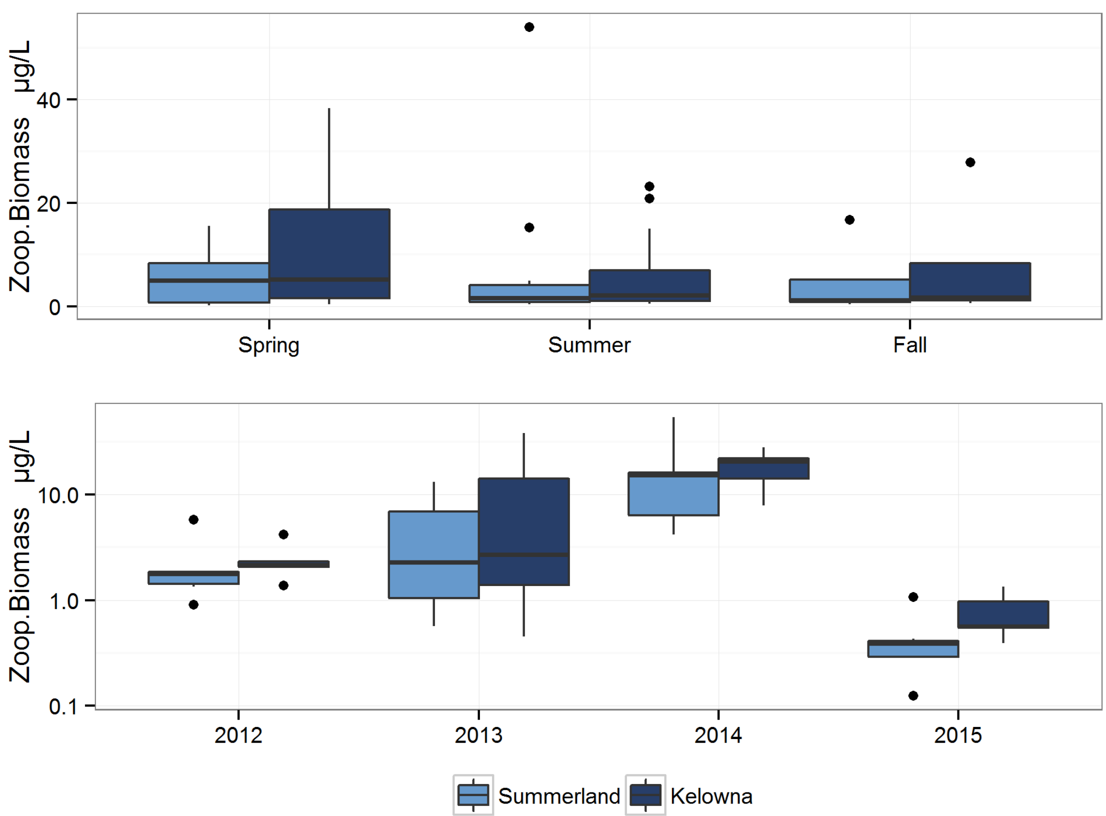

Figure 2.3.3: Zooplankton Biomass at the Kelowna and Summerland sampling locations by season (top) and year (bottom), 2012-2015

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 79 ± 26% at Kelowna and 59 ± 33% at Summerland (Table 2.3.5, Figure 2.3.4). The objective for Okanagan Lake is a minimum of 5% of the sample counts be cladocerans. 29% of samples at Kelowna and 25% of samples at Summerland met this objective. The average was 5±5% of zooplankton counts were cladocerans. 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 were no year-over-year trends in the zooplankton taxonomic data. (Figure 2.3.6).

Table 2.3.5: Average zooplankton by major taxonomic groups, 2015

Zooplankton Type	Kelowna	Summerland
Copepods	79%	59%
Cladocerans	4%	9%
Rotifers	17%	32%
Mysids	0%	0%
Chironomids	0%	0%
Total Zooplankton	100%	100%

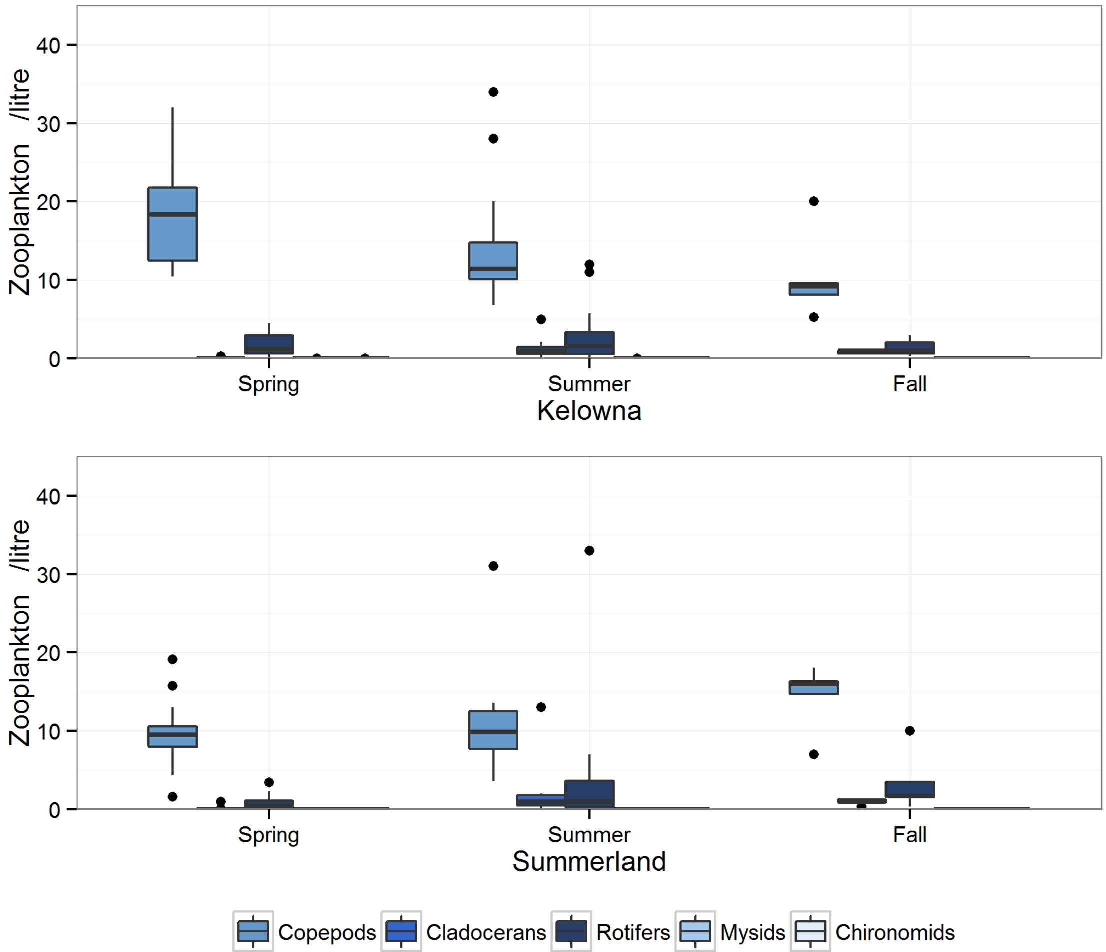

Figure 2.3.4: Breakdown of number of individual zooplankton per sample by major taxonomic types at Summerland (top) and Kelowna (bottom), 2011-2015.

3.0 Conclusions

This report summarizes the 2015 results and extracts trends from the data accumulated by the Okanagan Lake Collaborative Sampling program to date (2011-2015). The data range from physical to water chemistry through to taxonomic.

Each year the temperature of Okanagan Lake increased at the surface until the point where the lake became thermally stratified, usually in May. This physical dynamic isolates the deep water from the atmosphere and led to oxygen depletion below the thermocline in Armstrong Arm. The Armstrong Arm therefore failed to meet the dissolved oxygen objective in 2015. Surface water dissolved oxygen concentrations decreased year-over-year throughout the lake from 2011-2015, indicating probable climactic variation.

Chemical analysis of water samples revealed that silica concentrations decreased at Kelowna and Summerland from 2011-2015. Silica appeared to increase from spring to fall at all sites during 2015. Nitrogen increased in the Armstrong Arm from 2011-2015 but not at the other sites. Total nitrogen exceeded the water quality objectives at all sites except Okanagan Centre during 2015. Phosphorus concentrations were highest in the Armstrong arm where phosphorus concentrations exceeded the objective during 2015. Samples from Kelowna and Summerland also exceeded the objective but Okanagan Centre did not. Dissolved phosphorus increased year-over-year at all sites from 2011-2015. All sites exceeded the nitrogen to phosphorus ratio objective during 2015 and the ratio decreased in the Armstrong Arm from 2011-2015.

Chlorophyll-a, the primary photosynthetic pigment in algae, increased each spring during the annual diatom bloom and then decreased over the summer and into the fall. There were no year-over-year trends in the chlorophyll-a data. All sites met the seasonal average chlorophyll-a water quality objective 4-5 µg/L for Okanagan Lake. Phytoplankton biovolume met the objective in 2015 as well but a change in methodology prevented a trend analysis.

The taxonomic data indicated that diatoms and yellow-brown algae numerically dominated the phytoplankton samples in 2015. Diatoms were most numerous in early spring while a small bloom of *Dinobryon sp.* peaked in May at Kelowna and Summerland. 1/7 samples from Kelowna and 0/6 samples from Summerland exceeded the phytoplankton objective of <5% of algae as heterocystous cyanobacteria during 2015.

Zooplankton biomass increased year-over-year at Kelowna and Summerland from 2012-2015. Zooplankton biomass met the objective of >0.050 g/m^3 at Kelowna but not Summerland during 2015. Copepods dominated numerically all samples. The Okanagan Lake water quality objective of >5% of zooplankton as cladocerans was achieved in only 27% of samples in 2015.

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

- Chronically low Secchi depth in the Armstrong Arm
- Decreasing dissolved oxygen concentrations throughout the lake
- Increasing total nitrogen in the Armstrong Arm
- Increasing total phosphorus in the Armstrong Arm
- Increasing dissolved phosphorus throughout the lake

Tables 3.1 and 3.2 summarizes the findings of this report for 2015 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 wrong 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 be more productive than the deep basins of Okanagan Lake regardless of human activity. However, human activities have impacted this Arm.

Table 3.1: Okanagan Lake Water Quality Objectives and 2015 values with exceedances

Objectives (Nordin, 2005)	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth (growing season average)	6m	6m	7m	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)	<750	<750	<750	<750
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	8.7 ± 1.1	8.6 ± 2.0	8.8 ± 3.0	3.9 ± 1.3
Dissolved Oxygen	7.97 (Aug)	7.85 (Aug)	8.8 (Aug)	0.05 (Sept)
TP (mg/L)	0-10m: 0.003 20-45m: 0.0107	0-10m: 0.0127 20-45m: 0.0062	0-10m: 0.0054 20-45m: 0.0043	0-10m: 0.0096 20-45m: 0.0081
Chlorophyll-a (µg/L)	1.44 ± 1.12	1.54 ± 1.05	1.53 ± 0.99	3.87 ± 3.86
TN (mg/L)	0-10m: 0.266 20-45m: 0.241	0-10m: 0.234 20-45m: 0.235	0-10m: 0.0223 20-45m: 0.0224	0-10m: 0.313 20-45m: 0.287
N:P Ratio	0-10m: 89:1 20-45m: 23:1	0-10m: 18:1 20-45m: 38:1	0-10m: 4:1 20-45m: 5:1	0-10m: 33:1 20-45m: 35:1
Algae Taxonomy (% heterocystous cyanobacteria)	-	21 % (July)		
Algae Biomass (µL/L)	0.103 ± 0.107	0.132 ± 0.116		
Zooplankton Biomass (µg/L)	86.0 ± 38.5	48.2 ± 33.9		
Zooplankton Taxonomy (% chaldocerans)	2/7 samples >5%	2/8 samples >5%		

Legend:

Met objective in 2015	Did not meet objective in 2015	No Data/ No Objective

Table 3.2 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 2015	Did not meet objective in 2015	No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend

4.0 Recommendations

The Okanagan Collaborative Program is currently in the middle of a three year (2015-2017) term. At this time, no changes to the sampling program are required. It is recommended that at the end of the current term (2017) that a second detailed synthesis report be compiled summarizing the status of the program to date and make any necessary recommendations to the program moving forward.

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).

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. doi:10.1093/plankt/22.1.91

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.

Sokal, M. (2013). *Okanagan Lake Collaborative Monitoring Agreement 2013 Summary Report* (pp. 1–51). Penticton BC.

Appendices

Appendix 1 2015 Sampling Data

All data used in this report can be found in the data transfer file
2015 Ok Lake Collaborative Synthesis DataBase.xlsx