Kalamalka Lake Water Quality Study
Microflora, Water Chemistry & Thermal Profiles
2014

Final Version – June 2015

Prepared for*:* Greater Vernon Water and District of Lake Country

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Executive Summary

The purpose of this report is to summarize the 2015 results and compare them to trends found over the course of this 16-year study. The recommendations in this report are based on all results to date.

Key Findings of 2014 Study

Wood Lake

Wood Lake marled in late August/early September 2014 as it did in 2010 and 2011. Consistent with its meso-eutrophic character, 2014 Wood Lake algae production was more than double that of Kalamalka Lake, but unlike other years, no fall cyanobacteria bloom was detected. The influence of Wood Lake cyanobacteria on south Kalamalka Lake was therefore minimal in 2014.

Kalamalka Lake

Thermal stratification was established by the end of May in 2014. Oxygen super-saturation was seen in all 2014 profiles. Both the north and south ends of Kalamalka Lake are subject to significant seiche turbulence, with the south end being the most vulnerable. The North Arm experiences larger turbidity and bacterial spikes during seiches because of its fine sediments. Dissolved oxygen concentrations remain excellent throughout the Kalamalka Lake water column.

Oscillations in Kalamalka Lake pH data since 1970 were not significant and may be induced by weather patterns. Hardness, alkalinity, calcium, magnesium and sulphate (all related to marl formation) increased significantly in Kalamalka Lake since 2000. Marl settling usually increases turbidity at the intakes in late summer and reached 2.13 -2.19 NTU in 2014. As in most years, ultra-violet transmissivity was excellent throughout. Average annual turbidity declined significantly at some sites (0mS, 20mS, 30mN, 40mN) within Kalamalka Lake since 2004. Salinity continued to slowly increase in 2014, probably through urban sources, but remain well below drinking water guidelines. The 2014 ratios of Na : Cl indicate that Coldstream Creek and Wood Lake were more impacted by road salt than Kalamalka Lake. Trend analysis of Kalamalka Lake north and south end data showed a weak declining trend in annual average T-P since 1974. Despite significant nutrient loading from Coldstream Creek that has increased in recent decades, most phosphorus values met the 0.008 mg/L Objective set for Kalamalka Lake in the past decade.

2014 chlorophyll-a (chl-a) concentrations were on par with the data to date. Despite wide annual variations driven by weather, a statistically significant trend emerged where chl-a was lowest at the 40+m sites and highest at the 20 m sites over 1999 – 2014. Unlike 2013, cyanobacteria concentrations were lower in 2014 contributing to average annual productivity and TOC this year. No taste and odor complaints were received during the 2014 growing season at either intake. In the study data from 2000 to 2014, the best depths for low algae densities were N-40 m S-30 m.

Coldstream Creek always contained more bacteria than any site in the North Arm on all dates for *E. coli* and on all dates but one for total coliforms in the bimonthly 2011-2012 data. The bimonthly results suggest that completely evading the creek plume is not possible within the North Arm. In all of the results to date, the bacterial counts from the south end of Kalamalka Lake were far lower than those from the north end. The depths with the lowest bacterial counts were 30 m – 40 m at both ends of Kalamalka Lake.

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Glossary and Abbreviations

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

Term	Definition
Aerobes	Organisms that require >1-2 mg/L dissolved oxygen in their environment
Accrual rate	A function of cell settlement, actual growth and losses (grazing, sloughing)
Algae bloom	A superabundant growth of algae, a marked increase to >1000 cells/mL
Anaerobic/anoxic	Devoid of oxygen
Benthic	Organisms that dwell in or are associated with the sediments
Bioavailable	Available for use by plants or animals
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment
Desmids	Green single-celled algae with frustules, prevalent in acidic environments
Diatoms	Algae that have hard, silica-based "shells" called frustules
Fall overturn	Surface waters cool and sink, until a fall storm mixes the water column
Eutrophic	Nutrient-rich, biologically productive water body
Green algae	A large family of algae with chlorophyll as the main photosynthetic pigment
Inflow plume	A creek inflow seeks the layer of matching density in a receiving lake, mixing and diffusing as it travels; cold, TSS, and TDS increase water density
Light attenuation	Reduction of sunlight strength during transmission through water
Limitation,nutrient	A nutrient that limits or controls the potential growth of organisms e.g. P or N
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.
Mesotrophic	A water body having a moderate amount of dissolved nutrients
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Myxotrophic	Organisms that can be photosynthetic or can absorb organic materials directly from the environment as needed
Nano plankton	Minute algae that are less than 5 microns in their largest dimension
Oligotrophic	A water body having low dissolved nutrient concentrations that restrict microflora growth
Pico plankton	Minute algae that are less than 2 microns in their largest dimension
Pelagic	Open water deeper than 6 meters in a reservoir or lake (less productive)
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 envi	Devoid of oxygen with reducing conditions (-ve redox) e.g. swamp sediments
Residence time	Time for a parcel of water to pass through a reservoir or lake (flushing time)
Riparian	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 (> 1ºC/m); it separates the surface water (epilimnion) from the cold hypolimnion below
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

Lake Classification by Trophic Status Indicators

Trophic Status	Chlorophyll-a ug/L	Total P ug/L	Total N ug/L	Secchi disc m	primary production mgC/m^2/day	Growing season Phytoplankton abundance cells/mL
Oligotrophic	0 – 2	1–10	<100	> 6	50- 300	<1000
Mesotrophic	2 – 5	10–20	100 – 500	3 – 6	250 – 1000	1000 – 5000
Eutrophic	>5	> 20	500-1000	< 3	>1000	>5000

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

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

After Nordin,1985

Report Abbreviations

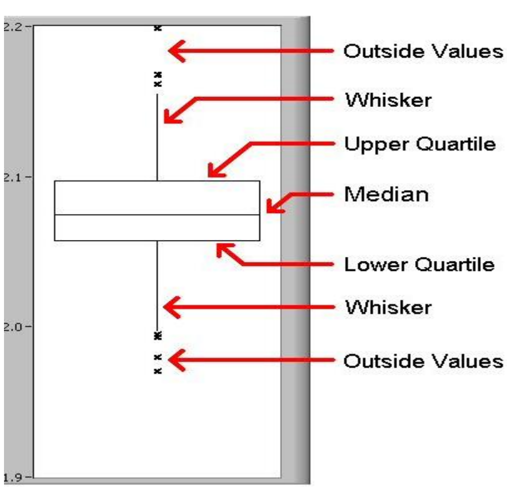
ENTITIES:
DLC District of Lake Country
RDNO Greater Vernon Water
RDNO Regional District of North Okanagan
MoE Ministry of Environment
IHA Interior Health Authority
LAC Larratt Aquatic Consulting

PARAMETERS:
TOC = total organic carbon
Chl-a = chlorophyll-a
DO = dissolved oxygen
DGT = Detection greater than
UVT = ultraviolet transmissivity at 254 nanometers
TDS = Total Dissolved Solids

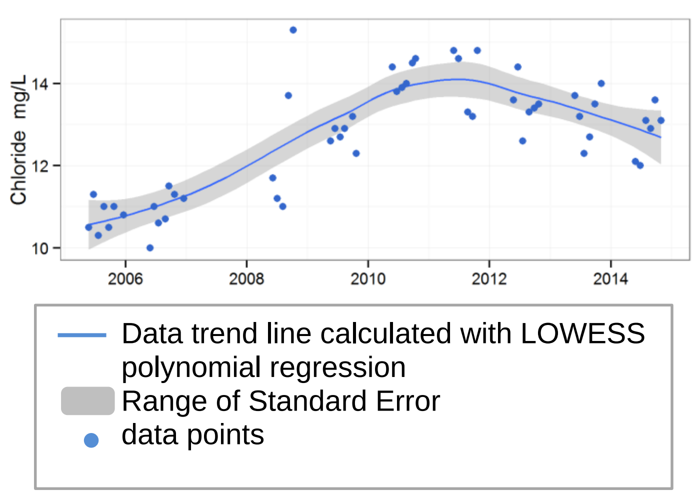
Sample Site GPS Co-ordinates

Kal N 47 m	N 50 12.740	W 119 17.222	Kal S 20 m	N 50 07.005	W 119 22.350
Kal N 40 m	N 50 12.977	W 119 16.896	Kal S 30 m	N 50 07.110	W 119 22.463
Kal N 35m	N 50.21929	W 119.2788	Kal S 40 m	N 50.127	W 119.374
Kal N 30 m	N 50 13.421	W 119 16.459			
Kal N 20 m	N 50.13.628	W 119 16.499	Coldstream Ck	N 50.22427	W 119.261962
Kal N 10 m	N 50 13.454	W 119 15.899	Wood Lk	N 50.1045	W 119.382
MoE Kal N	N 50.2224	W 119.2727	MoE Kal M	N 50.1589	W 119.3538
MoE Kal S	N 50.1347	W 119.3688	MoE Wood Lk	N 50.0749	W 119.3917
Note surface samples are collected at the 20 m sites					

Box Plot Legend



Trend Graph Legend



1.0 Introduction

An offensive taste and odor event occurred throughout Kalamalka Lake in summer 1999 that was apparently caused by an algae bloom. The taste and odor event and changes detected in water quality resulted in a jointly funded study between the Regional District of North Okanagan (now known as RDNO-Greater Vernon Water), City of Vernon water department (now a part of RDNO-RDNO) and the District of Lake Country (DLC). The Ministry of Environment (MoE) also partnered with this group through in-kind support. Larratt Aquatic has been retained since 1999 to study the impact of Kalamalka Lake water chemistry and microflora production as they pertain to drinking water quality.
The annual Kalamalka Lake study is now in its 16th year.

The 2014 study was focused on the following goals:

1) Define the physical and biological impacts on drinking water quality at the existing RDNO and DLC intakes
2) Provide baseline water chemistry for future additional water treatment
3) Study fluctuations in water chemistry and algae production in Kalamalka Lake
4) Evaluate water quality at different depths in the lake for potential benefits of intake extension
5) Evaluate source water quality fluctuations in Coldstream Creek and Wood Lake and their impacts on Kalamalka Lake
6) Co-operate with MoE in tracking long-term water quality and productivity changes in Kalamalka Lake and the implications of those changes for water resources

At each site, field water quality measurements, water chemistry samples and biological samples were taken monthly through the 2014 growing season from Kalamalka Lake and a portion of the contributing watershed (Table 1.0-1). Since the primary focus of this water quality study is on drinking water, the sample sites were located around the RDNO intake at the north end of the lake and the DLC intake at the south end of the lake. Additional samples were examined at each of the drinking water intakes for algae density and taxonomy.

Sampled water quality parameters included the following in 2014:
Field Meter Depth Profiles: temperature, pH, dissolved oxygen, TDS, conductivity
Lab Samples: alkalinity, chloride, sulfate, UVT, TOC, turbidity, pH, chlorophyll-a, conductivity, hardness, total calcium, total magnesium, total coliforms, *E. coli*

While the majority of the sample sites were located in Kalamalka Lake, the contributing watershed was also sampled (Figure 1.0-1). Inflows into Kalamalka Lake are primarily from Coldstream Creek, Wood Lake and groundwater. Coldstream Creek supplies approximately 80% of the annual inflow into Kalamalka Lake (Bryan, 1990). Water usually moves from Wood Lake into Kalamalka Lake through Oyama Canal, although lake water levels and winds can reverse the flow. During late summer and in very dry years, a net southerly flow occurs (MoE, 1975).

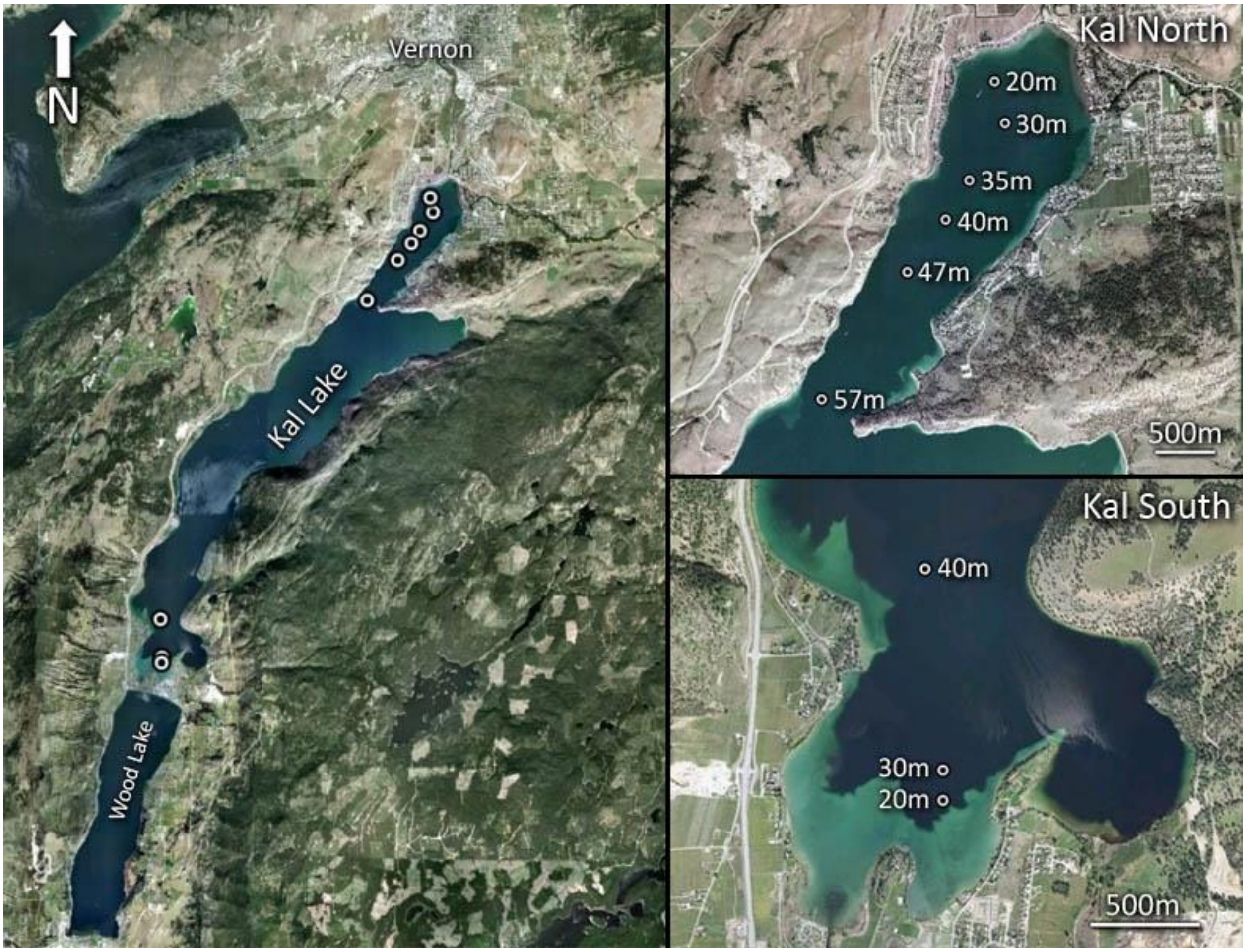


Figure 1.0-1: Location of Kalamalka Lake Sample Sites

Table 1.0-1 List of Kalamalka Lake sample sites in 2014

	North Sites	South Sites
Watershed sites	Coldstream Creek	Wood Lake
Kalamalka Lake sites	0, 20, 30, 35, 40 m	0, 20, 30, 40 m
Intake samples	20m RDNO intake (0.6 m clearance)	20m DLC intake (2.0 m clearance)

All of the depth samples were collected with 3 m clearance from the substrate. Details of sampling methods and procedures can be found in Appendix 2.

Over the years of study, many trends and influences on intake water quality have been identified and clarified. This research has been evaluated and re-directed on an annual basis by the participants. Other groups including BC Ministry of Environment, Agriculture Canada and UBC-O are conducting valuable research within the Kalamalka and Wood Lake watersheds. Their work is referenced in this study.

The purpose of this report is to summarize the findings of the 2014 study and compare them to trends over past years. This report offers recommendations based on the results to date, and suggests a focus for subsequent years.

Figure 1.0-2 Kalamalka Lake North Arm Looking Towards Coldstream

2.0 Results & Discussion

2.1 Contributing Watershed

2.1.1 Coldstream Creek

Spring 2014 was drier than 2013 with only 12.4 cm of rainfall (compared to 20.5 cm in 2013), resulting in a normal freshet. The Coldstream Creek freshet is typically strongest in April and May, and usually tapers off through June as indicated by lower total dissolved solids (TDS) (Figure 2.2-1). The low freshet TDS is a result of snowmelt water contributing the majority of freshet flows and diluting the base flow, which has a higher TDS from groundwater contributions. Similar results were obtained by the Coldstream Creek hydrometric station (08NM142).

TDS and conductivity in the Coldstream Creek freshet flows were far below the ambient levels in Kalamalka Lake and resulted in a buoyant plume entering the lake. This is despite the cold temperature of the creek water (Figures 2.1-2, 2.1-3).

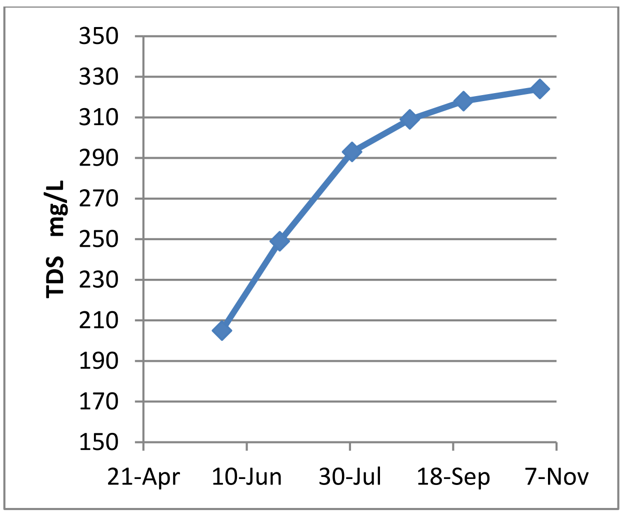


Figure 2.1-1: Total dissolved solids concentrations in Coldstream Creek over the 2014 sample season

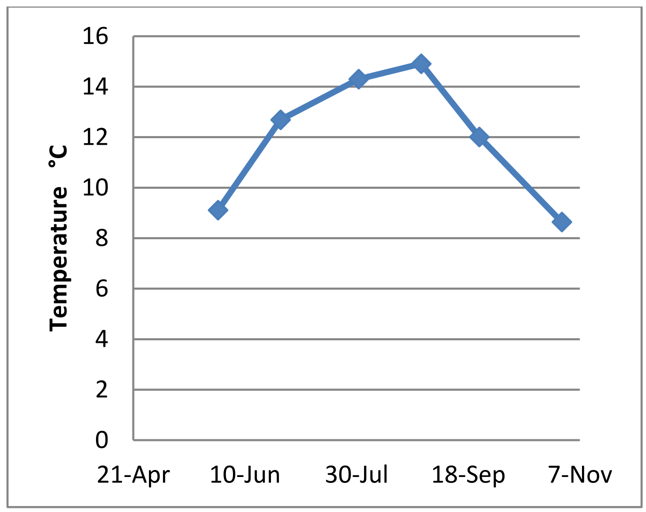


Figure 2.1-2: Coldstream Creek temperature in the 2014 sample season

During the times of the year when the TDS and conductivity were similar to Kalamalka Lake, the creek water sank to the depth in the lake with equal temperature. For example, in August 2014 the temperature of the creek was about 15°C (Figure 2.1-2), a temperature that corresponds to a depth of about 13 m in the lake (Figure 2.1-3).

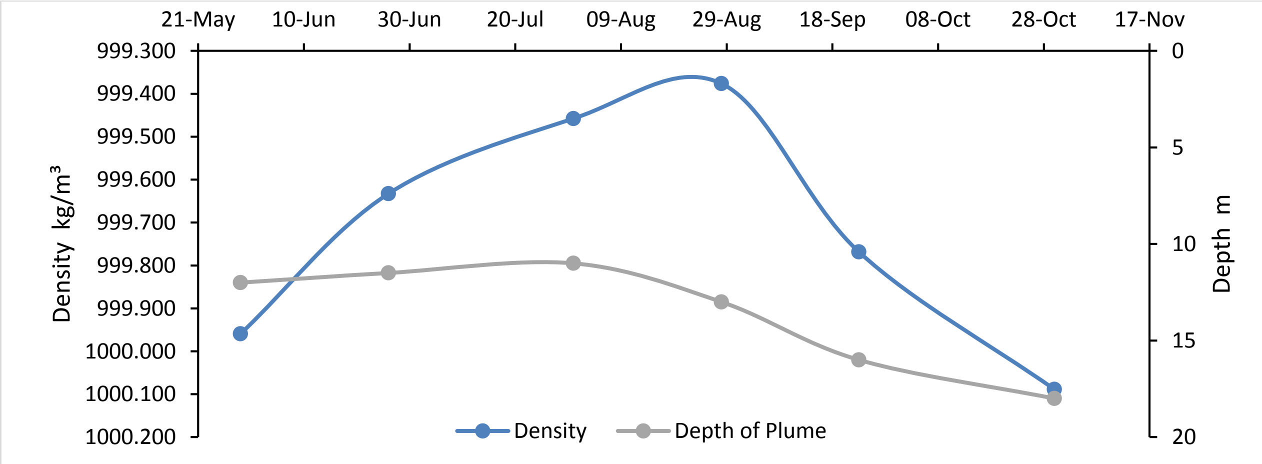
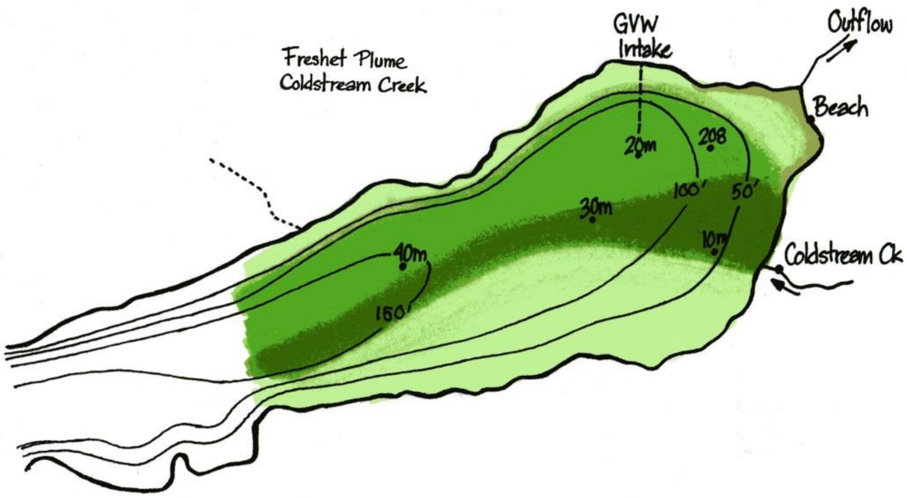


Figure 2.1-3: Density of Coldstream Creek water and the estimated depth that it would sink to in Kalamalka Lake during 2014

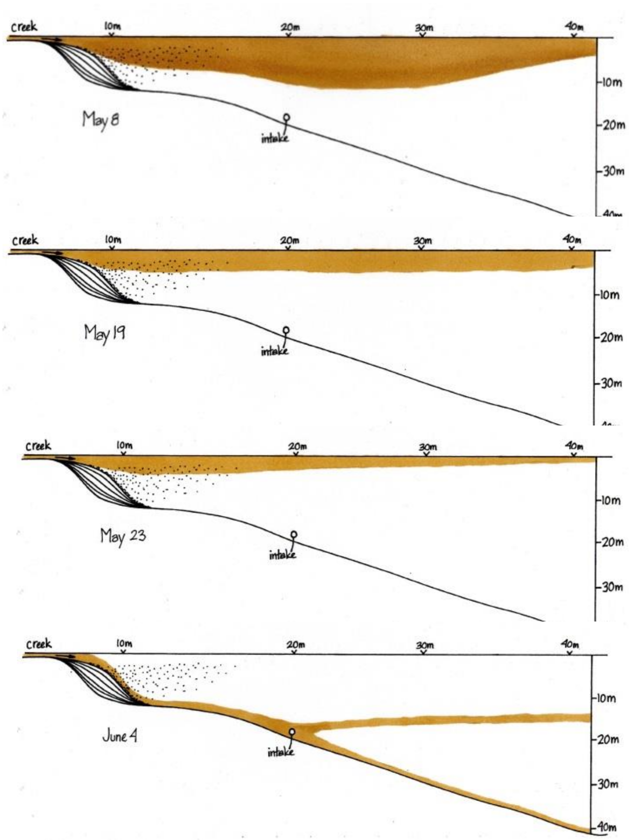
Coldstream Creek plume behaved as follows;

- During early to peak freshet, the plume enters surface water (0-6 m) and flowed across the entire arm, concentrating on the path shown in Figure 2.1-4. At times, it is visible from shore and from the air. This spares the N-Kal intake from high turbidity.
- Deposition of sand and coarse particles occurred near the mouth of Coldstream Creek. Deposition of fines imported by the plume were distributed throughout the North Arm but deposition was greater near the mouth where the plume was most concentrated.
- In recent years, the inflow plume split on a sand bar (encouraged by a large dock at the mouth built in 2005) with the majority of the flow travelling out into the Arm, deflected to the right, swinging towards the public beach and eventually travelling around to the 20 and 30 m sites (Figure 2.1-4).
- After the plume volume reduces and turbidity declines in late freshet, its conductivity increases and it mixes to depths >10-16 m; this may include the intake depth.
- In the summer, the plume frequently splits with part of the flow travelling along the thermocline (creek and thermocline temperatures are often <1°C different) but the majority of the flow from late spring through summer enters the deep water below the thermocline. An intake would have to be more than 3 m above the substrate to evade the freshet flows that travel along the bottom of the North Arm.
- Coldstream Creek density peaks in September during low flows when groundwater makes up a large percentage of the flow, and the plume travels near the thermocline depth.
- By early October, the plume usually travel near the 20 m depth even though its density is dropping because of conditions in Kalamalka Lake.
- The entire creek plume enters the hypolimnion in fall before overturn.

Monitoring of the Coldstream Creek plume in Kalamalka Lake has been discontinued since multiple years of study have provided the information needed to understand its characteristics over a range of freshets. The RDNO worked with MoE and MFLNRO to install the Water Quality Station at Kirkland Drive on Coldstream Creek and it was activated in March 2015. On-line information to the RDNO SCADA will provide real-time data on water quality changes in Coldstream Creek and provide early indicators enabling RDNO to respond in a timely manner at their Kalamalka intake.



Coldstream Creek Plume
diffuse freshet plume
moderate freshet plume
concentrated freshet plume
Storm flow plume and late freshet plume path



This series of illustrations are based on the 2008 freshet but also incorporate information from Coldstream Creek freshet monitoring to date. The most turbid flows are shown; the entire North Arm frequently exceeds 1 NTU throughout the freshet period. Turbidity was also high along the forming thermocline during late freshet, indicating a condition known as interflow where most of the creek plume travels along the bottom of the lake but some is suspended in the water column. During interflow, Coldstream Creek water was colder (9-15°C) and more dense than lake surface water (15-22 °C). The creek inputs sink and become trapped near the thermocline (10-16 m) with more turbid flows along the bottom of Kalamalka Lake.

Figure 2.1-4: Location of Coldstream Creek freshet plume in the North Arm of Kalamalka Lake during a large freshet year

2.1.2 Wood Lake

Wood Lake is the other main source of water entering Kalamalka Lake, accounting for 20% of the average annual inflow. The water quality in Wood Lake has a greater impact on the south end of the lake than on Kalamalka Lake as a whole. Wood Lake's high nutrient status is maintained by internal recycling during the summer and by high nutrient inflows from its watershed, particularly Middle Vernon Creek. During 2013, nutrients were monitored in greater frequency due to a massive decrease in Kokanee stocks in 2012 (M. Sokal. pers. comm). It was found that nutrients in Wood Lake are impacted by Middle Vernon Creek and internal loading. With respect to phosphorous, the internal loading in the summer is much greater than the influx from Middle Vernon Creek. However, it was noted that a reduction in any nutrient loading is important to maintaining a healthy balance within the system (Epp and Neumann, 2014).

Wood Lake is shallower and smaller than Kalamalka Lake, resulting in higher temperatures throughout the water column during the growing season (Figure 2.1-5). For example, peak water temperatures of 26°C occurred in the smaller lake, compared to 24°C in Kalamalka Lake. Normally water temperatures of 22°C extend to the 7 m depth in Wood Lake in mid-summer. Warm surface water favors cyanobacteria growth. Wood Lake thermal stratification had set up by late May and was broken down by late October in 2014.

Unlike Kalamalka Lake (Figure 2.2-1 and 2.2-2), a low dissolved oxygen (DO) zone formed above the Wood Lake sediments during late summer each year (Figure 2.1-5). It was thickest in the deepest zone of the lake, located to the south of the sample site. Overall, the 2014 low DO zone was similar to other recent years in its extent. Nutrients in the sediments are re-dissolved into the low DO zone in response to negative redox. These nutrients fertilize the entire lake after fall overturn. A blue-green algae (cyanobacteria) bloom marks the Wood Lake overturn every year despite cool, dark November/December conditions (refer to algae section). Overturn also coincided with the opening of nutrient-rich Lower Vernon Creek for fish flows, providing an additional late season nutrient source.

High productivity in Wood Lake exerts a strong influence on pH. Consistent with other years, the pH profile for the 2014 growing season shows that pH was elevated by photosynthesis to 8.6 – 8.9 in the surface water, and was depressed by decomposition to 7.0 – 7.6 in the bottom water (Appendix 1,3). In the past, surface pH exceeded 9 during algae blooms. Winter pH would be intermediate throughout the water column, but was not measured in this study.

pH showed an oscillating trend over the years of study (Figure 2.1-6). Water hardness increased from 2005-2012 and since hardness measures mainly calcium carbonate, the increased hardness increased the likelihood of marl events (Mann-Kendall, $p=0.003$) and they influence pH. Since 2012, hardness in Wood Lake has declined.

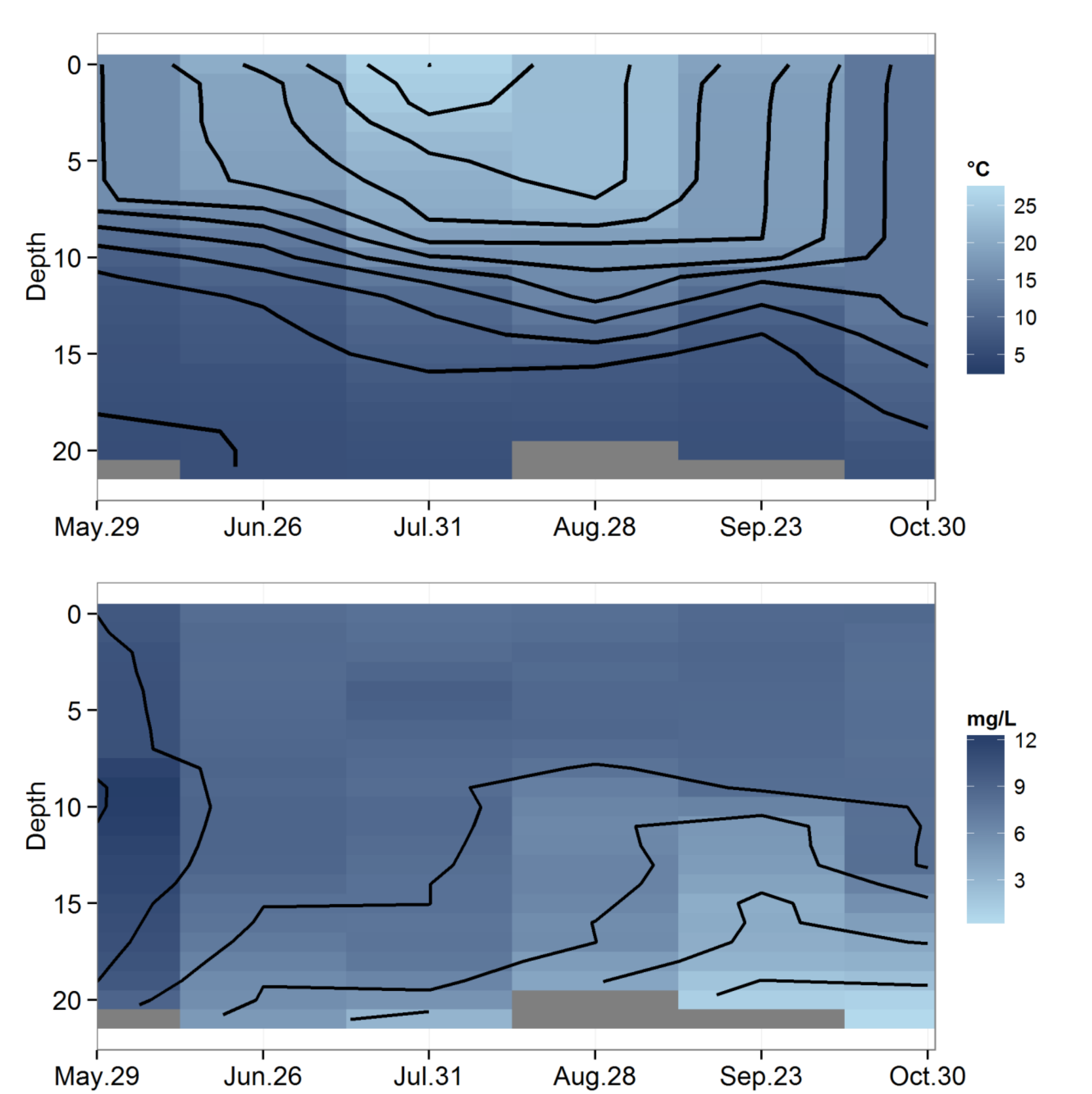


Figure 2.1-5: Temperature and dissolved oxygen profiles for Wood Lake in 2014

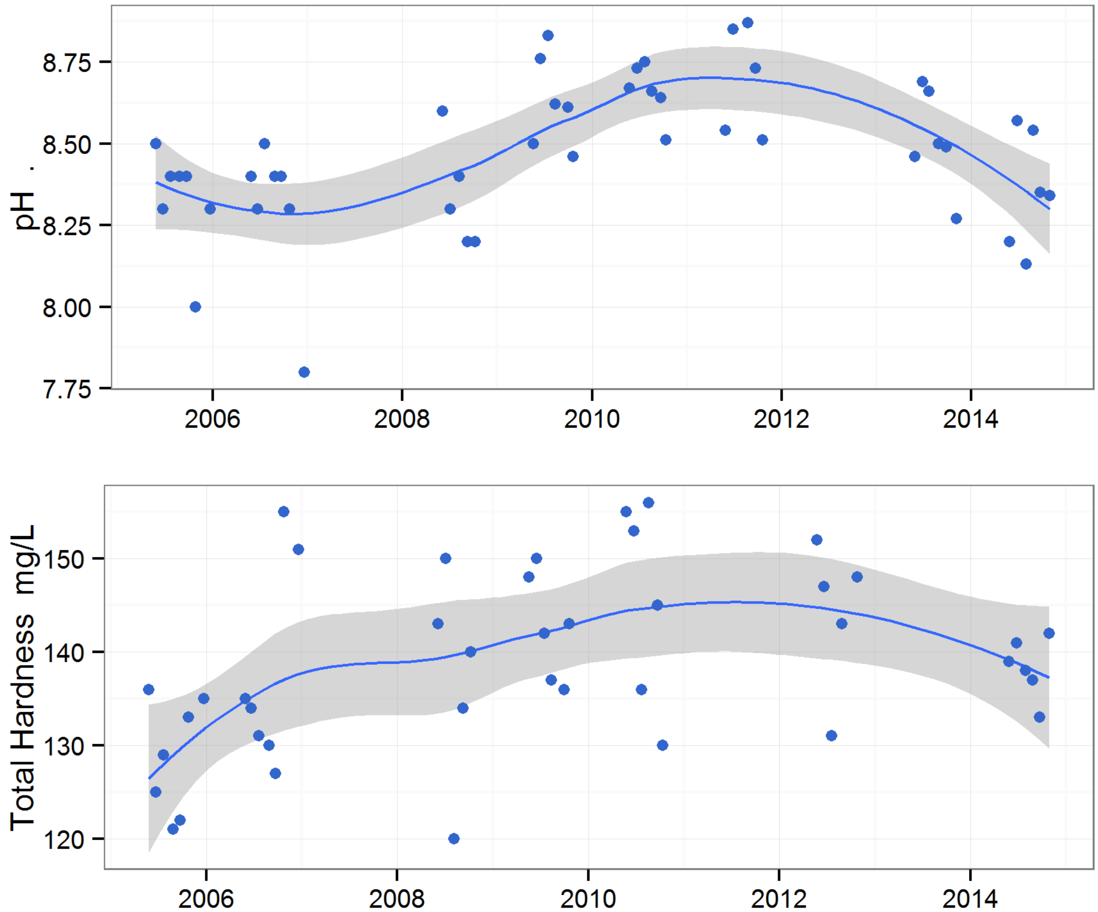


Figure 2.1-6: Wood Lake surface pH and hardness trends from 2005 - 2014

Chloride and sodium concentrations in Wood Lake both showed increasing trend to 2010, with decreasing trends thereafter (Figure 2.1-7). Since the main sources of salt include road salt and treated sewage, the decline in concentration suggests reduced anthropogenic impacts. The ratio of sodium to chloride has varied from 1.1 to 1.7 from 2005 to 2014.

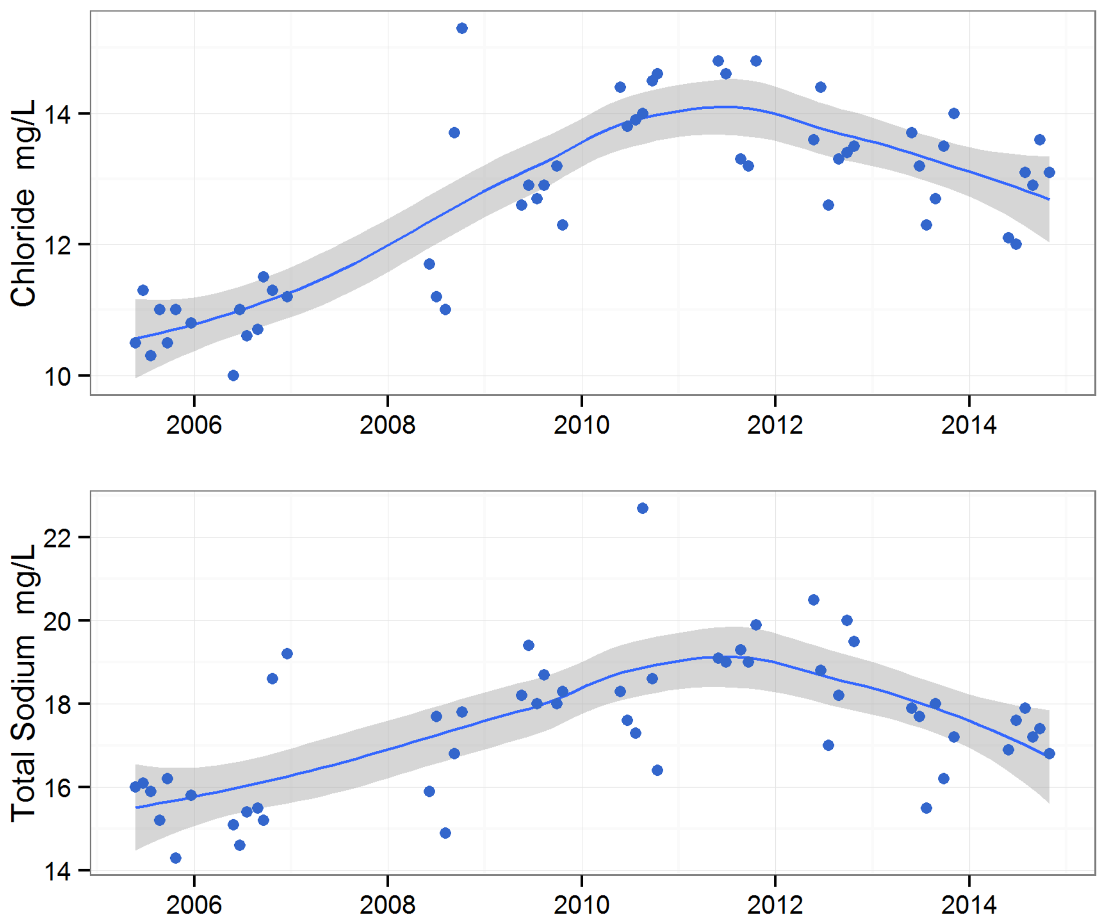


Figure 2.1-7: Chloride and sodium trends in Wood Lake surface water from 2005 - 2014

Wood Lake is a donor of nutrients to Kalamalka Lake every year. Both total nitrogen and TKN (organic N + ammonia) show a significant declining trend from 1970 to the early 1990`s (Mann-Kendall, $p<0.03$), with a smaller increase after that to exceed 0.60 mg/L T-N in the deep water during 2014 (Mann-Kendall, $p \leq 0.05$; Figure 2.1-8). During 2014, Wood Lake's 1-5-10m total nitrogen ranged from 0.347 to 0.424 mg/L T-N, about double the Kalamalka Lake values. In most years, dissolved nitrogen is rapidly absorbed by algae in Wood Lake, resulting in nitrate concentrations that were usually lower than those of Kalamalka Lake during the summer months, however, in the entire 1970 - 2014 data set, NO_2 + NO_3 averaged 0.100 ± 0.097 mg/L in Wood Lake and 0.068 ± 0.045 mg/L in the south end of Kalamalka Lake. During fall sampling when the anaerobic zone is well-established, the surface water measured 0.365 mg/L T-N, while the anaerobic zone measured a much higher 0.675 mg/L T-N caused by nitrogen release from anaerobic sediments (September 2014). While nitrogen concentrations were far below the level of concern for drinking water, these annual shifts in the N:P ratio of Wood Lake affect its algae production.

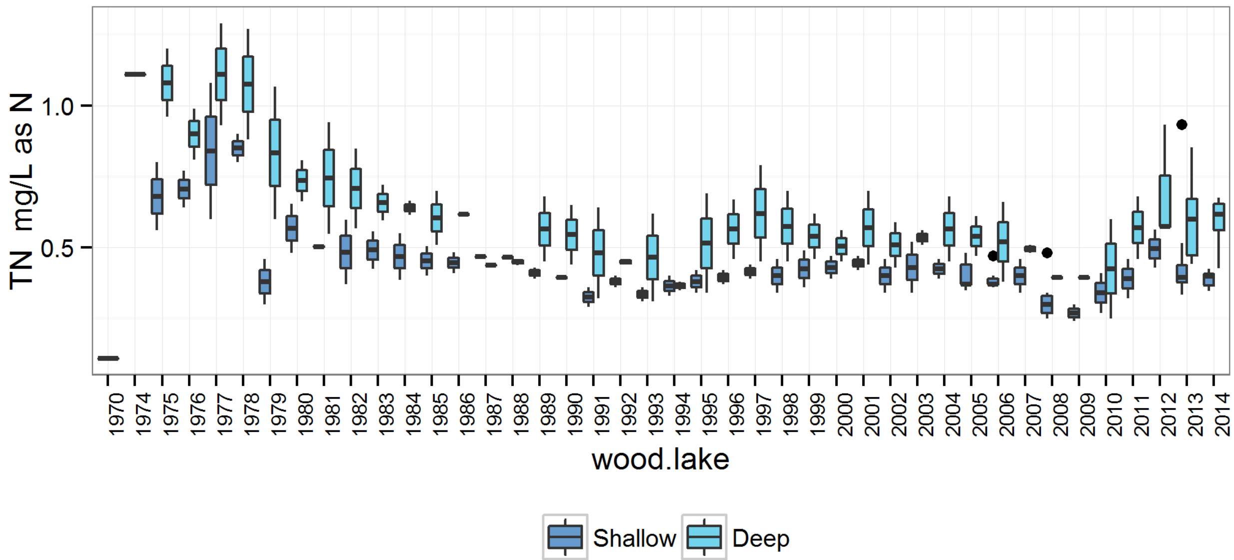


Figure 2.1-8: Total nitrogen in Wood Lake from 1970 - 2014
(deep =20-25-30 m composite and shallow = 1-5-10 m composite collected by MoE)

Wood Lake phosphorus concentrations improved during the early 1990's to 2008 compared to the 1970s and 1980s (prior to the Lake Country sewer system) (Figure 2.1-9). Unfortunately, from 1990 to 2014, dissolved phosphorus concentrations increased in the deep water of Wood Lake and averaged 0.088 ± 0.053 mg/L TDP in 2014 (Mann-Kendall, p=0.014). This trend did not carry over to total phosphorus. While averages are currently below the peak values (>0.10 mg/L T-P) seen between 1970 - 1984, they are still far above the proposed 0.020 mg/L guideline to prevent cyanobacteria blooms (IHA, pers comm), and the MoE Objective of 0.015 mg/L T-P (Figure 2.1-9). Phosphorus loading to mainstem Okanagan lakes may be affected by precipitation patterns, with wetter years having greater phosphorus inputs than drier years. Further, there may be an influence of the duration of ice cover, where the longer the period between ice-on and ice-off permit greater winter anaerobic conditions in the bottom water and greater nutrient release.

Wood Lake was classified as eutrophic in the 1980s (Nordin et al, 1988) and would be classified as meso-eutrophic based on 2014 nutrient concentrations (Figure 2.1-9). T-P ranged from a minimum of 0.008 mg/L at the surface to a very high 0.171 mg/L T-P in the anaerobic (low DO) zone during fall 2014. Phosphorus is released from the sediments to overlying anaerobic water, and this internal loading maintains the high productivity of Wood Lake.

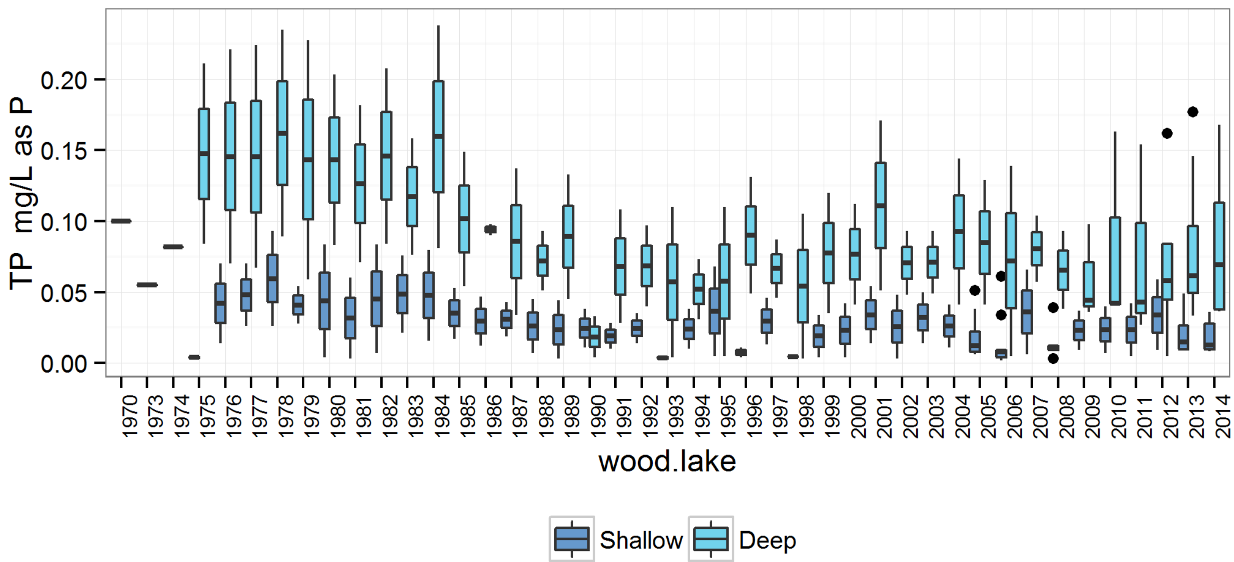


Figure 2.1-9: Total phosphorus in Wood Lake, 2014
(deep =20-25-30 m composite and shallow = 1-5-10 m composite collected by MoE)

Secchi depths in Wood Lake are affected by the nutrient-driven algae production and by marl precipitation. They were much better (deeper) in recent years than the historic measurements, suggesting a slow-down in production despite increased T-P concentrations (Table 2.1-1).

Table 2.1-1: Average summer secchi depths in Wood Lake

Summer secchi depth (m)	Comments on productivity and weather
2 – 2.5 m August, 1939	hot, dry weather
<2 m summer, 1970 – 73	Hiram-Walker pumping 1971-1992
7.7 m summer, 2007	low productivity summer
4.5 m summer, 2008	high productivity summer
4.9 m summer, 2009	high productivity, hot summer
4.5 m summer, 2010	moderate productivity + marl summer
4.1 m summer, 2011	moderate productivity + marl summer
7.7 m summer, 2012	low productivity summer, fall cyanobacteria bloom
5.6 m summer, 2013	high productivity, windy summer
5.0 m summer, 2014	moderate productivity, summer cyanobacteria bloom + marl

Occasionally Wood Lake experiences a late summer marl precipitation, as in 2010, 2011 and 2014 (Figure 2.1-10). The marl precipitation events coincided with increased calcium concentrations (Larratt et al, 2013). Marl events have a significant effect on lake productivity. Cyanobacteria numbers drop dramatically because the marl stripped phosphorus and small algae cells from the water column. The late August/early September 2014 marl event induced a decrease of 0.028 mg/L T-P (132%) in the epilimnetic total phosphorous readings between the spring peak and the September low, similar to what has happened in past marl years.

Figure 2.1-10: Marl precipitation in Wood Lake, 2014

Peak chlorophyll-a readings in Wood Lake often follow spring circulation (4 µg/L chl-a in 2014), and again in late fall following the lake overturn (3 µg/L chl-a in 2014). For example, 2009 had strong March to May cyanobacteria blooms with a measured peak chlorophyll-a of 15.3 µg/L. In 2011 and a spring bloom occurred, measuring 7 µg/L chl-a in June. Unlike other years when Wood Lake production was more than double that of Kalamalka Lake, during 2014 it was closer to that of Kalamalka Lake at 1.8 ± 1.3 µg/L chl-a compared to 1.3 ± 1.0 µg/L in S-Kal and 1.1 ± 0.7 µg/L in N-Kal samples (Table 2.2-10).

With its shallow bathymetry, Wood Lake has more water column interaction with its nutrient-rich sediments than Kalamalka Lake does, making Wood Lake consistently more productive than Kalamalka Lake. Overall, excess algae production in Wood Lake has declined since the 1970s. While lower algae production helps water purveyors, it may also slow down the prized Wood Lake kokanee fishery. Wood Lake has a weaker, sporadic marl precipitation and therefore does not have the reliable summer lull in algae production that Kalamalka Lake has. Total organic carbon in Wood Lake averaged 8.5 ± 1.8 mg/L during 2014 and 8.3 ± 2.5 mg/L from 2005-2014, over double the 4.0 mg/L B.C.WQ criteria (Table 2.2-11).

Wood Lake algae density and diversity exceeded that of Kalamalka Lake on most sample dates. It can be affected by cyanobacteria blooms on Ellison (Duck) Lake. Wood Lake did not experience a cyanobacteria bloom in September or October 2014 (Appendix 3). However, unlike 2011, no large cyanobacteria blooms were detected by algae counts, chl-a or, dissolved oxygen profiles from Wood Lake in 2012 through 2014 (Figure 2.1-5).

Cyanobacteria cells can accumulate to dangerous levels near the Oyama Canal after the Wood Lake overturn based on a chlorophyll-a of 35 µg/L-2006, 10 µg/L-2007 and 12.5 ug/L-2011. A dangerous accumulation was not detected in 2014. For reference, a cyanobacteria bloom with >50 µg/L chlorophyll-a will have a cell count approaching 100,000 cells/mL and toxicity would be probable. Cyanobacteria common to Wood Lake include *Anabaena, Anacystis, and Aphanizomenon* and they can produce a range of undesirable cyanotoxins (Appendix 6). The other common cyanobacteria species is *Gomphosphaeria* and it is not noted for toxicity. Risk of cyanobacterial toxicity in Wood Lake is therefore dependent upon species present and density. Wood Lake cyanobacterial species involved in the annual blooms vary by year and by season in response to factors including nutrient balances, weather and zooplankton grazing. They are listed from highest density to lowest density in Table 2.1-2.

Table 2.1-2: Variations in Wood Lake algae blooms by year and season

Year	Season	Cyanobacteria bloom
2007	Spring	Anacystis Gomphosphaeria
	Summer	Anacystis
	Fall	Anabaena Aphanizomenon
	Early winter	Aphanizomenon
2008	Spring	Gomphosphaeria Anacystis
	Summer	Anacystis
	Fall	Anabaena Anacystis Aphanizomenon
	Early winter	Aphanizomenon
2009	Spring	Anacystis Aphanizomenon
	Summer	Anacystis
	Fall	Anacystis Gomphosphaeria
	Early winter	Aphanizomenon Gomphosphaeria
2010	Spring	Anacystis (light)
	Summer	Anacystis (moderate)
	Fall	None – Wood Lake marled
	Early winter	None – Wood Lake marled
2011	Spring	Aphanizomenon Anabaena (light)
	Summer	Aphanizomenon (moderate)
	Fall	None – Wood Lake marled
	Early winter	None – Wood Lake marled
2012	Spring	Dinobryon spp. (chrysophyte)
	Summer	Tabellaria (diatom)
	Fall	Aphanizomenon
	Early winter	Aphanizomenon
2013	Spring	*Anacystis cyanea, Lyngbya (*large species)
	Summer	*Anacystis circinalis, Aphanizomenon elachista*
	Fall	*Lyngbya lrg sp*, *Aphanizomenon flos-aquae*
	Early winter	*Anacystis cyanea, Aphanizomenon elachista Lyngbya lrg sp*
2014	Spring	*Anacystis cyanea*
	Summer	*Anacystis cyanea, Aphanizomenon, Anabaena circinalis*
	Fall	*Anacystis cyanea, Gomphosphaeria lacustris*

Years with algae blooms in Wood Lake have apparently increased algae densities in South Kalamalka Lake, with donations of cyanobacteria being of greatest concern. A mild bloom of *Anacystis cyanea* occurred in spring 2014, but did not measurably affect South Kalamalka Lake counts. With the absence of a large bloom, the influence of the Wood Lake cyanobacteria on Kalamalka Lake was therefore minimal in 2014.

2.2 Kalamalka Lake

2.2.1 Thermal Structure

The thermal structure of Kalamalka Lake is typical for a large temperate lake. It is a warm monomictic lake, where the entire water column mixes from the fall to the spring, but is thermally stratified from May to early November every year. A thermocline defines the boundary between the warm surface layer and the deep cooler layer in the summer. Wind storms tip the water layers and deflect the thermocline in a process called seiching. Thermal stratification influences water chemistry and the water quality withdrawn by Kalamalka Lake intakes. A detailed discussion of thermal structure can be found in Appendix 4.

In 2012 and 2013, thermal stratification did not set up in Kalamalka Lake until June because of cool spring weather but hot weather in May 2014 warmed the lake more quickly and a thermocline was present at 6 m by the end of May (Figures 2.2-1 and 2.2-2). The epilimnion temperatures exceeded 22°C between the end of July and September at both ends of the lake in 2014. Normally, only 2-3 m depth exceeds 22°C in Kalamalka Lake. During mid-summer 2014 however, >22°C water extended to 8-9 m in north end of Kalamalka Lake. For reference, the maximum recommended temperature for water in a distribution system is 15°C.

Table 2.2-1 presents the thermocline positions in Kalamalka Lake measured in field meter profiles taken during sample trips. In general, the thermocline remained above 20 m during the summer months, meaning surface water was not collected by the intakes at either end of the lake on those dates. Tipping of the water layers by seiches is particularly evident in the difference in the north to south May and June data, reflecting windy weather in those months (Table 2.2-1; Figures 2.2-1, 2.2-2). The thermocline often deflects further in the north, caused by the shape of the North Arm and the turbulence it induces. However, large seiches are more frequent at the south end because it is not confined in an arm. Over the years of study, both intakes have withdrawn surface water during seiches, particularly in the spring and fall. The main transport mechanism of surface contaminants to the Kalamalka Lake intakes is seiches in the stratified May to October period.

Table 2.2-1: Thermocline position in Kalamalka Lake 2014

Thermocline Position (m)	N 20m	N 30m	N 35m	N 40m	S 20m	S 30m	S 40m	N Typical	S Typical
May 31	6	6	7	7	5	6	6	6 - 7	5 - 11
June 26	12	10	10	10	9	9	10	8 - 12	9 - 17
July 31	10	11	11	11	12	11	12	6 - 11	10 - 14
August 28	11	10	9	10	7	7	7	9 - 12	7 - 12
September 23	14	14	13	14	12	12	12	13 - 14	12 - 14
October 30	18	15	13	18	22	20	20	13 - 22	17 - 25

Note: Typical values based on 2012-2014 data

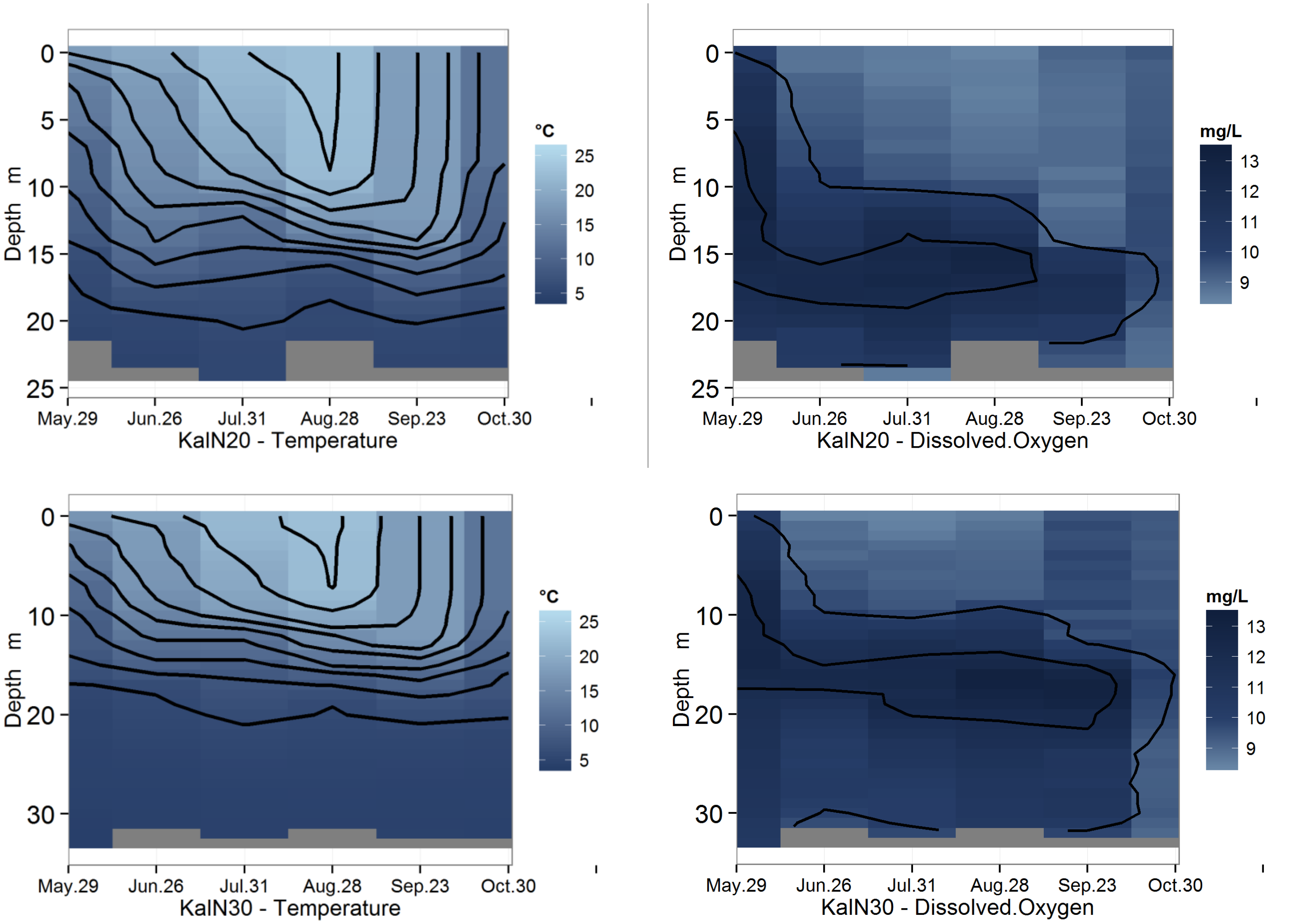


Figure 2.2-1: North Kalamalka Lake Intake site temperature and dissolved oxygen profiles in 2014 - 20 and 30 m sites

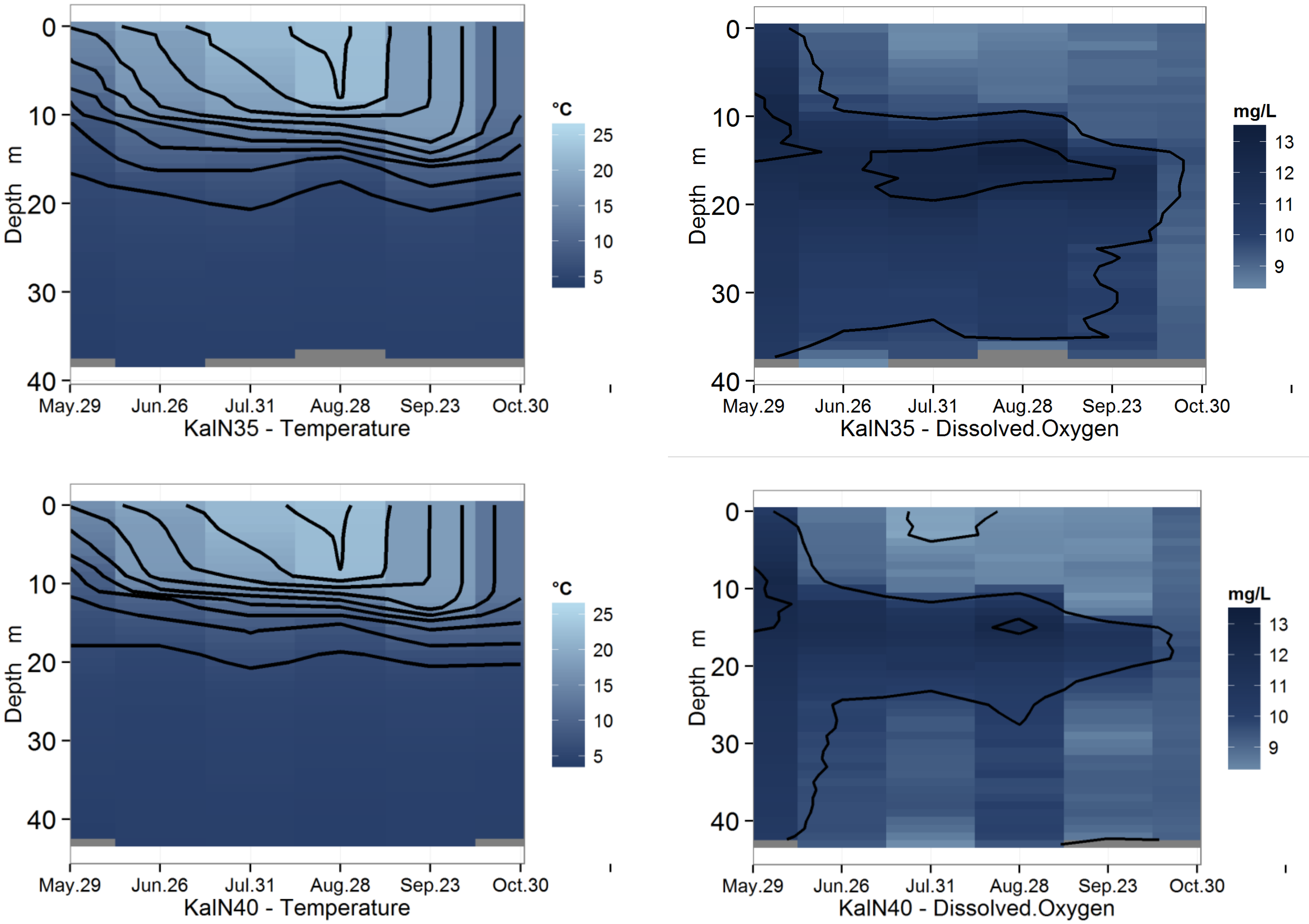


Figure 2.2-1 continued: North Kalamalka Lake Intake site temperature and dissolved oxygen profiles in 2014 - 35 and 40 m sites

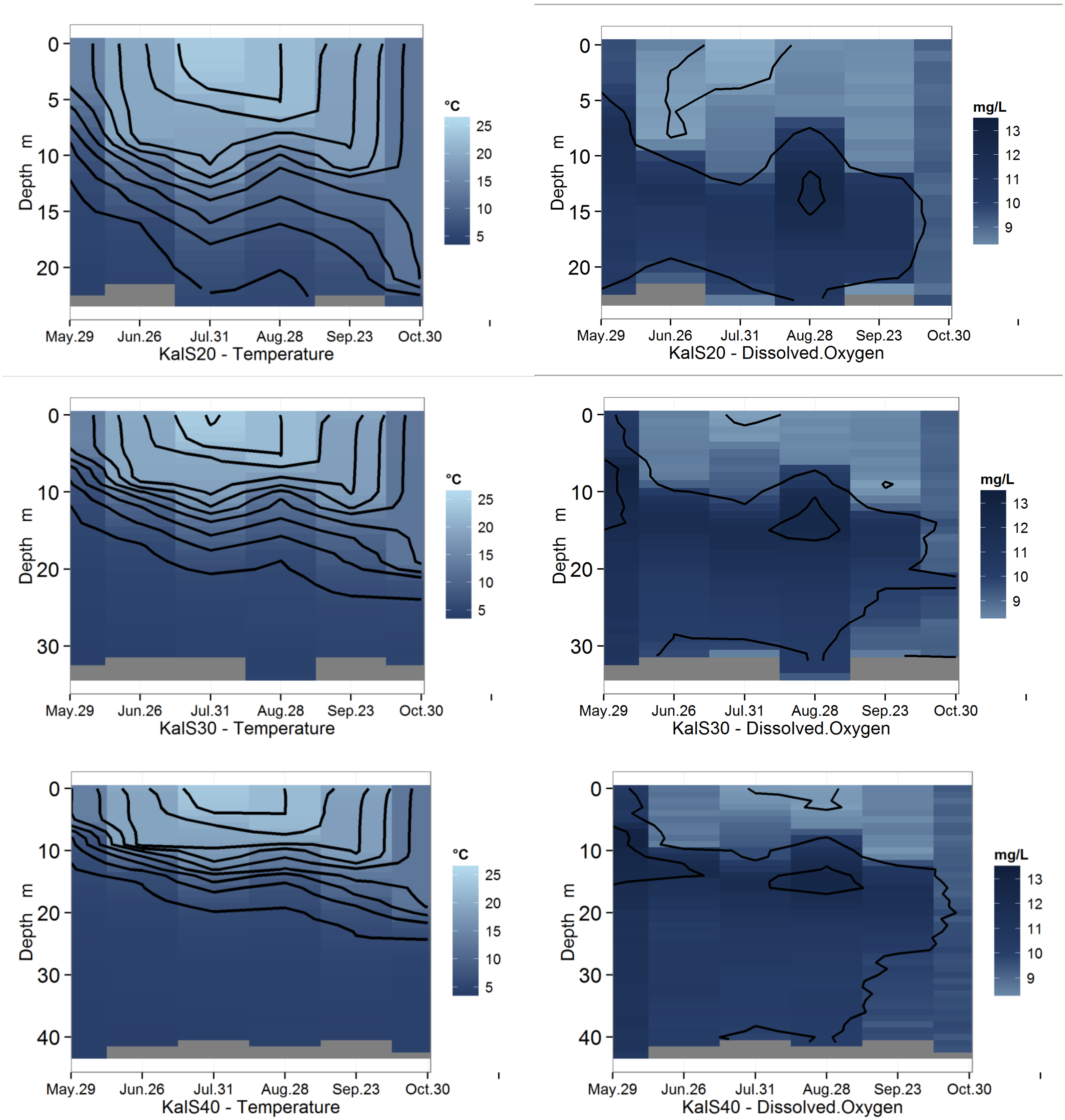


Figure 2.2-2: 2014 South Kalamalka temperature and dissolved oxygen profiles

North or south-west winds with gusts exceeding 30 km/h can generate a seiche, depending on the duration of the wind event. The bigger the storm, the bigger the seiche and the further down into the water column surface water travels. A typical period for a seiche to travel between the north and south ends (12.1 km) averaged 8-10 hours. The full length of Kalamalka Lake is 15.4 km and since seiches slowed down in the narrow North Arm, the actual seiche period on Kalamalka Lake was approximately 11.7 x 2 = 23.5 hours. In other words, it takes about a day for a seiche to travel to the opposite end of Kalamalka Lake and back again.

Large summer seiches are common in Kalamalka Lake. Each year, 7 - 12 major seiches were detected by the N-Kal and S-Kal thermistor chains (now decommissioned) (Figure 2.2-3). Seiche activity was greatest in the early summer as the water layers set up and again in the early fall as the surface layer cooled and lost buoyancy. Seiches that penetrated to 40 m were less severe and fewer than the ones that penetrated to 20 m.

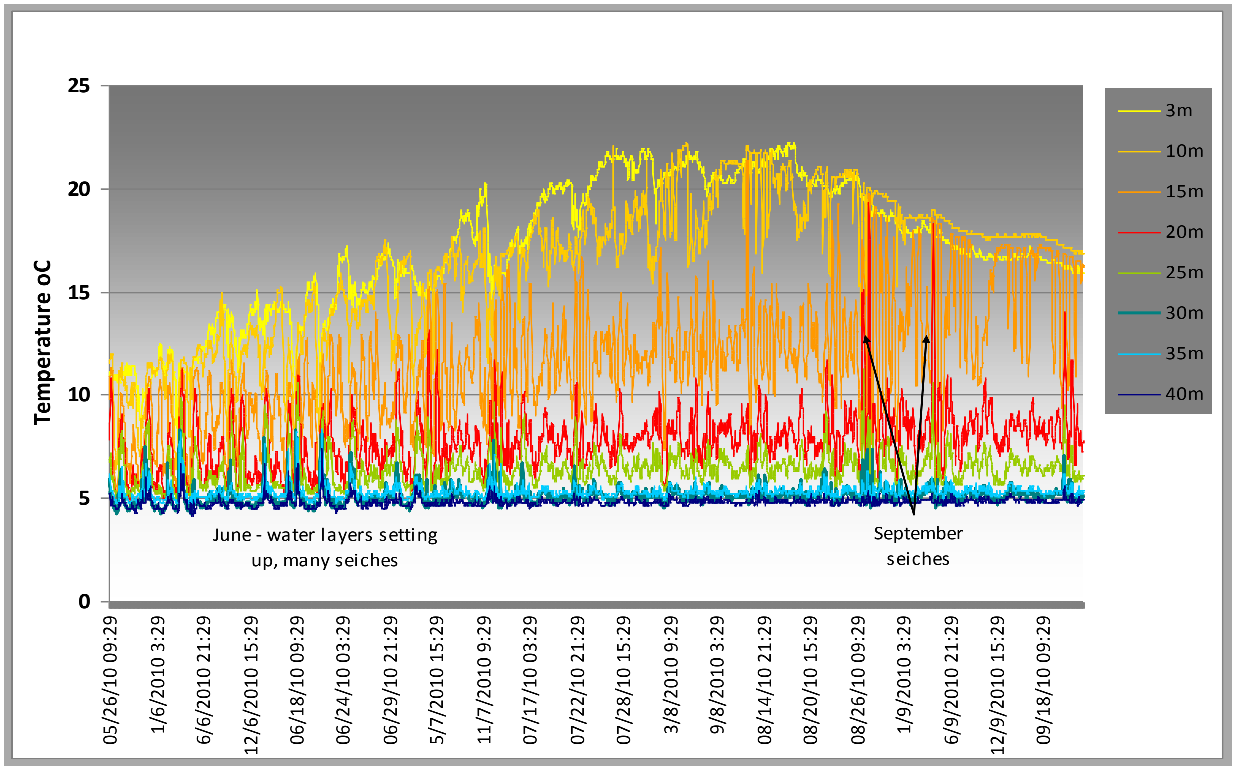


Figure 2.2-3: Example of South Kalamalka June – September thermistor data showing frequent seiches in the spring and fall

For the Kalamalka Lake water purveyors, seiches cause increased water temperature with a turbidity spike as surface water is transported down to intakes for a period of 2-10 hours before the oscillating thermocline rises again, returning the bottom water layer to the intake depth. The difference in the turbidity of the surface and deep water alone does not account for the turbidity spike (averaged 0.9 ± 0.3 NTU at 0 m and 1.0 ± 0.5 NTU at 20 m in 2014). Turbulence associated with the seiche can re-suspend fine material from the sediments.

The depth and location of an intake influences its susceptibility to seiches. The North Arm dampens seiches so that an intake positioned at 30 m would be much less impacted by seiches than the existing intake at 20 m, even though the distance between the two sites is only 365 m.

Temperature fluctuations at 30 and 40 m are very consistent from year to year, with less than 0.5 °C separating the seiche measurements over five years. In the most extreme seiche recorded to date, N-Kal intake water temperature rose from 7.2 to 22.2 °C for five hours on July 29-30 2002.

At the south end of Kalamalka Lake, seiches penetrate deeper into the water column because of the shape of the southern lake basin. Water temperature changes of 5-8°C within 48 hours are routine at the current Lake Country 20 m intake (Appendix 4). The compiled S-Kal thermistor data shows a marked seiche impact on the 30 m site in every growing season. To date, temperature deviations during seiches at the South 30 m site ranged from 4°C in a cool summer to 7°C in a warm fall with more intense seiches. Seiche temperature deviations were more intense in the fall than in the spring at the south end. For example, the maximum temperature deviation averaged 3.2°C at 30 m and 3.0°C at 40 m in the spring and 2.3°C at 30 m and 1.0 °C at 40 m in the fall (2010 report).

2.2.2 Kalamalka Lake Dissolved Oxygen

Every summer, dissolved oxygen (DO) concentrations were near saturation throughout the Kalamalka Lake water column. As in most years, summer 2014 profiles showed zones of oxygen super-saturation from May to September that reached to 20 m and raised DO to >12 mg/L because of microflora photosynthesis in the mid water column (Figures 2.2-1, 2.2-2). DO concentrations remained very high, often greater than 11 mg/L throughout the water column during the spring diatom bloom. Patterns of oxygen super-saturation vary from year to year, and in 2014, both ends of the lake showed high DO until mid-summer, and concluded with the marl precipitation.

Surface DO concentrations declined over the 2014 summer as they do every year, as a function of water temperature (Figures 2.2-1 2.2-2). Minimum dissolved oxygen concentrations occurred in a very narrow band (0.1 – 0.4 m) near the sediments and within the top 2-3 m of the water column. The lowest DO levels occurred at 0 m at the S-20 m 7.52 mg/L during July 2014. Although DO in the North Arm dropped to 3.58 - 4.33 mg/L during 2012, the lowest bottom readings were 8.2 mg/L DO during 2014. Anoxic conditions (<1 mg/L DO) have not occurred at any of the Kalamalka sample sites in 15 years of study. These results are consistent with the sediment trap and sediment sample data collected over the course of this study. The oxygen demand of the Kalamalka Lake sediments never depleted the hypolimnion as happens each year in Wood Lake.

2.2.3 General Water Quality & Nutrients

For 15 years, monthly water quality samples were collected during the growing season – the period with the highest frequency of water quality fluctuations. Every year, the single greatest impact on water quality in Kalamalka Lake is the size of the freshet, affecting nitrogen, phosphorus, pH, calcium, sulphate and organic/inorganic particulate inputs.

pH The pH in Kalamalka Lake is maintained in the narrow range of 7.6 – 8.8 by its alkalinity. Since both ends of the lake show matching trends, whole-lake influences are indicated (Figure 2.2-4). Of the 451 measurements collected by MoE from 1970 to 2010, less than 5% were below 8.0 and less than 7% were greater than 8.5 (Sokal, 2010). pH slowly declined from 1970 to 1988, but the observed decline in the MoE data may be weather-related and not significant over a longer time scale. In the data collected in this study since 2000, pH has oscillated without a trend. Similar to other years, surface pH averaged 8.2 ± 0.2 in the South and 8.2 ± 0.3 in the North Arm, while Wood Lake averaged 8.4 ± 0.2 in 2014. During 2009 to 2014, pH ranged from 8.08 to 8.7– a higher range than in the preceding six years (Figure 2.2-4). These were wet, high algae production years and increased photosynthesis apparently raised the pH of Kalamalka Lake.

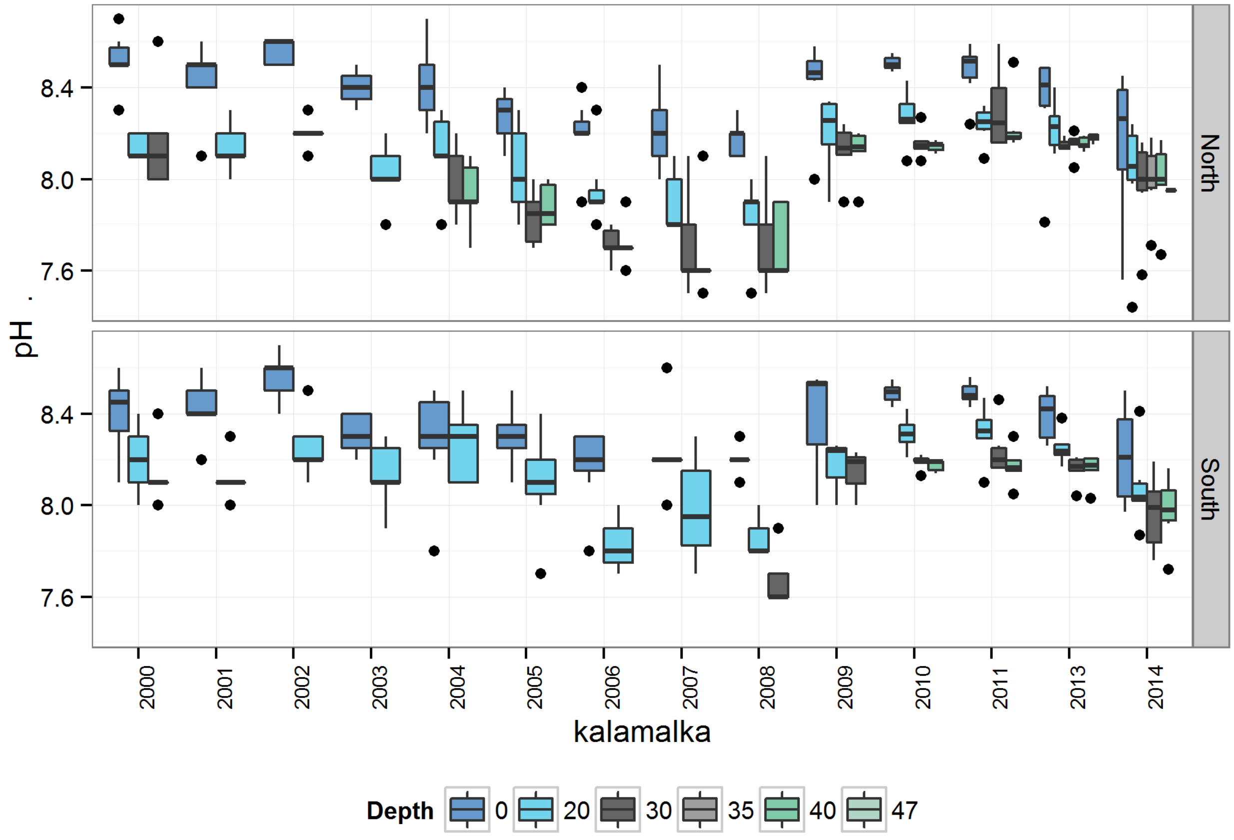
Table 2.2-2: Growing season pH in Kalamalka Lake, 2014 (lab chemistry data)

pH	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	7.86	8.2	8.23	8.07	8.02	8.01	8.01	8.5	8.02	7.79	7.92
Jun-26	8.25	8.57	8.45	8.24	8.15	8.13	8.14	7.97	8.05	8.08	8.09
Jul-31	8.25	8.54	8.3	8.04	7.98	7.95	7.99	8.15	8.02	7.98	7.97
Aug-28*	8.01	8.13	7.56	7.44	7.58	7.71	7.67	8.00	7.87	7.76	7.72
Sep-23	8.20	8.35	7.98	7.98	7.94	7.99	7.97	8.27	8.11	8.00	7.99
Oct-30	8.34	8.34	8.42	8.23	8.16	8.18	8.17	8.41	8.41	8.19	8.16
Average	8.15	8.36	8.16	8.00	7.97	8.00	7.99	8.22	8.08	7.97	7.98
StdDev	0.18	0.18	0.34	0.29	0.21	0.16	0.18	0.22	0.18	0.17	0.15

**Apparent pH drop on Aug 28 likely related to lab results. pH from DLC and RDNO did not demonstrate this drop.*

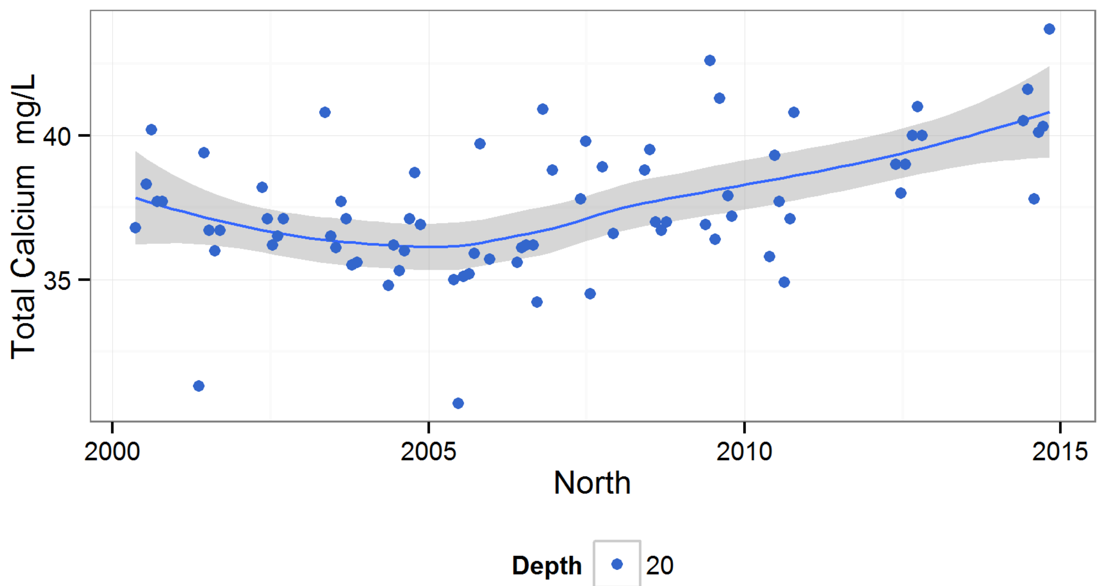
pH was fairly stable throughout much of 2014 except for a drop in pH in the August 28 samples at all sites - its cause is unclear. In most summer samples, pH was the lowest in deep samples because decomposition (lowers pH) increases with depth (Figure 2.2-4). The summer months with stable stratification, June through September, showed the highest surface water pH and lowest deep water pH. Average pH at 30 and 40 m in the North Arm was virtually identical every year (Table 2.2-2). It appears that pH oscillates on a decadal scale in Kalamalka Lake and there were no statistically significant trends in pH from 2000-2014 at either intake site (N-20m and S-20m).

Figure 2.2-4: pH for Kalamalka Lake, 2000-2014



Parameters that Affect Marl Precipitation

Hardness, alkalinity, calcium, magnesium and sulphate all contribute to the marl phenomenon in Kalamalka and Wood lakes. These parameters all increased significantly from 2000-2014 at all Kalamalka Lake sites (Mann-Kendall, $p \leq 0.05$), and does not match declining hardness in Wood Lake in recent years. These parameters will continue to be analyzed on a bi-annual schedule, with the next scheduled sampling in 2016.



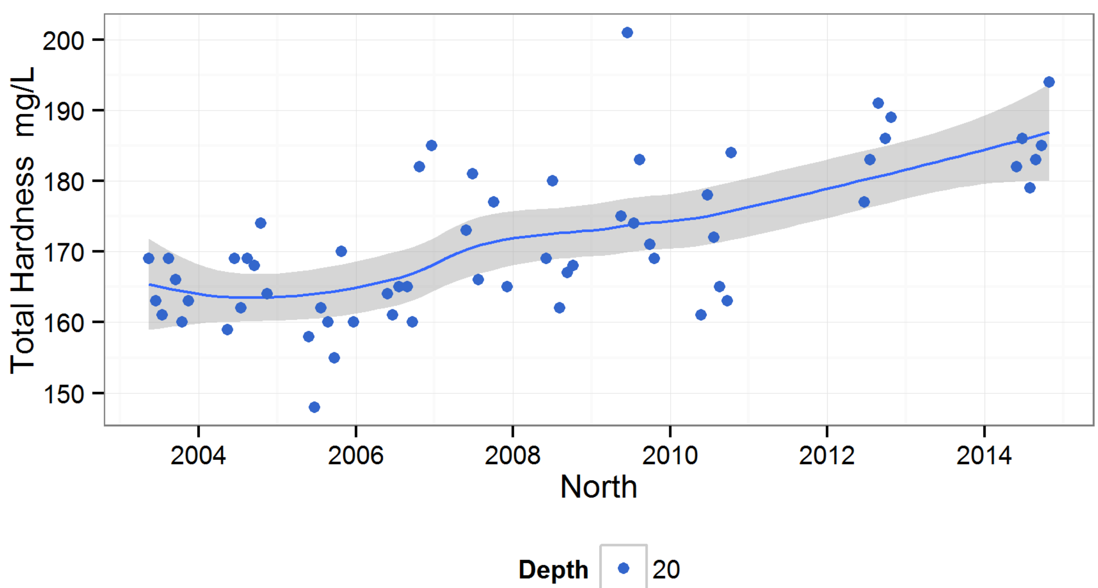


Figure 2.2-5: Total calcium and hardness at North intake site in Kalamalka Lake, 2000-2014

Because Kalamalka Lake is a marl lake, hardness and alkalinity are both high. When calcium concentrations exceed 30 mg/L in lakes and other conditions allow, calcite (calcium carbonate) and gypsum (calcium sulphate) can precipitate and form what is collectively known as marl (Wetzel, 2000). Total calcium concentrations ranged from 36 – 44 mg/L in Kalamalka Lake and 28 – 32 mg/L in Wood Lake during 2014 (Table 2.2-3). Temperature, pH and phytoplankton also factor into the formation of marl. Each year, the marl process is initiated in mid-summer by phytoplankton photosynthesis because it shifts the inorganic carbon balance and results in higher pH.

Every summer, a spike in deep water turbidity, alkalinity, conductivity and calcium concentrations and increased surface water clarity signal the marl precipitation. The marl event commences abruptly, with the dates ranging from July 20 to August 6, and it tapers off into October. The marl precipitation was also followed by a marked decline in surface algae density (Figure 2.2-6). Precipitated marl drops slowly through the water column to create a turbid layer near the sediments. Marl settling usually increases turbidity at the intakes in late summer.

Like most years, the marl effect on the intakes in 2014 was greatest in August. At the RDNO Kalamalka Lake intake, turbidity reached 2.19 NTU during the week of August 25th and returned to 2.13 NTU in the week of September 18th in 2014. The maximum grab-sample turbidity measurement occurred on August 28 when the turbidity was 1.5 NTU at the surface (Table 2.2-13; Figure 2.2-19).

Sulfate concentrations in south Kalamalka Lake were more than double the concentrations in Wood Lake during 2014 through groundwater contributions and Coldstream Creek inflows (Table 2.2-4). High sulphate concentrations contribute to the formation of calcium sulphate, a component of marl.

South Kalamalka 40m samples during 2013 and 2014 did not contain the elevated Ca and SO_4 found in 2012 samples. Groundwater may enter the lake near the S-40m site, but at this point, the results are inconclusive (Tables 2.2-3, 2.2-4).

Average alkalinity and calcium concentrations in Coldstream Creek were higher and more variable than Kalamalka Lake or Wood Lake (Table 2.2-3). Freshet contributes to this variability by diluting the mineral-rich groundwater base flows with surface water from melting snow and overland flow. Wood Lake had lower calcium concentrations than Kalamalka Lake, explaining why its marl events are less frequent than the annual marl event in Kalamalka Lake.

The fall increase in sulphate concentrations in Kalamalka Lake was unusually strong at 11-15% in 2012 but did not recur in 2013 or 2014 (Table 2.2-4). Seasonal delivery of sulfate in lake water depends on the types of minerals found in the watershed (Shaw et al., N.D.), and on fall rains and groundwater influxes. High sulphate concentrations have been documented in groundwater supplying the Kalamalka Lake drainage (Newmann et al, ND). Using the generalized Okanagan Basin water balance, about 40% of the inflow to Kalamalka Lake would be ground water (OBWB, 2011).

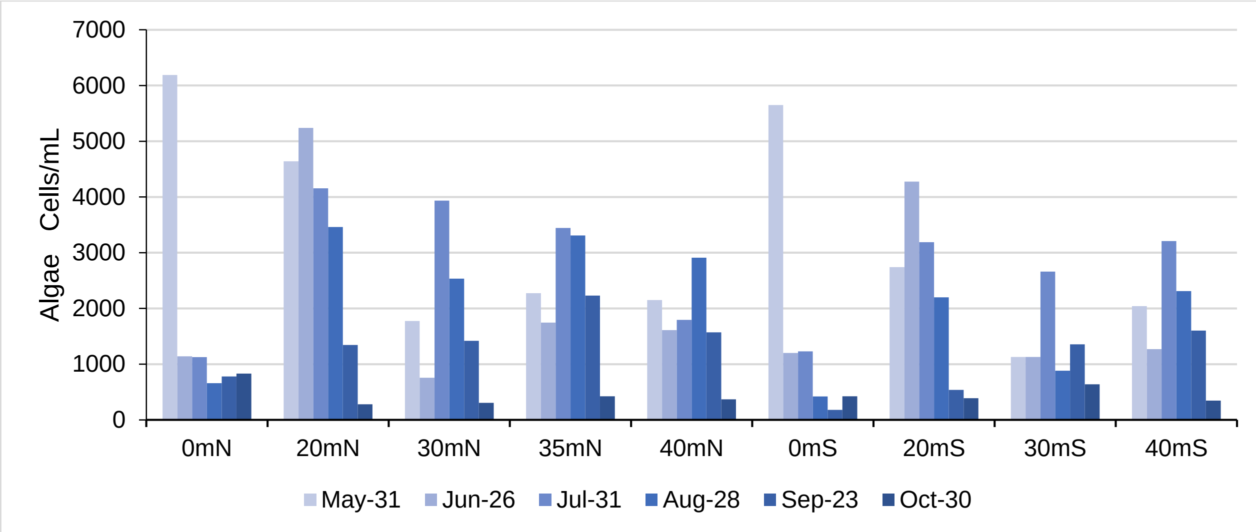


Figure 2.2-6: Algae counts in Kalamalka Lake during 2014.

Table 2.2-3: Total calcium in the 2014 growing season

T-Ca mg/L	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	59.8	30.7	39.8	40.5	40.6	40.7	39.7	37.8	39.3	40.3	40.0
Jun-26	77.1	31.7	40.6	41.6	40.5	40.6	40.0	40.8	41.2	40.8	39.9
Jul-31	81.2	29.4	37.0	40.1	39.1	39.0	39.5	37.6	39.5	40.7	38.6
Aug-28	76.0	29.3	36.5	37.8	37.5	38.2	36.9	36.6	38.1	39.4	38.4
Sep-23	81.8	28.2	37.5	40.3	38.6	38.9	39.3	35.9	38.8	38.5	39.4
Oct-30	85.6	29.3	36.2	43.7	38.2	38.4	37.4	36.8	36.5	39.2	37.2
Average	76.9	29.8	37.9	40.7	39.1	39.3	38.8	37.6	38.9	39.8	38.9
StdDev	9.1	1.2	1.8	1.9	1.3	1.1	1.3	1.7	1.6	0.9	1.1

Table 2.2-4: Total sulphate in the 2014 growing season

SO_4 mg/L	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	30.9	17.5	49.1	50.4	51.3	51.3	51.2	45.1	51	51.2	51.6
Jun-26	44.1	17.4	47.9	49.8	50.7	50.8	50.8	48.2	50.9	51	51.3
Jul-31	59.3	19.1	50.7	51.8	52.1	51.8	52	50.9	52.1	52.2	52.3
Aug-28	55.8	20.1	53.1	53.9	54.5	54.2	54.2	52.3	53.6	54.5	54.3
Sep-23	66.4	19.3	52.8	53.4	53.8	53.7	53.7	52.4	53.2	53.8	53.6
Oct-30	68.7	19.6	53.3	53.6	53.9	53.9	53.9	53	52.9	53.8	54
Average	54.2	18.8	51.2	52.2	52.7	52.6	52.6	50.3	52.3	52.8	52.9
StdDev	14.4	1.1	2.3	1.8	1.6	1.5	1.5	3.1	1.1	1.5	1.3

Sodium, Chloride and Conductivity
Sodium (Na) and chloride (Cl) concentrations are naturally low in the Okanagan mainstem lakes. Increasing concentrations are indicative of anthropogenic inputs in Kalamalka Lake. These ions can come from road salt, urban stormwater, agriculture, natural groundwater sources and from Coldstream Creek. Na and particularly Cl are conservative ions primarily removed from Kalamalka Lake through hydraulic flushing.

According to linear trend analysis, the concentrations of both Na and Cl increased significantly at both ends of Kalamalka Lake during 2005 to 2013 (Mann-Kendall, $p<0.001$), but declined slightly in 2014 (Figure 2.2-7). Despite the long term trend, sodium and chloride concentrations appear to have levelled off since 2012. This may be a result of the large freshet in 2012 skewing the trends or a sign of improved watershed protection. Further years of study will clarify this trend.

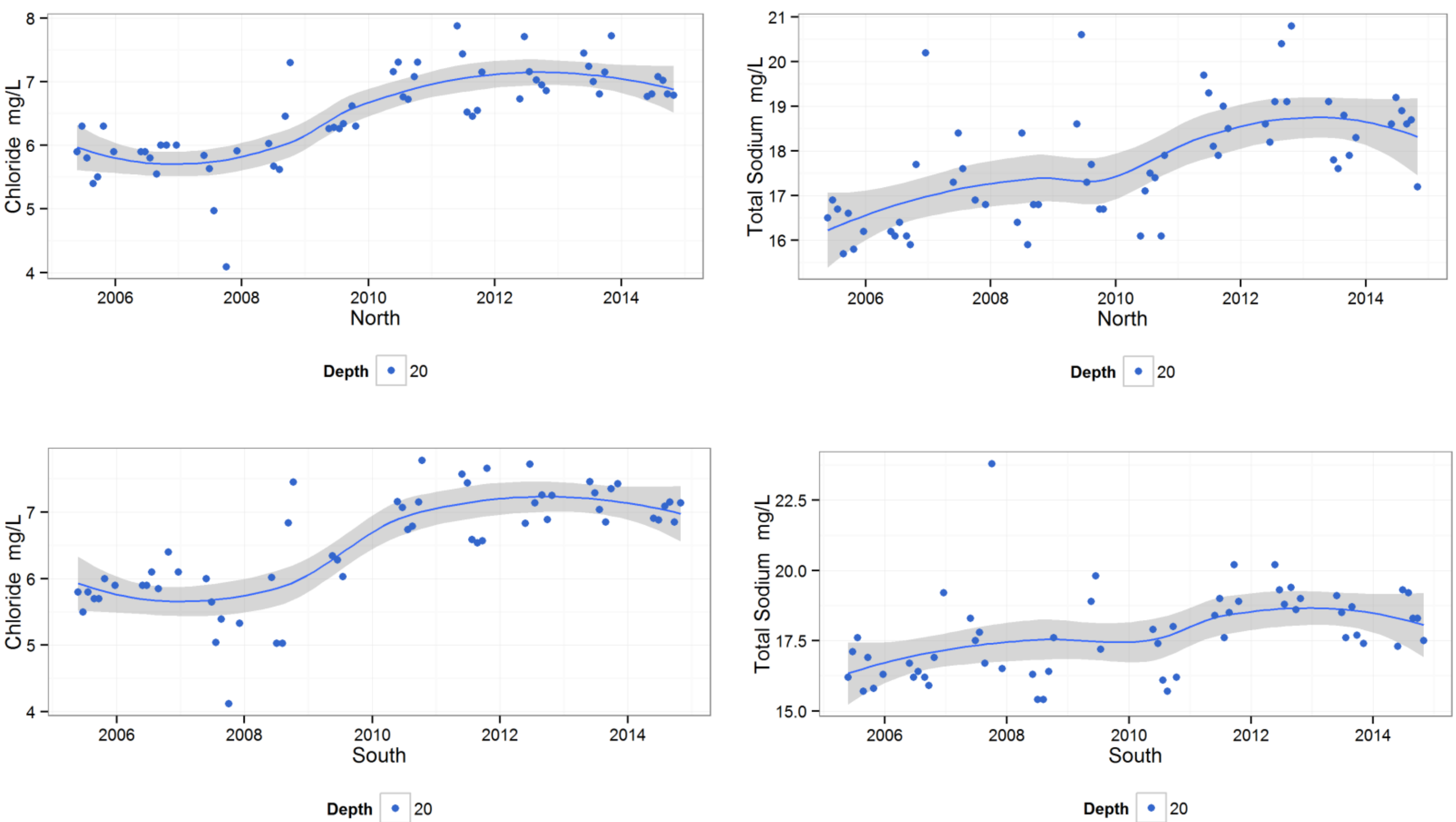


Figure 2.2-7: Growing season sodium and chloride in North and South Kalamalka Lake from 2005 - 2014

Coldstream Creek freshet inflows contained far less sodium than the receiving lake water at an average concentration of 15.3 mg/L versus 18.5 mg/L in the lake, despite stormwater and agricultural runoff contributions to creek flows. Elevated sodium at all North Arm depths during May occurs in most years (e.g., 2005 – 2013) but did not occur in 2014. Its occurrence is likely linked to urban stormwater and subsurface drainage reporting throughout the North Arm.

Throughout Kalamalka Lake, sodium accumulated in deep water during the stratified growing season, while chloride did not. During 2014, Kalamalka Lake Na and Cl concentrations ranged from 16.8 – 20.7 mg/L and 6.6 – 7.5 mg/L respectively (Tables 2.2-5, 2.2-6). Sodium averaged 16.1 mg/L in the MoE 1970-1988 data set and increased from that level in recent years. Chloride concentrations increased three-fold since the 1970s when they averaged 1.88 – 2.01 mg/L. Na and Cl concentrations do not show matched trends (Figure 2.2-7), suggesting that there are different sources for the ions or more likely, a delay in the arrival of sodium through soil retention. Soils do not detain chloride because it is particularly inert. For that reason, it can be used as a tracer for contaminated effluents such as highway run-off and sewage.

Table 2.2-5: Total sodium concentrations in 2014 growing season

T-Na mg/L	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	8.9	16.9	17.9	18.6	19.1	20.5	18.9	16.8	17.3	18	17.6
Jun-26	13.2	17.6	18.5	19.2	18.7	19	18.8	20.7	19.3	19.3	19
Jul-31	15.5	17.9	18.7	18.9	19	19.9	18.9	18.8	19.2	19.2	19.4
Aug-28	18	17.2	17.6	18.6	17.9	18.2	18.3	19.7	18.3	18.8	18
Sep-23	18.5	17.4	18.7	18.7	18.1	18.7	20.1	18.1	18.3	17.9	18.7
Oct-30	17.9	16.8	17	17.2	17.7	17.6	17.1	17.3	17.5	17.5	17.1
Average	15.3	17.3	18.1	18.5	18.4	19.0	18.7	18.6	18.3	18.5	18.3
StdDev	3.7	0.4	0.7	0.7	0.6	1.1	1.0	1.5	0.8	0.8	0.9

Table 2.2-6: Total chloride concentrations in 2014 growing season

Chloride mg/L	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	7.4	12.1	7	6.77	6.79	6.61	6.62	7.5	6.91	6.95	6.89
Jun-26	10.1	12	7.11	6.81	6.84	6.78	6.93	7.22	6.88	6.88	6.83
Jul-31	11	13.1	7.5	7.08	7	7.03	7.11	7.29	7.09	6.96	6.94
Aug-28	13.5	12.9	7.48	7.02	6.96	6.99	7.03	7.45	7.15	7.05	7.09
Sep-23	14.9	13.6	7.38	6.81	6.74	6.71	6.72	7.2	6.85	6.77	6.71
Oct-30	15.6	13.1	7.15	6.79	6.69	6.7	6.64	7.09	7.14	6.74	6.68
Average	12.1	12.8	7.3	6.9	6.8	6.8	6.8	7.3	7.0	6.9	6.9
StdDev	3.1	0.6	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.2

Both Wood Lake and Coldstream Creek can act as a chloride source to Kalamalka Lake (Table 2.2-6). Wood Lake Cl levels were roughly double the concentration of Kalamalka Lake in the monthly average data from 2005 to 2014. Chloride loading from Coldstream was very low in early spring with freshet dilution, while creek concentrations increased during the low flow months, suggesting urban road and agricultural watershed impacts. Although the flushing time of Kalamalka Lake is 55 to 65 years, rapid changes in salt ion concentrations have occurred in its water column.

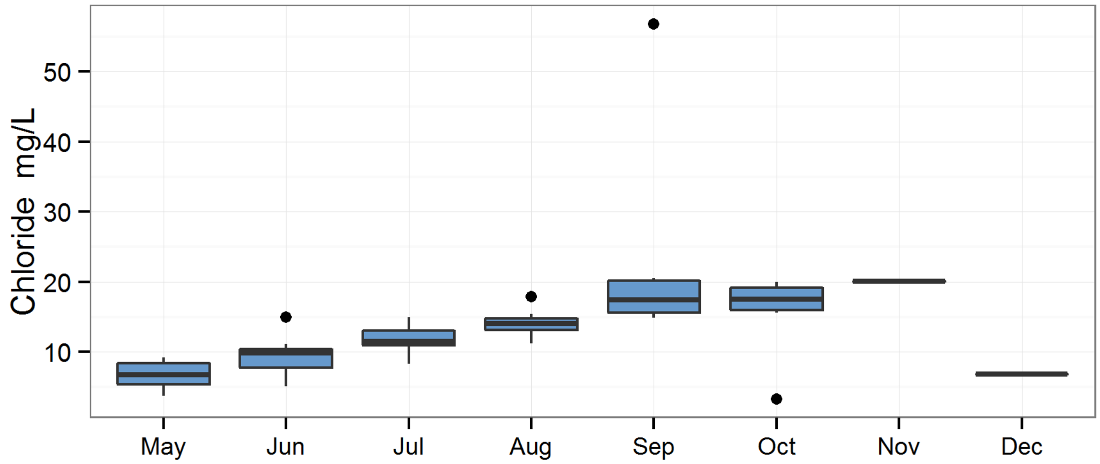


Figure 2.2-8: Monthly chloride concentrations in Coldstream Creek, 2005-2014

Watershed influences determine the ratio of Na to Cl in a lake. Road salt can depress the ratio to <1 because Na is preferentially absorbed by soils (Novotny et. al, 2007). As of 2014, the ratios were 1.25 for Coldstream Creek, 1.37 for Wood Lake, 2.54 for S-Kal and 2.73 for N-Kal, indicating greater road salt impacts in the creek and Wood Lake compared to Kalamalka Lake. Kalamalka and Wood lakes had declining trends for Na:Cl from 2005-2014 but Coldstream Creek did not (Mann-Kendall, p≤0.008; Figure 2.2-9).

Both ions remained well below their respective drinking water guidelines at all depths (Appendix 1). Their impact is more like to be environmental. Although Na and Cl are not toxic to aquatic organisms at concentrations found in Kalamalka or Wood Lake, algae and aquatic plants are influenced by the ratio between monovalent cations (Na^{+1} K^{+1}) and divalent cations (Ca^{+2} Mg^{+2}). Monovalent to divalent ratios below 1.5 favor diatoms while higher ratios favor desmids (Wetzel, 2001). The 2014 ratio in Kalamalka Lake was 0.58 and in Wood Lake was 0.48, explaining the dominance of diatoms over desmids in those lakes.

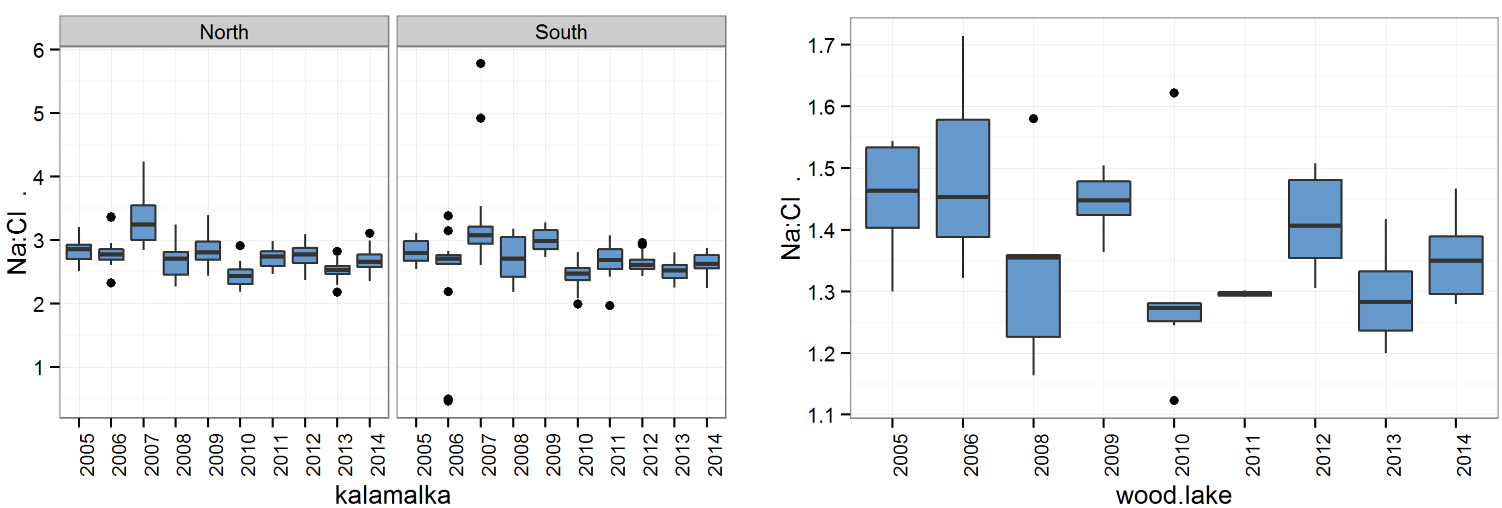


Figure 2.2-9: Ratios of sodium : chloride in Kalamalka and Wood lakes from 2005 - 2014

Like sodium and chloride, conductivity was lower in Kalamalka surface water and higher in deep water layer during the stratified growing season in all years of study including 2014. Conductivity ranged from 382 to 416 µS/cm in Kalamalka Lake during 2014 (Table 2.2-7). There was no significant difference between samples collected at 30 m and deeper samples since 2000. With the exception of freshet, conductivity was higher in Coldstream Creek than Kalamalka Lake or Wood Lake every year. Elevated conductivity in Coldstream Creek during low flow periods is caused by a combination of groundwater in base flows, marine shales in the watershed, extensive agricultural activities and urban stormwater. This caused shifts in creek conductivity from 300 µS/cm in freshet to 400-600 µS/cm in summer, and to 700-800 µS/cm in winter. Shifting differences in conductivity between Coldstream Creek and the North Arm caused the creek plume to travel in the surface water during freshet and plunge to deeper water through the rest of the stratified season (Figure 2.1-4).

Table 2.2-7: Water conductivity in the 2014 growing season

Cond. µS/cm	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	407	315	399	406	410	412	411	382	408	414	415
Jun-26	531	317	397	404	410	410	411	395	412	410	409
Jul-31	611	323	399	412	414	412	416	397	416	416	413
Aug-28	572	324	395	403	409	410	410	397	406	411	413
Sep-23	637	324	388	398	403	406	405	393	404	408	410
Oct-30	667	339	403	409	411	413	412	400	399	409	413
Average	571	324	397	405	410	411	411	394	408	411	412
StdDev	93	8	5	5	4	3	4	6	6	3	2

2.2.4 Nutrients

Nitrogen and phosphorus are the two most important nutrients controlling Kalamalka Lake productivity. Spring nutrient concentrations measured when the water columns were freely mixing provide an important predictor for productivity in the coming growing season. Spring (March data) 2014 total nitrogen in Kalamalka Lake ranged from 0.302 to 0.338 mg/L T-N while Wood Lake ranged from 0.424 to 0.426 mg/L T-N (Table 2.2-8). After thermal stratification established, the nutrient concentrations remained similar in Kalamalka Lake but diverged sharply in Wood Lake, where greater production strips nutrients from the surface water. For example, in 2014 Kalamalka Lake hypolimnion T-P concentrations ranged from 0.003 to 0.005 mg/L while Wood Lake's anaerobic hypolimnion concentration was 38 times higher at 0.139 mg/L.

Table 2.2-8: 2014 total nitrogen and total phosphorus (MoE data)

	Kalamalka Lake		Wood Lake	
Total Nitrogen (mg/L)	Shallow 0-5-10m	Deep 20-32-45m	shallow 0-5-10m	deep 20-32-45m
Spring	0.302 – 0.316	0.336 – 0.338	0.424	0.426
Fall	0.230 – 0.238	0.228 – 0.295	0.365	0.675
Total Phosphorus (mg/L)				
Spring	0.0044 – 0.0045	0.0046 – 0.0073	0.0360	0.0387
Fall	0.0032 – 0.0042	0.0026 – 0.0071	0.128	0.139

Note: Spring = March, Fall = September

The nutrient data accumulated from all sources over the years shows several important trends in Kalamalka Lake:

- Within Kalamalka Lake, the shallow ends were more productive than the main body of the lake.
- Nutrients at the north and south sites on Kalamalka Lake moved together (Figure 2.2-10), indicating whole-lake influences such as freshet nutrient inflow via Coldstream Creek, inflows from Wood Lake and normal or nutrient-enriched groundwater seepage or possible episodic overland flow from the spray effluent program. (For example, two samples with >4 mg/L nitrate were collected from Bailey Ck near Kekuli Bay Provincial Campground on April 6 2010 (Larratt, 2011).
- Wetter years usually had greater nutrient loading from larger spring inflows (Jensen 2004, pers comm.). Small peaks in south Kalamalka nutrients or in north Kalamalka nutrients in Figure 2.2-10 may relate to greater inflow from Wood Lake or Coldstream Creek, respectively.
- Dissolved nitrogen and phosphorus concentrations dropped gradually over every growing season through microflora consumption.
- Total phosphorus concentrations dropped during the summer marl events through co-precipitation and settling of small algae cells (Appendix 1,3).
- The statistical correlation between algae production in 2003 - 2014 and lake-wide annual average T-P ranged from R=0.11 (very weak) at the S-20m site to R=0.78 (strong) at the S-0m site, averaging 0.53 throughout the lake (weak). The relationship is weak because other factors affect Kalamalka lake production.

Trend analysis of Kalamalka Lake north and south end data showed a weak declining trend in annual average T-P since 1975 (Mann-Kendall, $p<0.001$), which is an encouraging development for water purveyors (Figure 2.2-10). This improvement is likely to relate to improved nutrient handling such as conversion of lakeshore septic systems to sewer.

Coldstream Creek influences Kalamalka Lake nutrient concentrations because it supplies 80% of the annual inflow to Kalamalka Lake. Coldstream Creek total nitrogen concentrations from recent years reached higher maximum values than in the 70s and 80s, and nutrient concentrations continued to increase through the fall and into the winter, rather than leveling off during July through December as was the case in the 70s (Sokal, 2010). Nitrate values now reach or exceed guideline levels for the protection of aquatic life in Coldstream Creek. Sources of nitrate likely include manure or fertilizer applications that elevate nitrate in groundwater and ultimately creek flow (Sokal, 2010). Many studies dating as far back as the 1970's have identified serious issues with agricultural practises in the Coldstream watershed and the need for better riparian protection (MoE 1978; Ecoscape 2009; Sokal 2010).

Spring nitrate concentrations set the tone for productivity in Kalamalka Lake in the subsequent summer. Large nitrate concentrations in the spring lead to larger algae production. The March MoE measurements in 2009 - 2014 showed high nitrate concentrations in Kalamalka Lake, ranging from 0.092 to 0.137 mg/L nitrate (Table 2.2-9). As in most years, nitrate concentrations fell below the detection limit through biological consumption over the 2014 growing season in Kalamalka Lake.

Winter samples were collected in 2005 through 2007 (Table 2.2-9). They showed far greater nitrate concentrations than any other season, suggesting that internal loading to a circulating water column is as important as freshet sources.

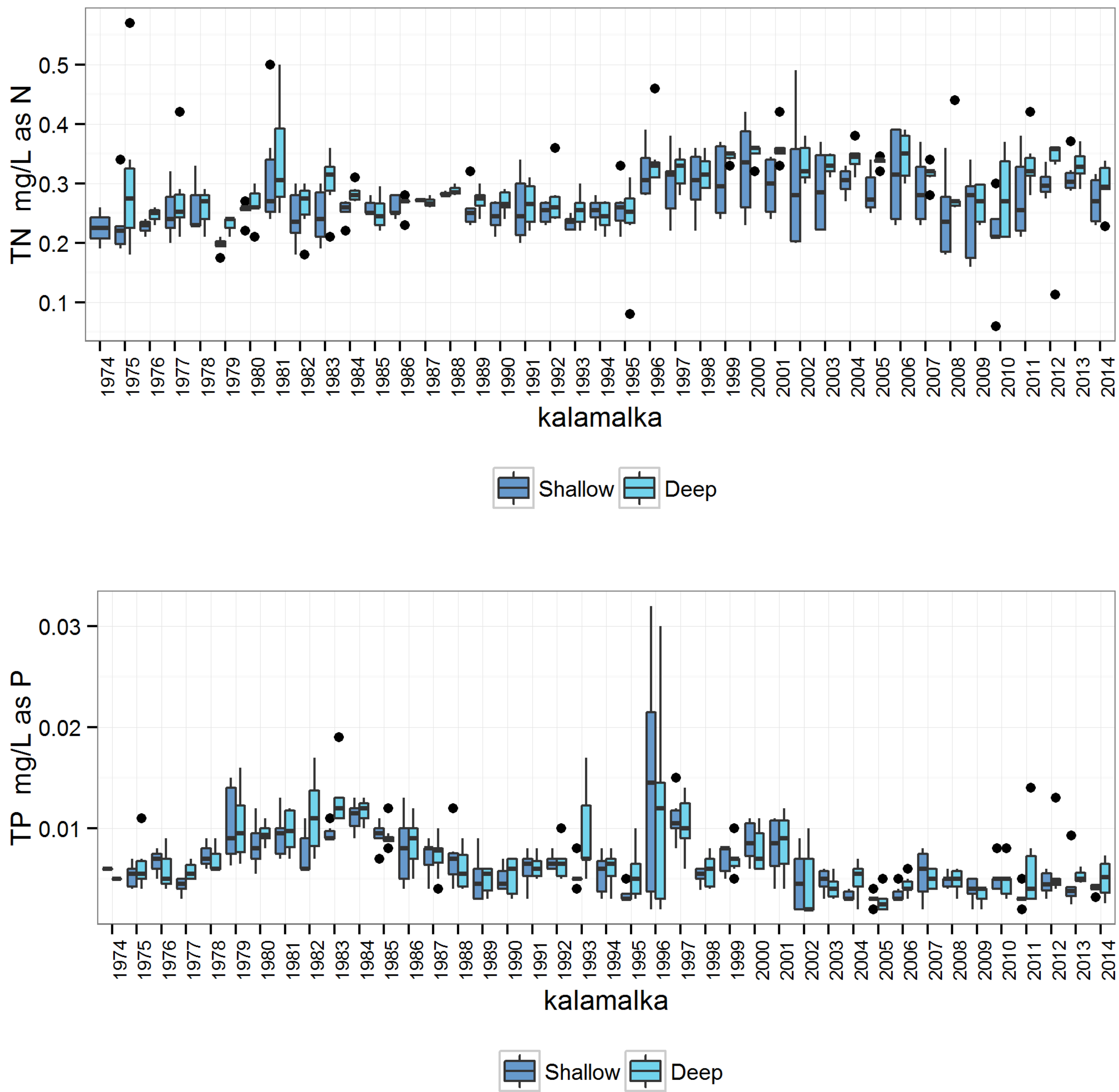


Figure 2.2-10: Nitrogen and phosphorus in Kalamalka Lake from shallow 1-5-10 m and deep 20-32-45 m composites from North Central and South sites, 1974 – 2014 - For reference, the MoE Objective is 0.008 mg/L T-P.

Table 2.2-9: Spring and fall nitrate/nitrite and total dissolved phosphorus concentrations in Kalamalka Lake (0-5-10m)

	Nitrate and nitrite		Total dissolved phosphorus	
(mg/L)	South	North	South	North
Spring 2003	0.016 – 0.024	0.044 – 0.065	0.003-0.004	0.003
Fall 2003	<0.002	<0.002	0.004-0.008	<0.002
Spring 2004	0.022 – 0.057	0.002	<0.002-0.003	<0.002-0.002
Fall 2004	0.025 – 0.072	0.002	<0.002-0.003	<0.002-0.005
Spring 2005	0.010	0.009 – 0.015	<0.002	<0.002
Fall 2005	<0.002 – 0.013	0.003	<0.002	0.002-0.003
Winter 2005	0.104	0.106	0.003	0.006
Spring 2006	0.008 – 0.057	0.018 – 0.029	0.003	0.003
Fall 2006	0.003	0.008	0.003	0.003
Winter 2006	0.127	0.124	0.003	0.003
Spring 2007	0.002 – 0.003	0.004 – 0.035	<0.002-0.008	<0.002
Fall 2007	0.002	0.003	0.004-0.008	<0.002
Winter 2007	0.069	0.084	0.007	0.006
Spring 2008	0.040	0.038	0.003	0.004
Fall 2008	0.005	<0.002	0.004-0.005	0.005-0.006
Spring 2009	0.127	0.137	0.003	0.002
Fall 2009	<0.002	0.035	0.002	0.002
Spring 2010	0.09	0.100	0.003	0.004
Fall 2010	<0.002	<0.002	0.005	0.002
Spring 2011	0.104	0.119	0.002	0.002
Fall 2011	<0 .002	<0.002	0.003	0.003
Spring 2012	0.0710	0.092	0.003	0.006
Fall 2012	<0 .002	<0.002	0.0035	0.0032
Spring 2013	0.0974	0.0865	0.0026	0.0025
Fall 2013	<0.002	0.0579	0.0035	0.0022
Spring 2014	0.103	-	0.0051	-
Fall 2014	<0.002	<0.002	0.0029	-

Note: MoE spring sampling date occurred in March after 2009; in earlier years it occurred in May as part of this study program

With lake mixing in the fall, nitrate concentrations were restored to Kalamalka Lake surface water by winter (Figure 2.2-11). Nitrate concentrations in Kalamalka Lake actually exceed those of Wood Lake, possibly because of greater microfloral consumption in the latter. Nutrients made available to the surface water by fall overturn and subsequent winter lake mixing triggered increased blue-green algae growth each year in Kalamalka Lake, but not to bloom status as occurs in Wood Lake (Appendix 3). There was a shift in nutrient concentrations in 1996 that likely occurred as a result of a change in lab or sampling methodology.

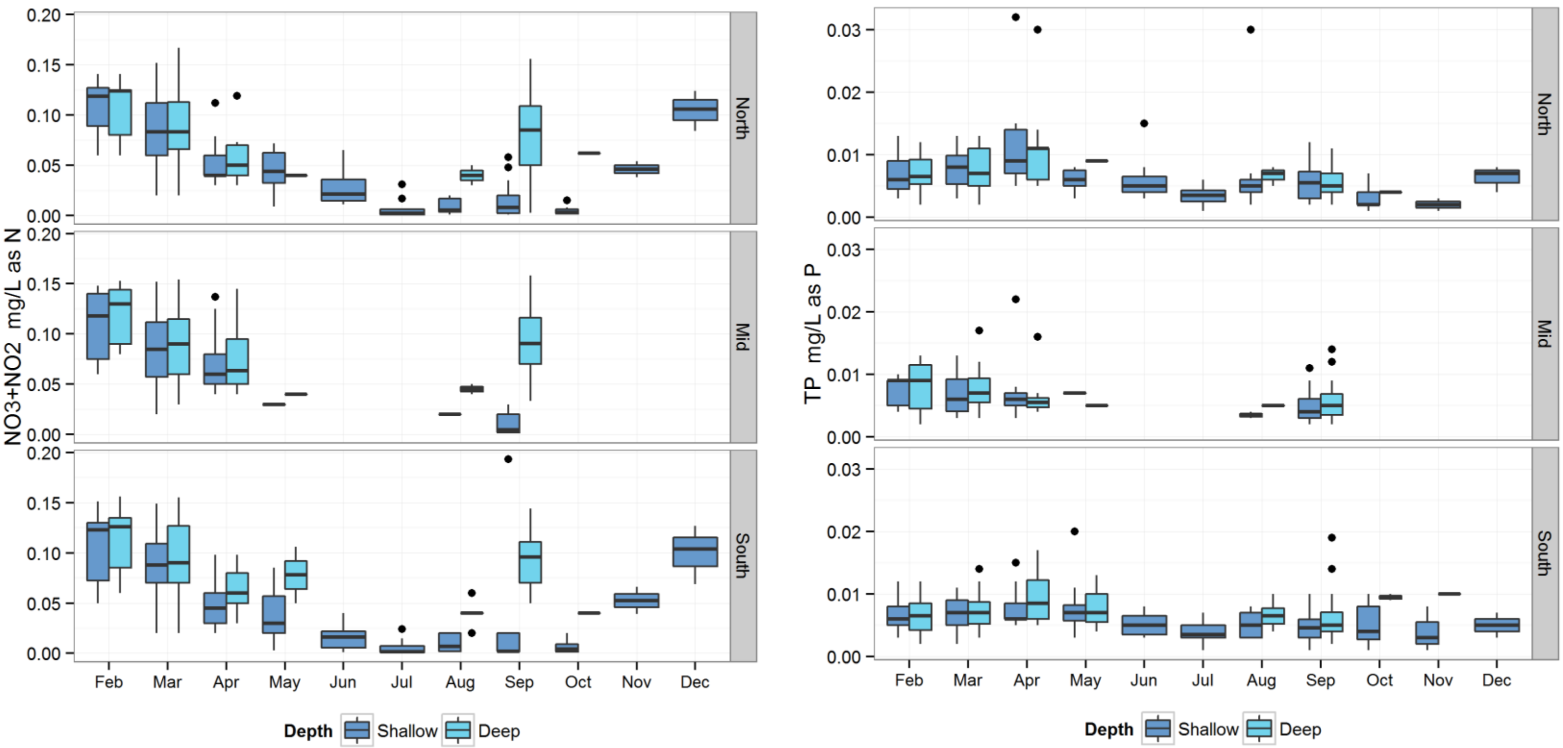


Figure 2.2-11: Monthly nitrate + nitrite and TP concentations in Kalamalka Lake, 1975-2014

In Coldstream Creek, the water quality objective of 0.015 mg/L T-P has not been met since it was set in 1985 (Sokal, 2010). Despite this creek loading, the 0.008 mg/L T-P objective (Nordin et al, 1988) for Kalamalka Lake has been met for the past decade (Figure 2.2-10). The annual marl precipitation helps maintain low phosphorus concentrations in Kalamalka Lake.

After all of the additions and consumptions of nutrients are tallied in Kalamalka Lake, the resulting N:P balance determines the type of algae that grow. In spring 2014, the average Kalamalka Lake surface DIN:DIP ratio (DIN = Dissolved inorganic N **:** DIP = Dissolved inorganic P) was 20:1 because DIP concentrations were very low. Like most years, the 2014 ratio showed phosphorous limitation, where phosphorous shortages constricted biological production. In contrast, during the heavy freshet 2008 year, the average surface DIN **:** DIP ratio was 1.8 **:** 1, with increased P concentrations. The 2008 ratio indicated nitrogen limitation, in which nitrogen shortages constrict biological production. MoE nutrient enrichment research conducted in the 1970s also indicated that Kalamalka Lake was more deficient in nitrogen than in phosphorus. Both N and P will direct algae growth in Kalamalka Lake through the annual productivity cycles.

2.2.5 Chlorophyll-a and Total Organic Carbon

Chlorophyll-a is a photosynthetic pigment found in most aquatic microflora. It provides a measurement of algae and photosynthetic bacteria production. Historic epilimnion chlorophyll-a measured 1.80 µg/L at the south end of Kalamalka Lake, and 1.26 µg/L in Kalamalka main basin in the 1970s (Bryan, 1990), compared to 0.4 – 4.0 µg/L in 2014 samples (Table 2.2-10). The range in chl-a currently found in Kalamalka Lake would classify it as oligo-mesotrophic.

Table 2.2-10: Chlorophyll-a concentrations (µg/L) in the 2014 growing season

Chl-a ug/L	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	-	4.0	2.0	2.0	1.0	1.0	0.9	3.0	1.0	1.0	1.0
Jun-26	-	1.0	0.9	4.0	1.0	1.0	1.0	0.8	2.0	1.0	0.9
Jul-31	-	0.9	0.8	2.0	2.0	2.0	1.0	0.5	2.0	1.0	1.0
Aug-28	-	1.0	0.7	2.0	0.9	0.8	1.0	1.0	1.0	1.0	0.9
Sep-23	-	1.0	0.4	0.6	0.7	0.6	0.7	0.7	0.8	0.8	0.7
Oct-30	-	3.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	1.0
Average	-	1.8	1.1	2.1	1.3	1.2	0.9	1.3	1.3	1.1	0.9
StdDev	-	1.3	0.7	1.1	0.6	0.6	0.1	1.0	0.5	0.4	0.1

Figure 2.2-12 shows the annual spring peak in chl-a when increased nutrients and day length coincides and permit diatom blooms. The monthly chl-a data usually showed decreased chl-a through the balance of the growing season at all depths. Minimum algae production usually occurred in August/September/October after marl precipitation removed phosphorus from solution and before overturn. However, there is considerable year-to-year variation in response to weather and watershed activities (Table 2.2-10; Figure 2.2-12).

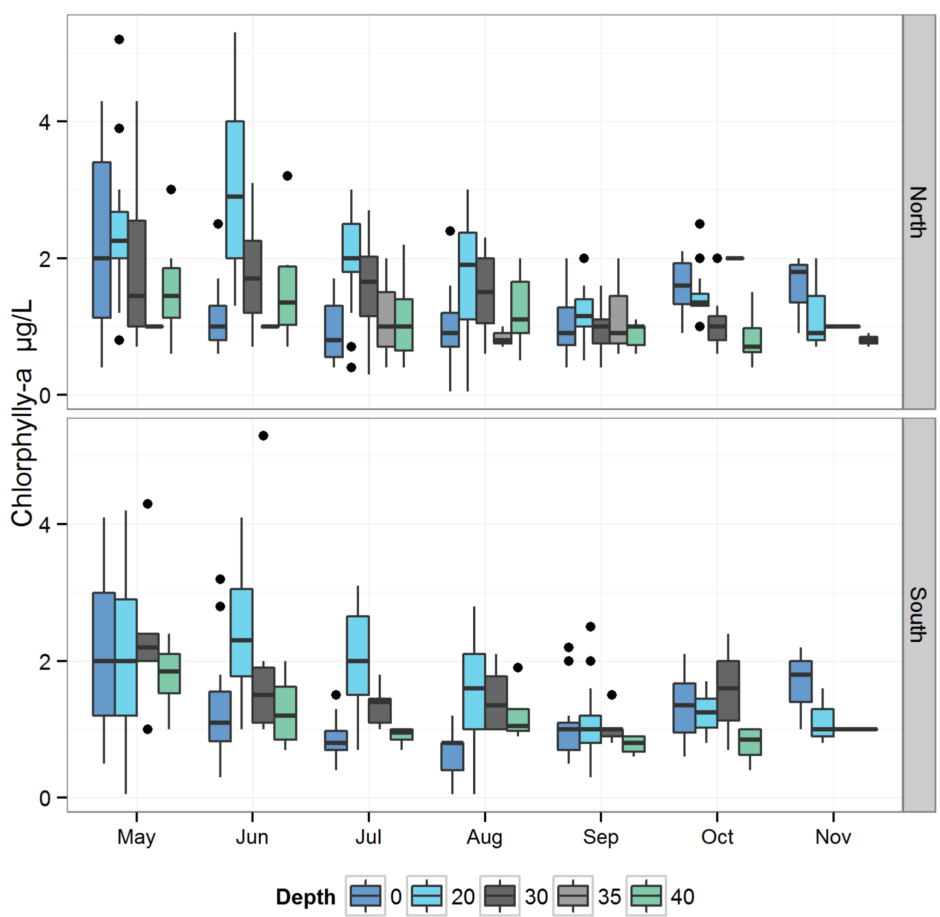


Figure 2.2-12: Chlorophyll-a by depth during the growing season in Kalamalka Lake from 1999 - 2014

Increasing phosphorous and chl-a concentrations were measured in Kalamalka Lake from 1971 to 1998 (BC MoE database). Within this study, chl-a increased steadily from 2000 to 2009 and then both ends of the lake showed declining trends to 2014 which was most pronounced in South Kalamalka samples (Figure 2.2-13). Productivity was moderate in 2014 samples. Whole-lake influences such as freshet volumes and weather are implicated. Since 1970, TN and TP have not correlated with chl-a ($R = 0.001$ for TP and $R = 0.096$ respectively), suggesting that other factors help determine productivity in addition to nutrients.

Peak chl-a occurred in June at 4 µg/L in the N-20m sample (Table 2.2-10). Despite these variations, a statistically significant trend emerged where chl-a was lowest at the N-40+m sites and highest at the N-20 m sites over 2000 – 2014 (Kruskal-Wallis Test, $p<0.001$; Figure 2.2-14). While in 2012 only 0.3 µg/L chl-a separated the 20 m and 40 m averages in the south and less in the north, in 2014 there was a difference of 1.2 µg/L in the north end and 0.4 µg/L in the south end (Table 2.2-10).

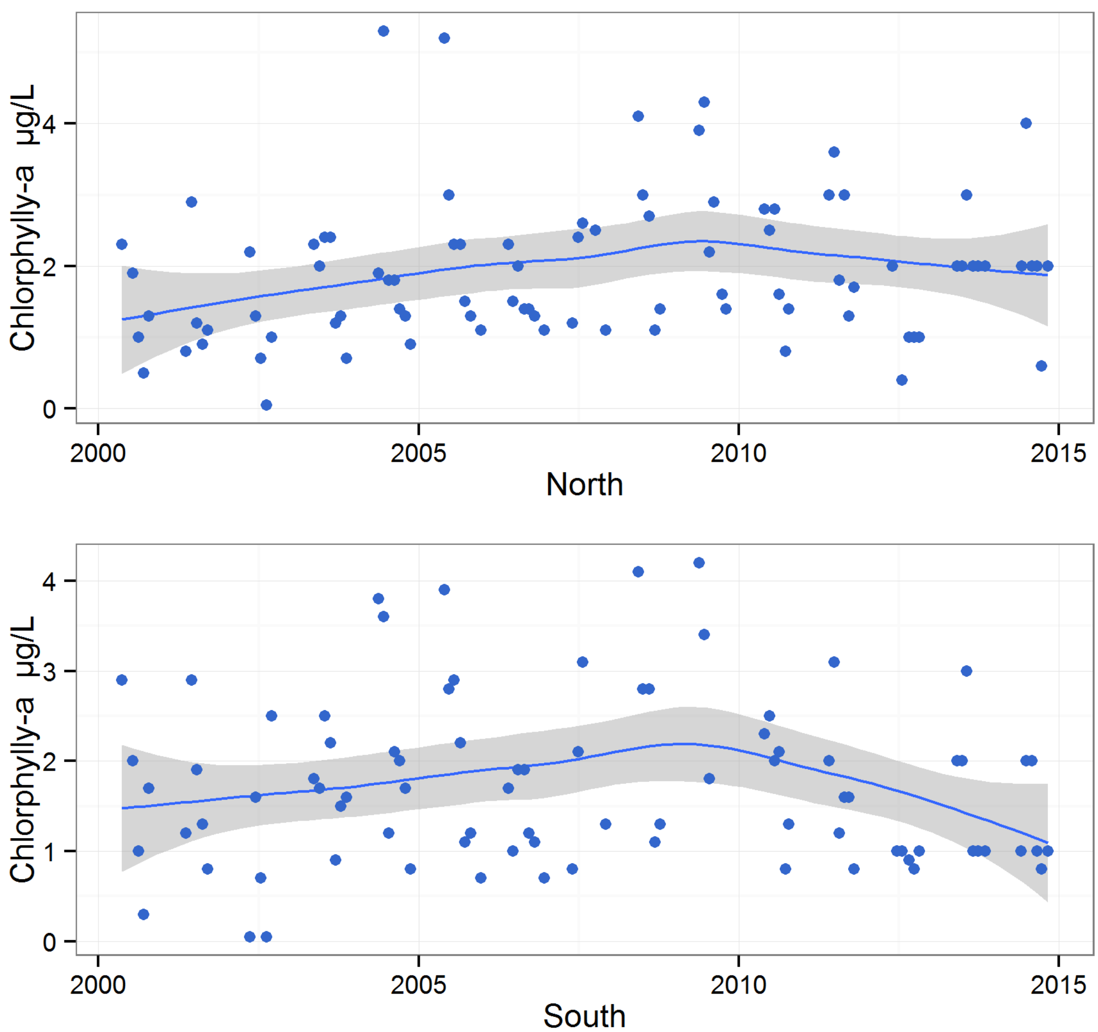
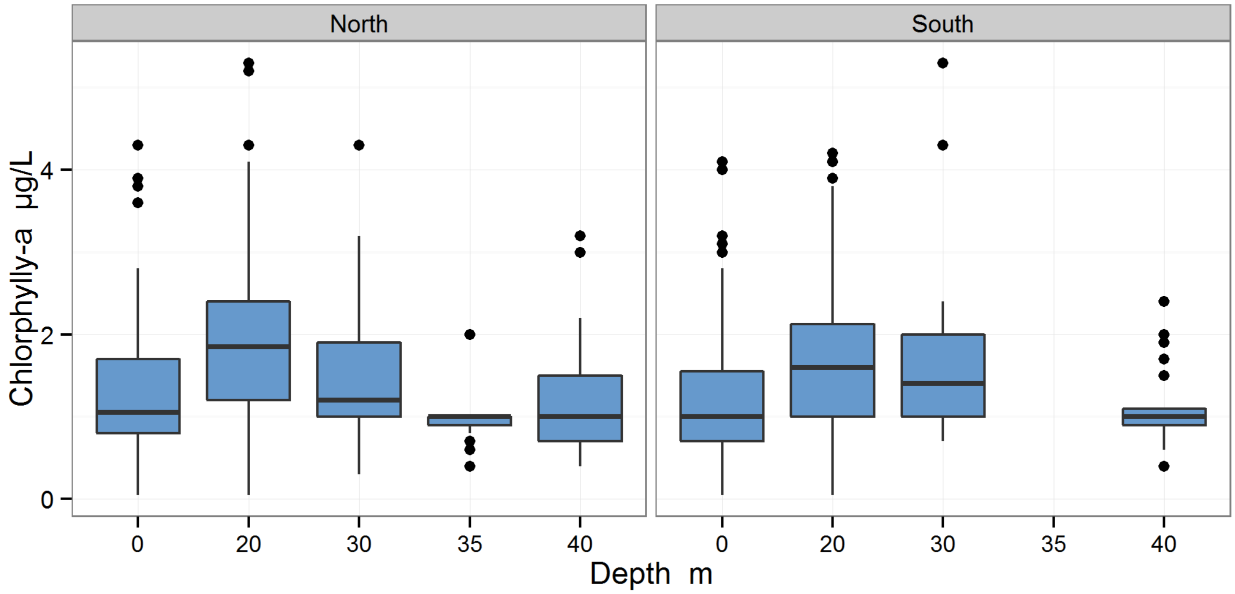


Figure 2.2-13: Chlorophyll-a concentrations in Kalamalka Lake at intake depth (20 m), 2000-2014



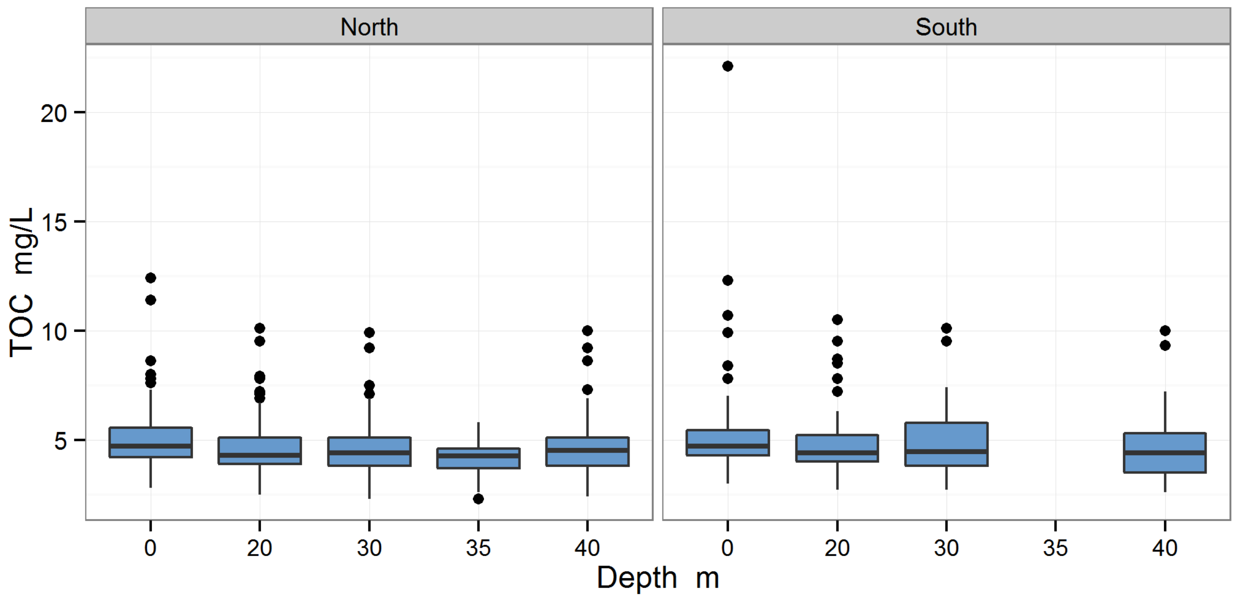


Figure 2.2-14: Average chlorophyll-a and total organic carbon by depth in Kalamalka Lake from 2000 - 2014

Over the years, 20 m samples contained more chlorophyll-a than the surface samples (Figure 2.2-14) because dying algae settle towards the bottom and because storms and seiches create turbulence that re-suspend low-light tolerant microflora from the sediments. Chlorophyll is a resilient molecule that persists even after the algae are dead.

Total organic carbon measures dissolved and suspended carbon bound in organic molecules and organisms. Median total and dissolved organic carbon levels in British Columbia lakes and rivers are generally less than 5 mg/L except for waters that have high natural sources (BC MoE ND). Both Coldstream Creek (in freshet) and Wood Lake (May-Nov) source water TOC exceeded that of Kalamalka Lake every year (Figure 2.2-15).

Throughout Kalamalka Lake, TOC concentrations were usually greatest in May and diminished through the growing season (Table 2.2-11, Figure 2.2-15). No sites had 2014 growing season averages below the BC guideline of 4.0 mg/L. Of these, the N-35m and S-40m sites had the lowest growing season TOC of the depths tested.

Table 2.2-11: Total organic carbon concentrations in the 2014 growing season

TOC mg/L	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	8.1	8.7	5.3	5.0	4.6	4.6	4.6	5.8	4.8	4.7	4.6
Jun-26	4.2	9.6	6.0	5.6	5.2	5.0	5.0	6.6	5.2	5.1	5.1
Jul-31	3.2	7.3	4.8	4.2	4.1	3.9	4.0	4.4	4.1	3.8	3.8
Aug-28	2.4	5.5	3.2	3.1	2.9	2.8	2.9	3.5	2.8	2.7	2.6
Sep-23	5.6	10.4	7.8	6.7	6.1	5.8	5.7	6.7	5.8	5.8	5.3
Oct-30	3	9.3	5.8	5.3	5.1	4.6	5.1	22.1	8.5	7.4	5.3
Average	4.4	8.5	5.5	5.0	4.7	4.5	4.6	8.2	5.2	4.9	4.5
StdDev	2.1	1.8	1.5	1.2	1.1	1.0	1.0	6.9	1.9	1.6	1.1

NOTE: greyed data appears to be in error – no evidence in other parameters

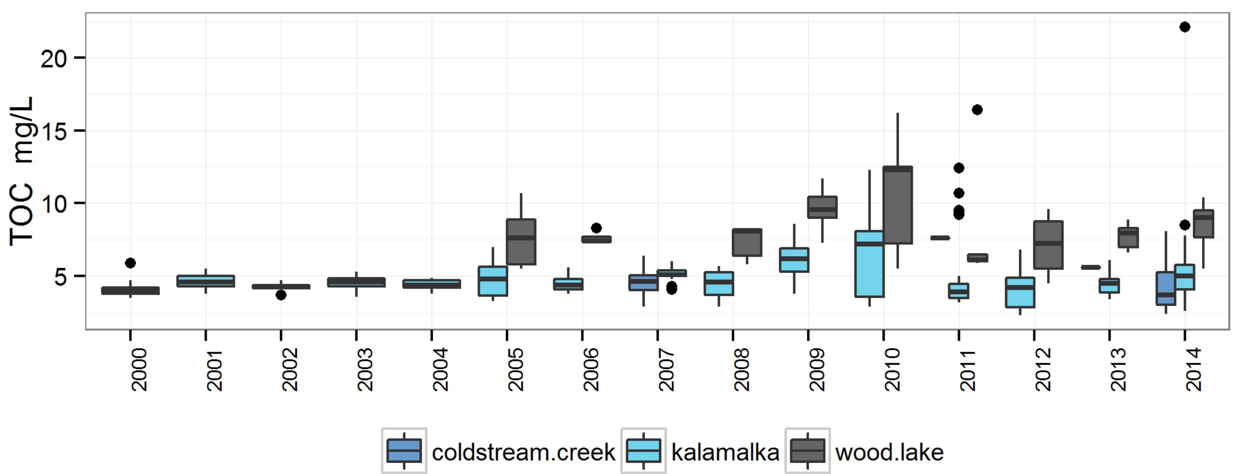


Figure 2.2-15: Total organic carbon in Coldstream Creek, Kalamalka, and Wood Lakes from 2000 – 2014

Large whole lake effects and weather influences TOC because all sites including Wood Lake show the same annual pattern (Figure 2.2-15). There may be an influence from Wood Lake because the S-0 m average TOC was higher than any other site in Kalamalka Lake during 2014. Kalamalka Lake

TOC concentrations peaked in 2009 and 2010, followed by lower concentrations in 2011 - 2013 (Figure 2.2-15).

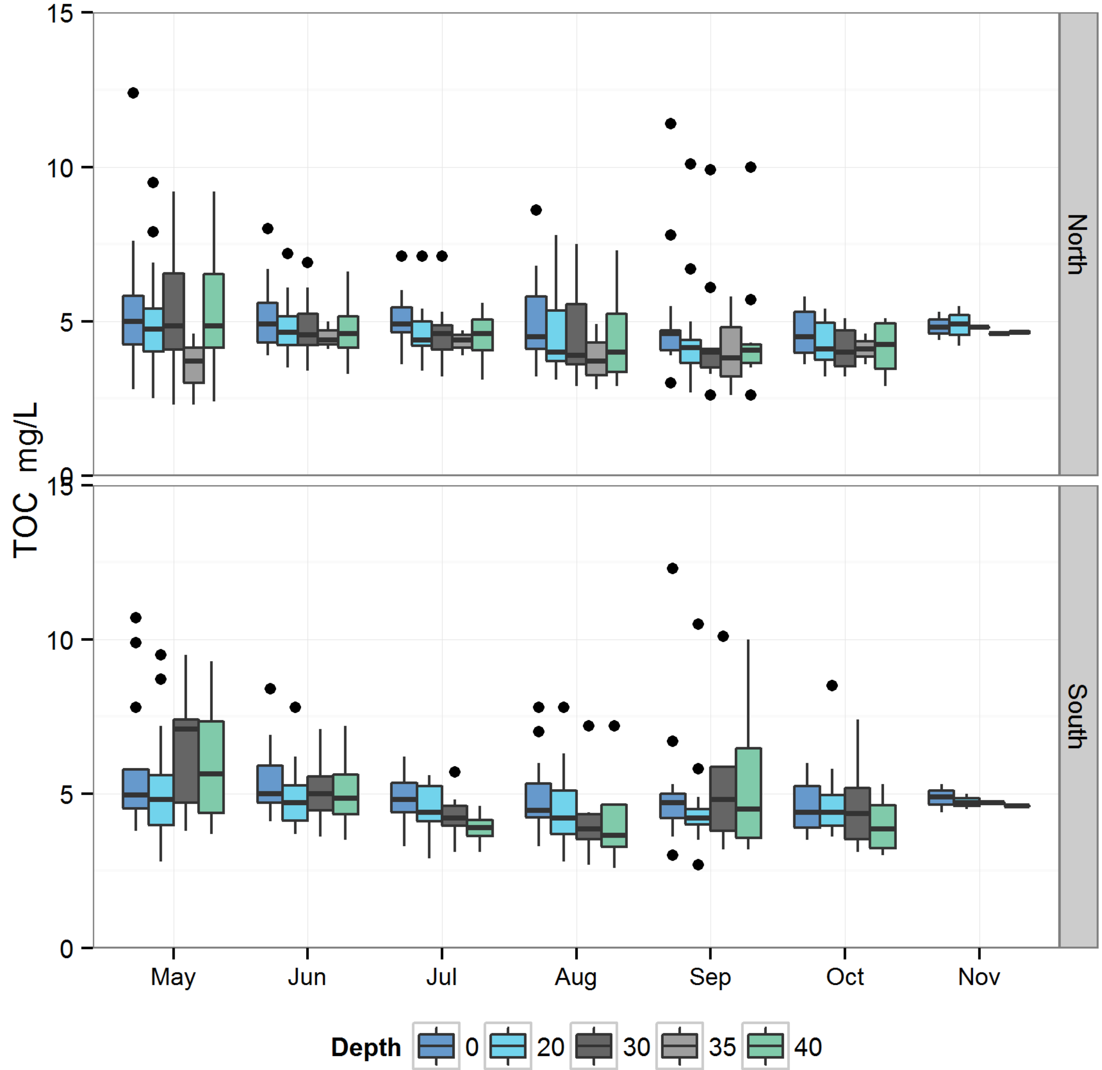


Figure 2.2-16: Monthly total organic carbon concentrations in Kalamalka Lake from 2000 to 2014.

Differences in average TOC concentrations between depths in North Kalamalka Lake were small and were not statistically significant when all years were analyzed because of inter-annual variability (Table 2.2-11). Figure 2.2-16 also demonstrates that variability in TOC concentrations were greatest during May and September when there was weak stratification and frequent seiches. Water purveyors can therefore anticipate greater chlorine demand to maintain residuals and/or increased treatment plant costs to maintain UV disinfection during those months.

TOC and chl-a concentrations in Kalamalka Lake are important since TOC impacts ultraviolet disinfection efficiency and cost. Chl-a measures microflora concentrations in the lake and proves that most of the organic carbon in Kalamalka Lake is particulate algae and photosynthetic bacteria as opposed to dissolved organic molecules. An increase in microflora algae productivity in the lake would increase the cost of UV disinfection and would increase the risk of taste and odour issues.

2.2.6 Water Transparency

Secchi Depth

Based only on secchi depth, Kalamalka Lake would be classified as oligotrophic with clear, transparent water. Years with lower secchi depths were affected by turbid freshets or more intense algae growth that affected the entire lake. Historic secchi depths from Kalamalka Lake measured 6 – 7 m in 1935 and 3.8 – 10.7 m (avg 6.5 m) from 1975 – 1988 (Bryan, 1990). From 1999 - 2014 growing season secchi depths ranged from 1.7 m during spring freshet algae production to 10.1 m post-marl precipitation which is similar to the 1975 – 1988 range.

Secchi depth averaged 5.3 ± 1.5 m in the north and 5.8 ± 1.5 m in south Kalamalka Lake during 2014 (Figure 2.2-17). Secchi depths appears to oscillate around a long term mean of (6.9 ± 2.6 m from 1971 to 2014) in Kalamalka Lake and has decreased again from 2011-2014 (Mann-Kendall, p=0.025).

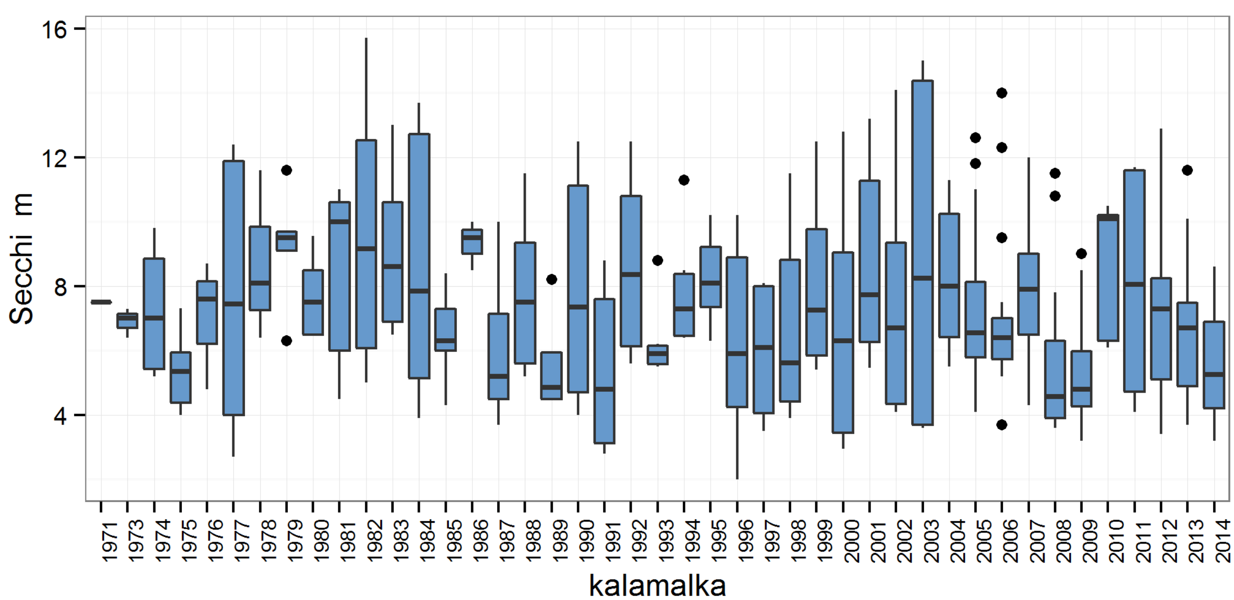


Figure 2.2-17: Annual secchi depths from all Kalamalka Lake sample sites 1971 - 2014

Doubling the secchi disk depth gives an approximate estimate of the depth that enough light penetrates the water column to support photosynthesis. Kalamalka Lake secchi depths average 2 - 4 m in the spring to 6 - 8 m in the late summer/fall, for a photic zone of 4 - 16 m.

During phases when light penetrated deeper into Kalamalka Lake, oxygen super-saturation extended beyond 20 m at all sites in the North Arm, strongly suggesting a photosynthetic bacterial and cyanobacterial *(Anacystis, Synechocystis)* component since their light requirements are lower than those of most algae (some cyanobacteria are myxotrophic). This provides another line of evidence suggesting that bacterial loading to the North Arm exceeds that of the southern end of the lake.

Turbidity and Ultraviolet Transmissivity (UVT)

Both turbidity and UVT are affected by suspended materials. Percent UVT represents the amount of light transmitted through a sample whereas turbidity is a measure of the amount of light scattered by particulate matter suspended in the sample. Measurements of turbidity and transmissivity are always similar but do not show matched patterns because dissolved organic molecules lower transmissivity but do not affect turbidity. Depending on the treatment design, UV disinfection loses efficiency below 85% UVT although with increased energy inputs, UV disinfection can now be utilized to 75% UVT (Phelan, 2013). Higher UVT reduces treatment costs.

%UVT in Wood Lake has always been lower than all of the Kalamalka Lake sites (Table 2.2-12). 2014 results were consistent with the higher productivity of Wood Lake. Spring transmissivity in Kalamalka Lake was lowered by freshet. For example, during the large 2008 freshet transmissivity measured only 66% at the lake surface because the Coldstream Creek freshet plume is buoyant.

Table 2.2-12: Ultraviolet transmissivity in the 2014 growing season

UVT (%)	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	-	75.1	88.9	90.5	91.3	91.6	91.6	85.4	90.5	91.0	90.8
Jun-26	-	74.5	89.0	90.4	91.0	91.0	91.2	89.8	90.6	90.8	90.9
Jul-31	-	77.8	89.1	90.7	90.4	91.3	90.9	90.3	91.2	92.7	92.7
Aug-28	-	77.1	89.8	90.4	91.0	91.2	91.1	88.5	89.6	90.2	90.8
Sep-23	-	79.7	90.4	90.7	91.5	91.9	91.5	89.0	89.3	90.7	91.3
Oct-30	-	80.6	89.2	90.0	89.8	91.0	91.5	90.6	90.5	92.7	91.8
Average	-	77.5	89.4	90.5	90.8	91.3	91.3	88.9	90.3	91.4	91.4
StdDev	-	2.4	0.6	0.3	0.6	0.4	0.3	1.9	0.7	1.1	0.8

None of the UV transmissivity samples collected to date from Kalamalka Lake intake depths indicated a problem for UV disinfection. %UVT remained in a suitable range during 2014, varying from 88.9 to 91.9 % in the north and from 85.4 to 92.7% in the south (Table 2.2-12). Average %UVT exceeding 90% occurred at all sites except the 0 m samples in 2014. Overall, %UVT has been stable since 2000 and the differences between north and south sites were small (Figure 2.2-18). While the UVT advantage of an intake at N-40 m versus N-20 m is <3% on average in the 2014 growing season, there is a small advantage to locating a north intake further from Coldstream Creek inflow during freshet and during intense summer storms. During a low freshet year such as 2014, transmissivity at N-30 m was superior to N-20m, but in a high freshet year, the reverse can occur. Similarly, the S-20 m intake and the proposed S-30 m and S-40 m intake depths had UV transmissivity that differed by only <1% in 2014.

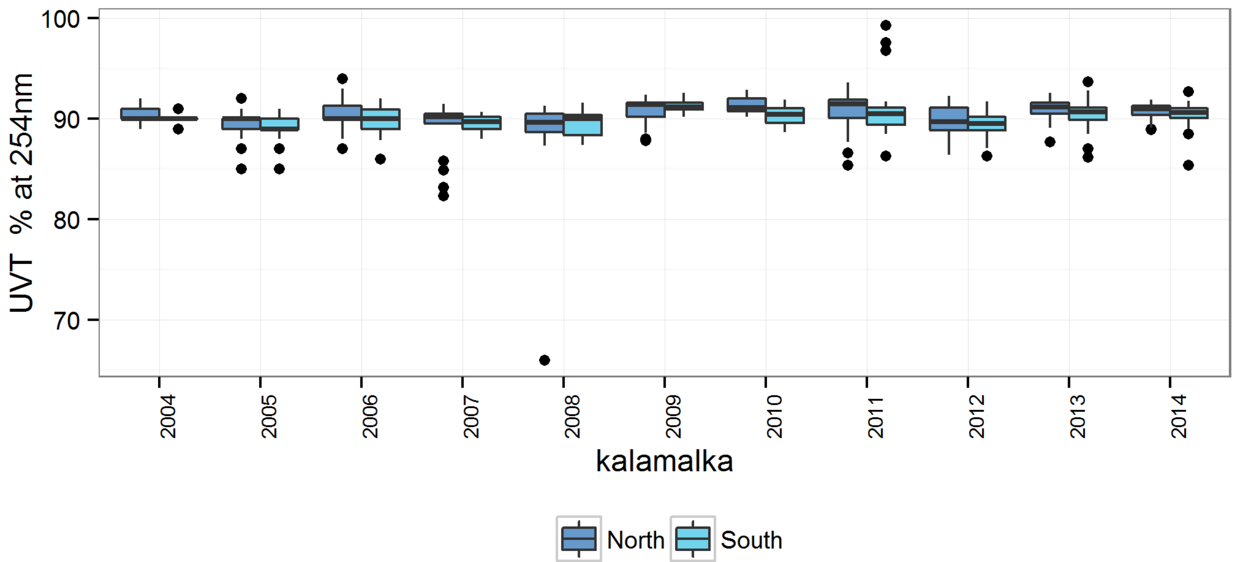


Figure 2.2-18: Kalamalka Lake UV Transmissivity (%UVT 254 nm) from 2004 – 2014 with all depths combined

Turbidity

Turbidity is naturally high in Kalamalka Lake during the marl precipitation. Other natural turbidity sources include freshet silt/debris from Coldstream Creek that contributes much of the spring turbidity in the North Arm, and algae throughout the lake. Turbidity and taste and odor events often coincide in Kalamalka Lake when the cause is algae-driven.

2014 was a moderate marl year resulting in turbidity ranging from 0.2 to 2.1 NTU in the north end of Kalamalka Lake and from 0.2 to 1.5 NTU in the south end (Table 2.2-13). Every year, August had the highest turbidity, with a pronounced spike at 20m corresponding to the marl precipitation and occasionally with higher concentrations of cyanobacteria and detritus as well (Figure 2.2-19). The 2014 data was consistent with this trend. By September, marl cleared from the upper 20 m and increased turbidity in deeper water.

Table 2.2-13: Turbidity in 2014

Turbidity mg/L	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	6.8	1.2	0.8	0.7	0.3	0.3	0.3	1.0	0.4	0.3	0.2
Jun-26	2.2	0.8	0.5	0.9	0.5	0.5	0.2	0.6	0.6	0.3	0.2
Jul-31	1.6	0.7	0.7	0.7	0.4	0.5	0.4	0.7	0.8	0.6	0.4
Aug-28	3	2.7	1.5	2.1	1.0	0.6	0.6	1.5	1.2	1.2	0.6
Sep-23	0.7	0.9	1.0	0.8	0.7	0.5	0.4	0.7	0.6	0.5	0.3
Oct-30	1.1	0.5	1.0	0.8	0.7	0.8	0.6	0.7	0.6	0.5	0.5
Average	2.6	1.1	0.9	1.0	0.6	0.5	0.4	0.9	0.7	0.6	0.4
StdDev	2.2	0.8	0.3	0.5	0.3	0.2	0.2	0.3	0.3	0.3	0.2

During high freshet years, turbidity from the Coldstream Creek plume raised turbidity in the deeper sites, particularly at the N-30m site which was frequently in the path of the plume. Even the 40m site was occasionally affected because the plume travels though the deeper trough in the center of the North Arm (Figure 2.2-19). Over the years of study, this study found that a small Coldstream freshet plume does not have a greater impact on the N-30m site than on the existing N-20m intake site, while a large freshet does.

Overall, 40 m samples had the lowest turbidity and averaged half of the surface or 20 m turbidity. North and south sites had similar growing season turbidities indicating that there were similar causes of turbidity at both ends of the lake and/or efficient mixing (Figures 2.2-19).

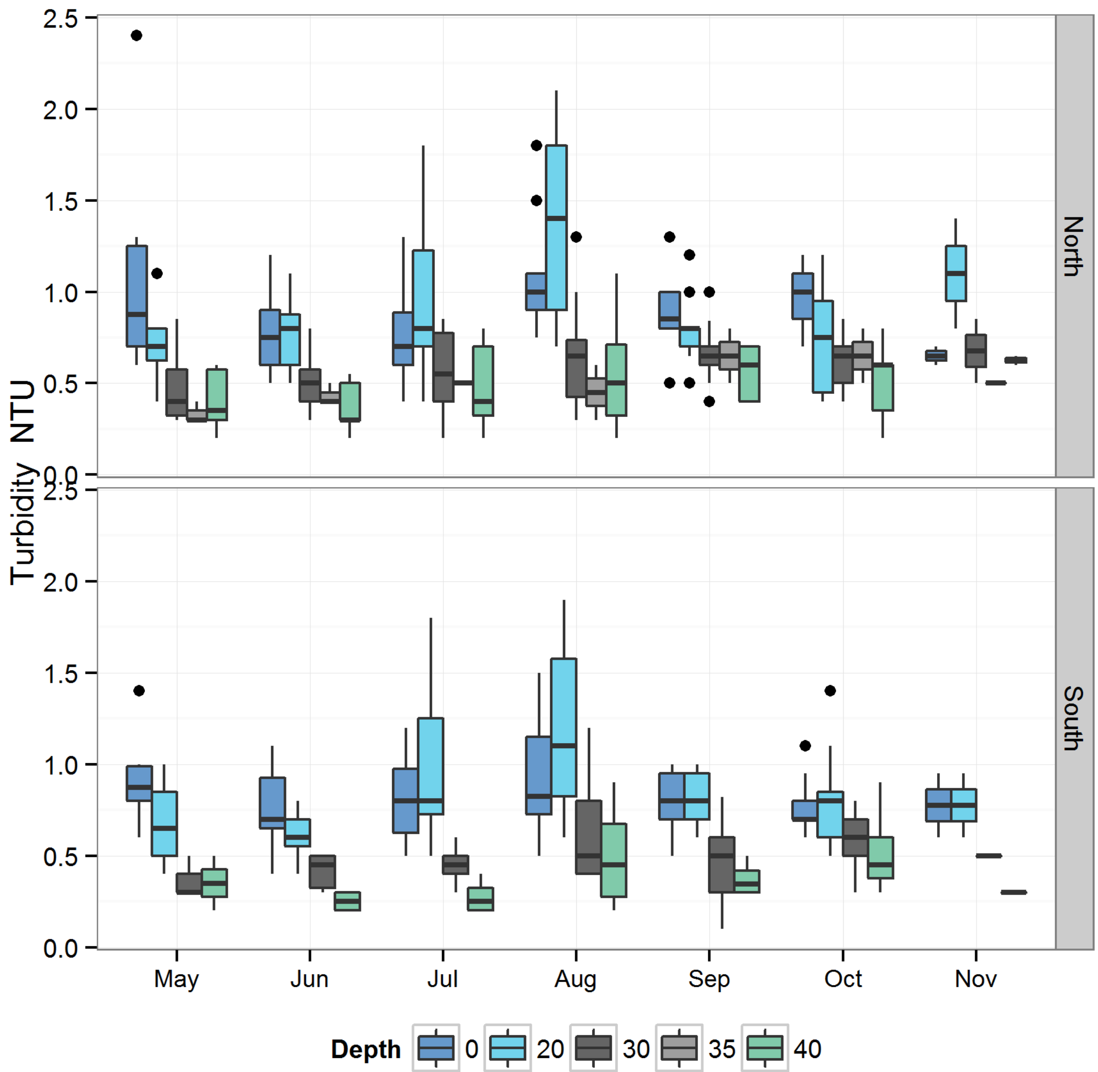


Figure 2.2-19: Monthly turbidity in Kalamalka Lake from 2004 – 2014

Average annual turbidity declined significantly throughout Kalamalka Lake since 2004 (Mann-Kendall, $p<0.001$; Figure 2.2-20). The decline appears to be levelling in recent years. A possibly reduced intensity of the marl precipitation may be causing the decline in Kalamalka Lake turbidity.

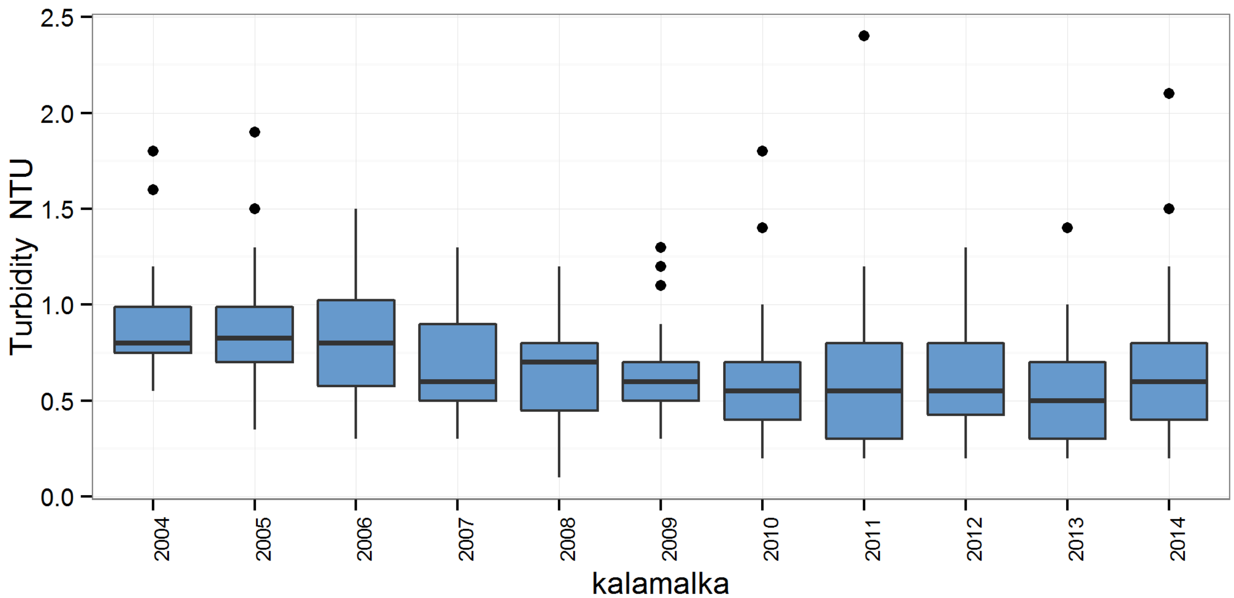
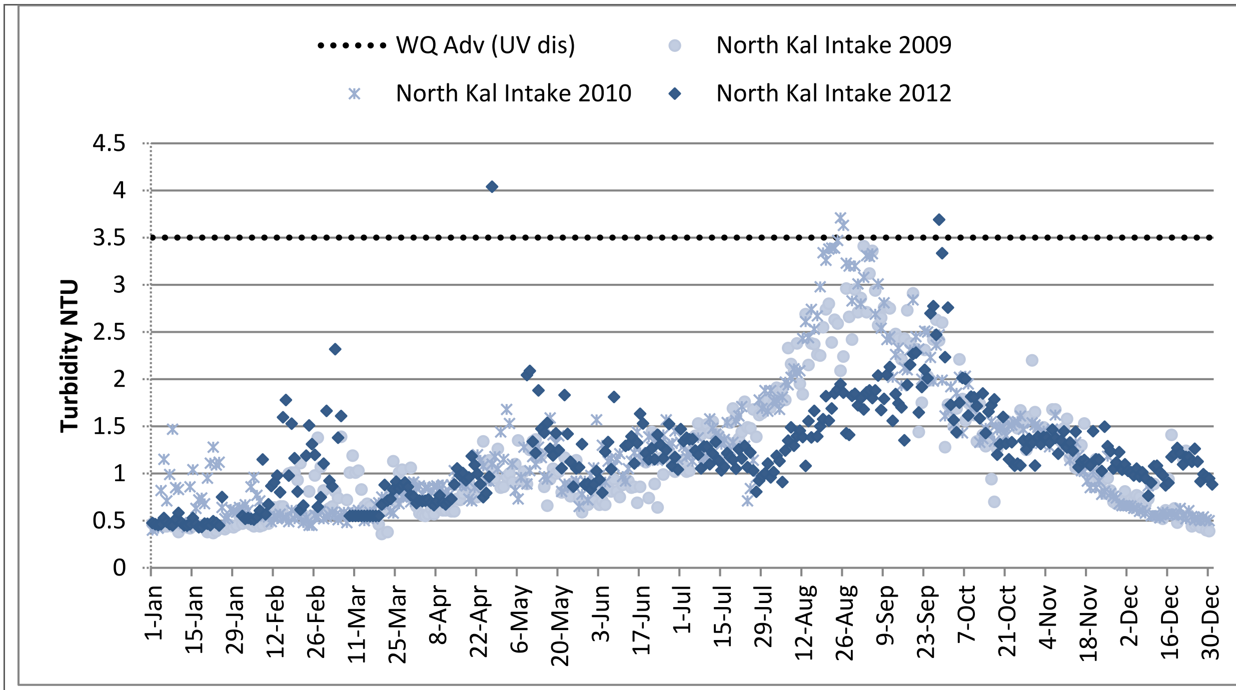
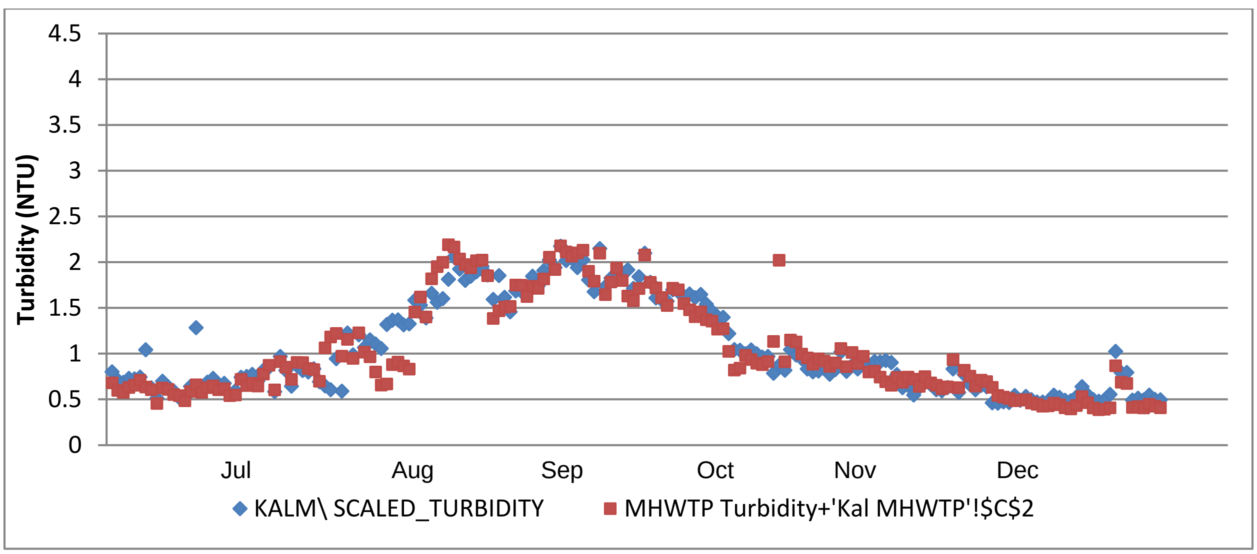


Figure 2.2-20: Annual turbidity in Kalamalka Lake, 2004-2014

Although the lake samples never had average turbidity above 1.8 NTU in any year of study, turbidity exceeding 2 NTU occurred in late summer at the N-Kal intake in most years (Figure 2.2-20). This is significantly more than what is measured in the lake at 20 m where the samples are taken 3 m off the bottom and again implicates the insufficient clearance between the intake and the bottom of the lake. Turbidity of this magnitude does not occur in the DLC S-Kal intake with 2 m clearance.



2009 – 2012 growing season turbidity at North Kalamalka Intake



2013 growing season turbidity at the N Kalamalka Intake

Figure 2.2-21: Turbidity at the RDNO North Kalamalka Intake from 2009 – 2013
Note: RDNO is able to turn off the Kalamalka Lake intake and use an alternate source if the turbidity and the %UVT do not meet the treatment and operational targets

An alternate water source is used and the North Intake is shut off when turbidity exceeds 5 NTU or appears to be rising to that level. For example, the Duteau Creek source was used from February 22- March 26 2013 when rototilling in Kalamalka Lake for milfoil removal elevated turbidity. This intake is also turned off briefly in spring when freshet increases turbidity. In 2014, the intake was shut off from April 23 to April 30. Because RDNO has dual disinfection provided by UV disinfection and chlorine, and because turbidity caused by the marl process is inorganic (microcrystals of calcium precipitate does not affect UVT), turbidity can reach 3.5 NTU (24-hour average) before a water quality advisory is discussed with IHA. This level was not exceeded in 2014 (Figure 2.2-21). For DLC, the turbidity trigger for a water quality advisory is 1 NTU over a 24-hour period, although after UV as secondary form of disinfection comes on-line, DLC may be able use the same guideline as RDNO, particularly since *E.coli* counts are very low in the DLC raw water.

Five types of events on Kalamalka Lake increase turbidity at the N-Kal intake versus three at the S-Kal intake**:**

1) **Coldstream Ck freshet plume:** During the freshet, turbidity measured at the N-Kal intake was as high as 3 NTU during the freshet but that was dilute compared to the 8-9 NTU passing over the intake in the surface water (field meter measurements).

2) **Summer turbidity events:** Turbidity was consistently better in the surface water than at either the N-Kal intake (0.6 m above substrate) or the S-Kal intake (2.0 m above substrate), respectively, during a summer turbidity event. After the marl precipitation, turbidity rose in the deep water throughout the lake (Table 2.2-13).

3) **Seiches:** Severe wind storms cause large seiches and triggered a turbidity event on Oct 18/19 2006 and on November 12 2007 at the N-Kal intake. Smaller seiche impacts occur at the S-Kal intake.

4) **Fall Overturn:** Turbulence generated by the fall overturn increases turbidity briefly to as much as 3.2 NTU at the N-Kal intake. Algae counts on this date were modest, but large amounts of fine detritus confirm seiche penetration to the intake depth (20 m) (Appendix 3). Seiches at fall overturn also penetrate to the S-Kal intake, but its greater clearance from the sediments provides protection.

5) **Rototilling (bottom disturbance):** A final cause of high turbidity (>5 NTU in 2007) was rototilling in the vicinity of the N-Kal intake. With the general flow of water in Kalamalka Lake, rototilling for milfoil control on the north beach area is “upstream” of the N-Kal intake. Water samples collected from the RDNO intake during rototilling have very high organic detritus and fine silt counts, far more than any other Kalamalka Lake water samples. These fine, silty sediments accumulate in aquatic plant beds. Since December is usually a low turbidity time of year, it was recommended that rototilling should be deferred to the freshet months or to November so additional turbidity notifications can be avoided. Accordingly, OBWB rototilling was completed in late October to early December in 2013 but may be later in some years. The November time frame worked well to reduce turbidity issues.

2.2.7 Algae

Algae community composition and numbers are variable from year to year in Kalamalka Lake. These variations help explain the transient water quality problems with taste and odor and turbidity experienced by RDNO and DLC. Within the large whole-lake algae patterns, the shallow ends where intakes are located have distinct algae communities. For example, the North Arm is affected by large freshets because they deliver nutrients that in turn control algae production, while in the south end, Wood Lake contributes cyanobacteria from blooms when water flows north through the Oyama Canal (Figures 2.2-21 to 2.2-22).

The marl character of Kalamalka Lake is a distinctive that limits its algae production relative to Okanagan Lake, despite their similar summer nutrient concentrations (Bryan, 1990). Since marl co-precipitates phosphorous, the timing of the marl precipitation in Kalamalka Lake affects algae growth. Algae growth also promotes the marl precipitation by raising pH. The other key trigger for marl precipitation is water temperature. Warm, dry years such as 2002-2004 favour earlier and larger marl precipitation (Walker et al., 1993) and they have smaller inflows, thus dry years tended to have lower productivity (Figures 2.2-21 and 2.2-22). The timing of the 2014 Kalamalka marl precipitation was normal, occurring in late July. Wood Lake did not marl in 2012-2014, allowing greater diatom densities there.

Like most regional lakes, Kalamalka Lake experiences a spring diatom/cyanobacteria bloom in response to circulating freshet nutrients and increasing day length. 2014 was another above-average year in the North Arm while algae counts in the south end were in line with the long term averages for Kalamalka Lake (Figures 2.2-21 and 2.2-22). Consistent with past years, the diatoms *Cyclotella, Fragilaria, Asterionella and Melosira* dominated May and June samples. The highest spring densities occurred in the surface and 20 m samples in both north and south sites (Appendix 3). These diatoms did not cause problems for RDNO or DLC, however, their silicate shell-like frustules are essentially made of glass and will reduce point-of-use filter longevity.

After the spring diatom bloom, algae numbers usually remain strong until the marl precipitation removes phosphorus from the Kalamalka Lake water column. A summer lull results, followed by a smaller fall bloom, led by cyanobacteria. This is consistent with a reduction in the lake nutrients following marl precipitation and is normal for the Okanagan region (Bryan, 1990). The fall 2014 cyanobacteria bloom in Kalamalka Lake was relatively mild. It was dominated numerically by *Lyngbya* throughout the water column. Both intake and 20 m samples contained more algae than either the surface or the deep samples (Figure 2.2-22 and 2.2-23). While the diatoms dominated by cell volume, the blue-green cyanobacteria dominated numerically in most fall samples collected in this study (Appendix 3). This is a function of the large difference in cell size between the two types of algae.

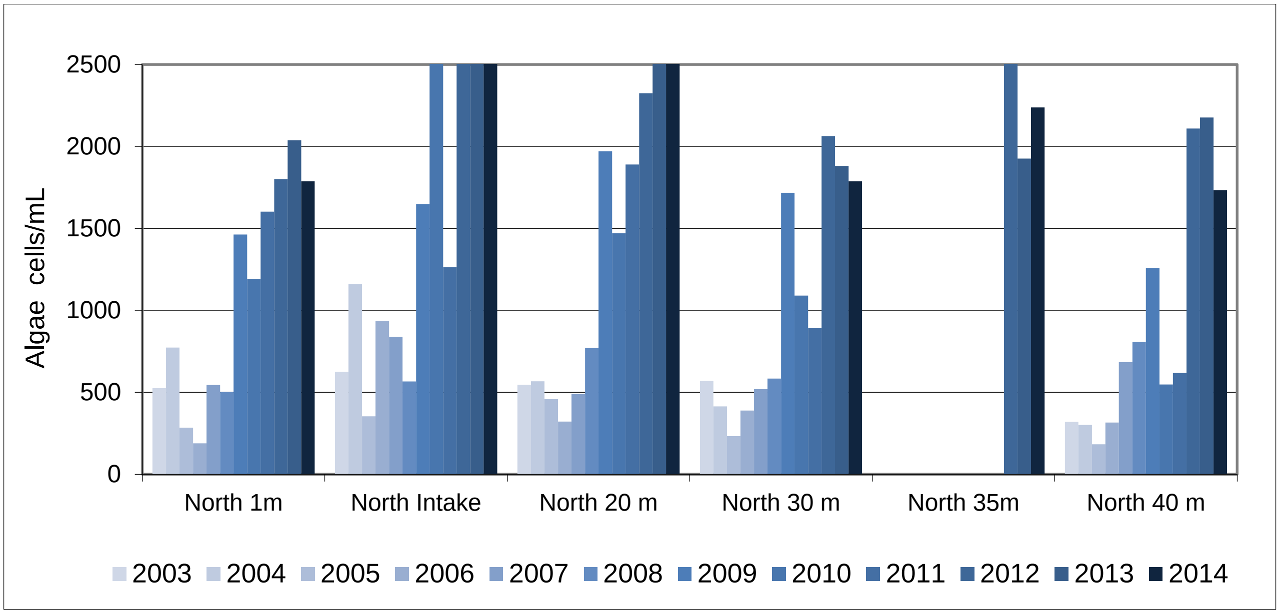


Figure 2.2-22: Average algae densities in North Kalamalka Lake since 2003
(2012 intake counts prorated with 2005-2011 monthly averages to fill in for missing samples)

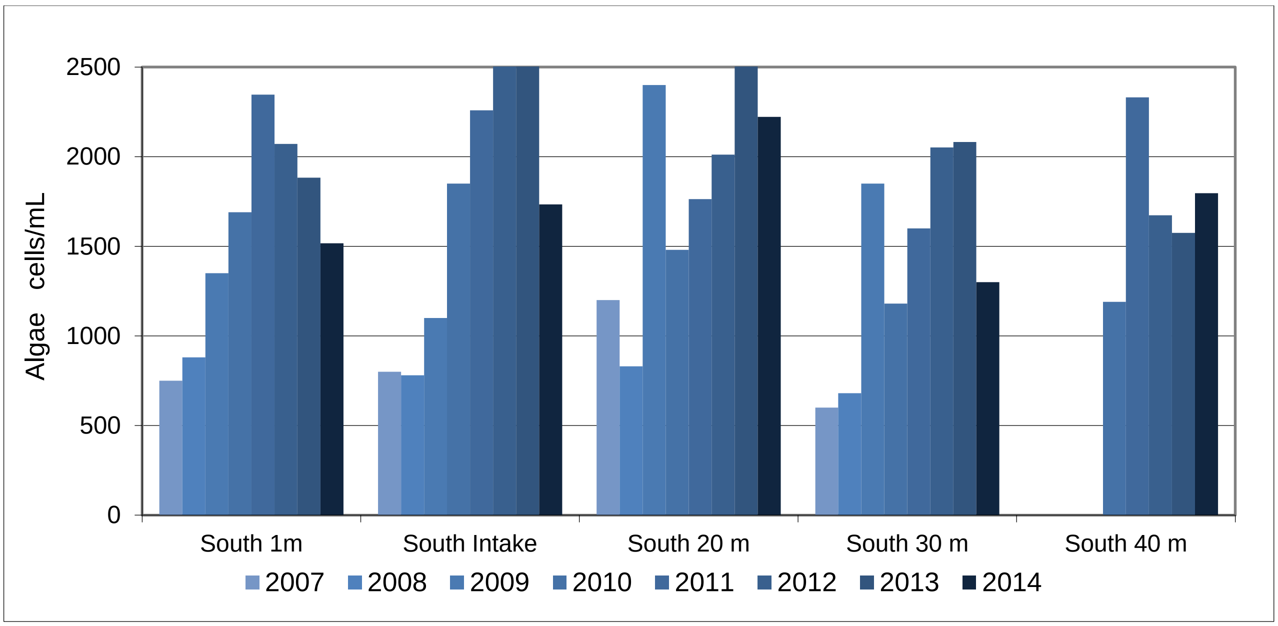


Figure 2.2-23: Average algae densities in South Kalamalka Lake since 2007
(2012 intake counts pro-rated with 2005-2011 monthly averages to fill in for missing samples)

Cyanobacteria (blue-green algae) are a key component of the Kalamalka Lake algae densities. Every year, 12 -15 blue-green cyanobacterial species are counted in Kalamalka Lake and every year they are dominated by *Lyngbya limnetica, and Anacystis cyanea* in the surface water as well as *Oscillatoria spp and Planktothrix agardii* in deeper water (Appendix 3). MoE data shows a gradual increase in the blue-green component since the 1970s, but there is considerable variation in the dominance of the cyanobacterial species from year to year. Several cyanobacteria species found in Kalamalka Lake are known to produce toxins (*Anacystis, Lyngbya, Anabaena, Limnothrix, Oscillatoria Planktothrix),* but to date, they have not been present in densities sufficient to present a toxin risk

(Appendix 6). Additionally, the microcystin group of toxins produced by these algae can be broken down by chlorine (Larratt, 2009). Other cyanobacteria toxins are less vulnerable to chlorine. Like most years covered in this study, cyanobacteria densities did not reach toxic thresholds during 2014 at any Kalamalka Lake sites.

The proportion of the algae counts from cyanobacteria were elevated in 2013 but declined in 2014. They accounted for 12 – 73% of the 2012 samples, 33 – 78% of the 2013 samples and 31-68% of the 2014 samples (Table 2.2-14). At the south and north ends of Kalamalka Lake, average cyanobacterial densities at the 40 m depth were lower than the 20 m depths by 15% and 9% respectively during 2014, but the difference was not statistically significant over the course of this study (Figure 2.2-24). Through the 2014 growing season, average cyanobacteria numbers varied as the surface and deep-water cyanobacteria populations oscillated (Figure 2.2-24). In 2014, the north 40 m site had the lowest average cyanobacteria densities of the North sites (677 cells/mL versus 808 - 1896 cells/mL).

Cyanobacteria spikes were regularly observed in N-Kal intake algae samples that were less intense at the adjacent 20 m grab sample. In 2014, the cyanobacteria drawn into both intakes included types associated with substrates and/or deep water. Increasing the intake clearance would reduce the cyanobacterial density and the susceptibility to seiche-related turbidity in the raw water. Cyanobacteria counts in the 2014 south intake samples were also higher than the other south sites, ranging from 1825 cells/mL in May to 425 cells/mL on August 28. S-Kal intake counts have been consistently higher than N-Kal intake counts but in 2014, the reverse was true where algae counts averaged 970 ± 519 cells/mL while they were 1896 ± 1236 cells/mL in N-Kal intake samples. Neither utility received taste and odor complaints from these high cyanobacteria densities.

Wood Lake often has a cyanobacteria bloom of *Aphanizomenon flos-aquae* but it was not detected in 2014. Instead, a small bloom of *Anacystis* developed in spring but did not have a noticeable impact on the south surface Kalamalka algae samples (Appendix 3).

Over the past 15 years of study, N-0m samples have regularly shown large numbers of the fishy-smelling *Dinobryon sertularia.* In 2011 through 2014, *Dinobryon* was also found in the south epilimnion samples in similar numbers (Appendix 3). *Dinobryon* usually stays high in the water column and rarely affects the RDNO or DLC intakes. The presence of *Dinobryon* in South samples during the last three years may indicate a change in water quality. This alga proliferates in lakes that receive bacteria-rich river discharges. In addition to photosynthesis, *Dinobryon* may be feeding on bacteria coming in from Coldstream Creek in the North Arm and from Wood Lake in the South.

Figure 2.2-24 summarizes the 2003 – 2014 data shown by year in Figures 2.2-22 and 2.2-23. Over the years, average algae densities in South Kalamalka Lake have exceeded those of the North Arm. At both ends of the lake, algae counts increased in the deep water (>40 m) because of larger populations of deep-water cyanobacteria species. The N-30 m depth can have far greater algae concentrations than the N-20 m site during a large runoff event, but overall it had lower algae densities than the N-20 m site.

Total algae counts in the North intake were higher than counts collected near the surface or at the N-20 m site, while S-Kal samples showed a smaller change between depths (Figure 2.2-24). The 0.6 m clearance of the N-Kal intake from the sediments is implicated since the S-Kal intake with 2 m clearance had similar algae counts to its adjacent 20 m lake samples in most years.

In south Kalamalka Lake, all sampled depths had similar algae densities (Figure 2.2-23). The 30 m algae samples showed a consistent, small advantage over the 20 m samples. Still, the 30 and 40 m samples routinely had 900 - 1200 cells/mL cyanobacteria (Appendix 3). Seiches are more intense in the south end and may be obscuring the difference between the algae counts at the deep sites.

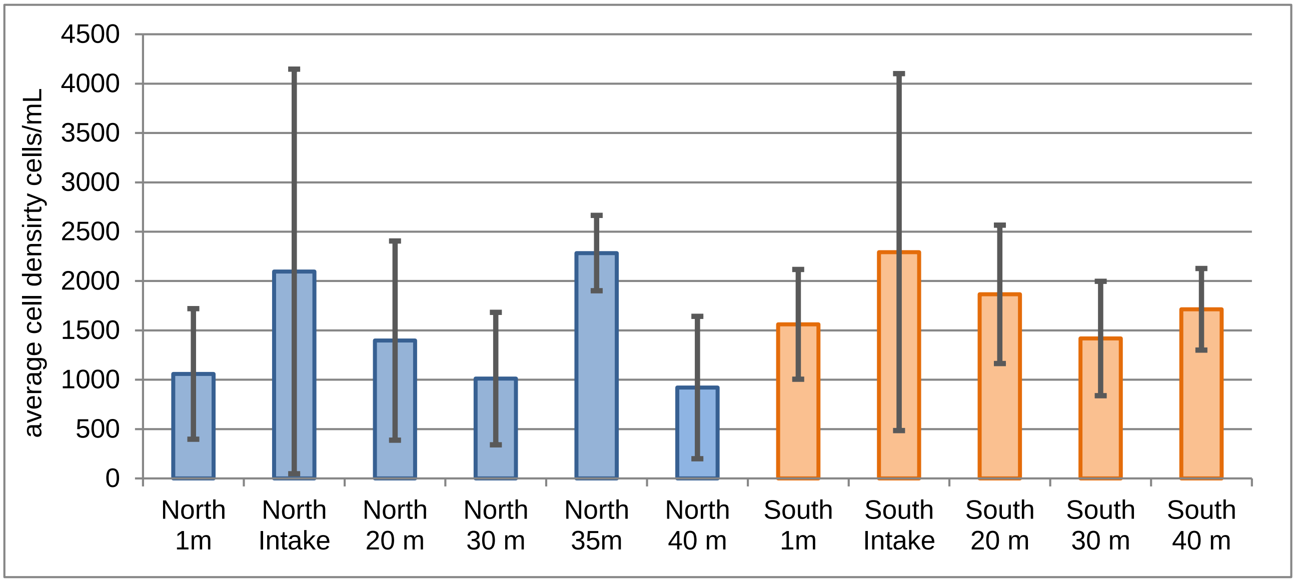


Figure 2.2-24: Average 2003 - 2014 total algae densities in North and South Kalamalka Lake sample depths, **showing standard deviations as error bars.**

Algae and Taste and Odor Events
Like many surface water supplies, high cyanobacteria counts and complaints of musty taste and odor in Kalamalka Lake water are correlated. Many blue-green cyanobacteria generate the compounds (MIB and geosmin) that are responsible for musty odors. These and other algae produce a further musty, decaying taste and odour when they are decomposed by *Actinomycetes*. Except for 2001 and 2002 when cyanobacteria were confined to September, these algae are common in Kalamalka Lake throughout the growing season. During the lake-wide 1999 taste and odor event that prompted this study, cyanobacteria counts exceeded 1700 cells/mL at the N-Kal intake. 2005, 2006 and 2009 also had mild odor events caused by algae. In 2014, the highest count from the North intake was 3250 cyanobacteria cells/mL and the South intake was 1825 cells/mL in June and May respectively (Appendix 3). The presences of A*ctinomycetes* decomposers and re-suspended detritus may also be required to induce a taste and odor event. A faint odor may have occurred but most consumers accept a very mild odor as natural. In the DLC system, Oyama customers are more aware of this odor because they are not on the system full time and are therefore less acclimatized than the rest of the DLC customers.

As usual, cyanobacteria counts were higher than those from the 20 m samples that are collected from 24 m depth so with 3-4 m clearance. An intake right on the bottom of Kalamalka Lake would be much more vulnerable to taste and odor events than one positioned more than 3 m from the substrate. Over the years of study, the N-Kal intake with a clearance of only 0.6 m experienced more problems with taste and odor and more cyanobacteria than the S-Kal 20 m intake with 2 m clearance (Table 2.2-14). In the 16 years of research to date, intake samples have occasionally exceeded the 2000 cyanobacteria cells/mL AWWA threshold of concern.

Table 2.2-14: Percent of 2014 algae sample density made up of cyanobacteria

North	Cyanobacteria	Density cells/mL	South	Cyanobacteria	Density cells/mL
Surface	13%	1788	Surface	14%	1517
Intake	55%	3417	Intake	56%	1734
20m	40%	3187	20m	42%	2222
30m	45%	1788	30m	49%	1300
35m	41%	2238	40m	46%	1796
40m	39%	1734			

There are other causes of taste and odor events in Kalamalka Lake besides algae blooms. During 2007, a seiche-induced turbidity/odor event took place in late September. In this case, the turbidity particles were primarily detritus, bacteria and decaying algae, rather than viable algae from the water column. Another event occurred December 2011 when Coldstream Creek inflows and the air above the lake throughout the North Arm smelled like manure and again on February 23 2012 when turbidity and bacterial densities spiked at the N-Kal intake

Nutrient loading can be reduced by improved riparian protection on Coldstream Creek, and by agricultural waste management plans and controls that prevent or significantly reduce agricultural manure/fertilizer impacts to drainage areas of Coldstream Creek, Kalamalka Lake and groundwater recharge areas. The reduction of nutrient loading will ultimately reduce the risk of taste and odor events in the North Arm and throughout Kalamalka Lake.

2.2.8 Bacteria

Total coliforms are a broad category of bacteria that indicate the amount of bacterial loading in the water. *E. coli (Escherichia coli*) are found in mammal or bird wastes and they serve as an indicator of fecal contamination. Only a few of the thousands of *E. coli* strains are disease-causing, however, if *E. coli* are present, the presence of other bacteria pathogens can be statistically correlated. *E. coli* counts do not correlate well with other classes of pathogens such as viruses (Carter et al. 1986; Keith et al, 1999).

2014 growing season bacterial counts were low in S-Kal samples and ranged from <1 – 4 CFU/100mL *E.coli.* Wood Lake samples were also low for *E.coli and* were consistently below detection in 2014 (Table 2.2-15). These values were lower than the <1 – 11 CFU/100 mL *E. coli* measured in North Kalamalka samples.

Coldstream Creek contains large numbers of bacteria that probably come from multiple locations where animals live near surface water (Sokal, 2010). Bacteriological grab samples taken from Coldstream Creek can miss pulses of pathogens, particularly during storm events. However, multiple years of sampling helps overcome this problem, as does sampling Kalamalka Lake where bacteria can remain suspended for weeks, making it easier to capture bacterial pulses missed in the creek samples. Figure 2.2-25 shows variable bacterial densities that likely reflect precipitation patterns, urban land use and farming practices.

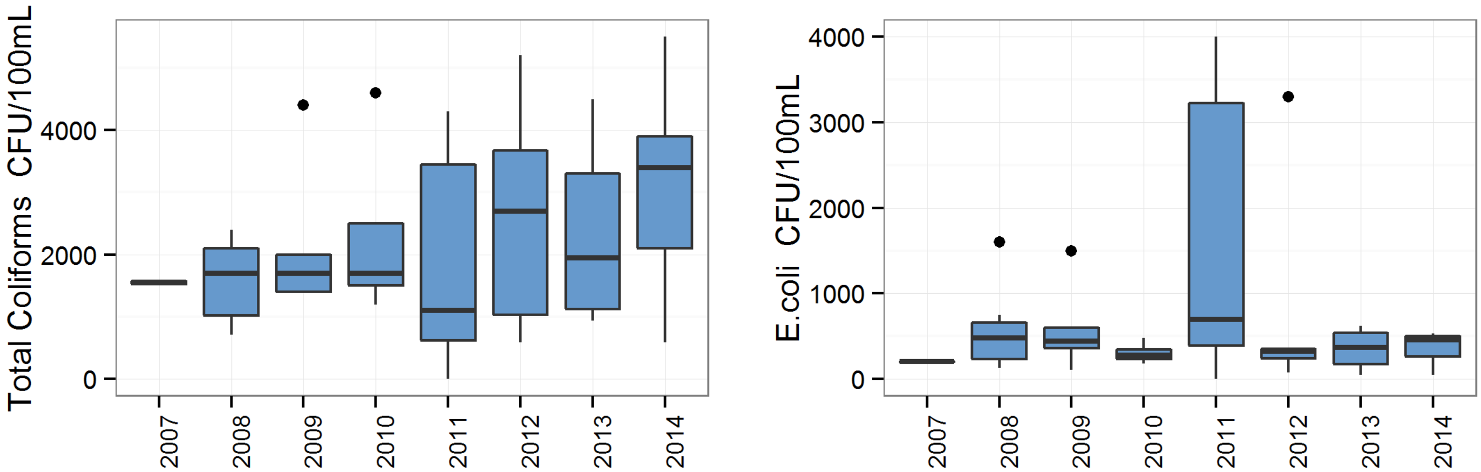


Figure 2.2-25 Total Coliforms in Coldstream Creek, 2007-2014
NOTE Overgrown treated as a count of 4000 CFU/100mL

May to October 2014 bacterial results from the mouth of Coldstream Creek were high (Appendix 1). 2. Like all years studied, a dramatic peak in Coldstream Creek *E. coli* counts (to 530 CFU/100 mL in 2014) occurred during the rising leg of freshet. In 2014, the total coliform counts ranged from 890 to 5500 colony-forming units (CFU) per 100 mL.

There was a significant difference between North and South Kalamalka sites from 2007-2014 for both total coliforms and *E. coli* (KW-Test, $p<0.001$). This north-to-south difference also occurred in the 2014 bacterial data (Table 2.2-15, Figure 2.2-26). High bacterial counts in Coldstream Creek continue to be a concern and doubtless contribute to the elevated bacterial counts in the North Arm compared to the south end of Kalamalka Lake or Wood Lake (KW Test, $p<0.001$; Appendix 1). With averages of 3098 ± 1857 CFU/100mL total coliforms and 360 ± 203 CFU/100mL *E. coli*, clearly Coldstream Creek has bacterial loading problems from its watershed. RDNO samples Coldstream Creek year-round and is studying the seasonal changes and land-use impacts.

Table 2.2-15: Bacteria counts (CFU/100mL) in North and South Kalamalka Lake during 2014

E. coli	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	530	<1	<1	1	<1	<1	<1	2	<1	<1	<1
Jun-26	260	<1	<1	5	<1	<1	<1	1	<1	<1	<1
Jul-31	-	<1	<1	1	<1	<1	1	<1	<1	<1	<1
Aug-28	500	<1	<1	11	<1	<1	<1	<1	<1	<1	<1
Sep-23	460	<1	2	3	<1	<1	<1	<1	<1	<1	<1
Oct-30	50	<1	5	5	5	1	<1	<1	4	<1	<1
Average	360	<1	2	4	1	<1	<1	<1	1	<1	<1
StdDev	203	<1	2	4	2	<1	<1	<1	1	<1	<1

Total Coliforms	CS.Ck.	Wood	0mN	20mN	30mN	35mN	40mN	0mS	20mS	30mS	40mS
May-31	3900	<1	<1	DGT1	1	<1	<1	DGT2	<1	<1	<1
Jun-26	2100	<1	<1	5	<1	1	<1	3	<1	<1	<1
Jul-31	-	<1	15	15	21	19	15	<1	8	9	15
Aug-28	3400	2	<1	Overgrown with	<1	<1	Overgrown with	1	<1	1	<1
Sep-23	5500	1	3	6	<1	1	3	<1	<1	2	1
Oct-30	590	3	11	5	6	12	5	<1	4	1	<1
Average	3098	1	5	8	5	6	5	1	2	2	3
StdDev	1857	1	6	5	8	8	6	1	3	3	6

NOTE Overgrown treated as a count of 4000 CFU/100mL

The total coliform data from 2007- 2014 showed no clear benefit with increasing depth, while the *E. coli* counts did show a small but statistically significant benefit with increasing depth at both ends of the lake (KW-Test, $p \le 0.001$). At N-Kal sites, *E. coli* were highest at the N-20m (10 ± 42 CFU/100) and lowest at the N-40m site (1 ± 2 CFU/100mL), while at S-Kal sites, S-0 m samples were highest (1 ± 2 CFU/100mL) and S-40 m samples were lowest (<1 ± <1 CFU/100mL; Figure 2.2-26).

Total coliform criteria for filtration deferral states that no more than 10% of samples should exceed 100 CFU/100ml in a six-month period, and *E. coli* criteria states not more than 10% of samples should exceed 20 CFU/100 mL in a six-month period. Both the monthly data and the growing season averages indicate that the 30m to 40m depths throughout Kalamalka Lake would consistently meet this criteria, while the seiche prone 20 m intake depths also contain low bacteria concentrations and meet these objectives except when the sediment is disturbed. The north intake is particularly susceptible to sediment disturbances. Although a surface intake would never be contemplated, the surface water also appears to meet the deferral criteria. Surface water may benefit from solar UV deactivation and predation by zooplankton.

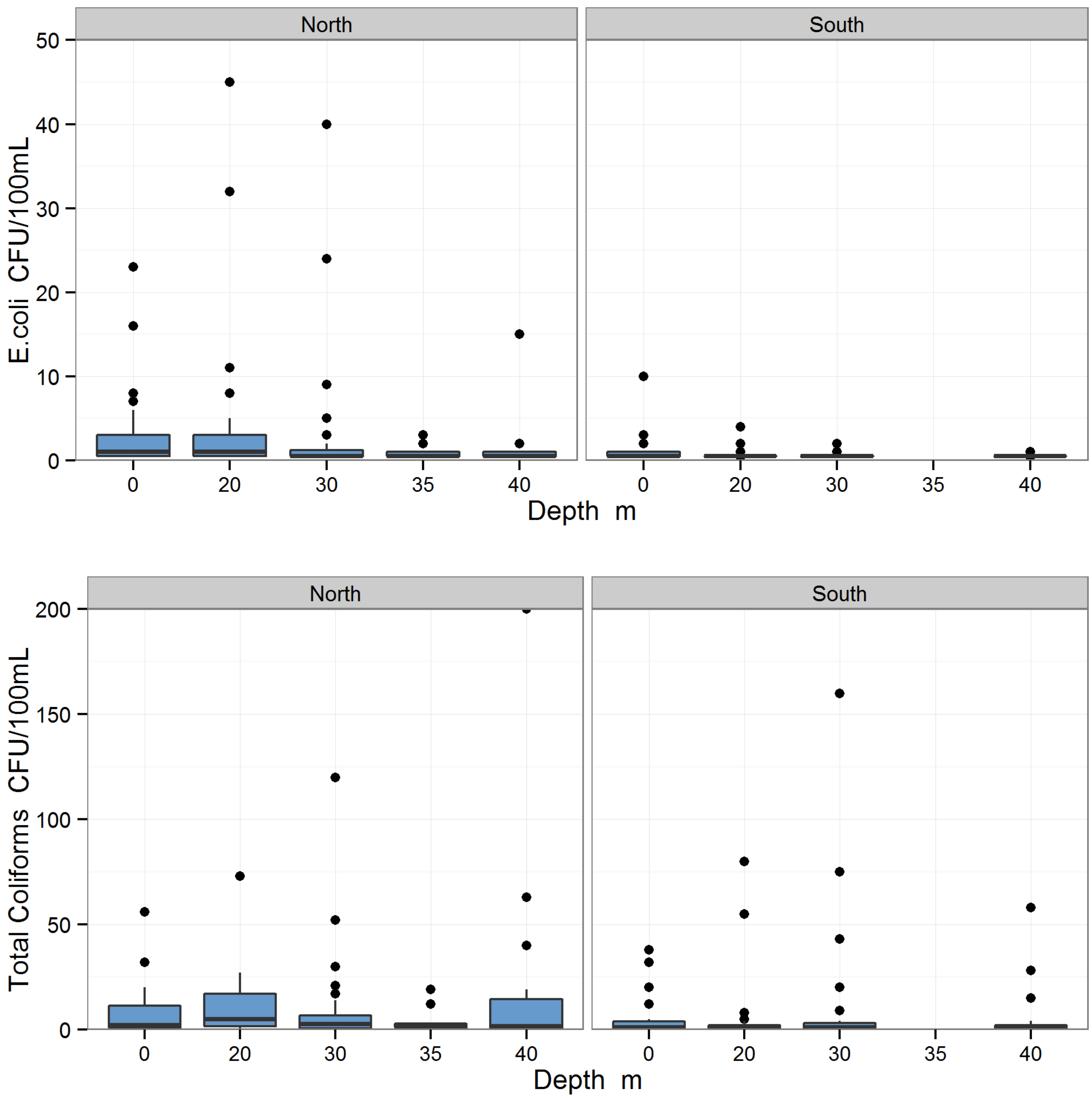


Figure 2.2-26: Bacterial densities in North and South Kalamalka Lake, 2007-2014
(Note: DGT numbers were plotted as actual values, overgrown "with" samples were plotted as 4000 CFU/100 mL)

2.2.9 Invasive Mussels

The water chemistry of Kalamalka and Wood lakes make them particularly vulnerable to invasive Dreissenid mussels. The consequences for RDNO and DLC include needing to protect the intakes from infestation (Figure 2.2-27). This is usually achieved with chlorine injection at the intake mouth, however consideration will have to be given to marl encrustation at the point of chlorine injection. Invasive mussels also selectively feed on algae but reject cyanobacteria, making cyanobacteria blooms more common. This alters the food webs of a lake with repercussions for lake ecology and fisheries. Additional impacts are outlined in Appendix 7.

Figure 2.2-27: Invasive dreissenid mussels in water line

3.0 Summary of Kalamalka Lake Study to date (1999 – 2014)

3.1 Freshet and Storm Flows

The Coldstream Creek freshet plume varies in size, duration and intensity from year to year and also within each freshet. During early freshet, Coldstream Creek has low density and it flows into the surface of Kalamalka Lake where it affects the entire North Arm. In late freshet, the inflow plume loses buoyancy and interflows into Kalamalka Lake; a portion of the flow travels along the bottom and affects the RDNO N-Kal intake.

In a large freshet, the water quality at 30 m is temporarily inferior to the water quality at the existing 20 m intake. In most freshets, the 40 m site had better quality than the 30 m site. During the balance of the year, there was little difference between the water quality at these two potential intake extension sites. Water at 47 m and 57 m still showed an impact from the diluted Coldstream freshet plume. Therefore, it is not possible to completely evade the influence of the Coldstream Creek plume in the North Arm.

During freshet and summer storms, Coldstream Creek responded within 24 hours with higher flows and turbidity spikes. Local storm drain water and disturbed riparian areas on Coldstream Creek contribute to this rapid response to storms.

Based on 2014 density calculations, Coldstream Creek plume stays high in the water column until later summer when it drops to the bottom of the north arm. By early October, the Coldstream Creek plume should travel near the 20 m depth and can impact the north intake. This makes the late October/early November period suitable for rototilling.

3.2 Seiches

The main transport mechanism of surface contaminants to the existing 20 m Kalamalka Lake intakes is seiches. Both ends of the lake experience seiches that tip the surface water to the intake depth. Seiches have the biggest impact on intake water quality in June and the fall. North or south-west winds with gusts exceeding 30 km/h can generate a seiche depending on the duration of the wind event. A typical period for the seiche to travel from the north to the south ends of the lake (15.4 km) would be approximately a day. The shape of the lake basin causes more intense seiches at the South end, while North end seiches have more turbulence associated with them.

RDNO's N thermistor chain indicated that an intake positioned deeper than 30 m would be much less impacted by seiches than the existing 20 m intake. Seiches produce noticeable spikes in water temperature, conductivity, turbidity, color and algae densities at the existing N-Kal and S-Kal 20 m intakes. At the south end of Kalamalka Lake, seiches penetrate deeper into the water column because of the shape of the southern lake basin. Water temperature changes of 5-8 °C within 48 hours are routine at the current Lake Country 20 m intake (Appendix 1). The compiled S-Kal thermistor data shows a marked seiche impact on the S-30m site in every growing season with temperature deviations from 4 °C in a cool summer to 7 °C in a warm fall with more intense seiches in the fall. These seiches temperature deviations are smaller than those seen at the existing intake.

Profiles from 2004 through 2014 also showed oxygen super-saturation near the thermocline during the summer caused by bacterial and cyanobacterial photosynthesis. Oxygen super-saturation was extensive in 2014, and occurred throughout Kalamalka Lake in response to algae production (Figures 2.2-1 and 2.2-2).

3.3 Water Chemistry

Over the past century, water quality was relatively stable in Kalamalka Lake (Bryan, 1980). Its unique marl precipitation provides some protection to Kalamalka Lake from phosphorus loading arising from human activities in its watershed.

Every year, the single greatest impact on water quality in Kalamalka Lake is the size of the freshet, affecting nitrogen, phosphorus, pH, calcium, sulphate and organic/inorganic particulate inputs. Low inflow years import far less phosphorus to Kalamalka Lake since P adheres to soil particles. Modest freshet flows usually result in small microfloral densities. Inflowing nutrients can impact several years of lake production because only 2% of the lake water exchanges each year. In general, nutrient concentrations at the North and South sites on Kalamalka Lake move together, indicating whole-lake influences such as freshet (P) or groundwater (N) nutrient inflow. Both nutrients control production. Phosphorus dropped at all sites over the course of this study, while nitrogen did not show a significant trend.

pH data from 2000-2014 suggests that pH oscillates on a weather-driven decadal scale in Kalamalka Lake. pH is impacted by photosynthesis so that a high productivity year has higher pH. Marl co-precipitates phosphorus and B12 vitamin, causing a rapid drop in summer algae production and this helps to maintain Kalamalka Lake water quality. Most water quality parameters are consistent throughout the summer and only minor change occurs with depth. The marl precipitation causes a small increase in calcium, conductivity and hardness in deeper water.

Salinity continued to slowly increase in 2014, probably through urban sources (Mann-Kendall trend for chloride, $p<0.001$ at 0mN and 0mS). Chloride concentrations have tripled since the 1970s, probably through road salt application, while sodium has slowly oscillated upward from 16 to 19 mg/L, but the rate of increase appears to be slowing in recent years. The ratios of Na:Cl indicate that Coldstream Creek and Wood Lake were more impacted by road salt than Kalamalka Lake where dilution is greater.

TOC production in Kalamalka Lake peaked in 2010 and has since declined. In 2014, all sites exceeded the recommended 4.0 mg/L. UV transmissivity was excellent throughout Kalamalka Lake and it showed a small improvement with increasing sample depth.

Wood Lake is smaller and receives more nutrients from internal loading than Kalamalka Lake does. It is productive and donates nutrients to Kalamalka Lake in most months when its water elevation exceeds that of Kalamalka Lake. Marl precipitation occurs sporadically in Wood Lake, assisted by inflow from Kalamalka Lake and from groundwater. Wood Lake's nutrient concentrations were lowest between 2006 and 2009 (minimum in 2009 of 0.33 mg/L TN: stable TP at 0.052 mg/L) to mesotrophic levels and have since increased, particularly total nitrogen.

3.4 Turbidity, UV Transmissivity and Particle Size

Kalamalka Lake has natural turbidity ranging near 1 NTU at 20 m due in part to marl precipitation. At 30-40 m, turbidity was lower, with growing season averages ranging from 0.3 – 0.6 NTU. Turbidity at both the North and South ends of Kalamalka Lake showed a significant declining trend since 2004. Average turbidity also declined with increasing depth throughout Kalamalka Lake. Since Coldstream and storm water flows are the dominant sources of turbidity in the North Arm, deeper sites that are further from the mouth should have lower annual turbidity, however the data shows that it is not possible to completely evade the freshet turbidity plume at any location within the North Arm.

Over the past decade, turbidity exceeding 1-2 NTU occurred at both intakes in the summer months. Samples with high turbidity also contained unusually high concentrations (>1000 cells/mL) of blue-green algae, detritus, bacteria and marl, indicating re-suspension of sedimented material. Turbidity was consistently better in the surface water than at the intake 20 m depths during the summer turbidity events, suggesting that distancing the N intake from the bottom by more than the current 0.6 m and the S intake by more than the current 2.0 m would be advisable (>3 m is recommended).

UV transmissivity ranged from 86 – 94 % in Kalamalka Lake with an average at the intakes of 90-91%. From 2004-2014, UV transmissivity was superior in deeper water.

Particle sizes were generally small with all particles less than 75 microns in diameter. Very fine (<1.5 microns) particles of marl are abundant and increase the turbidity and sedimentation rate of Kalamalka Lake. Rototilling on the main N end beach caused a large turbidity/ *E. coli* incident for RDNO's N-Kal intake. A disturbed sediment sample from 20 m contained 3.6 cfu/100 mL *E. coli* in 2014.

3.5 Microflora Production, Taste and Odor Events

A correlation between large freshets and greater algal production was noted in this study and previously by MoE. Large freshets import more phosphorus, a key nutrient controlling algal production in Kalamalka Lake. Years with large freshets are more likely to experience algae-driven water quality problems such as increased turbidity, chlorine demand, taste and odor and lowered UV transmissivity. 2013 was a departure from this trend where a near-normal freshet occurred and overall microflora productivity was high while 2014 was closer to historical norms.

Super-saturation of dissolved oxygen at depth indicates heavy microfloral growth. Periods of super-saturation coincided with elevated turbidity at the intakes. Super-saturation extended beyond 20 m at all sites in the North Arm, strongly suggesting a photosynthetic bacteria/cyanobacteria component since their light requirements are smaller than those of most algae.

Based on cell numbers, there was a predominance of cyanobacteria in most growing seasons. Over the 15 years of this study, the prevalence of cyanobacteria appears to be increasing in Kalamalka Lake. Average algae densities are usually, but not always lower at 40 m compared to surface, 20 and 30 m samples. Samples collected from 30 and 40 m contained less chlorophyll-a than samples from 20 m. Seiches create turbulence that suspend fine marl sediment and algal material from the substrate and increase turbidity at the intakes. To realize the benefit of lower algae production at the 30 or 40 m sites, a new intake should be positioned at least 3 m above the substrate. Samples collected from 47 m and 57 m in 2011 showed an increase in cyanobacteria concentrations over the 30 and 40 m samples.

The evidence to date indicates that periodic taste and odour problems occurring in Kalamalka Lake are caused by unusually high cyanobacteria concentrations. However, years like 2013 and 2014 had high cyanobacteria production and a taste and odor event did not result. The presences of A*ctinomycetes* decomposers and re-suspended detritus may also be required to induce an event. For example, a January 2010 nutrient influx from Coldstream Creek to the North Arm immediately triggered a complex algae bloom and also contributed to an unusually large spring diatom bloom. A February 23 2012 influx of creek flows apparently containing manure affected the N-Kal intake and triggered complaints. TOC and bacterial counts were very high during and following this event. The large diatom bloom that resulted plugged filters throughout the distribution system.

Cyanobacteria blooms are perennial at Wood Lake in the spring and late fall when nutrients were circulating, however, the fall bloom did not occur in 2014. One bloom was severe enough to close beaches on the May long weekend, 2008. A smaller bloom occurred in spring 2009 and again in March 2011 (not May when they typically occur). As in other years, Wood Lake production in 2014 was roughly double that of Kalamalka Lake.

3.6 Bacterial Loading

Coldstream Creek always contained more bacteria than any site in the North Arm on all dates for *E. coli* and on all dates but one for total coliforms in the bimonthly 2011-2012 data. *E. coli* spikes of >10 CFU/100mL occur in the North Arm. The 2011 and 2012 bimonthly results suggest that completely evading the creek plume is impossible within the N Arm. In all of the bacterial results to date, the bacterial counts from the south end of Kalamalka Lake were lower than those from the north end.

Within the N Arm, there were significantly higher *E. coli* counts at N-20m (intake depth) and a distinct declining trend with increasing water depth. A 30 m intake would provide water with lower *E. coli* loads than a 20 m intake with the same clearance for most of the year, but would provide inferior water during a large freshet as in 2008. The total coliform data showed no clear benefit of deeper intakes. North Arm sediments were dark and consisted of imported silt and marl that contained more viable bacteria, were more organic and consumed more oxygen within 0.5 m than the south sediments that were beige and marl-based.

Spikes in *E. coli* in north Kalamalka Lake can be the result of numerous factors:

- Cattle over winter in the Coldstream Valley from Oct until June the following year.
- Dairy waste spread in winter, especially on frozen ground.
- Freshet flushing of the watershed and creek sediments, especially the section from Noble Canyon intake to School Drive where creek was diverted – that creek bed is still forming, with lots of fines still to flush out.
- Rains flushing the Coldstream system and storm water inflows can cause slope failures from farm land into Coldstream Creek. Many storm water outfalls drain directly to Coldstream Creek or Kalamalka Lake.
- Sediment disturbance during rototilling for Eurasian milfoil control could cause brief *E. coli* spikes because viable bacteria can re-suspend from surface sediments.
- Canada Geese and gulls congregate in calm water areas near the shoreline and gulls congregate near the 40 m site.
- If agricultural waste (manure) is not managed properly, spills to either Coldstream Creek or the North Arm can cause significant *E. coli* spikes.
- Seiches can re-suspend viable bacteria from the sediments into the bottom water of the N Arm if they were recently deposited
- Natural UV sunlight disinfection is lowest during the winter months. Sunlight UV deactivation of bacteria is greatest near the surface in water with low turbidity and high transmissivity.

Bacteria counts from the South Kalamalka sites were far lower than counts from the N Arm sites in every year of this study.

4.0 Summary of Extended, Deeper Intake Benefits

Extending the drinking water intakes deeper into Kalamalka Lake theoretically reduces the risk of contaminants from land-based activities, bacterial loading and algae numbers. The biggest disadvantage to extending the intakes is the cost of installation and the cost of maintenance (Cotsworth, pers comm 2009). The imminent threat of invasive mussels will also add cost for additional maintenance or refitting the intake with chlorine injection to discourage their growth (Appendix 7).

Over the years of study of increasingly deeper potential intake sites, TOC, conductivity, and TDS did not vary with depth sufficiently to impact water quality, treatment or aesthetics (Table 4.0-1). Still other parameters including pH and UV transmissivity demonstrated slight improvement at deeper sites, but all monitored depths were well within desirable ranges for domestic water. A few parameters showed significant change that could affect water quality and they include chl-a, algae density, turbidity, and bacteria concentrations.

The importance of algae densities increases if filtration is considered in the future. The regular periods with large diatom densities would adversely affect filtration and may require an additional treatment prior to filtration. Diatom blooms are regular occurrences in the spring, but have occurred at other times in response to increased nutrient concentrations.

The differences in water quality described in this section are based on the growing season – the time of greatest frequency of water quality problems and the highest demands. During the fully mixing winter season, the differences in water quality between the depths would be less.

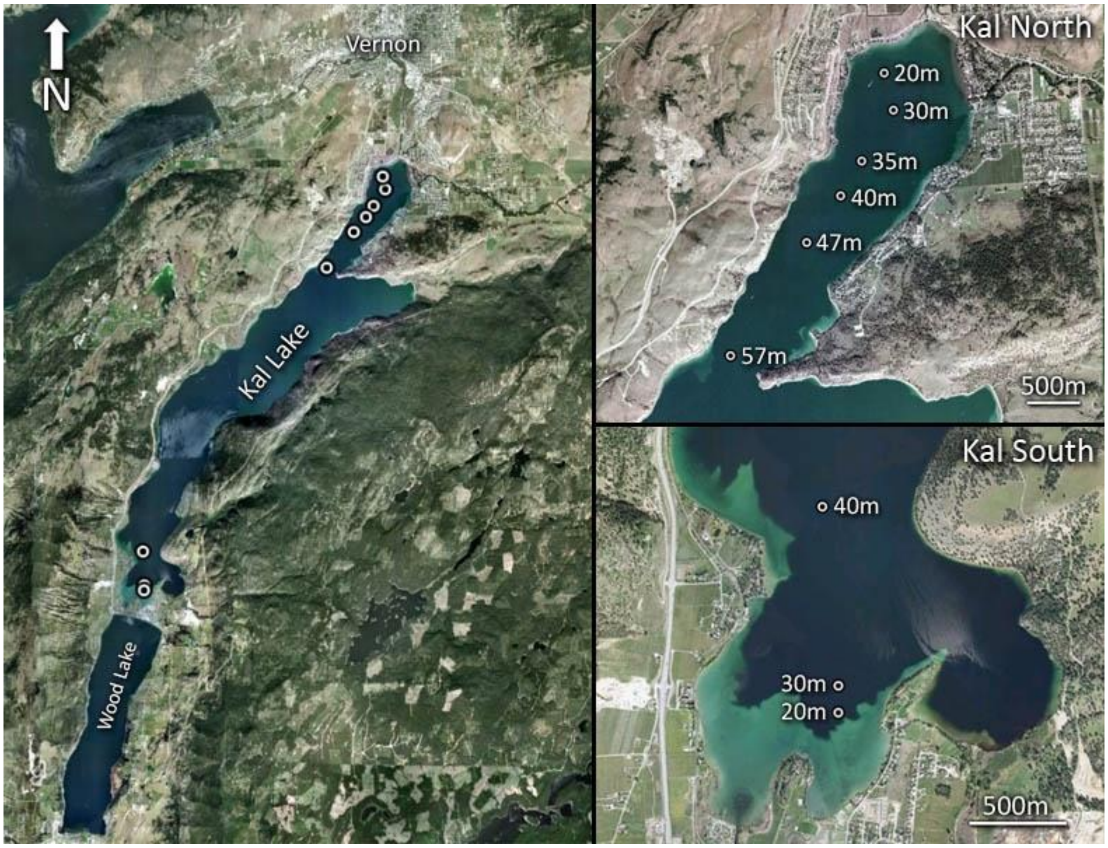


Figure 4.0-1: Kalamalka Lake Sample Sites

4.1 North Kalamalka Intake Extension

Additional monitoring was conducted at the N-35m depths in 2013 and 2014. Algae numbers and were higher at the N-35m site than the other north depths. In theory, this would make N-35m less desirable in instances were taste and odor issues are a concern. The UVT results were excellent at all Kalamalka sites.

Overall it appears that the N-40m site is the best option due its stable, high water quality and reasonable distance to the existing pumphouse. The N-30m showed poorer water quality than the N-20m intake in heavy freshets, but was superior at all other times. With more data, it may become apparent that the N-35m site is a reasonable compromise and it is 375m closer to the pumphouse than the N-40m site.

Based on all years of study, the advantages of extended intakes <u>with 3 m clearance</u> in north Kalamalka Lake over the existing RDNO 20 m intake site are detailed by site, below:

North 30 m (365m extension)

- N-30 m would have a mean annual temperature of 5.5 °C with a range of 4.3 – 8.0 °C under normal conditions
- Fewer seiches (4/year) and they would have smaller maximum temperature deviation of 1.5 – 10 °C
- Lower turbidity, usually 0.3 – 0.8 NTU , averaging 0.5 NTU (except during large Coldstream Ck freshet when turbidity has reached 1.7 – 3.6 NTU)
- Negligible change in UV transmissivity in most years but a significant decrease to 88% during large Coldstream Ck freshets

- *E. coli* normally range from <1 – 2 CFU/100 mL, but range from <1 – 40 CFU /100 mL in a large freshet and averaged 5 CFU /100mL in 2011-2012 bimonthly data
- Fewer incidents of high background bacteria counts (as happened in Aug 2009)
- Fewer cyanobacteria than 20 m, typically averaging 400-600 cells/mL (maximum of 1875 cells/mL in 2014) in the growing season, with annual average chl-a 0.9 -1.6 µg/L

North 35 m (900m extension)

- N-35 m would have a mean annual temperature of <5.0 °C with a range of approximately 4.2 – 7 °C under normal conditions
- N-35 m would have fewer seiches (2/yr), with a maximum temperature deviation of 1.5 – 7.5 °C
- Lower turbidity, usually 0.2 – 0.7 NTU, averaging 0.49 NTU and UVT of 91%
- *E. coli* usually non-detectable, i.e *E. coli* = <1 – 1 CFU/100mL, but ranged from <1 to 26 CFU/100mL and averaged <1 CFU/100mL to date
- Moderate cyanobacteria (average 1180 cells/mL, maximum of 1775 cells/mL in 2014) and moderate algae densities averaging 2290 cells/mL with annual average chl-a of 0.9 – 1.3 µg/L

North 40 m (1275m extension)

- N-40 m would have a mean annual temperature of 4.5 °C with a range of 4.1 – 5.4 °C under normal conditions
- N-40 m would evade most seiches, with a maximum temperature deviation of 1.5 – 4 °C
- Lower turbidity, usually 0.2 – 0.7 NTU, averaging 0.49 NTU
- *E. coli* usually non-detectable, i.e. *E. coli* = <1 – 1 CFU/100mL, but ranged from <1 to 15 CFU/100mL and averaged 1 CFU/100 mL to date
- Very low cyanobacteria (average 634 cells/mL, maximum of 1760 cells/mL in 2014) and very low algae densities of up to 1560 cells/mL with annual average chl-a of 0.9 – 1.2 µg/L

4.2 South Kalamalka Intake Extension

Possible intake extension sites at 30 m and 40 m depths have been studied in South Kalamalka Lake. As noted throughout this report, 40 m sites are, on average, the best sites for an intake. However, the distance required for this improvement may be cost-prohibitive. Additionally, the 2012 40 m calcium data was consistently elevated at this site, suggesting a localized groundwater input, but sampling in 2013 and 2014 did not show a significant increase. Scaling and deposition following chlorination could be an increased problem at this site if further sampling identifies elevated calcium. Using the data to date, it appears that the 30m site would provide the biggest benefit in terms of lower turbidity and chl-a, cooler temperatures and fewer seiche events with smaller temperature deviations compared to the existing intake. Extending the South Kalamalka Lake intake to 30 m is planned in the DLC Water Master Plan.

Based on all years of study, the advantages of extended intakes <u>with 3 m clearance</u> in south Kalamalka Lake over the existing DLC 20 m intake site are detailed by site, below:

South 30 m (205 m extension)

- S-30 m would have a mean growing season temperature of 5.5 °C with a range of 4.3 – 9.8 °C under normal conditions
- 8 – 10 seiches reach 30 m annually, with a maximum temperature deviation of 3.2 – 6 °C and a typical range of 2-3 °C fluctuation

- Lower turbidity, usually 0.2 – 0.8 NTU, averaging 0.49 NTU
- Negligible change in UV transmissivity except during marl events and fall overturn when it will increase slightly to average 92.4 ± 3.9% in August and 90.1 ± 1.9% in Oct
- <1 – 2 CFU/100 mL E. coli; <1 -8 CFU/100 mL total coliforms or excellent source water with fewer background bacteria spikes (e.g. July 2009)
- Lower algae production; algae growing season chl-a average of 1.2 – 2.4 µg/L, but algae blooms can reach >4.0 µg/L chl-a at S-30m
- Average cyanobacteria density here were usually similar or lower than those at the existing intake

South 40 m (1260 m extension)

- S-40m would have a growing season average temperature of 4.8 °C with a range of 4.1 – 8.1 °C under normal conditions
- 4 – 5 seiches reach 40 m annually, with a maximum temperature deviation of 3 °C
- Lower turbidity than 20 m, usually 0.2 – 0.7 NTU, averaging 0.38 ± 0.19 NTU
- Negligible change in UV transmissivity (except during fall overturn)
- Non-detectable *E. coli*; <1 – 3 CFU/100 mL total coliforms or excellent source water
- Lower algae production, growing season average chl-a of 1.1 ± 0.50 µg/L (can reach 2.5 µg/L) and average deep-water cyanobacteria density at S-40 m was not significantly different than the existing intake site in several years (e.g. average of 832 cells/mL at S-40m vs 970 cells/mL at intake in 2014) (Table 4.0-1).

Table 4.0-1: Average water quality change with current and potential intake depths, using 2013 only and combining all data to date

Kalamalka Lake 2014	South 20 m	South 30 m	South 40 m	North 20 m	North 30 m	North 35 m	North 40 m
Distance to pumphouse* m	550	755	1810	315	680	900	1590
Average temperature °C	6.8	4.7	4.4	5.6	4.6	4.4	4.3
# of seiches over 2 °C/yr	20	8	5	10	4	2	1
Max seiche temperature fluctuation °C	14	3.2	3	11.7	9.9	7.5	4
pH	8.08	7.97	7.98	8.00	7.97	8.00	7.99
Hardness mg/L	179	182	179	185	181	183	181
Total calcium mg/L	38.9	39.8	38.9	40.7	39.1	39.3	38.8
Total organic carbon mg/L	5.2	4.9	4.5	5.0	4.7	4.5	4.6
Chlorophyll-a µg/L	1.3	1.1	0.9	2.1	1.3	1.2	0.9
Turbidity NTU	0.70	0.57	0.37	1.00	0.60	0.53	0.42
UV Transmissivity %	90.3	91.4	91.4	90.5	90.8	91.3	91.3
Avg algae counts cells/mL	2222	1300	1796	3187	1788	2238	1734
E. coli CFU/100 mL	<1-4	<1	<1	1-11	<1-5	<1-1	<1-1
Total coliforms CFU/100mL	<1-8	<1-9	<1-15	1-OG	<1-21	<1-19	<1-OG

Kalamalka Lake 2000-2014	South 20 m	South 30 m	South 40 m	North 20 m	North 30 m	North 35 m‡	North 40 m
Distance to pumphouse* m	550	755	1810	315	680	900	1590
Average temperature °C	7.3	5.5	4.8	6.3	5	4.7	4.5
# of seiches over 2 °C/yr	20	8	5	10	4	2	1
Max seiche temperature fluctuation °C	14	3.2	3	11.7	9.9	7.5	4
pH	8.13	8.06	8.12	8.09	8.00	8.07	7.97
Hardness mg/L	170	174	173	171	173	184	172
Total calcium mg/L	37.4	38.4	38.3	37.5	37.9	39.9	37.6
Total organic carbon mg/L	4.7	4.9	4.8	4.7	4.7	4.1	4.7
Chlorophyll-a ug/L	1.7	1.6	1.1	1.9	1.5	1.1	1.2
Turbidity NTU	0.83	0.49	0.38	0.88	0.58	0.49	0.49
UV Transmissivity %	90.0	91.1	91.2	90.2	90.5	91.0	90.9
Avg algae counts cells/mL	82	99	195	60	92	113	174
E. coli cfu/100 mL	<1 - 4	<1 - 2	<1 – 1	<1-270	<1-40	<1-1	<1-1
Total coliforms cfu/100mL	<1-700	<1-500	<1- 100	<1-3700	<1-530	<1-19	<1-1000

***Minimum possible distance from pumphouse to sample site, actual engineered intake locations may vary
OG = overgrown
‡: 2012-2014 water chemistry data only

5.0 Recommendations

5.1 Coldstream Creek Protection

The long-term Kalamalka Lake study results have provided ample evidence to link the poor water quality from Coldstream Creek to a direct negative impact on water quality in the RDNO Kalamalka intake. Any improvements to water quality of Coldstream Creek would benefit the water quality at the north intake. The following section was provided by RDNO.

RDNO has initiated a Kalamalka Lake / Coldstream Creek Watershed Assessment Response Plan to support a Kalamalka Intake Protection Zone. The Source Assessment Report (Larratt 2011) provided recommendations to assist in formulating this plan. RDNO is working with the District of Coldstream to ensure land use policies and bylaws focus on the protection and improvements to Coldstream Creek watershed and the north-end of Kalamalka Lake to reduce negative impacts on Kalamalka Lake water quality. This will support RDNO's application for "Exclusion of Filtration" for RDNO Kalamalka Lake intake/ MHWTP.

There are two components to the Assessment Response Plan to ensure compliance with our permit to operate. The first condition on RDNO's permit to operate states "Provide a Source Protection Plan for each Water Source, Source Water Assessment / Source Water Assessment Response Plan (Kalamalka Lake Intake)" The terms and conditions on the permit to operate are placed under Section 8 of the *Drinking Water Protection Act*. As such, there is a legislative requirement to comply with all terms and conditions of the permit. (IH, July 13, 2010).

The Drinking Water Protection Act Part 3 Section 22 provides direction for the development of an "Assessment Response Plan"

> ***"22*** *(1) In addition to any changes to the terms and conditions of an operating permit made in response to an assessment, the drinking water officer may order the water supplier to prepare an assessment response plan if:*
>
> *(a) an assessment has identified threats to the drinking water provided by the water supply system, and*
> *(b) the water supply system is of a prescribed class.*
>
> *(2) The purpose of an assessment response plan is to identify the measures that may reasonably be taken in order to address identified threats to the drinking water that is provided by the water supply system.*
>
> *(3) An assessment response plan must be prepared in accordance with the regulations and the directions of the drinking water officer.*
>
> *(4) As examples of provisions that may be included in an assessment response plan, but without limiting the issues that may be addressed, the drinking water officer may require a plan to include provisions respecting any or all of the following:*
> *(a) public education and other means of encouraging drinking water source protection;*
> *(b) guides to best management and conservation practices;*
> *(c) infrastructure improvements;*
> *(d) cooperative planning and voluntary programs;*
> *(e) input respecting local authority zoning and other land use regulation.*
>
> *(5) The drinking water officer may order a water supplier to review and revise its assessment response plan in accordance with the directions of the drinking water officer."*

The second part is laid out in the attached document –DRINKING WATER TREATMENT OBJECTIVES (MICROBIOLOGICAL) FOR SURFACE WATER SUPPLIES IN BRITISH COLUMBIA

Page 6: Guidelines for Canadian Drinking Water recommend that filtration and one form of disinfection be used to meet the treatment objectives. Alternatively, two forms of disinfection (for example, chlorination and UV disinfection) may be considered if certain criteria are met. A water supply system may be permitted to operate without filtration if the *four following conditions* for exclusion of filtration are met, or a timetable to implement filtration has been agreed to by the drinking water officer:

i. Overall inactivation is met using a minimum of two disinfections, providing 4-log reduction of viruses and 3-log reduction of *Cryptosporidium* and *Giardia*.

ii. The number of *E. coli* in raw water does not exceed 20/100 mL (or if E. coli data are not available less than 100/100 mL of total coliform) in at least 90% of the weekly samples from the previous six months.

iii. Average daily turbidity levels measured at equal intervals (at least every four hours) immediately prior to where the disinfectant is applied, are around 1 NTU but do not exceed 5 NTU for more than two days in a 12-month period.

iv*. A watershed control program is maintained that minimizes the potential for fecal contamination in the source water. (Health Canada, 2003)*

Applying the exclusion of filtration criteria does not mean filtration will never be needed at some point in the future. A consistent supply of good source water quality is critical to the approach and, therefore, exclusion of filtration must be supported by continuous assessment of water supply conditions.

Changing source water quality can occur with changes in watershed conditions. Increased threats identified through ongoing assessment and monitoring may necessitate filtration. Maintaining the exclusion condition relies on known current and historic source water conditions, while at the same time provides some level of assurance to water suppliers that a filtration system may not be necessary unless the risk of adverse source water quality increases.

Efforts to reduce contaminants in Coldstream Creek should include (but should not be limited to) the following protection measures:

- Restore riparian zones and create sufficient buffers
- Reduce and/or pre-treat stormwater flowing directly into Coldstream Creek
- Work with the agricultural community to minimize effluent, manure and fertilizer releases to the creek
- Minimize salt entry to the watercourse

5.2 Intake Modifications

Low clearance of intake screens from the lake bottom can have a large negative impact on water quality because the withdrawal layer can include bottom water with re-suspended sediment. To avoid this, it is recommended that the intake screens be elevated a minimum of 3 m from the bottom of the lake to prevent the intake. This is especially true for the RDNO intake screen as the north end of the lake has fine, silty substrates and a minimal screen clearance of only 0.6 m from the lake bottom.

The study shows better water quality at deeper depths for both the north and south ends of the lake. On average, the 40m sites have the best overall water quality and the most protection from turbulence caused by seiches. However, occasionally deep-water cyanobacteria counts were elevated at the sites greater than 40 m.

Based on all data to date for South Kalamalka, it is recommended that the DLC extend their intake to 30 m. A 30 m intake would provide cooler water with improved and more stable water quality than the existing intake. This recommendation has been included in the DLC Water Master Plan to be implemented in 2015.

For the north, it is recommended that RDNO either install another intake at 30 m, having dual intakes at 20 m and 30 m, or extend the intake to 40 m. Water at 30 m at the north end of the lake provides inferior water quality during a heavy freshet year because the intake would be physically closer to the Coldstream Creek plume path. Having dual intakes, one at 20 m and one at 30 m, would allow a choice to use either the 20 m or the 30 m. The 30 m intake could be used for most of the year and the 20 m intake could be used during a large freshet. Alternatively, extending the RDNO intake to 40 m would provide water with lower temperature, fewer seiches, lower turbidity and better UV transmittance, but with periodic increased cyanobacteria counts. Utilizing the N-47m site is not recommended due to reduced water quality in combination with the costs involved.

The substantial cost of installing and maintaining deeper intakes would have to be weighed by both DLC and RDNO against the benefits of other forms of water treatment. An engineering cost-benefit assessment would benefit the decision-making process.

5.3 Kalamalka Lake Protection from Source Assessment Report

Recognition of intake protection zones (IPZ) and exclusion of new, high risk activities from these zones is important enough that a License of Occupation or a head-lease should be considered so protection of critical riparian areas around an intake come under the more focused attention of the local municipal government. The shoreline area should be regularly photographed for practices that can impact water quality. Please refer to the Source Assessment report for the remaining recommendations.

5.4 Invasive Mussels

Work with OBWB on initiatives to request senior government to install boat inspection/disinfection stations and to convince BC boat owners to Clean Drain Dry their boats when moving between lakes.

5.5 Data Base Maintenance

2014 was the 16th year of this study. 2014 data was added to the extensive database on Kalamalka Lake compiled for this project in 2013. We recommend that this database be updated annually and supplied to RDNO, DLC, and MoE.

In 2015, we recommend that the algae data be added to the database and be maintained moving forward.

6.0 Proposed Sampling Program for 2015

The water quality parameters recommended as part of this study are needed for the benefit of current and future water treatment and to track long-term trends that can impact domestic water quality.

As in all years, the proposed schedule covers the growing season when most water quality issues occur. We propose to monitor water quality, plankton algae, thermal structure and bacterial samples on a monthly basis, May – October, 2015. Sample locations should include raw intake water, surface water, and the intake depths (20 m), including any proposed depths for extended intakes*. Any sites that are no longer under consideration can be removed from the sampling schedule.*

Once again, we propose to collect samples for total coliform, *E. coli*, chlorophyll-a, pH, UVT, total organic carbon, sodium and chloride and have samples analyzed at Caro Labs, Kelowna, BC. A LAC Hanna multi-meter will be used to collect profiles for pH, conductivity, TDS, temperature and dissolved oxygen. Total alkalinity, T-calcium, T-iron, T-magnesium, T-hardness, sulphate and total suspended solids would be sampled again in 2016 year based on a biannual schedule.

MoE will conduct March and autumn sampling for nitrate + nitrite, ammonia, total N, ortho P, total dissolved P, and total P. These results are provided to this study.

Larratt Aquatic evaluates the whole and plankton tow samples for algae taxonomy and density. LAC also monitors all samples for the presence of invasive mussel veligers (larvae).

If a high turbidity phase greater than 3 NTU at an intake occurs in 2015, samples should be collected from every 5 m for turbidity, dissolved oxygen/temperature, pH, conductivity, TDS and microfloral identification, within the week where turbidity exceeds 2 NTU.

Repeat the collection of sediment samples by disturbing the substrate, collecting a water sample 1 m above the substrate, and analyze for bacterial parameters. Composite samples could be collected from Coldstream Creek, N-20m, N-30m, N-40m, N-50m and N-60m and from S-20m, S-30m and S-40m in mid-summer.

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