Vaseux Lake Land Use and Water Quality Assessment– Sedimentation, Nutrient Loading and Invasive Milfoil Study Year 2 Report

FINAL

Prepared for Regional District Okanagan Similkameen

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

Executive Summary

The main objective of this Vaseux Lake Land Use and Water Quality Assessment is to determine likely sources of nutrients and sediment contributing to the increased invasive milfoil (*Myriophyllum spicatum*) and to filamentous algae growth observed over the past few years in Vaseux Lake.

This study found that the thermal functioning and hydrology of Vaseux Lake have been stable through the decades since the detailed studies of the 1970's. Other features of the lake were found to be dynamic, including sedimentation rates, aquatic plant growth, and nutrient budgets.

The source of increasing sedimentation in Vaseux Lake was quickly determined to be the Shuttleworth Creek watershed. A major washout in May 2018 carried enough sediment into Vaseux Lake to cloud the entire lake and reduce water clarity to near zero. The large sandbar at the north end of Vaseux Lake changes shape with each freshet but has grown significantly within the past 10 years forming a new island in the process. Control of the plantbeds will not affect the sedimentation rate in the north end of Vaseux Lake because most sediment is deposited during freshet before active growth commences. Rather, reducing sedimentation will benefit macrophyte control efforts because fresh sediment is often nutrient-rich and provides a new growth substrate for macrophytes. Restoration of Shuttleworth Creek is essential if continued rapid expansion of the sandbars in Vaseux Lake is to be minimized.

The large shallow areas of Vaseux Lake are ideal habitat for aquatic macrophytes and would be densely populated even if invasive milfoil was not introduced. A study was undertaken in 1979 that mapped the milfoil beds in Vaseux Lake and this was used as a frame of reference for this study. The 2017 and 2018 plantbeds were both smaller than 1979 in the north and south ends of the lake but the same general areas were identified as having dense beds. During 2017, Eurasian milfoil was a minor component of the macrophyte community and native species were dominant throughout the lake. The population shifted in 2018 and was once again dominated by invasive milfoil. Lakeshore residents have confirmed that the composition of aquatic macrophytes varies from year to year. The diversity of macrophytes found in 2017 and 2018 indicates a dynamic balance between invasive milfoil and native species. Milfoil also appeared to prefer areas of 3-5 m depth as compared to the very shallow north end which was dominated by native species of *Potamogeton spp.* The extent and density of invasive milfoil was similar to what was measured in 1979 and indicates that the plantbeds are not rapidly increasing in size. Ongoing monitoring of the plantbeds is recommended because of the interannual variations in the Vaseux Lake macrophyte populations.

Nuisance filamentous algae blooms have been observed in some years throughout the plantbeds. These were not observed in either 2017 or 2018. Further monitoring of the plantbeds should be undertaken to assess the frequency and intensity of filamentous green algae blooms.

Research conducted from 2013-2017 has not indicted an impact from the Okanagan Falls wastewater treatment plant (WWTP) on the chemistry or biology of Vaseux Lake. An increasing trend in ammonia was noted in Okanagan River upstream of Vaseux Lake but this trend was also present upstream of the WWTP and is attributed to changes within the entire Okanagan Valley

watershed and not just Vaseux Lake.

Nutrient loading estimates revealed that Okanagan River inflows make up approximately 90% of nitrogen and phosphorus contributions to Vaseux Lake each year while internal recycling, local agriculture, and septic fields were relatively small contributors.

Piezometer samples around the perimeter of Vaseux Lake indicate that local groundwater contributes nitrogen and phosphorus to Vaseux Lake but the loads are expected to be low relative to other inflows such as Okanagan River. The east shore subdivision piezometer samples had over 8 times the phosphate of surface samples in Vaseux Lake while the south shore subdivision piezometer samples had 7 times more ammonia than lake surface water.

Enhancement goals include reducing or reversing the excessive milfoil/algae growth and sedimentation rates in Vaseux Lake. We identified five possible approaches that could be taken including restoration and sediment control of Shuttleworth Creek, engineered wetlands along Okanagan River, septic field upgrades, and rototilling of invasive milfoil plantbeds.

Report prepared by: Larratt Aquatic Consulting Ltd.
Heather Larratt: Aquatic Biologist, H. B.Sc. R.P. Bio
Jamie Self: Aquatic Biologist H. B.Sc, R.P.Bio

Acknowledgements
This report benefitted from the dedication and work of many people, including:

- Liisa Bloomfield, Shane Fenske and Janine Dougal of RDOS
- Norm Gaumond, Barry Underwood, Jim D'Andrea and other Residents of Vaseux Lake Association
- Chloe Landes-Michelli and Geoff Luscombe, environmental interns from Australia in 2017
- Alison Peatt of SOSCP

The authors gratefully acknowledge their contributions.

Preferred Citation:
Larratt, H., and J. Self, 2019. Vaseux Lake Land Use and Water Quality Assessment– Sedimentation, Nutrient Loading and Invasive Milfoil Study, Year 2 Report. Prepared by Larratt Aquatic Consulting Ltd. Prepared for Regional District of Okanagan Similkameen.

Table of Contents

Figures and Tables

Glossary

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

Term	Definition
Algae bloom	A superabundant growth of algae
Anaerobic/anoxic	Devoid of oxygen
Benthic	Organisms that dwell in or are associated with the sediments
Bioaccumulation	Removal of metal from solution by organisms via adsorption, metabolism
Bioavailable	Available for use by plants or animals
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment
Diatoms	Algae that have hard, silica-based "shells" frustules
Fall overturn	Surface waters cool and sink, until a fall storm mixes the water column
Epilimnion	A warm upper water layer in a stratified lake
Eutrophic	Nutrient-rich, biologically productive water body
Green algae	A large family of algae with chlorophyll as the main photosynthetic pigment
Hypolimnion	A cool deep water layer in a stratified lake, isolated by the thermocline
Inflow plume	A creek inflow seeks the layer of matching density in a receiving lake
Light attenuation	Reduction of sunlight strength during transmission through water
Limitation, nutrient	A nutrient will limit or control the potential growth of organisms e.g. P or N
Limnology	The study of the physical, chemical, and biological aspects of freshwater
Littoral	Shoreline between high and low water; the most productive area of a lake
Macronutrient	The major constituents of cells: N nitrogen, P phosphorus, C carbon, SO_4 sulphate, H
Micronutrient	Small amounts are required for growth; Si, Mn, Fe, Co, Zn, Cu, Mo etc.
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Reducing env.	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 (> 1°C/m); it separates the surface water (epilimnion) from the cold hypolimnion below
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

Abbreviations

Organizations Locations	Parameters and units
BCWQG BC Water Quality Guidelines	Chl-a chlorophyll-a
CDWQ Guidelines for Canadian Drinking Water Quality	DIN dissolved inorganic nitrogen
MoE Ministry of Environment	DO dissolved oxygen
LAC Larratt Aquatic Consulting Ltd.	DOP dissolved inorganic phosphorus
IH Interior Health	ML megaliter (1 million liters)
WWTP waste water treatment plant	TOC total organic carbon

Lake Classification by Trophic Status Indicators

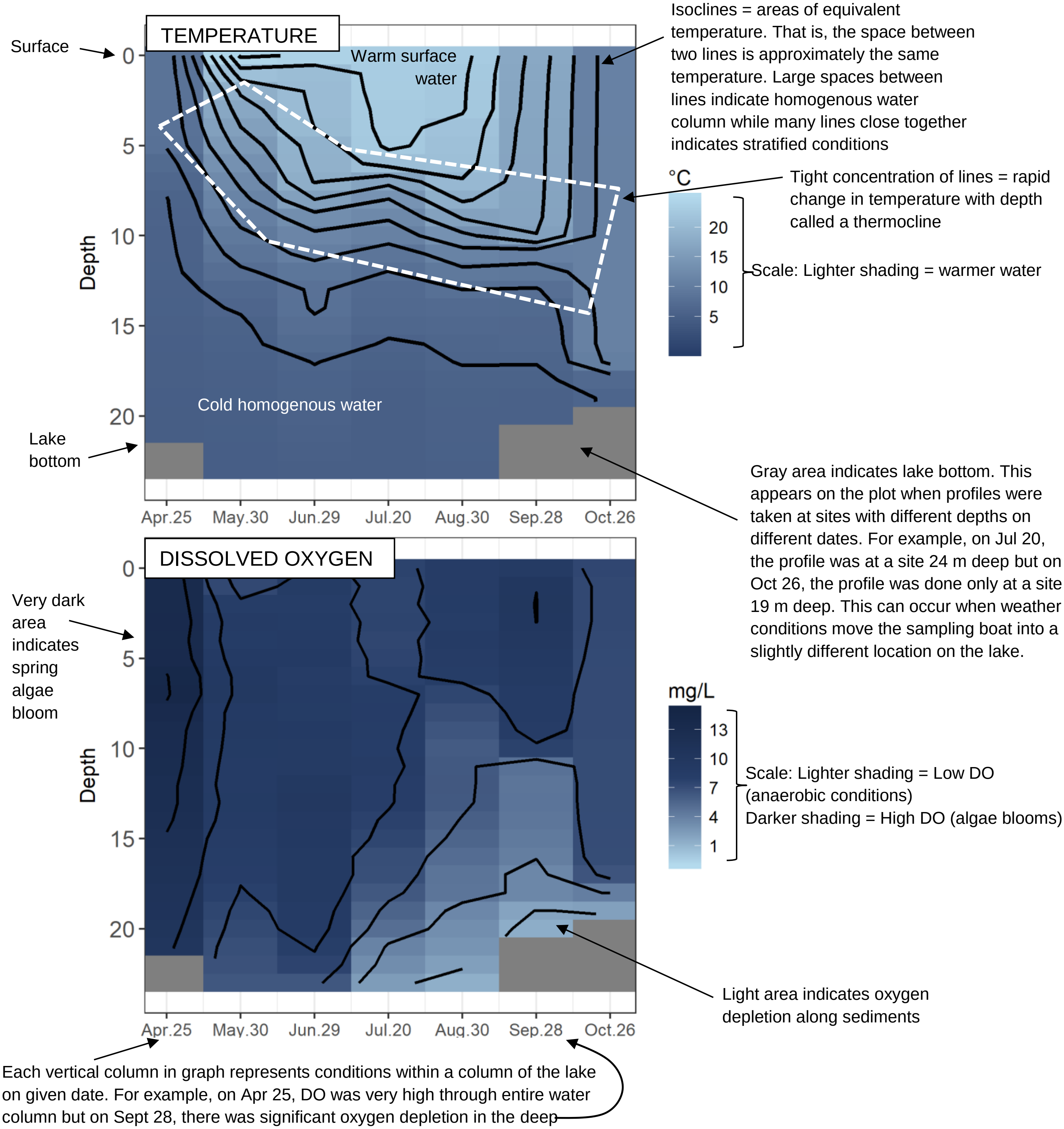
Trophic Status	chlorophyll-a ug/L	Total P ug/L	Total N ug/L	Secchi disc m	primary production mg C/m²/day
Oligotrophic	0 – 2	1 – 10	<100	> 6	50- 300
Mesotrophic	2 – 5	10 – 20	100 – 500	3 – 6	250 – 1000
Eutrophic	>5	> 20	500-1000	< 3	>1000

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

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

How to Read Temperature/DO Profile Plot

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



Data Analysis and Modelling

A thorough statistical data analysis on project data was conducted. A first step involved calculating descriptive statistics (average, mean, standard deviation, median) and generating box plots (e.g. Figure 0-1). Using these results as a guide, the following analyses were performed:

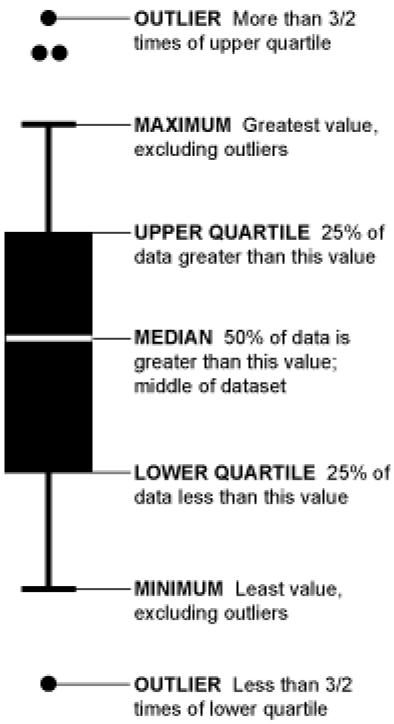


Figure 0-1: Example and description of boxplot

BACI Impact Assessment The Phase 1 data collection supported a preliminary Before–After Control-Impact (BACI) design. The BACI design and associated statistical test is based on repeated sampling of parameters over time in paired control and impact areas, and it requires that the sampling design produces enough samples to provide adequate statistical power and meet analysis requirements (Smith, 2006). This approach to impact assessment allows us to see differences between pairs of sites control (undeveloped) and impacted (shoreline residential) and control (light native aquatic vegetation) and impacted (milfoil bed), and using historic versus study results for before/after analysis. This was completed in Phase 2.

Trend analyses: The data base was analyzed for trends in water chemistry and aquatic plant growth.

Results below detection limits: Non-detect data occurs when the sample result is below the lab reportable detection limit (RDL). When this occurs in water or sediment chemistry required for analysis, the "<" value will be replaced with ½ of the detection limit and that value flagged as calculated. This is the standard procedure employed by BC MoE in their analyses to reduce bias.

Chloride Loading, Nutrient Loading Mean annual chloride and nutrient loading was based on groundwater discharge and water quality samples collected in this study, and compared to other Okanagan samples, including those from Swan Lake (WWAL, 2016). We had planned to develop a loading model for each parameter (Cl, N, P, key metals), but this work was suspended due to a funding shortfall.

Nutrient Budget Calculations The funding shortfall meant we could not complete nutrient budget calculations for Vaseux Lake. Instead we could only provide a preliminary ranking of the nutrient contributions (internal loading, inflow loading, point-source land-use loading shoreline residences, for example). The nutrient budget will also include internal loading of nutrients recycling from the substrates in anaerobic zones and from milfoil beds releasing nutrients to the water column using targeted water sampling and the available bathymetry of Vaseux Lake. For this, we used the bathymetric approach LAC developed that involves calculating the nutrients concentrations in water layer volumes (Figure 1-1).

1.0 Background

Vaseux Lake is a small, productive lake, located near the downstream end of the Okanagan Valley mainstem lakes (Figure 1-1). Its extensive shallows support excessive growth of the introduced and invasive Eurasian water milfoil (*Myriophyllum spicatum*), filamentous green algae, and other native aquatic macrophytes. Problems with excessive milfoil and algae growth in Vaseux Lake were reported back into the mid-1970s (Figure 3-15), but increasing sedimentation near the mouth of the lake has been observed in recent years and the productive growth was reported to be increasing again by long-time lakeshore residents. The Regional District of Okanagan Similkameen (RDOS) wanted this study to determine the causes of the 2015-2016 spike in milfoil and algae growth in Vaseux Lake.

Although the gradual infilling of productive lakes is a natural part of the lake aging process, a warming climate and increasing development in the Okanagan can unduly accelerate this process. Urbanization, agriculture and logging have been the major human impacts threatening water quality in the Okanagan River Basin (Dessouki, 2009).

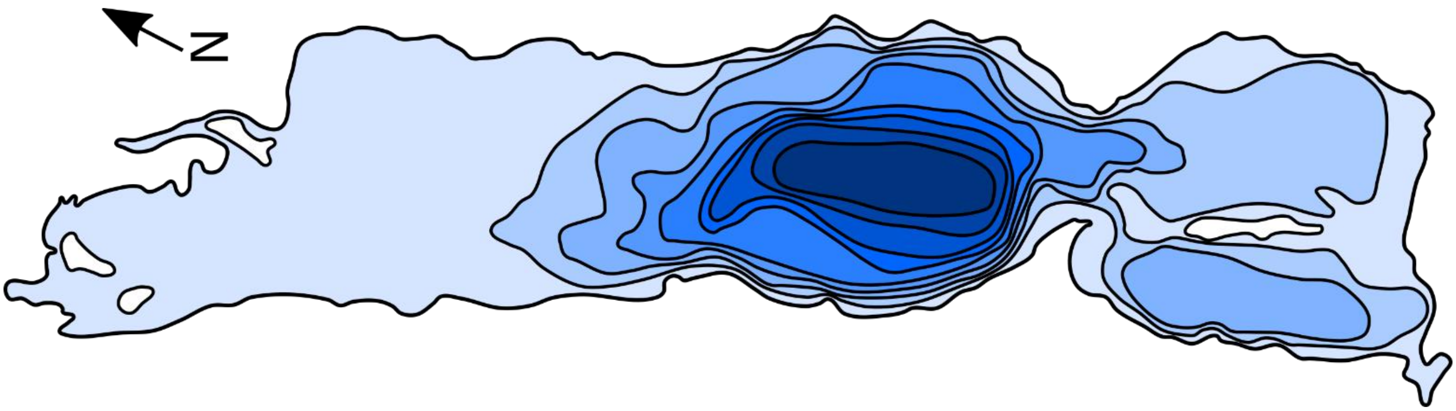


Figure 1-1: Bathymetric map of Vaseux Lake

1.1 Study Purpose

The main objective of this Vaseux Lake Land Use and Water Quality Assessment is to determine. likely sources of nutrients and sediment contributing to the increased milfoil and algae growth observed over the past few years in Vaseux Lake and provide options for lake enhancement. These four important, interlinked concerns will be addressed by this study. Phase 1 began in 2017 and targeted investigations on the interactions between land use and water quality. They involved the initial monitoring and sampling program on two dates to measure the influences of surrounding land uses on the water quality and sedimentation of Vaseux Lake. Phase 2 occurred in 2018 and with partial funding, it involved continued sampling on three dates, the further development of a Vaseux Lake database, and statistical data analyses. This report contains recommendations for remediation of identified point and non-point nutrient and sediment sources. This report provides the summary results from Phase 1 and 2.

2.0 METHODS

LAC has conducted an exhaustive review of information sources to allow focus on information gaps and avoid redundant sampling. For example, the Okanagan Basin Agreement (1973) conducted comprehensive studies on nutrient loading and concluded that the nutrient loading to Vaseux Lake was primarily from upstream sources and from septic fields, but not from agriculture or forestry. This information is dated but still relevant. More reports are provided in the Literature Cited.

2.1 Existing Water Quality Data

LAC performs the required monitoring of water quality on Vaseux Lake as a condition of the BC MoE Permit to Operate for the Okanagan Falls Wastewater Treatment Plant. It involves monthly sample collection and in-field monitoring from ice-off through November (ice-on) at the sample site located near the deepest area of Vaseux Lake (Figure 2-1). The water quality parameters already collected for the WWTP Permit are provided in Table 2-1. For statistical rigor and cost reductions, sampling for this study coincided with the Permit sampling.

Table 2-1: Water quality parameters collected monthly for the WWTP project

Analysis	Detection Limit
Chlorophyll-a	0.1 µg/L
Phosphorus, Total (persulfate)	0.002 mg/L
Phosphorus, Dissolved (persulphate)	0.002 mg/L
Phosphorus, dissolved reactive	0.005 mg/L
Nitrogen, Total (TKN + NO_2 + NO_3)	0.05 mg/L
Nitrogen, Organic (TKN - NH_3)	0.05 mg/L
Nitrogen, ammonia (NH_3)	0.020 mg/L
Nitrogen, nitrate (NO_3)	0.010 mg/L
Chloride	0.1 mg/L
Sulphate	1.0 mg/L
Total Metals + Hardness	Various

2.2 Initial Reconnaissance Sampling

In September 2017, a Hannah multi-meter with GPS was used at 50 – 60 perimeter sites to identify potential sample sites for piezometers (shallow groundwater) and lake sample sites, shown in Figure 2-1. The multi-meter parameters include: pH, temperature, dissolved oxygen, conductivity and total dissolved solids. This was used to determine areas of interest for more intensive sampling.

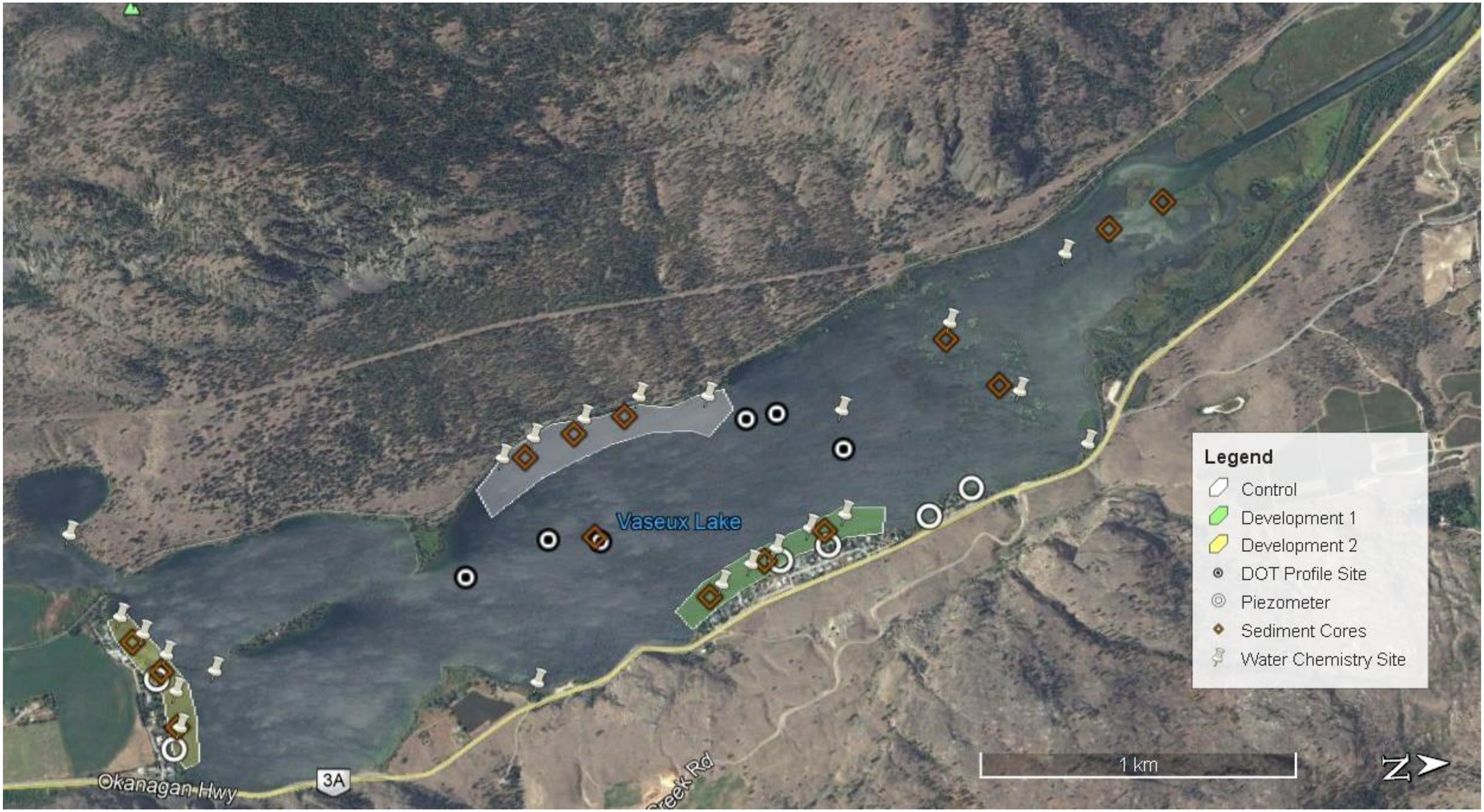


Figure 2-1: Map of Vaseux Lake with sample sites

2.3 Main Sampling Program

Using the reconnaissance sampling, 10 near-shore sites were selected for water quality sampling in October 2017. Samples were collected from 0.5 m to 1.0 m depth. These included those sites with the highest apparent impacts, and areas of greatest vulnerability (vicinity of septic disposal, or aquatic plant beds). Background samples were collected from Park areas of Vaseux Lake that are undeveloped for comparison to samples collected from the two residential areas, and the N and S ends of the lake. Unfortunately, no creek samples were collected in 2017 because all inflowing streams were dry following the record 2017 summer drought. Creek samples were collected in May 2018.

These sample sites included:

- Vaseux Control W shore
- Vaseux S shore composite
- Vaseux E shore composite
- Vaseux N end composite
- Vaseux Sundial well (14' deep, 7' of water on sample date)
- Vaseux well in Provincial Park (pump water station)
- Vaseux NE plant bed
- Vaseux NW plant bed
- Vaseux S plant bed
- Shuttleworth Creek
- Green Lake discharge
- Creek near boat launch

A Vaseux South duplicate sample was collected for QA/QC

Additionally, 6 drive point piezometers were installed on October 12 and sampled on November 8 2017. Shoreline flooding in May 2018 inundated most piezometers in 2018, nullifying their usefulness.

- Piezo 1: N end of Provincial Park in black sandy substrate, buried 30 cm
- Piezo 2: S end of the Provincial park, located below pit toilets, buried 30 cm
- Piezo 3: South end 216 Sundial, buried 50 cm in sandy substrate
- Piezo 4: South end, Sundial hotel buried 50 cm in sandy substrate
- Piezo 5: East subdivision 3140, 30 cm deep in cobble sand beach between retaining walls
- Piezo 6: East subdivision 3172, 45 cm deep in cobble/sand substrate

These piezo locations are identified in Figure 2-1. The piezo locations were chosen to detect impacts from long-term septic disposal on shallow groundwater solutions and facilitate calculation of nutrient budgets for the lake.

These sample sites are presented in Figure 2-1.

Table 2-2: Selected water quality parameters for Vaseux Lake Assessment, 2017

	Water Parameter	Rationale
Lab Analyses	Nutrients N's P's K Sulphate	Nutrients in water bodies can stimulate nuisance algae growth, ultimately altering habitat values for fish and waterfowl
	Metals scan	Metals (Fe, Ca, Mg etc.) help control the flux of nutrients in a lake water column and heavy metals that may accumulate in aquatic food chains (mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), and lead (Pb)
	Ions Cl	Chloride serves as a useful indicator of anthropogenic influence/ impacts due to its conservative properties
	Bacteria – *E. coli*	*E. coli* indicate recent fecal contamination and the possible presence of pathogens and measurable E. coli are often found in septic discharge
Multi-meter	pH	pH determines metal mobility, nutrient state, carbonate precipitation
	Temperature	Water temperature defines water layers and will also be monitored using light/temp loggers)
	Dissolved oxygen (DO)	Defines balance point between photosynthetic producers and decomposition consumers; DO controls the rate of internal sediment decomposition and metal/nutrient fluxes
	Conductivity /TDS	Measures amount of dissolved constituents

Table 2-3: Selected water quality parameters for Vaseux Lake Assessment, 2018

	Water Parameter	Rationale
Lab Analyses	Nutrients N's P's	Nutrients in water bodies can stimulate nuisance algae growth, ultimately altering habitat values for fish and waterfowl
	Ions Cl	Chloride serves as a useful indicator of anthropogenic influence/ impacts due to its conservative properties
Multi-meter	pH	pH determines metal mobility, nutrient state, carbonate precipitation
	Temperature	Water temperature defines water layers and will also be monitored using light/temp loggers)
	Dissolved oxygen (DO)	Defines balance point between photosynthetic producers and decomposition consumers; DO controls the rate of internal sediment decomposition and metal/nutrient fluxes
	Conductivity /TDS	Measures amount of dissolved constituents

All water samples were composites either temporally (creek or culvert flow) or spatially (depth composites in lake above or below thermocline). To match the WWTP Permit work, deep water column composites included a 1,5,10 m composite (above summer thermocline) and a 20,22,24 m composite (below summer thermocline). It is vital that both water layers be sampled separately and as composites to obtain high quality data. Prompt re-sampling of outlier samples was also undertaken**.** QA/QC for this study matches the existing permit program that meets provincial standards.

2.4 Sediment Sampling and Monitoring – Phase 1

Every lake accumulates sediment from external materials deposited by inflows and from incomplete decay of aquatic growth within the lake itself (Table 2-4). Sediment samples were collected in 2017 and results are found in Section 3.4.

Table 2-4: Selected sediment parameters for Vaseux Lake Assessment 2017

Sediment Parameter	Rationale
Volatile solids / dry weight	Allows calculation of percentage of organic (decaying plants, algae, etc.) and inorganic (sand, silt, clay) in lake sediments
Nutrients T-N P's	Nutrients in sediments are the primary source of nutrients for nuisance aquatic plant growth
Metals scan (K S Fe Na Pb Ca Cu etc.)	Iron (also Ca Mg etc) determine nutrient mobility from the sediment to the water column

2.5 Sediment Mapping – Phase 2

The extent of the inflow sediment bar was mapped using aerial imagery and compared to previous years to gauge the rate of expansion.

2.6 Aquatic Plant Mapping

Aquatic plant bed mapping was completed for Vaseux Lake in 2017 and repeated in 2018. Each mapped bed was given a percentage of invasive milfoil, as well as the other plants. The mapping was based on drone imagery, satellite imagery, and "ground-truthing" with a grid of GPS'd locations, according to the methods used by OBWB. This mapping was compared to historic maps for expansion of plant beds and species shifts.

Filamentous green algae populations were mapped using drone images, and photographs. We also collected grab algae samples and identified the filamentous species because this is relevant for control decisions.

2.7 Land Use Inventory and Survey

Mapping available from RDOS was utilized to inventory the land use in the vicinity of Vaseux Lake. Briefly, there are 2 residential subdivisions, and a highway in the riparian area, and small forage and vineyards within the watershed. Much of the west watershed is undeveloped park (Figure 2-1). Upstream sediment sources and channel stability issues were identified using GIS and drone imagery, and existing reports. It was rapidly apparent that Shuttleworth Creek is a major sediment contributor and effort was focused there.

2.8 Hydrogeologic Assessment

The hydrogeologic assessment was not funded, hampering our ability to complete water and nutrient budgets. Existing information indicates that only the top 4 meters of the upper, unconfined aquifer is interacting with Vaseux Lake. The Okanagan glacial aquifers have a typical hydraulic gradient of 0.1 with an estimated hydraulic conductivity of $1x10^{-5}$ m/s (OBWB 2009 and Smerdon 2009). The amount of aquifer interacting with Vaseux Lake (or any of the Okanagan mainstem lakes) and a typical groundwater discharge into Vaseux Lake can only be estimated, however, and loading rates are based on these estimates.

2.9 Internal Loading Estimate

Vaseux Lake exhibits internal nutrient loading when nutrients release from the sediments under anaerobic conditions. These nutrients accumulate in the hypolimnion until the lake overturns in the fall. After fall overturn these nutrients become available to algae and macrophytes and may trigger an algae bloom. Internal loading can be a dominant source of nutrients in some lakes and so using available data, an estimate for Vaseux Lake was calculated. This estimate was based on the method developed for Ministry of Environment in the Wood Lake nutrient budget report (Self and Larratt, 2016). It uses the volume of the epilimnion and hypolimnion and nutrient concentrations to calculate a mass load for each parameter.

2.10 Water Balance

Many estimates needed for calculation of the Vaseux Lake water balance already exist (Table 2-5). For example, the estimated water loss to evaporation is already calculated specifically for Vaseux Lake (Schertzer and Taylor 2009). Unfortunately, the loss of Phase 2 funding meant that the water balance and hydrologic assessments were not completed. Even with the incomplete table, it is clear that Okanagan River flows dominate the hydrology of Vaseux Lake. Aquifer 255 receives substantial recharge from Vaseux Creek and Vaseux Lake (Allard and Manwell, 2011).

Table 2-5: Available water balance parameters for Vaseux Lake

Parameter	Value	
Surface area (m^2)		2,752,000
Volume (m^3)		17,600,000
Mean depth (m)		6.4
Mean annual outflow (m^3)		529,200,000
Max depth (m)		28
Highest target elevation (m AMSL)		327.6
Residence Time (yr.)		0.03 (11 days)
Water Balance Fluxes (m^3/year)		
Inputs	Okanagan River inflow	>520 x 10^6
	Shuttleworth Creek	~11.1 x 10^6
	Inflowing creeks to Vaseux Lk	Not known
	Precipitation on lake surface[2]	0.85 x 10^6
	Groundwater inflow	Not known
	Total Inputs (known)	531.95 x 10^6
Outputs	Avg outflow to Osoyoos Lake [1]	529.2 x 10^6
	Evaporation (m^3/yr) ref[3]	2.8 x 10^6
	Groundwater use (net)[4]	~0.46 x 10^6
	Surface water licenses[5]	1.42 x 10^6
	Discharge to groundwater SW shore[6]	~1.1 x 10^3
	Total Outputs	532.88 x 10^6

References: ref[1] OBA 1973 ref [2] Schertzer and Taylor 2009; [3] Summit, 2005. [4]estimate based on number of residences and Okanagan averages on septic; [5] surface water licenses (Summit, 2013); [6]Summit, 2013; [7]based on 308mm annual average precip (Env. Canada, 2018)

3.0 RESULTS FROM PHASE 1 AND 2

3.1 Water Quality

3.1.1 Lake Profiles

The multimeter profiles collected in during 2017 and 2018 showed a consistent thermocline established at approximately 5 m by mid-May and then gradually descending to 8-10 m during the summer throughout the main basin of the lake (Figure 3-1). Temperature peaked at a very warm >25 °C at the surface to 8 °C at 25 m in the deep central basin during 2018. Dissolved oxygen was high at the surface and became anaerobic just below the thermocline by August in 2017 and in 2018. In the north end shallows there was oxygen depletion within the deepest meter of the water column even though it was shallower than the thermocline during 2017. This confirms that there is intense oxygen demand in Vaseux Lake sediments.

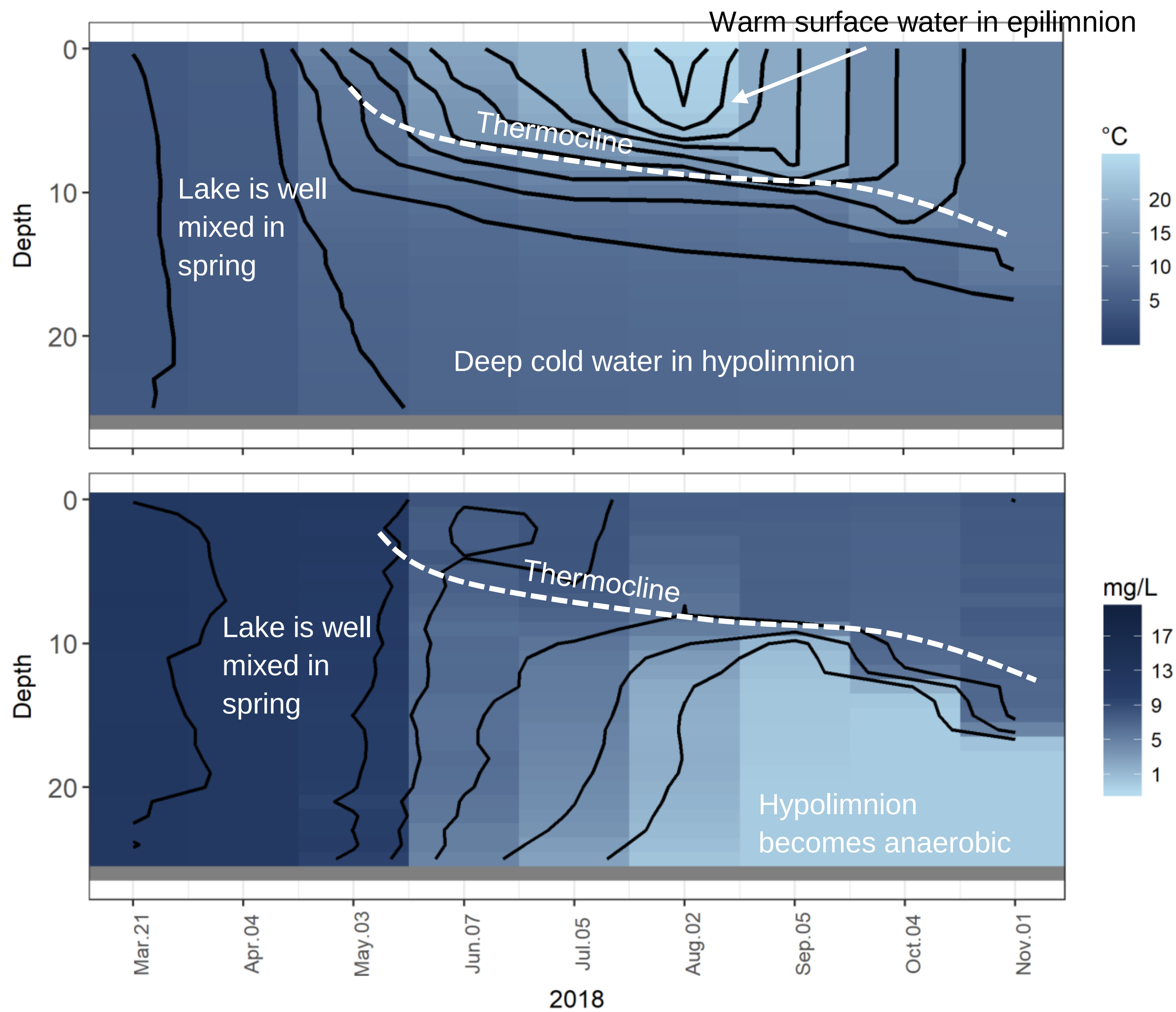


Figure 3-1: Temperature and dissolved oxygen profiles from Vaseux Lake during 2018

An August thermal survey from 1967 that showed a thermocline at 8.3 m with oxygen depletion to 3 mg/L below the thermocline – results that are very similar to those obtained in 2017 and 2018. These thermal profiles indicate that the physical functioning of Vaseux Lake is stable through the decades.

3.1.2 Water quality sampling program

Lake Samples Water chemistry samples measured chloride, dissolved nutrients, total metals, and bacteria at 7 surface water sites during 2017. Budget considerations reduced the number of parameters to just chloride plus nitrogen and phosphorus in 2018. These results were combined with the existing Vaseux Lake and Okanagan River monthly monitoring program data.

BC MoE Aquatic Life MAC Guidelines and the Canadian Drinking Water Guidelines for various metals were not exceeded in any of the lake samples collected for this project (Table 8-1).

Additional water chemistry samples were collected in Vaseux Lake monthly from ice-off to November from 2013-2018 as part of the WWTP monitoring program. These samples were collected at the deepest point in Vaseux Lake as 1,5,10 m composites and 20,22,24 m composites. Chloride averaged 6.4 ± 3.6 mg/L in the 2018 epilimnion samples (5.8 ± 0.9 mg/L during 2017). The nutrients that usually control biological productivity were comparable in both years of study. Total Nitrogen averaged 0.259 ± 0.119 mg/L as N and total phosphorus averaged 0.007 ± 0.007 mg/L as P during 2018 (0.217 ± 0.063 mg/L as TN and 0.008 ± 0.003 mg/L as TP during 2017). Ammonia averaged 0.024 ± 0.019 mg/L as N during 2017 and 0.031 ± 0.018 mg/L as N during 2018 in the epilimnion of Vaseux Lake (Figure 3-2). A significant increasing trend in ammonia was identified from 2013-2017 within Okanagan River upstream of Vaseux Lake (Mann-Kendall, $p<0.001$). This trend was also observed upstream of the Okanagan Falls WWTP (Mann-Kendall, $p=0.002$), indicating that larger Okanagan watershed trends are involved. Increased groundwater reporting to the mainstem lakes in recent years may contribute to this trend. Vaseux Lake exhibits internal nutrient loading each summer during the stratified period. The internal load was estimated and compared to external nutrient sources in Table 3-3.

Of the lake water samples collected from 2013-2018, only aluminum and total phosphorus exceeded their respective BC MoE Aquatic Life Guidelines. Aluminum exceeded its guideline only during freshet because it is commonly associated with sediment and increases during turbid freshet flows. Creek samples showed that they provide significant nutrient inputs to Vaseux Lake, notably, Shuttleworth Creek (Figure 3-2).

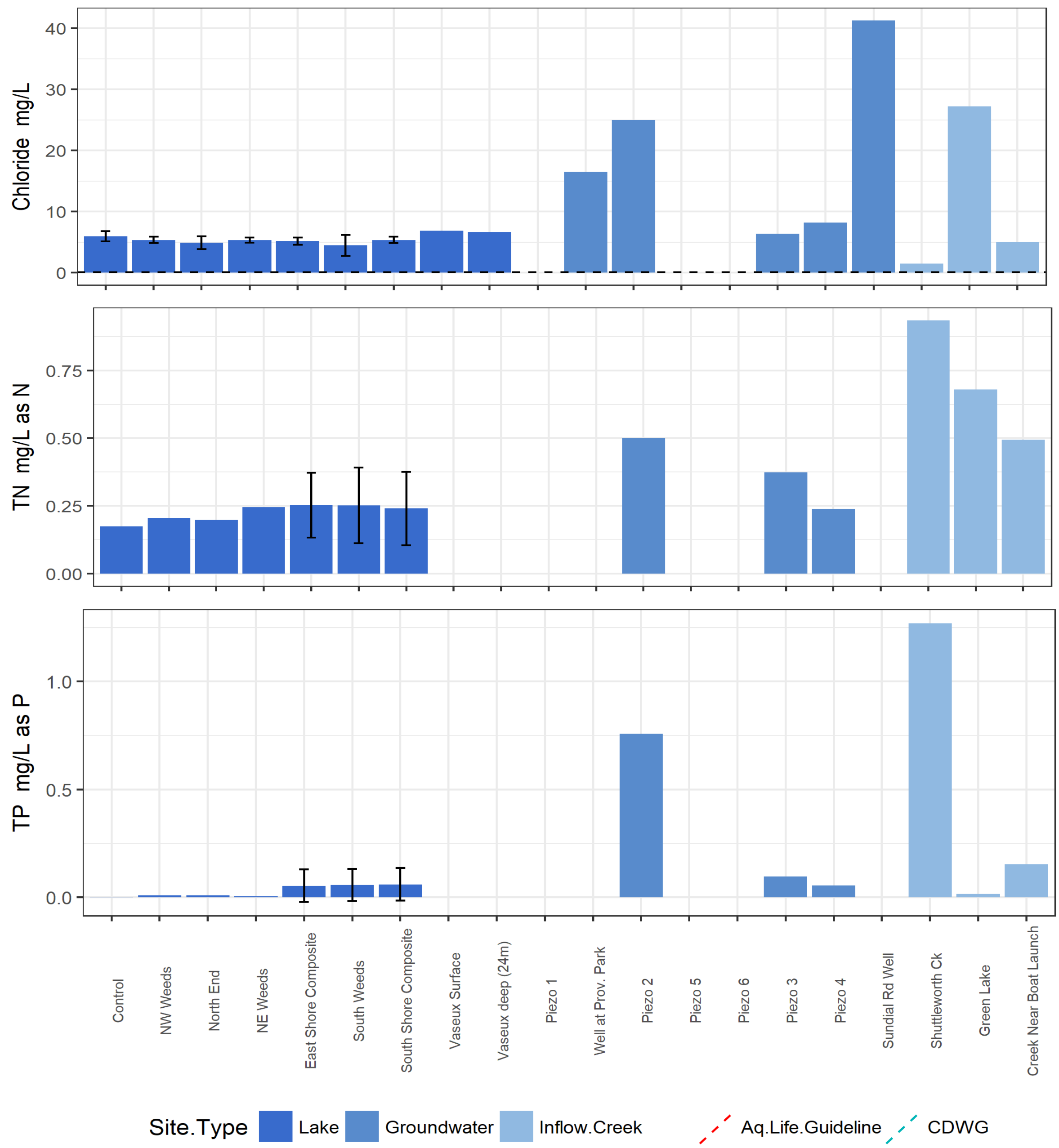


Figure 3-2: Chloride, total nitrogen, and total phosphorus concentrations at sample sites, 2017-2018

As of 2017, there were no detectable impacts from the WWTP on the chemistry or biology of Vaseux Lake (Self, 2018). There were no statistically significant differences between the control site or either the east subdivision or the south subdivision for any water chemistry parameter measured. For additional information please refer to the *2017 Vaseux Lake and Okanagan River Monitoring Report.*

The chlorophyll-a and phytoplankton analyses showed similar trends where higher algae counts led to higher chl-a concentrations (Figure 3-3). The correlation (R=0.59 in 2017 and 0.12 in 2018) was weak because photosynthetic bacteria also contribute chl-a. Algae counts in 2017 were similar to what was measured in 2013-2016 but the intense freshet in 2017 and 2018 contributed to high algae counts during summer 2018. No filamentous green algae blooms in the north end plant beds occurred during 2017 or 2018.

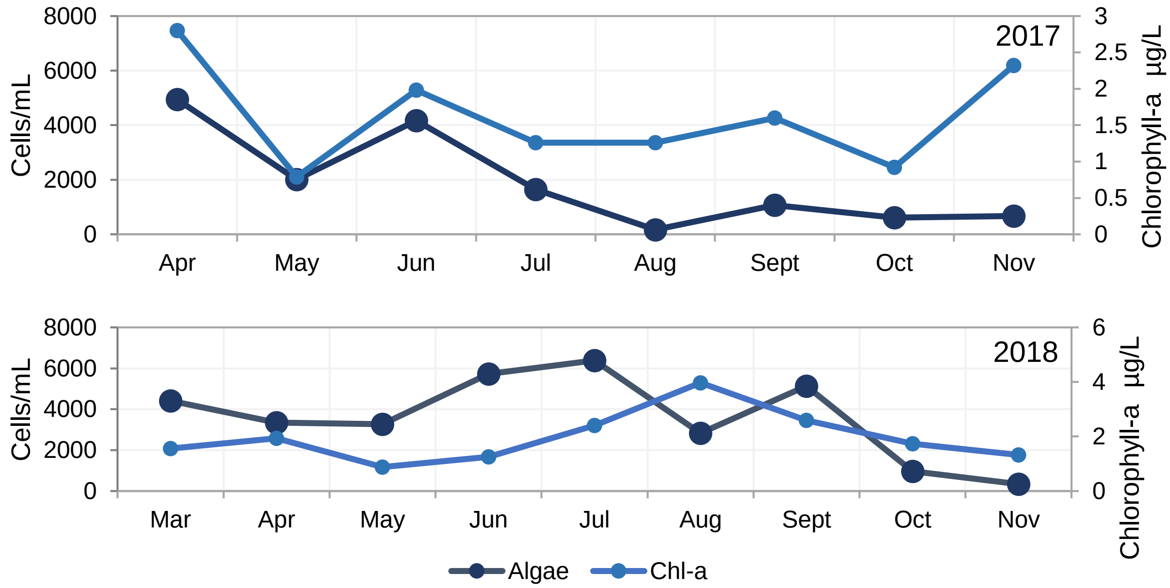


Figure 3-3: Chlorophyll-a and total algae counts in Vaseux Lake during 2017 and 2018

Fecal and coliform bacteria were measured in the lake samples during 2017 and the results were encouraging. While most strains of *E. coli* are harmless, their presence in a sample correlates to fecal pathogens. *E. coli* was below detection in 4 of 6 samples with a maximum measured value of 5 CFU/100mL in the NE plant beds, likely due to waterfowl (Figure 3-4). The other detectable *E. coli* sample was the east-shore composite at 1 CFU/100mL. These results are very low and would not be considered a problem from a drinking water source (before disinfection) or recreational perspective.

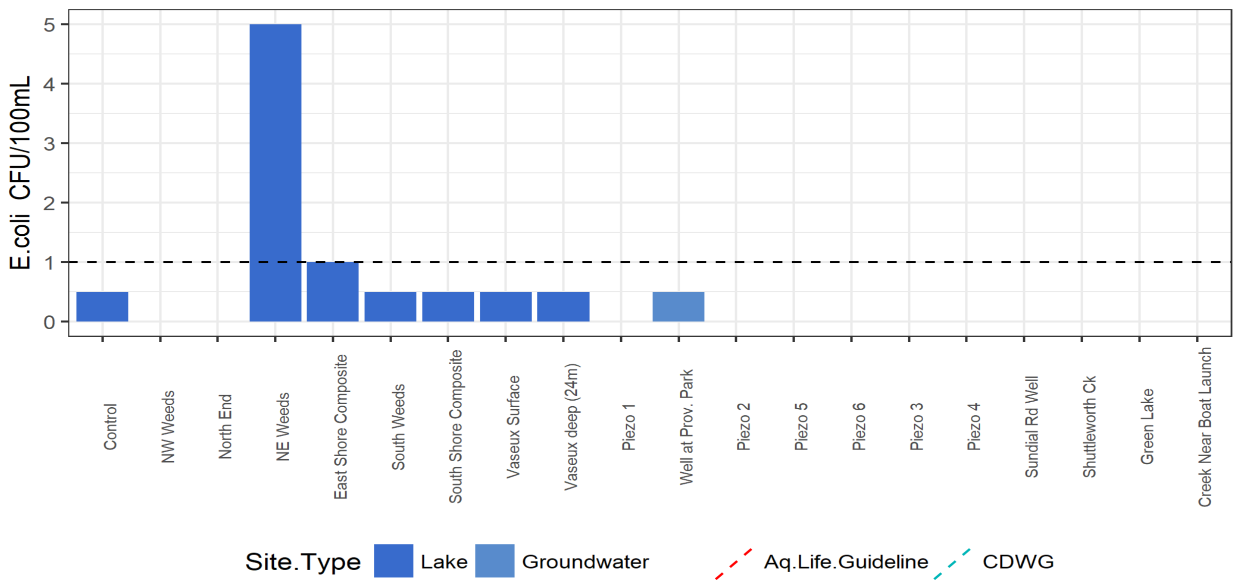


Figure 3-4: *E.coli* results from sample sites during 2017
Note: Reportable detection limit indicated with dashed black line

Groundwater Samples Water chemistry samples were also collected at 8 groundwater sites in 2017, and this effort was suspended in 2018 due to a funding shortfall. Of the 8 sites, 6 were piezometers installed as part of this study and two were existing wells. Chloride averaged 19.5 ± 14.3 mg/L in the groundwater and was significantly higher than the lake samples indicating that groundwater is contributing chloride to Vaseux Lake (KW-Test, $p=0.01$). Ammonia was detected in all groundwater samples, averaging 0.101 ± 0.068 mg/L as N. The increased ammonia concentrations in groundwater compared to lake water were not statistically significant (Figure 3-5). Dissolved reactive phosphorus (the most bioavailable form of phosphorus) was significantly higher in the groundwater samples than the lake samples (KW-test, $p=0.05$; Figure 3-5). Total phosphorus averaged a high 0.303 ± 0.393 mg/L as P in the groundwater samples during this study (2017-2018). Samples from the south subdivision suggest that septic fields contribute ammonia (7 times higher than lake concentrations) while the east shore subdivisions contribute phosphate (8 times higher than lake concentrations; Table 3-1).

Table 3-1: Nutrient concentrations in shoreline composites and piezometers comparing the east shore subdivision and the south shore subdivisions

Site	Sample Type	TN (mg/L as N)	TP (mg/L as P)	Ammonia (mg/L as N)	Ortho-P (mg/L as P)
Vaseux Lake	Lake	0.241 ± 0.100	0.011 ± 0.006	0.028 ± 0.018	<0.005
East Shore Composite	Lake	0.253 ± 0.120	0.055 ± 0.076	0.069 ± 0.030	<0.005
Piezometer 5	Groundwater	-	-	0.092	0.018
Piezometer 6	Groundwater	-	-	0.054	0.066
South Shore Composite	Lake	0.241	0.061	0.061 ± 0.051	<0.005
Piezometer 3	Groundwater	0.374	0.098	0.269	<0.005
Piezometer 4	Groundwater	0.239	0.056	0.146	<0.005

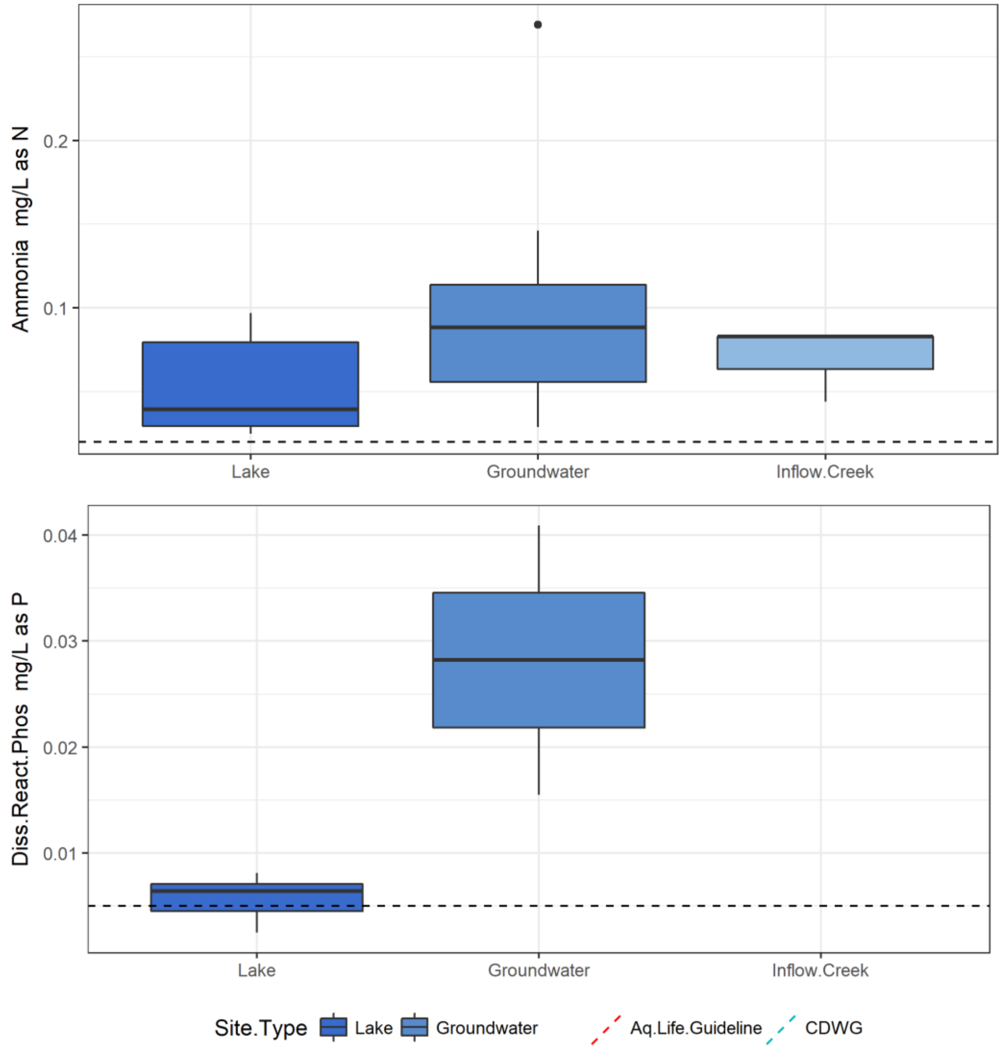


Figure 3-5: Ammonia and dissolved reactive phosphorus in lake and inflow samples, 2017-2018

Note: Dissolved reactive phosphorus was not measured in the inflow creeks

3.2 Loading Calculations

3.2.1 Chloride loading

Chloride is a conservative parameter that indicates human impact. There was no statistically significant North to South gradient in lake samples (KW-Test, $p=1.0$). This was likely because of the rapid flushing rate of Vaseux Lake and the dominance of Okanagan River on the water chemistry of Vaseux Lake epilimnion. Groundwater contained elevated chloride concentrations and ranged from 16.5 mg/L at the provincial park campground to 41.3 mg/L in a well on Sundial Rd. at the south end of the lake. These results are all far below guidelines. The groundwater samples from the Sundial well indicate human impact, likely through septic/agricultural influence, and the provincial park piezometer was probably affected by highway salt residuals. There has been an increasing trend in chloride values throughout the Okanagan, including discharges from Vaseux Lake (Dessouki, 2009).

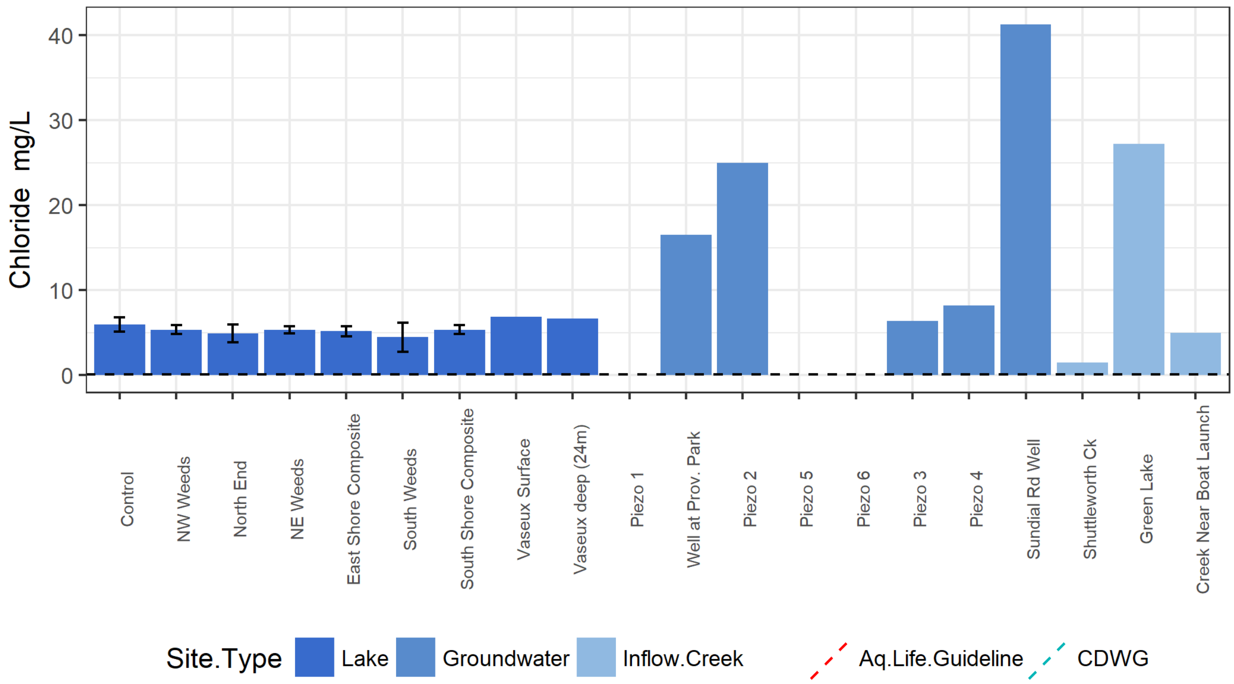


Figure 3-6: Chloride concentrations at Vaseux Lake sample sites, September 2017-2018
Note: Dashed line indicates lab reportable detection limit (sites are presented in North (left) to south (right) and split by surface , groundwater, and inflow sites.

Chloride loading estimates were unfinished in 2018 due to funding (Table 7.7-1). As with almost all water quality and hydrologic parameters for Vaseux Lake, Okanagan River flows dominate the chloride balance.

Table 3-2: Typical chloride loading estimates from groundwater, land use and inflows

	Land Use	**Okanagan Cl loading rate***	**Area adjacent to Vaseux**	**Cl loading estimate**
Land use Cl loading reporting to groundwater	Roads/Hwy 97	27-37 kg / 2lane/km/yr	3.9 km	140 kg/yr
	Residences on septic	440 mg/L, 6.8 kg/yr	65 residences	440 kg/yr
	Natural Cl loading in local groundwater	10 -17 mg/L	Not known	Not known
	Undeveloped slopes /wetland areas	No net loading expected		0 kg/yr
Cl loading from inflows and loss from discharge	Inflow from Okanagan R.	3.61 million kg in 2016		3610000 kg in 2016
	Inflow from Vaseux Cks			Not known
	Discharge to Osoyoos Lk	3.63 million kg in 2016		3630000 kg in 2016
Cl losses	Cl loss to ion exchange in soil solutions*[1]			Not Known
	Cl balance			

* corrected from NaCl (60.1%), CaCl (63.9%) and MgCl (74.5%) loading rates to Cl only
*[1] numerous authors

3.2.2 Nutrient loading

Nitrate, ammonia, and dissolved reactive phosphorus were measured because these are the most bioavailable forms of nitrogen (N) and phosphorus (P). The September 2017 measurements collected under this program were added to the existing Vaseux Lake and Okanagan River monthly monitoring program data.

Nitrate was below detection in all lake samples and also in the well sample at the provincial park. In the well on Sundial Rd., nitrate measured 0.128 mg/L as N, an unremarkable result for groundwater, but much higher than the lake samples (<0.005 mg/L). Ammonia in the groundwater samples ranged from 0.029 mg/L as N in the Sundial Rd. well to 0.117 mg/L as N in Piezo 1 (north end of provincial park; Figure 3-7). These results are also moderate for regional groundwater (Allard & Manwell, 2011), and again, they are much higher than the lake samples (0.028 ±0.018 mg/L as N; Table 3-1; Figure 3-5).

Dissolved reactive phosphorus ranged from below detection in the north end of the lake to 0.066 mg/L as P in Piezo 6 (Figure 3-7). Nutrients were higher in the groundwater than the surface water in part because soil solutions in contact with residential or agricultural nutrient sources will be elevated. For example, Piezo's 5 and 6 (E subdivision) appear to be intercepting more septic drainage than Piezo's 3 and 4 (S subdivision) based on ammonia and phosphorus results. For reference, Wells in and around Oliver as well as other areas in the South Okanagan with a long agricultural land use history exhibit elevated nitrate levels. Observed nitrate concentrations in the valley range from about 0.5 mg/L to more than 10 mg/L (Allard & Manwell, 2011; Geller and Manwell

2016).

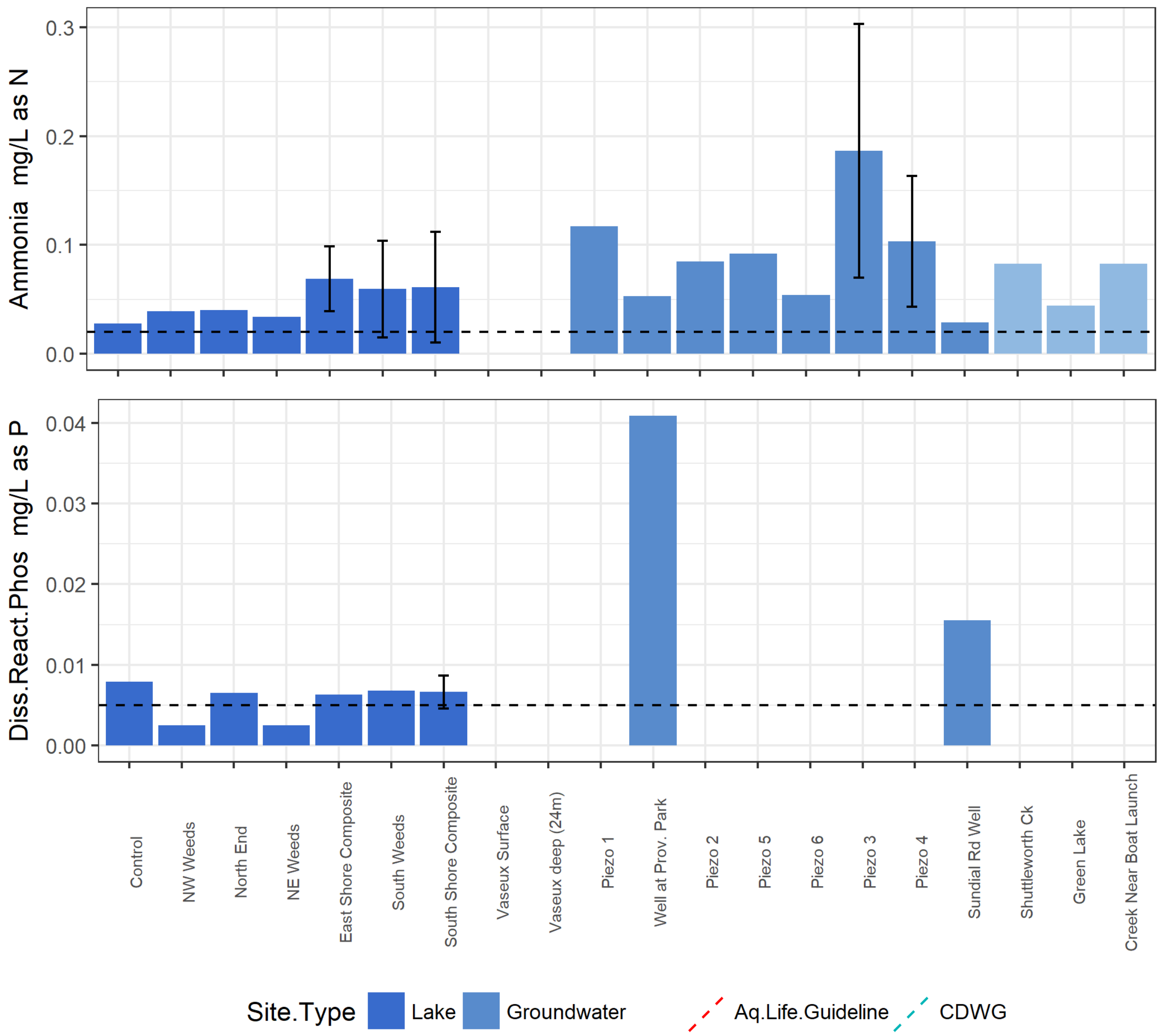


Figure 3-7: Ammonia and dissolved reactive phosphorus from Vaseux Lake assessment, 2017-2018
Note: Dashed line indicates lab reportable detection limit

Vaseux Lake plantbed water samples contained less dissolved reactive P (DRP) than the samples from open water (Figure 3.3-2). These preliminary results suggest nutrient consumption by the macrophytes and associated algae exceeds nutrient export from the sediments through leakage from the leaves. Total phosphorus was removed by Vaseux Lake, evidenced by a 50% decrease between the inflow and outflow to the lake in 2016 and a 72% decrease in 2017 (2017 Annual Vaseux Lake Monitoring Report). A phosphorus loss occurs because TP is often associated with particulates that settle out, it is consumed by plants and detained in lake sediments, and because it is retained in soil solutions.

Internal nutrient loading (recycling) was estimated using the anaerobic method from Self and Larratt, 2016 (Table 3-3). It was estimated that 17,000 ± 5800 kg of TN and 3,400 ± 1,200 kg of TP were contributed to Vaseux Lake through nutrient recycling from 2013-2018. These values represent approximately 6% and 12% of the total nutrient inflows based on available data (Table 3-3). In Vaseux Lake, the nutrients released into the hypolimnion do not mix with the surface waters, where macrophytes are growing, until after the growing season has ended. This combined with the rapid flushing rate of Vaseux Lake, means that internal nutrient recycling is less important to plantbed expansion than nutrients brought in via shallow inflows such as Okanagan River.

The 2016 loading estimate suggested that Vaseux Lake is a net source of total nitrogen while the 2017 estimate yielded the opposite result. It is likely that TN flowing in is similar to TN flowing out with significant variability year to year.

Nutrient loading estimates remain incomplete due to a funding shortfall. Available information was compiled into the loading Table 3-3. In the Okanagan, groundwater is expected to contribute about 20% of TN and 10% of TP entering the mainstem lakes (OBA 1973), however, the available data for Vaseux Lake shows that it is overwhelmingly affected by Okanagan River flows.

Table 3-3: Typical nutrient loading from groundwater, land use and inflows

	Land Use	(N,P) loading estimate	Percent
Land use N,P loading reporting to groundwater	Agriculture	2232 kg/yr TN and 9.1 kg/yr TP*	0.77% TN and 0.03%TP
	Residences on septic	345 kg/yr TN and 127 kg/yr TP*	0.12% TN and 0.47%TP
	Natural N/P loading in local groundwater	748 kg/yr TN and 36.3kg/yr TP*	0.26%TN and 0.13%TP
	Undeveloped slopes /wetland areas	272 kg/yr TN and 9.1 kg/yr TP*	0.09%TN and 0.03%TP
N,P loading from inflows and loss from discharge	Inflow from Okanagan R.	263,895 kg TN and 23,396 kg TP in 2017	91.3%TN and 86.4%TP
	Inflow from Vaseux Cks	4355 kg/yr TN and 118 kg/yr TP*	1.51%TN and 0.44%TP
	Discharge to Osoyoos Lk	190,017 kg TN and 6,285 kg TP in 2017	
N,P losses	Internal loss into refractory organic materials	Not known	
Internal Loading		TN=17,000 ± 5,800 kg TP= 3,400 ± 1,200 kg	5.93% TN and 12.5% TP
	N,P balance	Gain of 10,000kg N and loss of 6000kg TP	Gain of 0.13%TN and loss of 49%TP

Note: *OBA 1973; Internal loading estimate is based on several assumptions and the mass numbers have been rounded so as to not give a false sense of precision.

3.3 Sediment Mapping

Sediment accumulation in the north shallows of Vaseux Lake was a major concern expressed by residents and was a focus of this study. Sediment naturally accumulates where flowing water meets still water and this process forms deltas and alluvial fans. The plantbeds themselves do not play a meaningful role in the accumulation of coarse sediment in Vaseux Lake because most sediment arrives during freshet before the plants have put on much growth. However, they will colonize shallow areas and freshly deposited sediment is typically rich in nutrients. A large shallow (<1 m) sand and gravel bar is visible where the Okanagan River enters Vaseux Lake (Figure 3-8). Sediment accumulation within this area is currently faster than can be colonized by plants and so it appears as bare gravel in Figure 3-9.

Figure 3-8: Sand and gravel accumulation at north end of Vaseux Lake in 2017 (left) and 2018 (right)

Sand and gravel drop out of suspension rapidly explaining why the north end shows expanding sandbars. Silts and clays travel further into Vaseux Lake because of their slower fall velocities (~ 20m/day for silt; 1m/day for clay). Most silt should deposit in the lake, while clay-sized particles should be discharged in outflowing water.

The size and shape of the sand and gravel bar has changed significantly within recent years (Figure 3-9). There has also been an expansion of the two main islands and the formation of a third island within the past five years. A large increase in area occurred during 2018 because of the landslide in Shuttleworth Creek (Figure 3-10) in May with the western finger growing by over 70 m. Instability within the Shuttleworth Creek channel indicates that this creek has, and will continue to be, a significant sediment source to Vaseux Lake.

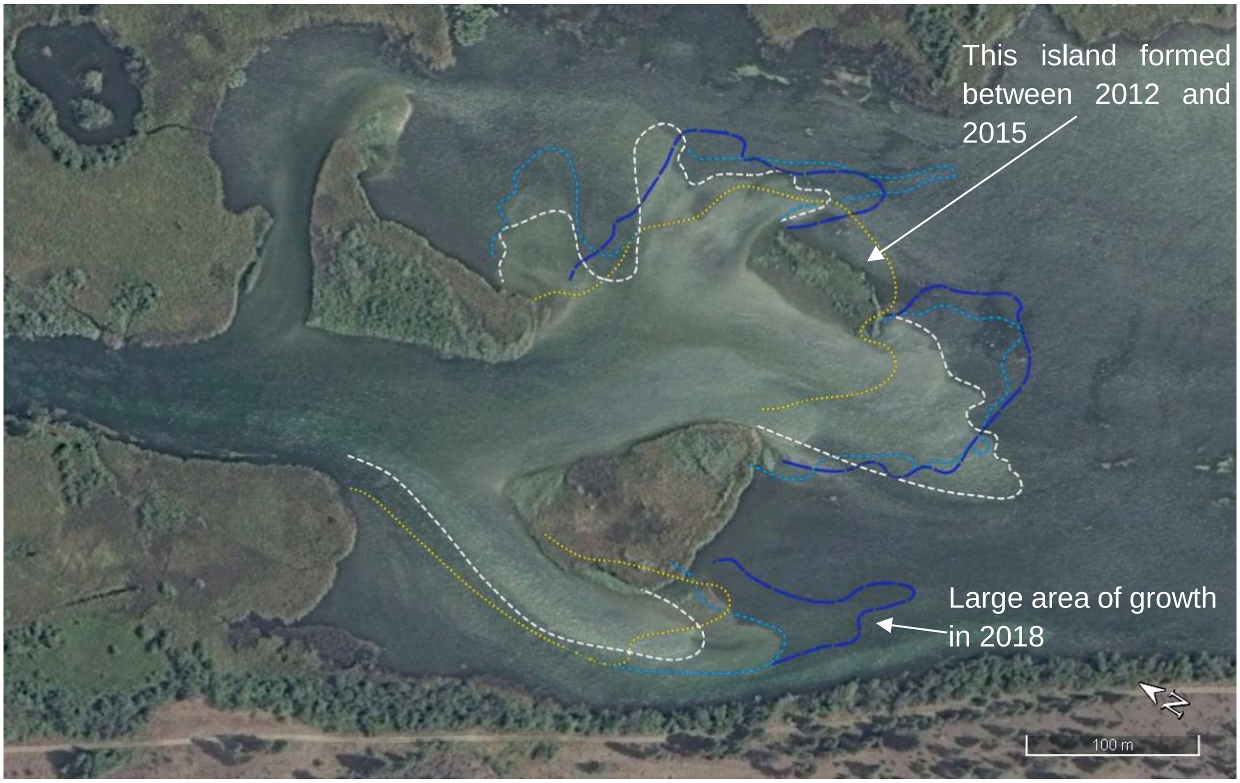


Figure 3-9: Sediment bar expansion at north end of Vaseux Lake comparing 2012 (yellow), 2016 (white), 2017 (light blue), and 2018 (dark blue) Note: The background photo is from 2016

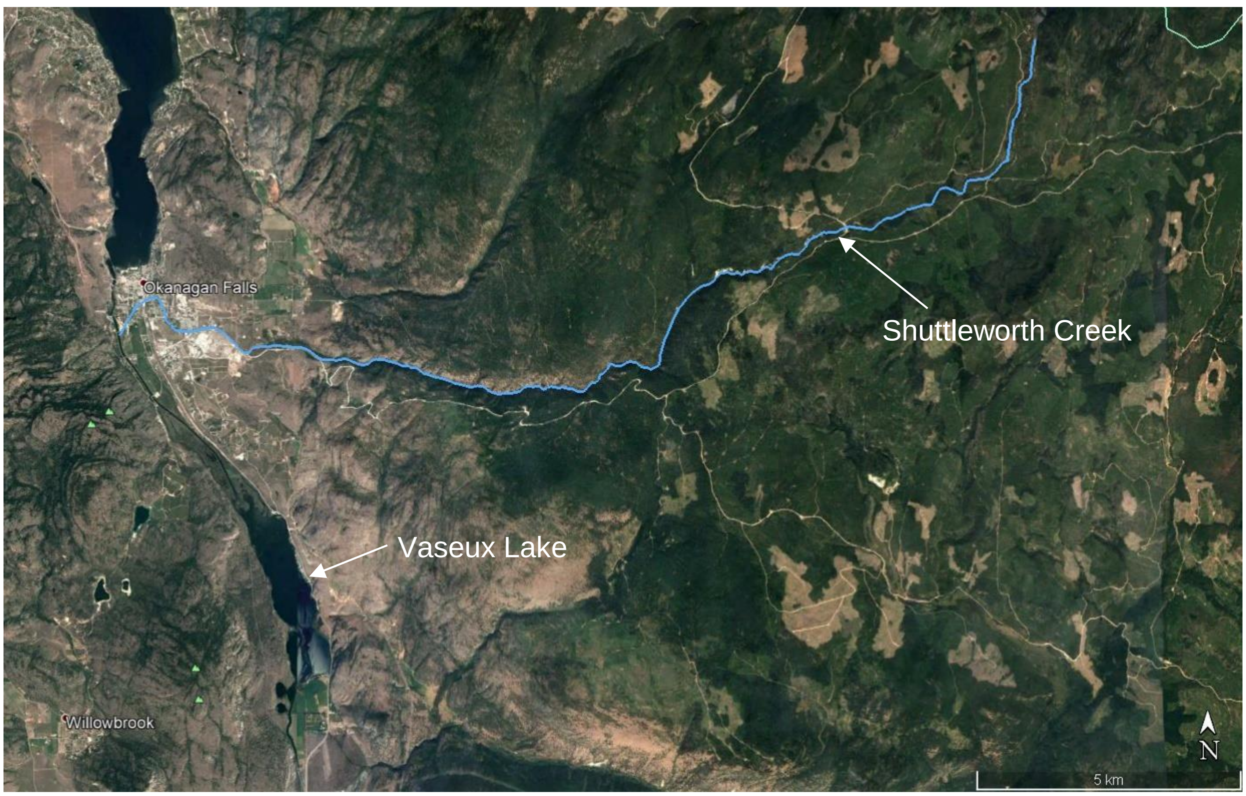


Figure 3-10: Map of Shuttleworth Creek watershed

3.4 Sediment Sampling and Monitoring – Phase 1 Only

3.4.1 Sediment Core Samples

Assessing the quality of sediment deposited in a lake allows effective basin management. Sediment quality is important because it can act as a sink for nutrients and metals, and conversely it can act as a source of constituents to the overlying water column. Once in the food chain, sediment-derived constituents may pose an even greater concern due to bioaccumulation (e.g., methyl-mercury). Sediment core samples can provide historical sediment deposition as well as magnitudes and trends in nutrients, metals etc. derived from the lake's basin that are associated with sediment.

Every lake accumulates sediment from external materials deposited from inflows and from incomplete decay of aquatic growth within the lake itself. The extent of anaerobic conditions is also relevant because anaerobic conditions reduce decomposition rates by orders of magnitude, thus increasing the rate of sediment accumulation as a lake ages. Further aquatic plants beds produce large quantities of labile organic material and reduce water velocities, both of which can increase sediment accumulation rates.

Table 3-4: Selected sediment parameters for Vaseux Lake assessment 2017

Sediment Parameter	Rationale
Volatile solids / dry weight	Allows calculation of percentage of organic (decaying plants, algae, etc.) and inorganic (sand, silt, clay) in lake sediments
Nutrients T-N P's	Nutrients in sediments are the primary source of nutrients for nuisance aquatic plant growth
Metals scan (K S Fe Na Pb Ca Cu etc.)	Iron (also Ca Mg etc) determine nutrient mobility from the sediment to the water column

The composite sediment cores collected from Vaseux Lake in 2017 showed that for most metals, the highest concentrations were found in the sediments from the deep central basin (Figure 3-12). This suggests that many metals are being sequestered in anaerobic sediment, likely through biological pathways such as sulphate reducing bacteria (SRB). The sediment from the main basins of the lake typically had higher metals concentrations than those that were freshly deposited at the very north end of the lake.

Mercury was below detection in all samples while lead was moderate and below the BC guideline (Figure 3-12). Nickel and iron were the only metals to exceed their respective BC sediment quality guidelines. Vaseux sediment also contained elevated concentrations of arsenic, cadmium, chromium, copper, lead, selenium, silver, thallium, and zinc. Several sediment metals were also higher than the BC average for uncontaminated lakes including aluminum, barium, phosphorus, sulfur, titanium, and vanadium. In the sediment, these do not pose a risk and comparing them to the aquatic guidelines is not relevant but if a rototilling program were undertaken it is likely that the machine would create a plume of turbid water that may exceed the aquatic life guidelines for a period of approximately 24 – 48 hours (Table 3-5). This plume would dilute with the adjacent lake volume over time, and silts would settle in <24 hours; clay particles within 1 week (Table 3-5).

Table 3-5: Size and fall velocity estimates for lake particulates

Material	Size	Fall velocity
Inorganic		
Sand	>63 – 100 microns	> 100 m/day
Silt	4 – 63 microns	21 m/day
Clay	0.1 – 4 microns	1 m/day
Biological		
Organic clumps	> 100 microns	>100 m/day
Large algae and diatoms	22 – 70 microns	< 50 m/day
Small algae	6 – 14 microns	<1 m/day
Lrg filament cyanobacteria	5w x 200l microns	0.1 m/day
Sm filament cyanobacteria	1w x 100l microns	>0.007 m/day
Giardia / crypto cysts	4 – 8 microns	0.02 - 0.1 m/day
Bacteria – *E. coli*	0.7 – 10 microns	>0.0035 m/day

(Dia and Boll, 2006; USGS 2007; Hayco, 2009; Larratt 2010)

Figure 3-11: Plume of suspended sediment from milfoil rototilling in Okanagan Lake at Casa Loma

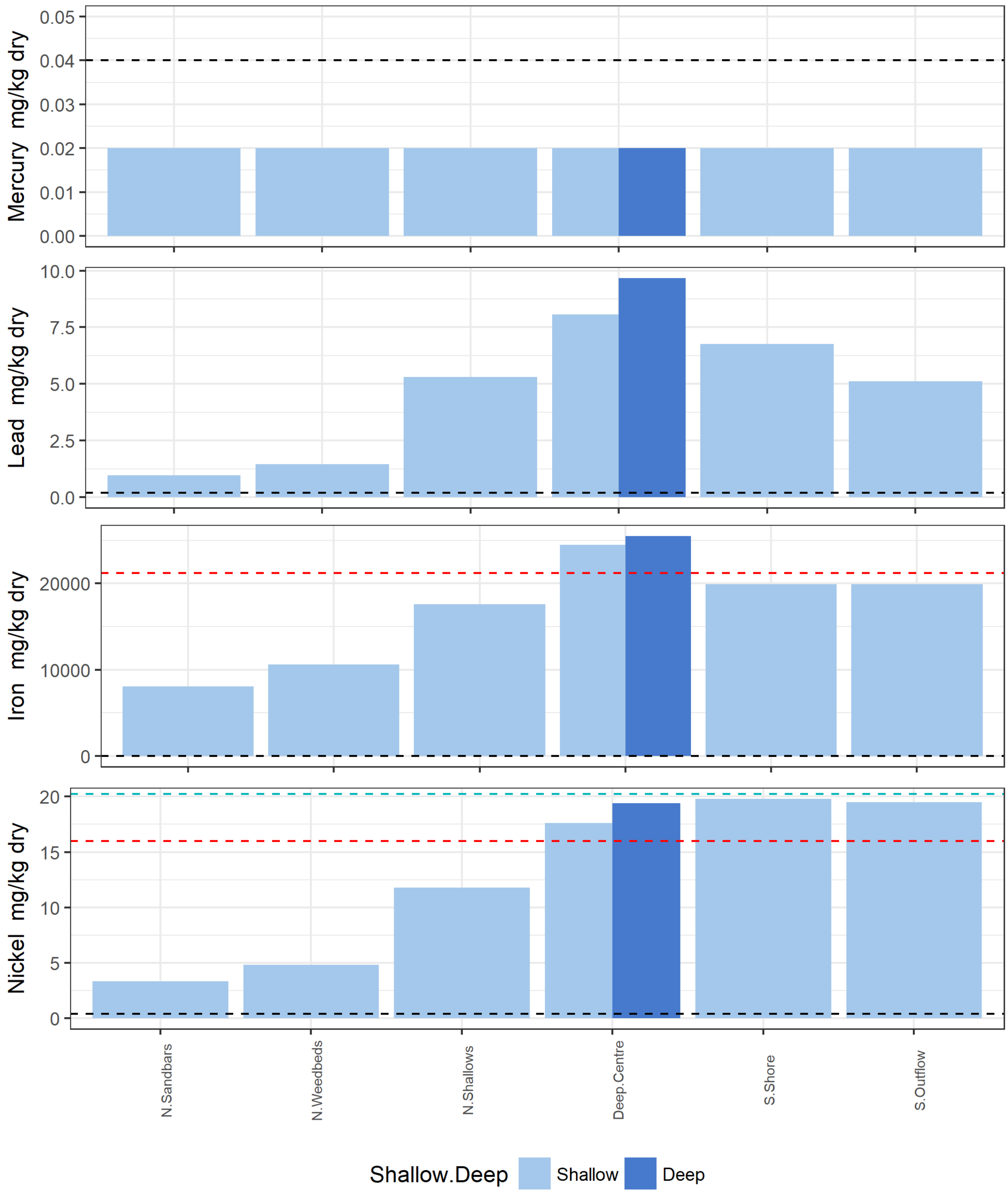


Figure 3-12: Mercury, lead, iron and nickel in Vaseux Lake sediments, September 2017

Note: Black dashed line = RDL; Red dashed line = guideline; cyan dashed line = BC Average; Lead results were far below the guideline and so it is not displayed on the graph

3.4.2 Sediment Traps

The sediment traps were installed in fall 2017 and retrieval was attempted in 2018 but the weather was too windy. They will be retrieved in March 2019 following ice-off and before the 2019 freshet. We know that the annual rate of sediment accumulation will be higher in the north end compared to the south.

3.5 Aquatic Plant Mapping

Excessive aquatic plant growth is not only unpleasant, it can cause serious problems for lake ecology and water flows in the Okanagan River system. These growths can slow water travel through Vaseux, pump nutrients out of the sediments into the water column, provide habitat for filamentous algae and reduce fishery potential in the areas covered by dense Eurasian milfoil beds. Most aquatic plants acquire their nutrients from the substrates through their roots but water column nutrients are also important because they supply phytoplankton (free floating algae) and periphyton (attached algae). Phytoplankton can shade and inhibit the growth of aquatic plants, especially during an algae bloom. Thus, lower phytoplankton populations can increase aquatic plant bed growth. Water column nutrients can also fuel filamentous algae that use macrophytes as a substrate (periphyton) and sometimes lead to unsightly surface blooms. There were no major filamentous algae blooms in 2017 or 2018.

Aquatic plant bed mapping was completed for Vaseux Lake in 2017 and 2018. The mapping was based on aerial imagery, and “ground-truthing” with a grid of GPS’d locations. Aquatic plant beds occurred throughout much of the lake but were most densely concentrated in shallow areas such as the north and south ends (Figure 3-13).

Common species included several native species (*Potamogeton natans*, *Potamogeton pectinatus*, *Potamogeton crispus*, and native milfoil), and invasive milfoil (*Myriophyllum spicatum*). *Potamogeton natans* was by far the dominant species in September 2017 while *Myriophyllum spicatum* was the overall dominant in 2018 (Figure 3-14).

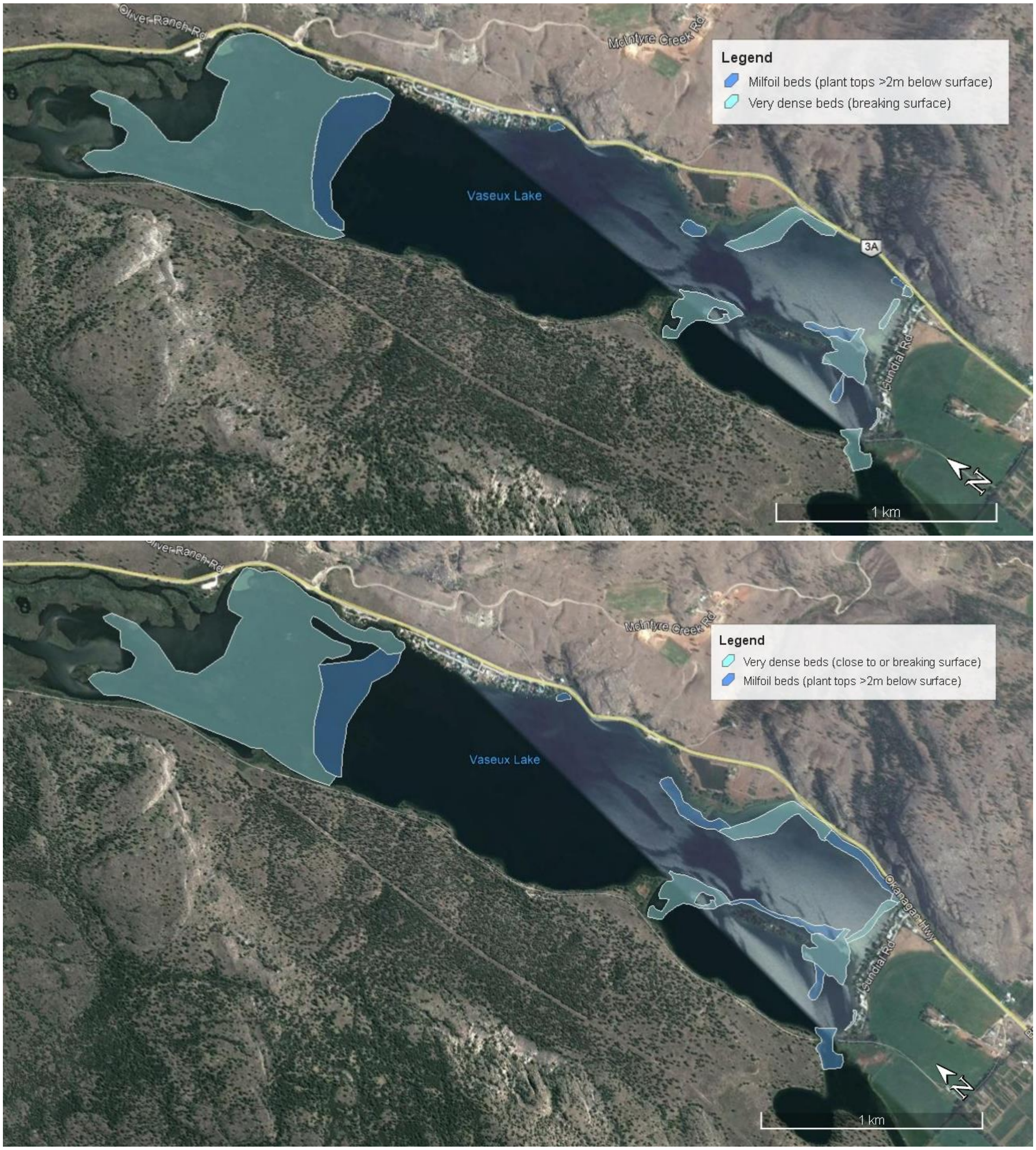


Figure 3-13: Plant beds in Vaseux Lake during September 2017 (top) and 2018 (bottom)

Figure 3-14: *Potamogeton natans* beds in Vaseux Lake, 2017

When historic mapping of plants beds was compared to 2017 and 2018 mapping, a remarkably similar story emerged (Figure 3-15). The area mapped as plantbeds in 1979 was larger than in 2017 or 2018 in the south end of the lake and similar in the north end. South end weed beds were larger in 2018 than 2017, likely related to the greater percentage of invasive milfoil in that year. Figure 3-15 also compares the density of Eurasian milfoil in the plant beds. The dark green (dense) areas were identified as >90% invasive milfoil in 1979 while the light green (moderate) areas were 30-89% milfoil. In 2017, only the areas identified as "Deep Milfoil" contained any meaningful percentage of milfoil and most of that was native milfoil (*M. exalbescens*) at the time of sampling. During 2018, invasive milfoil dominated the lake again. Lakeshore residents have indicated that invasive milfoil growth varies dramatically from year to year and that 2017 was a particularly light growth year.

Two years are insufficient to determine a trend but the current extent of the plant beds are not dramatically different than they were 40 years ago (Figure 3-15). Their composition, however, is apparently highly variable from year to year. The intense flooding in 2017 may have precluded invasive milfoil growth by causing a longer period of freshet turbidity shading the water column. The 1973 Okanagan Basin Agreement report concluded that," Vaseux has always been a productive lake and the extensive weed growth covering much of the lake's surface will remain an integral part of the lake's environment regardless of a varying nutrient input from Okanagan River." (Canada-British Columbia Consultative Board, 1974)

Algae take their nutrients directly from the water column and can get nutrients and support from macrophyte leaves. Changes in nutrient dynamics. plant growth and turbidity (shading) within Vaseux Lake can have an impact on algae communities. Although nuisance blooms have occurred in the past decade, filamentous green algae populations were small in both 2017 and 2018 and far below nuisance population densities.

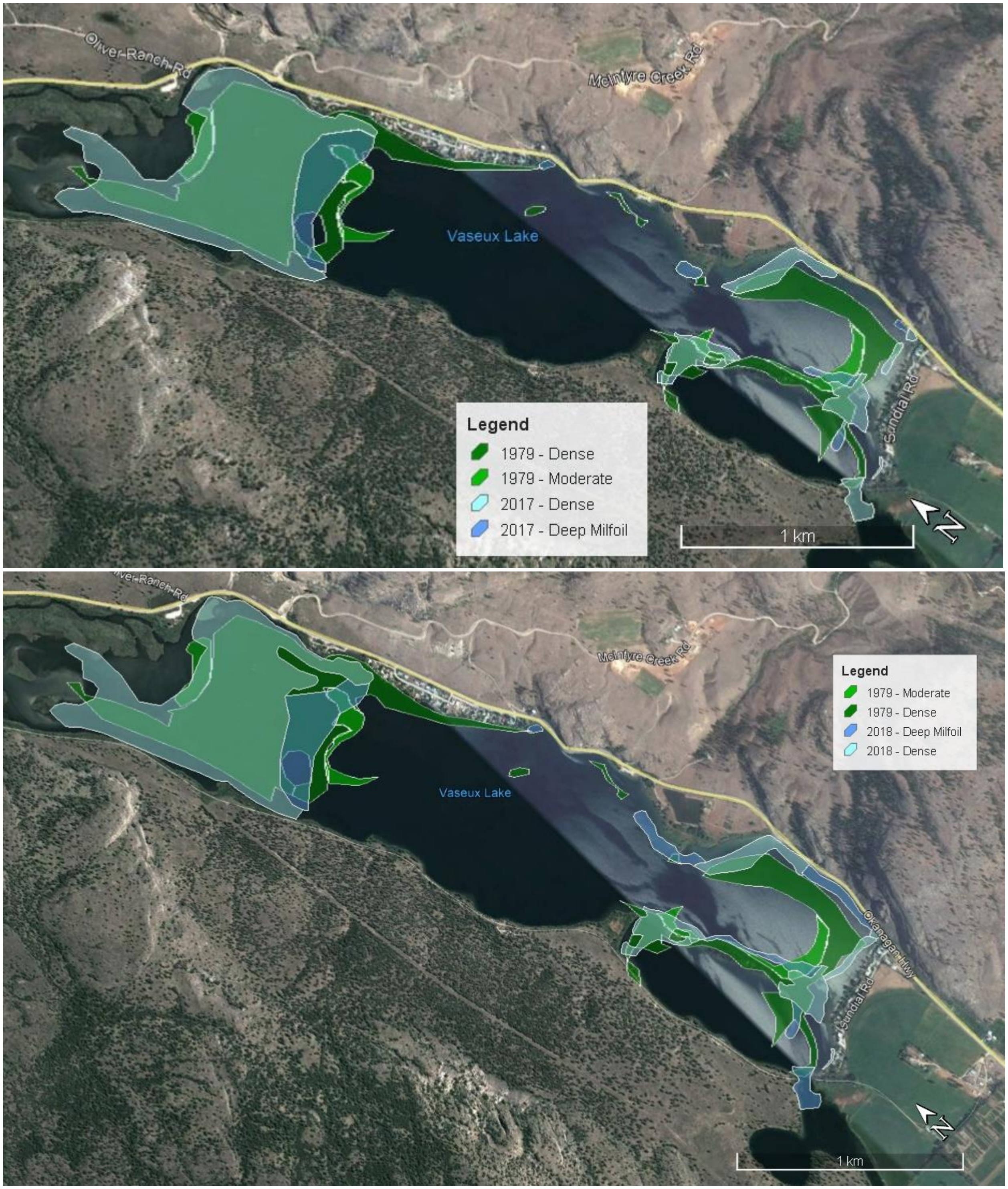


Figure 3-15: Plant beds in Vaseux Lake in 1979 compared to 2017 and 2018

3.6 Land Use Inventory and Survey

Mapping available from RDOS was utilized to inventory the land use in the vicinity of Vaseux Lake. Briefly, there are two residential subdivisions, and a highway in the riparian area, and small forage and vineyards within the watershed. Much of the immediate watershed is undeveloped park (Figure 3-16). The upstream watershed via the Okanagan River is heavily impacted with all forms of development including agriculture industry, forestry, resource extraction, sewage effluent disposal, and urban development housing over 200,000 people.

3.6.1 Immediate watershed land use impacts

Immediately surrounding Vaseux Lake are several land uses with water quality impact potential.

1) Highway 97 runs along the entire eastern shore. It is the major North-South traffic route through the Okanagan Valley. This road carries vehicles ranging from motorcycles to large trucks transporting hazardous materials.
2) Along the eastern shore between Highway 97 and the shoreline is a subdivision on Vaseux Lake Crescent with ~30 private dwellings. These properties are all on septic systems, many of which are decades old.
3) Vaseux Lake Provincial Park and Campground is located near the north end of the lake. This campground has 12 sites and a day-rest area.
4) At the south end of the lake is another subdivision along Sundial Rd. with ~20 private dwellings and two seasonal motels. Again, these properties are all on septic systems, many of which are decades old.
5) Agricultural land lies to the south of Sundial Rd. and may not impact Vaseux Lake

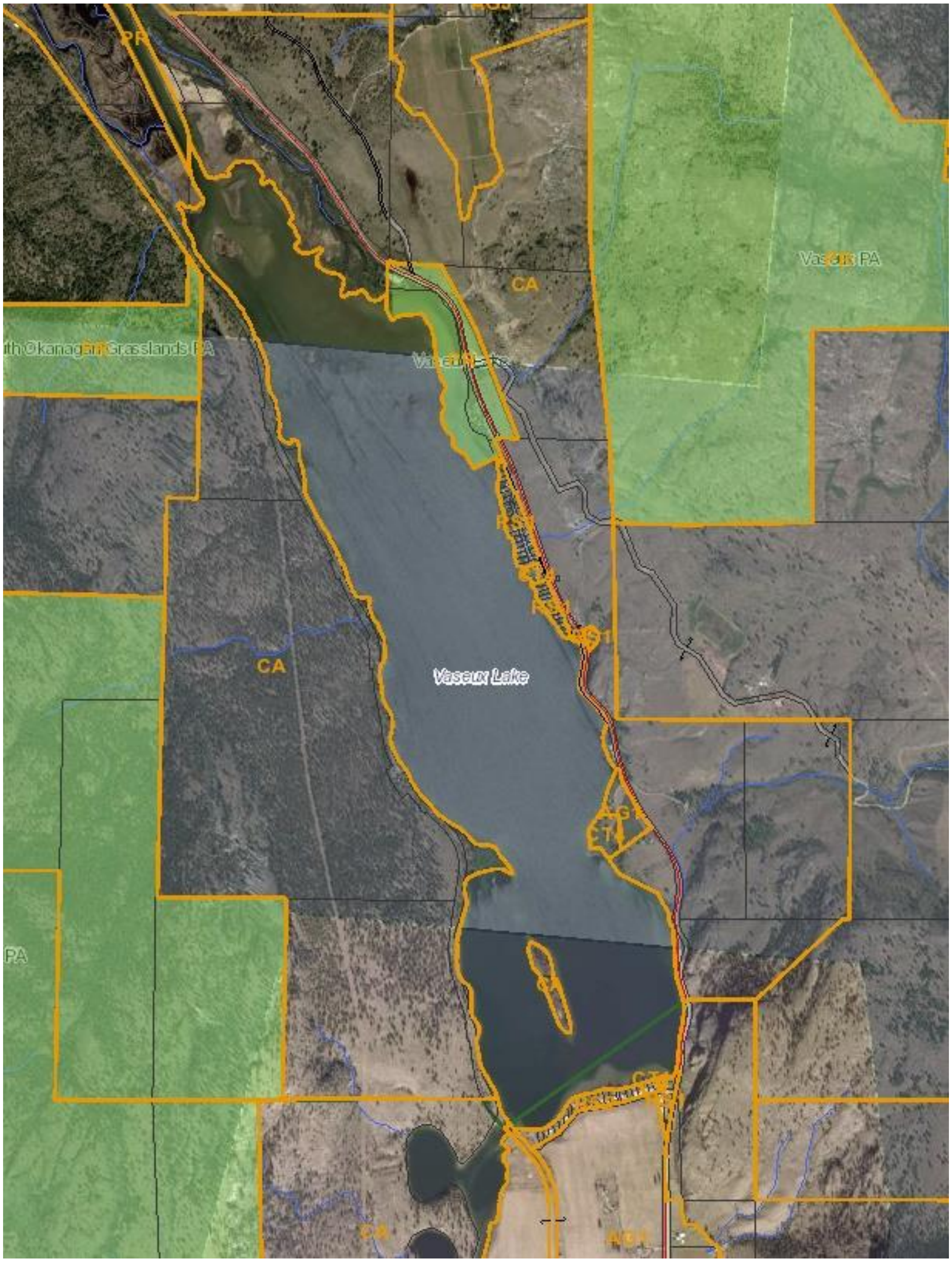


Figure 3-16: Land uses around Vaseux Lake
Source: RDOS online GIS system (RDOS, 2018)

3.6.2 Upstream land use impacts

Use of existing literature readily pinpointed the Shuttleworth Creek watershed as a significant sediment source to Vaseux Lake. Challenges with sedimentation from unstable slopes in the Shuttleworth Creek watershed were apparent in the literature and have been documented since at least the 1980's. For example, an Integrated Watershed Restoration Plan for Shuttleworth

Creek and Vaseux Creek watersheds was completed in 1998, which included a Sediment Source Survey (IWRP 1998). This followed a Watershed Restoration Program approved by Forest Renewal BC in 1996 and an analysis of channel stability and sediment sources in 1982 (Hawthorn and Karanka 1982).

A lower reach of Shuttleworth Creek was modified into a sediment trap, and this collects huge volumes of sand/cobble substrate (Figure 3-17). In fall 2017, the sediment trap was dredged. A major slope failure with its watershed in 2018 exceeded the capacity of this trap. Shuttleworth flows generated a sediment plume that travelled to Vaseux Lake and increased turbidity to 75 NTU as measured on May 11, 2018 (Figure 3-18). Fine sediments and nutrients delivered by this plume and the large freshet significantly increased algae production in Vaseux Lake above the historic average throughout the 2018 growing season (Figure 3-3). Instability in the Shuttleworth Creek drainage area will be worst during extreme flow events such as those that occurred in May 2017 and 2018. As the climate changes, the frequency of extreme flow events is expected to increase.

Figure 3-17: Shuttleworth Creek sediment catch basin being cleaned in October 2017

Figure 3-18: Shuttleworth Creek plume entering Okanagan River (top) and extreme turbidity in Vaseux Lake on May 11, 2018 (bottom)

The Okanagan Falls Wastewater Treatment Plant began operating in March 2013. It discharges tertiary treated (phosphorus removed) effluent into Okanagan River 2.5 km upstream of Vaseux Lake. From 2013-2017, the average nutrient load was only 27 ± 16 kg of TP or only 0.9% of the annual load contributed by Okanagan River. Nitrogen compounds are not removed during the WWTP process and averaged 1434 kg TN or only 0.5% of the annual load contributed by Okanagan River (Self, 2017).

The upstream wetlands act as a sediment filter and should also act as a nutrient filter. Although, the effectiveness of the wetlands was greatly reduced when the river was channelized in the 1950's.

4.0 VASEUX LAKE REMEDIATION

4.1 Investigating Vaseux Lake Remediation

The enhancement goals include reducing or reversing the excessive milfoil/algae growth and sedimentation rates in Vaseux Lake. LAC has designed and implemented many reservoir/lake management techniques over the past 35 years. Techniques that were reviewed for Vaseux Lake are provided in Appendix 6: Management techniques. The feasible options for addressing the interrelated concerns with excessive algae and milfoil growth, nutrient and sediment inflows in Vaseux Lake are outlined in Section 4.2.

4.2 Possible Solutions for Vaseux Lake

Lake Improvement Technique	Priority	Problem addressed	Cost	Risk	Desired outcome	Possible Consequences/challenges	Comment
Repairing Shuttleworth Ck. watershed and/or expanding sediment trap	Very High	Sediment, Nutrients	Very High / Moderate	Low	Stabilizing upstream watershed areas would reduce sediment accumulation at north end of Vaseux Lake and reduce nutrient load to Vaseux Lake.	No adverse consequences but significant challenges to stabilize slide-prone unstable riparian areas; upgrading sediment trap size and frequency of cleaning	Shuttleworth Creek identified as main source of sediment to north end of Vaseux Lake for decades; sediment trap may be most feasible option
Rototilling for plant mass removal, root disruption (through OBWB)	Mod	Invasive Milfoil	Low	Mod	Reduction in extent and density of invasive milfoil-leading plantbeds at south end of Vaseux Lake, to occur on high milfoil growth years. Plant removal would also cause some nutrient removal in the plant mass. Rototilling would be timed to minimize bird disturbance	-Damage to/removal of native plant beds. -Sediment resuspension and release of sediment metals to a plume that could exceed aquatic life guidelines for days after the rototilling. -Vaseux Lake is a migratory bird sanctuary so permits required	-Rototilling does not kill plants, and fragments can root and would be required every 2-3 years) -Sediment cores from Vaseux Lake contained moderate - heavy metals concentrations with Ni and Fe exceedances
Designed wetlands upstream of Vaseux Lake	Mod	Nutrients, metals, sediment	High	Low	Wetlands filter inflowing water of nutrients, metals, and settle sediment		Without restoration of Shuttleworth Ck., constructed wetlands in main channel would rapidly clog with sediment
Riparian restoration of other tributaries	High	Nutrients sediment	Not known	Low	Stability of upstream watershed would reduce sediment accumulation at north end of Vaseux Lake and reduction of nutrient loads to Vaseux Lake.	Loss of useable land for agriculture and development if riparian setbacks established	Restoration of riparian areas increases water quality and resiliency to extreme weather events that are recurring more frequently in recent years
Upgrading or removing old septic systems	Mod	Nutrients	High	Low	Old or abandoned septic systems continue to leach nutrients for decades, removal of these nutrient sources will reduce overall nutrient donation to Vaseux Lake	Identifying problem septic fields would be very challenging and expensive – especially extending sewer to the Vaseux subdivisions	Expanding the sewer system to this area would be very expensive and may not result in noticeably lower plant/algae growth

5.0 CONCLUSIONS

The source of increasing sedimentation in Vaseux Lake was quickly determined to be the Shuttleworth Creek watershed. A major washout and subsequent flooding in May 2018 carried enough sediment into Vaseux Lake to cloud the entire lake and reduce water clarity to near zero. The large sandbar at the north end of Vaseux Lake expands with each freshet but has grown significantly within the past 10 years forming a new island in the process. Restoration of Shuttleworth Creek or upgrading the sediment collection basin at its mouth is essential if continued rapid expansion of the Vaseux Lake sandbar is to be avoided. Control of the plantbeds will not greatly affect the sedimentation rate in the north end of Vaseux Lake because most sediment is deposited during freshet before the plants have put on much growth. Rather, reducing sedimentation will benefit macrophyte control efforts because fresh sediment is typically rich in nutrients and provides a new growth substrate for macrophytes.

Proliferation of invasive Eurasian milfoil is a concern throughout the Okanagan Valley, including Vaseux Lake. The large shallow areas of Vaseux Lake are ideal habitat for aquatic macrophytes and would be densely populated even if this milfoil was not introduced. The 2017 and 2018 plantbed extents were both smaller than those mapped in 1979 at the north and south ends of Vaseux Lake. In all three years, the same general areas were identified as having dense beds. During 2017, invasive Eurasian milfoil was a minor component of the macrophyte community and native species were dominant throughout the lake. The population shifted in 2018 and was once again dominated by invasive milfoil. Lakeshore residents have confirmed that the composition of aquatic macrophytes varies from year to year. Milfoil also appeared to prefer areas of 3-5 m depth as compared to the very shallow north end that was dominated by native *Potamogeton* species. Overall, the extent and density of invasive milfoil was similar to what was measured in 1979 and indicates that the plantbeds are not rapidly increasing in size. It is unclear if mechanical removal of the milfoil via rototilling will have long-term benefit or if incidental removal of the coexisting native macrophytes will provide more opportunities for invasive milfoil to spread. Rototilling would likely be required every 2-3 years and may release sedimented heavy metals.

Large blooms of filamentous algae have been observed in some years throughout the plantbeds. These were not observed in either 2017 or 2018. Further monitoring of the plantbeds should be undertaken to assess the frequency, intensity and impact of filamentous green algae blooms.

Research conducted from 2013-2017 has not indicted an impact from the Okanagan Falls wastewater treatment plant (WWTP) on the chemistry or biology of Vaseux Lake. An increasing trend in ammonia was noted in Okanagan River upstream of Vaseux Lake but this trend was also present upstream of the WWTP and is attributed to changes within the entire Okanagan Valley watershed and not just Vaseux Lake.

Nutrient loading estimates revealed that Okanagan River inflows make up approximately 90% of nitrogen and phosphorus contributions to Vaseux Lake each year while internal recycling, local agriculture, and septic fields were relatively small contributors.

Piezometer samples around the perimeter of Vaseux Lake indicate that local groundwater contributes nitrogen and phosphorus to Vaseux Lake but the loads are expected to be low relative to other inflows such as Okanagan River. The east shore subdivision piezometer samples were over 8 times higher in phosphate than surface samples in Vaseux Lake while the south shore subdivision piezometer samples were 7 times higher in ammonia than lake surface water.

Enhancement goals include reducing or reversing the excessive milfoil/algae growth and sedimentation rates in Vaseux Lake. We identified five possible approaches that could be taken including restoration and sediment control of Shuttleworth Creek, engineered wetlands, septic field upgrades, and rototilling of plantbeds.

6.0 RECOMMENDATIONS

Based on Year 1 and 2 results, we recommend the following be considered by RDOS:

- Obtain funding for retrieval and analysis of sediment traps currently deployed in Vaseux Lake (~$2000 one-time)
- Restoration of Shuttleworth Creek should take high priority based on catastrophic slope failure in 2018, and resultant flooding and sediment deposition through Okanagan River and the north end of Vaseux Lake.
- Detailed hydrological study should be conducted on Shuttleworth Creek to identify existing and potential future slope failures.
- Expand the capacity of the sediment collection basin at the mouth of Shuttleworth Creek by deepening it if possible, and by cleaning it out every year during summer low flows.
- Long-term plantbed monitoring in Vaseux Lake should be pursued to better understand trends and interannual variation in density and species abundance. This will also be informative in detailing filamentous green algae blooms. One trip each August should be sufficient to update maps and would be relatively inexpensive (~$3000/year for sampling, imaging and a small report).
- If rototilling is a preferred option for Vaseux Lake remediation, bench testing of metal release from sediments should be pursued
- Obtain special permission from Environment and Climate Change Canada to operate powered watercraft in Vaseux Lake for scientific research. This would reduce the time and cost of future studies on Vaseux Lake.
- If additional funding is secured in future years, completing the hydrogeological survey of Vaseux Lake should be a priority as this will allow the calculation of a full nutrient loading budget for Vaseux Lake.

7.0 Literature Cited

Allard, R., & Manwell, B. (2011). Review of Ambient Groundwater Quality Monitoring Networks in the Okanagan Kootenay Region. Retrieved from http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=23602

Associated Environmental. (2016). *Appendix S - Shuttleworth Creek*. Retrieved from https://www.obwb.ca/newsite/wp-content/uploads/OBWB_EFN_May2016_appendixS.pdf

British Columbia Government. Environmental Management Act - Contaminated Sites Regulation (2017). British Columbia, Canada. Retrieved from http://www.bclaws.ca/Recon/document/ID/freeside/375_96_08

British Columbia Ministry of Environment. (1990). *Okanagan Watershed Descriptions For: Chute Creek, Eneas Creek, Equesis Creek, Kelowna (Mill) Creek, Lambly Creek, Mission Creek, Naramata Creek, Naswhito Creek, Okanagan lake, Peachland Creek, Penticton Creek, Powers Creek, Robinson Creek, Shingle Creek,*. Retrieved from http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=32362

British Columbia Ministry of Environment. (2007). Okanagan Basin Historic Aquatic Plant Mapping 1976 to 1982. Retrieved February 13, 2018, from http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=39988

British Columbia Ministry of Environment. (2016). Approved Water Quality Guidelines. Retrieved March 11, 2016, from http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines

Canada-British Columbia Consultative Board. (1974). *1974 Okanagan Basin Study*. Victoria, BC: Government of British Columbia. Retrieved from http://www.obwb.ca/library/1974-okanagan-basin-study/

Canadian Council of Ministers of the Environment. (2018). Canadian Environmental Quality Guidelines (CEQG online). Retrieved from http://st-ts.ccme.ca/

Dai, X., & Boll, J. (2006). Settling velocity of Cryptosporidium parvum and Giardia lamblia. *Water Research*, *40*(6), 1321–1325. https://doi.org/10.1016/j.watres.2006.01.027

Dessouki, T. C. E. (2009). *Water quality assessment of the Okanagan River near Oliver, British Columbia (1990-2007)*.

Dobson Engineering. (1999). Watershed Assessment Report for the Vaseux Creek Watershed. Retrieved from http://www.obwb.ca/obwrid/docs/312_1999_Vaseaux_WAPpart1_2_3.pdf

Environment Canada. (2018). Canadian Climate Normals 1981-2010 Station Data - Oliver STP, British Columbia. Retrieved December 14, 2018, from http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=1039&autofwd=1

Geller, Douglas, J., & Manwell, B. R. (n.d.). Monthly Groundwater Budget Analysis for the Oliver , B.C. Area (Aquifers 254, 255, 256). Retrieved from http://a100.gov.bc.ca/appsdata/acat/documents/r50858/OliverWaterBudg_1473269910536_3267563510.pdf

Golder and Associates, & Summit Environmental Consultants. (2009). *Groundwater Objectives 2 and 3 Phase 2 Okanagan Water Supply and Demand Project*. Retrieved from http://a100.gov.bc.ca/appsdata/acat/documents/r17612/groundwater_report_1262973144610_a00f52d92cde53e9ef9d62637b0ad50dd66772edf70d912dce29574ecbfd6518.pdf

Harrington, J., & Nichol, C. (2013). *Hydrogeochemistry of the Kelowna Aquifer System By*. University of British Columbia. Retrieved from https://www.obwb.ca/newsite/wp-content/uploads/kelowna_water_quality_j_harrington_honours_thesis.pdf

Hawthorn, R. S., & Karanka, E. J. (1982). *Coldstream and Vaseux Creek Watersheds: Analysis of Channel Stability and Sediment Sources*. Retrieved from http://www.env.gov.bc.ca/wat/wq/studies/cvwatersheds.pdf

HayCo. (2009). *Kelowna Old Floating Pontoon Sinking - Technical Memo January 12, 2009 File V13201134 and February 13, 2009 File V13201184*.

Hy-Geo Consulting. (2007). *Observation Well Network Review Okanagan Region: Final Report Volume I of II*. Retrieved from http://a100.gov.bc.ca/appsdata/acat/documents/r9878/ObsWellNetworkReview-OkanaganRegion2007_1175190393490_89cb344a3b5c4bc8904f9359b246a81b.pdf

Jatel, N., Graham, G., Thomson, S., & Edwards, D. (2013). Okanagan Groundwater Monitoring Project Summary 2013.

Larratt, H. (2010). *District of Lake Country Source to Tap Assessment of the South Kalamalka Lake Intake – July 2010*.

Larratt, H., & Self, J. (2015). *Near-Shore Water Quality and Periphyton Production in the Cosens Bay Cottage Development Area of Kalamalka Lake, 2015, Year II*.

Naismith, H. (1962). *Late Glacial History and Surficial Deposits*. *British Columbia Department of Mines and Petroleum Resources* (Vol. 46). Retrieved from http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/BulletinInformation/BulletinsAfter1940/Documents/Bull46.pdf

Regional District Okanagan Similkameen. (2018). RDOS Online GIS. Retrieved February 10, 2018, from http://maps.rdos.bc.ca/Html5Viewer/?viewer=publicparcels

Schertzer, W. M., & Taylor, B. (2009). *Assessment of the Capability to Compute Evaporation from Okanagan Lake, Other Mainstem lakes and Basin Lakes and Reservoirs using the Existing Database*. Retrieved from http://www.obwb.ca/obwrid/detail.php?doc=332

Self, J., & Larratt, H. (2016). *Long-term Water Quality Trends , Nutrient Budgets , and Cyanobacteria Blooms as they Affect the Kokanee Fishery of Wood Lake*.

Self, J., & Larratt, H. (2017). *Impact of RDOS WWTP on Vaseux Lake and Okanagan River 2016 Annual Report*.

Smerdon, B. D., & Allen, D. M. (2009). *Regional-Scale Groundwater Flow Model of the Kelowna Area and the Mission Creek Watershed , Central Okanagan , BC*. Retrieved from http://a100.gov.bc.ca/appsdata/acat/documents/r16508/MissonCreek_ModelingFINAL_1246992266977_90bb817c46a0bd0c10b6206655956aeead91823f2e1f547095bcef8d86c0d7b

9.pdf

Smith, E. P. (2006). BACI Design. *Encyclopedia of Environmetrics*, *1*, 141–148. https://doi.org/10.1002/9780470057339.vab001

Summit Environmental Consultants. (2005). Okanagan Basin Water Supply and Demand Study : Phase 1. *Water*, (May). Retrieved from https://www.obwb.ca/fileadmin/docs/Supply_Demand_Phase1.pdf

Summit Environmental Consultants. (2010). Okanagan Water Supply and Demand Project – Phase 2 Summary Report, (July), 13–20. Retrieved from https://obwb.ca/wsd/wp-content/uploads/2011/02/

Summit Environmental Consultants. (2013). *Okanagan Basin Water Board Okanagan Hydrologic Connectivity Model : Summary Report*. Retrieved from https://www.obwb.ca/newsite/wp-content/uploads/2013/09/ohcm_final_report.pdf

Water Office. (2018a). Real-Time Hydrometric Data Graph for Okanagan River at Okanagan Falls (08NM002) [BC]. Retrieved December 14, 2018, from https://wateroffice.ec.gc.ca/report/report_e.html?type=realTime&stn=08NM002

Water Office. (2018b). Real-Time Hydrometric Data Graph for Okanagan River below McIntyre Dam (08NM247) [BC]. Retrieved December 14, 2018, from https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08NM247

Western Water Associates Ltd. (2016). *Swan Lake - Land Use and Water Quality Assessment, Vernon, BC*. Retrieved from https://www.obwb.ca/newsite/wp-content/uploads/160830_WWAL-Report_Swan-Lake_-text_figures_appendixC.pdf

8.0 Appendices

8.1 Appendix 1: Water Quality Data Base

TABLE 3
Current and Proposed ECA's in the Vaseux Creek Watershed

Sub-basin	Total Area (ha)	ECA above IDF/MS Line (%)			Total ECA (%)		
		1998	2003	2004+ (Info. Blocks)	1998	2003	2004+ (Info. Blocks)
Dutton (V-2)	2970	0.8	0.6	0.6	30.5	28.3	28.3
Venner (V3-1)	5091	45.3	40.0	40.0	45.8	40.4	40.4
McIntyre (V4)	3326	25.3	26.6	26.6	25.3	26.6	26.6
Underdown (V5)	2599	26.1	29.5	30.3	27.7	31.6	32.4
Solco (V3-1 and V3)	8194	35.3	32.3	32.7	35.5	33.0	33.4
Upper Vaseux (V4, V5 and V6)	12591	21.1	25.6	26.2	22.9	27.2	27.8
POI2	20785	26.7	28.2	28.8	27.9	29.4	30.0
POI1	29192	19.5	20.5	21.2	23.6	25.1	26.1

Dobson Engineering

The water quality data used in the preparation of this report can be found in the following files:

Vaseux Milfoil Study meterdata.xlsx
Vaseux Milfoil WQ.xlsx

8.2 Appendix 2: Water Quality, Sediment and Tissue Guidelines in BC

Generalized Water Quality Guidelines for the Protection of Aquatic Life						
Selected Analytes	Units			BC 2006		CCME
Water Quality General				Maximum	30-day average	
pH				6.5 - 9.0	-	6.5 - 9.0
Dissolved oxygen	mg/L			5 - 9 (min)	8 - 11 (min)	5.5 - 9.5
Total organic carbon	mg/L			-	± 20% of median	-
Suspended solids	mg/L			± 25	± 5	-
Turbidity	NTU			± 8	± 2	-
Metals						
Aluminum – diss.	mg/L			-	0.02	-
Arsenic – total	mg/L			0.005	-	0.005
Cadmium – total	mg/L			Cd calc	-	Cd calc
Chromium – total	mg/L			-	-	-
Chromium III ion	mg/L			0.009	-	0.0089
Chromium VI ion	mg/L			0.001	-	0.001
Copper – total	mg/L			Cu calc	≤ 0.00004	0.002 - 0.004
Iron – total	mg/L			0.3	-	0.300
Lead – total	mg/L			Pb calc	Pb calc	0.001 - 0.007
Mercury – total inorg.	mg/L			0.0001	0.00002	0.00026
Nickel – total	mg/L			0.0025 - 0.150	-	0.0025 - 0.150
Selenium – total	mg/L			0.002	0.00020	0.0010
Sodium – total	mg/L			-	-	-
Silver – total	mg/L			(0.0001 if hardness <100mg/L) - 0.003	0.00005 (hard <100 mg/L) - 0.0015	0.0001
Thallium – total	mg/L			0.0003	-	0.0008
Zinc – total	mg/L			Zn calc	Zn calc	0.03
Nutrients						
Ammonia as N	mg/L			0.752 - 27.7 temp/pH table	0.102 - 2.08 temp/pH table	0.019 un-ionized
Nitrate-N as N	mg/L			200	40	13
Nitrite-N as N	mg/L			0.06	0.02	0.06
Total phosphorus as P	mg/L			0.005 - 0.015 for lakes	-	-
Sulphate	mg/L			(100)	218 - 309 calc	-

Parameter/Analyte	Calculation
Cd	WQG Short-term = e^[1.03 * ln(Hardness) - 5.274]
Cu	0.94(hardness+2)/1000 BC MoE | $CWQG\ (\mu g/L) = 0.2 * e^{\{0.8545[\ln(hardness)]-1.465\}}$ CCME
Pb max	$e^{1.273(\ln(hardness)-1.46)}$/1000
Pb 30 day average	3.31 + $_e$(1.273 ln(average hardness) - 4.705) in ug/L
SO4 (proposed 2013)	Hardness(mg/L) soft (0-30)=128 (31-75)=218 hard(76-180)=309 very hard(181-250)
Zn max	(33+0.75(hardness-90))/1000
Zn 30 day average	(7.5+0.75(hardness-90))/1000

Water Quality Guideline References

LCR Objectives: Lower Columbia River from Birchbank to the International Border: Water quality Assessment and Recommended Objectives, MacDonald Envi Services Ltd. 1997
BC Water Quality Guidelines http://www.env.gov.bc.ca/wat/wq/BCguidelines Nagpal et al 2006
CCME 2005 Canadian Council of Ministers of the Environment f http://st-ts.ccme.ca/
http://www.env.gov.bc.ca/wat/wq/BCguidelines/sulphate/pdf/sulphate_final_guideline.pdf

Sediment metal quality guidelines						
Selected Analytes	Units	LCR Sediment	BC Working Guidelines 2006		CCME	
Sediment Quality		Objective	ISQG	PEL	ISQG	PEL
Total Metals	Dry wt.					
Arsenic	mg/kg	5.7	5.9	17	5.9	17
Cadmium	mg/kg	0.6	0.6	3.5	0.6	3.5
Chromium	mg/kg	36.4	37.3	90	37.3	90
Copper	mg/kg	35.1	35.7	197	35.7	197
Iron	mg/kg	-	21,200 (2%)	43,766 (4%)	-	-
Lead	mg/kg	33.4	35	91.3	35	91.3
Mercury	mg/kg	0.16	0.170	0.486	0.17	0.486
Nickel	mg/kg	-	16	75	-	-
Selenium	mg/kg	-	2	-	-	-
Silver	mg/kg	-	0.5(Ontario)	-	-	-
Thallium	mg/kg	-	-	-	-	-
Zinc	mg/kg	120	123	315	123	315

ISQG = interim sediment quality guideline (mg/kg = µg/g)
PEL = possible effects level

NOTE: It is noted here that the Objectives cited here are more stringent than the Contaminated Sites Regulations (CSR) Schedule 9 standards for sediment.
According to the 2009 BC Lab Manual for sediment samples, the < 2 mm fraction is analyzed

Sediment Guideline References

LCR Objectives: Lower Columbia River from Birchbank to the International Border: Water quality Assessment and Recommended Objectives, MacDonald Envi Services Ltd. 1997
BC Water Quality Guidelines http://www.env.gov.bc.ca/wat/wq/BCguidelines Nagpal et al 2006
CCME Canadian Council of Ministers of the Environment f http://st-ts.ccme.ca/

Tissue metals guidelines for consumers of fish, wet weight				
	Human Health[1]	**Wildlife[2]**	**CCME**	**BCMOE**
Analyte	µg/g	µg/g	µg/g	µg/g
Arsenic	3.5	0.47		
Cadmium		0.9		
Chromium		0.94		
Lead	0.5	0.80		0.80
Mercury	0.5	0.1	0.033	
Selenium	1.8	0.89		0.89

1. Canadian guidelines for chemical contaminants and toxins in fish and fish products. Based on fish protein (mussel) concentration (Ammend.no.11, 2011). (Can.Food.Insp.Agency 2011)
2 BC MoE 1987 and 2014; CCME 2006

8.3 Appendix 3: Initial reconnaissance sampling

In September 2017, a Hannah multi-meter with GPS was used at 50 + perimeter sites to identify potential sample sites for piezometers (shallow groundwater) and lake sample sites Figure 2-1. This effort showed uniform conditions around the perimeter of the lake and resulted in no changes to the sampling program design.

pH pH averaged 7.66 ± 0.09 along the developed eastern shore and 7.57 ± 0.09 along the south shore. These values were significantly different, but that difference was very small (T-test, $p<0.001$; Figure 8-1).

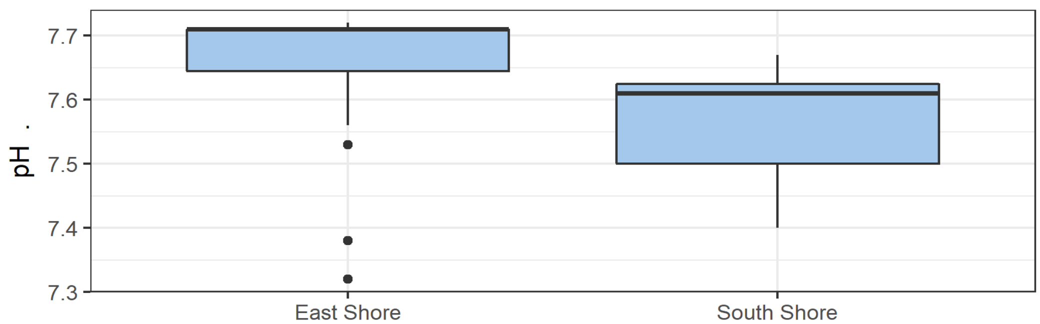


Figure 8-1: pH results from shoreline survey

Temperature Water temperature averaged 16.2 ± 0.1 °C along the eastern shore and 16.6 ± 0.6 °C along the south shore. The slight difference was statistically significant but again, very small (T-Test, $p<0.001$; Figure 8-2). The south shore had a higher average temperature and a larger range in temperatures and this was caused by very shallow water in that area.

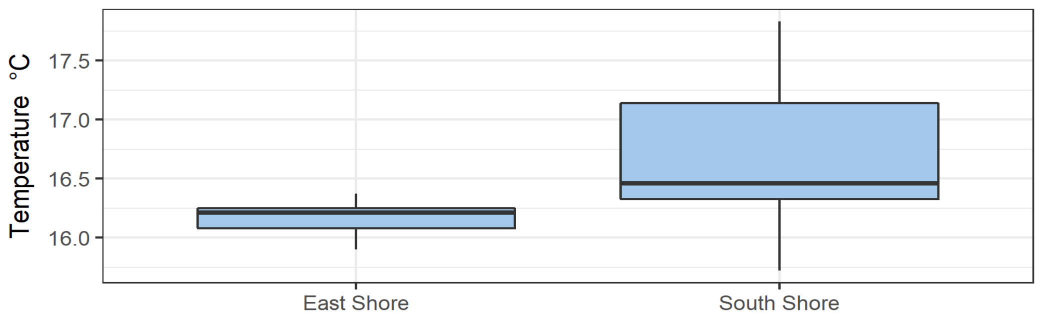


Figure 8-2: Temperature results from shoreline survey

Dissolved oxygen Dissolved oxygen was excellent along both shores and averaged 9.1 ± 0.3 mg/L on the east shore and 8.8 ± 0.1 mg/L along the south shore. These differences are very small and are not meaningful from a lake health perspective.

Conductivity & **total dissolved solids** Conductivity and TDS were very similar and averaged 274 ± 1 µS/cm and 137 ± 1 mg/L respectively along both shores. These are the parameters that would be affected if there was localized loading of metals or nutrients. Their uniform results indicate that point source loading was not detected in these shoreline survey profiles.

8.4 Appendix 4: Metals Exceedances in Groundwater Samples from 2017

Several of the groundwater sites exceeded the BC MoE Aquatic Life MAC Guidelines and the Canadian Drinking Water Guidelines for various metals while none of the lake samples exceeded guidelines (Table 8-1, Table 8-2). Vaseux Piezo 2 (located at S Prov Park) contained the most exceedances in terms of both number and scale. This piezo contained very muddy water and was not representative of true groundwater. These results are still concerning because they indicate that the soil along the shore of Vaseux Lake contains elevated heavy metals such as arsenic, cadmium, chromium, lead, and zinc. All six piezometers contained elevated chromium concentrations that exceeded the aquatic life guideline while the two deeper wells did not. Conversely, the two deeper wells exceeded the aquatic life guideline for copper. Piezo 3 exceeded the drinking water lead guideline while several sites exceeded the aquatic life guideline for zinc including both wells. Finally, the well on Sundial Rd. exceeded the drinking water guideline for uranium. This is concerning from a health perspective as that is a domestic well. However, this result does not signify contamination as the Okanagan region is naturally high in uranium. Of important note is the fact that mercury did not exceed relevant guidelines in either the lake or groundwater samples collected in Fall 2017.

Table 8-1: Exceedances of guidelines in groundwater chemistry samples from Fall 2017

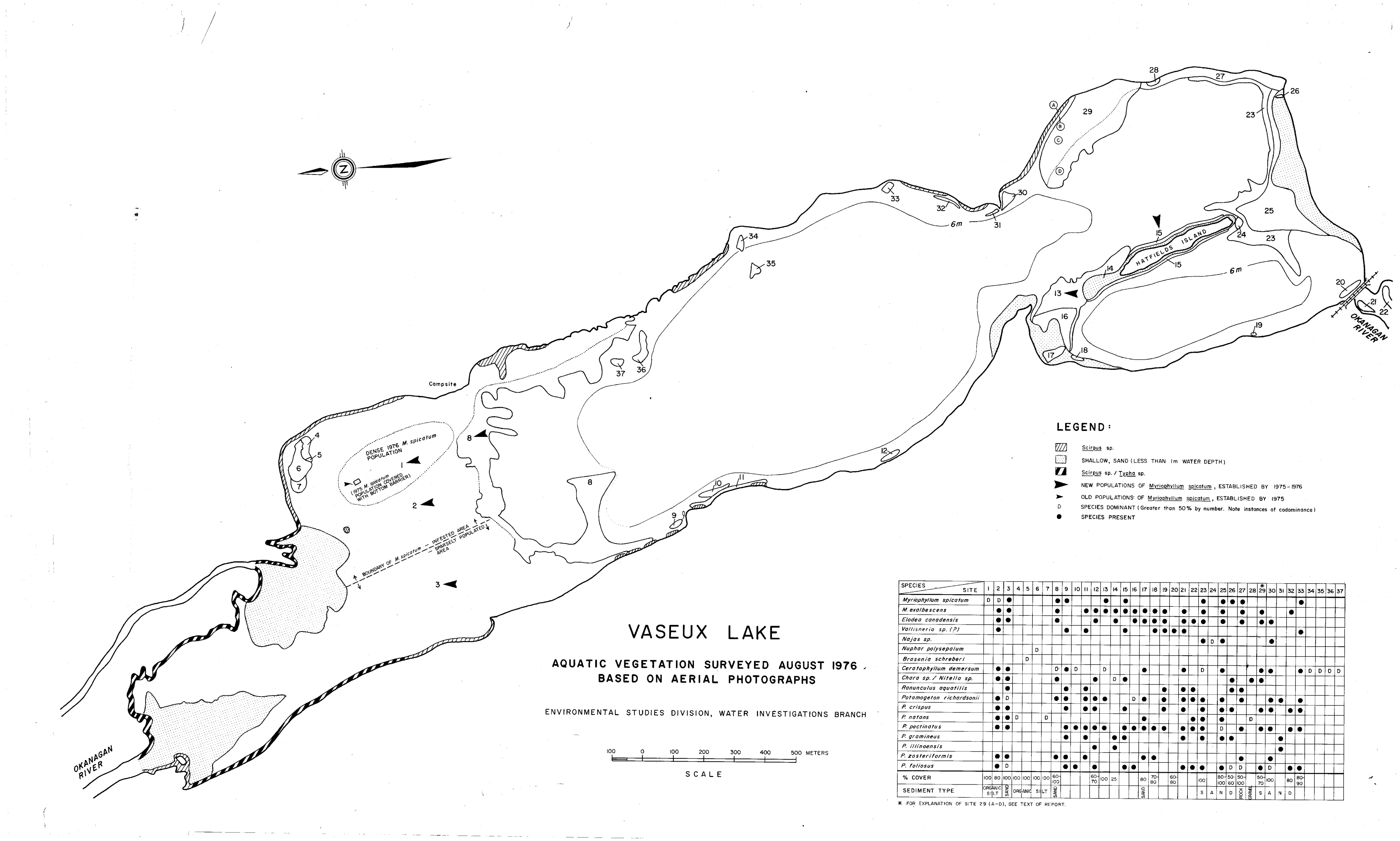
Site	Date	As	Cd	Cr	Cu	Fe	Pb	Se	Th	U	Zn
Vaseux Piezo 1	2017-11-08	✔	✔	0.00106	✔	13.3	✔	✔	✔	✔	✔
Vaseux Piezo 2	2017-11-08	0.0463	0.00137	0.0685	0.163	69.2	0.0565	0.00274	0.000556		0.334
Vaseux Piezo 3	2017-11-08	✔	✔	0.00799	✔	7.25	0.0104	✔	✔	✔	✔
Vaseux Piezo 4	2017-11-08	✔	✔	0.00128	✔	0.681	✔	✔	✔	✔	0.0814
Vaseux Piezo 5	2017-11-08	✔	✔	0.00227	✔	2.7	✔	✔	✔	✔	✔
Vaseux Piezo 6	2017-11-08	✔	✔	0.00129	✔	1.09	✔	✔	✔	✔	✔
Well @ Prov. Park	2017-10-12	✔	✔	✔	0.0141	0.816	✔	✔	✔	✔	0.125
Well @ Sundial Rd.	2017-10-12	✔	✔	✔	0.0187	1.15	✔	✔	✔	0.0276	0.187

Note: Red text=CDWG exceedance only; black text=BC MoE Aquatic Life MAC exceedance only; blue text=exceedance of both guidelines; ✔ denotes results met applicable guidelines. | Vaseux Piezo 2 had a low volume and contained substantial sediment, likely explaining the greater number and scale of exceedances at that site.

Table 8-2: Exceedances of guidelines in surface water chemistry samples from Fall 2017

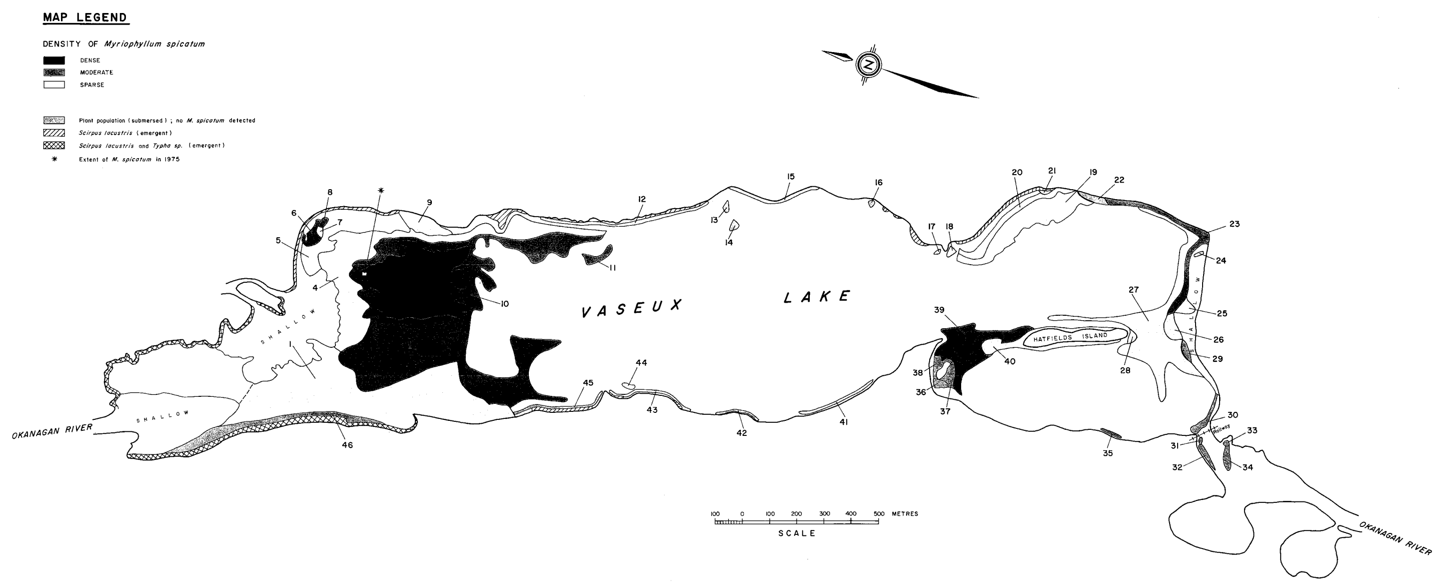
Site	Date	As	Cd	Cr	Cu	Fe	Pb	Se	Th	U	Zn
NW weed beds		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
N end Vaseux		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
NE weed beds		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
E shore comp.		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
S weed beds		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
S shore comp.		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Control area		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

8.5 Appendix 3: Mapping – Historic plant maps



SPECIES / SITE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	*29	30	31	32	33	34	35	36	37
Myriophyllum spicatum	D	D	●					●	●				●		●								●		●	●	●						●				
M. exalbescens		●	●					●			●	●	●	●	●	●	●	●	●		●		●		●		●		●			●					
Elodea canadensis		●	●					●				●		●		●	●	●	●		●	●	●		●		●		●	●							
Vallisneria sp. (?)		●							●		●				●			●	●	●	●												●				
Najas sp.																							●	D	●					●							
Nuphar polysepalum						D																															
Brasenia schreberi					D																																
Ceratophyllum demersum		●	●					D	●	D			D				●				●		D		●				●	●			●	D	D	D	D
Chara sp. / Nitella sp.		●	●					●				●		D	●											●		●	●								
Ranunculus aquatilis			●						●		●								●		●	●				●	●										
Potamogeton richardsonii		●	D					●	●		●	●	●			D	●		●		●	●	●		●		●			●	●		●				
P. crispus		●	●						●		●	●			●				●		●		●		●	●			●	●		●	●				
P. natans		●	●	D			D										●					●	●		●			D									
P. pectinatus		●	●						●	●	●	●	●		●	●	●	●	●		●	●	●		D		●		●	●		●	●				
P. gramineus									●		●			●	●						●		●		●	●					●						
P. illinoensis												●		●																	●						
P. zosteriformis		●	●					●	●		●						●	●									●			●							
P. foliosus		●	D						●	●		●			●	●					●	●	●		●	D	D		●	D		●	●				
% COVER	100	80	100	100	100	100	100	60-100				60-70	100	25			80	70-80		60-80			100		80-100	50-60	50-100		50-70	100		80	80-90				
SEDIMENT TYPE	ORGANIC SILT		SAND	ORGANIC SILT				SAND									SAND						S	A	N	D	ROCK	GRAVEL	S	A	N	D					

* FOR EXPLANATION OF SITE 29 (A-D), SEE TEXT OF REPORT.



Air Photo BC C 151	49	48	48	49	48	49	49	49	48	48	46	47	45	45	45	45	44	44	43	43	43	43	43
SPECIES / SITE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Myriophyllum spicatum	●	■	■	●	●	●	●	●	●	●	●	●			●			●	●	●	●		■
Alisma gramineum																							
Brasenia schreberi						●																	
Ceratophyllum demersum			●							■	■		●	●				●					
Elodea canadensis			●	●	●	●		●	●	●	●	●						●			●	●	●
Myriophyllum exalbescens	●		●	●	●	●	●	●	●	●					●		●				●		■
Najas flexilis																	●					●	●
Nuphar polysepalum						■																	
Potamogeton berchtoldii								●				●						●			■	●	●
P. crispus			●	●	●						●	●			●	●		●					●
P. gramineus												●			●	●	●				●		●
P. illinoensis																	●						
P. natans	●		●	●			■	■									●		●			●	
P. pectinatus	■	●	●	■	■	●	●	■	●		●	●				●		●		●	■	●	●
P. richardsonii	●	●	●	■	●		●		●	●	●	●					●	●	●		●	●	●
P. zosteriformis										●													
Ranunculus aquatilis				●	●		●	●	●			●											
Chara sp.				●		●				●		●			●	●	●					●	
Unidentified sp.					●				●			●											
Myriophyllum spicatum Affected area (ha)	15.50	11.02	7.53	7.77	3.53	.37	.02	.09	1.00	9.27	.28	.98			.56			.09	3.58	1.14	.04		1.16
Total Plant Density	M	D	D	D	D	D	M	M	D	D	D	M	D	D	S	S	M	M	D	M	M	M	D
M. spicatum present before 1977	●	●	●	●	●					●		●				●							●
Sediment	ORGANIC SILT									SAND							SAND				GRAVEL	ROCK	ROCK & SAND

Air Photo BC C 151	43	39	39	38	39	39	39	39	39	39	39	38	44	44	44	44	44	45	36	47	47	34	32
SPECIES / SITE	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
Myriophyllum spicatum	●	●	●	●	●							●				■	●	●		●	●		
Alisma gramineum																						●	
Brasenia schreberi																							
Ceratophyllum demersum			●	■	●	●		■			■	●	●		●	■	●				■	●	
Elodea canadensis	●		●	●	●		●	●	●	●	●	●	●			●	●	●	●			●	●
Myriophyllum exalbescens	●	●	●	●	●			●			●	●	●	●	●	●	●	●			●	●	
Najas flexilis	●		●		■				●	●			●		●		●				●	●	●
Nuphar polysepalum																							
Potamogeton berchtoldii	■	●	●	●	●			●		●							●					●	●
P. crispus	●		●	●	●			●				●	●	●		●	●	●	●	●			
P. gramineus	●	●					●							●		●	●	●	●	●		●	
P. illinoensis																							
P. natans		●	■			■				●			●			●		●				●	●
P. pectinatus	■		●	■				●		■			●		●	●	●	●	●	●		●	■
P. richardsonii	●	●	●	●				●		●	●	●	●	●	●	●	●	●	●	●	●	●	■
P. zosteriformis					■										●								
Ranunculus aquatilis	●								●			●								●			●
Chara sp.	●	●	●		●	●	■			●			●	■			●				●	●	●
Unidentified sp.				●	●				●			●	●				●	■	■	■	●	●	
Myriophyllum spicatum Affected area (ha)	.04	.26	.39	.89	.11							.07				2.90	1.39	.23		.26	.07		
Total Plant Density	D	M	M	D	M	M	S	D	D	D	D	M	M	S	S	D	M	S	M	M	M	S	M
M. spicatum present before 1977	●	●	●	●		●										●	●					●	
Sediment	SAND												SAND										SAND

CHART LEGEND

■ SPECIES DOMINANT

● SPECIES PRESENT

DENSITY OF AQUATIC PLANTS

D DENSE

M MODERATE

S SPARSE

REFERENCES		
DWG. No.	DESCRIPTION	DATE
4567-238	STUDIES ON AQUATIC MACROPHYTES - PART XIV	1976
	VASEUX LAKE BATHYMETRIC AND TOPOGRAPHIC SURVEY	JUNE 1977
BC C 151	AIR PHOTOGRAPHS SCALE 1:6000	JULY 1, 1977

REVISIONS		
No.	DESCRIPTION	DATE

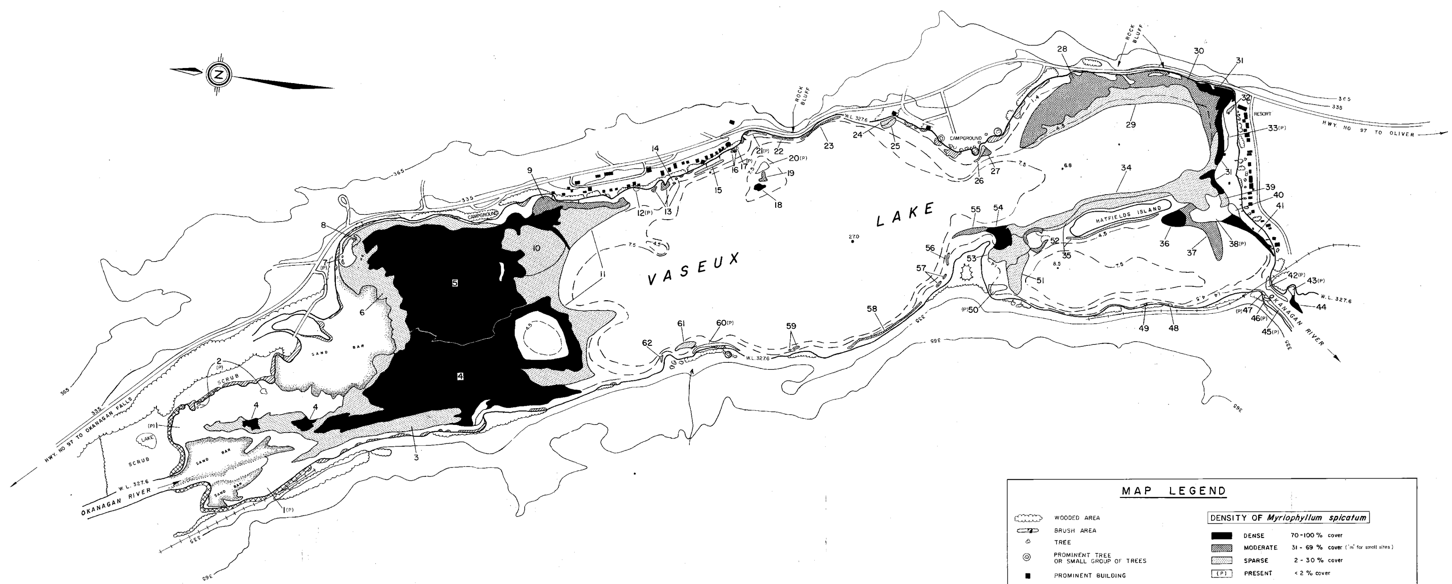
SURVEYED: P. Hepburn
DATE: July 1977
DESIGNED: P. Hepburn
DRAWN: P. Hepburn
TRACED: A. Fraser
CHECKED: R. Nijman
DATE: Feb. 1978

BRITISH COLUMBIA
MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL AND ENGINEERING SERVICES
WATER INVESTIGATIONS BRANCH

AQUATIC PLANT MANAGEMENT PROGRAM
STUDIES ON AQUATIC MACROPHYTES – PART XX

VASEUX LAKE
SURVEY OF *Myriophyllum spicatum*
& OTHER AQUATIC PLANTS

FILE No. 03-6533 0323538
SCALE 1:6000
DWG No. 5144-29
SHEET of



MAP LEGEND

WOODED AREA
BRUSH AREA
TREE
PROMINENT TREE OR SMALL GROUP OF TREES
PROMINENT BUILDING

DENSITY OF *Myriophyllum spicatum*

DENSE 70-100 % cover
MODERATE 31 - 69 % cover ('m' for small sites)
SPARSE 2 - 30 % cover
(P) PRESENT < 2 % cover

Aquatic vegetation (submersed); no *M. spicatum* detected
Scirpus lacustris (emergent)
Scirpus lacustris and *Typha sp.* (emergent)

Air Photo BC C 177	29-31	31	29-31	28-31	28 29	28 29	29	29	27 28	28	27 28	27	26	26	26	26	26	25	25	25	25	25	25	24	24	23	23	22 23	21-23	21	21
SITE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Site area (ha)	9.40	.03	7.25	20.93	20.10	5.06	.32	.06	1.0	2.2	6.18	.02	.06	.01	.07	.01	.01	.06	.04	.09	.06	.05	.07	.05	.08	.08	.05	3.42	2.50	2.02	1.00
% of site vegetated	40	80	60	90	100	80	80	70	60	20	100	40	60	50	20	40	60	80	40	80	20	20	40	80	100	60	80	60	20	60	90
% of *M. spicatum* in vegetation	<10	<10	20	80	100	30	<10	20	70	70	20	<10	80	100	100	100	<10	100	80	<10	<10	80	80	10	30	30	40	60	100	60	90
Distribution of aquatic vegetation	E	E	E	E	E	E	E	E	C	C	E	E	E	E	C	E	E	C	C	E	E	C	C	E	E	E	E	E	C	C	E
Site minimum depth (m)	.5	1.0	1.0	1.0	1.0	1.0	.9	1.0	1.7	2.6	2.8	1.4	.5	3.3	3.1	1.4	.8	2.9	2.9	4.1	1.3	1.4	.5	1.0	4.0	.8	3.4	2.0	3.6	.5	2.0
Site maximum depth (m)	1.3	1.0	1.0	3.5	3.0	1.0	1.0	1.0	3.4	3.9	5.7	1.7	2.2	4.0	4.0	3.7	3.1	4.0	3.2	5.2	2.3	4.0	2.5	4.0	5.0	3.4	5.2	3.0	5.5	3.5	3.6
Sediment type	St	St	St	St	St	St	St	St	St	Sd	St	St	St Cb	St Cb	St Cb	St Cb	St Cb	Bd	Bd	St Bd	St Bd	Bd	Pb	Cb	St Cb	Sd	Sd	St	St	St	St

Air Photo BC C 177	21	21	21	22 23	21	21	21	21	21	21	21	21	21	21	21	21	22	22	23	23	23	23	23	24	24	24	24 25	26	26	27	27
SITE NUMBER	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
Site area (ha)	.04	.17	2.90	1.25	.38	.90	.78	.12	.12	.47	.12	.07	.15	.13	.02	.03	.01	<.01	.15	.70	.16	.76	.60	.13	.03	.03	.18	.02	.09	.12	.01
% of site vegetated	80	<20	100	30	90	80	80	50	60	80	80	90	90	40	80	90	60	20	60	100	60	60	80	60	80	60	40	40	40	50	60
% of *M. spicatum* in vegetation	20	<10	30	80	80	70	<10	40	-	90	<10	<10	90	<10	<10	<10	40	80	<10	10	80	20	90	80	80	80	80	80	<10	40	20
Distribution of aquatic vegetation	E	E	E	B/C	E	E	E	E	E	E	E	E	E	C	E	E	E	E	E	E	C	E	C	E	E	E	C	C	E	C	E
Site minimum depth (m)	.3	.5	2.8	1.8	2.6	2.6	2.4	1.0	1.5	1.8	1.0	.7	1.7	1.2	1.2	1.2	1.1	1.2	1.4	2.6	1.7	1.5	1.5	3.0	2.1	2.7	1.6	1.6	.5	1.1	1.0
Site maximum depth (m)	.8	1.4	5.0	4.0	5.0	5.0	2.8	2.5	2.4	5.0	2.1	1.7	3.8	2.1	2.1	2.1	3.0	1.4	2.6	5.1	3.3	3.0	5.1	4.1	4.5	3.5	3.5	3.5	3.0	4.0	3.2
Sediment type	Sd	Sd	St Sd	St Cb	St	St	St	Sd	Sd	Sd	Pb	St	St	Sd Pb	Sd Pb	Sd Pb	Pb	Pb	St	St	St Cb	St	St	St	St	St	St Pb	St Pb	St Pb	St	St Pb

TABLE LEGEND

DISTRIBUTION OF AQUATIC VEGETATION

E EVEN
C CLUMPED
B BANDED

SEDIMENT TYPE

Cl CLAY
St SILT
Sd SAND
Pb PEBBLES
Cb COBBLES
Bd BOULDERS

100 0 100 200 300 400 500 METRES
SCALE

NOTES

(1) BATHYMETRIC CONTOURS BASED ON WATER LEVEL (WL) 1074.6 FT. (327.6 m) GEODETIC DATUM.
(2) BASE MAP DRAWN JUNE, 1978 by C. McKean.
(3) CONTOURS ARE IN METRES.
(4) % of *M. spicatum* in vegetation x % of site vegetated = Density of *M. spicatum*.

REFERENCES

DWG. No.	DESCRIPTION	DATE
4567-238	VASEUX LAKE BATHYMETRIC AND TOPOGRAPHIC SURVEY	JUNE, 1977
82E.023.3.2 82E.023.3.4 82E.023.1.2	PENTICTON - U.S.A. TOPOGRAPHIC	
BC C 151: 32-49	AIR PHOTOGRAPHS: (base map)	JULY 1977
BC C 177: 21-31	(aquatic vegetation)	JULY 31, 1978
	STUDIES ON AQUATIC MACROPHYTES - PART XX	1977

REVISIONS

No.	DESCRIPTION	DATE

SURVEYED Hepburn, Truelson
DATE July, 1978.
DESIGNED P. Hepburn
DRAWN P. Hepburn
TRACED R.M., J.L., A.F.
CHECKED
DATE Jan. 1979

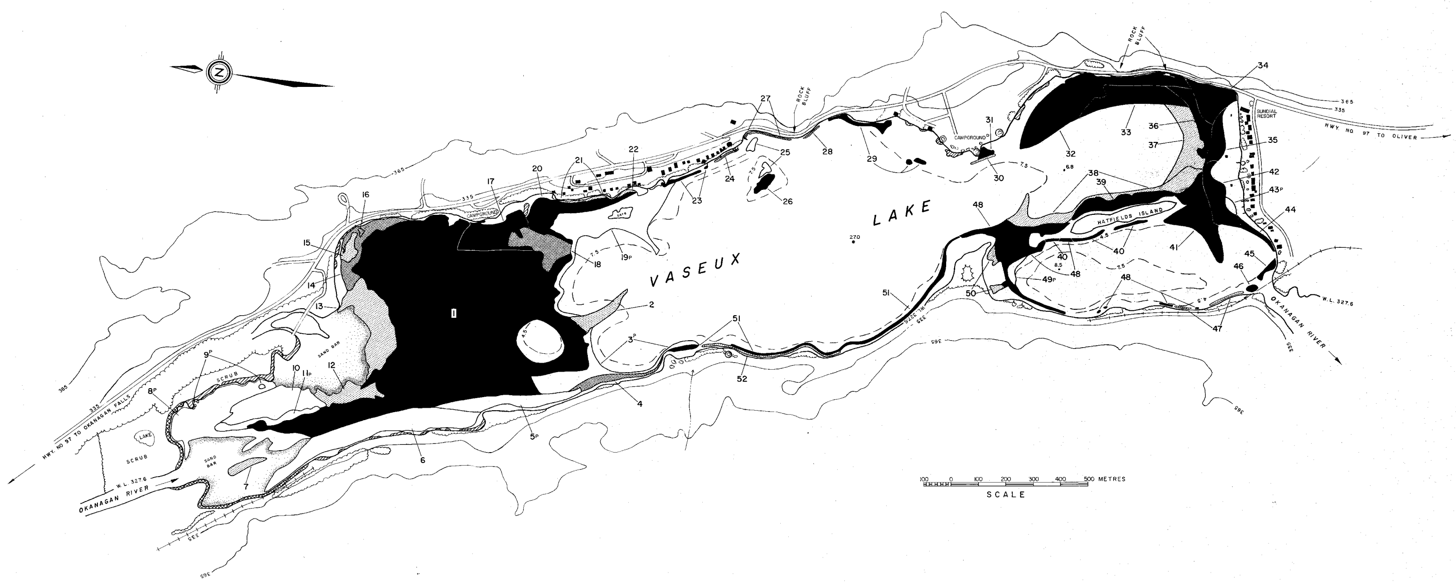
BRITISH COLUMBIA
MINISTRY OF THE ENVIRONMENT
ENVIRONMENTAL AND ENGINEERING SERVICES
WATER INVESTIGATIONS BRANCH

AQUATIC PLANT MANAGEMENT PROGRAM-1978
STUDIES ON AQUATIC MACROPHYTES – PART XXVI

VASEUX LAKE
SURVEY OF *Myriophyllum spicatum*
& OTHER AQUATIC PLANTS

FILE No. 0316533-D-1
SCALE 1:6000
DWG. No. 5144-009-01
SHEET 1 OF 1

DD



Air Photo Flight No.	BCC 221																									
Air Photo No.	113-117	117	117	115/116	115/116	113-115	113	112/113	112	113	113	114	114	115	115	115	116	117	117/118	117	117	117	118	118	119	119
SITE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Site area (ha)	44.50	.78	2.15	.72	1.80	5.22	.37	5.48	.04	2.55	.70	1.06	3.17	1.71	.37	.06	2.58	1.74	4.96	2.08	.13	.06	.13	.06	.26	.24
% of site vegetated	100	100	100	50	70	50	80	50	90	60	90	50	30	80	90	100	80	50	100	100	20	50	80	60	90	90
% of *M. spicatum* in vegetation	100	30	<10	70	<10	–	10	<10	<10	–	<10	20	20	60	10	50	100	100	<10	100	80	40	100	100	–	100
Distribution of aquatic vegetation	E	E	E	C	E	E	E	C	E	C	E	E	E	E	E	E	E	C	E	E	E	E	E	C	E	E
Site minimum depth (m)	1.2	3.5	2.8	1.0	2.1	.9	1.1	.5	.5	.8	1.2	1.2	.5	.8	.8	.8	1.0	2.2	3.5	2.4	1.0	1.0	2.2	2.0	3.5	4.0
Site maximum depth (m)	3.5	4.5	4.0	2.5	1.5	1.6	1.6	1.2	.8	1.2	1.5	1.5	1.2	1.3	1.3	1.3	2.0	4.0	6.0	3.5	2.4	2.4	2.5	3.8	5.5	4.0
Substrate type	St	St	St	St	St	St	St	St	St	St	St	Sd St	Sd	St	St	St	St	St	St	Sd St	Sd Pb	St	St Cb	St Cb	Sd	Sd

Air Photo Flight No.	BCC 221																		BCC 177 / BCC 221				BCC 221			
Air Photo No.	119	119	121	122	122	123	123	123	123	123	123	122	122	122	123	123	123	123	21 / 123	23 / –	23 / –	23 / 121	121	121	117-119	118 119
SITE NUMBER	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Site area (ha)	.10	.04	.45	.06	.14	5.06	2.32	1.63	1.09	1.02	1.80	2.00	1.36	.20	2.40	1.48	.14	.24	.13	.08	.09	2.80	.23	.33	.90	.28
% of site vegetated	50	60	80	70	90	90	70	90	70	80	70	100	80	70	100	80	50	70	80	80	30	90	100	60	80	50
% of *M. spicatum* in vegetation	100	100	100	10	90	90	100	100	100	100	10	30	100	100	70	90	<10	100	100	100	90	100	<10	30	100	20
Distribution of aquatic vegetation	C	C	E	E	E	E	E	E	E	E	E	E	C	C	E	E	E	E	C	C	E	C	E	C	C	E
Site minimum depth (m)	1.5	1.5	1.4	2.0	.8	2.1	1.8	1.8	1.0	4.5	5.0	4.0	1.5	2.0	2.7	2.0	1.0	1.0	.8	2.0	2.0	2.7	4.3	1.1	2.1	.8
Site maximum depth (m)	2.5	2.5	4.0	5.1	2.0	4.2	5.0	4.5	4.5	5.0	6.0	5.5	4.0	3.3	4.0	2.7	2.0	5.0	5.0	2.7	2.8	4.3	6.0	2.7	3.6	2.3
Substrate type	Cb Bd	Pb Bd	Sd Cb	Sd	Sd	St	St	Sd St	Sd	St	St	St	St Cb	St Pb	St	Sd	Sd	Sd	Sd St	St Pb	St Pb	St	St	St Cb	St	St Pb

TABLE LEGEND

DISTRIBUTION OF AQUATIC VEGETATION

- E EVEN
- C CLUMPED
- B BANDED

SUBSTRATE TYPE

- Cl CLAY
- St SILT
- Sd SAND
- Pb PEBBLES
- Cb COBBLES
- Bd BOULDERS

MAP LEGEND

- WOODED AREA
- BRUSH AREA
- TREE
- PROMINENT TREE OR SMALL GROUP OF TREES
- PROMINENT BUILDING

DENSITY OF *Myriophyllum spicatum*

- DENSE 70-100 % cover
- MODERATE 31-69 % cover
- SPARSE ≤30 % cover
- P PRESENT % cover too low to be estimated

- Aquatic vegetation (submersed); No *M. spicatum* detected
- *Scirpus lacustris* (emergent)
- *Scirpus lacustris* and *Typha sp.* (emergent)

(1.) BATHYMETRIC CONTOURS BASED ON WATER LEVEL (WL) 1074.6 FT. (327.6 m) GEODETIC DATUM.
(2.) BASE MAP DRAWN JUNE, 1978
(3) CONTOURS ARE IN METRES.
(4) DENSITY OF *M. spicatum* = % OF *M. spicatum* IN VEGETATION x % OF SITE VEGETATED.
(5) OKANAGAN RIVER NOT INCLUDED IN SURVEY.

REFERENCES		
DWG. No.	DESCRIPTION	DATE
4567-238	VASEUX LAKE BATHYMETRIC & TOPOGRAPHIC SURVEY	JUNE 1977
82E.023.3.2 82E.023.3.4 82E.033.1.2	PENTICTON-U.S.A. TOPOGRAPHIC 72-6T	
BC C 151: 32-49	AIR PHOTOGRAPHS: (base map)	JULY 1977
BCC177: 21-23	(aquatic vegetation)	JULY 31, 1978
BCC 221-112-123	" "	JULY 30, 1979
N.A.	STUDIES ON AQUATIC MACROPHYTES - PARTS XX, XXVI	1978, 1979

REVISIONS		
No.	DESCRIPTION	DATE

SURVEYED P. Hepburn DATE July 25-27, 1979
COMPILED P. Hepburn
CHECKED R. Nijman DATE Feb. 1980
DRAWN R. M., A. F.
CHECKED P. Dixon DATE Feb. 1980

Province of British Columbia
Ministry of Environment
INVENTORY AND ENGINEERING BRANCH

AQUATIC PLANT MANAGEMENT PROGRAM
STUDIES ON AQUATIC MACROPHYTES – PART XXI

VASEUX LAKE

SURVEY OF *Myriophyllum spicatum* & OTHER AQUATIC PLANTS
1979

FILE No. Branch 0316533-d-1
Section
SCALE 1:6000
DRAWING No. 5144-009-11
SHEET 1 of 1

DD

8.6 Appendix 6: Management techniques

Problem addressed:	Lake Improvement Technique	Examples of LAC Experience
Algae, Nutrients Sediment	aeration both stratification-retaining and destratification systems to improve water quality and reduce anaerobic sediment accumulation	Rose Valley Reservoir, Logan Lake Heustis Pit Lake
Algae	algae control with nutrient management and ionized copper	Rose Valley Reservoir, McKinley Reservoir, Garnett Valley Reservoir
Milfoil	lofted fabric barrier, limestone cap barrier	Logan Lake, Okanagan Lake, McKinley Reservoir
Milfoil, Sediment	reservoir re-contouring, mechanical removal	McKinley Reservoir, Kalamalka Lake
Nutrients, Sediment	strategic water wasting	McKinley Reservoir, Rose Valley Reservoir,
Nutrients, Milfoil	sediment capping with limestone to prevent nuisance aquatic plant growth	Okanagan Lake at Pritchard Arm
Sediment	increasing channel stability upstream of lake addressing point-sources of sediment	Mission Ck watershed, Lambly Ck watershed,
Milfoil	rototilling for plant mass removal, root disruption (OBWB)	Kalamalka Lake, Okanagan Lake
Sediment	alternate treatment of stormwater in constructed wetlands designed for periodic sediment removal	Kelowna, West Kelowna stormwater management
Nutrients, metals	nutrient and metal attenuation in designed wetlands with subsurface drainage through anaerobic media	Highmont tailings pond HVC, Bethlehem tailings pond HVC
Nutrients sediment	riparian stabilization helps prevent contaminants, nutrients, sediment from reaching the lake	Logan Lake constructed inflow wetlands, Highmont tailings pond HVC.

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