Vaseux Lake Milfoil Study Interim Report

Prepared for Regional District Okanagan Similkameen
March 2018

Executive Summary

This interim report reviews the results from the first phase of study to provide the basis for revising the Phase 2 work planned for 2018.

Important findings from Phase 1 include:

- Profound siltation of the North end of Vaseux Lake following the 2017 freshet flooding.
- Shuttleworth Creek provides a large portion of the sediment reporting to Vaseux Lake.
- The extent of aquatic plant beds is relatively unchanged from the 1970's, but the species composition has changed and is more variable including predominately native species in 2017.

- Lake water results showed that:
  - There was intense oxygen demand in the sediments sufficient to lower dissolved oxygen concentrations in the epilimnion in the shallow north end.
  - Water samples from the lake did not exceed any of the Canadian Drinking Water Guidelines or BC MoE Aquatic Life Guidelines.
  - Bacteria counts in Vaseux Lake were very low with *E.coli* below detection in 4 of 6 samples.

- Piezo/well water results showed that:
  - Nutrients were far higher in the groundwater samples than the lake samples and ammonia was present in all samples ranging from 0.029 mg/L as N in the Sundial Rd. well to 0.117 mg/L as N in Piezo 1. Dissolved reactive phosphorus ranged from below detection in the very north end of the lake to 0.066 mg/L as P in Piezo 6.
  - Groundwater samples also exceeded several metal guidelines including chromium, copper, lead and zinc.

- Sediment results showed that:
  - Mercury was below detection through Vaseux Lake sediments in 2017
  - Nickel and iron exceeded sediment quality guidelines for the protection of aquatic life
  - Sediments contained elevated levels of several hazardous metals including arsenic, cadmium, chromium, and lead. Rototilling could lead to water quality guideline exceedances of these metals for several days.

- Initial loading calculations revealed that:
  - Chloride (Cl) loading from 2016 indicated a net gain of chloride within Vaseux Lake.
  - In 2017, Cl loading was highest in Sundial samples, possibly due to septic drainage
  - In 2016, Vaseux Lake was a net source of total nitrogen (159,532 kg in and 169,654 kg out) and a sink for phosphorus (12,945 kg in and 6,974 kg out).

- No localized point-source loading was detected during the initial survey of the lake

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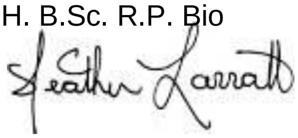

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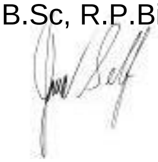

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Glossary: The following terms are defined as they are used in this report.

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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) eg. swamp sediments
Residence time	Time for a parcel of water to pass through a reservoir or lake (flushing time)
Riparian	The interface between land and a stream or lake
Secchi depth	Depth where a 20 cm secchi disk can be seen; measures water transparency
Seiche	Wind-driven tipping of lake water layers in the summer, causes oscillations
Thermocline	The lake zone of greatest change in water temperature with depth (> $1^oC/m$); it separates the surface water (epilimnion) from the cold hypolimnion below
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

Abbreviations

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

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

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

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

1.0 Background

Vaseux Lake is a small, productive lake, located near the downstream end of the Okanagan Valley mainstem lakes. 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 3.5-4), but increasing sedimentation near the mouth of the lake has been observed in recent years and the productive growth seems to be increasing again according to long-time residents. The Regional District of Okanagan Similkameen (RDOS) wants this study to determine the causes of the recent 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. We have designed a monitoring program to identify water quality, sedimentation and plant growth trends, identify the causes of the increased nuisance growths and provide options for lake enhancement. The enhancement goals include reducing or reversing the excessive milfoil/algae growth and sedimentation rates in Vaseux Lake.

1.1 Study Purpose

The main objective of the 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. 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 scheduled for 2018 will involve continued sampling on three dates, the further development of a Vaseux Lake database, and statistical data analyses. A report will be prepared of findings with recommendations for remediation and prevention of identified point or non-point nutrient and sediment sources.

This report provides the results from Phase 1. At RDOS' discretion, it can be submitted to OBWB as part of their required grant reporting.

2.0 METHODS

As part of preparing this proposal, LAC has conducted an exhaustive review of information sources to allow focus on information gaps and avoid redundant sampling. Many reports are available on the Vaseux watershed and these provide important background data and information to this study, streamlining the effort and sampling costs. 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, and not from agriculture or forestry. This information is dated but still relevant, and allows us to focus our efforts in developing a nutrient budget for the lake. More examples are provided in the Literature Cited for this proposal.

2.1 Existing Water Quality Data

Larratt Aquatic already 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 2.2-1). The water quality parameters already collected for the WWTP Permit are provided in Table 2.1-1. This monthly data can be utilized as part of the Vaseux Lake Assessment. For statistical rigor, sampling in the Vaseux Lake Assessment will coincide with the Permit sampling. This can also save analytic costs. For example, hardness from the Permit study can be used to calculate metal toxicity in this study. In some cases, Larratt Aquatic could perform sampling for both projects on the same field trip(s) for cost efficiency. Additionally, BC MoE (Penticton) has an extensive database of Okanagan Basin water quality that can be used to determine loading from upstream lakes.

Table 2.1-1: 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+NO2+NO3)	0.05 mg/L
Nitrogen, Organic (TKN-NH3)	0.05 mg/L
Chloride	0.1 mg/L
Sulphate	1.0 mg/L
Na, K, Mg, Hardness (Metals)	Various

Each WWTP field trip generated two sets of water quality samples, a 1,5,10 m composite (above thermocline) and 20,22,24 m composite (below thermocline). The water layers were sampled separately and as composites to obtain high quality lake data. Samples were collected after ice-off in March and in the in the first week of every month from April through November (9 sample sets annually). This monthly data is used to track lake nutrient dynamics, allowing the Vaseux Lake Assessment project to focus on perimeter sampling for point-sources of nutrients.

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 Figure 2.2-1. 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.

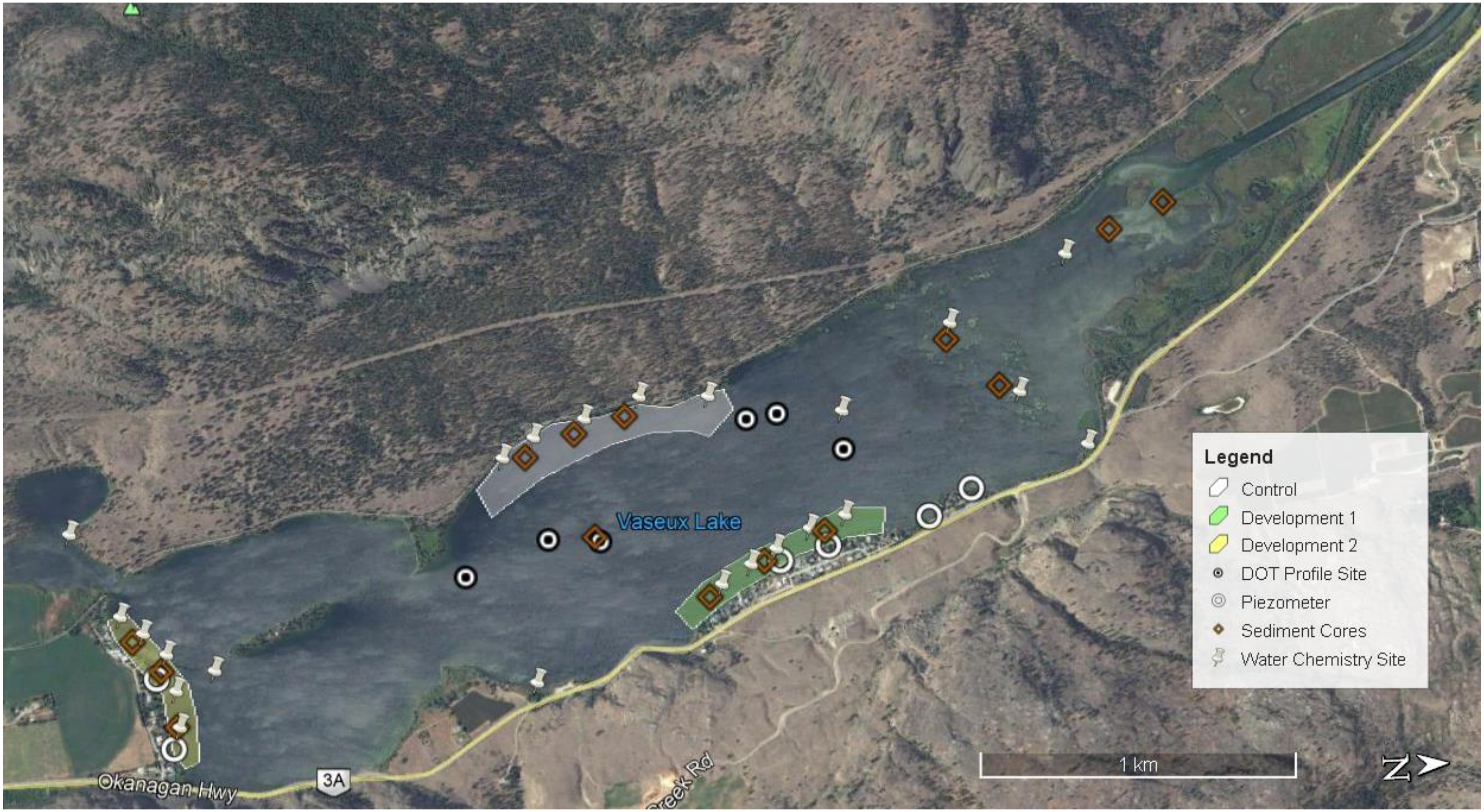

Figure 2.2-1: Map of Vaseux Lake with sample sites

2.3 Thermal Layering Assessment

We also used the multimeter to collect 6 profiles in September 2017. These profiles help define water layering. We located one August thermal survey from 1967 that showed a thermocline at 8.3 m with oxygen depletion to 3 mg/L below the thermocline. We will compare recent summer profiles to this one.

Thermal layering was confirmed by the addition of an anchored line of 5 temperature/light loggers at the deepest point in the lake. Six additional logger pairs will be anchored inside and outside dense plant beds to detect elevated water temperatures. In many of our studies of shallow lakes, the temperature in these plant beds are warmer than outside the plant beds and can exceed fish tolerances during hot summer days.

Identifying the rate of summer and winter expansion of the anaerobic zone and its horizontal extents was accomplished using the thermistor data and multimeter transects. Mapping of the lake zones will be accomplished using a technique LAC developed for low-elevation reservoirs.

2.4 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 1.0m depth. These included those sites with the highest apparent impacts, and areas of greatest vulnerability (vicinity of septic disposal, 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.

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

As well, a Vaseux S duplicate was collected for QA/QC

Additionally, 6 drive point piezometers were installed on October 12 and sampled on November 8 2017. The elevation of the top of each will be measured by Trimble to the nearest cm in 2018.

- 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 2.2-1. 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 2.2-1. Additional sites will be selected in 2018 as indicated by the 2017 data.

Table 2.4-1: Selected water quality parameters for Vaseux Lake Assessment, 2017-2018

	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

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 thermocline) and a 20,22,24 m composite (below thermocline). It is vital that both water layers be sampled separately and as composites to obtain high quality data. Additionally, QA/QC sampling is necessary as laid out by B.C. guidelines and prompt re-sampling of outlier samples was also undertaken**.** QA/QC for this study matches the existing permit program that meets provincial standards.

2.5 Sediment Sampling and Monitoring – Phase 1

Every lake accumulates sediment from external materials deposited from inflows and from incomplete decay of aquatic growth within the lake itself.

SEDIMENT CORE SAMPLES To determine the relative contributions of internal and external sediment sources we collected 7 batched sediment core samples for surficial 0 – 10 cm (recent) and 1 sediment core samples from deep 20 cm (historic, prior to European influence). These were compared to similar work conducted on other Okanagan mainstem lakes. They were collected as follows:

- V92-N-sandbar: a composite of 3 cores from inflow area of recent deposition *to determine the nutrient, metal organic content of imported sediments*
- V93-N-plantbed: dense aquatic plant beds (2 – 4 m depth) *to determine the effect of plant beds on sediment chemistry* V94-0-5cm deepest site in lake *to evaluate sediment focusing*
- V94-10-20cm: deepest site in lake *to evaluate pre-development sediments*
- V95-S-outlet: a composite of 3 cores in sandy outlet substrates *to determine*
- V96-S-subdiv: shallow substrates adjacent to residential area (3 cores composited to 1 sample from the S subdivision *to determine the effect of shoreline disturbance on sediment chemistry (*E subdivision too rocky)
- V-91-N-shallow: sample substrates adjacent to undeveloped park area, outside of dense beds *to establish control values for Vaseux Lake to compare to plant bed and shoreline disturbance values.*

The sediment cores were fractioned by sediment depth and at least 3 cores were collected and batched per sample to help overcome the inherent variability of sediment chemistry. The sediment quality parameters and their rationales are presented in Table 2.5-1.

SEDIMENT TRAPS The sediment traps were installed in 2017 and retrieved in 1 year to determine annual sediment accumulation. These rates can be compared to other Okanagan Lakes LAC studies. Five sediment traps were installed in 2017:

- 3 in the N inflow end where deposition is expected to be the most serious and
- 2 mid-lake, along the ridge south of the deep area, where sediment focusing occurs

SEDIMENT GAUGES Sediment gauges will be installed in early spring 2018 to avoid ice plucking over the 2017/2018 winter- (4) sediment gauges in the N inflow end where deposition is expected to be the most serious; and (1) in a southern shallow site within a dense aquatic plant bed, and (1) in a southern shallow site outside a dense aquatic plant bed to act as a control. These will be read on at least four 2018 field trips.

Table 2.5-1: Selected sediment parameters for Vaseux Lake Assessment 2017-2018

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

2.6 Aquatic Plant Mapping

Aquatic plant bed mapping was completed for Vaseux Lake in 2017 and will be repeated in 2018. Each mapped bed was given a percentage of invasive milfoil, as well as the other plants. The mapping will be 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. The expansion (or contraction) of invasive *Myriophyllum spicatum was mapped in 2017 and will be mapped again in 2018, and these maps compared to historic maps*.

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 2.2-1). 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 will use existing groundwater information together with piezometer results from this study and well logs. Information on the lithology beneath Vaseux Lake is available from the OBWB Supply and Demand Study (2009) and allowed estimation of groundwater contributions and hydraulic conductivity (rate of water movement in the aquifer) when combined with the results from piezometer samples of water quality and local well samples. These will also allow estimates of groundwater/subsurface drainage contaminant loading rates to Vaseux Lake.

For the purposes of this study it is assumed 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. These groundwater loading estimates for ions, metals and nutrients can be verified by comparing to actual water chemistry within Vaseux Lake.

Existing climatic and geologic information was reviewed and summarized as part of Phase 1 (2017) to facilitate the hydrogeologic and water balance assessments in Phase 2 (2018).

2.9 Water Balance Model

Many estimates needed for calculation of the Vaseux Lake water balance already exist, allowing this study to focus on the remaining items (Table 2.9-1). For example, the estimated water loss to evaporation is already calculated specifically for Vaseux Lake (Schertzer and Taylor 2009). This work and this table will be completed in 2018.

Table 2.9-1: 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	
	Inflowing creeks	
	Precipitation on lake surface	
	Groundwater inflow	
	Total Inputs	
Outputs	Avg outflow to Osoyoos Lake ref[1]	529.2×10^6
	Evaporation (m^3/yr) ref[2]	1.01×10^6
	Water Licenses	
	Discharge to groundwater (S end)	
	Total Outputs	

References: ref[1] OBA 1973 ref[2] Schertzer and Taylor 2009

2.10 Data Analysis and Modelling

A thorough statistical data analysis on project data and comparison to BC MoE historic data was conducted. A first step involved calculating descriptive statistics (average, mean, standard deviation, median) and generating box plots (e.g. Figure 2.10-1). Using these results as a guide, the following analyses were performed:

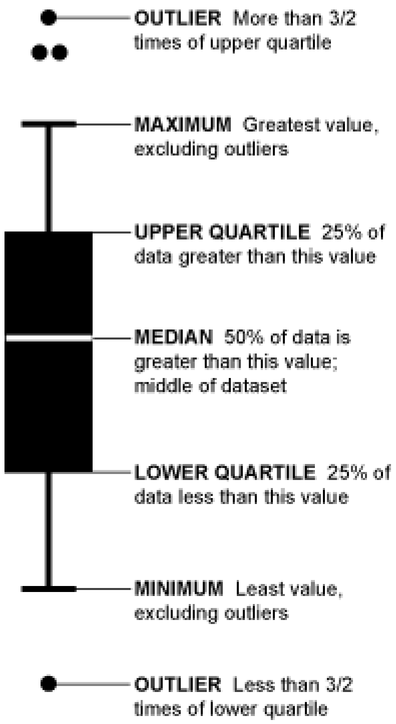

Figure 2.10-1: Example and description of boxplot

BACI Impact Assessment The Phase1 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 will be completed after Phase 2 in 2018.

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 are developing the loading model for each parameter (Cl, N, P, key metals), and this work will be completed after Phase 2.

Nutrient Budget Calculations After nutrient loading has been calculated, nutrient budgets for Vaseux Lake can be calculated. These allow us to rank 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 2.10-2).

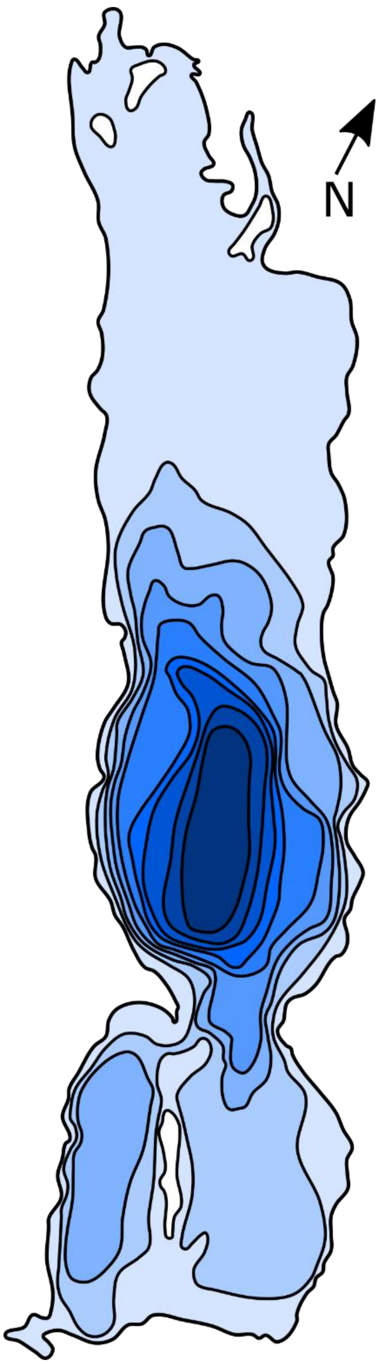

Figure 2.10-2: Bathymetric map of Vaseux Lake

3.0 RESULTS FROM PHASE 1

3.1 GIS Mapping

The final report will include detailed GIS mapping of Vaseux Lake, sample sites and well/piezometer locations, the later used to sample shallow groundwater. It will locate any contaminant point sources identified in the sampling. Most importantly, a complete map of aquatic plant growth (milfoils, pondweeds, etc).

3.2 Water Quality

3.2.1 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 2.2-1. 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 3.2-1).

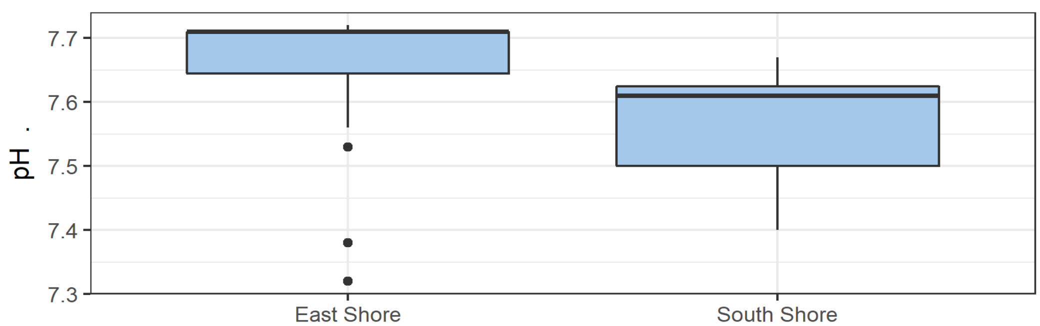

Figure 3.2-1: pH results from shoreline survey

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 3.2-2). 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.

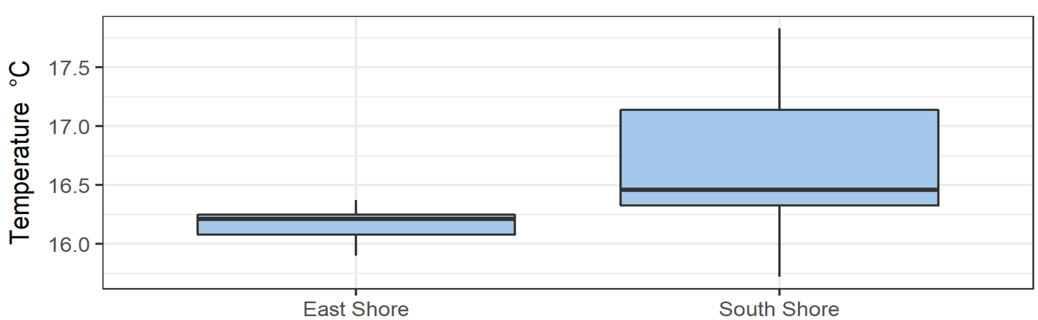

Figure 3.2-2: Temperature results from shoreline survey

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.

3.2.2 Lake Profiles

The multimeter profiles collected in September 2017 showed a consistent thermocline at 10-11m throughout the main basin of the lake (Figure 3.2-3). Temperature ranged from 16 °C at the surface to only 8 °C at 25 m in the deep central basin. Dissolved oxygen was high at the surface and became anaerobic just below the thermocline at sites that were deeper than10 m. In the north end shallows (North.Central in Figure 3.2-3) there was oxygen depletion within the deepest meter of the water column even though it was shallower than the thermocline. This confirms that there is intense oxygen demand in Vaseux sediments.

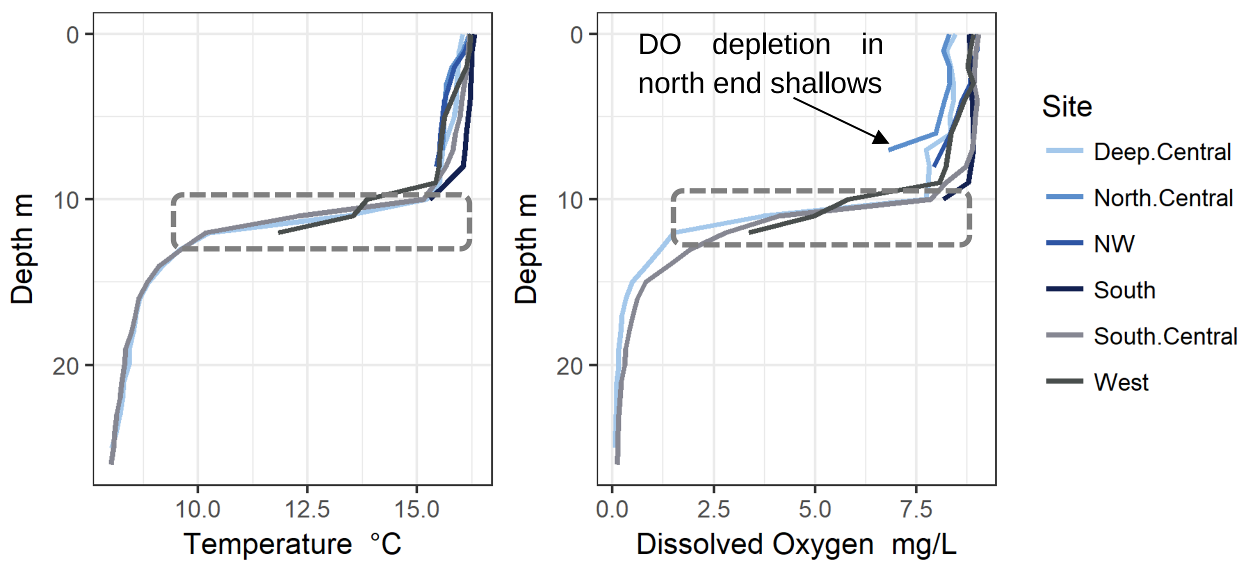

Figure 3.2-3: Temperature and dissolved oxygen profiles from Vaseux Lake in September 2017
Note: Dashed box highlights thermocline

We located one August thermal survey from 1967 that showed a thermocline at 8.3 m with oxygen depletion to 3 mg/L below the thermocline. These results were very similar to those obtained in September 2017 and to those from the monthly Vaseux Lake monitoring program. These thermal profiles indicate that the physical functioning of Vaseux Lake is stable through these decades.

3.2.3 Main water quality sampling program

Using the reconnaissance sampling, 10 sites were selected for water quality sampling in late September 2017. These included those sites with the highest apparent impacts, and areas of greatest vulnerability (stormwater discharge, vicinity of septic disposal, 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. Low water conditions following the 2017 summer drought meant that some of the sites were dry at the time of sampling in September.

Lake Samples Water chemistry samples measured chloride, dissolved nutrients, total metals, and bacteria at 7 surface water sites. BC MoE Aquatic Life MAC Guidelines and the Canadian Drinking Water Guidelines for various metals were not exceeded in any of the lake samples in September 2017 (Table 3.2-1).

Fecal and coliform bacteria were measured in the lake samples and the results were encouraging. *E. coli* is a marker species for fecal contamination because it only lives in the digestive system of warm-blooded animals (birds, mammals). Most strains of *E. coli* are harmless but their presence in a sample correlates to other more harmful pathogens. *E. coli* was below detection in 4/6 samples with a maximum measured value of only 5 CFU/100mL in the NE plant beds. 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 or recreational perspective.

Additional water chemistry samples were collected in Vaseux Lake monthly from ice-off to November from 2013-2017 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 5.8 ± 1.9 mg/L in the epilimnion samples while total nitrogen and total phosphorus averaged 0.217 ± 0.063 mg/L as N and 0.009 ± 0.013 mg/L as P respectively during 2017. Ammonia averaged 0.024 ± 0.019 mg/L as N in the epilimnion of Vaseux Lake during 2017. Of the lake samples collected from 2013-2017, only total phosphorus and aluminum 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. As of 2016, there were no detectable impacts from the WWTP on the chemistry or biology of Vaseux Lake (Self, 2017).

For additional information please refer to the *2017 Vaseux Lake and Okanagan River Monitoring Report.*

Groundwater Samples Water chemistry samples were also collected at 8 groundwater sites. Of the 8 sites, 6 were piezometers installed as part of this study and two were existing wells. Chloride averaged 28.9 ± 17.5 mg/L in the groundwater and was significantly higher than the lake samples indicating that groundwater is loading Vaseux Lake with chloride (KW-Test, $p=0.04$). Ammonia was present in all of the groundwater samples, ranging from 0.006 mg/L as N at Piezo 3 (south shore) to 0.117 mg/L as N at Piezo 1 (north end of Provincial Park shoreline). Ammonia was higher in the piezo samples than the well samples which ranged from 0.029 mg/L as N to

0.053 mg/L as N. Dissolved reactive phosphorus (the most bioavailable form of phosphorus) appeared to be higher in the groundwater samples but the difference was not statistically significant because of high variability. Phosphorus averaged 0.023 ± 0.023 mg/L as P in the groundwater samples from September 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 3.2-1, Table 3.2-2). 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 3.2-1: 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 3.2-2: 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		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

Duplicate Comparison (QA/QC) Duplicate samples are routinely collected as part of a water sampling program to quality assure the field and lab results. The consensus is that ~10% of samples collected should be duplicates and so one duplicate will be collected for each batch of water chemistry samples in this study. Water chemistry samples are naturally variable and it is not common for a duplicate pair to be exactly the same. A difference of <50% is considered the threshold of lab re-analysis. The first duplicate pair were collected as the south shore composite sample. The average difference between the samples was 3% with only 3 parameters exhibiting more than 15% difference, a very good result. No parameters exceeded 50% difference

3.3 Loading Calculations

3.3.1 Chloride loading

Chloride is a conservative parameter that indicates human impact. Chloride concentrations in Vaseux Lake ranged from 2.48 mg/L in the south end plant beds to 5.77 mg/L in the south shore composite sample. There was no statistically significant North to South gradient (KW-Test, $p=0.48$) indicating significant loading within Vaseux Lake. Groundwater contained higher chloride 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, but the groundwater samples from the Sundial well do indicate human impact, likely through septic field influence.

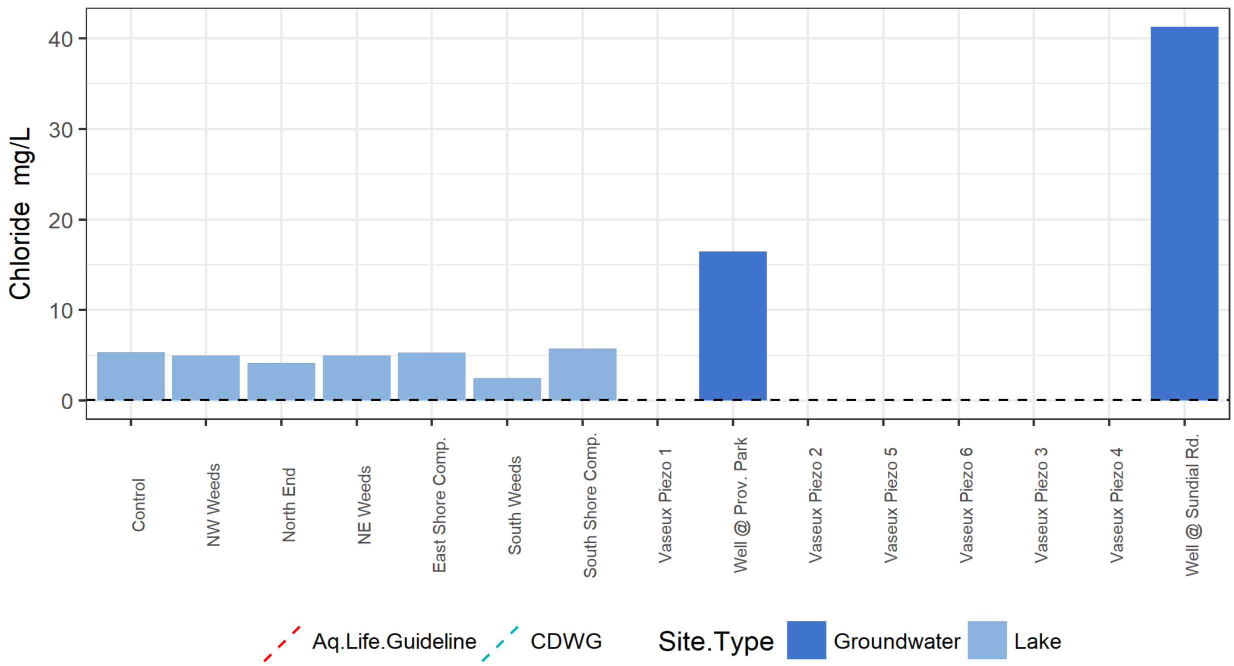

Figure 3.3-1: Chloride concentrations at Vaseux Lake sample sites, September 2017

Note: Dashed line indicates lab reportable detection limit (sites are presented in North (left) to south (right) and split by surface and groundwater.

<u>Chloride loading estimates will be completed following the 2018 sample season</u>. The unfinished chloride loading table can be found in Appendix 4.

3.3.2 Nutrient loading

In the September set of samples nitrate, ammonia, and dissolved reactive phosphorus were measured because these are the most bioavailable forms of nitrogen (N) and phosphorus (P). These measurements were used to complement the existing Vaseux Lake and Okanagan River monthly monitoring program.

Nitrate was below detection in all lake samples and also in the well sample at the provincial park. The well on Sundial Rd. measured 0.128 mg/L as N of nitrate, an unremarkable result for groundwater. Ammonia was only measured in the groundwater samples and 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 3.3-2).

Dissolved reactive phosphorus ranged from below detection in the very north end of the lake to 0.066 mg/L as P in Piezo 6 (Figure 3.3-2). Nutrients were higher in the groundwater than the surface water in part because nutrients are used by algae in the lake but are not accessible in the groundwater. Additionally, 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.

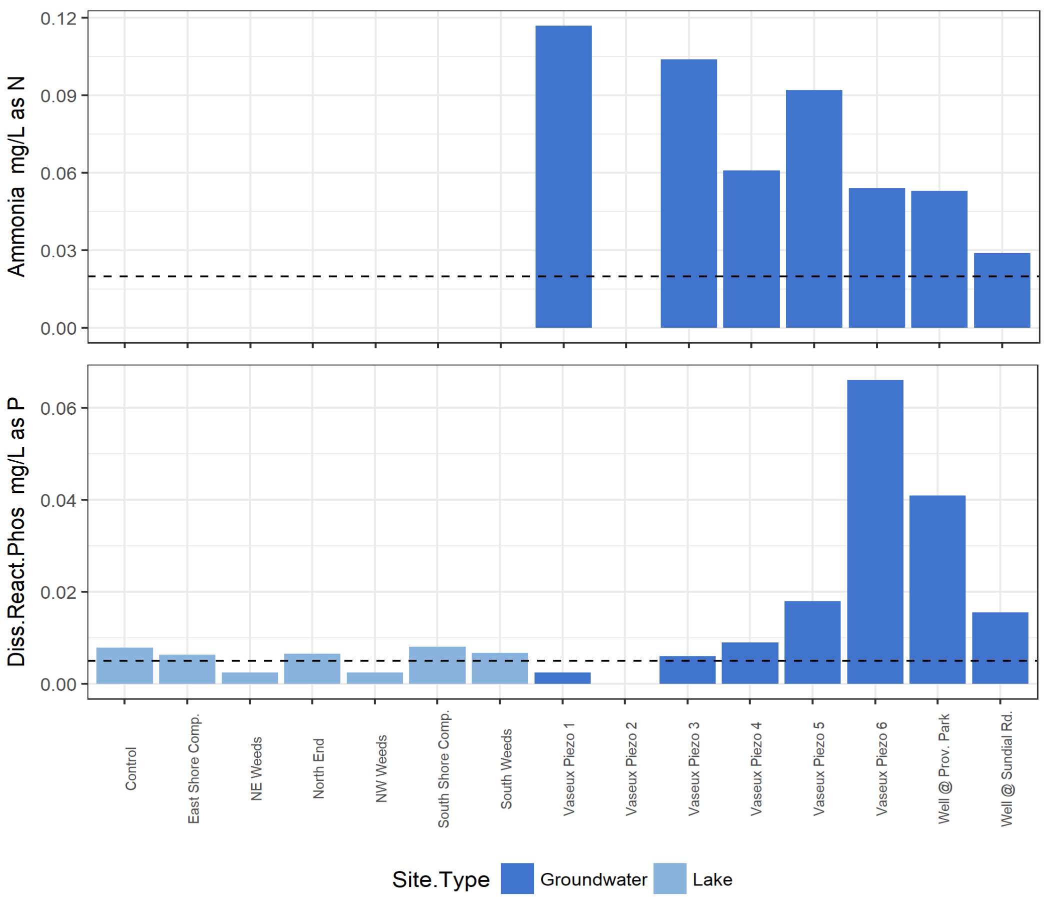

Figure 3.3-2: Ammonia and dissolved reactive phosphorus from Vaseux Lake assessment, Sept 2017

Note: Dashed line indicates lab reportable detection limit

When the lake samples are considered, it is interesting to note that the plantbed samples contained less dissolved reactive P (DRP) than the samples from open water (Figure 3.3-2). These preliminary results suggest nutrient consumption.

Vaseux Lake is a net source of total nitrogen increasing the load to downstream Okanagan River by 10,000 kg in 2016. This occurs because algae and bacteria in Vaseux Lake are able to fix atmospheric nitrogen. Total phosphorus was removed by Vaseux Lake decreasing by approximately 50% in 2016 between the inflow and outflow to the lake (Table 6.4-2).

Nutrient loading estimates will be completed following the 2018 sample season. The incomplete loading profile for Vaseux Lake nutrients can be found in Appendix 4.

3.4 Sediment Sampling and Monitoring – Phase 1

3.4.1 Sediment Core Samples

Assessing the quantity and 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 3.4-1: Selected sediment parameters for Vaseux Lake assessment 2017-2018

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 3.4-2). 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 3.4-2). Nickel and iron were the only metals to exceed their respective BC sediment quality guidelines. The sediment also contained elevated concentrations of a number of metals. These include: Arsenic, Cadmium, Chromium, Copper, Lead, Selenium, Silver, Thallium, and Zinc. 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 would may exceed the aquatic life guidelines for a period of approximately 24 – 48 hours (Figure 3.4-1). This plume would dilute with the adjacent lake volume over time, and silts would settle in <24 hours; clay particles within 1 week (Table 3.4-2). Several metals were also higher than the BC average for uncontaminated lakes including aluminum, barium, phosphorus, sulfur, titanium, and vanadium.

Table 3.4-2: 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 3.4-1: Plume of suspended sediment from milfoil rototilling in Okanagan Lake at Casa Loma

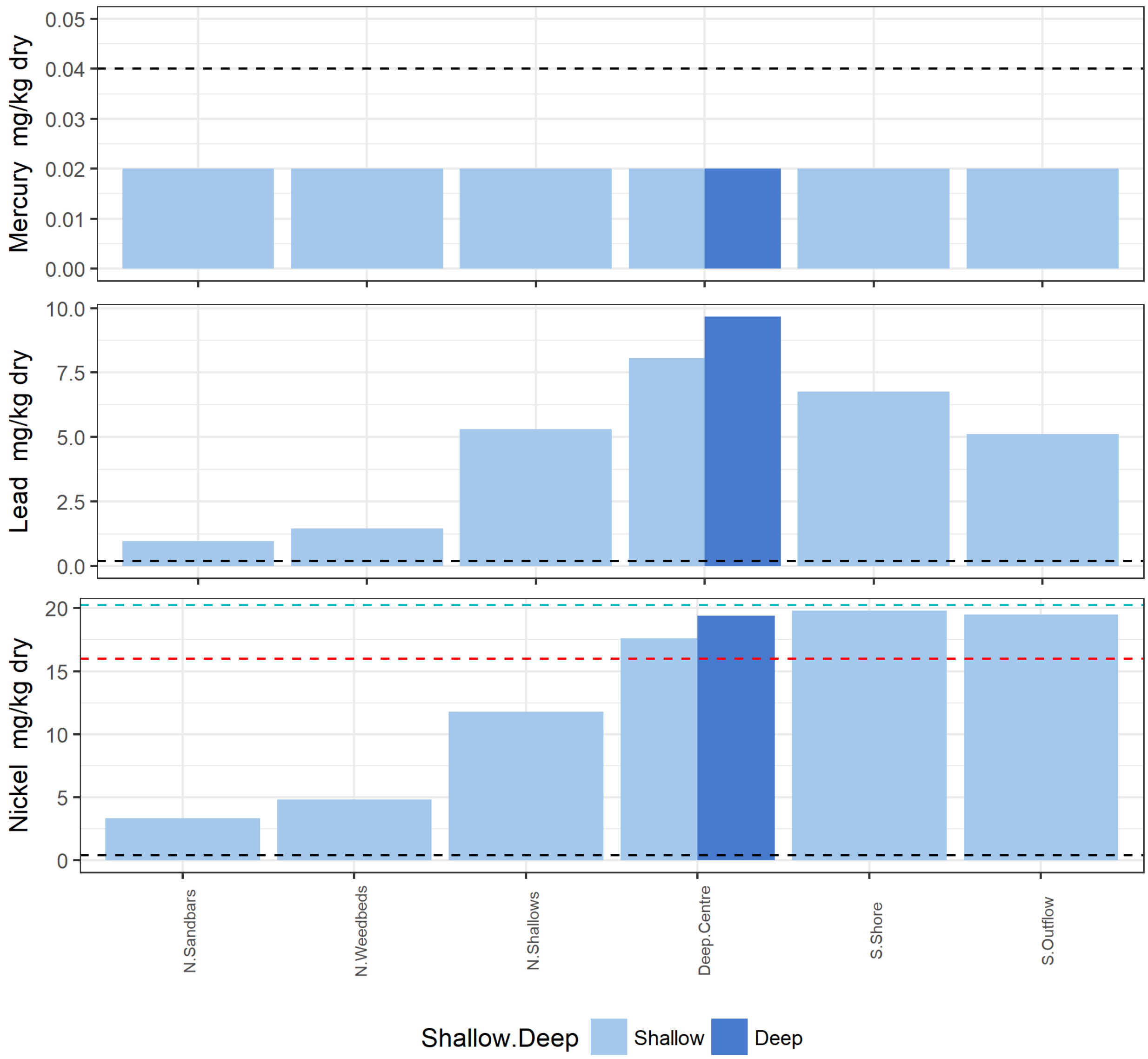

Figure 3.4-2: Mercury, lead, and nickel in Vaseux Lake sediments, September 2017

Note: Black dashed line = RDL; Red dashed line = guideline; cyan dashed line = BC Average

3.4.2 Sediment Traps

The sediment traps were installed in 2017 <u>and will be retrieved in one year to determine annual sediment accumulation.</u> We anticipate that the measured annual rate of accumulation will be higher in the north end compared to the south.

3.4.3 Sediment gauges

<u>Sediment gauges will be installed in early spring 2018 to avoid ice plucking over the 2017/2018 winter.</u> LAC plans to install them as follows: (4) sediment gauges in the N inflow end where deposition is expected to be the most serious; and (1) in a southern shallow site within a dense aquatic plant bed, and (1) in a southern shallow site outside a dense aquatic plant bed to act as a control. These will be read on at least 4 2018 field trips.

3.5 Aquatic Plant Mapping

Excessive aquatic plant growth is not only unpleasant, it can cause serious problems for lake ecology. These growths can slow water travel through Vaseux, pump nutrients out of the sediments and into the water column, provide habitat for filamentous algae and reduce fishery potential in the areas covered by dense 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. These algae suspended in the water column 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 and sometimes lead to unsightly surface blooms. We determined this effect using the phytoplankton and chl-a analyses performed under the WWTP Permit sampling.

The chl-a and phytoplankton analyses showed a similar trend where higher algae counts lead to higher chl-a concentrations (Figure 3.5-1). The correlation (R=0.59) was not perfect because photosynthetic bacteria are difficult to count on a microscope but will increase chl-a. Chlorophyll- and algae counts were similar to the 2013-2016 average and neither were particularly high. There was also not a filamentous green algae bloom in the north end plant beds during 2017.

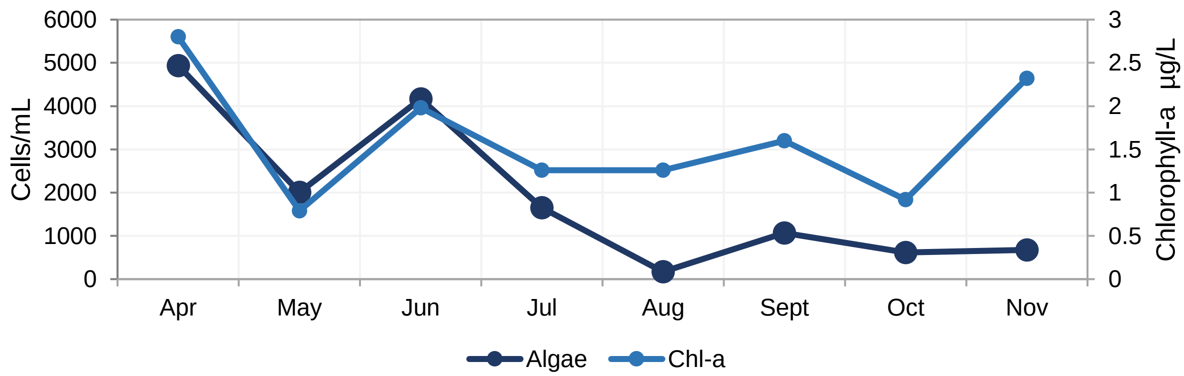

Figure 3.5-1: Chlorophyll-a and total algae counts in Vaseux Lake during 2017

Aquatic plant bed mapping was completed for Vaseux Lake in 2017 and will be repeated in 2018. The mapping was based on drone imagery, satellite 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 3.5-2).

Figure 3.5-2: Plant beds in Vaseux Lake during September 2017

Common species included several native species (*Potamogeton natans*, *Potamogeton pectinatus*, *Potamogeton crispus*, and native milfoil), and in some places invasive milfoil (*Myriophyllum spicatum*). *Potamogeton natans* was by far the dominant species in September 2017 (Figure 3.5-3).

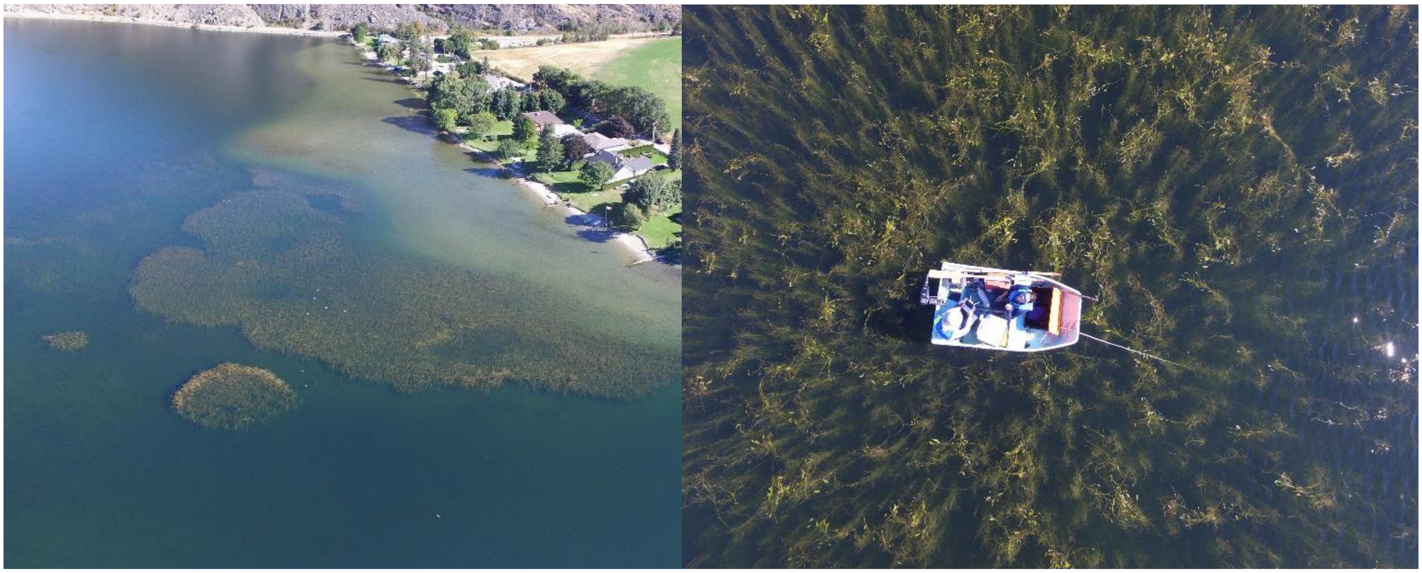

Figure 3.5-3: *Potamogeton natans* beds in Vaseux Lake during September 2017

When historic mapping of plants beds was compared to 2017 mapping, the 1979 vs 2017 mapping showed a remarkably similar story (Figure 3.5-4). The area mapped as macrophyte beds in 1979 was larger than in 2017 in the south end of the lake and similar in the north end. Figure 3.5-4 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. Local residents have indicated that invasive milfoil growth varies dramatically from year to year and that 2017 was a particularly good 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 3.5-4). Their composition, however, is apparently much more variable from year to year.

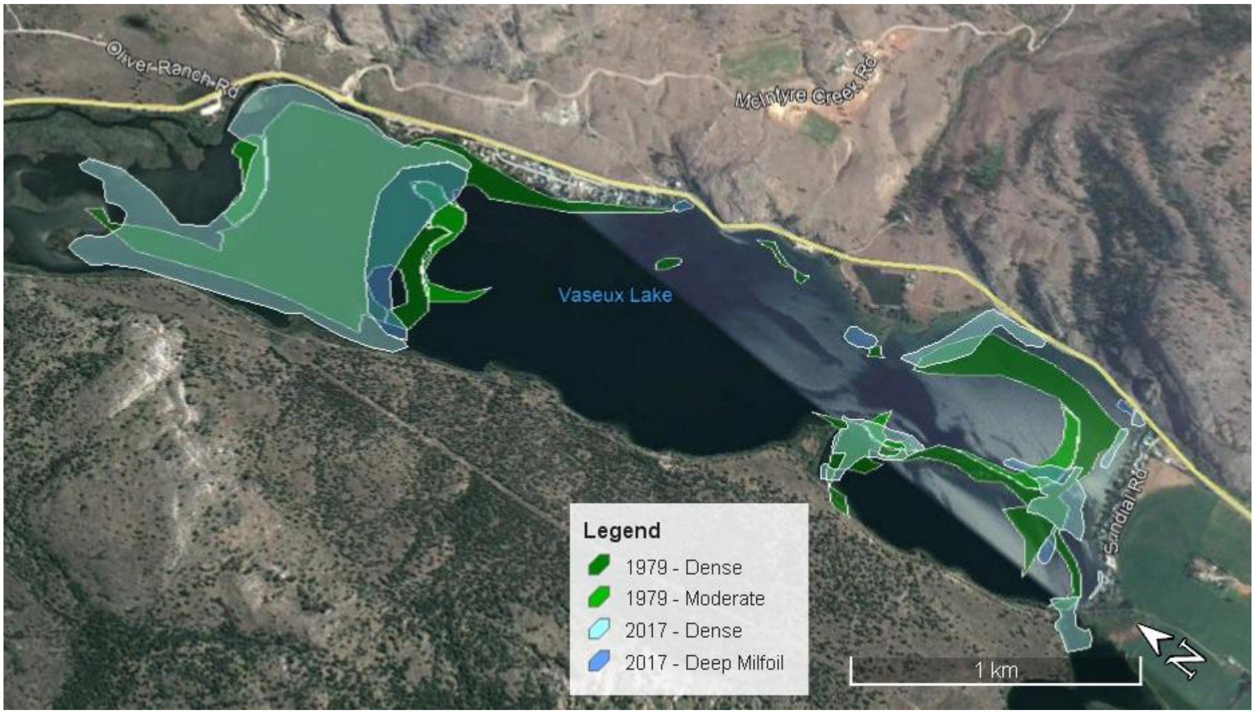

Figure 3.5-4: Plant beds in Vaseux Lake in 1979 compared to 2017

Filamentous green algae growth is stimulated by nutrients in the water column and can be exacerbated by nutrients released by milfoil leaves. Dense mats of these algae can clog pumps, block weirs and cause extreme diurnal swings in DO that are harmful to fish and fish food organisms (benthic invertebrates). During the September to November 2017 field season, filamentous green algae populations were very small and far below nuisance population densities.

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 2 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 3.6-1). 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.

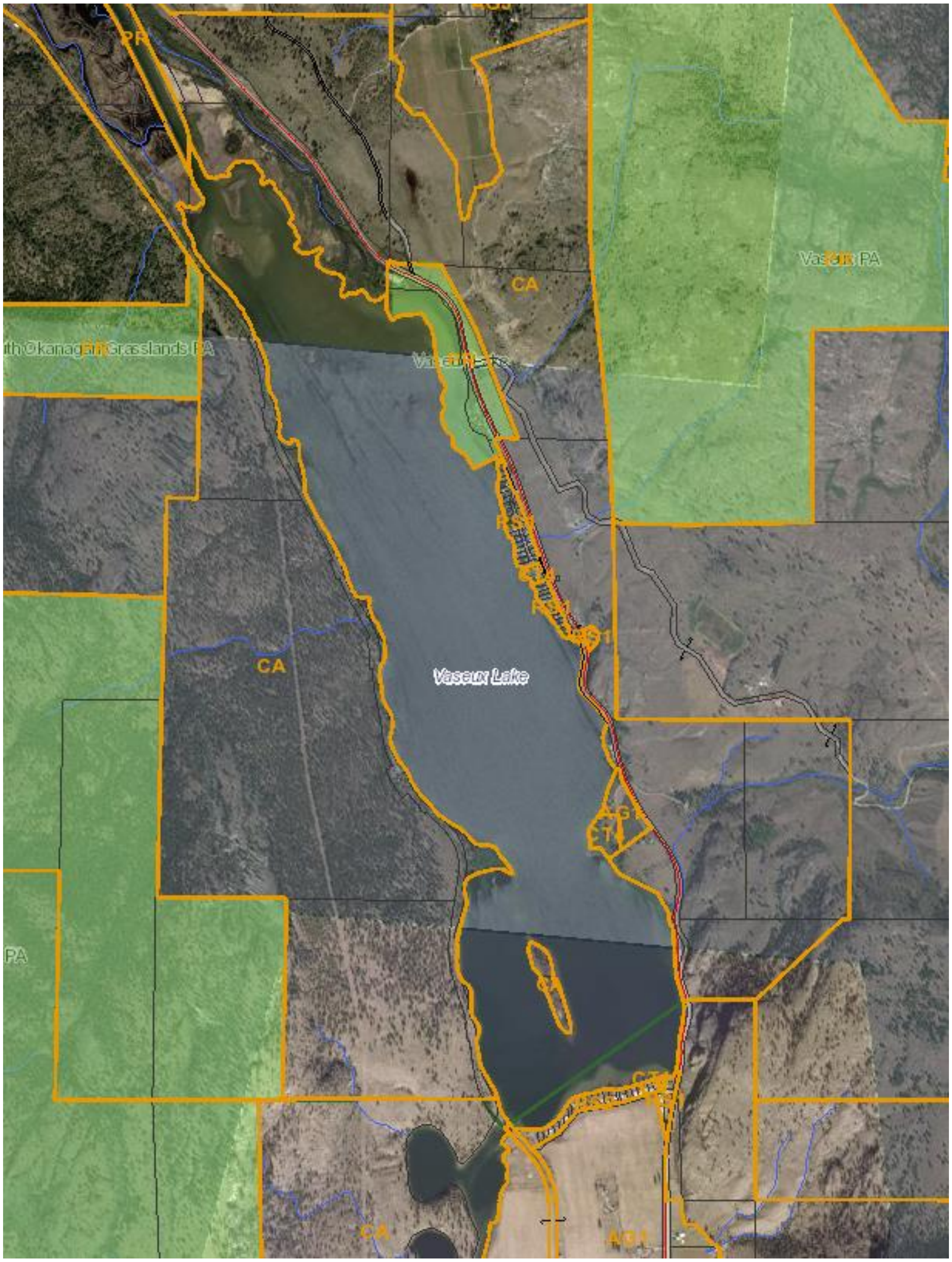

Figure 3.6-1: Land uses around Vaseux Lake
Source: RDOS online GIS system (RDOS, 2018)

3.6.2 Upstream land use impacts

Use of existing literature readily pinpointed the Shuttleworth watershed as significant sediment sources 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 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 3.6-2). In fall 2017, the sediment trap was dredged. Instability in the Shuttleworth Creek drainage area is will be worsened during extreme flow events such as those that occurred in May 2017. As the climate changes, the frequency of extreme flow events is expected to increase.

Figure 3.6-2: Shuttleworth Creek sediment catch basin being cleaned in October 2017

The Okanagan Falls Wastewater Treatment Plant began operating in March 2013. It discharges tertiary treated (phosphorus removal) effluent into Okanagan River 2.5 km upstream of Vaseux Lake. From 2013-2016 the average nutrient load was only 26 ± 19 kg of TP or only 0.2% of the annual load contributed by Okanagan River (equivalent to 5x 25kg bags of fertilizer). Nitrogen compounds are not removed during the WWTP process and averaged 1461 kg TN or only 0.4% 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.

3.7 Hydrogeologic Assessment

The hydrogeologic assessment will use existing groundwater information, piezometer results from this study and well logs. Information on the lithology beneath Vaseux Lake will allow estimation of groundwater contributions and hydraulic conductivity (rate of water movement in the aquifer) when combined with the results from piezometer samples of water quality and local well samples. These will allow the following estimates of groundwater/subsurface drainage contaminant loading rates to Vaseux Lake.

For the purposes of this study it was assumed 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.

Groundwater loading estimates for ions, metals and nutrients were verified by comparing the predicted loading with actual water chemistry within Vaseux Lake. The results of the hydrogeologic assessment will be included in the Year 2 Final Report.

3.8 Water Balance Model

Many estimates needed for calculation of the Vaseux Lake water balance already existed, allowing this study to focus on the missing items in Table 3.8-1. The goal of the water balance model is to quantify the major sources and outflows of water and use those values to calculate accurate loading estimates for nutrients to Vaseux Lake. The water balance model will be completed in 2018 as part of the Year 2 Final Report.

Table 3.8-1: 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	
	Inflowing creeks (McIntyre/Irrigation)	
	Precipitation on lake surface	
	Groundwater inflow	
	Total Inputs	
Outputs	Avg outflow to Osoyoos Lake ref[1]	529.2×10^6
	Evaporation (m^3/yr) ref[2]	1.01×10^6
	Water Licenses	
	Discharge to groundwater (S end)	
	Total Outputs	

References: ref[1] OBA 1973 ref[2] Schertzer and Taylor 2009

4.0 VASEUX LAKE REMEDIATION

4.1 Investigating Vaseux Lake Remediation

LAC has designed and implemented many reservoir/lake management techniques over the past 35 years. Relevant examples are provided in Table 4.1-1. Some of these could address the concerns in Vaseux Lake, that include the interrelated excessive algae and milfoil growth, nutrient and sediment inflows.

Table 4.1-1: 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	Greystokes watershed, Lambly 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.

Options will be selected in 2018 so that data from both Phase 1 and 2 will be considered. The sediment results and possible shifts in dominance of invasive milfoil will be of particular interest. The selected options will be presented in the Phase 2 report, due in late 2018.

5.0 RECOMMENDATIONS

Based on the 2017 results, we recommend the following be considered by RDOS:

- Creeks that report to Vaseux Lake should be inspected during freshet 2018
- Sampling program should continue through 2018
- Long-term plant bed monitoring should be pursued to better understand trends and interannual variation in density and species abundance; 1 trip each August should be sufficient to update maps and would be relatively inexpensive (~$2500/yr for sampling and small report)
- Add chloride analysis to 2018 piezo sampling

6.0 Literature Cited

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6.1 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

6.2 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

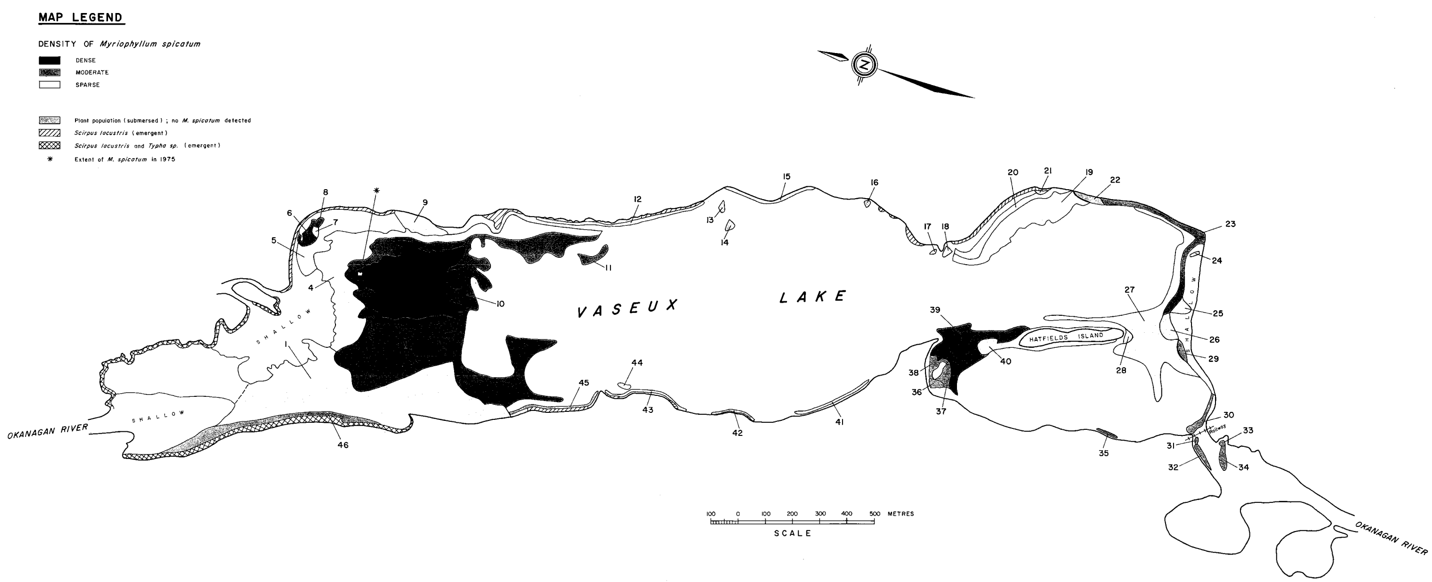
1. Canadian guidelines for chemical contaminants and toxins in fish and fish products. Based on fish protein (mussel) concentration (Ammend.no.11, 2011). (Can.Food.Insp.Agency 2011)

2 BC MoE 1987 and 2014; CCME 2006

6.3 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			REVISIONS		
DWG. No.	DESCRIPTION	DATE	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			

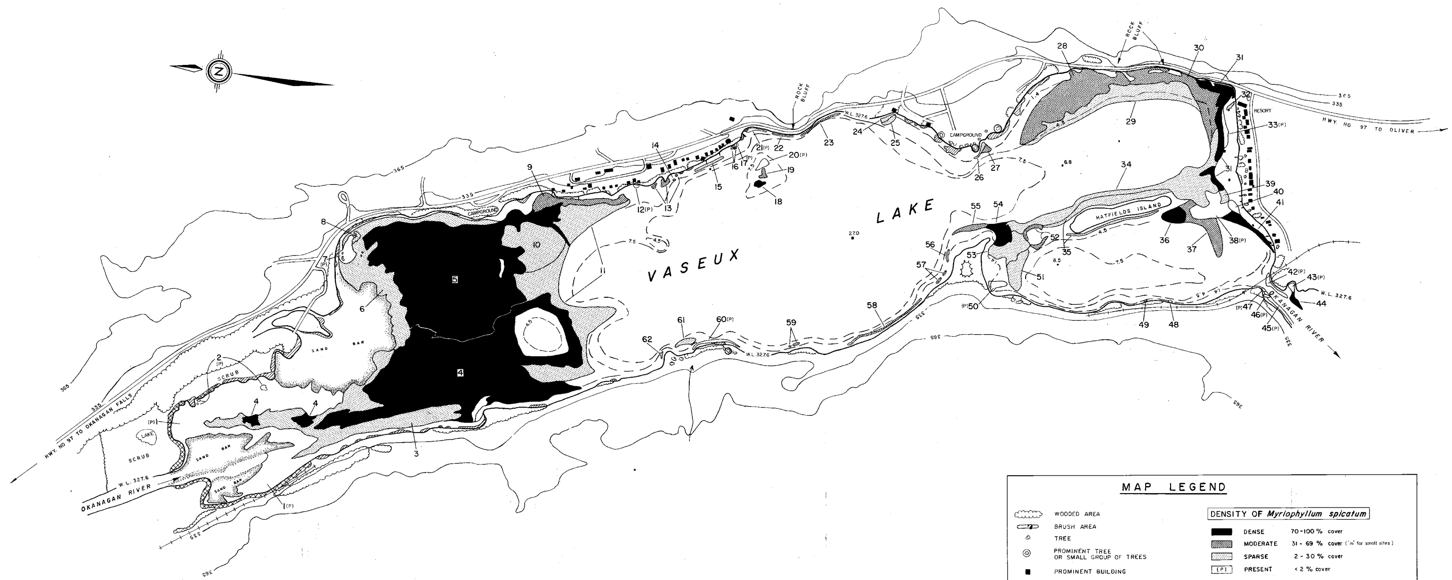
SURVEYED: P. Hegburn
DATE: July 1977
DESIGNED: P. Hegburn
DRAWN: P. Hegburn
TRACED: A. Fraser
CHECKED: R. Nijman
DATE: Feb. 1978

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)

SCALE 100 0 100 200 300 400 500 METRES

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	.18	.90	.78	.37	.12	.47	.12	.07	.15	.13	.02	.03	.01	5.01	.15	.70	.16	.76	.60	.13	.03	.03	.10	.02	.09	.12	.01
% of site vegetated	80	<20	100	30	90	80	80	50	60	80	60	90	90	40	80	90	60	20	60	100	60	60	80	60	60	40	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	C	E	C	E	E	E	E	E	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	3.6	1.7	1.5	3.5	3.0	2.1	2.7	1.6	1.6	.5	1.3	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	3.4	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	St	Sd	Sd	Pb	Pb	St	Sd Pb	Sd Pb	Sd Pb	Pb	Pb	St	St	St Cb	St	St	St	St	St Pb	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

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			REVISIONS		
DWG. No.	DESCRIPTION	DATE	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			

SURVEYED Hepburn, Truelson
DATE July, 1978.
DESIGNED P. Hepburn
DRAWN P. Hepburn
TRACED R.M., J.L., A.F.
CHECKED P. Kee
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. 0316533-0-1
SCALE 1:6000
DWG. No. 5144-009-01
SHEET 1 OF 1

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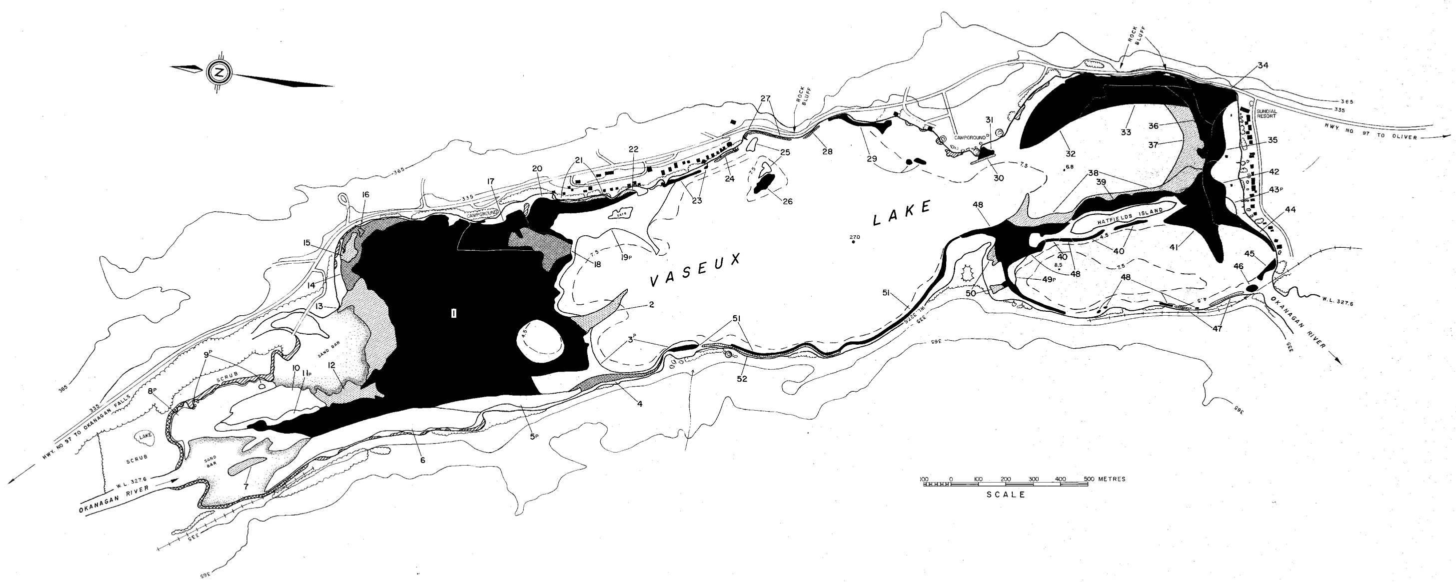

Air Photo Flight No.	BCC 221																									
Air Photo No.	113-117	117	117	117	115 116	113-115	113	112 113	112	113	113	114	114	115	115	115	116	117	117 118	117	117	117	118	118	119	119
SITE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Site area (ha)	44.50	.78	2.15	.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			
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 (W.L.) 1074.6 FT. (327.6 m) GEODETIC DATUM
(2) BASE MAP DRAWN JUNE, 1979
(3) CONTOURS ARE IN METRES
(4) DENSITY OF *M. spicatum* = % OF *M. spicatum* IN VEGETATION × % OF SITE VEGETATED
(5) OKANAGAN RIVER NOT INCLUDED IN SURVEY.

REFERENCES | REVISIONS

SURVEYED P. Hepburn DATE July 25-27, 1979
DRAWN R.M., A.F. 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

SCALE 1:6000
DRAWING No. 5144-009-11
SHEET 1 of 1

6.4 Appendix 4: Loading Tables

Table 6.4-1: Typical chloride loading from groundwater - land use and inflows

	Land Use	Okanagan Cl loading rate*	Area adjacent to Vaseux	Cl loading estimate and %
Land use Cl loading reporting to groundwater	Roads/Hwy 97	27-37 kg / 2lane/km		
	Residences on septic	440 mg/L, 6.8 kg/yr	65	
	Natural Cl loading in local groundwater			
	Undeveloped slopes /wetland areas	0 kg/yr		No net loading expected
Cl loading from inflows and loss from discharge	Inflow from Okanagan R.	3.61 million kg in 2016		
	Inflow from Vaseux Cks			
	Discharge to Osoyoos Lk	3.63 million kg in 2016		
Cl losses	Cl loss to ion exchange in soil solutions*[1]			
	Cl loading balance			

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

Table 6.4-2: Typical nutrient loading from groundwater - land use and inflows

	Land Use	Okanagan N,P loading rate*	Area adjacent to Vaseux	(N,P) loading estimate and %
Land use N,P loading reporting to groundwater	Roads/Hwy 97			
	Residences on septic			
	Natural N/P loading in local groundwater			
	Undeveloped slopes /wetland areas			
N,P loading from inflows and loss from discharge	Inflow from Okanagan R.	159,532 kg TN and 12,945 kg P in 2016		
	Inflow from Vaseux Cks			
	Discharge to Osoyoos Lk	169,654 kg TN and 6,974 kg TP in 2016		
N,P losses	Internal loss into refractory organic materials			
	N,P loading balance			

6.5 Appendix 5: Future Data Analysis and Modelling

These analyses will be completed as part of the year 2 final report.

6.5.1 BACI Impact Assessment

A Before–After Control-Impact (BACI) statistical test is based on repeated sampling of parameters over time in paired control and impact areas. Enough samples were collected to provide adequate statistical power and meet analysis requirements. 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.

6.5.2 Trend analyses

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

6.5.3 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 are developing the loading model for each parameter (Cl, N, P, key metals).

6.5.4 Nutrient Budget Calculations

After nutrient loading has been calculated, nutrient budgets for Vaseux Lake can be calculated. These will allow us to rank 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 will use the bathymetric approach LAC developed that involves calculating the nutrients concentrations in water layer volumes (Figure 2.10-2).

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