SWAN LAKE - LAND USE AND WATER QUALITY ASSESSMENT, VERNON, B.C.

Prepared for:

Regional District of
North Okanagan
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western water
ASSOCIATES LTD
Consultants in Hydrogeology and Environmental Science

July 29, 2016

Laura Frank, MA, MCIP, RPP, Regional Planning Projects Manager
Regional District of North Okanagan
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Via e-mail: laura.frank@rdno.ca

Dear Ms. Frank:

Re: PRELIMINARY LAND USE AND WATER QUALITY ASSESSMENT OF SWAN LAKE, NORTH OF VERNON, B.C.

Western Water Associates Ltd. (WWAL) is pleased to provide this report on the Land Use and Water Quality Assessment of Swan Lake. The program aimed to help elucidate the potential sources of water quality impact on Swan Lake.

We undertook a water quality sampling program in the area surrounding Swan Lake. Further, we assessed land use as it relates to potential water quality impact on Swan Lake by apportioning the mass flux of chloride and nutrients entering the lake from the various land uses surrounding the lake.

We trust that the professional opinions and advice presented in this document are sufficient for your current requirements. Should you have any questions, or if we can be of further assistance in this matter, please contact the undersigned.

WESTERN WATER ASSOCIATES LTD.

Reviewed by:

PROFESSIONAL PROVINCE OF B. R. MANWELL # 35085 BRITISH COLUMBIA ENGINEER

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EXECUTIVE -SUMMARY

In 2015, WWAL conducted a land use and water quality assessment for the RDNO in the vicinity of Swan Lake. The assessment included a first order approximation of the Swan Lake water budget (balance), which found that over 90% of the water in Swan Lake is derived from BX Creek inflow, with the remainder comprised of overland flow from surrounding lands and a small component of groundwater discharge. Water quality, as it relates to land use surrounding Swan Lake, was assessed based on an initial water quality sampling program conducted in 2015 and through apportioning of chloride by land use around the lake.

When we compared the surface waters at and around Swan Lake to provincial and federal aquatic life guidelines, we see the quality of water in Swan Lake and at the outlet of Swan Lake (Vernon Creek) is good. With only fluoride exceeding the Canadian water quality guidelines for the protection of freshwater aquatic life (CCME AL) in Swan Lake and in Vernon Creek. At the inlet of Swan Lake, Greenhow Creek (FS-43(SW)), we see exceedances of the CCME AL for uranium, chloride, and fluoride. Further, at a culvert draining into the northeast end of Swan Lake nitrate (at 5.98 mg/l) exceeded the CCME AL 30-day average (chronic) guideline (3 mg/l). However, this CCME AL guideline is based on 5 weekly samples collected within a 30-day period; which our sampling program did not involve, further sampling will help substantiate if nitrate is chronically elevated at this culvert.

When we compared groundwater and near-surface groundwater at the perimeter of Swan Lake to B.C. Contaminated Site Regulation (CSR) upper cap concentrations we are able to provide a preliminary assessment of land uses that could potentially degrade water quality in Swan Lake.

Specifically, ammonia at high concentrations was observed at two locations on the southeast shore of Swan Lake and is likely related to disposal of on-site wastewater at the shoreline. Given the ongoing measured impact at FS-32, which we believe is related to wastewater disposal at the shoreline, collection of wastewater from campgrounds and RV Parks surrounding Swan Lake should be considered in the Master Wastewater Recovery Plan. Further, at foreshore waters on the east, north, and southwest shores of Swan Lake, sulphate concentrations were found to be elevated above CSR Standards. We interpret these elevated sulphate concentrations to potentially be related to agricultural amendment applications in the area. The operators of agricultural lands above Swan Lake should create and implement Land Application Plans, which aim to reduce the input of sulphate into Swan Lake.

Uranium was above the B.C. CSR for Irrigation Water and Drinking Water upper caps of 0.01 and 0.02 mg/l, respectively at all but one (FS-31) sampled foreshore locations around Swan Lake. We recognize that uranium is found naturally occurring in Okanagan Valley sediments. However, background groundwater quality in deeper groundwater, present at MW-3 in the current study, showed uranium to be low. There is potential for land use surrounding Swan Lake (specifically anthropogenic input of calcium and chloride) to change the solution chemistry of the near-surface groundwater, resulting in increased solubility of uranium. The results assessed were a snap-shot in time and further sampling should be performed to substantiate or refute the finding from the 2015 study.

Using chloride as an indicator of water quality impact and estimating chloride mass loading rates from the land uses surrounding Swan Lake, agricultural activities around the lake most likely form the largest contribution to potential water quality impact on Swan Lake.

1. INTRODUCTION

In September 2014 the Reginal Distract of North Okanagan (RDNO) made a request for proposal to complete water quality monitoring on Swan Lake, located north of the City of Vernon and south of the Township of Spallumcheen, mostly within Electoral Area "B" of RDNO. The RDNO was interested in understanding what influence, if any, adjoining land uses, existing on-site wastewater systems and storm waters are having on water quality in Swan Lake. Western Water Associates Limited (WWAL) was awarded the contract to assess land use impact and water quality at Swan Lake. Work began on the project in the spring of 2015.

1.1 Project Objectives and Scope of Work

The objective of the water quality assessment was to design and undertake a program to measure the influence of surrounding land uses on potential water quality impact in Swan Lake. Our scope of work focused on assessment of the near-surface groundwater entering into Swan Lake to avoid the influence of dilution by surface waters on parameter concentrations. It was understood that potential water quality impact to Swan Lake would likely be due to a combination of both point source and non-point source contaminant inputs. Our program method involved identifying the point source and non-point source inputs along the 11.5 km perimeter of Swan Lake. Point source contamination from stormwater outfalls and other end of pipe inputs were assessed along with non-point contaminant sources derived from application of agricultural land amendments (fertilizers and/or manure) and operation of on-site wastewater disposal systems.

To identify and quantify point and non-point source nutrient and other contaminant loading into Swan Lake we completed the following tasks:

- Constructed a conceptual model of lake water flow (i.e. a water balance for Swan Lake);
- Performed an initial field reconnaissance to assess potential areas of interest;
- Performed additional sampling events during high, receding and low lake stages, with a focus on sampling at the areas of interest identified during the initial field reconnaissance; and
- Inventoried land use and estimated mass flux of nutrients entering along the perimeter of the lake.

2. SITE DESCRIPTION, GEOLOGIC, AND HYDROGEOLOGIC SETTING

The following sections summarize the physiographic, geologic, hydrogeologic, and hydrologic information compiled for the area around Swan Lake.

2.1 Site Description

Swan Lake is located north of the City of Vernon and south of the Township of Spallumcheen (Figure 1) in RDNO Electoral Area "B". The lake has an approximate surface area of $4X10^6$ m^2 (400 hectares). The Lake is surrounded primarily by Agricultural Land Reserve (zoned as Country Residential; 75%), and to a far less extent by residential development (16%), recreational commercial development (7%), and general industrial (2%) land use. However, there is significant commercial land use on the east side of Highway 97, which passes close by the east side of Swan Lake. Further, we understand there is a biosolids waste disposal facility located 1.4 km north of Swan Lake.

Qualitative surface water measurements taken at Swan Lake suggest the lake is mesotrophic, exhibiting an intermediate level of productivity (Nordin 1985). Further, there have been anecdotal observations of a plume, assumed to mean an algal bloom between Meadowlark Road and Elmwood Road on the east shore of Swan Lake. A large portion of the perimeter of Swan Lake, more prominently on the east shore, is bordered by wetland vegetation including cattail, willow, bulrushes and sedges as shown in Photos 1, 2 and 3, below.

Photo 1: Typical undeveloped riparian area on the east shore of Swan Lake, photo taken at FS-33, July 15, 2015, facing northwest.

Photo 2: Typical riparian area on the east shore of Swan Lake, showing willow photo taken at FS-33, July 15, 2015, facing west.

Photo 3: Typical wetlands area on the east shore of Swan Lake, showing cattails photo taken at FS-45, July 15, 2015, facing west.

2.2 Climate

The climate north of Vernon in the area of Swan Lake is mild. The warm season lasts from June to September with an average daily high temperature above 9°C. The hottest day of the year statistically is July 30, with an average high of 30°C and low of 14°C. The cold season lasts from November to February with an average daily high temperature below 3°C. Unlike nearby larger lakes such as Kalamalka and Okanagan Lake, Swan Lake typically freezes over for at least several weeks each winter. The average annual precipitation is 487 mm per year. The climate normals are provided in Table 1, below.

Table 1: 1981-2010 Climate Normals for Vernon Area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Daily Average (°C)	-2.8	-0.2	4.2	9.4	13.9	17.4	21	20.5	15.3	7.9	1.8	-2.2	8.8
Rainfall (mm)	11.6	11.7	17	27.2	46.3	49.6	35.4	31.9	32.7	40.7	31.1	9.7	344.9
Snowfall (cm)	40.5	13.5	11.7	1.8	0	0	0	0	0	0.9	26.5	47.3	142.1
Precipitation (mm)	52.2	25.2	28.7	29	46.3	49.6	35.4	31.9	32.7	41.5	57.5	57	487

Data Source: Environment Canada 2015 - Climate Station Number 1128583

2.3 Limnological Information

The following section was provided by Larratt Aquatic (2016) and summarizes the available limnological data available for Swan Lake. Swan Lake is located at the north end of the city of Vernon. The lake has a perimeter of 11.5 km and lies at an elevation of 390 m. Its surface area is 438.3 hectares, its maximum depth is 9.1 m, and its mean depth is 5.6 m. Swan Lake is classified as a dimictic lake. In three years of sampling, the maximum surface temperatures measured in 2009 and 2011 were 26.5°C (July 30th) and

23.0°C (July 7th), respectively. The maximum Secchi reading for all sampling years was 5.4 m and occurred on July 20th, 2009. The lowest Secchi depth measured over the 3 year sampling period was 1.65 m, on May 27th, 2009 (BCLSS 2013). Based on the average summer Secchi values, Swan Lake was exhibiting mesotrophic (3 - 6 m) conditions in all sampling years (Nordin 985). Anecdotal evidence suggests that Swan Lake experiences algae blooms, and if so, they may be most prominent during the spring and fall overturn periods when nutrient-rich bottom water is circulated throughout the lake. At this time, the thermal layering patterns and possible anaerobic conditions in deep water are not confirmed.

Swan Lake is one of the most important wetland habitats in the south central interior of B.C. and is recognized for its value to staging and breeding waterfowl. It is on a major provincial migratory corridor and is an important resting and feeding stop for migratory birds as well as providing essential nesting habitat, including one of the largest urban Great Blue Heron rookeries in western Canada.

Swan Lake is used for fishing, boating, waterskiing, swimming, flying (floatplanes), and winter ice sports (e.g., skating, ice racing of cars and motorbikes). Additionally, the south end of the lake is popular with birdwatchers. The lake has one boat launch, located about halfway down the lake on the east shore used by local residents and recreational users who visit Swan Lake (BCLSS 2013).

Swan Lake and Lower Vernon Creek are considered to be well-buffered to acidic inputs, and to have moderate water hardness. In Lower Vernon Creek metals that occasionally exceed criteria include aluminum, iron, and lead. The only known sources of metals to lower Vernon Creek are storm water runoff. Maximum concentrations of ammonia, nitrite, and nitrate were all below criteria. Phosphorus concentrations were high enough to cause excessive algal growths if phosphorus is the limiting factor (BC MoE 1999).

2.4 Surficial and Bedrock Geology

The following section describes the bedrock and surficial geology of the Swan Lake area. The geological Vernon Fault line (a buried bedrock structure) runs through the centre of Swan Lake from north to south, parallel to the valley bottom. Bedrock geology to the east and northeast of the site consists mainly of metamorphic rocks including schist, amphibolite, calc-silicate gneiss, and micaceous quartzite, which formed during the Paleo to Mesoproterozoic era (between 1000 and 2500 million years ago; Thompson et al 2004). The upland areas to the east of Highway 97 are comprised of calcareous quartzite of the Chase Formation and quartz-feldspar-muscovite-biotite schist of the Silver Creek Formation from the Devonian period (approximately 420 to 360 million years ago). Bedrock geology to the west of the Vernon Fault and Swan Lake include siliciclastic and volcanic rocks of the Harper Ranch Group, which formed during the Permian period (300 and 260 million years ago). Predominant metasedimentary and metavolcanic rock types in the formation are siltstone, sandstone, breccia, limestone, tuff, andesite, and skarn (Thompson 2004).

Surficial geology surrounding Swan Lake consists of lacustrine deposit, glacial deposits, and unconsolidated sediments of colluvium and alluvium from the Quaternary period approximately 2.6 million years ago to present (Thompson 2003). Thick lacustrine deposits consist of silt with minor clay and sands (Fulton 1995). These silt deposits underlie the adjoining uplands and were formed during the late glacial period at a time when the valley lake system stood at a higher elevation due to ice dams formed further down-valley (Nasmith 1962). Sediment chemistry for this region taken from uncontaminated lake sediments has shown elevated sulphur and lead; however, sediments are generally low in manganese and magnesium (Reiberger 1992).

2.5 Hydrology and Hydrogeology

There are eight surface water inlets into Swan Lake; all but three are unnamed and primarily ephemeral in nature (Figure 1). The three named tributaries are Greenhow Creek, Malysh Brook and B.X. Creek (MoE 2015). The majority of surface water (and groundwater flow) into Swan Lake occurs from the north and east side of the lake. Swan Lake has one outlet located at the south end of the lake, Vernon Creek, which has a regulated outflow structure. Typically, the majority of surface water flow into Swan Lake occurs during the spring freshet (March/April), when snow melt occurs within the valley bottom and during the summer melt (May/June) which drains the snow melt from the upper elevations closer to Silver Star. The remainder of the year, contribution to Swan Lake from the inlet tributaries are typically much lower.

There are three provincially mapped aquifers surrounding the site. Mapped sand and gravel aquifer 348 IIC underlies the site and is classified as low productivity, moderate demand, and low vulnerability (MoE 2015). Bedrock aquifer 358 IIC lies to the northeast and sand and gravel aquifer 349 IIC is located southeast of Swan Lake. The bedrock aquifer is characterized as having low demand, low productivity, and low vulnerability to surface contamination. Sand and gravel aquifer 349 IIC is characterized as having moderate productivity, moderate demand, and low vulnerability to surface contamination. Demand describes local reliance on the groundwater water source, productivity indicates the relative yield of wells completed in the aquifer, and vulnerability describes the potential for contaminants to migrate from the surface into the aquifer.

There are more than 180 wells reported in the vicinity of Swan Lake, with the majority completed in the unconsolidated sand and gravel aquifer (348 IIC). However, we understand that a majority of these wells are not in use, as community water supply is the primary water source throughout the area. Recorded well depths within the sand and gravel aquifer range from approximately 2.7 m (9 ft) to 64 m (212 ft) below ground surface (bgs). Wells that were completed in the bedrock aquifer indicate bedrock depth ranging from 1 m (3 ft) to 50 m (163 ft) bgs (MoE 2015). In 2009 further aquifer characterization was completed for the Okanagan Basin Water Board Groundwater Supply and Demand Study (Golder and Summit 2009). The surficial aquifer was estimated to have approximately 225 X10^3 m^3/day of groundwater flow through the aquifer, flowing from northeast to south.

3. METHODS – WATER BALANCE, SITE INVESTIGATION AND MASS FLUX ANAYSIS

The following sections outlines the methods used to create the Swan Lake water balance and complete the site investigation and mass flux estimates.

3.1 Swan Lake Water Balance

The water balance equation of Swan Lake is described as follows:

$$\Delta S = (Q_{in} + P + GW_{in}) - (Q_{out} + E + W_{use} + GW_{out})$$

Where:

ΔS	= Change in storage.
Q_{in}	= Total discharge of tributaries into Swan Lake.
P	= Total precipitation into Swan Lake.
GW_{in}	= Flux of groundwater into Swan Lake.
Q_{out}	= Total discharge of river and streams out of Swan Lake.
E	= Total evaporation from the lake surface.
W_{use}	= Domestic and agricultural water into or from Swan Lake.
GW_{out}	= Groundwater losses from Swan Lake to downgradient aquifers.

The data used in the Swan Lake water balance calculations were derived from several different sources as described below. The temperature data used to calculate evaporation and the precipitation data were taken from Environment Canada Climate Station No. 1128583, which has a record spanning 30 years from 1981 to 2010. The stream flow record for BX Creek was taken from a Kerr Wood Leidal (KWL) study performed between 2013 and 2015 (Mark Forsyth pers. com. June 2015). Older, government data (1959-1972), were not used because potential changes in the flow regime. Flow regime changes were due to alterations in the BX Creek irrigation program that ran until the late 1970's (i.e. water used to be diverted from a small dam above present-day Star Road into the now decommissioned Grey Canal system). The groundwater fluxes used in this report are taken from a 2009 study completed by Golder Associates and Summit Environmental for the Okanagan Basin Water Board (OBWB), which evaluated the groundwater supply and demand for the Okanagan Basin. Due to the relatively static nature of Swan Lake stage, it was suitable to use a 1959 Bathymetric map obtained from the Fisheries Inventory Summary System online data (FISS 1959). Results of the water balance are present in Section 4.1.

3.2 Field Investigation – Water Quality Sampling

The field investigation was approached in two stages; the first stage - initial field reconnaissance and the second stage - routine sampling. The purpose of the initial field reconnaissance was to identify areas of interest to be investigated during subsequent "routine" sampling program. These areas of interest are locations where non-point and point source contaminant indicators are found at concentrations markedly above ambient concentrations. Where ambient (background) concentrations were taken to be represented at MW-3. The indicator species in these areas include nutrients (i.e. nitrate, phosphate, and potassium), pathogenic bacteria, and other chemical species (i.e. chloride, dissolved sodium, dissolved calcium, sulphate, alkalinity, and uranium).

The initial site reconnaissance, conducted on April 2 and 3, 2015 (during seasonally high groundwater and surface water levels), involved recording field measured electrical conductivity and GPS coordinates at 62 locations along the 11.5 km perimeter of the lake (Figure 2). At 26 locations, water quality parameters listed in Table 2 (initial reconnaissance water quality survey) were assessed. From the 26 locations sampled and further desk top assessment, we identified 21 sampling locations, shown on Figure 3 to be included in the "routine" or subsequent two rounds of sampling in 2015.

The routine sample locations were sampled during two additional events, where water quality parameters listed in Table 2 (routine water quality survey) were assessed. The two additional sampling events occurred in July (seasonally receding water levels) and again in October/November (seasonally low gwater levels). Table 3 provides a summary of the 21 routine sample locations, which include 10 foreshore (near-surface groundwater), 3 groundwater, and 8 surface water locations.

Three wells were monitored during the Swan Lake investigation in 2015 (MW-1, MW-2, and MW-3). The groundwater wells were not sampled in April 2015, as they had not been located and access to the wells had not be granted at the time of the April 2015 initial assessment. The three groundwater monitoring wells utilized in this program were selected based their presence near the lake and being granted permission to access the wells during the sampling events. The three wells are grouped at the north end of the lake and that we do not know the actual depth of MW-3 are known study limitations. However, sampling of the groundwater wells has provided valuable information with respect to background water quality conditions, taken to be represented at MW-3 and illustrative of water quality impact observed at MW-1.

The three well were sampled during the July and October 2015 events. Well MW-1 is a 2 inch monitoring well located at the north end of the lake, approximately 35 m south of Highway 97 and 20 m west of Greenhow Creek and completed to a depth of 5.2 m (17 ft). Monitored well MW-2 is a drilled well completed to an approximate depth of 24 m (80 ft) and is located just under 900 m north-northeast of the Swan Lake shoreline. MW-2 was in use as a domestic supply source during the initial sampling event in July 2015; however, the property owner has since sold the land and the site is currently under development. Monitored well MW-3 is located approximately 800 m north of Swan Lake and is used as the domestic/commercial water supply for the offices located on that site. The depth of this well is unknown and MW-3 is a drilled 6 inch diameter domestic groundwater supply well.

3.2.1 Sampling Protocol

WWAL sampling protocol are based on procedures described in the British Columbia Field Sampling Manual for Continuous Monitoring and the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples (MoE 2003). To sample from the groundwater monitoring wells MW-1, a bladder or peristaltic pump with brand new or dedicated tubing was used to purge water from the wells until parameter stabilization was observed, followed by sample collection directly from the discharge tube into new sample bottles provided by the laboratory. The pump was decontaminated between sample locations. From the domestic wells (MW-2 and MW-3, the dedicated pumps were run till field measured parameters stabilized, at which time the water quality sample was taken. Clean nitrile gloves were worn while purging and sampling.

Sampling events included taking foreshore water samples of the near-surface groundwater, termed "hyporheic zone water", which is the zone of mixing between surface water and groundwater. This near-surface groundwater is the most likely receptor of non-point source contaminants such as septic systems and agricultural input. Our method for sampling the near-surface groundwater involves hand installation of mini-piezometers at the perimeter of the lake. By focusing on sampling near-surface groundwater we avoid dilution of the contaminants via mixing with surface water and we are able to assess water quality of near-surface groundwater at the perimeter of the lake, just before it enters the lake.

Surface water samples were taken as instantaneous grab samples. All samples were stored in coolers with ice and transported under chain-of-custody protocol to CARO Analytical Services, a laboratory accredited by the Canadian Association for Environmental Analytical Laboratories. Samples were submitted to the laboratory within the required holding time for bacteriological analysis.

All sampled locations were photographed and the GPS coordinates were recorded. A triplicate sample was taken and the relative standard deviation (RSD) was calculated to help assess quality of the data set, result for the RSD are provided in Section 4.2.3, below and the full QA/QC data set is provided in Appendix A.

Table 2: Summary of Water Quality Parameters for Initial and Routine Sampling

Water Quality Sampling Parameter Lists
Initial reconnaissance water quality survey: • Field measured dissolved oxygen, temperature, pH, electrical conductivity and oxidation reduction potential; • Ammonia; • Alkalinity; and • Full Ion Chromatography Scan (chloride, bromide, sulfate, nitrate, and ortho-phosphate).
Routine water quality survey: • Field measured dissolved oxygen, temperature, pH, electrical conductivity and oxidation reduction potential; • Ammonia; • Alkalinity; • Total Sulfide; • Full Ion Chromatography Scan (chloride, bromide, sulfate, nitrate, and ortho-phosphate); • Fecal Coliform, Total Coliforms & *E. coli* (only once on October 31, 2015); and • Dissolved Metals (only once on October 31, 2015);

Table 3: Summary of Locations Sampled for Water Quality

Location Relative to Swan Lake	Type of Sample	Routine Sampling Locations	Description of Location
EAST	FS	FS-3	East Shore - mid-lake, 500 m north of Meadowlark Road.
		FS-45	East Shore - north end of lake - downgradient of Swan Lake RV.
		FS-15	East Shore - north end of lake, downgradient of unknown tributary - just south of Elmwood Road.
		FS-32 (Leachate)	East Shore - south end of lake, just north of the Silver Star R.V. property.
		FS-33	East Shore - south end of lake, just south of the south end of Heron Road, downgradient of an unnamed tributary.
		FS-31	East Shore - south end of lake, downgradient of Silver Star R.V.
	SW	FS-101	East side of Swan Lake - storm drain (ditch) located on the east side of Hwy 97 north of Meadowlark Road and upgradient to FS-3.
		FS-103	Northeast of Swan Lake - storm drain (ditch) located on the Pleasant Valley Road.
		FS-104	East side, south end of Swan Lake - storm drain (ditch) located at junction of Stickle Road and Pleasant Valley Road.
		Site 3 (NE-Cowboys)	East side and north end of Swan Lake - unnamed tributary sampled east of Hwy 97, behind Cowboys Shop.

		Site 5 (NE-Culvert)	Northeast end of Swan Lake - culverted Malysh Brook, sampled west of Hwy 97, just north of Swan Lake R.V.
NORTH	FS	FS-43	North Shore - north end of Swan Lake, directly west of the main channel of Greenhow Creek.
	GW	MW-1	North end of Swan Lake - Monitoring Well - near FS-43 and FS-43 (SW).
		MW-3	Northeast of Swan Lake Monitoring well located on Kal Tire property. **Taken to represent ambient (background) groundwater quality.**
		MW-2	Northeast of Swan Lake Monitoring well located on TNT property.
	SW	FS-43 (SW)	North end of Swan Lake - Greenhow Creek just before it's confluence with Swan Lake.
WEST	FS	FS-21	West Shore - north end of lake, downgradient of hobby farms.
		FS-28	West Shore - south end of lake, downgradient of hobby farms.
		FS-29	West Shore - south end of lake, along a perched water pond, downgradient of hay fields and at the edge of Swan Lake.
SOUTH	SW	Vernon Creek (Outlet)	South end of Swan Lake - Outlet of Swan Lake (Vernon Creek).
		Swan Lake	Swan Lake sample taken from the south end of lake near Silver Star R.V.

Type of Samples: FS – foreshore (near-surface groundwater), GW – groundwater, and SW – surface water

3.3 Land Use Inventory and Mass Flux of Anthropogenic Impact Indicators

Impact of anthropogenic (human) pollution on fresh water bodies can come from both point source and non-point source inputs. A point source input is derived from the end of a pipe, like storm water outfalls or a community wastewater discharge system. Non-point source input is derived from a diffuse source such as agricultural runoff or multiple private on-site wastewater systems dispersed across a landscape. Some of the potential pollution sources for Swan Lake include input from human and animal waste matter, fertilizers from agricultural practices, industrial waste, and road salting practices. There are many chemicals that can contribute to the degradation of water or are indicators of anthropogenic input. Some of these anthropogenic indicator parameters are nutrients, which contribute to eutrophication of surface water bodies such as nitrogen and phosphorus or indicate anthropogenic input like chloride and sulfur, along with other metals associated with different land use practices. Urban and agricultural runoff, in turn, can contribute different mixtures of these constituents via storm flow in ditches as well as overland flow.

Chloride concentrations are of particular interest and form the focus of the land use and mass flux estimates for several reasons. Firstly, chloride serves as a useful indicator of anthropogenic influence/ impacts due to its conservative properties within the hydrosphere and its association with human and animal effluent as well as fertilizers, primarily in the form of potassium chloride. Secondly, the salinization of fresh water can lead to acidification, mobilization of toxic metals (Kaushal *et al*., 2005), and ultimately decreased water quality.

Chloride is introduced into the environment by way of natural and anthropogenic sources. Some of the natural sources include atmospheric deposition, and the natural weathering of bedrock, soil, and surficial materials. Typically, in pristine or unaffected fresh waters chloride concentrations are less than 3 mg/l. The primary anthropogenic inputs include surface runoff related to agricultural practices, industrial activities, on-site wastewater, and road salting.

The following sections describe the methods used to estimate the chloride mass loading into Swan Lake in two ways. The first mass flux estimate is based on land-use partitioning and the second is based on groundwater flow and the results from the foreshore water quality sampling. Both estimates are first order approximations and based on assumptions explained in the sections to follow.

3.3.1 Chloride Loading Based on Land-Use

In order to establish theoretical loading rates for chloride as it enters Swan Lake, the surrounding basin area was partitioned into four main land uses that contribute to the majority of the chloride loading. These included the following categories: Agricultural Lands, Residential, Industrial and Roadways surrounding Swan Lake (Figure 1). These main categories were then subdivided further into to more specific land-uses. Using both literature values and actual application rates provided by land users, average input values per unit area were estimated and used to calculate theoretical annual chloride mass flux into Swan Lake.

3.3.2 Chloride Loading Based on Groundwater Discharge and Water Quality

As will be seen in the water balance section below for Swan Lake, surface water contribution from BX Creek is significant; whereas, groundwater discharging via the alluvial aquifer associated with BX Creek accounts for a relatively small portion of the recharge to Swan Lake. Groundwater recharge (flow) into Swan Lake can transport with it, anthropogenic pollutants. To estimate ambient chloride concentration in the aquifer sampling location MW-3, 300 m northeast of the lake was used as a measure of 'background' chloride concentrations. The foreshore samples taken on the east and north shores of Swan Lake were used as an indication of the increase in chloride concentrations due to the different land-use practices upgradient of the lake. The ambient chloride concentrations used in this study is 16 mg/l. The geometric annual mean of the foreshore sampling on the east shoreline was calculated to be 154 mg/l. Using these measured chloride concentrations and the aquifer discharge into Swan Lake, an annual flux of chloride loading into Swan Lake was made. Further, an estimate of chloride mass flux into Swan Lake assuming no anthropogenic impact was calculated.

The groundwater recharge equation for an unconfined aquifer to Swan Lake is characterized by Darcy's Law and the equation is as follows:

$$Q = -K * i * A$$

Where:

Q = Discharge into Swan Lake (length^3/time)
k = Hydraulic conductivity (length/time)
i = Hydraulic gradient (length/length)
A = Cross sectional area (aquifer width (length) * saturated thickness (length))

4. RESULTS

The following sections summarize the results of the land use and water quality assessment of Swan Lake. Sections below include results on the following aspects of the study:

- Swan Lake seasonal water budget;
- Water quality assessment including assessment of water quality exceedances; and
- Estimates of mass flux of water quality indicator parameters.

4.1 Swan Lake Water Balance

The following section discusses the seasonal water budget for Swan Lake. The major components in the calculation included precipitation, evaporation, stream inputs, and output, gains and losses from groundwater and surface water use. Table 4 summarizes the water balance parameters and estimates and Table 5 is a monthly breakdown of the Swan Lake water budget estimates.

Swan Lake has a volume of approximately 24,744,000 m3 (FISS, 2013). Dividing the Volume of the inputs found in figures 1 and 2 Swan Lake has a calculated residence time of approximately 1 year. The primary influx of water into Swan Lake is from BX Creek which enters at the south end of the lake and accounts for 90% of total input. BX Creek is derived primarily from higher elevation snowmelt with 70% of the flow arriving during freshet in the months of April, May, and June (Figure 3). There are 3 smaller creeks at the north end of the lake (Greenhow Creek, Unnamed tributary Site 3 (NE-Cowboys), and Site 5 (NE-Culvert), which is Malysh Creek, culverted as it enters Swan Lake) that have been noted to contribute flow primarily during spring freshet. Site 3 (NE-Cowboys) and Site 5 (NE-Culvert) are ephemeral and stop flowing completely in the summer, fall, and winter. Greenhow Creek is reduced to almost negligible flows during baseflow (late summer, fall, and winter).

Precipitation is the second largest input of water into the lake accounting for 9% of the total influx. Seasonally, most of the precipitation occurs during the winter and late fall and enters the lake in early spring (Figure 3). Groundwater contributions to Swan Lake total 152,000 m^3/year and are primarily from the unconfined aquifer that surrounds much of the lake. The aquifer formation consists chiefly of lacustrine deposits on the order of 60 m thick (Golder and Summit, 2009). The primary groundwater flow direction is from north to south through the Spallumcheen aquifer and to a lesser extent from east to southwest from the BX Creek associated aquifer. For the water budgets estimates, it is assumed that the groundwater flow into Swan Lake is constant throughout the year.

The primary water output from Swan Lake is at the south end of the lake primarily through Vernon Creek (also referred to as Lower BX Creek), just 200 metres west of where BX Creek enters the lake (Figure 2). Annual output flows total 19,716,558 m^3, accounting for 94% of total output. Seasonally, the output via Vernon Creek mirrors the seasonal inputs from BX Creek with the majority of the flow occurring in the spring (Figure 3).

Total evaporation was calculated to be 1,001,911 m^3 annually and was estimated using average monthly temperatures as per recommendation of the latest Okanagan Basin Evaporation Study (Schertzer, 2009). A search of the MoE database revealed only 2 registered surface water licenses on Swan Lake. Of these two, only one reported the allowed quantity of 555 m^3/day. For the water balance calculations, it was assumed that the total allowed consumption was used, for a potential annual extraction of 197,580 m^3/year.

There is a difference of 3,520,800 m^3/year between outputs and inputs (about 14% of lake volume), indicating that more water is calculated to be entering Swan Lake than exiting, which is not supported by the observation of fairly stable lake levels over the long term. Some potential reasons for this discrepancy may include the following: a fluctuation in the lake level of 0.80 meters from one year to the next, an under estimation of evaporation, losses to groundwater likely occurring out the south end of the lake to the downgradient aquifer, losses from BX Creek to the underlying aquifer between the point where it leaves Swan Lake at Vernon Creek, and where the stream flow data was collected, and an over estimation of some of the inputs, in particular BX Creek. See recommendations regarding approaches to resolving the water budget uncertainties and apparent imbalance in Section 6.

Table 4: Water Balance Parameters for Swan Lake

Parameter	Value	
Surface Area (m^2)		4,382,745
Shore Line (m)		11,478
Volume (m^3)		24,743,646
Max Depth (m)		9
Residence Time (yr.)		1
Fluxes (m^3/year)		
Inputs	Average annual reported precipitation	2,134,396
	BX Creek inflow	22,126,435
	Site 3 (NE – Cowboys) Creek	1,606
	Greenhow Creek	12,149
	Site 5 (NE – Culvert)	10,263
	Groundwater flow (Aquifer 271)	152,000
	Total inputs	**24,436,849**
Outputs	BX Creek outflow	19,716,558
	Evaporation	1,001,911
	Water License	197,580
	Total Outputs	**20,916,049**

Note: General Facts (FISS, 2013)

Table 5: Water Balance, Monthly inputs and outputs for Swan Lake in Cubic Meters

Month	Inputs (m^3)				Outputs (m^3)		
	Precipitation	Groundwater (in)	BX creek (in)	Small Creeks (in)	BX creek (out)	Evaporation	Water Use
Jan	228,779	12,666	1,740,960	0	1,031,184	0	16,465
Feb	110,445	12,666	1,354,752	0	914,457	0	16,465
March	125,784	12,666	1,473,120	12,009	288,999	56,928	16,465
April	127,099	12,666	5,686,848	12,009	3,784,320	74,318	16,465
May	202,921	12,666	7,392,384	0	4,955,040	110,000	16,465
June	217,384	12,666	2,516,832	0	2,431,036	141,384	16,465
July	155,149	12,666	567,821	0	771,379	192,602	16,465
August	139,809	12,666	141,955	0	723,168	185,574	16,465
September	143,315	12,666	104,198	0	274,752	119,381	16,465
Oct	181,883	12,666	125,885	0	396,403	69,028	16,465
Nov	252,007	12,666	526,176	0	3,144,096	52,693	16,465
Dec	249,816	12,666	495,504	0	1,001,721	0	16,465
Total	**2,134,397**	**151,992**	**22,126,435**	**24,018**	**19,716,558**	**1,001,912**	**197,580**

4.2 Water Quality Assessment

The following section provides discussion on the overall water quality characteristics and lists parameters that exceeded the applicable B.C. Contaminated Site Regulation (CSR) standards (upper cap concentrations) in 2015. Table 6 provides ranked maximum concentrations of select water quality parameters from highest to lowest concentrations. Appendix A provides the full water quality database for all routine locations samples in 2015. Appendix B contains the water quality laboratory reports for all sampling events.

Figures 6 through 15 display the maximum concentrations of select water quality indicator parameters by routine sampled location. The water quality parameters shown by figure number are as follows:

- Figure 6: Maximum Chloride Concentrations;
- Figure 7: Maximum Nitrate Concentrations;
- Figure 8: Maximum Sodium Concentrations;
- Figure 9: Maximum Sulphate Concentrations;
- Figure 10: Maximum Ammonia Concentrations;
- Figure 11: Maximum Alkalinity Concentrations;
- Figure 12: Maximum Fluoride Concentrations;
- Figure 13: Maximum Uranium Concentrations;
- Figure 14: Maximum Potassium Concentrations; and
- Figure 15: Maximum Calcium Concentrations.

Figures 16 and 17 depicts Schoeller Plots, which are geochemical representations of the average millequivalents of major ions for the routine sampled locations.

4.2.1 Water Quality Characteristics

Overall, all foreshore (near-surface groundwater) locations along with groundwater monitoring well MW-1 showed anthropogenic input; with evidence of input observed as concentrations of chloride, nitrate, sodium, sulphate, ammonia, alkalinity, uranium, alkalinity, potassium and calcium well above ambient concentrations. Ambient water quality is thought to be represented at groundwater monitoring well MW-3. Surface waters, in general, showed the lowest concentrations of water quality impact parameters. Except at FS-43 (SW) which is Greenhow Creek, at the northern end of Swan Lake, along with storm ditches FS-103 and FS-104, where several water quality exceedances were observed. Note the following discussion of the water quality results are based on limited data, comprised of only one set of results for metals and only three sets of results for the anions and alkalinity. Future sampling for the routine parameter list will allow for a more statistically defensible assessment of the water quality surrounding Swan Lake.

East Shore

The foreshore sites at the southeast end of the lake (FS-31 and FS-32) both show impact likely derived from operation of on-site wastewater systems as is evident from the extremely elevated ammonia, chloride, sulphate, sodium, alkalinity, and potassium concentrations. Further, along the mid-east bank of Swan Lake, FS-33, FS-3, and FS-15 along with the ditch waters at FS-101, FS-103, and FS-104 consistently showed very high levels of indicator parameters compared to background (MW-3), see Figures 6 through 17 and refer to Table 6 for numerical values of indicator parameters.

FS-3 and the foreshore north and south of FS-3 indicated extremely elevated electrical conductivity and sulphate in the spring of 2015; however, into the summer and into the fall the sulphate levels came down by orders of magnitude, from 10,500 mg/l in April to about 500 mg/l in July and then 158 mg/l in October 2015. From conversation with fertilizer suppliers in the area (Patterson 2015), we understand there is application of sulphate rich agricultural amendments applied on the orchards upgradient of FS-3.

FS-15 is the discharge zone for relatively large catchment area compared to the other foreshore sites, located downgradient of an unnamed, often ephemeral, tributary (Figure 1). Likely, FS-15 is receiving waste streams (non-point source inputs) from upgradient land uses include agriculture and residential on-site wastewater.

FS-45, located directly down gradient of Swan Lake RV Park, showed elevated sodium, sulphate, uranium and fluoride compared to background (MW-3). However, concentrations of indicator parameters (chloride, sodium, nitrate, sulphate, ammonia, alkalinity, fluoride, potassium, uranium, and calcium) were lower than at the following locations (MW-1, FS-3, FS-15, FS-21, FS-32, FS-31, FS-43(SW), FS-43, FS-28, FS-101 and FS-103).

Site 3 (NE-Cowboys), is an ephemeral stream, present during the April 2015 sampling event but not present in July or October, showed the lowest concentrations for almost all indicator parameters, except for nitrate.

Site 5 (NE-Culvert) is a culvert which drains Malysh Creek and the area to the northeast of Swan Lake and it showed high levels of all water quality indicator parameters (chloride, sodium, nitrate, sulphate, ammonia, alkalinity, fluoride, potassium, uranium, and calcium), see Table 6. Though nitrate did not exceed the CSR DW upper cap of 10 mg/l, nitrate at Site 5 (NE-Culvert) showed the second highest nitrate concentration at 6 mg/l. The source of the nutrients (nitrate) is likely derived from non-point source operation of on-site wastewater systems and agriculture fertilizers.

Nitrate, present in the storm ditch waters above the east shore of Swan Lake at FS-101, FS-104, and Site 5 NE-Culvert were shown to be elevated at 6.56 mg/l, 9.35 mg/l and 5.98 mg/l, respectively. However, all sampled foreshore locations showed nitrate concentrations less than 1.15 mg/l. The overall reduction of nitrate from storm ditches to the foreshore water is likely the result of uptake of nutrients (nitrogen) into the riparian vegetation present along a majority of Swan Lakes shoreline.

North Shore

The groundwater at MW-3, located to the northeast of Swan Lake (Figure 5), represent ambient (background) conditions. Whereas groundwater at MW-1, surface water at FS-43 (SW), and foreshore water at FS-43 show high levels of the following indicator parameters: chloride, sodium, sulphate, uranium and calcium (Table 6). Based on the fact that these indicator parameters are low at MW-3 and high at MW-1, FS-43(SW) and FS-43, we believe there is significant anthropogenic input from upgradient land uses which includes road salting on the highway, a bio-solids disposal site (located 1.4 km north of Swan Lake) and agricultural land use.

West Shore

Three routine foreshore samples were taken on the west shore of Swan Lake at FS-21, FS-28, and FS-29 (Figure 5). FS-21 and FS-28 are both located downgradient of agricultural land (small hobby farms) and showed a moderate degree of impact. Of note, at FS-21 the sodium level is elevated above all other sampled locations. The source of the elevated sodium is not readily apparent but may be derived from domestic drinking water softeners. FS-29 is located at a perched pond, on the edge of Swan Lake, downgradient of agricultural land. FS-29 showed elevated water quality indicator parameters; specifically, ammonia and sulphate were high relative to the other sites (Table 6). FS-28, sampled downgradient of rural residence (small hobby farms) showed concentrations of indicator parameters above background (MW-3).

South Shore

The two samples taken at the south end of the lake are both surface water samples: Vernon Creek and Swan Lake. Vernon Creek, sampled at the outlet of Swan Lake, showed elevated chloride above the ambient groundwater concentrations at MW-3 (17 mg/l) at 50 mg/l. The other water quality parameter levels are low at the outlet of Vernon Creek, likely due to dilution from BX Creek. Based on the indicator parameters assessed, Swan Lake showed no indication of impact. With parameter concentrations from the surface water sample taken from Swan Lake appearing similar to the ambient groundwater at MW-3 (see Table 6).

Table 6: Sampled Sites Ranked by Concentration of Water Quality Parameters (all concentrations are in mg/l)

Chloride		Sodium (dissolved)		Nitrate (as N)		Sulphate		Ammonia (total, as N)	
Sampling Location	**Max**	**Sampling Location**	**Max**	**Sampling Location**	**Max**	**Sampling Location**	**Max**	**Sampling Location**	**Max**
FS-43	477	MW-1	294	FS-101	6.56	FS-3	10500	FS-32 (Leachate)	34.1
MW-1	431	FS-15	265	Site 5 (NE-Culvert)	5.98	MW-1	2540	FS-31	19.4
FS-15	387	FS-21	202	FS-104	9.35	FS-43	1330	FS-29	2.2
FS-32 (Leachate)	168	FS-3	175	FS-3	1.12	FS-29	1050	FS-103	1.1
FS-31	160	FS-32 (Leachate)	133	FS-15	1.08	FS-15	737	FS-28	0.537
FS-43 (SW)	151	FS-31	123	FS-31	1.08	FS-33	458	FS-21	0.416
Site 5 (NE-Culvert)	118	FS-103	99.3	FS-32 (Leachate)	1.03	FS-32 (Leachate)	378	FS-43	0.204
FS-33	111	FS-43 (SW)	98.5	FS-21	0.761	FS-21	291	MW-3	0.148
FS-3	103	FS-43	95.5	FS-28	0.4	FS-103	264	FS-45	0.141
FS-103	101	FS-28	77.2	FS-33	0.324	FS-28	219	FS-104	0.138
FS-104	73.9	FS-101	68.5	Swan Lake	0.271	FS-45	203	FS-101	0.104
FS-29	66.3	FS-45	47.2	FS-29	0.248	FS-43 (SW)	159	FS-15	0.094
FS-28	61.6	Site 5 (NE-Culvert)	38.1	MW-2	0.228	FS-101	136	FS-33	0.09
Vernon Creek (Outlet)	49.5	Swan Lake	25.9	Vernon Creek (Outlet)	0.199	FS-31	126	FS-3	0.07
MW-2	40.5	FS-104	25.8	Site 3 (NE-Cowboys)	0.175	Site 5 (NE-Culvert)	122	MW-2	0.065
FS-101	39	FS-29	25.7	FS-45	0.062	FS-104	71.2	FS-43 (SW)	0.054
FS-21	35.2	Vernon Creek (Outlet)	24	FS-43 (SW)	0.039	MW-3	71	Vernon Creek (Outlet)	0.054
FS-45	33.4	MW-3	15.7	FS-43	0.038	Swan Lake	55.2	Swan Lake	0.053
Swan Lake	28.7	MW-2	9.1	FS-103	<0.010	Vernon Creek (Outlet)	54.3	MW-1	0.052
MW-3	17.4	FS-33		MW-1	<0.010	MW-2	49	Site 5 (NE-Culvert)	0.024
Site 3 (NE-Cowboys)	9.29	Site 3 (NE-Cowboys)		MW-3	<0.010	Site 3 (NE-Cowboys)	31.3	Site 3 (NE-Cowboys)	

Alkalinity (total, as CaCO3)		Fluoride		Uranium (dissolved)		Potassium (dissolved)		Calcium (dissolved)	
Sampling Location	**Max**	**Sampling Location**	**Max**	**Sampling Location**	**Max**	**Sampling Location**	**Max**	**Sampling Location**	**Max**
FS-33	22500	FS-15	2.33	FS-15	0.247	FS-32 (Leachate)	28.5	MW-1	448
FS-103	15000	FS-3	1.61	MW-1	0.0461	FS-31	25.3	FS-21	355
FS-29	2110	FS-33	1.4	FS-21	0.0346	FS-15	13.2	FS-3	278
FS-32 (Leachate)	1600	FS-101	1.16	FS-3	0.0271	FS-3	9.42	FS-32	243
FS-31	1390	FS-45	1.01	FS-45	0.0269	FS-43 (SW)	9	FS-15	218
FS-28	1010	FS-32 (Leachate)	0.9	FS-29	0.0222	FS-29	8.78	FS-31	204
FS-15	979	FS-43	0.86	FS-28	0.0211	FS-101	8.59	FS-28	182
FS-3	831	FS-29	0.83	FS-43	0.02	FS-21	7.68	FS-103	145
FS-21	798	Site 5 (NE-Culvert)	0.77	FS-43 (SW)	0.0165	FS-43	6.9	FS-43	104
MW-1	436	FS-104	0.68	FS-101	0.0161	FS-45	6.09	FS-29	102
FS-104	427	FS-28	0.67	FS-103	0.015	FS-104	5.75	FS-43 (SW)	101
FS-45	421	FS-43 (SW)	0.66	FS-32 (Leachate)	0.0146	Site 5 (NE-Culvert)	5.43	FS-104	84.1
FS-101	419	FS-103	0.63	FS-104	0.0121	MW-1	5.33	MW-2	73.6
Site 5 (NE-Culvert)	315	FS-21	0.62	Swan Lake	0.00586	Swan Lake	5.09	Site 5 (NE-Culvert)	73.1
FS-43	305	FS-31	0.61	Site 5 (NE-Culvert)	0.00393	FS-103	5.06	FS-45	70.4
FS-43 (SW)	303	MW-1	0.35	MW-2	0.0034	Vernon Creek (Outlet)	4.44	Vernon Creek (Outlet)	70
MW-2	186	Vernon Creek (Outlet)	0.29	FS-31	0.00325	FS-28	3.53	MW-3	53.9
Vernon Creek (Outlet)	167	Swan Lake	0.27	Vernon Creek (Outlet)	0.00206	MW-2	2.84	Swan Lake	50.9
MW-3	164	MW-3	0.23	MW-3	0.0004	MW-3	2.42	FS-101	48.8
Swan Lake	146	Site 3 (NE-Cowboys)	0.16	FS-33		FS-33		FS-33	
Site 3 (NE-Cowboys)	78	MW-2	0.15	Site 3 (NE-Cowboys)		Site 3 (NE-Cowboys)		Site 3 (NE-Cowboys)	

4.2.2 Water Quality Exceedances

The following sections provide descriptions of the exceedances above the Contaminated Site Regulation (CSR) fresh water aquatic life, drinking water, irrigation water, and livestock water standards observed at the routine sampled sites during the three 2015 sampling events. Note that metals were only sampled once at the routine sites on October 29, 2015, except at FS-3 where metals were also assessed on July 15, 2015.

Appendix C provides further discussion by Larratt Aquatics regarding parameters of concern identified in the current study.

Comparison of the water quality results to the CSR standards was based on the potential water uses surrounding the lake. The area around the lake is serviced by municipal water supply; however, any property owner could install a water well, which could be used for drinking, irrigation, or livestock watering. Further, the foreshore samples (near-surface groundwater), at the perimeter of Swan Lake assessed in the current study is migrating into Swan Lake and therefore the CSR Freshwater Aquatic Life (AW) Standard is applicable as CSR AW have been created to apply to groundwaters. The water quality standards compared were as follows:

- BC CSR AW - BC CSR, Schedule 6, Generic Numerical Water Standards for Freshwater Aquatic Life;
- BC CSR DW - BC CSR, Schedule 6 and 10, Generic Numerical Water Standards for Drinking Water;
- BC CSR IW - BC CSR, Schedule 6, Generic Numerical Water Standards for Irrigation; and
- BC CSR LW - BC CSR, Schedule 6, Generic Numerical Water Standards for Livestock.

Table 7 provides a summary of exceedances by parameter and Table 8 summarizes the exceedances by standard and each table groups the sampled locations by area relative to Swan Lake, i.e. north, south, east, and west shores.

Further, the surface water results from the 2015 sampling are compared to the provincial and federal aquatic life guidelines and are summarized in Table 9. The guidelines used to compare the surface water result are as follows:

- BCAWQG AL - BC Approved Water Quality Guidelines for freshwater aquatic life;
- BCWWQG AL - Working Water Quality Guidelines for British Columbia for freshwater aquatic life; and
- CCME AL - Canadian environmental water quality guidelines for the protection of freshwater aquatic life.

4.2.2.1 Ammonia (total, as N)

Total ammonia exceeded the CSR AW upper cap limit at three locations: two foreshore locations on the east shore line (FS-31 and FS-32) and one foreshore location on the southwest side of the lake (FS-29).

FS-31 and FS-32 are both located in the vicinity of commercial and residential land uses and the ammonia exceedances may be due to the operation of on-site wastewater systems nearby.

FS-29 is a near-surface groundwater (foreshore) sample taken at the southwest end of the lake, higher concentrations of ammonia are likely associated with agricultural activities upgradient of the FS-29 location.

Figure 10 shows the spatial distribution of the maximum concentrations of ammonia sampled in 2015, around the perimeter of Swan Lake.

4.2.2.2 Sulphate

Total sulphate exceeded CSR for AW, LW, or DW upper cap concentrations at five locations; two locations on the east side (FS-3 and FS-15), two at the north (FS-43 and MW-1) and one at the southwest shore (FS-29).

On the east shore of Swan Lake sulphate exceeded at FS-3 and FS-15. FS-3 showed an extremely elevated sulphate concentration of 10,500 mg/l during the April 2, 2015 sampling. We did not interpret this result as erroneous because the field measured electrical conductivity was extremely elevated (13,320 µS/cm), thereby validating the sulphate laboratory results. During the July and October sampling events the sulphate concentrations were orders of magnitude lower than in April at about 500 mg/l and 100 mg/l, respectively. We interpret these results to be potentially indicative of impact from upgradient land uses, likely agricultural.

At FS-15, located downgradient of an unnamed tributary and just south of Elmwood Road, we see the largest number of water quality standard exceedances. Sulphate exceeded the CSR DW upper cap (500 mg/l) in July 2015 at 700 mg/l. The elevated sulphate concentration at FS-15 is thought to be of different origin than at FS-3 as the temporal variation of concentrations at FS-3 and FS-15 are substantially different. Further discussion on the other exceedances at FS-15 will be provided below.

Both FS-43 and MW-1, located at the most northern point of Swan Lake, showed the second and third highest sulphate concentrations for the routine sample locations (Table 6). The 2015 maximum concentrations at MW-1 and FS-43, were below FS-3 at 2,540 mg/l and 1,330 mg/l, respectively. The sources of sulphate, chloride, and sodium are thought to be from agricultural land use and biosolids disposal both occurring upgradient (north) of the northern area of Swan Lake.

FS-29 is a near-surface groundwater (foreshore) sample taken at the edge of an agricultural operation near the southwest part of the lake. Ammonia, sodium, alkalinity, and sulphate are all elevated at this location. Sulphate is found at a maximum concentration of 1,050 mg/l, above the CSR DW upper cap level. We believe sulphate at this location is likely associated with agricultural activity upgradient of the FS-29 location.

Figure 9 shows the spatial distribution of the maximum concentrations of sulphate sampled in 2015, around the perimeter of Swan Lake.

4.2.2.3 Nitrate

Nitrate exceeded the CCME AL of 3.0 mg/L in April 2015 at 6 mg/L; however, the CCME AL is a long-term exposure guideline for nitrate (as N) and in October 2015 the concentration at Site 5 was less than 1 mg/l. Figure 7 shows the spatial distribution of the maximum concentrations of nitrate sampled in 2015, around the perimeter of Swan Lake.

4.2.2.4 Uranium (dissolved)

Of the 19 locations sampled for uranium, 13 locations exceeded the CSR IW upper cap concentration of 0.01 mg/l and 8 were above the CSR DW upper cap concentration of 0.02 mg/l. Without exception, all of the Swan Lake foreshore samples were above the CSR IW upper cap. Uranium exceeded the CCME AL and the BCWWQG AL at surface water location FS-43(SW). See Table 6 for concentrations of uranium at the routine sample locations.

Note, the ambient groundwater in the area, represented at MW-3, showed a low uranium concentration of 0.0004 mg/l. As mentioned above, there were no foreshore locations sampled, which appear to be unaffected by anthropogenic input. There appears to be a relatively strong correlation between uranium and calcium, with a second order polynomial regression analysis providing an r^2 value of almost 0.7. For this calculated r^2 value, site FS-15 was removed, as FS-15 appears to be an outlier, with a very high uranium concentration compared to calcium concentration. Other researchers have seen a similarly strong correlation between uranium, calcium, and to a lesser degree chloride (Drage and Kennedy 2013 and Dong et. al. 2005). If the surficial deposits in the vicinity of Swan Lake are of similar origin and MW-3 is representative of ambient groundwater conditions, it is possible that anthropogenic input of calcium and chloride, via road salting, agricultural activity, operation of onsite wastewater systems, and other anthropogenic sources is influencing the solubility of uranium present in the surficial deposits, thus mobilizing uranium into the foreshore (near-surface) waters surrounding Swan Lake.

Figure 13 shows the spatial distribution of the concentrations of uranium sampled in 2015, around the perimeter of Swan Lake.

4.2.2.5 Chloride

Chloride is highly soluble and conservative, meaning, once it enters the environment it remains mobile and concentrations in water are primarily affected by dilution and not by chemical or biological reactions. Because of its anthropogenic origins and conservative properties, chloride is an important ion for identifying land use impacts in surface water bodies. Natural sources of chloride in aquatic systems include naturally-occurring saline lakes and groundwater discharges from saline aquifers as well as naturally occurring salt deposits. However, such natural sources are not observed in the vicinity of Swan Lake. Again, groundwater well MW-3 is taken to present background water quality and chloride levels at MW-3 were less than 20 mg/l.

Ten of the routine sample sites exceeded CSR guidelines. Seven locations, five foreshore (FS-3, FS-15, FS-31, FS-32, and FS-33) and two surface water locations (FS-103 and Site 5 (NE-Culvert)), all locations on the eastern side of Swan Lake, exceeded the CSR IW upper cap of 100 mg/l. Three locations (FS-43, FS-43 (SW), and MW-1), all on the north end of Swan Lake exceeded the CSR DW upper cap of 250 mg/l.

FS-43(SW) Greenhow Creek exceeded the CCME AL guideline for chloride (Table 9).

These exceedances are indication of intensive anthropogenic input at the east and even more so at the north end of Swan Lake. Section 4.3, below, provides estimates of chloride loading into Swan Lake, based on land-use practices surrounding the lake. Figure 6 shows the spatial distribution of the maximum concentrations of chloride sampled in 2015, around the perimeter of Swan Lake.

4.2.2.6 Sodium (dissolved)

Sodium exceeded the CSR DW upper cap concentrations of 200 mg/l at three locations around the lake. Two of the locations were foreshore sites (east side - FS-15 and northwest side - FS-21) and one groundwater site at the north end of the lake at MW-1. Again, MW-3 represents ambient groundwater in the vicinity of the site at below 16 mg/l. Figure 8 shows the spatial distribution of the maximum concentrations of sodium sampled in 2015, around the perimeter of Swan Lake.

4.2.2.7 Fluoride

Fluoride exceeded CSR upper cap concentrations at five locations (FS-3, FS-15, FS-33, FS-45, and FS-101). All but FS-101 were foreshore locations located on the east or north perimeter of the lake. The five locations are all above the CSR LW upper cap of 1 mg/l and FS-15 and FS-3 are above the CSR DW upper cap of 1.5 mg/l. Note that the CSR LW standard can vary with type of livestock and the actual standard should be decided after consulting with a BC ministry director. Figure 12 shows the spatial distribution of the maximum concentrations of fluoride sampled in 2015, around the perimeter of Swan Lake.

Surface water sites FS-43 (Greenhow Creek), Site 3, Site 5, Swan Lake and Vernon Creek all exceeded the CCME AW of 0.12 mg/L, which is the interim guideline for the protection of freshwater aquatic life for total inorganic fluorides.

There are anthropogenic sources of fluoride, such as agricultural fertilizers (contaminated rock-phosphate fertilizer), industrialization, and urbanization. High fluoride concentrations in Okanagan groundwater are typically associated with crystalline rocks containing fluorine-rich minerals, especially granites and volcanic rocks. Further, shallow aquifers in arid areas experience strong cyclic evaporation, which can increase fluoride concentrations. At this point, the origin of excessive fluoride at FS-15 an FFS-3 is unclear. Likely, there is naturally occurring fluoride, as a result the local surficial geology. However, FS-15 and FS-3 show elevated electrical conductivity, chloride, sodium, and sulphate; parameters associated with anthropogenic input. Further sampling will help provide a statistically based assessment which could aid in clarification of fluoride source.

4.2.2.8 Water Quality Exceedances that are Likely Naturally Occurring

4.2.2.8.1 Molybdenum (dissolved)

Molybdenum exceeded CSR IW upper cap concentrations of 0.01 mg/l at four foreshore locations (FS-3, FS-15, FS-32, and FS-45) and at surface water locations (FS-101 and FS-104). The CSR LW upper cap concentration of 0.05 mg/l was exceeded at only one location (FS-15).

4.2.2.8.2 Selenium (dissolved)

Selenium exceeded all of the CSR upper cap concentrations at FS-15 and all but the CSR LW upper cap at surface water location FS-104.

4.2.2.8.3 Magnesium (dissolved) and Manganese (dissolved)

Magnesium exceeded CSR DW upper cap of 100 mg/l at five foreshore locations (four on the east shore-FS-3, FS-15, FS-31, FS-32 and one on the west shore -FS-21) and one groundwater location (MW-1).

Manganese exceeded CSR IW upper cap concentration of 0.2 mg/ l at three foreshore locations (FS-32, FS-28, and FS-45) and exceeded the CSR DW upper cap of 0.55 mg/l at four foreshore locations (FS-3, FS-31, FS-21 and FS-29) and one groundwater location (MW-1).

Table 7: Exceedances of Contaminated Site Regulation Standards, by Parameter

Location Relative to Swan Lake	Type of Sample	Sampled Locations	Ammonia (total, as N)	Sulphate	Uranium (dissolved)	Chloride	Sodium (dissolved)	Fluoride	Magnesium (dissolved)	Manganese (dissolved)	Molybdenum (dissolved)	Selenium (dissolved)
East	FS	FS-3		X	X	X		X	X	X	X	
		FS-15		X	X	X	X	X	X		X	X
		FS-31	X			X			X	X		
		FS-32	X		X	X			X	X	X	
		FS-33				X		X				
		FS-45			X			X		X	X	
	SW	FS-101			X			X			X	
		FS-103			X	X						
		FS-104			X						X	X
		Site 5 (NE Culvert)				X						
North	FS	FS-43		X	X	X						
	SW	FS-43 (SW)			X	X						
	GW	MW-1		X	X	X	X		X	X		
West	FS	FS-21			X		X		X	X		
		FS-28			X					X		
		FS-29	X	X	X					X		

Note, there are no water quality exceedances for the background (ambient groundwater) at MW-3.

Table 8: Exceedances in Upper Cap for Contaminated Site Regulation, by Standard

Location Relative to Swan Lake	Type of Sample	Sampling Location	Guideline	Exceedances
EAST	FS	FS-3	BC CSR AW	Sulphate
			BC CSR IW	Chloride, Fluoride, Manganese (dissolved), Molybdenum (dissolved), Uranium (dissolved)
			BC CSR LW	Fluoride, Sulphate
			BC CSR DW	Fluoride, Magnesium (dissolved), Manganese (dissolved), Sulphate, Uranium (dissolved)
		FS-15	BC CSR AW	Selenium (dissolved)
			BC CSR IW	Chloride, Fluoride, Molybdenum (dissolved), Selenium (dissolved), Uranium (dissolved)
			BC CSR LW	Fluoride, Molybdenum (dissolved), Selenium (dissolved), Uranium (dissolved)
			BC CSR DW	Chloride, Fluoride, Magnesium (dissolved), Selenium (dissolved), Sodium (dissolved), Sulphate, Uranium (dissolved)
		FS-31	BC CSR AW	Ammonia (total, as N)
			BC CSR IW	Chloride, Manganese (dissolved)
			BC CSR DW	Magnesium (dissolved), Manganese (dissolved)
		FS-32	BC CSR AW	Ammonia (total, as N)
			BC CSR IW	Chloride, Manganese (dissolved), Molybdenum (dissolved), Uranium (dissolved)
			BC CSR DW	Magnesium (dissolved)
		FS-33	BC CSR IW	Chloride, Fluoride
			BC CSR LW	Fluoride
		FS-45	BC CSR IW	Fluoride, Manganese (dissolved), Molybdenum (dissolved), Uranium (dissolved)
			BC CSR LW	Fluoride
			BC CSR DW	Uranium (dissolved)

	SW	FS-101	BC CSR IW	Fluoride, Molybdenum (dissolved), Uranium (dissolved)
			BC CSR LW	Fluoride
		FS-103	BC CSR IW	Chloride, Uranium (dissolved)
		FS-104	BC CSR AW	Selenium (dissolved)
			BC CSR IW	Molybdenum (dissolved), Selenium (dissolved), Uranium (dissolved)
			BC CSR DW	Selenium (dissolved)
		Site 5 (NE-Culvert)	BC CSR IW	Chloride
NORTH	FS	FS-43	BC CSR AW	Sulphate
			BC CSR IW	Chloride, Uranium (dissolved)
			BC CSR LW	Sulphate
			BC CSR DW	Chloride, Sulphate
	SW	FS-43 (SW)	BC CSR IW	Chloride, Uranium (dissolved)
	GW	MW-1	BC CSR AW	Sulphate
			BC CSR IW	Chloride, Manganese (dissolved), Uranium (dissolved)
			BC CSR LW	Sulphate
			BC CSR DW	Chloride, Magnesium (dissolved), Manganese (dissolved), Sodium (dissolved), Sulphate, Uranium (dissolved)
WEST	FS	FS-21	BC CSR IW	Manganese (dissolved), Uranium (dissolved)
			BC CSR DW	Magnesium (dissolved), Sodium (dissolved), Uranium (dissolved)
		FS-28	BC CSR IW	Manganese (dissolved), Uranium (dissolved)
			BC CSR DW	Uranium (dissolved)
		FS-29	BC CSR AW	Ammonia (total, as N), Sulphate
			BC CSR IW	Manganese (dissolved), Uranium (dissolved)
			BC CSR LW	Sulphate
			BC CSR DW	Manganese (dissolved), Sulphate, Uranium (dissolved)

Note, there are no exceedances for the background (ambient groundwater) at MW-3.
Water Quality Standards Compared:

BC CSR AW	BC CSR, Schedule 6, Generic Numerical Water Standards for Freshwater Aquatic Life
BC CSR DW	BC CSR, Schedule 6 and 10, Generic Numerical Water Standards for Drinking Water
BC CSR IW	BC CSR, Schedule 6, Generic Numerical Water Standards for Irrigation
BC CSR LW	BC CSR, Schedule 6, Generic Numerical Water Standards for Livestock

Table 9: Exceedances in Provincial and Federal Aquatic Life Guidelines for Surface Waters Sampled in 2015

Sampling Location	Guideline	Exceedances
FS-43 (SW) Greenhow Creek	BCWWQG AL	Uranium (dissolved)
	CCME AL	Chloride, Fluoride, Uranium (dissolved)
Site 3 (NE-Cowboys)	CCME AL	Fluoride
Site 5 (NE-Culvert)	CCME AL	Fluoride, Nitrate (as N), Nitrate + Nitrite (as N) (calculated), pH [F]
Swan Lake	BCAWQG AL	Temperature [F]
	CCME AL	Fluoride
Vernon Creek (Outlet of Swan Lake)	BCAWQG AL	Temperature [F]
	CCME AL	Fluoride

[F] = Field Result(s)

Table 9 - Water Quality Guidelines Compared:

BCAWQG AL	BC Approved Water Quality Guidelines for freshwater aquatic life
BCWWQG AL	Working Water Quality Guidelines for British Columbia for freshwater aquatic life
CCME AL	Canadian water quality guidelines for the protection of freshwater aquatic life

4.2.3 Quality Control / Quality Assurance of Water Quality Data

The quality control/quality assurance for this project consisted of the following components:

- Field data was digitized and then reviewed prior to input into the water quality database
- A triplicate sample was taken at FS-15 on March 29, 2016 and the relative standard deviation was below 20% for all parameters above detection limits; except for antimony, cadmium and nitrate, at 21.7%, 33.3%, and 36.5%, respectively and these were all close to detection limits. See Appendix A for replicate sampling analysis; and
- Use of a Database Manager, where the data is stored and can be queried.

Quality of data will not affect study conclusions.

4.3 Land Use Inventory and Mass Flux of Anthropogenic Impact Indicators

Since chloride is a conservative ion, not subject to biological or geochemical sequestering and is derived primarily from human activity, it can be used as a measure of anthropogenic impact on the environment. The following section focuses on apportioning of chloride and other nutrients (sulphate) by land use as a means of quantifying the relative impact each land use category could have on water quality in Swan Lake. The apportioning of chloride was estimated by two methods. The first estimation method was based on assigning chloride mass flux values to land use and the second estimate of chloride mass flux was based on groundwater discharge to the lake and concentrations of chloride physically measured during the foreshore sampling for this project. The chloride flux estimate are first order approximations and assumptions for the calculations are stated.

4.3.1 Chloride Loading Based on Land Use Practices

The following section presents the apportioning of chloride to the various land uses classified around Swan Lake. As mentioned earlier, these land uses include the following categories: Agricultural Lands, Residential, Industrial, and Roadways surrounding Swan Lake (Figure 1). These main categories were then subdivided further into more specific land-uses that are described below and Table 10, below summarizes the chloride loading from the various land uses.

Road Salts

Standard road salt applications for British Columbia are between 60 to130 kilograms/kilometer for a two lane highway with the average of 42.5 kg/lane/km. Average conditions for application include early day application, when the surface temperature is -4°C and rising under snow, sleet or freezing rain conditions (Ministry of Environment, 1998). For the purpose of this study it was assumed that application only occurred on days that received greater than 5 cm of snow. Based on these calculations and assumptions an estimated total of **21,384 kg/year** of chloride is introduced to the ground surface and roadside ditches from road salting. It should be noted that in the northeast end of Swan Lake there is a road salt storage facility with a storage capacity of 1000 m^3.

Upon inspection it was noted that there is large evidence of brine runoff into infiltration pits as well as adjacent ditches. Although, it was not possible to investigate further into this matter due to property access restriction, this potential source of chloride contamination should be further assessed in the future. It could be seen, from off-site, that potential monitoring wells do exist on the salt-storage site and have likely been sampled in the past. Access to this data would help to improve the value of this study.

Agriculture

The four main subcategories for agriculture derived chloride around Swan Lake include the following: cherry and apple orchards, corn crops, irrigated grasslands, and hobby farms. The average chloride input from agricultural practices is estimated at 5,392 kg/km^2 (Mullaney, et al. 2009). Using satellite imagery and site visits the total area around Swan Lake used for the different types of agriculture was estimated at 12.7 km^2. Using these simplified estimates, agricultural practices potentially contribute a total of **65,633 kg/year** of chloride to the land.

Residential

The residential contribution of chloride to Swan Lake was estimated using the average loading of septic effluent per lot or unit, with a chloride concentration of 70 mg/l and the total area of all the different residential subdivisions (Katz, *et al.* 2011). It was assumed that all the residences were using septic fields as effluent disposal since they are not connected to the City of Vernon infrastructure and that the condition of the septic systems varies greatly depending on age. In total, an estimate of 780 units (or homes with septic fields) in the area was made, contributing approximately **3,739 kg/year** of chloride to the soil.

Industrial

Industrial inputs for the desktop study were based on the average amount of effluent produced per employee per day and standard concentrations of chloride (70 mg/l) obtain from previously completed studies (Katz, *et al.* 2011). Based on averages obtained from several of the larger industrial outfits in the area, we estimated 500 employees work full time in the area, amounting to **703 kg/year** of potential chloride input to septic fields and holding tanks. Note that several properties east of Swan Lake have holding tanks which are pump and haul systems and the Christian school has a sand mound type system.

Bio-Solids Disposal Facility

There is a bio-solid disposal site located approximately 0.5 km north of Swan Lake. Unfortunately, very little is known about the Operational Permit associated with this facility or the influence that the operation may have on the near-surface groundwater or downgradient surface water (Swan Lake). Inquiries were made by WWAL staff to the B.C. Ministry of Environment; however, no information was made available regarding the permit. We recommend further inquiry be made into whether groundwater monitoring downgradient of the facility is occurring. Despite this lack of information, operation of the bio-solids disposal facility is an important part of the chloride and nutrient balance of Swan Lake and is a data gap in the current study and should be considered further.

Table 10: Summary of Potential Chloride Loading into Swan Lake Estimated from Land Use .

	Total Area (km2)/ Length (km)	Number of Homes/ units/Employees	Concentration NaCl/Loading Rates	Chloride Loading (kg/yr)	Chloride loading (% of Total)
Roads/Highways	26.5		42 (kg/lane/km/snowday)	**21384**	**23**
Agricultural			5393 (kg/km2)		
Apple/Cherries	2.63		5394 (kg/km2)	14184	16
Corn	1.49		5395 (kg/km2)	8036	9
Irrigated Grasslands	2.54		5396 (kg/km2)	13698	15
Hobby Farms	5.51		5397 (kg/km2)	29715	32
Total	12.17		5398 (kg/km2)	**65633**	**72**
Residential					
Trailer Parks/Camping	0.1	269	1.3 kg/unit/year)	349.7	0
Country residential	1.44	498	6.77 kg/unit/year)	3371.46	4
Total	1.55	767		**3721**	**4**
Industrial	0.43	500	70 mg/l at 55 liters/day	**703**	**1**
Natural Grasslands	6.39			Retention	
Wetlands	1.25			Retention	
Total Chloride loading (kg/yr)				**91,441**	**100**

Chloride is associated with almost all land use around Swan Lake. Based on land use, a total of 91,441 kg of chloride (more than 90 metric tonnes) is estimated to be introduced to the land around Swan Lake every year. Without considering the bio-solids processing facility at the north end of the lake, the greatest source of chloride is apportioned to agricultural practices. With agricultural land use accounting for an estimated 65,633 kg/year or 72% of the total. More specifically, hobby farms may contribute 29,715 kg/year or 32% of the overall loading of chloride to the lake. This is followed by orchards and irrigated grassland, contributing 16% and 15%, respectively. The next largest contribution of chloride is estimated to be coming from road salting. Road salt amounts to 21,384 kg/year or 23% of the total chloride loading to the lake. To a lesser extent, residential areas and industrial practices contribute an estimated 4 % and 1%, respectively.

4.3.2 Chloride Loading Based on Groundwater Discharge and Water Quality

The lithology beneath Swan Lake is characterized as being a layered sequence of sediments. At the surface there is an unconfined sand and gravel aquifer with a saturated thickness of about 13 metres, underlain by a clay aquitard. Below this lies a deep, confined 40 to 60 meter thick sand and gravel aquifer (Golder and Summit, 2009). For the purposes of this study it is assumed that only the top 4 meters of the upper, unconfined aquifer is interacting with Swan Lake. The 'Swan Lake' Aquifer covers 6.28 km^2 and has an average hydraulic gradient (i) of 0.1 with an estimated hydraulic conductivity (k) of 1×10^{-5} m/s. The length of aquifer that is assumed to interact with Swan Lake is about 4,200 meters (OBWB 2009 and Smerdon 2009). The primary flow direction of the groundwater within the aquifer is from the east and a smaller portion from the north (OBWB 2009). Approximately 500 m north of Swan Lake a bedrock outcrop acts as a groundwater divide and is assumed to be a groundwater no-flow boundary separating the Swan Lake Aquifer from the larger Spallumcheen aquifer, which flows from north to south entering Okanagan Lake at the head of the lake.

Well logs for wells located north of Swan Lake indicate extensive clay and silt in the upper stratigraphy and bedrock below (MoE Well Plate Numbers 18089 and 62562). However, it is likely that immediately north of the lake (0 - 200 m) there is localized groundwater flow from the north flowing into Swan Lake or beneath Swan Lake. Accurately characterizing groundwater flow from the north is challenging due to a lack of information.

Using the assumed discharge of groundwater into Swan Lake, the chloride concentrations found in the background well (MW-3), and an average of the chloride concentrations from the foreshore samples the yearly loading of chloride was calculated. As seen in Table 11 the ambient loading of chloride amounts to 8,556 kg/year, while the loading of chloride based on the foreshore samples was calculated to be 81,589 kg/year. This is a difference of 73,033 kg/year of chloride attributed to human impact.

Table 11: Summary Table of Chloride Loading based on Groundwater Discharge and Measured Water Quality Results.

Parameter	Value Used in Estimate of Cl Mass Flux
Aquifer thickness – assumed to be discharging into Swan Lake	4 m
Aquifer Length	4,200 m
Area (a)	16,800 m^2
Gradient (i)	0.1
Hydraulic Conductivity (k)	0.00001 m/s
Groundwater discharge to Swan Lake	529,800 m^3/year
Background Cl Concentration (from MW-3)	16 mg/l
Average Foreshore Cl Concentration	154 mg/l
Background Cl Loading	8,556 kg/year
Foreshore Chloride Loading	81,589 kg/year

Note: all values in Table 10 are from Golder Summit 2009, except chloride concentrations which are from the current study.

Estimating the actual chloride flux into Swan Lake based on measured concentrations of chloride at the lake's foreshore provided results within the same order of magnitude as that calculated from the land use apportioning of chloride, 82,000 kg/year compared to 91,000 kg/year, respectively.

4.3.3 Sulphate Loading Based on Land Use Practices

Recall that sulphate concentrations on the east shore of the lake at FS-3 measured over 100,000 mg/l in April 2015 and still elevated, but at a much lower concentration in July and October 2015. Due to the elevated concentration of sulphate above background (70 mg/l at MW-3), we investigated the potential sources of sulphate further. Through personal communication with a local fertilizer supplier, it was determined that sulphate is applied to the apple and cherry orchards located primarily on the east side of the lake as well as a small area at the north end. According to our conversation with a local supplier, approximately 2,445 to 4,890 kg/km^2/year of sulfur is applied in the spring (Pers. Com. Patterson, July 2015). Based on land area and the application rate we calculated an estimated loading rate of **6,428 to 12,871 kg/year** of sulfur loading to the near-groundwater on the perimeter of Swan Lake.

5. CONCLUSIONS

After completion of this preliminary land use and water quality assessment, we provide the following conclusions:

C1 Swan Lake is a mesotrophic lake located on the northern fringes of the Vernon urban area and is surrounded by largely agricultural lands, but with a major transportation corridor on its east side and localized higher density development such as RV Parks along the lake shore. A first order approximation of the Swan Lake water budget (balance) was completed and found that over 90% of the water in Swan Lake is derived from BX Creek inflow. Uncertainties remain about the water budget as we did not achieve a close balance of inputs and outputs. These uncertainties include evaporation rates, groundwater inflows, and BX Creek losses to ground prior to discharge to the lake.

C2 Water quality impacts from land use surrounding Swan Lake were assessed in 2015 through a water quality sampling program and through apportioning of chloride by land use around the lake.

C3 Foreshore waters surrounding the entirety of Swan Lake are anthropogenically impacted from upgradient land uses. From the 2015 sampling program, we see elevated levels of groundwater quality indicator parameters within foreshore waters compared to background (ambient) water quality (taken to be represented in the groundwater at MW-3). Conclusions C4 through C8 provide a summary of the most pertinent water quality results. Swan Lake is mesotrophic, moderately productive; therefore, it will act as a natural sink for metals and nutrients and other contaminants, whereas rapid flushing of the lake will result in the loss of chloride.

C4 The sampling locations at the north end of Swan Lake (FS-43, FS-43 (SW) Greenhow Creek, and MW-1) showed the highest levels of chloride compared to the other sample sites (expect at FS-15). The source of the chloride is likely from a combination of road salting, agriculture, and from the bio-solids disposal facility located north of the lake.

C5 In 2015, ammonia, a reduced state of nitrogen, was present at elevated concentrations at two foreshore (near-surface groundwater) locations at the southeast shore of Swan Lake (max 34.1 mg/l at FS-32 and max 19.4 mg/l at FS-31). Concentrations of ammonia at the two locations exceed the BC Contaminates Site Regulation (CSR) for Fresh Water Aquatic Life (AW). Both locations are thought to be affected by septic effluent.

C6 During the spring (April 2015) sampling of foreshore waters on the east, north, and southwest shores of Swan Lake, sulphate concentrations were found to be elevated. Concentrations were above 10,000 mg/l at FS-3 (east) and above 1,000 mg/l at FS-43 (north), MW-1 (north), and FS-29 (west), all of which exceed the B.C. CSR for Fresh Water Aquatic Life upper cap of 1,000 mg/l. Later in the 2015 season, these very elevated concentrations of sulphate were not present at the above mentioned locations. Land use upgradient of the foreshore consists of light industrial, commercial, residential and agricultural land; specifically, apple and cherry orchards. From personal communication with an agricultural fertilizer supplier in the area we were able to estimate the application of sulphate to the orchards above the affected east foreshore area to be on the order of 6,428 to 12,871 kg/year.

C7 Uranium was present at all but one (FS-31) foreshore water sampling locations around Swan Lake at concentrations above the B.C. CSR for Irrigations Water and Drinking Water upper caps of 0.01 and 0.02 mg/l, respectively. Based on research in other geographic areas, it is possible that the impact from land use surrounding Swan Lake (specifically input of calcium and chloride) have changed the solution chemistry of the near-surface groundwater, resulting in increased solubility of uranium present in the parent rock. Specifically, from the one sampling event, completed in the fall of 2015, we see concentrations of dissolved uranium within the foreshore (near-surface groundwater) of Swan Lake at concentrations two to three orders of magnitude above background (ambient) levels observed in the groundwater at MW-3.

C8 Nitrate, present in the drainage ditch and storm culvert waters above the east shore of Swan Lake at FS-101, FS-104, and Site 5 (NE-Culvert) were shown to be elevated at 6.56 mg/l, 9.35 mg/l and 5.98 mg/l, respectively. However, all sampled foreshore locations at the lake shoreline showed nitrate concentrations less than 1.15 mg/l. The overall reduction of nitrate from storm ditches to the foreshore water is likely the result of uptake of nutrients (nitrogen) into the riparian vegetation present along a majority of Swan Lakes east shoreline.

C9 Chloride can be used as an indicator of anthropogenic input into the environment. By apportioning chloride to the land uses surrounding Swan Lake, we estimated chloride mass loading rates and found that agricultural activities around the lake form the largest contribution to the chloride budget.

C10 The following data gaps were recognized in the current study:

- The above mentioned uncertainties with regard to the water budget;
- Unable to assess potential contribution from the bio-solids disposal facility located north of the lake due to lack information provided by government on permitted volumes or other aspects of the disposal operation; and
- BX Creek and other potentially significant surface water inputs to Swan Lake were not sampled in 2015; the program in 2015 was focused on near-surface groundwater sampling, which helped elucidate land use effects. If further water quality initiatives occur, sampling of BX Creek and other significant surface water inputs should be included.

6. RECOMMENDATIONS

Based on the conclusions of the Swan Lake area water quality and land use study completed in 2015, we provide the following recommendations:

R1 Given the on-going measured impact at FS-32, collection of wastewater from commercial and residential land uses, which surround Swan Lake, should be considered in a Master Wastewater Recovery Plan.

R2 As mentioned in the conclusions above, during the initial sampling event in April 2015 there appeared to be a segment of the east foreshore of Swan Lake that showed extremely elevated levels of sulphate, well above the B.C. CSR Aquatic Waters upper cap of 1,000 mg/l. The elevated sulphate was corroborated by excessively elevated electrical conductivity along the same shoreline. Subsequent sampling along the east shoreline during the events in July and October

2015 showed lower, yet still elevated sulphate concentrations compared to background groundwater at MW-3. Given the location of apple and cherry orchards above the east shore and the mass flux of sulphur expected from application of soil fertilizer in the spring we believe the operators of the orchard lands above the east shore of Swan Lake should create and implement Land Application Plans, which aim to reduce the input of sulphate into the near-surface groundwater along the shore of Swan Lake.

R3 Due to the input of both naturally occurring and anthropogenic derived calcium and chloride from the various land uses around Swan Lake, we believe the solubility of uranium into the foreshore waters is increased. A strategy to reduce uranium input into Swan Lake foreshore waters, with an overall reduction in anthropogenic derived calcium and chloride, should be implemented. This strategic plan to reduce calcium and chloride input should involve recommending that the various land users surrounding the lake reduce application of calcium chloride containing chemicals.

R4 We observed a notable reduction of nitrate concentrations between the ditch (and storm drainage) waters and the foreshore waters on the east side of the lake. We see that the riparian zone is effective in reducing nutrient loading to the lake. Therefore, the land owners at the perimeter of the lake should be encouraged and/or provided incentive to maintain and cultivate planting of willow and cattails within the riparian zone to help maintain water quality of Swan Lake.

R5 We recommend further inquiry be made into whether groundwater monitoring downgradient of the bio-solids facility is occurring.

R6 Complete further sampling in 2016 to substantiate or refute the results and conclusions arrived at during the 2015 program. If further sampling occurs, include metals sampling during all three annual events and include sampling at BX Creek and other significant surface water inputs into the program. Further, at the outlet of Swan Lake (sample location name - Vernon Creek) the following additional parameters should be assessed, which relate to surface water quality assessment:

- Fecal coliform;
- Enterococci;
- Escherichia coli (E. coli.);
- Suspended solids;
- Periphyton chl-a;
- Dissolved oxygen; and Turbidity.

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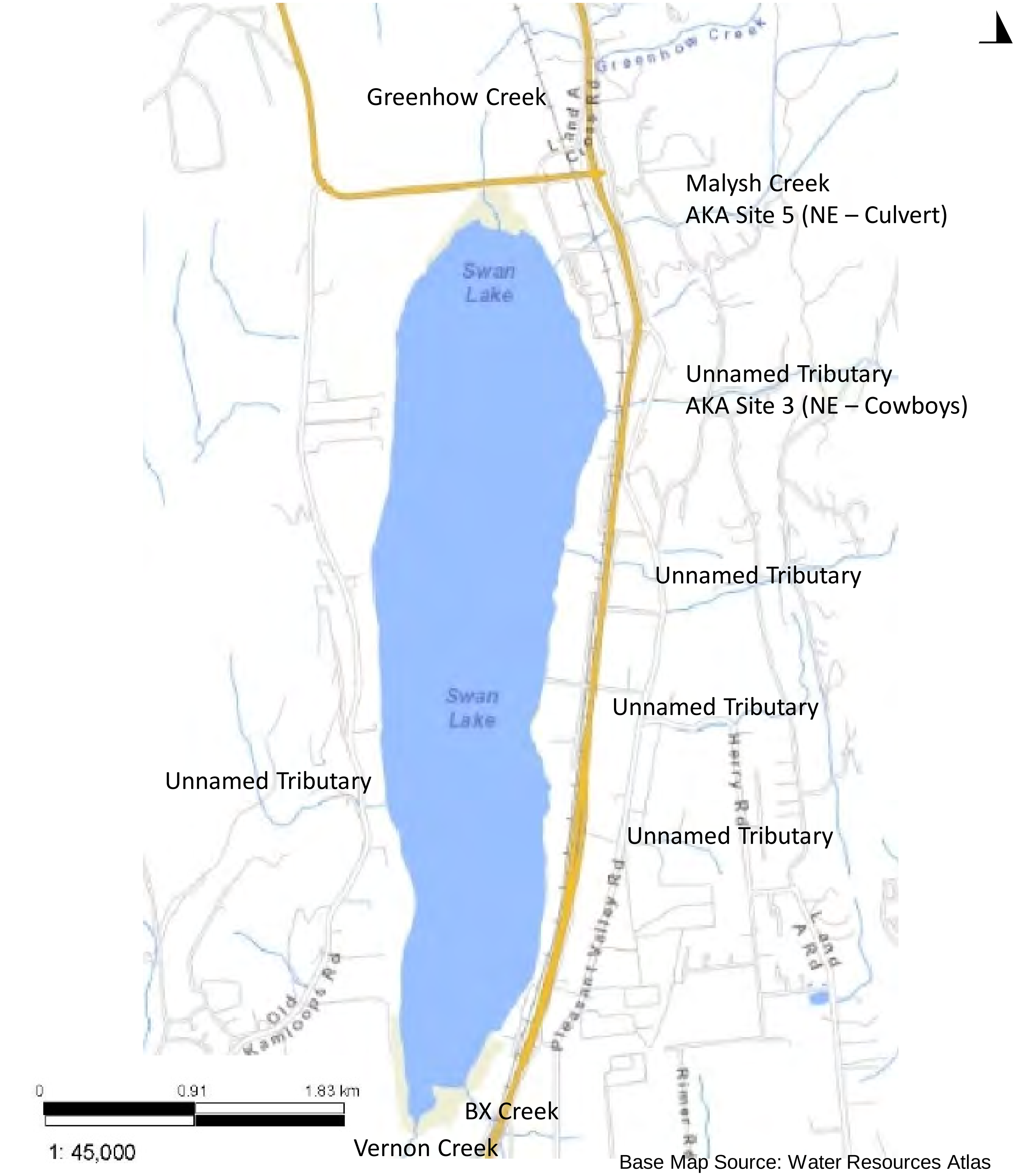
Figures



Regional District of North Okanagan	TITLE **Figure 1a:** Swan Lake Site Map.		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
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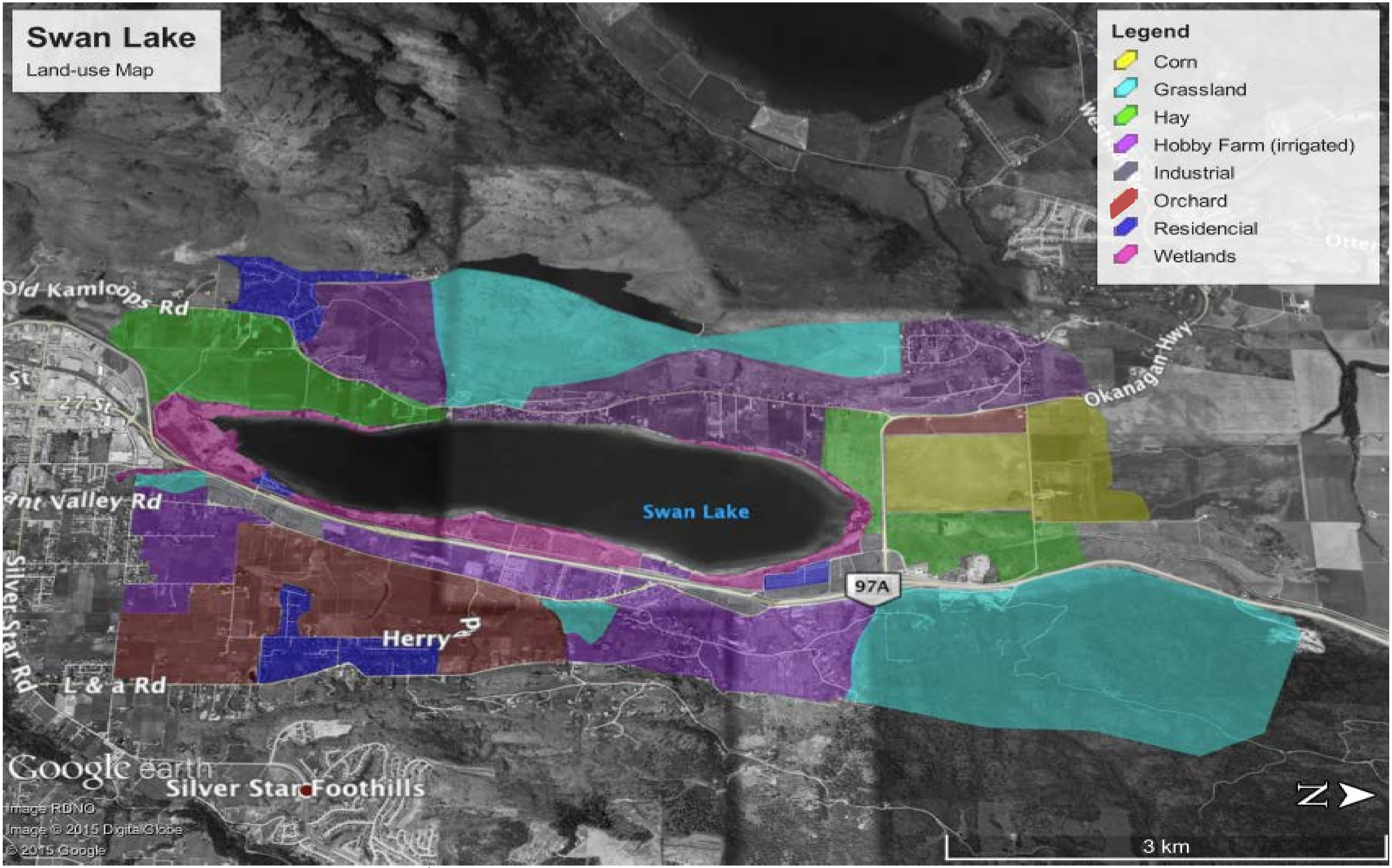

Regional District of North Okanagan	TITLE **Figure 1b:** Swan Lake with Surrounding Land Use Polygons.					
western water ASSOCIATES LTD	DRAWN	AMF	DATE	December 2015	PROJECT NO.	14-076-01
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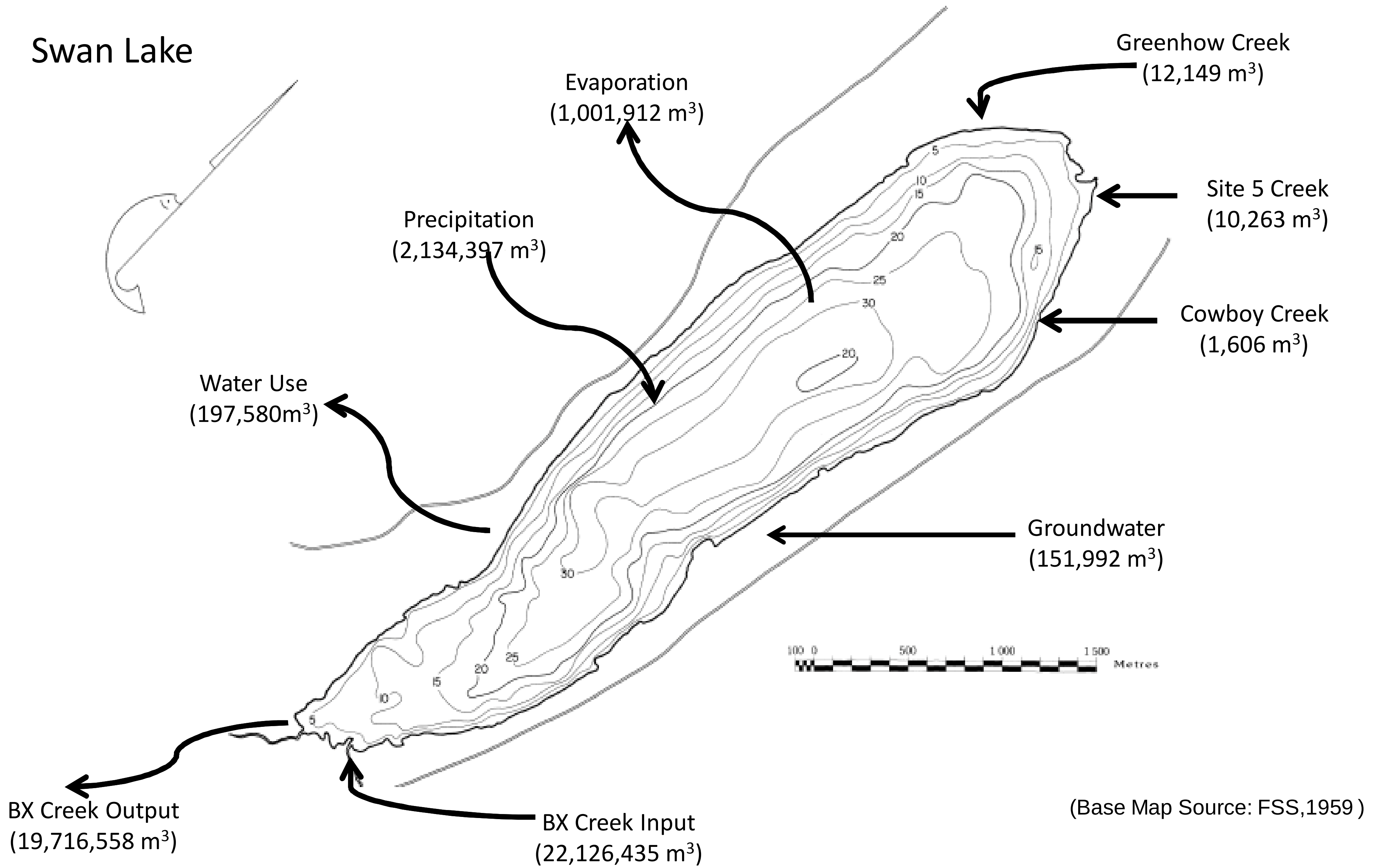

Regional District of North Okanagan	TITLE **Figure 2:** Bathymetric Map and Conceptual Water Balance.				
western water ASSOCIATES LTD	DRAWN AMF	DATE June 2015		PROJECT NO. 14-076-01	
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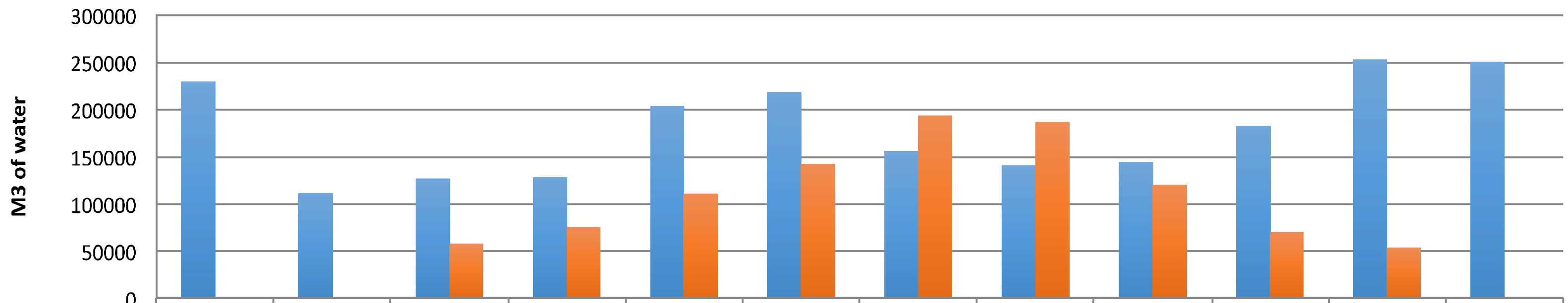
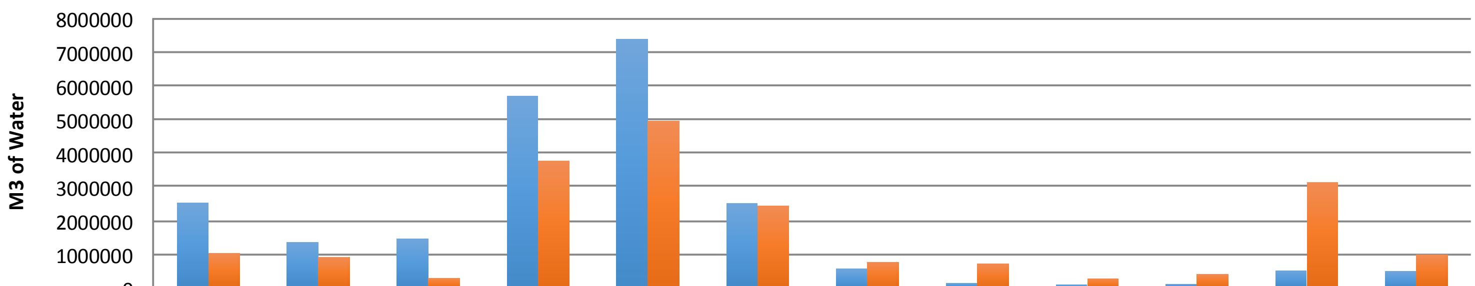
	REVIEWED	FILE NO.		FIGURE NO. 1	

Monthly Precipitation and Evaporation on Swan Lake



	Jan	Feb	March	April	May	June	July	August	September	Oct	Nov	Dec
Precip	228779	110445	125785	127100	202921	217384	155149	139810	143316	181884	252008	249816
Evaporation	0	0	56929	74318	110000	141385	192602	185575	119381	69029	52694	0

Monthly inputs and Outputs Via BX creek



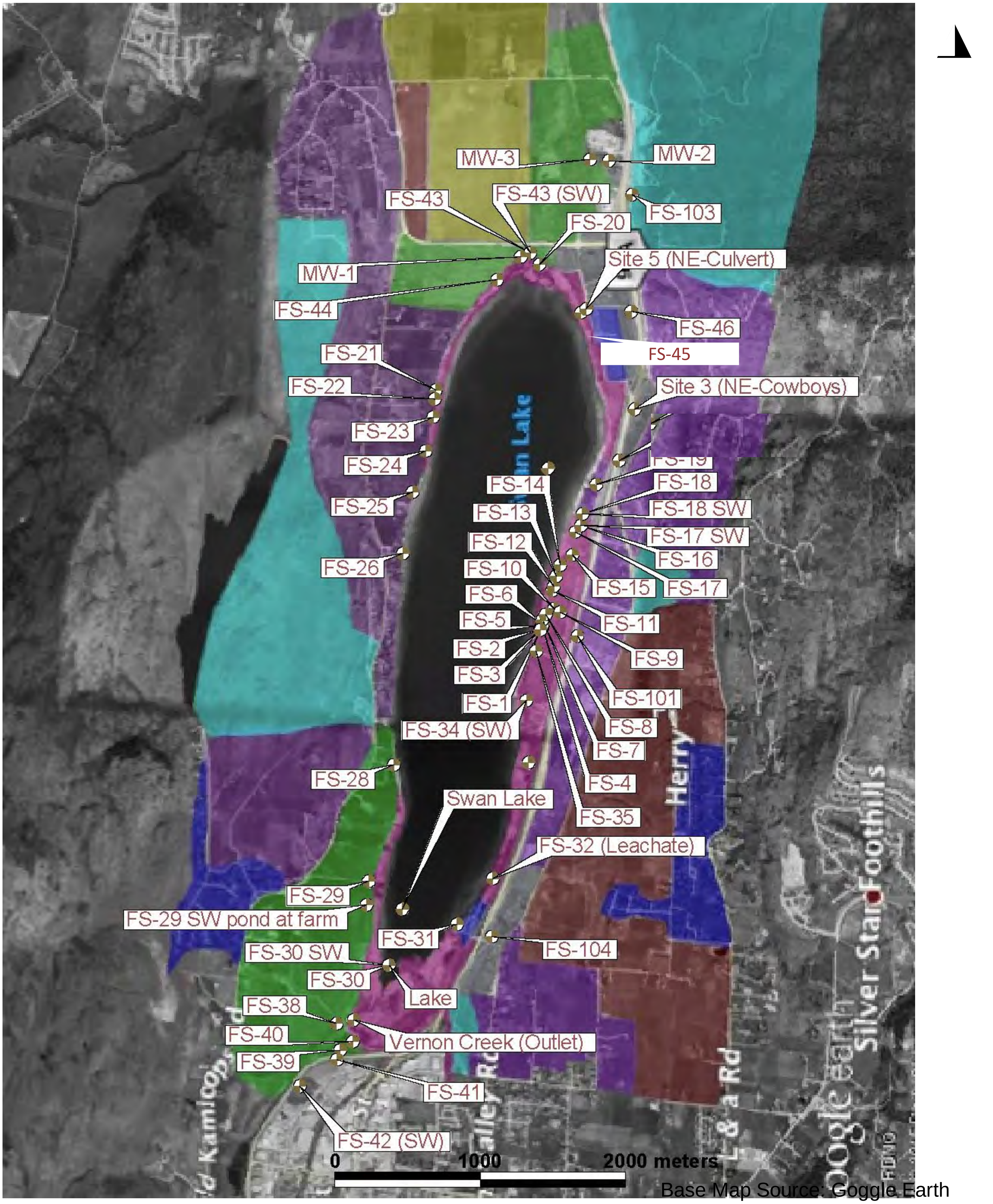
	Jan	Feb	March	April	May	June	July	August	September	Oct	Nov	Dec
Inputs from BX creek	2528409.6	1354752	1473120	5686848	7392384	2516832	567820.8	141955.2	104198.4	125884.8	526176	495504
outsputs from BX creek	1031184	914457.6	288999.36	3784320	4955040	2431036.8	771379.2	723168	274752	396403.2	3144096	1001721.6

Regional District of North Okanagan

TITLE **Figure 3:** Monthly Precipitation and Evaporation (upper), Monthly Inputs and Outputs via BX Creek.

western water associates ltd

DRAWN	AMF	DATE	June 2015	PROJECT NO.	14-076-01
CHECKED	BM	SCALE		DWG. NO.	na
REVIEWED		FILE NO.		FIGURE NO.	1



Regional District of North Okanagan	TITLE **Figure 4:** Initial Intensive Sampling Locations, Swan Lake, 2015.		
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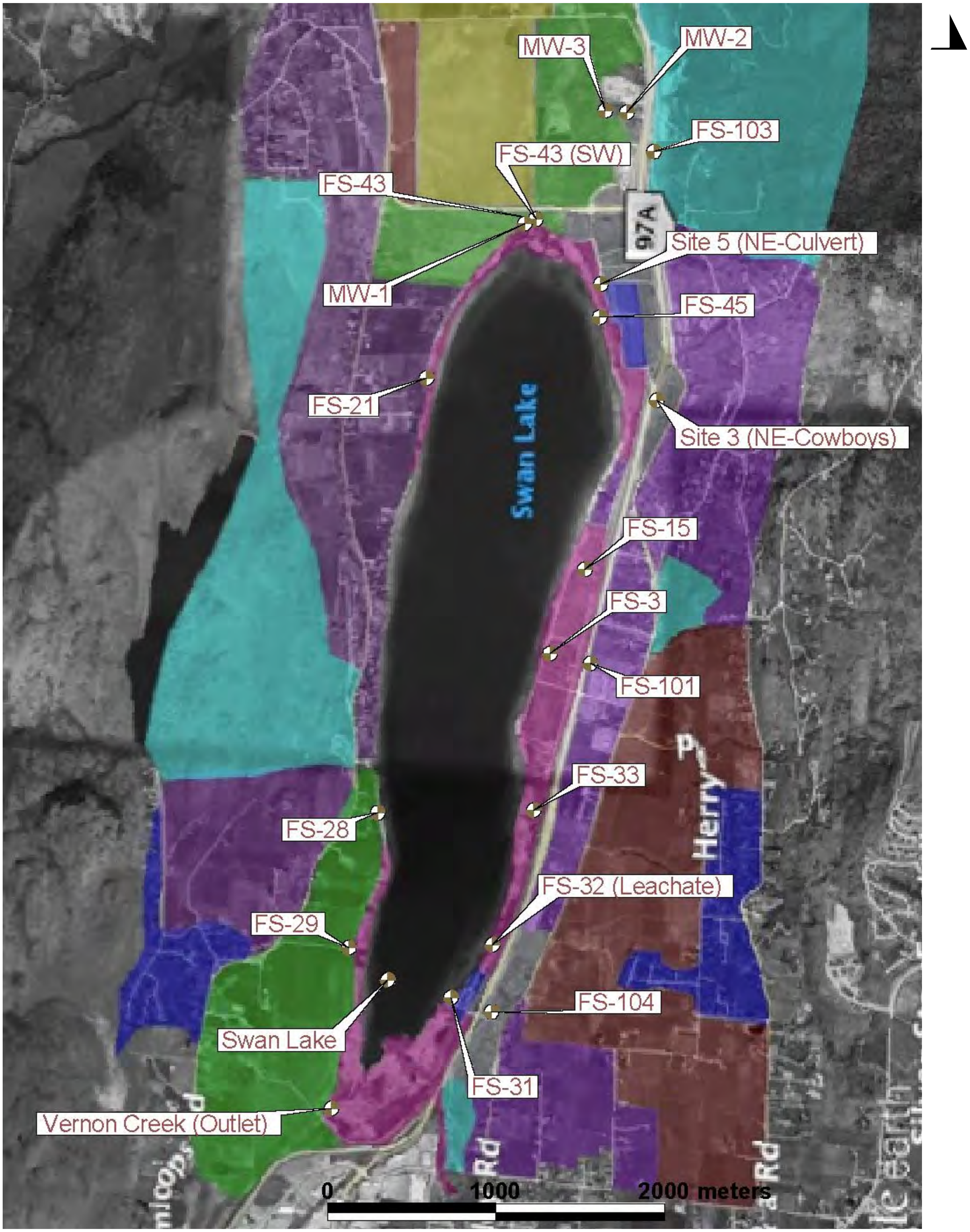
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 5:** Routine Sampling Locations, Swan Lake, 2015.					
western water ASSOCIATES LTD	DRAWN	BRM	DATE	December 2015	PROJECT NO.	14-076-01
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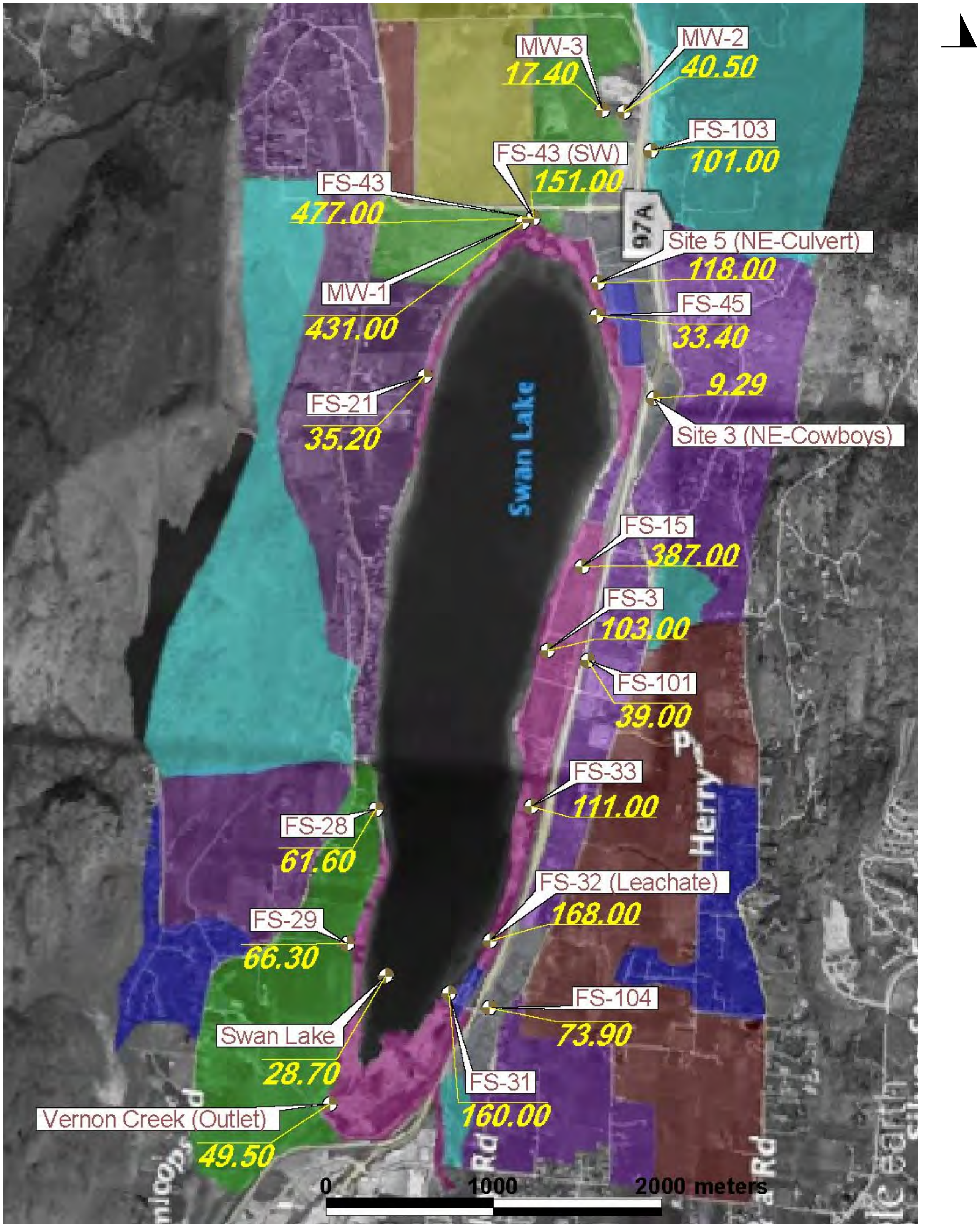
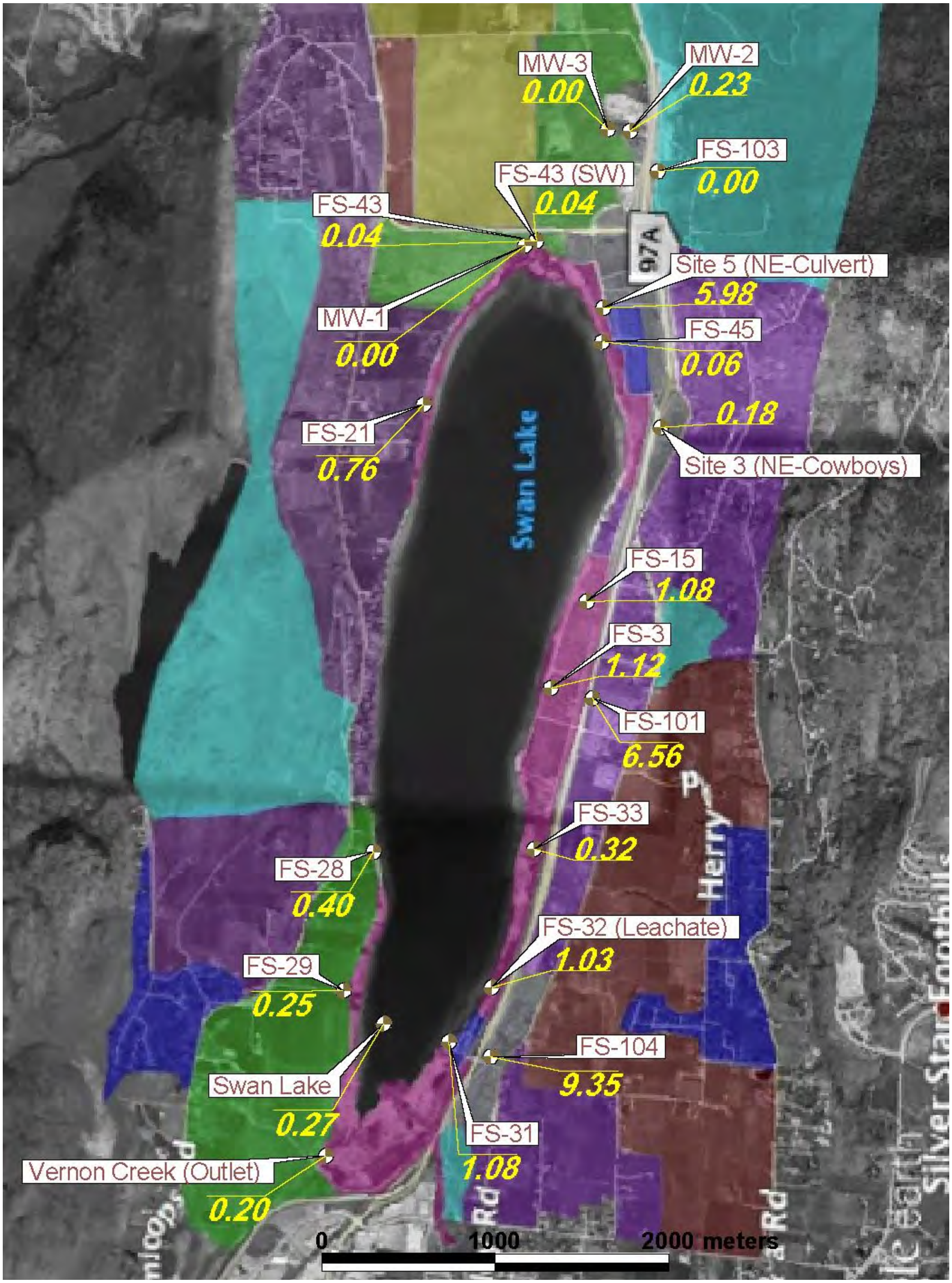
	REVIEWED	DG	FILE NO.		FIGURE REV NO.	1



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 6:** Maximum Chloride Concentrations, Swan Lake, 2015		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
	CHECKED	SCALE See Figure	DWG. NO. n/a
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 7:** Maximum Nitrate Concentrations, Swan Lake, 2015.		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
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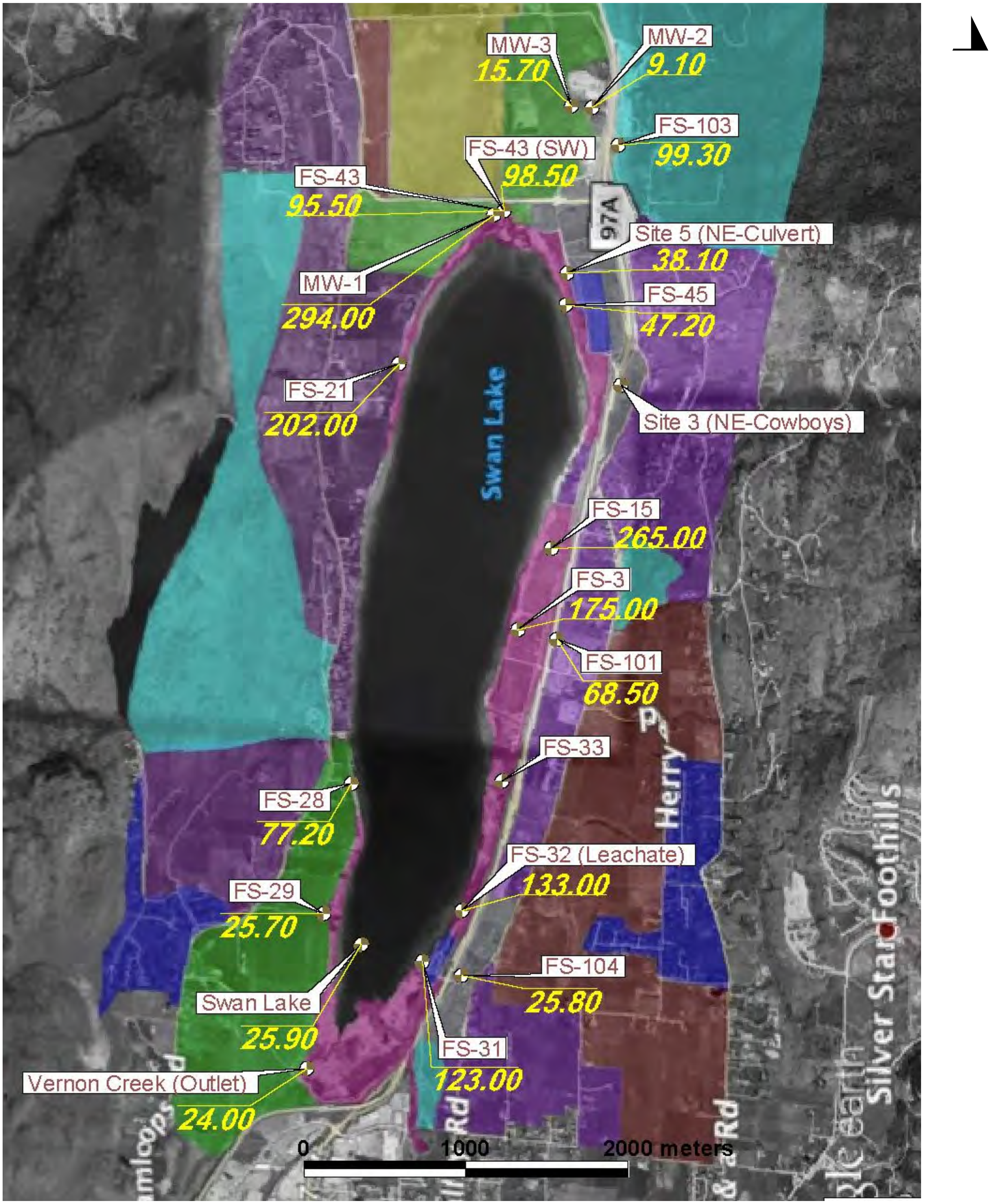
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 8:** Maximum Sodium Concentrations, Swan Lake, 2015		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
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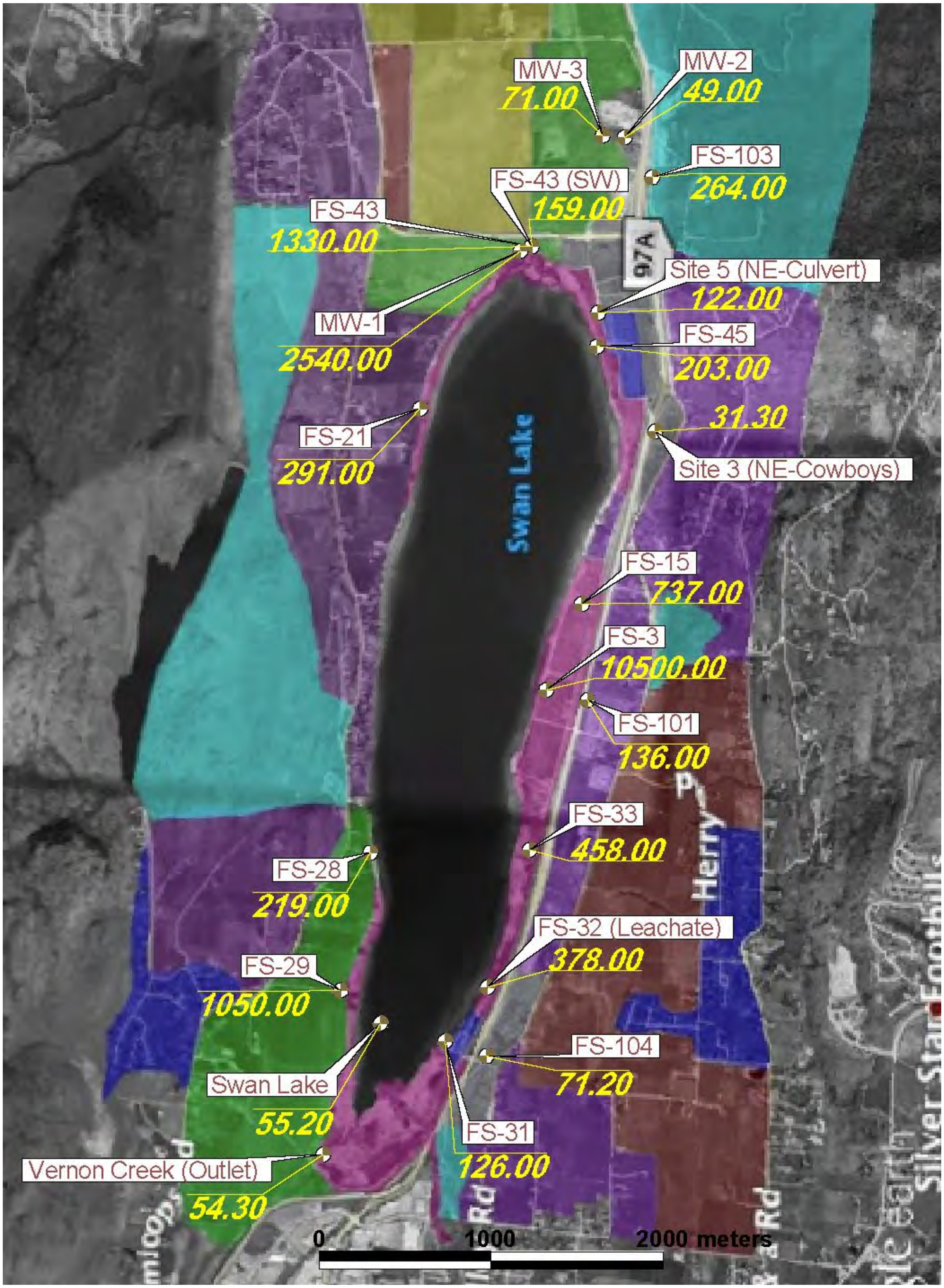
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 9:** Maximum Sulphate Concentrations, Swan Lake, 2015.				
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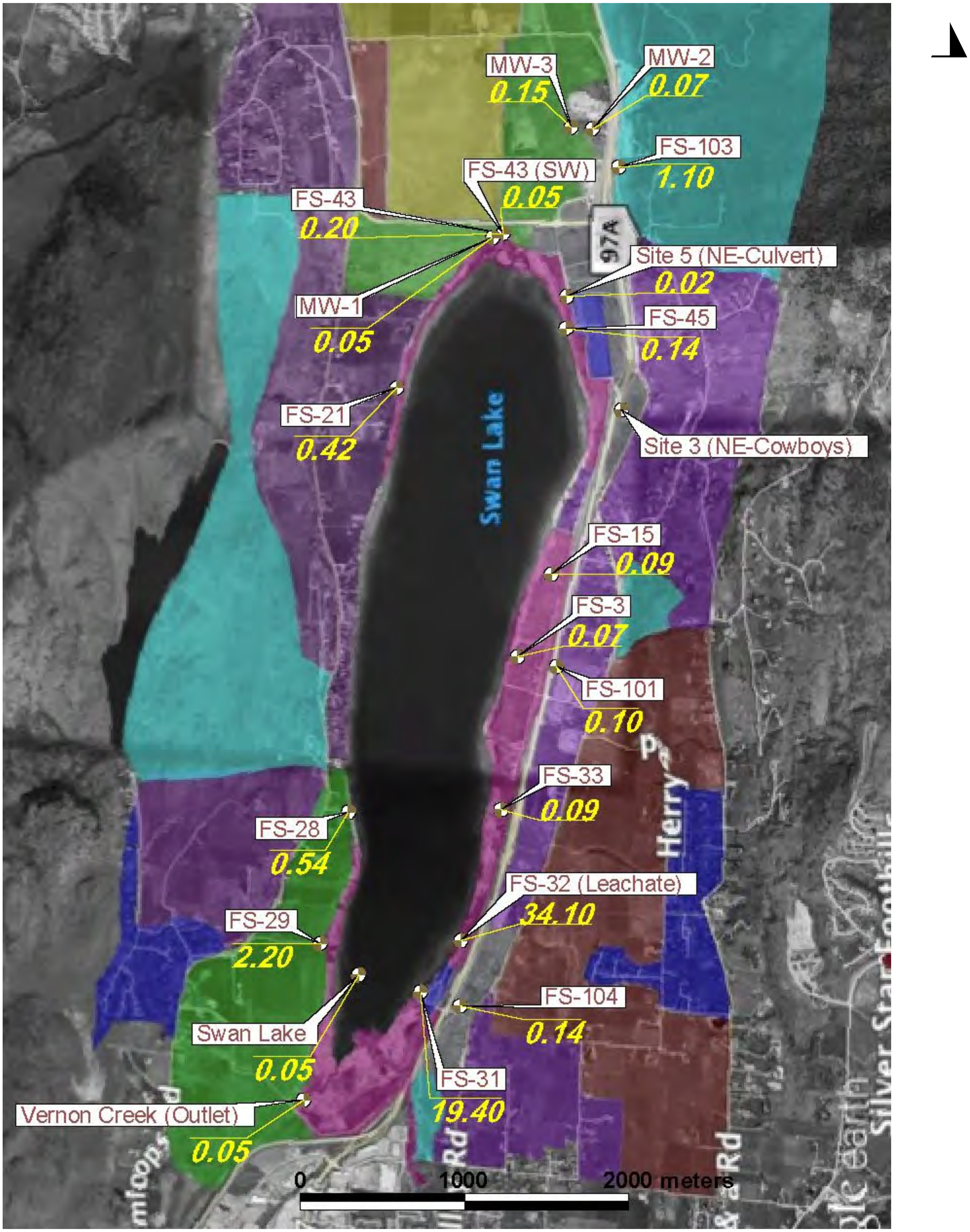
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1		



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 10:** Maximum Ammonia Concentrations, Swan Lake, 2015.		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
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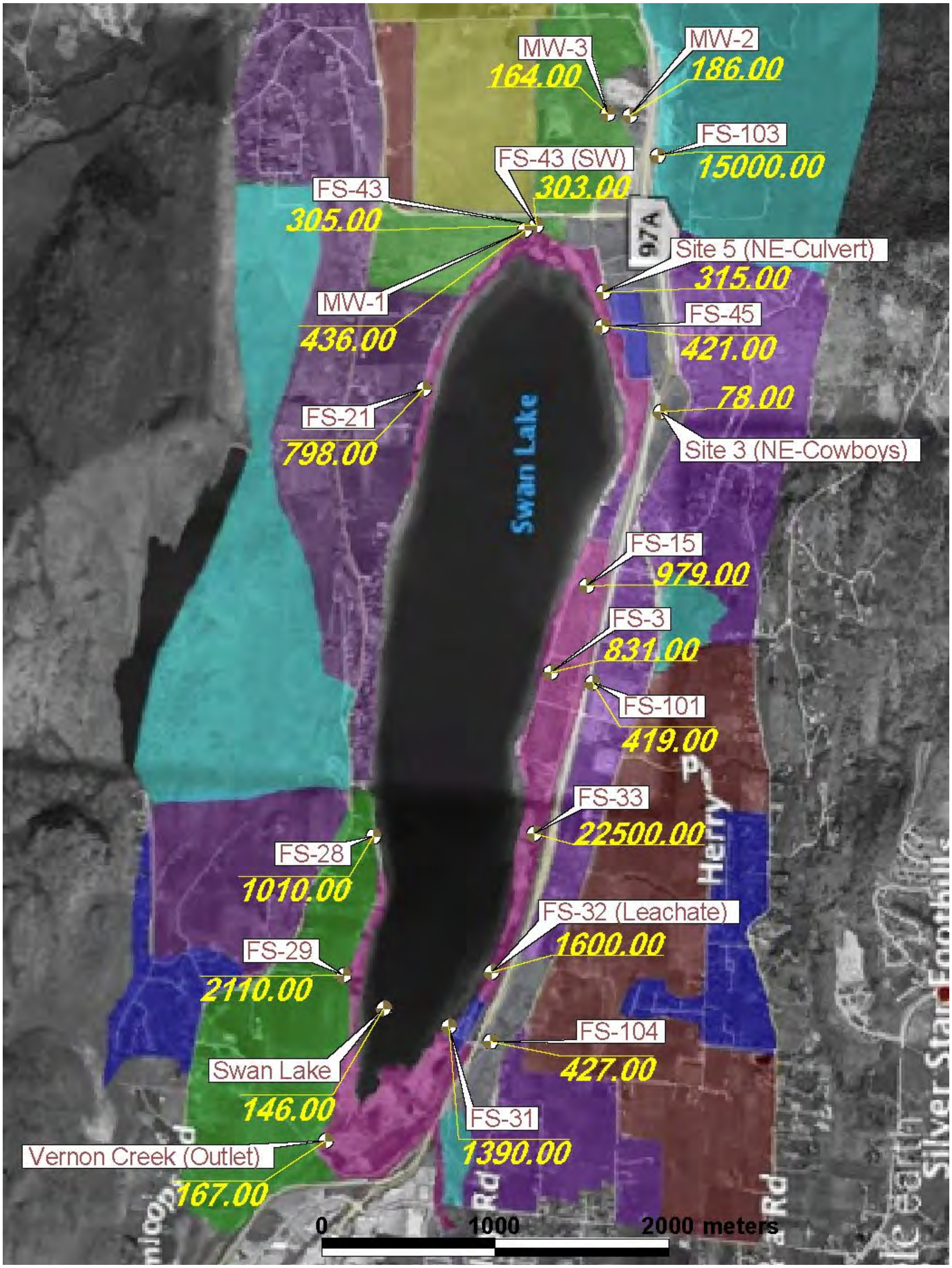
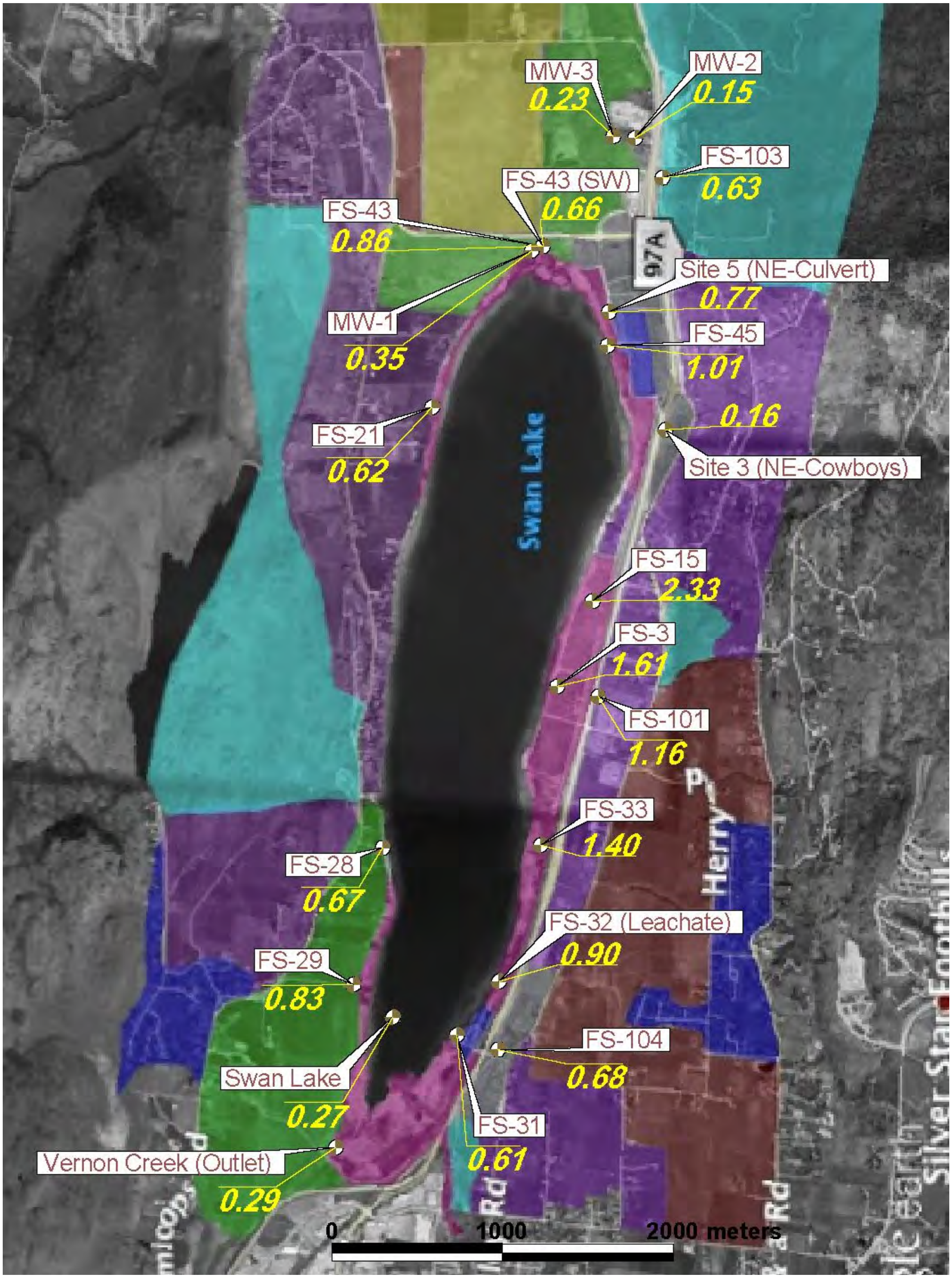
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 11:** Maximum Alkalinity Concentrations, Swan Lake, 2015.				
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01		
	CHECKED	SCALE See Figure	DWG. NO. n/a		
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1		



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Regional District of North Okanagan	TITLE **Figure 12:** Maximum Fluoride Concentrations, Swan Lake, 2015.		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
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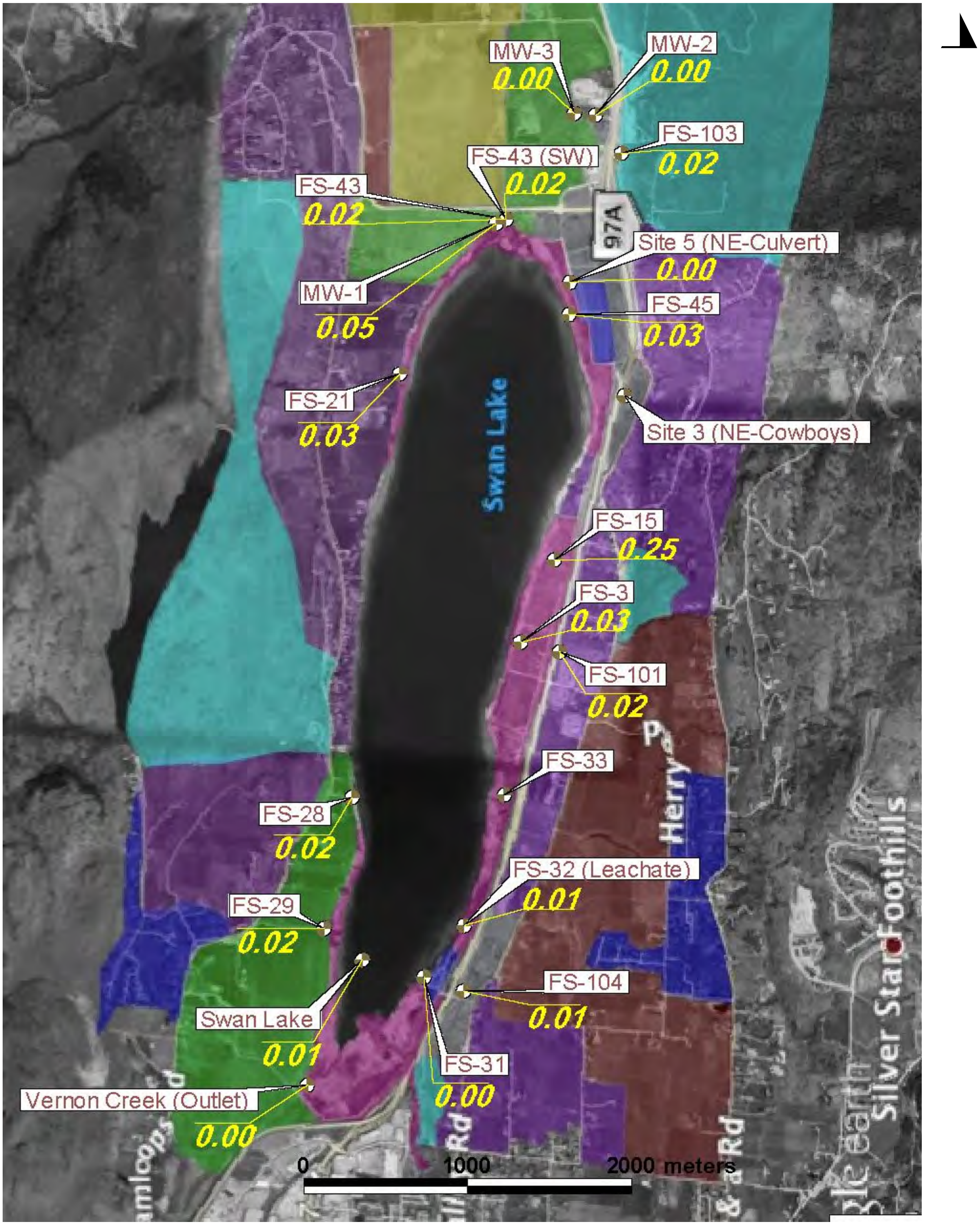
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



Base Map Source: Goggle Earth

Regional District of North Okanagan	TITLE **Figure 13:** Maximum Uranium Concentrations, Swan Lake, 2015		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
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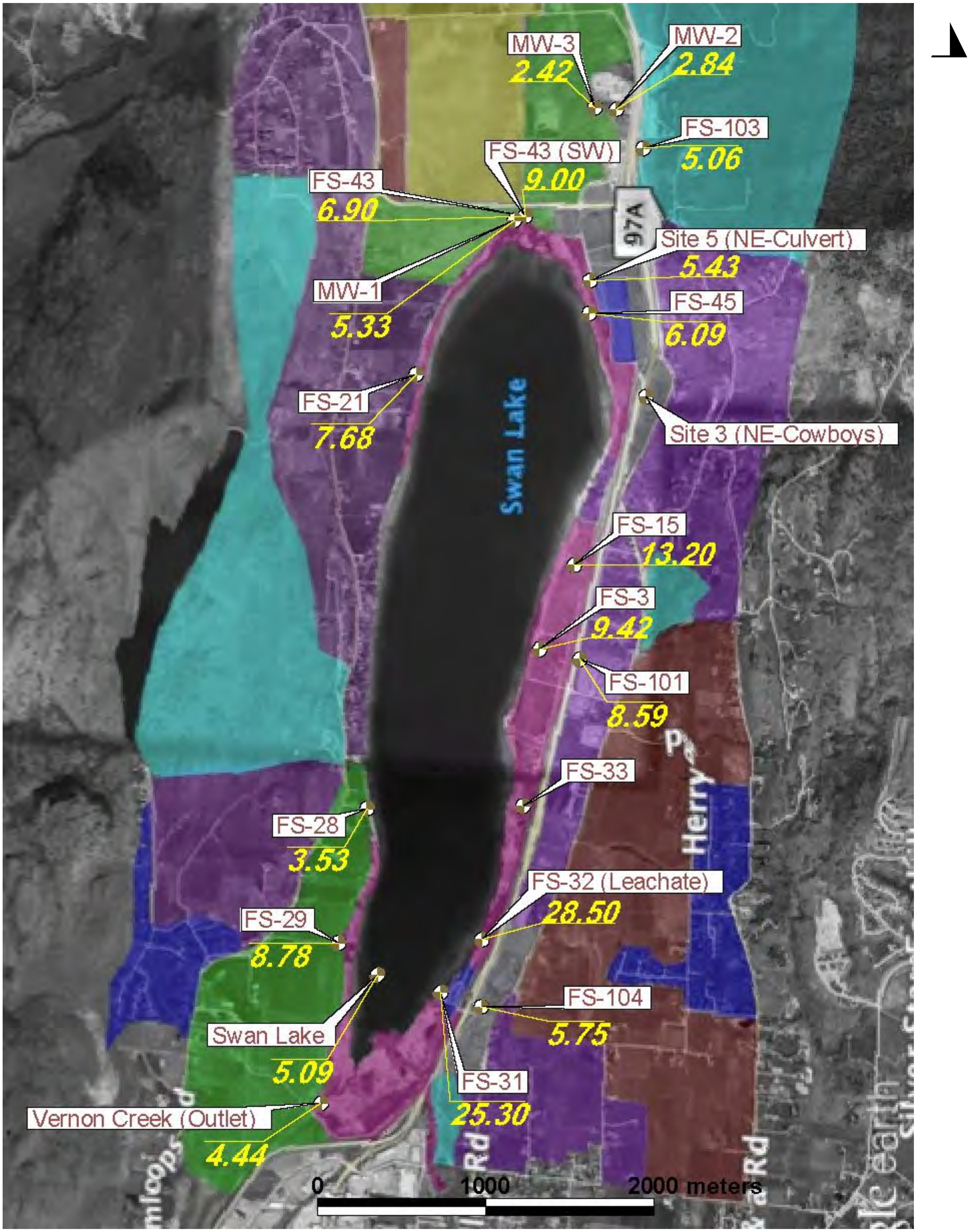
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



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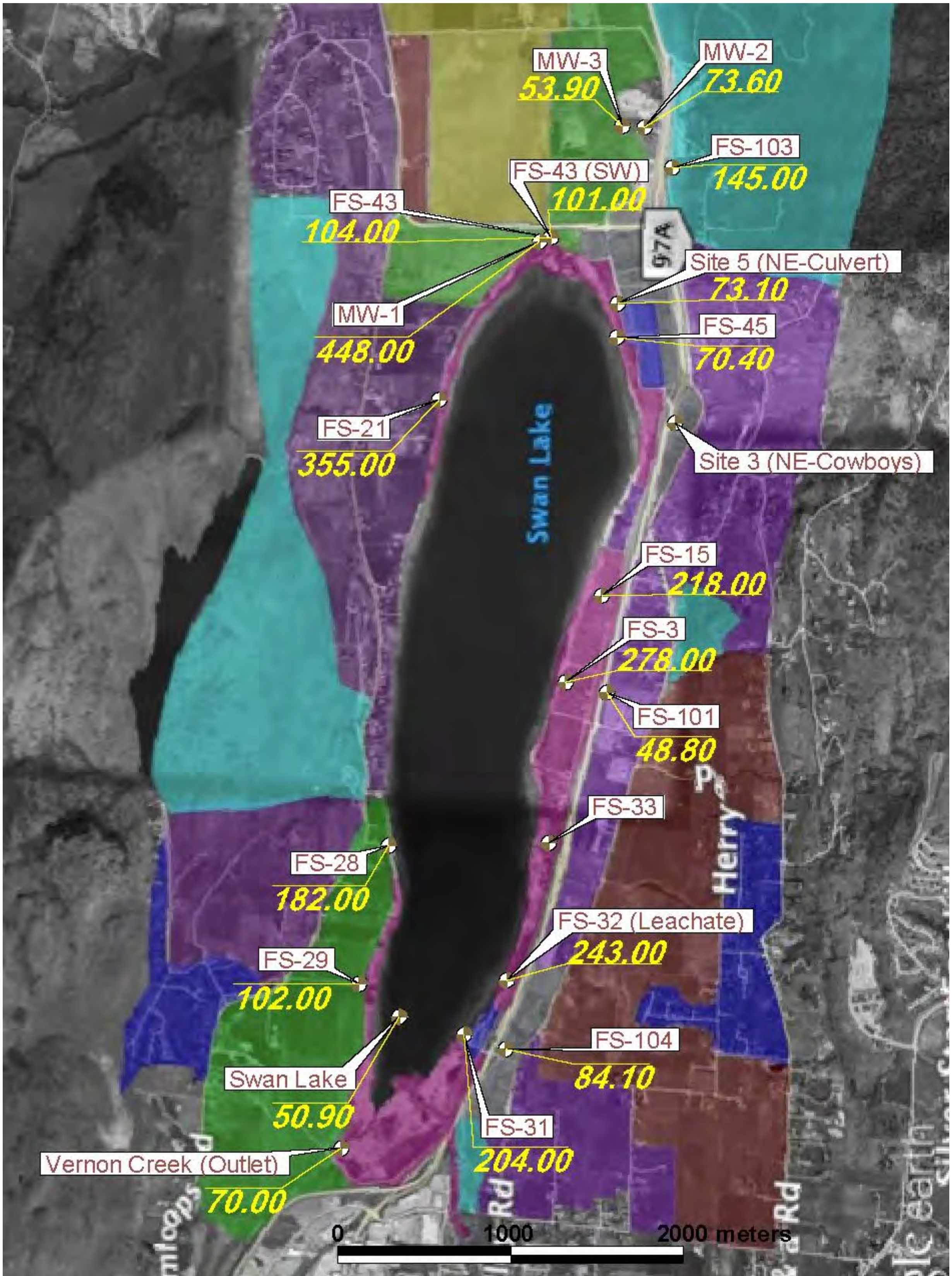
Regional District of North Okanagan	TITLE **Figure 14:** Maximum Potassium Concentrations, Swan Lake, 2015.		
western water ASSOCIATES LTD	DRAWN BRM	DATE December 2015	PROJECT NO. 14-076-01
	CHECKED	SCALE See Figure	DWG. NO. n/a
	REVIEWED DG	FILE NO.	FIGURE REV NO. 1



Base Map Source: Goggle Earth

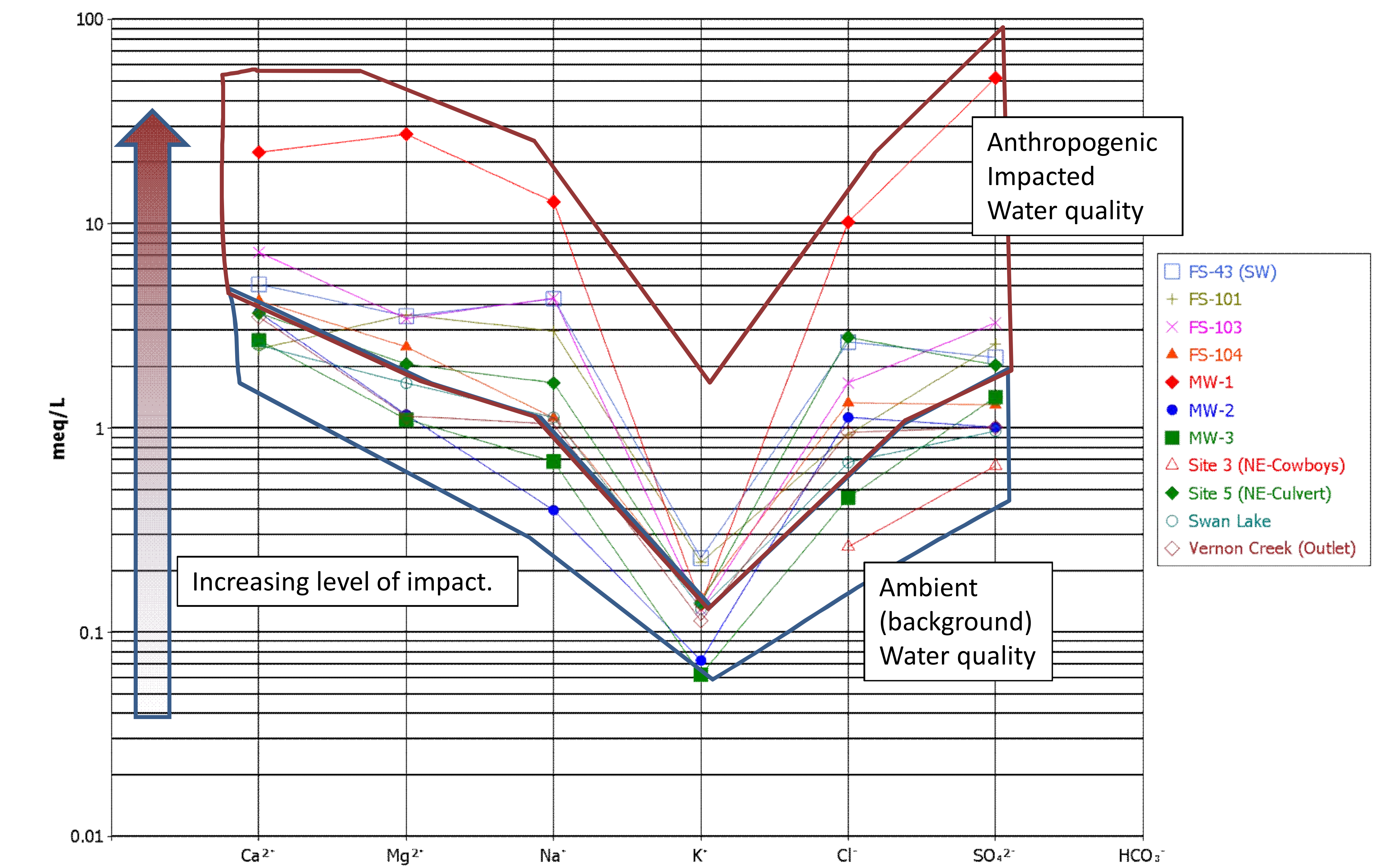
Regional District of North Okanagan

TITLE

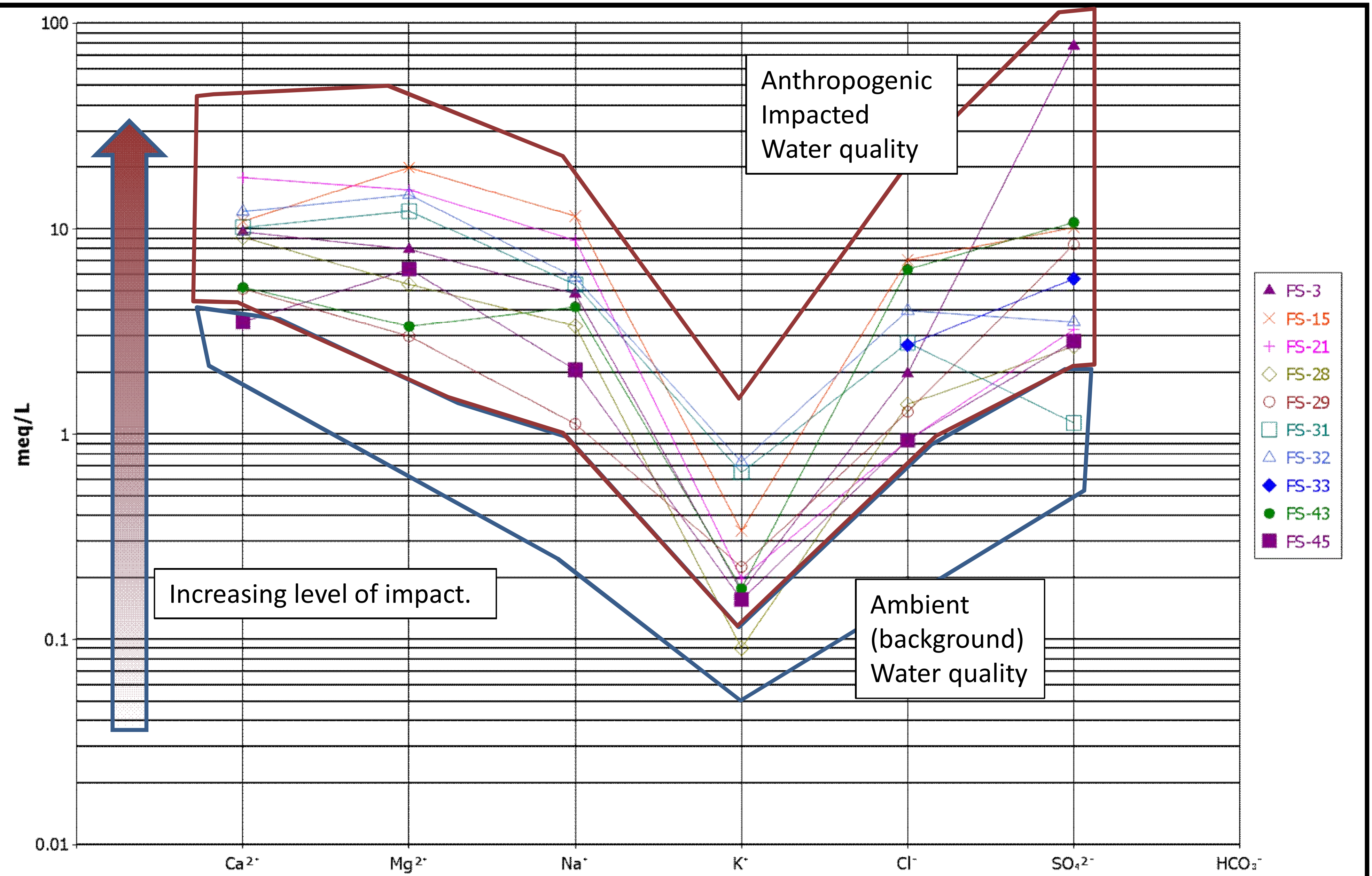
Figure 15: Maximum Calcium Concentrations, Swan Lake, 2015.

western water ASSOCIATES LTD

DRAWN	BRM	DATE	December 2015	PROJECT NO.	14-076-01
CHECKED		SCALE	See Figure	DWG. NO.	n/a
REVIEWED	DG	FILE NO.		FIGURE REV NO.	1



Regional District of North Okanagan	TITLE **Figure 16:** Schoeller (Geochemical) Plot for Groundwater and Surface Water Routine Sample Locations.		
western water ASSOCIATES LTD	DRAWN AMF	DATE December 2015	PROJECT NO. 14-076-01
	CHECKED BM	SCALE	DWG. NO. na
	REVIEWED	FILE NO.	FIGURE NO. 1



Regional District of North Okanagan	TITLE **Figure 17** Schoeller (Geochemical) Plot for Foreshore Routine Sample Locations. Note that none of the foreshore samples are within the background water quality polygon.				
western water associates ltd	DRAWN AMF	DATE December 2015		PROJECT NO. 14-076-01	
	CHECKED BM	SCALE		DWG. NO. na	
	REVIEWED	FILE NO.		FIGURE NO. 1	

Appendix C

Section 3.0 Parameters of concern identified in WWAL report section 4.2.2

(Excerpt from Peer Review of this report by Larratt Aquatic (Heather Larratt, H. B.Sc. R.P. Bio.), provided to the RDNO in May 2016)

3.0 Parameters of Concern identified in WWAL report section 4.2.2:

Ammonia mg/L:

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
3.7	FS-29 2.2, FS-31 19.4 FS-32 34.1	none	1.15 – 13.4	0.035- 0.053

Ammonia: The benchmark used was the CSR aquatic life guideline to demonstrate water quality exceedance. This is a misleading choice because ammonia will be oxidized (bacterially, etc.) to nitrate and also to nitrogen gas rapidly as the groundwater enters Swan Lake. Additionally, marginal riparian vegetation, aquatic macrophytes and algae will consume both forms of N, lowering its open-water concentrations, and gas evolution is also probable. Thus the exposure of aquatic life to N contributed from groundwater ammonia is highly unlikely to result in harm to the lake ecosystems through ammonia toxicity (also pH and temperature -dependent).

The impact of the total sum of the N's (ammonia, nitrate, nitrite, organic N) on Swan Lake would require a loading calculation. Together with phosphorus, nitrogen concentrations frequently determine overall lake productivity. Excess N and P loading can accelerate eutrophication processes and degrade water quality though excessive algae production, for example. Despite the groundwater concentrations, the 3 Swan Lake samples contained 0.035- 0.053 mg/L ammonia + <0.01 – 0.271 mg/L nitrate which would place the lake in the oligo-mesotrophic category. For reference, the BC MoE Objective for Okanagan Lake is 0.232 mg/L T-N and for Lower Vernon Creek is 10 mg/L nitrate + nitrite.

Sulphate mg/L:

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
1000	FS-3 10,500 - 100 FS-15 700 FS-29 1050	FS-43 1330	500	30 - 55

	(MW-1 2540)			

Sulphate: Sulphate is another important lake nutrient that causes problems when excessive amounts are present. Sulphate in excess of 0.5 mg/L is essential for algal growth and is never a problem in Okanagan lakes. A water quality guideline of 100 mg/L for dissolved sulphate was initially recommended, but has since been replaced by 500 mg/L or a site-specific objective that can be researched. The three Swan Lake samples collected as part of this study measured 30 – 55 mg/L, far below any guideline or regulation.

Uranium ug/L:

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
3000 (10 IW)	All site for IW none for AW	FS-43	15 – 33 (max 300)	5.9

Uranium: Uranium is often elevated in Okanagan groundwater that was in contact with gravel deposits, resulting in well water that exceeds drinking water standards for U. This has occurred in municipal supplies for Oliver and Faulder (near Summerland), and Okanagan deposits are sufficient to attract U mining interests. U mobility in gravel deposits is affected by parameters chiefly with Eh (redox potential) and pH and also with carbonate/bicarbonate concentrations, iron, calcite and microbial processes that are themselves influenced by preferentially reduced constituents such as nitrate (Goodwin, 1982; Finneran et al., 2002; Roed and Greenough, Ed., 2004; Zhou and Gu, 2005). In addition to altered U mobility with Ca and/or Cl identified by WWAL (Drage and Kennedy, 2013; Dong et al, 2005). Thus the indicated connection of the elevated U to the agricultural application of lime or other calcium mineral is not proved by 1 sampling event. Further, the Swan Lake sample is less than half of the conservatively set BC uranium guideline for the protection of aquatic life.

Chloride mg/L:

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
1500 (100 IW)	No exceedance for aquatic life, many for irrigation e.g. FS-43 477	SW FS-43 151	120 – 600	16 - 29

Chloride: The levels of chloride in Swan Lake indicate anthropogenic influence, as do all valley bottom lakes in the Okanagan, however, it is far below the aquatic life guideline. Road salt, agriculture and septic effluents are the most common contributors. For comparison, sodium concentrations ranged from 206 – 270 mg/L and chloride from 394 – 496 mg/L in Logan Lake during 2011 before decreasing slowly following a highways salt shed site remediation. None the less, the brine flow identified by WWAL should be addressed immediately. Salinized soils will take decades to reach moderate salinity levels. Again, using the Logan Lake example, soils located 500 m down-gradient from the former salt shed site exceeded 1550 mg/kg dry Cl.

Sodium mg/L:

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
- (DW 200)	FS-15 265 FS-21 202 (MW-1 294)	None	none	26

Sodium:

The Swan Lake sample measured 26 mg/L, while 3 shallow subsurface foreshore or well sites exceeded 200 mg/L Na. This elevated sodium would not cause environmental harm, but is not ideal for drinking water for individuals on a low sodium diet, for example. For comparison, soils located 500 m down-gradient from the Logan Lake former salt shed site exceeded 1600 mg/kg dry Na, ultimately contributing to concentrations in Logan Lake exceeding 270 mg/L. While this is not ideal and triggered a remediation of the salt shed site, there was no apparent harm to the ecology of Logan Lake or its vibrant rainbow trout fishery and waterfowl use from the elevated sodium.

Fluoride mg/L:

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
3	none	none	0.12 – 0.4	<0.10 – 0.27

Fluoride: Using the hardness-corrected CSR aquatic life 3.0 mg/L (not 1.0 for soft water as reported), no F exceedances occurred and 2 sites exceeded the CSR drinking water regulation. However, the more stringent BC aquatic life guideline was approached by Swan Lake. This may be a natural occurrence for this lake. The weathering of alkalic and silicic igneous and shales contributes much of the fluoride to natural waters. Fluoride levels in lakes are often regulated by the calcium-carbonate-phosphate-fluoride chemical system. The whole Okanagan Valley drainage basin appears to have naturally high fluoride with levels generally in the 0.2 to 0.3 mg/L range, and can be higher where there has been a history of fluoridation.

Molybdenum mg/L

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
10 (0.01for IW)	None for AW		1 - 2	0.004

Molybdenum: This metal rarely causes problems for aquatic life. Selected areas of the Okanagan have elevated molybdenum concentrations exceeding 0.01 mg/L due to localized deposits and its mobility in alkaline conditions. Molybdenum guidelines for irrigation are specific to forage crops to be fed to ruminants, because they can develop molybdenosis if a copper supplement is not provided. All other crops are not known to be affected, and molybdenum is a nutritional supplement required by many animals. For reference, the Okanagan River Objectives state; less than or equal to 0.02 mg/L average, 0.05 mg/L maximum or 20% maximum increase in Mo, whichever is greater and applies only during the irrigation season, May to September, inclusive.

Selenium mg/L

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
0.01	FS-104 0.0298 FS-15 0.0558		0.2 - 2	0.0007

Selenium: Concerns with enriched selenium subsurface drainage are broader than those for molybdenum, included high incidences of embryonic mortality and deformity in waterfowl. Se toxicosis can arise from agricultural drainage where fertilizers containing Se are employed. In the case with Swan Lake, waterfowl would have to come into contact with enriched subsurface seepage or consume plants/animals with that contact to become exposed to elevated Se. The lake itself has very low Se values, far below harm thresholds. This is important due to the extensive waterfowl/shorebird use of Swan Lake.

Manganese mg/L:

CSR AW	Foreshore max exceedance	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
- (DW 0.55) -(IW 0.2)	FS-3 1.14 FS-21 0.404 FS-31 0.387 FS-29 3.0		1.0 – 1.6	0.006

Magnesium and Manganese:
Groundwater contamination with manganese results from an overabundance of naturally occurring iron, sulphides, manganese, and substances such as arsenic. Excess iron and manganese are the most common natural contaminants found in groundwater and exceedances do not necessarily point to anthropogenic impact. Magnesium contributes to water hardness and conductivity and is not involved in toxicity, hence no guidelines are set for it except 100 mg/L for drinking water which is an aesthetic consideration and is currently 20.1 mg/L in the WWAL sample.

Phosphorus mg/L:

CSR AW	Foreshore max values	Surface flow Exceedance	Aquatic Life Guidelines	Swan Lake
none	FS-101 0.24 FS-31 0.21 FS-32 0.64	----	0.005 – .015	<.020

Phosphorus: Dissolved phosphorus measured <0.02 mg/L as P in the Swan Lake sample and unfortunately, this analysis needs lower detection limit methodology to be useful. For reference, the Objective set for Okanagan Lake is 0.008 – 0.010 mg/L T-P.

4.0 Parameters of Potential Concern

The following parameters were not covered in the WWAL report despite the results available from their sampling, because these parameters did not involve exceedances.

Lead, Arsenic and Mercury: Other parameters of concern are possible in a small shallow agriculturally impacted lake such as Swan Lake with poor historic practices as were generally employed in the Okanagan pre-1960. For example, the use of lead arsenate on orchards was common practice from the 1900's to the 1950's, leading to soil contamination with both metals. However, neither lead nor arsenic were elevated in the WWAL samples. Most samples were near the 0.0001 mg/L Pb detection limit in the shallow groundwater/subsurface flows entering Swan Lake that itself measured 0.0002 mg/L in the November sample. This may contradict evidence of orchard impacts on the lake.

Similarly, arsenic concentrations ranged from <0.0005 – 0.002 mg/L (MW-3) which does not exceed CSR regulations and the lake concentration was 0.0009 mg/L. (guideline for the protection of aquatic life is set a 0.005 mg/L in BC) These low arsenic values to not indicate the historic use of lead arsenate.

Mercury: Mercury was traditionally used in agricultural chemicals as a fungicide, mildewcide, or pesticide up to the 1960's. This mercury may then be deposited into lakes and streams, methylated, and ingested by fish, eventually reaching wildlife and humans. In recent research, biomagnification has been confined to methyl-mercury while other heavy metals once thought to biomagnify either do not, or there are confined conditions under which it occurs. Fortunately, Hg was not identified as a parameter of concern in the WWAL sampling. It rarely exceeded detection limits and did not approach guideline concentrations in any sample. For example, the BC Guideline for the protection of aquatic life is 1 ug/L and the Swan Lake sample measured <0.005 ug/L. Again this does not indicate damage to Swan Lake from historic agricultural practices.

Bacterial Indicators: Bacterial contamination of Swan Lake can occur from septic disposal, farm animal wastes and to a lesser extent, waterfowl. The samples collected as part of this study were elevated to 430 mpn *E. coli* at FS-3 for example, while the lake sample measures <3.0 mpn E. coli. The elevated level at FS-3 might not meet raw drinking water criteria, but that can only be determined from multiple samples collected at specific intervals.

Nitrate: Although nitrate poses little toxicity risk and therefore does not show up as exceedances, this is an environmentally important form of nitrogen that will influence lake productivity. For example, in this study maximum values over 5 mg/L were detected at 3 sites (FS-104, FS-101 and Site 5). Additionally, at 9.35 mg/L, site FS-104 is approaching the 10 mg/L drinking water guideline and is a concern not discussed in this report.

Alkalinity: Alkalinity affects water uses and despite not having guideline values, sites including FS-33 22500 mg/L and FS-103 15000 mg/L are very high and would affect use. Appendix 1 provides a table of the constituents contributing to alkalinity.

Western Water Associates Ltd.
Standard Report Limitations

1. This Document has been prepared for the particular purpose outlined in the work scope that has been mutually agreed to with the Client.
2. The scope and the period of service provided by Western Water Associates Ltd are subject to restrictions and limitations outlined in subsequent numbered limitations.
3. A complete assessment of all possible conditions or circumstances that may exist at the Site or within the Study Area referenced, has not been undertaken. Therefore, if a service is not expressly indicated, it has not been provided and if a matter is not addressed, no determination has been made by Western Water Associates Ltd. in regards to it.
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Groundwater Supply Development and Management

Source Water Assessment and Protection

Well Monitoring & Maintenance

Environmental & Water Quality Monitoring

Storm & Wastewater Disposal to Ground

Groundwater Modeling

Aquifer Test Design and Analysis

Geothermal / Geoexchange Systems

Policy and Guideline Development

Applied Research

Rural Subdivision Services

Environmental Assessment & Permitting

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