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St. Mary Lake Watershed Water Availability and Demand - Climate Change Assessment

FINAL
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Prepared for:

The North Salt Spring Waterworks
flowing fresh and clean

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ST. MARY LAKE WATERSHED AND LICENCED WATER WITHDRAWALS

St. Mary Lake is one of the water sources that the North Salt Spring Waterworks District (NSSWD) relies on to supply about 5,500 customers on Salt Spring Island: more than half the population of the year-round residents on the Island (based on 2013 values). Since 2006, a low weir at the outlet of St. Mary Lake, owned and operated by NSSWD, has controlled storage at St. Mary Lake to support summer water use and conservation flows downstream in Duck Creek.

At 1.823 km² in surface area, St. Mary Lake is the largest lake on Salt Spring Island. The watershed upstream of the outlet of the lake has an area of 6.47 km² and is primarily covered in second growth forest, rural residential development and agricultural fields. The watershed is underlain by complex geology typical of Salt Spring Island, including sandstone, shale, siltstone and conglomerates as part of the sedimentary rocks of upper Cretaceous age belonging to the Nanaimo Group. The surficial soils of the watershed consist primarily of thick, unconsolidated marine or fluvial deposits over compact unweathered till from the last glaciation.

In addition to licenced water withdrawals by NSSWD for water supply purposes, the lake also supports two other small waterworks districts managed by the Capital Regional District as well as several smaller private residential and agricultural water licences. At 90%, the NSWWD and CRD waterworks withdrawals make up the largest percentage of the total licenced withdrawal limit at St. Mary Lake with the remaining water licences issued for agricultural, industrial and individual domestic water uses. NSSWD holds four water licences which permit up to 264,507,500 imperial gallons or 1,202,000 m³ of water to be withdrawn from St. Mary Lake on an annual basis. The total licenced withdrawal limit for all water licence holders on the lake is 1,593,000 m³. No water demand forecasting based on population or land use was completed as part of this study as the water licence dictates the maximum amount of water that could be withdrawn in the future.

In addition to water licence withdrawals, a minimum downstream environmental flow of 9 L/s is required to be released to Duck Creek for conservation purposes. This is equal to an annual volume of up to 285,000 m³. Therefore, the maximum combined water withdrawal and conservation flow that St. Mary Lake and the watershed would have to support is equal to 1,878,000 m³ per year.

WATER BALANCE MODEL APPLICATION

Water balance (estimation of available water supply to the lake) and water budget (comparison of available water supply with the licenced water withdrawal limit and the required minimum downstream environmental flow) analyses were carried out in order to assess the capacity of existing storage to support licenced water withdrawals for NSWWD and other water licence holders around the lake.

Often water balance assessments rely on hydrometric records to provide an indication of water availability in a watershed. For the St. Mary Lake watershed, lake levels have been recorded since 1981 while discharge data was recorded in Duck Creek downstream of the lake from 1980 to 1998. Unfortunately, the historical discharge in Duck Creek is of relatively limited value for the water balance/budget given that most of the years of record only include discharges for the spring/summer period. The few years in which the station was operated year-round have significant gaps in the daily flow record such that there is not a single year of continuous daily discharge data.

Previous hydrological assessments carried out for St. Mary Lake relied on a relationship developed between discharges recorded in Duck Creek and lake levels to extend the discharge record sufficiently to provide a reasonable period of record for analysis. However, the relationship between lake level and discharge in Duck Creek has been modified by construction of the weir at the outlet of the lake in 2006.

Given the limitations of the historical water data for assessing water availability in St. Mary Lake, the water balance was carried out using a hydrological model developed based on the USGS Water Balance Model protocol. This model accounts for movement of water in a watershed through a series of theoretical storage volumes representing important physical hydrological processes such as evapotranspiration, lake evaporation, infiltration, soil moisture storage, groundwater storage and deep aquifer loss. The model converts inputs of precipitation and temperature to net inflow into St. Mary Lake (the model output). The modelled net inflows were used to assess available water supply to the lake under current climate conditions (1981 to 2010 climate normal period) and predicted future climate conditions (2050s).

To confirm if the model accurately represents hydrological processes in the watershed, the model was calibrated to the estimated lake net inflow known as 'back-calculated net inflow' for the period following construction of the weir (2007 to 2014). The back-calculated net inflow is based on conservation of volume which states that average inflow minus average outflow is equal to the change in volume over a specified period of time. The net inflow to the lake can be calculated as:

Net Inflow = Outflow to Duck Creek + Change in Lake Storage + Withdrawal

Outflow to Duck Creek was estimated based on a lake-level-versus-discharge relationship developed for the weir and outlet channel using discharge measurements collected in 2013, 2014 and 2015. Outflow including weir overflow and minimum conservation flow via fish ladder. *Change in Lake Storage* is the change in lake level multiplied by the lake surface area. Withdrawals from the lake were calculated based on the monthly average withdrawal data collected from NSSWD and CRD, as well the water licence information for the private uses.

This calculation results in what is known as Net Inflow is also equal to:

Net Inflow = Watershed Runoff + Direct Rainfall on the Lake Surface - Evaporation from the Lake Surface ±Groundwater in/out from Lake

In other words, net inflow is the water that is available to either be withdrawn from the lake or to replenish lake storage. In some summer months, net inflow is negative when evaporation from the lake surface is greater than watershed runoff and direct rainfall on the lake.

The comparison between the water balance model results and the back-calculated net inflow indicate that the model simulates the back-calculated net inflow, and thus the hydrological processes, at St. Mary Lake with a reasonable level of confidence. The average total annual modelled net inflow volume for the period between 2007 and 2014 is 1,959,000 m³, only 6,000 m³ (or 1%) greater than the average total annual back-calculated net inflow volume. The modelled total inflow volume for the spring/summer period from May to September is 364,000 m³, same as the back-calculated volume.

It should be noted that the above annual averages do not include the results from the 2009/10, 2010/11 and 2013/14 water years (November to following October), as the percent differences between the annual total modelled and back-calculated net inflows are significantly greater in these years than in other years. A review indicates that the back-calculated inflows for the winter months (January/February) for these years may be over-estimated due to uncertainty with the estimation of the outflows to Duck Creek. The model calibrate better in the summer period when the lake level is below the weir at most of the time. The modelled spring/summer net inflows were also out of calibration in 2010 and 2013 with high spring/summer precipitation and early spring water levels, allowing weir overflow at the outlet. However, given that the model compares well with back-calculated flows under average conditions, we consider that the model is suitable for the purpose of assessing water supply for St. Mary Lake.

WATER BUDGET RESULTS

The water balance model indicates that for an average year, under current (1981-2010) climate conditions, the total annual net inflow to St. Mary Lake is about 2,685,000 m³. Using estimates of monthly average 10-year return period high temperatures and total annual 10-year return period drought condition precipitation amount, the total annual net inflow volume for a 10-year return period drought condition is estimated to be 1,198,000 m³.

A monthly water budget was carried out to assess required storage volume to support water withdrawals and the downstream environmental flows through the dry summer period. This involves comparing average monthly net inflow from the water balance model with the maximum monthly surface water demands which equal to the monthly water withdrawal limits plus the required minimum environmental flow to Duck Creek. Monthly withdrawal limits are based on a monthly distribution of the total annual licenced withdrawal limit and minimum conservation flow requirements. A summary of the water budget results are shown below:

St. Mary Lake Water Budget Analysis Results for Current (1981-2010) Climate Conditions

Parameter	Average Year Conditions	10-year Return Period Drought Conditions
Lake Drawdown Period (Maximum surface water demand exceeds net inflow)	Apr-Sep	Apr-Oct
Lake Net Inflow During Lake Draw Down Period (in units of 1,000 m³)	-134	-266
Total Licenced Withdrawal Limit During Draw Down Period (in units of 1,000 m³)	992	1,101
Total Downstream Conservation Flow Volume during Lake Draw Down Period (in units of 1,000 m³)	142	166
Required Lake Storage (Withdrawal plus Conservation Flow minus Net Inflow) (in units of 1,000 m³)	1,269	1,533
Live Storage Volume with Existing Weir (El. 40.71 m) (in units of 1,000 m³)	1,294	
Percent Reduction in NSSWD Licenced Withdrawal Limit Required to balance with available Live Storage with Existing Weir (El. 40.71 m)	0.0%	29.6%
Live Storage Volume with Weir Raised To El. 41.0 m (in units of 1,000 m³)	1,823	
Percent Reduction in NSSWD Licenced Withdrawal Limit Required to balance with available Live Storage with Weir Raised To El. 41.0 m	0.0%	0.0%
Note: Percent Reduction in NSSWD Licenced Withdrawal Limit required to balance available live storage assumes all other licence holders withdrawing at full licenced withdrawal limit.		

The results of the water budget indicate that storage available with the current weir at El. 40.71 m would be sufficient to support withdrawals from St. Mary Lake at the licenced withdrawal limits and the minimum downstream conservation flow under an average net inflow year, but not under the 10-year return period drought condition year. However, if the weir were to be raised up to 41.0 m (such as stop logs or gates) this would provide sufficient water to support withdrawals up to the licenced withdrawal limit even in a 10-year return period drought condition year. The current storage water licences on the lake permit storage of water up to El. 41.0 m.

Using the calibrated water balance model, annual groundwater recharges were estimated to be 704,000 m^3/year and 620,000 m^3/year (or 11% and 14% of annual precipitation), under the current climate average and 10-year return period drought conditions respectively. This is greater than the groundwater recharge estimation of 3% of the total annual rainfall, suggested in a couple of previous hydrological studies.

A previous groundwater assessment carried out by WRI for the St. Mary Lake watershed estimated the annual groundwater demand of approximately 94,900 m^3 which is much less than the modelled recharge volumes. This indicates that there would be sufficient groundwater being recharged into the groundwater and available for the required groundwater uses.

CLIMATE CHANGE ASSESSMENT

Climate change projections based on output from global circulation models (GCM) indicate that annual average temperatures in the southern Vancouver Island and Gulf Islands region may increase by between 1.0°C to 2.3°C while total annual precipitation may increase (+12%) or decrease (-2%) by mid-century (2050s). Models indicate that the majority of the annual increase in precipitation is likely during the winter months, with a decrease predicted for summer months.

Using projected temperatures and precipitations from downscaled GCM results as input to the water balance model, annual net inflow to St. Mary Lake is predicted either to increase by 19.7% or decrease by 8.9% for the 2050s period. Model results indicate that spring/summer (May to September) net inflows could increase by up to 10.8% or reduce by much as 36.1%. These results show the magnitude of uncertainty with regard to climate change impacts on future water supply at St. Mary Lake.

Based on the worst case scenario of 8.9% decrease in annual net inflow, current available storage would not be sufficient to support licenced withdrawal limit volume under 2050s climate conditions.

RECOMMENDATIONS

Based on the results of the assessment of available water supplies at St. Mary Lake, it is recommended that:

1. Water rights on St. Mary Lake should be considered to be fully allocated (no additional water licences should be issued) given the limitations of current lake storage to support the maximum water demand at the licenced withdrawal limit and the minimum environment flow in Duck Creek under 10-year return period drought conditions.
2. St. Mary Lake water level, weather data (rainfall and temperature) and outflow to Duck Creek should continue to be monitored (minimum of one winter and two summer seasons) to collect data that could be used to refine the back-calculated net inflow estimates and to re-assess the water balance in order to better understand the uncertainties in the water balance model (i.e. groundwater recharge rates and minimum conservation flow releases). Installation of a monitoring system to record flow release to Duck Creek in the summer through the fish ladder should be included as part of the monitoring program.
3. Groundwater levels should be monitored in relation to St. Mary Lake levels, preferably by collaborating with existing well owners near the lake or with the Ministry of Environment groundwater monitoring network, to establish hydraulic gradients of groundwater flowing into or out of St. Mary Lake. This could provide a better understanding of the potential for water to seep from the lake into groundwater during the low flow summer season, and to confirm if groundwater recharge rates estimated using back-calculated net inflows and the water balance model are reasonable.

4. Groundwater extraction rates at select sites should be monitored to better define typical groundwater extraction quantities for different users (domestic, agricultural, etc.) within the watershed.
5. NSWWD water withdrawals from St. Mary Lake should be capped at 70.4% of the total annual licenced withdrawal limit (capped withdrawal of 846,500 m^3 per year or 2,319 MLD average day demand), until such time that sufficient surface water and groundwater data can be collected to reduce uncertainties in water balance model results, or current storage is expanded by raising the weir or providing seasonal storage (i.e. stop-logs or gates) up to El. 41.0 m.
6. NSWWD should work together with other St. Mary Lake water licence holders and stakeholders to develop a St. Mary Lake Water Management Plan, including a drought management strategy which identifies how lake storage, groundwater supplies and water withdrawals are to be co-operatively managed under drought conditions.
7. Increase in total water licence withdrawal from St. Mary Lake for the NSSWD should not be pursued unless agreement can be made with other licence holders for transfer of water rights or until additional storage at the lake can be secured.
8. Should NSWWD decide to increase maximum water withdrawal from St. Mary Lake beyond the recommended cap, investigations either should be carried out, or those already completed should be re-considered, to review potential impacts of either raising the St. Mary Lake weir by 29 cm or providing seasonal lake level control up to El. 41.0 m such as gates or stop logs. The investigations should include topographic survey or LiDAR survey to determine the extent of inundation, review of potential habitat impacts and review of potential impacts to lakeside property owners.
9. Given the uncertainty of potential future changes in available runoff as a result of climate change, NSWWD and other St Mary Lake stakeholders should develop an adaptive management approach for water management. This may include on-going monitoring of climate and water resources to assess trends in comparison with future climate projections, and development of flexible and robust physical infrastructure and policy/procedures which consider the impacts of uncertain future climate.
10. The community engagement and communication program should be continued and enhanced to provide meaningful science-based information on water supplies, water use and water conservation. Maintaining public involvement is a key part of the management and protection of the St Mary Lake watershed and aquifer.

Section 1

Introduction

1. Introduction

1.1 Overview

The North Salt Spring Waterworks District (NSSWD) provides potable water to the village of Ganges and a large portion of Salt Spring Island. Salt Spring Island is located off the south-east coast of Vancouver Island and is the largest of the southern Gulf Islands. In 2012, NSWWD delivered about 533,700 m³ of water to its customers from water supply reservoirs at St. Mary Lake and Maxwell Lake.

Currently NSSWD is developing an upgraded water treatment plant for the St. Mary Lake water supply as part of their on-going water quality improvement program. Part of the design and assessment of the new treatment plant is a review of water availability from St. Mary Lake under current and future water demand and climate conditions.

The following report outlines the results of the hydrological study carried out to review the water balance of St. Mary Lake and provide recommendations on water availability and future demand allocation.

1.2 Purpose and Scope

The objectives of this study are to:

1. Review previous hydrological assessments;
2. Estimate available surface water supply from St. Mary Lake under current and future climate forecasts;
3. Carry out a conceptual level groundwater assessment to review how groundwater may influence surface water supplies at St. Mary Lake; and
4. Compare water availability with the current licenced water demand.

1.3 Project Team

NSSWD retained Kerr Wood Leidal Associates Ltd. (KWL) to carry out the St. Mary Lake Watershed Water Availability and Demand – Climate Change Impacts Assessment Study. KWL led the consulting team and provided surface water hydrology expertise while Waterline Resources Inc. (WRI) was retained as the hydrogeology sub-consultant providing groundwater assessment and water budget expertise. The project team consisted of:

KWL

Craig Sutherland, M.Sc, P.Eng. – Water Resources Engineer and Lead Hydrologist

Wendy Yao, M.A.Sc. P.Eng. – Technical Review

David Murray, P.Eng. – Principal

WRI

Jessica Doyle, M.Sc, GIT – Hydrogeologist

Andrea Mellor, M.Sc, P.Geo. – Technical Review

Darren David, M.Sc, P.Geo – Principal

1.4 Past Reports

Several previous reports have been prepared regarding hydrology of the St. Mary Lake Watershed. The following reports have been reviewed as part of the water supply and climate change assessment:

Saltspring Island Water Allocation Plan, 1993. Report by Lyn Barnett, Bruno Bleck and Walter Van Bruggen. Downloaded from Ministry of Environment Website. http://www.env.gov.bc.ca/wsd/water_rights/wap/vi/saltspring/saltspring_wap.pdf

Hydrology of St. Mary Lake. Report prepared by Roy Hamilton, M.A.Sc., P.Eng. 1998. Provided by the North Salt Spring Waterworks District.

Nine Lakes on Salt Spring Island, B.C.: Size, Watershed, Inflow, Precipitation, Runoff and Evaporation. Report prepared by John B. Sprague, Sprague Associates Ltd. 2009. Provided by the North Salt Spring Waterworks District.

St. Mary Lake Watershed Management Plan. Report prepared by the St. Mary Lake Steering Committee. 2009. Downloaded from: http://www.cusheonlakestewardship.com/pdf/ssstmarylkwtrshedmgntmplan-1.pdf.

1.5 Units of Measure

The results of the hydrological analysis and water balance assessment are presented in metric units. Volumes are presented as either thousands of cubic meters (1,000 m^3) or as equivalent depth over the watershed area in millimeters (mm). The equivalent depth allows for comparison with rainfall and precipitation records which are also presented as a depth in millimeters (mm). Flow rates are presented in cubic meters per second (m^3/s), liters per second (L/s) or million litres per day (MLD). Surface area is presented in square kilometers (km^2). The only exception are water volumes and flow rates provided in water licences which are shown in both the imperial units provided in the original licence documents and the equivalent volumes converted to metric units for comparison with results from the analysis.

1.6 Elevation Data Correction

The lake outflow levels and water level data originally provided to KWL were based on the following assumptions:

Invert of low flow notch at the spillway = 40.60 m
Spillway crest (broad crested weir) elevation = 40.70 m
Tripp Road WTP Gauge @ 0.0 m reading = 40.07 m
Duck Creek Weir Gauge @ 0.0 m reading = 40.0 m

However, a recent survey performed on April 7, 2015 by Polaris Land Surveying Inc. showed the following true geodetic elevations regarding to the above reference elevations:

Invert of low flow notch at the spillway = 40.61 m
Spillway crest (broad crested weir) elevation = 40.71 m
Tripp Road WTP Gauge @ 0.0 m reading = 40.08 m
Duck Creek Weir Gauge @ 0.0 m reading = 40.01 m

As a result of this survey, the analysis performed in this study is based on the updated survey elevations for the outlet structures, including:

Invert of low flow notch at the spillway = 40.61 m
Spillway crest (broad crested weir) elevation = 40.71 m

In addition, the following corrections have been provided to the data previously received and used for this study:

Historical water level data recorded at the WTP - Add 0.01 m to the data based on the previous 40.07 m datum for 0.0 m gauge reading at the WTP
Water levels measured paired with the flow measurements - Add 0.01 m to the data based on the previous 40.0 m datum for 0.0 m gauge reading at the Duck Creek weir location

1.7 Technical Terminology

This report is a technical document covering aspects of hydrology and hydrogeology in the St. Mary Lake watershed. The terminology used in the report should be familiar to anyone with a background in either hydrology or hydrogeology. However, for clarity a glossary has been provided in Appendix A which defines most technical terms used in the document.

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Section 2

St. Mary Lake Watershed

2. St. Mary Lake Watershed

2.1 General Description

St. Mary Lake is located on the northern half of Salt Spring Island, which is the largest of the Gulf Islands off the east coast of Vancouver Island. The lake plays an important role on the island as it is one of the main water supply reservoirs used by NSSWD to provide potable water for residents of northern Salt Spring Island. NSSWD also supplies water to customers within its service area from Maxwell Lake, located on the slopes of Mt. Maxwell. A separate hydrology and storage assessment was carried-out for Maxwell Lake by KWL in 2014/2015.

St. Mary Lake is the largest lake on Salt Spring Island with a total watershed area of 6.47 km². The watershed delineation previously prepared by Grange Engineering and presented in the St. Mary Lake Watershed Management Plan (2009) was field checked and revised, and the area was re-calculated using Geographic Information System (GIS) as part of this study. The watershed area of 6.47 km² calculated by KWL is about 6.2% smaller than the watershed area of 6.898 km² presented in the St. Mary Lake Watershed Management Plan. The watershed area confirmed and re-calculated by KWL is used in this study.

The Provincial Ministry of Environment (MoE) Lakes mapping for St. Mary Lake (Drawing 4977-3) prepared in 1991 indicates that the lake surface area is 1.823 km², that the total volume of the lake is 15,964,000 m³ and that the lake has a maximum depth of approximately 16.7 m. Water level records collected by NSSWD indicate that the average lake surface elevation is 40.60 m above mean sea level, with a typical annual water level variation of about 0.8 m.

The remaining watershed consists of gently rolling topography surrounding the lake with steeper slopes on the north and south sides of the lake (Figure 2-1). The largest portion of the watershed runs northwest of the lake. The major tributaries to the lake include two small streams entering from the northwest and northeast. Provincial mapping indicates that the north-east tributary to St. Mary Lake drains a small valley then flows along the east-side of North End Road before flowing into a wetland area and under North End Road into St. Mary Lake. However, observations during field reconnaissance indicate that a high point along the east-side of North-End Road prevents drainage between the small valley and the wetland area. Therefore, this additional area identified in the provincial mapping does not contribute to the St. Mary Lake Watershed. Figure 2-1 shows the St. Mary Lake Watershed and the surrounding area, including the area that was confirmed to not lie within St. Mary Lake Watershed.

Water storage and outflow from St Mary Lake is regulated by a weir and fish ladder that discharge into Duck Creek, located at the south end of the lake. NSSWD operates the weir and maintains minimum conservation flows downstream in Duck Creek when lake levels are below the crest of the weir using gates and baffles mounted at the upstream end of the fish ladder. Duck Creek flows for approximately 3 km into the ocean at Duck Bay on the west side of Salt Spring Island, near Vesuvius (Figure 2-1).

The weir at the outlet of St Mary Lake consists of a broad crested weir having a total width perpendicular to the flow of 4.0 m with a low flow notch in the middle of the weir that is 0.1 m deep with an average width of 0.3 m. The crest of the low flow notch is at elevation 40.61 m such that the crest of the broad crested weir is at 40.71 m. The weir stores water in St Mary Lake from El. 40.71 m down to El. 40.0 m, which is the minimum lake level allowed by the water licence for storage, at which flow through the fish ladder can be maintained at 9 L/s. A copy of as-built drawings of the weir and fish ladder is included in Appendix B. Please note that a +0.01 m correction should be applied to the elevations shown in the as-built drawings based on the recent survey as described in Section 1.6 of this report.

2.2 Land-use and Land Cover

Land-uses in the St. Mary Lake Watershed consist of rural residential development and agricultural fields (Figure 2-2). The north-west region of the watershed is dominated by young forests while rural residential development remains to the eastern perimeter of St. Mary Lake. Agricultural land-use is most prevalent in the south-east area and scattered throughout the remainder of the watershed. At about 28%, the surface area of St. Mary Lake is also a relatively large percentage of the total watershed area.

A map of land cover and land-use within the St. Mary Lake Watershed based on 2009 land use information provided by St. Mary Lake Steering Committee is provided in Figure 2-2. Table 2-1 summarizes the percentage of the total basin area for each main land use category.

Table 2-1: St. Mary Lake Watershed Land Cover and Land Use Types

Land-Use/Land Cover	Percent of Total Basin
Young forest	46%
Rural Residential	14%
Agriculture	10%
St. Mary Lake	28%
Other	2%

The land-use and land cover data were used in the water balance modelling to provide information on the distribution of open space and forest cover in the watershed for estimation of evapotranspiration and direct runoff across the watershed.

2.3 Geology and Soils

The geology of Salt Spring Island is intricate and varies greatly throughout the island. The St. Mary Lake Watershed is underlain by sandstone, shale, siltstone and conglomerates as part of the sedimentary rocks of upper Cretaceous age belonging to the Nanaimo Group (Hodge, 1995).

The surficial soils of the watershed consist primarily of thick, unconsolidated marine or fluvial deposits over compact unweathered till from the last glaciation. The soils of the steep upper watershed area above the lake are mainly Saturna, Bellhouse, Haslam and Galiano. These are all loamy or sandy soils less than 100 cm deep over sandstone, siltstone or shale (Van Vliet et al, 1987). The bottomland near the lake is mainly Mexicana, which is gravelly sandy loam less than 100 cm deep over compact till. Further details of the geology and soils in the St. Mary Lake Watershed can be found in the Hydrogeological Assessment Report - St. Mary Lake Watershed Study prepared by WRI, included in Appendix C.

Figure 2-3 shows a map of the surficial geology of the St. Mary Lake Watershed and is based on the Ministry of Environment of BC's Soils of Gulf Islands of British Columbia – Volume 1, Soils of Salt Spring Island (1987).

2.4 Climate and Hydrology Data

Local Climate

The climate of the St. Mary Watershed can be classified as Mediterranean-maritime, similar to other parts of east-coast Vancouver Island and southern Gulf Islands, with mild/wet winters and warm/dry summers. Climate records at St. Mary Lake indicate that precipitation does fall as snow in the winter on occasion but air temperatures do not drop below freezing for extended periods of time and snow does not accumulate.

The 1981 to 2010 climate normal for Environmental Canada's (EC) St. Mary Lake climate station (Station ID 1016995) indicate that average daily temperatures range from 4.3°C in January to 18.4°C in August. Total average annual precipitation recorded at St. Mary Lake is 987 mm, of which approximately 80% falls within the six month period from October to March. The highest average monthly precipitation (167.9 mm) occurs in November and the lowest average monthly precipitation (23.2 mm) occurs in July. The average annual snowfall is about 32 cm but the average snow depth at month end is no greater than 0 cm, indicating that snow does not usually accumulate. A plot of average monthly precipitation and temperature for the St. Mary Lake Climate Station is shown in Figure 2-4.

Runoff from the St. Mary Lake watershed is driven by the variation in rainfall patterns with higher flows occurring during the late fall, winter and early spring (November to April) and lower flows in late spring, summer and early fall (May to October). Spring and summer base flows into St. Mary Lake are supplied from groundwater and occasional summer precipitation.

Climate Stations

The St. Mary Lake EC climate station is located at the NSSWD St. Mary Lake Pump Station and Water Treatment Plant on the western shore of the lake (see Figure 2-1).

Precipitation and temperature data at the St. Mary Lake Climate Station are collected by NSSWD staff and provided to EC each month. EC staff review the data for quality-control and post the data to the EC website at regular intervals. The record available at the time of conducting the current study was from December 1, 1975 to December 31, 2014. The precipitation data for the period between 2007 and 2014 was used in this study for confirming hydrological model calibration. This period was selected as it corresponds with the period after construction of the weir at the outlet of St. Mary Lake until the end of the period of record available at the time of this study. Further information regarding the selection of the calibration period is described in Section 3.2, below.

The precipitation and temperature data for the period between 1976 and 2006 (the data that has been verified and posted online by EC) was used for drought condition analysis.

In addition to the EC station, NSSWD also installed a second climate station at the St. Mary Lake Pump Station and Treatment Plant in April 2014. This new automated station records precipitation and temperature at 15-minute increments.

Spatial Climate Data

In addition to climate records from the EC St. Mary Lake climate station, climate data extracted from the ClimateBC model were also used in this study as part of the climate change impacts assessment. The ClimateBC model was developed by the University of British Columbia (UBC) Faculty of Forestry to spatially downscale both historical climate data based on PRISM gridded historical climate dataset (Daly et. al., 2002) and future climate projections based on Global Circulation Models (GCMs). ClimateBC can provide monthly average climate data for a specified latitude, longitude and elevation and time horizon.

Climate change projections are provided as changes in temperature and precipitation from a baseline reference period (the 1961-1990 climate 'normal'). However, as climate data were not collected at the St. Mary Lake Climate Station prior to December 1, 1975, the 1961-1990 climate normal data is not available from EC. Therefore the monthly average temperatures and precipitations for the 1961-1990 climate normal period were extracted from the ClimateBC model at the St. Mary Lake Climate Station location and used to predict monthly average temperatures and precipitations for the 2050s climate conditions in the climate change assessment.

Further discussion of climate data used for analysis of the future climate predictions is included in Section 4.

Climate Data

Climate data required in the study include monthly average temperatures and monthly average precipitation data used for model calibration as well as water supply analysis under current and future climate conditions. Since the St. Mary Lake watershed is relatively small, spatial variation in temperature and precipitation across the watershed is considered to be negligible. Therefore, the data from the St. Mary Lake Climate Station and data extracted from the ClimateBC Model described above are considered to be representative of the entire watershed. The sources of the climate data used in the study are summarized in Table 2-2.

Table 2-2: Source of the Climate Data used for St. Mary Lake Watershed

Climate Data	Use in this Study	Source
Monthly temperature and precipitation for 2007-2014 based on recorded average daily values	Water Balance Model Calibration (Section 3.2)	Environment Canada climate station at St. Mary Lake (Station ID. 1016995)
Average monthly temperature and precipitation for the 1981-2010 climate normal period	Average Current Climate Conditions Water Supply Analysis (Section 3.4)	Environment Canada climate station at St. Mary Lake (Station ID. 1016995)
10-year return period drought monthly temperature and precipitation based on data from 1976 to 2006 period	Current Climate Drought Conditions (10-year return period) Water Supply Analysis (Section 3.4)	Environment Canada climate station at St. Mary Lake (Station ID. 1016995)
Average monthly temperature and precipitation for 1961 to 1990 climate normal used as reference period for climate change analysis.	Future Climate Water Supply Analysis (Section 4.3)	ClimateBC Model, UBC Faculty of Forestry
Predicted changes in temperature and precipitation from the 1961-1990 reference period to the future 2050s Climate (2040 to 2069 climate normal period)	Future Climate Water Supply Analysis (Section 4.3)	Pacific Climate Impacts Consortium (PCIC) – Plan2Adapt

The climate data for the 1981-2010 climate normal period recorded for the EC climate station at St. Mary Lake are considered the most recent and relevant data for the current climate condition and are used for the current climate condition analysis for this study.

Hydrometric Stations

The Water Survey of Canada (WSC) operated a hydrometric station (08HA046 - DUCK CREEK AT OUTLET OF ST. MARY LAKE) downstream of the outlet of St. Mary Lake from 1980 to 1998. However, the station was operated seasonally for most of the period of record. The few years where the station was operated year-round there are significant gaps in the daily flow record, such that there is not a single year of continuous data. The data was also collected prior to the construction of the existing outlet weir. Therefore, the daily flow record for Duck Creek was not considered suitable for use in this hydrological study.

Lake Level

Water levels on St. Mary Lake have been recorded by NSSWD at the St. Mary Lake pump station and water treatment plant since 1981. Water level is recorded manually to the nearest 1 mm using a staff gauge with 1 cm increments. Water level is recorded about once every 5 days to 7 days. Linear interpolation between the recorded values was used to fill in the days with missing lake levels.

The recorded water level data between 2007 and 2014 have been used in this study for the purposes of model calibration. The period of record selected corresponds with the period from construction of the weir at the outlet of St. Mary Lake until the end of the available records at the time of completing this study. It should be noted that the recorded water level data was provided to KWL as that adjusted to geodetic datum assuming the 0.0 m gauge reading is at 40.07 m geodetic. However, the recent survey performed by Polaris Land Surveying Inc. indicates that the true geodetic elevation for the 0.0 m gauge reading is 40.08 m. As a result, a correction factor of +0.01 m has been applied to the recorded water level data set to convert the data to the corrected geodetic elevations.

Back-Calculated Net Inflow Data

Lake net inflow, rather than watershed runoff, is used in water balance assessments as it represents the volume of water available to replenish lake storage for water supply. Lake net inflow is the sum of water flowing into the lake from surface runoff, plus direct rainfall on the lake surface, less evaporation from the lake surface. Net inflows can be negative in summer when evaporation from the lake is greater than inflow and direct rainfall. Shallow groundwater also plays a role in net inflow and can often change in the year from positive inflow to the lake to negative seepage from the lake.

Lake net inflow can be compared directly with water withdrawal rates to assess storage requirements. Using watershed runoff to make the same comparison would require adding direct rainfall to the lake, subtracting lake evaporation and estimating groundwater inflow/seepage.

In order to calibrate the hydrological model used for assessing water availability, recorded lake net inflow data is required to check with the model results and to adjust model parameters to represent specific conditions in the St. Mary Lake watershed. It is not possible to directly measure lake net inflows to the lake. Therefore, historical ‘back-calculated net inflows’ have been estimated using the available recorded lake outflow and lake level data based on the following volume balance equation for the lake:

Total Inflow (WR + DR +/- GW) = Change in Lake Storage (ΔS) + Total Outflow (Outflow + WW + LE)

where

WR = Watershed Runoff including surface flow and shallow interflow into the lake.

DR = Direct Rainfall on the Lake

LE = Lake Evaporation

GW = Shallow Groundwater Inflow to lake/ Groundwater seepage from lake

ΔS = Change in Lake Storage

Outflow = Outflow to Duck Creek including weir overflow and minimum conservation flow through fish ladder

WW = Water Withdrawals from users around the lake including NSSWD

Rearrange the equation leads to the following equation for net inflow calculation:

Net Inflow (WR + DR - LE +/- GW) = Change in Lake Storage (ΔS) + Outflow + WW

Figure 2-5 shows the relationship between the components in the lake volume balance equation.

Change in Lake Storage

The change in lake storage was calculated using available water level records for each day. Missing data for the days between the recorded water level values were linearly interpolated. The change in lake storage over a day was then calculated using the change in water levels from the day before multiplied by the lake surface area. It is assumed that the lake surface area stays constant at different lake levels.

Lake Outflow

Lake outflow to Duck Creek includes two components:

1. Flow through the baffled fish ladder, and
2. Flow over the combined broad crested weir/low flow weir.

Flows through the fish ladder are maintained at approximately 9 L/s to support the required minimum conservation flow stipulated in the water licence for the St Mary Lake weir structure. Discussions with NSSWD staff indicate that the fish ladder is operated year-round such that flow is constantly released through the fish ladder, regardless of lake elevation. Although it is likely that actual flow releases via the fish ladder may vary, no suitable records of discharge are available. Therefore, it has been assumed that 9 L/s is constantly released through the fish ladder year-round.

Outflows from the lake to Duck Creek over the broad crested weir were initially calculated by theoretical weir formula. However comparison made between the theoretical rating curve developed for the weir and five pairs of manual water level and flow measurements collected in 2014 and 2015 shows that the actual flowrates through the weir were less than the theoretical values (see Figure 2-6). This indicates that the broad crested weir at the outlet of St Mary Lake is less efficient than a theoretical broad crested weir. This is consistent with the design of the weir and field observations that indicate that the sloping channel downstream of the weir installed to provide fish passage at higher discharges prevents free overflow of the weir. The recorded manual flow readings were measured with an OTT flow velocity meter when water levels in the lake were above the main weir crest elevation of El. 40.71 m and calculated using the velocity-area discharge method.

In order to give more accurate flow estimation, a rating curve was developed for the broad crested weir based on the actual recorded lake level and flow measurement data. The flow measurements were taken at the downstream of the weir and fish ladder outlet such that the measured flows included the approximately 9 L/s discharge through the fish ladder as well as flow through the low flow notch, estimated to be approximately 14 L/s when lake levels are at the main weir elevation of 40.71 m. As such, 23 L/s was subtracted from the flow measurements prior to developing the rating curve for the broad crested weir.

The rating curve was developed by developing a best-fit between the flow measurements with a power function to estimate discharges via the broad crest weir above the main weir elevation of 40.71 m. When lake levels are between the minimum lake operating level of 40.0 m and the invert of the low flow notch, a constant flow of 0.09 m^3/s is assumed. For the low flow notch section between elevations 40.61 and 40.71 m, flows are estimated based on the constant conservation flow plus theoretical weir formula assuming average weir width of 0.3 m.

The calculation for outflow from St Mary Lake is as follows

For Lake Levels >40.0 m but ≤ 40.61 m	$Q\ (m^3/s) = (9\ L/s)/1000$
For Lake Levels > 40.61 m but ≤40.71 m	$Q\ (m^3/s) = 0.45\ (WL - 40.61)^{1.5} + 0.009$
For Lake Levels > 40.71 m	$Q\ (m^3/s) = 7\ (WL-40.71)^{1.87} + 0.023$

Figure 2-6 shows the lake outflow rating curve developed for St. Mary Lake.

Water Withdrawal

In addition to outflows to Duck Creek, water withdrawals for waterworks purposes and other surface licenced uses also need to be accounted as a part of the water balance for calculating net inflows to the lake. Monthly average withdrawals between 2007 and 2014 were collected from NSSWD and CRD for use in this study. More details regarding the recorded water withdrawals are outlined in the subsequent Section 3.3.

Back Calculated Net Inflow

Given that daily water withdrawal data was not available for this study, the following steps were taken to calculate average monthly back calculated net inflow to St Mary Lake.

1. Calculate daily change in lake storage from linearly interpolated daily lake level records;
2. Calculate daily outflow to Duck Creek over the weir and/or through the fish ladder using the interpolated daily lake level data and the developed outflow rating curve;
3. Calculate daily net inflow (not including water withdrawals) by adding daily change in lake storage and daily outflow volume;
4. Use daily net inflow estimates to calculate monthly total net inflow (not including water withdrawals); and
5. Add the monthly water withdrawal volumes to the monthly net inflow volumes (not including water withdrawals) calculated in step 4 to estimate the total monthly back-calculated net inflow volumes.

The average monthly St. Mary Lake precipitation, back-calculated lake net inflows, outflows and water levels for the 2007 to 2014 period are shown in Figure 2-7.

Uncertainty in Net Inflow Calculation

As the net inflows calculated for St. Mary Lake provide the basis for the water availability estimates, it is important to understand the potential sources of error and potential magnitudes of uncertainty in the estimation of the net inflow record.

The potential sources of uncertainty in the net inflow calculation for St. Mary Lake include:

1. Random error in water level measurement as a result of manual staff gauge readings;
2. Linear interpolation of water level measurements to in-fill missing days between water level readings;
3. Lake seiche (i.e.: water surface sloping across or along lake as a result of wind) which affects the assumption that the lake surface is level and that difference in lake surface elevation can be used to calculate change in lake storage;
4. Limited discharge measurements used in the development of the outflow rating curve, resulting in uncertainty to flows estimated beyond the flow measurement range, e.g. when water levels are higher than the lake level at the highest measured flow (lake level = 40.955 m for flow of 0.484 m^3/s);
5. Backwater impacts due to downstream beaver dam activities or other temporary partial blockages of the downstream channel water way;
6. Assumption that environmental flows in Duck Creek have been maintained at 9 L/s on average when lake levels fall below the crest of the weir; and
7. Uncertainty in the actual water withdrawals from the lake, especially for the water withdrawals that are not recorded such as agricultural and individual domestic users.

It is anticipated that these uncertainties have the greatest impact on back-calculated net inflows through the fall and winter period as lake levels were recorded less frequently during this period. Less frequent collection of lake level data could miss changes in lake levels in between the measures due to inflow events (e.g. rainfalls), and rainfall is more common in the fall and winter periods. As such, the assumption of linear interpolation to estimate daily lake levels between the recorded lake level data would not necessarily represent actual fluctuation in lake level, and could underestimate the actual change in lake storage during the fall and winter periods.

In addition, a number of lake levels recorded in the winter and fall period were greater than the range of lake levels recorded for the flow measurements used in developing the rating curve. The flows estimated for these high water levels may not be accurate due to uncertainties with the rating curve at high lake level conditions. Beaver dam activities, or other partial blockage in the downstream channel, also could result in backwater impacts on lake levels when flows were released from the weir in the winter period. Uncertainty associated with estimated high outlet flows and/or beaver dam activities is likely responsible for a number of winter months having back-calculated lake net inflows greater than the monthly total precipitation.

Spring/summer back-calculated net inflows are likely to be more representative of actual net inflow to the lake as historical lake levels have been recorded more frequently in spring/summer. In addition, smaller rainfall events during the spring and summer season result in less dramatic changes in lake levels, and hence linear interpolation between recorded data points to estimate daily values is likely to be more representative of actual conditions.

The assumption that outflow from the lake to Duck Creek is maintained at the minimum conservation flow of 9 L/s also has an influence on spring/summer back-calculated net inflow estimates if the actual releases are not at exactly 9 L/s at all time. Nevertheless, according to NSSWW, it is reasonable to assume on average conditions over the spring/summer period flows have been released at 9 L/s.

The exception to the preceding statement would be in years when lake levels do not overtop the weir (e.g. latter part of 2008) and release of 9 L/s is assumed to be continuous throughout the year. It is unlikely that flows would be maintained at 9 L/s through the winter period; therefore, back-calculated inflows would likely underestimate actual inflows.

In summary, the uncertainties in the back-calculated net inflow to St Mary Lake mostly derive from the limitations of the available lake level record for St Mary Lake, the limited manual discharge measurements taken for development of the weir rating curve and the assumption that 9 L/s is constantly being released through the fish ladder. However, the back-calculated net inflow provides the best current estimate of water availability to St Mary Lake for the purposes of hydrological model calibration, especially during the critical summer low flow period for which there appears to be less uncertainty in the back-calculated net inflow (compared to the values calculated for the winter period).

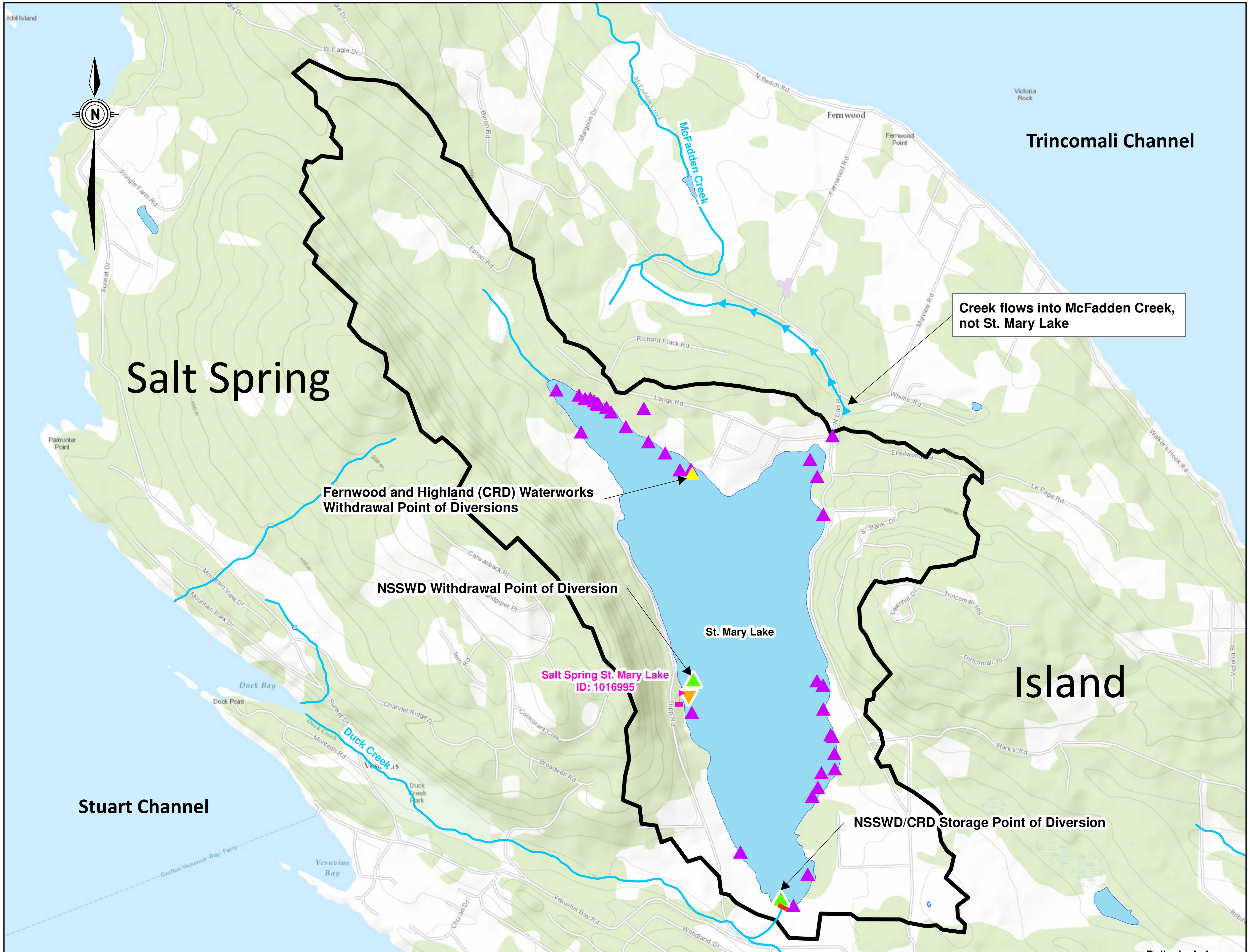
Continuing the manual flow measurements, lake level measurements and climate records developed for this study into the future will assist with reviewing inflow records and will reduce the uncertainty in the net inflow estimates.

2.5 Groundwater

Groundwater plays an important role in the overall water balance of St. Mary Lake. A hydrogeological review was carried out by WRI and is summarized in the letter report included in Appendix C.

Although the WRI report has provided an overview of the groundwater hydrogeology, a full groundwater budget could not be completed due to limitations in groundwater availability and demand data.

For the hydrological modelling performed in this study, the groundwater budget is estimated using groundwater storage, release and deep aquifer loss through model calibration as well as estimates of groundwater extraction based on number of wells in the watershed and typical water extraction rates for domestic users.



St. Mary Lake Watershed
Water Availability and Demand - Climate Change Assessment

Legend

- Weir and Fish Ladder
- Environment Canada Climate Station
- NSSWD Lake Level Gauge

Surface Water Licence - Point of Diversion

- Other
- North Salt Spring Waterworks District (NSSWD)
- Capital Regional District (CRD) Waterworks
- Lake
- Watercourse
- St. Mary Watershed

Source Basemap: NTS 1:50,000 Digital Topographic Mapping

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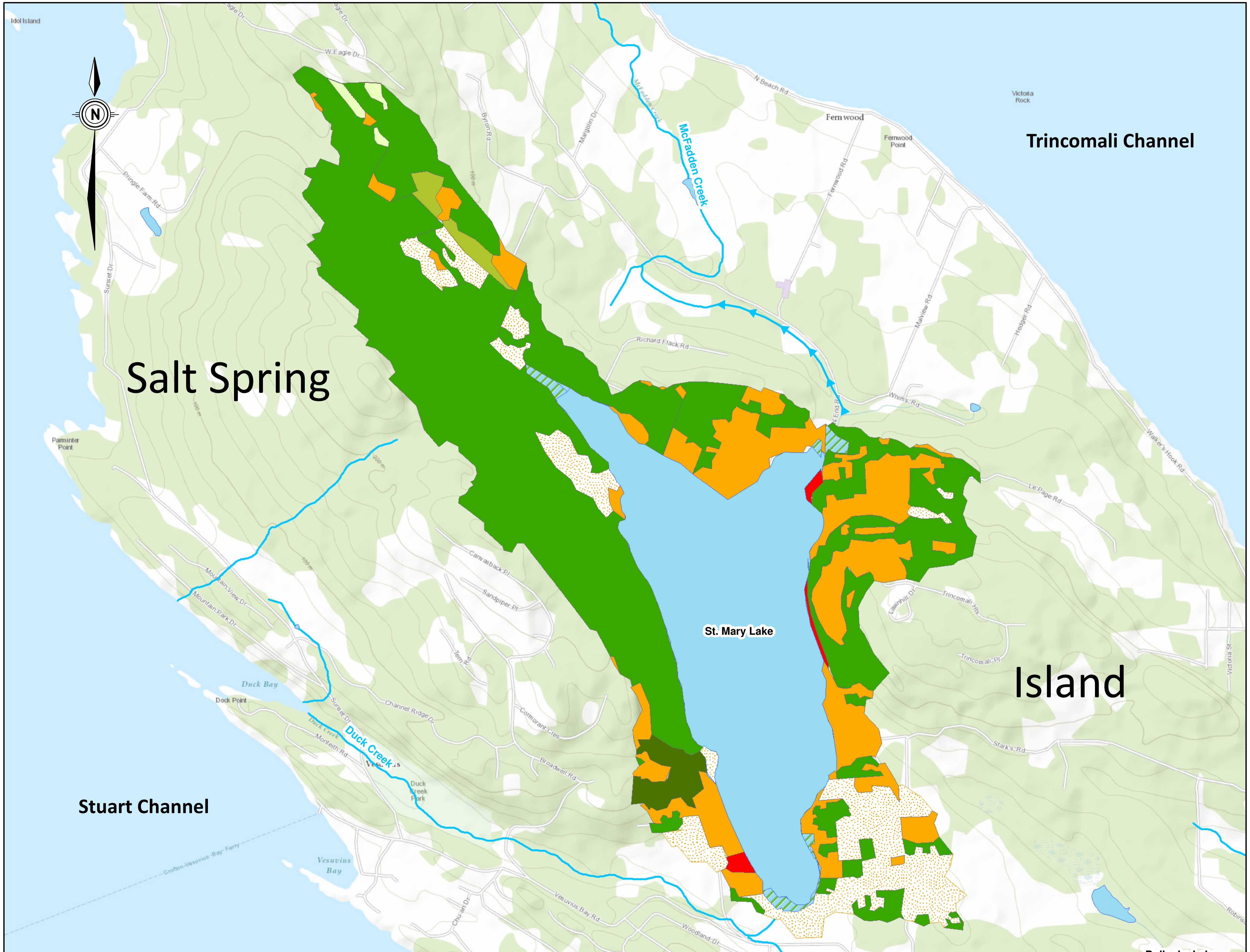
500 0 500 (m)
1:19,872

Project No.	Date
2932.004	October 2014

St. Mary Lake Watershed Map

Figure 2-1

Path: Q:\2900-2999\2932-004\430-GIS\MXD-Rp\2932004_LocationMap_MS.mxd Date Saved: 06/10/2014 4:15:26 PM
Author: MScruton



St. Mary Lake Watershed
Water Availability and Demand -
Climate Change Assessment

Legend

Watercourse

Land Cover

- Agriculture
- Developed
- Herbaceous
- Lake
- Mature Forest
- Rural
- Wetlands
- Woodland
- Young Forest

Land Cover data sourced from the St. Mary Lake Watershed Management Plan prepared by the St. Mary Lake Steering Commitee, 2009

Source Basemap: NTS 1:50,000 Digital Topographic Mapping

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Project No.	Date
2932.004	October 2014

Land Cover in the
St. Mary Lake Watershed

Figure 2-2

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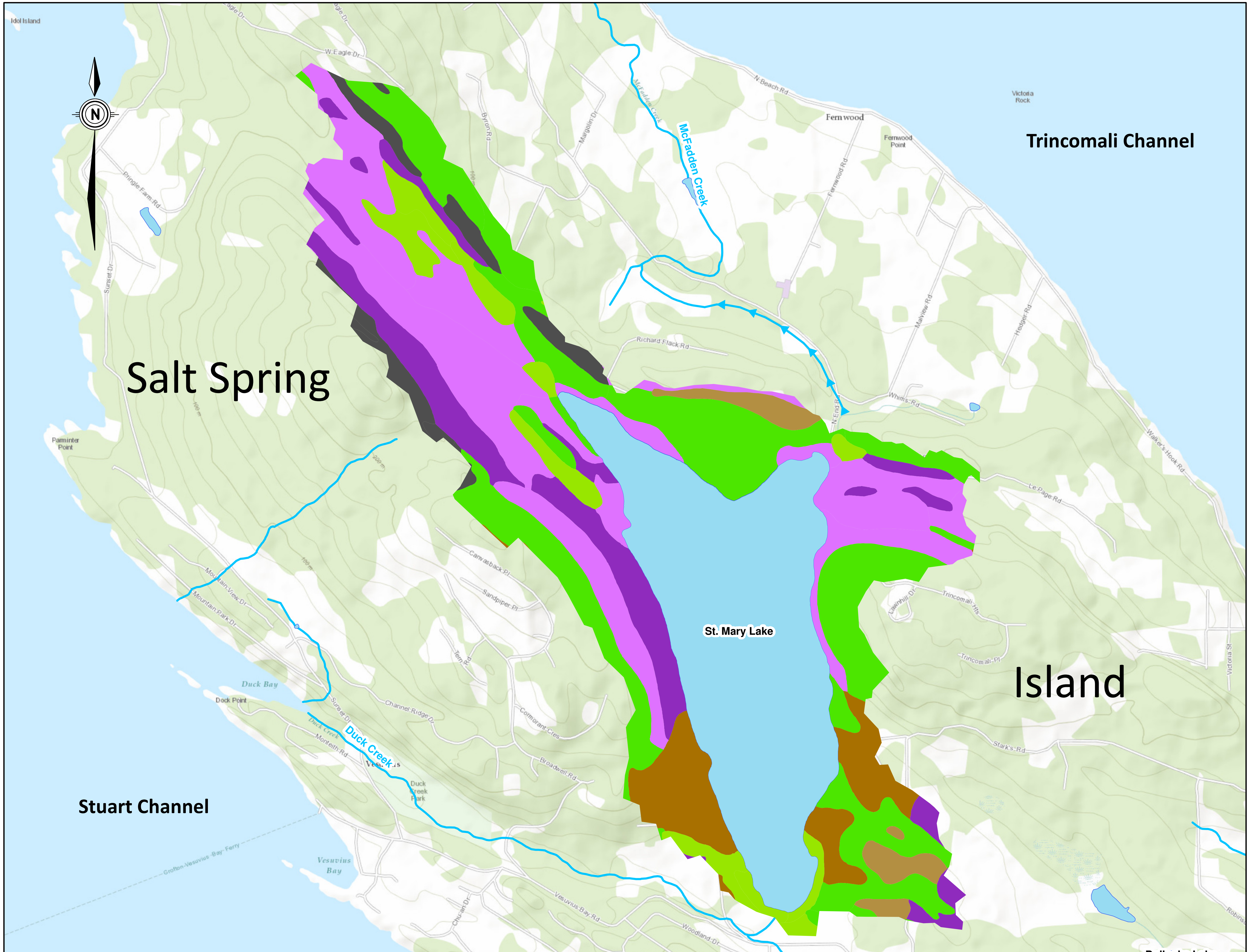
Author: MScruton



St. Mary Lake Watershed
Water Availability and Demand -
Climate Change Assessment

Legend

Watercourse

Soil Type

- bedrock
- gravelly loamy sand
- gravelly sandy loam
- lake
- loamy sand
- sandy clay loam
- shaly loam to shaly silt loam
- shaly sandy loam

Soil Data sourced from Agriculture Canada - Soils of the Gulf Islands of British Columbia, Report No. 43, 1987

Source Basemap: NTS 1:50,000 Digital Topographic Mapping

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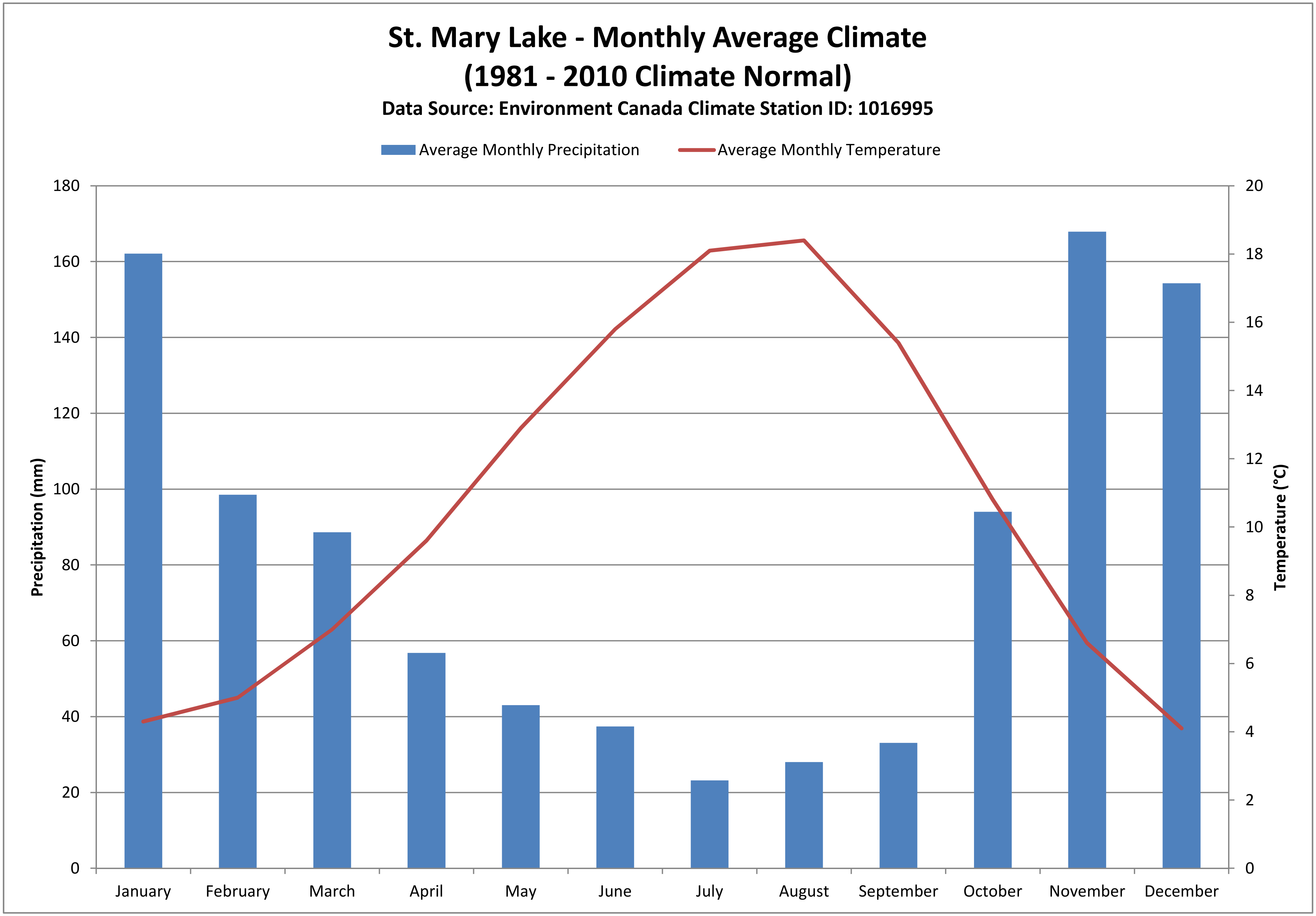
Project No.	Date
2932.004	October 2014

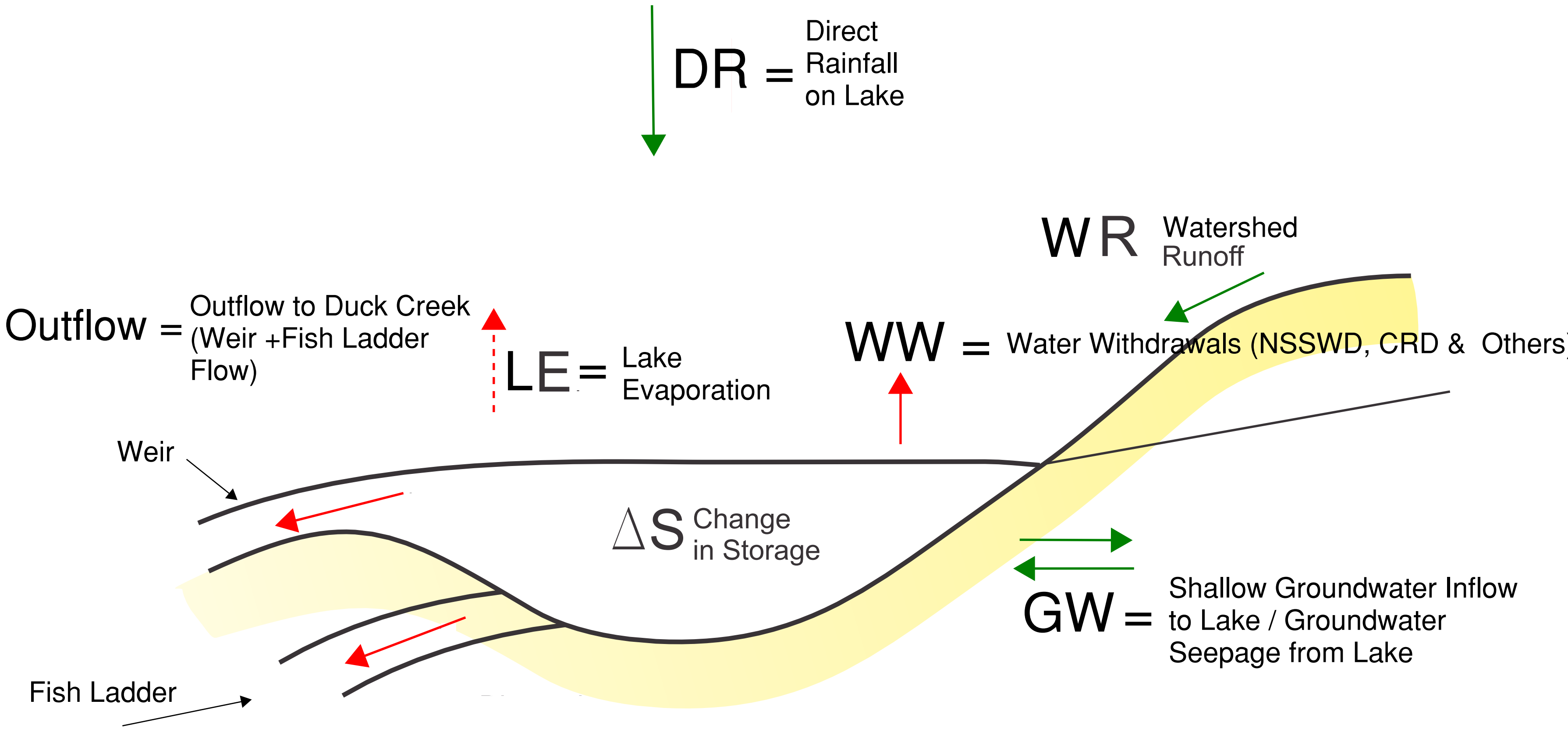
Surficial Soils in the St. Mary Lake Watershed

Figure 2-3

Path: Q:\2900-2999\2932-004\430-GIS\MXD-Rp\2932004_SoilMap_MS_20141003.mxd Date Saved: 06/10/2014 4:16:22 PM
Author: MScruton

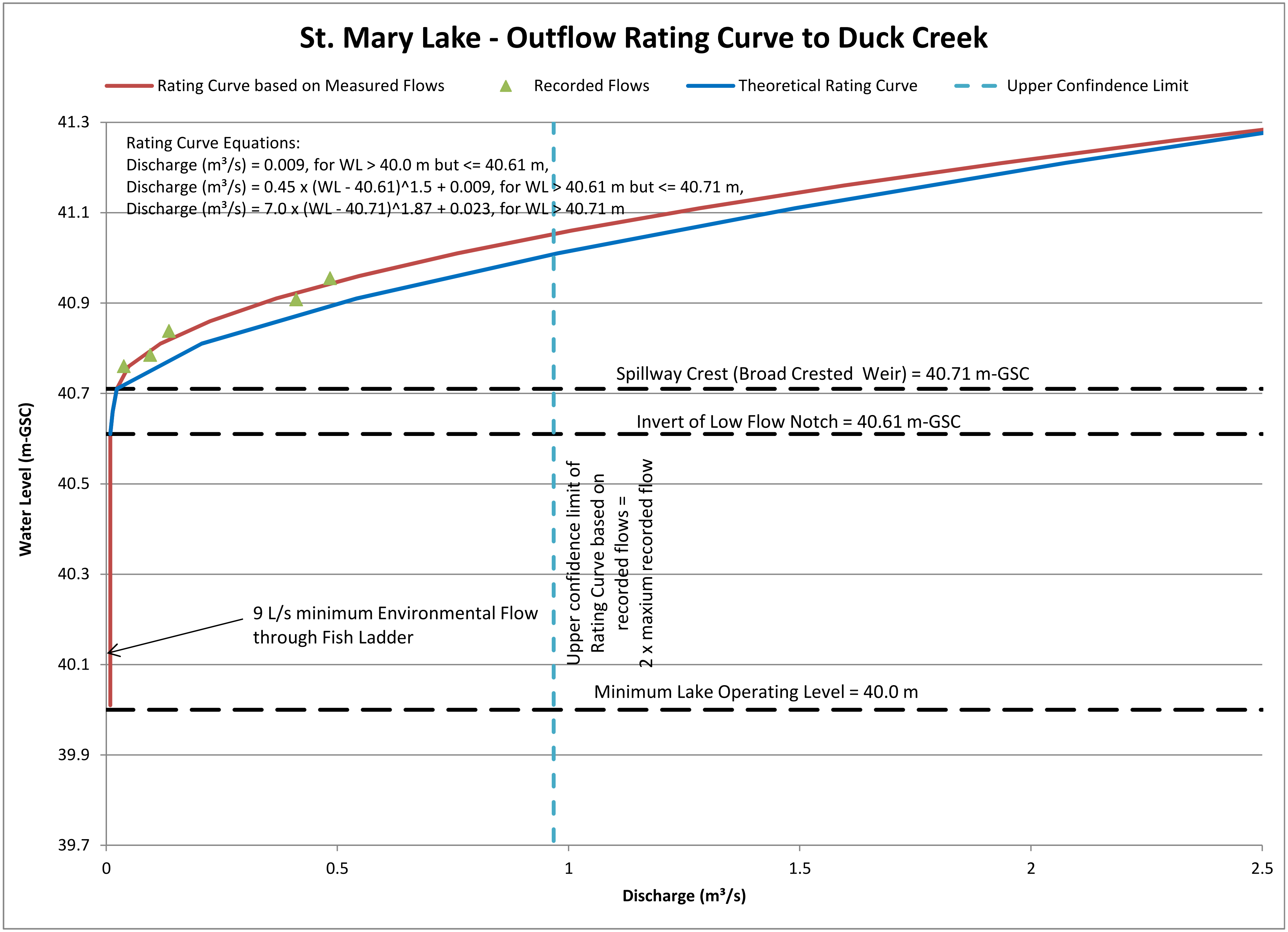

St. Mary Lake - Monthly Average Climate
(1981 - 2010 Climate Normal)
Data Source: Environment Canada Climate Station ID: 1016995
Average Monthly Precipitation
Average Monthly Temperature
Precipitation (mm)
Temperature (°C)
0
20
40
60
80
100
120
140
160
180
0
2
4
6
8
10
12
14
16
18
20
January
February
March
April
May
June
July
August
September
October
November
December

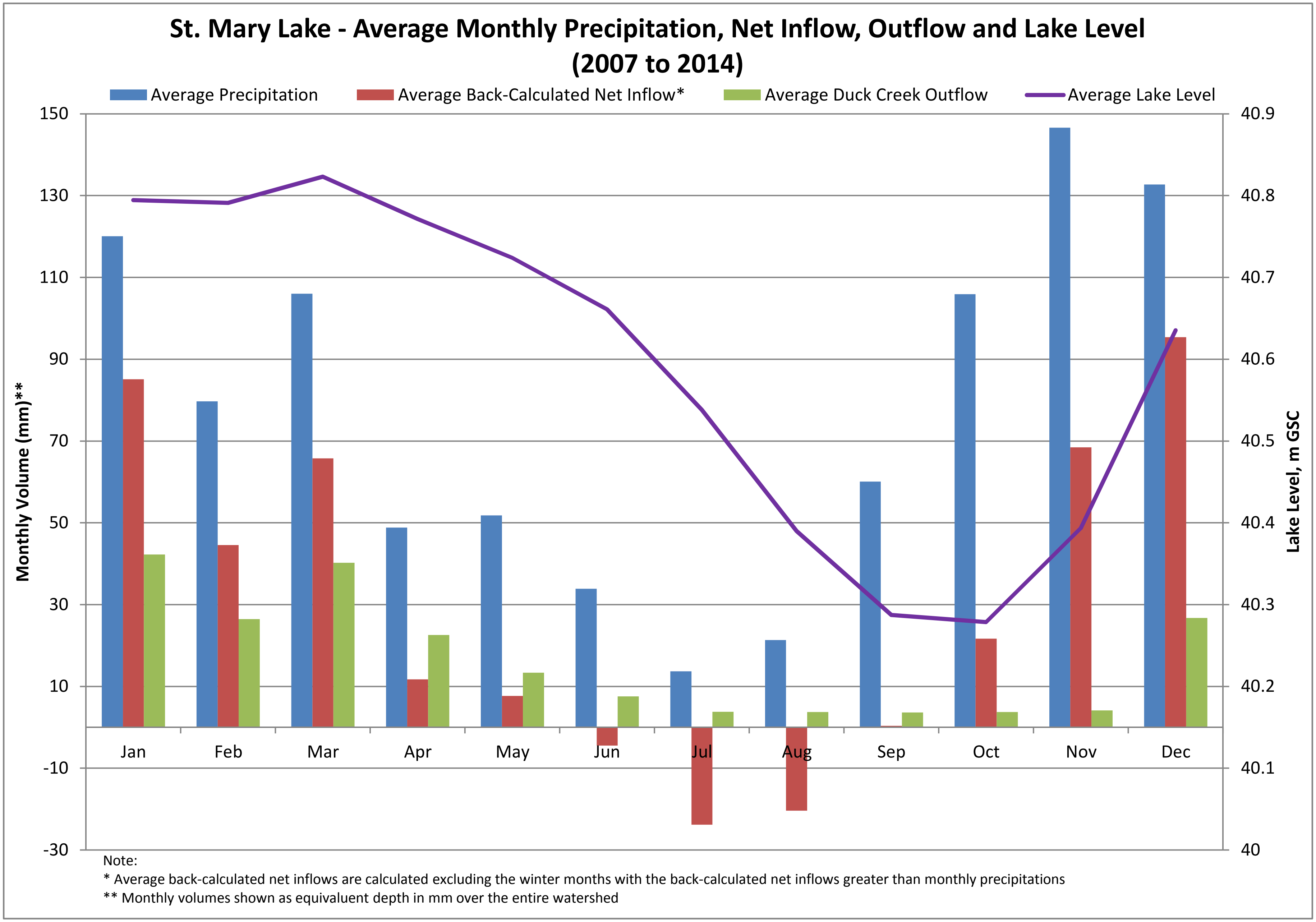
724-006\500-Drawings\724006Fig3-1.CDR



$$\text{Net Inflow } (WR + DR - LE \pm GW) = \Delta S + \text{Outflow} + WW$$

KERR WOOD LEIDAL consulting engineers	St. Mary Lake Watershed Water Availability and Demand - Climate Change Assessment
Project No. 2932-004 / Date May 2015	**Lake Volume Balance Schematic**
N.T.S.	**Figure 2-5**


St. Mary Lake - Outflow Rating Curve to Duck Creek
Rating Curve based on Measured Flows
Recorded Flows
Theoretical Rating Curve
Upper Confindence Limit
Rating Curve Equations:
Discharge (m³/s) = 0.009, for WL > 40.0 m but <= 40.61 m,
Discharge (m³/s) = 0.45 x (WL - 40.61)^1.5 + 0.009, for WL > 40.61 m but <= 40.71 m,
Discharge (m³/s) = 7.0 x (WL - 40.71)^1.87 + 0.023, for WL > 40.71 m
Spillway Crest (Broad Crested Weir) = 40.71 m-GSC
Invert of Low Flow Notch = 40.61 m-GSC
Upper confidence limit of Rating Curve based on recorded flows = 2 x maxium recorded flow
9 L/s minimum Environmental Flow through Fish Ladder
Minimum Lake Operating Level = 40.0 m
Water Level (m-GSC)
Discharge (m³/s)
41.3
41.1
40.9
40.7
40.5
40.3
40.1
39.9
39.7
0
0.5
1
1.5
2
2.5



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St. Mary Lake Watershed Water Availability and Demand - Climate Change Assessment
Monthly Average Precipitation, Lake Net Inflow, Outflow and Lake Water Level
Figure 2-7

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Section 3

Current State of Water Resources - Supply and Demand

3. Current State of Water Resources – Supply and Demand

3.1 Supply and Demand Water Balance

A water balance assessment provides a comparison of water availability and demand in a watershed. It is based on the conservation of volume, which for a water balance assessment means that the total volume of water can be accounted for as it moves through the watershed and is consumed by water users.

Some of the main assumptions used in a water balance assessment include:

1. The watershed is a closed system bounded by the height of land (the watershed boundary) and that all shallow groundwater and surface water eventually flows to the outlet of the watershed: for this study, the outlet of St. Mary Lake.
2. Water flowing into deep groundwater is “lost” to the system and does not eventually flow to the outlet of St. Mary Lake.
3. A watershed hydrological model calibrated to back-calculated lake net inflows accurately accounts for movement of water through the various components of the water cycle and estimates net inflows to the lake based on precipitation and temperature records, soils mapping and land cover.
4. Water withdrawals are considered to be removed from the system and do not flow back into the watershed.

The first three assumptions simplify the complex nature of water movement through the watershed. Modelling provides good estimates of average water flow through the system and, as such, good indication of average available water supplies.

The final assumption is valid as the majority of the water withdrawn from St. Mary Lake is distributed to properties outside of the watershed boundary.

The following section outlines the hydrological modelling and water balance assessment carried out for the St. Mary Lake Watershed.

3.2 Watershed Hydrological Modelling

Monthly Water Balance Model

To quantify available water supply within the watershed, a monthly water balance model was developed based on the USGS method (USGS, 2007). The monthly water balance model calculates the monthly average net inflows to St. Mary Lake using inputs of land cover, soil type, precipitation and temperature across the basin.

The model accounts for movement of water through the various components of the water cycle within the watershed, including:

1. Precipitation (Rain and Snow depending on temperature);
2. Snowpack Accumulation and Snow Melt (which has been found to be not applicable within the study watershed);
3. Evapotranspiration (depending on temperature, hours of sunlight, land cover and soil moisture);

4. Evaporation from the lake surface (dependant on temperature and hours of sunlight);
5. Soil Moisture Storage (dependant on precipitation, soil type, evapotranspiration and infiltration to groundwater);
6. Surface Water Storage;
7. Groundwater Storage (dependant on soil type and infiltration); and
8. Groundwater Deep Aquifer Loss.

A schematic of the water balance model process is shown in Figure 3-1.

Monthly average lake net inflows estimated by the water balance model account for the storage changes in the entire watershed including in soils, in groundwater and in the lake, and the losses via watershed evapotranspiration, lake evaporation and deep aquifer seepage. The model calculates the total lake net inflows (or watershed supply), that are available for licenced withdrawals and outflows to Duck Creek. The model is also used to assess how projected changes in temperature and precipitation could impact available water supplies under future climate conditions.

The monthly time step used in this study is considered appropriate given the limitations of the data available for calibration. More sophisticated hydrological models typically run on daily time increment, but would require both input and calibration data at least daily intervals.

Given that the focus of this study is to review the overall water balance in the watershed, using a monthly time step provides sufficient resolution to simulate the influence of seasonal changes in precipitation and water availability within the limitations of the available data. In addition, climate change projections from GCMs are readily available at monthly time steps.

No detailed groundwater modelling was conducted as part of this study. Groundwater was modelled as a single storage reservoir, which does not account for variations in aquifer characteristics and geological formations across the watershed. Therefore, the hydrological model cannot be used to assess the distribution of groundwater availability from one part of the watershed to another. However, this approach does provide a reasonable estimate of the seasonal fluctuation of groundwater availability across the entire watershed.

Model Calibration

To confirm that the hydrological model is accurately representing the hydrological process within the St. Mary Lake watershed, the monthly water balance model was run continuously for the period of 2007 to 2014 and calibrated by comparing the model output with the monthly back-calculated lake net inflows.

Monthly average temperatures and monthly average precipitation for the continuously-modelled period of 2007 to 2014 were used as the climate inputs to the model.

Model parameters such as groundwater infiltration percentage, groundwater runoff factor and groundwater deep aquifer loss percentage were adjusted until a good match between the back-calculated lake net inflow data and the modelled output was achieved. Due to the uncertainty in the back-calculated net inflows during the fall/winter period as described in Section 2.4, the calibration was focused mainly on matching the flows in the spring/summer period (May to October). Table 3-1 provides a summary of the parameters calibrated for the St. Mary Lake water balance model.

Table 3-1: St. Mary Lake Hydrological Model Calibrated Parameters

Parameter	Value	Description
Max Snow Melt Rate	100%	Max % of accumulated snowpack which can melt in one month
Direct Runoff (DR)	• 5% for typical land • 95% for bedrock	% of rainfall which flows directly to surface runoff (ie: impervious areas)
Groundwater Runoff (GW) Factor	7%	% of groundwater storage that is released to surface runoff each month
Soil Moisture Capacity (SMC)	Varies from 50 to 300 mm/month depending on soil type	Amount of water that can be stored in the soil (sands/gravels have a low SMC)
Max Soil Infiltration Rate (IR)	Varies from 50 to 400 mm/month depending on soil type	Maximum infiltration rate to soil moisture capacity
Max Groundwater Recharge	30% of IR (mm/month)	Maximum rate that groundwater storage is recharged from soil moisture storage.
Deep Aquifer Loss	8%	% of groundwater storage that is lost to deep aquifer per month

Figure 3-2 shows the comparison of the average modelled and back-calculated monthly lake net inflows for the simulation period of 2007 to 2014. The figure shows a very good match of the modelled average monthly lake net inflows to the back-calculated values for the entire calibration period. Charts comparing model results with back-calculated monthly lake net inflows for each modelled years are included in Appendix D. Results for the individual years show that in general the model provides reasonable simulation for the monthly lake net inflows. The modelled results match better to the back-calculated values in the summer months than in the winter period.

The calibration results are also summarized in Table 3-2 showing the volumetric comparison of modelled and back-calculated net inflows for each water year (October to September of the following year) and spring/summer season through the calibration period. The modelled and back-calculated annual “runoff factors” (ratio between total annual runoff volume and total annual precipitation volume) were also calculated and summarized in Table 3-2.

The results in Table 3-2 indicate that the modelled annual lake net inflows for the 2007/08, 2008/09, 2011/12 and 2012/13 water years compare well with the back-calculated lake net inflows with annual net inflow volume differences less than 6%. The modelled and back-calculated runoff factors for these years are also very similar ranging from 0.25 to 0.42, and 0.25 to 0.43, for the modelled and back-calculated values respectively.

For the other three water years (2009/10, 2010/2011 and 2013/2014) in the calibration period, the modelled annual lake net inflow volumes are 24% to 31% less than the back-calculated volumes. The modelled runoff factors for these three water years are also less than the runoff factors estimated based on the back-calculated lake net inflows. This could be possibly due to beaver dam activities, or possibly other partial blockage in the downstream channel that caused backwater impacts on the lake levels in the winter period and therefore result in higher than actual back-calculated net inflows (see also Uncertainty in Net Inflow Calculation in Section 2.4 of this report).

The average annual net inflows were calculated, excluding the three water years with the suspected higher than actual back-calculated winter net inflows as discussed above. The results show that the modelled total average annual lake net inflow volume of 1.959,000 m³ is only 6,000 m³ greater than the average total annual back-calculated net inflow volume or a difference of about 1%. The average annual runoff factors for the modelled and back-calculated net inflows are both at 0.34.

The spring/summer (May to September) volumetric results summarized in Table 3-2 show the modelled and back-calculated spring/summer net inflows agree well in 5 out of the 7 years of the total calibration period, except in 2010 and 2013. It was noticed that both these two years had greater than average spring/summer rainfall volumes and there were extended periods in the spring when the lake level was above the effluent weir. The challenge with the calibration for these two years is likely due to the uncertainties with estimating the outflow to Duck Creek as discussed in Section 2.4. Excluding the data for 2010 and 2013, the modelled average spring/summer net inflow volume is 364,000 m³, same as the back-calculated average spring/summer lake net inflow volume.

Based on the calibration results discussed above, it is considered that the model developed for the St. Mary Lake watershed has been reasonably calibrated and it is suitable to use this model to perform the water availability assessment required in this assignment.

Table 3-2: St. Mary Lake Water Balance Model Calibration Results (2007 to 2014)

Parameters	Water Year (Oct to Sep)							Range[1]		Average[1]
	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	Min	Max	
Annual Precipitation, 1,000 m^3	5,236	4,444	7,851	6,043	5,041	7,462	4,498	4,444	7,462	5,546
Annual Net Inflow, 1,000 m^3 (Modelled)	1,868	1,128	3,760	2,471	1,707	3,134	1,325	1,128	3,134	1,959
Annual Runoff Factor (Modelled)	0.36	0.25	0.48	0.41	0.34	0.42	0.29	0.25	0.42	0.34
Annual Net Inflow, 1,000 m^3 (Back-Calculated)	1,767	1,093	5,268	3,247	1,757	3,198	1,908	1,093	3,198	1,953
Annual Runoff Factor (Back-calculated)	0.34	0.25	0.67	0.54	0.35	0.43	0.42	0.25	0.43	0.34
Annual Net Inflow Difference (Modelled - Back-calculated), 1,000 m^3	101	36	-1,508	-776	-50	-63	-583	-63	101	6
% Difference Between Modelled and Back-calculated Total Annual Net Inflow	6%	3%	-29%	-24%	-3%	-2%	-31%	-3%	6%	1%
Parameters	**Spring/Summer Period (May to Sep)**							**Range[2]**		**Average[2]**
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Min**	**Max**	
Spring/Summer Percipitation,1,000 m^3	951	948	1,548	1,113	702	1,812	904	702	1,113	924
Spring/Summer Net Inflow, 1,000 m^3 (Modelled)	-327	-420	-52	-199	-397	-39	-475	-475	-199	-364
Spring/Summer Net Inflow, 1,000 m^3 (Back-Calculated)	-314	-493	64	-191	-365	-121	-457	-493	-191	-364
Spring/Summer Net Inflow Difference (Modelled - Back-calculated),1,000 m^3	-13	73	-117	-9	-31	82	-18	-31	73	0
% Difference Between Modelled and Back-calculated Spring/Summer Net Inflow	4%	-15%	-181%	5%	9%	-67%	4%	-15%	9%	1%

Note:

1. Range and average values for water year do not include 2009/10, 2010/11 and 2013/14 water years due to large differences between modelled and back-calculated net inflow volumes and runoff factors.
2. Range and average values for spring/summer period do not include the spring/summer of 2010 and 2013 due to large differences between modelled and back-calculated net inflow volumes.

Water Balance Model Results - Current Climate

Average monthly lake net inflows for the St. Mary Lake Watershed for an average year under the current climate condition were calculated using the monthly water balance model and monthly average temperature and precipitation data for the 1981 to 2010 climate normal period. The results are summarized in Table 3-3.

Table 3-3: St. Mary Lake Water Balance Model Results – Current Climate (1981 to 2010) Condition

Month	Average Year			10-year Return Period Drought		
	Average Temp. °C	Average Precip. mm	Modelled Average Lake Net Inflow, mm	Average Temp. °C	Average Precip. mm	Modelled Average Lake Net Inflow, mm
Jan	4.3	162.1	109.6	5.8	113.2	53.4
Feb	5.0	98.5	67.7	6.6	74.9	43.1
Mar	7.0	88.6	42.0	8.3	64.2	25.0
Apr	9.6	56.8	17.9	10.7	40.5	11.0
May	12.9	43.0	4.0	14.4	31.5	-2.7
Jun	15.8	37.4	-6.0	17.4	27.6	-12.8
Jul	18.1	23.2	-17.7	19.6	17.1	-23.1
Aug	18.4	28.0	-14.8	19.7	22.2	-19.4
Sep	15.4	33.1	-4.2	16.8	26.3	-8.6
Oct	10.8	94.0	25.6	11.9	65.7	14.6
Nov	6.6	167.9	74.8	8.2	120.0	42.0
Dec	4.1	154.3	116.0	6.2	113.9	62.7
Total		**986.9**	**414.9**		**717.0**	**185.2**
Spring/ Summer (May to Sep)		**164.7**	**-38.7**		**124.6**	**-66.6**
Note: Modelled lake net inflow volume is shown as equivalent depth in mm over the entire watershed.						

10-year Return Period Drought Water Supply

In addition to the average current climate conditions, the 10-year return period drought condition was selected as the lake net inflow scenario representing lake net inflow availability and storage requirements under severe dry weather conditions. The available monthly temperature and precipitation data from Environment Canada for the St. Mary Lake Climate Station (1976 to 2006) were used to perform the drought analysis (Appendix E).

The Log Pearson Type III extreme value distribution was used to estimate the 10-year return period drought total annual precipitation (10-year return period low) and average monthly temperatures (10-year return period high). The 10-year return period drought total annual precipitation was then distributed over the months using the relative monthly average precipitation vs. average annual precipitation ratios calculated from the climate record. These monthly average precipitation and monthly temperature data were used as input to the water balance model to estimate monthly average lake net inflows for the 10-year return period drought condition. The results are also presented in Table 3-3 above.

3.3 Water Demand and Storage

Licenced Surface Water Withdrawal Limits

A total annual withdrawal limit of 1,593,000 m³ (rounded to the nearest 1,000 m³) is licenced for St. Mary Lake for the purposes of municipal water supply, agriculture, industrial uses and private domestic water supply. A summary of the annual licenced withdrawal volumes and the number of licences is shown in Table 3-4 below.

Table 3-4: Summary of St. Mary Lake Water Licences and Total Surface Water Withdrawal Limit

Type	Total Annual Volume (1,000 m³)	Percent	Total Number
Agriculture	102.6	6.4%	12
Domestic	28.21	1.8%	30
Industrial	29.87	1.9%	6
Waterworks	1,432.3	89.9%	9
Total Withdrawal Limit	1,593		53*
Max. Daily (L/s)	50.5		
Note: Total number of 53 water licences does agree with the total added up number of the individual water licences (57). This is because that there are 4 private licences issued for both agriculture and domestic uses.			

As outlined in Table 3-4, municipal waterworks make up the largest percentage of the total licenced withdrawal limit from St. Mary Lake. There are three waterworks districts that withdraw water from St. Mary Lake:

- the North Salt Spring Waterworks District,
- Highland Waterworks, and
- Fernwood Waterworks.

Both the Highland and Fernwood Waterworks Districts are managed and operated by the Capital Regional District (CRD). A summary of the waterworks water licences is shown in Table 3-5.

Table 3-5: Summary of St. Mary Lake Waterworks Licences

Licence Number	Annual Volume		Date of Precedence
	Imperial (1,000 gal)	Metric (1,000 m³)	
North Spring Waterworks District			
C032525	45,625	207.415	June 26, 1967
C047548	136,875	622.246	Oct 8, 1975
C101050	80,000	363.687	Mar 4, 1988
C120417	2,007.5	9.126	April 21, 1969
Sub Total	**264,508**	**1,202.47**	
Highland Waterworks (CRD)			
C065711	21,619	96.236	Mar 6, 1968
C065712	4,876	22.126	Mar 31, 1970

Licence Number	Annual Volume		Date of Precedence
	Imperial (1,000 gal)	Metric (1,000 m³)	
C065713	1,703	7.741	Dec 11, 1973
Sub Total	**28,198**	**126.10**	
Fernwood Waterworks (CRD)			
C104325	4,563	20.743	Feb 14, 1992
C120491	18,250	82.966	Oct 10, 1963
Sub Total	**22,813**	**103.71**	
Total Annual Volume All Waterworks licences	**275,519**	**1,432.3**	

Note:
1. The Salt Spring Island Fire Protection District licence to withdraw up to a maximum of 80 L/s from St. Mary Lake for fire water supply has not been included in the analysis as it would be a short term demand.
2. Imperial units are the licenced quantities shown on the water licences with converted metric values shown that were used in this study.

Current Surface Water Withdrawal

Average current waterworks withdrawals from the three waterworks districts were calculated using available recorded water usage data for the period between 2007 and 2014. These data are used in the study for calibration of the water balance model to account for the effect of actual water withdrawals from the lake during the calibration period. The current average total annual amounts from each of the waterworks districts are shown in Table 3-6.

Table 3-6: Current Waterworks Water Demand – Average Total Annual Volume (2007 to 2014)

Average Annual Withdrawal (1,000 m³)			
NSWWD	Highland (CRD)	Fernwood (CRD)	Total
395.0	77.6	23.2	495.8

Total average annual withdrawal is equal to 1.412 MLD average day demand.

In addition to the withdrawals from the waterworks, withdrawals from other water licences were also estimated based on the full licenced amount in calculating the total current average monthly water withdrawals that used as a part of the lake outflows for model calibration.

Surface Water Storage

In addition to water licences to permit withdrawals, there are water licences that permit storage of water in St. Mary Lake. The total licenced storage on the lake is about 400,881 m³. A summary of the breakdown of the water licences for storage is shown in Table 3-7.

Table 3-7: St. Mary Lake Water Licences for storage (as of June 2013)

Licencee	Licence Number	Storage Volume (ac-ft)	Storage Volume (1,000 m³)
North Salt Spring Waterworks District	C101050	300	370
Capital Regional District (Waterworks)	C104325	25	30.8
Total		325	400.8

Note: Imperial units provide quantities in the licence while the quantities converted to metric units are those used in this study.

The volume of water licences for storage are based on increase in positive storage in the lake above the original outlet elevation of 40.53 m (based on letter prepared by Mr. Hamilton dated October 28, 1997). The water licences allows for storage between El. 40.0 m to El. 41.0 m.

Based on the existing St. Mary Lake surface area of 1.823 km², the total live storage available is calculated to be 1,294,000 m³ between the minimum licence allowed lake storage level at El. 40.0 m and the weir crest at El. 40.71 m. The small v-notch in the crest of the weir which has an invert elevation of 40.61 m has been ignored for the purposes of calculating storage volume. This indicates that actual live storage in the lake is about three times the total licenced storage as the weir is designed to allow lake level to be drawn down below original lake outlet down to El. 40.0 m.

It should be noted that the existing weir has been designed such that it can be raised by 0.29 m in the future to crest El. 41.0 m. This would provide an additional 528,670 m³ of storage to a total of 1,823,000 m³ available live storage in the lake.

Conservation Flow

The NSSWD is required under water licence to release a minimum conservation flow to Duck Creek. As reported in the environmental assessment report for the upgrading of the St. Mary Lake weir, a conservation flow of 9 L/s is suitable for minimum conservation flow based on 10% of estimated mean annual discharge for Duck Creek (Hamilton, 1998). This is equivalent to up to 285,000 m³ per year.

Monthly Distribution of Water Withdrawals

The water balance assessment for St. Mary Lake has been performed on a monthly basis, monthly distribution data of the current water demand and the licenced withdrawal limit for assessment of available storage are required. The licenced withdrawal limit is assumed to represent the maximum potential future withdrawal and is used for the purposes of assessment of St. Mary Lake storage capacity.

The monthly distribution of current water demand is assumed to consist of:

1. Average monthly recorded water usage for the NSSWD and the two CRD water works systems for the period from 2007 to 2014;
2. Equal withdrawal each month throughout the year for industrial water usage at the licenced withdrawal limit; and
3. Equal withdrawal each month during the summer period from July to September for agricultural water usage at the licenced withdrawal limit.

The monthly distribution of the total licenced withdrawal limits is assumed to consist of:

1. Monthly distribution of domestic and waterworks withdrawal limits based on average of monthly recorded water usage for the NSSWD and the two CRD water works systems for the period from 2007 to 2014;
2. Equal withdrawal in each month throughout the year for industrial licenced amount; and
3. Equal withdrawal in each month during the summer period from July to September for agricultural licenced amount for irrigation purposes.

Based on the above assumptions, the total current monthly and the total licenced monthly withdrawal limits from St. Mary Lake were estimated and summarized in Table 3-8 and Table 3-9, respectively.

Figure 3-3 and Figure 3-4 show the monthly distribution of the current monthly withdrawals and the licenced withdrawal limits, respectively.

Table 3-8: Monthly Distribution of Current Water Withdrawal

Month	Recorded Waterworks Withdrawal 2007 – 2014 Avg. 1000 m³	Licenced Withdrawal Limits, 1000 m³			Current Water Withdrawal 2007 – 2014 Avg. 1000 m³
		Domestic	Agricultural	Industrial	
Jan	32.61	1.86		2.53	37.00
Feb	29.90	1.70		2.37	33.97
Mar	33.13	1.89		2.53	37.55
Apr	34.50	1.96		2.45	38.91
May	42.66	2.43		2.53	47.62
Jun	49.47	2.81	25.65	2.45	80.38
Jul	64.62	3.68	25.65	2.53	96.47
Aug	61.00	3.47	25.65	2.53	92.64
Sep	44.73	2.55	25.65	2.45	75.37
Oct	36.11	2.05		2.53	40.69
Nov	33.07	1.88		2.45	37.40
Dec	33.98	1.93		2.53	38.44
Total	**495.8**	**28.2**	**102.6**	**29.9**	**656.4**
Summer May to Sep					**392.5**

Table 3-9: St. Mary Lake Monthly Total Licenced Withdrawal Limits

Month	Licenced Withdrawal Limits, 1000 m³					Total Licenced Withdrawal Limits
	NSSWD Waterworks	Other Waterworks	Domestic	Agricultural	Industrial	1000 m³
Jan	79.09	15.12	1.86		2.53	98.59
Feb	72.53	13.86	1.70		2.37	90.46
Mar	80.36	15.36	1.89		2.53	100.13
Apr	83.67	15.99	1.96		2.45	104.07
May	103.46	19.77	2.43		2.53	128.20
Jun	119.99	22.93	2.81	25.65	2.45	173.84
Jul	156.73	29.95	3.68	25.65	2.53	218.53
Aug	147.94	28.27	3.47	25.65	2.53	207.86
Sep	108.49	20.73	2.55	25.65	2.45	159.86
Oct	87.58	16.74	2.05		2.53	108.90
Nov	80.21	15.33	1.88		2.45	99.87
Dec	82.41	15.75	1.93		2.53	102.63
Total	**1,202**	**229.8**	**28.2**	**102.6**	**29.9**	**1,592.9**
Summer May to Sep						**888.3**

3.4 Water Budget – Current Climate Conditions

A water budget has been carried out for St. Mary Lake to assess if the current available storage is sufficient to support both total licenced withdrawal limit and the minimum conservation flows in Duck Creek. The total licenced withdrawal limit has been used to represent the maximum possible withdrawals from the lake. In other words, it is assumed that the water demand from the lake will be maintained below the licenced withdrawal limit. Therefore, for clarity the term maximum surface water demand is used in the remainder of this section to represent the sum of the licenced withdrawal limit and the minimum conservation flow release to Duck Creek.

By comparing the modeled monthly average net inflows to St. Mary Lake with maximum monthly surface water demands, monthly storage requirement volumes can be calculated. The monthly storage requirement is equal to the amount of additional water required to support maximum surface water demands on a monthly basis. When the monthly lake net inflow is less than the maximum monthly surface water demand, the difference between the lake net inflow and the maximum monthly surface water demand is the monthly storage requirement. The maximum accumulated storage requirement volume is the total lake storage required to support maximum surface water demands, including both licenced withdrawals at the withdrawal limits and minimum conservation flows. The lake storage is supplied by water stored in the lake when lake net inflows are greater than the surface water demands.

Figure 3-5 and Figure 3-6 shows the comparison between the modelled lake net inflows and maximum surface water demands (the sum of the maximum licenced withdrawal limits and the minimum environmental flows), and the estimated storage requirement for St. Mary Lake under the current climate (1981 to 2010 climate normal period) annual average and the 10-year return period drought conditions. Table 3-11 summarizes the water balance assessment results.

Table 3-10: Water Balance Assessment Results – Current Climate (1981-2010 Climate Normal)

Parameter	Average Year	10-Year Return Period Drought*
Annual Precipitation, mm	987	717.0
Annual Lake net Inflow, mm	415	185.2
Annual Lake net Inflow, 1,000 m³	2,685	1,198
Annual Maximum Surface Water Demand, 1,000 m³	1,878	1,878
Lake Draw Down Period when required surface water demand is greater than net inflow.	Apr-Sep	Apr-Oct
Precipitation during Lake Draw Down Period, mm	221.5	230.8
Lake Net Inflow during Lake Draw Down Period, mm	-20.8	-41.0
Lake Net Inflow during Lake Draw Down Period, 1,000 m³	-134	-266
Licenced Withdrawal Volume during Lake Draw Down Period, 1,000 m³	992	1,101
Fisheries Releases during Lake Draw Down Period, 1,000 m³	142	166
Required Storage*, 1,000 m³ (Licenced Withdrawal Volume + Fisheries Release - Lake Net Inflow)	1,269	1,533
Percent Reduction in NSSWD Licenced Withdrawal	0.0%	29.6%

Parameter	Average Year	10-Year Return Period Drought*
Limit required to balance with available Live Storage with Existing Weir at El. 40.71 m**		
Percent Reduction in NSSWD Licenced Withdrawal Limit required to balance with available Live Storage with Weir raised to El. 41.0 m**	0.0%	0.0%

* Available storage with current weir at El. 40.71 m is 1,294,330 m³ while storage available with weir raised to El. 41.0 m is 1,823,000 m³.
**Percent reduction in NSSWD licenced withdrawal limit assumes all other licence holders withdrawing water at their respective licence limits.

The results of the water budget indicate that under the average current climate condition, the estimated lake net inflows would exceed the total maximum surface water demands between October and March, but would be less than the maximum surface water demands during the spring/summer period between April and September. The shortfall should be supported by storage in St. Mary Lake during these months.

On an annual basis, the estimated total lake net inflow of 2,685,000 m³ exceeds the total annual maximum surface demand of 1,877,000 m³, indicating that the lake could be refilled at the end of the year if sufficient storage is available. The estimated total storage requirement is 1,269,000 m³ which is less than the current available storage of 1,294,000 m³. This means that the storage currently available at St. Mary Lake is sufficient to support the maximum surface water demand under average inflow conditions. Additional storage would not be required.

Under the current climate 10-year return period drought condition, the water budget indicates that lake net inflows would exceed the maximum surface water demands between November and March, but would be less than the maximum surface water demands between April and October. The estimated total annual lake net inflow is about 1,198,000 m³, which is less than the total maximum surface water demand. This indicates that the lake could not be refilled after such a drought year. However, assuming that the 10-year return period drought year is followed by an average climate year, the lake would then be refilled by the end of the average climate year.

The water budget estimates that the total storage requirement under the 10-year return period drought condition is 1,533,000 m³. This is greater than the currently available live storage in St. Mary Lake. Therefore, additional 239,000 m³ of live storage would be required to support the maximum surface water demand.

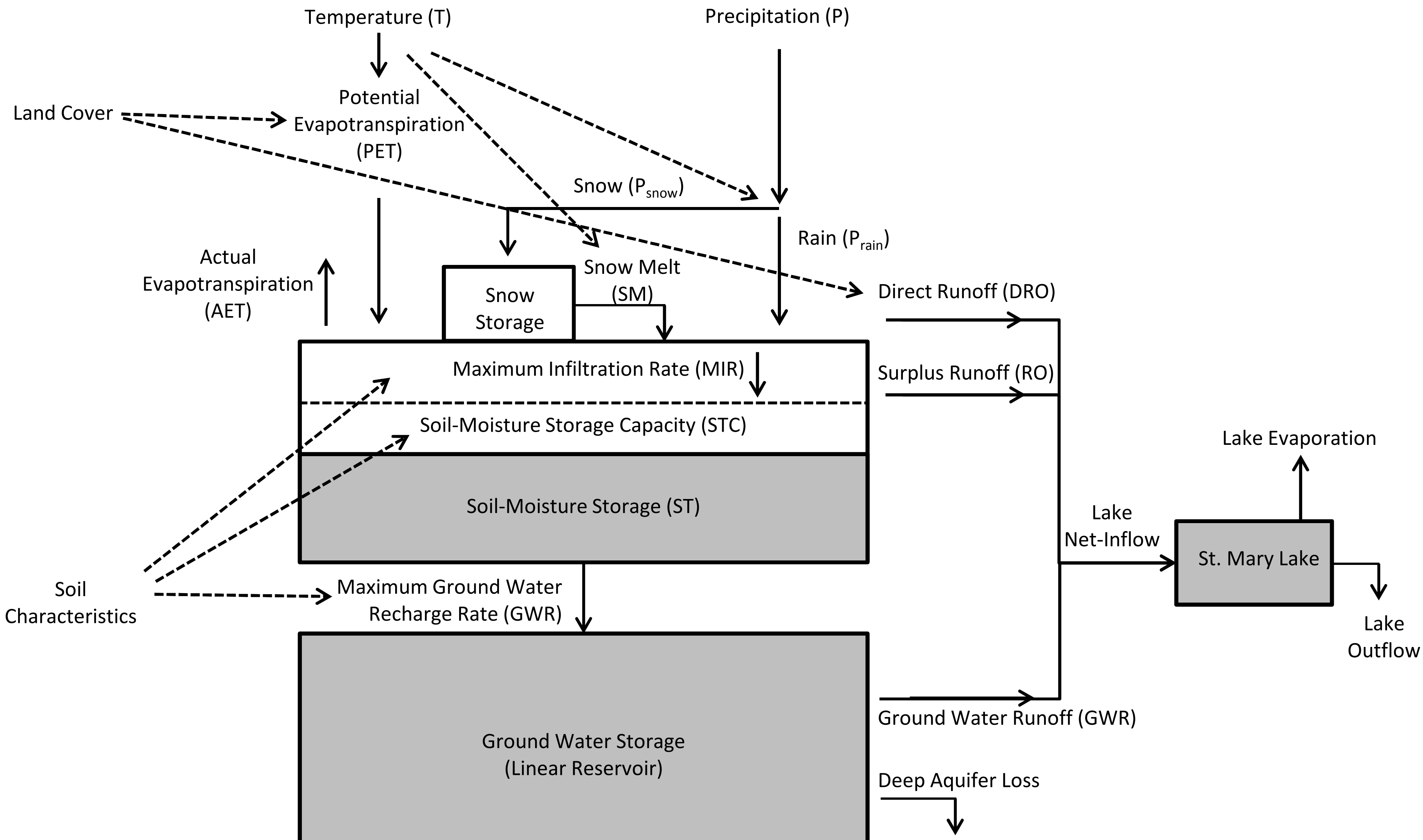
If the currently available lake storage in St. Mary Lake were to be maintained into the future, the total NSSWD water withdrawal would have to be limited 29.6% less than the current licenced withdrawal limit in order to balance with available storage under the 10-year return period drought condition. This calculation assumes that withdrawals for other waterworks, domestic, industrial and agricultural water withdrawals meet the total licenced withdrawal limits for these uses in the future.

As indicated in Section 3.7, additional storage in the lake can be provided by raising the existing outlet weir. If the weir were raised by 0.29 m to elevation 41.0 m, the total storage capacity would be increased to 1,823,000 m³. The water budget indicates that this additional storage volume would be sufficient to support the total maximum surface water demand under both the current climate annual average and 10-year return period drought conditions.

3.5 Groundwater Balance – Current Climate Conditions

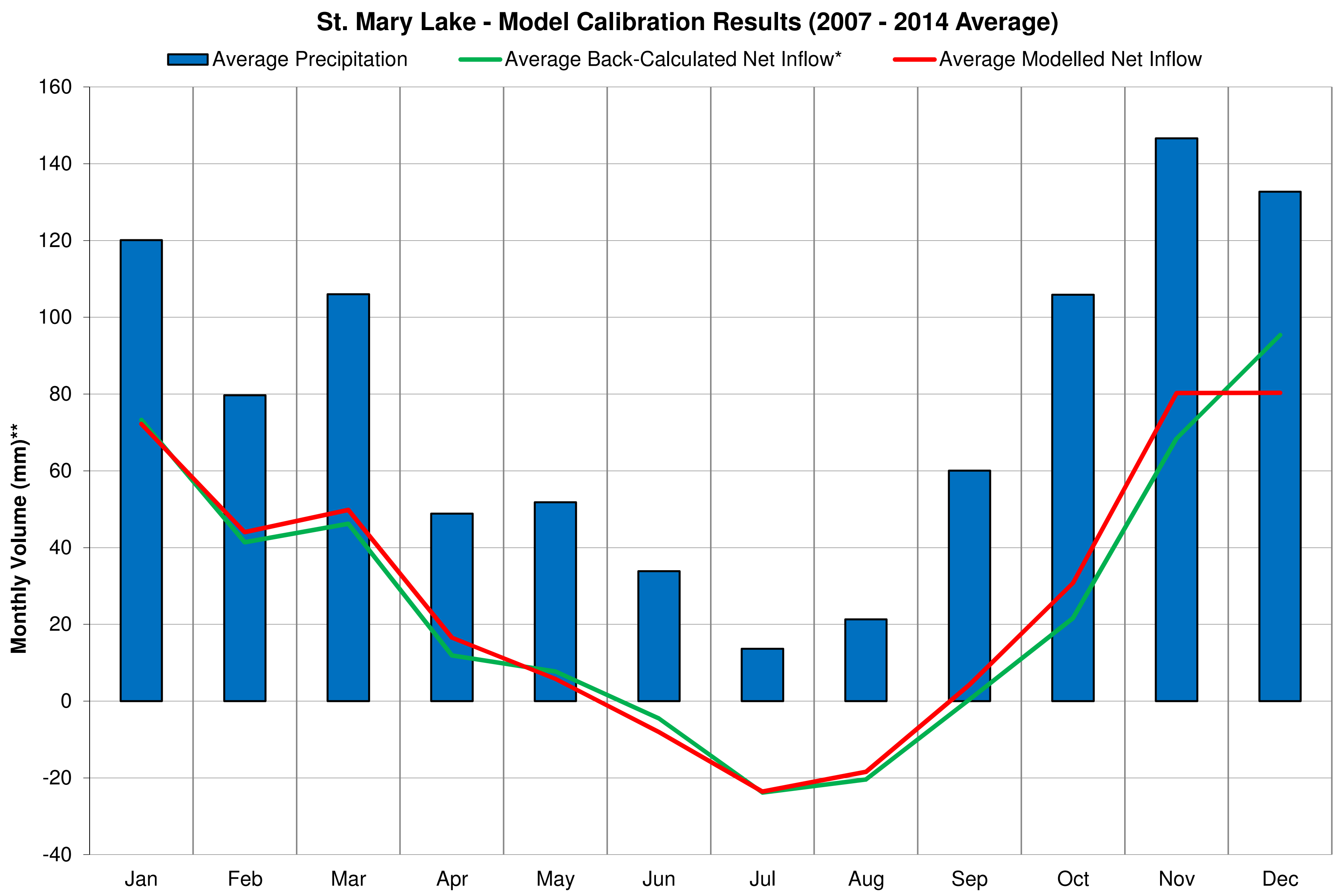
Previous groundwater budget studies on Mayne Island (Fowraker, 1974) and Salt Spring Island (Hodge, 1995) suggest that typically 3% of annual rainfall recharges to bedrock aquifers in the Gulf Islands. The results of the calibrated water balance model developed in this study indicate that groundwater recharge (or loss) to deep aquifer is likely around 704,000 m^3/year and 620,000 m^3/year, respectively under the current average and 10-year return period drought conditions. These estimated losses are equivalent to about 11% and 14% of total annual rainfall, under both the current average and 10-year return period drought climate conditions respectively. These values are approximately 4 to 5 times higher than the previous estimates. Since a more accurate quantification of the loss to groundwater cannot be confirmed without further detailed hydrogeological field data and assessment, the modelled groundwater losses have been kept in the water balance assessment as they provides better model calibration and are more conservative for lake storage requirement assessment.

Aquifer water budget carried out by WRI indicates that groundwater within St. Mary Watershed may not be over-stressed. A comparison of estimated groundwater recharge with estimates of groundwater extraction indicates that between 15% and 38% of annual recharge may be extracted within the watershed for groundwater use. As no records are available on groundwater use in the watershed, the groundwater budget is based on rough estimate of groundwater extraction according to the number of wells in the watershed and typical annual extraction rates for domestic users. It should be noted that groundwater budgets completed at the regional watershed scale as part of the current study, may differ considerably from local-scale water budgets. This is particularly true in structurally complex bedrock aquifers that are observed beneath the St. Mary Lake Watershed. For further details please refer to the Hydrogeological Assessment Report - St. Mary Lake Watershed Study prepared by WRI included in Appendix C. Groundwater demand estimated by WRI is approximately 94,900 m^3/year, which is much less than the estimated deep aquifer losses by the water balance model for both the current average and 10-year return period drought climate conditions. There would be sufficient groundwater being recharged into the groundwater and available for the required groundwater uses.



Monthly Water Balance Adapted From USGS Monthly Water Balance Model

Source: McCabe and Markstrom, 2007



Note:
* Average back-calculated net inflows are calculated excluding the winter months with the back-calculated net inflows greater than monthly precipitations
** Monthly volumes shown as equivaluent depth in mm over the entire watershed

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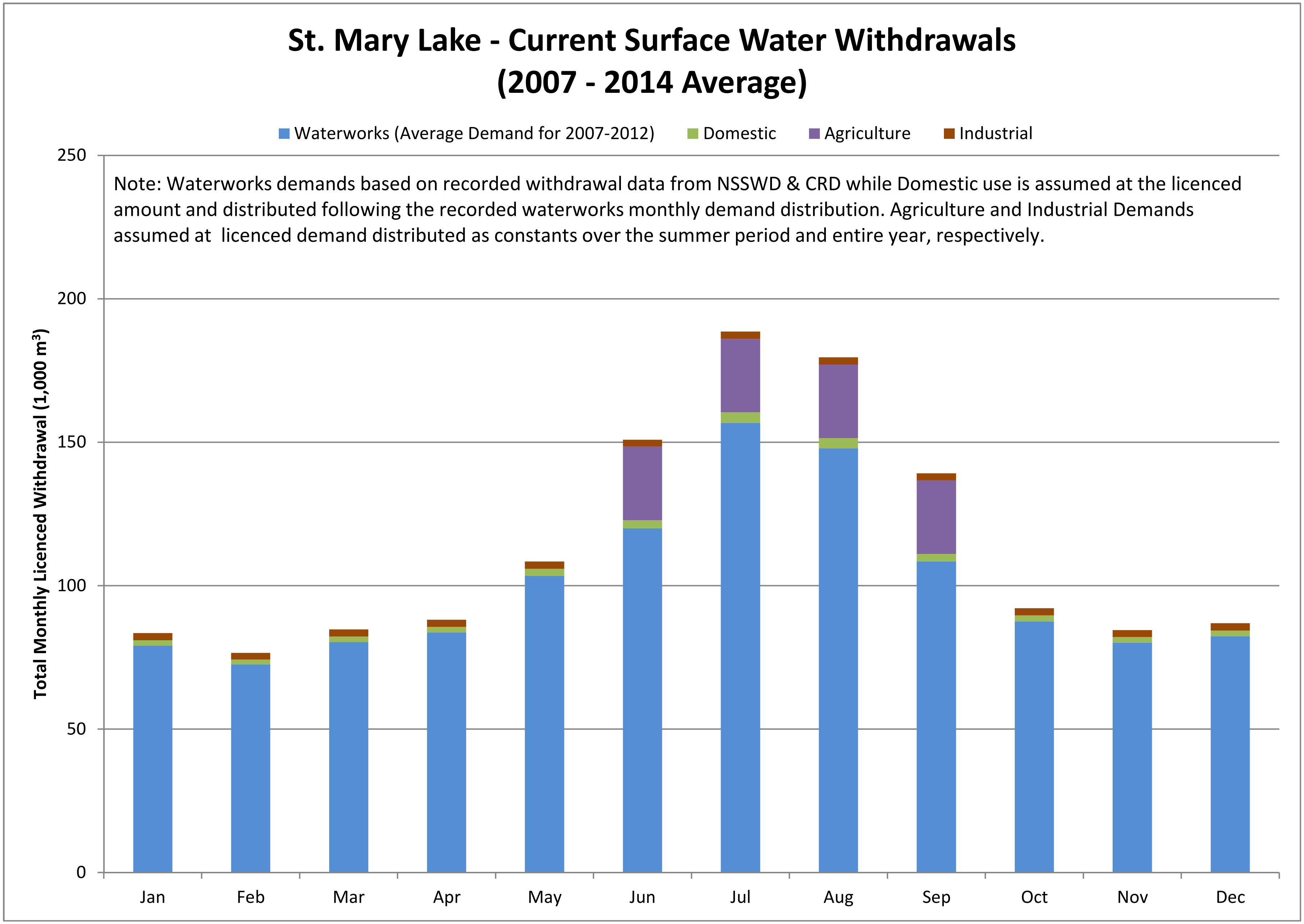
St. Mary Lake Watershed Water Availibility and Demand - Climate Change Assessment
Model Calibration Results Summary
Figure 3-2



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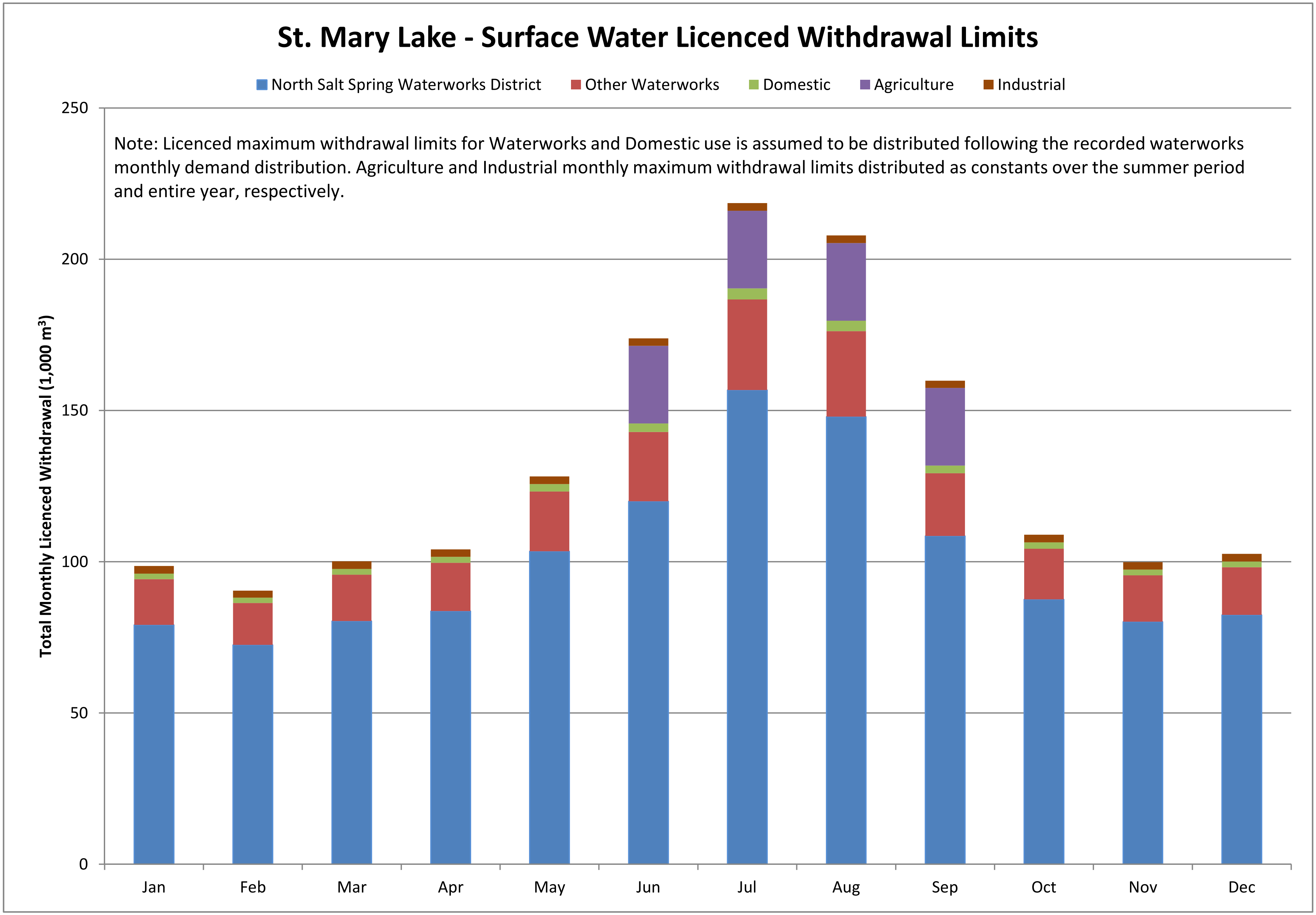
St. Mary Lake Watershed Water Availibility and Demand - Climate Change Assessment
Monthly Distribution of Current Surface Water Withdrawals
Figure 3-3



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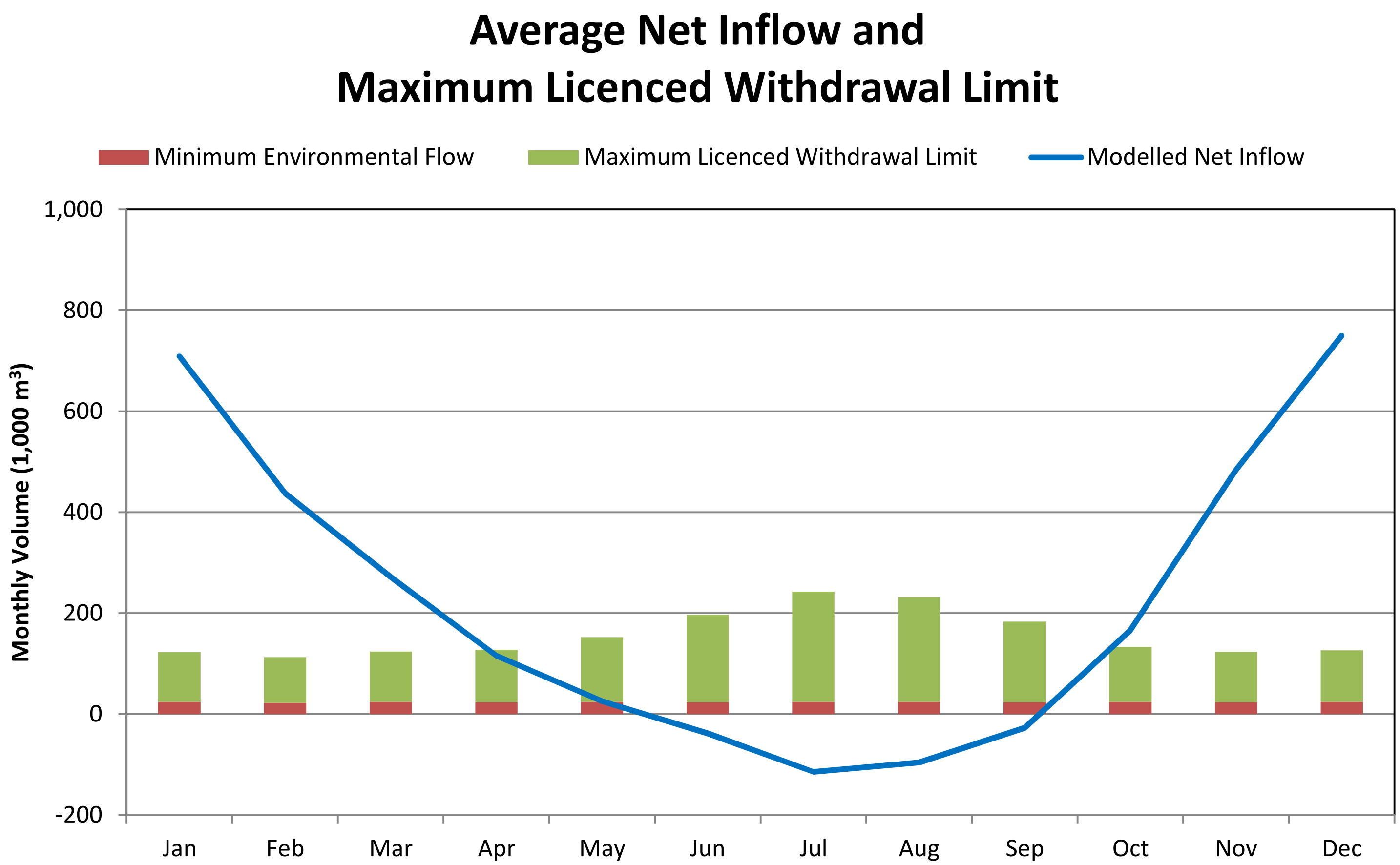
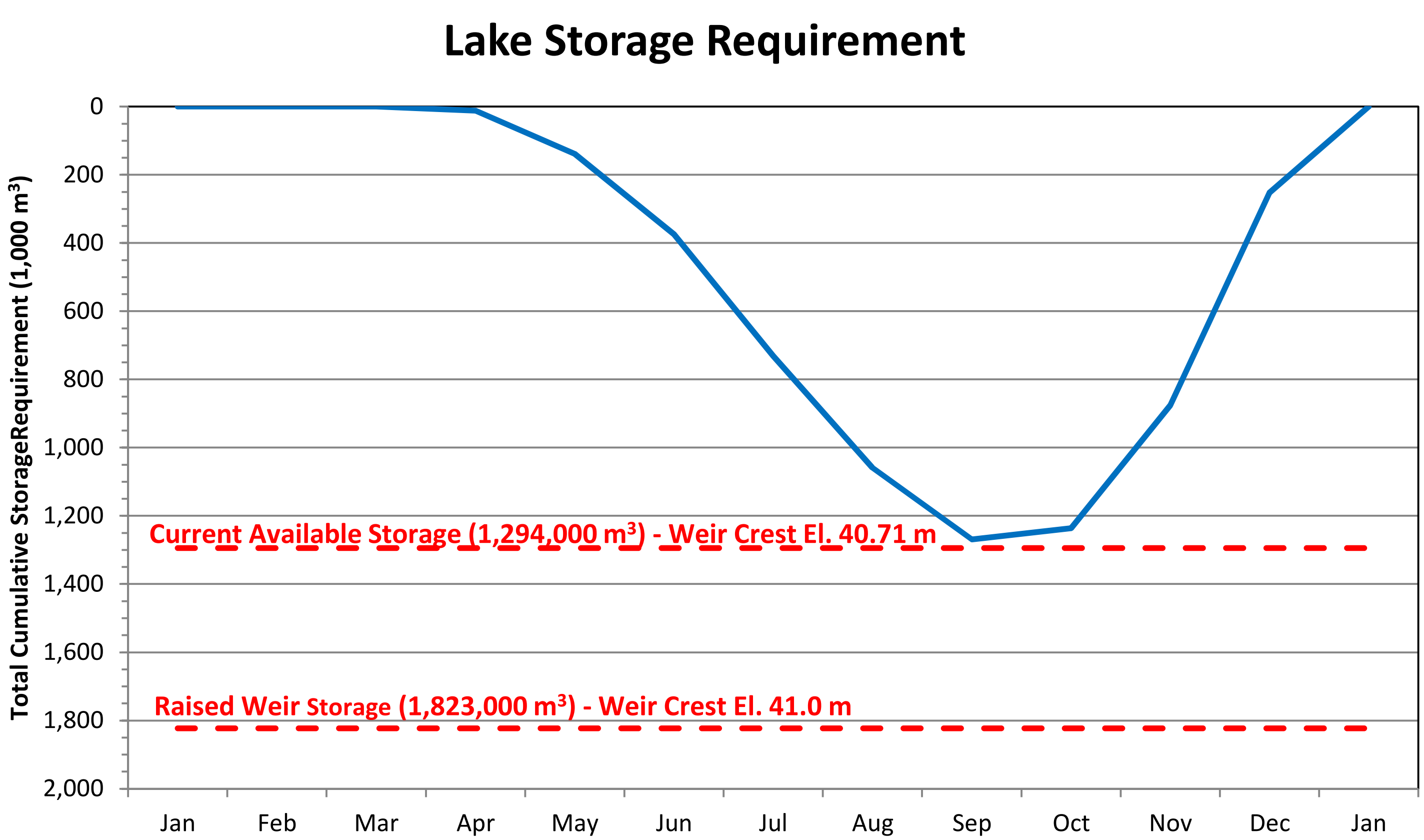
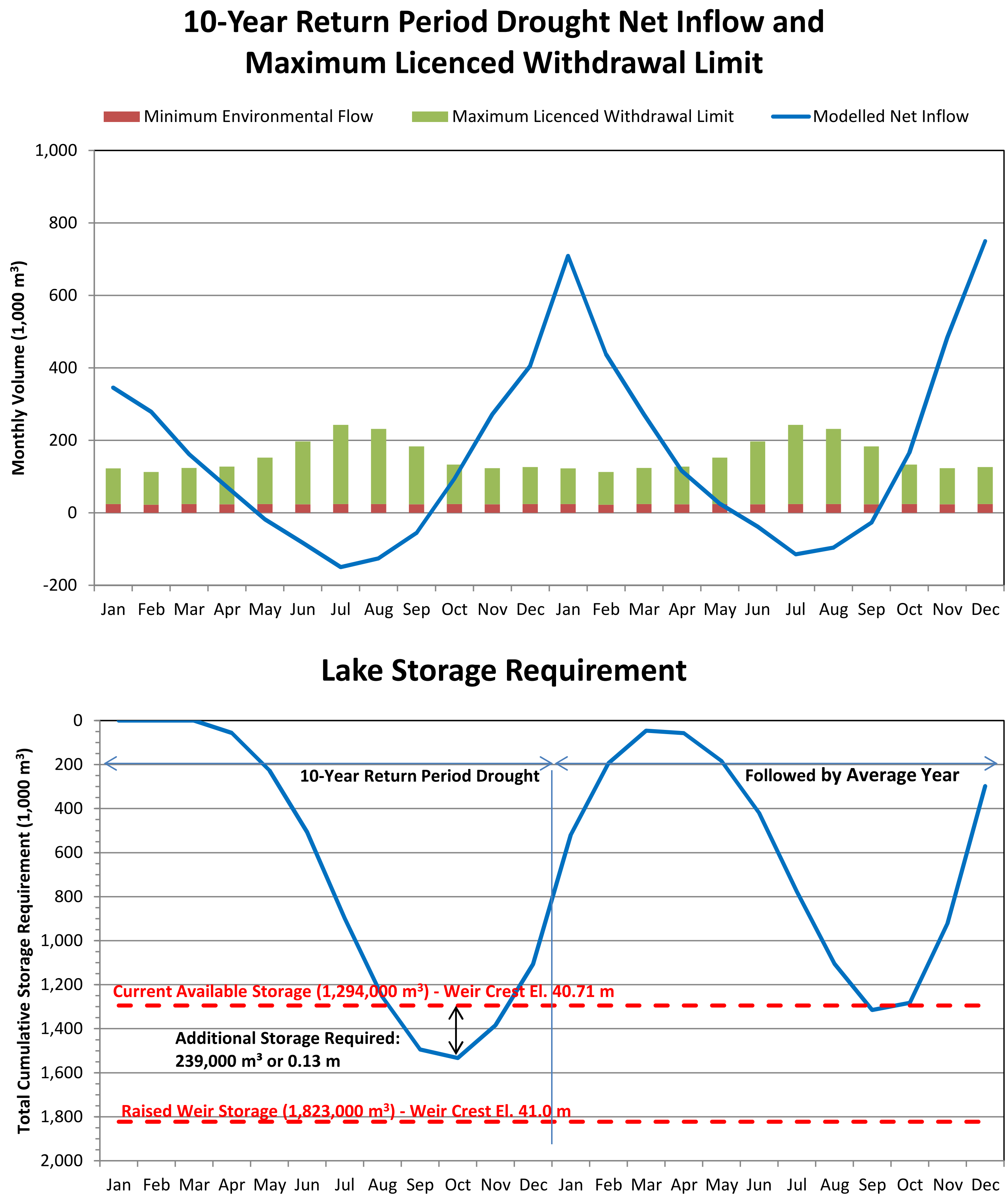
St. Mary Lake Watershed Water Availibility and Demand - Climate Change Assessment
Monthly Distribution of Licenced Maximum Withdrawal Limits
Figure 3-4





Note: Assumes water demand at licenced withdrawal limit for all licence holders and lake at full storage on January 1.



Note: Assumes water demand at licenced withdrawal limit for all water icence holders and lake at full storage at start of 10-Year Return Period Drought.

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Section 4

Climate Change Impacts

4. Climate Change Impacts

4.1 Global Perspective

The International Panel on Climate Change (IPCC) has stated that global climate records and modelling indicate warming of the global climate system is unequivocal (IPCC, 2013). Evidence of the warming can be found in increased observed temperatures, widespread melting of snow and ice, and increased sea levels. In order to better understand how to adapt to these changes in the study area, a review of past trends and future projections for the Southern Gulf Islands region is required.

In addition to climate change, defined as the long term trends in climate, climate variability, defined as shorter term annual or decadal cycles in climate, can also play an important role in the hydrological regime of a region. Climate variability is impacted by phenomena such as the El Niño Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO) which are driven by changes in sea surface temperatures and ocean currents (CIG, 1999). The ENSO can oscillate from cool phase to warm phase on an annual basis but often varies in two to three year cycles. The PDO cycles between warm and cool phases about once in every 20 to 30 years. We may have recently shifted from a warm to cool PDO phase, which may have the effect of slowing warming trends in Southwestern BC for the next 20 to 30 years. Figure 4-1 shows the definitions of Climate Change and Variability.

4.2 Regional Climate Change Forecasts

Similar to other regions in South-Western British Columbia, the climate forecast for the Southern Gulf Islands indicate that:

1. Summers are likely to become warmer and drier; and
2. Winters are likely to become warmer and slightly wetter.

The Pacific Climate Impacts Consortium (PCIC) at the University of Victoria has developed the Plan2Adapt tool for planning and assessment of climate change impacts (Murdoch and Spittlehouse, 2011). The tool provides a summary of global circulation model (GCM) and regional circulation model (RCM) results for regions across BC. The GCM and RCM models provide climate forecasts for a range of future greenhouse gas (GHG) emissions scenarios based on potential future economic and political drivers. For the Southern Gulf Islands region, the ensemble of GCM and RCM results for the 2050s are shown in Table 4-1. The ensemble of GCM and RCM results used in the Plan2Adapt tool is based on the results of 30 individual GCM and RCM model runs.

The regional forecasts based on GCM output provide a reasonable estimate of future climate average conditions. However, extreme conditions, such as high intensity rainfall events and prolonged dry periods, are not easily modelled using GCMs and are therefore not as well understood. Nevertheless, general consensus is that both the intensity and frequency of large rainfall events and the length of dry periods are likely to increase.

Table 4-1: Climate Forecasts for the Southern Gulf Islands (2050s)

Climate Variable	Season	Ensemble Median	Range (25th to 75th Percentile)
Mean Temperature (°C)	Annual	+1.6 °C	+1.0 °C to +2.3 °C
Precipitation (%)	Annual Summer (June to Aug) Winter (Dec to Feb)	+6% -18% +5%	-2% to +12% -28% to +1% -4% to +15%

Note: The table shows projected changes in average (mean) temperature, precipitation and several derived climate variables from the baseline historical period (1961-1990) to the 2050s for the Southern Gulf Islands. The ensemble median is a mid-point value, chosen from the PCIC Planners Ensemble of Global Climate Model (GCM) projections with the range indicating high and low range of ensemble protections.

4.3 Future Changes in Water Supply

Impacts to future water supply (lake net inflows) at St. Mary Lake were assessed using the calibrated monthly water balance model with the monthly average temperature and precipitation predictions for the 2050s used as input. The forecast monthly average temperatures and precipitation used in the model are based the GCM and RCM model result summaries provided in the Plan2Adapt tool.

Given the uncertainty in climate change predictions, a range of GCM model results were used to develop a high bound and a low bound estimate of changes in water supply. The bounds of the estimate are based on the 25-th percentile (high bound) to 75-th percentile (low bound) range of GCM predictions in the Planner's Ensemble of GCM models developed by the Pacific Climate Impacts Consortium (PCIC, 2013). The high bound estimate are based on GCM predictions indicating larger increase in temperatures while low bound estimates are based on GCM predictions indicating smaller increase in temperatures under the average annual condition. The predicted average annual monthly temperatures and precipitation from the GCM as well as the modelled net inflow based on the GCM results for the high bound and low bound predictions for predicted future climate (2050s) condition are presented in Table 4-2.

Table 4-2: St. Mary Lake Water Balance Model Results – Future Climate (2050s) Condition

Month	2050s Climate 25-th Percentile (High Bound Prediction)			2050s Climate 75-th Percentile (Low Bound Prediction		
	Average Temp. °C	Average Precip. mm	Modelled Average Lake Net Inflow, mm	Average Temp. °C	Average Precip. mm	Modelled Average Lake Net Inflow, mm
Jan	5.3	136.5	89.8	4.3	154.0	99.8
Feb	7.1	99.9	64.1	5.7	112.0	81.2
Mar	8.0	85.0	40.1	7.0	99.2	49.9
Apr	10.3	50.0	16.4	9.5	54.5	18.0
May	13.5	40.0	3.9	12.6	48.0	7.0
Jun	16.9	28.4	-9.5	16.0	35.6	-6.3
Jul	19.8	15.5	-22.7	18.8	22.4	-18.9
Aug	19.9	18.4	-19.8	19.2	25.1	-17.0

Month	2050s Climate 25-th Percentile (High Bound Prediction)			2050s Climate 75-th Percentile (Low Bound Prediction		
	Average Temp. °C	Average Precip. mm	Modelled Average Lake Net Inflow, mm	Average Temp. °C	Average Precip. mm	Modelled Average Lake Net Inflow, mm
Sep	17.0	34.7	-4.8	15.8	47.1	0.6
Oct	12.5	94.9	25.0	11.5	107.4	29.9
Nov	8.3	153.7	64.9	7.4	189.5	95.5
Dec	6.1	176.2	130.5	5.0	191.0	157.0
Total		**933.2**	**377.9**		**1,085.8**	**496.7**
Spring/ Summer (May to Sep)		**137.0**	**-52.9**		**178.1**	**-34.5**
Note: Modelled lake net inflow volume is shown as equivalent depth in mm over the entire watershed.						

The water balance model predicts decreased annual lake net inflow and less summer (May to September) lake net inflow under the high bound climate change predictions, but increased annual and summer net inflows under the low bound climate change prediction. A summary of the predicted changes in net inflow to St. Mary Lake are presented in Table 4-3.

The high bound climate change prediction indicates that net inflows would decrease in both the winter and summer months with a decrease in overall annual lake inflow. The predicted decrease in summer net inflow is mostly driven by increased summer temperatures and evaporation from the lake surface combined with a 16.8% decrease in summer precipitation. Although the low bound climate change prediction indicates that average monthly precipitation could be slightly lower in June, July and August, the modelled monthly net inflow in these months would be greater compared with the net inflows estimated for the current climate conditions. This is likely because of increased rainfall in the other months that maintains soil moisture and groundwater storage later into the early summer months which is then released to maintain higher net inflow the during the dry summer months.

Table 4-3: St. Mary Lake Water Balance Model Results – Predicted Changes in Lake Net Inflow for Future Climate (2050s) Condition

Period	Percent change in net inflow predicted under future climate conditions	
	25-th Percentile Prediction (High Bound)	75-th Percentile Prediction (Low bound)
Annual	-8.9%	+19.7%
Spring/Summer (May-Sep)	-36.1%	+10.8%
Fall/Winter (Oct-Apr)	-5.0%	+17.1%
Note: Percent change based on water balance model results for 1981 to 2010 normal period.		

4.4 Water Balance – Future Climate Conditions (2050s)

A comparison of modelled lake net inflows based on predicted climate for 2050s period and the maximum surface water demands at the licenced withdrawal limits and the minimum conservation flows was performed and the results are shown in Figures 4-2, for the 2050s climate 25-th percentile (High Bound) and 75-th percentile (Low Bound) climate change predictions respectively. Table 4-4 summarized the future climate water balance assessment results.

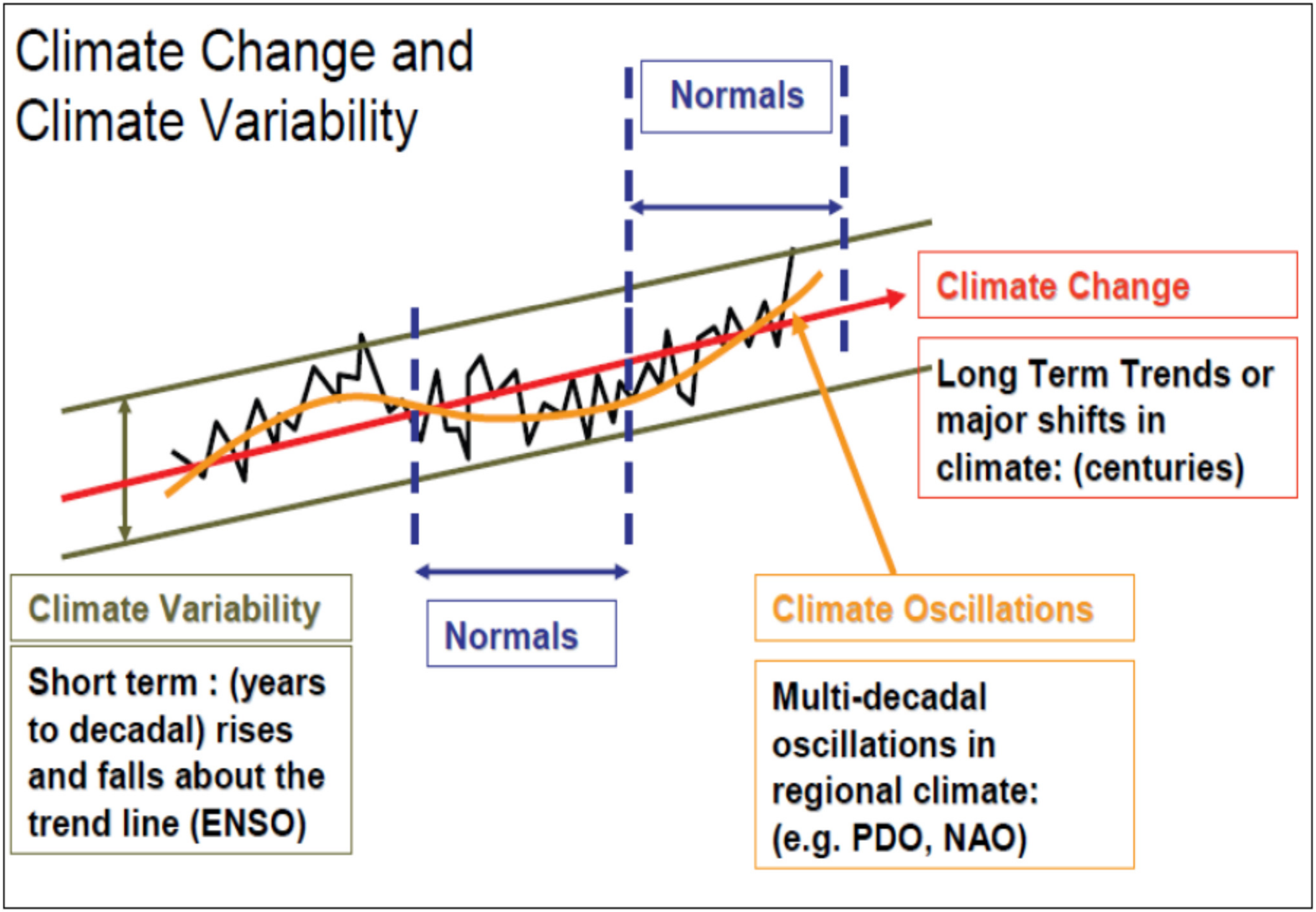
Table 4-4: St. Mary Lake Water Balance Assessment Results – Future Climate (2050s Climate)

Parameter	2050s Climate –25th Percentile (High Bound)	2050s Climate – 75th Percentile (Low Bound)
Annual Precipitation, mm	933.2	1085.8
Annual Lake Inflow, mm	377.9	496.7
Annual Lake Inflow, 1,000 m^3	2,445	3,214
Lake Draw Down Period (when maximum surface water demand is greater than lake net inflow)	Apr - Sep	Apr - Sep
Precipitation during Lake Draw Down Period, mm	187	233
Lake Inflow during Lake Draw Down Period, mm	-37	-17
Lake Inflow during Lake Draw Down Period, 1,000 m^3	-236	-107
Licenced Withdrawal Volume during Lake Draw Down Period, 1,000 m³	992	992
Fisheries Releases during Lake Draw Down Period, 1,000 m³	142	142
Required Storage*, 1,000 m³	1,371	1,241
Percent Reduction in NSSWD Total Water Licence Volume to balance with available Live Storage with Existing Weir at El. 40.71 m	10.6%	0.0%
Percent Reduction in NSSWD Total Water Licence Volume to balance with available Live Storage with Weir raised to El. 41.0 m	0.0%	0.0%
Note: * For comparison, the required storage to support total withdrawal limit and minimum conservation flows under current (1981-2010) climate conditions is 1,269,000 m³		

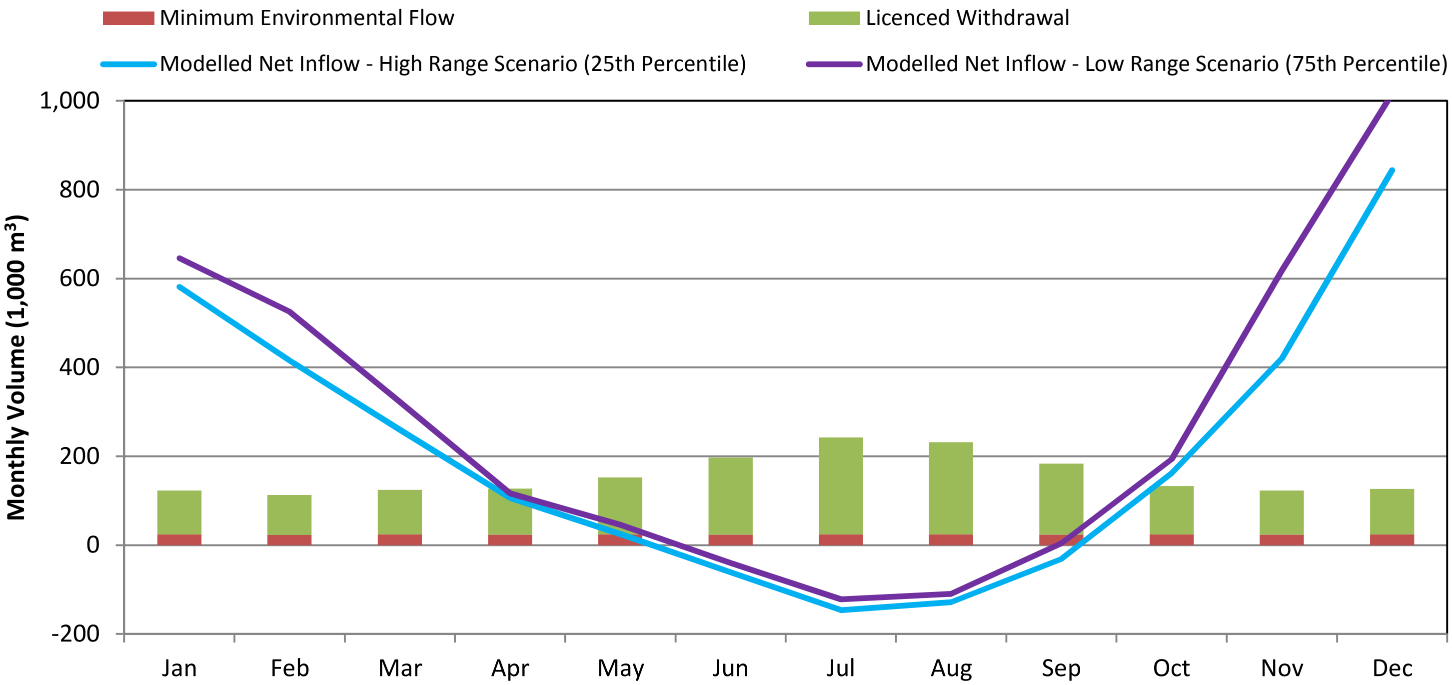
The water balance assessment under predicted high bound (25-th percentile) for 2050s climate conditions indicates that both annual and spring/summer net inflow to St. Mary Lake could decrease. This would put increased pressure on available storage in St. Mary Lake to support the maximum surface water demands. Reduction in up to 10.6% of the NSSWD water licence amount would balance storage deficit with the currently available storage (Weir Crest at El. 40.71 m). Increasing lake storage by raising the weir by 0.29 m to El. 41.0 m would provide sufficient storage to support entire water licence amount under the 25-th percentile predicted average climate conditions by 2050s.

With the 75-th percentile predication, lake inflows would be increased compared with the net inflows estimated for the current climate conditions. The currently available storage would provide sufficient storage to support the maximum surface water demands.

Due to the uncertainty in future climate modelling results, no drought analysis has been carried out.

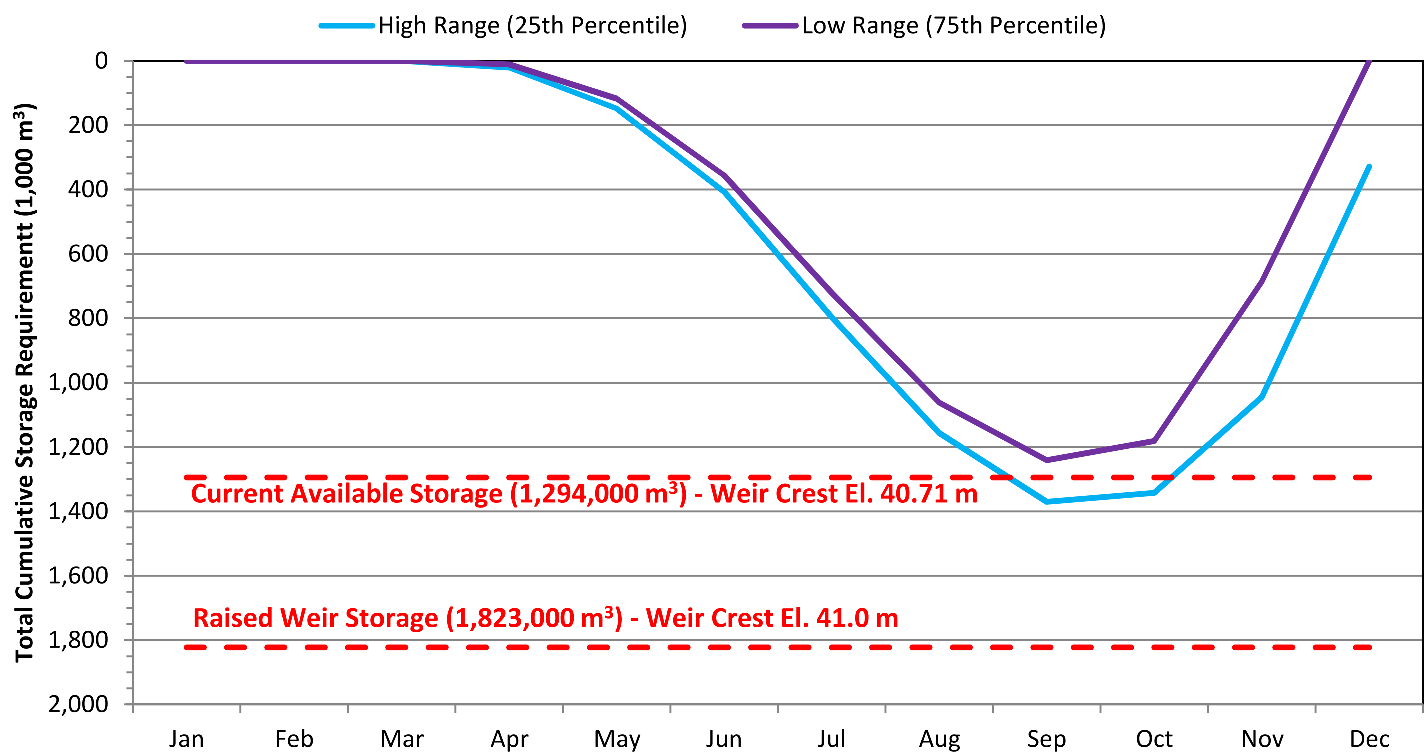

Climate Change and
Climate Variability
Normals
Climate Change
Long Term Trends or major shifts in climate: (centuries)
Climate Variability
Short term : (years to decadal) rises and falls about the trend line (ENSO)
Normals
Climate Oscillations
Multi-decadal oscillations in regional climate: (e.g. PDO, NAO)

Average Future (2050s) Net Inflow and Maximum Licenced Withdrawal Limit



Note: Future Lake Net Inflow based on PCIC Planners Circulation Model Ensemble Results representing the 25th to 75th percentile of range of model results

Lake Storage Requirement



Note: Assumes water demand at licenced withdrawal limit for all licence holders and lake at full storage on January 1.

Section 5

Summary and Conclusions

5. Summary and Conclusions

5.1 Summary

The assessment of water availability and demand within the St. Mary Lake Watershed indicate that:

1. St. Mary Lake has a surface area of 1.823 km² and lies within a 6.47 km² watershed;
2. Climate records from the St. Mary Lake climate station indicate that average total annual precipitation for the 1981 to 2010 climate normal period is 987 mm, with approximately 80% of the annual precipitation typically falling in the six-month period from October to March;
3. St. Mary Lake supports domestic and waterworks withdrawals for residential and commercial development around the lake, agricultural withdrawals for irrigation and stock watering and industrial withdrawals for light industrial activities, an emergency water source for fire suppression as well as minimum conservation flows of 9 L/s (10% of Mean Annual Discharge) in Duck Creek downstream of St. Mary Lake;
4. The total volume of licenced storage in St. Mary Lake is 400,800 m³ under licences held by NSWWD and CRD;
5. NSWWD currently withdraws about 395,000 m³/year from St. Mary Lake on average with two other water works managed by CRD withdrawing an additional 100,800 m³ for a total of 495,800 m³ (1,358 million litres per day (MLD) on average).
6. Total annual licenced withdrawal limit volume within the St. Mary Lake Watershed is 1,593,000 m³ (4,364 MLD on average).
7. Under the current 1981 to 2010 climate condition, during the fall, winter and early spring period from October to March, net inflows to St Mary Lake would exceed the maximum surface water demands. However, during the dry spring and summer period from April to September maximum surface water demands would exceed net inflows.
8. Summer water demands are supported by water stored in St. Mary Lake by a weir at the outlet managed by NSWWD. The weir stores approximately 1,294,000 m³ between the minimum water level allowed by the water licence for storage (El. 40.0 m) and the crest of the weir (40.71 m);
9. Water balance modeling indicates that the total annual St. Mary Lake net inflow (watershed runoff plus direct rainfall on the lake minus evaporation) for the 1981 to 2010 climate normal period is about 2,685,000 m³ or equivalent to 415 mm of depth across the watershed, while the average summer net inflow during the lake draw down period (April to September) is -134,000 m³, equivalent to about -20.8 mm over the watershed or about -73.7 mm over the lake surface (negative net inflow indicates that evaporation, are greater than watershed runoff into the lake);
10. A comparison of the maximum surface water demand with modelled net inflow to the lake for the 1981 to 2010 period indicates that the total water deficit is 1,269,000 m³ and 1,533,000 m³ for the average year and 10-year drought conditions respectively. This indicates that the licenced withdrawal limit could only be supported by the currently available 1,294,000 m³ storage under the current average climate condition, but not under 10-year return period drought condition;
11. An additional 529,000 m³ of storage could be added to the lake by raising the weir to El. 41.0 m for a total of 1,823,000 m³, which would provide sufficient storage to support the maximum required

demand at the licenced withdrawal limit for both average year and the 10-year return period drought under current (1981 to 2010) climate conditions;

12. The water balance model indicates that groundwater recharge (or loss) rates are estimated to be about 11% of annual precipitation under the current average climate condition, greater than values estimated by previous groundwater studies in the region;
13. Regional climate change forecasts indicate that average temperatures are likely to continue to increase by between +1.0 °C to +2.3 °C with general increase in winter precipitation (-4% to +15%) and a general decrease in summer precipitation (-28% to +1%) by the 2050s;
14. Using the monthly water balance model calibrated to hydrological conditions in the watershed and using predicted 2050s temperature and precipitation as input, a range of lake inflow predictions for future climate conditions have been developed, with total spring/summer net inflow for average year conditions predicted to increase by 10.8% or decrease by 36.1% indicating the range of uncertainty in climate change forecasts;
15. The forecast decrease in summer net inflow could put more pressure on the existing lake storage to support the maximum surface water demand, with future NSSWD withdrawal having to be limited to 89.4% of the total licenced withdrawal limit with the current weir (crest elevation of 40.71 m) for average year conditions for predicted future (2050s) climate conditions using high bound results;
16. Due to limitations of climate modelling in representing extreme conditions, it is difficult to quantify impacts on drought and available water supply at St. Mary Lake. However, given a reduction in average summer precipitation and increase in average summer temperatures, it is likely that the frequency and length of summer droughts will increase. This will result in increased pressure on water availability while at the same time potentially increasing summer water demand as a result of increased irrigation use for both agricultural and residential users.

5.2 Conclusions

The outcome of the analysis for current climate (1981-2010) conditions indicates that current St. Mary Lake storage with the weir crest at El.40.71m can support the maximum surface water demand at the licenced withdrawal limit under the average net inflow condition but not the 10-year return period drought net inflow conditions.

In order for existing storage with weir crest at El. 40.71 m to support the maximum surface water demand under the 10-year drought conditions, the NSSWD withdrawal limit from St Mary Lake would have to be reduced by 29.6% with the total withdrawal volume limited to 846,500 m³/year or 2,319 MLD average day demand. This assumes that all other water licence holders would be withdrawing water from St. Mary Lake at their respective licenced limits.

If the weir were to be raised to El. 41.0 m, the lake would provide sufficient storage volume to support water withdrawals at the total licenced withdrawal limit under average year and the 10-year return period drought conditions.

The water balance and water budget assessment for future climate conditions for the 2050s period indicate that projected changes in temperature and precipitation could result in a decrease in spring/summer (May-Sep) lake net inflow by up to 36.1%. This indicates that increased pressure could be placed on existing storage to support the maximum surface water demand at the licenced withdrawal limit. Using the high bound estimates, NSSWD water withdrawals would have to be limited to 89.4% of the total water licenced withdrawal limit during average year conditions in order for the current storage (weir at El. 40.71 m) to be sufficient to support the maximum surface water demand.

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Section 6

Recommendations and Submission

6. Recommendations and Submission

6.1 Recommendations

Based on the outcome of the hydrological analysis and water balance carried out for St. Mary Lake, we make the following recommendations:

1. Water rights on St. Mary Lake should be considered to be fully allocated (no additional water licences should be issued) given the limitations of current lake storage to support the maximum water demand at the licenced withdrawal limit and the minimum environment flow in Duck Creek under 10-year return period drought conditions.
2. St. Mary Lake water level, weather data (rainfall and temperature) and outflow to Duck Creek should continue to be monitored (minimum of one winter and two summer seasons) to collect data that could be used to refine the back-calculated net inflow estimates and to re-assess the water balance in order to better understand the uncertainties in the water balance model (i.e. groundwater recharge rates and minimum conservation flow releases). Installation of a monitoring system to record flow release to Duck Creek in the summer through the fish ladder should be included as part of the monitoring program.
3. Groundwater levels should be monitored in relation to St. Mary Lake levels, preferably by collaborating with existing well owners near the lake or with the Ministry of Environment groundwater monitoring network, to establish hydraulic gradients of groundwater flowing into or out of St. Mary Lake. This could provide a better understanding of the potential for water to seep from the lake into groundwater during the low flow summer season, and to confirm if groundwater recharge rates estimated using back-calculated net inflows and the water balance model are reasonable.
4. Groundwater extraction rates at select sites should be monitored to better define typical groundwater extraction quantities for different users (domestic, agricultural, etc.) within the watershed.
5. NSWWD water withdrawals from St. Mary Lake should be capped at 70.4% of the total annual licenced withdrawal limit (capped withdrawal of 846,500 m³ per year or 2,319 MLD average day demand), until such time that sufficient surface water and groundwater data can be collected to reduce uncertainties in water balance model results, or current storage is expanded by raising the weir or providing seasonal storage (i.e. stop-logs or gates) up to El. 41.0 m.
6. NSWWD should work together with other St. Mary Lake water licence holders and stakeholders to develop a St. Mary Lake Water Management Plan, including a drought management strategy which identifies how lake storage, groundwater supplies and water withdrawals are to be co-operatively managed under drought conditions.
7. Increase in total water licence withdrawal from St. Mary Lake for the NSSWD should not be pursued unless agreement can be made with other licence holders for transfer of water rights or until additional storage at the lake can be secured.
8. Should NSWWD decide to increase maximum water withdrawal from St. Mary Lake beyond the recommended cap, investigations either should be carried out, or those already completed should be re-considered, to review potential impacts of either raising the St. Mary Lake weir by 29 cm or providing seasonal lake level control up to El. 41.0 m such as gates or stop logs. The investigations

should include topographic survey or LiDAR survey to determine the extent of inundation, review of potential habitat impacts and review of potential impacts to lakeside property owners.

9. Given the uncertainty of potential future changes in available runoff as a result of climate change, NSWWD and other St Mary Lake stakeholders should develop an adaptive management approach to water management. This may include on-going monitoring of climate and water resources to assess trends in comparison with future climate projections, and development of flexible and robust physical infrastructure and policy/procedures which consider the impacts of uncertain future climate.
10. The community engagement and communication program should be continued and enhanced to provide meaningful science-based information on water supplies, water use and water conservation. Maintaining public involvement is a key part of the management and protection of the St Mary Lake watershed and aquifer.

6.2 Report Submission

We trust that this report provides a summary of the water demand and availability within the St. Mary Lake Watershed. Should you have any questions please contact the undersigned at (250) 595-4223.

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Section 7

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7. References

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Statement of Limitations

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Revision History

Revision #	Date	Status	Revision	Author
0	June 4, 2015	FINAL	Final	WY
A	May 20, 2014	DRAFT	Issued for Review	CS/WY

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Appendix A

Glossary of Technical Terms

Term	Definition
Back-calculated Net Inflow	Back-calculated Net Inflow is an estimate of the volume of water flowing into a lake based on records. It is estimated using records of lake water level, lake outflow and lake withdrawals considering the lake to be a closed system. Back-calculated net inflow is an estimate of the surface water and groundwater inflow to the lake minus lake evaporation and groundwater seepage from the lake over a specified period. For this study, a monthly time period is used.
Deep Aquifer Loss	Deep Aquifer Loss is the water which flows into deeper aquifers and is not available to flow into surface water bodies within the watershed. This water is considered an output or a loss in the watershed water balance. For modelling in this study, the rate at which water flows from groundwater storage to deep aquifer storage on a monthly basis is defined by the Deep Aquifer Loss rate.
Evaporation	Evaporation is the process by which water is transferred from surface water bodies (ie: lakes and rivers) to the atmosphere. The rate of evaporation is driven by air temperature, water temperature, wind speed and solar radiation. For this study, monthly average air temperature and maximum daylight hours per month have been used as indices for lake evaporation.
Evapotranspiration and Potential Evapotranspiration	Evapotranspiration is the process by which water is transferred from soil moisture to the atmosphere through either transpiration from trees and plants or direct evaporation from the soil surface. The rate of evapotranspiration is driven by air temperature, wind speed, solar radiation and plant species or land cover. For this study, monthly average air temperature and maximum number of hours of daylight per month are used as an index of the monthly rate of potential evapotranspiration using an equation developed by Hamon in 1961. Potential evapotranspiration (PET) is the maximum rate of evapotranspiration assuming unlimited soil moisture supply. Actual evapotranspiration is limited by the amount of water available in soil moisture at any given time. The water balance model includes a PET adjustment factor to account for variations in PET as a result of land cover.
Groundwater Recharge	Groundwater Recharge is the process by which water flows from shallow soil moisture storage into groundwater in the subsoil. For modelling in this study, water can flow from soil moisture to groundwater storage at the maximum groundwater recharge rate when soil moisture storage is at the soil moisture capacity.
Groundwater Storage	Groundwater Storage is the capacity of subsoil (ie: below the root zone) to store water. This water is available to flow into surface water bodies through groundwater seepage (ie: springs or seeps). For modelling in this study, groundwater storage is replenished at the ground water recharge rate and

Term	Definition
	depleted by groundwater seepage to surface water, estimated by the groundwater runoff factor, and loss to deep aquifers at the deep aquifer loss rate.
Hydrogeology	Hydrogeology is the study of the movement of water through surficial soils (inorganic subsoil) and bedrock through space and time. Hydrogeology in this study focuses primarily on groundwater as it relates to surface water supplies.
Hydrology	Hydrology is the study of the movement of water in all its phases through the environment across time. Hydrology in this study focuses primarily on surface water hydrology which includes storage and movement of water in surface features such as soil, lakes and streams as well as transfers to and from the atmosphere in the form of precipitation, evaporation and evapotranspiration.
Land Use and Land Cover	In hydrological modelling, land-use is typically defined as the type of development allowed on a piece of property defined by zoning bylaws or community plans while land cover is defined as the development on property at a given point in time. For instance, a zoning map defines land-use while an airphoto shows land cover at a given point in time. Land-use often defines a future watershed condition while land cover defines current watershed conditions. For this study, the terms land use and land cover are used interchangeably. The water balance model used in this study is based on land cover/ land use developed from mapping prepared in 2009.
Licenced Withdrawal Limit	The Licenced Withdrawal Limit is the maximum volume of water permitted to be withdrawn by water licence holders from surface water sources. For the purposes of this water budget assessment, the licenced withdrawal limit is considered to be the maximum potential future demand used in assessment of the available storage.
Maximum Soil Infiltration Rate	Maximum Soil Infiltration Rate is the largest rate at which precipitation can be absorbed into the soil. The rate at which precipitation is infiltrated to soil is inversely related to the amount of water in soil moisture. For modelling purposes, it is conventional to consider that when soil moisture is empty (or soil is dry) that precipitation can infiltrate at the maximum infiltration rate while when soil moisture storage is at the soil moisture capacity (ie: the soil is saturated) the infiltration rate is zero. The maximum soil infiltration rates used in the water balance modelling are dependent on sub-soil types identified in surficial geology mapping prepared for Salt Spring Island in 1987.
Modelled Net-inflow	The modelled net-inflow is the sum of the surface water runoff, ground water runoff, direct rainfall on lake surface minus lake evaporation estimated by the water balance model. Modelled net-inflow is considered to be the supply in the water budget

Term	Definition
	calculations to assess available storage.
Precipitation	The total volume of rainfall and snowfall over a given period. Precipitation is recorded as a depth, the total volume of precipitation falling across the watershed over a given period is calculated by multiplying the depth of precipitation by the watershed area.
Soil Moisture Capacity and Soil Moisture Storage	The capacity of soil within the root zone of plants and trees to store water. The soil moisture capacity defines the total volume of water that can be stored in the soil while storage moisture storage is the amount of water in soil moisture at any given time. The soil moisture can transferred back to atmosphere via evapotranspiration and can pass into groundwater storage through groundwater recharge. When soil moisture storage is at soil moisture capacity all excess precipitation is considered to be surface runoff. Soil moisture capacity is dependent on soil type. For water balance modelling purposes, soil moisture capacities have been based on standard values with some adjustments made during model calibration to represent local conditions in the St. Mary Lake watershed.
Storage Requirement	The Storage Requirement is the amount of storage required to support a given water demand over a specified time interval. For this study, it has been calculated on monthly interval using the difference between the monthly modelled lake net-inflow and the total monthly demand, including licenced withdrawal limit for and the minimum fisheries release to Duck Creek.
Surface Water Runoff	Water available to flow into surface water bodies across the land surface and through shallow horizontal flow through soils (known as interflow) over a given time period. It is the excess water available from precipitation after all other hydrological processes are accounted for including evapotranspiration and replenishment of soil moisture storage. A portion of surface water runoff includes Direct Runoff which includes precipitation that runs off directly to surface water bodies. This is usually represented by a percentage of precipitation in a given period and is typically based on an estimate of the impervious area within a watershed.
Water Balance	Accounting of water as it passes through the watershed. It is based on the law of conservation of mass in a closed system such that the volume of water entering the system must be equal to the amount of water leaving the system plus change of volume of water within the system. Water balance for this study considers precipitation as input to the closed system with lake outlflow, deep aquifer loss, evaporation and evaporation as outputs. Storage in the system includes lake storage, soil moisture storage and groundwater storage. The purpose of water balance is to convert precipitation and temperature as

Term	Definition
	inputs into the volume of surface water available for use in water budget. For this study, a monthly time-step has been used for modelling such that the model converts average monthly precipitation and temperature to average monthly net-inflow.
Water Budget	Comparison of the amount of surface water available in the watershed over-time (supply) and the amount of water required for use over time (demand). When the volume of water for demand is greater than the volume of water available in supply over a given time period, for this study a monthly time period is used, then the difference must be provided by storage. For this study, the modelled net-inflow volume is considered to be the supply while the demand is considered to be licenced withdrawal limits and minimum conservation flow released from the lake to Duck Creek.
Watershed	Surface area over which all water falling on the land drains to a single point, with the boundary defined by the height of land. For this study, the watershed is considered to be that area upstream of the outlet of St Mary Lake and forms the limit of the study area. The watershed area also defines the boundary of the closed system used for surface water balance calculations.
Water Withdrawal	Water withdrawn from St Mary Lake for waterworks, domestic, industrial or agricultural uses. The term water withdrawal is also used in this study to indicate a recorded amount of water withdrawn from the lake rather than the Licenced Withdrawal Limit which is the maximum amount of water that is permitted to be withdrawn from the lake in accordance with the water licence.

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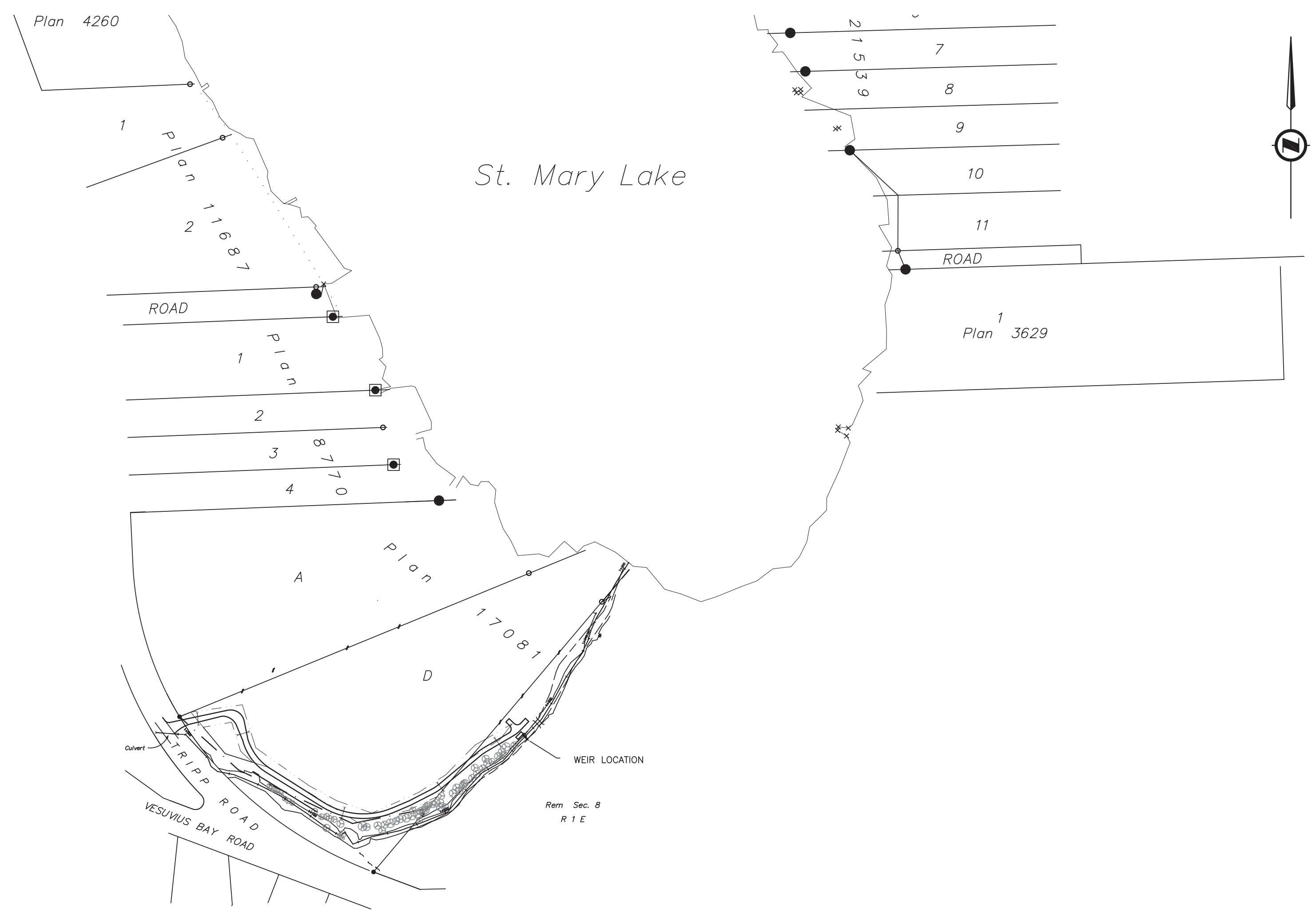
Appendix B

St. Mary Lake As-built Drawings for the Outlet Structure

NORTH SALT SPRING WATERWORKS DISTRICT
ST. MARY LAKE - DUCK CREEK
PROPOSED WEIR



LOCATION PLAN
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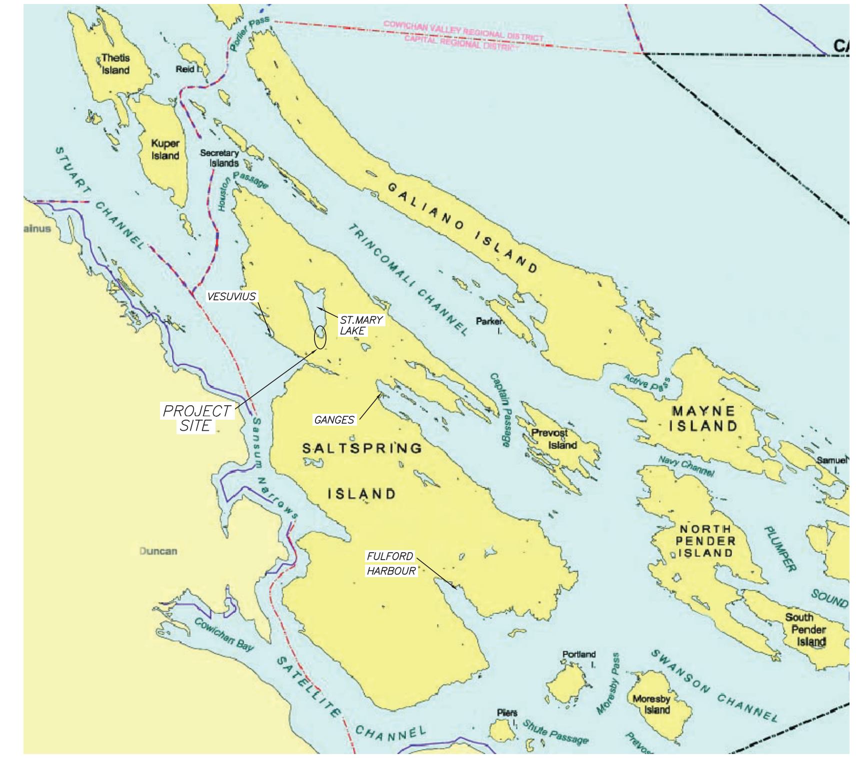

KEY PLAN
Scale=NTS

DRAWING INDEX

2129-1-2	LOCATION PLAN, KEY PLAN & NOTES
2129-1-3	SITE PLAN & CREEK IMPROVEMENTS
2129-1-4	DETAILS
2129-1-5	CROSS-SECTIONS

LEGEND

PROPOSED			EXISTING	
WATERMAIN	WATER VALVE	DITCH	ANCHOR	
SANITARY SEWER	HYDRANT	CULVERT	UTILITY POLE	
STORM DRAIN	WATER METER	CATCH BASIN	FENCE	
CURB AND GUTTER	AIR VALVE	MANHOLE	SLOPE	
EDGE OF PAVEMENT	CLEANOUT			

No.	REVISION DESCRIPTION	DATE	BY
D	As Constructed	07.03.01	FL
C	For Tender	06.07.28	FL
B	For Agency Review	06.03.13	JDF
A	For Approval	06.02.20	JDF

DESIGN: DWA
DRAWN: JDF
APPROVED: DWA
DATE: 05.11.21
SCALE: AS SHOWN
BENCHMARK:

ANDERSONCIVIL Consultants Inc.
#206B-335 Wesley Street, Nanaimo, B.C. V9R 2T5
Tel 250 754 1877 Fax 250 754 4375 email civileng@andersoncivil.com

CLIENT: NORTH SALT SPRING WATERWORKS
PROJECT: ST. MARY LAKE - DUCK CREEK PROPOSED WEIR LOCATION PLAN, KEY PLAN & NOTES

SHEET No. 1 OF 4
DRAWING No. 2129-1-2
CAD FILE No.
REV. D

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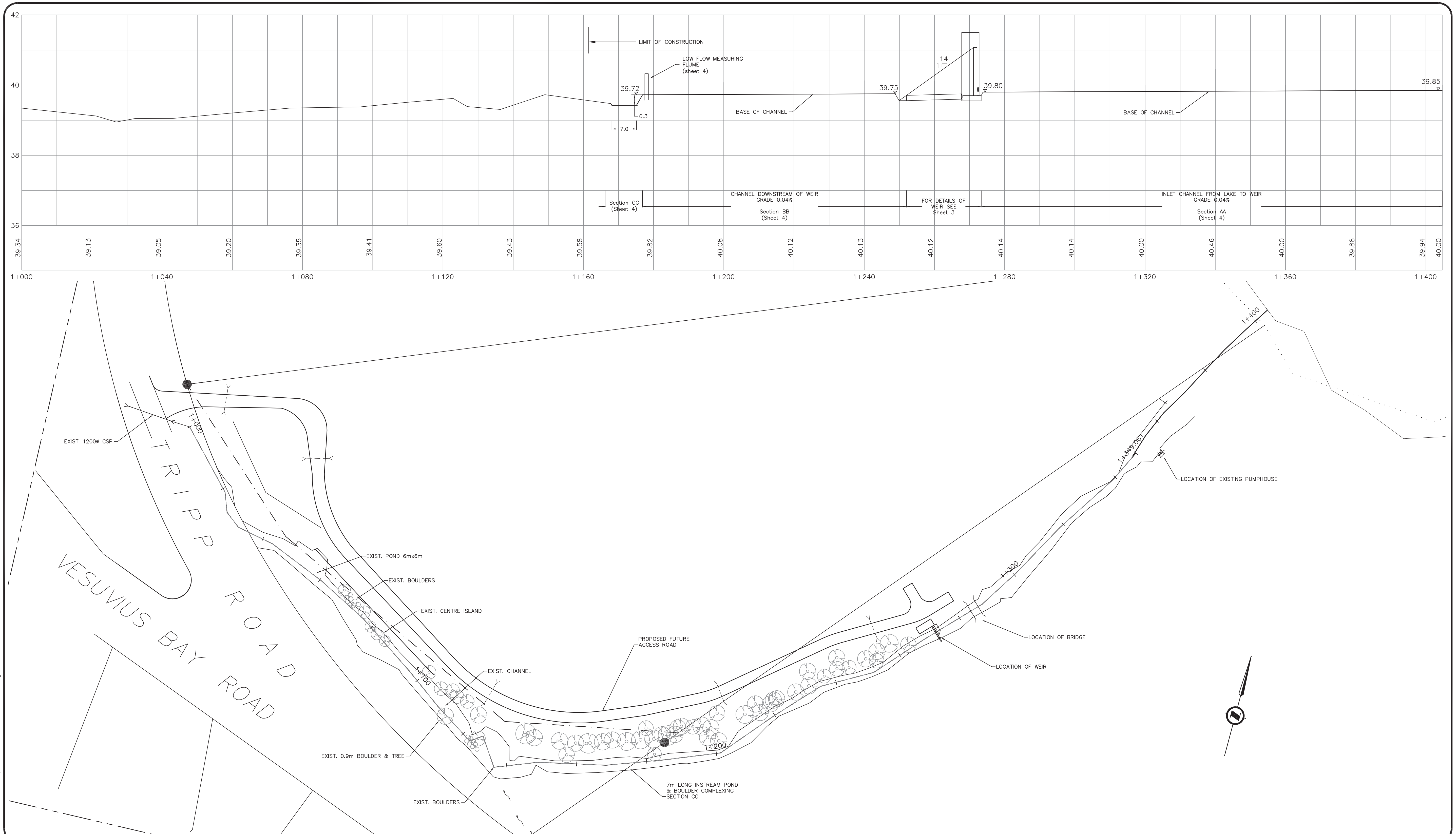

LEGEND							
PROPOSED				EXISTING			
—W—	WATERMAIN	⧓	WATER VALVE	⁓→	DITCH	←	ANCHOR
—S—	SANITARY SEWER		HYDRANT		CULVERT	⌀	UTILITY POLE
—D—	STORM DRAIN	Ⓜ	WATER METER		CATCH BASIN		FENCE
—C—	CURB AND GUTTER	Ⓐ	AIR VALVE	Ⓓ Ⓢ	MANHOLE		SLOPE
—EP—	EDGE OF PAVEMENT		CLEANOUT				

No.	REVISION DESCRIPTION	DATE	BY
D	As Constructed	07.03.01	FL
C	For Tender	06.07.28	FL
B	For Agency Review	06.03.13	JDF
A	For Approval	06.02.20	JDF

DESIGN:	DWA
DRAWN:	JDF
APPROVED:	DWA
DATE:	05.11.21
SCALE:	Hz 1:500 Vt 1:50
BENCHMARK:	

ANDERSONCIVIL Consultants Inc.
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CLIENT: NORTH SALT SPRING WATERWORKS

PROJECT: ST. MARY LAKE - DUCK CREEK
PROPOSED WEIR
SITE PLAN & CREEK IMPROVEMENTS

SHEET No. 2 OF 4

DRAWING No. 2129-1-3

CAD FILE No.

REV. D

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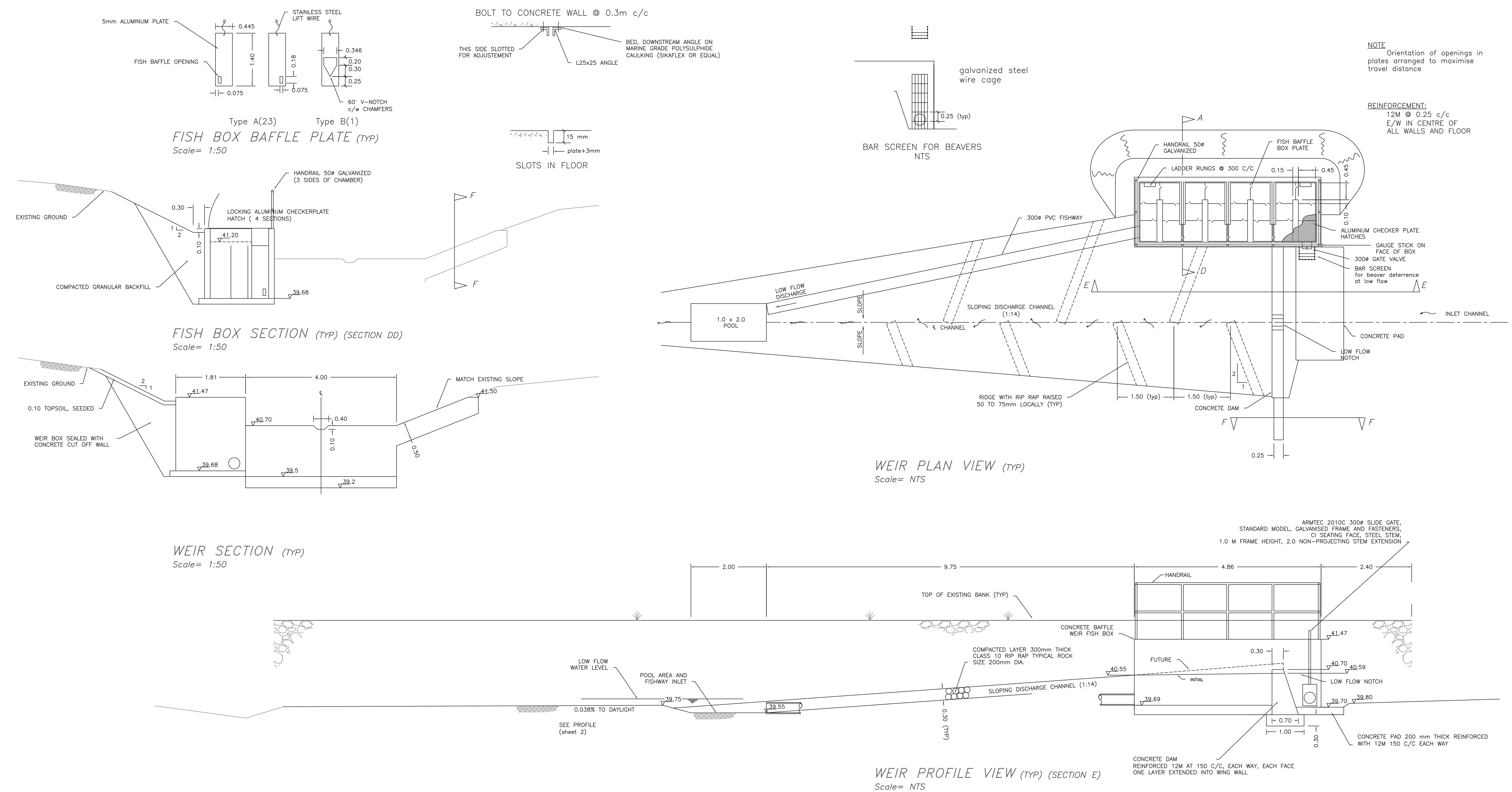

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SANITARY SEWER	HYDRANT	CULVERT	UTILITY POLE
STORM DRAIN	WATER METER	CATCH BASIN	FENCE
CURB AND GUTTER	AIR VALVE	MANHOLE	SLOPE
EDGE OF PAVEMENT	CLEANOUT		

No.	REVISION DESCRIPTION	DATE	BY
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C	For Tender	06.07.28	FL
B	For Agency Review	06.03.13	JDF
A	For Approval	06.02.20	JDF

DESIGN: DWA
DRAWN: JDF
APPROVED: DWA
DATE: 05.11.21
SCALE: AS SHOWN
BENCHMARK:

ANDERSONCIVIL Consultants Inc.
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Tel 250 754 1877 Fax 250 754 4375 email civileng@andersoncivil.com

CLIENT: NORTH SALT SPRING WATERWORKS
PROJECT: ST. MARY LAKE - DUCK CREEK PROPOSED WEIR DETAILS

SHEET No. 3 OF 4
DRAWING No. 2129-1-4
CAD FILE No.
REV. E

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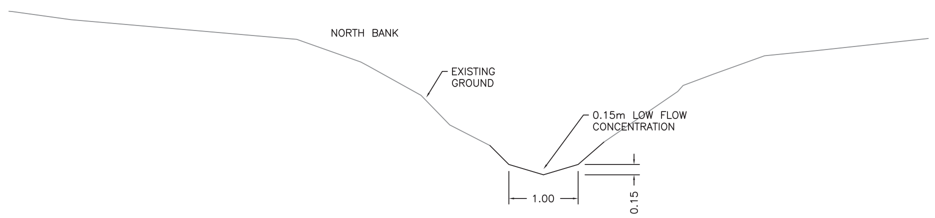

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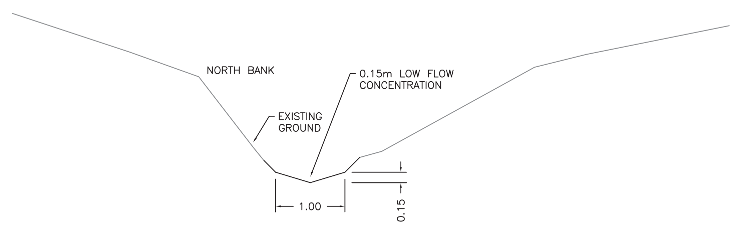

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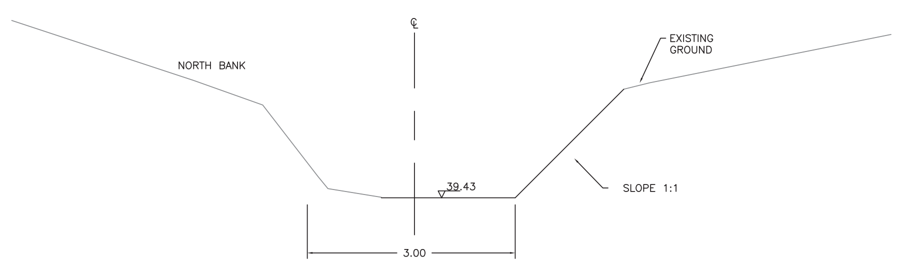

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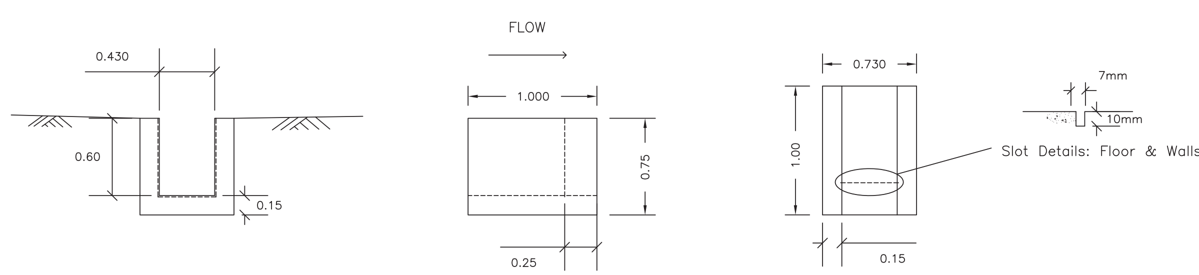

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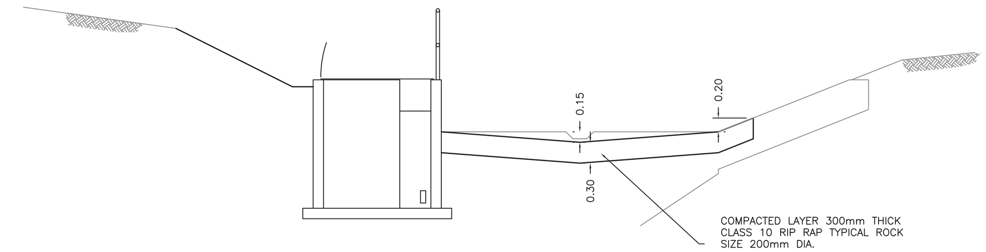

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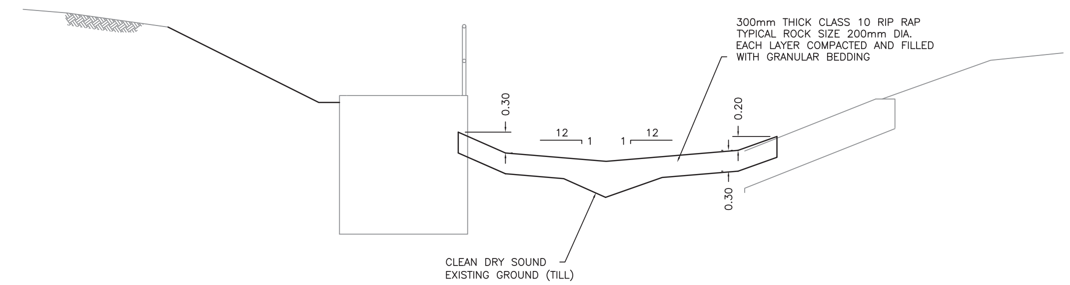

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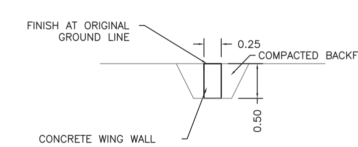

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LEGEND

PROPOSED			EXISTING	
W WATERMAIN	WATER VALVE	DITCH	ANCHOR	
S SANITARY SEWER	HYDRANT	CULVERT	UTILITY POLE	
D STORM DRAIN	WATER METER	CATCH BASIN	FENCE	
C CURB AND GUTTER	AIR VALVE	MANHOLE	SLOPE	
EP EDGE OF PAVEMENT	CLEANOUT			

No.	REVISION DESCRIPTION	DATE	BY
C	As Constructed	07.03.01	FL
B	For Tender	06.07.28	FL
A	For Agency Review	06.03.13	JDF

DESIGN:	DWA
DRAWN:	JDF
APPROVED:	DWA
DATE:	05.11.21
SCALE:	AS SHOWN
BENCHMARK:	

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CLIENT: NORTH SALTSPRING WATERWORKS
PROJECT: ST. MARY'S LAKE - DUCK CREEK PROPOSED WEIR CROSS-SECTIONS

SHEET No. 4 OF 4
DRAWING No. 2129-1-5
CAD FILE No.
REV. C

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KERR WOOD LEIDAL
consulting engineers

Appendix C

Groundwater Report

Waterline Resources Inc.

2301 McCullough Road, Unit D
Nanaimo, British Columbia
Canada V9S 4M9
Tel: 250.585.0800
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Toll Free: 1.888.641.6795
www.waterlineresources.com

June 27, 2014
2291-13-001

Kerr Wood Leidal Associates Ltd.
201 – 3045 Douglas Street
Victoria, British Columbia, V8T 4N2

Attention: Craig Sutherland

Dear Mr. Sutherland:

RE: Hydrogeological Assessment Report - St. Mary Lake Watershed Study

1.0 INTRODUCTION

Waterline Resources Inc. (Waterline) was retained by Kerr Wood Leidal Associates Ltd. (KWL) to complete the groundwater component of the St. Mary Lake Hydrology Assessment and Lake Level Monitoring Study – Update for the North Salt Spring Waterworks District. St. Mary Lake is located in the northeastern part of Salt Spring Island, British Columbia (Figure 1).

1.1 Objectives and Scope of Work

The primary objective of this study was to complete a desk-top hydrogeological assessment as a component of the St. Mary Lake hydrology assessment undertaken by KWL. A secondary objective of the work was to develop a conceptual model of the hydrogeology beneath the St. Mary Lake Watershed and identify any potential groundwater-surface water interactions. To meet this objective, Waterline completed the following scope of work:

- Review available geological mapping and aquifer mapping;
- Review available well log data within the Watershed;
- Review available ground water level data;
- Develop a conceptual hydrogeological model for the watershed which defines the approximate extent and thickness of aquifers and aquitards within the Watershed;
- Estimate groundwater recharge rates, groundwater use and groundwater balance/budget to the extent of the data;
- Compare the groundwater budget results with the surface water balance results and integrate as appropriate; and
- Prepare a letter report summarizing the study results, the data gaps identified, and study conclusions and recommendations.

2.0 REGIONAL SETTING

2.1 Site Topography and Drainage

The St. Mary Lake Watershed (the Study Area) is situated at an elevation of approximately 42 metres above sea level (masl). Topography within the Study Area slopes gently towards the Lake in the north and south and is moderately to steeply sloping towards the Lake in the east and west (Figure 2). Surface water drainage is directed from the lake to the ocean via Duck Creek at the west end of the lake.

2.2 Surficial and Bedrock Geology

Surficial geology within the Study Area is mainly comprised of Quaternary glacial till, glacio-marine deposits. Surficial deposits around St. Mary Lake are generally thin, recent lacustrine sediments that blanket the bedrock. The mapped surficial geology is presented in Figure 3.

The bedrock geology of Salt Spring Island has been mapped and described in detail by Greenwood and Mihalynuk (2009). Geological formations, mapped within the Study Area, are presented in Figure 4 and are described as follows:

- **KS – Spray Formation:** Recessive-weathering sandstone-mudstone turbidite and massive mudstone;
- **KGs – Geoffrey Formation (sandstone):** Thick-bedded sandstone;
- **KGc – Geoffrey Formation (conglomerate):** Interbedded within KGs;
- **KN – Northumberland Formation:** Weathered mudstone and fine-grained sandstone;
- **KD – DeCourcy Formation:** Thick bedded sandstone and arkostic arenite with minor pebbly conglomerate;
- **KCd – Cedar Disctrict Formation:** Interbedded sandstone and mudstone;
- **KP – Protection Formation:** Thick-bedded medium-grained sandstone;
- **KG – Ganges Formation:** Thin-bedded medium-grained sandstone; and
- **KEs – Extension Formation:** Pebble and cobble conglomerate with coarse-grained sandstone facies at top and bottom of unit.

The Study Area extends across a major synclinal fold across that has been displaced by the St. Mary Lake Fault (Figure 4). Bedrock mapping shows steeply dipping bedding (i.e., 65° to 85°) on the southwest limb on the fold axis and moderately dipping bedding (i.e., 20° to 35°) on the northeast limb (Greenwood and Mihalynuk, 2009). The St. Mary Lake Fault system extends north-south across St. Mary Lake and is inferred to the coast. This major structural deformity undoubtedly affects the flow of groundwater within the Study Area. The major and minor faults serve as conduits connecting multiple hydrostratigraphic zones and may also provide direct connection with the marine environment. This is important when considering the potential for salt water intrusion and, as will be shown, some water wells within the St. Mary Lake Watershed are known to contain salt water.

2.3 Mapped Aquifers and Groundwater Flow

The British Columbia Ministry of Environment (BC MoE) completed a preliminary mapping assessment of aquifers on Salt Spring Island. The aquifer mapped in the vicinity of St. Mary Lake is Aquifer #721, shown on Figure 5. This bedrock aquifer and is classified as IIB, which means it exhibits low productivity, moderate demand and moderate vulnerability (BC MoE, 1994). It should be noted, that the complex folded geometry and lithology likely means that there are multiple hydrostratigraphically active zones in the vicinity of the St. Mary Lake watershed. These zones are likely controlled by the geometry of the stratigraphy (i.e., sandstone/conglomerate versus mudstones/shale) and structure (folds and faults). The area mapped by BC MoE assumes that the bedrock exhibits intense vertical fracturing extending to surface. The majority of the aquifer(s) is likely unconfined or semi-confined and direct recharge occurs seasonally during the winter rainy season. The aquifer may be confined locally in areas that are covered by low permeability bedrock units or low permeability unconsolidated materials (silt or clay).

There is no recent water level data available to evaluate current groundwater flow patterns. Although groundwater flow through the aquifer(s) is complex, this is a gravity-driven system and groundwater flow is expected to generally follow the topographic gradient towards the ocean. The cross section presented in Figure 6 shows the complex nature and structure of the bedrock. As shown, local shallow groundwater within the Watershed likely recharges the underlying bedrock aquifer(s) by direct infiltration from precipitation at higher elevations and slower percolation through overburden materials and the lake bottom.

Saline groundwater was reported by Hodge (1995) south and southeast of St. Mary Lake. Driller's reports for three of the wells displayed on Figure 6 (i.e., GIC # 36859, 12685, 37537) indicate that the groundwater in the well was saline at the time of drilling. Driller's reports are provided for reference in Attachment 1.

3.0 GROUNDWATER BUDGET ASSESSMENT

3.1 Water Budget Equation and Key Parameters

A water balance equation for aquifers is as follows:

$$\mathbf{Rp + Rr + Rf + Rt + Si + Ig = Et + Tp + Se + Og + \Delta S}$$

Where:

Rp = recharge from precipitation;
Rr = recharge from reservoir seepage;
Rf = recharge from field irrigation;
Rt = recharge from tanks (if available);
Si = influent seepage from rivers;
Ig = inflow from other basins;
Et = evapotranspiration;
Tp = draft from ground water;
Se = effluent seepage to rivers;
Og = outflow to other basins; and
ΔS = change in ground water storage.

The above equation considers only one aquifer or watershed system and does not account for the interflows between aquifers in a multi-aquifer system.

Several key parameters are required in order to compete a groundwater budget assessment. They include:

- **Recharge:** An understanding of rates and locations of water that recharged the aquifer. Recharge locations are mainly controlled by land use and cover, topography and surficial geology. Recharge rates are usually highly uncertain and often require numerical modeling to quantify.
- **Aquifer Parameters**: The specific yield/storativity and transmissivity data is required to account for the variation of these aquifer parameters within the Study Area.
- **Water Levels and Drawdown**: Long-term groundwater level data is of critical importance to developing an understanding of aquifer response to individual precipitation events, seasonal changes, tidal fluctuations, long-term climate variability indicators (e.g., Pacific Decadal Oscillation), and groundwater use in the Watershed. These data are needed to manage groundwater resources and determine if natural phenomenon and groundwater withdrawal is causing water levels to decline over time.
- **Groundwater Extraction and Discharge**: A complete inventory of active water wells operating in the area, their running hours each month, and discharge are required for estimating groundwater withdrawals within the Watershed.

Computations of water budget parameters will invariably involve errors, due to insufficient or poor quality input data. As all of the data required to complete an accurate groundwater budget is unavailable only a conceptual assessment could be completed as part of the current study.

3.2 Groundwater Recharge

Previous work by Foweraker (1974) on Mayne Island and by Hodge (1995) at Scott Point on Salt Spring Island suggest that approximately 3% of total precipitation recharges the bedrock aquifers. This is equivalent to 29.61 mm/yr of recharge per square meter based on 987 mm/yr of total precipitation. Hodge (1995) noted that this recharge rate is highly dependent on bedrock storativity and permeability and therefore could easily vary by at least an order of magnitude.

Land use can also significantly affect recharge. Field irrigation, reservoir and septic tank infiltration, and impermeable surfaces affect surface and groundwater water budget parameters and must be known if reasonably accurate water budgets are to be developed. Figure 7 shows the land use designations in the Study Area which is comprised the following six zones:

- Agriculture;
- Developed;
- Rural;
- Forest;
- Wetlands; and
- Lakes.

The map shows that the majority of the Study Area is forested but has areas of rural zoning to the east, and agriculture zoning to the south. Only a small portion of the study area is zoned developed or wetland.

As recharge from reservoir seepage, field irrigation, septic field and tanks is not specifically measured or known, it is impossible to assess these parameter independently at this time. In addition, the lack of physical data (i.e., water level hydrographs, bedrock permeability, storativity) makes it impossible to estimate aquifer recharge using standard hydrogeological methods.

The only quantitative data available to estimate recharge is KWL's surface water balance estimate indicates that approximately 620,000 m^3/yr (97mm/yr per square meter) of water is lost to the deep groundwater system within the Study Area (Craig Sutherland, Personal Communication). KWL calculated this recharge value by comparing the St. Mary Lake Watershed Hydraulic Model results to the back calculated lake inflows whereby modeled parameters including groundwater infiltration percentage, groundwater runoff factor, and groundwater deep aquifer loss percentage were adjusted until a good match between the recorded data and the model output was achieved. The recharge value used from the KWL report is referred to the deep aquifer loss parameter (KWL, 2014). This value represents approximately 10% of the total annual precipitation of 6,385,000 m^3/yr (987 mm/yr per square meter) across the Watershed.

Although a more detailed assessment could be developed by conducting a field survey and applying land zoning data, this was outside the scope of the present study. The KWL study indicates that groundwater recharge could be over three times higher than indicated by Foweraker (1974) on Mayne Island by Hodge (1995). Further groundwater studies would be required to further quantify the estimate.

3.3 Aquifer Parameters

To Waterline's knowledge, no aquifer testing has been conducted and no public data is currently available for wells tested in the Study Area. In general, this type of data is not collected in BC unless a public utility system is being considered (e.g., Cedar Lane Groundwater Supply System). As there is no available data, it is not possible to complete an accurate assessment of aquifer productivity and long-term sustainable yield of the aquifer with any degree of accuracy at this time.

3.4 Water Levels and Drawdown

According to the BC Groundwater Observation Well Network website, there are only two active BC MoE Observations wells on Salt Spring Island (BC MoE, 2014a). These include Obs Well #281 located on Long Harbour Road and Obs Well #373 located at Mt. Belcher Heights. According to Dr. Diana Allen (personal communication, 2014), a new BC MoE observation well has been established within the St. Mary Lake Watershed. However, the location of the well is unknown and the data record would likely be too short to provide any meaningful trends for the current study. No other water level data is available within the St Mary was available to assess current water levels, long term water level trends, drawdown, well to well interference, or recharge.

Based on the water levels recorded in Obs Well #281 on Long Harbour Road and Obs Well #373 at Mt. Belcher Heights, overall water level trends are generally flat (i.e., not declining). Water levels fluctuate seasonally suggesting rapid recharge follows precipitation trends. Within the Study Area, it is expected that water levels may also fluctuate seasonally, however; site specific data would be required to confirm a similar aquifer response in the Study Area. Waterline is aware of anecdotal reports indicating wells running dry along Stark Road during the summer season. This could be caused by a number of different factors including a low permeability aquifer, over-pumping of the aquifer, or lower recharge in that local area.

3.5 Groundwater Extraction

As no quantitative water use data is available and the number of active water wells within the Watershed is not known with any degree of certainty, only a crude estimate of groundwater use can be made based on the wells listed in the BC MoE database, land use data, and known surface water service areas in the region.

Three surface water service areas are located within the Study Area (Figure 8), and are listed as follows:

- North Salt Spring Waterworks District;
- Fernwood Water Service Area; and
- Highland Water Service Area.

All three of the service areas are sourced by surface water. There are no other waterworks serviced by groundwater in the Study Area (Ron Stepaniuk, personal communication).

According to the BC MoE Wells Database (BC MoE, 2014b), 69 water wells exist within the Study Area. Table 1 summarizes the wells by aquifer type and well use. Wells classified by aquifer type (unconsolidated or bedrock) are displayed on Figures 3, 4 and 5 and by use on Figures 7 and 8. It is important to note that well logs are submitted to BC MoE on a voluntary basis and as a result there is likely a significant number of wells that have not been accounted for within the Study Area as not all drillers submit their well logs to the government database. Table 1 summarizes the available information in the BC MoE Wells database.

Table 1: Summary of Recorded Groundwater Wells

Aquifer Type	**Number of Wells**
Unconsolidated	9
Bedrock	39
Unknown	22
Well Use	**Number of Wells**
Private Domestic	16
Other, Unknown	53

Although 69 wells are reported to exist, as many as 50% could be unreported based on Waterline's previous experience in BC. Field verification would be required to confirm the actual number of active wells. Eight of the 16 domestic wells and 17 of the 53 unknown/other wells plot within the water service areas and may or may not be in use. Nevertheless, Waterline has included these wells in the assessment as they could be used for irrigation or other purposes.

In order facilitate a groundwater budget estimate, Waterline assumed that all water wells divert and use a maximum of 2.5 m^3/d, which is a value used per dwelling in rural areas according to the British Columbia Subdivision Application Guide (BC MoT, 2005). Therefore, based on 104 wells pumping (i.e., 69 wells listed plus 50% uncertainty in the BC Wells database) at 2.5 m^3/d, total groundwater extraction is estimated to be 94,900 m^3/yr. A field verification survey and groundwater monitoring program is recommended to confirm the assumptions used in this estimate.

3.6 Conceptual Water Budget Assessment

Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of various human activities on the hydrologic cycle within a defined water region or watershed. Given enough data, it is possible to quantitatively evaluate individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in the groundwater regime due to changes in components of the system. The basic concept of water budget is that water inputs to the system, minus water output from the system is equal to the change in storage of the system over a specified period of time.

A quantitative water budget is near impossible to complete without the key data parameters indicated. In such cases, it is possible to complete a "conceptual" water budget that generalizes the major inputs and outputs of the system and helps to identify key parameters that are missing (i.e., data gaps) which can assist groundwater managers to plan future studies. Given the lack of data available, Waterline has completed a conceptual water budget using the following equation:

Recharge = Discharge + Change in Storage

Groundwater system recharge is assumed to equal KWL's estimate of groundwater loses from the surface water balance (620,000 m^3/yr). This value has been calculated using a surface water model and therefore has taken precipitation, evaporation, evapotranspiration, run-off and stream flows into account. The groundwater discharge (use) component is the assumed total groundwater extraction by wells (94,900 m^3/yer). Therefore, the difference between recharge and discharge (525,100 m^3/yr) is that which remains in storage. Based on this assessment, groundwater extraction accounts for approximately 15% of the conceptual groundwater balance.

Hodge (1995), calculated that groundwater extraction accounted for 38% of the available groundwater budget within the St. Mary Lake Region. As discussed in section 3.2, this value assumes a smaller rate of recharge (approximately 3% versus 10% of total precipitation).

Clearly, in order for sustainable groundwater management to occur, site specific data needs to be gathered to quantify the groundwater budget. It should also be noted that aquifer water budgets completed at the regional watershed scale as is being done in the current study, may differ considerably from local-scale water budgets. This is particularly true in structurally complex bedrock aquifers that are observed beneath the St Mary Lake Watershed. Areas where a higher density of water wells exist and the cumulative effect of well to well interference is high, and/or aquifer permeability is low, and/or aquifer recharge rates are low could result in a locally stressed aquifer(s) even though the regional aquifer system does not appear to be over-stressed. As more groundwater data is collected, the issues related to scaling of water budgets can be further clarified and addressed. At present, the two primary indicators that suggest the shallow groundwater in the St. Mary Lake Watershed is under stress is the anecdotal information in the Stark Road area, and the presence of saline groundwater identified in several wells. However, because surface water and groundwater systems are often very closely linked, if the surface water system is under considerable stress, it can be deduced that the groundwater system by default is also being stressed.

4.0 CONCLUSIONS

Quantitative water budgets are near impossible to complete without key data parameters including long-term groundwater monitoring, aquifer testing and groundwater quality data. The intent of the enclosed conceptual groundwater budget is to assess the major inputs and outputs of the water system that can assist groundwater managers to plan future studies. Based on the desk-top hydrogeological assessment study, Waterline has reached the following conclusions:

- There is one mapped aquifer within the Study Area (i.e., Aquifer# 721) which is a bedrock aquifer, classified as IIB (low productivity, moderate demand and moderate vulnerability).
- Groundwater flow through the aquifer is complex as it is controlled by fractures and faults in the bedrock which is not fully understood at this time and could represent multiple aquifers.
- Within the Study Area, shallow groundwater is likely recharged at high elevations by direct infiltration of precipitation, and discharged at low elevations into St. Mary Lake. Deeper groundwater is likely recharged by St. Mary Lake.
- Within the Watershed, 69 wells have been recorded in the BC MoE Wells Database, although the number of active wells remains uncertain. Based on Waterline's experience, there could be 50% more wells in addition to those reported, suggesting over 100 wells may exist within the Study Area.

- There are no groundwater hydrographs, water use data, or aquifer test data available within the Study Area. Therefore, it is not possible to assess present groundwater conditions in the aquifer, quantify groundwater use, or assess aquifer productivity and sustainability with any degree of accuracy at this time. Groundwater monitoring data would be required to move beyond a conceptual groundwater budget.
- The total annual volume of surface water lost to the underlying groundwater system(s) was calculated by KWL to be 620,000 m^3/yr, representing approximately 9.8% of the total volume of precipitation received by the Study Area on an annual basis. This estimate appears to be three times the amount of recharge estimated by Hodge (1995) who reported 3% of the total annual precipitation.
- Total groundwater extraction was estimated to be 94,900 m^3/yr, assuming an average extraction of 2.5 m^3/d by 104 wells.
- Based on the conceptual water budget developed by Waterline, groundwater extraction accounts for approximately 15% of estimated groundwater recharge based on the surface water balance completed by KWL. This contrasts Hodge (1995), which suggests that 38% of the recharge was being extracted. Although both estimates indicate that the regional groundwater system is not being over-stressed, given the generally small size of the Watershed, the groundwater-surface water system(s) should be considered and managed as a single resource. Ultimately, if the surface water system becomes stressed, it is inevitable the groundwater system will also become stressed by default. More data is required in order to fully quantify groundwater recharge, use, and assess the hydraulic connectivity between groundwater and surface water.
- Aquifer water budgets, which are being completed at the regional watershed scale as part of the current study, may differ considerably from local-scale water budgets. This is particularly true in structurally complex bedrock aquifers that are observed beneath the St. Mary Lake Watershed.
- In order for sustainable groundwater management to occur, site specific data needs to be gathered to better quantify groundwater budget parameters. Long-term groundwater monitoring, aquifer testing and groundwater quality sampling is required to obtain the required information to complete a quantitative water budget.

5.0 RECOMMENDATIONS

Based on the above conclusions, Waterline has provided the following recommendations for consideration:

- Complete a field verification survey to determine the number of active water supply wells within the St. Mary Lake Watershed.
- Establish several long-term water level monitoring wells within the St. Mary Lake Watershed. Assess if the well recently selected/installed by BC MoE is sufficient to determine the regional scale stress on the mapped aquifer(s). It may be possible to obtain permission from private well owners to install water level data loggers in their wells. If possible, it would also be useful to install flow meters to monitor groundwater

pumping rates for wells with different uses (e.g., domestic, agriculture, etc.). This will help to assess well performance, aquifer performance, cumulative impacts from groundwater extraction, and climate change/variability impacts.

- A Water Management Plan (WMP) that considers groundwater and surface water as a single resource should be developed. As part of the WMP process, it will be important to develop appropriate Bylaws and Policies to guide future land development that can potentially affect the long-term yield and groundwater quality in the aquifer(s). Development planning should also be considered in conjunction with watershed(s) and aquifer management so that a proper balance can be established and maintained.
- Waterline recommends that a community engagement and communication program be establish if not already in place. Maintaining public involvement is a key part of the management and protection of the St. Mary Lake Watershed and underlying aquifers.

6.0 CLOSURE

The North Salt Spring Waterworks District has taken a proactive step with the initiation of the present water project. The cooperation of all private landowners, drillers, water practitioners, developers, corporations, municipal/provincial/federal regulatory officials is now required to move the water management process forward to a sustainable future. It is also imperative that residents take a leadership role by providing access to existing water wells which are completed into a community resource.

The enclosed report and the information included were compiled exclusively for the KWL and its client. The work was carried out in accordance with the scope of work for this project and accepted hydrogeological practices. No other warranty, expressed or implied, is made as to the professional services provided to the client. Any use which a third party makes of this report, or any reliance on or decisions to be made based upon it, are the responsibility of such third parties. Waterline accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

Waterline Resources Inc. trusts that the information provided in this document is sufficient for your requirements. Should you have any questions or concerns, please do not hesitate to contact the undersigned.

Respectfully submitted,

Waterline Resources Inc.

Jessica Doyle M.Sc., G.I.T.
Hydrogeologist

Darren David M.Sc., P.Geo.
Principal Hydrogeologist

Reviewed By:

Andrea Mellor M.Sc., P.Geo.
Hydrogeologist

7.0 REFERENCES

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Stepaniuk, R., 2014. Personal communication via Craig Sutherland.

Sutherland, C., June 5, 2014. Personal communication.

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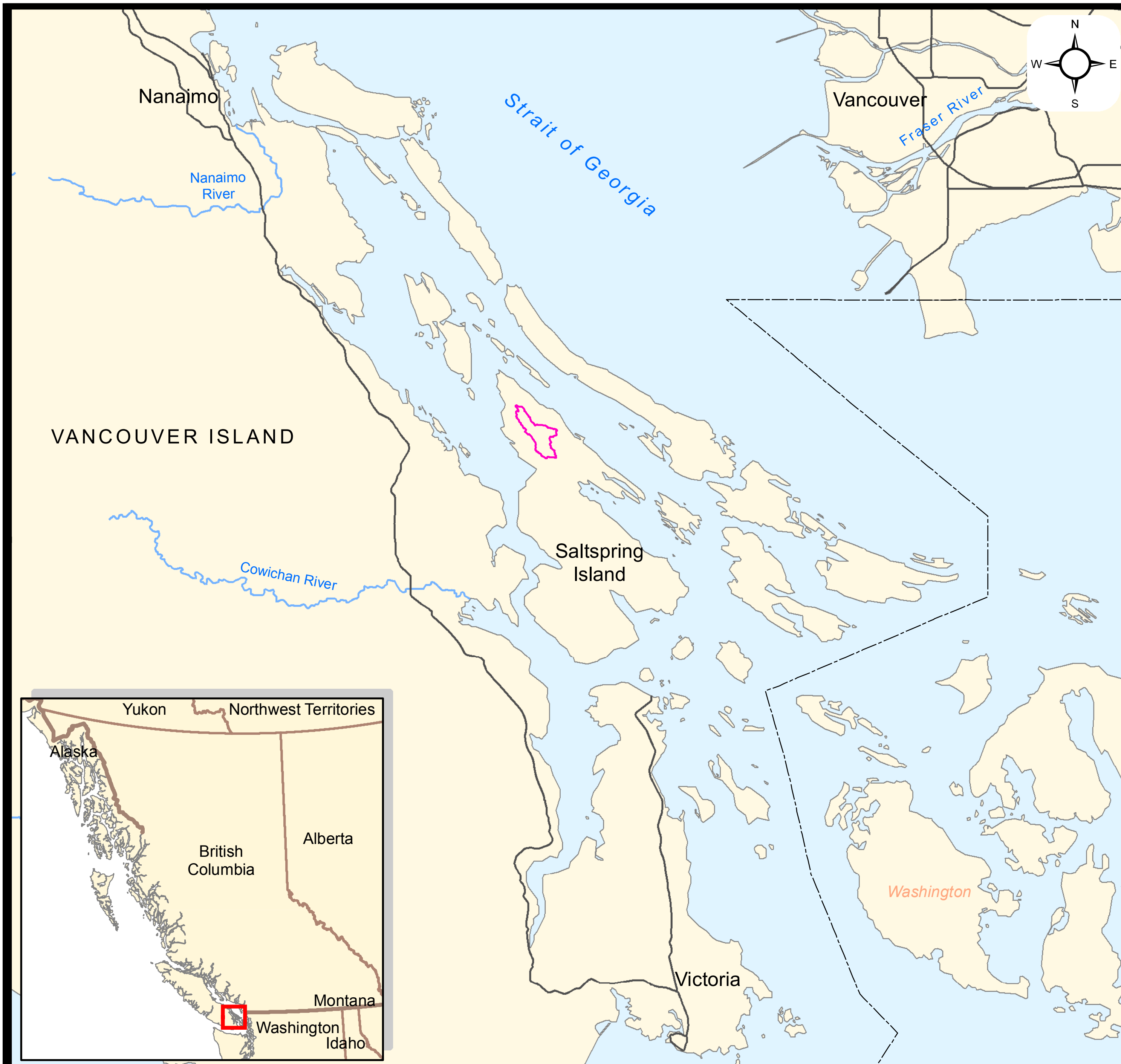
FIGURES



St. Mary Lake Watershed

Canada/USA border

Highways

Rivers

Scale: 1: 500,000 0 5 10 km

Coordinate System: NAD 1983 UTM Zone 10N

Sources:
Watershed boundary via Kerr Wood Leidal Associates Ltd.
Basemap - ESRI Data and Maps for ArcGIS 2013

PROJECT

St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

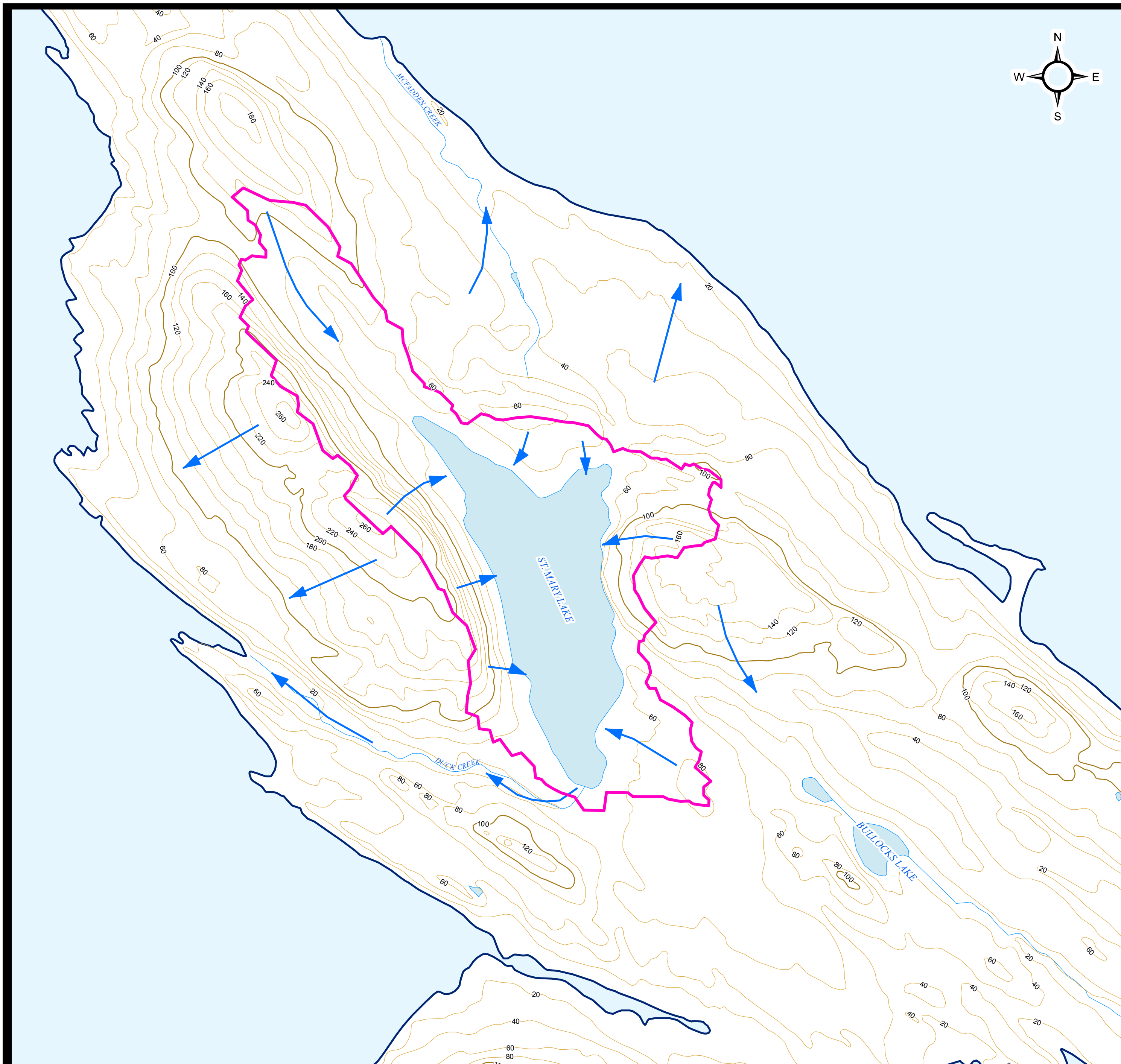
TITLE

STUDY AREA

Waterline Resources Inc.

PREPARED BY:	Waterline Resources Inc.
PROJECT:	2291-13-001
COMPILED BY:	rflemming
DATE ISSUED:	17/06/2014
DATE REVISED:	

Figure 1



St. Mary Lake Watershed

Interpreted Surface Drainage

Elevation contour 100 m

Elevation contour 20 m

Surface Water Lines (BC WSA 1:50K)

Lakes

Scale: 1: 42,419

0 0.5 1 km

Coordinate System: NAD 1983 UTM Zone 10N

Sources:
Water Features - British Columbia Watershed Atlas (1:50k)
Watershed boundary data via Kerr Wood Leidal Associates Ltd.
Contours and Roads - CanVec, Government of Canada, Natural Resources Canada, Earth Sciences Sector, Mapping Information Branch, Centre for Topographic Information, expressed in meters above sea level

PROJECT

St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

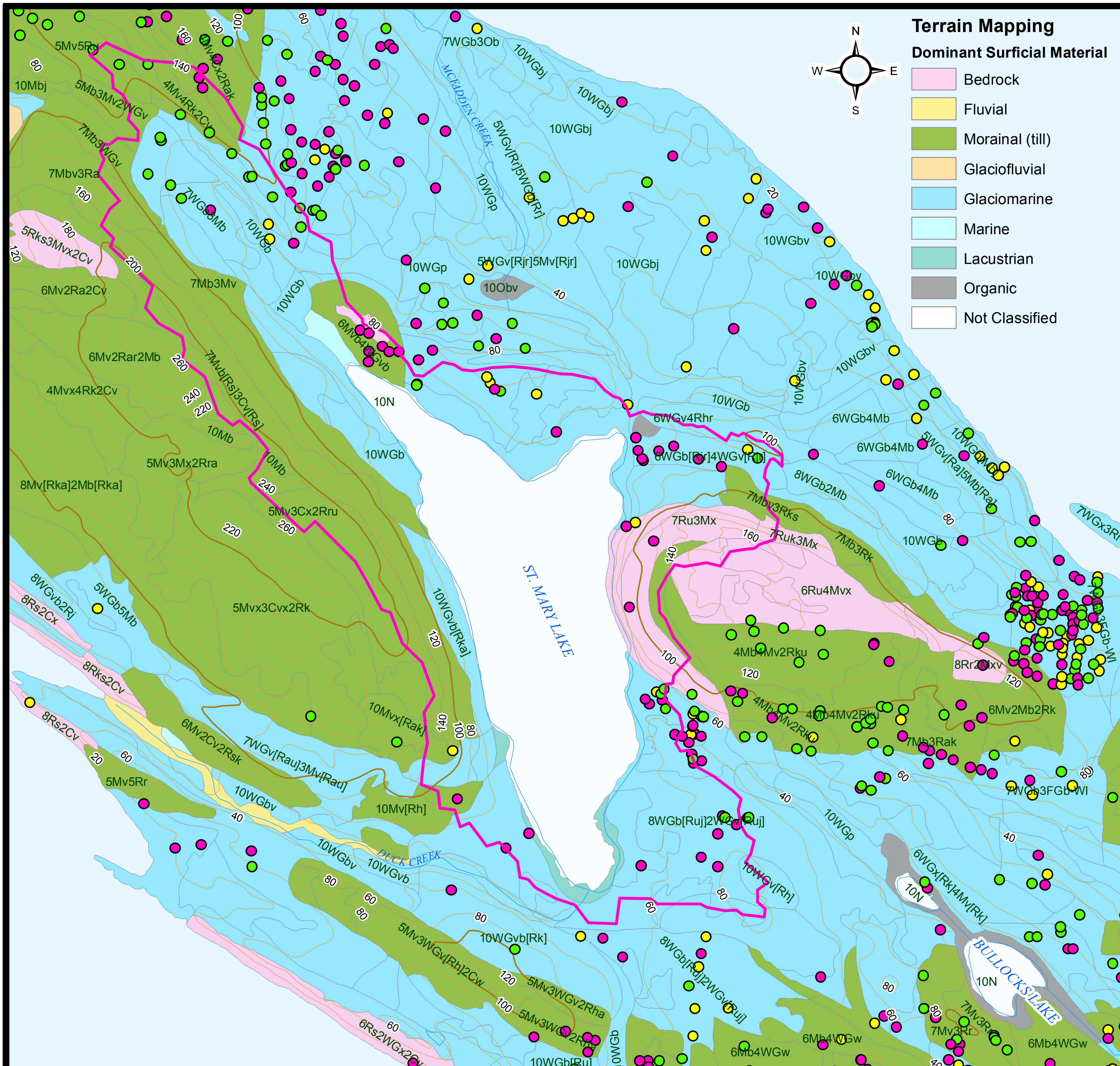
TITLE

SITE TOPOGRAPHY AND DRAINAGE

Waterline Resources Inc.

PREPARED BY:	Waterline Resources Inc.
PROJECT:	2291-13-001
COMPILED BY:	rflemming
DATE ISSUED:	17/06/2014
DATE REVISED:	

Figure 2



Scale: 1:30,000 0 0.5 1 km

Coordinate System: NAD 1983 UTM Zone 10N

St. Mary Lake Watershed

Water Wells by Aquifer Type

- Unknown
- Bedrock
- Overburden

Elevation contour 100 m

Elevation contour 20 m

Surface Water Lines (BC WSA 1:50K)

Surface Water Bodies (BC WSA 1:50K)

Sources:
Wells from BCGOV ENV Water Protection and Sustainability Branch, Downloaded 2013-08-23
Contours from Government of Canada, Natural Resources Canada, Earth Sciences Sector, Mapping Information Branch, Centre for Topographic Information, expressed in meters above sea level
Watershed boundary data via Kerr Wood Leidal Associates Ltd.
Terrain Mapping (TER) Polygons, BC Ecosystems Branch (MOE). Downloaded 2013-11-13 from Data BC

PROJECT

St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

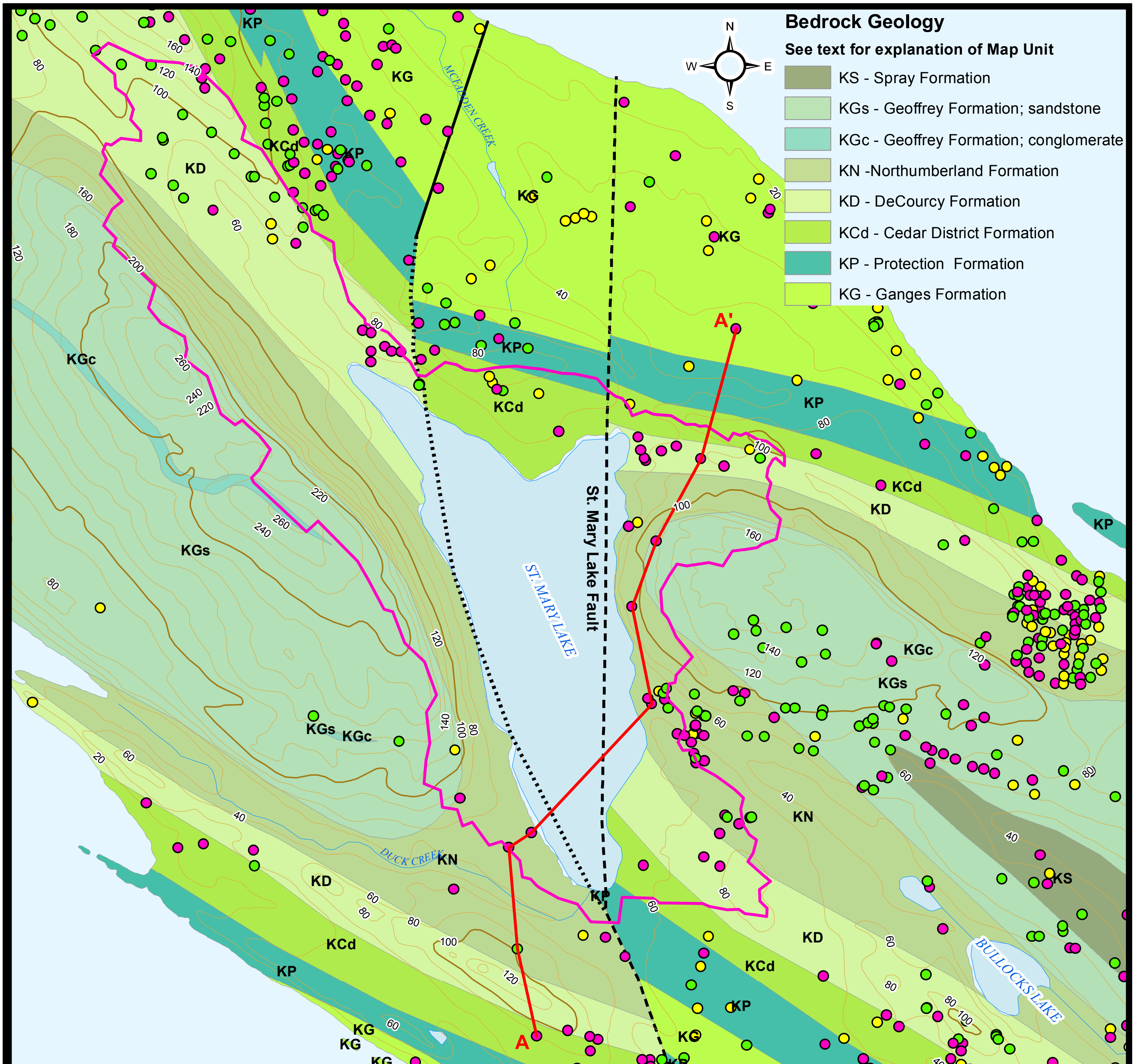
TITLE

SURFICIAL GEOLOGY

Waterline Resources Inc.

PREPARED BY:	Waterline Resources Inc.
PROJECT:	2291-13-001
COMPILED BY:	rflemming
DATE ISSUED:	17/06/2014
DATE REVISED:	

Figure 3



Coordinate System: NAD 1983 UTM Zone 10N Scale: 1:30,000

0 0.5 1 km

Cross Section Line (A - A')

St. Mary Lake Watershed

Water Wells by Aquifer Type

Unknown

Bedrock

Overburden

Elevation contour 100 m

Elevation contour 20 m

Surface Water Lines (BC WSA 1:50K)

Surface Water Bodies (BC WSA 1:50K)

St. Mary Lake Fault

defined

approximate

inferred

Sources:
Wells from BCGOV ENV Water Protection and Sustainability Branch, Downloaded 2013-08-23
Contours from Government of Canada, Natural Resources Canada, Earth Sciences Sector, Mapping Information Branch, Centre for Topographic Information, expressed in meters above sea level
Watershed boundary via Kerr Wood Leidal Associates Ltd.
Greenwood, H.J. and Mihalynuk M.G. (2009): Open File 2009-11, Geology of Saltspring Isl.; BC Ministry of Energy, Mines and Petroleum Resources

PROJECT

St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

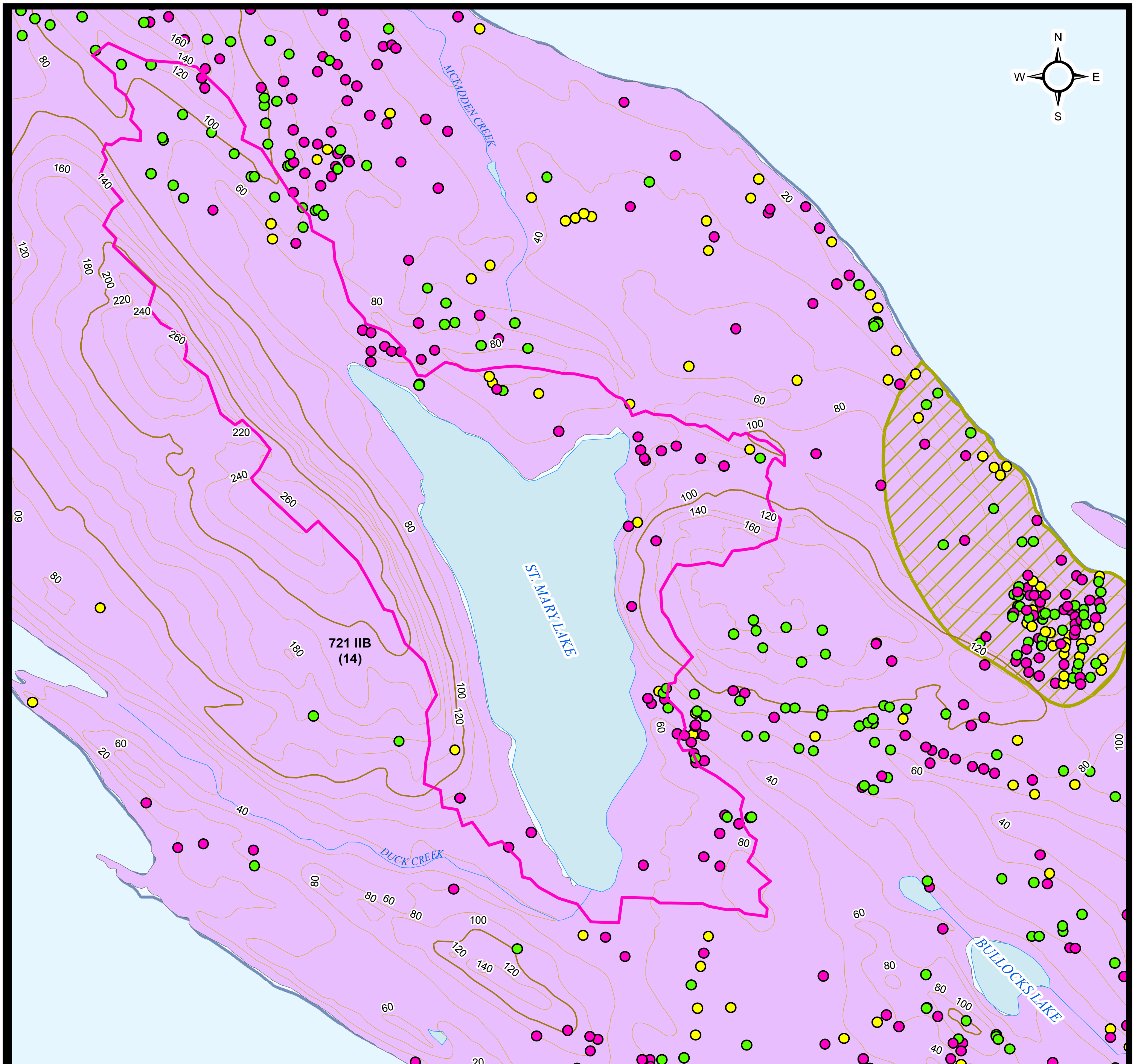
TITLE

BEDROCK GEOLOGY

Waterline Resources Inc.

PREPARED BY:	Waterline Resources Inc.
PROJECT:	2291-13-001
COMPILED BY:	rflemming
DATE ISSUED:	17/06/2014
DATE REVISED:	

Figure 4



St. Mary Lake Watershed

Sand and Gravel Aquifer (155)

Bedrock Aquifer (721)

Water Wells by Aquifer Type

Unknown

Bedrock

Overburden

Elevation contour 100 m

Elevation contour 20 m

Surface Water Lines (BC WSA 1:50K)

Surface Water Bodies (BC WSA 1:50K)

Scale: 1:30,000 0 0.5 1 km

Coordinate System: NAD 1983 UTM Zone 10N

Sources:
Wells from BCGOV ENV Water Protection and Sustainability Branch, Downloaded 2013-08-23
Aquifer boundary from BCGOV ENV Water Protection and Sustainability Branch, 2013
Contours from Government of Canada, Natural Resources Canada, Earth Sciences Sector, Mapping Information Branch, Centre for Topographic Information, expressed in meters above sea level
Watershed boundary and zoning data via Kerr Wood Leidal Associates Ltd.

PROJECT

St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

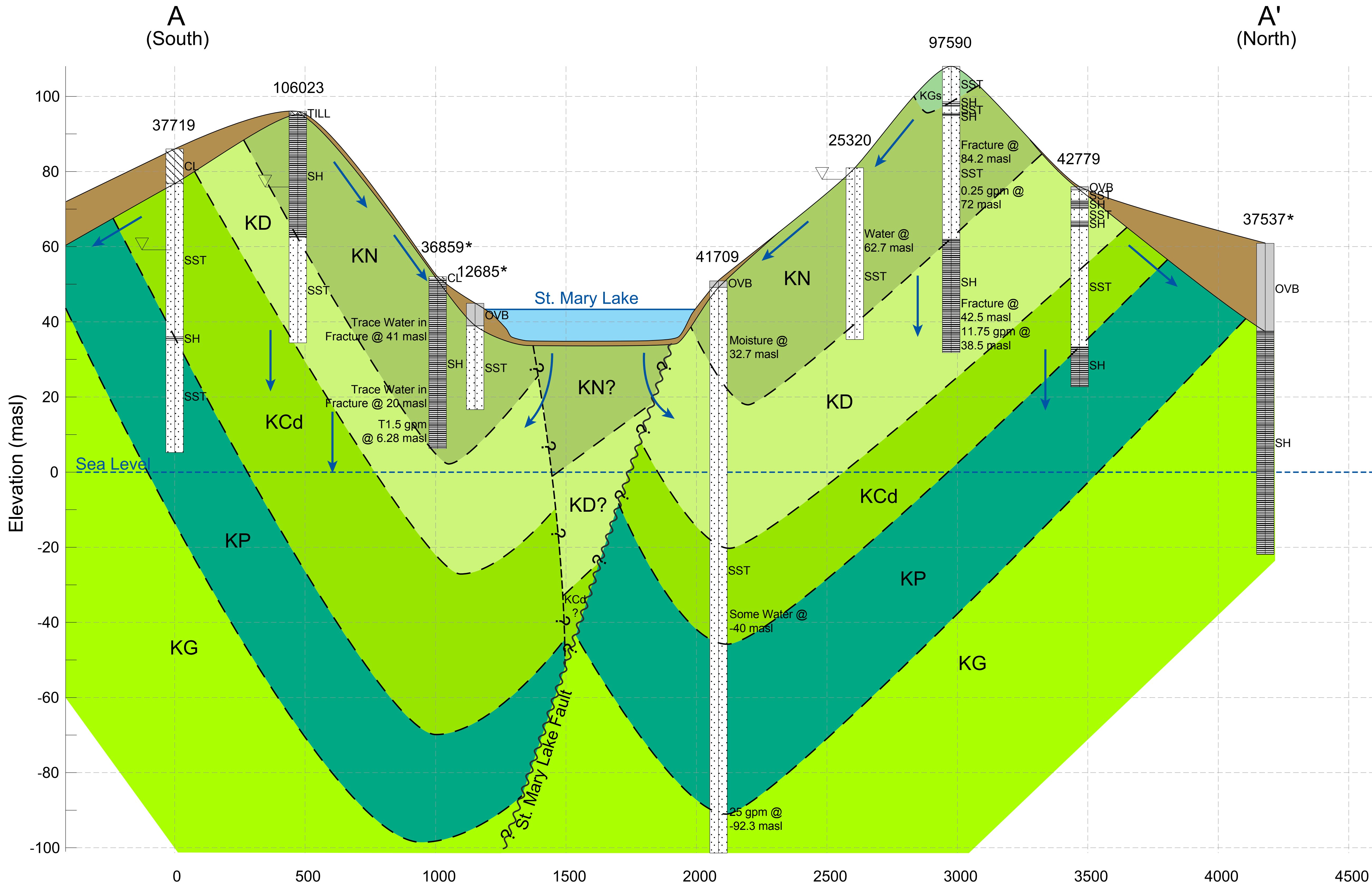
TITLE

MAPPED AQUIFERS

Waterline Resources Inc.

PREPARED BY:	Waterline Resources Inc.
PROJECT:	2291-13-001
COMPILED BY:	rflemming
DATE ISSUED:	17/06/2014
DATE REVISED:	

Figure 5



Vertical Exaggeration: 14:1

NOTES:

- Water levels shown are those taken during the drilling of the borehole.
- Data concerning the various strata have been obtained at the borehole locations only. The soil stratigraphy between boreholes has been inferred from geological evidence and so may vary from that shown.
- Geology data including mapped formations and structure (bedding and faults) are sourced from Greenwook, H.J. and Mihalynuk, M.G. (2009): Openfile 2009-11 Geology of Saltspring Island; BC Ministry of Energy, Mines and Petroleum Resources.

LEGEND:

Static Groundwater Level at the Time of Completion
Interpreted Ground Surface
Inferred Fault Line
Approximate Fault Line
* Salt Water Recorded in BC MOE Drilling Logs
Approximate Groundwater Flow Direction

Overburden (OVB)
Till
Clay (CL)
Shale (SH)
Sandstone (SST)

Overburden
KGs Geoffrey Formation; Sandstone
KN Northumberland Formation
KD DeCourcy Formation
KCd Cedar District Formation
KP Protection Formation
KG Ganges Formation

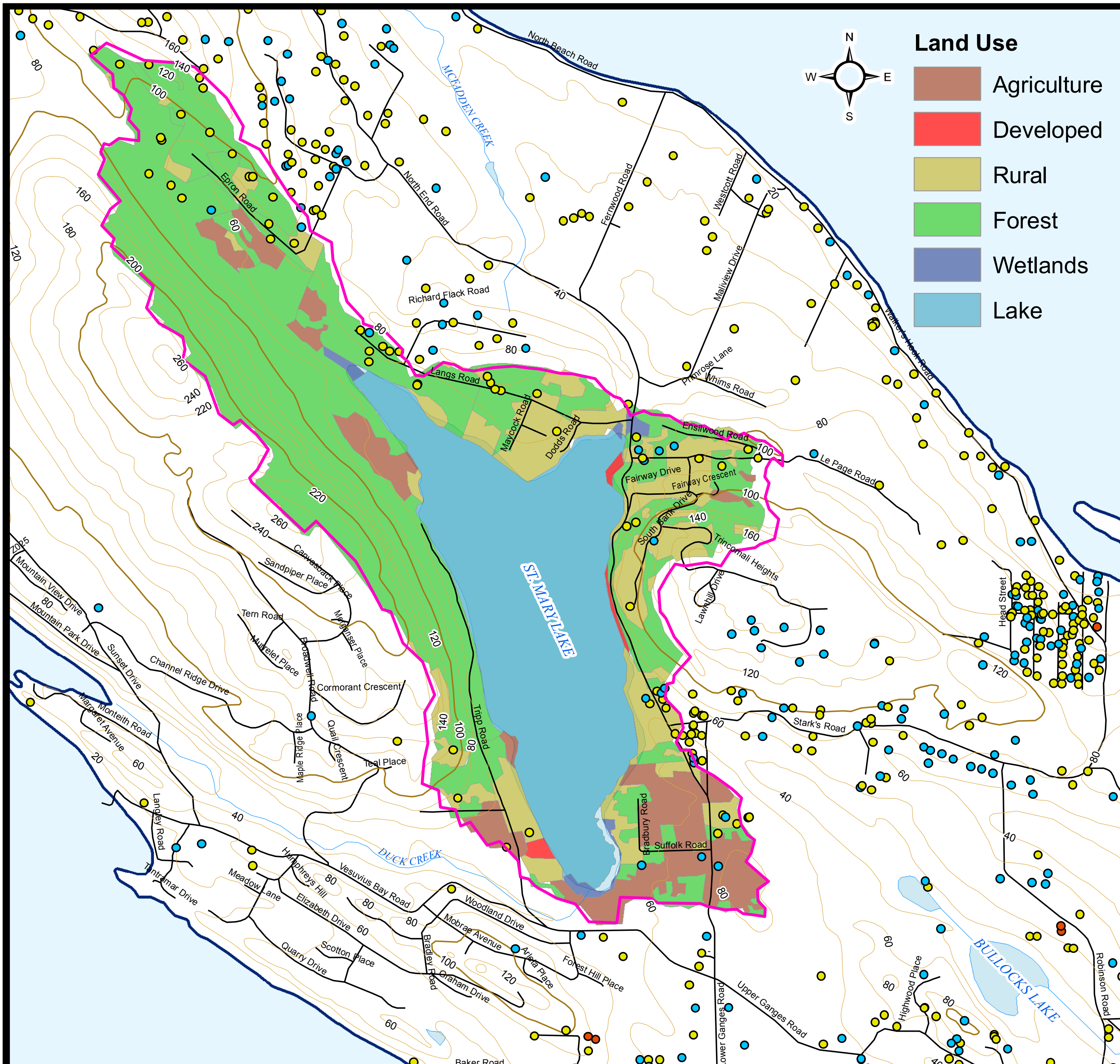
PROJECT
St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

TITLE
SCHEMATIC HYDROGEOLOGICAL CROSS-SECTION A-A'

Waterline Resources Inc.

PREPARED BY: Waterline Resources Inc.
PROJECT: 2291-13-001
COMPILED BY: CGD
DATE ISSUED: June 2014
REVISED: --

FIGURE 6



Scale: 1:30,000

0 0.5 1 km

Coordinate System: NAD 1983 UTM Zone 10N

St. Mary Lake Watershed

Water Wells by Use

- Commercial, Industrial
- Domestic
- Municipal, Commercial
- Other, Unknown

- Elevation contour 100 m
- Elevation contour 20 m
- Road
- Surface Water Lines (BC WSA 1:50K)
- Surface Water Bodies (BC WSA 1:50K)

Sources:
Wells from BCGOV ENV Water Protection and Sustainability Branch, Downloaded 2013-08-23
Contours from Government of Canada, Natural Resources Canada, Earth Sciences Sector, Mapping Information Branch, Centre for Topographic Information, expressed in meters above sea level
Watershed boundary and zoning data via Kerr Wood Leidal Associates Ltd.

PROJECT

St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

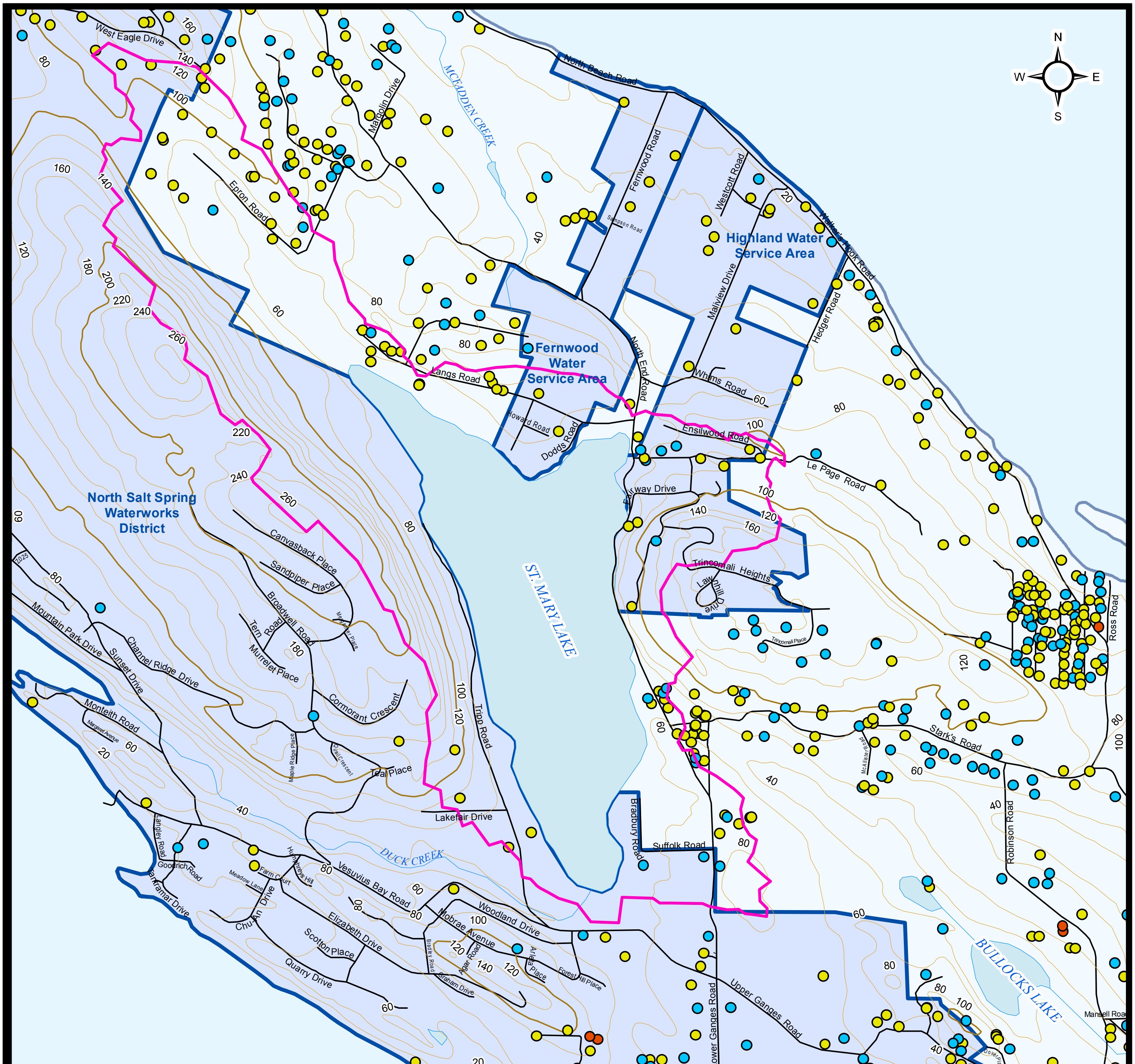
TITLE

WATERSHED ZONING

Waterline Resources Inc.

PREPARED BY:	Waterline Resources Inc.
PROJECT:	2291-13-001
COMPILED BY:	rflemming
DATE ISSUED:	17/06/2014
DATE REVISED:	

Figure 7



Coordinate System: NAD 1983 UTM Zone 10N

Scale: 1:30,000 — 0, 0.5, 1 km

St. Mary Lake Watershed

Water Service Area

Road

Elevation contour 100 m

Elevation contour 20 m

Water Wells by Use

Commercial, Industrial

Domestic

Municipal, Commercial

Other, Unknown

Surface Water Lines (BC WSA 1:50K)

Surface Water Bodies (BC WSA 1:50K)

Sources:
Wells from BCGOV ENV Water Protection and Sustainability Branch, Downloaded 2013-08-23
Contours from Government of Canada, Natural Resources Canada, Earth Sciences Sector, Mapping Information Branch, Centre for Topographic Information, expressed in meters above sea level
Watershed boundary data via Kerr Wood Leidal Associates Ltd.
Water Service Area boundaries digitized from CRD data, 2012

PROJECT

St. Mary Lake Watershed Study, Hydrogeological Assessment
Salt Spring Island, British Columbia

TITLE

WATER SERVICE AREAS

Waterline Resources Inc.

PREPARED BY: Waterline Resources Inc.
PROJECT: 2291-13-001
COMPILED BY: rflemming
DATE ISSUED: 17/06/2014
DATE REVISED:

Figure 8

Attachment 1
Driller Reports for Wells use in the Cross Section

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 106023	Construction Date: 9999-11-19 00:00:00.0
Owner: POOL	Driller: Island Well Drilling
Address: 220 MOBRAE AVENUE	Well Identification Plate Number:
Area: NORTH SALT SPRING ISLAND	Plate Attached By:
WELL LOCATION:	Where Plate Attached:
COWICHAN Land District	PRODUCTION DATA AT TIME OF DRILLING:
District Lot: Plan: VIP13212 Lot: 8	Well Yield: 15 (Driller's Estimate) Gallons per Hour (U.S./Imperial)
Township: Section: 7 Range: 1 W	Development Method:
Indian Reserve: Meridian: Block: 3	Pump Test Info Flag: N
Quarter:	Artesian Flow:
Island: SALT SPRING ISLAND	Artesian Pressure (ft):
BCGS Number (NAD 83): 092B083323 Well:	Static Level: 60 feet
Class of Well: Water supply	WATER QUALITY:
Subclass of Well: Domestic	Character:
Orientation of Well: Vertical	Colour:
Status of Well: New	Odour:
Well Use: Private Domestic	Well Disinfected: N
Observation Well Number:	EMS ID:
Observation Well Status:	Water Chemistry Info Flag:
Construction Method:	Field Chemistry Info Flag:
Diameter: inches	Site Info (SEAM):
Casing drive shoe: N	Water Utility:
Well Depth: 202 feet	Water Supply System Name:
Elevation: feet (ASL)	Water Supply System Well Name:
Final Casing Stick Up: 24 inches	SURFACE SEAL:
Well Cap Type:	Flag: N
Bedrock Depth: feet	Material:
Lithology Info Flag: Y	Method:
File Info Flag: N	Depth (ft):
Sieve Info Flag: N	Thickness (in):
Screen Info Flag: N	WELL CLOSURE INFORMATION:

	Reason For Closure:
Site Info Details:	Method of Closure:
Other Info Flag:	Closure Sealant Material:
Other Info Details:	Closure Backfill Material:
	Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe
-2	25	6	null	N

GENERAL REMARKS:
WATER SOURCE: 15 GPH @ 114 FEET

LITHOLOGY INFORMATION:

From 0 to 3 Ft. CLAYEY BROWN TILL brown clayey till

From 3 to 17 Ft. CRUMBLY BROWN SHALE brown shale

From 17 to 22 Ft. FRACTURED SHALE fractured shale

From 22 to 110 Ft. SHALE shale

From 110 to 132 Ft. SHALEY SANDSTONE shaley sandstone

From 132 to 141 Ft. GREY SANDSTONE grey sandstone

From 141 to 202 Ft. CHIEFLY SHALEY SANDSTONE WITH THIN LAYERS OF SHALE THROUGHOUT shaley sandstone

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 97590

Owner: BRENT

Address: SOUTHBANK DRIVE

Area: SALT SPRING ISLAND

WELL LOCATION:

COWICHAN Land District

District Lot: Plan: Lot:

Township: Section: Range:

Indian Reserve: Meridian: Block:

Quarter:

Island:

BCGS Number (NAD 83): 092B083343 Well:

Class of Well: Water supply

Subclass of Well: Domestic

Orientation of Well: Vertical

Status of Well: New

Well Use: Private Domestic

Observation Well Number:

Observation Well Status:

Construction Method:

Diameter: inches

Casing drive shoe:

Well Depth: 250 feet

Elevation: feet (ASL)

Final Casing Stick Up: inches

Well Cap Type:

Bedrock Depth: feet

Lithology Info Flag: Y

File Info Flag: N

Sieve Info Flag: N

Construction Date: 2002-03-28 00:00:00.0

Driller: Albert Kaye & Sons Drilling

Well Identification Plate Number:

Plate Attached By:

Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:

Well Yield: 12 (Driller's Estimate) U.S. Gallons per Minute

Development Method:

Pump Test Info Flag: N

Artesian Flow:

Artesian Pressure (ft):

Static Level:

WATER QUALITY:

Character:

Colour:

Odour:

Well Disinfected: N

EMS ID:

Water Chemistry Info Flag: N

Field Chemistry Info Flag:

Site Info (SEAM):

Water Utility:

Water Supply System Name:

Water Supply System Well Name:

SURFACE SEAL:

Flag: N

Material:

Method:

Depth (ft):

Thickness (in):

Liner from To: feet

Screen Info Flag: N Site Info Details: Other Info Flag: Other Info Details:	WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
WORK METHOD: ROTARY; STEEL CASING 20 FEET; WELL IS LINED WITH 4 INCH CSA PVC WITH BUILT IN LEG FOR PUMP

LITHOLOGY INFORMATION:

From 0 to 9 Ft. BROKEN sandstone

From 9 to 31 Ft. sandstone

From 31 to 35 Ft. shale

From 35 to 41 Ft. sandstone

From 41 to 43 Ft. shale

From 43 to 151 Ft. .25 Gallons per Minute (U.S./Imperial) @ 118 FEET. FRACTURES 78, 120'. sandstone

From 151 to 250 Ft. 11.75 Gallons per Minute (U.S./Imperial) @ 228 FEET. FRACTURES 215, 230' shale

- Return to Main
- Return to Search Options
- Return to Search Criteria

Information Disclaimer

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 42779

Owner: SAVIN

Address: 171 LE PAGE RD

Area:

WELL LOCATION:

COWICHAN Land District

District Lot: Plan: 18663 Lot: A

Township: Section: 13 Range: 1E

Indian Reserve: Meridian: Block:

Quarter:

Island: SALTSPRING

BCGS Number (NAD 83): 092B083343 Well: 8

Class of Well:

Subclass of Well:

Orientation of Well:

Status of Well: New

Well Use: Unknown Well Use

Observation Well Number:

Observation Well Status:

Construction Method: Drilled

Diameter: 0.0 inches

Casing drive shoe:

Well Depth: 175 feet

Elevation: 0 feet (ASL)

Final Casing Stick Up: inches

Well Cap Type:

Bedrock Depth: 3 feet

Lithology Info Flag:

File Info Flag:

Sieve Info Flag:

Screen Info Flag:

Construction Date: 1979-07-01 00:00:00.0

Driller: Tri-K Drilling

Well Identification Plate Number:

Plate Attached By:

Where Plate Attached:

PRODUCTION DATA AT TIME OF DRILLING:

Well Yield: .8 (Driller's Estimate) Gallons per Minute (U.S./Imperial)

Development Method:

Pump Test Info Flag:

Artesian Flow:

Artesian Pressure (ft):

Static Level:

WATER QUALITY:

Character:

Colour:

Odour:

Well Disinfected: N

EMS ID:

Water Chemistry Info Flag:

Field Chemistry Info Flag:

Site Info (SEAM):

Water Utility:

Water Supply System Name:

Water Supply System Well Name:

SURFACE SEAL:

Flag:

Material:

Method:

Depth (ft):

Thickness (in):

WELL CLOSURE INFORMATION:

Reason For Closure:

Site Info Details:	Method of Closure:
Other Info Flag:	Closure Sealant Material:
Other Info Details:	Closure Backfill Material:
	Details of Closure:

Screen from	to feet	Type	Slot Size	
Casing from	**to feet**	**Diameter**	**Material**	**Drive Shoe**

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From 0 to 3 Ft. HARDPAN

From 3 to 12 Ft. SANDSTONE

From 12 to 17 Ft. BAD SHALE

From 17 to 19 Ft. SANDSTONE

From 19 to 30 Ft. SANDSTONE

From 30 to 35 Ft. SHALE

From 35 to 140 Ft. SANDSTONE

From 140 to 175 Ft. SHALE

From 0 to 0 Ft. WATER: .5 GPM @ 35'

From 0 to 0 Ft. .25 GPM @ 162'

From 0 to 0 Ft. TOTAL WATER: .75 GPM

- Return to Main
- Return to Search Options
- Return to Search Criteria

Information Disclaimer

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 41709	Construction Date: 1979-02-07 00:00:00.0
Owner: H SCHUBART	Driller: Ken's Drilling
Address: NORTH END RD	Well Identification Plate Number:
Area:	Plate Attached By:
WELL LOCATION:	Where Plate Attached:
COWICHAN Land District	PRODUCTION DATA AT TIME OF DRILLING:
District Lot: Plan: 9325 Lot: B	Well Yield: 2.5 (Driller's Estimate) Gallons per Minute (U.S./Imperial)
Township: Section: 10 Range: 1E	Development Method:
Indian Reserve: Meridian: Block:	Pump Test Info Flag:
Quarter:	Artesian Flow:
Island: SALTSPRING	Artesian Pressure (ft):
BCGS Number (NAD 83): 092B083341 Well: 17	Static Level:
Class of Well:	WATER QUALITY:
Subclass of Well:	Character:
Orientation of Well:	Colour:
Status of Well: New	Odour:
Well Use: Unknown Well Use	Well Disinfected: N
Observation Well Number:	EMS ID:
Observation Well Status:	Water Chemistry Info Flag:
Construction Method: Unknown Constru	Field Chemistry Info Flag:
Diameter: 6.5 inches	Site Info (SEAM):
Casing drive shoe:	Water Utility:
Well Depth: 500 feet	Water Supply System Name:
Elevation: 0 feet (ASL)	Water Supply System Well Name:
Final Casing Stick Up: inches	SURFACE SEAL:
Well Cap Type:	Flag:
Bedrock Depth: 6 feet	Material:
Lithology Info Flag:	Method:
File Info Flag:	Depth (ft):
Sieve Info Flag:	Thickness (in):
Screen Info Flag:	WELL CLOSURE INFORMATION:
	Reason For Closure:

Site Info Details:	Method of Closure:
Other Info Flag:	Closure Sealant Material:
Other Info Details:	Closure Backfill Material:
	Details of Closure:

Screen from	to feet	Type	Slot Size	

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
2.5 GPM

LITHOLOGY INFORMATION:

From	0	to	6	Ft.	OVERBURDEN
From	6	to	30	Ft.	BEDROCK, SANDSTONE
From	30	to	75	Ft.	BEDROICK, SANDSTONE, SOME MOISTURE @ 60'
From	75	to	200	Ft.	SANDSTONE .5 GPM
From	200	to	275	Ft.	SANDSTONE, SOME QUARTZ, LARGE CHUNKS
From	275	to	350	Ft.	SANDSTONE, GRANITE & SOME WATER @ 300'
From	0	to	0	Ft.	1 GPM
From	350	to	400	Ft.	SANDSTONE, LARGE PIECES OF QUARTZ &
From	0	to	0	Ft.	GRANITE STILL COMING UP
From	400	to	450	Ft.	BEDROCK 1 GPM
From	450	to	500	Ft.	WATER @ 470' 2.5 GPM

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 37719 Owner: HALCYON AND DAYS Address: BAKER ROAD Area: WELL LOCATION: COWICHAN Land District District Lot: Plan: 31374 Lot: B Township: Section: 6 Range: 1E Indian Reserve: Meridian: Block: Quarter: Island: SALTSPRING BCGS Number (NAD 83): 092B083323 Well: 13 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 265 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: 30 feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag:	Construction Date: 1977-07-20 00:00:00.0 Driller: Island Well Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 5 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level: 88 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure:

Site Info Details: Other Info Flag: Other Info Details:	Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
THIS WELL CAVED IN.

LITHOLOGY INFORMATION:

From 0 to 30 Ft. CLAY HARDPAN

From 30 to 156 Ft. SHALEY SANDSTONE

From 156 to 164 Ft. GREY SANDSTONE

From 164 to 167 Ft. SHALE

From 167 to 189 Ft. SHALEY SANDSTONE

From 189 to 265 Ft. SHALEY SANDSTONE WITH SHALE

From 0 to 0 Ft. LENSES

- Return to Main
- Return to Search Options
- Return to Search Criteria

Information Disclaimer

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 37575	Construction Date: 1977-07-01 00:00:00.0
Owner: M JENKINS	Driller: Tri-K Drilling
Address: HEDGER RD	Well Identification Plate Number:
Area:	Plate Attached By:
WELL LOCATION:	Where Plate Attached:
COWICHAN Land District	PRODUCTION DATA AT TIME OF DRILLING:
District Lot: Plan: 1973 Lot: 5	Well Yield: .5 (Driller's Estimate) Gallons per Minute (U.S./Imperial)
Township: Section: 15 Range: 2N	Development Method:
Indian Reserve: Meridian: Block:	Pump Test Info Flag:
Quarter:	Artesian Flow:
Island: SALTSPRING	Artesian Pressure (ft):
BCGS Number (NAD 83): 092B093121 Well: 2	Static Level:
Class of Well:	WATER QUALITY:
Subclass of Well:	Character:
Orientation of Well:	Colour:
Status of Well: New	Odour:
Well Use: Unknown Well Use	Well Disinfected: N
Observation Well Number:	EMS ID:
Observation Well Status:	Water Chemistry Info Flag:
Construction Method: Drilled	Field Chemistry Info Flag:
Diameter: 0.0 inches	Site Info (SEAM):
Casing drive shoe:	Water Utility:
Well Depth: 272 feet	Water Supply System Name:
Elevation: 0 feet (ASL)	Water Supply System Well Name:
Final Casing Stick Up: inches	SURFACE SEAL:
Well Cap Type:	Flag:
Bedrock Depth: 77 feet	Material:
Lithology Info Flag:	Method:
File Info Flag:	Depth (ft):
Sieve Info Flag:	Thickness (in):
Screen Info Flag:	WELL CLOSURE INFORMATION:
	Reason For Closure:

Site Info Details:	Method of Closure:
Other Info Flag:	Closure Sealant Material:
Other Info Details:	Closure Backfill Material:
	Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
OWNER SAYS WATER HAS A HIGH SALT CONTENT & THEREFORE IS NOT CONSUMABLE.

LITHOLOGY INFORMATION:

From 0 to 45 Ft. HARD PAN

From 45 to 60 Ft. SANDY

From 60 to 77 Ft. HARDPAN

From 77 to 160 Ft. SHALE WITH LAYERS OF SANDSTONE

From 0 to 160 Ft. WATER - .5 GPM

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 36859 Owner: PHYLLIS COLEMAN Address: Area: WELL LOCATION: COWICHAN Land District District Lot: Plan: 24136 Lot: 2 Township: Section: 9 Range: 1W Indian Reserve: Meridian: Block: Quarter: Island: SALTSPRING BCGS Number (NAD 83): 092B083341 Well: 15 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 6.5 inches Casing drive shoe: Well Depth: 150 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: 2 feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag:	Construction Date: 1977-03-23 00:00:00.0 Driller: Ken's Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 2 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level: WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure:

Site Info Details: Other Info Flag: Other Info Details:	Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size	
Casing from	**to feet**	**Diameter**	**Material**	**Drive Shoe**

GENERAL REMARKS:
ONWER SAYS THAT WATER IS NOT DRINKABLE. YIELD: (EST) 2 GPM

LITHOLOGY INFORMATION:

From 0 to 2 Ft. RED CLAY

From 2 to 15 Ft. BROWN SHALE

From 15 to 150 Ft. BLACK SHALE

From 0 to 0 Ft. TRACE OF WATER @ 35' FRACTURE @ 105'

From 0 to 0 Ft. 1.5 GPM WATER UP TO 2 GPM @ 150'

From 0 to 150 Ft. T.D.

- Return to Main
- Return to Search Options
- Return to Search Criteria

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 25320 Owner: P WILLIAMS Address: Area: WELL LOCATION: COWICHAN Land District District Lot: Plan: 23295 Lot: 9 Township: Section: 12 Range: 1E Indian Reserve: Meridian: Block: Quarter: Island: SALTSPRING BCGS Number (NAD 83): 092B083343 Well: 10 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Unknown Constru Diameter: 0.0 inches Casing drive shoe: Well Depth: 150 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag:	Construction Date: 1971-09-01 00:00:00.0 Driller: Tri-K Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 1.5 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level: 10 feet WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name: Water Supply System Well Name: SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure:

Site Info Details: Other Info Flag: Other Info Details:	Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From 0 to 0 Ft. SANDSTONE

From 0 to 0 Ft. WATER @ 60'

- Return to Main
- Return to Search Options
- Return to Search Criteria

Information Disclaimer

BRITISH COLUMBIA

Report 1 - Detailed Well Record

Well Tag Number: 12685 Owner: J CATTO Address: TRIPP RD Area: WELL LOCATION: COWICHAN Land District District Lot: Plan: 11687 Lot: 1 Township: Section: 9 Range: 1E Indian Reserve: Meridian: Block: Quarter: Island: SALTSPRING BCGS Number (NAD 83): 092B083341 Well: 9 Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 0.0 inches	Construction Date: 1950-01-01 00:00:00.0 Driller: D. S. Godwin Well Identification Plate Number: Plate Attached By: Where Plate Attached: PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level: WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM): Water Utility: Water Supply System Name:

Casing drive shoe: Well Depth: 93 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: 20 feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag: Site Info Details: Other Info Flag: Other Info Details:	Water Supply System Well Name: SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in): WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:

Screen from	to feet	Type	Slot Size

Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
WATER IS SALTY - WELL USELESS

LITHOLOGY INFORMATION:

From 0 to 20 Ft. ? DUG

From 20 to 93 Ft. SANDSTONE

- Return to Main
- Return to Search Options
- Return to Search Criteria

Information Disclaimer

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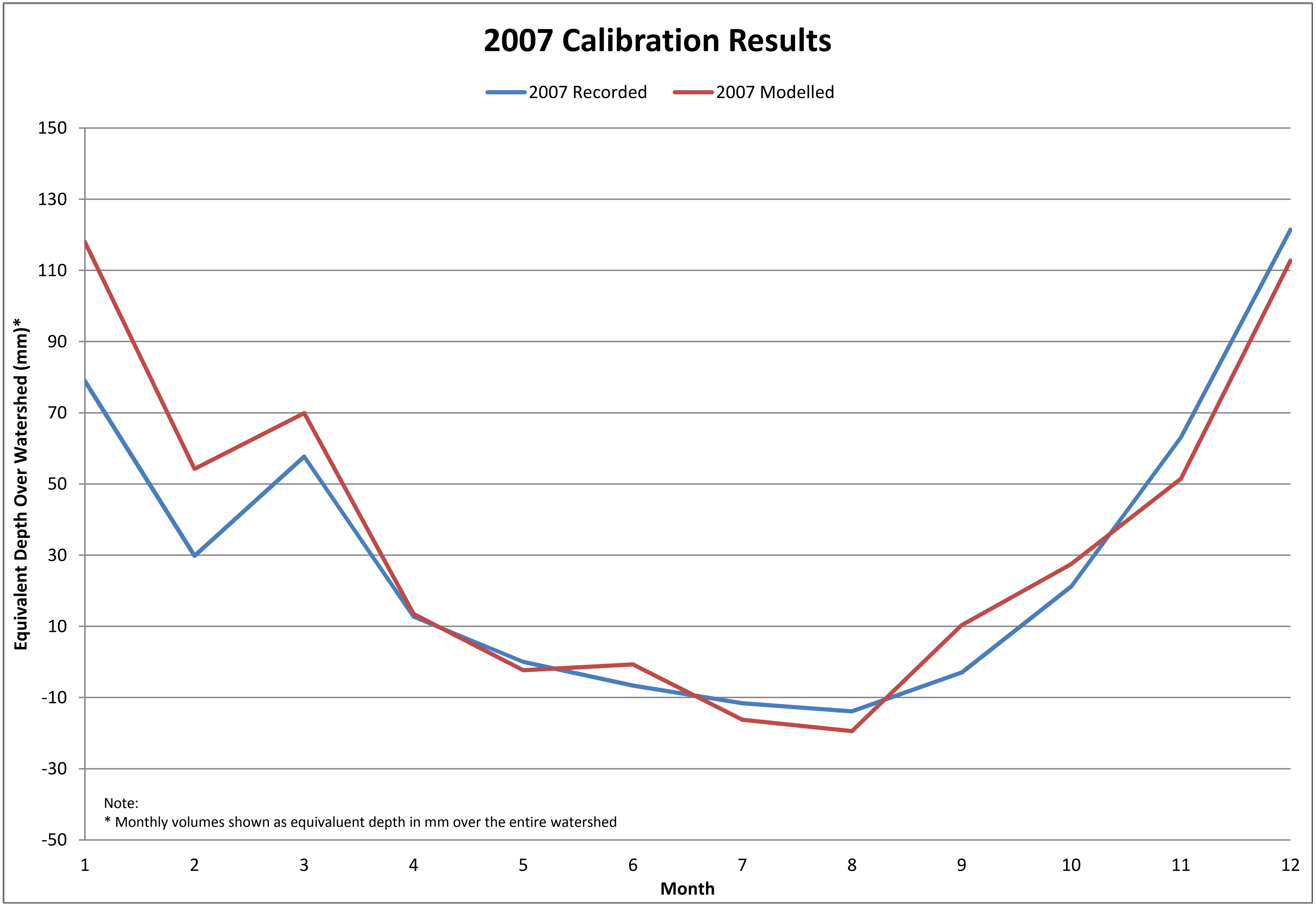
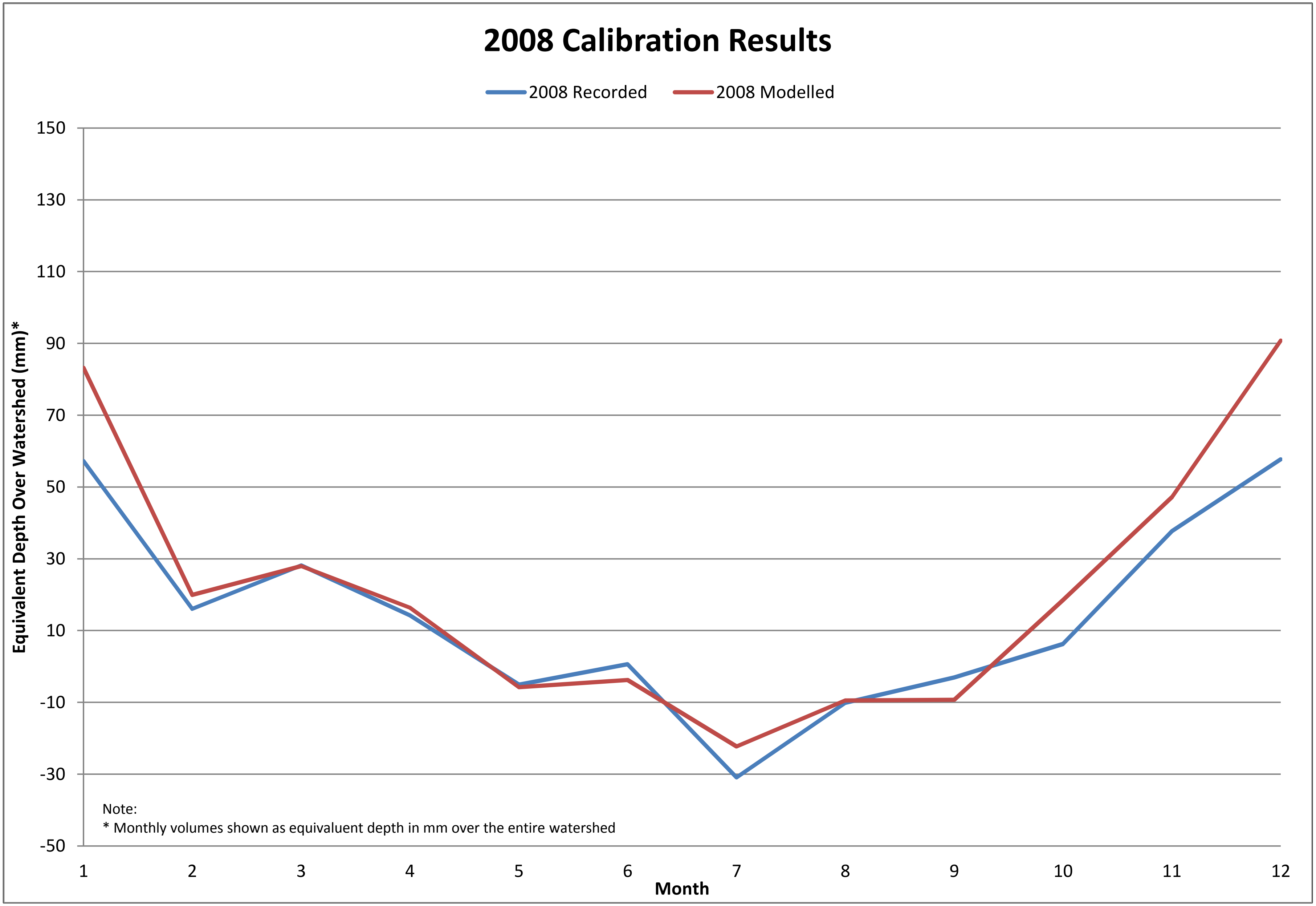
Appendix D

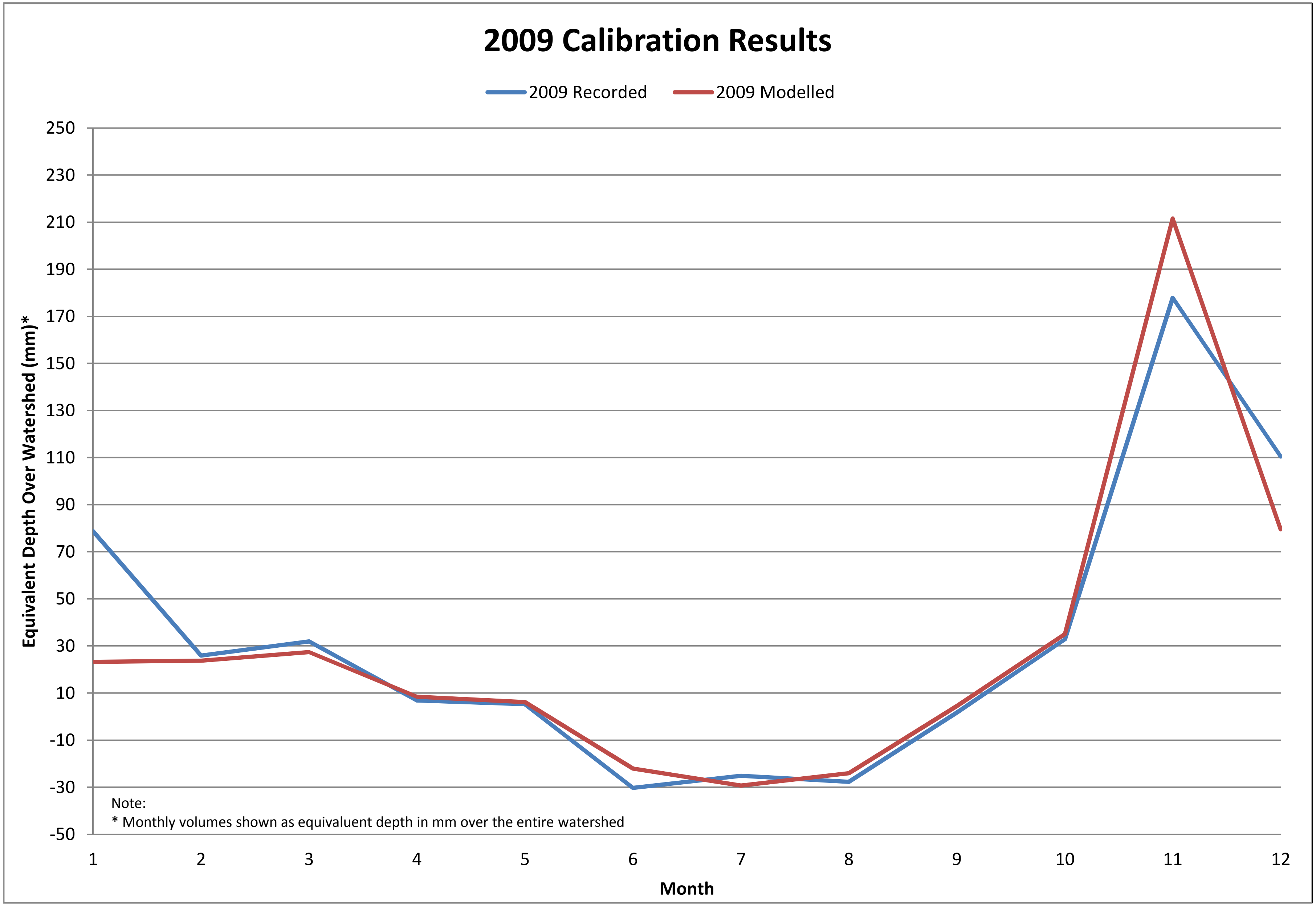
Water Balance Model Calibration Results for Each Year between 2007 and 2014

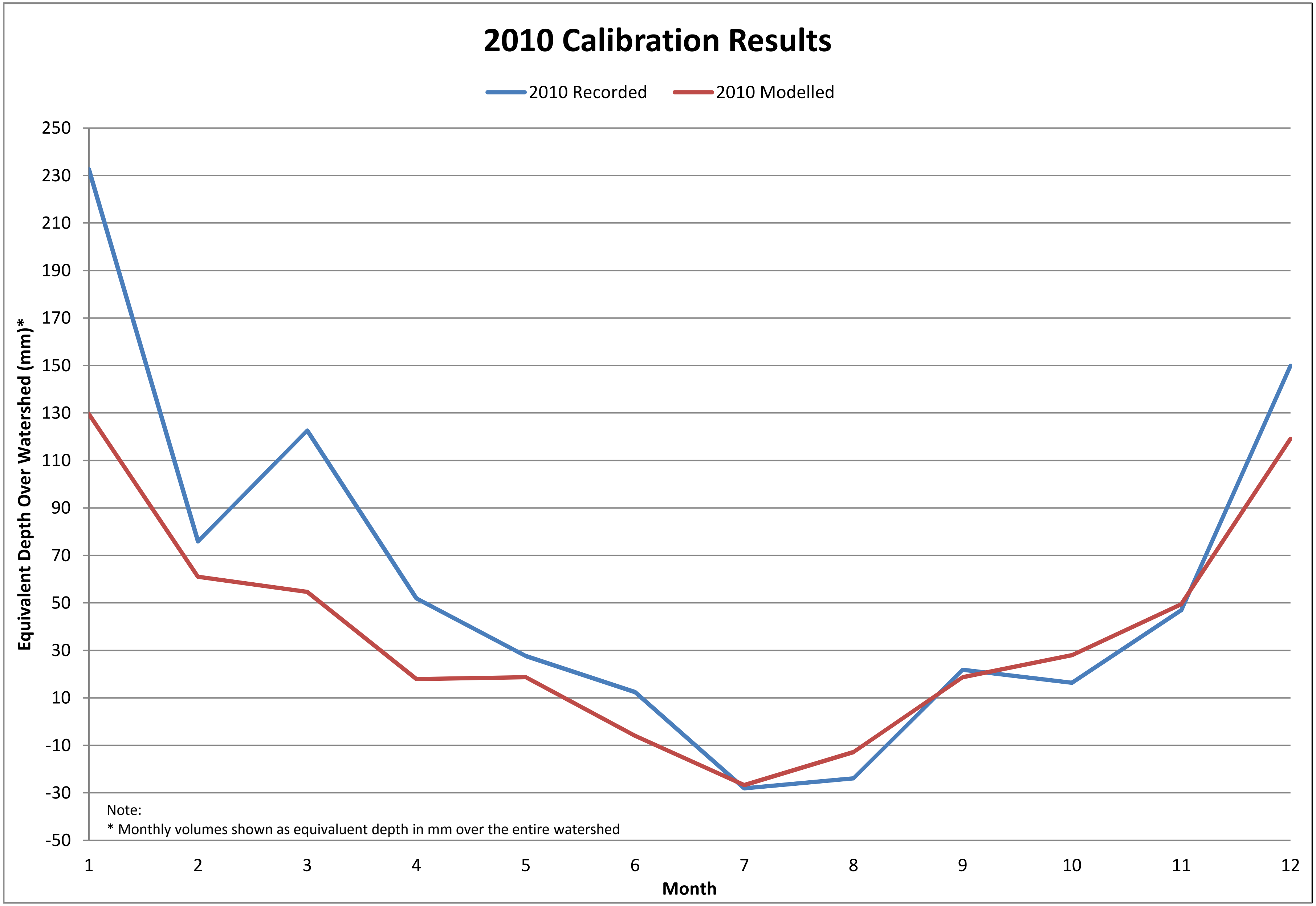


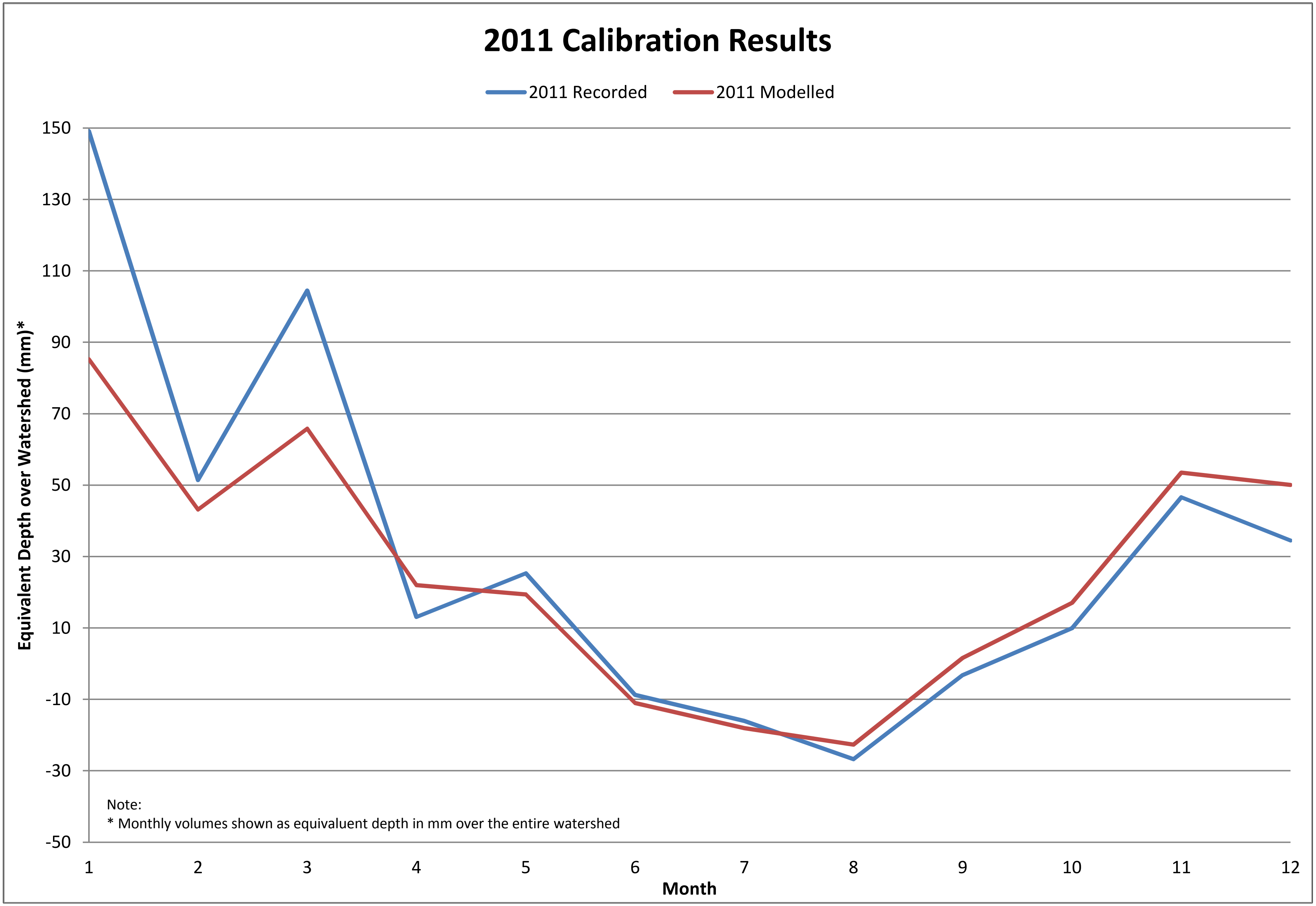
KERR WOOD LEIDAL
consulting engineers



KERR WOOD LEIDAL
consulting engineers


2009 Calibration Results
2009 Recorded
2009 Modelled
Equivalent Depth Over Watershed (mm)*
250
230
210
190
170
150
130
110
90
70
50
30
10
-10
-30
-50
Note:
* Monthly volumes shown as equivaluent depth in mm over the entire watershed
1
2
3
4
5
6
7
8
9
10
11
12
Month


2010 Calibration Results
2010 Recorded
2010 Modelled
Equivalent Depth Over Watershed (mm)*
250
230
210
190
170
150
130
110
90
70
50
30
10
-10
-30
-50
1
2
3
4
5
6
7
8
9
10
11
12
Month
Note:
* Monthly volumes shown as equivaluent depth in mm over the entire watershed



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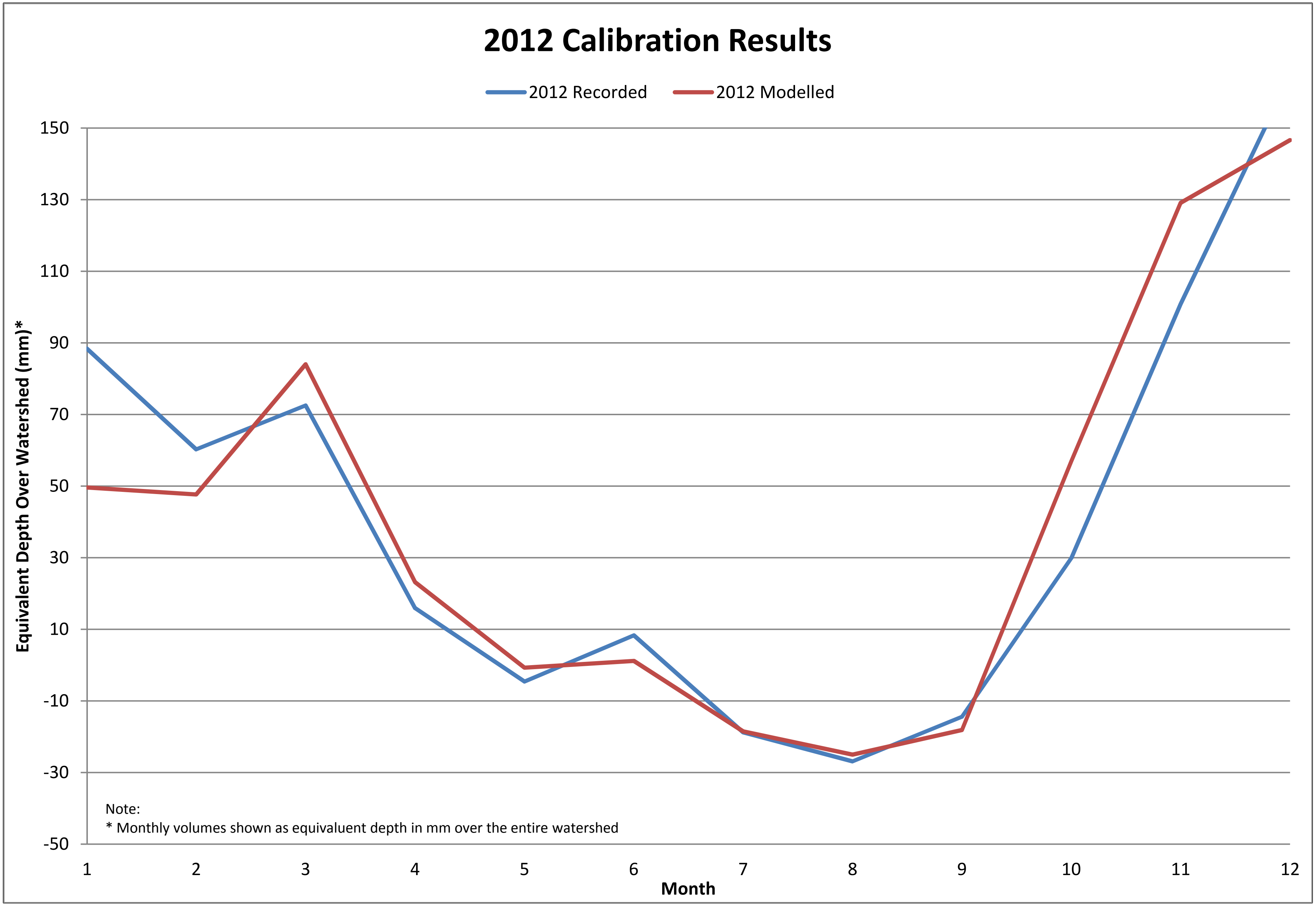

KERR WOOD LEIDAL
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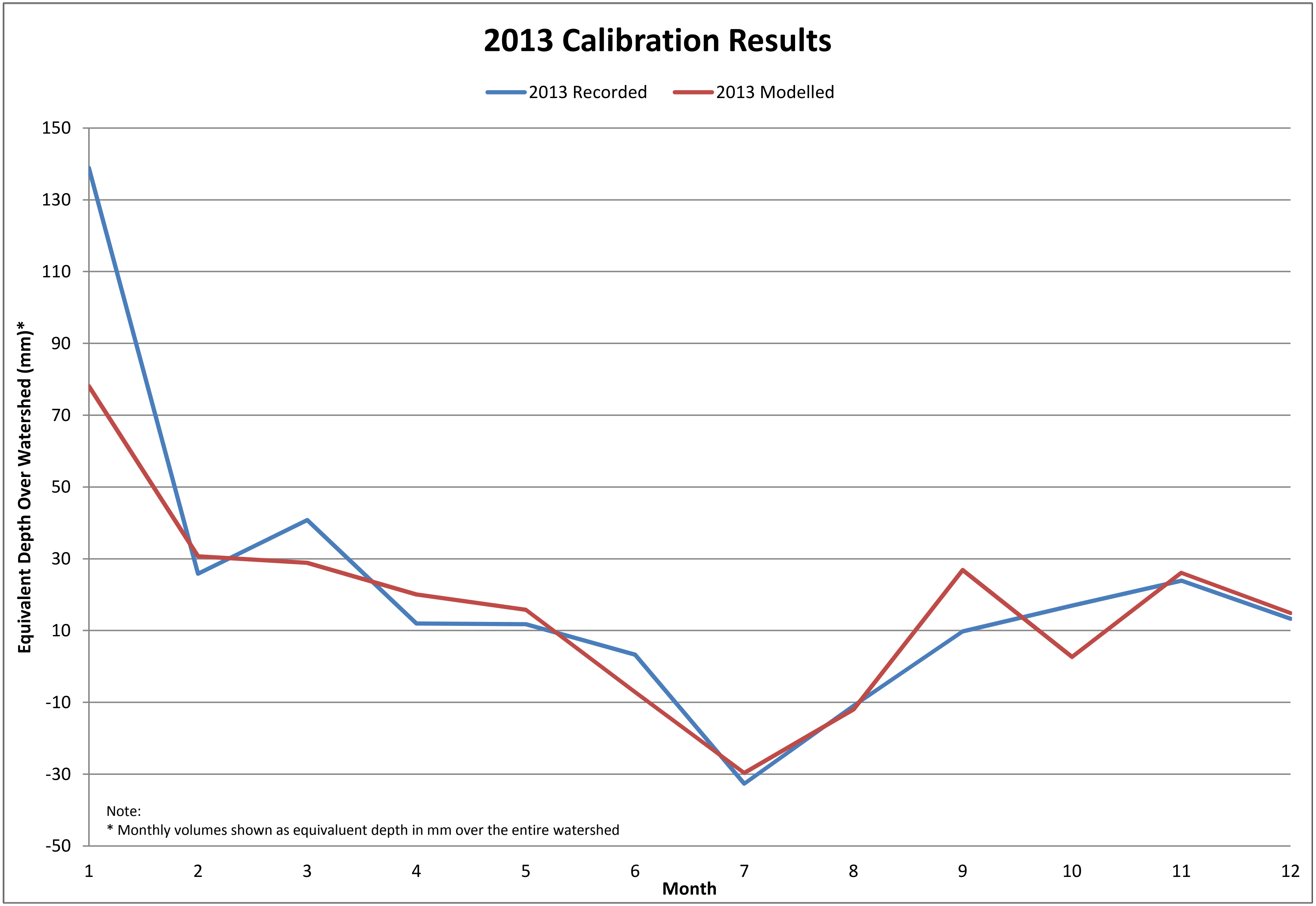
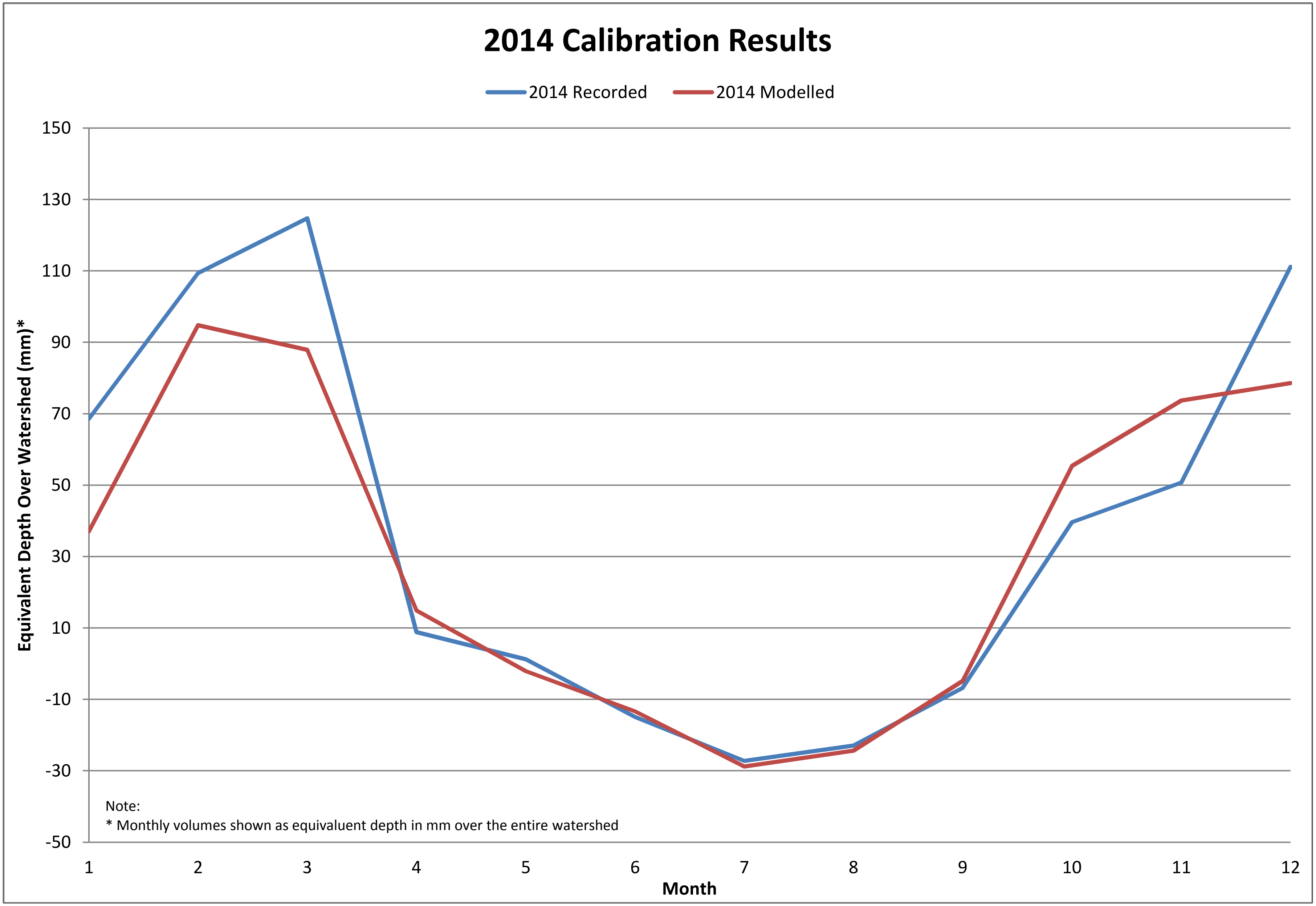

2013 Calibration Results
2013 Recorded
2013 Modelled
150
130
110
90
70
50
30
10
-10
-30
-50
Equivalent Depth Over Watershed (mm)*
1
2
3
4
5
6
7
8
9
10
11
12
Month
Note:
* Monthly volumes shown as equivaluent depth in mm over the entire watershed



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Appendix E

Recorded Temperature and Precipitation Data for Drought Analysis

Climate Station Name:	SALTSPRING ST MARY'S L
Climate Station ID:	1016995
Latitude	48.89
Longitude	-123.55
Elevation	45.7
Units	Degrees Celcius, °C

Monthly Average Temperature Data

Year	January	February	March	April	May	June	July	August	September	October	November	December
1976	4.2	3.9	4.3	8.4	11.1	13.1	16.5	15.6	15.3	10.5	6.6	5.8
1977	3.0	6.8	5.6	9.7	11.2	15.7	16.6	19.7	13.7	10.0	5.1	3.0
1978	3.3	5.0	7.2	9.0	11.8	16.9	18.7	17.6	13.6	11.3	4.6	2.4
1979	0.2	3.6	7.3	9.1	13.3	15.5	18.3	18.0	15.9	11.3	5.8	6.0
1980	0.9	4.9	5.7	10.1	12.7	14.2	17.3	17.0	14.4	11.1	7.0	5.3
1981	5.1	5.3	7.6	8.5	11.9	13.3	17.0	18.4	13.8	8.8	7.2	3.7
1982	2.3	4.2	5.2	7.4	12.3	17.4	16.4	16.9	14.7	10.4	4.6	4.2
1983	5.7	6.0	7.9	9.5	13.9	14.8	16.4	17.6	13.4	9.3	7.2	1.1
1984	4.7	5.8	7.6	8.7	10.4	13.8	17.5	16.9	13.3	8.1	5.2	1.0
1985	1.9	3.3	5.0	8.2	11.5	14.8	19.5	17.3	13.6	10.1	1.0	1.7
1986	5.4		7.4	7.8	11.9	16.0	16.1	20.0	14.9	12.0	7.0	5.1
1987	4.3	6.2	7.4	9.8	12.9	16.0	17.2	18.1	16.3	12.6	8.2	4.0
1988	3.5	5.6	6.6	9.6	12.1	14.6	17.7	17.8	14.8	11.7	7.2	5.0
1989	3.9	0.3	5.1	10.8	12.9	16.6	17.3	17.4	16.5	11.0	7.4	6.1
1990	4.7	3.2	6.8	10.6	12.4	15.0	19.5	19.2	16.7	9.8	7.1	1.9
1991	2.3	7.2	5.6	9.0	12.0	14.3	17.8	18.2	16.3	10.5	7.8	6.2
1992	6.2	7.0	9.4	10.6	14.2	17.7	18.4	18.2	14.3	11.6	7.1	3.1
1993	0.9	3.7	7.5	9.5	14.6	15.5	16.3	17.8	15.9	12.1	5.5	5.2
1994	6.4	3.8	7.5	10.6	13.9	15.0	19.2	18.6	16.4	10.7	5.4	4.5
1995	4.4	5.8	6.9	9.8	15.1	16.6	18.7	16.2	17.1	10.7	8.4	4.8
1996	3.4	4.5	6.9	9.8	11.4	15.4	19.3	18.8	14.3	10.3	5.5	2.1
1997	3.6	5.2	6.2	9.1	14.5	15.5	18.7	20.1	16.7	11.0	7.8	5.6
1998	4.3	6.7	8.0	10.3	14.2	17.2	20.0	20.1	17.3	11.3	8.2	4.4
1999	5.0	5.3	6.3	9.4	11.7	15.1	17.5	18.8	16.0	10.9	7.6	5.4
2000	3.8	5.4	7.1	10.4	12.0	16.3	18.1	17.7	15.3	11.1	6.0	3.5
2001	5.0	4.3	7.2	9.1	12.5	13.5	17.8	17.8	15.4	10.4	7.2	3.4
2002	4.9	5.0	5.1	9.6	13.0	17.6	18.7	19.2	16.1	10.7	8.2	5.5
2003	6.4	5.5	7.4	8.9	12.3	17.2	19.1	18.8	16.3	11.9	4.9	4.2
2004	4.3	5.6	8.4	11.6	14.6	17.4	20.1	19.5	14.7	11.2	7.2	5.6
2005	3.8	4.8	8.4	10.6	14.6	15.9	18.5	19.4	15.3	11.3	6.1	5.1
2006	6.2	4.7	6.6	9.8	13.7	17.2	19.4	18.5	16.1	11.1	5.9	4.5
Maximum	6.4	7.2	9.4	11.6	15.1	17.7	20.1	20.1	17.3	12.6	8.4	6.2
Minimum	0.2	0.3	4.3	7.4	10.4	13.1	16.1	15.6	13.3	8.1	1.0	1.0
10-year Return Period Drought	5.8	6.6	8.3	10.7	14.4	17.4	19.6	19.7	16.8	11.9	8.2	6.2

Climate Station Name:	SALTSPRING ST MARY'S L
Climate Station ID:	1016995
Latitude	48.89
Longitude	-123.55
Elevation	45.7
Units	millimeters, mm

Annual Precipitation Totals

Year	Annual Precipitation
1976	742
1977	873
1978	725
1979	915
1980	1243
1981	964
1982	1000
1983	1333
1984	1201
1985	614
1986	802
1987	667
1988	742
1989	682
1990	1123
1991	988
1992	1012
1993	794
1994	995
1995	1151
1996	1211
1997	1174
1998	1051
1999	1274
2000	805
2001	905
2002	772
2003	993
2004	973
2005	974
2006	1215
Maximum	1333
Minimum	614
10-year Return Period Drought*	717

* - Based on best fit of log pearon type III extreme value distribution