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Maxwell Lake, Rippon Creek and Larmour Creek Watersheds Water Availability - Climate Change Assessment

Final Report – Rev 0
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Prepared for:

The North Salt Spring Waterworks

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MAXWELL LAKE WATERSHED AND LICENCED WATER WITHDRAWALS

Maxwell 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). The Maxwell Lake watershed is located on the North and East faces of Mount Maxwell. Water can be diverted from neighbouring Rippon and Larmour Creek watersheds to Maxwell Lake by means of a weir structure and pipeline. The water licence allows diversion only during the winter months (November 1st to March 31st).

The lake has been licenced for use as a water supply since 1914, first by the Ganges Power and Water Utility and then after 1948 by NSSWD. A dam and spillway were constructed at the outlet of the lake in 1995 to raise full supply level by approximately 1.0 m. In 2003, the spillway was raised by an additional 0.6 m. The total licenced withdrawal limit for Maxwell Lake to the NSSWD water system is 663,729 m^3 per year. NSWWD hold water licences to store up to 1,077,642 m^3 at Maxwell Lake. However, currently the total physical storage at the lake is 819,000 m^3. The total volume of water that can be diverted from Rippon Creek and Larmour Creek from November 1st to March 31st is 448,812 m^3 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 current water withdrawals and licenced water withdrawal limit) analyses were carried out in order to assess the capacity of existing storage to support both current water withdrawals and to support potential future water withdrawals from NSWWD.

The water balance was carried out using a hydrologic model based on the USGS Water Balance Model. 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 Maxwell Lake, Rippon Creek and Larmour Creek (the model output). The model was used to assess available water supply to the lake under current climate conditions (1981 to 2010 climate normal period) and projected future climate conditions (2050s).

To confirm if the model accurately represents hydrological processes in the watershed, the model was run and compared to an independent estimate of lake inflow known as back-calculated net inflow. Unlike watershed runoff which is the total inflow to the lake, back-calculated net inflow is the estimated difference between watershed runoff (including direct precipitation on the lake) minus evaporation from the lake surface and seepage losses. 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 back-calculated net inflow is based on lake level records and estimated outflow from Maxwell Lake for the period from 2010 to 2013. Outflow from the lake was estimated based on lake-level-versus-discharge relationship developed for the weir and discharge measurements collected in 2014 and 2015. Net inflow was adjusted to account for estimated diversion volume from Rippon Creek and Larmour Creek during the diversion period.

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 Maxwell Lake with a

reasonable level of confidence. The percentage difference between the average total annual back-calculated net inflow and the average total annual modelled net inflow is 8% and -5.1% for 2013 and 2014, respectively.

WATER BUDGET RESULTS

Water balance modeling indicates that the average annual net inflow for the 1981 to 2010 climate normal period is about 753,000 m^3, with 434,000 m^3 from the Maxwell Lake watershed and 319,000 m^3 diverted from Rippon Creek and Larmour Creeks. The average summer (May to September) net inflow is about -81,000 m^3 (negative net inflow indicates evaporation higher than inflow to the lake). Under a 10-year return period drought year, the annual net inflow is reduced to about 282,000 m^3, 152,000 m^3 from the Maxwell Lake watershed and 131,000 m^3 diverted from Rippon Creek and Larmour Creeks. The summer (May to September) net inflow decreases to -121,000 m^3.

A monthly water budget was carried out to assess required storage volume to support water withdrawals through the dry summer period. This involves comparing average monthly net inflow from the water balance model with monthly water withdrawals. Monthly withdrawals are based on a monthly distribution of the total annual licenced withdrawal limit. A summary of the water budget results are shown below:

Maxwell Lake Water Balance Assessment Results – Current Climate (1981 – 2010 Climate Normal) Condition

Parameter	Current Climate Average Year	Current Climate 10-Year Return Period Drought Year
Annual Precipitation, mm	987	717
Annual Precipitation Volume Combined Watershed, 1,000 m^3	2,090	1,518
Annual Maxwell Lake Net-Inflow, 1000 m^3	434	152
Annual Rippon Creek and Larmour Creek Diversion Volume, 1,000 m^3	319	131
Total Annual Inflow to lake, 1,000 m^3	753	282
Current Annual Withdrawal, 1,000 m^3	332	
Licenced Annual Withdrawal, 1,000 m^3	664	
Spring/Summer (May-Sept) Precipitation, mm	165	125
Spring/Summer (May-Sept) Lake Net-Inflow, 1,000 m^3	-81	-121
Current Summer Withdrawal, 1,000 m^3	161	
Licenced Summer Withdrawal, 1,000 m^3	323	
Required Storage for the Current Withdrawal, 1,000 m^3	254	320
Required Storage for the Maximum Licenced Withdrawal Limit, 1,000 m^3	465	540
Available physical storage, 1,000 m^3	819	819

1. For the 10-year return period drought year assessment, assume the 10-year return period drought year is followed by average runoff years.
2. Assume water is diverted from Rippon Creek and Larmour Creek from Nov 1 to Mar 31, but not the other period of the year.

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 projected for summer months.

Using the monthly water balance model calibrated to current climate and hydrological conditions in the watershed, the average summer (June to August) net inflows to the lake are projected to decrease by between 9% and 16% by 2050s. The decrease is mostly as a result of increased temperatures and lake evaporation. However, the total annual inflows to the lake are projected to increase by between 10% and 13%, which would allow the lake to be refilled more readily during the winter period.

The water budget analysis showed total cumulative storage requirements of between 450,000 m^3 to 489,000 m^3 to support water withdrawal at the licenced withdrawal limit under projected 2050s average climate conditions.

Due to limitations of climate modelling in representing extreme conditions, it is difficult to quantify impacts on drought and available water supply at Maxwell 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 could result in increased pressure on water availability from Maxwell Lake into the future.

CONCLUSIONS

The outcome of the analysis indicates that Maxwell Lake with the weir crest at El. 314.86 m-GSC:

1. Under average inflow and 10-year return period drought conditions there is sufficient storage volume to support current (2014) withdrawals to the NSSWD water system such that the lake can be refilled prior to the following summer draw down period;
2. Under average inflow there is sufficient storage volume to support withdrawal to NSWWD water system up to the licenced withdrawal limit such that the lake can be refilled prior to following summer draw down period; and
3. Although there is sufficient storage to support withdrawal to NSWWD water system up to the licenced withdrawal limit there would not be sufficient inflow under 10-year drought conditions to refill Maxwell Lake prior to following summer draw down period

RECOMMENDATIONS

Based on the outcome of the hydrological and water balance analysis carried out for Maxwell Lake, we recommend that:

1. Withdrawals from Maxwell Lake be capped at 72% of the licenced withdrawal limit (477,900 m^3) such that inflow from Larmour Creek, Rippon Creek and Maxwell Lake watersheds can refill Maxwell Lake after 10-year drought conditions;

2. The cap should remain in-place until such time that sufficient data is collected at Maxwell Lake to complete a multi-year drought analysis;

3. NSWWD consider installing water level sensors to record lake level, spillway outflow level and Rippon Creek Parshall flume level to provide continuous hydrometric records at the lake for operations purposes as well as to provide average daily record which can be used for future multi-year water balance assessment;

4. Once sufficient data has been collected at Maxwell Lake, carry out a multi-year drought analysis to assess if multiple years of Larmour Creek, Rippon Creek and Maxwell Lake watershed inflow could refill Maxwell Lake after 10-year return period drought conditions; and

5. Using hydrometric data collected; conduct a review of Maxwell Lake water balance at regular intervals (approximately every 10 years) to assess potential future impacts to water availability as a result of changing climate and changes in water withdrawal.

Section 1

Introduction

1. Introduction

1.1 Overview

The North Salt Spring Waterworks District (NSSWD) provides potable water to a defined service area on Salt Spring Island, the largest of the southern Gulf Islands off the south-east coast of Vancouver Island. The service area includes the Village of Ganges and a large portion of the northern end of the island. In 2012, NSWWD delivered about 533,700 m^3 of water to its customers from water supply reservoirs at St. Mary Lake and Maxwell Lake.

To quantify available water resources for long term planning, NSSWD has retained Kerr Wood Leidal (KWL) to review water availability from Maxwell Lake under current and future water withdrawal and climate conditions.

The following report outlines the results of the hydrological study carried out to review the water balance of Maxwell Lake and provide recommendations on maximum water availability.

1.2 Purpose and Scope

The objectives of this study are to:

1. Review previous hydrological assessments;
2. Estimate available surface water supply from Maxwell Lake under current and future climate projections; and
3. Compare water availability with current and future water withdrawal.

1.3 Project Team

NSSWD retained Kerr Wood Leidal Associates Ltd. (KWL) to carry out the Maxwell Lake Watershed Water Availability – Climate Change Impacts Assessment Study. The project team consisted of:

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

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

David Murray, ASc.T., P.Eng. – Principal

1.4 Past Reports

Several previous reports have been prepared regarding hydrology of the Maxwell Lake Watershed. These reports have been reviewed as part of the water supply and climate change assessment:

Salt Spring Island Water Allocation Plan. Report prepared by Regional Water Management Vancouver Island Region. 1993. Downloaded from: http://www.env.gov.bc.ca/wsd/water_rights/wap/vi/saltspring/saltspring_wap.pdf.

Hydrology of Maxwell Lake Water Supply. Unpublished report prepared by Roy Hamilton, M.A.Sc., P.Eng. for North Salt Spring Waterworks District.1995.

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

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 licenced 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.

Elevations referenced in this report are shown both metres above the MoE Datum and in metres above geodetic datum (m-GSC). The elevations referenced to MoE datum are based on relative elevation compared to the control monument (88HAW031) installed by Ministry of Environment (MoE) in 1988. The geodetic elevations are based on GPS surveys carried out by Polaris Land Surveying Inc. as outlined in letter dated April 23, 20. Elevations above geodetic datum are referenced to Canadian Geodetic Vertical Datum of 1928 (CGVD28).

The following equation should be used to convert from MoE datum to geodetic datum:

Metres above geodetic (m-GSC) = Metres above MoE Datum (m-MoE) + 310.36 m

Further details on surveyed elevations can be found in the letter prepared by Polaris Land Surveying Inc. dated April 23, 2015 provided in Appendix A. Further details on conversion of water level staff gauge readings to geodetic datum is provided in the description of Lake Level and Storage in Section 2.4.

1.6 Design Criteria

The quantity and timing of inflow to Maxwell Lake varies from year to year from wet years to very dry years. It is not possible to establish a storage volume capable of supporting withdrawals under all inflow conditions, there is always a chance that there could be a drier year than what has been recorded in the past. Therefore, it is necessary to establish design criteria under which it is acceptable that the available storage cannot support the full withdrawal volume. Based on typical standards for bulk water system storage analysis, the NSSWD has selected a 10-year return period drought condition as the design criteria. This drought has a 10% chance of occurring in any given year. The assessment considers that the lake should refill the year after the 10-year drought conditions. Should inflow be less than this quantity, water withdrawals would have to be reduced in accordance with guidance in a drought management plan.

1.7 Technical Terminology

This report is considered to be a technical document covering aspects of hydrology and hydrogeology with respect to the Maxwell 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 B which defines most technical terms used in the document.

1.8 Photographs

Photographs taken by Mr. Craig Sutherland, P. Eng. and Mr. Max Scruton, E.I.T. of KWL during site visits on June 25, 2014 and September 24, 2014 are included in Appendix C for reference. Photos referenced throughout the report text are identified by photo numbers included in the photo appendix.

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Section 2

Maxwell Lake Watershed

2. Maxwell Lake Watershed

2.1 General Description

Maxwell Lake is located near Mount Maxwell on the western side 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 used by NSSWD as one of the primary water supply sources for Salt Spring Island since 1914. NSSWD also supplies water to customers within the waterworks service area from St. Mary Lake. A separate hydrology and storage assessment was carried-out for St. Mary Lake by KWL in 2014.

Maxwell Lake has a watershed area of 1.063 km^2 and a lake surface area of about 0.302 km^2. A photo of the lake from the dam is shown in Photo C-1 in Appendix C. The watershed is located on the North and East faces of Mount Maxell. Water can be diverted from neighbouring Rippon and Larmour Creek watersheds to Maxwell Lake by means of a weir structure and pipeline. The water licence allows diversion only during the winter months (November 1st to March 31st). The combined Rippon Creek and Larmour Creek catchment area is 1.054 km^2. Figure 2-1 shows the Maxwell Lake watershed and the surrounding area, including the diversion watersheds.

The outflow from the lake, located on the north end of the lake is regulated by a dam and broad crested weir spillway that discharges into Maxwell Creek (see Photo C-2 and C-3). A copy of the spillway rating curve for the Maxwell Lake spillway is shown in Figure 2-2. The values used in spillway rating curve are based on theoretical broad crested weir spillway equation.

The lake has been licenced for use as a water supply since 1914, first by the Ganges Power and Water Utility and then after 1948 by NSSWD. A dam and spillway were constructed at the outlet of the lake in 1995 to raise full supply level by approximately 1.0 m. In 2003, the spillway was raised by an additional 0.6 m. A copy of the construction drawings prepared in 1995 and 2003 upgrade as well as a letter from Wolfe Milner Land Survey outlining survey completed to confirm and correct the spillway crest elevation are included in Appendix A.

Maxwell Lake has a live storage volume of 819,000 m^3 and an active storage depth of 3.2 m. The full supply elevation of the lake is 4.5 m above MoE Datum (314.86 m-GSC). Typically the annual water level variation is about 0.9 m. A copy of the area-elevation curve for Maxwell Lake is shown in Figure 2-3. The curve shown is based on data provided in previous Maxwell Lake study and extrapolated to include higher lake levels as a result of raising the spillway in 2003.

Water is withdrawn from the lake for water supply purposes via an approximately 300 mm diameter submerged intake pipe where the top inside elevation is about 1.53 m above MoE datum (311.89 m-GSC). A flow meter is installed in the water intake pipe to record total water withdrawals from the lake.

2.2 Land-use and Land Cover

Besides the lake, land cover in the Maxwell Lake watershed consists primarily of second growth Douglas fir forests and bedrock outcrops. The watershed has no major development and remains relatively untouched with the exception of a gravel road leading up to the Mount Maxwell Provincial Park. The watershed will be protected from future development as a portion of the watershed lies within the Mount Maxwell Ecological Reserve zone while the remainder is mostly owned by NSSWD with only a small portion privately owned. The land-use and land cover data were used in the water balance modelling to provide an indication of the distribution of open space and forest cover in the watershed to assist with estimation of evapotranspiration and runoff across the watershed.

2.3 Geology and Soils

The geology of Salt Spring Island is intricate and varies greatly throughout the island. The Maxwell Lake watershed is underlain by Nitnat Formation, consisting of pyroxene-phyric mafic agglomerate, with the other half underlain by Comox Formation, consisting of fine to medium grained sandstone (Greenwood and Mihalynuk, 2009). The surficial soils of the watershed consists primary of thick, unconsolidated marine or fluvial deposits over compact unweathered till from the last glaciation and metamorphic bedrock outcrops. The soils of the steep upper watershed area are mainly Saturna, Mexicana, and Rumsley. These are all sandy to gravelly loam over sandstone or intrusive bedrock (van Vliet et al, 1987). A map showing the surficial geology of the Maxwell Lake watershed based on the Ministry of Environment of BC's Soils of Gulf Islands of British Columbia – Volume 1, Soils of Salt Spring Island (1987) is shown in Figure 2-4.

2.4 Climate and Hydrological Data

Regional Climate

The climate of the Maxwell Lake watershed can be classified as Mediterranean-maritime, similar to other parts of the east-coast of Vancouver Island and southern Gulf Islands with mild-wet winters and warm-dry summers. Climate records from the nearby St. Mary Lake Climate Station indicate that precipitation does fall as snow in the winter on occasions 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 Environment Canada's St. Mary Lake climate station (Station ID 1016995) indicate that average daily temperatures in the region range from 4.3 °C in January to 18.4 °C in August. The recorded total average annual precipitation recorded is 987 mm, of which approximately 80% falls within the six month period from October to March. The highest average monthly precipitation of 168 mm occurs in November and the lowest average monthly precipitation of 23 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 the regional average monthly precipitation and temperature is shown in Figure 2-5.

The runoff from the Maxwell 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 baseflows are supplied from groundwater and occasional summer precipitation.

Climate Stations

NSWWD operates a climate station at St. Mary Lake (Station ID 1016995) with daily precipitation record since December 1, 1975. The data is reported monthly to Environment Canada for publication in the national climate database. The date for the period from January 1, 2010 to December 31, 2013 was used in the study for hydrological model calibration and the complete data set was used for drought condition analysis.

NSSWD also has a climate station installed at the Maxwell Lake dam which records daily rainfall and temperature. Records are hard-copy up until January 2013 when they became digital records. The data are not used in this study; however, it could be used in the future to monitor the water balance of the lake. A comparison of the St. Mary Lake and Maxwell Lake average monthly temperature data indicates that in general temperatures at Maxwell Lake are approximately 1 °C cooler than at St Mary Lake.

Therefore, temperature data from the St. Mary Lake climate station have been adjusted by -1 °C for use in calibration of the Maxwell Lake hydrological model.

Spatial Climate Data

In addition to climate records from the 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 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.

Future climate change projections are provided as relative change in temperature and precipitation from a baseline reference period, the 1961-1990 Climate Normal period. However, as data for the St. Mary Lake Climate Station is not available prior to December 1, 1975, a 1961-1990 climate normal is not available. The monthly average temperatures and precipitation for the 1961-1990 climate normal was extracted from the ClimateBC model at the St. Mary Lake Climate Station location to be used in the climate change assessment.

The 1981-2010 climate normal extracted from the ClimateBC model has been compared with the climate normal based on records from the St. Mary Lake Climate Station. In general, the data extracted from the ClimateBC model tends to under-predict both temperature and precipitation. For example, the 1981-2010 average annual temperatures are 10.7 °C and 10.4 °C, and the 1981-2010 average total annual precipitation is 987 mm and 953 mm for the St. Mary Lake Climate Station and the ClimateBC model output, respectively.

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

Climate Data

Climate data required in the study include monthly average temperature and monthly average precipitation data used for model calibration and the current and future climate condition water supply analysis. Since the Maxwell Lake watershed is relatively small, spatial variation in temperature and precipitation across the watershed is considered to be negligible. The sources of the climate data used in the study are summarized in Table 2-1.

Table 2-1: Sources of the Climate Data used for the Maxwell Lake Watershed

Climate Data	Use in this Study	Source
Average monthly temperature and precipitation data for 2010 - 2013 based on recorded average daily values – St. Mary Lake	Water balance model calibration and validation (Section 3.2)	Environment Canada climate station at St. Mary Lake (Station ID. 1016995)
Average monthly temperature data for 2013 based on recorded average daily values - Maxwell Lake	Used to check the adjustment factor to convert the temperature data of the St. Mary Lake EC station to temperature data at Maxwell Lake	NSWWD climate station at Maxwell Lake dam
Average monthly temperature and precipitation data for the 1981 to 2010 climate normal period	Current climate annual average annual condition water supply analysis (Section 3.2)	Environment Canada climate station at St. Mary Lake (Station ID. 1016995)
10-year return period drought monthly temperatures and precipitations based on St. Mary Lake EC station data from 1975 to 2007 period	Current climate drought conditions (10-year return period) water supply analysis (Section 3.2)	Environment Canada climate station at St. Mary Lake (Station ID. 1016995)
Average monthly temperature and precipitation data for the 1961 to 1990 climate normal period	Used as reference period for climate change water supply analysis (Section 4.3)	ClimateBC Model, UBC Faculty of Forestry
Projected 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) – Plan2Aapt

The climate data for the 1981 to 2010 climate normal period are considered the most recent and relevant data for the current climate condition and are used for the current climate condition analysis.

The 1961 to 1990 period forms the basis of the climate change projections with changes to temperature and precipitation data from the 1961 to 1990 climate normal period data. Climate data used for analysis of the future climate conditions are discussed further with more details in Section 4 of this report.

Back-Calculated Lake Net Inflow Data

The term “net inflow” means the amount of water flowing into the lake from surface water and shallow groundwater. Net inflows can often be negative in summer when losses such as evaporation from the lake and seepage from the lake to groundwater are higher than inflow to the lake.

In order to calibrate/validate the hydrological model used for assessing water availability, a record of lake net inflows from the Maxwell Lake watershed to the lake is required to compare model results and to adjust model parameters to represent specific conditions in the watershed. It is not possible to directly measure such net inflows to the lake. Therefore, an alternative method called Back-calculated Net Inflow was used to develop an estimate of historical net inflows to the lake using available recorded data, namely the rate of outflow from the lake and the lake level. Back-calculated net inflow is equal to the runoff from the watershed (including direct precipitation on the lake) minus evaporation from the lake and seepage losses. Net inflow is the water that is available to either be withdrawn from the lake or to replenish lake storage

Inflows to Maxwell Lake are comprised of both the watershed runoffs from the Maxwell Lake watershed and the diversion flows from Rippon and Larmour Creeks. In order to estimate net inflows to the lake from the Maxwell Lake watershed only, the diversion flows from Rippon and Larmour Creeks need also to be accounted in the calculation.

The net inflows to the lake from the Maxwell Lake watershed are back-calculated using the following mass balance equation:

Equation 1: *Net Inflow (Maxwell Lake Watershed+Direct Precipitaiton-Lake Evaporation+/-Lake Seepage) = Change in Storage + Lake Outflow to Maxwell Creek downstream + Water Supply Withdrawal –Rippon and Larmour Creek Diversion flow*

Figure 2-6 shows the components of the back-calculated net-inflow as a schematic of the watershed showing inflows and outflows from Maxwell Lake. Each of the components is described in more detail below.

Lake Level and Change in Storage

The change in lake storage over each month was calculated using available water level records. Maxwell Lake water levels have been recorded above the MoE Datum. The water levels are measured by a pair of manual staff gauges. Higher lake levels above 4.0 m above MoE datum are measured using staff gauge installed adjacent to the spillway (see Photo C-2) while lower lake levels below 4.0 m above MoE datum are measured using the original MoE staff gauge installed on a pile in the lake near the Rippon Creek diversion pipe outlet (see Photo C-4). The locations of the staff gauges are shown on Figure 2-1.

The datum of the two staff gauges were confirmed based on a level survey carried out by KWL on September 24, 2014. The conversion factors between the staff gages and geodetic elevations are shown below:

When lake levels are greater than 4.0 m use spillway staff gauge reading:

Water Elevation (m-GSC) = Dam/Spillway Staff Gauge Level + 310.36 m

When lake levels are less than 4.0 m use MoE staff gauge reading:

Water Elevation (m-GSC) = MoE Staff Gauge Level + 310.44 m

Water levels are recorded by NSSWD staff at roughly 2-3 day intervals. Missing data for the days between the recorded water level values were linearly interpolated. Lake levels are converted to storage volumes using the lake area-storage-level curve (see Figure 2-3). The change in lake storage over the month was then calculated using the difference in storage between the first day of the month in question and the first day of the following month.

Lake Outflow to Maxwell Creek

Outflows from the lake to Maxwell Creek have been recorded by NSWWD staff originally using a Parshall flume and then more recently, after construction of the dam in 1995, using a v-notch weir downstream of the spillway (Photo C-5). However, the data from the v-notch weir for calibration and validation period (2010 to 2013) is intermittent and there are concerns about quality of the data due to debris and vegetation accumulation at and near the weir. Therefore, the data from the v-notch weir has not been used in this study.

Rather, outflows from the lake were estimated using a lake level versus outflow relationship developed from the weir formula for the dam spillway (see Figure 2-2). This relationship was field-checked using a manual discharge measurement on June 3, 2014 using an OTT flow velocity meter and the velocity-area discharge calculation method. The manual discharge measurement is plotted on Figure 2-4 for comparison. Additional manual flow measurements were not possible as lake levels remained below spillway crest, such that no flow as observed over the spillway, throughout the remainder of the study period.

For back-calculation of net inflow, the outflow is assumed to be zero when water levels fall below the spillway crest elevation.

Water Supply Withdrawal

Withdrawals from the lake for water supply are measured and recorded by NSSWD using a flow meter installed in the large diameter water supply pipe downstream of the dam. Monthly withdrawal volumes for the period of 2010 and 2013 were calculated based on this data set and used to calculate the back-calculated lake net inflows for model calibration and validation.

Rippon Creek and Larmour Creek Diversion Flow

The Rippon Creek diversion is regulated by a stop-log structure in Rippon Creek, downstream of the confluence with Larmour Creek (Photo C-6). The diversion licence permits operation of the diversion from November 1st to March 31st of each year. The structure has a diversion capacity of 0.03 m^3/s. It consists of a PVC culvert and then a 200 mm diameter aluminium pipe into Maxwell Lake (Photo C-7). Flows in excess of 0.03 m^3/s overtop the stop-log structure and continue to flow downstream along Rippon Creek's natural channel. Flows less than or equal to 0.03 m^3/s are considered to be fully diverted to Maxwell Lake.

Flow in Rippon Creek has been measured using a Parshall flume with a 0.3 m wide throat upstream of the diversion structure since October 1, 1994 (Photo C-8). The Rippon Creek flows were estimated using the water levels collected by NSWWD at the Parshall flume approximately once a week during the diversion period. Water levels are then converted to flow using the following rating-curve equation:

Equation 2: $\boldsymbol{Rippon\ Creek\ Flow\ \left(\frac{m^3}{s}\right) = 0.0006244 * Parshall\ Flume\ Water\ Level\ (cm)^{1.522}}$

In addition to flow from Rippon Creek, the diversion structure also captures flow from Larmour Creek. Diversion from Larmour Creek is also permitted by water licence held by NSSWD for the period from November 1st to March 31st. Water from Larmour Creek is diverted into Rippon Creek through a constructed open channel immediately upstream of the Rippon Creek.

Flows from Larmour Creek are not recorded. For this study, they are estimated to be 10% of the Rippon Creek flows based on the watershed area ratio.

As per the water licence, it is assumed that the diversion from Rippon and Larmour Creeks to Maxwell Lake would only occur in the period from November 1st to March 31st of each year. No diversion to the lake would occur from April 1 to October 31.

Although calculated monthly average flow in Rippon and Larmour Creek may be less than the diversion threshold 0.03 m^3/s, this does not necessarily mean that the entire monthly volume is diverted. This is because on certain days or periods within the month, flow may increase above 0.03 m3/s even though the average flow for the month is less than 0.03 m^3/s. Therefore, monthly diversion factors have been calculated using the flow records from Rippon Creek. These factors indicate the ratio between the monthly diversion volumes and the total monthly runoff volumes from the Rippon and Larmour watersheds. Table 2-2 summaries the monthly diversion factors calculated and used in this study.

Table 2-2: Rippon Creek and Larmour Creek Monthly Diversion Factors

Month	Year 2010	Year 2011	Year 2012	Year 2013	Average
November	0.67	>1.00	N/A	>1.00	0.72
December	0.70	>1.00	N/A	>1.00	0.90
January	0.59	0.82	0.93	0.62	0.74
February	>1.00	>1.00	>1.00	>1.00	>1.00
March	>1.00	0.79	0.92	>1.00	0.93

When the diversion factors are greater than 1.0, then the monthly diversion volume is calculated by multiplying the maximum diversion rate of 0.03 m^3/s by the number of seconds in the month. When the diversion factor is less than 1.0, the monthly diversion volume is calculated by multiplying the combined average monthly flow volume of Rippon Creek and Larmour Creek by the diversion factor.

Maxwell Lake Watershed Back-Calculated Net Inflow

The average Maxwell Lake back-calculated net inflows, outflows and water levels calculated based on the recorded data between January 2010 and March 2014 are shown in Figure 2-7.

Uncertainty in Net inflow Calculation

As the back-calculated net inflow developed for Maxwell Lake provides 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 Maxwell 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 seiching (i.e.: water surface sloping across or along lake as a result of wind) which effects the assumption that lake surface is level and that difference in lake surface elevation can be used to calculate change in lake storage;
4. Lake level versus spillway rating curve;
5. Limited flow measurements from the Rippon Creek Parshall flume used in the development of the Rippon Creek and Larmour Creek average monthly flows and diversion factors;
6. Random errors in water withdrawal measurements in the water supply main; and
7. Assumption that outflow from Maxwell Lake is zero when lake levels fall below the crest of the weir (i.e.: no seepage through the dam).

It is anticipated that these uncertainties have the greatest impact on back-calculated net-inflows through the fall and winter period as water levels were recorded less frequently during this period. In addition, the assumption of using linear interpolation to estimate daily lake levels between the recorded lake levels would not include potential peak inflows as resulting from winter storms. Therefore, it is likely that the back-calculated net inflow for the fall and winter period is likely under-estimating the actual net-inflow to the lake. Furthermore, uncertainties in the estimates of the monthly volume of flow diverted from Rippon Creek and Larmour Creek also impact winter (November 1st to March 31st) back-calculated net inflow estimates.

2.5 Groundwater

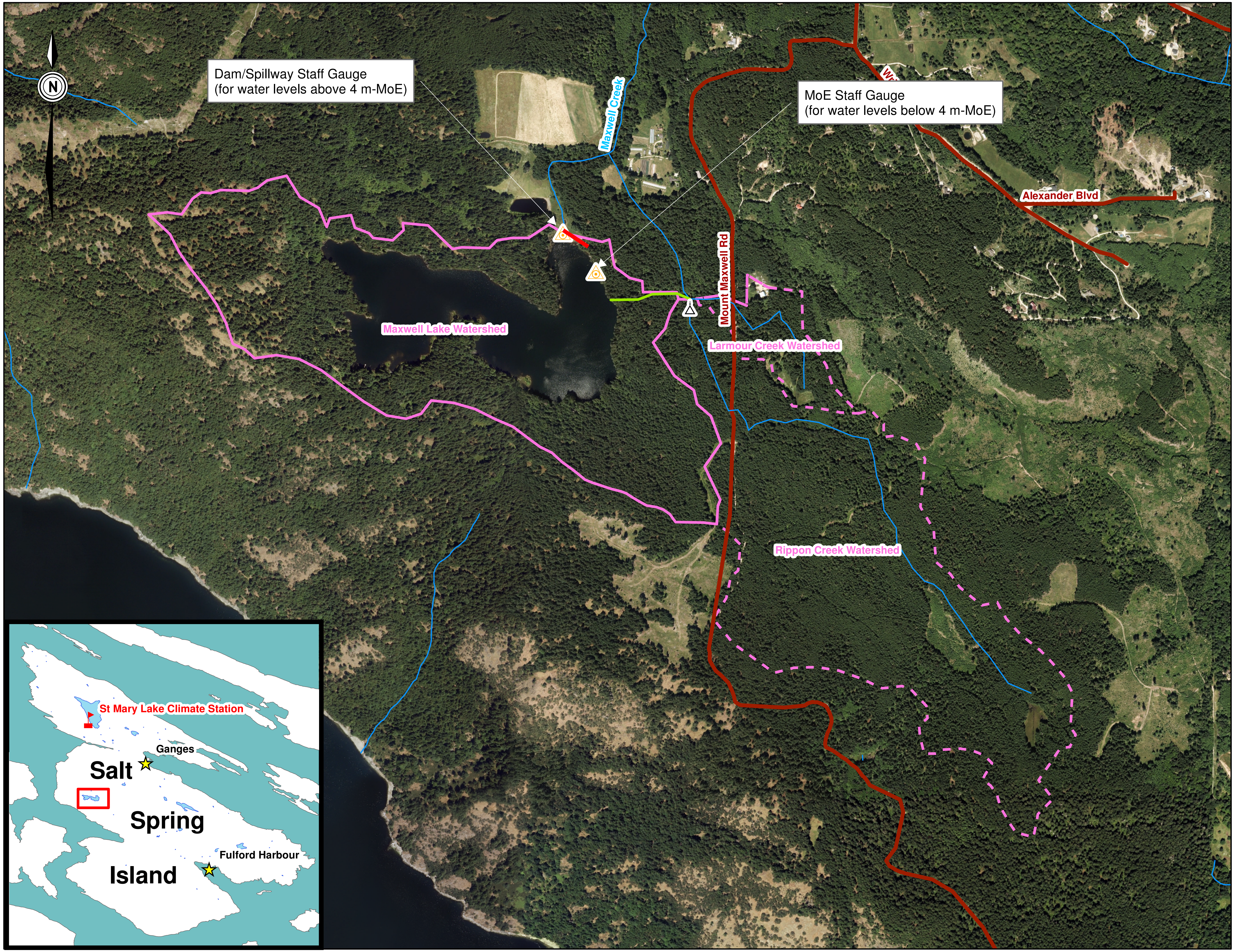
The aquifer underlying the study area was mapped by the BC Ministry of Environment (BC MoE) preliminary aquifer mapping (Aquifer #721) and is indicated to have low productivity. The BC Wells Database shows one well located within the watershed (Well Tag 81046). It has a total depth of about 250 m and has a yield of about 2 USGPM.

Given the nature of bedrock aquifers and the low productivity of the aquifer underlying the Maxwell Lake watershed as indicated in the above mentioned documents, it is likely that general groundwater flow in the watershed is slow and would likely sustain reasonable inflow through the summer period. However, groundwater flow tends to follow fissures in the rock matrix and therefore, is very heterogeneous in nature.

There is very little if any withdrawal from groundwater within the watershed and there likely will never be any change in withdrawal rates as the watershed is almost entirely protected. Therefore, any change in the groundwater regime into the future is likely to be only the result of changing climate and rainfall patterns due to long-term climate change impacts.

Groundwater plays an important role in the overall water balance of a watershed. However, for this study it is assumed that only limited groundwater flow from deep bedrock aquifer groundwater is available to recharge the lake and has been considered a loss in the water balance for the lake.

Maxwell Lake Watershed - Water Availability and Demand - Climate Change Impact Assessment



Legend

- Maxwell Lake Dam
- Maxwell Lake Staff Gauges
- Rippon Creek Flow Gauge (Parshall Flume)
- Rippon Creek Diversion Pipe
- Watercourse
- Roads
- Maxwell Lake Watershed
- Diversion Watershed

Reference: Orthophoto from CRD Geospatial Data Basemaps.

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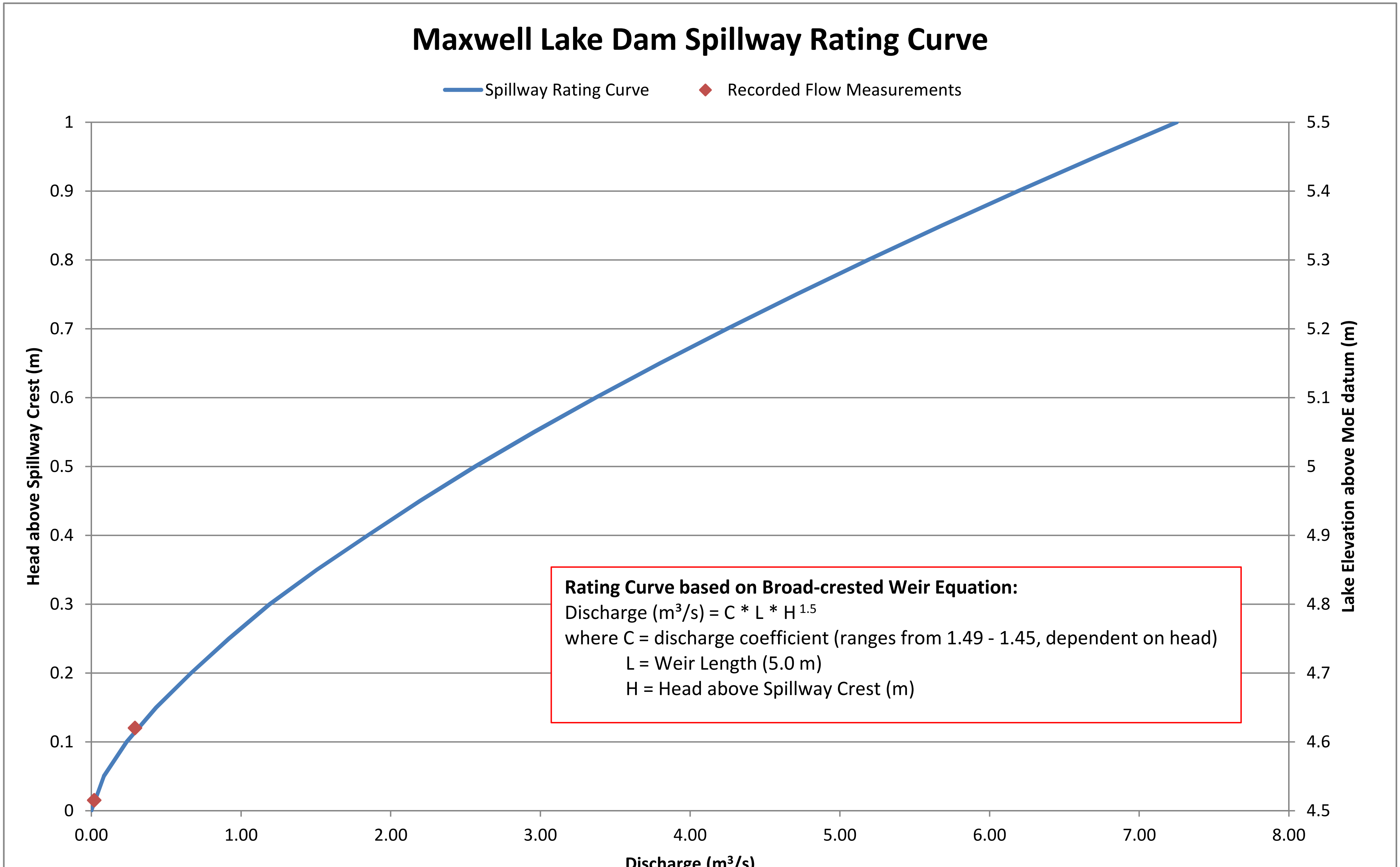
Project No.	Date
2932-006	March 2015

Maxwell Lake & Watershed General Location Map

Figure 2-1

Path: Q:\2900-2999\2932-006\430-GIS\MXD-Rp\2932006_GeneralLocation.mxd Date Saved: 18/11/2014 10:58:18 AM
Author: MScruton



Note: Spillway Crest Elevation at 314.9 m-GSC

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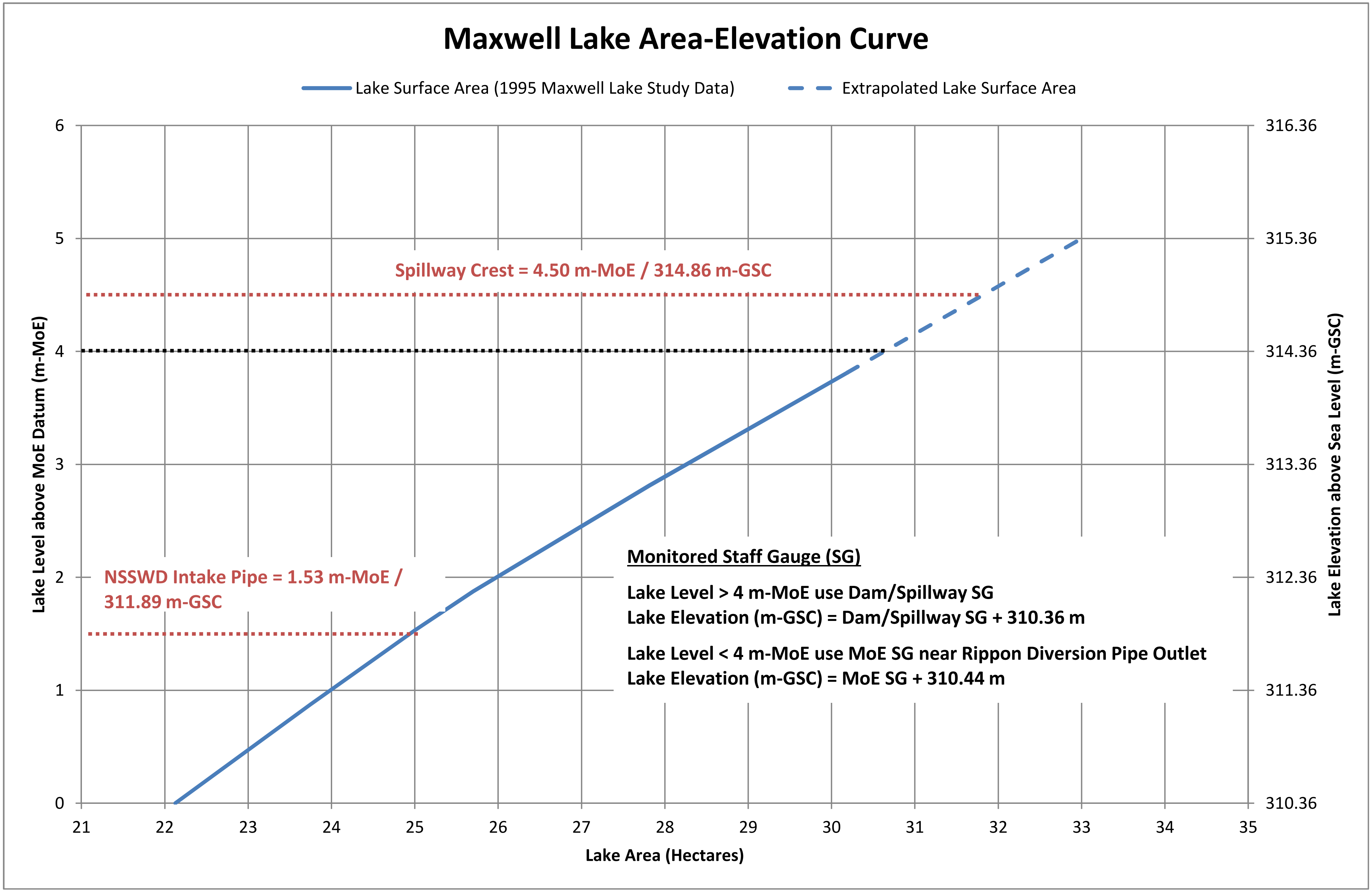
Maxwell Lake Watershed Water Availability and Demand - Climate Change Impact Assessment
Maxwell Lake Dam Spillway Rating Curve
Figure 2-2



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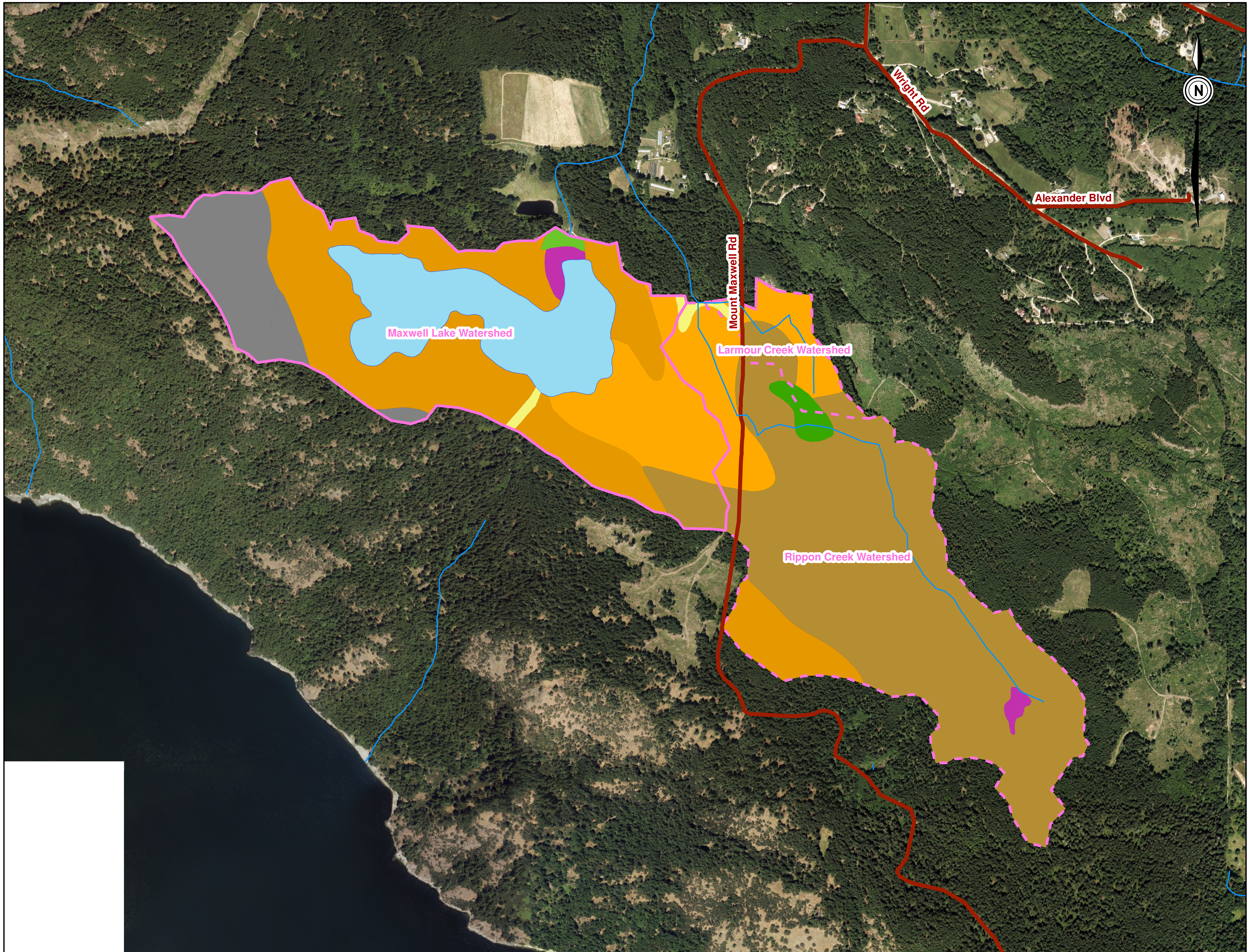
Maxwell Lake Watershed Water Availability and Water Demand - Climate Change Impact Assessment
Maxwell Lake Area-Elevation Curve
Figure 2-3



Maxwell Lake Watershed Water Availability and Demand - Climate Change Impact Assessment

Legend

- Watercourse
- Roads
- Maxwel Lake Watershed
- Diversion Watershed

Soil Type

- Bedrock
- Channery sandy loam to channery loamy sand
- Gravelly sandy loam to gravelly loam
- Gravelly sandy loam to gravelly loamy sand
- Humic organic soil
- Loam to sily clay loam
- Loamy sand to sandy loam
- Silt loam to fine sandy loam
- Lake

Reference: Orthophoto from CRD Geospatial Data Basemaps.

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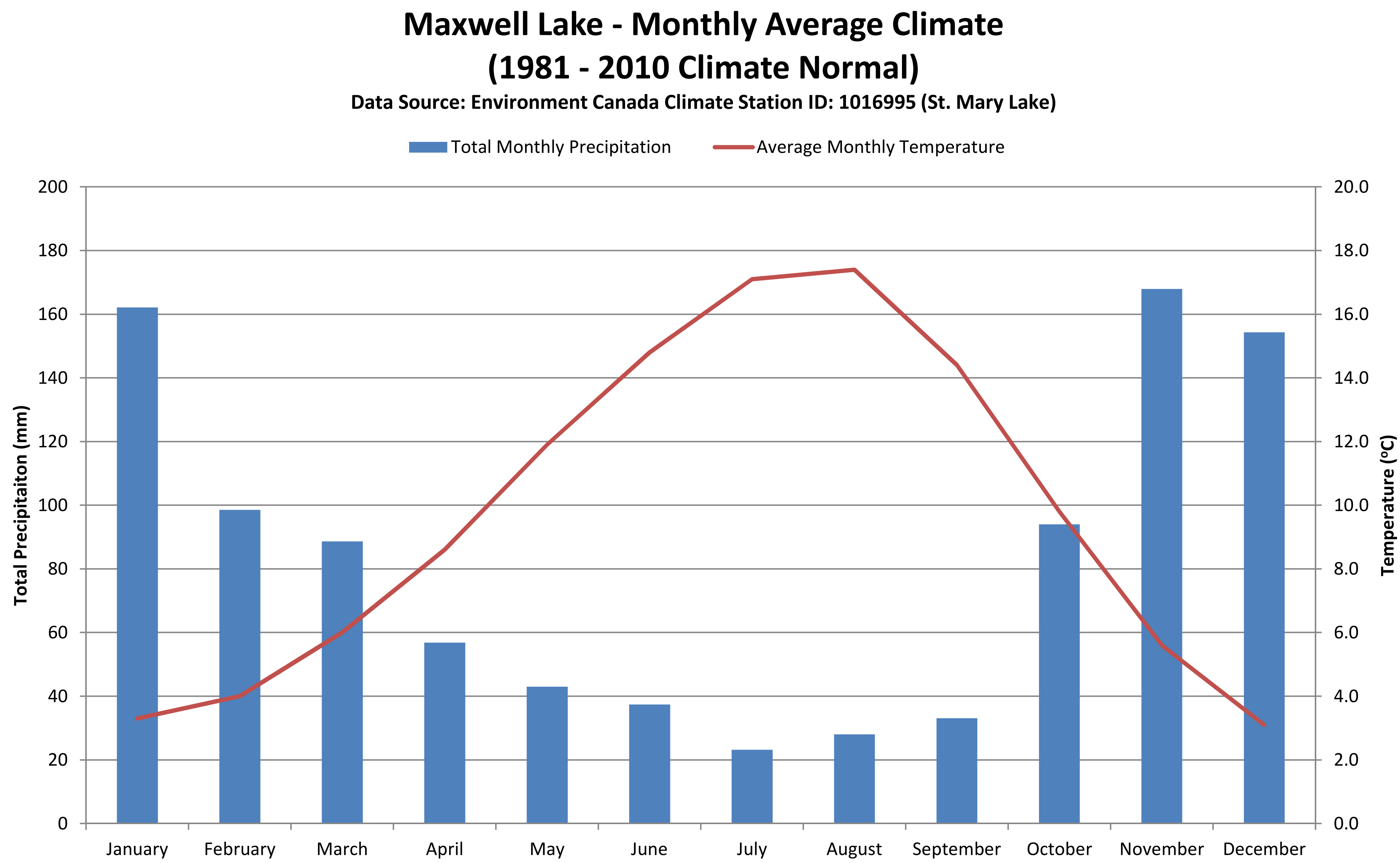
Project No.	Date
2932-006	November 2014

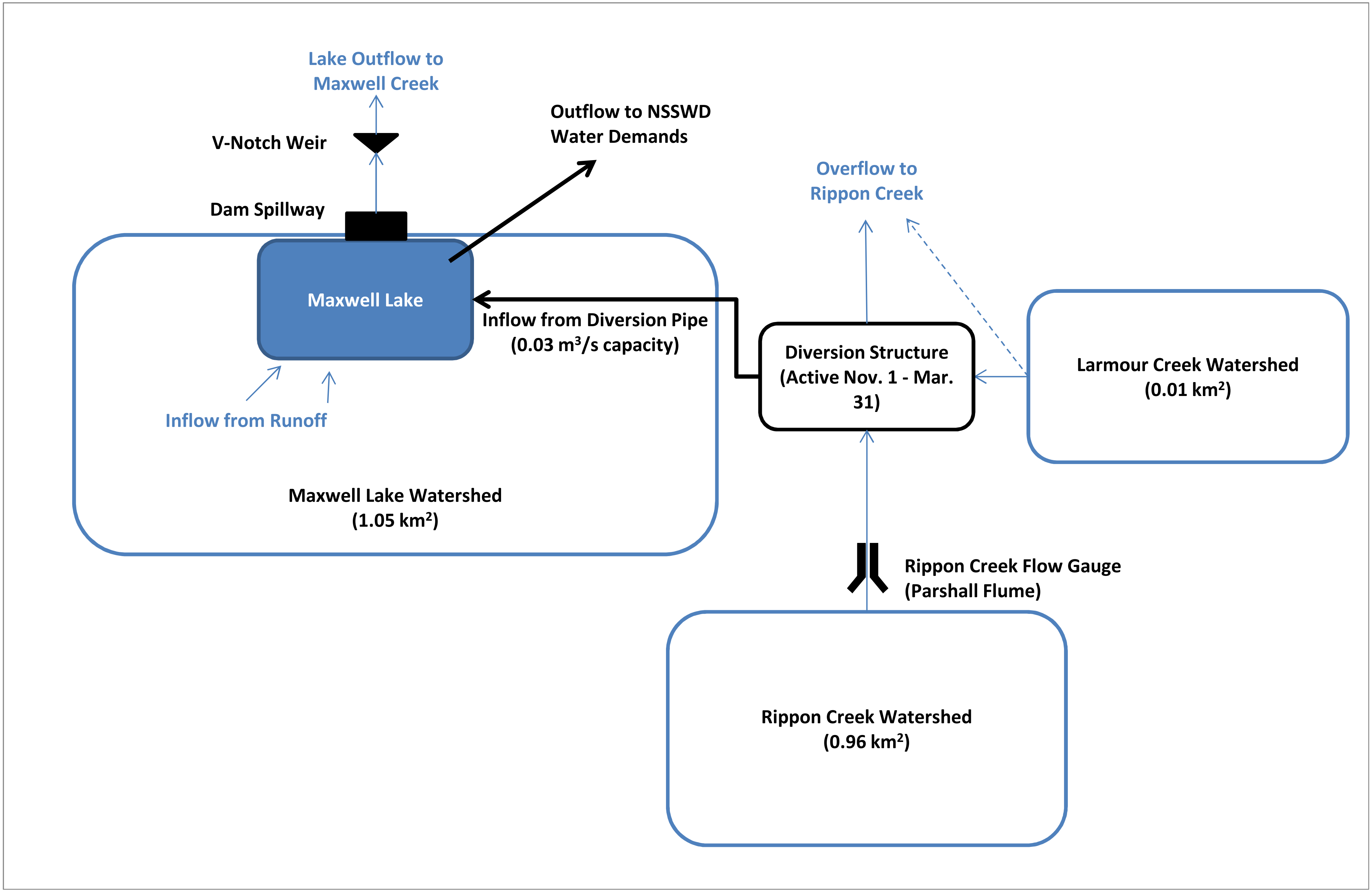
Maxwell Lake Soils

Figure 2-4

Path: Q:\2900-2999\2932-006\430-GIS\MXD-Rp\2932006_SoilMap.mxd Date Saved: 17/11/2014 4:28:38 PM
Author: MScruton

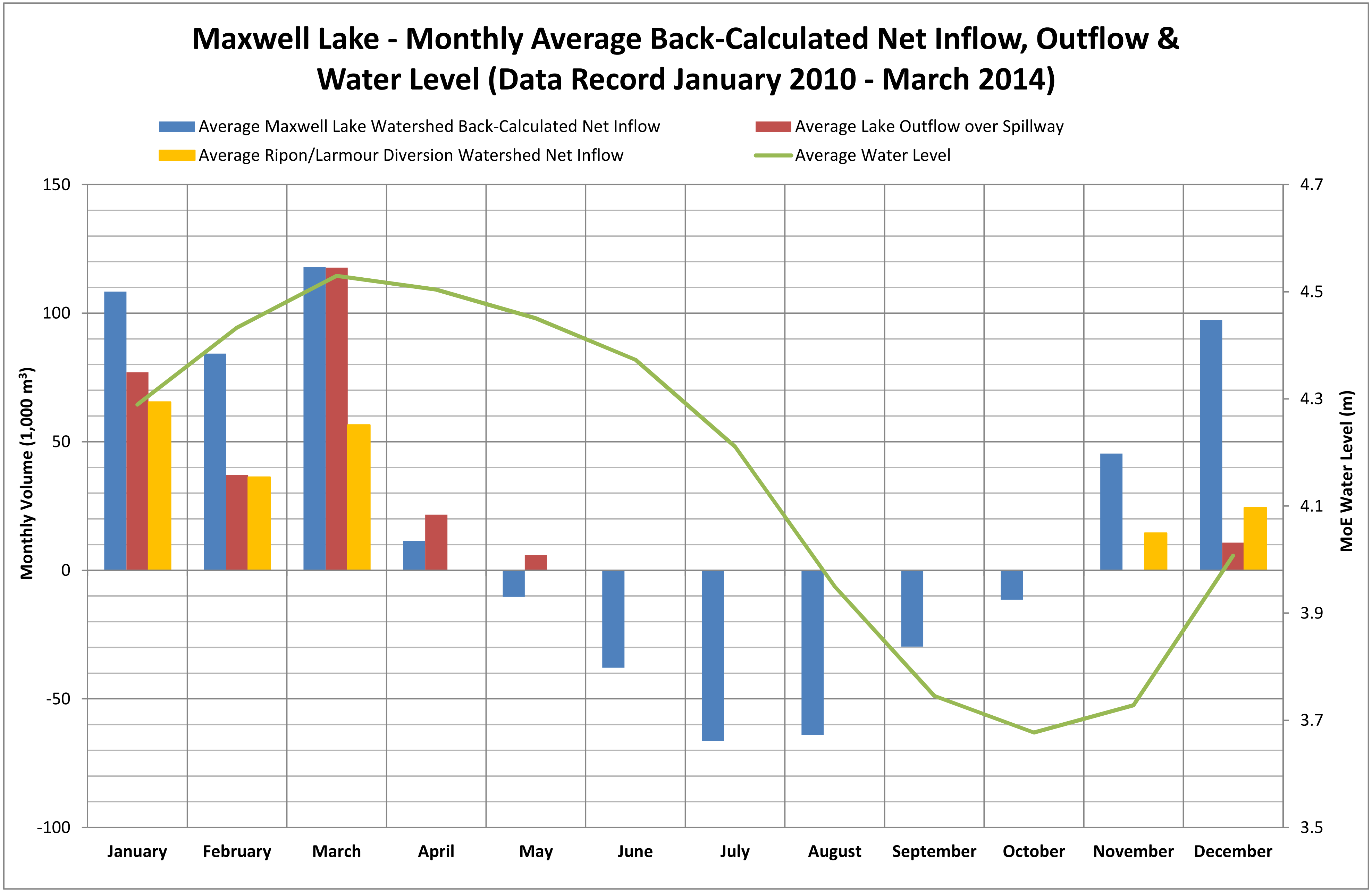


Note: St. Mary Lake temperature data was adjusted by -1 °C to account for elevation difference between Maxwell Lake and St Mary Lake.



Lake Outflow to Maxwell Creek
V-Notch Weir
Outflow to NSSWD Water Demands
Dam Spillway
Overflow to Rippon Creek
Maxwell Lake
Inflow from Diversion Pipe (0.03 m³/s capacity)
Diversion Structure (Active Nov. 1 - Mar. 31)
Larmour Creek Watershed (0.01 km²)
Inflow from Runoff
Maxwell Lake Watershed (1.05 km²)
Rippon Creek Flow Gauge (Parshall Flume)
Rippon Creek Watershed (0.96 km²)

Figure 2-6



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Maxwell Lake Watershed Water Availability and Demand - Climate Change Impact Assessment
Maxwell Lake Monthly Average Back-Calculated Net Inflow, Outflow, and 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 Withdrawal

3.1 Supply and Withdrawal Water Balance

A water balance provides a comparison of the water availability and withdrawal in a watershed. It is based on the conservation of mass, which for water balance assessments 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 water balance assessment are that:

1. Watershed is a closed system bounded by the height of land or the watershed boundary and that all shallow groundwater and surface water eventually flows to the outlet of the watershed, the outlet of Maxwell Lake for this study;
2. Diversion from Rippon Creek and Larmour Creek from November 1st to March 31st, is an inflow to the Maxwell Lake watershed and is calculated based on the monthly average diversion factors outlined in Section 2.3;
3. Water flowing into deep groundwater aquifer and lake seepage is "lost" to the system and does not eventually flow back to Maxwell Lake; and
4. Water withdrawals are considered to be removed from the system and do not flow back into the watershed;

The assumptions simplify the complex nature of water movement through the watershed. However, a watershed hydrological model or water balance model calibrated to recorded discharges should be reasonably accurate to account for movement of water through the various components of the water cycle to estimate surface water availability based on precipitation and temperature records, soils mapping and land cover.

The final assumption is valid as all water withdrawn from the lake is distributed to properties outside of the watershed boundary.

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

3.2 Watershed Hydrological Modelling

Monthly Water Balance Model

To quantify available water supplies within the watershed, monthly water balance models were developed based on the USGS method (USGS, 2007) to calculate the monthly average net inflows from the Maxwell watershed and from the diversion watersheds to the Lake. According to land cover, soil type, precipitation and temperature across the basin, the models account 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 (dependant on temperature but has been found to be insignificant within the study watersheds);
3. Evapotranspiration (dependant 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);
8. Groundwater deep aquifer loss; and
9. Lake seepage loss.

Monthly average net inflows to the lake estimated by the water balance model account for the storage changes in the contributing watersheds 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 water supply) that are available for the current withdrawal and licenced withdrawals limit under the current climate condition, as well to assess how projected changes in temperature and precipitation could impact available water supplies under future climate conditions.

The monthly water balance model used in this study is considered appropriate given the limitations of the data available for calibration, especially lake levels which have been recorded roughly once a week. More sophisticated hydrologic models typically run on daily time increment and therefore require both input and calibration data at least daily intervals. Given that the focus of this study is to review 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 data available. In addition, results from global circulation models are readily available at monthly time steps rather than daily time step. Therefore, the water balance model used for climate change impact assessment must also be set at monthly increments in order to use the climate model results as inputs.

As outlined previously, the primary focus of this assessment is surface water supplies. No detailed groundwater modelling was conducted as a part of this study. Groundwater was modelled as a single storage reservoir in each watershed model, which does not account for variations in aquifer characteristics and geological formations across the watershed. Therefore, the models cannot be used to assess the distribution of groundwater availability from one part of watershed to another. However, this approach does provide a reasonable estimate of the seasonal fluctuation of groundwater availability across the entire watershed. A schematic of the water balance model process is shown in Figure 3-1.

Model Calibration and Validation

To confirm that the water balance model developed in this study is representing the hydrological processes within the contributing watersheds, the monthly water balance model developed for the Maxwell Lake watershed was calibrated by comparing the model output with the back-calculated average monthly lake net inflows from the Maxwell Lake watershed without the diversions. During model calibration, the parameters, such as groundwater infiltration percentage, groundwater runoff factor, groundwater deep aquifer loss percentage and the lake seepage factor were adjusted until a good match between the recorded data and model output was achieved. The model parameters are then validated by comparing model results using the calibrated parameters with back-calculated inflows for a year independent from the calibration period to check if parameters are transferrable between years with different weather conditions (ie: dry year versus wet year).

The hydrological model was run continuously for the period between September 1st, 2010 and December 31st, 2013. As described in the foregoing Section 2.4 of the report, the monthly average lake net inflows from the Maxwell Lake watershed were back-calculated using the recorded Maxwell Lake water levels, the lake outflow rating curve, estimated diversion flows and the water consumption data.

The model was calibrated to the year 2013 and validated for the year 2012. Data from 2010 to 2011 were used as run-up years to stabilize the model and eliminate the influence of assumed initial watershed conditions (i.e.: groundwater storage, etc.) in model results. Table 3-1 is a summary of the parameters calibrated for the Maxwell Lake water balance model.

Table 3-1: Maxwell 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%	% of rainfall which flows directly to surface runoff (ie: impervious areas)
Ground Water Runoff (GW) Factor	15%	% of ground water storage that is release to surface runoff each month
Soil Moisture Capacity (SMC)	Varies from 150 to 275 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 50-300 mm/month depending on soil type	Maximum infiltration rate to soil moisture capacity
Max Ground Water Recharge	15% of IR (mm/month)	Maximum rate that ground water storage is recharged from soil moisture storage.
Deep Aquifer Loss	20%	% of groundwater storage that is lost to deep aquifer

Figure 3-2 compares the model calibration results with the recorded monthly watershed runoffs for the year 2013. The results are also summarized in Table 3-2.

Table 3-2: Maxwell Lake Watershed Water Balance Model Calibration/Validation Results

Parameter	Model Calibration (2013)		Model Validation (2012)	
	Modelled Lake Net Inflow	Back-calculated Net Inflow	Modelled Lake Net Inflow	Back-calculated Net Inflow
Annual Precipitation, 1,000 m^3	744		1,138	
Annual Direct Lake Net Inflow, 1,000 m^3	149	138	559	590
Annual Direct Net Inflow Difference, 1,000 m^3	11		-30	
Annual Direct Net Inflow, % Error	8.0 %		-5.1 %	
Spring/Summer (May-Sept) Precipitation, 1,000 m^3	298		115	
Spring/Summer (May-Sept) Direct Lake Inflow, 1,000 m^3	-29	-47	-113	-96
Spring/Summer (May-Sept) Direct Lake Inflow Difference, 1,000 m^3	18		-17	
Total Average Withdrawal (May-Sept) (2010-2013), 1,000 m^3	161			
Fall/Winter (Oct-April) Precipitation, 1,000 m^3	447		1,023	
Fall/Winter (Oct-April) Direct Lake Inflow, 1,000 m^3	179	186	672	686
Fall/Winter (Oct-April) Direct Lake Inflow Difference, 1,000 m^3	-7		-14	
Total Average Withdrawal (Oct-April) (2010-2013), 1,000 m^3	170			

The calibration and validation results indicate that the model provides a reasonable estimate of average monthly lake net inflows from the Maxwell Lake watershed. For the calibration period, the total modelled annual lake net inflow of 149,000 m^3 is 11,000 m^3 more than the back-calculated lake net inflow volume (about 8.0% total annual volume error). The 2012 validation period yielded similar results as the 2013 calibration period showing that calibrated model parameters are representative across variable temperature and precipitation conditions. The total modelled annual lake net inflow of 559,000 m^3 is 30,000 m^3 less than the back-calculated lake net inflow volume (about 5.1% total annual volume error). The 2012 validation results are shown in Figure 3-3 and also summarized in Table 3-2.

For seasonal variations, the model also generally indicates a good fit to the back-calculated monthly lake net inflows from the Maxwell Lake. For the summer/spring period, the model over-predicted the calibration year and under-predicted total volume as compared with the back-calculated net inflows. For the fall/winter period, the model under-predicted both the calibration and validation year compared to the back-calculated net inflow. The differences between the modelled runoff and the back-calculated net inflow are small relative to the purpose of the model for predicting water supply availability. The total volume difference between the model runoff and back-calculated net-inflow for the fall/winter and spring/summer periods is less than 10% of the total average water withdrawal for the same periods.

Based on the data available at the time of this study as well as the model calibration and validation, it is considered that the water balance model developed for the Maxwell Lake watershed is accurately representing hydrological processes within the watershed. Therefore the model results are considered to be suitable for assessment of water supplies for Maxwell Lake under current and future climate conditions.

Water Balance Model Results - Current Climate

Using the calibrated monthly water balance model, average monthly water supply volumes (or lake net inflows) from the Maxwell Lake watershed for the annual average condition of the 1981 to 2010 climate normal period were calculated. The monthly diversion flows were calculated based on the estimated watershed runoffs from the Rippon Creek and Larmour Creek watersheds and the estimated average monthly diversion factors as described in Section 2.4. A model for the Rippon Creek watershed was developed to estimate the current climate annual average condition monthly flows from Rippon Creek, based on the calibrated hydrological parameters, the watershed information (such as watershed catchment areas, land use and soil information), and the average temperature and precipitation data for the current climate (1981 to 2010 climate normal period). Larmour Creek flows were estimated to be 10% of the Rippon Creek flows according to the watershed area ratio. The current climate monthly diversion flows were estimated using the average monthly diversion factors as described in Section 2.4.

The total monthly lake net inflows were then estimated by adding the simulated lake net inflows from the Maxwell Lake watershed and the estimated monthly diversion flows.

Table 3-3 shows the results.

10-year Return Period Drought Water Supply

In addition to the current climate annual average condition, the 10-year return period drought condition was also assessed to check the lake net inflow availability and storage requirements under severe dry weather conditions. The available data from the St. Mary Lake climate station from Environment Canada for the period of 1975 to 2007 were used in this study to perform the drought analysis. The data used for current climate 10-year return period drought analysis are included in Appendix D of this report. The Log Pearson Type III extreme value distribution was used to estimate the total annual precipitation and average monthly temperatures for the 10-year return period drought condition. 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 temperature and precipitation data were used as inputs to the water balance model to estimate monthly average lake net inflows for the 10-year return period drought condition. The results are summarized in Table 3-4.

Table 3-3: Estimated Maxwell Lake Net Inflows – Current Climate (1981 to 2010) Condition

Month	1981-2010 Climate Normal Annual Average Condition			
	Precipitation	Temperature	Modelled Net Inflow (1,000 m^3)	Total Net Inflow

	(mm)	(°C)	Lake	Diversion	
January	162	3.3	116	102	218
February	99	4.0	91	68	159
March	89	6.0	41	49	90
April	57	8.6	14	0	14
May	43	11.9	-2	0	-2
June	37	14.8	-13	0	-13
July	23	17.1	-28	0	-28
August	28	17.4	-25	0	-25
September	33	14.4	-13	0	-13
October	94	9.8	25	0	25
November	168	5.6	74	17	91
December	154	3.1	154	84	238
Total	**987**		**434**	**319**	**753**
May - Sep	**165**		**-81**	**0**	**-81**

Table 3-4: Estimated Maxwell Lake Net Inflows – Current Climate (1981 to 2010) 10-Year Return Period Drought Condition

Month	1981-2010 Climate Normal 10-Year Return Period Drought Condition				
	Precipitation (mm)	Temperature (°C)	Modelled Net Inflow (1,000 m^3)		Total Net Inflow (1,000 m^3)
			Lake	Diversion	
January	113	4.8	106	38	144
February	75	5.6	33	45	78
March	64	7.3	23	21	44
April	40	9.7	3	0	3
May	31	13.4	-12	0	-12
June	28	16.4	-23	0	-23
July	17	18.6	-35	0	-35
August	22	18.7	-31	0	-31
September	26	15.8	-20	0	-20
October	66	10.9	9	0	9
November	120	7.2	43	9	53
December	114	5.2	55	18	73
Total	**717**		**152**	**131**	**282**
May - Sep	**125**		**-121**	**0**	**-121**

The estimated net inflows to Maxwell Lake indicate the importance of the Rippon Creek and Larmour Creek diversion in supplying water to Maxwell Lake. The diversion volume makes up about 42% and 46% of the average year and 10-year return period drought conditions, respectively.

3.3 Water Withdrawal and Storage

Current Surface Water Withdrawal

Current monthly surface water withdrawals of the NSSWD were calculated using available recorded water usage data from the Maxwell Lake water intake flow meter logs for the period from 2010 to 2013.

These data are used in the study for back-calculated net inflow, as well are used as the current surface water withdrawals to assess the current and future water balance between the water availability and withdrawal. The total annual water usage volumes from Maxwell Lake are summarized in Table 3-5. A summary of the recorded average monthly withdrawals for the period from 2010 to 2013 is shown in Figure 3-4.

Table 3-5: Current NSSWD Water Withdrawal (2010 – 2013)

Month	Monthly Withdrawal (1,000 m^3)				
	2010	2011	2012	2013	Average
January	20.671	22.253	23.644	19.557	21.531
February	18.043	50.425	21.294	18.416	27.045
March	18.089	41.365	26.940	19.262	26.414
April	20.280	29.604	28.995	21.585	25.116
May	27.968	29.550	29.304	26.849	28.418
June	24.890	29.209	30.527	25.631	27.564
July	40.260	36.551	33.573	37.928	37.078
August	37.796	41.415	38.283	35.532	38.256
September	28.468	35.128	33.423	24.799	30.454
October	21.653	24.744	32.695	19.253	24.586
November	25.335	22.303	27.695	18.207	23.385
December	22.762	23.717	24.144	18.966	22.397
Total	306.216	386.263	350.517	285.985	332.245

Licenced Surface Water Withdrawal Limit

The licenced withdrawal limit for Maxwell Lake is 146 x 10^6 Imperial gallons or 663,729 m^3 per year, which is authorized by five separate water licences. All the licences are issued to NSWWD for municipal water supply. The licenced withdrawal limit is approximately the double of the current average withdrawal from the lake to the NSSWD system. A summary of the Maxwell Lake water licences are shown in Table 3-6.

Table 3-6: Summary of NSSWD Water Withdrawal Licences

Licence #	Maximum Annual Withdrawal		Date of Precedence
	Imp Gal/Year	m^3	
058203	18,250,000	82,966	1939
058204	4,380,000	19,911	1914
058205	50,370,000	228,986	1953
065784	73,000,000	331,864	1984
Total	**146,000,000**	**663,729**	

The licenced withdrawal limit is used in the study as potential maximum future surface water withdrawal to assess the current and future water balance between the water availability and withdrawal. It is assumed that the licenced withdrawal has the same monthly distribution ratios as those estimated based on the average monthly waterworks usages for the period from 2010 to 2013. Monthly distribution of the allocated licenced withdrawal limit were then calculated and are shown in Figure 3-4 in comparison with the current monthly withdrawals.

Licenced Lake Storage

In addition to water licences to permit withdrawals, there are also three water licences that permit storage of water in Maxwell Lake for waterworks uses. Two of these licences allow for diversion of water from Rippon Creek and Larmour Creek to be stored in Maxwell Lake. The diversion licences allow for diversion for the period from November 1 and March 31. A summary of the water licences for storage and diversion to Maxwell Lake are shown in Table 3-7.

Table 3-7: Water Licences for Storage and Diversion from Rippon Creek and Larmour Creek

Licence #	Watercourse	Total Annual Diversion and Storage Volume				Notes
		Acre Feet/Year	m^3	Acre Feet/Year	m^3	
065785	Maxwell Lake	510	628,830			
101070	Rippon Creek			200	246,600	Diversion from Nov 1 to Mar 31
110780	Larmour Creek			164	202,212	Diversion from Nov 1 to Mar 31
Total		**510**	**628,830**	**364**	**448,812**	
Total Licenced Volume					**1,077,642**	

Physical Reservoir Storage

The water licences for storage quantify the maximum volume of water allowed to store in the lake for licenced water use. Typically, the total licenced storage volume is equal to the total available live storage in the reservoir or lake. However, this is not the case for Maxwell Lake. The actual live storage in the lake is found to be less than the total licenced storage.

The area-elevation and storage-elevation curves for the lake presented in the previous Hydrology of Maxwell Lake report dated January 1995 indicates that Maxwell Lake had a total storage volume of 626,000 m^3 at the spillway elevation of 313.9 m GSC after the spillway was raised in 1995. The spillway was further raised by 0.6 m in 2003 and the total physical storage in the lake was increased to approximately 819,000 m^3. This has been calculated by extrapolating the area-elevation curve and recalculating storage. A topographic survey completed in 2015 by Polaris Land Surveying Inc. determined that the raised crest is at elevation 314.86 m GSC rather than 314.4 m GSC as shown in the original record drawings. This is the result of a shift in the datum elevation of the MoE monument (88HAW031). In other words, the spillway is not 0.46 m higher relative to the surrounding land. It is just that the datum established for the original benchmark was incorrect.

The area-elevation curve for Maxwell Lake is shown in Figure 2-3.

3.4 Water Budget – Current Climate Conditions

A water budget has been carried out for Maxwell Lake to asses if the water supply and storage that is currently available is sufficient to support the current withdrawal and the licenced withdrawal limit from Maxwell Lake.

By comparing the modelled monthly average net inflows to Maxwell Lake with the monthly surface water withdrawals, a monthly storage requirement can be calculated. The monthly storage requirement is equal to the amount of additional water required to support withdrawals on a monthly basis. In other words, when the monthly lake net inflow is less than the maximum monthly water withdrawals, the difference between the lake net inflow and the water withdrawal is the monthly storage requirement. The monthly storage requirements are added together and the maximum accumulated storage requirement volume is the total lake storage required to support water withdrawals on an annual basis.

To evaluate Maxwell Lake storage requirement under the current climate condition, both the current withdrawals and licenced withdrawal limit were compared with lake net inflows estimated from the water balance model for both the 1981-2010 Climate Normal annual average and 10-year return period drought conditions. Figure 3-5 shows the comparison between the modelled net inflows to the lake and the required surface water withdrawals under both the average inflow and 10-year return period drought conditions. The results show that the modelled lake inflows would support both the current and licenced withdrawal in the winter period (November to February), but not in the summer period (April to September) without using storage.

Storage requirements for the current withdrawal and licenced withdrawal limit were calculated and are plotted in Figure 3-6 and Figure 3-7, respectively. The results indicate that the estimated lake net inflow could support current withdrawals on an annual basis, such that lake storage is refilled after each year, under both the current climate average inflow (1981-2010 period) and 10-year return period drought conditions. The required storage volumes are estimated to be 254,000 and 320,000 m^3, respectively. These volumes are less than the total licenced lake storage volume of 1,077,642 m^3 and the current available lake physical storage capacity of 819,000 m^3 at the existing spillway crest elevation. The results indicate that the available storage at Maxwell Lake is capable of supporting the current withdrawal under both the current climate average and 10-year return period drought inflow conditions.

Under the maximum allocated withdrawal or licenced withdrawal condition, the estimated current climate lake average inflow (1981-2010 period) could support the withdrawal on an annual basis with the lake storage can be refilled after each year. The required storage volume is estimated to be 465,000 m^3, below the licenced lake storage amount and the lake available storage capacity. However, the estimated 10-year return period drought condition lake net inflow could not support the licenced withdrawals with storage on an annual basis, which means that the lake storage cannot be refilled in the spring of next year. Assuming a 10-year return period drought year would be followed by average inflow years, our analysis results show that the lake storage would eventually be fully refilled in the 4th average inflow year if sufficient lake storage is available. The storage deficit volume estimated for such a condition is 540,000 m^3. Therefore, the current Maxwell Lake available storage capacity of 819,000 m^3

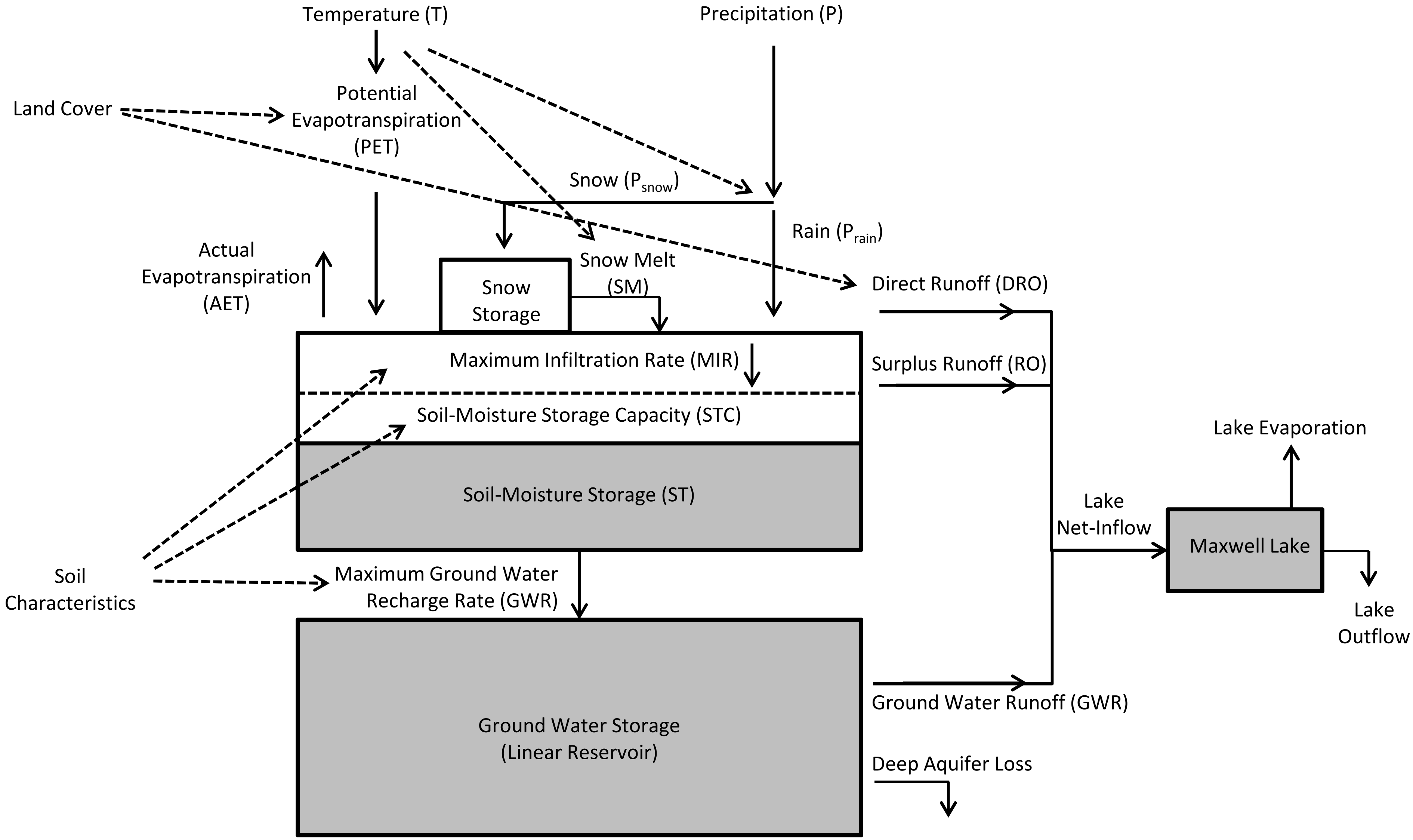
would also support both the licenced withdrawal under the current climate average and 10-year return period drought inflow conditions. A summary of the results is shown in Table 3-8.

Table 3-8: Maxwell Lake Water Balance Assessment Results – Current Climate (1981 – 2010 Climate Normal) Condition

Parameter	Current Climate Average Year	Current Climate 10-Year Return Period Drought Year[1]
Annual Precipitation, mm	987	717
Annual Precipitation Volume Combined Watershed[2], 1,000 m^3	2,090	1,518
Annual Maxwell Lake Net-Inflow, 1000 m^3	434	152
Annual Rippon Creek and Larmour Creek Diversion Volume[3], 1,000 m^3	319	131
Total Annual Inflow to lake, 1,000 m^3	753	282
Current Annual Withdrawal, 1,000 m^3	332	
Licenced Annual Withdrawal, 1,000 m^3	664	
Spring/Summer (May-Sept) Precipitation, mm	165	125
Spring/Summer (May-Sept) Lake Net-Inflow, 1,000 m^3	-81	-121
Current Summer Withdrawal, 1,000 m^3	161	
Licenced Summer Withdrawal, 1,000 m^3	323	
Required Storage for the Current Withdrawal, 1,000 m^3	254	320
Required Storage for the Licenced Withdrawal, 1,000 m^3	465	540
Available physical storage, 1,000 m^3	819	819

1. For the 10-year return period drought year assessment, assume the 10-year return period drought year is followed by average runoff years.
2. Annual volume of precipitation falling over combined watershed areas for Maxwell Lake, Rippon Creek and Larmour watersheds.
3. Water licence permits diversion from Rippon Creek and Larmour Creek only from Nov 1st to Mar 31st.

Under average year conditions, there is sufficient inflow to refill Maxwell Lake to the full supply level with both current withdrawals and the licenced withdrawal limit. However, under 10-year drought conditions both the current withdrawal and the licenced withdrawal limit is greater than the total annual inflow. Assuming that the 10-year drought year is followed by an above average year, there would be sufficient inflow to refill Maxwell Lake with the current withdrawals. However, with the licenced withdrawal limit the lake would not refill even assuming that the year following the drought has above average net inflow. Under these conditions, there would be an 189,000 m^3 shortfall in the available net-inflow to refill Maxwell Lake. As such, the total annual withdrawal from Maxwell Lake would have to be reduced to 72% of the licenced withdrawal limit to allow the lake to refill after the 10-year return period drought condition.



Monthly Water Balance Adapted From USGS Monthly Water Balance Model

Source: McCabe and Markstrom, 2007

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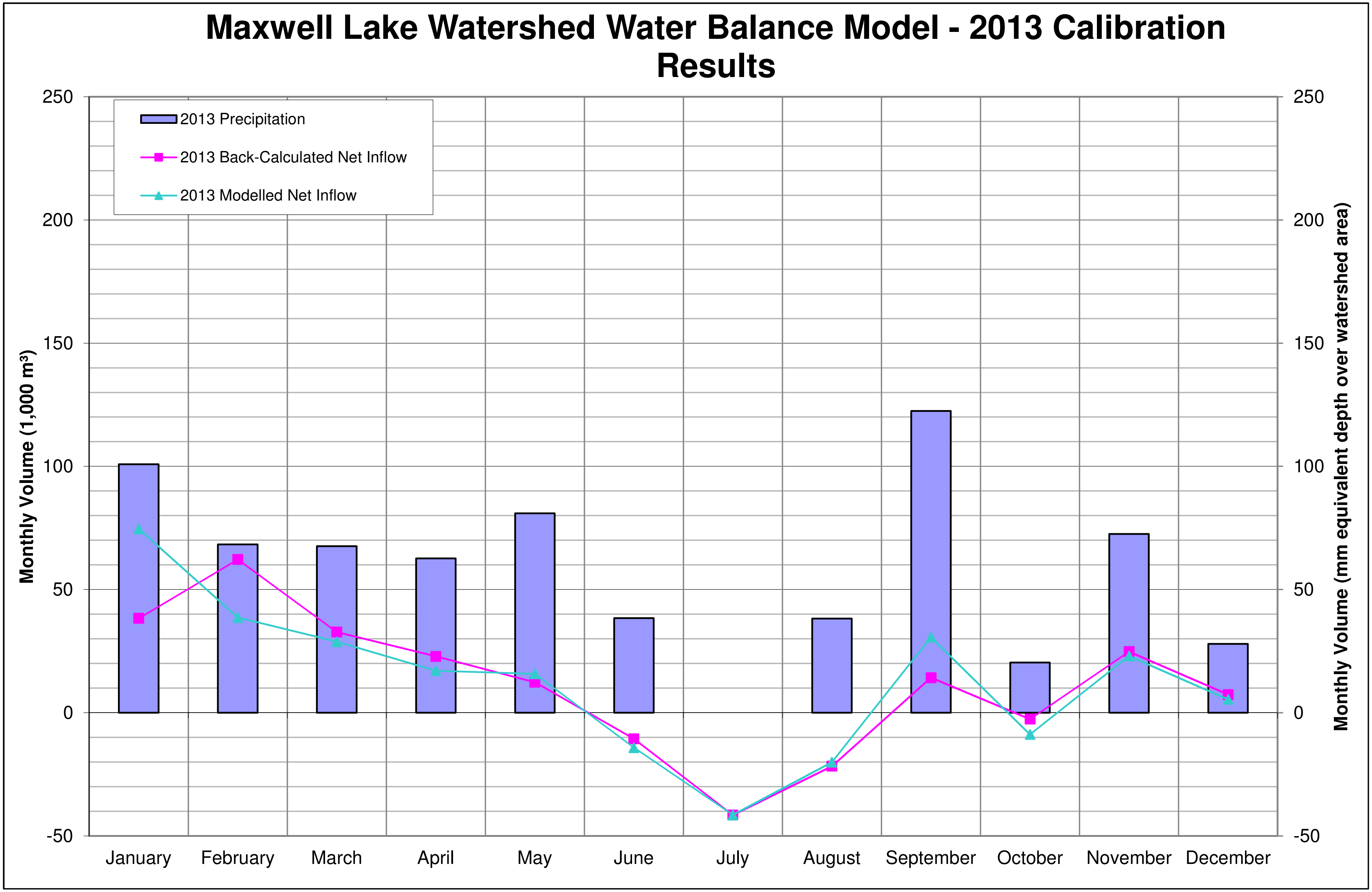
Maxwell Lake Watershed Water Availability and Demand - Climate Change Assessment
Water Balance Model Schematic
Figure 3-1



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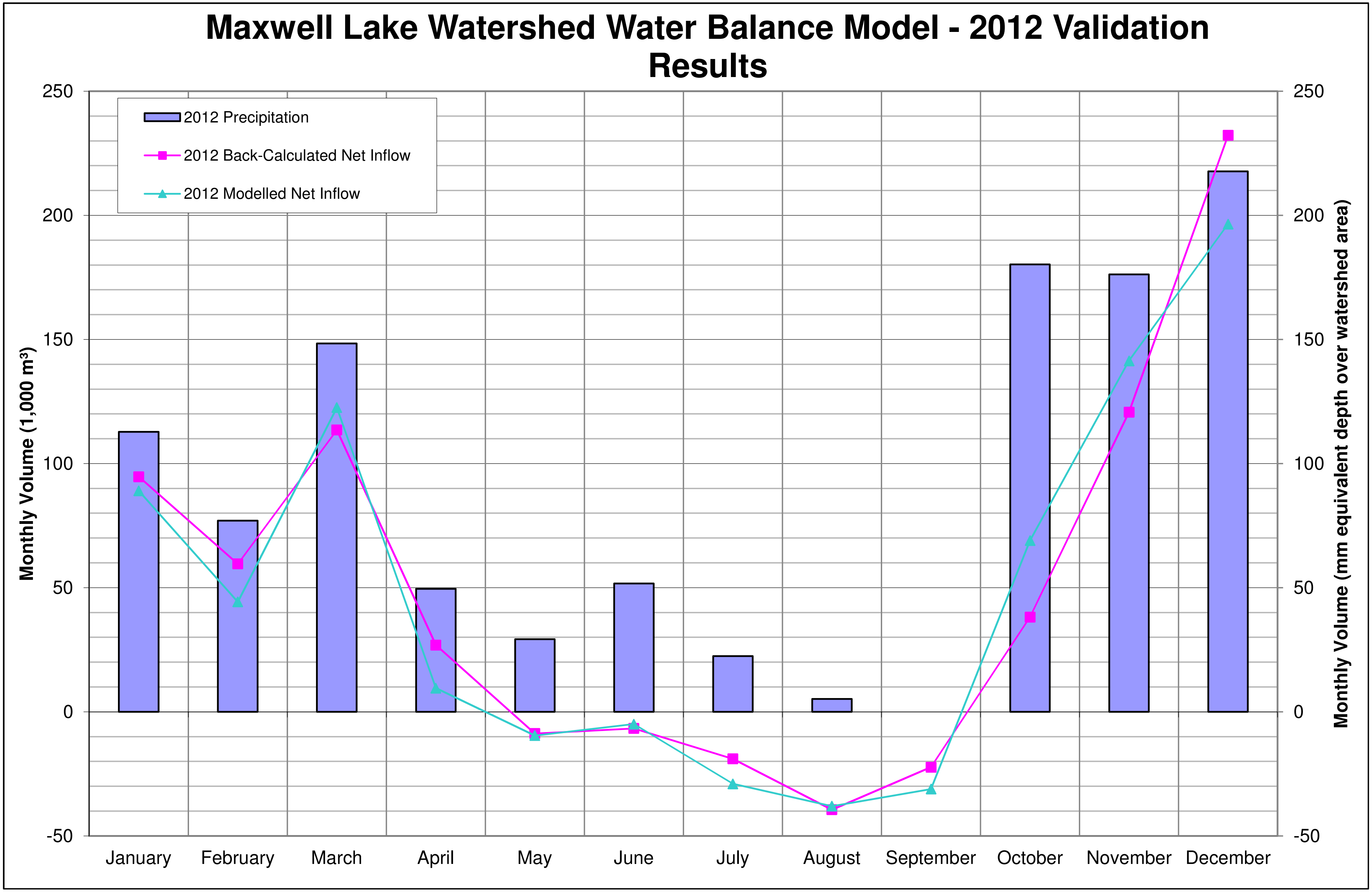
Maxwell Lake Watershed Water Availability and Water Demand - Climate Change Impact Assessment
Water Balance Model - 2013 Calibration Results
Figure 3-2



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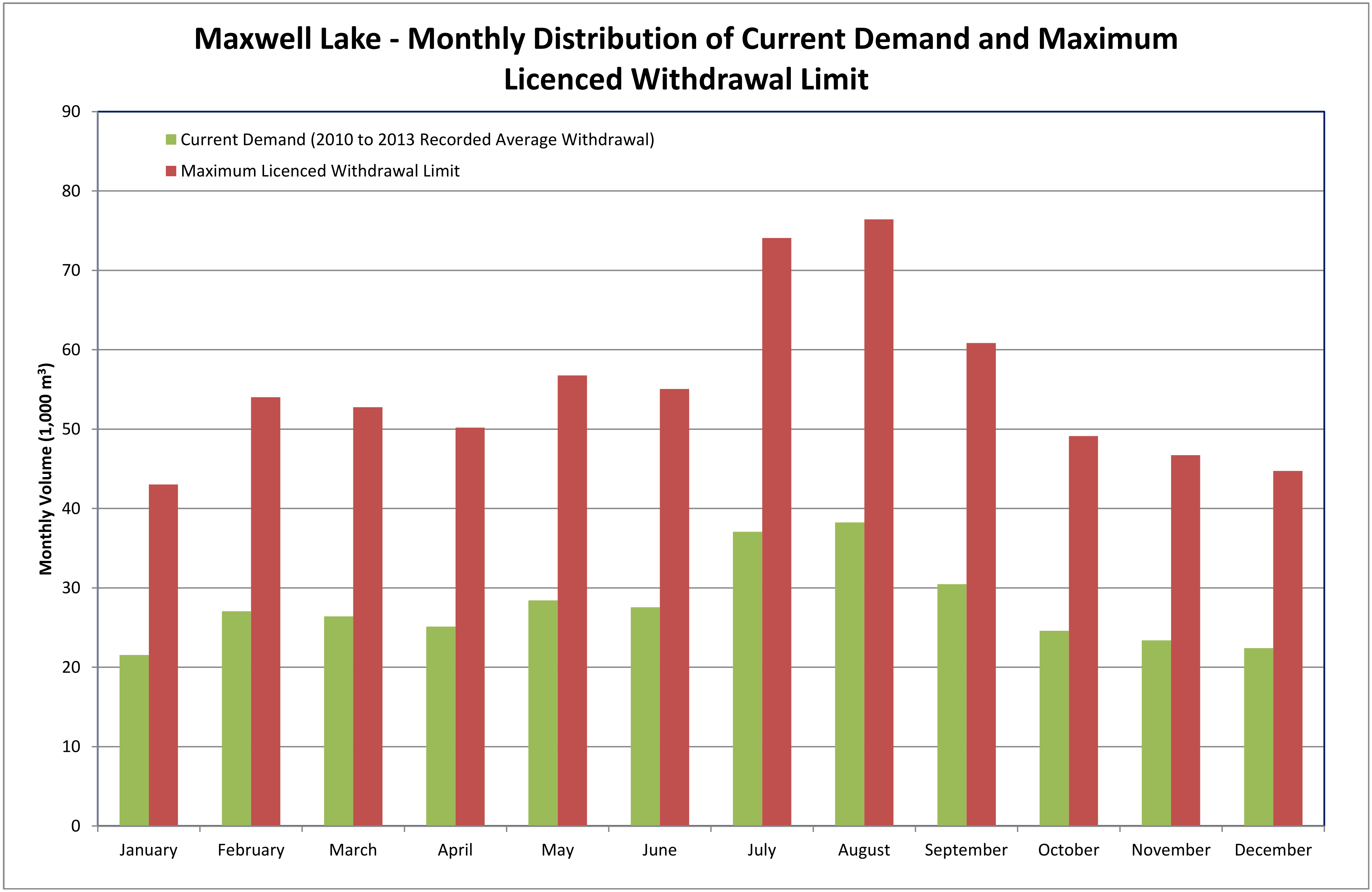
Maxwell Lake Watershed Water Availability and Water Demand - Climate Change Impact Assessment
Water Balance Model - 2012 Validation Results
Figure 3-3



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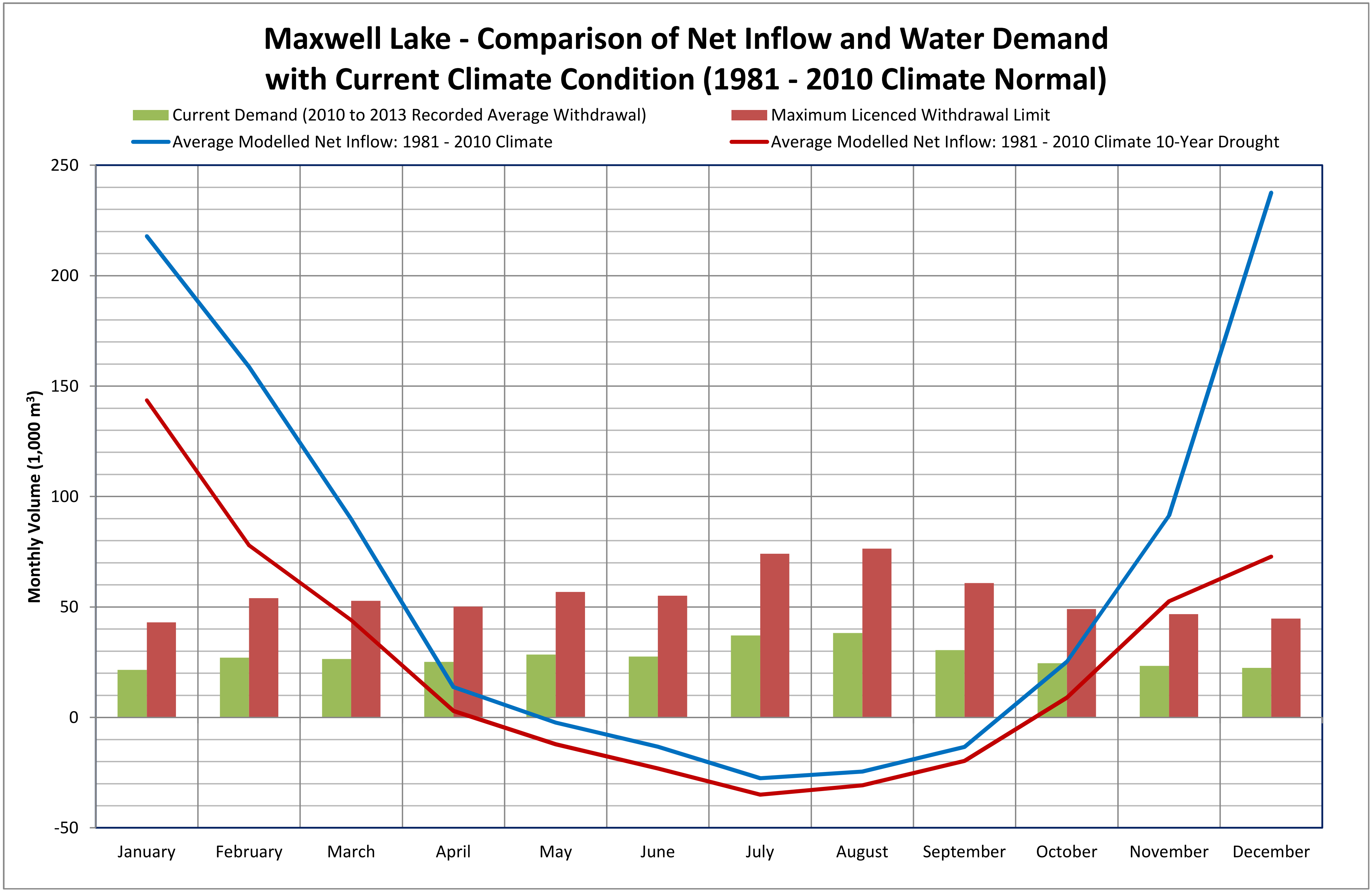
Maxwell Lake Watershed Water Availability and Demand - Climate Change Impact Assessment
Current Water Demand and Maximum Licenced Withdrawal Limit
Figure 3-4



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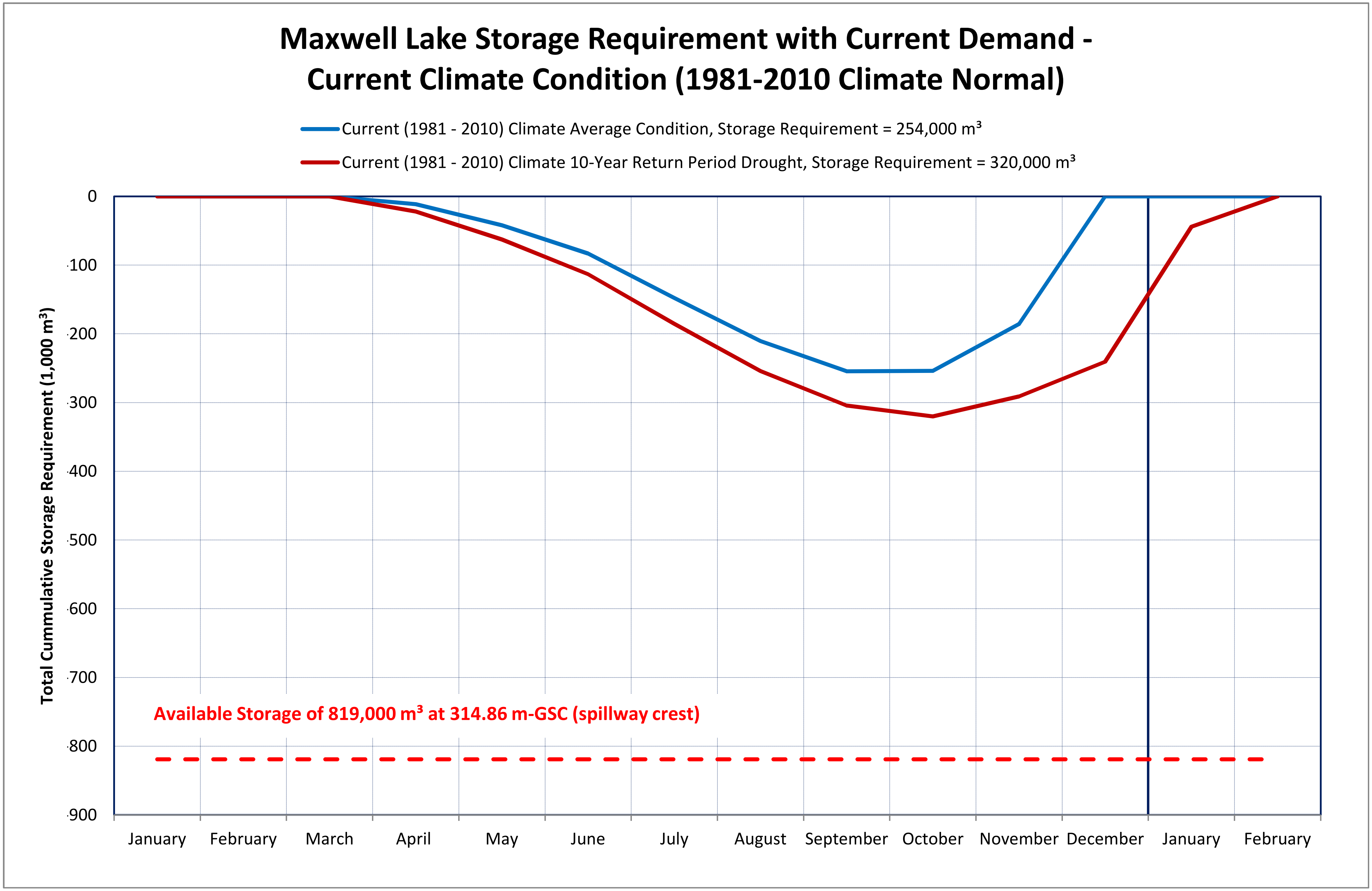
Maxwell Lake Watershed Water Availability and Water Demand - Climate Change Impact Assessment
Comparison of Net Inflow and Demand - Current Climate Normal Condition (1981-2010)
Figure 3-5



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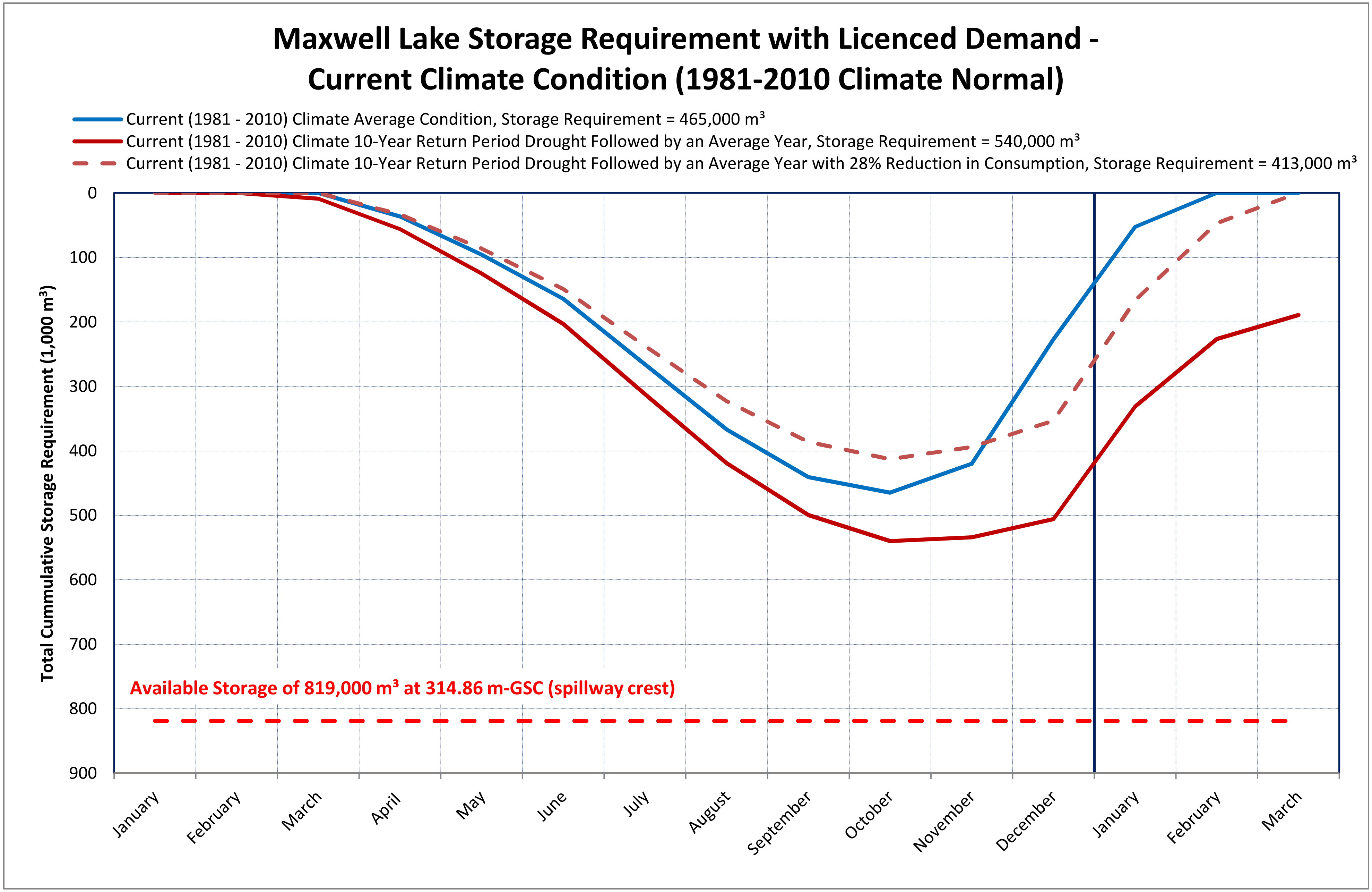
Maxwell Lake Watershed Water Availability and Demand - Climate Change Impact Assessment
Storage Requirements with Current Demand - Current Climate Normal Condition (1981 - 2010)
Figure 3-6



Maxwell Lake Storage Requirement with Licenced Demand -
Current Climate Condition (1981-2010 Climate Normal)
Current (1981 - 2010) Climate Average Condition, Storage Requirement = 465,000 m³
Current (1981 - 2010) Climate 10-Year Return Period Drought Followed by an Average Year, Storage Requirement = 540,000 m³
Current (1981 - 2010) Climate 10-Year Return Period Drought Followed by an Average Year with 28% Reduction in Consumption, Storage Requirement = 413,000 m³
Total Cummulative Storage Requirement (1,000 m³)
0
100
200
300
400
500
600
700
800
900
Available Storage of 819,000 m³ at 314.86 m-GSC (spillway crest)
January
February
March
April
May
June
July
August
September
October
November
December
January
February
March

Figure 3-7

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Section 4

Climate Change Impacts

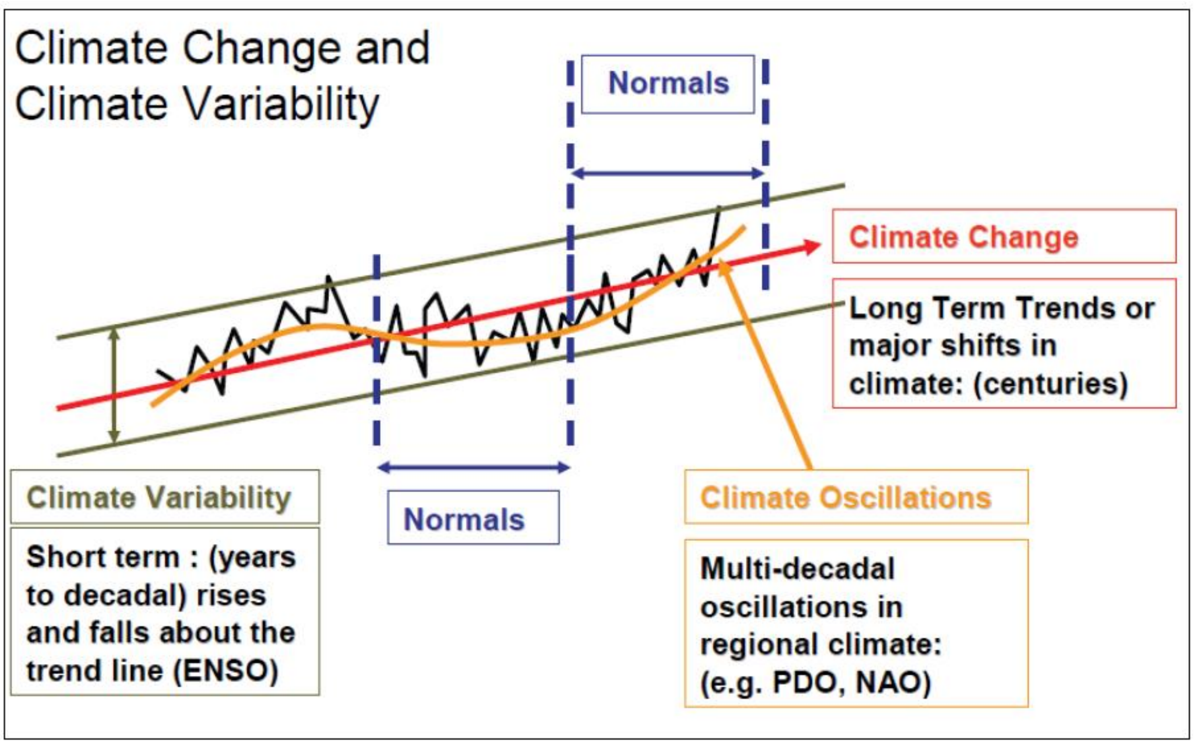
4. Climate Change Impacts

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 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.

Figure 4-1: Definition of Climate Variability and Climate Change.



4.2 Regional Climate Change Projections

Similar to other regions in South-Western British Columbia, the climate projections 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 Plan2 Adapt 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 projections 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.

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

Climate Variable	Season	Ensemble Median	Range (25^{th} to 75^{th} Percentile)
Mean Temperature (°C)	Annual	+1.6 °C	+1.0 °C to +2.3 °C
Precipitation (%)	Annual	+6%	-2% to +12%
	Summer	-18%	-28% to +1%
	Winter	+5%	-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.

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

4.3 Future Changes in Water Supply

Impacts on future water supply (lake net inflows) to Maxwell Lake were assessed using the calibrated monthly water balance models with monthly average temperature and precipitation projections for the 2050s as model inputs. The projected 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 projections, 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 projections in the Planner's Ensemble of GCM models developed by the Pacific Climate Impacts

Consortium (PCIC, 2013). The high bound estimate is based on GCM projections indicating larger increase in temperatures while the low bound estimate is based on GCM projections indicating smaller increase in temperatures. The projected 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 projections for future climate (2050s) condition are presented in Table 4-2.

The water balance model projections indicate decreased annual lake net inflow and less summer (May to September) lake net inflow under the high bound climate change condition, but increased annual and summer net inflows under the low bound climate change condition.

Table 4-2: Estimated Maxwell Lake Net Inflows – 2050s Climate High Bound Condition

Month	2050s Climate High Bound Condition				
	Precipitation (mm)	Temperature (°C)	Modelled Net Inflow (1,000 m³)		Net Inflow (1,000 m³)
			Lake	Diversion	
January	137	4.3	93	83	176
February	100	6.1	86	67	153
March	85	7.0	38	43	81
April	50	9.3	10	0	10
May	40	12.5	-4	0	-4
June	28	15.9	-19	0	-19
July	15	18.8	-34	0	-34
August	18	18.9	-31	0	-31
September	35	16.0	-14	0	-14
October	95	11.5	24	0	24
November	154	7.3	64	13	77
December	176	5.1	170	89	259
Total	**933**		**383**	**295**	**679**
May - Sep	**137**		**-102**	**0**	**-102**

Table 4-3: Estimated Maxwell Lake Net Inflows – 2050s Climate Low Bound Condition

Month	2050s Climate low bound Condition				
	Precipitation (mm)	Temperature (°C)	Modelled Net Inflow (1,000 m³)		Net Inflow (1,000 m³)
			Lake	Diversion	
January	154	3.3	108	90	198
February	112	4.7	105	84	190
March	99	6.0	48	57	106
April	55	8.5	16	0	16
May	48	11.6	1	0	1
June	36	15.0	-14	0	-14
July	22	17.8	-29	0	-29
August	25	18.2	-27	0	-27
September	47	14.8	-7	0	-7
October	107	10.5	31	0	31
November	190	6.4	90	23	114
December	191	4.0	192	141	333
Total	**1086**		**515**	**397**	**912**
May - Sep	**178**		**-76**	**0**	**-76**

4.4 Water Budget – Future Climate Conditions (2050s)

The future climate condition water supply was assessed by comparing the maximum licenced withdrawal limit with the projected 2050s high bound and low bound climate lake inflows. The results are shown in Figure 4-2. Required storage volumes under the future climate 2050s conditions are plotted in Figure 4.3. Table 4-4 summarized the future climate water balance assessment results.

The results indicate that the net inflows to the lake would support both the current and licenced withdrawal in the winter period (November to March), but not in the summer period (April to October) without using storage. The estimated lake inflow could support the current withdrawal on an annual basis with the lake storage can be fully refilled after each year, under both the 2050s climate high bound and low bound average lake net inflow conditions. The required storage volumes are estimated to be 278,000 and 246,000 m^3, respectively. These volumes are below both the licenced lake storage amount of 1,077,642 m^3 and the current available storage capacity of 819,000 m^3.

Both the estimated 2050s climate high bound and low bound lake average inflows could also support the licenced withdrawal on an annual basis with the lake storage can be refilled after each year. The required storage volumes are estimated to be 489,000 m^3 and 450,000 m^3, respectively. These volumes are below the licenced and available lake storage volumes.

Maxwell Lake currently has enough storage to support the 2050s climate conditions under the current and licenced withdrawals. However, under the high bound scenario the total licenced annual withdrawal is nearly 99% of the average annual net inflow to the lake. Therefore, it is unlikely that sufficient surplus water would be available to recover storage volume during lower than average years.

Due to the uncertainty in future climate modelling results, no drought analysis is carried out for the 2050s future climate conditions. However, it is anticipated to be more severe than the current climate (1981-2010 climate normal) which would apply a greater stress on the storage supply in Maxwell Lake.

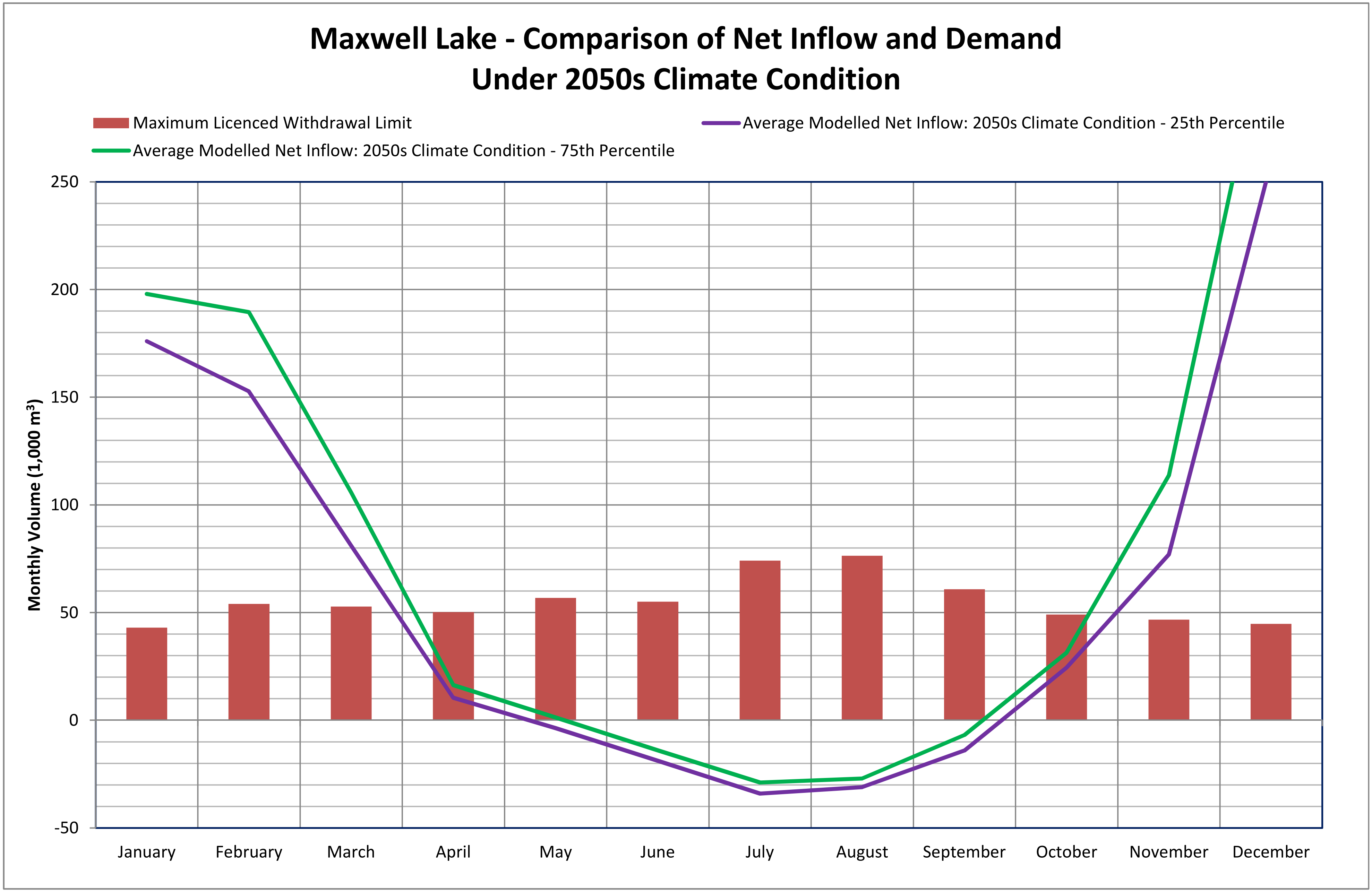
Table 4-4: Maxwell Lake Water Balance Results – 2050s Climate Condition

Parameter	2050s Climate Condition - High Bound	2050s Climate Condition - Low Bound
Annual Precipitation, mm	933	1,086
Annual Precipitation Volume Combined Watershed[1], 1,000 m^3	1,967	2,299
Annual Lake Direct Net-Inflow, 1000 m^3	383	515
Annual Rippon Creek and Larmour Creek Diversion Volume[2], 1,000 m^3	295	397
Total Annual Lake Net-Inflow, 1000 m^3	679	912
Licenced Annual Withdrawal Limit, 1,000 m^3	664	
Spring/Summer (May-Sept) Precipitation, mm	137	178
Spring/Summer (May-Sep) Lake Net-Inflow, 1,000 m^3	-102	-76
Licenced Summer Withdrawal Limit, 1,000 m^3	323	
Required Storage, 1,000 m^3	489	450
Available Physical Storage, 1,000 m^3	819	819

Note: Analysis indicates that for average year the required storage to support licenced withdrawal is less than available storage but it does not indicate conditions for lower than average years or drought conditions. Under the high bound scenario the total licenced annual withdrawal is nearly 99% of the average annual net inflow to the lake. Therefore, it is unlikely that sufficient surplus water would be available to recover storage volume on an annual basis.

1 - Annual volume of precipitation falling over combined watershed areas for Maxwell Lake, Rippon Creek and Larmour watersheds.

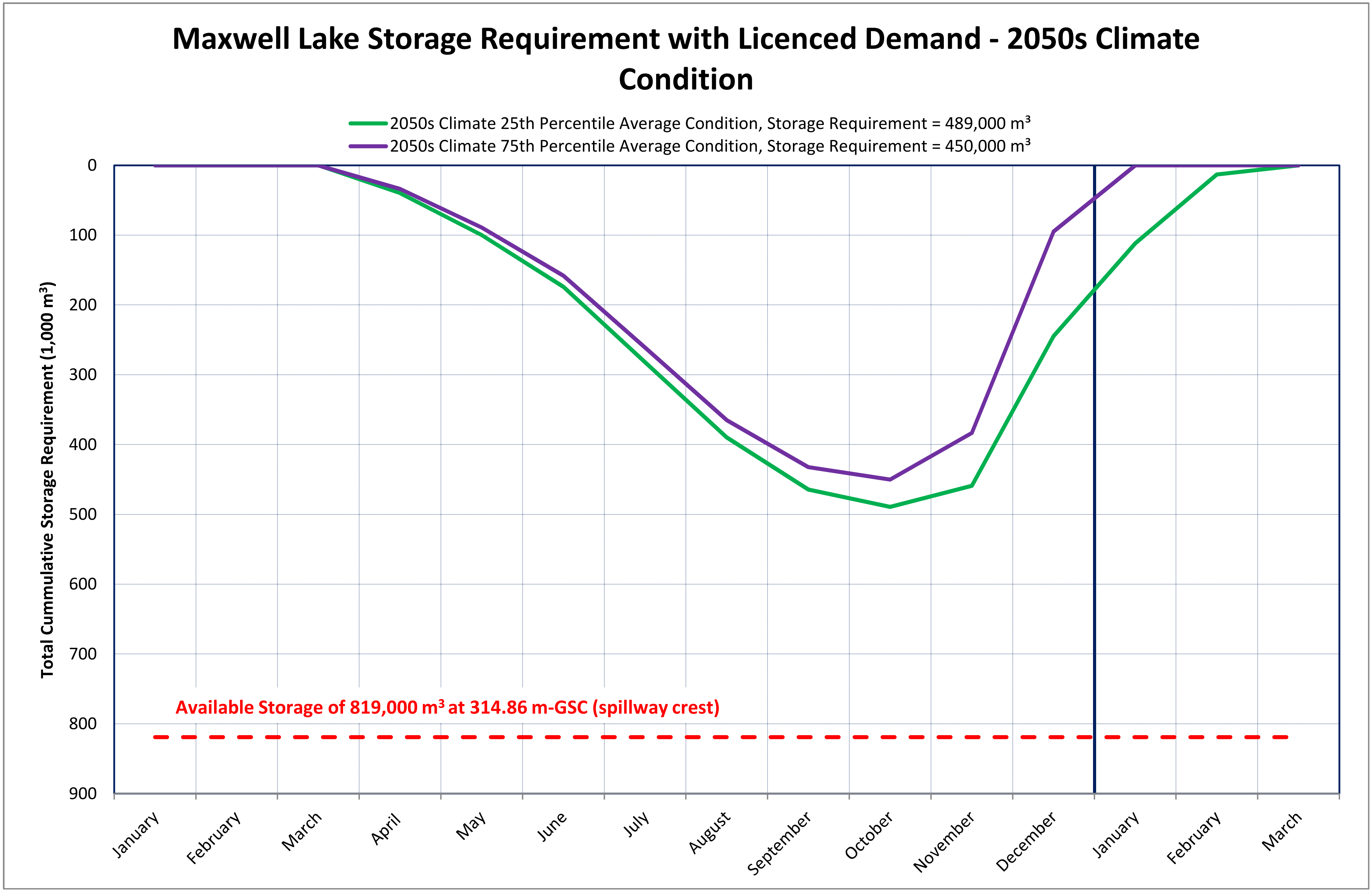
2 - Water licence permits diversion from Rippon Creek and Larmour Creek only from Nov 1st to Mar 31st.



Maxwell Lake Watershed Water Availability and Demand - Climate Change Impact Assessment

Comparison of Net Inflow and Demand - 2050s Climate Condition

Figure 4-2


Maxwell Lake Storage Requirement with Licenced Demand - 2050s Climate Condition
2050s Climate 25th Percentile Average Condition, Storage Requirement = 489,000 m³
2050s Climate 75th Percentile Average Condition, Storage Requirement = 450,000 m³
Total Cummulative Storage Requirement (1,000 m³)
0
100
200
300
400
500
600
700
800
900
Available Storage of 819,000 m³ at 314.86 m-GSC (spillway crest)
January
February
March
April
May
June
July
August
September
October
November
December
January
February
March

Section 5

Summary and Conclusions

5. Summary and Conclusions

5.1 Summary

Finding from the assessment of water availability and withdrawal within the Maxwell Lake watershed can be summarized as follows:

1. Maxwell Lake has a surface area of about 0.302 km^2 and lies within a 1.063 km^2 watershed.
2. Rippon Creek and Larmour Creek, which have a total combined watershed area of 1.054 km^2, can be diverted into Maxwell Lake during the period from November 1 to March 31.
3. 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 falling in the six-month period from October to March.
4. Maxwell Lake only supports waterworks withdrawals for NSSWD as there are no licenced requirements for minimum conservation flows downstream in Maxwell Creek.
5. A dam and spillway structure at the outlet of Maxwell Lake, which is owned and operated by NSWWD stores approximately 819,000 m^3 at the spillway crest elevation of 314.86 m above geodetic survey datum.
6. NSWWD currently withdraws about 332,245 m^3/year from Maxwell Lake on average.
7. Total annual licenced water withdrawal limit for Maxwell Lake is 663,729 m^3 (1,818 m^3/day average).
8. During the period from November to February, total lake inflow exceeds both the current withdrawals and the licenced withdrawal limit. However, during the dry spring and summer period from May to September water withdrawals exceed lake inflow.
9. Water balance modeling indicates that the average annual net inflow for the 1981 to 2010 climate normal period is about 753,000 m^3, with 434,000 m^3 from the Maxwell Lake watershed and 319,000 m^3 diverted from Rippon Creek and Larmour Creeks. The average summer (May to September) net inflow is about -81,000 m^3 (negative net inflow indicates evaporation higher than inflow to the lake). Under a 10-year return period drought year, the annual net inflow is reduced to about 282,000 m^3, 152,000 m^3 from the Maxwell Lake watershed and 131,000 m^3 diverted from Rippon Creek and Larmour Creeks. The summer (May to September) net inflow decreases to -121,000 m^3.
10. A comparison of current water withdrawals with net inflows to the lake indicates that the total lake inflow would refill the lake on an annual basis with total cumulative storage requirement of 254,000 m^3 and 320,000 m^3 for the average year and 10-year drought conditions respectively.
11. With water withdrawals increased to the licenced withdrawal limit, the model indicates that Maxwell Lake could support withdrawals and be refilled with average year inflow with total cumulative storage requirement of 465,000 m^3. Under 10-year drought conditions Maxwell Lake would have sufficient storage to support the licenced withdrawal limit with a total cumulative storage requirement of 540,000 m^3. However, the model indicates that there would not be sufficient inflow to refill the lake by the following spring. Withdrawal from the lake would have to be limited to 72% of the licenced withdrawal limit such that the lake could refill the year following the 10-year return period drought.

12. Regional climate change projections indicate that average temperatures are likely to continue to increase by between +1.0 °C to +2.3 °C with increase in winter precipitation (-4% to +15%) and decrease in summer precipitation (-28% to +1%) by the 2050s.
13. Using the monthly water balance model calibrated to current climate and hydrological conditions in the watershed, the average summer (June to August) net inflows to the lake are projected to decrease by between 9% and 16% by 2050s. The decrease is mostly as a result of increased temperatures and lake evaporation. However, the total annual inflows to the lake are projected to increase by between 10% and 13%, which would allow the lake to be refilled more readily during the winter period.
14. The water budget analysis showed total cumulative storage requirements of between 450,000 m^3 to 489,000 m^3 to support water withdrawal at the licenced withdrawal limit under projected 2050s average climate conditions.
15. Due to limitations of climate modelling in representing extreme conditions, it is difficult to quantify impacts on drought and available water supply at Maxwell 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 could result in increased pressure on water availability from Maxwell Lake into the future.

5.2 Conclusions

The outcome of the analysis indicates that Maxwell Lake with the weir crest at El. 314.86 m-GSC:

1. Under average inflow and 10-year return period drought conditions there is sufficient storage volume to support current (2014) withdrawals to the NSSWD water system such that the lake can be refilled prior to the following summer draw down period;
2. Under average inflow there is sufficient storage volume to support withdrawal to NSWWD water system up to the licenced withdrawal limit such that the lake can be refilled prior to following summer draw down period; and
3. Although there is sufficient storage to support withdrawal to NSWWD water system up to the licenced withdrawal limit there would not be sufficient inflow under 10-year drought conditions to refill Maxwell Lake prior to following summer draw down period.

In order to allow the lake to refill prior to the following summer draw down period given withdrawals at the licenced withdrawal limit, the model indicates that withdrawal from Maxwell Lake would have to be limited to 72% of the licenced withdrawal limit.

Although it may be possible that the lake has sufficient storage to support demand over multiple years without refilling of Maxwell Lake, this type of analysis is beyond the scope of this study. In addition, there is not sufficient continuous water level data, and flow data for the Rippon and Larmour Creek diversion to adequately conduct a multi-year drought assessment.

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Section 6

Recommendations and Closing

6. Recommendations and Submission

6.1 Recommendations

Based on the outcome of the hydrological and water balance analysis carried out for Maxwell Lake, we recommend that:

1. Withdrawals from Maxwell Lake be capped at 72% of the licenced withdrawal limit (477,900 m^3) such that inflow from Larmour Creek, Rippon Creek and Maxwell Lake watersheds can refill Maxwell Lake after 10-year drought conditions;
2. The cap should remain in-place until such time that sufficient data is collected at Maxwell Lake to complete a multi-year drought analysis;
3. NSWWD consider installing water level sensors to record lake level, spillway outflow level and Rippon Creek Parshall flume level to provide continuous hydrometric records at the lake for operations purposes as well as to provide average daily record which can be used for future multi-year water balance assessment;
4. Once sufficient data has been collected at Maxwell Lake, carry out a multi-year drought analysis to assess if multiple years of Larmour Creek, Rippon Creek and Maxwell Lake watershed inflow could refill Maxwell Lake after 10-year return period drought conditions; and
5. Using hydrometric data collected; conduct a review of Maxwell Lake water balance at regular intervals (approximately every 10 years) to assess potential future impacts to water availability as a result of changing climate and changes in water withdrawal.

6.2 Report Submission

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

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

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Section 7

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Statement of Limitations

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Revision History

Revision #	Date	Status	Revision	Author
0	April 28, 2015	FINAL	Issued as Final	CS/WY
C	March 30, 2015	DRAFT	Issued for Review	CS/WY
B	November 17, 2014	DRAFT	Issued for Review	CS/WY
A	August 26, 2014	DRAFT	Issued for Review	CS/WY

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Appendix A

Glossary

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 depleted by groundwater seepage to surface water, estimated

Term	Definition
	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 calculations to assess available storage.
Precipitation	The total volume of rainfall and snowfall over a given period.

Term	Definition
	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 outflow, 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 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

Term	Definition
	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.

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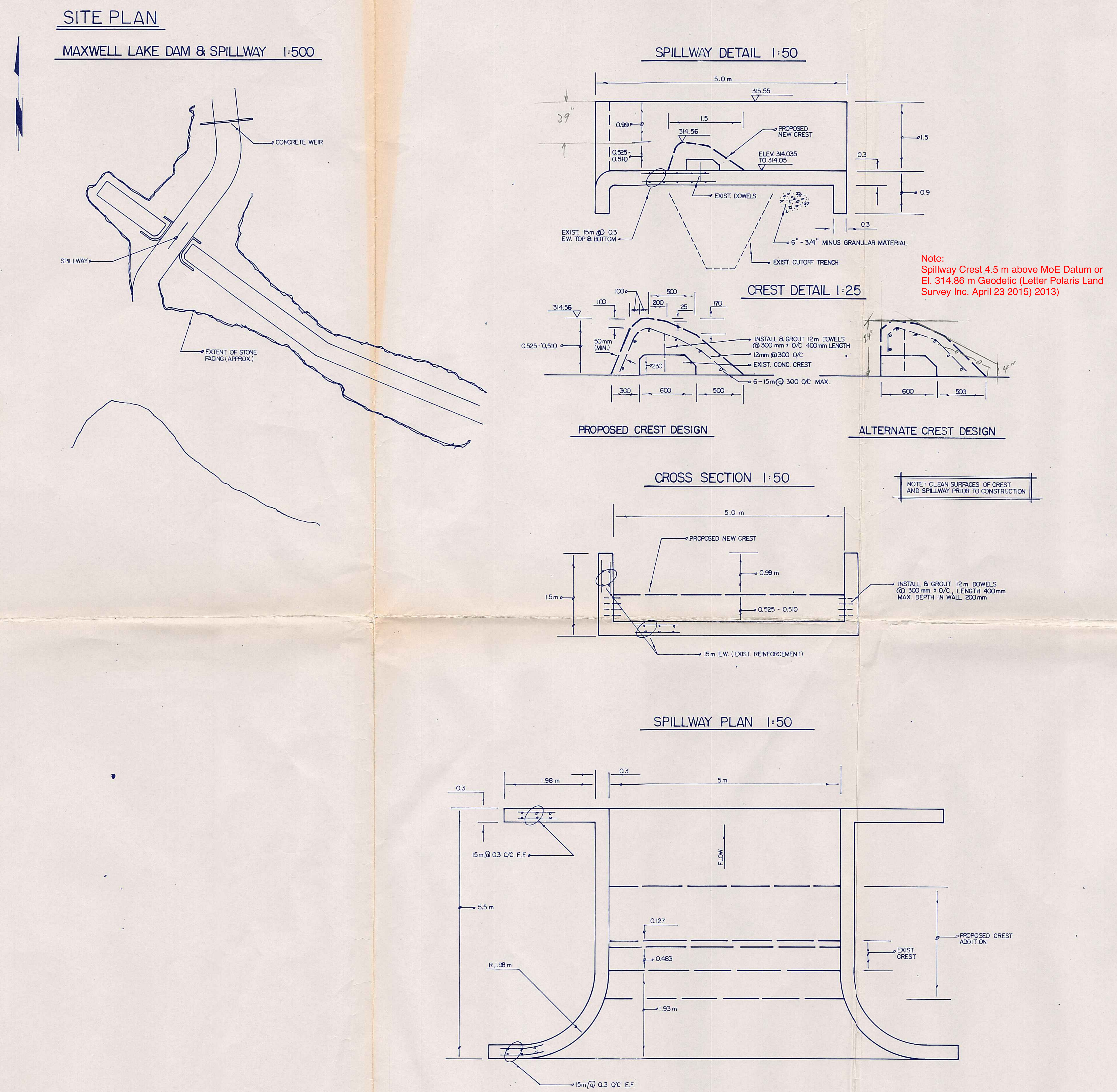
Appendix B

Constructions Drawings of Maxwell Lake Dam



NOTES

1. ALL CONSTRUCTION AND MATERIALS TO BE IN ACCORDANCE WITH NORTH SALT SPRING WATERWORKS DISTRICT STANDARDS AND SPECIFICATIONS.
2. MINISTRY OF ENVIRONMENT PERMIT TO BE OBTAINED BEFORE STRUCTURE WORKS COMMENCE; COMPLY WITH PROVISIONS THERETO.
3. STRUCTURE AS-BUILT INFORMATION FROM THURBER, DELCAN CORPORATION AND NORTH SALT SPRING WATERWORKS DISTRICT RECORDS.
4. CONCRETE IN ACCORDANCE WITH CSA A23.1 AND A23.2.
5. MINIMUM COMPRESSIVE STRENGTH OF CONCRETE 30 Mpa AT 28 DAYS.NON-REACTIVE UNDER ALKALINE CONDITIONS, AIR ENTRAINMENT 6% ± 1%.
6. ALL REINFORCING SHALL BE DEFORMED BARS TO CSA G30.16, GRADE 400, ASTM A184 AND A304.
7. 50mm MINIMUM CLEAR COVER TO REINFORCING.
8. PLACE VERTICAL STEEL INSIDE HORIZONTAL STEEL.
9. CLEAN-UP AND REINSTATE AREA AFTER CONSTRUCTION OF WORKS.

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA M. SISKA

MIKE SISKA P. Eng.
Consulting Engineering and Project Management
1076 Davie Street
Victoria, B.C.
V8S 4E3
Tel/Fax (250) 598-1224

NORTH SALT SPRING WATERWORKS DISTRICT

MAXWELL LAKE - SPILLWAY CREST

PLAN, SECTIONS AND DETAILS

B.M. 88HAW032 GEODETIC	ELEV. 315.14 m
DESIGN M.S. / DRAWN JJS	CHECKED
SCALES AS SHOWN	DATE MAY 03

GENERAL NOTES:

1. ELEVATION DATUM IS GEODETIC, (Based on British Columbia Control Survey 88HAW 032).
2. BASE DRAWING FROM SURVEY PROVIDED ON DISK BY WOLFE-MILNER & ASSOCIATES, B.C.L.S., SURVEYED FEBRUARY 18, 1993.
3. CONTOURS AND GROUND LINES GENERATED BASED ON SURVEY PROVIDED NOTE 2.
4. COORDINATES SHOWN ARE ARBITRARY; BASED ON ORIGINAL SURVEY.
5. NORTH DIRECTION DERIVED FROM COMPASS OBSERVATION.
6. BORROW AREAS A & B GRADED TO SMOOTH SURFACE; FINAL CONTOURS NOT SURVEYED. ORIGINAL GROUND CONTOURS SHOWN BY DOTTED LINE; PRESENT GROUND SURFACE WILL BE LOWER.

Note Elevations on this drawing are incorrect and should be adjusted by +0.72' (+0.22 m).

Control Monument 88HAW031 El. - 315.36 m
(based on survey completed by Polaris Land Survey

REV.	DESCRIPTION	DATE	BY
C	AS-BUILT	FEB. '95	JCS
B	OUTFLOW CHANNEL, REISSUED FOR TENDER	JUNE 06/94	JCS
A	ISSUED FOR TENDER	AUG. 10/93	JCS

REVISION

DESIGNED JCS
DRAWN DRB
DATE AUGUST 10/93
APPROVED John Sobkowicz
SCALE 1" = 20'

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA J. C. SOBKOWICZ
Mar. 2 95

NORTH SALT SPRING WATERWORKS DISTRICT

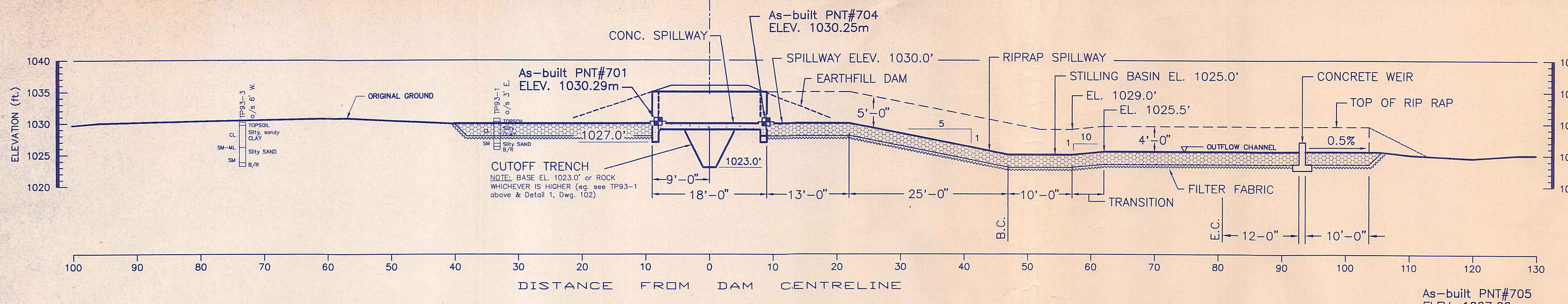
GENERAL ARRANGEMENT

MAXWELL LAKE PROPOSED DAM SALT SPRING ISLAND, B.C.

THURBER

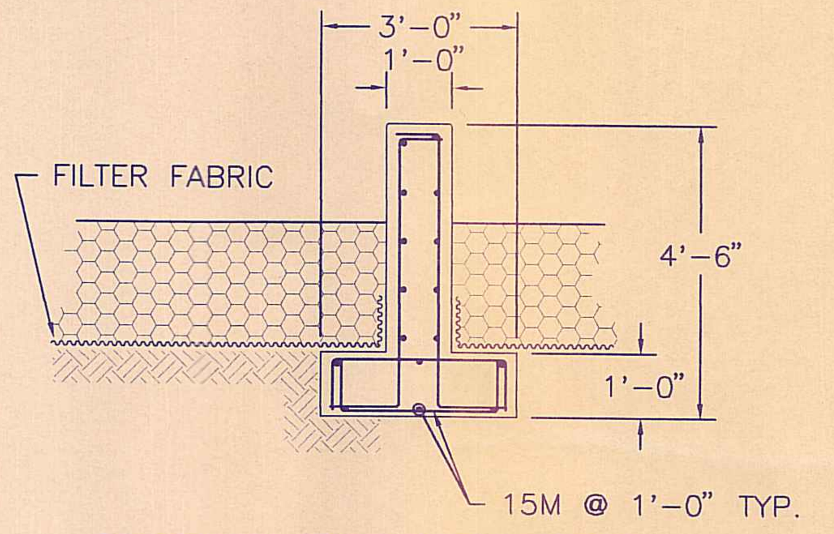
DWG. NO. 14-11-1-101 C

CANCEL PRINTS BEARING EARLIER LETTER

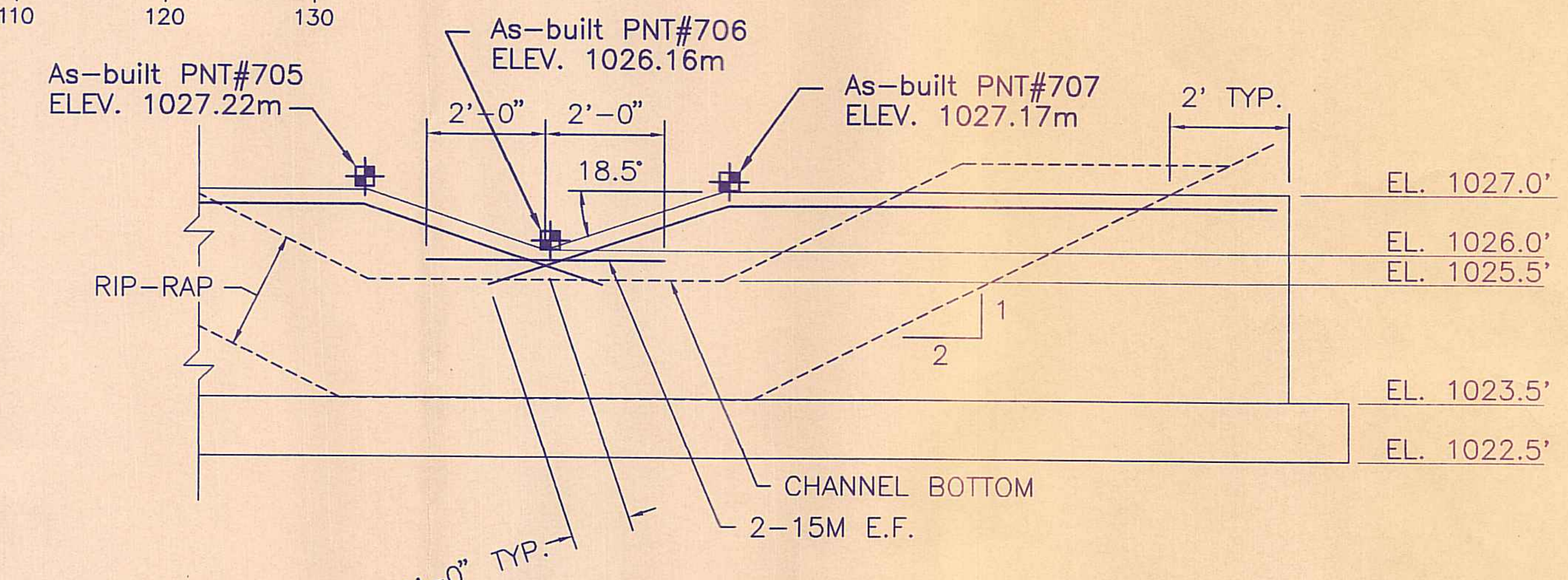


TYPICAL SECTION F/101 THROUGH CENTRELINE OF SPILLWAY & OUTFLOW CHANNEL

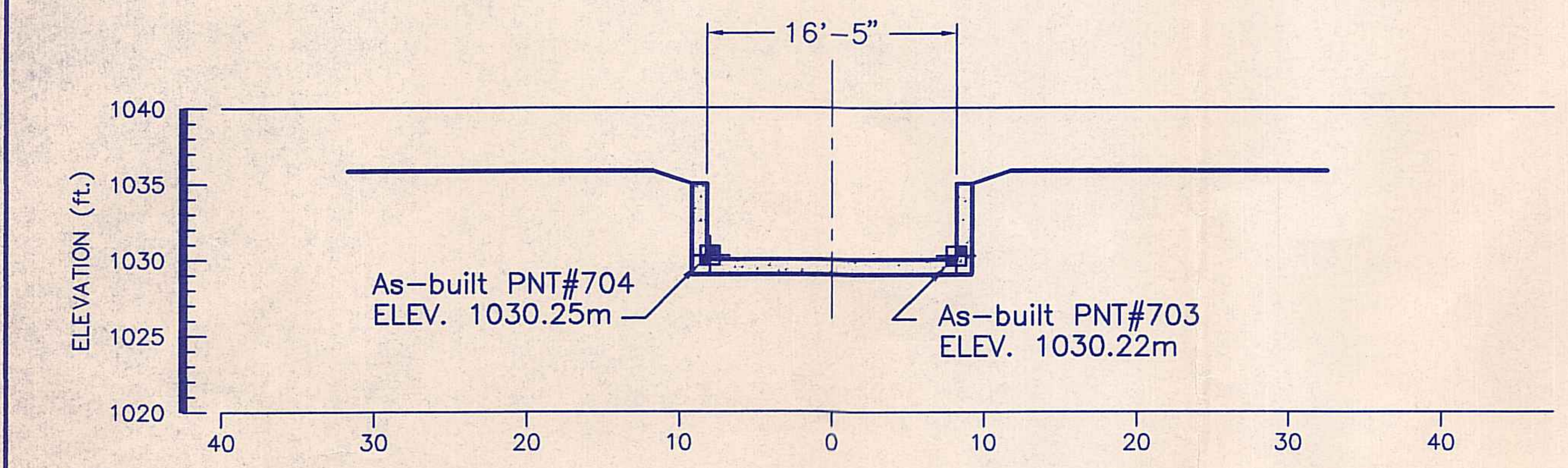
SCALE: 1"=10'



SECTION THROUGH WEIR

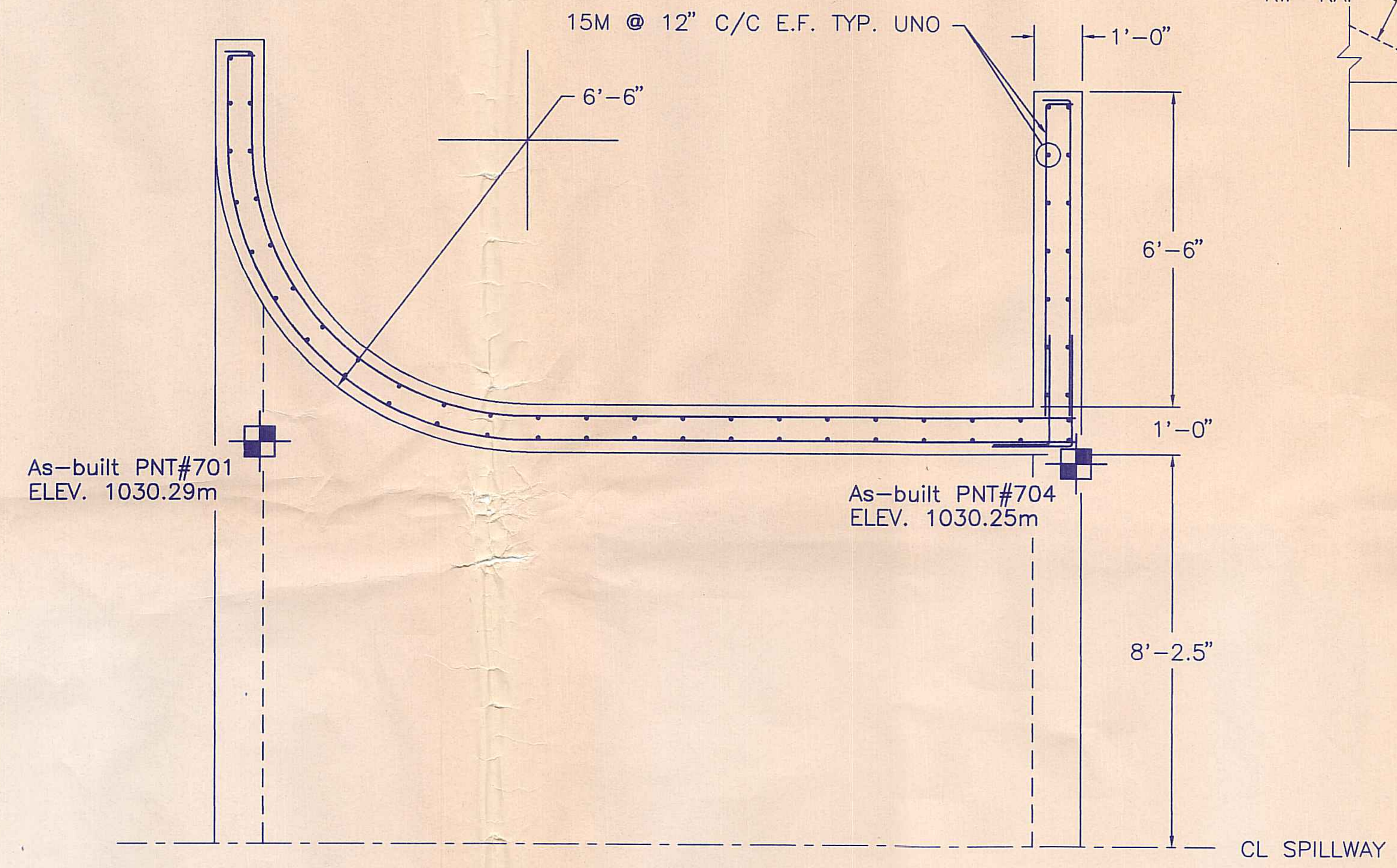


CONCRETE WEIR

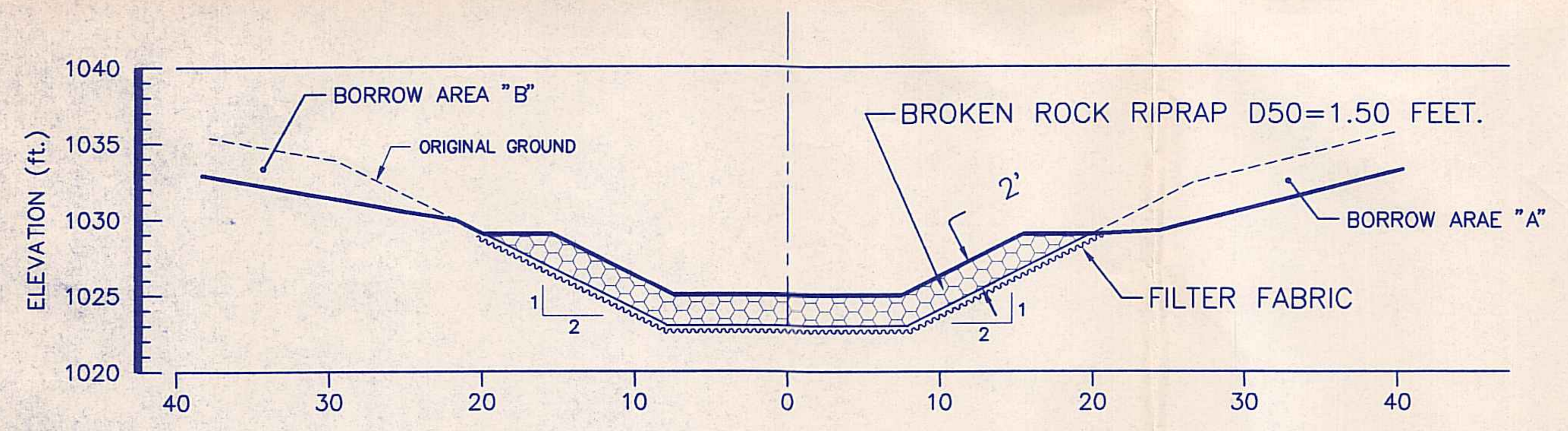


TYPICAL SECTION G/101 THROUGH CENTRELINE OF MAIN DAM AND CONCRETE PORTION OF SPILLWAY

SCALE: 1"=10'

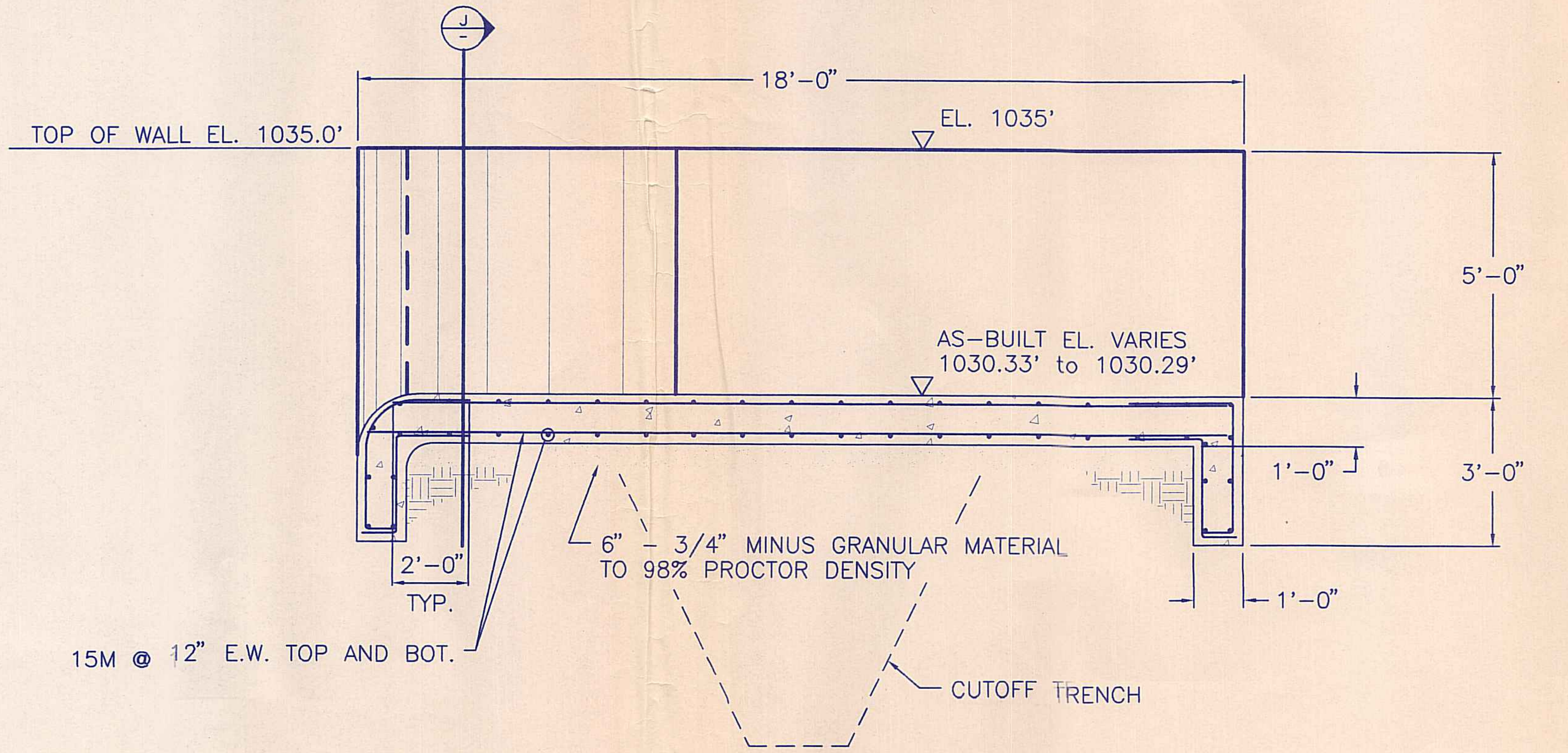


CONCRETE SPILLWAY – HALF PLAN

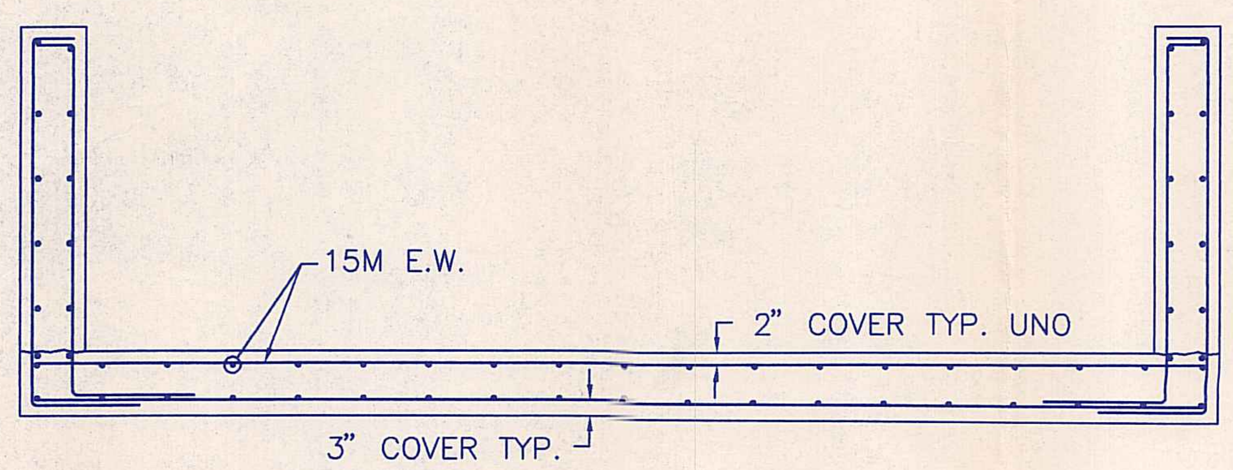


TYPICAL SECTION H/101 THROUGH RIPRAP PORTION OF SPILLWAY & OUTFLOW CHANNEL

SCALE: 1"=10'



CONCRETE SPILLWAY – ELEVATION



TYPICAL SECTION J/101 THROUGH SPILLWAY

Note Elevations on this drawing are incorrect and should be adjusted by +0.72' (+0.22 m).

Control Monument 88HAW031 El. - 315.36 m
(based on survey completed by Polaris Land Survey

NOTES:

CONCRETE

1.1 ALL CONCRETE TO BE MIXED, PLACED AND CURED IN ACCORDANCE WITH CSA CAN3 A23.1 AND A23.2.
1.2 MINIMUM COMPRESSIVE STRENGTH OF CONCRETE 30 MPa AT 28 DAYS. W/C RATIO MAX. 0.35. AGGREGATE TO BE NON-REACTIVE UNDER ALKALINE CONDITIONS.
1.3 CHAMFER ALL CORNERS 3/4".

2. REINFORCING STEEL

2.1 ALL REINFORCING SHALL BE DEFORMED BARS TO CSA G30.16, GRADE 400.
2.2 MINIMUM CLEAR COVER TO REINFORCING
- CAST AGAINST EARTH 3"
- ALL OTHER 2"
2.3 PLACE VERTICAL STEEL OUTSIDE HORIZONTAL STEEL IN WALLS.

3. GENERAL ITEMS

3.1 ALL MISCELLANEOUS STEEL TO CONFORM TO CSA G40.21 - 300W.
3.2 GALVANIZE ALL MISCELLANEOUS STEEL WITH ZINC COATING 600 g/m TO CSA G164-M1981.

REFER TO GENERAL NOTES ON DWG. 101

REV.	DESCRIPTION	DATE	BY
C	AS-BUILT	FEB. '95	JCS
B	OUTFLOW CHANNEL, REISSUED FOR TENDER	JUNE 06/94	JCS
A	ISSUED FOR TENDER	AUG. 10/93	JCS

REVISION

PROFESSIONAL ENGINEER – PROVINCE OF BRITISH COLUMBIA – J. C. SOBKOWICZ
Mar 2 / 95

DESIGNED DELCAN	NORTH SALT SPRING WATERWORKS DISTRICT	THURBER
DRAWN DELCAN	SPILLWAY PLAN, SECTIONS & DETAILS	
DATE AUGUST 10/93		
APPROVED John Sobkowicz		
SCALE AS SHOWN	MAXWELL LAKE PROPOSED DAM — SALT SPRING ISLAND, B.C.	DWG. NO. 14-11-1-103 C

CANCEL PRINTS BEARING EARLIER LETTER

MARCH 01, 1995

TED00831.DWG

Polaris Land Surveying Inc.
241 Fulford-Ganges Road
Salt Spring Island, BC, V8K 2K7
Salt Spring: 250-537-5502
Toll free: 877-603-7398
Duncan: 250-746-0775
ssi@plsi.ca

Polaris Reference: 0430-003

April 23rd, 2015

North Salt Spring Waterworks District
761 Upper Ganges Rd,
Salt Spring Island, BC V8K 1S1

Attention: Meghan McKee, Water Quality Specialist

Re: Elevations of water gauges and weirs at St. Mary Lake and Maxwell Lake

At the request of the District, we have undertaken a control survey at St. Mary Lake and Maxwell Lake in order to confirm the elevations of the weirs and water gauges. As such, we established control points at the Tripp Road pumphouse, at the Duck Creek weir and at the Maxwell Lake weir.

These control points were established through GPS measurements to British Columbia Active Control Point 'BCNS' and Geodetic Control Monument '99H2256'. The measurements were put through a network adjustment and were also checked using Natural Resource Canada's Precise Point Positioning software.

Once the GPS control points were established, level loops were ran from the control points to the weirs and water gauges. These loops were ran twice to confirm the measurements.

The results of our measurements, taken on April 7th, is as follows:

Duck Creek	*True Elevation*
Top of Weir:	40.71 metres
Water level:	40.81 metres
Water Gauge @ 0.80:	40.81 metres
Bolt on railing:	41.53 metres (local benchmark)

Tripp Road	
Water level:	40.81 metres
Water Gauge @ 0.80:	40.88 metres
North rim oil separator manhole:	42.71 metres (local benchmark)

The result of these measurements is that in order to obtain true elevations, a correction of 0.01 metres needs to be added to gauge readings at Duck Creek and a correction of 0.08 metres needs to be added to gauge readings at Tripp Road.

Alternatively, a correction of **0.07 metres can be added at Tripp Road** to bring both gauges on to the same system.

Maxwell Lake

Top of Weir:	314.86 metres
Water level:	314.86 metres
Water Gauge @ 0.50:	314.86 metres
Control Monument 88HAW031:	315.36 metres (local benchmark)

In addition to taking measurements to the water gauges and weirs, while on site we also determined the elevation of features such as manhole rims and protruding bolts that can be used as benchmarks should any future elevations need to be calculated.

All of the elevations expressed in this report are referred to the *Canadian Vertical Geodetic Datum of 1928 (CGVD28)*. CGVD28 is a vertical datum that was designed to approximate mean sea level, based on tide gauge readings. This datum is maintained by the Canadian Geodetic Survey branch of Natural Resources Canada.

The St. Mary Lake water license refers to elevations based on 'G.S.C. datum'. We assume that G.S.C. means Geodetic Survey of Canada. It is critical that any elevation determinations are related to the appropriate datum and while technically there isn't a 'G.S.C. datum', we can assume that what the licence meant is a datum provided by the Geodetic Survey of Canada branch. And the only datum GSC provided in 2001 was CGVD28. Therefore all of our elevations are referred to the CGVD28 datum.

The concept of datums can be tough to grasp, but it is an important concept. Last year the GSC branch released a new and more accurate vertical datum (CGVD2013) which is to replace CGVD28. Provincially we have yet to adopt this new datum but it is something to pay attention to going forward as locally there is a difference of about 0.15 metres between the two datums. As governments begin to adopt this new datum, understanding and applying this difference will be essential in order to avoid potential errors.

Finally, a note on the accuracy of our elevations. We believe that we have established these elevations to an accuracy of 0.01 – 0.02 metres.

Sincerely,
Polaris Land Surveying Inc.

Jordan Litke, BCLS

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consulting engineers

Appendix C

Photos

Appendix C - Photographs

Photo C-1: Maxwell Lake looking south from the dam crest. Water level at approximately 4.5 m above MoE Datum (314.9 m-GSC) or at Full Supply Level. May 2014.

Photo C-2: Maxwell Lake Dam Spillway. Looking from dam to left abutment. Note staff gauge immediately upstream of weir used to measure high lake levels above 3.0 m above MoE Datum (). May 2013.

Appendix C - Photographs

Photo C.3: Maxwell Lake Outlet Channel looking downstream towards Maxwell Creek.

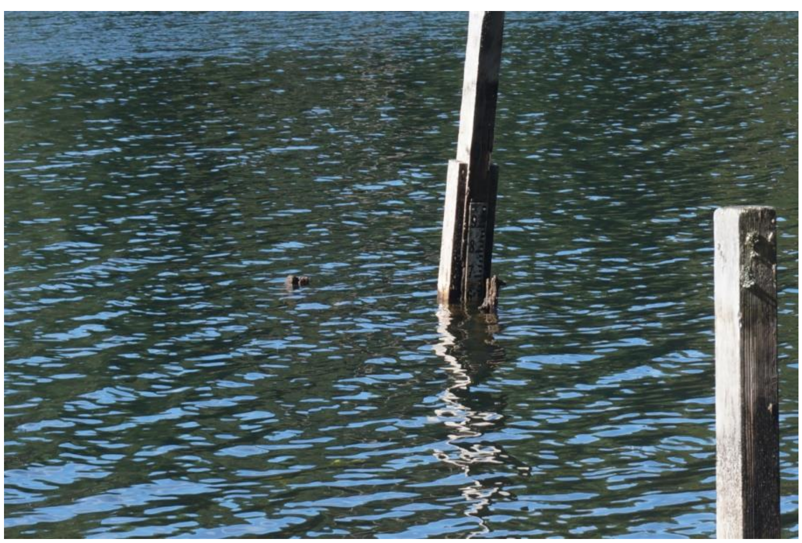

Photo C-4: Maxwell Lake Lower Staff Gauge. Located on pile near the eastern shore of the lake adjacent to small warf.

Appendix C - Photographs

Photo C-5: V-notch weir downstream of Maxwell Lake spillway used by NSSWD staff to estimate spillway discharge. Data has not been used in this study due to potential error in data as a result of debris accumulation.

Photo C-6: Rippon Creek diversion structure. Stop-logs are installed between concrete headwalls during the diversion period (November 1 to March 31) to direct flow into diversion pipe located behind the trash rock.

Appendix C - Photographs

Photo C-7: Rippon Creek diversion pipe. Manhole is located at the connection between concrete culvert and steel pipe. Photo shows Maxwell Lake in the back ground. Total length of diversion is approx..

Photo C-8: Rippon Creek Flow Measurement Weir (Parshall Flume). Looking Downstream. Weir is located upstream of the diversion structure.

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Appendix D

Climate Data

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