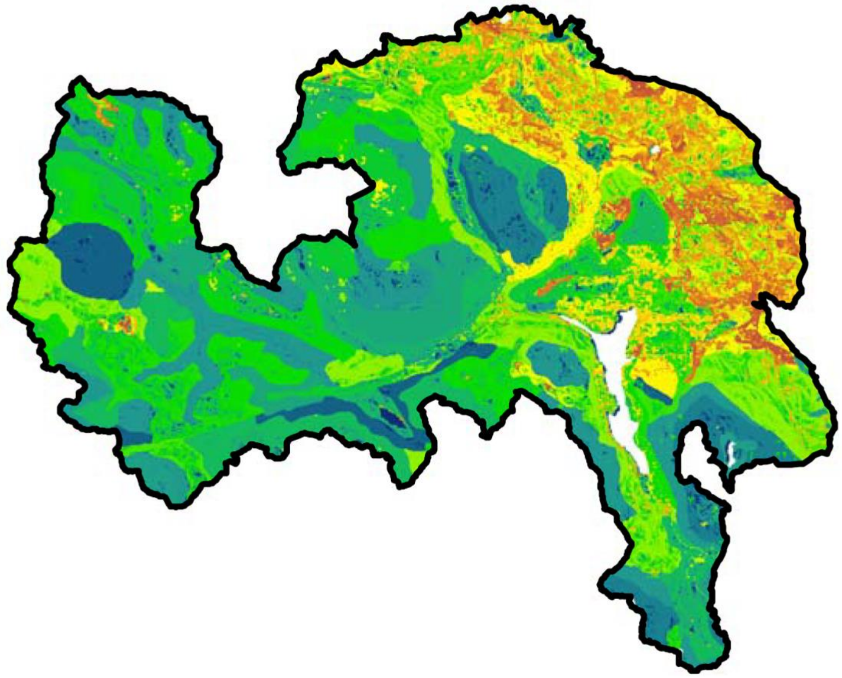
WATER SCIENCE SERIES

Preliminary Groundwater Budgets, Cobble Hill / Mill Bay Area, Vancouver Island, B.C.

Mike Harris and Steven Usher



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EXECUTIVE SUMMARY

With the advent of the *Water Sustainability Act*, British Columbia now requires the authorization of groundwater use. As part of the water diversion authorization process, the B.C. Ministry of Environment and Climate Change Strategy (ENV) has recognized the need to establish the nature and present condition of the groundwater resource in key areas of high groundwater use. Preliminary groundwater budgets are being established for the aquifer study areas that have previously been delineated by the province. This report provides the preliminary groundwater budget for eleven such aquifer areas in the South Cowichan region of Vancouver Island, specifically: five overburden aquifer areas (0197, 0199, 0201, 0205, and 0206); and six bedrock aquifer areas (0198, 0200, 0202, 0203, 0204, and 0207).

The water budgets were established with the methodology previously described in Preliminary Conceptual Models and Water Budget Methodologies for Aquifers in British Columbia, previously prepared for the ENV by Hy-Geo Consulting (2014). This document describes a method for examining source water quantities, ground and surface water flow, anthropogenic use, and groundwater discharge. Source water is largely defined by that available for recharge, and a method used in Ontario for determining the amount of recharge on the basis of the physical setting (topography, soils and land cover) has been adopted here. It was found to calibrate well against independent streamflow data for the region.

To accomplish the water budget for each aquifer area, a conceptual hydrogeologic model was developed for each aquifer. It is important to understand the geologic setting to identify the groundwater pathways into and out of each aquifer. In the case of five overburden aquifers there exists a pattern in the geologic distribution of glacial till and outwash deposits that governs groundwater pathways there. Similarly, in the six bedrock aquifers it was found that geologic structure and rock type greatly influenced the pathways, and there is much interaction between adjacent aquifers. It has been concluded that the existing aquifer areas be re-evaluated and it is recommended their boundaries better defined to represent independent groundwater flow systems to substantially reduce estimation errors in the water budget.

The water budget was calculated for the average annual condition for a thirty-year period from 1977 to 2006 inclusive. This period was selected to allow calibration against available streamflow records. In addition, the extreme hot/dry and wet/cold periods were determined based on the most extreme three year period for each. Recharge of the water table comes from the surplus portion of precipitation that does not run off, i.e. recharge = surplus - runoff. Surplus is defined as the precipitation minus evaporation and plant uptake (transpiration). The average annual surplus for the average condition was found to be 761 mm. The hot/dry year was 1989, which had a surplus of just 512 mm. The wet/cold year was 1999, with a surplus of 1,263 mm. All three conditions were used to determine the water budget for each aquifer.

An excel spreadsheet has been developed to summarize the calculations for each aquifer study area. This spreadsheet allows interaction between the eleven aquifers and surrounding area. It is equipped with a "dashboard" feature that allows one to see the monthly water budget both graphically and in a tabulated fashion. The supporting calculations can be adjusted by future analysts as more accurate information comes available.

The analysis has demonstrated that the groundwater recharge is highly seasonal, with the bulk of the infiltration of surplus water occurring between November and February. The deficit season in the summer is about 6 months in a normal year and 8 months in a dry year. Low groundwater level conditions are accentuated when there is reduced precipitation in the preceding wet season.

Climate change predictions provided by the Pacific Climate Impacts Consortium (PCIC, 2017) indicate that whereas the temperatures will climb into the future, increasing the length of the summer season, significantly more precipitation is likely in the winter months. Whereas rainfall intensities will increase, causing higher event and seasonal runoff, the net recharge may still be higher into the future but occurring in the winter months. Conversely, the summer dry periods are expected to grow in length. Anthropogenic use in the hotter summers (and with greater demand due to increasing population) will also increase, further deepening the contrast between seasons. Water storage will become increasingly important.

The water budget for each aquifer area has been assessed for water quantity stress levels by examining the ratio of existing consumptive use to available water. A 100% consumptive use was assigned to all domestic and municipal water supplies to provide a conservative assessment. A water quantity stress level was considered to be low if this ratio was less than 10%, moderate when it lay between 10 and 25%, and a significant water quantity stress threshold was considered to be greater than 25% of the annual consumptive demand. This protocol was applied to the wet/cold, normal and hot/dry conditions, using the available recharge as the available water. Overburden aquifers 0197 and 0206 exhibit an annual high stress level, and aquifers 0198, 0204 and 0205 exhibit a moderate stress level rating. However, it is expected that portions of these aquifers are still highly stressed based on local water supply and high local consumptive uses. In general, the inland areas receive more recharge than the coastal areas and also have less consumptive use, so are less stressed.

There are a number of data gaps and assumptions in the analyses used to prepare these water budgets. The hydraulic conductivity values used for groundwater flow calculations are the single most sensitive factor and need to be assessed in more detail than possible here. Water usage figures are generally known, but given the high seasonality of the water resource, they should be recorded for known water users on a frequent basis going forward, to establish actual water use. Streamflow measurements were only available for two gauging stations on the Koksilah River and Shawnigan Creek. The groundwater to surface water interaction is not well known, and a program of baseflow measurements, if even on a spot measurement basis, should be undertaken to better understand this significant water pathway. The geologic model used herein is based on water well records only, yet showed consistent patterns, particularly in the distribution of overburden materials. A more detailed geologic model should be developed for each aquifer area to better inform the water budget and to identify potentially sustainable water sources. An effort should be made to refine which water uses are consumptive and by how much, as this greatly influences the stress assessment.

Section 8 of this report outlines recommendations for further work to better support water allocation decisions. The various organizations responsible for water supply in the area may wish to pursue these recommendations to improve the sustainability of long-term water management. The eleven aquifers may be prioritized based on size, population, the available recharge and the ensuing stress assessment.

Contents

1. INTRODUCTION

In 2016, the *Water Sustainability Act* (WSA) came into force. The WSA calls for the authorization of groundwater use in addition to the authorization of diversion and use of water from streams. To provide regional or aquifer context to assess applications for groundwater use, a program of understanding the water resources of B.C. was begun. This study was undertaken to understand the water resources for eleven aquifer areas on Vancouver Island in the Cobble Hill and Mill Bay area by calculating water budgets for each. The study area is shown on Figure 1.

1.1 Terms of Reference

The study area is limited to the Ministry of Environment & Climate Change Strategy (ENV) mapped aquifer boundaries for the developed aquifers listed in Table 1, as per the terms of the ENV Contract #GS16JHQ-169. An extended study area (Figure 1) includes the headwaters of the Koksilah River and Shawnigan Creek to enable calibration of the meteorologically derived water surplus against measured streamflow.

Table 1: Study area aquifers.

Number	Name*	Type**	Classification***	Developed Area (km^2)
0197	Cherry Point	Surficial (4b)	IIC(11)	39.48
0198	Cowichan Station	Bedrock (5a)	IIIC(7)	6.18
0199	Dougan Lake	Surficial (4b)	IIC(9)	3.40
0200	Kelvin Creek	Bedrock (6b)	IIIB(9)	26.90
0201	Kingburne	Surficial (4b)	IIC(8)	2.11
0202	North Shawnigan	Bedrock (6b)	IIB(10)	21.00
0203	Shawnigan Lake	Bedrock (6b)	IIA(12)	31.00
0204	Cobble Hill	Bedrock (6b)	IIB(11)	16.58
0205	Carlton	Surficial (4b)	IIC(9)	2.73
0206	Mill Bay	Surficial (4a)	IIA(11)	2.57
0207	Bamberton	Bedrock (6b)	IIB(12)	25.1

* Aquifer names as per Worley Parsons (2009)
** Aquifer types as per Wei et al. (2009)
*** Aquifer classification as per Ronneseth et al. (1991)

Groundwater water budgets for the Cobble Hill / Mill Bay Area have been developed in accordance with:

- General principles described in “Preliminary Conceptual Models and Water Budget Methodologies for aquifers in British Columbia” (Hy-Geo Consulting, 2014);
- The terms and conditions described in SLR’s proposal, “Monthly Groundwater Budgets for Aquifers in the Cobble Hill / Mill Bay Area, Vancouver Island, B.C., SRFP No. RFPGS16JHQ-012” (December 4th 2015). Prepared by SLR Consulting (Canada) Ltd. for the B.C. ENV;
- Addenda to the contract was developed with supportive funding of the Cowichan Valley Regional District (CVRD) to expand the terms of reference to include:
    - Calculation and impact of land use and population build out scenarios;
    - Inclusion of recently completed climate projections for the area; and
    - Inclusion of the Agricultural Water Demand Model spatial data and projected increases in groundwater extraction.

This report identifies data limitations that preclude following specific elements of these documents, in accordance to discussions with the ENV and CVRD during the study.

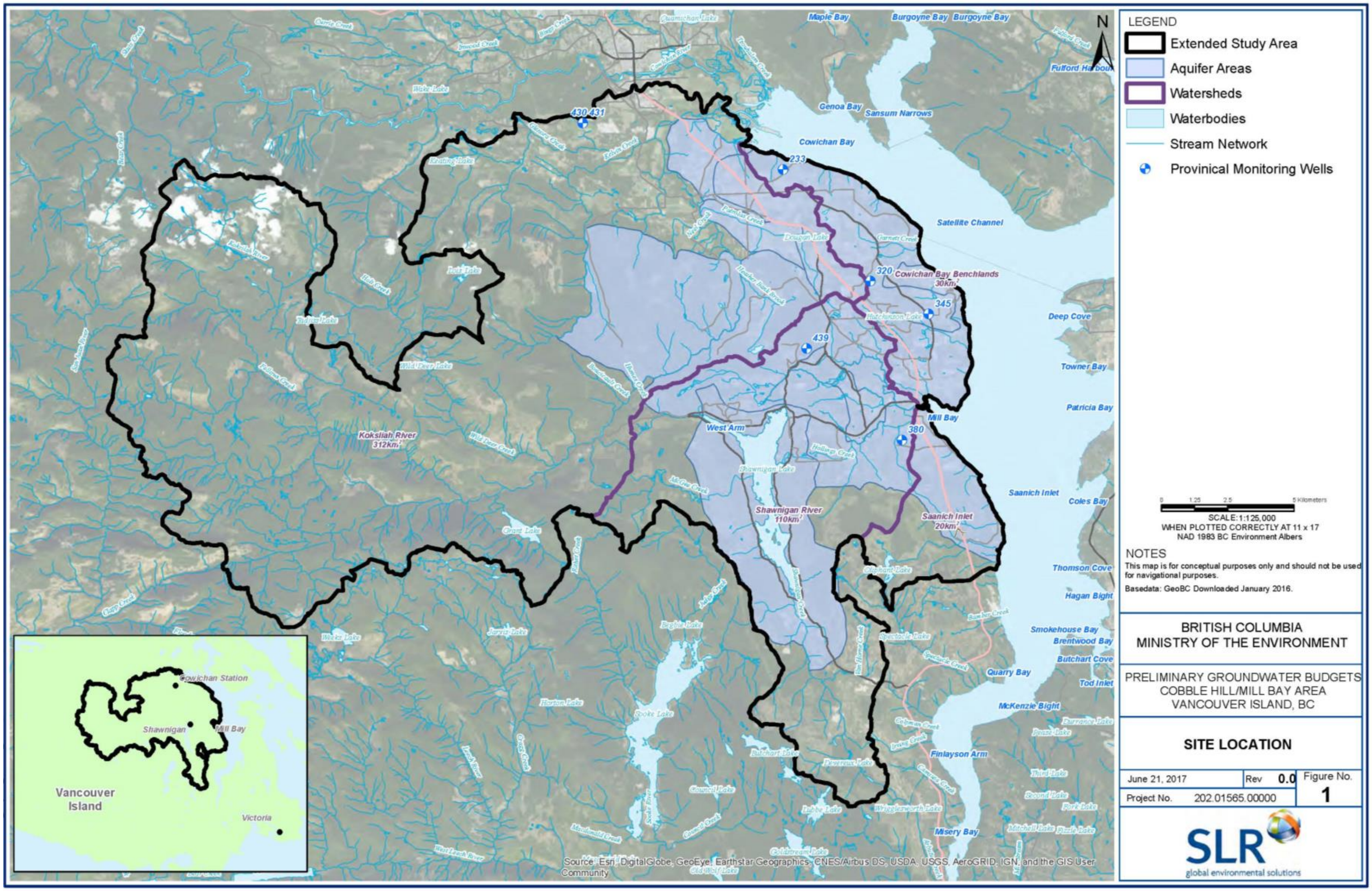

Figure 1: Study area.

1.2 Objectives

The objectives of this project are:

- Develop a conceptual hydrogeological model of the study area that includes aquifer-specific characterizations of:
  - Groundwater occurrence and movement;
  - Groundwater recharge;
  - Groundwater exchange with surface waters;
  - Groundwater exchange between aquifers;
  - Natural groundwater discharge; and
  - Natural and anthropogenic groundwater use.
- Develop preliminary, three-year (hot-dry, wet-cold, average) monthly groundwater budgets for the Cobble Hill / Mill Bay Area, with safety factors based on data input uncertainties;
- Provide estimates of groundwater exchange (inflow and outflow) with surface waters;
- Provide qualitative assessments of potential impacts from groundwater pumping on surface flows;
- Provide estimates of available groundwater for future allocation decisions based on:
  - Considerations of existing groundwater use;
  - Maintaining current groundwater levels;
  - Meeting requirements for groundwater-dependent base flows in connected surface waters; and
  - Recommended safety factors;
- Qualitatively evaluate data limitations; and
- Provide recommendations for future monitoring, data collection activities, and associated analyses to improve water balance evaluations and confidence in groundwater allocation decisions.

The participation of the CVRD in this study enabled the study team to add further objectives:

- Consideration of climate change using existing predictions provided by CVRD; and
- Consideration of the anticipated effects of future development and provide recommendations to initiate mitigation planning.

1.3 Limitations

Due to the regional nature of the study and the limited amount of aquifer-specific climatic, hydrometric, and hydraulic monitoring information available, presented groundwater budget estimates are intended to provide preliminary relative stress assessments for the ENV aquifers within the study area only. These should be periodically updated as more reliable, site-specific information becomes available to develop an increasingly comprehensive understanding of local groundwater flow systems. The groundwater budgets presented in this report are intended to provide approximate aquifer-specific quantities of groundwater that may be available for use, and should be suitable for regional-scale allocation planning. However, the presented estimates should be considered qualitative due to the inherently high degrees of uncertainty in many of the groundwater budget's input data, and are not intended to be used as a standalone tool by water managers in the evaluation of site-specific groundwater and/or surface water use applications. Rather, the estimates of the aquifer water budgets can provide the following:

1) A conceptual understanding of the aquifer;

2) Preliminary estimates of inflows, outflows and surplus/deficits of groundwater in the aquifer; and
3) Identification of the main uncertainties that need to be addressed.

2. METHODOLOGY

To prepare the water budgets for each aquifer, several steps were necessary. An understanding of the geologic setting and how it influences the groundwater and surface water system was developed first from existing information. Using existing climatological information, the availability of water was explored by determining the surplus between precipitation and actual evapotranspiration. This surplus was partitioned into recharge and runoff and is the driving force in each individual groundwater budget. The interaction between aquifers was examined with Darcian groundwater flow equations using simple pathway geometries (water table, area available for flow) and estimated hydraulic conductivity. Groundwater use was derived from previous reporting efforts by others and is described below.

2.1 Geologic Setting

2.1.1 Data Sources

This study has relied upon published geologic and physiographic information, and professional knowledge of the study area, as follows:

- Publicly-available information on the study area's regional and aquifer-specific environmental settings:
  - A Preliminary Assessment of Water Supply & Needs within the South Cowichan Region (WorleyParsons, 2009);
  - Soils of Southern Vancouver Island" (Jungen et al., 1985);
  - Physiography: Holland (1976), TRIM contour maps, aerial photographs, Google Earth imagery;
  - Bedrock geology: B.C. Geological Survey (BCGS) website, scientific literature;
  - Surficial geology / soils: scientific literature, Jungen soils maps;
  - Hydrology: B.C. Water Resource Atlas website (Province of British Columbia, 2016), BCGS website;
  - Hydrogeology: B.C. Water Resource Atlas website, ENV aquifer classification mapping;
  - Selected site-specific hydrogeological assessments;
  - Scientific literature. ENV well records;
  - Pacific Climate Impacts Consortium (PCIC) regional climate projections;
  - Agricultural water demand;
  - Municipal Official Community Plans for future development patterns; and
  - Interpretations of the study area's hydrogeological settings and physical attributes based on the author's familiarity with the study area and site-specific groundwater exploration / development experience.

Publicly-available information is assumed to be correct and has not been verified for accuracy or completeness.

2.1.2 Approach

A summary table of key attributes was compiled for each aquifer. These are found as Table 1 in each aquifer appendix. For example, the information for the overburden aquifer at Cherry Hill (aquifer 0197) is found in Table G.1 of Appendix G. The information in each summary table includes:

- ENV aquifer criteria;
- Location information;
- Climate information;
- Physiography summary;
- Geology;
- Hydrology;
- Land cover;
- Hydrogeology; and
- Groundwater development statistics.

Compilation of this information allowed the analysts to identify the key features in understanding each aquifer study area. From the geologic mapping, a conceptual site model was derived for each aquifer. This included a series of cross sections for the overburden aquifers and a structural geology map for the bedrock aquifers. Due to budgetary limitations drawings of these were not published for each aquifer. An example is, however, provided in Figure 2 for the North Shawnigan bedrock aquifer (aquifer 0202), which is overlain by the Kingburne surficial aquifer (aquifer 0201). The model shows a 200 m depth (vertically exaggerated for illustration purposes) of bedrock below the topographic surface. The traces of offsetting faults are shown on the floor of the model and are based on the current BCGS mapping. (The faulting is nearly vertical in orientation but the 10 times exaggeration makes them appear vertical on the figure.)

The bedrock formations were characterized by rock types, and the geologic structures that define their limits. This was done with consideration for potential groundwater flow pathways and connectivity to adjacent bedrock aquifers. Section 2.2.6 details the methodology for estimating bedrock hydraulic conductivity used in the lateral groundwater flow calculations.

2.2 Water Budget Methodology

Determination of the groundwater budgets largely follows the methodology of Hy-Geo Consulting (2014). The sources of water to each aquifer were determined, such as recharge of precipitation. The pathways in and out of each aquifer were considered and groundwater flow quantified. Water withdrawals that are consumptive in nature were examined, such as irrigation. Those water uses, such as rural wells, that are mostly non-consumptive (because of a return of the water to the ground locally in septic beds) were conservatively assumed to be 100% consumptive. Municipal water use based on groundwater sources was included, when the return was to a downstream water body through municipal sewers. Groundwater to surface water interaction was qualitatively assessed as “in” or “out”, as no measurements other than head or the presence of cold-water in the stream, were available to quantify it. The following subsections describe the methodology.

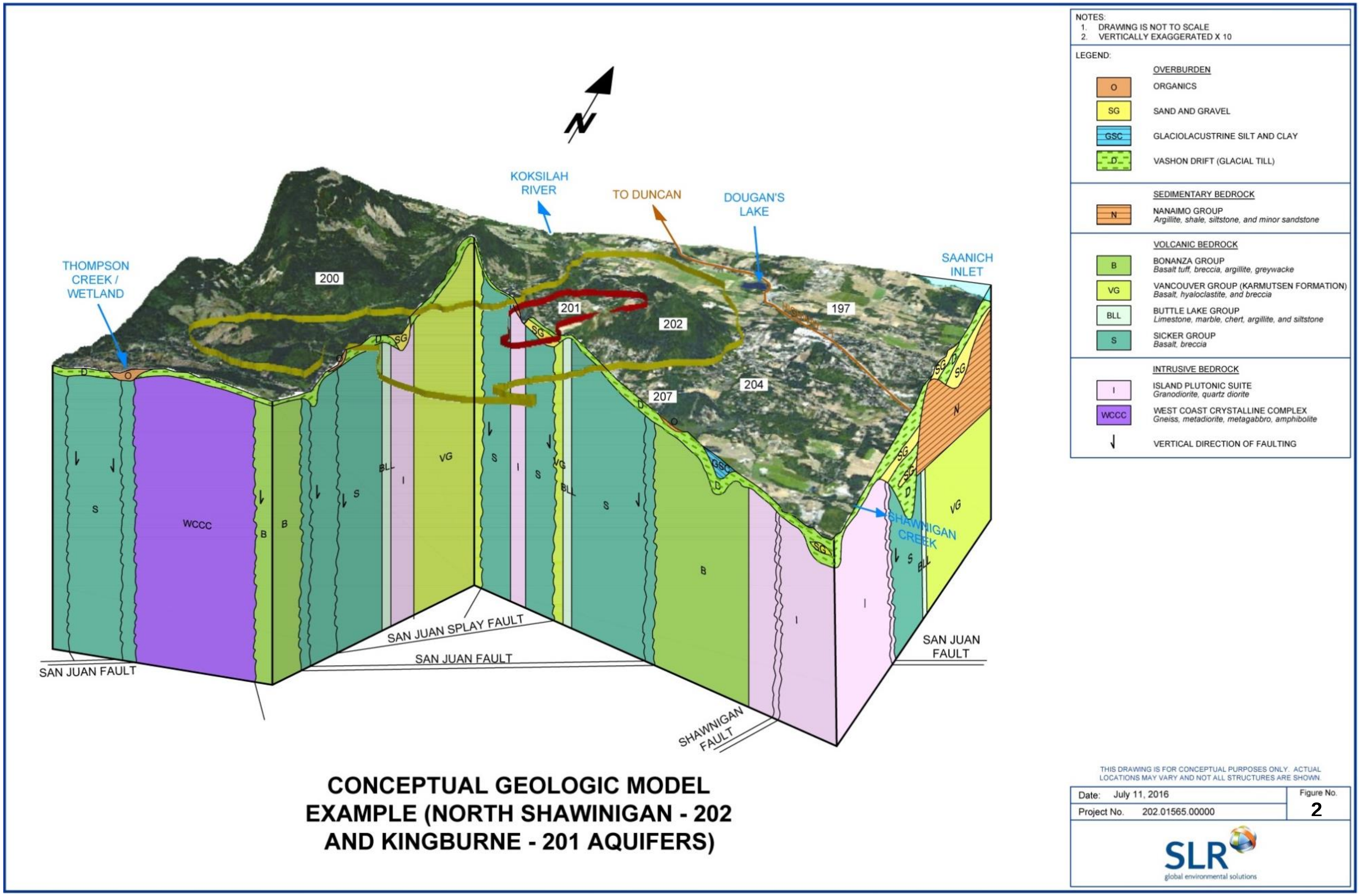

Figure 2: Conceptual geologic model example - North Shawnigan bedrock aquifer (0202) overlain by the Kingburne surficial aquifer (0201).

2.2.1 Recharge Methodology

The recharge of meteoric water (precipitation, snowmelt) is the driving force behind groundwater flow patterns. Thus, understanding the availability of water for recharge is an important first step. Recharge, is defined as the "process by which water is added to the zone of saturation to replenish an aquifer" (Ward & Elliot, 1995). A significant amount of precipitation is initially lost to evaporation and to plant uptake (transpiration), and is termed "evapotranspiration." Of some influence is water held in the shallow soils that can act as temporary storage in times when precipitation is not plentiful. During short periods, there is also winter snowpack storage, although this is generally only a factor at higher elevations in the study area.

The surplus precipitation left after evapotranspiration is available for both runoff and for infiltration and recharge of the water table. There are a number of factors that influence the percentage of surplus that will contribute to groundwater recharge: topographic slope, surficial soils, and vegetation or land cover. This study employs the method of MOEE (1995) wherein partitioning relationships are calculated based on those recharge factors, and applied in a GIS platform discretized on a 50 m grid.

Three steps were used to produce recharge estimates for the study area:

1. Calculation of water surplus available for infiltration and runoff from local long term meteorological records, on a monthly basis using the method of Thornthwaite and Mather (1957);
2. Partitioning surplus into runoff and infiltration volumes by the calculation of the infiltration factor; and
3. Extraction of recharge distribution for each aquifer area for input into the water balance.

2.2.2 Water Surplus

As identified above, the water surplus is the amount of precipitation remaining after losses back to the atmosphere (by way of evapotranspiration, a function of temperature, solar intensity and available precipitation). To determine surplus, meteorological information, including average monthly temperature, total monthly precipitation, and station latitude was collected from Environment Canada (EC). This meteorological information was obtained from the following stations:

1. Nanaimo Airport Meteorological Station 1025370
2. Cowichan Lake Forestry Meteorological Station 1012040
3. Shawnigan Lake Meteorological Station 1017230
4. Victoria International Airport Meteorological Station 1018620

These particular stations, which bracket the study area, were chosen using the following basic criteria.

1. Data for both precipitation and temperature were available for a continuous 30-year period. The period of record was ultimately chosen to be 1977 to 2006, in part to be coincident with streamflow records on the Koksilah River and Shawnigan Creek; and
2. The stations were within or in close proximity to the regional watershed boundaries.

A number of other stations found within the regional boundary were not used in the study because they did not meet the criteria. In most situations, the stations had not collected data for a continuous 30-year period. Other stations such as Sooke Lake North, located centrally within the study area had collected data for more than 30 years but only precipitation was recorded, not temperature.

The four meteorological stations are located throughout and beyond the regional watersheds. Within the GIS platform, a simple geostatistical interpolation method (Inverse Distance Weighting, IDW) was used to create a contoured surface representing estimated surplus throughout the study area. The method used was chosen for two reasons: 1) IDW is an exact interpolation method, meaning known values, i.e. calculated surplus are maintained at each location; 2) adjustments can be made to the method's search neighbourhood to account for the direction of prevailing winds and the location landform features such as mountain ranges and coastlines. The results for the average annual condition are shown on Figure 3.

On rare occasions, a month of records would be missing from the data set. These records were populated using temperature and precipitation values recorded in the same month from other years with similar weather patterns. A year over year and month-by-month comparison was completed to identify the most suitable replacement data. Using the EC data, monthly average precipitation and monthly average temperature where calculated over a 30 year period from 1977 to 2006. This period was selected as having the most coincident data between the four stations. The climate is described in Section 3 below.

2.2.2.1 *Average Annual Surplus*

To determine the average annual water balance, the 30-year period data were employed. The average monthly values for temperature and for precipitation were used, applying the method of Thornthwaite and Mather (1957) to calculate the actual evapotranspiration for each station. Snowfall depths are supplied in centimetres by EC and were converted to equivalent depths of water by dividing by 10 (a generally accepted method). The method of Thornthwaite and Mather requires specification of a soil moisture storage depth, which was estimated at 150 mm throughout the study area, and applies to the unsaturated zone above the water table. The soil moisture acts as a mitigating factor, allowing plants to draw water when there is no recharge. The method requires that soil moisture is replenished before recharge (a portion of surplus) is allowed to reach the water table. The actual value would vary of course with different soil types (gravels being low, and clays being high), but 150 mm was selected as an average value for ease of calculation[1]. Using the annual actual evapotranspiration so calculated, this was subtracted from the precipitation to determine the annual surplus for each station.

2.2.2.2 *Hot/Dry Conditions and Wet/Cold Conditions*

The weather patterns in the study area vary widely due to the proximity of the Seymour range of the Insular Mountains to the west. In addition, the area, particularly near the marine coast, is prone to long periods in the summer without rainfall. In such conditions, the availability of water is limited by a lack of recharge, and soil moisture storage can become depleted. To assess the implications of this, examination of the hottest and driest annual conditions was undertaken. A corollary examination of the wettest and coldest annual conditions was also performed. Normally this would be done for any 12-month period, however the extensive dry summer of one year may affect not only the remainder of the year, but also the following year where there may have been normal conditions. For this reason, a 36-month period was examined.

[1] It is of course possible to assign the soil moisture storage value to every soil "polygon", however that would require a specific water surplus calculation for each respective polygon. The meteorological data would then also have to be estimated for each polygon to do this. The complexity of this is beyond the scope of this preliminary wter budget study.

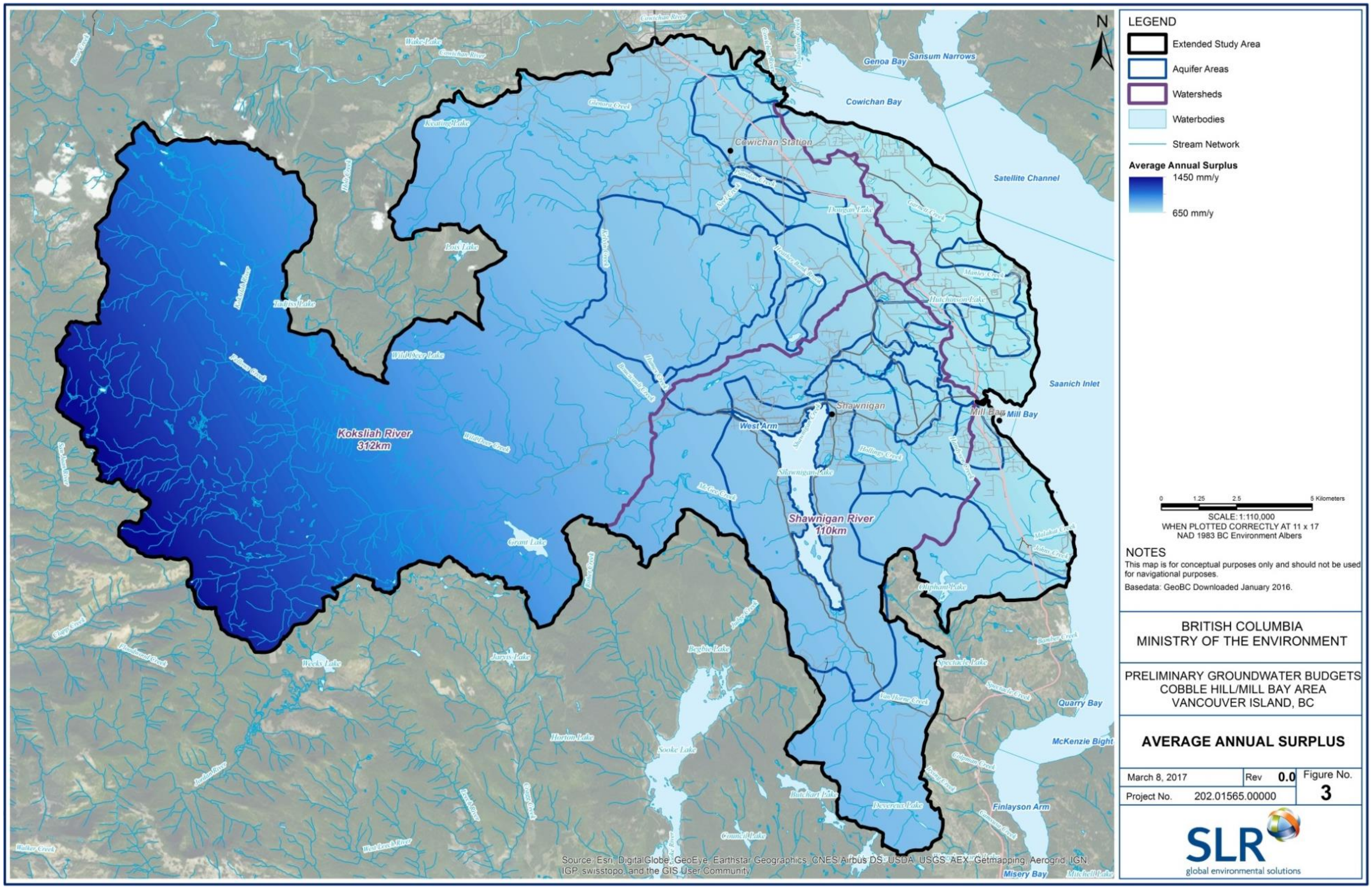

Figure 3: Average annual surplus in the study area.

The three-year moving average was calculated for the 1977 to 2006 period and candidate three year periods selected. Table 2 presents the calculated ratios for this period and highlights the extreme conditions so derived. The years chosen for the hot/dry period were 1987-1989 where the moving average ratio was 100.1 for the Shawnigan Lake station. Examination of the other, more remote meteorological stations showed that Nanaimo had the same conditions. Both Victoria International Airport and Cowichan Lake Forestry stations experienced a slightly lower ratio for the 1985-1987 period, but that 1987-1989 was within 5 points. For these reasons, the period 1987-1989 was selected as the driest/hottest historic period.

Table 2: Selection of extreme climate years.

YEAR	***1977***	***1978***	***1979***	***1980***	***1981***	***1982***	***1983***	***1984***	***1985***	***1986***
# OF YEARS	1	2	3	4	5	6	7	8	9	10
NANAMIO A										
MEAN TEMP	9.48	9.58	9.83	9.51	9.93	9.45	9.97	9.36	8.83	10.03
TOTAL PRECIP (MM)	983.4	973.1	1,117.5	1,335.4	1,282.9	1,078.6	1,695.3	1,344.4	776.1	1,197.5
PRECIP/TEMP RATIO	103.7	101.6	113.7	140.4	129.3	114.1	170.1	143.7	87.9	119.4
3Y MOVING AVERAGE		101.2	106.4	118.6	127.8	127.9	137.8	142.6	133.9	117.0
COWICHAN LAKE FORESETRY										
MEAN TEMP	9.11	9.53	9.75	9.53	9.90	9.17	9.68	8.89	8.44	9.89
TOTAL PRECIP (MM)	1,885.8	1,477.3	2,009.1	2,344.9	2,093.9	2,356.5	2,922.5	2,258.0	1,229.6	2,194.3
PRECIP/TEMP RATIO	207.0	155.1	206.1	246.0	211.5	257.1	302.1	253.9	145.7	221.8
3Y MOVING AVERAGE		186.0	189.4	202.4	221.2	238.2	256.9	271.0	233.9	207.1
SHAWINIGAN LAKE										
MEAN TEMP	9.30	9.56	9.68	9.21	9.53	9.06	9.61	8.91	8.60	9.93
TOTAL PRECIP (MM)	1,098.5	796.9	1,188.4	1,488.2	1,352.2	1,236.0	1,556.0	1,433.6	773.9	1,297.8
PRECIP/TEMP RATIO	118.1	83.4	122.8	161.6	142.0	136.4	161.9	160.9	90.0	130.7
3Y MOVING AVERAGE		104.1	108.1	122.6	142.1	146.7	146.8	153.1	137.6	127.2
VICTORIA INTERNATIONAL										
MEAN TEMP	9.27	9.48	9.75	9.46	9.86	9.39	10.13	9.33	8.80	9.94
TOTAL PRECIP (MM)	802.7	647.5	780.7	1,035.2	989.9	811.1	1,029.1	953.0	509.0	830.4
PRECIP/TEMP RATIO	86.6	68.3	80.1	109.4	100.4	86.4	101.6	102.1	57.8	83.5
3Y MOVING AVERAGE		77.8	78.3	86.0	96.6	98.7	96.1	96.7	87.2	81.2

YEAR	***1987***	***1988***	***1989***	***1990***	***1991***	***1992***	***1993***	***1994***	***1995***	***1996***
# OF YEARS	11	12	13	14	15	16	17	18	19	20
NANAMIO A										
MEAN TEMP	10.97	10.10	9.95	9.96	10.08	10.78	9.78	10.41	10.73	9.42
TOTAL PRECIP (MM)	892.8	967.9	835.6	1,289.4	1,167.9	1,047.3	884.7	1,073.8	1,417.2	1,355.9
PRECIP/TEMP RATIO	81.4	95.8	84.0	129.5	115.9	97.1	90.4	103.2	132.1	144.0
3Y MOVING AVERAGE	96.2	98.9	87.1	103.1	109.8	114.2	101.2	96.9	108.6	126.4
COWICHAN LAKE FORESETRY										
MEAN TEMP	10.37	9.70	9.41	9.81	9.90	10.80	9.67	10.18	10.45	9.16
TOTAL PRECIP (MM)	1,892.6	2,022.2	1,633.3	2,503.3	2,082.0	2,052.5	1,640.3	2,336.7	2,708.2	2,246.8
PRECIP/TEMP RATIO	182.6	208.5	173.6	255.2	210.3	190.0	169.7	229.7	259.2	245.3
3Y MOVING AVERAGE	183.4	204.3	188.2	212.4	213.0	218.5	190.0	196.5	219.5	244.7
SHAWINIGAN LAKE										
MEAN TEMP	10.55	10.00	9.64	9.93	10.08	10.72	9.66	10.17	10.52	9.22
TOTAL PRECIP (MM)	952.6	1,122.2	942.7	1,509.6	1,221.2	1,118.3	923.0	1,257.8	1,432.3	1,416.9
PRECIP/TEMP RATIO	90.3	112.2	97.8	152.1	121.1	104.4	95.6	123.7	136.2	153.7
3Y MOVING AVERAGE	103.6	111.1	100.1	120.7	123.7	125.9	107.0	107.9	118.5	137.9

Table 2 (Continued): Selection of extreme climate years.

VICTORIA INTERNATIONAL										
MEAN TEMP	10.31	9.69	9.51	9.70	9.78	10.64	9.80	10.46	10.73	9.61
TOTAL PRECIP (MM)	656.7	822.8	675.6	1,138.4	877.1	809.1	692.7	905.0	988.7	1,120.3
PRECIP/TEMP RATIO	63.7	84.9	71.1	117.4	89.7	76.0	70.7	86.5	92.1	116.6
3Y MOVING AVERAGE	68.4	77.4	73.2	91.1	92.7	94.3	78.8	77.7	83.1	98.4

YEAR	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***
# OF YEARS	21	22	23	24	25	26	27	28	29	30
NANAMIO A										
MEAN TEMP	10.33	10.88	9.74	9.72	9.77	9.91	10.54	10.97	10.23	10.21
TOTAL PRECIP (MM)	1,307.9	1,272.2	1,496.6	977.9	990.8	1,079.6	1,143.4	1,166.7	1,143.8	1,427.4
PRECIP/TEMP RATIO	126.6	116.9	153.6	100.6	101.4	108.9	108.5	106.4	111.8	139.8
3Y MOVING AVERAGE	134.2	129.2	132.4	123.7	118.6	103.7	106.3	107.9	108.9	119.3
COWICHAN LAKE FORESETRY										
MEAN TEMP	9.96	10.73	9.43	9.49	9.46	9.85	10.31	10.90	10.28	10.07
TOTAL PRECIP (MM)	2,910.1	2,551.5	2,755.2	1,687.8	1,907.0	2,032.2	2,540.8	1,839.4	2,069.8	2,719.9
PRECIP/TEMP RATIO	292.2	237.9	292.1	177.8	201.6	206.3	246.5	168.8	201.3	270.2
3Y MOVING AVERAGE	265.6	258.5	274.1	235.9	223.8	195.3	218.1	207.2	205.5	213.4
SHAWINIGAN LAKE										
MEAN TEMP	10.16	10.58	9.38	9.50	9.63	9.86	10.48	10.94	10.26	10.28
TOTAL PRECIP (MM)	1,565.5	1,487.8	1,710.2	943.8	1,115.2	1,104.8	1,382.0	1,104.2	1,089.6	1,594.6
PRECIP/TEMP RATIO	154.1	140.6	182.3	99.3	115.9	112.1	131.9	100.9	106.2	155.2
3Y MOVING AVERAGE	148.0	149.5	159.0	140.7	132.5	109.1	120.0	115.0	113.0	120.8
VICTORIA INTERNATIONAL										
MEAN TEMP	10.52	10.87	10.00	9.85	10.01	10.06	10.73	11.05	10.38	10.42
TOTAL PRECIP (MM)	1,170.6	1,018.5	1,135.2	695.5	840.8	701.4	1,021.8	850.6	791.6	1,049.5
PRECIP/TEMP RATIO	111.3	93.7	113.5	70.6	84.0	69.7	95.3	77.0	76.2	100.8
3Y MOVING AVERAGE	106.7	107.2	106.2	92.6	89.4	74.8	83.0	80.7	82.8	84.7

Hottest three year period with the least rainfall
Second hottest period with the least rainfall
Coldest three year period with the most rainfall
Second coldest period with the most rainfall

The corresponding cold/wet period was selected as 1997-1999, where the 3-year sliding average ratio was 159.0 mm/^{o}C at Shawnigan Lake. Cowichan Lake Forestry station had the same period, while Victoria International Airport's cold/wet period was offset by a year 1996-1998. Nanaimo had a different cold/wet period of 1982-1984 (which was the second coldest period for Cowichan Lake Forestry and Shawnigan). However, 1997-1999 was the second coldest/wettest period at Nanaimo. For these reasons, the period 1997-1999 was selected as the representative cold/wet period. Of note, the final year, 1999 was the wettest year in the thirty-year period, with 1710 mm of rainfall at Shawnigan Lake (and second wettest at Nanaimo and Victoria, and third wettest at Cowichan Lake).

Once these periods were chosen, the monthly surplus and deficit were calculated by the method of Thornthwaite and Mather (1957) for the hot/dry and wet/cold periods. It is intended that this bracketing information may be used by analysts in the future when comparing to current conditions. The analysis of the extreme conditions into the future will mean a similar stressed condition, but applied to the conditions of climate change (see Section 3.2.3).

2.2.2.3 *Calibration*

The surplus is the most important input to the water budget for any aquifer, as it determines the water available for groundwater recharge. It is therefore important to assess this calculated amount against independent data, to ensure predicted conditions are reasonable. To do this, a comparison against measured streamflow in the Koksilah River and the Shawnigan Creek was made. Since surplus is available for both runoff and infiltration, and streamflow is made up of both storm runoff and baseflow (assumed to be groundwater discharge) a comparison of the streamflow and surplus above key streamflow stations can be made. This assumes that there is no net change in aquifer storage, which is reasonable over a thirty year period. To bracket the analysis the two extreme periods were also chosen for comparison, 1987-1989 and 1997-1999. To make the data sets comparable, the catchment area (m^2) above each gauge was multiplied by the surplus (m/year) to determine the total annual surplus in cubic metres (m^3). The daily average flows at the two stations were summed to yield an annual volume for each, also in m^3. The comparison was made on an annual basis to accommodate the large seasonal fluctuations, and the temporal lag created when comparing immediate surface water flow conditions with slower groundwater flow conditions.

The results of this comparison are given in Table 3 below. It was found that in the hot/dry period (1987-1989) the surplus compared to within 9.5% of the measured total streamflow in the Koksilah River, and to within 6.0% in Shawnigan Creek. In both cases, the surplus methodology under predicted the streamflow. This is however considered to be excellent agreement (within 10%, the typical gauge error) and lends confidence in the use of the surplus calculated by these methods, as the input to the water balance. In the cold/wet period (1997-1999) the differential was plus 1.6% in Shawnigan Creek, also considered excellent agreement. However, in the Koksilah River the differential was minus 21.6%, a value that is normally in acceptable agreement, but about a 12% swing (21.6% minus 9.5%) from the hot/dry condition at that station, so is somewhat suspect. Examination of the streamflow records shows three months were missing from the period in question and was augmented with unusually high estimates. Doing a pro rata with the results in the Shawnigan basin for the same period (which assumes similar rainfall patterns in the two watersheds in the months in question) reduces the reported streamflow volumes significantly and the results (-4.7%) appear more reasonable . Without a detailed examination of the data, there are inherent uncertainties, as things such as the release of water in storage could have artificially drawn up other numbers as well.

It should be noted that the catchment areas for each gauge extended beyond the individual aquifers considered in this project. This is shown on Figure 4. Once the methodology was deemed acceptable, the calculated surplus was used in subsequent calculations on an aquifer by aquifer basis. In general, it is concluded that the methodology calculates a realistic surplus and it calibrates well against available streamflow observations.

Table 3: Comparison of annual surplus to streamflow.

River	Period	Area (hectares)	Three year average annual surplus (m)	Total Predicted Volume (m^3)	Total gauged volume (m^3)	Percent difference from gauge
Koksilah River at Cowichan Station	1987-1989 (hot/dry)	27,944	0.750	207,483,267	231,887,291	- 9.5%
	1997-1999 (cold/wet)		1.332	372,355,385	474,827,040	-21.6%
Shawnigan Creek at Mill Bay	1987-1989 (hot/dry)	9,133	0.565	52,087,767	55,438,042	-6.0%
	1997-1999 (cold/wet)		1.085	99,379,785	97,796,131	+1.6%

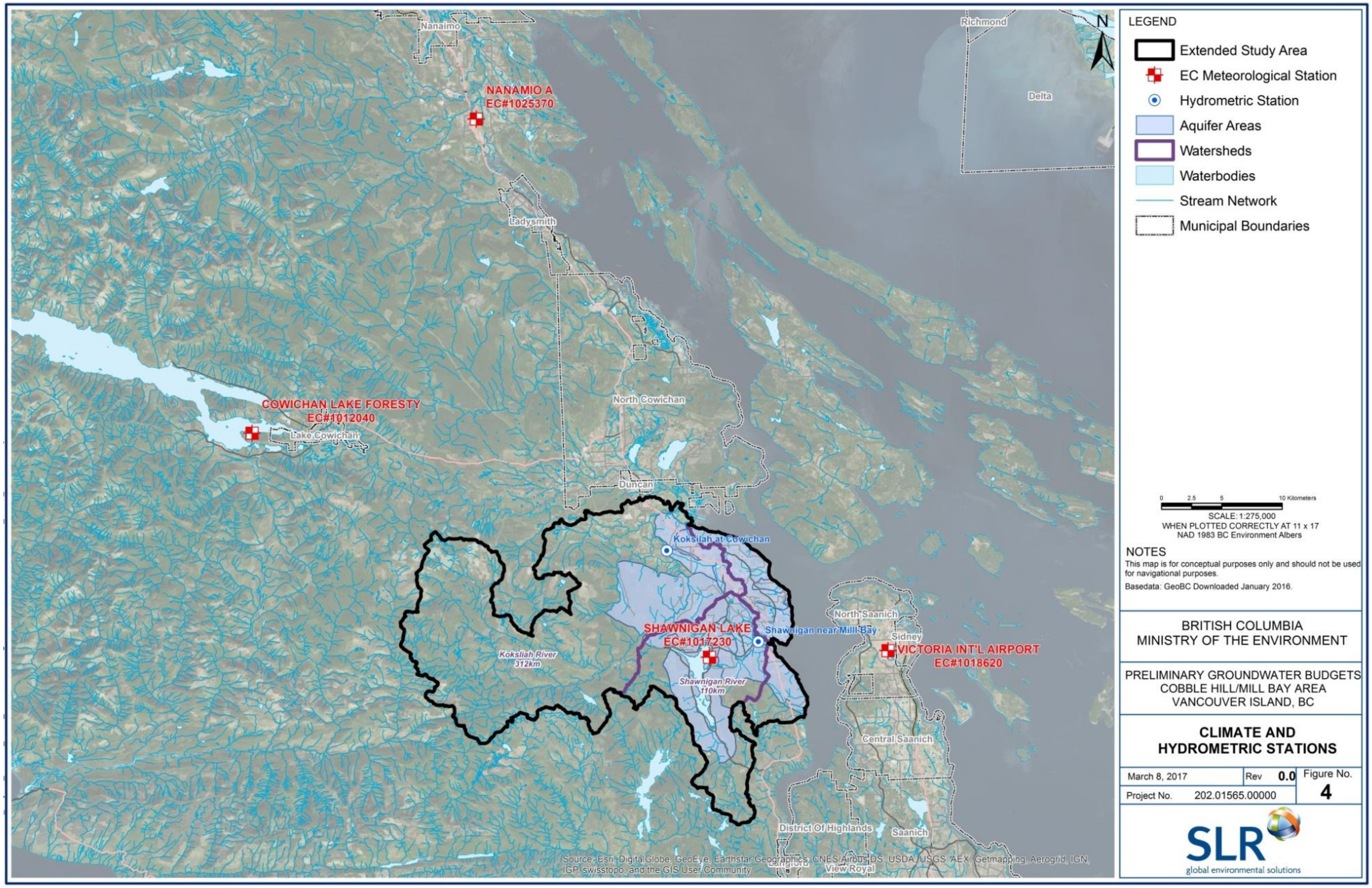

Figure 4: Climate and hydrometric stations.

2.2.3 Calculation of Infiltration Factor

The approach used to calculate the infiltration factor is based on that outlined in the ENV's "Hydrogeological Technical Information Requirements for Land Development Applications" (MOEE, 1995). A partitioning coefficient is calculated from the sum of individual infiltration coefficients from three factors:

1. Land cover type
2. Degree slope, and
3. Soil types

These are determined based on existing information and their individual distributions mapped on a 50 m by 50 m grid. The cell-by-cell infiltration factors were summed over the study area, to provide spatially discrete infiltration factors. When multiplied by the surplus, the infiltration that would enter the groundwater system throughout the study area is determined. The three data layers are described in more detail below.

2.2.3.1 Land Cover Factor

Land cover and vegetation have significant effects on the surplus by way of interception and/or dispersion by foliage, which prevents or slows precipitation from reaching the ground leading to longer exposure to the atmosphere and increased evaporation. As well, vegetation of differing heights and types also influence the potential for recharge with a range of uptake and transpiration rates. Trees and large rooted vegetation slows overland flow providing more time for infiltration of water and hence more recharge. MOEE (1995) simply applied a factor of 0.2 for forested areas, and 0.1 for cropped areas. These can be further refined to cover a broader spectrum of land cover conditions. Based on land cover data provided by CVRD (2013), the study area was divided into seven distinct classifications. Each classification was provided with an infiltration factor (F_{cover}) based on the area's ability to allow infiltration, as follows:

- 0.1 - Agriculture
- 0.1 - Exposed/barren
- 0.2 - Forest/shrub
- 0.1 - Rural development
- 0.05 - Urban development
- 0.0 - Open water
- 0.0 - Wetland

There were two modifications to the original data layer. The first being the delineation of newly logged areas around Shawnigan Lake, within the boundaries of aquifer 0203, the classification of those areas was changed to "exposed/barren". The second change was made to differentiate between true urban areas with storm water management systems with sealed underground piping and, rural developments where storm water is managed by dispersion on lawns and runoff controlled within open ditches. These areas were divided and provided with appropriate infiltration factors, 0.05 for true urban areas and 0.1 for rural developments.

Further to these two changes, examination of aerial photographs indicates that the urban development area is comprised of a mix of transportation, residential subdivisions, commercial/industrial and misclassified agricultural field and cultural grasslands. The range of land use infiltration factors is 0 to 0.1 for these various uses. It was not possible within the scope of this project to further subdivide this area (which comprises about half of aquifer 0197 as the most poignant example). Using the areas and factors identified above means that infiltration will be underestimated, which then becomes a conservative limit, and recharge should actually be greater than calculated in this report.

Consideration has also been given to the likelihood that land development is planned into the future, primarily through the Official Community Planning (OCP) process. The modified land cover mapping (CVRD, 2017a) was compared to the "build out" under the current OCP to see if any significant changes might occur to the infiltration factor. It was found that about a 1% reduction in the overall infiltration factor might be anticipated from build-out. This is higher in areas of low infiltration and lower in areas of high infiltration, so is site specific. This is, however, difficult to judge as the urban development area is poorly differentiated (in terms of land use as described above). Given that the surplus can vary by over 200% from year to year, the subtle underestimation by 1% is not viewed as regionally significant. It is conversely important on a local level to understand that while this is not a key factor for the water balance of an overall aquifer area, it is significant for any land subdivision involving urbanization, as it can have a great local influence. Understanding that the system can be stressed in the summer season and more so in the hot/dry years, it should be a goal of future land development to ensure post development recharge for any given land parcel is the same or greater than the pre-development recharge.

2.2.3.2 *Topography/Slope Factor*

Local topography can have an influence on infiltration that is dependent on degree of slope. Low slopes promote infiltration and steep slopes promote runoff and decreased infiltration. The MOEE (1995) method provides the following range of infiltration factors for slope:

- 0.10 - Hilly land, average slope of 28 m to 47 m per km;
- 0.20 - Rolling land, average slope of 2.8 to 3.8 m per km; and
- 0.30 - Flat land with average slope not exceeding 0.6 m per km.

For this study, topographic factors were calculated based on actual slope. Slope was determined using GeoBC 1:20,000 Digital Elevation Model (DEM), to calculate the steepest slope (in degrees) between cells which was assigned to the centre cell. Application of the generalized infiltration factors recommended by MOEE (1995), were refined by developing a relationship between the infiltration factor and degree of slope. The resulting empirical relationship is shown in Figure 5, which also shows the above ranges in red.

The horizontal range bars in Figure 5 show the range of slope associated with the guidelines in the MOEE (1995) report. The points were best described by a power fit, shown on the chart. This relationship was used to derive an infiltration factor based on slope. For slopes less than 0.03°, the infiltration factor was assigned to 0.3. Slope factors (F_{slope}) ranged from 0.1 to 0.3 with the higher values in the flat lying areas.

2.2.3.3 *Soil Factor*

Soils infiltration factors were initially based on the following MOEE (1995) criteria:

- 0.1 - Tight impervious clay
- 0.2 - Medium combinations of clay and loam
- 0.4 - Open sandy loam

This range in soil infiltration factor was initially applied to the provincial soils mapping for the study area: National Soil Database, Agriculture and Agri-Food Canada (Jungen, 1985). It is our experience that the soils have to be greater than 0.3 m thick, to absorb most precipitation events. Thinner deposits would mean the rate of water entry would reflect the underlying bedrock.

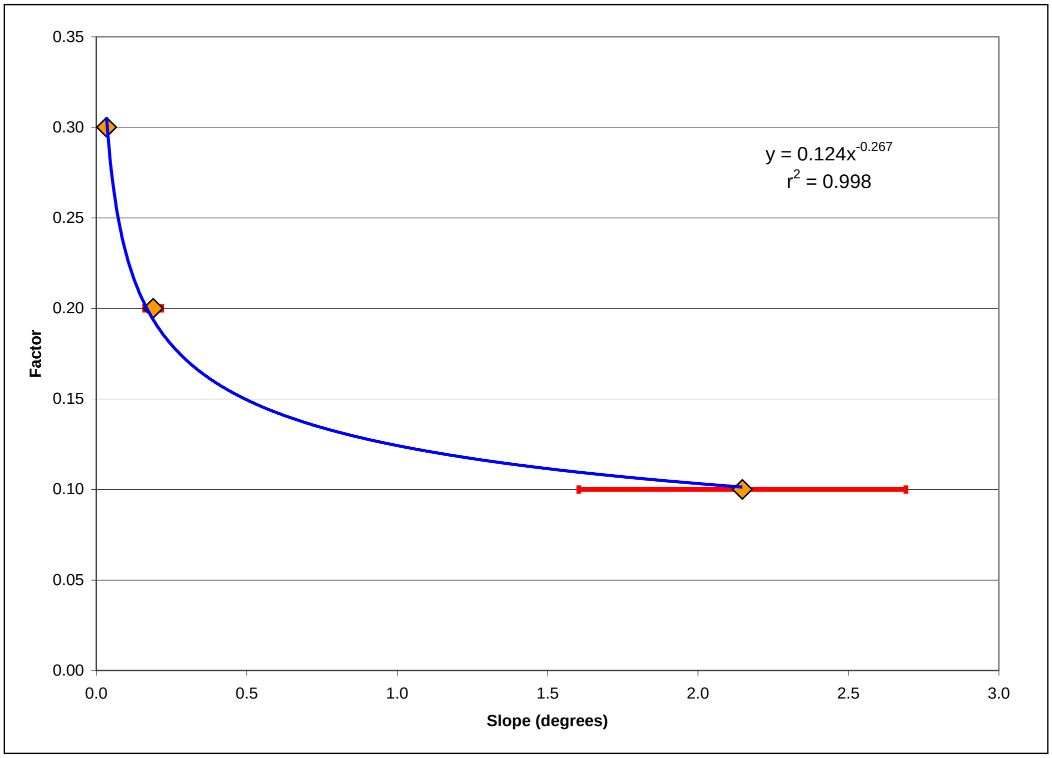

Figure 5: Relationship between infiltration factor and slope.

Thus, a more refined range soils infiltration factor (F_{soil}) is possible for different types of soils in this study area as follows:

- 0.05 – Open bedrock with little to no soil cover
- 0.1 – Clay, organics over clay, poorly drained soils
- 0.2 – Silt and clay, duric layers, imperfect drainage
- 0.3 – Silt, silty sand, weakly duric soils of moderate drainage
- 0.35 – Sand, sand and gravel, well drained
- 0.4 – Gravel, sand and colluvium, bedrock regolith, exhibiting rapid drainage

A local knowledge of physical characteristics such as cemented layers in duric soils was applied to reduce the factor where this would restrict infiltration. It was also clear from the soils mapping that there were minor and major presence of differing soils within each mapped unit. Where possible, an estimate of the relative abundance of different types within each polygon was made and a weighted average was developed. Once the study team had agreed on the factors to be applied to each soils unit, this was applied to the soils layer of the GIS platform for each cell within each unit.

2.2.3.4 Infiltration Factor

The final infiltration coefficient is calculated by adding the three factors together for each cell in the GIS platform,

$$I.F. = F_{cover} + F_{slope} + F_{soil}$$

Figure 6 graphically presents the areal distribution of the infiltration factor throughout the study area. Individual maps for the aquifers are provided in the appendices.

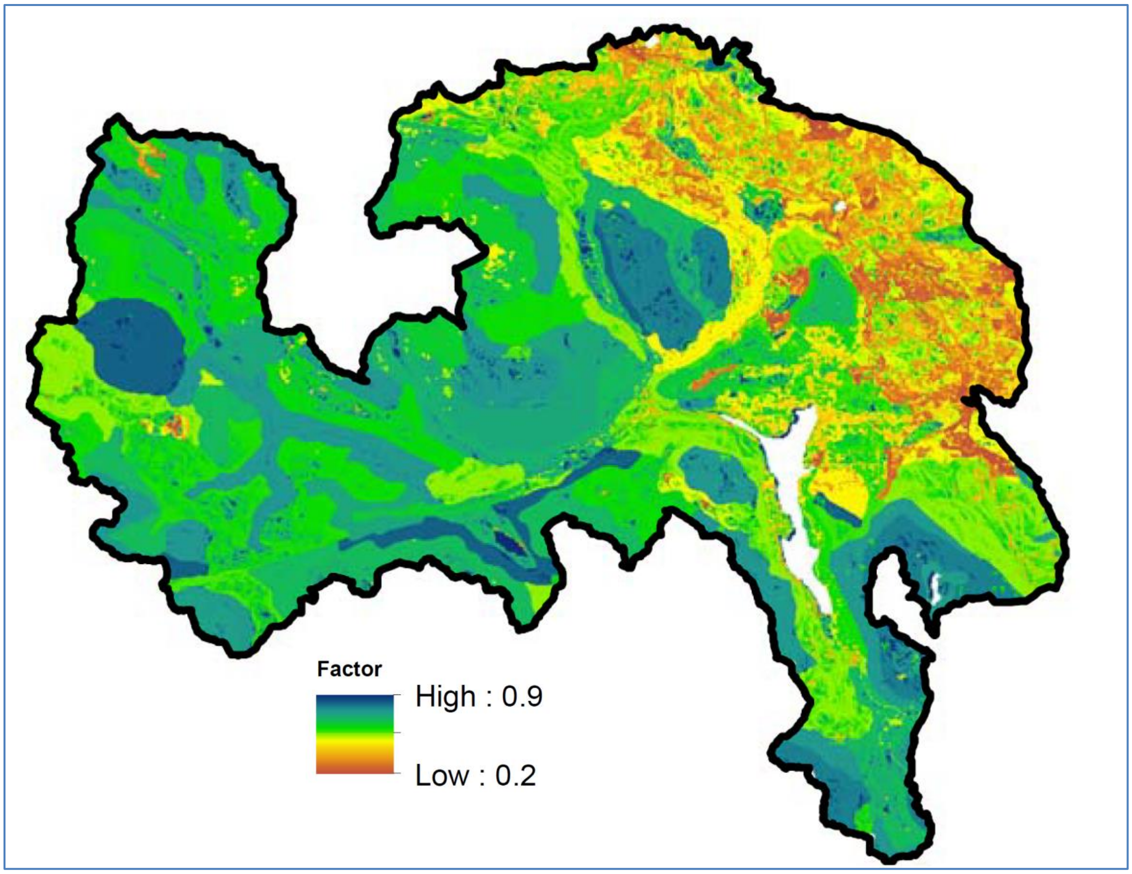

Figure 6: Distribution of calculated infiltration factor in the study area.

2.2.4 Recharge

Recharge is determined by multiplying the infiltration factors by the surpluses on a cell-by-cell basis in the GIS platform. The surplus also varies spatially with distance between the meteorological stations as described in Section 2.2.2 and shown on Figure 3. By this method, spatially discrete recharge and runoff values can be calculated. The model produces a scalable result that can be easily compared to known flows and volumes and provides enough detail to accurately estimate recharge for smaller regions within the study area.

This methodology relies on the four meteorological stations and an interpolated (kriging) surface of surplus across the study area. To simplify this for future estimates, it was found that the Shawnigan Lake station, which is central to the study area, yields a surplus that is close to the average condition for the full study area. Areas near the marine shore are, however, drier and upland areas are wetter. A correction factor was developed based on the thirty-year period that allows one to work with the one station's data when relating to any individual aquifer. These factors are presented in Table 4, and it can be seen that they vary between just 1.03 and 1.13, which demonstrates that the Shawnigan Lake Meteorological Station is an appropriate choice. In this manner, future analysts will not have to analyse all four stations and re-interpolate the surfaces[2].

[2] This assumes that today's 30 year factors will remain the same into the future. This could be rigourously tested by examining other 30-year time frames in the record, or periodically readjusting as climate changes, by re-interpolating the four stations. This is however beyond the scope of this preliminary study.

Table 4: Weighted surplus factors for application to Shawnigan Lake Station by aquifer.

Aquifer Number	30 Year Average Shawnigan Surplus (mm)	30 Year Average Aquifer Surplus* (mm)	Weighted Surplus Factor
0197	760.9	782.6	1.03
0198	760.9	807.6	1.06
0199	760.9	804.7	1.06
0200	760.9	855.3	1.12
0201	760.9	822.6	1.08
0202	760.9	829.6	1.09
0203**	760.9	859.0	1.13
0204	760.9	778.1	1.02
0205	760.9	805.9	1.06
0206	760.9	793.4	1.04
0207	760.9	805.9	1.06

* Based on GIS averaged surplus across aquifer.

** Shawnigan Lake Meteorological Station is located in aquifer 0203

These factors have been used in the spreadsheet for determining the recharge volumes by multiplying them by the Shawnigan Lake average annual surplus, times the area of the aquifer. The same factors are used for the hot/dry and wet/cold scenarios.

2.2.5 Vertical Leakage Between Aquifers

Several of the overburden aquifers overlie portions or all of other bedrock aquifers. In most cases there is downward vertical leakage, as evidenced by higher heads in shallow overburden wells than in the deeper bedrock wells. The ability of the bedrock to accept this water must also be considered. For example, the Nanaimo Group is largely characterized by low permeability shale. Without direct measurement of hydraulic conductivity and specific vertical hydraulic gradients, this cannot be calculated. In an attempt to understand the significance of this factor, estimates of leakage per square metre have been made, based on professional experience in similar settings. By way of example, a rock type that exhibits a receiving downward gradient of 0.1 and has a hydraulic conductivity of 10^{-7} m/s will receive a flow of Q = K x dh/dL x A, where K is the hydraulic conductivity, dh/dL is the hydraulic gradient, and A is the area perpendicular to flow. Expressed per unit area, this downward groundwater flow will be:

$$Q/A = K \times dh/dL$$

$$= 10^{-7}\ \text{m/s} \times 0.1 \times (3600\ \text{s/hr} \times 24\ \text{hr/day} \times 365\ \text{day/yr})$$

$$= 0.315\ \text{m}^3/\text{year}/\text{m}^2.$$

The estimates used in this study are shown in Table 5. For each bedrock aquifer, the area in contact with the overburden above was multiplied by the leakage factor to produce an annual volumetric leakage to the bedrock below. It is recommended that a more rigorous process to estimate leakage be investigated, based on location specific measurements of bedrock hydraulic conductivity and vertical hydraulic gradients, in a distribution that is statistically defendable.

Table 5: Estimated leakage into bedrock aquifers per square metre.

Bedrock Type	**Affected Aquifers**	**Leakance Factor (m^3/year/m^2)**
Shale (Nanaimo Group)	Leakage from AQ199 Leakage from AQ197 Leakage into AQ198 from AQ197	0.100
Island Plutonic Suite	Leakage into AQ207 from AQ205 Leakage into AQ207 from AQ206 Leakage into AQ204 from AQ197	0.300
Bonanza Group Volcanics	Leakage into AQ207 from AQ205	0.100
Buttle Lake Limestone	Leakage into AQ202 from AQ201	0.300
Sicker Volcanics	Leakage into AQ202 from AQ201 Leakage into AQ204 from AQ197	0.300

2.2.6 Lateral Movement Into or Out of Bedrock Aquifers

Determination of lateral movement of groundwater into or out of bedrock aquifers was done using Darcy's principle for groundwater flow. Flow out of an aquifer is taken as a negative number in the spreadsheet, which is conveyed as a positive number into the receiving aquifer. The calculation is always performed in the originating aquifer spreadsheet, and then the result conveyed to the receiving aquifer spreadsheet. The flow is calculated as:

$$Q = K \times dh/dL \times A$$

where K is the bedrock hydraulic conductivity. The force is expressed by the hydraulic gradient (dh/dL), which is the change in head over a distance parallel to the direction of flow. The area (A) is the area perpendicular to flow that the water passes through.

Sufficient direct measurements of hydraulic conductivity are not available over this wide study area. Using the accumulated knowledge of the geologic setting, empirical estimates of the "mountain block scale" bulk hydraulic conductivities (K_{mb}) of the study area's bedrock aquifers were generated using a qualitative methodology modified from Voeckler and Allen (2012). This defines the following three hydrostructural domains within each aquifer, based on their probability of containing known or potential geological structures that may host zones with increased secondary porosity (fractures, faults):

- Low Lineament Density Zones (LDZs) that do not contain regional geological structures or contacts mapped by the B.C. Geological Survey (BCGS) or significant topographic lineaments on aerial photographs or 1:20,000 scale TRIM topographic maps;
- Moderate LDZs that do not contain regional geological structures or contacts mapped by the BCGS but host weak to moderate topographic lineaments suggestive of the presence of unmapped, minor faults or fracture zones; and
- High LDZs that contain regional geological structures and/or contacts mapped by the BCGS, or strong topographic lineaments suggestive of the presence of unmapped, major faults or fracture zones.

Estimates of K_{mb} in areas with low LDZs were based on typical K ranges presented in the scientific literature for analogous rock types to those found within the study area (Freeze and Cherry, 1979; Heath, 1983; Bear, 1979; Domenico, and Schwartz, 1990). Estimates of K_{mb} in areas with moderate LDZs were based on assessments of whether the zones were located in areas dominated by compressional or extensional tectonic stress regimes, and SLR's field knowledge of relative competencies and susceptibilities to ductile deformation specific to each rock type. Estimates of K_{mb} in areas with high

LDZs were based on the locations of areas with known elevated well yields or increased probabilities for the development of wells with elevated yields, based on SLR's field knowledge of fractured matrix microstructural characteristics specific to each rock type (including typical secondary void aperture, frequency / density, persistence, and connectivity).

For the purposes of K_{mb} estimation, actual and potential fracture zones were assumed to be vertical and hydraulically anisotropic along the strike of the parent structures, with fracture apertures remaining consistent with increasing depth. A minimum K_{mb} "threshold value of 10^{-9} m/s was used to identify hydrostructural domains that may not contain appreciable amounts of extractable groundwater or structures capable of conveying groundwater between aquifers (i.e., structures that may represent hydraulic barriers as opposed to conduits).

Since SLR's methodology did not include the use of modelling software, statistical analyses, or site-specific hydraulic testing, K_{mb} values presented and employed by the groundwater balance model should be considered preliminary and conceptual.

Direct measurements of the hydraulic gradient along groundwater flow paths are not available. However, it is well known that in low permeability materials the water table and underlying potentiometric surfaces generally mimic the topographic surface. As a reasonable approximation, we have used the topographic gradient as a surrogate for the horizontal hydraulic gradient in the bedrock. In the overburden where there are deposits of more permeable material, flatter gradients may persist. Fortunately, there are many more well records in the overburden aquifers to rely upon. An approximate water table map (Figure 23, for example in aquifer 0197) was drawn for each overburden aquifer based on shallow wells and flow directions and horizontal hydraulic gradients were graphically determined. Where the edge of the aquifer lies at the top of a hill, this is defined as a groundwater flow divide and zero groundwater is expected to discharge into or out of the aquifer.

The third component of the Darcy Principle is the vertical cross-sectional area available for horizontal groundwater flow. For the bedrock aquifers, the active zone of groundwater flow has been estimated to be 200 m deep. In areas where rivers incise the bedrock (for example the Koksilah River opposite of aquifers 0200 and 0202), a thickness of just 40 m was used to convey water at these boundaries. The breadth of each bedrock unit was used times this depth to calculate the area. In overburden aquifers, several hand drawn cross-sections were compiled from the water well records, identifying the positions of aquifers and aquitards. An average saturated thickness of permeable material was estimated from the cross sections, which was in turn multiplied by the breadth of the deposit to derive an area available for horizontal flow. This gross approximation is possible because the well records yielded a predictable pattern in aquifer distribution with depth, which is not readily apparent in the current documentation.

2.2.7 Surface Water / Groundwater Exchange Methodology

Each aquifer has a series of watercourses crossing them, as detailed in Section 3.4 below. In addition, there are several lakes such as Dougan Lake and Shawnigan Lake that influence groundwater flow and discharge along watercourses.

As discussed in Section 2.2.2, there are just two federal gauging stations in the study area. The delineation of aquifers generally uses the major watercourses as a boundary. This has the complication of being unable to use the streamflow data for any single aquifer unit, as it is a shared discharge/recharge boundary.

For streams that cross over the aquifer a review of the nearby potentiometric surface (as defined by shallow wells) with respect to the elevation of the stream was conducted to see if there were upward hydraulic gradients. This was further checked by examining provincial records through ENV staff to determine if the stream in question was cool water (implying a mix of cold and warm water) or cold water, and also to see if there were records of cold water fish in the streams. If these factors agreed and a stream was determined to have groundwater input, a simple calculation of specific flux times streambed area, described below, was undertaken to estimate groundwater discharge.

Several scientific papers were examined: Sowden, et al., (1985); Curry et al., (1995a, 1995b). The work of Curry et al. (1995a, 1995b) examined numerous sites in both rivers and creeks in bedrock and overburden settings. Their biologists documented physical conditions, water temperatures and chemistry. They measured groundwater influx using stream piezometers, following the methods of Lee and Cherry (1978).

The key parameter that must be considered is the groundwater influx, expressed as "specific discharge." Specific discharge is defined as the amount of groundwater entering the creek base, per unit area per unit time. It is generally expressed in units of m/s, that is, a flow expressed in m^3/s per m^2 of creek bottom. In these cold water streams, Curry et al. (1995a, 1995b) showed that a mean specific discharge of 3.2×10^{-5} m/s was needed for fish to want to select spawning sites. He also showed that 3.4×10^{-5} m/s was needed on average to sustain incubation and emergence over the winter, and that a minimum value of 0.9×10^{-5} m/s was needed during the coldest periods to keep the incubation sites from freezing. For the purposes of this assessment, it is assumed that cold-water streams have a specific discharge of 3×10^{-5} m/s. It has also been assumed that the discharge sites comprise 10% of the streambed. Therefore, as a gross approximation losses from groundwater to the stream may be calculated as the streambed area (length x width) times the specific discharge times 10%. The spreadsheet allows these to be used as variables, and if site-specific information is developed in future, they may be adjusted.

Based on host soils, and the shape of their valleys, several short streams are clearly conveyance watercourses. These have neither a loss nor gain from groundwater and are treated as a "zero" in the water budget. Losing streams are somewhat more problematic. The only diagnostics are documented warm water conditions, coupled with an elevation higher than the local potentiometric surface. To approximate losses from the creek to the aquifer, we assume the streambed condition will be the same as for the upward flowing streams (10% permeable coverage) and simply reverse that calculation. Where local soils did not indicate the likely presence of any permeable substrate, the streamflow gain/loss was reduced by a factor of three for the spreadsheet calculations. No allowance has been made for seasonality since it was beyond the scope of this study to search for detailed stream characterizations. This methodology, which is not widely used, is a very gross approximation in the absence of measured gradients or streamflow values. In other jurisdictions the streams are inventoried for width, depth, temperature and spot baseflow measurements, and such a onetime program would be invaluable to help calibrate the above assumptions.

The spreadsheet used to determine the water budgets contains the calculations for each significant watercourse. The net effect of the streams on groundwater discharge or recharge is then reported in the water budget summary table contained in each aquifer summary in Sections 4 and 5 of this report. As the stream specific information is gathered, the spreadsheets are capable of being updated as required.

2.2.8 Groundwater Pumping Impact Assessment

With the implementation of the *Water Sustainability Act* (WSA), a comprehensive inventory of both surface water and groundwater use will be developed in the form of water allocation amounts (not actual use). Thus, there is no database of the total groundwater use in British Columbia from which to assess groundwater pumping. Hatfield Consultants (2015) analyzed the potential groundwater use in

2015, to aid in the transition to the new groundwater licensing system under the WSA. Hatfield (2015) used a GIS-based methodology to calculate the likely groundwater use in each aquifer.

Initially, Hatfield (2015) used GIS to compile the primary land use and water use in the study area. The annual water use was then calculated by assigning the primary land uses (i.e., residential, industrial, commercial, etc.) an estimated or known water use per day. Each land use category encompasses all the variations; for example, the industrial category includes pulp and paper plants, mining operations, aquaculture, aggregate quarries and other smaller operations. The land uses were assigned a potential annual usage and through GIS queries, the total annual water use in each aquifer was calculated. The annual usage by land use type was determined by assumed values or standard water demand. For example, the assumed value for a multifamily residential lot was 0.775 m^3/day, which was determined by the average household size reported by the census and the average consumption per day per person reported by EC. Another example, the standard demand for a pulp and paper mill is 104,000 m^3/day, which is the median value of the current range of volumes that have been licensed. This method did not account for whether the water was being drawn from surface water or groundwater sources.

The values reported by Hatfield (2015) were used in the current water budget analysis but through consultation with the Cowichan Valley Regional District and the Mill Bay Waterworks District adjustment factors were used to produce a more realistic consumptive water use impact on the groundwater. For example, the majority of domestic users in the Cobble Hill/Mill Bay area have septic beds instead of municipally supplied sewer systems. In theory, this means that any water that is removed from the aquifer will be returned to the aquifer through infiltration to the septic bed, resulting in a net zero loss to the water supply within the aquifer. The spreadsheet has been prepared so that some fraction of consumptive use can be used, however for the purposes of this work (that is, to be conservative) we have assumed 100% consumptive use for all water taking. Where the individual aquifers have isolated water treatment systems, as determined from dialogue with the municipalities, a representative fraction of consumptive use could be used in the spreadsheet, however a 100% consumptive factor has been assumed as a starting point. Finally, all groundwater takings for irrigation purposes is also assumed to be 100% consumptive, and should future study determine a lesser amount the factor can be adjusted in the spreadsheet. In addition, future study will have to update water usage figures based on build out and a likely greater future demand.

For agricultural takings Ministry of Agriculture data were used for withdrawal from groundwater for irrigation based on van der Gulik et al. (2003). In a few key instances (aquifers 198, 203 and 206), values did not exist and estimates from Hatfield (2015) were used. The source of information is documented in each aquifer summary in the appendices.

With respect to surface water diversion and use, some are purposely not accounted for in the groundwater budgets. For example, in aquifer 0198, all stream water diverted for irrigation is from the Koksilah River and is not taken from the underlying bedrock aquifer. In this case, the water so diverted is from the collective sources feeding the Koksilah River, and while they are geographically within the aquifer area under consideration, they are not from that aquifer source. For these types of cases, the water taken is not considered as part of the water budget for the aquifer. Conversely, in the example of aquifer 0199, there is clear groundwater discharge into the Patrolas Creek, and all the surface water diversions are thus sourced from the aquifer via that creek. These water diversions are therefore part of their respective water balances. The water takings have been reported in Hatfield (2015) as their peak licensed capacity. It is our experience that the actual water taking is some fraction of this amount. Conversely, not all water takings are reported and thus there could be more water extracted than identified. However, there is no ability to judge what is actually being taken or is not being reported, as water diversions are generally not required to be metered in British Columbia. Thus, these amounts are conservatively over-estimated as the full quantity diverted in the spreadsheet summary. It is a recommendation of this report that all groundwater diverted under an authorization be considered for reporting on a daily basis, as is the case in other jurisdictions in Canada. In addition, key streams should be considered for ongoing flow monitoring to establish a basis for impact assessment.

2.3 Spreadsheet Summaries

The water budget for each aquifer area was calculated using an excel spreadsheet. The calculation was split into four separate components:

- Groundwater recharge that is the infiltration of meteoric water that reaches the water table;
- Groundwater flow through the subsurface (i.e., lateral groundwater flow through geologic units, vertical groundwater flow from overburden aquifers, discharge to the marine environment, etc.);
- Groundwater flow into or out of surface water bodies; and
- Water usage from the aquifer and hydraulically connected streams.

2.3.1 Groundwater Recharge

The spreadsheet includes both the area of each aquifer and the surplus weighting factor (called the Station Coefficient Factor developed in Section 2.2.4 above. These two values are fixed. The Shawnigan Lake station surplus is multiplied by the weighting factor and then applied to the aquifer area to calculate the volume of groundwater recharge in cubic metres per year. Table 6 below shows example recharge calculations for aquifer 0202. The effect of climate change on recharge is discussed in Section 3.2.3.

Table 6: Aquifer 0202 - example recharge calculation.

Variable	**Representative past Climatic Condition**		
	Hot/Dry	**Average**	**Cold/Wet**
Annual surplus (mm/year)	606	761	1,354
Station Coefficient Factor	0.975	0.975	0.975
Infiltration Coefficient	0.562	0.562	0.562
Area (m^2)	18,884,419	18,884,419	18,884,419
Annual infiltration volume (m^3/year)	6,273,162	7,872,973	14,012,739
Average Infiltration Rate (m/year)	0.332	0.417	0.742

2.3.2 Lateral and Vertical Groundwater Contributions

For the groundwater flow through the subsurface, each bedrock aquifer was divided into individual flow segments, which are identified by segment numbers (QGW#). These segments were determined by the hydraulic properties of the aquifer, as described in Section 2.2.6. The calculation table in the water budget spreadsheet allows for input of width (breadth) of each segment, the thickness of the saturated zone, the estimated hydraulic conductivity (K_{mb}), and the change of hydraulic head over a distance. For the purpose of this analysis, groundwater flowing out of the aquifer was assigned a negative value and groundwater flowing into the aquifer was assigned a positive value. For example, Table 7 below presents a row from the aquifer 0202 table.

Table 7: Aquifer 0202 - example of lateral groundwater contributions to aquifer 0199.

GW Flow Segment	Direction of Flow	Source or Receptor of Water	Width (m) - L	Depth (m) - D	Area (m^2) - A	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh	GW Flow (m^3/yr)
$Q_{GW}24$	Out	AQ 199	214	200	42,840	0.000000001	600	80	-180

The lateral groundwater flow in Table 7 was calculated as follows:

$$Q = K \times \frac{dh}{dl} \times A = K \times \frac{dh}{dl} \times L \times D = 0.000000001\, {}^{m}/_{s} \times \frac{80m}{600m} \times 214m \times 200m = 5.7 \times 10^{-6}\, {}^{m^3}/_{s}$$
$$= 180\, {}^{m^3}/_{year}$$

The amount of water flowing out of a segment will be equal to the amount of water flowing into the adjacent segment in the next aquifer. Within the spreadsheet, the flow was calculated in the originating aquifer as a negative outflow value, and the amount then transferred to the accepting aquifer as a positive inflow value, and labelled as to source.

In addition to the lateral groundwater flow, the vertical flow contributions were calculated for aquifers that have portions covered with overburden aquifers. This leakage is described in Section 2.2.5 above. For example, aquifer 0202 is partially overlain by aquifer 0201. Table 8 below shows the parameters used to calculate vertical leakage from aquifer 0201 into aquifer 0202.

Table 8: Aquifer 0202 - example of vertical groundwater contributions from aquifer 0201.

GW Flow Segment	Direction of Flow	Source or Receptor of Water	Leakance Factor (m/yr)	Area (m^2) - A	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh	GW Flow (m^3/yr)
$Q_{GW}48$	In	Leakage from AQ 201	0.300	2,112,633	--	--	--	633,790

The vertical groundwater flow was calculated in Table 8 as follows:

$$Q = Leakance \times A = 0.300\, {}^{m}/_{year} \times 2{,}112{,}633 m^2 = 633{,}790\, {}^{m^3}/_{year}$$

All of the lateral and vertical groundwater flows were summed to determine the total amount of groundwater entering or leaving each aquifer.

2.3.3 Surface Water Contributions

For each of the aquifers, the streams were categorized as a gaining stream, losing stream or as a conveyance feature, as per the methodology described in Section 2.2.7. The type of stream was determined by looking at available temperature records, and at nearby water well records by considering the hydraulic conductivity of the geologic unit underlying the stream. For gaining streams, the water levels in nearby water wells would be higher than the stream level indicating that groundwater would be moving up into the creek. For losing streams, the water levels in nearby water wells would be lower than the stream level indicating that water is moving down from the stream to the water table. The amount of permeable substrate available for movement into/out of the groundwater system has been assumed to be 10% based on the experience of the authors. This can be adjusted in the spreadsheet (under "Percent Permeable") where more information becomes available. For conveyance features, the hydraulic conductivity is very low indicating that the water is likely moving through the stream only and is not infiltrating down to the subsurface. An example of the surface water contribution table for aquifer 0202 is presented below in Table 9.

Table 9: Aquifer 0202 - example of surface water contributions to aquifer.

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable (%)	Length (m) - L	Width (m) - w	Flux (m/s) - F	SW Flow (m^3/yr)
Haril Creek	Unknown	Downward	10%	3800	2	0.00003	719,021

The flow to or from the streams is calculated as follows:

$$Q = L \times w \times F \times \% = 3800m \times 2m \times 0.0003\, {}^{m}/_{s} \times 0.1 = 0.023\, {}^{m^3}/_{s} = 719{,}021\, {}^{m^3}/_{year}$$

Similar to the groundwater contributions, if the water is flowing into the aquifer it is assigned a positive value and if the water is flowing out of the aquifer it is assigned a negative value.

All of the surface water flows were summed to determine the total amount of groundwater entering or leaving the aquifer. Monthly partitioning of this is described in Section 0.

2.3.4 Water Usage Contributions

The water usage contributions were calculated by taking the volumes reported in the Hatfield (2015) report. An adjustment factor as described in Section 2.2.8 above was applied to reflect likely actual usage where possible. An example of the water usage contribution from aquifer 0202 is seen below in Table 10.

Table 10: Aquifer 0202 - example of water usage contributions.

Water Usage	Groundwater Usage Volume (m^3/yr)			Comments
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	0	100%	0	Assuming 100% consumptive
Commercial	7,300	100%	7,300	Assuming 100% consumptive
Domestic	110,837	100%	110,837	Assuming 100% consumptive
Irrigation	6,458	100%	6,458	Assuming that 100% of the water is taken from a surface water source, AFTER having left the aquifer. (Min. of Ag)
Other	10,950	100%	10,950	Assuming 100% consumptive
Water Supply Systems	56,310	100%	56,310	Assuming 90% percent goes to septic beds, and 10% leaves the watershed as treated sanitary sewer discharge, usually to a large water body.
Total			**-191,855**	

The water usages were calculated as follows (the above example of domestic values was used for this example):

$$Q = Volume \times Adjustment = 110{,}837\, {}^{m^3}/_{year} \times 1.0 = 110{,}837\, {}^{m^3}/_{year}$$

In this example, the 100% consumptive use has been assumed to be conservative. The spreadsheet is set up to allow any percent consumptive to be used. Similar to the groundwater contributions, if the water is flowing into the aquifer it is assigned a positive value and if the water is flowing out of the aquifer it is assigned a negative value.

2.3.5 Flow Summary

All three types of groundwater contributions were summarized in a table, which then calculated the net gains and losses in each aquifer. An example from aquifer 0202 is seen below in Table 11.

The direct recharge was calculated by multiplying the area by the infiltration factor (in this case, 0.466 as determined by the GIS analysis). The leakage down from the overburden was calculated by multiplying the area by the infiltration factor the bedrock might accept (0.300). The losses are the sum of the negative values in each of the respective tables and the gains are the sum of the positive values in each of the respective tables. These values were rounded and carried to Section 4.3 of this report.

Table 11: Aquifer 0202 – flow summary.

Summary – 30-Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate (m/yr)**	**Q (m^3/yr)**
Gain	Direct Recharge to 0202	18,884,419	0.466	**8,801,581**
Gain	Leakage down from 0201	2,112,633	0.300	**633,790**
Loss	Lateral Ground Water	--	--	**-16,947,772**
Gain	Lateral Ground Water	--	--	**3,695,718**
Loss	Surface Water	--	--	**0**
Gain	Surface Water	--	--	**1,173,139**
Loss	Well Water Usage	--	--	**-191,855**
Net Gain				**14,304,227**
Net Loss				**-17,139,627**
Net Total (Gain - Loss)				**-2,835,400**

2.4 Uncertainty Evaluation and Groundwater Availability Assessments

Groundwater availability depends upon the accuracy of water budget estimates. An over estimate of groundwater inflows to an aquifer might over predict groundwater availability. Conversely, use of peak withdrawal volumes, instead of actual values, might suggest an aquifer is overused, when there is still water available. Thus, it is a good idea to understand the influence of the variability in the parameter estimates used in a water budget. This of course can be improved by drawing on specific independent observations such as water level maintenance or decline to provide additional insight. (This is necessarily done on a more aquifer specific basis.)

The summary of the water budget for each aquifer was examined. The degree of uncertainty was assessed for the various components. In the case of recharge, it is a function of the available water. Topography and soils do not vary from year to year, and ground cover can change with forestry and land development. The degree of change does not generally exceed 5 to 15% of the watershed, thus the estimates of recharge are tightly constrained when compared to other components.

The stream losses and gains are based on very high-level estimates and have no calibration with real time data. Streamflow measurements, when available, can have an error of estimation of plus or minus 20%. However, hydrometric data were essentially unavailable for this study. Thus, the estimation techniques used here can be off by 100 to 500 percent, and are thus not well constrained. On the other hand, the stream flows are not significant compared to the groundwater flow, so there is only a moderate influence on the water balance.

The greatest source of uncertainty in the water budget occurs from the groundwater flow estimates. Hydraulic conductivity estimates are logically easy to see in their relative magnitude between rock types or soil types. However, their absolute value could be off by as much as 1000% (i.e., one order of magnitude or more). Hydraulic gradients are constrained by the topography and are usually overestimated, but to within 20% or so. Cross sectional area contributing flow can be quite subjective in fractured bedrock. We have generally used a "skin" of 200 m for this work, but this is subjective and may change by 100% or more. All these factors contribute to the calculation of groundwater flow by the Darcy principle. Thus, selection of hydraulic conductivity has a very high influence on the water budget. Further to this, the way aquifer boundaries are drawn can also affect uncertainty. With the current boundaries, flux must be calculated across the boundaries. It is our understanding that these boundaries were not necessarily drawn years ago with calculation of flux in mind.

The initial water balance trials usually found that "water in" to "water out" was within 200%, and very often within 50% of each other. Varying recharge made little difference, as described above. Understanding streamflow more accurately can account for part of the differences. However, adjusting the hydraulic conductivity by a factor of 2 or 3 or 10 caused the water budget to swing widely from positive to negative and in total amounts. Therefore, estimates of groundwater availability have a high uncertainty. For each aquifer, we comment on the water budget and the inherent constraints, and the uncertainties where no data exists to calibrate or corroborate the interpretation. Section 6 of this report will show that when considered on the whole of the study area (that is, all eleven aquifer areas), the agreement between water in and water out is quite close. Thus, caution should be exercised on the smaller sub-divided areas and need to be supported by more specific information.

Finally, it is important to understand the level of stress on an aquifer area. In other jurisdictions, stress thresholds have been developed to determine when a watershed or sub-watershed is under some threat from an availability point of view. For example, the Province of Ontario developed water quantity stress thresholds which were used to trigger further study, and implemented a three tier water budget analysis process (Ontario, 2013). The stress thresholds were assigned when consumptive use (i.e., water that is not returned to the watershed) exceeds a certain value as a percentage of the available water. For example, a water quantity stress level was considered to be low if this was less than 10%, moderate when it lay between 10 and 25%, and a significant water quantity stress threshold was considered to be greater than 25% of the inflow. We have adopted this protocol and applied it to the wet/cold, normal and hot/dry conditions, using the available recharge as the available water.

2.5 Monthly Water Budget

Based on the annual water budgets prepared here, monthly water budgets were prepared to examine how water availability varies throughout a typical year. Several components of the water budget are amenable to such an undertaking, whereas it has been found that others are not. For example, the calculation of water surplus, which governs recharge patterns, is calculated on a monthly basis. Figure L-5 in Appendix L shows the monthly variance in the surplus, for each of the average annual, hot/dry and cold/wet conditions. A deficit condition prevails each summer to early autumn period, and a surplus condition in the eight or so months beginning late in the calendar year. So this is useful for seasonal calculations. Some water usage varies subtly year-round but is steady, such as municipal or domestic groundwater use, and a monthly pattern is not significant.

Other components of the water budgets are difficult to determine on a monthly basis. Irrigation uses generally prevail in the drier months and growing seasons. Whereas irrigation values are mostly based on van der Gulik et al. (2003), which took into account crop types and irrigation practices, there are insufficient groundwater usage data to be able to reliably predict actual use, short of interviewing all irrigators. There is often not a requirement to measure, which is a recommendation of this report.

The leakage of water to depth from overburden aquifers into bedrock will be ongoing year round, and there will only be subtle shifts in driving gradients as water tables rise and fall seasonally. Thus, empirical estimates of the seasonal shift are qualitative at best. The calculated lateral flows into and out of the various aquifers are similarly constrained. It has been determined that the saturated thickness is probably the most sensitive factor, and the lateral gradient would fluctuate by a small fraction. The data does not exist to quantify this. The water budgets presented below in Sections 4 and 5, and explained above in Section 2.2.6 used lateral hydraulic gradients estimated from potentiometric surfaces in overburden, and topography in bedrock. Potentiometric surfaces were derived from water well information, specifically static levels from all different times of the year. Derivation of subtle changes in gradient by season is not possible with this data and surrogate processes are used below.

The subsections below describe how a monthly partitioning was achieved based on the above limitations. The following factors should be ascertained and documented to improve monthly water budget estimates:

- For surface water, monthly streamflow profiles, preferably under baseflow conditions;
- An assessment of individual aquifers to establish hydraulic gradients and hydraulic conductivity conditions, as well as seasonal water level measurements; and
- Reporting of metered daily water use by all groundwater users.

Sections 4 and 5 provide guidance on the influence of extreme conditions such as the hot/dry and the cold/wet conditions discussed in Section 2.2.2.2.

The following subsections derive the monthly factors for the components of the water budget. These monthly factors are multiplied by the annual volumes to derive the monthly volumes to be expected.

2.5.1 Monthly Variance in Recharge

The water budgets described in Section 2.2 were calculated on a monthly basis. Therefore, there exist values of monthly surplus and deficits and an overall pattern can be seen. To estimate monthly factors, a monthly fraction was derived by dividing the amount of the surplus/deficit by the total average annual surplus. For example, Table 12 shows the average surplus in February is 124.7 mm, which when divided by the average annual surplus of 760.9 mm yields a monthly partitioning factor of 0.164. This method, which is applied to the water budget derived from Thornthwaite and Mather, uses the average annual amounts for each month, so the length of the month has been included in the analysis. Hence, the results may be applied to all aquifers as a general pattern. Table 12 shows these results for the wet/cold, average annual and hot/dry conditions. Section 3.2.3 discusses the anticipated effects with regard to future conditions.

Since the recharge is proportional to the surplus, these factors can be applied to partition the average annual recharge on a monthly basis by simply multiplying them by the average annual recharge amount for each aquifer. It is important to note that this applies to the recharge water and that subsequent rise and fall of the water levels in the aquifer will typically have a time lag, due to the relatively slow movement of groundwater flow.

Table 12: Derivation of monthly partitioning factors.

Month	Wet/Cold Climate		Average Climate		Hot/Dry Climate	
	Surplus/*Deficit* (mm)	**Wet/Cold Partitioning Factor**	**Surplus/*Deficit* (mm)**	**Average Annual Partitioning Factor**	**Surplus/*Deficit* (mm)**	**Hot/Dry Partitioning Factor**
Jan	355.1	0.281	191.3	0.251	156.9	0.307
Feb	359.5	0.285	124.7	0.164	90.0	0.176
Mar	133.3	0.105	89.9	0.118	139.9	0.273
Apr	*-16.0*	*-0.013*	21.6	0.029	8.4	0.016
May	*-13.0*	*-0.010*	*-26.0*	*-0.034*	*-33.0*	*-0.064*
Jun	*-34.0*	*-0.027*	*-41.0*	*-0.054*	*-42.0*	*-0.082*
Jul	*-44.0*	*-0.035*	*-40.0*	*-0.052*	*-36.0*	*-0.070*
Aug	*-18.0*	*.-0.014*	*-18.0*	*-0.024*	*-15.0*	*-0.029*
Sep	-8.0	-0.006	-6.0	*-0.008*	*-10.0*	*-0.019*
Oct	126.1	0.100	65.8	0.086	25.5	0.050
Nov	203.8	0.161	201.8	0.265	100.1	0.196
Dec	217.9	0.173	196.8	0.259	127.0	0.248
Sum	**1262.8**	**1.000**	**760.9**	**1.000**	**511.9**	**1.000**

2.5.2 Monthly Variance in Water Movement Dictated by Driving Head

Several components of the water budget rely on the driving head. For example, lateral groundwater flow will depend upon the position of the water table. Similarly, leakance from the overburden to the bedrock will be governed by potentiometric head. For the formulation of streamflow gains and losses presented in Section 2.2.7, the movement is governed by the vertical groundwater pathway. River heads do not vary appreciably, but the head in the receiving aquifer will, so the change in vertical gradient governs flow into or out of the aquifer beneath the stream.[3] Quantification of this is described in Section 0 below.

To determine the monthly partitioning factors, the likely change in driving head was examined by using the provincial groundwater monitoring network. Three provincial observation wells (OW) exist in the area and were initially examined: OW233 in Cowichan Bay, OW345 at the Arbutus Ridge Golf Course, and OW320 just east of Cobble Hill (Figure 1). All three are in the deep overburden aquifer 0197. OW233 could not be used as anthropogenic water withdrawals nearby affect the data and masks the natural hydrograph. Similarly, the pumping well at the golf course draws OW345 down substantially in the June to September period. This too was the case for OW320 although it showed much less influence. Based on discussions with staff from the ENV and the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNR), representative groundwater level information is available from an alternative well (88-2) in the report by Kreye et al. (1996). This monitoring information spans both a nearly typical year (1991) and the hot/dry scenario of 1989. This information has been assumed to represent natural water fluctuations, which are up to 2 m per year. Figure 7 has been prepared for both a nearly typical year (1991) and the key hot/dry year of 1989. Unfortunately, an example of a wet/cold year was not found in the period of record.

[3] Consideration was given to using the streamflow patterns to derive monthly availability of surface water from the stream, however this was discarded as stage (as a surrogate for driving head) of a river is not linearly related to streamflow (although they are proportional).

Figure 7 shows there is a seasonal rise in water levels over the first part of each year to about May. At this point the rainfall ceases, and as seen in Table 12 in the previous subsection, there is a deficit in the water surplus also beginning in May. Water levels begin to decline at that point, falling steadily to the end of the year. There are limitations however as 1991 did not experience a large amount of late year rainfall and the hydrograph does not respond upwards as would be expected. It is concluded that the available examples are not ideal, and it is recommended that a suitable example be found and incorporated in future. Figure 7 expresses the differences between the average annual head for each case and the monthly head in this well.

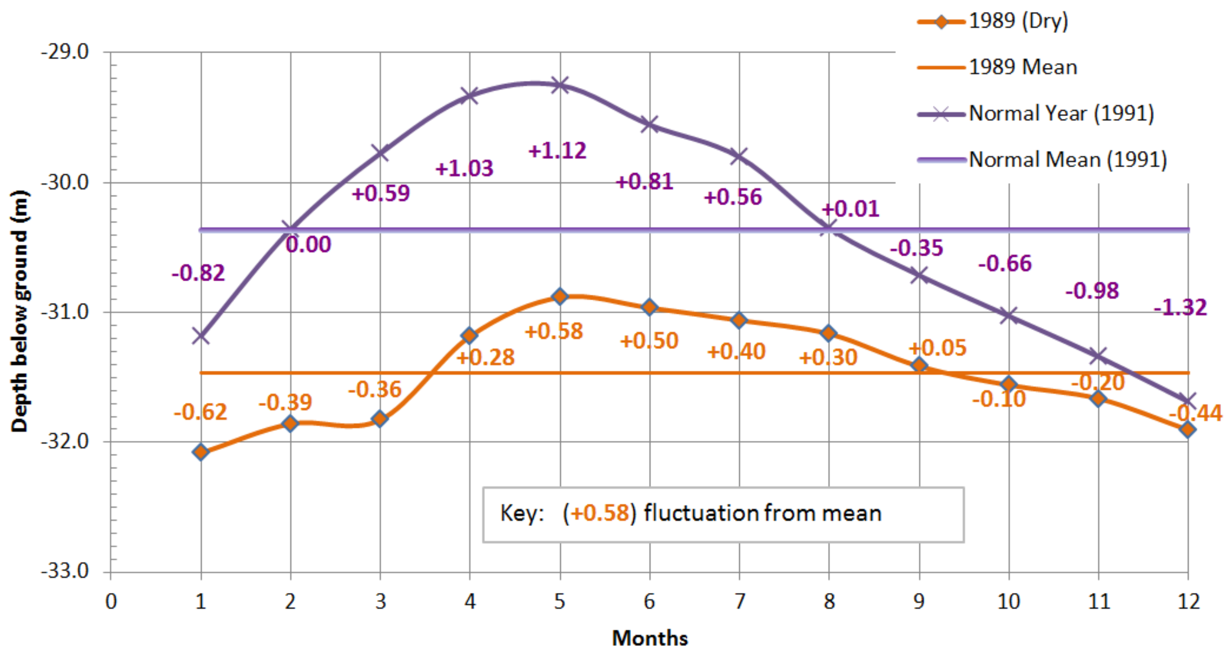

Figure 7: Representative well 88-2 annual hydrographs.

Based on this information monthly partitioning factors were derived that will govern groundwater flow as a function of hydraulic gradient, using the following formula:

$Q_{month} = Q_{annual} \;\; X \;\; \{ (dh + h_{diff}) / dh \} \;\; X \;\; \{ Days_{month} / Days_{year} \}$

where Q_{month} is the flow for the month in question,
Q_{annual} is the average annual flow determined from the annual water budget,
dh is the head difference along each flow pathway
h_{diff} is the monthly head change as calculated above from 88-2,
$Days_{month}$ is the number of days in the month in question
$Days_{year}$ is the number of days in 1989 and in 1991, which is 365.

It was found that h_{diff} does not vary greatly when compared to the dh along each pathway, so only a very subtle variation exists between months. In fact, the length of the month has a much greater influence on the result. Table 13 lists the monthly partitioning factors, as derived above. Multiplying these factors by Q_{annual} yields estimates of monthly flows.

These factors are applied to the total horizontal groundwater inflow and outflow in the spreadsheets when deriving seasonal fluctuations. They are also applied to the leakance from the overburden to the bedrock, a vertical groundwater flow pathway.

Table 13: Monthly partitioning factors based on potentiometric head change.

Month	Cold/Wet Factor	Average Annual Factor	1989 Hot/Dry Factor
Jan	0.081	0.081	0.082
Feb	0.078	0.078	0.076
Mar	0.087	0.087	0.084
Apr	0.086	0.086	0.083
May	0.090	0.090	0.087
Jun	0.086	0.086	0.084
Jul	0.087	0.087	0.087
Aug	0.085	0.085	0.086
Sep	0.081	0.081	0.082
Oct	0.082	0.082	0.085
Nov	0.078	0.078	0.081
Dec	0.079	0.079	0.083
Total	**1.000**	**1.000**	**1.000**

2.5.3 Monthly Variance in Water Movement Below Streams Dictated by Driving Head

For the formulation of streamflow gains and losses presented in Section 2.2.7, the movement is governed by the groundwater pathway, as mentioned above. River heads do not vary appreciably, but the head in the receiving aquifer will, so the change in vertical gradient governs flow into or out of the aquifer. This can present a counter-intuitive effect, in that for both losing and gaining streams, the aquifer nets more water in dry conditions, and nets less water in wet months.

There are four scenarios, which are combinations of losing or gaining streams, in wet or dry months. These can be expressed in the following manner:

- For the case of a GAINING STREAM, the aquifer has a potentiometric head higher than the stream level and is losing water to the stream. In a dry month, the potentiometric head goes down by more than the stream level and thus the upward gradient is reduced and thus the aquifer loses less water. That is, it retains more water, which is a relative INCREASE in aquifer storage.
- For the case of a LOSING STREAM, the aquifer has a potentiometric head lower than the stream level and is gaining water from the stream. In a dry month, the potentiometric head goes down by more than the stream level and thus the downward gradient is increased and thus the aquifer gains more water. This too is a relative INCREASE in aquifer storage.
- For the case of a GAINING STREAM, where the aquifer is losing water to the stream, there is a relative DECREASE in aquifer storage in a wet month. This is because the potentiometric head goes up by more than the stream level and thus the upward gradient is increased and thus the aquifer loses more water.
- For the case of a LOSING STREAM, where the aquifer is gaining water from the stream, there is a relative DECREASE in aquifer storage in a wet month. This is because the potentiometric head goes up by more than the stream level and thus the downward gradient is decreased and thus the aquifer gains less water.

Table 14 has been set up to show the monthly factors for these conditions. Since it is partly head driven, then it is reasonable to make use of the pattern of monthly changed established in Section 2.5.2 above. However, the pattern is altered to reflect the fact that both losing and gaining steams contribute more water to the aquifer in dry months and contribute less in wet months. This was done by reversing the factors around the relative proportion of the month. For example in April, a short and wet month, the potentiometric factor is 0.087, whereas the month just occupies 0.082 of the year. The difference is 0.005, which is then subtracted from the monthly proportion to give 0.077. This is a relative reduction in a wet month, as per the last two bullets above.

Table 14: Derivation of aquifer gains/losses from streams by month.

Month	Factor	Monthly Proportion of Year	Difference from Monthly Proportion	Monthly Aquifer from Stream Factors
Jan	0.086	0.085	-0.001	0.084
Feb	0.077	0.077	0.000	0.077
Mar	0.088	0.085	-0.003	0.082
Apr	0.087	0.082	-0.005	0.077
May	0.089	0.085	-0.004	0.081
Jun	0.084	0.082	-0.002	0.080
Jul	0.083	0.085	0.002	0.087
Aug	0.082	0.085	0.003	0.088
Sep	0.078	0.082	0.004	0.086
Oct	0.081	0.085	0.004	0.089
Nov	0.081	0.082	0.001	0.083
Dec	0.084	0.085	0.001	0.086
Total	**1.00**	**1.00**	**0.00**	**1.00**

2.5.4 Monthly Variance in Consumptive Use

As mentioned previously there are two specific patterns to consumptive use. The first is associated with steady uses such as municipal water taking, or industrial uses where the process is carried out year round. The second are irrigation related uses where the pumping period is largely in the growing season and more of a maintenance level in the latter part of the summer. Multiplying these factors by the annual consumptive use yields estimates of monthly consumptive uses. Table 15 has been prepared to show these factors by month.

Table 15: Consumptive use patterns.

Month	Annual Use Factor	Irrigation Use Factor
Jan	0.06	0.00
Feb	0.07	0.00
Mar	0.08	0.00
Apr	0.08	0.00
May	0.09	0.10
Jun	0.10	0.25
Jul	0.11	0.30
Aug	0.12	0.30
Sep	0.10	0.05
Oct	0.08	0.00
Nov	0.07	0.00
Dec	0.06	0.00
Total	**1.00**	**1.00**

In the first instance, a representative allocation for the steady uses has been adopted that reflects the lower needs in the cooler months, and increased need in the hotter months, when uses of water for cooling become more acute. The steady use factors are not derived from any specific data but reflects our experience in British Columbia. It is recommended that municipal records be examined to see if a more local pattern can be established.

The agricultural demand model prepared by van der Gulik et al. (2003) did not include monthly breakdown and the annual amounts were used in this report. Therefore, in the second instance, a qualitative allocation for irrigation uses has been adopted based on the examination of some irrigation well data from the area. Once daily records are required to be collected, then this pattern can be more clearly established to more realistically define the monthly water budget.

2.5.5 Summary of Monthly Factors

To derive the monthly water budgets presented in the individual aquifer sections of the spreadsheet, the annual use was multiplied by the factors derived above. Figure 8 shows the monthly variation of these factors, which are found in the last tab of the spreadsheet.

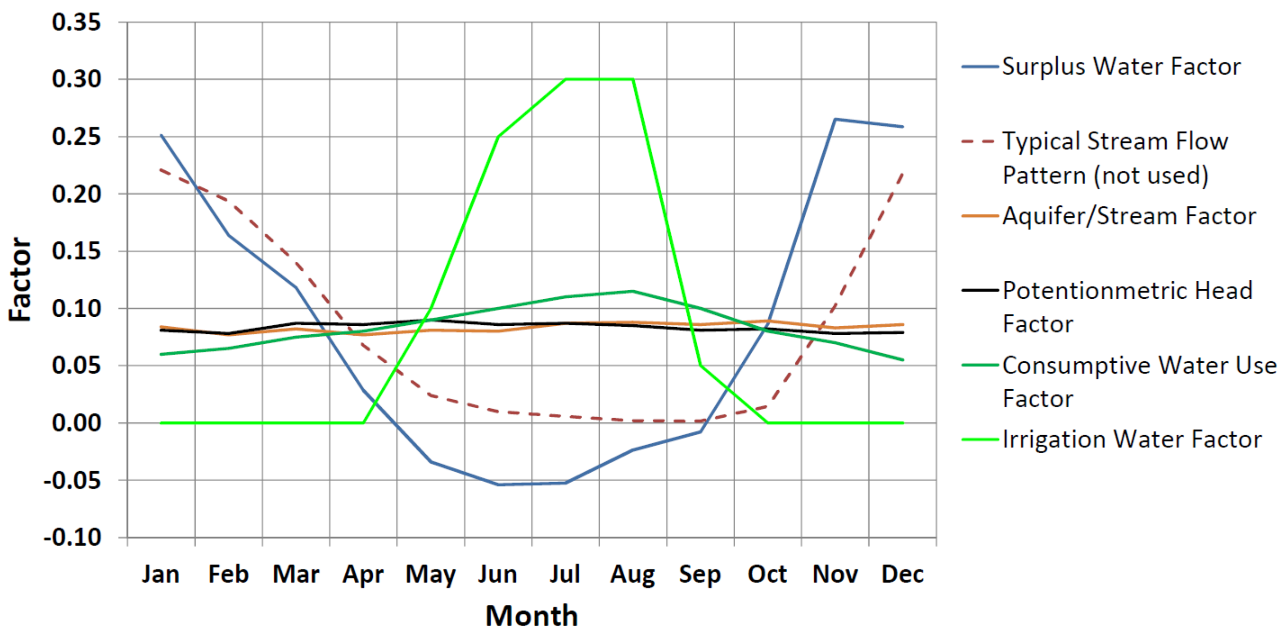

Figure 8: Monthly allocation factors.

2.6 Factor of Safety for Groundwater Allocation

Groundwater conditions in many aquifers in B.C. exist in dynamic equilibrium – taken over a long term, inputs of water into the aquifer approximately balances the outputs of water from the aquifer. Within a year, however, the balance may not zero. In a year when there is extra recharge, the outflows will begin to increase to maintain a balance. Sometimes the outflows may take longer than that particular year, and in a dry year there may be residual surpluses from previous years. This depends upon the local aquifer complexity such as the presence or absence of aquitards, the local storage capability, and the length of groundwater pathways.

When consumptive uses occur in an aquifer area, there may be less outflow as a result of this use of the resource. Where water is abundant this works perfectly well. However, in a dry year there is not as much water available for use, particularly because natural ecologic uses such as cold-water streams, groundwater fed wetlands, still need some of the available water to be sustained. When anthropogenic consumptive uses accumulate over time, these types of natural systems will be stressed more than they normally might be, particularly in those hot/dry years. In addition, there is a strong seasonality to the natural movement of water in the study area, given the very low precipitation for 4 or 5 months (summer-early fall) of the year.

The amount of available water is simply not the available recharge, but that portion of the recharge that is not needed to sustain natural systems or pre-existing uses. For the analyst to provide adequate protection, future allocations should have a factor of safety to allow for those very dry years, and to ensure that the aquifer is not "mined" of its water. Factors of safety will therefore have to be aquifer specific, taking into account natural uses of the groundwater, existing flow patterns, abundance of precipitation (and thus surplus, which recharge depends upon), land use, climate change, and current stress on the system.

Other jurisdictions have adopted arbitrary factors of safety, for example, in 2006 the Province of Ontario adopted a value of 10% for sustenance of the natural environment in their source protection planning guidance documents (Ontario, 2013). This was their starting point for planning purposes, and a suggested starting point for this study area is provided in the ensuing paragraph. However, as British Columbia develops their approach, consideration should be given to basing the sustenance of the natural environment more on specific ecologic conditions at any locale, perhaps as a responsibility of the water licence applicant.

For the purposes of this report, a factor of safety of 20% is adopted for on-going diversions, and 40% for the months of June to September for seasonal diversions. These factors have been used for the more stressed: aquifers 0197 and 0206, and eastern parts of aquifers 0204 and 0207. In the aquifers where there is presently little consumptive use, the factors of safety can be reduced to 10% and 20% (aquifers 0200, 0202, 0203, inland parts of aquifers 0204 and 0207). The use of these factors would be simple for examining the water available for allocation. In a particular water budget, a line item would be developed that took the surplus water for each month and reserve the factor of safety percentage. The remainder would then be available for allocation. This should be applied to the hot/dry conditions to determine the remainder for allocation, so that overallocation is avoided.

It is essential to understand that these factors of safety are subjective, based on professional judgement. It is recommended that these be refined based on an aquifer-by-aquifer understanding of the natural and built environments, and as additional monitoring information and knowledge is gained over time.

3. REGIONAL ENVIRONMENTAL SETTING

3.1 Location

The study area is located on southeast Vancouver Island adjacent to the marine shorelines of Cowichan Bay, Satellite Channel, and Saanich Inlet. The study area covers approximately 16,700 hectares and is centred on Latitude 48°40’41” and Longitude 123°36’20” (UTM 5391830mN 455420E Zone 10) as shown on Figure 1. Map coverage of the study area is provided by NTS map sheets 092B/12 and 092B/13 (1:50,000 scale) and TRIM map sheets 092B.052, 092B.062, 092B.063, 092B.072, and 092B.073 (1:20,000 scale).

The study area is located within the municipal jurisdiction of the Cowichan Valley Regional District, and includes Electoral Area C and parts of A, B, D, and E.

3.2 Climate

The climate of the study area is described as "Transitional Cool Mediterranean" and characterized by warm, humid summers and mild, wet winters (Tuller, 1979). The study area is positioned within the rain shadow of the Vancouver Island Insular Ranges to the west, but is also influenced to a limited extent by the Olympic Mountains to the south. The majority of the area's precipitation falls during the winter as rain. Moisture deficits are common in summer due to normal dry conditions. Prevailing winds blow mainly from the southeast in winter, while northwest winds dominate in summer.

3.2.1 Average Annual Conditions

The study area contains one active weather station maintained by EC, "Shawnigan Lake EC#1017230" (EC, 2000), which is located centrally to the study area near its south end at an elevation of 159 m above mean sea level (amsl) (Figure 4). Historical weather statistics for this station over the period 1977 to 2006 indicate the mean daily temperature for this area is 9.8°C. December is the coldest month of the year with a mean daily temperature of 3.1°C, while August is the warmest month with a mean daily temperature of 17.8°C. Generally, the Shawnigan Lake area is prone to prolonged periods of heavy rainfall and intense, short-duration storm events during the winter months, and is relatively free of heavy precipitation during the summer. The Shawnigan Lake station receives on average 1,240 mm of precipitation per year, with over 80% of this amount falling between the months of October and March. The minimum mean monthly precipitation is 23.2 mm occurring in July, while the maximum mean monthly precipitation is 220.8 mm occurring in November. The study area also experiences limited amounts of snowfall during the winter months, with maximum mean monthly accumulations of 21.5 cm occurring in January at higher elevations. Monthly average temperature, rainfall, and snowfall, and total precipitation data recorded at this station for the 1977-2006 period are listed in Table 16.

Table 16: Climate normal statistics, Shawnigan Lake EC#1017230 – 1977 to 2006.

Monthly Average	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	3.1	4.3	6.0	8.7	12.1	15.1	17.6	17.8	14.8	10.0	5.5	3.1	9.8
Rainfall (mm)	179.9	125.3	112.0	68.4	48.9	39.5	23.3	28.3	37.4	109.1	210.7	187.6	1170.4
Snowfall (cm)	21.5	13.4	5.9	0.1	0.0	0.0	0.0	0.0	0.0	0.6	10.1	18.9	70.5
Precipitation (mm)	201.4	138.7	117.9	68.5	48.9	39.5	23.3	28.3	37.4	109.7	220.9	206.2	1240.5

Two other active weather stations maintained by EC are located within 2 km of the north and south ends of the study area, "Sooke Lake North EC#1017563" and "Duncan Kelvin Creek EC #1012573", respectively, however they do not have temperature data. Station Sooke Lake North is situated at an elevation of 231 m amsl, receives higher annual precipitation (1,497 mm) than Shawnigan Lake, and may provide analogous weather information for much of the study area's upland topographic zones south, west, and north of Shawnigan Lake. Conversely Duncan Kelvin Creek is situated at an elevation of only 103 m amsl, but also receives higher annual precipitation (1,361mm) than Shawnigan Lake. It may provide analogous weather information for the study area's lowland topographic zones above Mill Bay and Cowichan Bay.

An analysis of historical weather data from these active stations and two inactive climatic stations in the Mill Bay and Glenora areas by Worley Parsons (2009) indicated that total annual precipitation varied significantly between the stations. This suggests that the study area's variable terrain may have created area-specific microclimates that could significantly impact the water surplus locally.

To examine this variation throughout the study area, four active EC weather stations within or in close proximity to the study area and were used to calculated climate norms and mean water surplus between 1977 to 2006. Values were extrapolated between stations, accounting for prevailing winds and terrain when possible. The stations included Shawnigan Lake EC#1017230, Victoria International Airport EC#1018620, Nanaimo EC#1025370 and Cowichan Lake Forestry Station EC#1012040, as shown on Figure 4. The two stations at Sooke Lake and Duncan Kelvin Creek did not include temperature data so had to be excluded from the analysis.

Average monthly actual evapotranspiration (AET) data for the study area were taken from water budget tabulations for the four stations using the Thornthwaite and Mather (1957) method. The method accounts for water availability in the following fashion. When the total available free water equals or exceeds the potential evapotranspiration (PET) for the period, actual evapotranspiration (AET) is set equal to PET. When the total available free water is less than the PET for the period, water is drawn from soil storage (assumed to be 150 mm on average as described in Section2.2.2.1) to satisfy the evaporative demand. A summary of estimated annual AET and surplus from the Thornthwaite and Mather analysis at the four stations is provided in Table 17. Estimates of monthly AET and surplus at the Shawnigan Lake EC#1017230 station are presented in Table 18.

Table 17: Estimates of average annual AET and surplus by meteorological station.

Meteorological Station	Latitude	Longitude	Elevation (amsl)	Average Annual Precipitation (mm)	Average Annual AET (mm)	Average Annual Surplus (mm)
Nanaimo A	49.05^{o} N	123.87^{o} W	28.0	1,157	493	664
Cowichan Lake Forestry	48.82^{o} N	124.18^{o} W	176.8	2,163	558	1,605
Shawnigan Lake	48.65^{o} N	123.63^{o} W	159.0	1,241	480	761
Victoria International Airport	48.65^{o} N	123.43^{o} W	19.5	878	463	415

Table 18: Estimates of average monthly AET and surplus , Shawnigan Lake EC#1017230 station (1977-2006).

Month	Temperature (°C)	Precipitation (mm)	Actual Evapotranspiration (mm)	Surplus (mm)
Jan	3.1	201	10	191
Feb	4.1	139	14	125
Mar	6.0	118	28	90
Apr	8.7	68	47	21
May	12.1	49	75	-26
Jun	15.1	39	80	-41
Jul	17.6	23	63	-40
Aug	17.8	28	46	-18
Sep	14.8	37	43	-6
Oct	10.0	110	44	66
Nov	5.5	221	19	202
Dec	3.1	206	9	197
YEAR	**9.8**	**1,241**	**480**	**761**

3.2.2 Extreme Annual Conditions

The study area is subject to extreme seasonal swings, with very wet conditions from November to May and then very dry conditions from June to September. As shown in Table 17 above, precipitation is higher in the upland area towards the south and west. Seasonal water shortage conditions are prevalent throughout the developed region, particularly when a dry year occurs, or a series of dry years occur. However, one dry year may not seem too adverse, if there are wet years bracketing them. As described in Section2.2.2.2, the meteorological records were assessed for critical 36-month periods of hot/dry and cold/wet conditions as a basis to assess these extreme annual conditions. Table 19 summarizes the results.

Table 19: Summary of extreme annual surplus (mm) for Shawnigan Lake station.

Year(s)	Annual Surplus (mm)	Average Surplus (mm) (3-year or 30-year)
Cold and Wet		
1997	982	1100
1998	1054	
1999	1263	
Hot and Dry		
1987	559	556
1988	598	
1989	512	
Average Annual		
1977-2006	--	761

The annual surplus in 1999 represents an extreme year, as it is the highest in the 30-year period, and was preceded by two above average years. The average surplus of 1100 mm is 45% greater than the 30-year average of 761 mm. The maximum surplus of 1263 mm observed in 1999 is 66% greater.

For the hot/dry condition, the numbers are also revealing. The three-year average low surplus of 556 mm is 27% smaller than the 30-year average of 761 mm. The minimum surplus of 512 mm, observed in 1989, is 33% lower, and followed on the heels of two very dry years.

These conditions have a great influence on the aquifer water budgets presented in Sections 4 and 5 of this report, as the recharge is the key source of water, and the driving force for groundwater and surface water flow.

3.2.3 Climate Change

Whereas the hot/dry and cold/wet conditions considered above are based on historical climate records for the area, consideration has to be given to potential future conditions that exceed historical records. In particular, the projected changes in climate may introduce a condition that is more severe than that used here. To examine this scenario, the CVRD has provided future climate scenarios for 2020, 2050 and 2080, as derived by the regional climate service, Pacific Climate Impacts Consortium (PCIC). PCIC maintains a series of global climate models that provide a range of results into the future, the median value of which has been used here.

The CVRD stretches from the Malahat to south of Nanaimo and from the southern Gulf Islands to the west coast of Vancouver Island. The CVRD covers an area of approximately 3,475 km^2. The western portion of the CVRD is predominately mountainous terrain. The remainder of the region features valleys, agricultural land, lakes and rivers, and urban landscapes. CVRD staff selected the climate change results for the study area, which is the eastern portion of the CVRD.

3.2.3.1 *Nature of Precipitation Events*

The intensity and magnitude of precipitation on events are projected to increase. The U.S. Pacific Northwest models predict increased extreme precipitation in the winter, and increasing rain-on-snow events accompanied by more severe flooding (Municipality of North Cowichan, 2012). The data provided from PCIC projects for 2050 a 17% increase from the baseline of 75 mm single-day maximum precipitation events. For the 2080's the single-day maximum precipitation increase further by 30% from the baseline. The change in the five-day maximum precipitation is predicted to increase as well but not as great as the single-day maximum precipitation. In the 2020's, the five-day maximum precipitation is expected to increase 10% from the baseline of 177 mm while in the 2080's it is expected to increase 23% from the baseline. The increase in intensity and magnitude may result in a shift to more rain-driven streamflow. The following sections anticipate a greater recharge, but this will be somewhat tempered by the possibility that more intense events will reduce the time available for water to soak in. A net increase in recharge should however be anticipated.

3.2.3.2 *Nature of Anticipated Water Use and Landform Changes*

With the longer summers, there will be a longer growing season, and hence a greater demand for irrigation water. If irrigation is conducted efficiently, this water will be returned to the atmosphere as evapotranspirative losses from the water budget. If the population continues to increase, the need for more agricultural land will occur. Conversion of forested lands to agriculture will reduce the Infiltration factor by about 0.1, and hence a net loss in recharge will occur, unless the planning process is amended to mandate balancing pre and post development recharge. Commensurate with the greater populations will be an increase in land development, taking some forests and some agricultural lands and further reducing infiltration factors. Whereas this latter effect was discussed in Section 2.2.3.1, the net of these factors is beyond the scope of this preliminary water budget to assess into the future.

3.2.3.3 *Precipitation and Temperature Change Projections*

The PCIC has an online tool for climate change projections called Plan2Adapt, which are based on a standard set of global climate models. Using projections from this tool, CVRD provided local area climate projections downscaled specifically to the region, which were then applied to the study area (CVRD, 2017b). Based on these results, temperature for the Cowichan region as a whole shows a strong increasing trend. This is also reflected for the study area. The annual mean temperature in the 2020s is projected to change +1.3°C from the baseline[4] (1980 - 2000). Annual temperatures continue to rise as the projected change in the 2050s from the baseline is +2.8°C and +4.6°C in the 2080's. The annual trend indicates an increase in precipitation. The projected change in annual precipitation in the 2020's from baseline is +3% with the summer decreasing by 9% and the autumn/winter increasing by 5%. In the 2050's, annual precipitation is projected to increase by 6% from baseline, with winter precipitation increasing 5% from baseline and summer precipitation decreasing 22% from baseline. Projections for the 2080's show annual precipitation increasing by 12% from baseline, with winter precipitation increasing 13% from baseline but summer precipitation decreasing 34% from baseline.

[4] The baseline used by PCIC is not coincident with the 30-year average used in this report, although a brief review shows that they are similar in pattern and magnitude.

3.2.3.4 *Effect on Water Surplus*

Precipitation does not strictly govern the availability of groundwater resources, rather it is the recharge that results from the water surplus, after evapotranspiration has occurred, that is the most important factor. To understand this, the Thornthwaite and Mather method was applied to the predicted 2020, 2050 and 2080 data sets produced by PCIC. Their results are presented in seasonal format, and were converted to monthly values as follows. For each month in a three-month season, the temperature was distributed according to the pattern in today's average annual values. The precipitation was similarly subdivided on a pro-rata basis by month length and the average annual pattern. Once monthly values of each season were so derived, the Thornthwaite and Mather method was applied to the synthesized monthly data, utilizing the geographic coordinates of the Shawnigan Lake Station as an approximate centroid of the study area. It may be worthwhile to examine the underlying daily data sets produced by them to more accurately apply the Thornthwaite and Mather analysis, however this was beyond the scope of this present project.

Table 20 has been prepared to show the results of this analysis. Summary charts of each component of the surplus calculation are shown in Figure 9, and may be compared to the results of the average annual and hot/dry conditions. As described in Section 3.2.3.3 above, temperature rises into the future, and is even hotter than the 1989 hot/dry scenario. Annual precipitation also rises, increasing 187 mm by 2080. This is expected to include increased intensity storms, which will generate more runoff and the ratio of infiltration to runoff will be lower. Actual evapotranspiration rises in response to both increased temperature and more available water, but by only as much as 34 mm in 2080. Thus, the actual surpluses available for recharge and runoff are also greater in the future scenarios, reaching an additional 153 mm in 2080. Recharge should increase accordingly, and one could interpret that there will be more groundwater, on an average annual basis, than is the present case.

How this is distributed seasonally is important. The monthly results have been grouped by similar conditions. The summer season (June, July, August) used by the PCIC is generally a critical season. The winter season with an abundance of water extends beyond the PCIC winter condition of December, January and February, as November and March have been added here on the basis of their high precipitation. The amount of precipitation in these months rises from the average annual condition of 885 mm to 1044 mm in 2080 (Table 20). This increase of 159 mm is fully 85% of the full year gain between the two scenarios. Most of the difference is gained in the "shoulder months", and a moderate loss of 19 mm occurs in the summer season.

The observed seasonal changes in evapotranspiration are of some interest. A marginal decrease actually occurs in the summer, more in response to the reduction of available water and counter to the increased temperatures. (This makes sense because evapotranspiration can only occur if there is water to tap, regardless of how hot it gets.) The major increase in evapotranspiration occurs in the shoulder months, due to both the warmer temperatures and the increase in available water. Winter evapotranspiration increases are marginal because while temperatures are higher on average, they are still low, and little plant activity occurs.

Finally, the seasonal distribution of surplus is important to understand because this provides groundwater recharge. Winter surplus gains are very strong, largely because of the greater precipitation, and not much change in evapotranspiration. The shoulder months do not see much change in surplus, mostly because the increase in precipitation is matched by the increase in evapotranspiration. Finally, the summer surplus continues in a deficit condition, largely unchanged between now and the future condition, because the minor precipitation reductions are matched by the lower evapotranspiration values.

Table 20: Comparison of climate change scenarios to existing conditions.

Scenario	Annual Totals				Seasonal Precipitation (mm)			Seasonal Actual Evapotranspiration (mm)			Seasonal Surplus (mm)		
	Annual Mean Temp. °C	**Total Precip. (mm)**	**AET (mm)**	**Surplus (mm)**	**Long Winter** Nov - Mar	**Shoulder Months** Apr, May, Sep, Oct	**Summer** Jun - Aug	**Long Winter** Nov - Mar	**Shoulder Months** Apr, May, Sep, Oct	**Summer** Jun - Aug	**Long Winter** Nov - Mar	**Shoulder Months** Apr, May, Sep, Oct	**Summer** Jun - Aug
30 yr mean	9.8	1241	480	761	885	264	91	81	81	190	805	55	-99
Hot/Dry (1989)	9.6	943	431	512	680	177	86	66	186	179	614	-9	-93
2020	10.9	1298	494	805	936	275	88	89	219	186	847	55	-98
2050	12.4	1332	502	830	960	293	79	92	233	178	868	61	-99
2080	14.2	1428	514	914	1044	313	72	98	244	173	946	69	-101

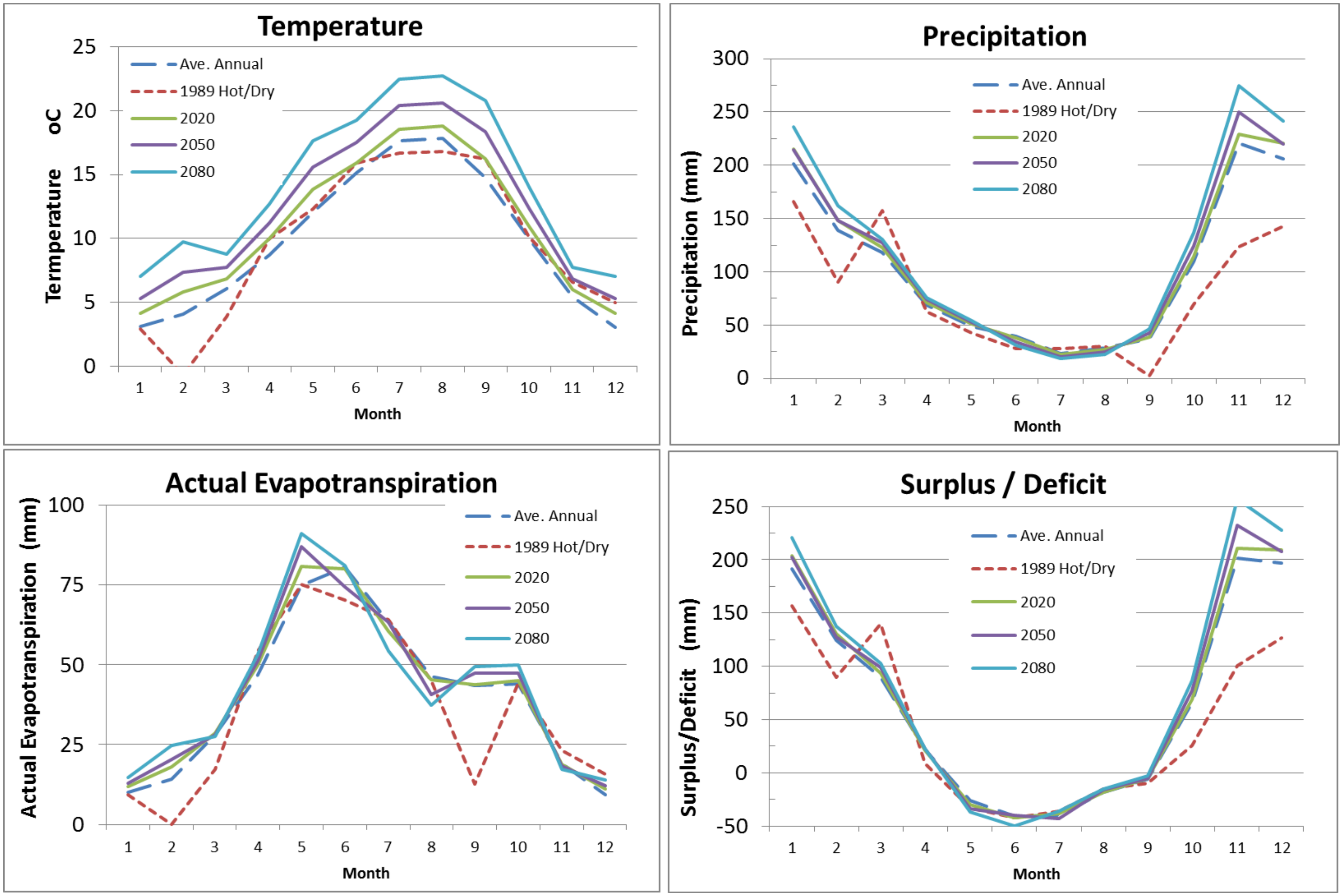

Figure 9: Monthly climate variable for climate change scenarios to existing conditions.

Based on the above observations an annual increase in groundwater recharge may be predicted due to climate change. However, that will be tempered by continuing deficit conditions in the summer months, with all the recharge occurring in the winter months.

3.2.3.5 *Conclusions on Climate Change*

Climate change models generally predict the study area will experience hotter, longer and drier summers and warmer and wetter winters. Rainfall events will be more intense and of greater magnitude. However, precipitation and more importantly, water surplus will be greater, and where entering the aquifers, will enhance groundwater storage. The response to these conditions may mean greater water use in the summer, and even a longer growing season requiring greater irrigation withdrawal.

3.3 Physiography

The study area is positioned within the Nanaimo Lowlands portion of the Coastal Trough / Georgia Depression zone of British Columbia's western system physiographic sub-province (Holland, 1976). The Nanaimo Lowlands is a strip of low-lying country along the east and south peripheries of Vancouver Island below 600 m elevation that extends for 280 km from Sayward on Johnstone Strait to Jordan River west of Victoria, and reaches a maximum width of 32 km between Galiano Island and Shawnigan Lake. The portion of the Nanaimo Lowland that hosts the study area includes both upland and lowland terrain styles, with differences in topographic form being related to variations in underlying bedrock and surficial geologies.

The rolling to locally rugged, upland topography of the southwest half of the study area is primarily the result of the mature dissection of a tertiary-aged erosional surface sedimentary, volcanic, and metamorphic rocks that have been heavily faulted, folded, and intruded by numerous plutons. This portion of the study area was further modified by continental ice-sheet and valley glaciation during the Pleistocene period that resulted in the development of east-northeast and north-northwest trending lines of elongated bedrock hills with striated and fluted surfaces, fault-line bedrock scarps, and fault-controlled valleys containing ground moraine and ice-contact glaciofluvial deposits. Elevations within this part of the study area reach maximums of over 500 m amsl east of Kelvin Creek and along the edge of the Malahat Ridge southeast of Shawnigan Lake.

The topography of the northeast half of the study area is primarily gently rolling to undulating, and the result of continental ice-sheet glaciation that covered this area's underlying, Cretaceous-aged sedimentary rocks with thick, arealy-extensive mantles of ground moraines and outwash materials in a wide range of geomorphological shapes and textures. Isostatic rebound of the land surface since ice retreat has also resulted in the rejuvenation of watercourses (such as the deeply incised lower reaches of the Koksilah River, Shawnigan Creek, and Hollings Creek), and the cutting of narrow ravines in the lower courses of minor streams as they approach the marine shoreline along Cowichan Bay, Satellite Channel, and Saanich Inlet. Elevations within this portion of the study area range from approximately the 120 m amsl elevation contour along the base of the upland areas to the west, to sea level along its east edge.

A map showing the study area's terrain and key topographic features is presented as Figure 10.

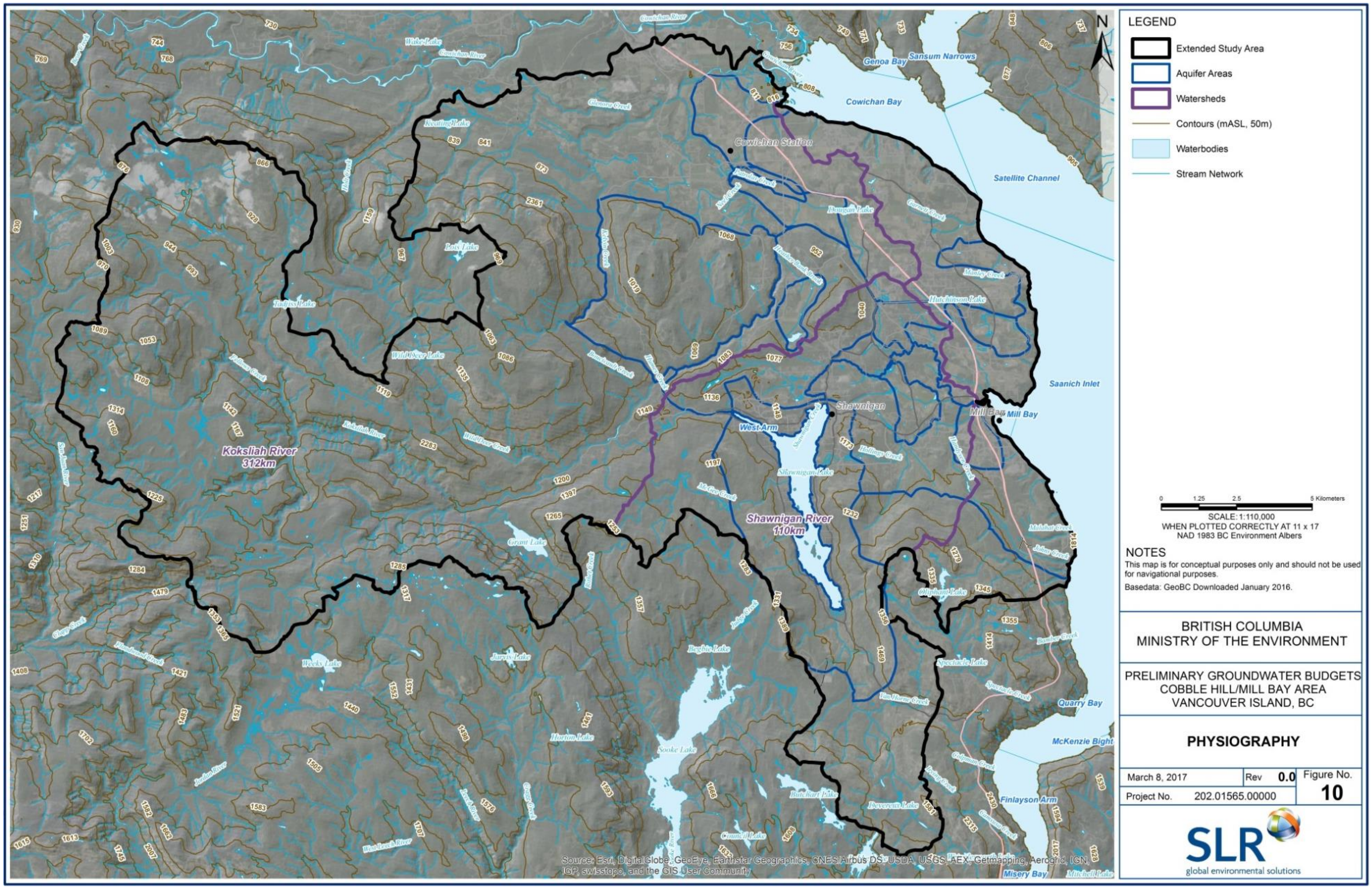

Figure 10: Study area terrain and key topographic features.

3.4 Hydrology

Based on information obtained from provincial government sources (ENV, 2016; BCGS,2016), four watersheds (Figure 1) are present within the study area that contain defined surface water catchments:

- The Cowichan Bay Benchlands Watershed, which consists of at least six small sub-catchments north of the mouth of Shawnigan Creek in the northeast part of the study area. These catchments contain numerous small watercourses, water bodies, and wetlands that flow in radial and parallel patterns directly into Cowichan Bay and Satellite Channel;
- The Saanich Inlet Watershed, which consists of at least five small sub-catchments south of the mouth of Shawnigan Creek in the southeast part of the study area. These catchments also contain numerous small watercourses, water bodies, and wetlands that flow in radial and parallel patterns directly into Saanich Inlet;
- The Shawnigan Watershed, which consists of two large sub-catchments in the central and south parts of the study area (the Shawnigan Creek and Hollings-Handysen Creeks drainage systems). The majority of this watershed is centred on Shawnigan Lake, which receives centripetal inflow from numerous watercourses, while the remaining portion downstream of Shawnigan Lake contains two dendritic systems of watercourses and wetlands that flow into Mill Bay; and
- The Koksilah Watershed, consists of two large sub-catchments in the central and northwest parts of the study area (the Koksilah River and Kelvin Creek drainage systems) that flow in dendritic and rectangular patterns towards the Cowichan River estuary.

Key hydrological features present within these watersheds include those listed in Table 21.

Table 21: Key hydrological features by watershed.

Cowichan Bay Benchlands Watershed	**Saanich Inlet Watershed**	**Shawnigan Watershed**	**Koksilah Watershed**
Garnett Creek	Malahat Creek	Shawnigan Creek	Koksilah River
Manley Creek	John’s Creek	Shawnigan Lake	Kelvin Creek
Wace Creek	Wheelbarrow-Bird Creek	West Arm Creek	Heather Bank Brook
Sylvan Brook	Wilkin Creek	McGee Creek	Patrolas Creek
Hook Creek	Frayne Creek	Hartl Creek	Dougan Lake
Wilmot Creek	Service Creek	Hollings Creek	Kingzett Lake
Ordano Brook		Handysen Creek	Neel Creek
Shearing Creek		Palmer Creek	Weeks Creek
		Chandler Creek	Kenneth Creek
		Old Baldy Creek	Dougan’s Ditch
		Burnham Creek	Giese Brook
		Timothy Brook	Treffry Creek
		Silver Mine Lakes	Spears Creek
		Averill Brook	
		Brayshaw Creek	
		Prellwitz Creek	
		Nott Creek	
		Taggart Creek	
		Ericson Creek	
		Goodhope Creek	
		Hutchinson Lake	
		Eddy-Kilmalu Creek	

3.5 Geology

3.5.1 Bedrock Geology

The study area is situated on the Vancouver Island portion of the North American tectonic plate, below which the Juan de Fuca plate is currently subducting at a rate of approximately five centimetres per year. The current subduction trench is located approximately 200 kilometres southwest of Vancouver Island, and seismicity related to the oblique convergence of these plates is periodically recorded throughout southern Vancouver Island and the southern British Columbia mainland. An extensive geological record of convergent margin processes on southern Vancouver Island has been intermittently studied over a period of almost 100 years by a wide range of workers (including Clapp, 1919; Muller, 1971 and 1983; Massey, 1986; Brandon et al., 1986; Brandon, 1989; Yorath et al., 1995; WorleyParsons, 2009). Interpretations of the region's deep crustal structure have also been augmented by geophysical surveys of the Lithoprobe transect in 1984 (Yorath et al., 1999) and more recent seismic tomography by the Geological Survey of Canada. The B.C. Geological Survey is conducting an ongoing program of 1:50,000 geological mapping on Vancouver Island, including recent work in the Duncan / Cowichan Lake area (Massey et al., 2005). Figure 11 shows the bedrock units.

Information drawn from these sources indicates that bedrock units within the study area are part of two discrete crustal elements known as the Wrangellia and Overlap Terranes. The Wrangellia Terrane may have originally formed off the coast of North America and accreted onto the continental margin in Mesozoic times (Monger, 1993). The boundary between the Wrangellia and Overlap Terranes is represented by a northwest-trending contact that bisects the north half of the study area south of Cowichan Bay area and meets the marine shoreline at Cherry Point. The Pacific Rim Terrane, a Jurassic-Cretaceous aged subduction complex, is interpreted to be thrust beneath Wrangellia Terrane along the east-northeast trending San Juan Fault, which passes through the centre of the study area north of Shawnigan Lake.

Wrangellia Terrane rocks within the study area consist of two heterogeneous assemblages of sedimentary, igneous, and metamorphic rocks of various ages that appear to be in structural contact with each other:

- Assemblage A, consisting of four related subunits bounded to the north by the Overlap Terrane angular unconformity and south by the east-northeast trending San Juan Fault:
    - A middle to upper Devonian-aged, basaltic island arc unit (Sicker Group, Duck Lake Formation, map unit muDSiD), represented by an east-northeast trending wedge of volcanic and sedimentary rocks in the centre of the study area that pinches out eastwards near Cherry Point;
    - A Mississippian to lower Permian-aged calcareous sedimentary unit (Buttle Lake Group, Mount Mark Formation, map unit PnPBM), represented by several small, east-northeast trending slivers of metamorphosed limestone that were historically mined at the Cobble Hill quarry and host a number of small karst formations west of Cobble Hill village;
    - A middle to upper Triassic-aged oceanic basaltic plateau unit (Vancouver Group, Karmutsen Formation, map unit uTrVK), represented by two ovoid blocks of volcanic rock along the north side of the Sicker Group rocks that outcrop on the summits of Cobble Hill and the hills east of Kelvin Creek; and
    - A middle to upper Triassic-aged carbonate reef unit (Vancouver Group, Quatsino Formation, map unit uTrVQ), represented by one small, northwest-trending sliver of metamorphosed limestone on the east shore of Shawnigan Lake to the immediate south of Old Baldy Mountain; and

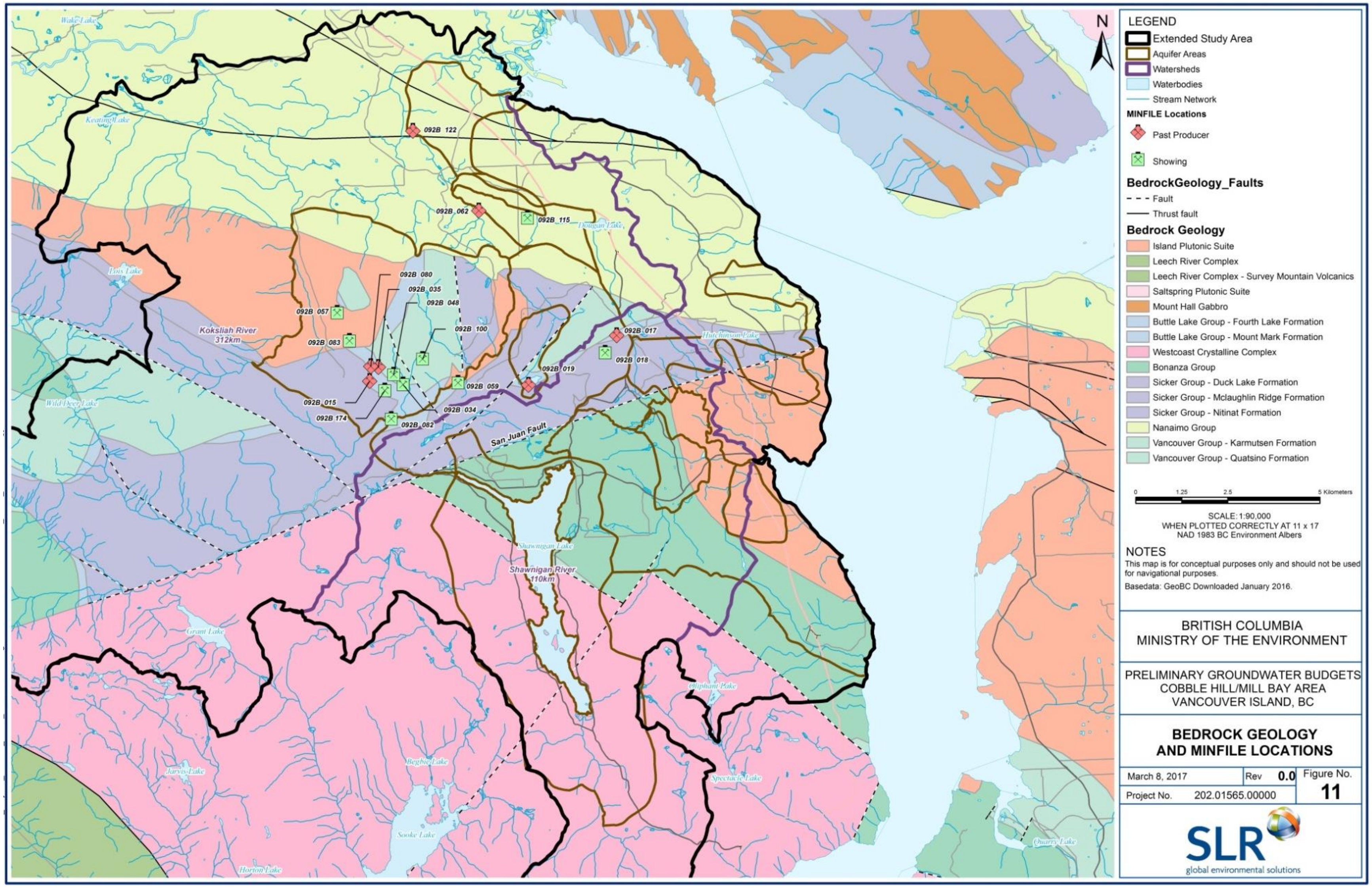

Figure 11: Bedrock geology and Ministry of Energy and Mines oil & gas well sites.

- Assemblage B, consisting of three related, tectonic underthrust subunits bounded to the north by the San Juan Fault and south by the Leech River Fault 8 km southwest of the study area:
    - A lower Jurassic-aged, basaltic to andesitic island arc unit (Bonanza Group, map unit lJBca), represented by a northwest-trending belt of volcanic and intrusive rocks that form a series of conical hills to the west, north, and east of Shawnigan Lake;
    - Two lower Jurassic-aged metamorphosed intrusive units (Westcoast Crystalline Complex, Wark and Colquitz Gneiss Formations, map unit PzJWg), represented by a northwest trending belt of locally foliated, dioritic to gabbroic plutons around the west, south, and east sides of Shawnigan Lake. These units may either represent the eroded roots of the overlying Bonanza Group volcanic arc rocks (DeBari et al., 1999; Larocque and Canil, 2010; Canil et al., 2010) or be a separate imbricated terrane; and
    - A lower to middle Jurassic-aged intrusive unit (Island Plutonic Suite, map unit EMJIlgd), represented by a northwest-trending belt of un-foliated granodioritic plutons that underlie the Mill Bay / Cherry Point area northeast of the Bonanza Group and southeast of the Sicker Group rock packages and may be coeval with the Bonanza Group volcanic units.

Rocks within the Overlap Terrane consist of sedimentary members of the upper Cretaceous-aged Nanaimo Group that unconformably overlie the Wrangellia Terrane rocks. Nanaimo Group rocks within the study area are represented by the Comox and Haslam Formations, a conformable sequence of marine and non-marine sedimentary units that grade upwards from carbonate-rich deltaic sandstone and conglomerate, through rhythmic marine beds of siltstone, sandstone, and coal-bearing shale, into pure shale and mudstone. Nanaimo Group rocks tend to be erosionally recessive and are rarely exposed within the study area due to their deep burial by glacial sediments, but are commonly encountered at depths of over 100 m by drilled wells throughout the Cowichan Bay and Cherry Point areas.

The structural geology of the study area is complex and reflective of its varied tectonic settings. Rocks within the Wrangellia Terrane generally exhibit a coarse, northwest-trending fabric. Most major, high-angle faults that have been identified in this terrane assume north to northwest orientations may be extensional (including the Spectacle, Oliphaunt, and John's Faults at the south end of the study area), with the exception of the east-northeast trending San Juan Fault, which is a regional-scale, low-angle, mainly compressional thrust fault with local transcurrent (extensional) components that bisects the study area north end of Shawnigan Lake and offsets the older faults. One regional-scale, northeast-trending high-angle structure, the Shawnigan Fault, has also been identified crossing the south end of the study area from Shawnigan Lake to Mill Bay, appears to offset the contact between the Bonanza Group, Westcoast Crystalline Complex, and Island Plutonic Suite rocks in a left-lateral sense, and may be extensional. Rocks of the Wrangellia and Overlap Terranes more recently underwent extensive folding and faulting along a northwest axis during the Late Tertiary era when the Cascade and Olympic Mountains were being formed in Washington State. This late-stage deformation has manifested as a series of major, northwest-trending low-angle, compressional thrust faults and fold axes that affect all of the study area's rocks (in particular the Nanaimo Group), and which are locally offset by minor, northeast-trending extensional faults.

A map showing the boundary between the Wrangellia and Overlap Terranes, bedrock geological units, and key structures present within the study area is presented as Figure 11.

The B.C. Ministry of Energy and Mines MINFILE database (BCMEM, 2016) indicates the presence of seven past producers and eleven showings within the study area that may suggest the locations of areas of naturally-occurring mineralization and/or bedrock-hosted resource extraction with potential to impact local groundwater quality, as listed on Table 22 and shown on Figure 11.

Table 22 MINFILE sites.

MINFILE No.	Name*	Status	Deposit Type	Commodities
092B 122	Koksilah	Past Producer	Sandstone	Sandstone, dimension stone, building stone
092B 080	Bluebell	Past Producer	Shear zone / skarn	Copper, silver
092B 035	Viva	Past Producer	Skarn	Copper, silver
092B 015	King Solomon	Past Producer	Skarn	Copper, silver, zinc
092B 062	Hillbank	Past Producer	Shale	Shale, aggregate, building stone
092B 017	Bonner's Quarry	Past Producer	Limestone	Limestone
092B 019	Raymond	Past Producer	Limestone	Limestone
092B 115	Bear Creek	Showing	Lacustrine	Diatomite
092B 018	Cobble Hill	Showing	Limestone	Limestone
092B 059	Sil 4 / Northstar	Showing	Shear zone / skarn	Copper, silver
092B 175	Riverside Road	Showing	Mineralized volcanic rocks	Copper, silver
092B 100	Blocks 383 / 217	Showing	Skarn	Copper
092B 057	Strip / Western	Showing	Skarn	Copper, silver
092B 083	Dora-Mabel	Showing	Shear zone / skarn	Copper, silver
092B 048	Wallace	Showing	Skarn	Copper
092B 174	Two Shafts	Showing	Mineralized intrusive rocks	Copper, silver
092B 034	Finlay / Pacific Star	Showing	Shear zone / skarn	Copper, iron, silver, zinc
092B 082	WAE / Fallside	Showing	Vein, skarn	Copper, zinc, gold

3.5.2 Surficial Geology

The surficial geology of the study area has been intermittently studied for over 100 years by a number of workers (including Clapp, 1912; Fyles, 1963; Halstead, 1965; Hickock et. al. 1984; Hicock, 1976; Clague 1977; Alley et al., 1979; Blyth et Al., 1993; Huntley, 2001; WorleyParsons, 2009). Information drawn from these sources indicates that four laterally-extensive, unconsolidated stratigraphic units are present within the study area. Dominant landforms and sediments in the region are late glacial in age and record the advance, maximum, and retreat phases of the late Pleistocene-aged Fraser Glaciation. Minor landforms and sediments are of post-glacial age and represent the fluvial and marine reworking of all earlier deposits. The thickness of the surficial cover within the South Cowichan region generally increases from southwest to northeast.

The stratigraphy of these units (WorleyParsons, 2009) is described below, from older to younger:

- Advance-phase glacial outwash materials, known as the "Quadra Sands", represent the oldest surficial deposits in the area. These include ice-distal sand and gravel-rich glaciofluvial sediments and glaciolacustrine deposits, ice-proximal gravel-rich outwash, and ice-contact moraines. Quadra Sand deposits do not outcrop within the study area, but have been recognized at depths of over 100 m below surface and up to elevations of 80 m below mean sea level beneath the Cowichan Bay / Cherry Point area, and likely occur in elongated lenses or beds with thicknesses in the range 15 to 20 m. The sand and gravel textured deposits are generally permeable;
- Glacial maximum materials, known as the "Vashon Drift", include over-compacted sand-silt textured ground moraine and glacigenic debris flows, with minor interbedded, subglacial and/or ice-contact glaciofluvial sand and gravel interbeds. These moraine deposits overlie the Quadra Sand materials described above, and can locally exceed 60 m in thickness. Deposits of Vashon Drift outcrop at surface at all elevations and in most parts of the study area, and usually directly overlie bedrock where the Quadra Sand is absent. Glaciofluvial deposits of the Vashon Drift

- Retreat-phase glacial materials, known as the “Capilano Sediments”, include silt-clay textured glaciomarine and minor sand-gravel textured glaciofluvial outwash sediments. These deposits are the product of wasting tidewater glaciers and sediment deposition along retreating ice-margins, and mainly outcrop in the Koksilah River valley and Cowichan Bay areas. Capilano Sediments overlie winnowed deposits of the Vashon Drift, and are present on hillsides up to elevations of roughly 80 m above mean sea level. Glaciomarine and glaciolacustrine deposits of the Capilano Sediments occur as draping veneers and blankets up to 15 m thick, while glaciofluvial deposits are confined to impersistent, linear deposits and kame deltas that occupy glacial meltwater channels; and
- Post-glacial materials, known as the “Salish Sediments”, represent the youngest surficial deposits in the area, and include sand-gravel textured alluvial, deltaic, as well as silt-clay textured lacustrine, organic, and marine veneers to blankets formed by the reworking of earlier surficial deposits. Salish Sediments overlie all other glacial deposits, and are present along most watercourses, in estuaries, and along shorelines throughout the study area.

Colluviated veneers to blankets of Vashon Drift, and Capilano Sediments materials are commonly present in areas of steep, upland terrain around Shawnigan Lake and on the flanks of the study area’s larger hills in the Cobble Hill / Kelvin Creek areas where the mass-wastage of these units and weathered or fractured bedrock has taken place. Colluvial debris flows and small, aggraded pods of Salish Sediments fluvial materials are also commonly present at the termini of the numerous ravines along the Cowichan Bay, Satellite Channel, and Saanich Inlet shorelines.

The B.C. Ministry of Energy and Mines MINFILE database (BCMEM, 2016) indicates the presence of fourteen aggregate (sand and gravel) pits within the study area (Figure 12).

3.5.3 Soils

Soils present within the study area have been periodically mapped and described for over 60 years by a number of workers (Day et al., 1959; Jungen, 1985). Information drawn from these sources indicates that a wide range of soil types are present within the study area, with their specific natures and characteristics being primarily related to soil parent materials and climatic, vegetation, and landscape (slope, aspect, and elevation) settings:

- Podzolic soils are the most widespread soil type within the study area, particularly in well-drained, forested areas within its southwest half. Podzolic soils are primarily present over medium to coarse-textured morainal and gravelly glaciofluvial fluvial parent materials in areas with higher levels of precipitation, low moisture deficits, cool to moderately-cold soil temperature regimes, and humid to perhumid soil moisture regimes. These soils tend to be bright reddish-coloured, deeply weathered, strongly leached and very acidic, have low base saturations, and are commonly underlain by compact to platey, strongly-cemented, low-permeability duric (hardpan) layers;
- Brunisolic soils are primarily present within the northeast half of the study area in well-drained areas with lower levels of precipitation and higher moisture deficits over loose, morainal and glaciofluvial parent materials, and also occur over relatively young fluvial and fine-textured marine parent materials. The climate regime for these soils is semi-arid, while the temperature regime is mildly mesic. Compared to podzolic soils, brunisolic soils tend to be less acidic and leached, have lighter colours and higher base saturations, and lack underlying duric layers;
- Gleysolic soils are generally present in imperfectly to poorly-drained areas of low relief such as within depressional areas between the Cobble Hill uplands, adjacent to Shawnigan Creek in the Cameron-Taggart Road area, and west of Dougan Lake. Gleysolic soils usually form over low-

permeability marine and fluvial surficial materials where persistent moisture accumulation has occurred, and tend to be strongly gleyed and mottled with peraquic to aquic moisture regimes;

- Regosolic soils are generally present in well-drained areas with steep, rubbly colluvium deposits at higher elevations within the southwest half of the study area, and over recently-deposited fluvial or marine deposits. Soil horizon development in regosolic soils is restricted to an immature state due to the unstable geomorphic settings of their parent materials; and
- Organic soils are often present in the same very poorly drained, low-lying areas that host gleysolic soils, particularly where raw to humic organic materials have accumulated over an extended period of time under conditions of continual water saturation and/or perennially high water tables. Folisolic organic soils are also present in imperfectly to well-drained forested upland parts of the study area where deep blankets of poorly-decomposed forest litter have accumulated.

A plan showing soil associations mapped within the study area is presented as Figure 13, while Table 23 classifies the associations by type, parent material, drainage, and relative permeability.

Table 23: Soil associations.

Soil Type	Dominant Parent Material	Drainage	Relative Permeability	Soil Associations
Podzolic	Morainal, fluvial	Imperfect to moderate	Low to moderate	Shawnigan, Somenos
Brunisolic	Morainal, fluvial, marine	Good	Moderate	Chemainus, Crofthill, Qualicum, Quamichan
Gleysolic	Marine, fluvial	Poor	Low	Cowichan, Dashwood, Dashwood Creek, Fairbridge, Finlayson, Tagner, Tolmie
Regosolic	Colluvial, bedrock	Rapid	High	Ragbark, Rosewall, Squally
Organic	Organic	Poor	Low	Arrowsmith, Azilion

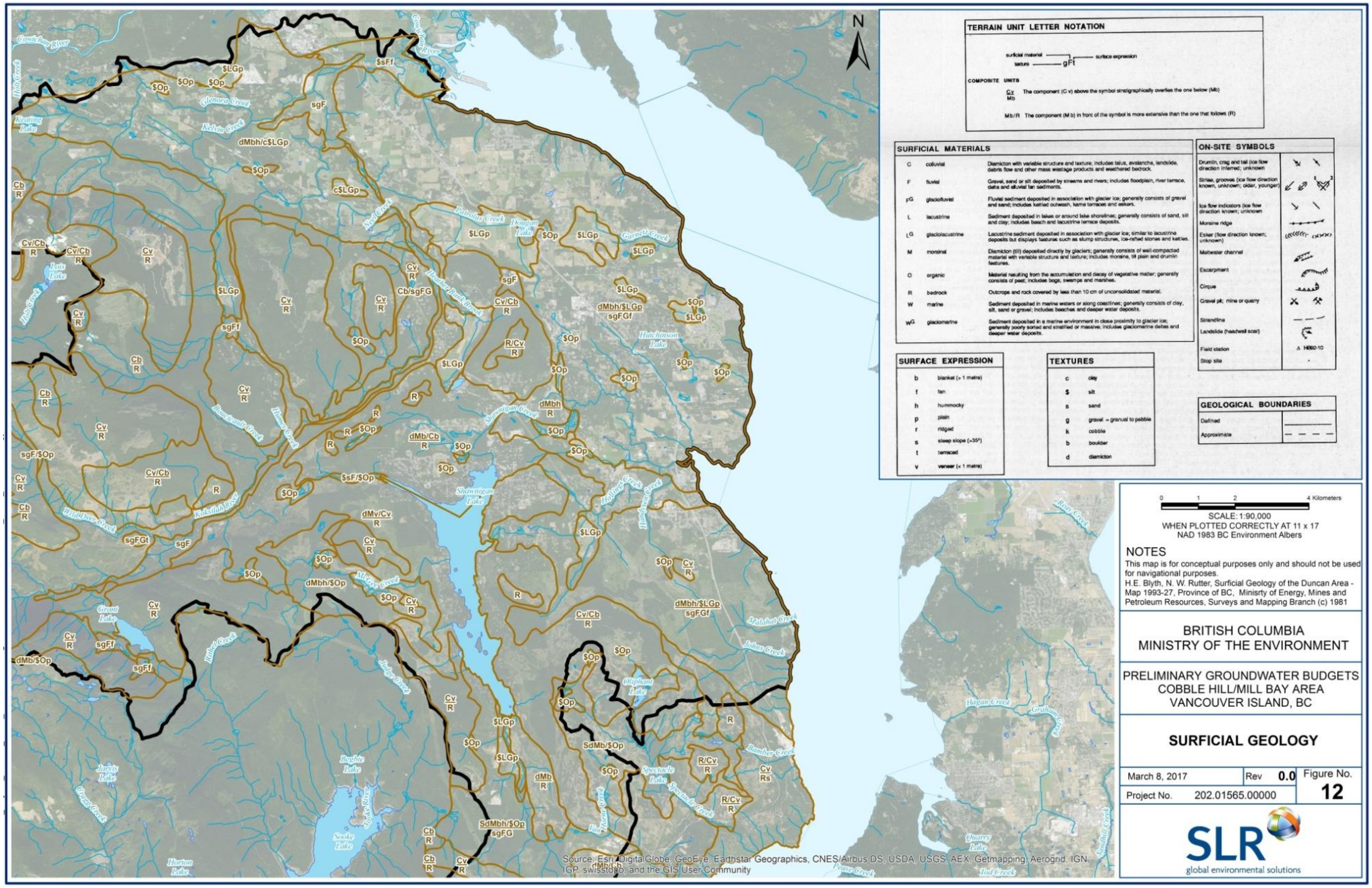

Figure 12: Surficial geology.

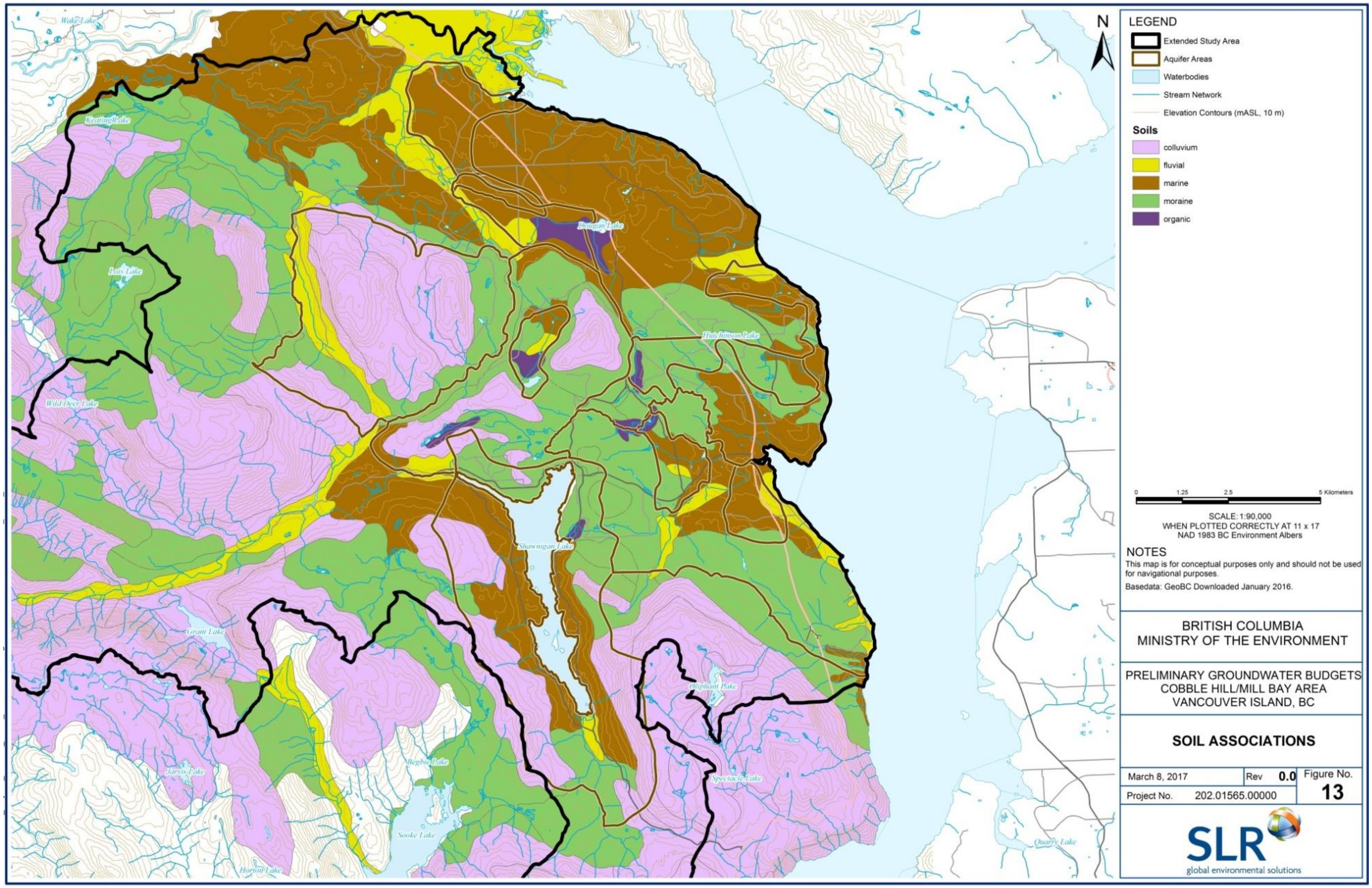

Figure 13: Distribution of soil associations within the study area.

3.6 Hydrogeology

Groundwater occurrence and distribution within the Nanaimo and Georgia Lowlands has been extensively studied as part of a provincial government review of groundwater resources in British Columbia (Ronneseth et al., 1991). Historical groundwater development and vulnerability on Vancouver Island has been assessed by the B.C. government as part of its ongoing provincial aquifer mapping classification program (Kreye et al., 1994). A detailed review of technical literature on the hydrogeology of the South Cowichan region was also recently undertaken by WorleyParsons (2009). Information drawn from these sources indicates groundwater is present within the study area in several hydrostratigraphic settings, many of which constitute aquifers that yield usable quantities of groundwater to wells, springs, or supply baseflow to streams.

3.6.1 Bedrock Aquifers

Moderately productive bedrock aquifers occur within the study area in the following settings:

- Open joints, faults, and fracture systems in all bedrock types, particularly in areas affected by extensional deformation such as along the trends of the Shawnigan, Devereaux, Spectacle, and Oliphaunt Faults, some sections of the San Juan Fault, within older, fractured volcanic rock packages such as the Sicker and Karmutsen Groups, and within fractured felsic variants of the metamorphic Westcoast Crystalline Complex and intrusive Island Plutonic Suite. The most productive portions of these aquifers are usually where swarms of multiple, subparallel faults are present, or where fault zones with differing orientations intersect;
- Dissolution voids and channels in carbonate sedimentary rocks, in particular the Buttle Lake and Vancouver Group metamorphosed limestones; and
- Along bedding plane partings and within intergranular pore spaces in Nanaimo Group sandstones.

Bedrock aquifers also occur within fractured volcanic rocks of the Bonanza Group and fractured mafic variants of the metamorphic Westcoast Crystalline Complex, although comparatively less productive due to these units' equigranular crystalline textures and comparatively ductile deformation styles. Similarly, bedrock aquifers occur within fractured Nanaimo Group shales and mudstones, although these are also less productive due their comparatively fewer connected intergranular pore spaces and ductile deformation styles.

Wells completed within unfractured volcanic, intrusive, and metamorphic rocks contain very little usable groundwater due to their low primary porosities. Similarly, wells completed within bedrock zones affected by compressional deformation such as within some sections of the San Juan Fault and the thrust faults that affect the Nanaimo Group and other rock units. Consequently, bedrock in these settings may represent barriers to groundwater flow.

The degree of confinement of bedrock aquifers depends largely on the structural geometry and connectivity of their void systems, and the presence of overlying, hydraulically-restrictive bedrock and/or surficial materials.

Groundwater inflow into unconfined bedrock aquifers is primarily from the vertical infiltration of precipitation, snowmelt, and surface water sources (including "losing" watercourses and sheet flow) in areas with exposed bedrock or shallow, permeable surficial cover at higher elevations, and to a lesser extent from the vertical infiltration of groundwater from overlying permeable surficial aquifers. Limited groundwater inflow to aquifers under all types of confinement also occurs laterally from void systems in undeveloped or adjacent aquifers containing groundwater at higher hydraulic heads than the receiving aquifers, and from surface runoff and near-surface soil drainage from adjacent, topographically-elevated areas.

Groundwater outflow from bedrock aquifers occurs naturally in several ways depending on their landscape positions, depths and permeabilities of surficial cover, and degrees of confinement. Unconfined aquifers in areas with exposed bedrock or shallow, permeable surficial cover at higher elevations may lose significant amounts of stored groundwater by evapotranspiration and discharge into surface waters as base flow (including springs, wetlands, "gaining" watercourses, and lakes, while semi-confined and confined aquifers at lower elevations with thick or impermeable surficial covers may primarily lose stored groundwater through discharge into lakes, the marine environment, and downgradient aquifers with lower hydraulic heads.

Groundwater movement within bedrock aquifers generally follows regional topographic trends by flowing from higher elevations towards lower elevations, although flows at the local level may be highly anisotropic depending on the structural geometries and degrees of confinement of their void systems. Groundwater divides are often coincident with surface water divides on a regional scale, although groundwater within major fault systems may flow across local surface water catchment boundaries. Interstitial flow velocities within bedrock aquifers are often very rapid compared to surficial aquifers, particularly those hosted by karstified limestone of the Buttle Lake and Vancouver Groups.

Most private properties in the upland portions of the study area around Shawnigan Lake, and in the Cobble Hill, Koksilah, and Mill Bay / Arbutus Ridge areas are serviced by wells completed within bedrock aquifers. Although areally-extensive bedrock aquifers are known to exist in the lower-elevation Cowichan Bay and Cowichan Station areas, these aquifers are largely undeveloped since most groundwater users in these areas rely on wells completed within overlying surficial aquifers.

The B.C. government has mapped, classified, and ranked six bedrock aquifers within the study area based on their locations and developed areas, host lithologies, levels of development, and vulnerability to contamination, respectively, which collectively cover over 125 km^2. The bedrock aquifers are listed in Table 24 and their locations within the study area are shown in Figure 14.

Table 24: Mapped bedrock aquifers within the study area.

Aquifer No.	Name	Developed Area (km^2)
0198	Cowichan Station	6.18
0200	Kelvin Creek	26.90
0202	North Shawnigan	21.00
0203	Shawnigan Lake	31.00
0204	Cobble Hill	16.58
0207	Bamberton	25.1

It is important to recognize how bedrock aquifer boundaries were originally delineated for these aquifers back in the mid to late 1990's (M. Wei, personal communication, 2016). How the boundaries were delineated affects calculation of lateral groundwater flow into and out of these aquifers and uncertainty in the water budgets for these aquifers:

- Bedrock aquifers have not been mapped underneath aquifers 0197 and 0205 even though clearly bedrock underlies these surficial aquifers. The mapper could have thought mapping bedrock aquifers underneath those surficial aquifers were not necessary or he could have omitted those areas altogether.

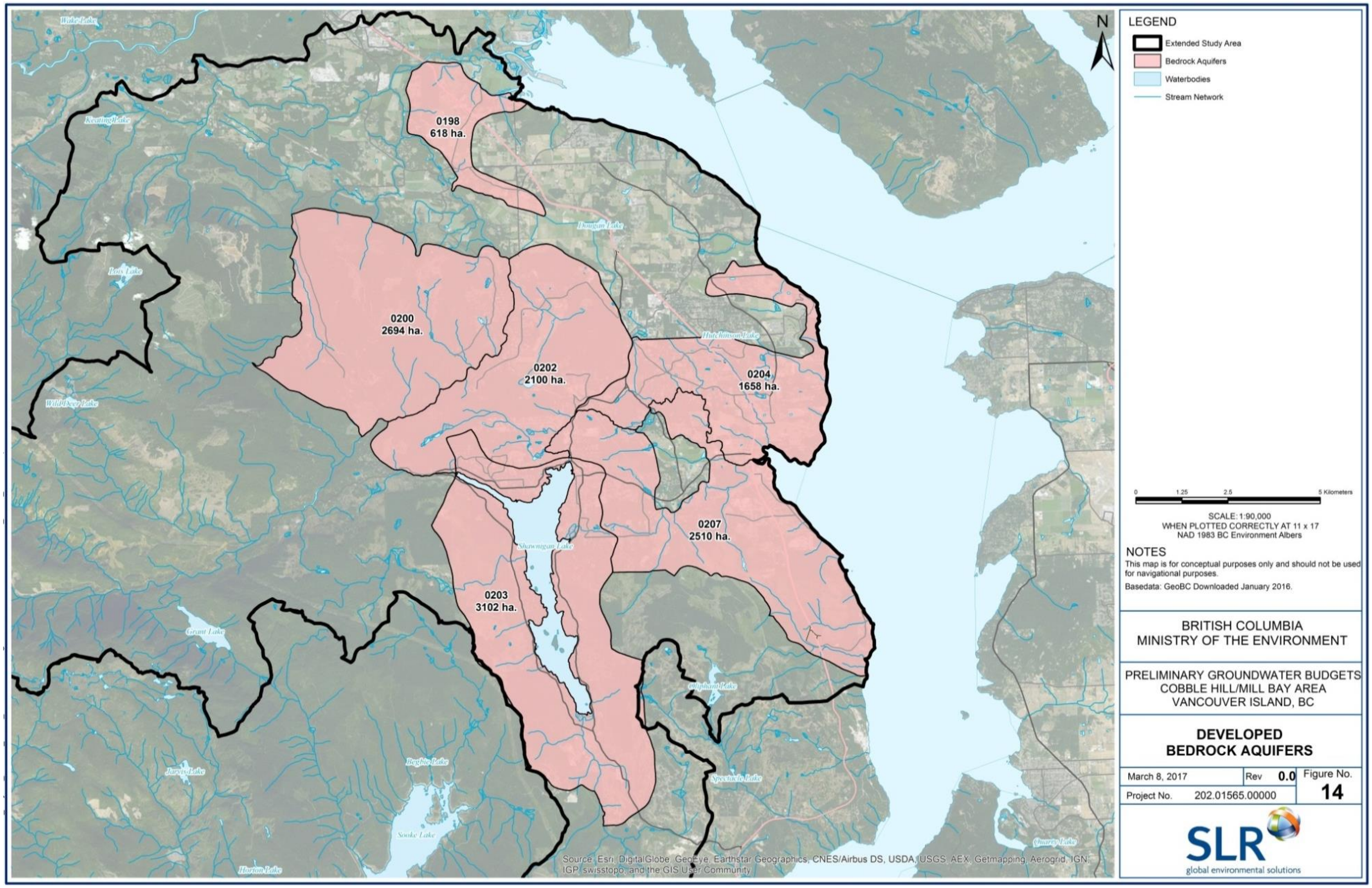

Figure 14: Location of mapped bedrock aquifers within the study area.

- Some of the bedrock aquifer boundaries follow streams, implying these boundaries are no flow boundaries along the thalweg of stream valley bottoms. Lateral groundwater flow would not occur across these boundaries.
- The boundary for aquifer 0203 generally follows the local watershed, again implying a no-flow boundary. Lateral groundwater flow would not occur across these boundaries.
- The northern boundary for aquifer 0204 is along Hutchison Road, roughly south of where aquifer 0197 occurs.
- The northern boundary of aquifer 0200 appears to generally follow an elevation contour. Groundwater lateral flow would have to be calculated across this boundary.

The point is that some boundaries may be arbitrarily drawn but the consequence is that if those boundaries are accepted as defining the study area, groundwater flux would have to be calculated across them and those calculations have inherent uncertainties associated with the calculations.

3.6.2 Surficial Aquifers

Moderately to highly productive surficial aquifers occur within the study area in sand and gravel deposits with high primary porosity in the following settings:

- Deep, proglacial outwash and ice-contact materials of the Quadra Sands between Vashon Drift ground moraines and the underlying bedrock surface;
- At intermediate depths within permeable glaciofluvial outwash and ice-contact interbeds between low-permeability ground moraine units of the Vashon Drift;
- Shallow glaciofluvial ice-contact, outwash, and deltaic materials of the Capilano Sediments; and
- Shallow post-glacial alluvial and deltaic materials of the Salish Sediments.

Wells completed within the study area’s unconsolidated to semi-consolidated ground moraine, debris flow, lacustrine, or marine deposits contain very little usable groundwater due to their fine-grained textures, dense consistencies, and inherently low permeability. Consequently, these types of surficial materials may represent barriers to vertical and horizontal groundwater flow, and also limit recharge when at surface.

The degree of confinement of the study area’s surficial aquifers depends largely on their internal stratigraphy of their void systems, and the presence of overlying, hydraulically-restrictive surficial units.

Groundwater inflow into unconfined surficial aquifers is primarily from the vertical infiltration of precipitation, snowmelt, and surface water sources in areas with exposed permeable surficial materials. Limited groundwater inflow to aquifers under all types of confinement also occurs laterally from undeveloped or adjacent bedrock or surficial aquifers containing groundwater at higher hydraulic heads than the receiving aquifers.

Groundwater outflow from the study area’s surficial aquifers occurs naturally in several ways depending on their landscape positions and degrees of confinement. Unconfined aquifers at higher elevations may lose significant amounts of stored groundwater by discharge into surface water. Semi-confined and confined aquifers at lower elevations with thick or impermeable, overlying surficial units may primarily lose stored groundwater through discharge into lakes, the marine environment, and downgradient aquifers with lower hydraulic heads.

Groundwater movement within unconfined surficial aquifers generally follows regional and local topographic trends by flowing from higher elevations towards lower elevations, although flows at the local level may be highly anisotropic depending on their internal stratigraphies and degrees of confinement. Groundwater divides in unconfined and semi-confined surficial aquifers are usually coincident with surface water divides on regional and local scales, although confined groundwater within deeply buried Quadra Sands deposits may flow across local surface water catchment boundaries. Interstitial flow velocities (expressed as the average linear velocity, $V = K(dh/dL)/n$) where n is the porosity within surficial aquifers are comparatively slow compared to groundwater velocities in bedrock aquifers. This is because of the typically much lower porosity of fractured bedrock compared to sand and gravel. (The amount of groundwater flow per unit area, or flux, will be much greater in the overburden aquifers due to the greater storage of unconsolidated materials in comparison to fractured rock.)

The B.C. government has mapped, classified, and ranked five surficial aquifers within the study area, as listed in Table 25 and shown on Figure 15, which collectively cover over 50 km^2.

Table 25: Mapped overburden aquifers within the study area.

Aquifer No.	Name	Developed Area (km^2)
0197	Cherry Point	39.48
0199	Dougan Lake	3.40
0201	Kingburne	2.11
0205	Carlton	2.73
0206	Mill Bay	2.57

3.6.3 Aquifer Connectivity

Many of the study area's aquifers interact hydraulically with each other, depending on their relative spatial, topographic, and geological settings. A summary of expected interactions is listed in Table 26.

Table 26: Aquifer interactions.

Aquifer	Name	0197	0199	0201	0205	0206	0198	0200	0202	0203	0204	0207
0197	Cherry Point		I/O				O		I		I/O	
0199	Dougan Lake	I / O					I / O	I	I			
0201	Kingburne								I / O			
0205	Carlton										N	I / O
0206	Mill Bay										N	I / O
0198	Cowichan Station	I	I									
0200	Kelvin Creek								O			
0202	North Shawnigan	O	O	I				I		O	O	O
0203	Shawnigan Lake								O			O
0204	Cobble Hill	I			N	N			I			I
0207	Bamberton				I / O	I / O			I	I	N	

Notes: I = Groundwater inflow / O = Groundwater outflow / N – Neutral interaction

3.6.4 Provincial Well Monitoring Network

Several provincial monitoring well locations are found within the study area. These are shown on Figure 1. A total of five monitoring well locations are shown, of which one is in the bedrock, and four are in the overburden soils. The bedrock well is B.C .Observation Well 439 and is in aquifer 0202. One of the overburden wells is in aquifer 0206 (No. 380), and the other three (233, 320 and 435) are in aquifer 0197.

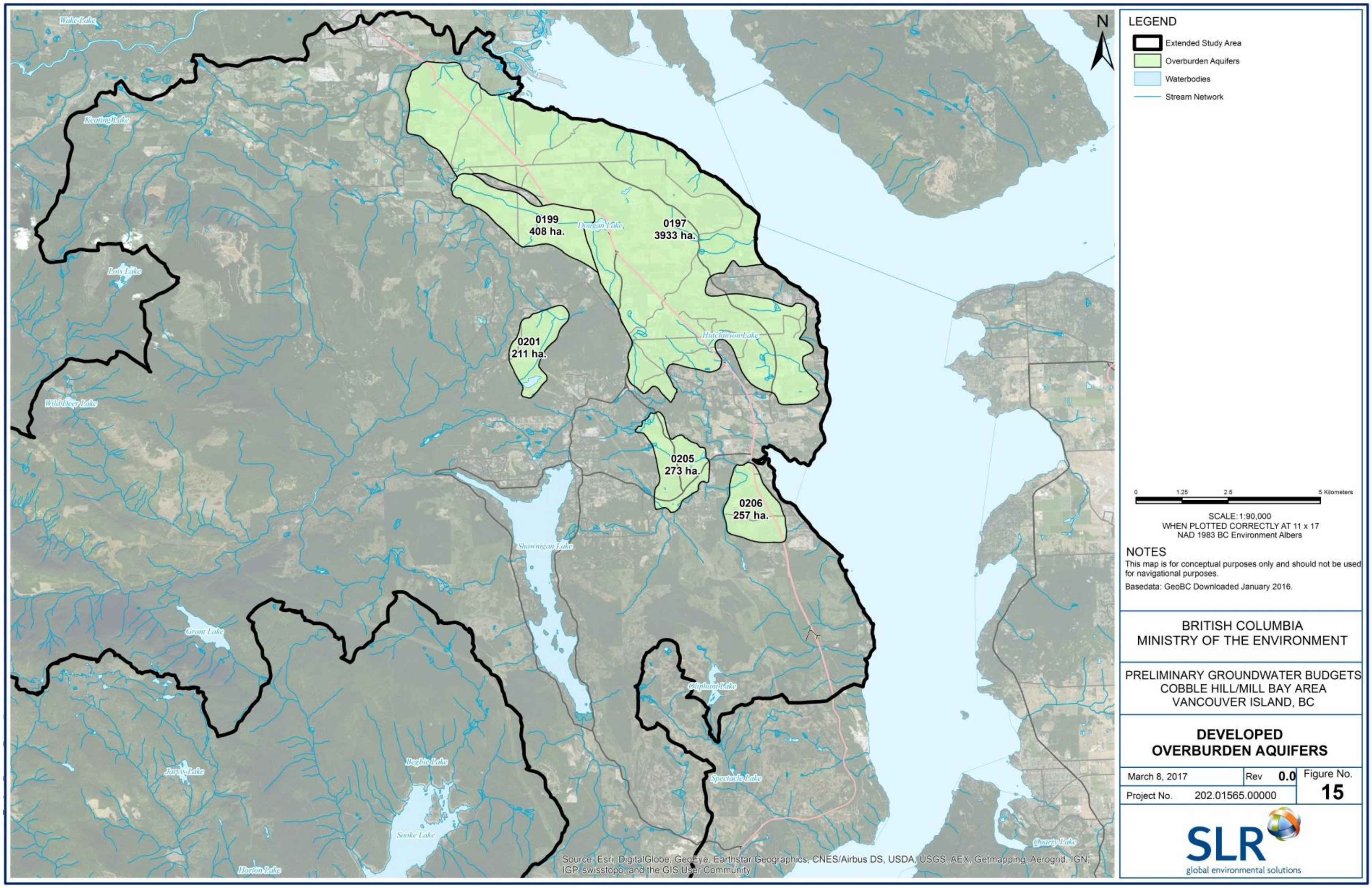

Figure 15: Location of mapped overburden aquifers within the study area.

3.7 Recharge

Using the methods presented in Section 2.2.4, the average annual recharge has been calculated from the water surplus for the full study area. This is presented on Figure 16 for the full study area, including the upstream headwaters. It has then been broken down by each aquifer area and individual maps presented in the appendix for each.

It is useful to see how the recharge distribution is spread across the study area and the influence of soil, cover and topography on these values. Figure 16 has been annotated with six different points, labelled A, B, C, etc. Area A in aquifer 0200 has been selected to demonstrate the effect of soil cover. This area is characterized by permeable colluvial gravels that have a high infiltration factor of 0.4. The forest cover is uniform and exhibits a factor of 0.2. The effect of topography on infiltration is fairly uniform throughout the study area, such that the slope factor is set to the minimum 0.1 to reflect the steep slopes. As these latter two factors are uniform inside and out of the soil polygon, it is clear that the recharge is driven by the high soils factor.

Area B lies in aquifer 0199 and is characterized by a flat lying area exhibiting a high infiltration factor (0.3) due to the low slopes. The area is largely farmed and exhibits a lower infiltration factor (0.1) when compared to the areas flanking it to the south. Finally, the soils have some influence as the east half is quite organic with a low infiltration factor of 0.1, but the western side hosts more permeable soils and it reaches as high as 0.35. Thus, area B exhibits a greater recharge area on Figure 16 due to flat slopes and the western half of soils.

Area C is in the far west of the watersheds and was selected because it shows as a distinctive bulls-eye on Figure 16. Heavily forested and in a very steep part of the countryside, the land cover and slope factors are uniform in the area. However, due to the gravelly soils over bedrock, the infiltration factor for soils is 0.4 in contrast to the surrounding areas with low permeability moraine. For this reason it shows as an area of low runoff (390 mm/yr) and high recharge (910 mm/yr), like area A. This is even further emphasized by the fact that it lies at the western edge of the study area where the annual surplus is quite high (1,300 mm/yr compared to Shawnigan lake where it is just 851 mm/yr).

Mill Bay (area D on Figure 16) lies in an area of low recharge and moderate runoff, in part due to a lower annual surplus near the inlet (755 mm/yr). The relatively lower recharge is also affected by the moraine and marine soils of only moderate infiltration capacity, and particularly by the low factor (0.05) for the greater urban land coverage. This is also apparent along the whole shoreline extending to the north of Mill Bay.

In area E on Figure 16 lies Cobble Hill in aquifer 0202. Compared to the surrounding area it exhibits greater recharge. This is because of a combination of being wooded, and having relatively coarse soils. From a slope perspective the amount of recharge is lessened by the steep slopes, yet still it is a significant recharge feature in the area.

Finally, area F, which is the upstream Koksilah valley, has been selected for discussion because it is a significant longitudinal feature. It hosts similar soils, is relatively flat and land cover is consistently forested. Thus there is little variance in the three contributing factors. However, recharge at the upper end to the west is 868 mm/yr, and downstream to the east it is just 682 mm/yr. This is due entirely to the amount of precipitation that falls, and the fact that it (and therefore the surplus) reduces dramatically to the east as one descends ultimately to the marine shore.

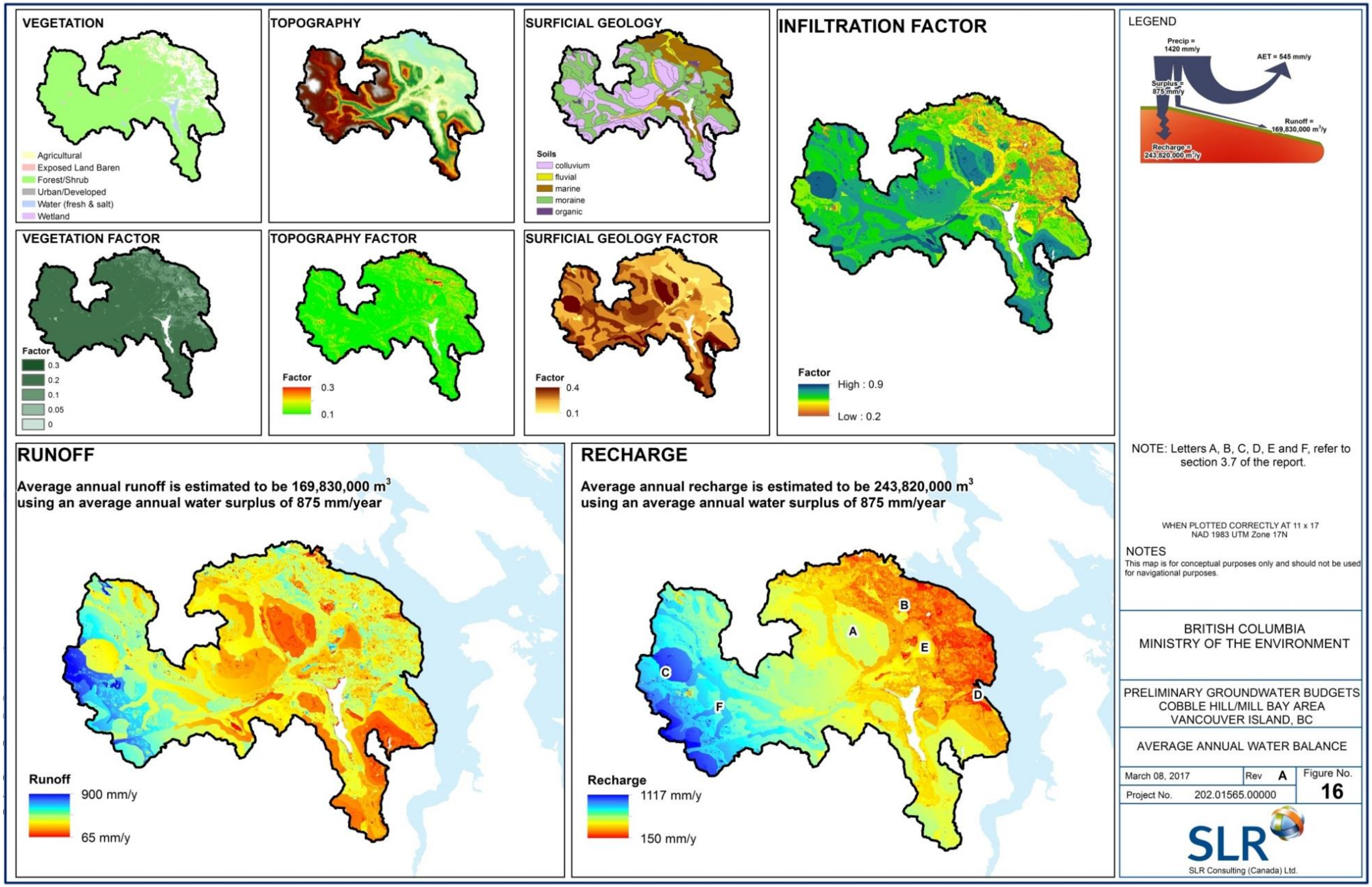

Figure 16: Average annual water budget.

3.7.1 Comparison of Recharge Estimation Techniques

The methodology employed to calculate recharge for the purpose of this report is not widely used in British Columbia. First order estimates are often determined by the analyst selecting a simple percentage of precipitation. Informal discussion with practitioners in the study area has found that this percentage ranges from 15% to 30%, depending upon the experience of the individual. The methodology used here calculates the recharge based on soil type, ground slope and soil cover, as applied to the average annual surplus, which varies substantially by geographical position. Thus, the estimates used here can be evaluated on the 50 m grid used in the GIS platform for any given point. Using this same method, the percentage of precipitation estimated to recharge the ground can be spatially determined. It was found that this percentage varied from 12% to 55%, and is quite location specific. For example, greater than 30% of the precipitation recharges the groundwater in most of the upland areas. In the developed area, such as aquifer 0197, this percentage is lower, but only occasionally dips below 20%. It will be a recommendation of this report that the recharge be mapped and used as a tool for the ENV analysts when assessing water taking applications.

3.7.2 Comparison of Recharge by Climatic Conditions

It is useful to compare the recharge rate by aquifer and by climatic conditions. Table 27 below provides this comparison. In general, recharge is significant in the cold and wet years, although the ability of the fractured bedrock and thin drift areas to retain that water as storage is limited. The hot and dry years have a significantly lower rate of infiltration, of course driven by water availability. There is also a pattern to the infiltration rate between aquifers, with the inland aquifers (e.g., 0200, 0202, 0203) displaying a greater recharge rate transitioning to the lower rates near the shore (e.g., 0197, 0204, 0205, 0206).

Table 27: Comparison of recharge rate by aquifer and climatic condition.

Aquifer	Infiltration Rate ($m^3/yr/m^2$)		
	Cold, Wet	30 yr Average	Hot, Dry
Bedrock 198*	*0.100*	*0.100*	*0.100*
Bedrock 200	0.886	0.534	0.359
Bedrock 202	0.773	0.466	0.314
Bedrock 203	0.831	0.501	0.337
Bedrock 204	0.600	0.362	0.243
Bedrock 207	0.711	0.429	0.288
Surficial 197	0.608	0.366	0.246
Surficial 199	0.684	0.412	0.277
Surficial 201	0.665	0.401	0.270
Surficial 205	0.627	0.378	0.254
Surficial 206	0.589	0.355	0.239

** Leakance from overburden, not direct recharge*

4. BEDROCK AQUIFER DESCRIPTIONS / WATER BUDGETS

4.1 Aquifer 0198 (Cowichan Station)

4.1.1 Location, Access, and Land Use

Aquifer 0198 (Cowichan Station) is located at the north end of the study area adjacent to the Cowichan River estuary and approximately 150 m east and south of the lower Koksilah River floodplain, and covers 6.2 km^2.

The aquifer is centred at Latitude 48°44'34" Longitude 123o40'02" (UTM 450950E 53990850N Zone 10) and accessible by the Trans-Canada Highway and Bench, Wilson, and Lakeside Roads.

The land surface above aquifer 0198 is moderately developed. Most of the aquifer's central and south surfaces have been developed for rural-residential (44%) or agricultural (14%) purposes. The balance of its surface (42%) consists of undeveloped, forested properties, of which approximately 10% has been recently harvested.

4.1.2 Classification, Extent, and Well Information

Aquifer 0198 is classified by the ENV as a Class IIIC(7) aquifer, which indicates that it is lightly developed with low vulnerability to surface contamination.

The horizontal extent of aquifer 0198 is defined by the occurrence of registered wells that draw groundwater from bedrock below surficial aquifer 0197. The north and west perimeters of aquifer 0198 are defined by the boundary with adjacent surficial aquifer 0186, while its northeast and south perimeters are constituted by the Cowichan Bay marine shoreline and Patrolas Creek, respectively. Undeveloped extensions of aquifer 0198 may underlie adjacent surficial aquifers 0186, 0197, and 0199 to the west, southeast, and south, respectively.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 28.

Table 28: Aquifer 0198 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	54.6	Mean	0.15	Mean	14.0	Mean	9.7
Median	68.6	Median	0.13	Median	13.6	Median	13.7
Range	16.2 - 161.5	Range	0.06 -1.26	Range	0.0 - 41.1	Range	0.5 - 49.7

4.1.3 Physiography and Hydrology

Aquifer 0198 is situated within a lowland area and has a low gentle slope. Surface topography above aquifer 0198 is dominated by a low, northwest-trending, elongated dome with planar to undulating terrain within its central and west portions that slopes gently towards the Koksilah River valley, and mainly undulating to hummocky terrain in its east portions with low to moderate slopes towards the Cowichan River valley. Surface elevations above aquifer 0198 range from 60 m amsl above the aquifer's northwest corner to sea level above its northeast corner at Cowichan Bay.

The boundaries of aquifer 0198 straddle the Koksilah and Cowichan watersheds. Surface drainage patterns above aquifer 0198 are radial, with Weeks Creek, Giese Brook, Treffry Creek, Spears Creek, and at least two unnamed watercourses flowing towards the Koksilah River as it meanders around the aquifer's west and north perimeters. At least twelve springs occur above the periphery of aquifer 0198, eight of which are clustered at its east end adjacent to the Cowichan Bay shoreline.

4.1.4 Geology and Soils

Bedrock within aquifer 0198 consists of folded and fractured shale and mudstone sedimentary rocks of the Nanaimo Group's Haslam Formation. Although bedrock is not exposed within the boundaries of the aquifer, available well records suggest that its surface is irregularly-shaped with numerous linear ridges and narrow depressional areas suggestive of a buried, cuesta-type paleosurface.

The tectonic setting of aquifer 0198 may be mainly compressional due to proximity to the west-northwest trending sole fault of the regional Cowichan fold and thrust system, although small areas of extensional fracturing may be locally present due to the area's complex history of structural deformation.

Aquifer 0198 is entirely covered by a 20 to 50 m thick, texturally-variable mantle of dense, unconsolidated Vashon Drift morainal and loose glaciofluvial outwash / ice-contact materials capped by an almost continuous surface blanket of compact, fine-grained, semi-consolidated Capilano Sediments glaciomarine materials.

Soils above the aquifer generally consist of imperfectly-drained, gleyed eluviated dystric brunisols of the Finlayson Soil Association, which have developed in areas of gentle relief over deep blankets of silty and/or clayey glaciomarine materials.

4.1.5 Hydrogeology

Groundwater within aquifer 0198 occurs primarily within open fracture systems, and to a lesser extent along geological contacts and sedimentary bedding partings, likely within 200 m of surface.

The groundwater storage potential and bulk hydraulic conductivity (K_{mb}) of aquifer 0198 may be generally very low due to the fine-grained, ductile nature of its host rocks and their compressional tectonic setting, with unfractured blocks of rock forming aquitards with K_{mb} values of between $1x10^{-9}$ and $1x10^{-8}$ m/s. However, low-productivity wells have been completed in bedrock where extensional fracture zones have been intersected, although K_{mb} values within these zones may not exceed $1x10^{-7}$ m/s due to the host rocks' propensities to develop wide schistose zones with occluded fractures around fault structures.

The degree of hydraulic confinement of water-bearing zones within aquifer 0198 may be moderately high due to the laterally-persistent surface presence of a glaciomarine aquitard throughout the area.

Regional groundwater flows may trend towards the east-northeast from higher elevations within the Cowichan River valley towards the Cowichan Bay shoreline, although local flows may be highly anisotropic and dissimilar to the area's terrain and drainage patterns due to the aquifer's confined setting, the presence of structural flow barriers, and the irregular shape of the bedrock surface. Hydraulic gradients within aquifer 0198 may be low due to its depressed topographic setting, although groundwater may locally move rapidly due to its dominant occurrence within open fractures.

Aquifer 0198 may receive vertical inflow from the base of aquifer 0197 and the upgradient portions of aquifers 0186 (not in study area but northwest of aquifer 0198) and 0199, but may receive negligible recharge from the vertical infiltration of precipitation, snowmelt, stream losses, or irrigation / sewerage dispersal returns due to its semi-confined to confined state. Aquifer 0198 may receive lateral inflow from water-bearing fracture zones within bedrock aquifer 0196 to the west and south.

Negligible groundwater outflow occurs from aquifer 0198 due to evapotranspiration or discharges to local springs or surface watercourses on top of the overburden, as well as the low degree of hydraulic interaction with overlying and surrounding watercourses or water bodies due to the aquifer's depth below the ground surface and it's semi-confined to confined state. Limited groundwater outflow from water-bearing fracture zones may occur towards its downgradient, undeveloped portions towards the east and northeast, and possibly upwards into the basal portions of surficial aquifer 0197 depending on whether locally-elevated hydraulic heads are present.

4.1.6 Water Budget

As identified above, bedrock aquifer 0198 is blanketed by relatively low permeability overburden of substantive thickness. Part of this includes portions of aquifer 0197 (79.7 ha) and aquifer 0199 (500.0 ha). A thin slice of land (38.6 ha) between aquifer 0197 and aquifer 0199 also covers the bedrock. Examination of water well records shows there is a downward gradient to aquifer 0198 from above. Given the low permeability of the shale bedrock, leakage from above is likely to be fairly limited. A low value of 100 mm/year/m^2 has been estimated for vertical leakage based on professional judgement[5].

Groundwater inflow occurs laterally from the bedrock east of aquifer 0198. Groundwater outflow occurs along the north, west and southern boundaries of aquifer 0198. Calculation of these amounts has assumed a K_{mb} of 10^{-8} m/s. One major stream and several minor ones cross the northern arm of the aquifer, but since they are perched on low permeability soils they have been deemed to be conveyance features only and do not interact with the bedrock. The springs on the north side emanate from the overburden and are not part of the bedrock flow system. Thus, there are no groundwater/surface water interactions to quantify in this case.

Water takings in the geographic aquifer 0198 area were determined by Hatfield (2015) and used directly according to the methodology outlined in Section 2.2.8 above. The irrigation licenses are all along the Koksilah River and are not derived from the aquifer (at least not until it discharges to the river). Table 29 summarizes the water budget in terms of the losses and gains described above.

Table 29: Bedrock aquifer 0198 annual water budget for average climate conditions.

Component	Cubic metres per year	
Gains =	827,400	% of Gain
Downward Leakage from aquifer 0197	500,000	60
Downward Leakage from aquifer 0199	79,600	10
Downward Leakage from remaining overburden	38,600	5
Lateral groundwater inflow	209,200	25
Losses =	- 295,700	% of Loss
Lateral groundwater outflow	57,400	19
Water Usage: Municipal and Domestic	121,500	41
Water Usage: Commercial and Industrial	116,800	40
Water Usage: Irrigation	0	0
Streamflow Losses	0	0
Net Water Balance =	+ 531,700	

The water budget shows a 64% retention of the aquifer gains which appears that there is a surplus of water in the bedrock available for use. However, this may simply be an overestimation of the leakage from above. For example, a leakage rate of just 50 mm/yr would mean a surplus of just 222,600 m^3/yr.

[5] This is based on experience in groundwater modelling work. To test the assumption, one can use an estimated hydraulic conductivity of 10^{-8} m/s, and a typical vertical gradient of 0.3 m/m and calculate a Darcy flux of about 3 x 10^{-9} m/s, which is 0.094 m^3/yr/m^2, or about 94 mm/yr per square metre. This is roughly the same as the 100 mm/yr/m^2 used here, which may therefore be considered a reasonable estimate

Similarly, if the bedrock hydraulic conductivity was in reality an order of magnitude lower, which is well within reason, the surplus would be further reduced to just 86,000 m^3/yr.

In a hot and dry year such as 1989 where the surplus was 29% lower than normal, one could expect a similar reduction in downward leakage from the overburden. The total downward leakage of 618,200 m^3/yr (for an average year) could therefore be just 439,000 m^3/yr, a loss of 179,200 m^3 in such a year, which would have a significant effect on the above sums. By similar logic, the 60% increase in recharge for that very wet year in 1999, would have added 371,000 m^3, and a clear surplus would be present. If future conditions realize the increase in surplus predicted in Section 3.2.3 (as qualified there), the hot/dry condition will not be as bad, and the wet/cold condition will have a higher surplus.

The monthly water budget for the average annual conditions is shown on Figure 17. This bedrock aquifer does not receive direct recharge driven by the monthly surplus, but rather the overburden acts as a slow reservoir. Therefore, the month-to-month variance is not great, with a seasonal decline beginning in May and recovering in October. The calculations herein have assumed a uniform leakance rate of 100 mm/year for both the hot/dry and wet/cold conditions, so the water budget values are very similar between the three scenarios on Figure 17. It should be anticipated that once this value is calibrated, that these monthly values would be less in the hot/dry year and higher in the wet/cold year. The analysis implies that bedrock water supplies will be protected from seasonal swings in bedrock aquifer 0198.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the normal year:

238,300/618,200 X 100% = 38.5% (Significant Stress Level)

Recharge of this aquifer is based on leakage estimates through the overburden aquitard and what the bedrock might accept (assumed to be 100 mm/yr). As implied above, work should be undertaken to more accurately define this value, and if it is higher than assumed, the available water may be greater, and thus the stress assessments would be lower.

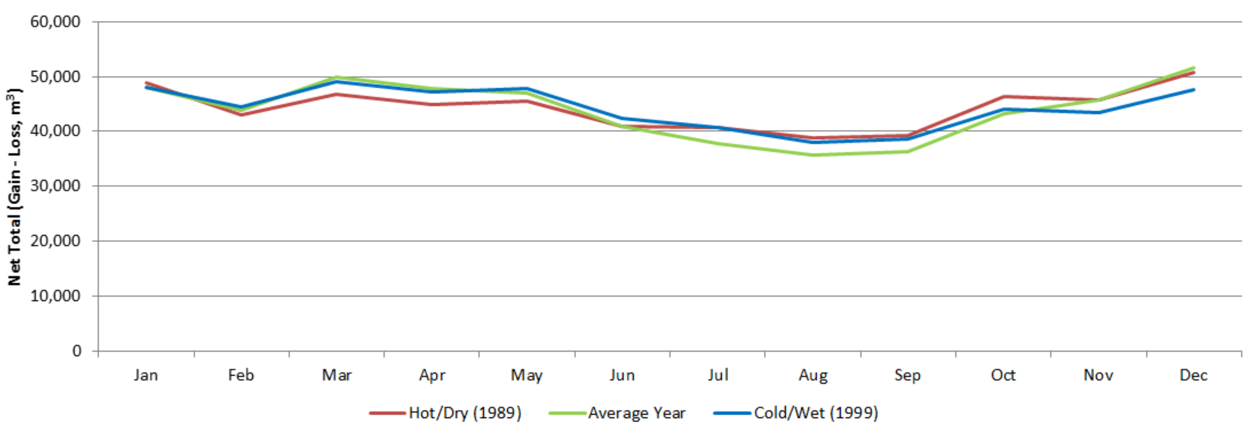

Figure 17: Monthly water budget for bedrock aquifer 0198.

4.1.7 Bedrock Aquifer 0198 Conclusions

The above water budget suggests there is an annual surplus in bedrock aquifer 0198. However, the uncertainties in the calculations far outweigh the calculated surplus, and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIIC(7), and is not highly developed. It can be seen in Section 4.1.6 that a significant portion of the available water is being tapped already. For future supplies, it is reasonable to assume that if wells can find any permeable horizons in the low permeability bedrock, then useable quantities of water may be available. Given the uniformity of the bedrock no specific geologic targets for water development can be identified for aquifer 0198. The likelihood of identifying high yield zones is also low, and water supplies based on individual wells uniformly spread out is recommended. This is because there is likely very little available storage in the aquifer due to the lack of major structures and the aquifer's likely low hydraulic conductivity. Potential well interference between existing and future/proposed wells in aquifer 0198 could be high due to the likely low storativity of this shale bedrock.

This small aquifer area is significantly stressed under both normal and hot/dry conditions, as well as during wetter years. These relatively high stress assessments are in part mitigated by the above conclusion that this bedrock aquifer is not overly affected by seasonal effects. However, authorization of new groundwater use needs to consider the proximity of existing supplies, and long term availability of water, regardless of refined water quantity stress level assignments.

4.2 Aquifer 0200 (Kelvin Creek)

4.2.1 Location, Access, and Land Use

Aquifer 0200 (Kelvin Creek) is located in the northwest part of the study area northwest of the middle reaches of Koksilah River and east of the headwaters of Kelvin Creek, and covers 26.9 km^2.

The aquifer is centred at Latitude 48°41'49" Longitude 123°41'34" (UTM 448950E 5393900N Zone 10) and accessible by along its west and east sides by Mountain and Riverside Roads, respectively.

The land surface above aquifer 0200 is very lightly developed. Over 96% of the aquifer's surface consists of undeveloped, forested properties, of which approximately 30% has been recently harvested. The remaining 4% of its surface along its east margin has been developed for rural-residential purposes.

4.2.2 Classification, Extent, and Well Information

Aquifer 0200 is classified by the ENV as a Class IIIB(9) aquifer, which indicates that it is lightly developed with moderate vulnerability to surface contamination.

The horizontal extent of aquifer 0200 is defined by the occurrence of registered wells that divert groundwater from upland bedrock areas northwest of the Koksilah River. The aquifer's north perimeter is defined by the boundary with adjacent surficial aquifer 0196 and following a topographic contour, while Kelvin Creek constitutes its west perimeter and Koksilah River and the boundary of adjacent bedrock aquifer 0202 forms its east and southeast perimeters (imply as a no-flow boundary). Undeveloped extensions of aquifer 0200 underlie adjacent upland areas to the west and southwest.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 30

Table 30: Aquifer 0200 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	73.5	Mean	0.16	Mean	-	Mean	12.1
Median	68.6	Median	0.19	Median	3.0	Median	11.9
Range	24.4 – 166.7	Range	0.02 – 1.58	Range	0.0 – 28.7	Range	0.0 – 44.2

4.2.3 Physiography and Hydrology

Aquifer 0200 is situated within an upland area of generally higher relief. Surface topography above aquifer 0200 is mostly rugged to rolling apart from its relatively low-relief east flank, with four large, sub-conical hills separated by narrow valleys dominating its terrain. Surface elevations above aquifer 0200 range from 480 m amsl in its southwest corner to 40 m amsl at its northeast corner within the Koksilah River valley.

Aquifer 0200 is located entirely within the Koksilah watershed, with the nearest marine shoreline being 4.1 km to the northeast at Cowichan Bay. Surface drainage patterns above aquifer 0200 are radial, with Kudrick Brook and Upex Creek flowing north and west towards Kelvin Creek, and Rosedale Creek and at least fourteen unnamed streams flowing northeast, east, and southeast towards Koksilah River. At least four springs occur around the southwest and east peripheries of aquifer 0200, and at least ten small wetlands occur in low-lying areas that constitute the headwaters of many of its streams.

4.2.4 Geology and Soils

Bedrock within the southeast half of aquifer 0200 consists of fractured basaltic volcanic rocks of the Sicker Group's Duck Lake Formation and the Vancouver Group's Karmutsen Formation, while its northwest half and south and east fringes mainly consist of fractured granodioritic intrusive rocks of the Island Plutonic Suite. Fractured and karstified limestone of the Buttle Lake Group's Mount Mark Formation occurs within the central and southeast portions of the aquifer, while its northern fringe consists of folded and fractured shale sedimentary rocks of the Nanaimo Group's Haslam Formation.

The tectonic setting of aquifer 0200 may be mainly compressional due to its location approximately 1 km northwest of a northeast-trending splay of the regional, east-northeast trending San Juan Fault. However, the presence of at least five strong and four weak topographic lineaments that trend north and north-northwest through its central and east portions suggest that major and minor extensional faults may occur in these areas. In addition, extensional fracture zones may be present along the contacts between the aquifer's main geological units due to differences in their structural competencies, particularly along the boundaries between volcanic, intrusive, and limestone units.

Aquifer 0200 is mostly covered by loose to compact, impersistent, sandy veneers to blankets of unconsolidated Vashon Drift morainal deposits, which are often colluviated on the flanks of the area's steeper hills. The Kelvin Creek / Koksilah River valleys along the aquifer's west and east sides contain relatively thicker, incised blankets of compact Vashon Drift morainal materials capped by deposits of loose, medium to coarse-grained Capilano Sediments glaciofluvial outwash and fine-grained glaciolacustrine materials, as well as small aggraded pods of loose, coarse-grained Salish Sediments fluvial materials.

Soils above the central upland parts of aquifer 0200 generally consist of rapidly-drained, orthic dystric brunisols of the Rosewall Soil Association, which have developed in areas of moderate to high relief over veneers of sandy and/or sand-gravelly colluvial or morainal materials less than 1 m thick over bedrock. Soils around the flanks of the aquifer's hills and within the Koksilah River and Kelvin Creek valleys mainly consist of imperfectly to well-drained, duric dystric brunisols of the Qualicum and Shawnigan Soil Association that have developed in areas of moderate relief over deep blankets of gravelly-sandy morainal and glaciofluvial materials. Surface water infiltration rates to the bedrock surface within aquifer 0200 may be locally restricted in areas where low-permeability; near-surface duric soil layers are present.

4.2.5 Hydrogeology

Groundwater within aquifer 0200 occurs primarily within open fracture systems, and to a lesser extent within dissolution voids and along geological contacts and sedimentary bedding partings.

The groundwater storage potential and K_{mb} of aquifer 0200 may be variable due to the heterogeneous nature and structural complexity of its host rocks. Relatively lightly fractured blocks of Vancouver Group volcanic rocks and Nanaimo Group sedimentary rocks may form effective aquitards with K_{mb} values of between $1x10^{-9}$ and $1x10^{-7}$ m/s due to their fine-grained, ductile natures. Blocks of Sicker Group volcanic rocks, Buttle Lake Group limestone, and Island Intrusive Suite intrusive rocks may display comparatively higher K_{mb} values of between $1x10^{-6}$ and $1x10^{-5}$ m/s and constitute "leaky" aquitards or low-productivity aquifers due to their relatively brittle natures, lack of schistose zones, and open fracture systems. Low to moderate productivity wells have been completed within most of the aquifer's bedrock units where extensional fracture zones have been intersected, with K_{mb} values potentially reaching $1x10^{-5}$ m/s within more brittle, heavily-fractured host rocks and considerably higher in areas of karstified limestone.

The degree of hydraulic confinement of water-bearing zones within aquifer 0200 may be generally low due to the absence of a laterally-persistent surface aquitard, but will be contingent on whether the host fracture systems are in direct hydraulic connection with the ground surface. Over 30% of the wells completed within aquifer 0200 are reported by the ENV as not having a confining layer.

Regional groundwater flows within aquifer 0200 may be radial from higher elevations towards Kelvin Creek and Koksilah River, but local flows may be highly anisotropic, dissimilar to the area's terrain and drainage patterns, and largely controlled by the structural geometries, connectivities, and degrees of confinement of its water-bearing fracture systems and the presence of structural flow barriers. Hydraulic gradients within aquifer 0200 may be moderate to high based on the area's upland topographic setting and rugged terrain, with groundwater locally moving rapidly due to its dominant occurrence within open fractures.

Aquifer 0200 may receive vertical inflow from precipitation, snowmelt, and stream losses at higher elevations. However, the volume of water that infiltrates into the aquifer's extensional faults and fracture systems will be contingent on the number and orientation of fractures exposed at surface and may be relatively low due to area's susceptibility to rapid surface runoff on its steep, recently logged hill slopes. The aquifer may also receive small amounts of vertical inflow from irrigation / sewerage dispersal returns along its east side due to its comparatively developed condition. The aquifer may receive lateral inflow from water-bearing fracture zones within undeveloped bedrock aquifers at higher elevations to the west and southwest.

Groundwater outflow from aquifer 0200 may primarily take place through base flow discharge to the lower reaches of its internal streams and incised reaches of Kelvin Creek and Koksilah River, through low-elevation springs (particularly along its north periphery), and as lateral discharge along open fracture systems into adjacent aquifers 0196 to the north and 0202 to the northeast.

4.2.6 Water Budget

As identified above, bedrock aquifer 0200 aquifer is characterized by shallow overburden over steep bedrock and is largely undeveloped. (Thicker overburden is present in the Kelvin Creek and Koksilah River valleys.) The area experiences an average recharge of 534 mm/yr from precipitation and snowmelt, largely due to its westerly position in the study area where the annual surplus is very high. This reduces to 359 mm/yr in a hot/dry year, and could be as high as 886 mm/yr in a cold/wet year.

Examination of water well records shows there is a downward gradient in aquifer 0200. Groundwater flow patterns are radially outward in all directions, which accounts for the majority of outflow from the aquifer. (Some minor groundwater inflow occurs at the westerly tip of the aquifer where water enters and then flows through to subsequently discharge to Kelvin Creek.) The outflow is dominantly along the more permeable north to northwest trending geologic lineaments. There are five main watercourses that are gaining water from the aquifer and represent a water loss (Table 31).

All irrigation water takings in the geographic aquifer 0200 area are from surface water sources and are thus not included, as that water is already accounted for in the water courses. Hatfield (2015) identified no commercial or industrial water takings. All residential developments are on well and septic fields, so water that is taken is returned locally to the aquifer.

Table 31 summarizes the water budget in terms of the losses and gains described above.

Table 31: Bedrock aquifer 0200 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	15,051,600	% of Gains
Recharge	14,377,400	96
Lateral groundwater inflow	674,200	4
Losses =	- 17,157,800	% of Losses
Lateral groundwater outflow	15,125,800	88
Water Usage: Municipal and Domestic	44,300	0
Water Usage: Commercial and Industrial	0	0
Water Usage: Irrigation	900	0
Streamflow Losses	1,986,800	12
Net Water Balance =	- 2,106,200	

The water budget shows a 15% loss of the aquifer gains which results in a deficit of water in the bedrock under normal conditions. This is counterintuitive for this large area, with little water use. However, this is considered good agreement between water in and water out. For example, just a 13% decrease in the K_{mb} used in the calculations would cause a perfect balance between gains and losses.

In a hot and dry year such as 1989 where the surplus was 29% lower than normal, one could expect a similar reduction in recharge. The total recharge of 14,377,400 m^3 (for an average year) could be reduced by 4,169,400 m^3 in such a hot/dry year. This would lower regional water levels in the bedrock aquifer, which in turn would reduce the lateral hydraulic gradient by a small percentage and thus mitigate lateral groundwater outflow losses. However, it can be seen that this would have a significant effect on the above surplus, and might even worsen the perceived deficit. By similar logic, the 60% increase in recharge for that very wet year in 1999, would have added just over 8,600,000 m^3, and a clear surplus would be present, regardless of coincident increases of lateral outflows.

The monthly water budget shown on Figure 18 reveals that in an average year there is a surplus condition from November to February, and that a clear deficit occurs in the seven months from April to September (green line). March and October are nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs in the period from October to March. The hot/dry year (red line) is revealing, where a small surplus from November to March and steady deficit in the other seven months. The degree of deficit is similar in the summer period between all three scenarios.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 45,230/9,672,200 X 100% = 0.5% (Low Stress Level)
- Normal. 45,230/14,377,400 X 100% = 0.3% (Low Stress Level)
- Cold/Wet. 45,230/23,859,900 X 100% = 0.2% (Low Stress Level)

The aquifer is deemed to currently be under low stress on an annual basis, largely due to the low consumptive use in comparison to the size of the resource.

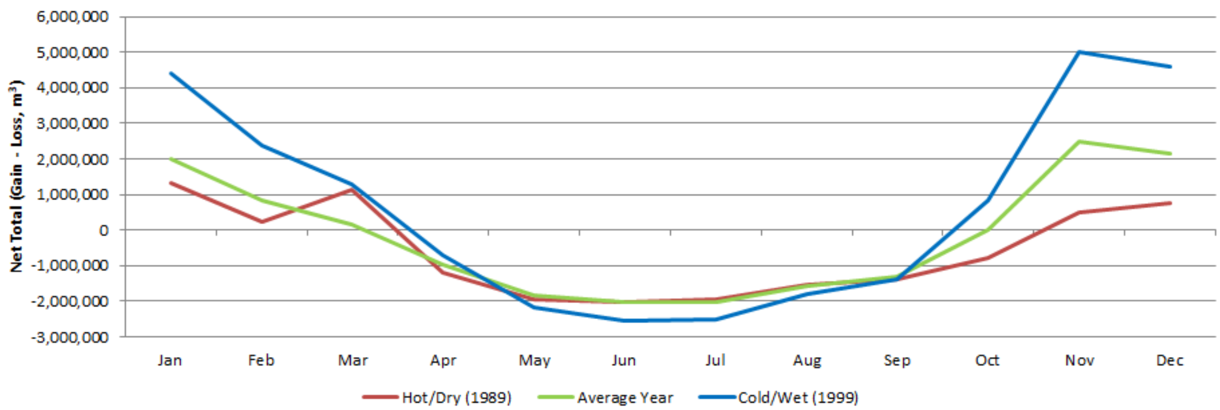

Figure 18: Monthly water budget for bedrock aquifer 0200.

4.2.7 Bedrock Aquifer 0200 Conclusions

The above water budget suggests there is an annual deficit in aquifer 0200. The aquifer has previously been classified as Class IIIB(9), and is only lightly developed. There are many permeable zones along topographic lineaments that suggest the presence of underlying geological structures with hydraulic conductivities in the useable range of 10^{-6} to 10^{-5} m/s. These are however separated by lower permeability bedrock where only low yield wells are possible. The northern portion of the aquifer area however is overlain by the low permeability rocks of the Nanaimo group, where the likelihood of identifying high yield zones is also low, and water supplies based on individual wells uniformly spread out is recommended. This is because there is likely very little available storage in the aquifer due to the lack of major structures and the aquifer's low hydraulic conductivity.

It is reasonable to use the geologic mapping to identify specific geologic targets for water development within the southern majority of aquifer 0200. The likelihood of identifying high yield zones is moderately good in this area, particularly where fault intersections occur. The vast majority of the water appears to exit the aquifer area as discharge to streamflow, and this remains a viable target for water use.

4.3 Aquifer 0202 (North Shawnigan)

4.3.1 Location, Access, and Land Use

Aquifer 0202 (North Shawnigan) is located in the centre of the study area south and east of the middle reaches of Koksilah River and approximately 900 m north of Shawnigan Lake, and covers 21.0 km^2.

The aquifer is centred at Latitude 48°40'36" Longitude 123°38'28" (UTM 452800E 5391700N Zone 10) and accessible by Colman, Ingot, Thain, Kingburne, and Gregory Roads.

The land surface above aquifer 0202 is lightly developed. Over 78% of the aquifer's surface consists of undeveloped, forested properties, of which approximately 5% has been recently harvested. The balance of its surface along its southeast and northwest margins has been developed for rural-residential (19%) and agricultural (3%) purposes.

4.3.2 Classification, Extent, and Well Information

Aquifer 0202 is classified by the ENV as a Class IIB(10) aquifer, which indicates that it is moderately developed with moderate vulnerability to surface contamination.

The horizontal extent of aquifer 0202 is defined by the occurrence of registered wells that draw groundwater from upland bedrock areas southeast of the Koksilah River and below surficial aquifer 0201, which it underlies and surrounds. The aquifer's west and southwest perimeters are defined by Koksilah River and the boundary of adjacent bedrock aquifer 0200, while its north perimeter coincides with the south edge of the Dougan Lake topographic depression. The aquifer's northeast and east perimeters are defined by Shawnigan Creek, the Esquimalt and Nanaimo Railway, and the boundaries of adjacent surficial aquifer 0197 and bedrock aquifers 0204 and 0207, while its south perimeter is formed by its boundary with adjacent bedrock aquifer 0203. Undeveloped extensions of aquifer 0202 underlie adjacent upland areas to the southwest.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 32.

Table 32: Aquifer 0202 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	78.9	Mean	0.23	Mean	-	Mean	7.7
Median	83.1	Median	0.19	Median	2.1	Median	8.4
Range	13.7 – 182.9	Range	0.02 – 5.68	Range	0.0 – 53.3	Range	0.0 – 81.7

4.3.3 Physiography and Hydrology

Aquifer 0202 is situated within an upland area of moderately high relief. Surface topography above aquifer 0202 is mostly rugged to undulating, with the exception of a large, level depression in its central-northwest part north of Kingzett Lake. A distinctive line of five large, sub-conical hills, including Cobble Hill, bisect the aquifer along a northeast trend, while and a sixth isolated, conical hill occupies its north corner. Terrain northwest of the line of hills drops sharply towards the Koksilah River valley, while terrain to the southeast displays a more gentle, undulating surface and southeast-facing aspect. Surface elevations above aquifer 0202 range from 320 m amsl at the summit of the northeast hill near its east side to 60 m amsl at its north end adjacent at the edge of the Dougan Lake depression.

The boundaries of aquifer 0202 straddle the Koksilah and Shawnigan watersheds, with the nearest marine shoreline being 4.3 km east at Satellite Channel. Surface drainage patterns above aquifer 0202 are rectangular to radial and largely controlled by the area's line of hills, with Heather Bank Brook, and Kenneth Creek flowing north and northwest towards Koksilah River, and Burnham Creek, Timothy Brook, and Hartl Creek flowing southeast and east towards Shawnigan Creek. At least ten springs occur around the east and northeast peripheries of aquifer 0202, and at least twelve small, hydraulically-connected wetlands and two small lakes occur in low-lying areas along the Hartl and Timothy Creek drainage systems at the south end of the aquifer.

4.3.4 Geology and Soils

Bedrock within aquifer 0202 mostly consists of a V-shaped block of fractured basaltic volcanic rocks of the Sicker Group's Duck Lake Formation, with its east end consisting of a triangular block of fractured basaltic volcanic rocks of the Vancouver Group's Karmutsen Formation and a small area of karstified and fractured limestone of the Buttle Lake Group's Mount Mark Formation. A narrow linear belt along the northwest side of the aquifer consists of fractured granodioritic intrusive rocks of the Island Plutonic Suite. The extreme north end of the aquifer area consists of consists of folded shale sedimentary rocks of the Nanaimo Group's Haslam Formation, while the southeast corner consists of relatively unfractured andesitic volcanic rocks of the Bonanza Group.

The tectonic setting of aquifer 0202 may be mainly compressional due to its location straddling the regional, east-northeast trending San Juan Fault and its northeast-trending splay, although the presence of at least twelve weak topographic lineaments that trend north, north-northwest, and west-trending within the aquifer suggests that minor extensional faults may also occur in the area. In addition, extensional fracture zones may be present along the contacts between the aquifer's main geological units due to differences in their structural competencies, particularly along the boundaries between volcanic and limestone units.

The upland portions of aquifer 0202 are mostly covered by loose to compact, impersistent, sandy veneers to blankets of unconsolidated Vashon Drift morainal deposits, although thicker blankets of compact morainal materials mask the bedrock surface over most of its low-lying southeast portion. A 2 km^2, crescent-shaped bedrock depression in the west-central part of the aquifer contains a 50 to 60 m thick deposit of Vashon Drift compact morainal / glaciolacustrine and loose glaciofluvial ice-contact materials that host overburden aquifer 0201.

Soils above the upland parts of aquifer 0202 generally consist of well to rapidly-drained, orthic and/or duric dystric brunisols of the Rosewall, Hiller, and Shawnigan Soil Associations, which have developed in areas of moderate to high relief over veneers to blankets of sandy and/or sand-gravelly colluvial or morainal materials less than 1 m thick over bedrock. Soils around the flanks of the aquifer's hills and within its low-lying southeast portion mainly consist of imperfectly to well-drained, duric dystric brunisols of the Qualicum and Shawnigan Soil Association that have developed in areas of moderate relief over deep blankets of gravelly-sandy morainal materials. Soils within the topographic depression in the west-central part of the aquifer consist of roughly equal portions of terric mesisols of the Arrowsmith Soil Association and orthic humic gleysols of the Cowichan Soil Association, which have developed in depressional areas over deep, water-saturated deposits of organic and silty-clay glaciolacustrine materials, respectively. Surface water infiltration rates to the bedrock surface within aquifer 0202 may be locally restricted in areas where low-permeability; near-surface duric or silty-clay soil layers are present.

4.3.5 Hydrogeology

Groundwater within aquifer 0202 occurs primarily within open fracture systems, and to a lesser extent within dissolution voids and along geological contacts and sedimentary bedding partings.

The groundwater storage potential and K_{mb} of aquifer 0202 may be variable due to the heterogeneous nature and structural complexity of its host rocks. Relatively lightly fractured blocks of Vancouver and Bonanza Group volcanic rocks and Nanaimo Group sedimentary rocks may form effective aquitards with K_{mb} values of between $1x10^{-9}$ and $1x10^{-7}$ m/s due to their fine-grained, ductile nature, while blocks of Sicker Group volcanic rocks, Buttle Lake Group limestone, and Island Intrusive Suite intrusive rocks may display comparatively higher K_{mb} values of between $1x10^{-6}$ and $1x10^{-5}$ m/s and constitute "leaky" aquitards or low-productivity aquifers due to their relatively brittle natures, lack of schistose zones, and open fracture systems. Low to moderate productivity wells have been completed within most of the aquifer's bedrock units where extensional fracture zones have been intersected, with K_{mb} values potentially reaching $1x10^{-5}$ m/s within more brittle, heavily-fractured host rocks and considerably higher in areas of karstified limestone. Wells completed within fractured Bonanza Group volcanic rocks generally display low productivities due to their propensity to develop wide schistose zones with occluded fractures around fault structures.

The degree of hydraulic confinement of water-bearing zones within the upland portions of aquifer 0202 may be generally low due to the absence of a laterally-persistent surface aquitard, but will be contingent on whether the host fracture systems are in direct hydraulic connection with the ground surface. In contrast, the degree of hydraulic confinement of water-bearing zones within the lower-lying portions of aquifer 0202 covered by thick blankets of low-permeability morainal and glaciolacustrine materials may be comparatively higher. Over 40% of the wells completed within aquifer 0202 are reported by the ENV as not having a confining layer.

Regional groundwater flows within aquifer 0202 may be radial from higher elevations towards Koksilah River and Shawnigan Creek, but local flows may be highly anisotropic, dissimilar to the area's terrain and drainage patterns, and largely controlled by the structural geometries, connectivities, and degrees of confinement of its water-bearing fracture systems and the presence of structural flow barriers. Hydraulic gradients within aquifer 0202 may be moderate to high based on the area's upland topographic setting and rugged terrain, with groundwater locally moving rapidly due to its dominant occurrence within open fractures.

Aquifer 0202 may receive vertical inflow from precipitation, snowmelt, stream losses at higher elevations, irrigation / sewerage dispersal returns at lower elevations, and infiltration from the base of the overlying aquifer 0201. Lateral inflow may also occur from water-bearing fracture zones with the adjacent aquifer 0200 to the northwest and undeveloped bedrock aquifers to the southwest.

Groundwater outflow from aquifer 0202 may primarily take place through evapotranspiration and base flow discharge to the lower reaches of its internal streams, the incised reaches of Koksilah River and Shawnigan Creek along its northwest and southeast borders, and low-elevation springs along its north, east, and southeast peripheries. Lateral discharge may occur through open fracture systems into adjacent aquifers 0204 and 0207 to the east, and aquifers 0197 and 0199 to the northeast and north, respectively.

4.3.6 Water Budget

As identified above, bedrock aquifer 0202 is characterized by shallow overburden over steep bedrock and is moderately developed. The area experiences an average recharge of 466 mm/yr, largely due to its relatively westerly position in the study area where the annual surplus is very high. This reduces to 314 mm/yr in a hot/dry year, and could be as high as 773 mm/yr in a cold/wet year. Aquifer 0201 overlies aquifer 0202 and shows downward gradients, indicating a recharge of the bedrock in that area. Based on the moderate K_{mb} values for that area, a leakage of 300 mm/yr has been estimated for this 2.1 square kilometre area.

Examination of water well records shows there is a downward gradient in aquifer 0202. Groundwater flow patterns are radially outward in all directions, which accounts for the majority of outflow from the aquifer. The outflow is dominantly along the more permeable geologic lineaments. Inflow occurs principally along three faults crossing under the Koksilah River from aquifer 0200 to the north. There are three main watercourses, Hartl Creek, Timothy Brook, and Heather Bank Brook, which are in areas of strong downward gradients and were thus assumed to be losing streams[6], contributing water to the groundwater system. No stream temperature information was available to confirm this. Overburden however is shallow where these creeks flow across aquifer 0202 and thus this leakage is a contribution to aquifer 0202.

Based on van der Gulik, et.al., 2003, the withdrawal from groundwater for irrigation is about 6,500 m^3 per year. All other irrigation water takings in the geographic aquifer 0202 area are from surface water sources and are thus not included, as that water is already accounted for in the water courses. Hatfield

[6] It is possible that Hartl Creek may be a gaining creek in its lower reaches, but no information on this was available at the time of writing.

(2015) identified limited commercial water takings, which we have assumed to be 100% consumptive in nature.

Table 33 summarizes the water budget in terms of the losses and gains described above. The water budget shows a 20% loss of the aquifer gains which would indicate there is a deficit of water in the bedrock available for use. The comparison of water in to water out is considered to be in close agreement. For example, a 20% decrease in the K_{mb} used in the calculations would cause a perfect balance between gains and losses. (Variance of bulk K by 20% is very much within reason, which can easily vary by more than an order of magnitude.)

Table 33: Bedrock aquifer 0202 annual water budget for average climate conditions.

Component	Cubic metres per year		
	Gains =	14,304,200	% of Gains
Recharge		8,801,600	62
Downward Leakage from aquifer 0201		633,800	4
Lateral groundwater inflow		3,695,700	26
Streamflow Losses to aquifer 0202		1,173,100	8
	Losses =	- 17,139,600	% of Losses
Lateral groundwater outflow		16,947,700	99
Water Usage: Municipal and Domestic		178,100	1
Water Usage: Commercial and Industrial		7,300	0
Water Usage: Irrigation		6,500	0
	Net Water Balance =	- 2,835,400	

In a hot and dry year such as 1989 where the surplus was 29% lower than normal, one could expect a similar reduction in recharge and downward leakage from the overburden. The total downward leakage of 633,800 + 8,801,600 = 9,435,400 m^3 (for an average year) could therefore be just 5,592,300 m^3, a loss of a further 3,843,100 m^3 in such a year, which would have a significant effect on the above sums. (However, lateral outflows would be reduced by a reduction in driving head caused by lower water table positions.) By similar logic, the 60% increase in recharge for that very wet year in 1999, would have added over 5.600,000 m^3, and a clear surplus would be present.

The monthly water budget shown on Figure 19 reveals that in an average year there is a surplus condition from November to February, and that a clear deficit occurs in the seven months from April to October (green line). March is nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs in January and February, and March and October become surplus months. The hot/dry year (red line) is revealing, where there is only a small surplus from November to March and steady deficit in the other seven months. The degree of deficit is similar in the summer period between all three scenarios, generally because this period is always in deficit and the annual water budget is governed more by the additional rain in the wetter months.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 191,900/5,921,200 X 100% = 3.2% (Low Stress Level)
- Normal. 191,900/8,801,600 X 100% = 2.2% (Low Stress Level)
- Cold/Wet. 191,900/14,606,600 X 100% = 1.3% (Low Stress Level)

These factors are low, but greater than aquifer 0200 due to the higher water use. Nevertheless, the aquifer is deemed to be currently under low stress on an annual basis.

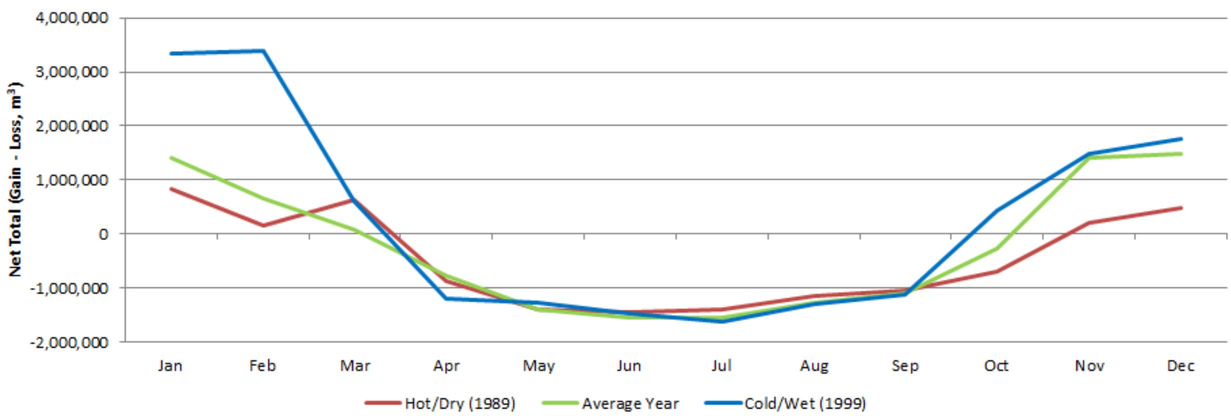

Figure 19: Monthly water budget for bedrock aquifer 0202.

4.3.7 Bedrock Aquifer 0202 Conclusions

The above water budget suggests there is an annual deficit in aquifer 0202. However, the uncertainties in the calculations far outweigh the calculated deficit and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIB(10), and is moderately developed. There are many permeable zones along geologic lineaments with hydraulic conductivities in the useable range of 10^{-6} to 10^{-5} m/s. Notably these are the San Juan Fault and its splay fault. These are however separated by lower permeability bedrock where low yield wells are present. The northern portion of the site, however, is overlain by the low permeability rocks of the Nanaimo group, where the likelihood of identifying high yield zones is also low. This is also true in the area south of the San Juan fault and north of Shawnigan Lake, where the Bonanza volcanics display K_{mb} in the order of 10^{-9} m/s. In these two areas water supplies based on individual wells uniformly spread out is recommended. Licensing of large water supplies in such areas will require longer term pumping tests to demonstrate sustainability and a lack of well interference.

It is reasonable to use the geologic mapping to identify specific geologic targets for water development within the majority of aquifer 0202. The likelihood of identifying high yield zones is moderately good in the area north of the San Juan Fault within the brittle Sicker Group and potentially along the splay fault. However, wells with high sustainable yields may only be possible in areas with elevated EPM (equivalent porous media) such as at fault intersections or areas with anastomosing fault swarms. Attention would have to be paid to whether the faults are compressional or not, as this in part governs whether they are open (in extension) or closed (in compression).

4.4 Aquifer 0203 (Shawnigan Lake)

4.4.1 Location, Access, and Land Use

Aquifer 0203 (Shawnigan Lake) is located at the south end of the study area, surrounds Shawnigan Lake, and covers 31.3 km^2.

The aquifer is centred at Latitude 48°37’12” Longitude 123°38’18” (UTM 452950E 5385400N Zone 10) and accessible by Renfrew and Shawnigan Lake Roads.

The land surface above aquifer 0203 is lightly developed. Over 83% of the aquifer’s surface consists of undeveloped, forested properties, of which approximately 65% has been recently harvested. The balance of its surface in its northeast portion and within a thin strip surrounding Shawnigan Lake has been developed for rural-residential (12%), urban (3%), and institutional (2%) purposes.

4.4.2 Classification, Extent, and Well Information

Aquifer 0203 is classified by the ENV as a Class IIA (12) aquifer, which indicates that it is moderately developed with high vulnerability to surface contamination.

The horizontal extent of aquifer 0203 is defined by the occurrence of registered wells that draw groundwater from upland bedrock areas around Shawnigan Lake. The aquifer's north and northeast perimeters are defined by the boundary of adjacent bedrock aquifer 0207, while the remainder of its east perimeter is roughly defined by the west-facing scarp of Malahat Ridge. The southwest perimeter of the aquifer is defined by the hydrological divide between surface waters flowing towards Shawnigan and Sooke Lakes. Undeveloped extensions of aquifer 0203 underlie adjacent upland areas to the northwest, west, south, southeast, and east.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 34.

Table 34: Aquifer 0203 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	70.5	Mean	0.22	Mean	-	Mean	5.7
Median	63.1	Median	0.19	Median	0.3	Median	5.9
Range	6.4 – 205.7	Range	0.01 – 4.42	Range	0.0 – 59.7	Range	0.0 – 59.7

4.4.3 Physiography and Hydrology

Aquifer 0203 is situated within an upland area of moderately high relief, and contained within the north-south oriented, U-shaped valley hosting Shawnigan Lake that contains mainly rugged to undulating terrain apart from several comparatively planar areas adjacent to the south, west, and north ends of the Lake. Surface elevations above aquifer 0203 range from 580 m amsl along the crest of Malahat Ridge on the southeast side of the aquifer to 120 m amsl at its north end at the outlet of Shawnigan Lake.

Aquifer 0203 is located entirely within the Shawnigan watershed, with the nearest marine shoreline being 4.4 km southeast at Finlayson Arm. Surface drainage patterns above aquifer 0203 are parallel-centripetal, with watercourses flowing towards Shawnigan Lake including McGee Creek, Shawnigan Creek, Palmer Creek, Chandler Creek, Old Baldy Creek, and at least fifteen short, unnamed streams. Numerous springs and pocket wetlands also occur at elevations above the west side of Shawnigan Lake.

4.4.4 Geology and Soils

Bedrock within the northern third of the aquifer area mainly consists of relatively lightly fractured andesitic volcanic rocks of the Bonanza Group, with the exception of a small area of fractured, Sicker Group' Duck Lake Formation volcanic rocks at its extreme north end. Bedrock within the southern two-thirds of aquifer 0203 consists of fractured and metamorphosed intrusive rocks of the Westcoast Crystalline Complex, with felsic and mafic variants known locally as the Colquitz and Wark Gneiss, respectively. A thin, northwest-trending wedge of karstified, Vancouver Group's Quatsino Formation limestone is present along the contact between Westcoast Crystalline Complex and Bonanza Group rocks on the east side of Shawnigan Lake and west flank of Old Baldy Mountain that is part of a series of southeast-trending, skarnified and mineralized limestone pods that extend along the north side of Oliphant Lake towards Bamberton.

The tectonic setting of aquifer 0203 is complex, with evidence for both compressional and extensional structural deformation. The northern one-third of the aquifer is crossed by a regional, northwest-trending thrust fault that forms the contact between Westcoast Crystalline Complex intrusive rocks to the southwest and Bonanza Group volcanic rocks to the northeast, while the extreme northwest tip of the aquifer is crossed by the regional, east-northeast trending San Juan Fault. In contrast, southern two-thirds of the aquifer display numerous indications of extensional faulting of several different ages, with the most recent being the regional, northeast-trending Shawnigan Fault that crosses the south tip of Shawnigan Lake. The presence of at least five strong and two weak topographic lineaments that trend northwest within the aquifer and appear to be offset by the Shawnigan Fault suggest that major and minor extensional faults may also occur in this area, including linear topographic features resembling narrow, fault-bounded valleys that host the headwaters of Shawnigan and McGee Creeks.

The upland portions of aquifer 0203 are mostly covered by loose to compact, impersistent, sandy veneers to blankets of unconsolidated, colluviated Vashon Drift morainal deposits, although small, free-draining, gravelly Capilano Sediments kame terrace and delta deposits also occur in several locations at mid-elevations along the west and east sides of the Shawnigan Lake valley. Thicker compact blankets of Vashon Drift morainal materials overlain by glaciofluvial and fluvial deposits of the Capilano and Salish Sediments, respectively, generally mask the bedrock surface at the south end of the aquifer within the Shawnigan Creek valley, and at its north end along the north and northwest sides of Shawnigan Lake. A small deposit of Capilano Sediments glaciolacustrine silt-clay occurs at the south end of Shawnigan Lake.

Soils above the upland portions of aquifer 0203 generally consist of well to rapidly-drained, orthic dystric brunisols, duric humo-ferric podzols, and duric dystric brunisols of the Squally, Dashwood, and Shawnigan Soil Associations, respectively, which have developed in areas of moderate to high relief over veneers to blankets of sandy and/or sand-gravelly colluvial or morainal materials over bedrock. Soils around the flanks of the aquifer’s hills in its relatively low-lying northeast and north parts mainly consist of imperfectly to well-drained, duric dystric brunisols of the Shawnigan Soil Association that have developed in areas of moderate relief over deep blankets of gravelly-sandy morainal materials. Soils at the extreme south end of Shawnigan Lake within the planar, low-lying floodplain of Shawnigan Creek consist of imperfectly to poorly-drained gleyed dystric brunisols of the Chemainus Soil Association that have developed over deep, silty deposits of glaciolacustrine materials. Surface water infiltration rates to the bedrock surface within aquifer 0203 may be locally restricted in areas where low-permeability; near-surface duric or silty-clay soil layers are present.

4.4.5 Hydrogeology

Groundwater within aquifer 0203 occurs primarily within open fracture systems, and to a lesser extent within dissolution voids and along geological contacts.

The groundwater storage potential and K_{mb} of aquifer 0203 may be variable due to the heterogeneous nature and structural complexity of its host rocks. Relatively lightly fractured blocks of Bonanza Group volcanic rocks and Work Gneiss mafic intrusive rocks may form effective aquitards with K_{mb} values of between $1x10^{-9}$ and $1x10^{-7}$ m/s due to their relatively ductile nature, while blocks of Sicker Group volcanic rocks, Vancouver Group Quatsino Formation limestone, and Colquitz Gneiss felsic intrusive rocks may display comparatively higher K_{mb} values of between $1x10^{-6}$ and $1x10^{-5}$ m/s and constitute “leaky” aquitards or low-productivity aquifers due to their relatively brittle natures, lack of schistose zones, and open fracture systems. Low to moderate productivity wells have been completed within most of the aquifer’s bedrock units south of the contact between the Westcoast Crystalline Complex and Bonanza Group rocks where extensional fracture zones have been intersected, with K_{mb} values potentially reaching $1x10^{-5}$ m/s within more brittle, heavily-fractured host rocks and considerably higher in areas of karstified limestone. Wells completed within fractured Bonanza Group volcanic rocks generally display low productivities due to their propensity to develop wide schistose zones with occluded fractures around fault structures.

The degree of hydraulic confinement of water-bearing zones within the upland portions of aquifer 0203 may be generally low due to the absence of a laterally-persistent surface aquitard, but will be contingent on whether the host fracture systems are in direct hydraulic connection with the ground surface. In contrast, the degree of hydraulic confinement of water-bearing zones within the lower-lying portions of aquifer 0203 covered by thick blankets of low-permeability morainal and glaciolacustrine materials may be comparatively higher. About half of the wells completed within aquifer 0203 are reported by the ENV as not having a confining layer.

Regional groundwater flows within aquifer 0203 may be radially inward from higher elevations towards Shawnigan Creek and Lake, but local flows may be highly anisotropic, dissimilar to the area's terrain and drainage patterns, and largely controlled by the structural geometries, connectivities, and degrees of confinement of its water-bearing fracture systems and the presence of structural flow barriers. Hydraulic gradients within aquifer 0203 may be moderate to high based on the area's upland topographic setting and rugged terrain, with groundwater locally moving rapidly due to its dominant occurrence within open fractures.

Aquifer 0203 may receive vertical inflow from precipitation, snowmelt, and stream losses at higher elevations, but likely receives little vertical recharge from irrigation / sewerage dispersal returns due to its relatively undeveloped state. Lateral inflow may occur from water-bearing fracture systems from the undeveloped portions of the aquifer to the west, south, and southeast, and from surface runoff and near-surface soil drainage from adjacent, topographically-elevated areas.

Groundwater outflow from aquifer 0203 may primarily take place through base flow discharge to the lower reaches of its internal streams and low-elevation springs around Shawnigan Lake, and to Shawnigan Lake. Lateral discharge may also occur through open fracture systems into adjacent aquifers 0202 and 207 to the north and northeast, respectively.

4.4.6 Water Budget

As identified in Section 4.4.1, the aquifer 0203 bedrock aquifer is characterized mostly by shallow overburden over bedrock and is only lightly developed. Some areas to the north and south have thicker overburden. Most importantly, aquifer 0203 hosts Shawnigan Lake towards which groundwater flows radially inward. The area experiences an average recharge of 501 mm/yr, largely due to its relatively westerly position in the study area where the annual surplus is very high. This reduces to 337 mm/yr in a hot/dry year, and could be as high as 831 mm/yr in a cold/wet year.

Groundwater flow patterns are inward to the lake in all directions. With the exception of where McGee Creek enters the aquifer, all boundaries to aquifer 0203 are topographic divides, which we have assumed to be groundwater divides. There are four places where certain geologic faults enter aquifer 0203 and hydraulic head drives lateral groundwater into it. These include the two faults under McGee Creek, and two topographic lineaments that suggest the presence of underlying geological structures at the south end and the Shawnigan Fault where it enters the eastern boundary. However, the amount of water is not great as the permeabilities of these features in the West Coast Crystalline Complex are not great. We also considered the possibility of water entering aquifer 0203 from the south west through the Shawnigan Fault. Here, Sooke Lake lies at elevation 200 m amsl on one end of the fault, and then Shawnigan Lake is at 120 masl at the other. However, the intervening hills reach 380 m in elevation and likely create a groundwater divide between the two.

Discharge to the lake accounts for the majority of outflow from the aquifer. To quantify this accumulated amount, examination of the measured streamflow records was conducted, and a prorata applied to the catchment areas. Since streamflow is composed of baseflow and of runoff, it is convenient to use the Infiltration Factor for the watershed (0.58) as a surrogate baseflow index. This provides an estimate of that portion of the streamflow that was derived from groundwater discharge (assuming the long term change in storage is zero).

As part of the many streams identified in Section 4.4.3, there are two main watercourses, McGee Creek and combination Van Horn Creek/Shawnigan Creek, which cross the aquifer area for lengths of over 2 km each. These creeks appear to be in areas of upward gradients and were thus assumed to be gaining streams, taking water from the groundwater system. No stream temperature information was available to confirm this. Overburden however is shallow where these creeks flow across aquifer 0203 and thus this leakage is a loss from aquifer 0203.

The Ministry of Agriculture report (van der Gulik et al., 2003), is silent on water taking for irrigation in aquifer 203, and thus we rely on Hatfield (2015) to provide an estimate for irrigation. Most irrigation water takings in the geographic aquifer 0203 area are from internal surface water sources and are thus deemed to be a loss (assuming 100% consumption). There are only limited water takings from groundwater for irrigation, again assumed to be 100% consumptive. Hatfield (2015) identified limited commercial water takings (and no industrial takings) which we have assumed to be consumptive in nature. All residential development that are on wells have been assumed to be 100% consumptive as a conservative assumption. Table 35 summarizes the water budget for aquifer 0203 in terms of the losses and gains described above.

Table 35: Bedrock aquifer 0203 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	15,573,800	% of Gains
Recharge	15,535,800	100
Lateral groundwater inflow	38,000	0
Losses =	- 16,837,900	% of Losses
Lateral groundwater outflow to Shawnigan Lake	15,374,100	91
Minor Lateral groundwater outflow	5,900	0
Groundwater Losses into Creeks	965,000	6
Water Usage: Municipal and Domestic	390,900	2
Water Usage: Commercial and Industrial	14,600	0
Water Usage: Irrigation	87,400	1
Net Water Balance =	-1,264,100	

The water budget shows only an 8% loss of the aquifer gains. This comparison of water in to water out is considered to be in close agreement.

In a hot and dry year such as 1989 where the surplus was about 33% lower than normal, one could expect a similar reduction in recharge. The total recharge of 15,535,800 m^3 (for an average year) was found to be 10,451,500 m^3 (Appendix D), a loss of 5,084,300 m^3 in such a year, which would have a significant effect on the above sums, and create a greater deficit condition. (Lateral outflows and upwelling into McGee and VanHorn creeks would be however reduced by a reduction in driving head caused by lower water table positions.) Appendix D shows that there is a 66% increase in recharge for that very wet year in 1999, would have added over 10,200,000 m^3, and a clear surplus would be present.

The monthly water budget shown on Figure 20 reveals that in an average year there is a surplus condition from October to December, and that a deficit occurs in the remaining nine (green line). This is different than other bedrock aquifers, in part because the system is dominated by discharge to Shawnigan Lake (which is numerically tied to the streamflow in Shawnigan Creek by the methodology used here). In effect, the short relative distance to the lake from all parts of the watershed, dictates that groundwater losses are more susceptible to seasonal conditions and in the early part of year are of similar order of magnitude to the recharge amounts. In the cold/wet year (blue line) a much stronger surplus occurs in January to March. The hot/dry year (red line) is revealing, where a small surplus only in March, October and November and an increased deficit in the other seven months.

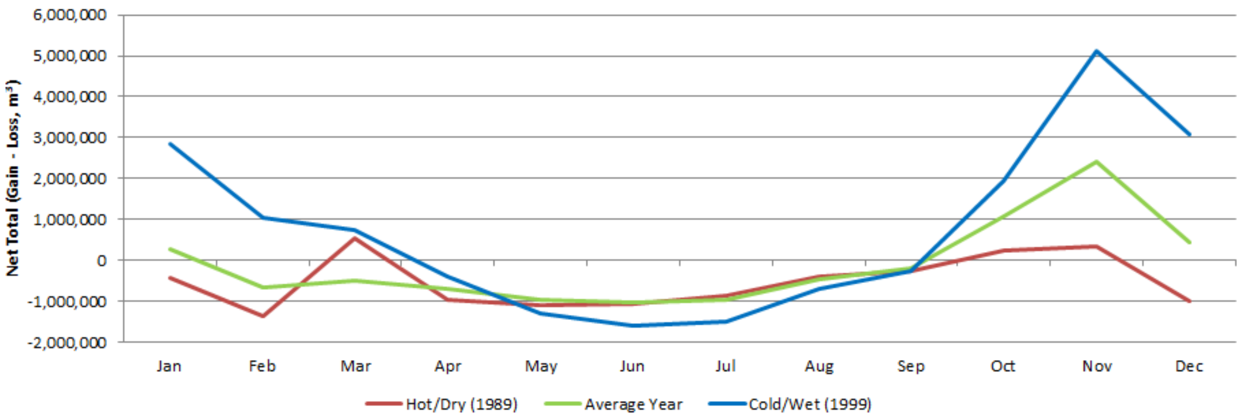

Figure 20: Monthly water budget for bedrock aquifer 0203.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 492,900/10,451,500 X 100% = 4.7% (Low Stress Level)
- Normal. 492,900/15,535,800 X 100% = 3.2% (Low Stress Level)
- Cold/Wet. 492,900/25,782,200 X 100% = 1.9% (Low Stress Level)

The aquifer is deemed to currently be under low (but not insignificant) stress on an annual basis, largely due to the size of the resource.

4.4.7 Bedrock Aquifer 0203 Conclusions

The above water budget suggests there is a small annual deficit in aquifer 0203. However, the uncertainties in the calculations far outweigh the calculated deficit, and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIA (12), and is moderately developed. It is reasonable to assume that if wells can find any permeable horizons in the low permeability bedrock, then useable quantities of water may be available. The likelihood of identifying high yield zones is low, and water supplies based on individual wells uniformly distributed is recommended. This is because there is likely very little available storage in the aquifer due to the lack of primary porosity and the aquifer's low hydraulic conductivity. Potential well interference between existing and future/proposed wells in aquifer 0203 could be high due to the low storativity of this bedrock. Water supplies with moderate sustainable well yield could be achieved in areas underlain by West Coast Crystalline rocks with larger conductivity – such as at fault intersections or areas with anastomosing fault swarms. Licensing groundwater use will have to consider the sustainability of the aquifer (particularly in the deficit months) and major water taking applications should be supported by long term pumping tests, preferably conducted in the deficit months.

4.5 Aquifer 0204 (Cobble Hill)

4.5.1 Location, Access, and Land Use

Aquifer 0204 (Cobble Hill) is located on the east side of the study area adjacent to the Saanich Inlet marine shoreline, and covers 16.6 km^2.

The aquifer is centred at Latitude 48°40'19" Longitude 123°33'41" (UTM 458650E 5391150N Zone 10) and is accessible by the Trans-Canada Highway and Cobble Hill, Telegraph, Kilmalu, and Chapman Roads.

The land surface above aquifer 0204 is moderately developed. Most of the aquifer's central and east surfaces have been developed for rural-residential (45%), agricultural (6%), or urban (5%) purposes. The balance of its surface (44%) consists of relatively undeveloped, forested properties.

4.5.2 Classification, Extent, and Well Information

Aquifer 0204 is classified by the ENV as a Class IIB(11) aquifer, which indicates that it is moderately developed with moderate vulnerability to surface contamination.

The horizontal extent of aquifer 0204 is defined by the occurrence of registered wells that draw groundwater from lowland bedrock areas northeast of Shawnigan Creek and below overburden aquifer 0197. The aquifer's south perimeters are defined by Shawnigan Creek and the Mill Bay shoreline, with Saanich Inlet forming its east perimeter. The west perimeter of the aquifer is defined by the boundary of adjacent bedrock aquifer 0202 and the base of Cobble Hill. Undeveloped extensions of aquifer 0204 underlie surficial aquifer 0197 to the north.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 36.

Table 36: Aquifer 0204 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	80.2	Mean	0.32	Mean	-	Mean	6.1
Median	70.1	Median	0.25	Median	3.0	Median	5.2
Range	5.3 – 260.6	Range	0.03 – 8.52	Range	0.0 – 62.5	Range	0.0 – 50.3

4.5.3 Physiography and Hydrology

Aquifer 0204 is situated within a lowland area of moderate to gentle relief. Surface topography above the west, north, and east portions of aquifer 0204 is elevated and mostly hummocky to undulating, with a northwest-trending fabric. Terrain in its central and southern portions is comparatively lower and undulating to planar, with a gentle southeast aspect. Surface elevations range from 140 m amsl at the top of a conical hill at the aquifer's west end to sea level along its east side.

The boundaries of aquifer 0204 straddle the Shawnigan and Cowichan watersheds. Surface drainage patterns above most of aquifer 0204 are rectangular-dendritic, with Burnham Creek, Averill Brook, Brayshaw Creek, Prellwitz Creek, and Nott Creek flowing towards Shawnigan Creek. Drainage along the aquifer's east periphery is parallel-radial, with Manley Creek, Wace Creek, Sylvan Brook, Hook Creek, and Eddy-Kilmalu Creek flowing directly into Saanich Inlet. Numerous springs occur along the Saanich Inlet shoreline and at least five small pocket wetlands occur in low-lying areas between its low hills that constitute the headwaters of some of its streams.

4.5.4 Geology and Soils

Bedrock within the southeast half of aquifer 0204 consists of fractured granodioritic intrusive rocks of the Island Plutonic Suite, while most of its northwest half consists of fractured basaltic volcanic rocks of the Sicker Group's Duck Lake Formation and a thin, east-northeast trending sliver of limestone of the Buttle Lake Group's Mount Mark Formation. The extreme northeast part of the aquifer adjacent to Saanich Inlet consists of folded shale sedimentary rocks of the Nanaimo Group's Haslam Formation, while the extreme southwest corner consists of relatively unfractured andesitic volcanic rocks of the

Bonanza Group. Although bedrock is not continuously exposed within the boundaries of the aquifer, available well records suggest that its surface is irregularly-shaped.

The tectonic setting of aquifer 0204 is complex, with evidence for both compressional and extensional structural deformation. The northwest and north portions of the aquifer may be dominated by compressional deformation due to the presence of the regional, east-northeast trending San Juan Fault that crosses the aquifer in this area, although the presence of at least two strong and six weak, northwest-trending topographic lineaments north of the San Juan Fault suggests that extensional faults may also occur in the area. In contrast, the southeast portion of the aquifer hosts the regional, northeast-trending Shawnigan Fault and at least one strong and five weak, west-northwest trending topographic lineaments that suggests extensional deformation may be dominant in this area.

Aquifer 0204 is mostly covered by compact, sandy veneers to blankets of unconsolidated, Vashon Drift morainal deposits, although small deposits of Capilano Sediments glaciolacustrine and / or glaciomarine silt-clay occur in the headwater areas of Brayshaw and Nott Creeks in the northwest part of the aquifer area, in the Cameron-Taggart Road area within the Shawnigan Creek floodplain, adjacent to the north and east sides of Mill Bay at its southeast corner, and along the Saanich Inlet shoreline.

Soils above much of the central and west portions of aquifer 0204 generally consist of imperfectly to well-drained, duric dystric brunisols of the Somenos and Dashwood Creek Soil Association, which have developed in areas of moderate relief over variably-thick veneers and blankets of sandy and/or sand-gravelly morainal materials. Soils above the aquifer's east periphery adjacent to Saanich Inlet and in its southeast portion north of Mill Bay generally consist of imperfectly to poorly-drained, gleyed eluviated dystric brunisols and orthic humic gleysols of the Finlayson and Tagner Soil Associations, respectively, which have developed in areas of gentle relief over deep blankets of silty and/or clayey glaciomarine materials. Soils within depressional areas in the headwaters of Brayshaw Creek and the Cameron-Taggart Road area within the Shawnigan Creek floodplain consist of terric mesisols of the Arrowsmith Soil Association that have developed over shallow, water-saturated organic deposits. Surface water infiltration rates to the bedrock surface within aquifer 0204 may be locally restricted in areas where low-permeability; near-surface duric or silty-clay soil layers are present.

4.5.5 Hydrogeology

Groundwater within aquifer 0204 occurs primarily within open fracture systems, and to a lesser extent within dissolution voids and along geological contacts and sedimentary bedding partings.

The groundwater storage potential and K_{mb} of most of aquifer 0204 may be low to moderate due to the widespread presence of brittle bedrock units, with the exception of those areas consisting of Bonanza Group volcanic rocks or Nanaimo Group sedimentary rocks. Relatively lightly fractured or unfractured blocks of Bonanza and Nanaimo Group rocks may form effective aquitards with K_{mb} values of between $1x10^{-9}$ and $1x10^{-7}$ m/s due to their relatively ductile nature, while blocks of Sicker Group volcanic rocks and Island Plutonic Suite intrusive rocks may display comparatively higher K_{mb} values of between $1x10^{-6}$ and $1x10^{-5}$ m/s and constitute "leaky" aquitards or low-productivity aquifers due to their relatively brittle nature, lack of schistose zones, and open fracture systems. Moderately productive wells have been completed within most of the aquifer's bedrock units where extensional fracture zones have been intersected, with K_{mb} values potentially reaching $1x10^{-5}$ to $1x10^{-4}$ m/s within more brittle, heavily-fractured host rocks. Wells completed within Bonanza and Nanaimo Group rocks generally display low productivities due to their propensity to develop wide schistose zones with occluded fractures around fault structures. For the purpose of the water budget a K_{mb} of 5×10^{-5} m/s was selected, based on professional judgement, for the San Juan Fault as it is a major structural feature.

The degree of hydraulic confinement of water-bearing zones within the central and west portions of aquifer 0204 may be generally low due to the absence of a laterally-persistent surface aquitard, but will be contingent on whether the host fracture systems are in direct hydraulic connection with the ground surface. In contrast, the degree of hydraulic confinement of water-bearing zones within the lower-lying portions of aquifer 0204 covered by near-surface blankets of low-permeability glaciomarine materials north of Mill Bay and along the Saanich Inlet shoreline, as well as the northern portions of the aquifer overlain by morainal materials within adjacent aquifer 0197, may be comparatively higher. Over 30% of the wells completed within aquifer 0204 are reported by the ENV as not having a confining layer.

Regional groundwater flows within aquifer 0204 may trend from higher elevations within the Cobble Hill uplands towards Shawnigan Creek to the southeast and Saanich Inlet to the east. Local flows may differ and are controlled by the structural geometries, connectivities, and degrees of confinement of its water-bearing fracture systems and the presence of structural flow barriers. Hydraulic gradients within aquifer 0204 may be variable based on the area's moderate steep to gentle terrain, with groundwater locally moving rapidly due to its dominant occurrence within open fractures.

Aquifer 0204 may receive vertical inflow from precipitation, irrigation / sewerage dispersal returns, stream losses at higher elevations, and infiltration from the base of the overlying aquifer 0197 along its north side. Lateral inflow may occur from water-bearing fracture zones within the undeveloped portions of the aquifer to the north and adjacent aquifers 0202 to the west.

Groundwater outflow from aquifer 0204 may take place through baseflow discharge to the lower reaches of Shawnigan Creek, and the lower reaches of the its numerous internal streams, pocket wetlands, and springs, and the marine environment. Although aquifer 0204 is in contact with aquifers 0205 and 0206 along its south edge, it is unlikely to receive inflow from, or contribute outflow to, these aquifers due to their relative hydrological settings south of Shawnigan Creek.

4.5.6 Water Budget

As identified in Section 4.5.1, bedrock aquifer 0204 is characterized by variably thick overburden on top of bedrock and is moderately developed. It is comprised of two pieces, the main portion lying north of Shawnigan Creek, and smaller portion north along the shore of Saanich Inlet. The "neck" between these two lies along the steep shoreline. The area experiences an average recharge of 362 mm/yr, which is much lower than that in the wetter areas to the west. This reduces to 243 mm/yr in a hot/dry year, and could be as high as 600 mm/yr in a cold/wet year. Part (512.6 ha) of overburden aquifer 0197 overlies the northern flank of the main body of aquifer 0204, and based on downward gradients derived from the water well records, it recharges the bedrock. Given the higher permeability bedrock below the aquifer 0197 sediments, a leakage rate of 300 mm/yr was adopted. In addition, analysis presented in Section 5.1 shows groundwater discharges laterally from overburden aquifer 0197 into aquifer 0204 as well.

Groundwater flow patterns are inward from the north and west. Groundwater discharges from the bedrock to the Inlet to the east and to Shawnigan Creek to the south. Calculations of out flow were based on the bedrock mapping and K_{mb} determinations described above. More significant discharge pathways include the permeable zones associated with the San Juan Fault to the Inlet, and another ESE trending fault that passes under Shawnigan Creek. Discharge to the Inlet is also greater from the Island Plutonic Suite under the southeast majority of aquifer 0204 due to these higher permeability rocks.

There are several main watercourses traversing the aquifer of which Nott, Eddy Kilmalu and Prellwirtz Creeks are in areas of downward gradients. Thus, these creeks appear to be contributing water to the groundwater system. No stream temperature information was available to confirm this. Overburden however is shallow where these creeks flow across aquifer 0204 and thus this leakage is a gain to aquifer 0204.

Most irrigation water takings in the geographic area of aquifer 0204 area are from internal surface water sources, or irrigation wells and are thus deemed to be a loss (assuming 100%). Hatfield (2015) identified both industrial and commercial water takings which we have assumed to be 100% consumptive in nature. Based on discussion with the municipality, most of the residential development uses individual well and septic fields, so what water is taken is generally returned locally to the aquifer. However, we have conservatively assumed all domestic groundwater use is 100% consumptive. Some local collection systems are reported but are just 2% of the residential use.

Table 37 summarizes the water balance for aquifer 0204 in terms of the losses and gains described above.

Table 37: Bedrock aquifer 0204 annual water budget for average climate conditions.

Component		Cubic metres per year	
	Gains =	17,558,800	% of Gains
Recharge		4,142,300	23
Downward Leakage from aquifer 0197		1,537,900	9
Lateral overburden inflow from aquifer 0197		682,300	4
Lateral groundwater bedrock inflow		10,218,000	58
Streamflow Losses to aquifer 0204		978,300	6
	Losses =	- 13,614,400	% of Losses
Lateral groundwater outflow		13,006,200	96
Water Usage: Municipal and Domestic		309,200	2
Water Usage: Commercial and Industrial		62,100	0
Water Usage: Irrigation		236,900	2
	Net Water Balance =	3,944,400	

The water budget shows about 22% retention of the aquifer gains which appears that there is a surplus of water in the bedrock available for use. The comparison of water in to water out is considered to be in reasonable agreement when considering uncertainty in aquifer parameters. For example, about a two times higher K_{mb} used in the calculations would cause a perfect balance between gains and losses. In any event, current usage is a very small part (~4%) of the water that is moving through the system.

In a hot and dry year such as 1989 where the surplus was 34% lower than normal, one could expect a similar reduction in recharge and leakage from the overburden. The total downward leakage of 4,142,300+1,537,900 = 5,680,200 m^3 (for an average year) could therefore be just 4,324,600 m^3, a loss of 1,355,600 m^3 in such a year, which would have a significant effect on the above sums, albeit still a surplus. (Lateral outflows would be however reduced by a reduction in driving head caused by lower water table positions.) The increase in recharge for that very wet year in 1999, would have added over 2,700,000 m^3, and a clear surplus would be present.

The monthly water budget shown on Figure 21 reveals that in an average year there is a surplus condition from October to March, and that a minor deficit occurs in the six months from April to September (green line). In the cold/wet year (blue line) a much stronger surplus occurs in January and February, and marginally more in October to December. The hot/dry year (red line) is not drastically worse than the average condition. The deficit months are similar for all three cases for the same reasons as discussed before, that is, the normal and wet conditions are dry conditions in these months anyway.

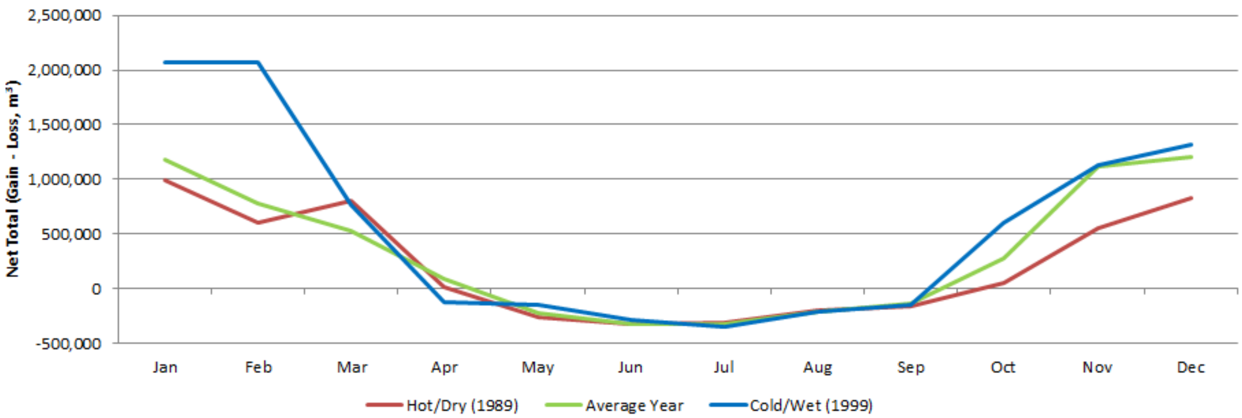

Figure 21: Monthly water budget for bedrock aquifer 0204.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 608,200/2,786,700 X 100% = 21.8% (Moderate Stress Level)
- Normal. 608,200/4,142,300 X 100% = 14.7% (Moderate Stress Level)
- Cold/Wet. 608,200/6,874,400 X 100% = 8.8% (Low Stress Level)

Recharge of this aquifer is based on just recharge and not leakage estimates through the overburden aquitard. If this leakage were considered as well the cold/wet and normal periods would be classified as low stress, with the hot/dry continuing to be moderately stressed. However the stress level is still elevated and there is significant consumptive use in aquifer 0204 (third highest of the eleven aquifer study areas).

4.5.7 Bedrock Aquifer 0204 Conclusions

The above water budget suggests there is an annual surplus in aquifer 0204. However, the uncertainties in the calculations far outweigh the calculated surplus, and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIB(11), and is moderately developed. It is reasonable to assume that if wells can find any permeable horizons in the low permeability bedrock in the northern portion along the shore, then useable quantities of water may be available. The likelihood of identifying high yield zones is low, and water supplies based on individual wells uniformly spread out is recommended. This is because there is likely very little available storage in the aquifer due to the lack of major structures and the aquifer's low hydraulic conductivity. Potential well interference between existing and future/proposed wells in aquifer 0204 could be high due to the low storativity of the bedrock.

The southern portion of the aquifer area is underlain by more permeable bedrock with many minor faults crossings. It is reasonable to use the geologic mapping to identify specific geologic targets for water development within aquifer 0204. The likelihood of identifying high yield zones is moderately good in the area north and adjacent to the San Juan Fault, and along the NW trending faults south of there that intersect the Shawnigan Fault.

Groundwater taking licensure should consider the size of the proposed taking, and should consider the proximity of neighbouring wells. The seasonality is also important, and pumping tests should be conducted at the critical time of the year and be long enough in duration to ensure a measure of sustainability. Whether the year is wet or dry should also be considered, as this will affect water availability. Given that the aquifer is under moderate stress levels in both normal and hot/dry years, a better understanding of bedrock recharge rates and localized stressed areas is recommended.

4.6 Aquifer 0207 (Bamberton)

4.6.1 Location, Access, and Land Use

Aquifer 0207 (Bamberton) is located at the southeast corner of the study area south of Shawnigan Creek and adjacent to the Saanich Inlet marine shoreline, and covers 25.10 km^2. We note that the bedrock under overburden aquifer 0206 is included in the aquifer 0207, whereas the bedrock under overburden aquifer 0205 is not. There are many productive bedrock wells under both aquifers 0205 and 0206. For this reason we have included the 2.7 km^2 of bedrock under aquifer 0205 in the water budget calculations herein and suggest the actual bedrock aquifer area is closer to 27.8 km^2.

The aquifer is centred at Latitude 48°38'20" Longitude 123°34'43" (UTM 457400E 5387500N Zone 10) and accessible by the Trans-Canada Highway and Mill Bay, Butterfield, Frayne, Shawnigan Lake – Mill Bay, and Sylvester Roads.

The land surface above aquifer 0207 is lightly developed. Over 71% of the aquifer's surface consists of undeveloped, forested properties, of which approximately 40% has been recently harvested. The balance of its surface within its central and northern portions has been developed for rural-residential (18%), urban (10%) and agricultural (1%) purposes.

4.6.2 Classification, Extent, and Well Information

Aquifer 0207 is classified by the ENV as a Class IIB(12) aquifer, which indicates that it is moderately developed with moderate vulnerability to surface contamination.

The horizontal extent of aquifer 0207 is defined by the occurrence of registered wells that draw groundwater from bedrock south of Shawnigan Creek between the Shawnigan Lake catchment divide and the Saanich Inlet shoreline, and below overburden aquifer 0206. The south perimeter of aquifer 0207 is roughly defined by the base of the Malahat Ridge and Old Baldy Mountain upland areas, while its north perimeter is defined by Shawnigan Creek. The northwest perimeters are defined by the boundaries of adjacent bedrock aquifers 0203 and 0202. Undeveloped extensions of aquifer 0207 underlie upland areas to the south and surficial aquifer 0205 south of Shawnigan Creek.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 38.

Table 38: Aquifer 0207 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	81.0	Mean	0.31	Mean	-	Mean	8.0
Median	74.4	Median	0.25	Median	4.6	Median	7.6
Range	6.7 – 208.8	Range	0.02 – 12.62	Range	0.0 – 64.3	Range	0.0 – 61.0

4.6.3 Physiography and Hydrology

Aquifer 0207 is situated within a lowland area of moderate relief. Surface topography above aquifer 0207 consists of a mixture hummocky, rolling, and undulating terrain with a marked northwest-trending fabric. The east margin of the aquifer along the Saanich Inlet shoreline contains at least seven narrow ravines incised into overburden with short streams. Surface elevations range from 360 m amsl on the northeast flank of Old Baldy Mountain to sea level along its east side.

The boundaries of aquifer 0207 straddle the Shawnigan and Saanich Inlet watersheds. Surface drainage patterns within the northeast two-thirds of aquifer 0207 are rectangular-dendritic, with Taggart Creek, Ericson Creek, Hollings Creek, Burt Brook, Handysen Creek, and Goodhope Creek flowing towards Shawnigan Creek. Drainage along the aquifer's east periphery is parallel-radial, with Wheelbarrow-Bird Creek, Wilkin Creek, Frayne Creek, Malahat Creek, John's Creek, and Service Creek flowing directly into Saanich Inlet. Numerous springs occur in the headwater areas of Taggart, Burt, and Goodhope Creeks in the Shawnigan Creek catchment, and at the headwaters of Wheelbarrow-Bird and Wilkin Creeks and near the mouth of John's and Service Creeks in the Saanich Inlet watershed.

4.6.4 Geology and Soils

Bedrock within the northeast one-third of aquifer 0207 consists of fractured granodioritic intrusive rocks of the Island Plutonic Suite, while the remainder of the aquifer consists of fractured andesitic volcanic rocks of the Bonanza Group. Although bedrock is not continuously exposed within the boundaries of the aquifer, available well records suggest that its surface is irregularly-shaped.

The tectonic setting of aquifer 0207 is mainly extensional, with numerous indications of normal faulting of differing ages. The regional, northeast-trending Shawnigan Fault bisects the aquifer through its centre and offsets the northwest-trending contact between the Bonanza Group and Island Plutonic Suite rocks, and a strong, northwest-trending lineament that is traceable for almost the entire length of the aquifer area and hosts the upper reaches of John's and Hollings Creeks. In addition, the aquifer area contains at least two other strong and sixteen moderate to weak topographic lineaments with a variety of trends that suggest the presence of extensional faults in these areas.

The upland portions of aquifer 0207 in its northwest corner are mostly covered by loose to compact, impersistent, sandy veneers to blankets of unconsolidated, colluviated Vashon Drift morainal deposits that partially cover and flank the hills. The remaining, more low-lying portions of aquifer 0207 are uniformly covered by a thick, compact blanket of unconsolidated Vashon Drift morainal deposits with the exception of one large, ovoid bedrock depression at the headwaters of Hollings and Rogers Creeks that contains a fine-grained deposit of Capilano Sediments glaciolacustrine material, and two large areas with a number of small bedrock depressions in the northeast and north portions of the aquifer that contain texturally-variable, interbedded deposits of Vashon Drift morainal, glaciofluvial, and glaciolacustrine materials hosting aquifers 0205 and 0206. There exist small deposits of Capilano Sediments glaciomarine silt-clay and Salish Sediments fluvial materials southwest of Mill Bay at the aquifer's northeast corner, and in a narrow band along the Saanich Inlet shoreline from Mill Bay to the mouth of John's Creek at its southeast corner.

Soils above the upland portions of aquifer 0207 generally consist of imperfectly to well-drained, duric and orthic dystric brunisols of the Somenos, Shawnigan, Ragbark, and Qualicum Soil Associations, which have developed in areas of moderate relief over variably-thick veneers and blankets of sandy and/or sand-gravelly colluvial and morainal materials. Soils on and around the flanks of the aquifer's hills along its northwest and west peripheries mainly consist of well to rapidly-drained, orthic dystric brunisols of the Rosewall Soil Association that have developed in areas of moderate to high relief over veneers to shallow deep blankets of gravelly-sandy colluviated morainal materials. Soils within a large triangular area south and southwest of Mill Bay that fronts onto Saanich Inlet and hosts aquifer 206 consist of well to rapidly-drained orthic and duric dystric brunisols of the Dashwood Creek and Quamichan Soil Associations, which have developed in areas of gentle relief over thick blankets of sandy-gravelly morainal or glaciofluvial materials. Soils within the depressional areas at the headwaters of Hollings / Rogers Creeks and the middle reaches of Shawnigan Creek consist of imperfectly to poorly-drained gleyed dystric brunisols and terric mesisols of the Chemainus and Arrowsmith Soil Associations, respectively that have developed over deep, silty deposits of glaciolacustrine materials and/or shallow, water-saturated organic deposits.

4.6.5 Hydrogeology

Groundwater within aquifer 0207 occurs primarily within open fracture systems and to a lesser extent along geological contacts.

The groundwater storage potential and K_{mb} of most of aquifer 0207 may be variable due to the widespread presence of both brittle and ductile bedrock units. Relatively lightly fractured or unfractured blocks of Bonanza Group rocks may form effective aquitards with K_{mb} values of between $1x10^{-9}$ and $1x10^{-7}$ m/s due to their relatively ductile nature, while blocks of Island Plutonic Suite intrusive rocks may display comparatively higher K_{mb} values of between $1x10^{-6}$ and $1x10^{-5}$ m/s and constitute "leaky" aquitards or low-productivity aquifers due to their relatively brittle natures, lack of schistose zones, and open fracture systems. Moderate to highly productive wells have been completed within the aquifer's Island Plutonic Suite units where extensional fracture zones have been intersected, with K_{mb} values potentially reaching $1x10^{-4}$ m/s within more brittle, heavily-fractured host rocks. Wells completed within Bonanza Group rocks generally display low productivities due to their propensity to develop wide schistose zones with occluded fractures around fault structures.

The degree of hydraulic confinement of water-bearing zones within the upland portions of aquifer 0207 in its northwest corner may be generally low due to the absence of a laterally-persistent surface aquitard, but will be contingent on whether the host fracture systems are in direct hydraulic connection with the ground surface. In contrast, the degree of hydraulic confinement of water-bearing zones within the lower-lying portions of aquifer 0207 covered by near-surface blankets of low-permeability glaciomarine materials or compact morainal materials may be comparatively higher. Over 30% of the wells completed within aquifer 0207 are reported by the ENV as not having a confining layer.

Regional groundwater flows within aquifer 0207 may trend from higher elevations within the Malahat Ridge and Shawnigan uplands towards Shawnigan Creek to the north and Saanich Inlet to the east, although local flows may be highly anisotropic and largely controlled by the structural geometries, connectivities, and degrees of confinement of its water-bearing fracture systems and the presence of structural flow barriers. Hydraulic gradients within aquifer 0207 may be variable based on the area's moderate steep to gentle terrain, with groundwater locally moving rapidly due to its dominant occurrence within open fractures.

Aquifer 0207 may receive vertical inflow from precipitation and stream losses at higher elevations although a significant portion of these waters may runoff instead of infiltrate due to the steepness of the terrain and/or the presence of dense morainal overburden and duric soils. Aquifer 0207 may also receive vertical inflow in its northern areas from the upgradient portions of overlying aquifers 0205 and 0206, and from irrigation / sewerage dispersal returns in more populated areas. Lateral inflow may occur from water-bearing fracture zones within the undeveloped portions of the aquifer to the south, from adjacent aquifers 0202 and 0203 to the northwest and west, respectively, and from surface runoff and near-surface soil drainage from adjacent, topographically-elevated areas.

Groundwater outflow from aquifer 0207 may take place through evapotranspiration and base flow discharge to the lower reaches of its internal streams, low elevation wetlands and springs, and the marine environment. Outflow from aquifer 0207 may also occur to the downgradient (lower elevation) portions of overlying aquifers 0205 and 0206. Although aquifer 0207 is intermittently in contact with bedrock aquifer 0204 along its north side, it is unlikely to receive inflow from, or contribute outflow to, this aquifer due to its relative hydrological setting north of Shawnigan Creek.

4.6.6 Water Budget

Bedrock aquifer 0207 slopes to the Inlet and the direction of groundwater flow is in this direction along the southern arm of the aquifer area. The northern part flows centripetally inward towards the Hollings-Handysen Creek drainage system. A small area at the north end flows towards Shawnigan Creek. The area experiences an average recharge of 429 mm/yr. This reduces to 288 mm/yr in a hot/dry year, and could be as high as 711 mm/yr in a cold/wet year. Overburden aquifers aquifer 0205 (272.9 ha) and aquifer 0206 (257.4 ha) overlie parts of the northern portion of the aquifer area. Based on downward gradients derived from the water well records, it is assumed they both recharge the bedrock aquifer 0207.[7] Given the higher permeability bedrock below the aquifer 0206 sediments, a leakage rate of 300 mm/yr was adopted. Half the bedrock beneath aquifer 0205 is low permeability and half is higher. A composite leakage rated of 200 mm/yr was therefore applied below aquifer 0205.

Groundwater inflow occurs laterally from the bedrock west of aquifer 0207, however this is not great given the presence of low permeability Bonanza group bedrock. Groundwater outflow occurs along the eastern shore of aquifer 0207 and is much higher than the inflow due to the more permeable Island Plutonic Suite bedrock. Several streams cross the aquifer area and where the overburden is thin streamflow losses recharge the aquifer. These include the upper reaches of Hollings Creek, a short unnamed creek, and John's Creek along the south of the aquifer area. (Other creeks such as Rogers and Handysen are not deemed to feed the aquifer. For example, please see Section 5.5.)

Most irrigation water takings in the geographic area of aquifer 0207 are surface water sources that are not fed by the aquifer are thus deemed to not be a draw on it. Hatfield (2015) identified both industrial and commercial water takings which we have assumed to be 100% consumptive in nature. Based on discussion with the municipality, 75% of the residential developments use well and septic fields, so what water is taken is conservatively assumed to be 100% consumptive. The other 25% have treated wastewater discharged to the Inlet, so their water use is really 100% consumptive. The Ministry of Agriculture (van der Gulik et al., 2003) identifies significant groundwater use for irrigation, which has been taken as 100% consumptive.Table 39 summarizes the water budget in terms of the losses and gains described above.

Table 39: Bedrock aquifer 0207 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	12,796,700	% of Gains
Recharge	9,654,600	76
Downward Leakage from aquifer 0205	545,700	4
Downward Leakage from aquifer 0206	772,100	6
Lateral groundwater inflow	30,500	0
Streamflow Losses to aquifer 0207	1,793,800	14
Losses =	- 9,888,600	% of Losses
Lateral groundwater outflow	9,475,600	96
Water Usage: Municipal and Domestic	265,000	3
Water Usage: Commercial and Industrial	47,400	0
Water Usage: Irrigation	100,600	1
Net Water Balance =	+ 2,908,100	

[7] There is some debate on whether there is groundwater inflow up into aquifer 0206 along the Handysen fault; however it is assumed for the present that this is not the case. See Section 5.5.

The water budget shows a 23% retention of the aquifer gains which appears that there is a surplus of water in the bedrock available for use. However, this may simply be an underestimation of the lateral groundwater discharge to the inlet. For example, if the bulk K_{mb} of the bedrock was in reality 33% higher, which is well within reason, the water in and water out would balance.

In a hot and dry year such as 1989 where the surplus was 33% lower than normal, one could expect a similar reduction in recharge and leakage from the overburden. The total downward recharge of 9,654,600 m^3 (for an average year) could therefore be just 6,495,000 m^3 (Appendix F), a loss of 3,159,600 m^3 in such a year, which would have a significant effect on the above sums creating a deficit condition. (Lateral outflows would be however reduced by a reduction in driving head caused by lower water table positions.) By similar logic, the increase in recharge for that very wet year in 1999, would have added over 6,300,000 m^3, and a clear surplus would be present.

The monthly water budget shown on Figure 22 reveals that in an average year there is a surplus condition from November to March, and that a clear deficit occurs in the seven months from April to September (green line). October is nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs from October to March. The hot/dry year (red line) is revealing, where a small surplus from November to March and steady deficit in the other seven months. As in the other aquifers, the deficits in the three scenarios are similar due to a lack of rainfall (and vary slightly due to temperature), but the surpluses vary widely due to rainfall.

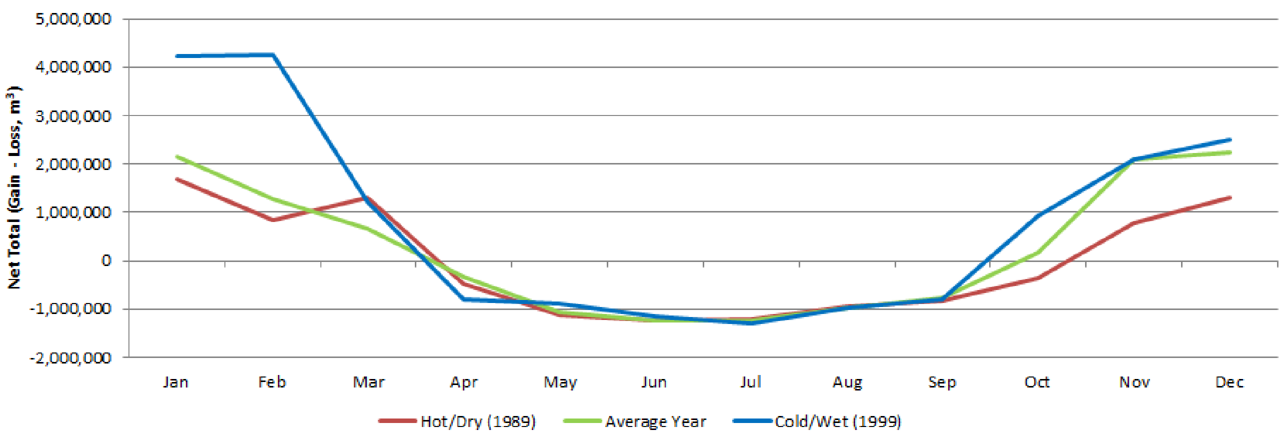

Figure 22: Monthly water budget for bedrock aquifer 0207.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 413,000/6,495,000X 100% = 6.4% (Low Stress Level)
- Normal. 413,000/9,654,600 X 100% = 4.3% (Low Stress Level)
- Cold/Wet. 413,000/16,022,200 X 100% = 2.6% (Low Stress Level)

Recharge values used in these stress factor calculations only include recharge from precipitation and do not include leakage estimates from aquifer 0205 and aquifer 0206. If this leakage were considered as well, all three periods would continue be classified as low stress. However there is significant consumptive use in aquifer 0207 (fourth highest of the eleven aquifers), consistent with the developed portion of the aquifer area.

4.6.7 Bedrock Aquifer 0207 Conclusions

The above water budget suggests there is a considerable annual surplus in aquifer 0207. However, the uncertainties in the calculations far outweigh the calculated surplus, and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIB(12), and is moderately developed. It is reasonable to assume that if wells can find any permeable horizons in the low permeability bedrock, then useable quantities of water may be available. Water supplies will be limited in the Bonanza Group underlying the western and southern two thirds of the aquifer area. The likelihood of identifying high yield zones is low, and water supplies based on individual wells uniformly spread out is recommended. This is because there is likely very little available storage in this part of the aquifer due to the aquifer's low hydraulic conductivity due to a lack of fracturing. Potential well interference between existing and future/proposed wells in this part of aquifer 0207 could be high due to the low storativity of this bedrock.

Under the northeastern third of the aquifer, the Island Plutonic Suite bedrock is more permeable and periodically provides high yields. Where geologic lineaments occur, such as the Shawnigan fault, drilling in such targets may yield moderately successful wells, particularly where it intersects other geologic lineaments.

As with the other bedrock aquifers, the review of groundwater license applications should consider the size of the proposed taking, and should consider the proximity of neighbouring wells. Although the aquifer may be considered at a low stress level as a whole, there will be portions where licensing new groundwater takings may be problematic for that reason. The seasonality is also important, and pumping tests should be conducted at the critical time of the year and be long enough in duration to ensure a measure of sustainability. Whether the year is wet or dry should also be considered, as this will affect water availability beyond what a pumping test would identify.

5. SURFICIAL AQUIFER DESCRIPTIONS / WATER BUDGETS

5.1 Aquifer 0197 (Cherry Point)

5.1.1 Location, Access, and Land Use

Aquifer 0197 (Cherry Point) is located on the northeast side of the study area and adjacent to the Cowichan Bay and Satellite Channel marine shorelines. Based on ENV, it covers 39.48 km^2. We note that the small (14.6 ha) lands surrounding Dougan Lake has been included both aquifer 0199 and aquifer 0197 in the ENV system. There are not two overburden aquifers overlapping here, as water well records show just one aquifer. For the purpose of this water budget, we have elected to subtract that piece from aquifer 0197 and leave it in aquifer 0199 to avoid double counting. Therefore, the total area has been taken as 39.33 km^2.

The aquifer is centred at Latitude 48^{o}43'08" Longitude 123^{o}36'09" (UTM 455660E 53963990N Zone 10) and accessible by the Trans-Canada Highway and Cowichan Bay, Koksilah, Telegraph, Cherry Point and Cobble Hill Roads.

The land surface above aquifer 0197 is moderately developed. Most of the aquifer's surfaces have been developed for rural-residential (37%), urban (14%), or agricultural (12%) purposes. The balance of its surface (37%) consists of non-contiguous, undeveloped and forested properties.

5.1.2 Classification, Extent, and Well Information

Aquifer 0197 is classified by the ENV as a moderate-priority Class IIC(11) aquifer, which indicates that it is moderately developed with low vulnerability to surface contamination.

The horizontal extent of aquifer 0197 is defined by the occurrence of registered wells completed in unconsolidated granular materials within a 3.5 km wide zone parallel to the marine shoreline between the Cowichan River estuary and Mill Bay. The northeast and east-central perimeters of aquifer 0197 are defined by the marine shoreline, while the south perimeter is defined by an sinuous boundary with adjacent bedrock aquifer 0204 where it partly overlies aquifer 0204 and pinches out towards the south and southeast near Boatswains Bank, Padur Ridge, and Arbutus Ridge. The north and west perimeters of the aquifer are defined by the boundaries of adjacent overburden aquifers 0186, 0187, 0188, and 0199, while its southwest perimeter is defined by the boundary of adjacent bedrock aquifer 0202 where the aquifer's host materials pinch out westwards. Aquifer 0197 entirely overlies bedrock aquifer 0198 at its northwest end.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 40.

Table 40: Aquifer 0197 well statistics.

Well Depth (m)		**Well Yield (L/s)**		**Confining Layer Depth (m)**		**Static Water Level Depth (m)**	
Mean	43.5	Mean	1.12	Mean	-	Mean	29.5
Median	39.5	Median	0.63	Median	20.0	Median	27.4
Range	4.3 – 128.0	Range	0.01 – 17.35	Range	0 – 87.8	Range	0.0 – 93.0

5.1.3 Physiography and Hydrology

Aquifer 0197 is situated on a broad, northwest-trending, domed bench flanked along its northeast and east peripheries by steep bluffs along the marine shoreline. The area is bordered to the northwest by the Glenora uplands, north and west by the Cowichan River, Koksilah River, and Dougan Lake valleys, southwest by the Cobble Hill uplands, and south by the lower reaches of Shawnigan Creek. The northeast and east margins of the aquifer along the Cowichan Bay and Satellite Channel shorelines contain at least eleven narrow ravines with short streams.

Aquifer 0197 is situated within a lowland area of gentle relief surrounded by low hills. Surface topography above aquifer 0197 generally consists of a mixture of undulating to gently rolling terrain, although a relatively chaotic area of roughly west-northwest oriented surface depressions, ponds, and low conical hills are present between Dougan Lake and Cherry Point. Surface elevations range from 120 m amsl at the summits of several northwest-elongated hills in the aquifer's southeast corner to sea level along the marine shoreline.

The boundaries of aquifer 0197 straddle the Koksilah, Shawnigan Creek, and Cowichan watersheds, with surface drainage patterns over the domed parts of aquifer 0197 being generally radial to parallel. Wilmot Creek, Ordano Brook, Garnett-Shearing Creeks, Manley Creek, Wace Creek, Sylvan Brook, and at least eleven unnamed streams flow directly into Cowichan Bay and Satellite Channel along the aquifer's northeast side. Eddy-Kilmalu Creek, Nott Creek, Prellwitz Creek, and Brayshaw Creek flow south into Shawnigan Creek at the south end of the aquifer area, while Dougan's Ditch, Patrolas Creek, Weeks Creek, Geise Brook, Treffrey Creek, and Spears Creek and at least three unnamed streams flow into the Koksilah River along the aquifer's west side and north end. At least twenty-six springs occur around the periphery of aquifer 0197, many of which are licensed, particularly along its northeast margin along the marine shoreline, while at least eleven springs occur within its central portions.

5.1.4 Geology and Soils

The central and northern parts of aquifer 0197 are underlain by folded and fractured shale, mudstone, and siltstone sedimentary rocks of the Nanaimo Group's Haslam Formation, which host aquifer 0198 at its northwest end. The south end of the aquifer is underlain by basaltic volcanic rocks of the Sicker Group's Duck Lake Formation with minor amounts of basaltic volcanic rocks of the Vancouver Group's Karmutsen Formation, limestone of the Buttle Lake Group's Mount Mark Formation, and granodioritic intrusive rocks of the Island Plutonic Suite, which host aquifer 0204 at its southeast end. Although bedrock is not exposed within the boundaries of the aquifer, available well records suggest that its surface is irregularly-shaped with numerous linear ridges and narrow depressional areas suggestive of a buried, cuesta-type palaeosurface. The tectonic setting of the bedrock units underlying aquifer 0197 may be complex, with evidence for both compressional and extensional structural deformation.

Aquifer 0197 consists of a 20 to more than 125 m thick, texturally-variable mantle of dense, coarsely-stratified Vashon Drift morainal and loose glaciofluvial outwash and ice-contact units overlying bedrock, which are capped in its central and northwest portions by a discontinuous surface blanket of compact, fine-grained, Capilano Sediments glaciomarine materials. A cluster of roughly west-northwest oriented, glaciofluvial and glaciolacustrine "kame-kettle" deposits of the Capilano Sediments with local veneers of Salish Sediments organic material occur at surface in the centre of the aquifer area between Dougan Lake and Cherry Point at the marine shoreline. Small, colluvial debris flow deposits are commonly present at the termini of the numerous short ravines that occur along the Cowichan Bay and Satellite Channel shorelines. Thin, discontinuous lenses and linear deposits of coarse sand and gravel locally occur immediately above the bedrock surface in a number of areas, including southwest of Cowichan Bay shoreline and near Arbutus Ridge. They may either represent small proglacial or sub-marginal outwash deposits of the Vashon Drift or remnants of the older Quadra Sands Formation.

Soils above the central and northwest portions of aquifer 0197 generally consist of imperfectly-drained, gleyed eluviated dystric brunisols of the Finlayson Soil Association, which have developed in areas of gentle relief over deep blankets of silty or clayey glaciomarine materials. Poorly-drained depressional areas, including low-lying kettle hollows between Dougan Lake and Cherry Point, often contain orthic humic gleysols of the Tagner Soil Association, which are a variant of Finlayson soils that have developed over silty or clayey glaciomarine and/or glaciolacustrine materials, and terric mesisols of the Arrowsmith Soil Association developed over shallow organic deposits.

5.1.5 Hydrogeology

Groundwater within aquifer 0197 occurs within intergranular pore spaces in at least three loose, fine to coarse-grained, glaciofluvial outwash and ice-contact deposits of sand and gravel, while dense deposits of morainal, glaciolacustrine, and glaciomarine materials generally constitute aquitards. The aquifer displays a moderately high level of internal stratigraphic complexity, with the depths, thicknesses, and lateral continuities of potentially water-bearing units varying significantly between locations. Groundwater also occurs within glaciofluvial kame deposits of the Capilano Sediments east of Dougan Lake, although the volume of groundwater present in this setting may be relatively minor since most of these deposits are mounded and free-draining.

The northwest portion of the aquifer from Cowichan Bay Road to Bench Road overlying aquifer 0198 is capped at surface by a moderately persistent, 10 to 15 m thick aquitard of glaciomarine silt and clay that pinches out near the Cowichan Bay shoreline near Ordano Brook. A generally unsaturated, 5 to 25 m thick sand-gravel unit that also pinches out towards the east is sandwiched between the surface aquitard and an underlying, strongly persistent, 10 to 30 m thick morainal aquitard. A second, 5 to 15 m thick saturated sand-gravel unit located between the lower morainal aquitard and the underlying, irregularly-shaped bedrock surface supplies groundwater to most of the wells in this area, is moderately to highly productive along its east side.

The north-central portion of the aquifer from Bench Road to Dougan Lake is considerably thicker than its northern portion and contains a higher proportion of water-bearing units to aquitards. Aquitards are also locally impersistent and variable in thickness and depth, with sand-gravel units being exposed at surface northeast of Dougan Lake. An upper sand-gravel unit is present throughout the area that varies in thickness from 5 m on the aquifer's west side to almost 80 m adjacent to the Satellite Channel shoreline, and is generally unsaturated to depths of between 25 and 70 m below surface. This unit is underlain by a 10 to 15 m thick morainal aquitard that either directly overlies an irregularly-shaped bedrock surface or separates the upper sand-gravel unit from a lower series of small, disconnected sand-gravel units over bedrock. Aquifer 197 is typed as "4b – confined aquifer" but exhibits areas where these aquifer units are unconfined, or semi-confined, based on discontinuous aquitards. There will be places where these units are connected to surface water.

The middle and south-central portions of the aquifer from Dougan Lake to Aros Road are slightly thinner and stratigraphically less complex, with a strongly persistent deposit of compact glaciomarine material forming a continuous surface aquitard. This aquitard overlies a 40 to 70 m thick, mainly saturated sand-gravel unit that pinches out towards the southeast at Padur Ridge near Manley Creek and may directly overlie an irregular bedrock surface in most areas.

The stratigraphy of the southern portion of the aquifer from Aros Road to its sinuous south border is comparatively more complex, with the upper aquitard becoming significantly less persistent and unsaturated sand-gravel units extending from surface to depths of up to 40 m throughout most of the area. The total thickness of the sand-gravel units in this area varies from a maximum of 75 m in the vicinity of Fisher Road west of the Trans-Canada Highway to less 15 m thick near the aquifer's south end around Chapman Road, with the exception of a localized area near the Satellite Channel shoreline west of Arbutus Ridge where available well records indicate the presence of deep, saturated, highly-productive, sand-gravel units at depths of over 125 m below surface.

The groundwater storage potential and hydraulic conductivity of aquifer 0197 may be variable due to its textural variability, stratigraphic complexity, and local presence of thick sequences of near-surface, unsaturated sand-gravel units. Areas of the aquifer where loose, coarse-textured proglacial, glaciofluvial, and/or ice-contact deposits occur within which moderate to high-productivity wells have been completed, may display elevated K_{mb} values in the range $1x10^{-6}$ to $1x10^{-4}$, although the storage potential of these zones may be low due to their reduced lateral persistence. Conversely, areas of the aquifer where compact, persistent morainal and/or fine-grained glaciomarine and glaciolacustrine deposits occur may display comparatively lower K_{mb} values ranging from $1x10^{-9}$ to $1x10^{-7}$ m/s and represent aquitards.

The degrees of hydraulic confinement of water-bearing sand-gravel units within aquifer 0197 may be variable, with groundwater being semi-confined to confined in areas overlain by persistent, thick aquitards, but unconfined in other areas where aquitards are either impersistent of absent. Groundwater within near-surface water-bearing units in the northwest and south portions of the aquifer, as well as those occurring at depth within bedrock surface channels, may occur in semi-confined to confined states, while groundwater in the central parts of the aquifer may be mainly unconfined.

Figure 23 has been prepared to illustrate regional groundwater flow patterns. Representative water levels from the water well records, were plotted for the topmost saturated aquifers and contoured on the figure[8]. Regional groundwater flows within the near-surface water-bearing units of aquifer 0197 may mirror its surface topography, with radial flows from its central, northwest-trending elevated areas towards the Koksilah River, Patrolas Creek, Cowichan River, and Shawnigan Creek valleys and the marine shoreline. Local groundwater flow patterns within the semi-confined or confined water-bearing units, particularly those located within the sand and gravel filled bedrock channels, may differ from topography and be influenced by their stratigraphic settings, local variations in hydraulic head, and the shape of the underlying bedrock surface. Regional hydraulic gradients within aquifer 0197 are generally low to moderate based on the area's low topographic setting and gently-sloping terrain.

Aquifer 0197 may receive vertical inflow from precipitation, stream losses, and irrigation / sewerage dispersal returns in areas where surface aquitards do not impede infiltration, although deeper semi-confined zones may receive comparatively less recharge from these sources. Aquifer 0197 may also receive lateral inflow from water-bearing fracture systems in adjacent aquifers 0202 and 0204 along its southeast and south borders.

Groundwater outflow from aquifer 0197 may take place through evapotranspiration from its water-bearing units where persistent surface aquitards do not occur and the water table is close to surface, and discharge to the lower reaches of its peripheral streams, the Koksilah River at its northwest corner, low-elevation springs along its northeast, east, and south edges, and the marine environment. Groundwater outflow may also occur to the underlying aquifer 0198 at its northwest end, to downgradient portions of adjacent aquifers 0186 and 0199 along its north and northwest borders, and to fracture systems within adjacent aquifer 0204 at its south.

5.1.6 Water Budget

Overburden aquifer 0197 lies in the most heavily populated area along the shore of Cowichan Bay and extends down to the Satellite Channel. As such, it has the highest consumptive use of the eleven aquifer areas studied. It covers an area of 39.3 km^2 (3,933.2 ha) and overlies portions of bedrock aquifers aquifer 0198 (500.0 ha) and aquifer 0204 (512.6 ha). Recharge is an average of 366 mm/yr, which is among the lowest of the aquifers, largely due to lying in the drier part of the study area. This reduces to 246 mm/yr in a hot/dry year, and could be as high as 608 mm/yr in a cold/wet year. As discussed above, lateral groundwater flow is radially in all directions:

- To the Koksilah River and Cowichan Bay in the northwest;
- To the marine shoreline;
- To aquifer 0204 to the south; and
- Westerly into aquifer 0199 south of Dougan Lake.

Groundwater flow also enters aquifer 0197 from bedrock aquifer 0202 to the west.

Underlain primarily by the low permeability Nanaimo Group bedrock over much of the area, a leakage out of the aquifer has been assumed to be 100 mm/yr. (This was subdivided between what enters aquifer 0198, and what exits the bottom of the aquifer area where there are no identified bedrock aquifers.) For the area where the more permeable Sicker volcanics occur (primarily aquifer 0204), the leakage has assumed to be 300 mm/yr.

[8] This figure is not a water table map, as it ignores perched zones, and it is not a rigorously researched potentiometric surface, as that is beyond the scope of this study. Rather, it is meant to convey the general patterns and likely directions of groundwater flow. It has been used however to provide horizontal gradients in the calculations of lateral groundwater flow used in Section 5.1.6.

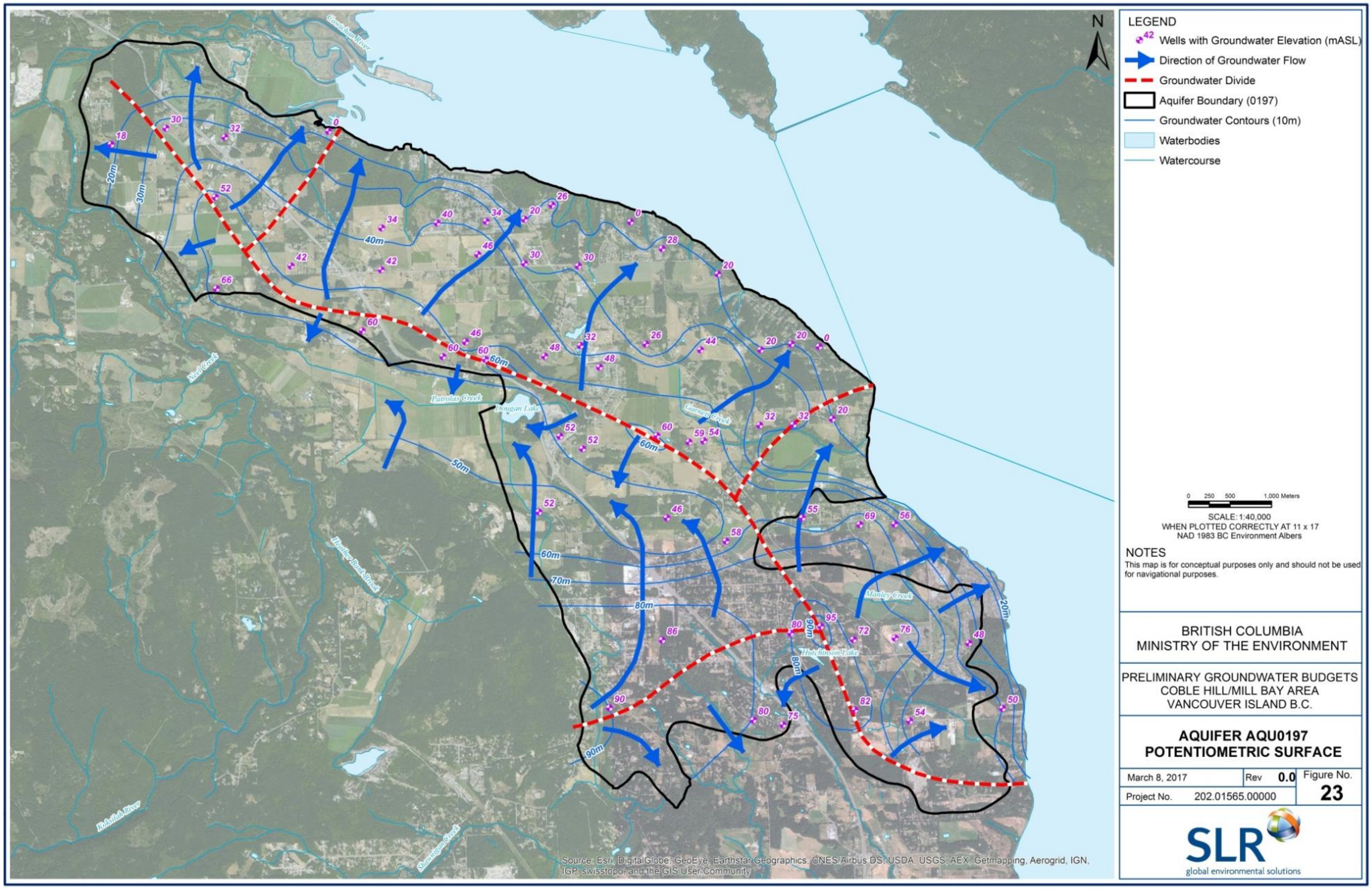

Figure 23: Aquifer 0197 potentiometric surface.

The kame like deposit centred northeast of Dougan Lake is the headwater for several streams (Patrolas Creek, and Garnett Creek). Since this deposit sits on top of a substantial aquitard, it has been assumed that the full recharge of the feature feeds the streams and that water is lost by streamflow. Certainly the streams cross areas of low permeability sediments and can be considered conveyance features.

There are substantial commercial and industrial water takings in the geographic area of aquifer 0197 as determined by Hatfield (2015). These have been assumed to be 100% consumptive. Based on discussion with the municipality, 85% of the rural population relies on wells and septic beds. The remaining 15% of the population relies on wells but have sewer connections where the water is conveyed for treatment and discharge to the Bay or Inlet. To be conservative, both types are assumed to be 100% consumptive. Irrigation from groundwater sources reported by the Ministry of Agriculture (van der Gulik et al., 2003) was similarly assumed to be 100% consumptive (with no remainder being returned to the aquifer). Table 41 summarizes the water budget in terms of the losses and gains described above.

Table 41: Overburden aquifer 0197 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	11,019,600	% of Gains
Recharge	10,747,900	98
Lateral groundwater inflow (from aquifer 0202)	271,700	2
	Losses = 15,159,800	% of Losses
Leakage down to aquifer 0198	500,000	3
Leakage down to aquifer 0204	1,537,900	10
Leakage to undesignated bedrock	1,922,500	13
Lateral groundwater outflow	5,881,500	39
Losses to Surface Water	741,300	5
Water Usage: Municipal and Domestic	1,399,800	9
Water Usage: Commercial and Industrial	489,100	3
Water Usage: Irrigation	2,687,700	18
Net Water Balance =	- 4,140,200	

The water budget shows a 37% deficit in the aquifer gains which appears to be very significant. However, this deficit may simply be an overestimation of groundwater outflow. For example if the bulk hydraulic conductivities used in the groundwater flow calculations were decreased by about four times there would have been little net surplus or net deficit. This will be important to refine in future, as the estimated water usage is greater than the estimated deficit. Another source of uncertainty is the assumption of 100% consumptive use for domestic water use, particularly for that 85% of the systems that have septic beds. If the septic beds return, say 50% of the water to the ground, the consumptive use may actually be lower. Similarly, irrigation, which is significant in aquifer 0197, is usually not efficient and there can be up to a 20% return to the ground. If these two factors are considered, the consumptive value in Table 41 above maybe reduced by 25%. In any event, there is a deficit condition, albeit within the range of the uncertainty of the calculation assumptions. Of some interest, there has been no depletion in long-term water levels at provincial observation wells OW320 and OW345 in aquifer 0197, which have 22 and 15 years of record, respectively. Although this would seem to say there is currently no long term deficit, it needs confirmation by refining the assumptions with more verified information. Aquifer 0197 is a complex assembly of individual aquifers and aquitards and bears further study on a more detailed level than is possible here.

It is important to understand that these are average numbers and aquifer 0197 covers the largest area of the eleven aquifer areas considered in this report. Individual areas within aquifer 0197 are more stressed than others, particularly in drier years. Where particular problems exist it would be wise to reduce the water budget exercise to a smaller more representative area, to obtain a better understanding.

In a hot and dry year such as 1989, where the surplus was about 33% lower than normal, one could expect a similar reduction in recharge. The recharge of 10,747,900 m^3 (for an average year) could therefore be just 7,230,600 m^3, a loss of 3,517,300 m^3 in such a year, which would have a significant effect on the above sums, creating a greater deficit condition. From a mitigative perspective, lateral outflows and losses to bedrock would also decrease due to a reduction in driving head caused by lower water table positions. By similar logic, the 67% increase in recharge for that very wet year in 1999, would have added over 7,000,000 m^3, and a clear surplus would be present in similar wet years.

The monthly water budget shown on Figure 24 reveals that in an average year there is a surplus condition from November to February, and that a clear deficit occurs in the six months from April to September (green line). We note that the groundwater levels in observation wells (particularly 320) generally continue to rise in April, peaking in May. This would seem to indicate a time lag, which is consistent with groundwater flow rates. March and October are nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs in January and February, and March and October become surplus months. The hot/dry year (red line) is revealing, where a small surplus from November to March, largely due to a lack of rainfall, and steady deficit in the other seven months.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 4,576,600/7,230,600 X 100% = 63.3% (High Stress Level)
- Normal. 4,576,600/10,747,900 X 100% = 42.6% (High Stress Level)
- Cold/Wet. 4,576,600/17,836,700 X 100% = 25.7% (High Stress Level)

Aquifer 0197 hosts the highest population density and most industrial and commercial users of the eleven aquifer areas being studied. In addition, it hosts the greatest amount of groundwater pumping for agricultural use. For these reasons the consumptive use of groundwater is the highest in the study area. This is reflected in the high stress level determined by the water quantity stress assessment above.

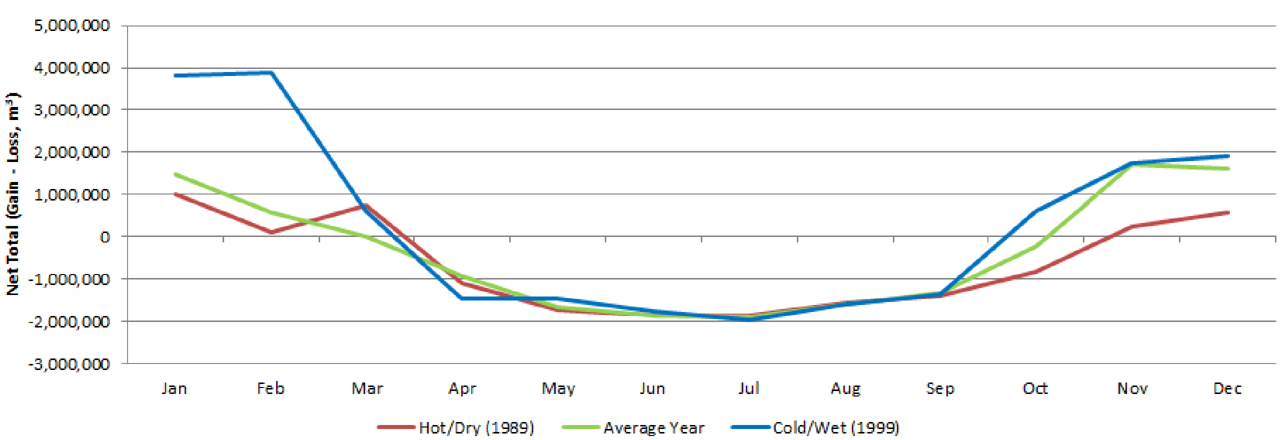

Figure 24: Monthly water budget for overburden aquifer 0197.

5.1.7 Overburden Aquifer 0197 Conclusions

As described above, overburden aquifer 0197 covers a large areal extent and is stratigraphically complex. In short, it is a composite of several water bearing zones with significantly different geological and hydraulic characteristics and variable storage capacity. Whereas the above water budget suggests there is a deficit in aquifer 0197, local conditions can vary widely within the aquifer area. The magnitude of the actual deficit may be different than that calculated here, as the uncertainties in the calculations are greater than the calculated deficit, and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIC(11), and is only moderately developed. However, there are individual areas that are highly developed, and development pressures are increasing. The industrial and agricultural water uses are more than half of the estimated consumptive uses, and compared to other aquifer areas are substantive, all of which contributes to the high stress level assigned above.

The overburden aquifer, as described above hosts several layers of areally extensive but often discontinuous aquifers and aquitards. The underlying bedrock surface has much relief and often hosts deposits of permeable materials in the low areas. There appears to be a capacity for private residential wells in most of the areas, however high capacity wells will have to target specific deposits and licensure must consider mutual well interference. For example, the saturated part of the kame deposit (below the water table) can have a high yield and considerable local storage. Long term testing[9] is necessary to show sustainability where the saturated thickness of these permeable deposits is not great. The deep Quadra sands for example at the north end lie below sea level yet carry fresh water in useable quantities. At the southeast end of aquifer 0197 near Manley Creek there is a buried bedrock ridge that holds very permeable outwash materials on the inland side. The long term sustainability of these individual sources is presently unknown and bears future scrutiny. The geologic distribution of sediments should be considered when planning groundwater supplies wherever possible.

5.2 Aquifer 0199 (Dougan Lake)

5.2.1 Location, Access, and Land Use

Aquifer 0199 (Dougan Lake) is located in the northwest part of the study area west of Dougan Lake and south of the Trans-Canada Highway, and covers 3.40 km^2. There is a 68.2 ha triangle of land south of Dougan Lake that is not assigned to any aquifer, likely because there are few water wells in it. This study has found that groundwater from aquifer 0197 flows westerly under this land joining aquifer 0199. It was deemed to be an important feature and this area has been added to aquifer 0199 for the purpose of the water budget. Therefore, the revised area of the aquifer 0199 is 4.08 km^2.

The aquifer is centred at Latitude 48^{o}43’02” Longitude 123^{o}38’36” (UTM 452700E 5396250N Zone 10) and accessible by Lakeside Drive, Hillbank Road, and Forrest Road.

The land surface above aquifer 0199 is intensively developed. Most of the aquifer’s central and southern surfaces have been developed for agricultural (37%) and rural-residential (37%) purposes. The balance of its surface (26%) consists of moderately contiguous, undeveloped and forested properties.

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[9] Pumping tests at a minimum should be 72 hours long to determine if an aquifer is unconfined or not. If equilibrium is not achieved, longer tests of a week to a month or more are needed to provide enough data to extrapolate long term effects, and effects on ecologic features and other wells.

5.2.2 Classification, Extent, and Well Information

Aquifer 0199 is classified by the ENV as a Class IIC(9) (moderate priority), which indicates that it is moderately developed with low vulnerability to surface contamination.

The horizontal extent of aquifer 0199 is defined by the occurrence of registered wells completed in unconsolidated granular materials within the Dougan Lake / Patrolas Creek valley. The northeast and east perimeters of the aquifer are defined by the boundaries of adjacent surficial aquifer 0197 and adjacent bedrock aquifer 0198 (which it partly overlies). The boundaries of bedrock aquifer 0196 and undeveloped extensions of bedrock aquifers 0200 and 0202 form its west and south perimeters. Undeveloped extensions of aquifer 0199 extend to the southeast of Dougan Lake.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 42.

Table 42: Aquifer 0199 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	15.4	Mean	0.69	Mean	9.5	Mean	6.0
Median	14.6	Median	0.63	Median	8.5	Median	5.8
Range	4.3 – 36.6	Range	0.25 – 3.15	Range	-	Range	0.0 – 25.0

5.2.3 Physiography and Hydrology

Aquifer 0199 is situated in a low-lying area of gentle relief on a west-northwest trending, planar to gently undulating bench that overlooks the Koksilah River valley along its southwest side. The aquifer is bordered at its south end by the Cobble Hill uplands, on its northeast side by the low, northwest-trending, dome area hosting surficial aquifer 0197, and to the east by Dougan Lake. Surface elevations range from 60 m amsl at its east end to 20 m amsl at its northwest corner adjacent to Koksilah River.

Aquifer 0199 is located within the Koksilah River watershed, with nearest marine shoreline being 2.3 km northeast at Cowichan Bay. Surface drainage patterns over the aquifer are rectangular and anthropogenically modified, with Patrolas Creek flowing northwest along the north side of the bench from Dougan Lake into Koksilah River and functioning as a collector for four tributary ditches that extend at right-angles off the stream's main stem.

5.2.4 Geology and Soils

Aquifer 0199 is underlain by folded and fractured shale and mudstone sedimentary rocks of the Nanaimo Group's Haslam Formation. Bedrock is not exposed at surface within the aquifer's boundaries. The tectonic setting of the bedrock units underlying aquifer 0197 may be complex, with evidence for both compressional and extensional structural deformation.

Aquifer 0199 consists of an elongated deposit of southwest-dipping, coarsely-stratified glaciofluvial and glaciolacustrine Capilano sediments ice-contact and Salish Sediments organic materials overlying an irregularly-shaped bedrock surface. The aquifer generally varies in thickness from 5 m at its northwest end to over 15 m, with the exception of at its east end where available well records indicate thickness of over 50 m.

Soils within the north, central, and east portions of aquifer 0199 consist of a mixed assemblage of imperfectly to poorly-drained, gleyed eluviated dystric brunisols and orthic humic gleysols of the Finlayson and Tagner Soil Associations, respectively, which have developed in areas of gentle relief over deep blankets of silty or clayey glaciolacustrine materials. In contrast, soils within the south portion and southwest margin of the aquifer consist of well to rapidly-drained orthic dystric brunisols of the Quamichan Soil Association, which have developed in areas of gentle relief over deep blankets of sandy gravelly glaciofluvial materials. Terric mesisols of the Arrowsmith soil association, which have developed over deep, water-saturated deposits of organic materials, occur at the east end of the aquifer adjacent to Dougan Lake.

5.2.5 Hydrogeology

Groundwater within aquifer 0199 occurs within intergranular pore spaces in at least three loose, fine to coarse-grained, glaciofluvial deposits of sand and gravel, while dense deposits of glaciolacustrine materials generally have low hydraulic conductivity and constitute confining aquitards. The aquifer displays a high level of internal stratigraphic complexity, with the depths, thicknesses, and lateral continuities of potentially water-bearing units varying significantly between locations. Sand-gravel units display varying degrees of saturation between locations, and are generally between 5 and 15 m thick with the exception of at the aquifer's east end where available well records indicate the presence of granular materials over 50 m thick.

The groundwater storage potential and K_{mb} of aquifer 0199 may be variable due to its textural variability and stratigraphic complexity. Areas of the aquifer where loose, coarse-textured glaciofluvial deposits occur may display locally elevated K_{mb} values ranging from $1x10^{-5}$ to $1x10^{-4}$ m/s, although the storage potential of these zones may be low due to their reduced lateral persistence. Conversely, areas of the aquifer where compact, fine-grained glaciolacustrine deposits occur may display comparatively lower K_{mb} values ranging from $1x10^{-9}$ to $1x10^{-8}$ m/s.

Groundwater within aquifer 0199 is generally unconfined due to the southwest-dipping, planar configuration of its water-bearing units, which are exposed at surface between similarly-inclined aquitard units.

Regional and local groundwater flow patterns within aquifer 0199's water-bearing units are generally west and southwest towards the Koksilah River. Hydraulic gradients within aquifer 0199 are low based on the area's relatively gentle relief.

Aquifer 0199 may receive vertical inflow from precipitation, stream losses, and irrigation / sewerage dispersal returns. Aquifer 0199 may receive lateral inflow from Dougan Lake at its east end and surficial aquifer 0197 to the north and east, from water-bearing fracture systems within developed and undeveloped portions of adjacent bedrock aquifers 0196, 0200, 0202, and 0198 along its northwest, southwest, and south borders, and from surface runoff and near-surface soil drainage from adjacent, topographically-elevated areas.

Groundwater outflow from aquifer 0199 may take place through evapotranspiration and baseflow discharge to the lower reaches of Patrolas Creek and Koksilah River at its northwest corner. Lateral discharge may occur to the adjacent bedrock aquifers 0196 and 0198 and surficial aquifers 0186 and 0197 at its west end.

5.2.6 Water Budget

Overburden aquifer 0199 lies in the Patrolas Creek subwatershed of the greater Koksilah watershed and slopes to the south covering 328 ha. For the purpose of the water budget this includes an 83 ha triangle of land south of Dougan Lake, which previously has not been classified. This was done as that particular land provides recharge that feeds the aquifer. Recharge for this enhanced area is an average of 412 mm/yr. This reduces to 277 mm/yr in a hot/dry year, and could be as high as 684 mm/yr in a cold/wet year. Groundwater flow is towards the Koksilah River for the western two thirds of the aquifer area but the bulk of the movement is westerly from Dougan Lake. Leakage out of the aquifer to the low permeability bedrock of aquifer 0198 and the rest of the bedrock (presently undesignated as an aquifer) below has been assumed to be 100 mm/yr.

There is substantial groundwater flowing westerly into the eastern end of the aquifer from aquifer 0197. Patrolas Creek is a warm water stream that lies in low permeability soils and is assumed to be a conveyance feature. Reports of cold-water species may be related to the cold-water coming from Dougan Lake, or perhaps in the lower reaches of the creek.

There are no commercial water takings in the geographic area of aquifer 0199, however Hatfield (2015) determined some industrial takings which we have assumed are 100% consumptive. The rural population relies on wells and septic beds again assumed to be 100% consumptive. The irrigation licenses are partly from Patrolas Creek and represent a loss to the system. Groundwater use for irrigation supply is also prevalent and has been estimated from the agricultural demand model (van der Gulik et al., 2003). All irrigation is assumed to be 100% consumptive. Table 43 summarizes the water budget in terms of the losses and gains described above.

Table 43: Overburden aquifer 0199 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	3,130,100	% of Gains
Recharge	1,351,900	43
Lateral groundwater inflow from aquifer 0197	1,778,200	57
Streamflow losses from Patrolas Creek	0	0
Losses =	- 2,679,600	% of Losses
Leakage down to aquifer 0198	79,700	3
Leakage down to undesignated bedrock	248,300	9
Lateral groundwater outflow	2,056,400	77
Water Usage: Municipal and Domestic	24,000	1
Water Usage: Commercial and Industrial	109,500	4
Water Usage: Irrigation	161,700	6
Net Water Balance =	+ 450,500	

The water budget shows nearly a surplus of about 33% of the recharge. Should the calculated inflow from aquifer 0197 have been based on a hydraulic conductivity of 25% less (which is not unreasonable), a nearly neutral balance would have been determined. In a hot and dry year such as 1989 where the surplus was 33% lower than normal, one could expect a similar reduction in recharge. The recharge of 1,351,900 m^3 (for an average year) could therefore be just 909,400 m^3 (Appendix H), a loss of 442,500 m^3 in such a year, which would have a significant effect on the above sums, creating a deficit condition. Similarly, groundwater inflow from aquifer 0197 might be lower in that case due to lower driving heads. (From a mitigative perspective, lateral outflows and losses to bedrock would be reduced by a reduction in driving head caused by lower water table positions.) By similar logic, the increase in recharge for that very wet year in 1999, would have added just under 900,000 m^3 (Appendix H), and an even greater surplus would be present.

The monthly water budget shown on Figure 25 reveals that in an average year there is a surplus condition from November to February, and that a clear deficit occurs in the seven months from April to September (green line). March and October are nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs from October to March. The hot/dry year (red line) reveals a modest surplus from November to March and steady deficit in the other seven months.

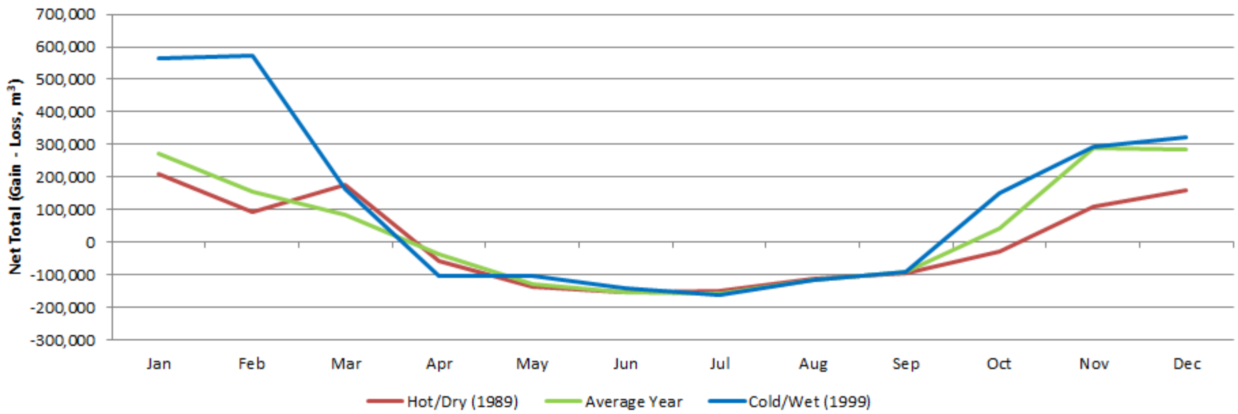

Figure 25: Monthly water budget for overburden aquifer 0199.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 295,200/909,400 X 100% = 32.5% (High Stress Level)
- Normal. 295,200/1,351,900 X 100% = 21.8% (Moderate Stress Level)
- Cold/Wet. 295,200/2,243,500 X 100% = 13.1 % (Moderate Stress Level)

Aquifer 0199 appears to be moderately stressed, and highly stressed in the hot/dry condition, primarily because of the high irrigation withdrawls. The above calculations consider just recharge water, however, significant lateral groundwater inflow (1,778,200 m^3) from the east is likely occurring. If this additional water were considered in the stress factor, a low stress level would be assigned, albeit still significant.

5.2.7 Overburden Aquifer 0199 Conclusions

The above water budget suggests there is a surplus in aquifer 0199, despite the moderate stress level. The uncertainties in the calculations could drive this either way, and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIC(9), and is only moderately developed, but due to the high irrigation uses is assessed as moderately stressed. The deeper overburden in the buried bedrock valley along the east end of the aquifer, where the deep sands lie should be targeted for further supply as the aquifer beds thin to the west. Licensure of groundwater takings should consider the proximity to other water supplies, and if the proposed water taking is high, the time of year (and type of year) of the well testing be considered to ensure the taking is sustainable. Continued licensure of surface water takings should consider the seasonality of Patrolas Creek, where some study of streamflow would be of benefit to existing and prospective water users.

5.3 Aquifer 0201 (Kingburne)

5.3.1 Location, Access, and Land Use

Aquifer 0201 (Kingburne) is located in the centre of the study area east of the Koksilah River between the Kelvin and Cobble Hill uplands, and covers 2.11 km^2.

The aquifer is centred at Latitude 48°41’05” Longitude 123°38’33” (UTM 452750E 5392600N Zone 10) and accessible by Thain and Kingburne Roads.

The land surface above aquifer 0201 is moderately developed. Most of the aquifer’s north and central surfaces have been developed for agricultural (50%) and rural-residential (30%) purposes. The balance of the aquifer's surface consists of moderately non-contiguous, undeveloped and forested properties (15%) and a former limestone quarry at its south end that contains Kingzett Lake (5%).

5.3.2 Classification, Extent, and Well Information

Aquifer 0201 is classified by the ENV as a Class IIC (8) aquifer, which indicates that it is moderately developed with low vulnerability to surface contamination.

The horizontal extent of aquifer 0201 is defined by the occurrence of registered wells completed in unconsolidated granular materials over bedrock aquifer 0202, with Thain Road and the base of Cobble Hill forming most of its east perimeter. The south perimeter of the aquifer extends around Kingzett Lake. Almost all of the aquifer's registered wells have been completed within a 250 m wide band along its west margin.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 44.

Table 44: Aquifer 0201 well statistics.

Well Depth (m)		**Well Yield (L/s)**		**Confining Layer Depth (m)**		**Static Water Level Depth (m)**	
Mean	18.6	Mean	0.83	Mean	9.3	Mean	6.9
Median	16.8	Median	0.76	Median	10.7	Median	6.1
Range	7.0 – 49.9	Range	0.38 – 4.73	Range	0.0 – 48.2	Range	2.4 – 25.9

5.3.3 Physiography and Hydrology

Aquifer 0201 is situated in a low-lying, north-northeast trending, planar to gently undulating bench that has a low topographic rise in its northwest corner. The bench overlooks the Koksilah River valley along its west side, and is bordered along its east and southwest sides by the bases of two northeast-elongated hills. Surface elevations range from 160 m amsl at its south end to 120 m amsl along its northwest border adjacent to Koksilah River.

Aquifer 0201 is located within the Koksilah River watershed, with the nearest marine shoreline being 5.3 km northeast at Cowichan Bay. Surface drainage patterns over aquifer 0201 are rectangular and anthropogenically modified, with Heather Bank Brook flowing north-northeast along its east side from Kingzett Lake into Heather Bank Swamp at the aquifer's north end, before turning sharply northwest towards Koksilah River. The bench also contains one unnamed stream that flows north-northwest through the centre of the north part of the aquifer before joining Heather Bank Brook.

5.3.4 Geology and Soils

The northwest half and southeast end of aquifer 0201 is mainly underlain by fractured basaltic volcanic rocks of the Sicker Group's Duck Lake Formation, with a minor occurrence of fractured granodioritic intrusive rocks of the Island Plutonic Suite at its northwest margin. The remainder of the aquifer along its eastern margin and within its southeast portion is underlain by roughly equal proportions of fractured basaltic rocks of the Vancouver Group's Karmutsen Formation and fractured and karstified limestone of the Buttle Lake Group's Mount Mark Formation. The tectonic setting of the bedrock units underlying Overburden aquifer 0201 and then the underlying bedrock aquifer 0202 may be mainly compressional due to their location straddling the northeast-trending splay of the regional, east-northeast trending San Juan Fault.

Aquifer 0201 consists of an elongated deposit of coarsely-stratified morainal, glaciofluvial, and glaciolacustrine Vashon Drift ice-contact and Salish Sediments organic materials overlying an irregularly-shaped bedrock surface. Available well records from along the aquifer's west side indicate that the aquifer varies in thickness from 5 m at its north end to over 55 m in its central areas.

Soils within the aquifer's level and depressional portions consist of a mixed assemblage of imperfectly to poorly-drained orthic humic gleysols and terric mesisols of the Cowichan and Arrowsmith Soil Associations, respectively, which have developed over deep, water-saturated deposits of silty-clay glaciolacustrine and organic materials. Soils in the elevated northwest corner of the aquifer consist of imperfectly to well-drained, duric dystric brunisols of the Shawnigan Soil Association that have developed over deep blankets of gravelly-sandy morainal materials.

5.3.5 Hydrogeology

Groundwater within aquifer 0201 occurs within intergranular pore spaces in at least two fine to coarse-grained, glaciofluvial deposits of sand and gravel, while dense deposits of glaciolacustrine and morainal materials generally contain little extractable groundwater and constitute aquitards. The aquifer displays a high level of internal stratigraphic complexity, with the depths, thicknesses, and lateral continuities of potentially water-bearing units varying significantly between locations. Sand-gravel units display varying degrees of saturation between locations, and are generally between 5 and 15 m thick with the exception of at the aquifer's extreme northwest end where available well records indicate the presence of deep, granular materials over 25 m thick.

The groundwater storage potential and K_{mb} of aquifer 0201 may be variable due to its textural variability and stratigraphic complexity. Areas of the aquifer where loose, coarse-textured glaciofluvial deposits occur may display locally elevated K_{mb} values ranging from $1x10^{-5}$ to $1x10^{-4}$ m/s, although the storage potential of these zones may be low due to their reduced lateral persistence. Conversely, areas of the aquifer where compact, fine-grained glaciolacustrine and / or morainal deposits occur may display substantially lower K_{mb} values ranging from $1x10^{-9}$ to $1x10^{-8}$ m/s and may represent aquitards.

Groundwater within aquifer 0201 is variably unconfined to semi-confined due to the stratigraphic complexity and configurations of its host units. Regional and local groundwater flow patterns within aquifer 0201's water-bearing units are generally towards the Koksilah River, although the presence of a near-surface, buried bedrock ridge along the north and central parts of the aquifer's west side suggests that groundwater flows may be channelled towards the southwest by the shape of the bedrock surface. Hydraulic gradients within aquifer 0201 are low based on the area's relatively gentle relief.

Aquifer 0201 may receive vertical inflow mainly from precipitation, snowmelt, and irrigation returns, and to a lesser extent from stream losses and sewerage dispersal returns. Aquifer 0201 may receive lateral inflow from Kingzett Lake at its south end, water-bearing fracture systems within adjacent bedrock aquifer 0202 along its north, east, and south borders, and surface runoff and near-surface soil drainage from adjacent, topographically-elevated areas.

Groundwater outflow from aquifer 0201 may take place through evapotranspiration from its unconfined water-bearing units, baseflow discharge to the lower reaches of Heather Bank Brook and springs at its northeast end, and infiltration from its base into the underlying bedrock aquifer 0202. Lateral discharge may occur to adjacent bedrock aquifer 0202 along its northwest and west borders.

5.3.6 Water Budget

Overburden aquifer 0201 lies entirely within the greater bedrock aquifer 0202 area and covers 211.3 ha. Recharge is an average of 401 mm/yr restricted by some of the low permeability soils at surface. This reduces to 270 mm/yr in a hot/dry year, and could be as high as 665 mm/yr in a cold/wet year. Groundwater flow is nominally towards the Koksilah River but the bulk of the movement is in a buried bedrock valley along the western edge of the aquifer area. Leakage out of the aquifer to aquifer 0202 below has been assumed to be 300 mm/yr.

Heather Banks Brook is a warm water stream that lies in low permeability soils and exhibits a downward gradient in nearby wells. It is fed by discharge from the former quarry in Kingzett Lake. It is assumed to be a losing stream which augments the aquifer, albeit at a low rate of 5 L/s for its 2,500 m reach across aquifer 0201 (Appendix I).

There are no commercial or industrial water takings in the geographic aquifer 0201 area as determined by Hatfield (2015). The rural population relies on wells and septic beds, and water use is assumed to be 100% consumptive. The irrigation licenses are partly along the Koksilah River and do not draw from the aquifer (at least not until it discharges to the river). One well is listed as an irrigation well, reported in the Ministry of Agriculture database, and it is assumed that its taking is 100% consumptive. Table 45 summarizes the water budget in terms of the losses and gains described above.

Table 45: Overburden aquifer 0201 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	1,004,500	% of Gains
Recharge	846,800	84
Streamflow losses to aquifer 0201	157,700	16
Losses =	- 680,700	% of Losses
Leakage down to aquifer 0202	633,800	93
Lateral groundwater outflow	2,800	< 1
Water Usage: Municipal and Domestic	15,600	2
Water Usage: Commercial and Industrial	0	0
Water Usage: Irrigation	28,500	4
Net Water Balance =	+ 323,800	

The water budget shows a 38% retention of the aquifer gains which suggests a surplus of water in the overburden available for use. However, this may simply be an underestimation of groundwater outflow and/or an overestimation of streamflow contributions. In any event, the availability of water outstrips the current usage.

In a hot and dry year such as 1989 where the surplus was 33% lower than normal, one finds a similar reduction in recharge. The recharge of 1,004,500 m^3 (for an average year) could therefore be just 569,700 m^3 (Appendix I), a loss of 434,800 m^3 in such a year, which would have a significant effect on the above sums, creating a deficit condition. By similar logic, the increase in recharge for that very wet year in 1999, would have added about 560,000 m^3, and a clear surplus would be present.

The monthly water budget shown on Figure 26 reveals that in an average year there is a surplus condition from November to March, and that a clear deficit occurs in the seven months from April to September (green line). October is nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs from October to March. The hot/dry year (red line) shows a moderate surplus from November to March and steady deficit in the other seven months. As with all of the aquifers in the study area, the deficit months have similar magnitude deficits.

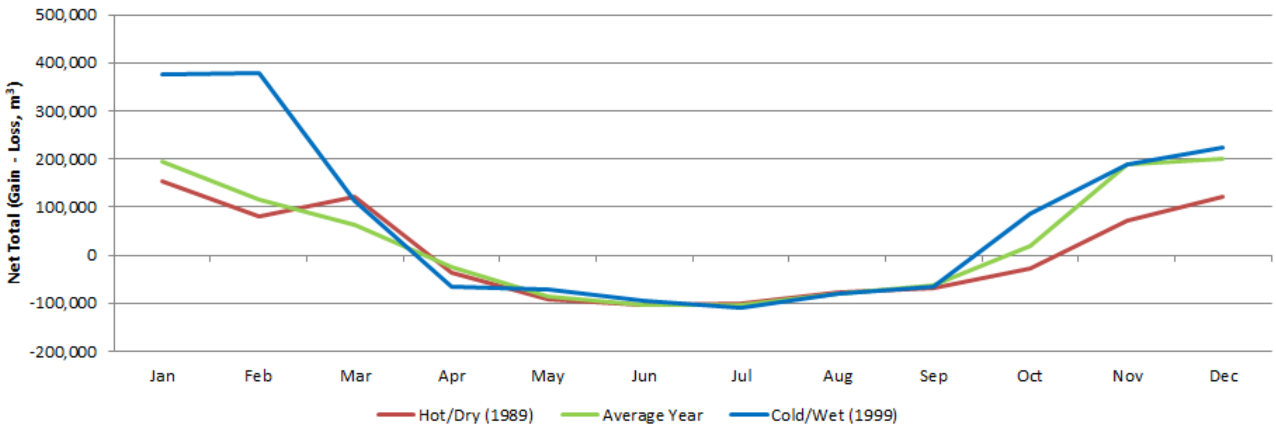

Figure 26: Monthly water budget for overburden aquifer 0201.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 44,100/569,700 X 100% = 7.7% (Low Stress Level)
- Normal. 44,100/846,800 X 100% = 5.2% (Low Stress Level)
- Cold/Wet. 44,100/1,405,300 X 100% = 3.1% (Low Stress Level)

Aquifer 0201 can therefore be classed as having a low stress level. The existing consumptive water taking is about two thirds agricultural and one third domestic.

5.3.7 Overburden Aquifer 0201 Conclusions

The above water budget suggests there is an annual surplus in aquifer 0201. The magnitude of this may be variable, as the uncertainties in the calculations are similar to the calculated surplus, and this conclusion should be treated with caution. The aquifer has previously been classified as Class IIC (8), and is only moderately developed. The deeper overburden in the buried bedrock valley along the west edge of the aquifer should be targeted for further supply as the overburden likely thins and appears more finer grained at surface to the east. Licensure of groundwater takings should consider the proximity to other water supplies, and if the proposed water taking is high, the time of year (and type of year) of the well testing be considered to ensure the taking is sustainable.

5.4 Aquifer 0205 (Carlton)

5.4.1 Location, Access, and Land Use

Aquifer 0205 (Carlton) is located in the southeast part of the study area south of Shawnigan Creek and west of Mill Bay, and covers 2.73 km^2.

The aquifer is centred at Latitude 48°39’26” Longitude 123°35’19” (UTM 456650E 5389500N Zone 10) and accessible by Shawnigan Lake – Mill Bay, Cameron-Taggart, and Carlton Roads.

The land surface above aquifer 0205 is moderately developed. Most of the aquifer has been developed for rural-residential (48%) and agricultural (30%) purposes. The balance of the aquifer’s surface consists of non-contiguous, undeveloped and forested properties (22%).

5.4.2 Classification, Extent, and Well Information

Aquifer 0205 is classified by the ENV as a Class IIC(9) aquifer, which indicates it is moderately developed with low vulnerability to surface contamination.

The horizontal extent of aquifer 0205 is defined by the occurrence of registered wells completed in unconsolidated granular materials over bedrock aquifer 0207, with Shawnigan Creek and adjacent bedrock aquifer 0204 forming its northwest perimeter, Hollings Creek roughly forming its southeast perimeter, and Ericson Creek forming its northeast perimeter. The outline of aquifer 0205 as defined by the ENV contains eighteen wells completed in bedrock aquifer 0207 along its northwest, west, southeast, and northeast perimeters, which indicates that the surface area of this aquifer may actually be closer to 2.0 km^2.

Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 46.

Table 46: Aquifer 0205 well statistics.

Well Depth (m)		Well Yield (L/s)		Confining Layer Depth (m)		Static Water Level Depth (m)	
Mean	28.9	Mean	0.83	Mean	20.7	Mean	10.8
Median	30.5	Median	0.85	Median	23.5	Median	12.8
Range	4.9 – 67.1	Range	0.19 – 3.16	Range	0.0 – 65.5	Range	0.0 – 37.8

5.4.3 Physiography and Hydrology

Aquifer 0205 is situated within an area of low relief on two gently rolling to undulating, low domed hills with a general east to southeast aspect. Broad, shallow topographic depressions are present in the north, central, and south parts of the aquifer that host Cameron-Taggart Wetland, Ericson Creek, North and South Taggart Creeks, and Knight Brook. Surface elevations range from 120 m amsl at its southwest corner to 40 m amsl along its east border adjacent to Taggart Creek.

Aquifer 0205 is located within the Shawnigan Creek watershed, with the nearest marine shoreline being 1.6 km east at Mill Bay. Surface drainage patters over aquifer 0205 are radial in its southern third and parallel in its central and north portions within the Taggart and Ericson Creek valleys, although drainage in its extreme northwest corner flows towards Shawnigan Creek.

5.4.4 Geology and Soils

Aquifer 0205 is underlain by andesitic volcanic rocks of the Bonanza Group and granodioritic intrusive rocks of the Island Plutonic Suite. The tectonic setting of the bedrock units underlying aquifer 0205 may be mainly extensional due to their location proximal to the regional, northeast-trending Shawnigan Fault, which occurs roughly 200 m to the southeast.

Aquifer 0205 consists of an elongated deposit of east-dipping, coarsely-stratified morainal, glaciofluvial, and glaciolacustrine materials of the Vashon Drift and Salish Sediments organic materials overlying a steep-sided, north-south trending bedrock embayment. The thickness of the aquifer is highly variable, with available well records in its north portion indicating an average thickness of 15 m, but much greater thicknesses in its central and south portions of over 90 m. Analyses of well records indicate that a second, narrow, northeast-trending bedrock embayment filled with stratified morainal and glaciofluvial materials occurs adjacent to the east and southeast borders of the aquifer, which may represent the erosionally-recessive surface trace of the Shawnigan Fault.

Soils above most of the aquifer’s northern half and southeast margin consist of imperfectly-drained, gleyed eluviated dystric brunisols and orthic humic gleysols of the Finlayson and Tagner Soil Associations, respectively, which have developed in areas of gentle relief over deep blankets of silty or clayey materials. The poorly-drained depressional area at the aquifer’s north end, which hosts the Cameron-Taggart wetland, contains terric mesisols of the Arrowsmith Soil Association developed over shallow organic deposits. The remainder of the aquifer in its southwest quadrant imperfectly to well-drained, duric dystric brunisols of the Shawnigan and Qualicum Soil Association, which have developed in areas of moderate relief over deep blankets of gravelly-sandy morainal materials.

5.4.5 Hydrogeology

Groundwater within aquifer 0205 occurs within intergranular pore spaces in at least three loose, fine to coarse-grained, glaciofluvial deposits of sand and gravel, while dense deposits of morainal and glaciolacustrine materials generally contain little groundwater and constitute aquitards. The aquifer displays a high level of internal stratigraphic complexity, with the depths, thicknesses, and lateral continuities of potentially water-bearing units varying significantly between locations. Sand-gravel units display varying degrees of saturation between locations, and are generally between 10 and 20 m thick with the exception of in the centre of the aquifer where available well records locally indicate the presence of granular materials over 50 m thick.

The groundwater storage potential and bulk hydraulic conductivity of aquifer 0205 may be variable due to its textural variability and stratigraphic complexity. Areas of the aquifer where loose, coarse-textured glaciofluvial deposits occur may display locally elevated bulk hydraulic conductivity values ranging from $1x10^{-5}$ to $1x10^{-4}$ m/s, although the storage potential of these zones may be low due to their reduced lateral persistence. Conversely, areas of the aquifer where compact, fine-grained morainal or glaciolacustrine deposits occur may display substantially lower bulk hydraulic conductivity values ranging from $1x10^{-9}$ to $1x10^{-8}$ m/s.

The degree of confinement of water-bearing units within aquifer 0205 is variable. Groundwater hosted by near-surface granular units in hydraulic connection with the ground surface are generally in an unconfined state, while deeper units overlain by persistent, east-dipping aquitards are locally semi-confined to confined.

Regional groundwater flow patterns within aquifer 0205's unconfined water-bearing units reflect the area's topography, are generally east-northeast towards Shawnigan Creek and east-southeast towards Hollings Creek. Local groundwater flow patterns in areas where the aquifer's water-bearing units are semi-confined or confined may be variable and largely controlled by the shape of the bedrock surface. Hydraulic gradients within aquifer 0205 are low to moderate based on the area's relatively gentle relief.

Aquifer 0205 may receive vertical inflow from precipitation, stream losses, and irrigation / sewerage dispersal returns in areas where persistent surface aquitards are absent. The aquifer may receive lateral inflow from water-bearing fracture systems within adjacent bedrock aquifer 0207 along its west border, however this has not been quantified and is not included in the water budget. It may also receive surface runoff and near-surface soil drainage from adjacent, topographically-elevated areas.

Groundwater outflow from aquifer 0205 may take place through evapotranspiration from its unconfined water-bearing units, baseflow discharge to the lower reaches of Taggart Creek and Ericson Creek along its east side, and Knight Brook and Hollings Creek along its southeast margins. Vertical and lateral discharge may also occur through infiltration into the underlying bedrock aquifer 0207.

Although aquifer 0205 is in contact with adjacent bedrock aquifer 0204 and the Cameron-Taggart wetland along its northwest edge, it is unlikely to receive inflow from, or outflow to, these features due to their relative hydrological settings.

5.4.6 Water Budget

Overburden aquifer 0205 lies above the north part of aquifer 0207 and covers 272.9 ha. Recharge is an average of 378 mm/yr restricted in places by the low permeability aquitards at surface. This reduces to 254 mm/yr in a hot/dry year, and could be as high as 627 mm/yr in a cold/wet year. Recharge of precipitation is the sole input of water to the aquifer, assuming no inflow from aquifer 0207. Groundwater flow is nominally towards the east moving across a north-south trending bedrock valley infilled in part with aquifer materials. Leakage out of the aquifer down to aquifer 0207 below has been assumed to be 200 mm/yr, based on the fact that half of the bedrock is low permeability Bonanza Group (100 mm/yr) and half is more permeable Island Plutonic Suite (300 mm/yr).

Taggart Creek is a cold water stream that flows easterly across the aquifer area to Shawnigan Creek, and where a high water table is seen in nearby wells. It is assumed to be a gaining stream which is a draw on the aquifer.

Both commercial and industrial water takings in the geographic aquifer 0205 area were identified by Hatfield (2015), and are taken to be 100% consumptive. The rural population relies on wells and septic beds, and their water use is conservatively assumed to be 100% consumptive. The portion of irrigation takings from the creeks, are taken after the creeks have received groundwater so have not been included in the water budget to avoid double counting. The Ministry of Agriculture reports groundwater supplies for irrigation, taken here as 100% consumptive. Finally, there is municipal groundwater taking, identified by Hatfield (2015), and assumed here to be 100% consumptive. Table 47 summarizes the water budget in terms of the losses and gains described above.

Table 47: Overburden aquifer 0205 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	1,030,600	% of Gains
Recharge	1,030,600	100
Losses =	-1,261,900	% of Losses
Leakage down to aquifer 0207	545,700	43
Lateral groundwater outflow	413,100	33
Discharge to Taggart Creek	170,300	13
Water Usage: Municipal and Domestic	18,200	1
Water Usage: Commercial and Industrial	59,000	5
Water Usage: Irrigation	55,600	4
Net Water Balance =	- 231,300	

The water budget shows virtually no retention of the aquifer gains, in fact a deficit of about 22%. However, the variability in parameter estimation of both overburden hydraulic conductivity and streamflow could swing the result to either a surplus or a deficit. In any event the current consumptive usage is comparatively low.

In a hot and dry year such as 1989 where the surplus was 33% lower than normal, one finds a similar reduction in recharge. The recharge of 1,030,600 m^3 (for an average year) could therefore be just 693,300 m^3, a loss of 337,300 m^3 in such a year, which would have a significant effect on the above sums, creating a substantial deficit condition. However, lateral outflows and losses to the bedrock in aquifer 0207 would be reduced by a reduction in driving head caused by lower water table positions. By similar logic, the 60% increase in recharge for that very wet year in 1999, would have added just under 700,000 m^3, and a clear surplus would be present.

The monthly water budget shown on Figure 27 reveals that in an average year there is a surplus condition from November to February, and that a clear deficit occurs in the six months from April to September (green line). March and October are nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs in the November to February period, and in fact, March and October become surplus months. The hot/dry year (red line) shows a small surplus from November to March and steady deficit in the other seven months.

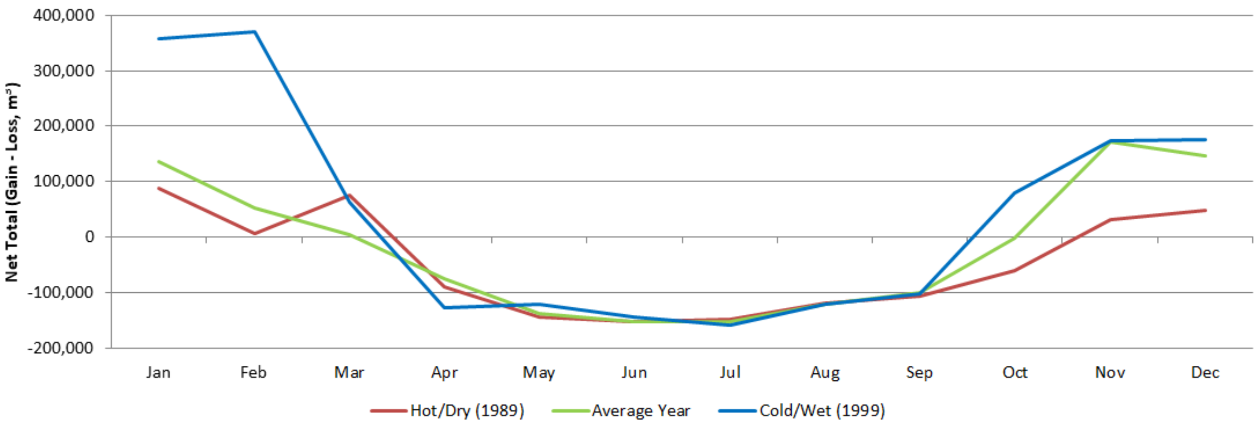

Figure 27: Monthly water budget for overburden aquifer 0205.

The water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 132,800/693,300 X 100% = 19.1% (Moderate Stress Level)
- Normal. 132,800/1,030,600 X 100% = 12.9% (Moderate Stress Level)
- Cold/Wet. 132,800/1,710,300 X 100% = 7.8% (Low Stress Level)

Aquifer 0205 can therefore be classed as having a low stress level only in a wet/cold year and is moderately stressed in normal or more hot/dry conditions. This is primarily because of the greater population and water taking for such a small area. The existing consumptive water taking is equally domestic and agricultural with some commercial and industrial uses. (There is considerable agricultural water taking from the creeks that does not get counted by this groundwater budget. That is, the water taking is after the water has left the aquifer, as described previously. This can result in additional environmental stress to the stream.)

5.4.7 Overburden Aquifer 0205 Conclusions

The above water budget suggests there is a deficit in aquifer 0205. In addition, the aquifer exhibits a moderate stress level when considered as a single unit. The drier months are always in a deficit condition and if the rains in winter period are not substantive water supplies can be taxed. Groundwater largely occurs in the infilled bedrock valley which should be a target for local groundwater supply. Irrigation withdrawal from the creeks may be sustainable, as long as the ecological function of the cold-water is not impaired. The aquifer has previously been classified as Class IIC(9), and is only moderately developed. Licensure of water taking will have to consider the proximity to other water supplies, and if the proposed water taking is high, the time of year (and type of year) of the well testing should also be considered to ensure the taking is sustainable.

5.5 Aquifer 0206 (Mill Bay)

5.5.1 Location, Access, and Land Use

Aquifer 0206 (Mill Bay) is located in the southeast part of the study area southwest of Mill Bay, and covers 2.57 km^2. The aquifer is centred at Latitude 48°38’42” Longitude 123°33’42” (UTM 458650E 5388150N Zone 10) and accessible by the Trans-Canada Highway, Deloume, and Frayne Roads.

The land surface above aquifer 0206 is moderately developed. Most of the aquifer has been developed for urban (57%) and rural-residential (5%) purposes. The balance of the aquifer's surface consists of non-contiguous, undeveloped and forested properties (38%), of which 10% have been recently harvested.

5.5.2 Classification, Extent, and Well Information

Aquifer 0206 is classified by the ENV as a Class IIA (11) aquifer, which indicates that it is moderately developed with high vulnerability to surface contamination.

The horizontal extent of aquifer 0206 is defined by the occurrence of registered wells completed in unconsolidated granular materials over bedrock aquifer 0207, with Shawnigan Creek and bedrock aquifer 0204 forming its north perimeter. Handysen Creek roughly parallels the aquifer's southwest perimeter. Statistics currently on file with the ENV relating to water supply wells completed in this aquifer is listed in Table 48.

Table 48: Aquifer 0206 well statistics.

Well Depth (m)		**Well Yield (L/s)**		**Confining Layer Depth (m)**		**Static Water Level Depth (m)**	
Mean	19.0	Mean	0.99	Mean	7.2	Mean	7.2
Median	18.6	Median	0.75	Median	7.5	Median	6.7
Range	7.0 – 51.8	Range	0.09 – 22.08	Range	-	Range	0.0 – 38.1

5.5.3 Physiography and Hydrology

Aquifer 0206 is situated within an area of moderate relief on a gently rolling to undulating, north-northeast sloping, domed hillside northeast of Malahat ridge, which is locally incised at its north end in its east-central area by watercourses. Surface elevations range from 160 m amsl at its southwest corner to 20 m amsl at its north end in Shawnigan Creek.

The boundaries of aquifer 0206 straddle the Shawnigan and Saanich Inlet watersheds, with the nearest marine shoreline being 85 m northeast of its north end at Mill Bay. Surface drainage patterns over aquifer 0206 are mostly radial with Goodhope Creek flowing north into Hollings Creek and Wheelbarrow-Bird Creek, Wilkins Creek, and Frayne Creek flowing northeast and east into Saanich Inlet. Drainage at the aquifer's north end is comparatively rectangular with the lower reaches of Hollings Creek following a sinuous path to the north before flowing into Shawnigan Creek. Numerous springs occur above the northeast portion of the aquifer. Wheelbarrow Springs (at the head of Wheelbarrow Creek) is a locally well-known spring that supplied water to Brentwood College and later to the community of Mill Bay. The spring flow is reported to be ~380 m^3/day (~140,000 m^3/year) (M. Wei, 2016, pers. comm.).

5.5.4 Geology and Soils

Aquifer 0206 is underlain by granodioritic intrusive rocks of the Island Plutonic Suite. The tectonic setting of the bedrock units underlying aquifer 0206 may be mainly extensional due to their location proximal to the regional, northeast-trending Shawnigan Fault and a series of north-trending topographic lineaments, which occur roughly 150 m east of the aquifer.

Aquifer 0206 consists of an elongated deposit of northeast-sloping, coarsely-stratified morainal, glaciofluvial ice contact and glaciomarine units of the Vashon Drift and Capilano Sediments, which overlies a series of steep-sided bedrock embayments. The thickness of the aquifer is highly variable, with available well records indicating thicknesses ranging from 10 m at its north end to over 55 m in the centre of its east border area. Analyses of well records indicate that additional narrow, north to northeast-trending bedrock embayments filled with stratified morainal and glaciofluvial materials occur adjacent to the west border of the aquifer, which may represent the erosionally-recessive surface trace of the Shawnigan Fault and other sub-parallel structures.

Soils above most of aquifer 0206 consist of imperfectly to well to rapidly-drained, orthic and duric dystric brunisols of the Qualicum and Dashwood Creek Soil Associations, respectively, which have developed in areas of moderate relief over variably thick sandy gravelly veneers to blankets of glaciofluvial materials over compact morainal deposits. Soils above the aquifer's north margin consist of imperfectly-drained, gleyed eluviated dystric brunisols and orthic humic gleysols of the Finlayson and Tagner Soil Associations, respectively, which have developed in areas of gentle relief over deep blankets of silty or clayey materials. Soils above the aquifer's south margin consist of moderately to well-drained, duric and orthic dystric brunisols of the Somenos and Ragbark Soil Associations, which have developed in areas of moderate relief over variably-thick veneers and blankets of sandy and/or sand-gravelly colluvial and morainal materials.

5.5.5 Hydrogeology

Groundwater within aquifer 0206 occurs within intergranular pore spaces in at least three loose, fine to coarse-grained, glaciofluvial deposits of sand and gravel, while dense deposits of morainal and glaciomarine materials generally constitute aquitards. The aquifer displays a high level of internal stratigraphic complexity, with the depths, thicknesses, and lateral continuities of potentially water-bearing units varying significantly between locations. Sand-gravel units display varying degrees of saturation between locations and are generally between 5 and 15 m thick, with the exception of areas underlain by deep bedrock channels where granular units can exceed 30 m in thickness. Aquitard units tend to be laterally impersistent and spatial controlled by the shape of the bedrock surface. Figure 28 is a representative south to north cross-section that shows the local hydrogeology (Kreye et al., 1996).

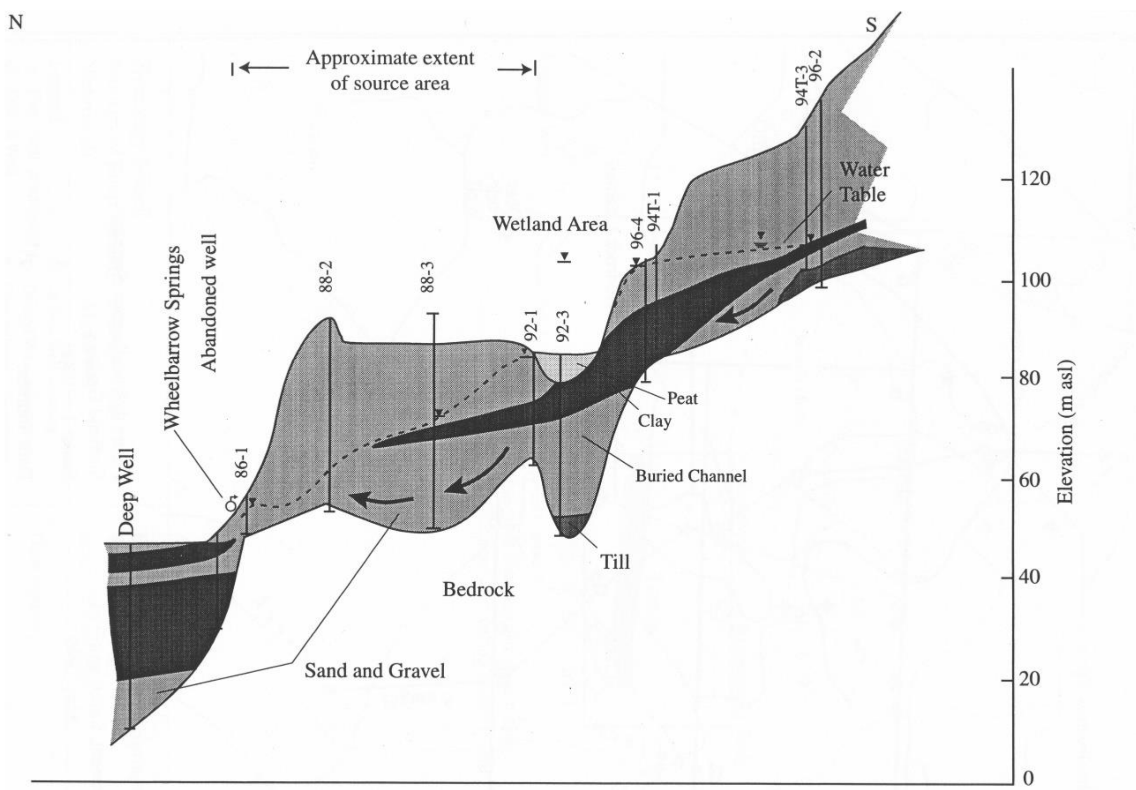

Figure 28: Aquifer 0206 schematic cross section (source: Kreye et al., 1996).

Available well records indicate that highly-productive sand-gravel deposits are often hosted within bedrock channels, particularly within its northern portion. These linear features exhibit hydraulic boundaries such as the rising bedrock surface making saturated thicknesses inconsistent. This often translates into storage challenges where developed water-bearing units may not be capable of sustaining high rates of well extraction under conditions of limited recharge.

The groundwater storage potential and bulk hydraulic conductivity of aquifer 0206 may be variable due to its textural variability, stratigraphic complexity, and local presence of thick sequences of near-surface, unsaturated sand-gravel units. Areas of the aquifer where loose, coarse-textured glaciofluvial deposits occur within which high-productivity wells have been completed, may display elevated bulk hydraulic conductivity values in the range $1x10^{-4}$ to $1x10^{-3}$ m/s. The case study in Kreye et al. (1996) states that transmissivity ranges from 4 to 122 m^2/day with a median value of ~20 m^2/day or assuming a 10 m aquifer thickness, the bulk hydraulic conductivity is ~10^{-5} m/s. Conversely, areas of the aquifer where compact morainal and/or fine-grained glaciomarine deposits occur may display comparatively lower bulk hydraulic conductivity values ranging from $1x10^{-9}$ to $1x10^{-7}$ m/s.

Groundwater within aquifer 0206 is generally unconfined due to the northeast-sloping, somewhat planar configuration of its water-bearing units, which are locally exposed at surface between similarly-inclined aquitard units. However, some of the deeper, saturated sand-gravel units within the north portion of the aquifer that are overlain by persistent aquitards may be semi-confined and support flowing artesian wells.

Regional groundwater flow patterns within aquifer 0206 are generally towards the north towards Mill Bay and Shawnigan Creek. Flow patterns within the aquifer’s deeper semi-confined units may be different to local terrain patterns and influenced by the shape of the bedrock surface and upgradient hydraulic heads within bedrock aquifer 0207. Hydraulic gradients within aquifer 0206 are probably moderate based on the area’s moderately sloping terrain and irregularly-shaped bedrock surface.

Aquifer 0206 receives vertical inflow from precipitation, stream losses, and irrigation / sewerage dispersal returns. Aquifer 0206 may also receive significant lateral inflow from water-bearing fracture systems within bedrock aquifer 0207 along its west border (particular adjacent to the Shawnigan Fault zone along its northwest edge), as well as surface runoff and near-surface soil drainage from adjacent, topographically-elevated areas.

Groundwater outflow from aquifer 0206 takes place through baseflow discharge to the lower reaches of its internal watercourses and the many springs within, and along the east and north periphery of the aquifer. Lateral discharge occurs to the bedrock aquifer 0207 along its east border.

Although aquifer 0206 is in contact with adjacent bedrock aquifer 0204 along its north edge, it is unlikely to receive inflow from, or outflow to this aquifer due to its relative hydrological setting north of Shawnigan Creek.

5.5.6 Water Budget

Overburden aquifer 0206 lies above the north part of aquifer 0207 and covers 257.3 ha. Recharge is an average of 355 mm/yr reduced by its location in the drier part of the greater study area. This reduces to 239 mm/yr in a hot/dry year, and could be as high as 589 mm/yr in a cold/wet year. The presence of only a thin saturated zone in the overburden above the bedrock near surface at the upgradient western boundary of aquifer 0206 led us to assume that there is no overburden inflow of groundwater to the aquifer. Groundwater flow is towards the northeast moving across a series of NW trending bedrock valleys that are partially in filled with aquifer materials. Groundwater either discharges to Shawnigan Creek or ultimately to Saanich Inlet or exits by leakage out of the aquifer to aquifer 0207. This downward leakage has been assumed to be 300 mm/yr, based on the presence of the more permeable Island Plutonic Suite (300 mm/yr).

Hollings Creek flows northerly across the lower north end of the aquifer area to Shawnigan Creek. Nearby water wells exhibit a high water table. Because of the high water table and position of Hollings Creek at the bottom of a sloping area, it is assumed to be a gaining stream which is a draw on the aquifer. Handysen Creek on the other hand (which is a tributary of Hollings Creek) flows about 50 m west and parallel to the western boundary of the aquifer and in places crosses permeable sands and gravel, and has been assumed to be a losing creek. This water has been included in the water budget based on its immediate proximity to the aquifer.

This aquifer area has the second highest usage of the eleven studied here. No industrial water takings were recorded for the aquifer area, however commercial usage was identified by Hatfield (2015), and is taken to be 100% consumptive. Seventy percent of the rural population relies on wells and septic beds and 30% rely on a sewer collection system, which then discharges the treated water to infiltration basins. Both water uses are taken as 100% consumptive. The largest water taking is that of the Mill Bay Waterworks District well fields, where the peak year (2014) pumping data were used (Thurber, 2016). This groundwater use has also been assumed to be 100% consumptive. The irrigation takings are from the creeks, after they have received groundwater so they have not been included in the water budget to avoid double counting. On the other hand, the Ministry of Agriculture reports (van der Gulik et al., 2003) irrigation from groundwater sources, which are conservatively assumed to be 100% consumptive. Table 49 summarizes the water budget in terms of the losses and gains described above.

Table 49: Overburden aquifer 0206 annual water budget for average climate conditions.

Component	**Cubic metres per year**	
Gains =	1,140,000	% of Gains
Recharge	912,900	80
Discharge from Handysen Creek	227,100	20
Losses =	-1,929,500	% of Losses
Leakage down to aquifer 0207	772,100	40
Lateral groundwater outflow	373,700	19
Discharge to Hollings Creek	208,100	11
Water Usage: Municipal and Domestic	513,400	27
Water Usage: Commercial and Industrial	18,300	1
Water Usage: Irrigation	43,900	2
Net Water Balance =	- 789,500	

The water budget shows a substantial deficit of about 69% of the aquifer gains. Next to leakage down to the bedrock, the consumptive water taking is the biggest draw on the aquifer. The downward leakage could be smaller if less than 300 mm/yr is adopted in the assumptions (Table 5), but little else would make a substantial difference to the balance. It is concluded that aquifer 0206, of all those studied here, is likely in a deficit position. This is corroborated by the observation of declining water levels in the area. Examination of water level in some of the Mill Bay Waterworks District wells show a slow decline for wells 1387, 15603, and 21614 in the order of 10's of metres in the period from 2010 to 2015, Thurber (2016). Long term monitoring data for observations wells unaffected by pumping should be examined to further assess this preliminary finding.

In a hot and dry year such as one similar to 1989 where the surplus was 33% lower than normal, one could expect a similar reduction in recharge. The recharge of 912,900 m^3 (for an average year) could therefore be just 614,200 m^3 (Appendix K), a loss of 298,700 m^3 in such a year, which would worsen the deficit condition. However, lateral outflows and losses to the bedrock in aquifer 0207 would be lessened by a reduction in driving head caused by lower water table positions. By similar logic, the increase in recharge for that very wet year in 1999, would have added about 600,000 m^3, and a clear surplus would be present.

The monthly water budget shown on Figure 29reveals that in an average year there is a surplus condition from November to February, and that a clear deficit occurs in the seven months from April to October (green line). March is nearly neutral. In the cold/wet year (blue line) a much stronger surplus occurs in January and February, and March and October become surplus months. The hot/dry year (red line) shows a small to moderate surplus from November to March and steady deficit in the other seven months. Water levels in monitoring wells however peak in April and May, indicating a time lag in the groundwater system. In any event the deficit period appears to be longer in aquifer 0206, perhaps due to the smaller precipitation and hence recharge.

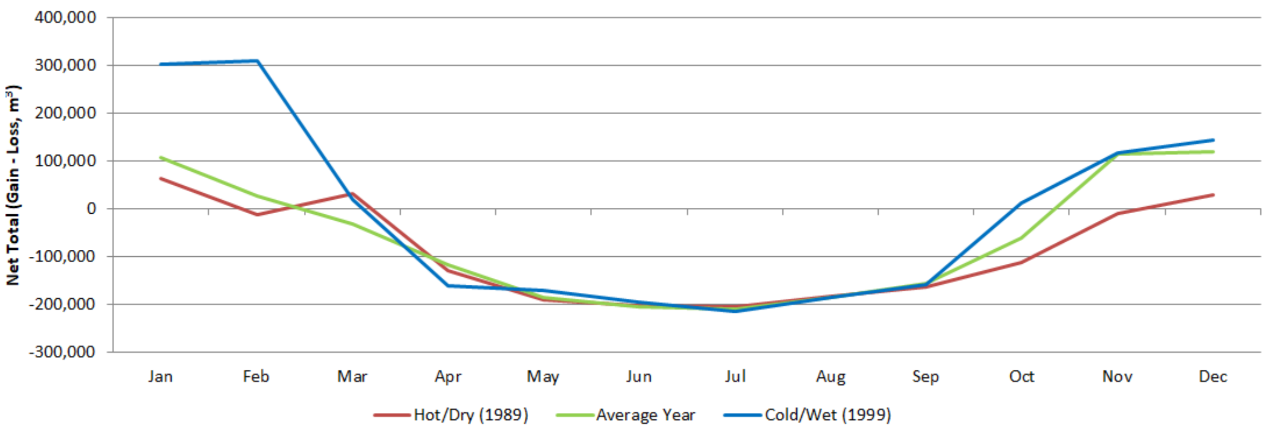

Figure 29: Monthly water budget for overburden aquifer 0206.

The annual water quantity stress factors were calculated by dividing the consumptive water usage values by the available recharge for the three types of years:

- Hot/Dry. 575,600/614,200 X 100% = 94% (High Stress Level)
- Normal. 575,600/912,900 X 100% = 63% (High Stress Level)
- Cold/Wet. 575,600/1,515,100 X 100% = 38% High Stress Level)

Aquifer 0206 can therefore be classed as having a very high stress level for all types of years, and is indeed at the high end of the spectrum in that regard. The bulk of the water taking in this small aquifer is for domestic purposes, and the assumption of 100% consumption may be overly conservative. There are several systems where the treated effluent is returned to the ground by infiltration basins, which certainly lessens the calculated impact. Over half the population are on rural septic systems, which return the water to the ground too and so are likely only 10% consumptive. It is recommended that the degree of consumption and the degree of return be more fully understood and this preliminary water budget refined with that information. In addition, a comprehensive analysis of water level changes and trends with time, and preparation of physical geologic model of the overburden to characterize the aquifers, should be undertaken.

5.5.7 *Overburden Aquifer 0206 Conclusions*

The above water budget suggests there is a strong deficit in aquifer 0206, likely due to the assumed consumptive uses. Groundwater largely occurs in the infilled bedrock valleys which would normally be a target for local groundwater supply. However, municipal experience is that high yield wells cannot be sustained pointing to a lack of storage in the aquifer, perhaps on a seasonal basis. Certainly the seven month long period of deficit under all three water budget conditions points to the reasons why.

Irrigation withdrawal from the creeks and springs may be sustainable, as long as the ecological function of the cold-water is not impaired and pumping wells are away from the spring source area. The aquifer has previously been classified as Class IIC(9), and is only moderately developed. Allocation of groundwater should consider existing uses and the seasonal depletion of the aquifers. Given the question of sustainability, pumping tests of long enough duration (See Footnote 9 in Section 5.1.7 should be conducted in support of large withdrawal applications, and consideration given to the time of year and the type of year the tests are done to be representative of critical conditions. Water storage should also be considered, on the local scale and perhaps on the municipal scale.

6. SUMMARY OF FULL STUDY AREA

6.1 Overall Water Budget

There is substantial interaction in terms of groundwater flow between aquifer areas, and losses of water to the rivers that run between them. It is useful to step back and look at the total water moving through the region in a normal year. Table 50 summarizes the net gains and losses documented in the previous eleven subsections. The gains from recharge plus streamflow losses to the ground and lateral groundwater inflow (about 93,400,000 m^3) compares well with the losses to other streams, the ocean, laterally to other aquifers and consumptive water use (96,500,000 m^3). That is, the net difference is about 3,200,000 m^3, which is about 3.4% of the gains. Notwithstanding the above documented variability in the calculated numbers for individual aquifers, this provides a measure of confidence in the water budget for the full study area, because “water in” is approximately the same as “water out”.

The average annual recharge to the full study area is about 68,000,000 m^3 per year. (This may be as low as 46,000,000 m^3 in a hot/dry year, and as high as 112,000,000 m^3 in a cold/wet year.)

Table 50: Summary of average annual water budgets and comparison to key factors.

Aquifer Number	Recharge, Average Annual (m^3)	Gains (m^3)	Losses (m^3)	Net Water Balance (m^3)	Consumptive Use (m^3)	Stress Factor (Use/Recharge) %
0197	10,747,900	11,019,600	15,159,800	-4,140,200	4,576,600	42.6
0198	618,200*	827,400	295,700	531,700	238,300	38.5
0199	1,351,900	3,130,100	2,679,600	450,500	295,200	21.8
0200	14,377,400	15,051,600	17,157,800	-2,106,200	45,200	0.3
0201	846,800	1,004,500	680,700	323,800	44,100	5.2
0202	8,801,600	14,304,200	17,139,600	-2,835,400	191,900	2.1
0203	15,535,800	15,573,800	16,837,900	-1,264,100	492,900	3.1
0204	4,142,300	17,558,800	13,614,400	3,944,400	608,200	14.7
0205	1,030,600	1,030,600	1,261,900	-231,300	132,800	12.9
0206	912,900	1,140,000	1,929,500	-789,500	575,600	63.1
0207	9,654,600	12,796,700	9,888,600	2,908,100	413,000	4.2
Total	**68,020,000**	**93,437,200**	**96,645,500**	**-3,208,300**	**7,613,800**	**11.2**

* Subtle differences between the values in this table and the summary spreadsheet are due to rounding of significant digits, most values are within 100 m^3.

6.2 Stress Analysis

Anthropogenic consumptive water use for the 11 aquifers sums to just about 7,600,000 m^3/yr, which is a small proportion of the average annual recharge (11%), and based on the conservative assumptions discussed above, is likely smaller. By comparison it is almost 7 % of the recharge in a cold/wet year and just under 17% for a hot/dry year which experiences considerably less recharge. Water use will be higher in the future, and unless planning controls maintain pre and post development recharge conditions, the amount of future recharge will drop and these percentages could become higher.

This conclusion is of some interest, as it would appear only a small proportion of the natural recharge is used in a consumptive manner, for the study area as whole. However, each individual aquifer area has its own constraints, and some of the more coastal areas, which receive less recharge per square metre (Section 3.7.2), also have the higher consumptive usage. For example, Figure 30 below shows that aquifers 0197/0198/0199/0206 have consumptive uses of 43%, 38%, 22% and 63% of the average annual recharge volume, respectively, with an area weighted average of about 41%. The average for all 11 aquifer areas is 11%.

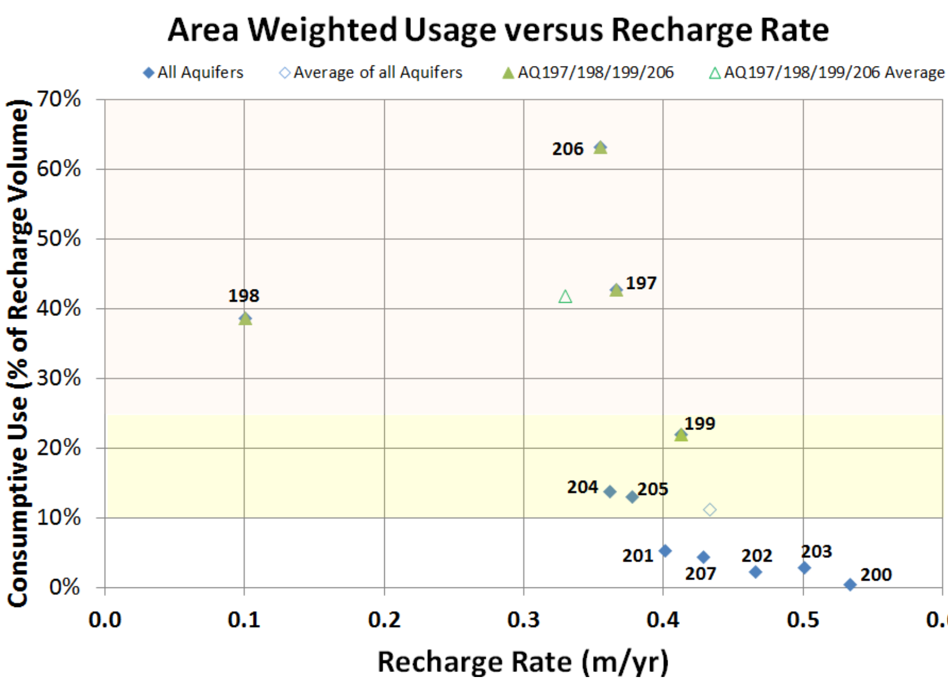

Figure 30: Consumptive use in comparison to average annual recharge rate.

The individual aquifer and area wide stress levels are much lower for the wet/cold condition, due primarily to the greater amount of recharge. Conversely, the hot/dry condition has greater stress levels as seen in Sections 4 and 5 of this report. Table 51 has been compiled to compare the stress levels under these different climatic conditions.

Examination of Table 51 shows mostly low stress for most aquifers in the wet/cold years and high to moderate stress for hot/dry years in the majority of aquifers. Aquifer 0198 stress levels are the same for all three conditions only because the assumed amount of leakage from above is the same. It is reasonable to think that there will be some variance, and once the actual amount of leakage is determined (here we have assumed 100 mm per year), then the actual stress level can be calculated. Aquifers 0197 and 0206 are highly stressed in all three climate conditions, primarily because of their high population and correspondingly high water use. Aquifers 0199, 0204 and 0205 are moderately stressed in the average condition, becoming more stressed as conditions become drier.

Table 51: Comparison of stress factors between climatic conditions. Explanation of shaded cells: Pink cells denote a high stress level, blue cells denote a moderate stress level, and gray cells denote a low stress level.

.		Wet / Cold		Average Annual		Hot / Dry	
aquifer Number	**Water Use m^3**	**Recharge, (m^3)**	**Stress Factor (%)**	**Recharge (m^3)**	**Stress Factor (%)**	**Recharge, (m^3)**	**Stress Factor (%)**
0197	4,576,600	17,836,700	25.7	10,747,900	42.6	7,230,600	63.3
0198	238,300	618,200*	38.5	618,200*	38.5	618,200*	38.5
0199	295,200	2,243,500	13.2	1,351,900	21.8	909,400	32.4
0200	45,200	23,859,900	0.2	14,377,400	0.3	9,672,200	0.5
0201	44,100	1,405,300	3.1	846,800	5.2	569,700	7.7
0202	191,900	14,606,600	1.3	8,801,600	2.1	5,921,200	3.2
0203	492,900	25,782,200	1.9	15,535,800	3.1	10,451,500	4.7
0204	608,200	6,874,400	8.8	4,142,300	14.7	2,786,700	21.8
0205	132,800	1,710,300	7.7	1,030,600	12.9	693,300	19.2
0206	575,600	1,515,100	38.0	912,900	63.1	614,200	93.7
0207	413,000	16,022,200	2.6	9,654,600	4.2	6,495,000	6.4
Total	**7,613,800**	**112,474,300**	**6.8**	**68,020,000**	**11.2**	**45,962,000**	**16.6**

Those aquifer areas that receive more recharge (0200, 0201, 0202, 0203, and 0207) are generally further inland, are less developed, and thus have lower consumptive uses. Conversely, aquifers in lowland areas receive less recharge and generally are in the more developed parts of the study area. Such aquifers (197/0198/0199/0206) are classified as mostly high stressed (or close to it) from a water quantity perspective. Aquifers 0204 and 0205 are intermediate in geographic location, population and precipitation, and indeed are only just moderately stressed.

It is useful to consider if these results can be used to establish a general guidance for groundwater allocation. While the stress levels are an excellent tool for understanding the relative problems between aquifers, they are based on a general understanding of each aquifer area and are not accurate due to the number of assumptions made. The parameters with the most influence on the groundwater budget are the hydraulic conductivity of the soils and rock, and in the more developed aquifer areas, the degree of consumptive use. Each aquifer area deserves a much more detailed local assessment of their respective areas, beyond the scope of this regional study, with particular attention paid to water bearing aquifers and geologic structure.

6.3 Strategic Planning

Monitoring goals should be developed to identify key needs such as streamflow characterization, important ecologic function to be protected, and water level patterns with time in both unaffected and affected areas. An understanding of actual consumptive use will be important for those aquifer areas currently identified as highly stressed, to develop a more realistic understanding of water use. The above stress analysis does however serve to identify where these efforts should proceed to have the greatest benefit.

For example, aquifer 0206 has a high consumptive use for a small area with limited recharge, and thus the 63% stress result is understandable. Conversely, aquifer 0200 has little consumptive use and is in an area of higher surplus (and thus higher recharge), so the low stress level (< 1 %) is also understandable.

Monitoring resources would logically be directed to the former area. With this in mind one can rank the aquifers by stress level, as long as one understands the limitations of the ranking.

In the bedrock aquifers for example, those nearest the most populated areas are the most stressed, but overall, they are low to moderately stressed. Table 52 below illustrates this. In this case, the bottom four should merit an inventory of key things like streamflow and perhaps a representative provincial observation well to establish a long term database, but until consumptive use begins to increase significantly, a more detailed aquifer assessment is probably not warranted. Aquifers 0198 and 0204 probably should be reversed, based on both consumptive use, and the reason for their respective stress ratings. The moderate stress level determined for aquifer 0198 is based on a conservative over estimate of consumptive use, but also on a tentative estimate of recharge, that requires scrutiny. On the other hand, aquifer 0204 is in a much more populated area with lower recharge potential due to a low surplus. A higher fraction of the water taking is for irrigation uses.

Table 52: Bedrock aquifers ranked by stress assessment.

Aquifer Number	Consumptive Use (m^3)	Average Annual Recharge (m^3)	Stress Factor Ranking
0198	238,300	618,200	39%
0204	608,200	4,142,300	15%
0207	413,000	9,654,600	4%
0203	492,900	15,535,800	3%
0202	191,900	8,801,600	2%
0200	45,200	14,377,400	0.3%

So, bedrock aquifers 0204 and 0198 deserve much higher attention than the other four (subject to refinement of the ranking for aquifer 0198). The installation of key observation wells is recommended to begin to establish long term seasonal and annual patterns of water levels, against which the effect of water withdrawal can be judged. Two observation wells should be adequate in aquifer 0198, and given the greater area and unique geometry, up to four to six observation wells in aquifer 0204 is recommended. Selection of locations should be based on the aquifer geometry, local use, and knowledge of the bedrock types and structural features. Thus, there would be benefit of formal hydrogeologic study in these two cases. This certainly should include an understanding of the bedrock groundwater contribution to Shawnigan Creek (from aquifer 0207 as well). An initial program of spot baseflow measurements to understand groundwater/surface water interaction would also be of benefit.

An overall study of consumptive use patterns for the differing types of groundwater uses should be performed at the outset, to be applied to all aquifers, to better refine the stress factor ranking.

With respect to the overburden aquifers, the stress rankings are higher. Table 53 has been prepared to rank them by stress ranking, similar to the bedrock as described above.

Table 53: Overburden aquifers ranked by stress assessment.

Aquifer Number	Consumptive Use (m^3)	Average Annual Recharge (m^3)	Stress Factor Ranking
0206	575,600	912,900	63%
0197	4,576,600	10,747,900	43%
0199	295,200	1,351,930	22%
0205	132,800	1,030,600	13%
0201	44,100	846,800	5%

Only aquifer 0201 is of low stress, primarily due to the low consumptive use, and may be treated the same as aquifer 0200 and 0202 as described above. Aquifer 0205 should be scrutinized as much of the consumption is from bedrock wells below it in aquifer 0207. In addition, a large proportion of the consumptive use is from rural wells that actually return a good deal of water to the ground through septic systems. It is anticipated that the ranking may reduce and the same kind of approach as for 200, 201, and 202 may suffice (understanding of streamflow contributions, and a few well selected observation wells).

Aquifer 0199 is moderately stressed, largely due to irrigation withdrawals. This aquifer merits a hydrogeological study that establishes the linkage between the aquifers and the watercourses, particularly Patrolas Creek. Existing wells have been drilled mainly at its central and west ends, while there is tremendous undeveloped potential at its east end around Dougan Lake. The implementation of at least four observation wells, two in the valley at either end, paired with two on the high ground to the north are recommended to establish vertical and horizontal hydraulic gradients, as well as a long term record of seasonal water levels. Consideration should be given to establishing two streamflow measurement stations on Patrolas Creek to establish a rating curve near Duggan Lake and at the downstream end to examine seasonal changes in baseflow and water usage. Spot baseflow measurements in different seasons on the major contributing tributaries would be of benefit as well in both dry and wet years.

Overburden aquifer 0206 and 0197 are both ranked as high stress in this report. It is anticipated that a more rigorous examination of the consumptive versus the non-consumptive uses will reduce their actual stress values, however they should both remain as highly stressed. Aquifer 0206 suffers from a very small recharge area, and a high population. Existing water levels are falling, based on monitoring of production wells by Mill Bay Waterworks District (Thurber, 2016). Observation wells should be added to this area to capture information both close to those wells and remote. Linkage between Wheelbarrow Springs and the aquifers has been proven in past, and evaluation of future allocation should be based on an integrated understanding of these linkages. The interaction between groundwater and surface water in Handysen and Hollings Creeks should be established by formal study, with a focus on determining and quantifying the losing and gaining watercourses and reaches. The key to this aquifer is the apparent fact that much of the winter recharge drains away during the summer, and wells become stressed. An understanding of these pathways through geologic study is of paramount importance, as is the understanding the movement of groundwater along them.

Overburden aquifer 0197 lies in the driest setting of the study area, along the marine shore, and also hosts easily the highest use of groundwater of all the aquifers. It is stratigraphically complex and covers a very large area. Consideration should be given to establishing logical sub-basins in the groundwater system. This should be done on the basis of the presence of distinct aquifers, groundwater flow directions, and key hydraulic boundaries such as gaining streams and topographic highs. They should then be studied independently through instrumentation and an understanding of the function of the surface water with respect to aquifer discharge and recharge. Of most importance should be establishing the geologic framework, perhaps through systematic evaluation of the extensive water well database. It is clear from examination of water well records, that there are distinct horizons and stacked aquifers that represent water exploration targets (see Section 5.1 above). Once established, review of known hydraulic parameters to establish a range of conditions is recommended, which should be supplemented with pumping tests where exploration targets are evaluated. Use of the geologic modelling tools, including systematic geologic cross-sections, would allow the analyst to select good observation well locations. Study on a town-by-town basis is not recommended as these patterns extend beyond that scale. Spot baseflow measurements as described above would help in the initial characterization of the stream interaction with the groundwater.

As these more populated and highly stressed aquifers will be subject to land development pressures, consideration of the implications on their ability to sustain such development needs to be made. As more paving and rooftops are introduced, subdivision by subdivision, more runoff will occur, and the retention time on the landscape will be reduced. Evaporation from impermeable surfaces will increase. There will be less area available for groundwater recharge. Experience dictates that this can be managed in a way that minimizes the change in the water balance. New developments should be required to match the post-development groundwater recharge to the pre-development recharge. In this way there is not a cumulative effect. As existing developed areas have their infrastructure renewed, implementation of groundwater recharge friendly features such as permeable pavement, soakaway pits for rooftop water, and the use of infiltration basins for clean stormwater are possible. In the bigger picture, this area of the province experiences considerable surplus that is lost to streamflow in the winter months. Capture of this water for later use through storage may be the long-term solution, and thus long range planning for infrastructure that supports this should begin now.

7. CONCLUSIONS

The primary purpose of the study was to explore the use of water budgets as a tool to help water allocation activities under the new *Water Sustainability Act*. It is concluded that this is a useful tool and components of the analysis, such as the recharge calculation methodology, will be of use to the ENV towards this end.

Further to this overarching conclusion we provide the following specific conclusions.

With Respect to Methodology

The methodology employed to calculate the aquifer area water budgets is consistent with those used by others with minor modifications. Calculation of surplus in a GIS platform was compared to measured streamflow for consistent catchment areas. Calculated surplus and measured streamflow were consistent within 9.6% for two separate three year periods and for two separate watersheds. This is considered very good agreement between independent sets of data, and lends confidence in using the surplus values generated here for the water budgeting exercise.

The use of the surplus partitioning methodology presented here determines recharge based on topography, soils and land cover. The water budget for the entire study area matched the “water in” to the “water out” to within 3%. This is considered excellent agreement and lends confidence in the use of the calculated recharge values.

Several major data gaps inhibit the prediction of monthly water budgets. These include a lack of seasonal streamflow data against which to calibrate, a lack of seasonal water use data, and only broad estimates of hydraulic conductivity. Also there are insufficient hydraulic head data on a seasonal basis (except for some limited data in aquifer 0197 and 0206). Having identified this, it can be concluded from the preliminary analysis of the water surplus performed here that a deficit condition prevails each summer to early autumn period that depletes streamflow and groundwater levels. A surplus condition beginning late in the year and lasting about five months serves to recover groundwater levels and stream baseflows. This is of course observed in practice where observation wells show declining summer water levels, and municipal well yields decline. Soil moisture storage is tapped in the summer period and can be nearly depleted in a hot/dry year, but otherwise recovers each year.

With Respect to Geology

Section 3.5 and 3.6 provide a detailed description of the study area geology, which is well documented in the scientific literature. The area is dominated by primarily low permeability bedrock of volcanic origin with intrusive features, extensive prehistorical faulting, and having been scoured by glacial processes. At the north end of the study area, low permeability sedimentary bedrock underlies the overburden deposits, and will be underlain by the volcanic rocks at depths that are not generally tapped as aquifers in this area.

The higher permeability zones in the bedrock are generally structurally related and represent targets for future water exploration. Groundwater is expected to cross between aquifer areas along these features, and thus water originating in one aquifer area may feed another. In all cases there is low storativity in the bedrock and its structural features, and thus these local aquifers are both susceptible to seasonal and annual dry conditions but also to rapid recovery in wetter periods. They are also prone to mutual interference between water wells.

Moderately to highly productive surficial aquifers occur within the study area in sand and gravel deposits with high primary porosity in the following settings:

- Deep, proglacial outwash and ice-contact materials of the Quadra Sands between Vashon Drift ground moraines and the underlying bedrock surface;
- At intermediate depths within permeable glaciofluvial outwash and ice-contact interbeds between low-permeability ground moraine units of the Vashon Drift;
- Shallow glaciofluvial ice-contact, outwash, and deltaic materials of the Capilano Sediments; and
- Shallow post-glacial alluvial and deltaic materials of the Salish Sediments.

Groundwater movement within unconfined surficial aquifers generally follows regional and local topographic trends by flowing from higher elevations towards lower elevations, although flows at the local level may be highly anisotropic depending on their internal stratigraphy, boundary conditions, and degrees of confinement. Groundwater divides in unconfined and semi-confined surficial aquifers are usually coincident with surface water divides on regional and local scales, although confined groundwater within deeply buried Quadra Sands deposits may flow across local surface water catchment boundaries. Interstitial flow velocities within surficial aquifers are slow compared to bedrock aquifers due to their stratigraphy and pore space connectivity. On the other hand, water storage is greater in the surficial aquifers due to higher porosity. Consequently, wells constructed in surficial aquifers are generally more productive than bedrock wells.

Climate Conclusions

Four climate stations have been used to identify that precipitation varies widely across the region but follows a distinct pattern. Precipitation is highest upland to the south west, and drops dramatically as one approaches the marine shoreline to the northeast. Therefore, the water surplus is greatest in the south western aquifers and diminishes towards the shore. It has been concluded that the Shawnigan Lake weather station is most representative of the study area and that its data set can be used (with the application of correction factors as listed in Table 4 in Section 2.2.4) in future water budgets.

The average annual surplus for the study area is 761 mm/year, available for recharge and runoff, based on 30 years of data from 1977 to 2006. The corresponding amount for the hottest and driest period (1987-1989) was 556 mm/yr. For the wettest and coldest period (1997-1999) in this 30 year period of record, the surplus is 1100 mm/yr. The calculation of surplus was calibrated against streamflow stations on the Koksilah River and on Shawnigan Creek, and found to agree within 9.6% where the data periods matched. It has been concluded that the method of calculating surplus used here is acceptable.

Temperature and precipitation data adapted from climate change predictions by PCIC indicate that whereas the temperatures will climb, increasing the length of the summer season, significantly more precipitation is likely in the winter months. Whereas rainfall intensities will increase, causing greater seasonal runoff, the net recharge may still be higher into the future. Anthropogenic use in the hotter summers (and with greater demand due to increasing population) will also increase, further deepening the contrast between seasons. This includes a greater agricultural demand on water resources. Along with the increased population will be a greater urban land cover, further inhibiting groundwater recharge unless mitigated. Water storage will become increasingly important.

Water Budget Conclusions

The water budget for each aquifer area has been found to balance within acceptable ranges of parameter estimation. The most sensitive parameter is that of hydraulic conductivity, when compared to the other factors such as water use and streamflow. Estimation of the downward leakage into the bedrock from the overburden is based on experience and has not been calibrated. The water budget for the full study area, as identified in Section 6 shows very close agreement, providing confidence in the results of the study.

There are several sources of uncertainties in the water budget calculations, especially for bedrock aquifers:

1) Boundaries between bedrock aquifers typically require flux to be calculated – this involves estimating hydraulic conductivity, hydraulic gradient and cross-sectional area. In the study area, these parameters must be estimated and the range of values are difficult to bound due to lack of data;
2) For most of the aquifers, there is no groundwater level data to calibrate the calculation of surplus/deficit and existing wells may be influenced by anthropogenic activity, or have the correct period of record..

Recharge has been identified as the key element in judging water supply. More than any other component, recharge is most easily constrained and estimated from readily available and current data. It is also the most easily managed for future land development, whereby recharge can be mandated to be maintained or even enhanced through engineering design. Assessment of temporary water takings can be based on current climatic conditions. Assessment of long-term water takings can be assessed against the risk of hot/dry years. This will prevent approval of water takings that may inadvertently cause over-extraction and water shortages. The water license can also be used as an instrument to ensure no further depletion of the water budget by promoting recharge and sustainable water use.

A simple methodology comparing consumptive water use versus annual recharge has been used in this report to assess water quantity stress by aquifer and climatic variability. Assessment of the individual aquifers shows that those in the developed areas are more stressed than the others. Future water approvals in such stressed areas may have to consider water conveyance from less stressed areas, and/or use of temporary storage to bridge over the key dry months. The stress assessment used is a simple preliminary method, and should be refined to include ecologic contributions, such has been done in other jurisdictions.

Significant gaps prevent a fully calibrated monthly water budget to be developed but the preliminary budgets are useful to provide an initial conceptual understanding of the sources of water for the aquifers, provide an initial estimate of water availability, and help identify what information is needed to improve water budget estimates in the study area. There is a need to better classify monthly streamflow, monthly water use, and provide aquifer parametric characterization to better define monthly groundwater flow contributions.

8. RECOMMENDATIONS

Many of the objectives of this study may be better met in the future should resources be put towards the following recommendations.

1. ***Update and refine aquifer mapping***: Water budgets developed in this study utilized aquifer mapping completed in 1996. This mapping is outdated as there is substantial hydrogeologic information from hundreds of wells drilled after 1996, and the mapping is incomplete in areas where it is based on surface features rather than geologic or hydrogeologic information. The ENV should update and refine aquifer mapping throughout the study area using three-dimensional (3D) geologic mapping tools to identify patterns in overburden distribution and structural bedrock features. This mapping would advance understanding of the regional hydrogeologic characteristics, improve aquifer delineation and knowledge of groundwater availability and exploration potential, and would support and substantiate water budget analyses and rationale for groundwater allocation targets.
2. ***Expand the observation well network:*** Available data from provincial groundwater observation wells provide an incomplete representation of the study area. The province should expand the observation well network in key areas to establish long-term seasonal and annual patterns of water levels against which the effect of water withdrawal can be related. Recommended areas based on the stress analysis (Section 6.2) are:
   - Two observations in bedrock aquifer 0198, which exhibits high demand as a percentage of recharge;
   - Up to six observation wells in bedrock aquifer 0204, because of its large area, location, unique geometry, and high volume of groundwater demand;
   - Multiple observation wells in overburden aquifer 0206, with consideration of nested wells in the overburden and bedrock aquifers to characterize inter-aquifer fluxes;
   - Up to six observation wells in overburden aquifer 0197, because the aquifer hosts the highest groundwater use of all study area aquifers, it is stratigraphically complex and covers a very large area, and it lies in the driest setting of the study area;
   - Up to four observation wells in overburden aquifer 0199, with two in the valley at either end, paired with wells on the high ground to the north to characterize vertical and horizontal hydraulic gradients;

   Siting and prioritization of new observation wells would be substantially informed by results from 3D geologic modeling and mapping. The mapping should be completed first, as feasible.
3. ***Collect hydrometric information:*** Hydrometric data are crucial for characterizing groundwater connectivity and interaction with surface streams. However, there is limited hydrometric data in the study area, which constrains water budget analyses and increases uncertainty in water budget results. The province should expand collection of hydrometric information. Specifically the province should undertake a one-time program to collect and inventory width, depth, temperature, and spot baseflow measurements of streams throughout the study area. The province should further collect continuous hydrometric measurements in the following priority areas, either by establishing formal hydrometric stations or by informal temporary stations:
   - Upstream and downstream stations on Handysen and Hollings Creeks to characterize losing and gaining reaching and associated fluxes to/from aquifer 206;
   - Two hydrometric stations on Patrolas Creek to establish a rating curve near Duggan Lake and at the downstream end to examine seasonal changes in baseflow and water usage; and

- Representative streams and creeks throughout aquifer 0197, in areas where surface water/groundwater fluxes are a significant component in the water budget results, or areas where there is a need to better characterize groundwater connectivity with fully allocated streams.

4. ***Verify groundwater and surface water use estimates***: Water use records are unavailable with the exception of a few large water utilities, as there are no requirements to measure surface and groundwater use. Consequently, water budget analyses relied on unverified water use estimates. The province should undertake efforts to collect water use information in order to verify estimation methods and to refine the water budget analyses and results. This could include voluntary and collaborative measurements by individual or targeted users, or more general water use surveys of known or licensed users. The province should consider formal policies mandating water use measuring and reporting, similar to other provinces, in order to promote equitable beneficial use and informed management of groundwater resources.
5. ***Maintain ongoing collection of meteorological records:*** Long-term climate records are essential to water budget analyses and for monitoring climate change. The Shawnigan Lake station is central to the study area and has long-term records that are representative of average conditions for the full study area. Provincial and local officials should support ongoing collection of climate data at this station.
6. ***Refine water budgets in priority area:*** Aquifer water budgets developed in this study provide initial estimates of aquifer fluxes and groundwater availability based on the available information. The preliminary water budgets also highlight data gaps and priority areas of concern for groundwater allocation. Water budget in the following priority areas should be refined and routinely updated:
    - Overburden aquifers 0206, 0197, and 0198;
    - Subareas within aquifer areas with observed groundwater issues of concern, such as downward trending groundwater levels or reduced baseflow in connected streams; and
    - Areas of high groundwater demand or hydrogeologic areas of concern identified through 3D hydrogeologic modelling under recommendation #1.

    All aspects of the water budget should be reviewed and refined, including:
    - Detailed data compilation of groundwater well records, hydrogeologic records, aquifer testing and parameter estimation, groundwater level data, updated climate and hydrologic records;
    - Review and update of groundwater and surface water use information including any new groundwater and surface water licenses;
    - Evaluation, update, and refinement of aquifer boundaries to integrate recent well records and geologic understanding, and to more rigorously quantify inflows and outflows;
    - Installation of groundwater observation wells to establish long term records of water level changes and seasonality;
    - Collection of hydrometric data in key surface water features and assessment groundwater connectivity and associated calculation of groundwater/surface water fluxes. Where relevant, consider and assess groundwater pumping impacts on surface waters
    - Update groundwater flux calculations to adjacent aquifers, incorporating updated information on aquifer hydraulic properties and hydraulic gradients;
    - Update aquifer stress analysis and estimates of available groundwater allocation potential, considering recommended safety factors in Section 2.6

7. ***Guidance on assessing proposed groundwater extraction:*** Groundwater taking licensure should consider the size of the proposed taking, and should consider the proximity of neighbouring wells. The seasonality is also important, and pumping tests should be conducted at the critical time of the year and be long enough in duration to ensure a measure of sustainability. Whether the year is wet or dry should also be considered, as this will affect water availability, and the proponent should do this by examining recent (leading up to and including the test period) meteorological information in comparison to the long term data found in Table 2. Pumping tests at a minimum should be 72 hours long to determine if an aquifer is unconfined or not. If equilibrium is not achieved, longer tests of a week to a month or more are needed to provide enough data to extrapolate long term effects, and effects on ecologic features and other wells.

   With respect to ecologic features, Section 2.6 suggested preliminary factors of safety to water allocations to protect the natural environment (wetlands, cold-water streams, etc.). Consideration should be given to basing the sustenance of the natural environment more on site specific ecologic conditions at any locale, as a responsibility of the water licence applicant.

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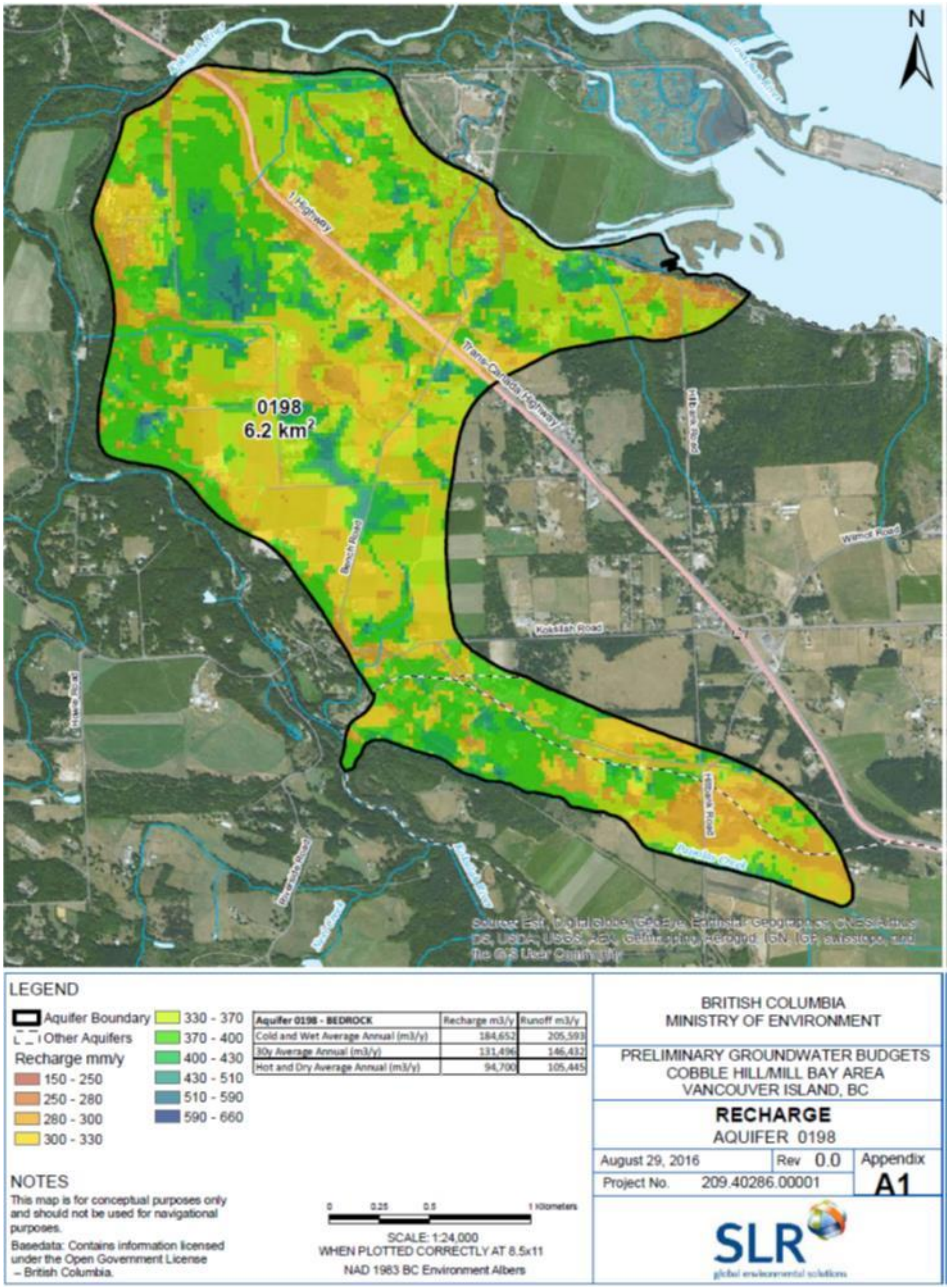
APPENDIX A: AQUIFER 0198 (COWICHAN STATION)



Aquifer 0198 - BEDROCK	Recharge m3/y	Runoff m3/y
Cold and Wet Average Annual (m3/y)	184,652	205,593
30y Average Annual (m3/y)	131,496	146,432
Hot and Dry Average Annual (m3/y)	94,700	105,445

Figure A-1: Recharge distribution for bedrock aquifer 0198.

Table A-1: CHM aquifer criteria: Aquifer #0198 Cowichan Station (Bedrock).

BCMOE Criteria	
AQ tag	198 Cowichan Station
AQ classification	IIIC(7)
AQ type	BCMOE / SLR Classification = 5a
Location	Cowichan Station / Duncan South of Koksilah River; west-southwest of Cowichan Bay & east of Koksilah River
Perimeter (km)	16.12
Area (km^2)	6.18
Aquifer materials	Bedrock
Lithostratographic unit	Nanaimo Series
Productivity	Low
Vulnerability	Low
Demand	Low
Use	Domestic
Location	
NTS 50000	Lat / Long (Centre)
TRIM 20000	UTM Zone 10 (Centre)
Lat / Long (Centre)	Lat / Long (Centre)
UTM Zone 10 (Centre)	UTM Zone 10 (Centre)
Climate	
Nearest active EC weather station / distance / elevation	EC1012573 Duncan Kelvin Creek / 2.67 km to west-southwest ; EC1017230 Shawnigan Lake / 7.1 km to south
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland
Elevation range (m amsl)	0 - 60 m amsl
Distance to marine	Abuts Cowichan Bay at NE corner
Geomorphological setting	Glacial outwash fan
Topography	Gentle hillslope on west / level areas on east
Terrain	Undulating to hummocky on west edge / planar to undulating elsewhere
Aspect	East / east-northeast
Slope	Planar to slightly concave eastwards
XS max grade (m/m)	0.0207 to east-northeast
Roughness coefficient	0.50 (partly cleared / deciduous - coniferous cover)
Geology	
Terrane	Overlap
Bedrock (age ; formation ; lithology)	Upper Cretaceous; Nanaimo Group (uKN); mainly shale + subordinate sandstone
Structure	2 E-ESE thrust faults cross centre of AQ
Surficial (formation; lithology; thickness)	Vashon Drift : Cowichan Head Formations, morainal; silt-sand-gravel; deep blankets (> 30 - 70 m)
Surficial designation (1993)	W // dMbh/$LGp // sgFGf
Soils (association; parent; texture; drainage; type; comments)	FF2/d (Finlayson SA); marine; si-cy; imperfect; GLE.DYB ; stone-free, fine-textured soils
Restrictive layers	Yes - surface si-cy soils, dense till
Estimated permeability	Low @ surface from dominant M-LG / high at bedrock ct from dominant FG
Hydrology	
GW / SW basin coincidence	No
Catchments	Koksilah / Garnett
Drainage regime	Radial
Surface waters	Five small streams, radial drainage / west & north boundaries ~ 100 m from Koksilah River
Runoff coefficient	~70% cleared-agricultural / ~30% forested / flat - rolling terrain / = 0.35
Nearest Active EC hydrometric station;	EC 08HA003 Koksilah River @ Cowichan Station; 200 m SW; active real time

distance; type	
Land Cover	
Vegetation zone	CgF-wC
Primary land uses	Agricultural / forestry
Degree of development	Moderate to high, mainly agricultural. Very low impervious cover
Evapotranspiration potential	Negligible, confined
Relative environmental sensitivity	Low
Hydrogeology	
Groundwater occurrence (primary / secondary)	Void infillings - bedding partings, bedrock fractures & faults
Primary porosity	Low
Secondary porosity	Low to moderate (probable low open void space due to ductile rock)
Confinement	Confined / thick overburden with K-restrictive layers / water-bearing units below sea level; WP = 0 to 41 m, avg 3.6 m
Aquifer thickness	Bedrock aquifer / assume < 150 m
Hydraulic anisotropy	High
Hydraulic gradient	Unknown - confined
Storage potential	Low - secondary voids only
Yield potential	Low; WP = 0.06 - 1.26 L/s / average 0.13 L/s
Flow velocities	Low - moderate
Flow directions	E / ENE towards Cowichan Bay / modified E - ESE by thrust faults
Static water levels	WP = variable 0.5 - 49.7 m bgs / avg 9.7 m bgs
Hydraulic connection with surface waters	None
Hydraulic connection to adjacent AQ	
Over / Under	Overlain by surficial AQ197 & AQ199
Upgradient	Upgradient contact with bedrock AQ 196 (not in study area)
Downgradient	Downgradient contact with undeveloped extension of bedrock AQ198
Vulnerability to surface contamination	Low - confined
Recharge	
Vertical inflow	None from precipitation-snowmelt, stream loss, irrigation, sewage disposal. Low to moderate recharge from overlying surficial AQ197 & AQ199
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock sources AQ196 (not in study area); possible increased K along thrust faults
Temporal variability	Low, confined
MBR	Negligible
Discharge	
Evapotranspiration	Negligible, confined
Outflow to marine	Low
Outflow to surface waters	None
Outflow to other AQ	None
Temporal variability	None
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #233; 1.4 km SE; completed in surficial AQ197; irrelevant
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	109,500
Commercial	7,300
Domestic	53,687
Irrigation from GW (MoAg)	0
BCMOE Obs	0
Other	67,300
Water Supply Systems	465

Table A-2: Annual Summary of AQ198 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration/ Exfiltration Factor**	**Q (m^3/yr)**
Gain	Leakage down from surficial sediment	385,626	0.100	38,563
Gain	Leakage down from 197	4,999,983	0.100	499,998
Gain	Leakage down from 199	796,597	0.100	79,660
Loss	Lateral Groundwater	--	--	-57,415
Gain	Lateral Groundwater	--	--	209,186
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-238,252
Net Gain				**827,407**
Net Loss				**-295,667**
Net Total (Gain - Loss)				**531,740**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration/ Exfiltration Factor**	**Q (m^3/yr)**
Gain	Leakage down from surficial sediment	385,626	0.100	38,563
Gain	Leakage down from 197	4,999,983	0.100	499,998
Gain	Leakage down from 199	796,597	0.100	79,660
Loss	Lateral Groundwater	--	--	-57,415
Gain	Lateral Groundwater	--	--	209,186
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-238,252
Net Gain				**827,407**
Net Loss				**-295,667**
Net Total (Gain - Loss)				**531,740**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration/ Exfiltration Factor**	**Q (m^3/yr)**
Gain	Leakage down from surficial sediment	385,626	0.100	38,563
Gain	Leakage down from 197	4,999,983	0.100	499,998
Gain	Leakage down from 199	796,597	0.100	79,660
Loss	Lateral Groundwater	--	--	-57,415
Gain	Lateral Groundwater	--	--	209,186
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-238,252
Net Gain				**827,407**
Net Loss				**-295,667**
Net Total (Gain - Loss)				**531,740**

Table A-3: Monthly Summary of AQ198 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Leakage down from surficial sediment	3,124	3,008	3,355	3,316	3,471	3,316	3,355	3,278	3,124	3,162	3,008	3,046	**38,563**
Leakage down from 197	40,500	39,000	43,500	43,000	45,000	43,000	43,500	42,500	40,500	41,000	39,000	39,500	**499,998**
Leakage down from 199	6,452	6,213	6,930	6,851	7,169	6,851	6,930	6,771	6,452	6,532	6,213	6,293	**79,660**
Lateral Groundwater	-4,651	-4,478	-4,995	-4,938	-5,167	-4,938	-4,995	-4,880	-4,651	-4,708	-4,478	-4,536	**-57,415**
Lateral Groundwater	16,944	16,317	18,199	17,990	18,827	17,990	18,199	17,781	16,944	17,153	16,317	16,526	**209,186**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-14,295	-15,486	-17,869	-19,060	-21,443	-23,825	-26,208	-27,399	-23,825	-19,060	-16,678	-13,104	**-238,252**
Net Gain	**67,020**	**64,538**	**71,984**	**71,157**	**74,467**	**71,157**	**71,984**	**70,330**	**67,020**	**67,847**	**64,538**	**65,365**	827,407
Net Loss	**-18,946**	**-19,965**	**-22,864**	**-23,998**	**-26,610**	**-28,763**	**-31,203**	**-32,279**	**-28,476**	**-23,768**	**-21,156**	**-17,640**	-295,667
Net Total (Gain - Loss)	**48,074**	**44,573**	**49,120**	**47,159**	**47,857**	**42,394**	**40,782**	**38,050**	**38,544**	**44,079**	**43,382**	**47,725**	531,740
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Leakage down from surficial sediment	3,162	2,931	3,239	3,201	3,355	3,239	3,355	3,316	3,162	3,278	3,124	3,201	**38,563**
Leakage down from 197	41,000	38,000	42,000	41,500	43,500	42,000	43,500	43,000	41,000	42,500	40,500	41,500	**499,998**
Leakage down from 199	6,532	6,054	6,691	6,612	6,930	6,691	6,930	6,851	6,532	6,771	6,452	6,612	**79,660**
Lateral Groundwater	-4,708	-4,364	-4,823	-4,765	-4,995	-4,823	-4,995	-4,938	-4,708	-4,880	-4,651	-4,765	**-57,415**
Lateral Groundwater	17,153	15,898	17,572	17,362	18,199	17,572	18,199	17,990	17,153	17,781	16,944	17,362	**209,186**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-14,295	-15,486	-17,869	-19,060	-21,443	-23,825	-26,208	-27,399	-23,825	-19,060	-16,678	-13,104	**-238,252**
Net Gain	**67,847**	**62,883**	**69,502**	**68,675**	**71,984**	**69,502**	**71,984**	**71,157**	**67,847**	**70,330**	**67,020**	**68,675**	827,407
Net Loss	**-19,003**	**-19,850**	**-22,692**	**-23,826**	**-26,438**	**-28,648**	**-31,203**	**-32,337**	**-28,533**	**-23,940**	**-21,328**	**-17,869**	-295,667
Net Total (Gain - Loss)	**48,844**	**43,033**	**46,810**	**44,849**	**45,547**	**40,854**	**40,782**	**38,820**	**39,314**	**46,389**	**45,692**	**50,805**	531,740
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Leakage down from surficial sediment	3,124	3,008	3,355	3,316	3,471	3,316	3,355	3,278	3,124	3,162	3,008	3,046	**38,563**
Leakage down from 197	40,500	39,000	43,500	43,000	45,000	43,000	43,500	42,500	40,500	41,000	39,000	39,500	**499,998**
Leakage down from 199	6,452	6,213	6,930	6,851	7,169	6,851	6,930	6,771	6,452	6,532	6,213	6,293	**79,660**
Lateral Groundwater	-4,651	-4,478	-4,995	-4,938	-5,167	-4,938	-4,995	-4,880	-4,651	-4,708	-4,478	-4,536	**-57,415**
Lateral Groundwater	16,944	16,317	18,199	17,990	18,827	17,990	18,199	17,781	16,944	17,153	16,317	16,526	**209,186**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-14,295	-15,486	-17,869	-19,060	-21,443	-23,825	-26,208	-27,399	-23,825	-19,060	-16,678	-13,104	**-238,252**
Net Gain	**67,020**	**64,538**	**71,984**	**71,157**	**74,467**	**71,157**	**71,984**	**70,330**	**67,020**	**67,847**	**64,538**	**65,365**	827,407
Net Loss	**-18,946**	**-19,965**	**-22,864**	**-23,998**	**-26,610**	**-28,763**	**-31,203**	**-32,279**	**-28,476**	**-23,768**	**-21,156**	**-17,640**	-295,667
Net Total (Gain - Loss)	**48,074**	**44,573**	**49,120**	**47,159**	**47,857**	**42,394**	**40,782**	**38,050**	**38,544**	**44,079**	**43,382**	**47,725**	531,740

Table A-4: Monthly Coefficients used in Calculations for AQ198.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table A-5: Groundwater Flow Components: Aquifer #0198, Cowichan Station (Bedrock).

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}1$	Out	Inlet	1,560	200	312,000	0.00000001	150	20			13,119		
$Q_{GW}2$	Out	Koksilah R.	1,700	200	340,000	0.00000001	165	20			12,997		
$Q_{GW}3$	Out	AQ 186	445	200	89,000	0.00000001	150	20			-3,742		
$Q_{GW}4$	Out	AQ 186	130	200	26,000	0.00000001	225	20			-729		
$Q_{GW}5$	Out	AQ 186	1,500	200	300,000	0.00000001	550	40			-6,881		
$Q_{GW}6$	Out	AQ 186	90	200	18,000	0.00000001	270	20			-420		
$Q_{GW}7$	Out	AQ 186	1,560	200	312,000	0.00000001	465	40			-8,464		
$Q_{GW}8$	Out	Koksilah R.	2,675	200	535,000	0.00000001	305	20			-11,063		
$Q_{GW}9$	In	AQ 197	--	--	--	--	--	--	--	--	204,984		
$Q_{GW}10$	Zero	AQ 197	760	200	152,000	0.00000001	1	0			0		
$Q_{GW}11$	In	AQ 197	90	200	18,000	0.00000001	1,705	20			67		
$Q_{GW}12$	Zero	AQ 197	535	200	107,000	0.00000001	1	0			0		
$Q_{GW}13$	In	AQ 197	130	200	26,000	0.00000001	2,800	20			59		

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Q_{GW}14	In	AQ 197	1,115	200	223,000	0.00000001	690	40			4,077		
Q_{GW}15	In	Leakage from AQ 197	Leakance Factor (m/yr) =	0.100	4,999,983	--	--	--			499,998		
Q_{GW}16	In	Leakage from AQ 199	Leakance Factor (m/yr) =	0.100	796,597	--	--	--			79,660		
Total											**731,429**	**0**	**0**

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
None										
Total							**0**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	109,500	100%	109,500							100% Consumptive
Commercial	7,300	100%	7,300							100% Consumptive
Domestic	53,687	100%	53,687							100% Consumptive
Irrigation	0	100%	0							100% Consumptive
BC ENV Obs	0	100%	0							100% Consumptive
Other	67,300	100%	67,300							100% Consumptive
Water Supply system	465	100%	465							100% Consumptive
Total			**-238,252**							

APPENDIX B: AQUIFER 0200 (KELVIN CREEK)

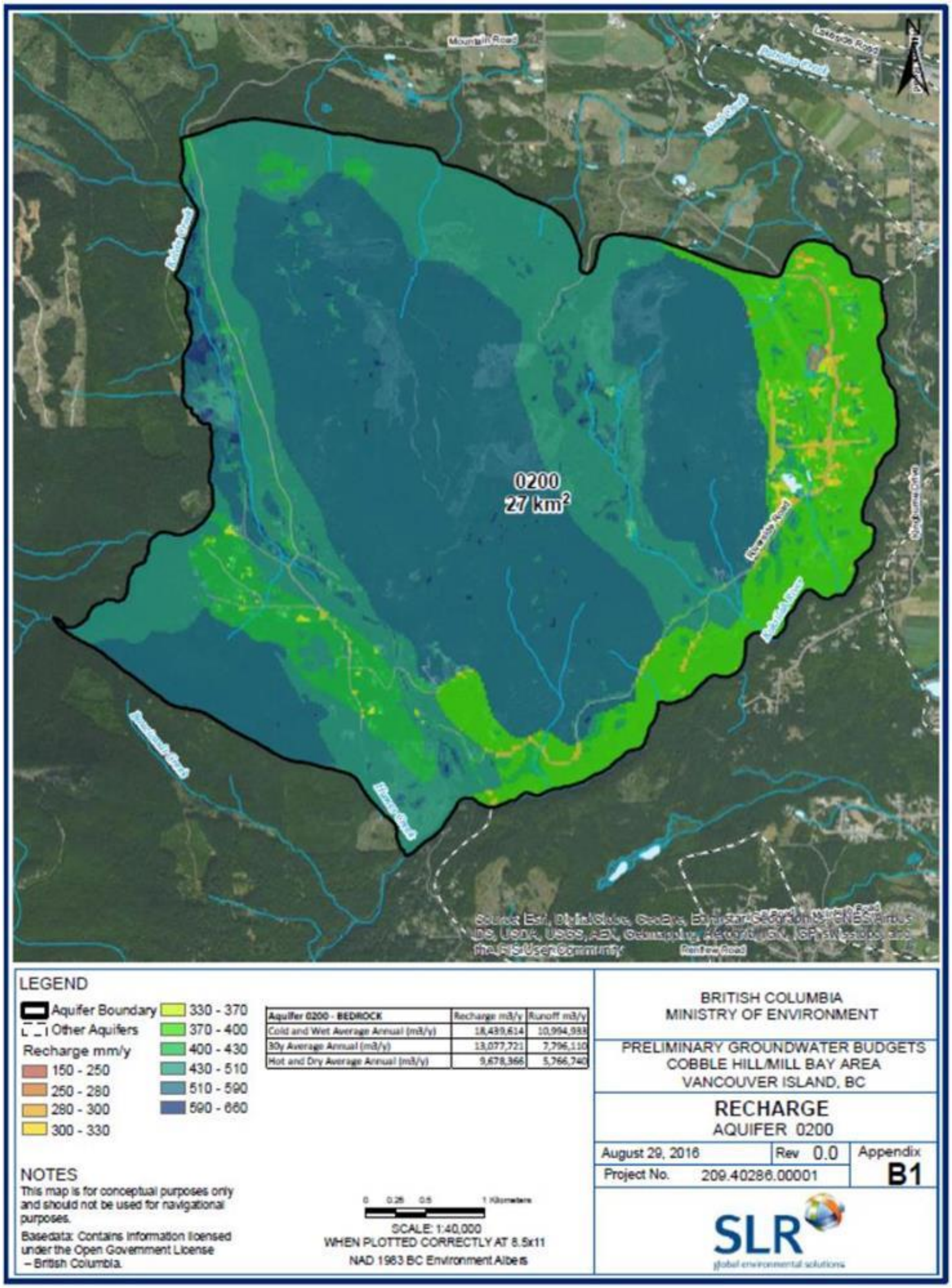


Figure B-1: Recharge distribution for bedrock aquifer 0200.

Table B-1: CHM Aquifer Criteria: Aquifer #0200, Kelvin Creek (Bedrock).

BCMOE Criteria	
AQ tag	200 Kelvin Creek
AQ classification	IIIB(9)
AQ type	BCMOE Classification = 6b (SLR Classification = 6a / 6b / 5a-5b)
Location	Cobble Hill / Duncan (between Koksilah River & Kelvin Creek)
Perimeter (km)	24.06
Area (km^2)	26.9
Aquifer materials	Bedrock
Lithostratographic unit	Sicker Volcanics
Productivity	Low
Vulnerability	Moderate
Demand	Low
Use	Domestic
Location	
NTS 50000	092B/12
TRIM 20000	Straddles 092B.062 & 092B.072
Lat / Long (Centre)	48^{o}41'49" / 123^{o}41'34"
UTM Zone 10 (Centre)	448940E / 5393900N
Climate	
Nearest active EC weather station / distance / elevation	EC1012573 Duncan Kelvin Creek / 1.7 km to northwest; EC1017230 Shawnigan Lake / 4.3 km to southeast
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Outer Mountain Area / Insular Mountains / Vancouver Island Ranges
Elevation range (m amsl)	40 - 480 m amsl
Distance to marine	4.12 NE
Geomorphological setting	Upland / foothills area with draped glacial moraine
Topography	Locally rugged. Three N-elongated, sub-conical hills , local fluvial incisions
Terrain	Rugged to rolling in upland areas, rolling to undulating between topographic highs
Aspect	Radial around central hills, generally towards east
Slope	Mainly radial & convex / planar, concave along west edge
XS max grade (m/m)	0.0630 to east-northeast
Roughness coefficient	0.65 (mainly coniferous cover)
Geology	
Terrane	Overlap / Wrangellia
Bedrock (age ; formation ; lithology)	
Primary	SE half = Devonian Sicker Group (muDSiD) & Triassic Karmutsen Fm Volcanics (uTrVK); basaltic (55%)
Secondary	NW half, E & SE fringes = Jurassic Island Plutonic Suite (EMJlgd); granodioritic (35%)
Tertiary	North end = Upper Cretaceous Nanaimo Group (uKN), shale(5%); Central / SE areas = Carboniferous-Permian Buttle Lake Formation (PnPBM); limestone (5%)
Structure	AQ lies NW of major NE splay of San Juan Fault. N and NNW mapped faults cross east-centre
Surficial (formation; lithology; thickness)	Vashon Drift Formation, morainal; silt-sand; shallow blankets & veneers (> 5 m)
Surficial designation (1993)	Generally Cb-Cv // R ; E flank = Cb //sgFG
Soils (association; parent; texture; drainage; type; comments)	Generally RL5R0S1/ed (Rosewall/Shawingan SAs), E & SE flanks - S1v/ed; colluvial / moraine; gsl / si-s; rapid - good; O.HFP / DU.DYB; coarse-textured soils + duric zones
Restrictive layers	RL soils - no / S soils yes (near-urface duric layers)
Estimated permeability	RL soils - high; S soils low to moderate

Hydrology	
GW / SW basin coincidence	No
Catchments	Kelvin / Koksilah
Drainage regime	Radial, concentrated along SE border with Koksilah River
Surface waters	One small tribuary of Kelvin Ck along NW side; two small tributaries of Koksilah River in SE area; scattered small wetlands; SE border formed by Koksilah River
Runoff coefficient	~35% forested / 50% cleared-forested / 10% rural residential; rolling to rugged terrain / moderate slope = 0.45
Nearest Active EC hydrometric station; distance; type	EC 08HA003 Koksilah River @ Cowichan Station; 1.93 km NE; active realtime + Shawnigan Creek @ Mill Bay; 6.97 km SE (inactive)
Land Cover	15 within and along AQ boundaries, Koksilah River, Kelvin Creek, unnamed streams, springs; relevant
Vegetation zone	
Primary land uses	Cgf-wC
Degree of development	Forestry / rural residential
Evapotranspiration potential	Low to moderate, mainly forestry & rural residential. Very low impervious cover
Relative environmental sensitivity	High
Hydrogeology	Low
Groundwater occurrence (primary / secondary)	
Primary porosity	Void infillings - bedrock fractures & faults, karst solution cavities
Secondary porosity	Low
Confinement	Moderate (probable good open void space due to brittle rock & local karst solution cavities)
Aquifer thickness	Unconfined to semiconfined - assume bedrock fractures / karst cavities generally daylight to surface. East fringe locally semi-confined by duric till blankets; WP = 0 to 28.7 m, avg 3.0 m
Hydraulic anisotropy	Bedrock aquifer / assume < 150 m
Hydraulic gradient	High
Storage potential	Low - moderate due to proximity / presence of large structures & brittle rocks
Yield potential	Low - moderate; WP = 0.02 - 1.58 L/s / average 0.19 L/s
Flow velocities	Moderate to high
Flow directions	Radial, generally E or SE to Koksilah River
Static water levels	WP = variable 0 - 44.2 m bgs / avg 11.9 m bgs
Hydraulic connection with surface waters	High - likely provides baseflow to Koksilah River mainstem & tributaries + Kelvin Creek tributaries
Hydraulic connection to adjacent AQ	
Over / Under	None
Upgradient	Upgradient contact with undeveloped extension of bedrock AQ 200 (not in study area)
Downgradient	Downgradient contacts with bedrock AQ202 (in study area), bedrock AQ 196 (not in study area), and undeveloped extension of AQ200
Vulnerability to surface contamination	High
Recharge	
Vertical inflow	Mainly precipitation, limited snowmelt / sewerage. Negligible to low from stream loss.
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock sources / possible increased K along faults
Temporal variability	High, linked to precipitation trends
MBR	High from internal and upgradient (west and southwest) rocky hills
Discharge	
Evapotranspiration	High
Outflow to marine	None

Outflow to surface waters	High to Koksilah River along SE border
Outflow to other AQ	High - possible MBR zone to downgradient aquifers
Temporal variability	High, linked to precipitation trends
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #233; 3.6 km NE; completed in surficial AQ197; irrelevant Well #320; 4.8 km E; completed in surficial AQ197; irrelevant
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	0
Commercial	0
Domestic	44348
Irrigation from GW (MoAg)	882
BCMOE Obs	0
Other	0
Water Supply Systems	0

Table B-2: Direct Recharge Calculation for AQ200.

	Direct Recharge Calculation		
	Hot/Dry	**Average**	**Cold/Wet**
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.12	1.12	1.12
Infiltration Coefficient	0.626	0.626	0.626
Area (m^2)	26,939,892	26,939,892	26,939,892
Q (m^3/yr)	9,672,233	14,377,387	23,859,860
Average Infiltration Rate	0.359	0.534	0.886

Table B-3: Annual Summary of AQ200 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 200	26,939,892	0.534	14,377,387
Loss	Lateral Groundwater	--	--	-15,125,850
Gain	Lateral Groundwater	--	--	674,170
Loss	Surface Water	--	--	-1,986,768
Gain	Surface Water	--	--	0
Loss	Well Usage	--	--	-45,230
Net Gain				**15,051,556**
Net Loss				**-17,157,848**
Net Total (Gain - Loss)				**-2,106,292**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 200	796,597	0.359	9,672,233
Loss	Lateral Groundwater	--	--	-15,125,850
Gain	Lateral Groundwater	--	--	674,170
Loss	Surface Water	--	--	-1,986,768
Gain	Surface Water	--	--	0
Loss	Well Usage	--	--	-45,230
Net Gain				**10,346,403**
Net Loss				**-17,157,848**
Net Total (Gain - Loss)				**-6,811,445**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 200	796,597	0.886	23,859,860
Loss	Lateral Groundwater	--	--	-15,125,850
Gain	Lateral Groundwater	--	--	674,170
Loss	Surface Water	--	--	-1,986,768
Gain	Surface Water	--	--	0
Loss	Well Usage	--	--	-45,230
Net Gain				**24,534,030**
Net Loss				**-17,157,848**
Net Total (Gain - Loss)				**7,376,182**

Table B-4: Monthly Summary of AQ200 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 200	3,615,457	2,354,969	1,699,513	408,140	-491,273	-774,700	-755,805	-340,112	-113,371	1,242,980	3,813,744	3,717,845	14,377,387
Lateral Groundwater	-1,225,194	-1,179,816	-1,315,949	-1,300,823	-1,361,327	-1,300,823	-1,315,949	-1,285,697	-1,225,194	-1,240,320	-1,179,816	-1,194,942	-15,125,850
Lateral Groundwater	54,608	52,585	58,653	57,979	60,675	57,979	58,653	57,304	54,608	55,282	52,585	53,259	674,170
Surface Water	-438,442	-384,915	-278,046	-134,436	-47,668	-19,334	-11,482	-3,730	-3,136	-28,781	-203,406	-433,393	-1,986,768
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Usage	-2,714	-2,940	-3,392	-3,618	-4,071	-4,523	-4,975	-5,201	-4,523	-3,618	-3,166	-2,488	**-45,230**
Net Gain	**3,670,065**	**2,407,555**	**1,758,166**	**466,118**	**60,675**	**57,979**	**58,653**	**57,304**	**54,608**	**1,298,262**	**3,866,329**	**3,771,104**	**17,526,818**
Net Loss	**-1,666,349**	**-1,567,672**	**-1,597,387**	**-1,438,877**	**-1,904,338**	**-2,099,380**	**-2,088,211**	**-1,634,741**	**-1,346,223**	**-1,272,719**	**-1,386,388**	**-1,630,823**	**-19,633,110**
Net Total (Gain - Loss)	**2,003,715**	**839,883**	**160,779**	**-972,759**	**-1,843,663**	**-2,041,402**	**-2,029,559**	**-1,577,436**	**-1,291,616**	**25,543**	**2,479,941**	**2,140,281**	**-2,106,292**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 200	2,965,569	1,700,561	2,644,211	158,719	-623,539	-793,595	-680,225	-283,427	-188,951	481,826	1,891,402	2,399,681	**9,672,233**
Lateral Groundwater	-1,240,320	-1,149,565	-1,270,571	-1,255,446	-1,315,949	-1,270,571	-1,315,949	-1,300,823	-1,240,320	-1,285,697	-1,225,194	-1,255,446	**-15,125,850**
Lateral Groundwater	55,282	51,237	56,630	55,956	58,653	56,630	58,653	57,979	55,282	57,304	54,608	55,956	**674,170**
Surface Water	-438,442	-384,915	-278,046	-134,436	-47,668	-19,334	-11,482	-3,730	-3,136	-28,781	-203,406	-433,393	**-1,986,768**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-2,714	-2,940	-3,392	-3,618	-4,071	-4,523	-4,975	-5,201	-4,523	-3,618	-3,166	-2,488	**-45,230**
Net Gain	**3,020,851**	**1,751,798**	**2,700,841**	**214,675**	**58,653**	**56,630**	**58,653**	**57,979**	**55,282**	**539,130**	**1,946,010**	**2,455,637**	**12,916,140**
Net Loss	**-1,681,475**	**-1,537,420**	**-1,552,009**	**-1,393,500**	**-1,991,227**	**-2,088,024**	**-2,012,631**	**-1,593,181**	**-1,436,930**	**-1,318,097**	**-1,431,766**	**-1,691,327**	**-19,727,585**
Net Total (Gain - Loss)	**1,339,376**	**214,378**	**1,148,832**	**-1,178,825**	**-1,932,574**	**-2,031,393**	**-1,953,978**	**-1,535,203**	**-1,381,648**	**-778,967**	**514,244**	**764,311**	**-6,811,445**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 200	5,999,999	3,908,168	2,820,412	677,325	-815,288	-1,285,647	-1,254,289	-564,430	-188,143	2,062,776	6,329,064	6,169,915	**23,859,860**
Lateral Groundwater	-1,225,194	-1,179,816	-1,315,949	-1,300,823	-1,361,327	-1,300,823	-1,315,949	-1,285,697	-1,225,194	-1,240,320	-1,179,816	-1,194,942	**-15,125,850**
Lateral Groundwater	54,608	52,585	58,653	57,979	60,675	57,979	58,653	57,304	54,608	55,282	52,585	53,259	**674,170**
Surface Water	-438,442	-384,915	-278,046	-134,436	-47,668	-19,334	-11,482	-3,730	-3,136	-28,781	-203,406	-433,393	**-1,986,768**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-2,714	-2,940	-3,392	-3,618	-4,071	-4,523	-4,975	-5,201	-4,523	-3,618	-3,166	-2,488	**-45,230**
Net Gain	**6,054,606**	**3,960,753**	**2,879,065**	**735,303**	**60,675**	**57,979**	**58,653**	**57,304**	**54,608**	**2,118,058**	**6,381,649**	**6,223,174**	**28,641,827**
Net Loss	**-1,666,349**	**-1,567,672**	**-1,597,387**	**-1,438,877**	**-2,228,353**	**-2,610,327**	**-2,586,696**	**-1,859,059**	**-1,420,996**	**-1,272,719**	**-1,386,388**	**-1,630,823**	**-21,265,646**
Net Total (Gain - Loss)	**4,388,257**	**2,393,082**	**1,281,678**	**-703,574**	**-2,167,678**	**-2,552,348**	**-2,528,043**	**-1,801,754**	**-1,366,388**	**845,339**	**4,995,261**	**4,592,351**	**7,376,182**

Table B-5: Monthly Coefficients used in Calculations for AQ200.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table B-6: Groundwater Flow Components: Aquifer #0200, Kelvin Creek (Bedrock)

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}1$	Zero	N/A	2,405	200	481,000	0.000001	1	0			0		
$Q_{GW}2$	Out	Koksilah R.	370	180	66,600	0.000001	930	140			-316,174		
$Q_{GW}3$	Out	Koksilah R.	148	180	26,640	0.00001	600	40			-560,079		
$Q_{GW}4$	Out	Koksilah R.	518	180	93,240	0.000001	735	100			-400,057		
$Q_{GW}5$	Out	Koksilah R.	111	180	19,980	0.00001	310	40			-813,018		
$Q_{GW}6$	Out	Koksilah R.	703	180	126,540	0.000001	540	60			-443,396		
$Q_{GW}7$	Out	Koksilah R.	111	180	19,980	0.00001	245	40			-1,028,717		
$Q_{GW}8$	Out	Koksilah R.	481	100	48,100	0.000001	210	60			-433,395		
$Q_{GW}9$	Out	Koksilah R.	185	100	18,500	0.00001	520	100			-1,121,954		
$Q_{GW}10$	Out	Koksilah R.	481	100	48,100	0.000001	375	60			-242,701		
$Q_{GW}11$	Out	Koksilah R.	296	80	23,680	0.00001	290	60			-1,545,047		
$Q_{GW}12$	Out	Koksilah R.	1,147	80	91,760	0.000001	275	60	-	-	-631,362		
$Q_{GW}13$	Out	Koksilah R.	185	80	14,800	0.00001	230	40			-811,709		

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}14$	Out	Koksilah R.	1,480	140	207,200	0.000001	1,160	80			-450,639		
$Q_{GW}15$	Out	Koksilah R.	74	140	10,360	0.00001	495	80			-528,021		
$Q_{GW}16$	Out	Koksilah R.	333	140	46,620	0.000001	210	40			-280,040		
$Q_{GW}17$	Out	Koksilah R.	777	140	108,780	0.000000001	140	60			-1,470		
$Q_{GW}18$	Zero	N/A	148	200	29,600	0.000000001	1	0			0		
	Out	N/A	74	200	14,800	0.00000001	175	60			-1,600		
$Q_{GW}19$	Zero	N/A	222	200	44,400	0.000000001	1	0			0		
$Q_{GW}20$	Out	N/A	111	200	22,200	0.0000001	210	60			-20,003		
$Q_{GW}21$	Out	N/A	185	200	37,000	0.000000001	80	20			-292		
$Q_{GW}22$	Out	N/A	222	200	44,400	0.000001	70	20			-400,057		
$Q_{GW}23$	Out	N/A	111	200	22,200	0.00001	70	20			-2,000,283		
$Q_{GW}24$	Out	N/A	666	200	133,200	0.0000001	165	40			-101,833		
$Q_{GW}25$	Out	N/A	148	200	29,600	0.00001	310	40			-1,204,472		
$Q_{GW}26$	Out	N/A	370	200	74,000	0.000001	120	20			-388,944		
$Q_{GW}27$	Out	N/A	814	200	162,800	0.000000001	185	40			-1,110		
$Q_{GW}28$	Out	N/A	148	200	29,600	0.0000001	460	60			-12,176		
$Q_{GW}29$	Out	N/A	2,479	200	495,800	0.000000001	505	140			-4,335		
$Q_{GW}30$	Out	Humes Crk	259	20	5,180	0.000000001	220	60			-45		
$Q_{GW}31$	Out	Humes Crk	333	20	6,660	0.000001	175	60			-72,010		
$Q_{GW}32$	Out	Humes Crk	148	20	2,960	0.00001	1,190	20	-	-	-15,688		
$Q_{GW}33$	Out	Humes Crk	2,220	20	44,400	0.000001	350	15	-	-	-60,009		
$Q_{GW}34$	Out	Humes Crk	148	20	2,960	0.00001	1,190	20	-	-	-15,688		
$Q_{GW}35$	Out	Humes Crk	1,665	60	99,900	0.000001	155	60	-	-	-1,219,528		
$Q_{GW}36$	In	N/A	962	200	192,400	0.000001	180	20	-	-	674,170		
Total											-14,451,680	0	0

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Riverside Creek	Unknown	Downward	10%	1,000	2	0.00003	-189,216			Creek is being fed by a pond that empties into the Koksilah River.
Unknown Creek Name (south-east edge)	Unknown	Downward	10%	5,200	2	0.00003	-983,923			Creek is being fed by wetlands that empties into the Koksilah River.
Unknown Creek Name (south edge)	Unknown	Downward	10%	2,900	2	0.00003	-548,726			
Upex Creek	Unknown	Zero	0%	3,400	2	0.00003	0			Conveyance feature across the thick over burden.
Batty's Creek	Unknown	Downward	10%	1,400	2	0.00003	-264,902			
Total							**-1,986,768**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustmen t Factor	Adjusted Volume Removed	
Industrial	0	100%	0							100% consumptive
Commercial	0	100%	0							100% consumptive
Domestic	44,348	100%	44348							Assuming 100% percent goes to septic beds
Irrigation	882	100%	882							Assuming that 100% of the water is taken from a surface water source.
BC ENV Obs	0	100%	0							100% consumptive
Other	0	100%	0							100% consumptive
Water Supply system	0	100%	0							100% consumptive
Total			**-45,230**							

APPENDIX C: AQUIFER 0202 (NORTH SHAWNIGAN)

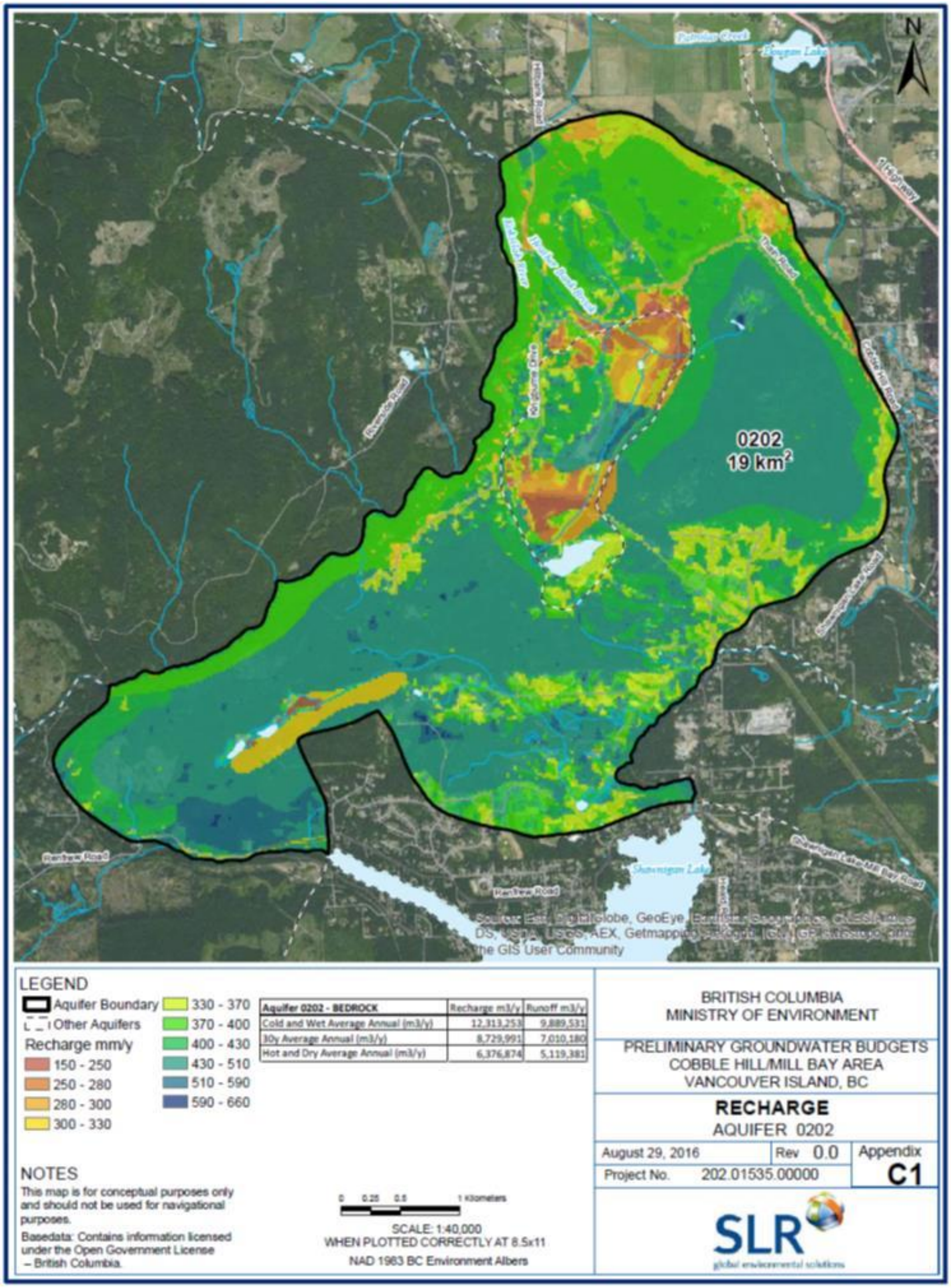


Figure C-1: Recharge distribution for bedrock aquifer 0202.

Table C-1: CHM Aquifer Criteria: Aquifer #0202, North Shawnigan (Bedrock).

BCMOE Criteria	
AQ tag	202 North Shawnigan
AQ classification	IIB(10)
AQ type	BCMOE Classification = 6b (SLR Classification = 6a / 5a-5b-6b)
Location	Shawnigan Lake / Cobble Hill; north of Shwnigan Lake , bounded to NW by Koksilah River, includes Cobble Hill & Thain wetland
Perimeter (km)	25.31
Area (km^2)	21
Aquifer materials	Bedrock
Lithostratographic unit	Bonanza Group and Sicker Volcanics
Productivity	Low
Vulnerability	Moderate
Demand	Moderate
Use	Multiple
Location	
NTS 50000	092B/12
TRIM 20000	Straddles 092B.062 and 092B.072
Lat / Long (Centre)	48o40'36" / 123o38'28"
UTM Zone 10 (Centre)	452800E / 5391700N
Climate	
Nearest active EC weather station / distance / elevation	EC1017230 Shawnigan Lake / 750 m to southeast; EC1015136 Mill Bay SW1 / 4.5 km to east-southeast
IDF Curve	Unknown
Physiography	
Physiographic zone	Straddles: Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland & Canadian Cordillera / Western System / Outer Mountain Area / Insular Mountains / Vancouver Island Ranges
Elevation range (m amsl)	60 - 320 m amsl
Distance to marine	4.3 km to east
Geomorphological setting	NE-trending series of low bedrock hills, flanked to south by deep moraine; North-central part of AQ hosts a NE-trending, elongated depression containing glaciofluvial/lacustrine materials
Topography	NE-trending line of low, sub-conical hills flanked to south by bench-like areas dropping to Shawnigan Lake; northeast area hosts large depression
Terrain	Rolling along NW side of hills, rolling to undulating elsewhere , planar in NE depression
Aspect	NW - SE trending, separated by NW line of sub-conical hills
Slope	Generally convex to planar on and flanking hills, concave around central depression
XS max grade (m/m)	0.27 to east- northeast to west-southwest, near south end
Roughness coefficient	0.60 (partly cleared, mainly coniferous cover)
Geology	
Terrane	Wrangellia / Overlap
Bedrock (age ; formation ; lithology)	
Primary	Central NE-trending V belt = Devonian Sicker Group Volcanics (muDSiD); basaltic (70%)
Secondary	E portion NE-trending central belt triangle = Triassic Karmutsen Volcanics (uTrVK); basaltic (15%)
Tertiary	North end = Upper Cretaceous Nanaimo Group (uKN); shale (5%); SSE corner = Jurassic Bonanza Group Volcanics (IJBca); andesitic (5%)
Subsidiary	Central NE-trending zone = Carboniferous Buttle Lake Group (PnPBM); limestone (2.5%); NW corner = Jurassic Island Plutonic Suite (EMJgd); granodioritic (2.5%)

Structure	2 major ENE faults cross centre of AQ - south = San Juan Fault / north = SJF splay. N-trending faults mapped in SW corner; NE end of AQ contains Wrangellia / Overlap terrane unconformity
Surficial (formation; lithology; thickness)	Vashon Drift, morainal & colluvial / Capilano Formation, glaciofluvial/lacustrine in NE depression; silt-sand; shallow - moderate blankets & veneers (> 10 m)
Surficial designation (1993)	Hilly areas = Cv/Cb/R; morainal blankets = dMb/Cb/R; NE depression = $LGp
Soils (association; parent; texture; drainage; type; comments)	Hilly areas = RL5S5/gf (Rosewall/Shawnigan), colluvial-moraine veneers, rapid - good, O.HFP-shli & DU.DYB; Morainal blankets = S1vQ5RL5/ef (Shawnigan, Qualicum,Rosewall), morainal & glaciofluvial blankets, moderate to good, DU-DYB; NE depressional area = C1AR1/b (Cowichan, Arrowsmith), marine/lacustrine blankets, imperfect to poor, O.HG & T.M
Restrictive layers	Yes - surface duric layers in Shawnigan soils / surface si-cy textures in Cowichan - Arrowsmith soils
Estimated permeability	Low - moderate @ surface from dominant M-LG / high at bedrock ct from dominant Cb-Cv
Hydrology	
GW / SW basin coincidence	No
Catchments	Koksilah / Shawnigan
Drainage regime	Radial
Surface waters	Three watercourses & wetland chains (incl. Hartl CK), three small waterbodies (inc Cobble Hill Quarry Lake & Silver Mine lakes), radial drainage / north boundary formed by Koksilah River
Runoff coefficient	~15% cleared-agricultural / ~75% forested / 10% rural residential /moderate slope = 0.60
Nearest Active EC hydrometric station; distance; type	EC 08HA003 Koksilah River @ Cowichan Station; 2.7 km NW; active realtime; + Shawnigan Creek @ Mill Bay; 4.5 km SE (inactive)
Surface water diversions ; relevance	22 within AQ boundaries, Koksilah & Hartl Ck, springs ; relevant
Land Cover	
Vegetation zone	Cgf-wC
Primary land uses	Forestry / agricultural / rural residential
Degree of development	Low, mainly forestry & agricultural. Very low impervious cover
Evapotranspiration potential	High
Relative environmental sensitivity	Moderate
Hydrogeology	
Groundwater occurrence (primary / secondary)	Void infillings - bedrock fractures & faults, karst solution cavities
Primary porosity	Low
Secondary porosity	Moderate (probable good open void space due to brittle rock & local karst solution cavities; elevated along SJF and splays)
Confinement	Unconfined to semiconfined - assume bedrock fractures / karst cavities generally daylight to surface. Morainal blanket areas locally semi-confined by duric till blankets; WP = 0 - 53.3 m, avg 2.1 m
Aquifer thickness	Bedrock aquifer / assume < 150 m
Hydraulic anisotropy	High
Hydraulic gradient	Moderate to high based on terrain
Storage potential	Low - moderate due to proximity / presence of large structures & brittle rocks
Yield potential	Low - moderate; WP = 0.02 - 5.68 L/s / average 0.19 L/s
Flow velocities	Moderate to high
Flow directions	Radial, generally NW to Koksilah River or SE to Shawnigan Creek
Static water levels	WP = variable 0 - 81.7 m bgs / avg 8.4 m bgs
Hydraulic connection with surface waters	High - likely provides baseflow to Koksilah River mainstem & tributaries + Hartl Creek mainstem & tributaries
Hydraulic connection to adjacent AQ	

Over / Under	NE part overlain by surficial AQ201
Upgradient	Upgradient contact with bedrock AQ 200 & undeveloped extension of AQ202
Downgradient	Downgradient contact with surficial AQ 199, surficial AQ 197, bedrock AQ 204, bedrock AQ207, bedrock AQ203, undeveloped extension to bedrock AQ 202
Vulnerability to surface contamination	Moderate to high
Recharge	
Vertical inflow	Mainly precipitation, limited snowmelt / irrigation / sewerage. Low from stream loss. Low from from overlying surficial AQ201
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock sources / possible increased K along thrust faults
Temporal variability	High, linked to precipitation trends
MBR	High from internal (Cobble Hill) and upgradient (northwest) rocky hills
Discharge	
Evapotranspiration	High
Outflow to marine	None
Outflow to surface waters	High to Koksilah River along NW border & internally to Hartl Ck
Outflow to other AQ	High - possible MBR zone to downgradient aquifers
Temporal variability	High
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #320; 2.0 km ENE; completed in surficial AQ197; irrelevant
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	0
Commercial	7300
Domestic	110837
Irrigation from GW (MoAg)	6458
BCMOE Obs	0
Other	10950
Water Supply Systems	56310

Table C-2: Direct Recharge Calculation for AQ202.

	Direct Recharge Calculation		
	Hot/Dry	**Average**	**Cold/Wet**
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.09	1.09	1.09
Infiltration Coefficient	0.562	0.562	0.562
Area (m^2)	18,884,419	18,884,419	18,884,419
Q (m^3/yr)	5,921,169	8,801,581	14,606,582
Average Infiltration Rate	0.314	0.466	0.773

Table C-3: Annual Summary of AQ202 Water Budgets.

Gains and Losses	Source	Area (m^2)	Infiltration Rate	Q (m^3/yr)
Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 202	18,884,419	0.466	8,801,581
Gain	Leakage down from 201	2,112,633	0.300	633,790
Loss	Lateral Ground Water	--	--	-16,947,772
Gain	Lateral Ground Water	--	--	3,695,718
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	1,173,139
Loss	Water Usage	--	--	-191,855
Net Gain				**14,304,227**
Net Loss				**-17,139,627**
Net Total (Gain - Loss)				**-2,835,400**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 202	18,884,419	0.314	5,921,169
Gain	Leakage down from 201	2,112,633	0.300	633,790
Loss	Lateral Ground Water	--	--	-16,947,772
Gain	Lateral Ground Water	--	--	3,695,718
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	1,173,139
Loss	Water Usage	--	--	-191,855
Net Gain				**11,423,816**
Net Loss				**-17,139,627**
Net Total (Gain - Loss)				**-5,715,811**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 202	18,884,419	0.773	14,606,582
Gain	Leakage down from 201	2,112,633	0.300	633,790
Loss	Lateral Ground Water	--	--	-16,947,772
Gain	Lateral Ground Water	--	--	3,695,718
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	1,173,139
Loss	Water Usage	--	--	-191,855
Net Gain				**20,109,229**
Net Loss				**-17,139,627**
Net Total (Gain - Loss)				**2,969,602**

Table C-4: Monthly Summary of AQ202 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 202	2,213,319	1,441,670	1,040,412	249,856	-300,749	-474,258	-462,690	-208,211	-69,404	760,930	2,334,706	2,275,998	**8,801,581**
Leakage down from 201	51,337	49,436	55,140	54,506	57,041	54,506	55,140	53,872	51,337	51,971	49,436	50,069	**633,790**
Lateral Groundwater Loss	-1,372,770	-1,321,926	-1,474,456	-1,457,508	-1,525,300	-1,457,508	-1,474,456	-1,440,561	-1,372,770	-1,389,717	-1,321,926	-1,338,874	**-16,947,772**
Lateral Groundwater Gain	299,353	288,266	321,527	317,832	332,615	317,832	321,527	314,136	299,353	303,049	288,266	291,962	**3,695,718**
Surface Water Loss	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Gain	258,889	227,283	164,179	79,381	28,147	11,416	6,780	2,202	1,852	16,995	120,106	255,908	**1,173,139**
Water Usage	-48,245	-31,425	-22,679	-5,446	6,556	10,338	10,086	4,539	1,513	-16,587	-50,891	-49,612	**-191,855**
Net Gain	**2,822,898**	**2,006,655**	**1,581,258**	**701,575**	**424,358**	**394,092**	**393,533**	**374,749**	**354,055**	**1,132,944**	**2,792,514**	**2,873,938**	**15,852,569**
Net Loss	**-1,421,015**	**-1,353,351**	**-1,497,135**	**-1,462,955**	**-1,826,048**	**-1,931,766**	**-1,937,147**	**-1,648,771**	**-1,442,173**	**-1,406,304**	**-1,372,818**	**-1,388,486**	**-18,687,969**
Net Total (Gain - Loss)	**1,401,883**	**653,304**	**84,123**	**-761,380**	**-1,401,690**	**-1,537,674**	**-1,543,614**	**-1,274,022**	**-1,088,119**	**-273,360**	**1,419,696**	**1,485,452**	**-2,835,400**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 200	1,815,469	1,041,053	1,618,739	97,165	-381,720	-485,825	-416,421	-173,509	-115,673	294,965	1,157,883	1,469,042	**5,921,169**
Leakage down from 201	51,971	48,168	53,238	52,605	55,140	53,238	55,140	54,506	51,971	53,872	51,337	52,605	**633,790**
Lateral Groundwater	-1,389,717	-1,288,031	-1,423,613	-1,406,665	-1,474,456	-1,423,613	-1,474,456	-1,457,508	-1,389,717	-1,440,561	-1,372,770	-1,406,665	**-16,947,772**
Lateral Groundwater	303,049	280,875	310,440	306,745	321,527	310,440	321,527	317,832	303,049	314,136	299,353	306,745	**3,695,718**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	70,388	76,254	87,985	93,851	105,583	117,314	129,045	134,911	117,314	93,851	82,120	64,523	**1,173,139**
Water Usage	-11,511	-12,471	-14,389	-15,348	-17,267	-19,186	-21,104	-22,063	-19,186	-15,348	-13,430	-10,552	**-191,855**
Net Gain	**2,240,877**	**1,446,350**	**2,070,403**	**550,365**	**482,250**	**480,993**	**505,712**	**507,249**	**472,334**	**756,824**	**1,590,693**	**1,892,914**	**12,996,963**
Net Loss	**-1,401,229**	**-1,300,501**	**-1,438,002**	**-1,422,013**	**-1,873,443**	**-1,928,623**	**-1,911,982**	**-1,653,081**	**-1,524,575**	**-1,455,909**	**-1,386,199**	**-1,417,217**	**-18,712,775**
Net Total (Gain - Loss)	**839,648**	**145,849**	**632,401**	**-871,648**	**-1,391,193**	**-1,447,631**	**-1,406,269**	**-1,145,832**	**-1,052,242**	**-699,085**	**204,493**	**475,697**	**-5,715,811**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 200	4,107,534	4,158,649	1,542,299	-185,076	-150,374	-393,287	-508,959	-208,211	-92,538	1,458,632	2,357,408	2,520,506	**14,606,582**
Leakage down from 201	51,337	49,436	55,140	54,506	57,041	54,506	55,140	53,872	51,337	51,971	49,436	50,069	**633,790**
Lateral Groundwater	-1,372,770	-1,321,926	-1,474,456	-1,457,508	-1,525,300	-1,457,508	-1,474,456	-1,440,561	-1,372,770	-1,389,717	-1,321,926	-1,338,874	**-16,947,772**
Lateral Groundwater	299,353	288,266	321,527	317,832	332,615	317,832	321,527	314,136	299,353	303,049	288,266	291,962	**3,695,718**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	258,889	227,283	164,179	79,381	28,147	11,416	6,780	2,202	1,852	16,995	120,106	255,908	**1,173,139**
Water Usage	-11,511	-12,471	-14,389	-15,348	-17,267	-19,186	-21,104	-22,063	-19,186	-15,348	-13,430	-10,552	**-191,855**
Net Gain	**4,717,114**	**4,723,634**	**2,083,146**	**451,719**	**417,802**	**383,754**	**383,447**	**370,210**	**352,542**	**1,830,646**	**2,815,216**	**3,118,446**	**21,647,675**
Net Loss	**-1,384,281**	**-1,334,397**	**-1,488,845**	**-1,657,933**	**-1,692,941**	**-1,869,981**	**-2,004,520**	**-1,670,835**	**-1,484,493**	**-1,405,066**	**-1,335,356**	**-1,349,426**	**-18,678,073**
Net Total (Gain - Loss)	**3,332,833**	**3,389,237**	**594,300**	**-1,206,214**	**-1,275,138**	**-1,486,227**	**-1,621,073**	**-1,300,624**	**-1,131,951**	**425,580**	**1,479,859**	**1,769,020**	**2,969,602**

Table C-5: Monthly Coefficients used in Calculations for AQ202.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table C-6: Groundwater Impacts: Aquifer #0202, North Shawnigan (Bedrock).

Groundwater Flow	**Direction of Flow**	**Source or Receptor of Water**	**Length (m)**	**Depth (m)**	**Area (m)**	**Hydraulic Conductivity (m/s) - K**	**Distance (m) - dL**	**Hydraulic Head (m) - dh**			**GW Flow (m^3/yr)**		
								Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
$Q_{GW}1$	Out	N/A	428	200	85,680	0.000000001	150	20			-360		
$Q_{GW}2$	Out	N/A	321	200	64,260	0.00001	150	20			-2,702,004		
$Q_{GW}3$	Out	N/A	179	200	35,700	0.000001	140	20			-160,834		
$Q_{GW}4$	Out	N/A	250	200	49,980	0.00001	140	20			-2,251,670		
$Q_{GW}5$	N/A	N/A	607	200	121,380	0.000001	1	0			0		
$Q_{GW}6$	Out	N/A	536	200	107,100	0.000001	205	60			-988,538		
$Q_{GW}7$	Out	Koksilah R.	179	40	7,140	0.000001	155	80			-116,215		
$Q_{GW}8$	Out	Koksilah R.	107	40	4,284	0.00001	145	80			-745,381		
$Q_{GW}9$	Out	Koksilah R.	143	40	5,712	0.000001	155	80			-92,972		
$Q_{GW}10$	Out	Koksilah R.	107	40	4,284	0.00001	145	80			-745,381		
$Q_{GW}11$	Out	Koksilah R.	536	40	21,420	0.000001	125	80			-432,321		
$Q_{GW}12$	In	Koksilah R.	107	40	4,284	0.00001	--	--	--	--	1,028,717		
$Q_{GW}13$	Out	Koksilah R.	536	40	21,420	0.000001	195	60			-207,846		
$Q_{GW}14$	In	Koksilah R.	143	40	5,712	0.00001	--	--	--	--	1,121,954		
$Q_{GW}15$	Out	Koksilah R.	428	40	17,136	0.000001	320	80			-135,100		

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Q_{GW}16	In	Koksilah R.	143	40	5,712	0.00001	--	--	--	--	1,545,047		
Q_{GW}17	Out	Koksilah R.	1,535	40	61,404	0.000001	350	60			-331,961		
Q_{GW}18	Out	Koksilah R.	179	40	7,140	0.00001	110	20			-409,395		
Q_{GW}19	Out	Koksilah R.	1,250	40	49,980	0.000001	200	80			-630,468		
Q_{GW}20	Out	Koksilah R.	179	40	7,140	0.00001	735	40			-122,540		
Q_{GW}21	Out	Koksilah R.	357	40	14,280	0.000001	250	80			-144,107		
Q_{GW}22	Out	Koksilah R.	214	40	8,568	0.000000001	260	60			-62		
Q_{GW}23	Out	AQ 199	107	200	21,420	0.00000001	510	60			-795		
Q_{GW}24	Out	AQ 199	214	200	42,840	0.000000001	600	80			-180		
Q_{GW}25	Out	AQ 199	143	200	28,560	0.00000001	665	100			-1,354		
Q_{GW}26	Out	AQ 199	1,821	200	364,140	0.000000001	575	100			-1,997		
Q_{GW}27	Out	AQ 197	143	200	28,560	0.0000001	235	20			-7,665		
Q_{GW}28	Out	AQ 197	286	200	57,120	0.000000001	235	20			-153		
Q_{GW}29	Out	AQ 197	1,178	200	235,620	0.0000001	335	100			-221,806		
Q_{GW}30	Out	AQ 204	1,285	200	257,040	0.000001	525	140			-2,161,604		
Q_{GW}31	Out	AQ 204	179	200	35,700	0.00001	150	20			-1,501,114		
Q_{GW}32	Out	AQ 204	821	200	164,220	0.000001	555	80	-	-	-746,500		
Q_{GW}33	Out	AQ 204	143	200	28,560	0.00001	100	20	-	-	-1,801,336		
Q_{GW}34	Out	AQ 204	179	20	3,570	0.00001	1,900	40	-	-	-23,702		
Q_{GW}35	Out	Shawnigan Crk	131	100	13,090	0.00001	315	20	-	-	-262,099		
Q_{GW}36	Out	Shawnigan Crk	179	20	3,570	0.000000001	65	10	-	-	-17		
Q_{GW}37	Out	Shawnigan Crk	179	20	3,570	0.00000001	65	10	-	-	-173		
Q_{GW}38	Out	Shawnigan Crk	1,250	20	24,990	0.000000001	65	10	-	-	-121		
Q_{GW}39	N/A	AQ 203	2,499	200	499,800	0.000000001	1	0	-	-	0		
Q_{GW}40	N/A	AQ 203	678	200	135,660	0.00001	1	0	-	-	0		
Q_{GW}41	N/A	AQ 203	500	200	99,960	0.000001	1	0	-	-	0		
Q_{GW}42	N/A	AQ 203	286	200	57,120	0.0001	1	0	-	-	0		
Q_{GW}43	N/A	AQ 203	286	200	57,120	0.000001	1	0	-	-	0		
Q_{GW}44	N/A	AQ 203	107	200	21,420	0.0001	1	0	-	-	0		
Q_{GW}45	N/A	AQ 203	214	200	42,840	0.000001	1	0	-	-	0		
Q_{GW}46	N/A	AQ 203	357	200	71,400	0.00001	1	0	-	-	0		
Q_{GW}47	N/A	AQ 203	107	200	21,420	0.000000001	1	0	-	-	0		
Q_{GW}48	In	Leakage from AQ 201	Leakance Factor (m/yr) =	0.300	2,112,633	--	--	--			633,790		
Total											-12,618,265		

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Haril Creek	Unknown	Downward	10%	3800	2	0.00003	719,021			
Timothy Brook	Unknown	Downward	10%	1100	2	0.00003	208,138			
Heather Bank Brook	Unknown	Downward	10%	1300	2	0.00003	245,981			
Total							**1,173,139**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	0	100%	0							100% consumptive
Commercial	7,300	100%	7300							100% consumptive
Domestic	110,837	100%	110837							100% consumptive
Irrigation	0	100%	0							100% consumptive
BC ENV Obs	0	100%	0							100% consumptive
Other	10,950	100%	10950							100% consumptive
Water Supply system	56,310	100%	56310							100% consumptive
Total			**-185,397**							100% consumptive

APPENDIX D: AQUIFER 0203 (SHAWNIGAN LAKE)

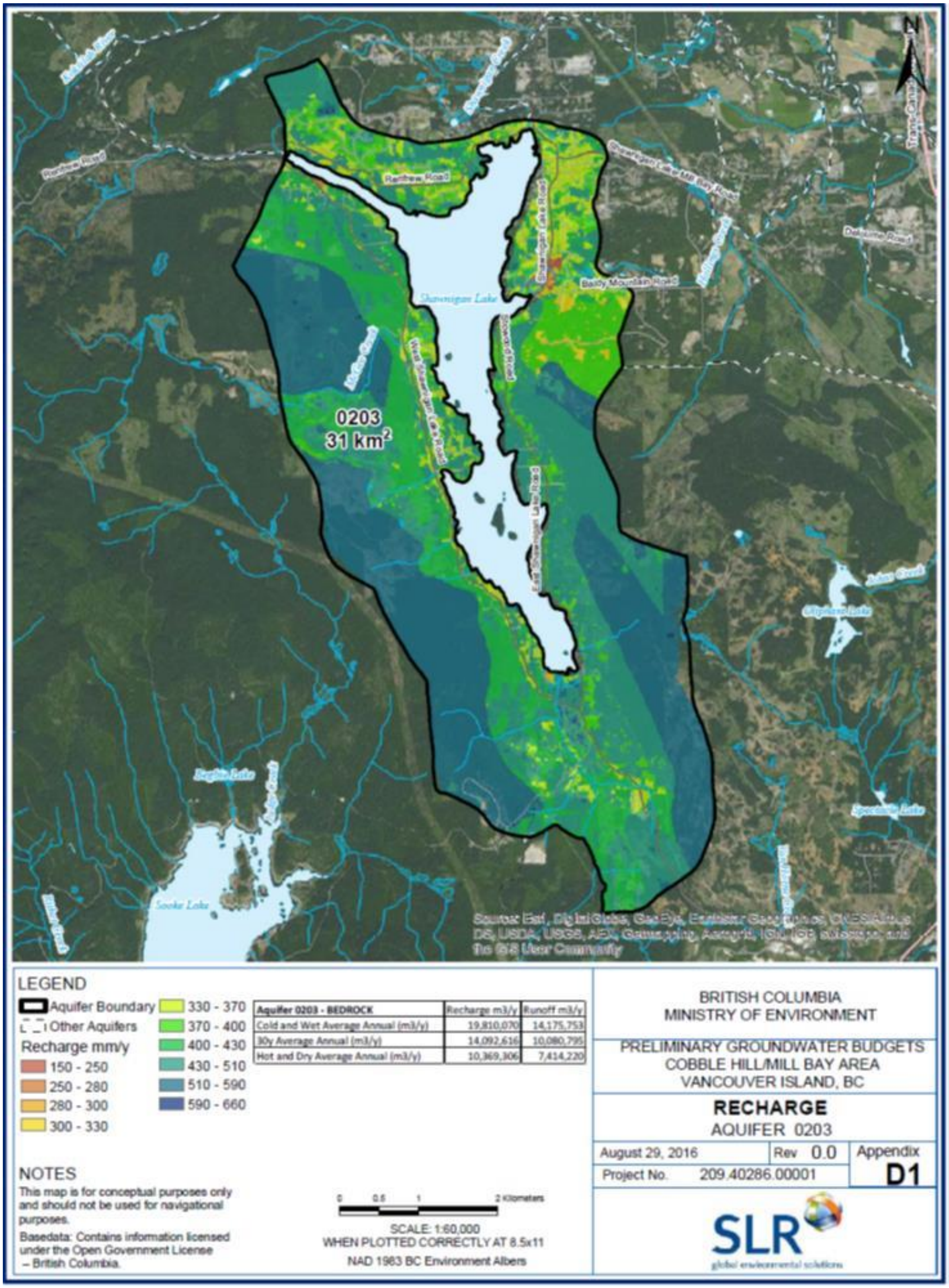


Figure D-1: Recharge distribution for bedrock aquifer 0203.

Table D-1: CHM Aquifer Criteria: Aquifer #0203, Shawnigan Lake (Bedrock).

BCMOE Criteria	
AQ tag	203 Shawnigan Lake
AQ classification	IIA(12)
AQ type	BCMOE Classification = 6b (SLR Classification = 6b / 6a / 5b)
Location	Shawnigan Lake / Cobble Hill; Shawnigan Lake watershed basin
Perimeter (km)	54
Area (km^2)	31
Aquifer materials	Bedrock
Lithostratographic unit	Wark-Colquitz Gneiss & Bonanza Group
Productivity	Low
Vulnerability	High
Demand	Moderate
Use	Multiple
Location	
NTS 50000	092B/12
TRIM 20000	Straddles 092B.062 & 092B.052
Lat / Long (Centre)	48°37'12" / 123°38'18"
UTM Zone 10 (Centre)	452960E / 5385390N
Climate	
Nearest active EC weather station / distance / elevation	EC1017230 Shawnigan Lake / NE corner of AQ ; EC1017563 Sooke Lake North / 1.9 km to southwest
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Outer Mountain Area / Insular Mountains / Vancouver Island Ranges
Elevation range (m amsl)	120 - 580 m amsl
Distance to marine	4.4 km southeast to Findlayson Arm
Geomorphological setting	Shawnigan Lake basin: linear, U-shaped valley, basal morainal blankets & veneers, lateral glaciofluvial terraces & kames, exposed higher areas
Topography	U-shaped basin, overall drainage towards north-northwest
Terrain	Undulating to hummocky & rugged at higher elevations; undulating to planar at lower elevations
Aspect	Basinal centred on Shawnigan Lake: ENE and WSW at valley head and flanks, N to NE at north outflow
Slope	Variable, planar-convex-concave depending on centripetal stream locations & subcatchment morphologies
XS max grade (m/m)	0.001 to N-S; max gradient = 0.14 west side, E-W
Roughness coefficient	0.65 (partly cleared / coniferous cover)
Geology	
Terrane	Wrangellia
Bedrock (age ; formation ; lithology)	
Primary	South 2/3 = Palaeozoic to Jurasssic Westcoast Crystalline Complex (Wark / Colquitz Gneiss) (PzJWg); variably gabbroic to granodioritic (65%)
Secondary	North 1/3 = Jurassic Bonanza Group Volcanics (IJBca); basaltic-andesitic (30%);
Tertiary	Small Middle-Upper Triassic Quatsino Formation (uTrVQ) limestone wedge at contact on east side of Lake (5%)
Structure	Several major, high-angle faults: (1) NE-trending Shawnigan Fault; follows Sooke Lk -> Lubbe Lake -> S Baldy Mountain Pass -> Mill Bay lineament; crosses AQ at southern third; BCGS = offsets PzJWg:IJBca contact; (2) NW-trending Spectacle Lake & Oliphant Faults; follow Spectacle Creek and Bamberton / Oliphant Lake lineaments; intersects AQ on SE side, does not appear to cross Shawnigan Fault; not mapped by BCGS; (3) N-trending Devereaux/Stebbings Fault swarm; follows south end of Shawnigan Creek lineament; intersects south end of AQ, does not seem to cross Shawnigan Fault; not mapped by BCGS; (4) Numerous other high-

	angle & low angle minor structures known at south end of AQ basin, variable strikes & dips, not mapped by BCGS
Surficial (formation; lithology; thickness)	Capilano Formation glaciofluvial / Vashon Drift morainal; silt-sand-gravel; generally moderately shallow blankets (< 10 m); higher areas - mainly colluvial veneers; mid-elevations = morainal-glaciofluvial materials; basal areas = glaciofluvial & glaciolacustrine materials
Surficial designation (1993)	Higher elevations = CbCv/R Mid-elevations =dMbvCbv/R & $dMbh/$oP/SGfg Lower elevations = $oP & $LGp
Soils (association; parent; texture; drainage; type; comments)	Higher elevations = SL1S3/ef (Squally/Shawnigan), colluvial-moraine veneers, rapid, O.DYB-shli & DU.DYB; Mid-elevations = S3S1/e & D2S3RL5/Fe (Shawnigan / Dashwood/Rosewall), morainal & glaciofluvial blankets & veneers, moderate to good, DU-DYB; Low ares = Q/CH4 (Qualicum/Chemainus), marine/fluvialblankets, imperfect to poor, D.DYB & O.DYB
Restrictive layers	Yes - surface duric layer in morainal areas
Estimated permeability	Low-moderate @ surface in duric morainal areas / high in colluvial & bedrock areas
Hydrology	
GW / SW basin coincidence	Yes - Occupies lake area and headwaters of Shawnigan watershed
Catchments	Shawnigan & lower McGee
Drainage regime	Centripetal, overall flow to north
Surface waters	Shawnigan Lake; Shawnigan / McGee Creeks; numerous small streams centred on Shawnigan Lake
Runoff coefficient	~60% cleared-forestry / ~30% forested / 10% rural residential / moderate slope = 0.60
Nearest Active EC hydrometric station; distance; type	Shawnigan Creek @ Mill Bay; 4.1 km E (inactive); EC 08HA003 Koksilah River @ Cowichan Station; 9.0 km NNW; active realtime;
Surface water diversions ; relevance	6 within south end of AQ area, numerous diversion licences on Shawnigan Lake; somewhat relevant
Land Cover	
Vegetation zone	CwH:a
Primary land uses	Cgf-wC
Degree of development	Shawnigan Lake village at NE corner; Highly developed throughout for forestry purposes. Extensive rural residential. Very low impervious cover
Evapotranspiration potential	High
Relative environmental sensitivity	High
Hydrogeology	
Groundwater occurrence (primary / secondary)	Void infillings - bedrock fractures & faults, karst solution cavities
Primary porosity	Low to negligible
Secondary porosity	Low to moderate in gneissic areas, higher in fractue zones & faults; low in volcanics areas due to ductile rock
Confinement	Higher areas = Unconfined to semiconfined - assume bedrock fractures generally daylight to surface. Morainal blanket areas locally semi-confined by duric till blankets; WP = 0 - 59.7 m, avg 0.3 m
Aquifer thickness	Bedrock aquifer / assume < 150 m
Hydraulic anisotropy	High
Hydraulic gradient	Moderate to high based on terrain
Storage potential	Low - secondary voids only
Yield potential	Low; WP = 0.01 - 4.42 L/s / average 0.19 L/s
Flow velocities	Low - moderate
Flow directions	Centripetal towards Shawnigan Lake / modified faults
Static water levels	WP = variable 0 - 59.9 m bgs / avg 5.9 m bgs
Hydraulic connection with surface waters	High

Hydraulic connection to adjacent AQ	
Over / Under	None
Upgradient	Upgradient contact with undeveloped west, south, & east extensions of bedrock AQ 203 (not in study area); bedrock AQ 202;
Downgradient	Downgradient contact in NE quarter with bedrock AQ207
Vulnerability to surface contamination	High
Recharge	
Vertical inflow	Mainly precipitation, limited snowmelt / sewerage. Moderate to high from stream loss. Moderate irrigation return at north end (Shawnigan Lake School)
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock sources (west = AQ203 extension / south & east from undeveloped MBR bedrock area (Malahat Ridge);
Temporal variability	High
MBR	High from surrounding rocky hills to the west, south, and east
Discharge	
Evapotranspiration	High
Outflow to marine	None
Outflow to surface waters	High to Shawnigan Lake & feeder streams
Outflow to other AQ	Moderate in NE quarter to bedrock AQ 207
Temporal variability	High
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #320 = 5.3 m northeast of north end of AQ; completed in surficial materials; irrelevant
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	0
Commercial	14600
Domestic	211827
Irrigation from GW (MoAg)	87428
BCMOE Obs	0
Other	29200
Water Supply Systems	149851

Table D-2: Direct Recharge Calculation for AQ203.

	Direct Recharge Calculation		
	Hot/Dry	**Average**	**Cold/Wet**
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.130	1.130	1.130
Infiltration Coefficient	0.583	0.583	0.583
Area (m^2)	31,016,823	31,016,823	31,016,823
Q (m^3/yr)	10,451,518	15,535,762	25,782,231
Average Infiltration Rate	0.337	0.501	0.831

Table D-3: Annual Summary of AQ203 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 203	31,016,823	0.501	15,535,762
Loss	Lateral Ground Water	--	--	-5,852
Gain	Lateral Ground Water	--	--	37,955
Loss	Surface Water	--	--	-16,339,122
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-492,906
Net Gain				**15,573,717**
Net Loss				**-16,837,880**
Net Total (Gain - Loss)				**-1,264,163**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 203	31,016,823	0.337	10,451,518
Loss	Lateral Ground Water	--	--	-5,852
Gain	Lateral Ground Water	--	--	58,211
Loss	Surface Water	--	--	-16,339,122
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-492,906
Net Gain				**10,509,729**
Net Loss				**-16,837,880**
Net Total (Gain - Loss)				**-6,328,151**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 203	31,016,823	0.831	25,782,231
Loss	Lateral Ground Water	--	--	-5,459
Gain	Lateral Ground Water	--	--	32,103
Loss	Surface Water	--	--	-16,339,122
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-492,906
Net Gain				**25,814,334**
Net Loss				**-16,837,487**
Net Total (Gain - Loss)				**8,976,847**

Table D-4: Monthly Summary of AQ203 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 203	3,906,752	2,544,708	1,836,442	441,023	-530,855	-837,117	-816,700	-367,515	-122,505	1,343,126	4,121,015	4,017,389	**15,535,762**
Lateral Groundwater Loss	-474	-456	-509	-503	-527	-503	-509	-497	-474	-480	-456	-462	**-5,852**
Lateral Groundwater Gain	3,074	2,960	3,302	3,264	3,416	3,264	3,302	3,226	3,074	3,112	2,960	2,998	**37,955**
Surface Water Loss	-3,605,732	-3,165,534	-2,286,639	-1,105,597	-392,019	-159,002	-94,429	-30,672	-25,789	-236,695	-1,672,802	-3,564,214	**-16,339,122**
Surface Water Gain	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-29,574	-32,039	-36,968	-39,432	-44,362	-49,291	-54,220	-56,684	-49,291	-39,432	-34,503	-27,110	**-492,906**
Net Gain	**3,909,826**	**2,547,668**	**1,839,744**	**444,288**	**3,416**	**3,264**	**3,302**	**3,226**	**3,074**	**1,346,238**	**4,123,975**	**4,020,387**	**18,248,408**
Net Loss	**-3,635,780**	**-3,198,029**	**-2,324,116**	**-1,145,533**	**-967,762**	**-1,045,913**	**-965,857**	**-455,369**	**-198,058**	**-276,607**	**-1,707,762**	**-3,591,786**	**-19,512,572**
Net Total (Gain - Loss)	**274,046**	**-650,361**	**-484,372**	**-701,245**	**-964,346**	**-1,042,649**	**-962,555**	**-452,143**	**-194,984**	**1,069,631**	**2,416,213**	**428,601**	**-1,264,163**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 203	3,204,503	1,837,574	2,857,253	171,507	-673,777	-857,535	-735,030	-306,262	-204,175	520,646	2,043,791	2,593,022	**10,451,518**
Lateral Groundwater	-480	-445	-492	-486	-509	-492	-509	-503	-480	-497	-474	-486	**-5,852**
Lateral Groundwater	4,773	4,424	4,890	4,831	5,064	4,890	5,064	5,006	4,773	4,948	4,715	4,831	**58,211**
Surface Water	-3,605,732	-3,165,534	-2,286,639	-1,105,597	-392,019	-159,002	-94,429	-30,672	-25,789	-236,695	-1,672,802	-3,564,214	**-16,339,122**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-29,574	-32,039	-36,968	-39,432	-44,362	-49,291	-54,220	-56,684	-49,291	-39,432	-34,503	-27,110	**-492,906**
Net Gain	**3,209,277**	**1,841,998**	**2,862,143**	**176,338**	**5,064**	**4,890**	**5,064**	**5,006**	**4,773**	**525,594**	**2,048,506**	**2,597,853**	**13,286,508**
Net Loss	**-3,635,786**	**-3,198,017**	**-2,324,098**	**-1,145,515**	**-1,110,666**	**-1,066,319**	**-884,187**	**-394,122**	**-279,734**	**-276,625**	**-1,707,779**	**-3,591,810**	**-19,614,659**
Net Total (Gain - Loss)	**-426,509**	**-1,356,019**	**538,045**	**-969,177**	**-1,105,602**	**-1,061,429**	**-879,123**	**-389,116**	**-274,961**	**248,969**	**340,727**	**-993,956**	**-6,328,151**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 203	6,483,414	4,223,046	3,047,650	731,896	-880,975	-1,389,230	-1,355,347	-609,906	-203,302	2,228,972	6,838,992	6,667,020	**25,782,231**
Lateral Groundwater	-442	-426	-475	-469	-491	-469	-475	-464	-442	-448	-426	-431	**-5,459**
Lateral Groundwater	2,600	2,504	2,793	2,761	2,889	2,761	2,793	2,729	2,600	2,632	2,504	2,536	**32,103**
Surface Water	-3,605,732	-3,165,534	-2,286,639	-1,105,597	-392,019	-159,002	-94,429	-30,672	-25,789	-236,695	-1,672,802	-3,564,214	**-16,339,122**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-29,574	-32,039	-36,968	-39,432	-44,362	-49,291	-54,220	-56,684	-49,291	-39,432	-34,503	-27,110	**-492,906**
Net Gain	**6,486,014**	**4,225,550**	**3,050,443**	**734,657**	**2,889**	**2,761**	**2,793**	**2,729**	**2,600**	**2,231,605**	**6,841,496**	**6,669,556**	**30,253,094**
Net Loss	**-3,635,748**	**-3,197,998**	**-2,324,082**	**-1,145,499**	**-1,317,847**	**-1,597,992**	**-1,504,470**	**-697,727**	**-278,823**	**-276,575**	**-1,707,731**	**-3,591,755**	**-21,276,247**
Net Total (Gain - Loss)	**2,850,266**	**1,027,552**	**726,362**	**-410,842**	**-1,314,957**	**-1,595,232**	**-1,501,677**	**-694,998**	**-276,223**	**1,955,030**	**5,133,765**	**3,077,801**	**8,976,847**

Table D-5: Monthly Coefficients used in Calculations for AQ203.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table D-6: Groundwater Flow Components: Aquifer #0203, North Shawnigan (Bedrock)

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}1$	Zero	AQ 202	428	200	85,680	0.00001	1	0			0		
$Q_{GW}2$	Zero	AQ 202	571	200	114,240	0.000001	1	0			0		
$Q_{GW}3$	Zero	AQ 202	762	200	152,320	0.0001	1	0			0		
$Q_{GW}4$	Zero	AQ 202	190	200	38,080	0.000001	1	0			0		
$Q_{GW}5$	Zero	N/A	476	200	95,200	0.00001	1	0			0		
$Q_{GW}6$	Zero	N/A	1,142	200	228,480	0.000000001	1	0			0		
$Q_{GW}7$	Zero	N/A	143	200	28,560	0.00000001	1	0			0		
$Q_{GW}8$	Zero	N/A	2,570	200	514,080	0.000000001	1	0			0		
$Q_{GW}9$	In	N/A	143	200	28,560	0.0000001	2,200	40			1,638		
$Q_{GW}10$	In	N/A	476	200	95,200	0.000000001	2,200	40			55		
$Q_{GW}11$	In	N/A	143	200	28,560	0.0000001	2,200	40			1,638		
$Q_{GW}12$	Zero	N/A	3,570	200	714,000	0.000000001	1	0	-	-	0		
$Q_{GW}13$	Zero	N/A	333	200	66,640	0.0000001	1	0			0		
$Q_{GW}14$	Zero	N/A	1,904	200	380,800	0.000000001	1	0			0		
$Q_{GW}15$	In	N/A	1,904	200	380,800	0.00000001	1,410	100			8,517		

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}16$	In	N/A	857	200	171,360	0.000000001	635	40			340		
$Q_{GW}17$	In	N/A	143	200	28,560	0.0000001	1,015	80			7,099		
$Q_{GW}18$	Out	N/A	1,142	60	68,544	0.000000001	220	40			-393		
$Q_{GW}19$	Zero	N/A	1,047	200	209,440	0.000000001	1	0					
$Q_{GW}20$	Zero	N/A	143	200	28,560	0.0000001	1	0			0		
$Q_{GW}21$	Zero	N/A	476	200	95,200	0.000000001	1	0			0		
$Q_{GW}22$	Zero	N/A	3,094	200	618,800	0.00000001	1	0			0		
$Q_{GW}23$	Zero	N/A	143	200	28,560	0.0000001	1	0			0		
$Q_{GW}24$	Zero	N/A	619	200	123,760	0.000000001	1	0			0		
$Q_{GW}25$	In	N/A	762	200	152,320	0.000000001	260	40			739		
$Q_{GW}26$	Zero	N/A	857	200	171,360	0.000000001	1	0			0		
$Q_{GW}27$	In	N/A	286	200	57,120	0.0000001	645	60			16,757		
$Q_{GW}28$	In	N/A	571	200	114,240	0.000000001	645	60			335		
$Q_{GW}29$	In	N/A	143	200	28,560	0.00000001	645	60			838		
$Q_{GW}30$	Zero	AQ 207	2,523	200	504,560	0.000000001	1	0			0		
$Q_{GW}31$	Zero	AQ 207	143	200	28,560	0.00000001	1	0			0		
$Q_{GW}32$	Zero	AQ 207	571	200	114,240	0.000000001	1	0			0		
$Q_{GW}33$	Zero	AQ 207	143	200	28,560	0.00000001	1	0	-	-	0		
$Q_{GW}34$	Zero	AQ 207	952	200	190,400	0.000000001	1	0	-	-	0		
$Q_{GW}35$	Out	AQ 207	238	200	47,600	0.0000001	550	20	-	-	-5,459		
$Q_{GW}36$	Zero	AQ 202	3,094	200	618,800	0.000000001	1	0	-	-	0		
Total											32,103		

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Major River Out	--	Percent of Catchment Area=	33%	Infiltration Factor=	0.58	79,778,200	-15,374,121			Average annual flow calculated from flow station down gradient of Shawnigan Lake. Assuming AQ203 takes up 33.26% of the creeks catchment area.
McGee Creek	Unknown	Upward	10%	2,800	2	0	-529,805			
Van Horn Creek	Unknown	Upward	10%	2,300	2	0	-435,197			
Total							**-16,339,122**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustmen t Factor	Adjusted Volume Removed	
Industrial	0	100%	0							100% consumptive
Commercial	14,600	100%	14,600							100% consumptive
Domestic	211,827	100%	211,827							100% consumptive
Irrigation	6,458	100%	6,458							100% consumptive
BC ENV Obs	0	100%	0							100% consumptive
Other	29,200	100%	29,200							100% consumptive
Water Supply system	149,851	100%	149,851							100% consumptive
Total			**-411,936**							100% consumptive

APPENDIX E: AQUIFER 0204 (COBBLE HILL)

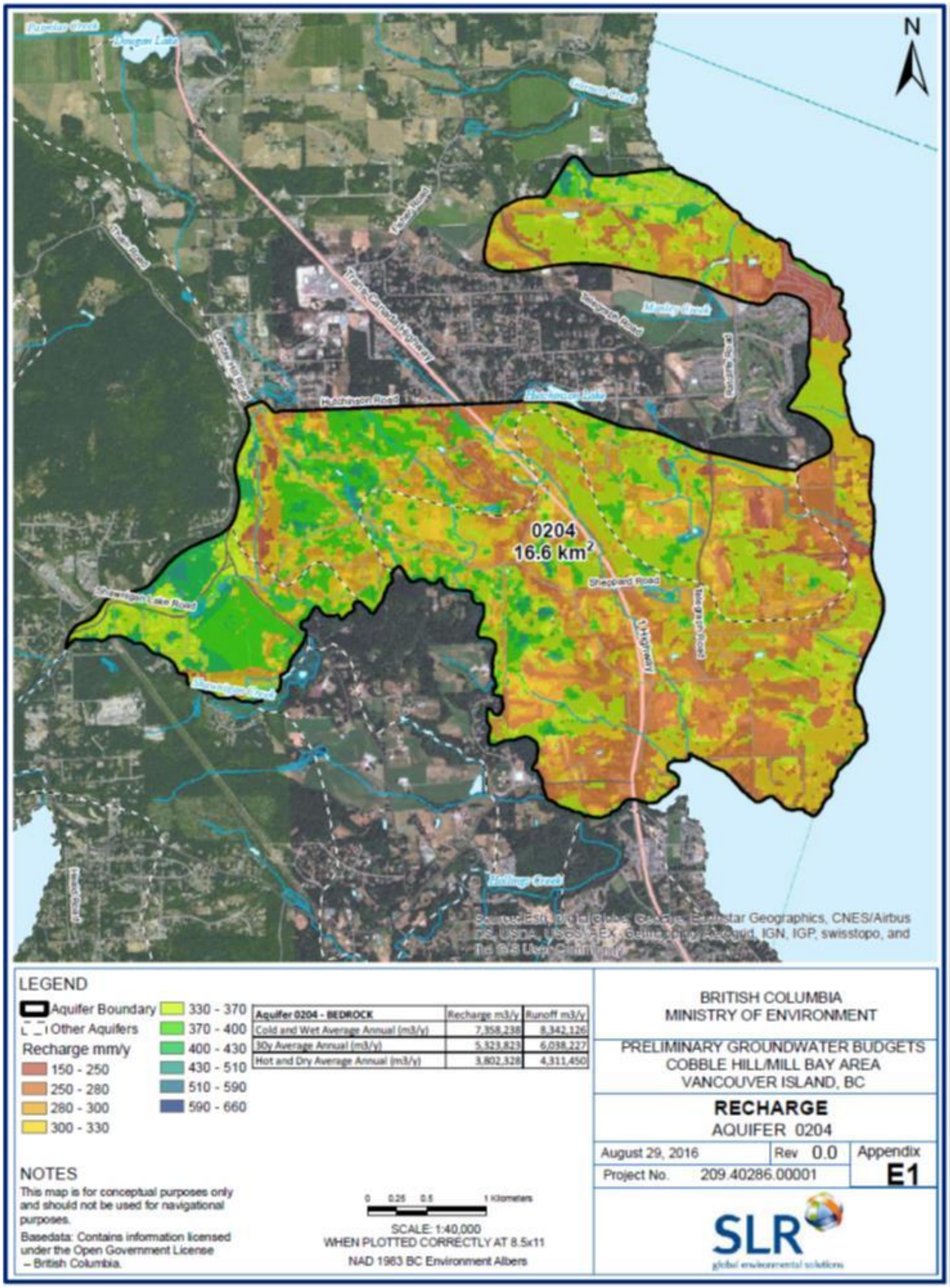


Figure E-1: Recharge distribution for bedrock aquifer 0204.

Table E-1: CHM Aquifer Criteria: Aquifer #0204, Cobble Hill (Bedrock).

BCMOE Criteria	
AQ tag	204 Cobble Hill
AQ classification	IIB (11)
AQ type	BCMOE Classification = 6b (SLR Classification = 6b / 6a)
Location	Cobble Hill / Mill Bay
Perimeter (km)	31.99
Area (km^2)	16.58
Aquifer materials	Bedrock
Lithostratographic unit	Lower to Middle Jurassic Island Intrusions
Productivity	Moderate
Vulnerability	Moderate
Demand	Moderate
Use	Multiple
Location	
NTS 50000	092B/12
TRIM 20000	Straddles 092B.062 & 092B.063
Lat / Long (Centre)	48°40'19" / 123°33'41"
UTM Zone 10 (Centre)	458655E / 5391148N
Climate	
Nearest active EC weather station / distance / elevation	EEC1015136 Mill Bay SW1 / 475 m to south EC1017230 Shawnigan Lake / 1.65 km to southwest
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland
Elevation range (m amsl)	0 - 140 m amsl
Distance to marine	Abuts Mill Bay and Saanich Inlet along east edge
Geomorphological setting	West end = + east -central area = hilly terrain / bedrock dominated?; central and east portions = undulating glacial outwash fan
Topography	Isolated, NW-trending, elongated conical hills within a planar to undulating area east of Shawnigan Creek mainstem. Contains most of Shawnigan Creek's south-flowing tributaries
Terrain	Undulating to hummocky at higher elevations; undulating to planar at lower elevations
Aspect	West 3/4 = half-basinal, sloping to south and southwest towards Shawnigan Creek mainstem. East 1/4 = southwest, southeast, and northeast-facing slopes off elongated hill.
Slope	West 3/4 = variable, planar-concave towards Shawnigan Creek; East 1/4 = generally convex, except within minor stream / tributary catchments
XS max grade (m/m)	0.035 to ESE towards Mill Bay / 0.057 east side SSE towards Mill Bay
Roughness coefficient	0.65 (partly cleared / deciduous-coniferous cover)
Geology	
Terrane	Wrangellia / Overlap
Bedrock (age ; formation ; lithology)	
Primary	East / southeast 2/3 = Early to Middle Jurassic Island Plutonic Suite (EMJIgd); granodioritic intrusive rocks (65%)
Secondary	Northwest 1/3 = Middle to Upper Devonian Sicker Group Duck Lake Volcanics (muDSiD); basaltic volcanic rocks (25%)
Tertiary	Southwest corner = Jurassic Bonanza Group Volcanics (lJBca); basaltic-andesitic (5%)
Subsidiary	Northeast corner / "peninsula" = Upper Cretaceous Nanaimo Group (uKN); shale (5%)
Structure	East-northeast trending San Juan Fault crosses AQ; AQ south of SJF crossed by at least one west-northwest trending thrust fault that does not cross the SJF

Surficial (formation; lithology; thickness)	Vashon Drift morainal; silt-sand; generally shallow to moderately deep blankets (3 - 10 m) / higher areas - locally colluvial veneers on steeper slopes at mid-elevations. Small blankets of Capilano Formation glaciolacustrine materials in morainal hollows & at west end within Shawnigan Creek mainstem area / Salish Formation fluvial blankets and veneers along Shawnigan Creek & tributaries
Surficial designation (1993)	Generally dMbh/$LGP//sgFGf. isolated depressional areas = $Op
Soils (association; parent; texture; drainage; type; comments)	Higher elevations = SE1v8DD1v1QU11/de (Somenos moraine / Dashwood marine / Quamichan fluvial); predominantly gravelly-sandy loam D.DYB Lower elevations centred on Mill Bay = FF1v8TT72/de (Finlayson & Tagner marine). predominantly silty-clay loam GLE.DYB, stonefree
Restrictive layers	Yes - surface duric layer in morainal areas; low permeability soils in silt-clay-rich areas
Estimated permeability	Low-moderate @ surface in duric morainal areas / low in silt-clay rich areas
Hydrology	
GW / SW basin coincidence	No - straddles catchment divide between Shawnigan Creek mainstem-tributaries and streams flowing direcrtly into Saanich Inlet. Occupies north side of Shawnigan Creek catchment only.
Catchments	Shawnigan Creek / Saanich inlet streams
Drainage regime	Dendritic within Shawnigan Creek catchment / radial in hilly areas
Surface waters	Shawnigan Creek (along south border); six unnamed streams directly flowing into Saanich Inlet and/or Mill Bay
Runoff coefficient	~50% cleared-agricultural / ~30% forested / 20% rural residential / moderate slope = 0.55
Nearest Active EC hydrometric station; distance; type	Shawnigan Creek @ Mill Bay; south border of AQ (inactive); EC 08HA003 Koksilah River @ Cowichan Station; 6.8 km NW; active realtime;
Surface water diversions ; relevance	> 20 licences along Shawnigan Creek & south side of AQ / >15 within AQ along unnamed steams; Generally low relevancy due to high overburden thicknesses, elevated along incised sections of Shawnigan Creek
Land Cover	
Vegetation zone	Cgf-wC
Primary land uses	Cgf-wC
Degree of development	Extensive rural residential / agricultural development. Very low impervious cover
Evapotranspiration potential	High
Relative environmental sensitivity	Moderate in terrestrial areas, high along Shawnigan Creek corridor
Hydrogeology	
Groundwater occurrence (primary / secondary)	Void infillings - bedrock fractures & faults
Primary porosity	Low to negligible
Secondary porosity	Low to moderate in Sicker Volcanics & Island Intrusives area; higher in fractue zones & faults, especially along SJF; low in Bonanza Volcanics areas due to ductile rock
Confinement	Morainal blanket areas locally semi-confined by duric till blankets; WP = 0 - 62.5, avg 3.0 m
Aquifer thickness	Bedrock aquifer / assume < 150 m
Hydraulic anisotropy	High
Hydraulic gradient	Low to moderate based on terrain
Storage potential	Low - secondary voids only
Yield potential	Low-moderate; WP = 0.03 - 8.52 L/s / average 0.25 L/s
Flow velocities	Low - moderate
Flow directions	Generally south and southeast towards Shawnigan Creek and Mill Bay / Saanich Inlet. East edge flow possible to east towards Saanich Inlet (i.e. east of surface water divide)
Static water levels	WP = variable 0 - 50.3 m bgs / avg 5.2 m bgs
Hydraulic connection with surface waters	Generally low to moderate due to deep overburden cover, high in areas where Shawnigan Creek is deeply incised

Hydraulic connection to adjacent AQ	
Over / Under	North 1/4 partly overlain by surficial AQ197
Upgradient	Upgradient contact to north with undeveloped extension of bedrock AQ204; upgradient contact to west with bedrock AQ202; cross-gradient? contacts along south border with bedrock AQ207, surficial AQ 205, & surficial AQ206
Downgradient	None - discharge to marine
Vulnerability to surface contamination	Low-moderate due to deep overburden cover
Recharge	
Vertical inflow	Moderate recharge from Shawnigan Creek stream losses in deeply incised areas. Limited recharge from precipitation / irrigation-sewerage return due to deep overburden cover. Negligible recharge from snowmelt due to low elevation
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock sources
Temporal variability	Low - moderate due to deep overburden cover
MBR	Moderate at west end of AQ only from Cobble Hill
Discharge	
Evapotranspiration	High
Outflow to marine	Low-moderate - may be below base of Saanich Inlet due to deep overburden cover
Outflow to surface waters	High to Shawnigan Creek & tributaries in deeply incised areas
Outflow to other AQ	None
Temporal variability	Low - moderate due to deep overburden cover
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #345 = within pocket created by AQ's northeast "horn; Well #320 = 500 m east of north end of AQ; both completed in surficial materials; irrelevant
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	36500
Commercial	25550
Domestic	263671
Irrigation from GW (MoAg)	236911
BCMOE Obs	0
Other	29200
Water Supply Systems	16288

Table E-2: Direct Recharge Calculation for AQ204.

	Direct Recharge Calculation		
	Hot/Dry	**Average**	**Cold/Wet**
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.020	1.020	1.020
Infiltration Coefficient	0.466	0.466	0.466
Area (m^2)	11,453,503	11,453,503	11,453,503
Q (m^3/yr)	2,786,717	4,142,343	6,874,388
Average Infiltration Rate	0.243	0.362	0.600

Table E-3: Annual Summary of AQ204 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 204	11,453,503	0.362	4,142,343
Gain	Leakage down from 197	5,126,386	0.300	1,537,916
Loss	Lateral Groundwater	--	--	-13,006,240
Gain	Lateral Groundwater	--	--	10,900,306
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	978,247
Loss	Water Usage	--	--	-608,120
Net Gain				**17,558,812**
Net Loss				**-13,614,360**
Net Total (Gain - Loss)				**3,944,452**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 204	11,453,503	0.243	2,786,717
Gain	Leakage down from 197	5,126,386	0.300	1,537,916
Loss	Lateral Groundwater	--	--	-13,006,240
Gain	Lateral Groundwater	--	--	10,900,306
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	978,247
Loss	Water Usage	--	--	-608,120
Net Gain				**16,203,186**
Net Loss				**-13,614,360**
Net Total (Gain - Loss)				**2,588,826**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 204	11,453,503	0.600	6,874,388
Gain	Leakage down from 197	5,126,386	0.300	1,537,916
Loss	Lateral Groundwater	--	--	-13,006,240
Gain	Lateral Groundwater	--	--	10,900,306
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	978,247
Loss	Water Usage	--	--	-608,120
Net Gain				**20,290,857**
Net Loss				**-13,614,360**
Net Total (Gain - Loss)				**6,676,496**

Table E-4: Monthly Summary of AQ204 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 204	1,041,668	678,502	489,656	117,591	-141,543	-223,203	-217,759	-97,992	-32,664	358,121	1,098,798	1,071,167	**4,142,343**
Leakage down from 197	124,571	119,957	133,799	132,261	138,412	132,261	133,799	130,723	124,571	126,109	119,957	121,495	**1,537,916**
Lateral Groundwater Loss	-1,053,505	-1,014,487	-1,131,543	-1,118,537	-1,170,562	-1,118,537	-1,131,543	-1,105,530	-1,053,505	-1,066,512	-1,014,487	-1,027,493	**-13,006,240**
Lateral Groundwater Gain	882,925	850,224	948,327	937,426	981,028	937,426	948,327	926,526	882,925	893,825	850,224	861,124	**10,900,306**
Surface Water Loss	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Gain	215,880	189,525	136,904	66,194	23,471	9,520	5,654	1,836	1,544	14,171	100,153	213,395	**978,247**
Water Usage	-36,487	-39,528	-45,609	-48,650	-54,731	-60,812	-66,893	-69,934	-60,812	-48,650	-42,568	-33,447	**-608,120**
Net Gain	**2,265,044**	**1,838,209**	**1,708,685**	**1,253,472**	**1,142,911**	**1,079,207**	**1,087,779**	**1,059,085**	**1,009,040**	**1,392,227**	**2,169,132**	**2,267,182**	**18,271,972**
Net Loss	**-1,089,993**	**-1,054,015**	**-1,177,152**	**-1,167,186**	**-1,366,836**	**-1,402,552**	**-1,416,195**	**-1,273,456**	**-1,146,981**	**-1,115,161**	**-1,057,055**	**-1,060,940**	**-14,327,521**
Net Total (Gain - Loss)	**1,175,052**	**784,194**	**531,533**	**86,286**	**-223,925**	**-323,345**	**-328,416**	**-214,370**	**-137,941**	**277,066**	**1,112,077**	**1,206,242**	**3,944,452**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 204	854,426	489,958	761,837	45,729	-179,651	-228,647	-195,983	-81,660	-54,440	138,821	544,942	691,385	**2,786,717**
Leakage down from 197	126,109	116,882	129,185	127,647	133,799	129,185	133,799	132,261	126,109	130,723	124,571	127,647	**1,537,916**
Lateral Groundwater	-1,066,512	-988,474	-1,092,524	-1,079,518	-1,131,543	-1,092,524	-1,131,543	-1,118,537	-1,066,512	-1,105,530	-1,053,505	-1,079,518	**-13,006,240**
Lateral Groundwater	893,825	828,423	915,626	904,725	948,327	915,626	948,327	937,426	893,825	926,526	882,925	904,725	**10,900,306**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	215,880	189,525	136,904	66,194	23,471	9,520	5,654	1,836	1,544	14,171	100,153	213,395	**978,247**
Water Usage	-36,487	-39,528	-45,609	-48,650	-54,731	-60,812	-66,893	-69,934	-60,812	-48,650	-42,568	-33,447	**-608,120**
Net Gain	**2,090,240**	**1,624,787**	**1,943,552**	**1,144,295**	**1,105,596**	**1,054,330**	**1,087,779**	**1,071,523**	**1,021,478**	**1,210,241**	**1,652,591**	**1,937,152**	**16,943,566**
Net Loss	**-1,102,999**	**-1,028,002**	**-1,138,133**	**-1,128,168**	**-1,365,925**	**-1,381,983**	**-1,394,419**	**-1,270,130**	**-1,181,763**	**-1,154,180**	**-1,096,074**	**-1,112,965**	**-14,354,740**
Net Total (Gain - Loss)	**987,241**	**596,785**	**805,419**	**16,128**	**-260,329**	**-327,653**	**-306,640**	**-198,607**	**-160,285**	**56,061**	**556,517**	**824,187**	**2,588,826**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 204	1,933,155	1,957,211	725,862	-87,104	-70,772	-185,095	-239,535	-97,992	-43,552	686,485	1,109,482	1,186,242	**6,874,388**
Leakage down from 197	124,571	119,957	133,799	132,261	138,412	132,261	133,799	130,723	124,571	126,109	119,957	121,495	**1,537,916**
Lateral Groundwater	-1,053,505	-1,014,487	-1,131,543	-1,118,537	-1,170,562	-1,118,537	-1,131,543	-1,105,530	-1,053,505	-1,066,512	-1,014,487	-1,027,493	**-13,006,240**
Lateral Groundwater	882,925	850,224	948,327	937,426	981,028	937,426	948,327	926,526	882,925	893,825	850,224	861,124	**10,900,306**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	215,880	189,525	136,904	66,194	23,471	9,520	5,654	1,836	1,544	14,171	100,153	213,395	**978,247**
Water Usage	-36,487	-39,528	-45,609	-48,650	-54,731	-60,812	-66,893	-69,934	-60,812	-48,650	-42,568	-33,447	**-608,120**
Net Gain	**3,156,531**	**3,116,918**	**1,944,892**	**1,135,881**	**1,142,911**	**1,079,207**	**1,087,779**	**1,059,085**	**1,009,040**	**1,720,590**	**2,179,816**	**2,382,256**	**21,014,905**
Net Loss	**-1,089,993**	**-1,054,015**	**-1,177,152**	**-1,254,290**	**-1,296,064**	**-1,364,444**	**-1,437,971**	**-1,273,456**	**-1,157,869**	**-1,115,161**	**-1,057,055**	**-1,060,940**	**-14,338,409**
Net Total (Gain - Loss)	**2,066,538**	**2,062,903**	**767,740**	**-118,409**	**-153,153**	**-285,237**	**-350,192**	**-214,370**	**-148,829**	**605,429**	**1,122,761**	**1,321,316**	**6,676,496**

Table E-5: Monthly Coefficients used in Calculations for AQ204.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table E-6: Groundwater Flow Components: Aquifer #0204, Cobble Hill (Bedrock).

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}1$	Out	Shawnigan Crk	518	80	41,400	0.000001	315	20			-82,895		
$Q_{GW}2$	Out	Shawnigan Crk	207	80	16,560	0.00005	345	40			-3,027,456		
$Q_{GW}3$	Out	Shawnigan Crk	1,725	80	138,000	0.000000001	255	40			-683		
$Q_{GW}4$	In	Shawnigan Crk	173	80	13,800	0.00000001	--	--			113		
$Q_{GW}5$	Out	Shawnigan Crk	173	80	13,800	0.000000001	215	20			-40		
$Q_{GW}6$	In	Shawnigan Crk	242	80	19,320	0.0000001	--	--			72		
$Q_{GW}7$	Out	Shawnigan Crk	173	20	3,450	0.000000001	765	10			-1		
$Q_{GW}8$	Out	Shawnigan Crk	1,829	20	36,570	0.000001	765	10			-15,075		
$Q_{GW}9$	In	Shawnigan Crk	173	20	3,450	0.0001	--	--			500,371		
$Q_{GW}10$	Out	Shawnigan Crk	12,089	20	241,780	0.000001	620	20			-245,960		
$Q_{GW}11$	In	Shawnigan Crk	173	20	3,450	0.0001	--	--			16,564		
$Q_{GW}12$	Out	Shawnigan Crk	1,173	20	23,460	0.000001	150	20	-	-	-98,645		
$Q_{GW}13$	Out	Ocean	138	60	8,280	0.0001	240	20			-2,175,984		

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}14$	Out	Ocean	1,380	60	82,800	0.000001	315	40			-331,579		
$Q_{GW}15$	Out	Ocean	1,656	80	132,480	0.000001	260	40			-642,752		
$Q_{GW}16$	Out	Ocean	173	80	13,800	0.00001	360	40			-483,552		
$Q_{GW}17$	Out	Ocean	621	80	49,680	0.000001	1,090	80			-114,988		
$Q_{GW}18$	Out	Ocean	104	80	8,280	0.00001	105	20			-497,368		
$Q_{GW}19$	Out	Ocean	932	80	74,520	0.000001	850	40			-110,591		
$Q_{GW}20$	Zero	Ocean	138	60	8,280	0.00001	1	0			0		
$Q_{GW}21$	Out	Ocean	276	60	16,560	0.000001	205	40			-101,900		
$Q_{GW}22$	Out	Ocean	69	60	4,140	0.0000001	145	40			-3,602		
$Q_{GW}22b$	Out	Ocean	2,588	60	155,250	0.000000001	210	60			-1,399		
$Q_{GW}23$	Out	Ocean	1,553	200	310,500	0.000000001	455	60			-1,291		
$Q_{GW}24$	Out	Under AQ 197	173	200	34,500	0.0000001	175	20			-124		
$Q_{GW}25$	In	Under AQ 197	1,518	200	303,600	0.000000001	445	40			86,061		
$Q_{GW}26$	Out	Under AQ 197	173	200	34,500	0.0000001	215	20			-101		
$Q_{GW}27$	In	Under AQ 197	1,863	200	372,600	0.000000001	1,345	6			5,242		
$Q_{GW}28$	In	Under AQ 197	138	200	27,600	0.0000001	145	40			240		
$Q_{GW}29$	In	Under AQ 197	621	200	124,200	0.000001	205	40			76,425		
$Q_{GW}30$	Zero	Under AQ 197	104	200	20,700	0.00001	1	0			0		
$Q_{GW}31$	Zero	Under AQ 197	518	200	103,500	0.000001	1	0			0		
$Q_{GW}32$	Out	Under AQ 197	414	200	82,800	0.00005	515	20	-	-	-5,070,254		
$Q_{GW}33$	In	Under AQ 197	1,208	200	241,500	0.000001	505	20	-	-	301,622		
$Q_{GW}34$	Zero	Under AQ 197	173	200	34,500	0.00001	1	0	-	-	0		
$Q_{GW}35$	In	Under AQ 197	690	200	138,000	0.000001	845	40	-	-	206,010		
$Q_{GW}36$	In	Under AQ 197	104	200	20,700	0.00001	845	40			309,015		
$Q_{GW}37$	In	Under AQ 197	242	200	48,300	0.000001	845	40			72,104		
$Q_{GW}38$	In	Under AQ 197	69	200	13,800	0.00001	845	40			206,010		
$Q_{GW}39$	In	Under AQ 197	656	200	131,100	0.000001	185	20			446,959		
$Q_{GW}40$	In	Under AQ 197	104	200	20,700	0.00001	185	20			705,725		
$Q_{GW}41$	In	Under AQ 197	345	200	69,000	0.000001	185	20			235,242		
$Q_{GW}42$	In	Under AQ 197	104	200	20,700	0.00001	185	20			705,725		
$Q_{GW}43$	In	Under AQ 197	311	200	62,100	0.000001	185	20			211,717		
$Q_{GW}44$	In	Under AQ 197	138	200	27,600	0.0001	1,010	20			1,723,552		
$Q_{GW}45$ & 47	In	AQ 202 ($Q_{GW}30$)	1,285	200	257,040	0	525	140	0	0	2,161,604		
$Q_{GW}46$	Zero	N/A	138	200	27,600	0.00001	1	0			0		
$Q_{GW}48$	In	AQ 202 ($Q_{GW}31$)	179	200	35,700	0	150	20	0	0	1,501,114		
$Q_{GW}49$	In	AQ 202 ($Q_{GW}32$)	821	200	164,220	0	555	80	-	-	746,500		
$Q_{GW}50$	In	AQ 197	750	10	7,500	0.00001	680	10			34,782		

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Q_{GW}51	In	AQ 197	625	10	6,250	0.00001	600	5			16,425		
Q_{GW}52	In	AQ 197	150	10	1,500	0.000001	600	5			394		
Q_{GW}53	In	AQ 197	750	10	7,500	0.0001	1,500	40			630,720		
Q_{GW}54	In	Leakage from AQ 197	Leakance Factor (m/yr) =	0.300	5,126,386	--	--	--			1,537,916		
Total											-568,018		

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Nott Creek	Unknown	Downward	10%	870	2	0.00003	164,618			
Eddy Kilman Creek	Unknown	Downward	10%	3700	2	0.00003	700,099			
Prellwire Creek	Unknown	Downward	10%	600	2	0.00003	113,530			
Total							**-568,018**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustmen t Factor	Adjusted Volume Removed	
Industrial	36,500	100%	36,500							100% consumptive
Commercial	25,550	100%	25,550							100% consumptive
Domestic	263,671	100%	263,671							100% consumptive
Irrigation	236,911	100%	236,911							100% consumptive
BCMOE Obs	0	100%	0							100% consumptive
Total			**-562,632**							

APPENDIX F: AQUIFER 0207 (BAMBERTON)

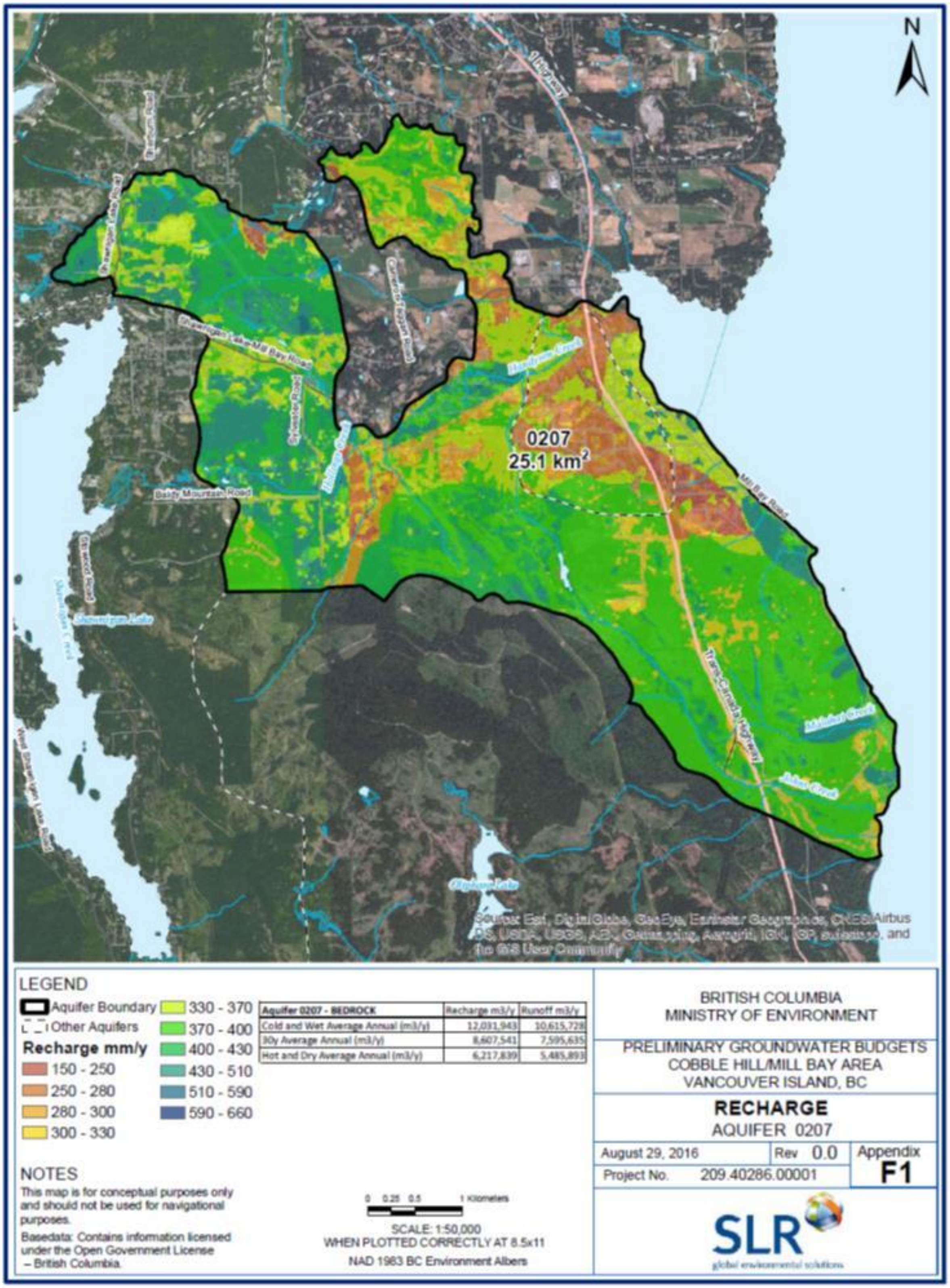


Figure F-1: Recharge distribution for bedrock aquifer 0207.

Table F-1: CHM Aquifer Criteria: Aquifer #0207, Bamberton (Bedrock).

BCMOE Criteria	
AQ tag	207 Bamberton
AQ classification	IIB (12)
AQ type	BCMOE Classsification = 6b (SLR Classification = 6a / 6b)
Location	Mill Bay / Shawnigan Lake
Perimeter (km)	38.03
Area (km^2)	25.1 (probably larger since bedrock zone below surficial AQ205 has not been defined as part of AQ 207)
Aquifer materials	Bedrock / Bonanza Group & Lower to Middle Island Intrusions
Productivity	Moderate
Vulnerability	Moderate
Demand	Moderate
Use	Multiple
Location	
NTS 50000	092B/12
TRIM 20000	Straddles 092B.062 & 092B.063
Lat / Long (Centre)	48°38'20" / 123°34'43"
UTM Zone 10 (Centre)	457397E / 5387490N
Climate	
Nearest active EC weather station / distance / elevation	AQ Contains EEC1015136 Mill Bay SW1 at its north end EC1017230 Shawnigan Lake adjacent to AQ's northwest side EC104820 Malahat 2.2 km to the south
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Outer Mountain Area / Insular Mountains / Vancouver Island Ranges
Elevation range (m amsl)	0 - 360 m amsl
Distance to marine	Abuts Mill Bay and Saanich Inlet along east edge
Geomorphological setting	Northeast-facing flank of Malahat Ridge, containing several NW-trending, elongated hills. Large morainal blanket with subordinate colluvial component in steeper areas. North end of AQ adjacent to Mill Bay = glaciofluvial outwash fan?
Topography	Broad, northwest-trending sidehill containing elongated domes, bisected by a northeast-trending, V- to U-shaped valley lineament running from the south side of Old Baldy Mountain towards Mill Bay (Shawnigan Lake Fault trace)
Terrain	Undulating to hummocky at higher elevations; undulating at lower elevations. Common short ravines at southeast corner into Saanich Inlet
Aspect	Overall slope towards the northeast and Saanich Inlet / Mill Bay. Local areas in southeast protion with elongated hills have radial aspects.
Slope	Generally variably moderate to steep (convex & radial), apart from around Mill Bay area (low to moderate concave)
XS max grade (m/m)	0.066 ENE from Old Baldy Mopuntain towards Mill Bay
Roughness coefficient	0.60 (generally coniferous cover with extensive logged areas)
Geology	
Terrane	Wrangellia
Bedrock (age ; formation ; lithology)	
Primary	Southwest half = Jurassic Bonanza Group Volcanics (lJBca); basaltic-andesitic (60%) - suspected more lithologies present than identified by BCGS - (limestone?)
Secondary	East / southeast 2/3 = Early to Middle Jurassic Island Plutonic Suite (EMJIgd); granodioritic intrusive rocks (40%)
Structure	Northeast-trending Shawnigan Fault bisects AQ, only mapped 1/2 across AQ but suspected to reach Mill Bay shoreline; Assumed fracture zones along Bonanza Group / Island Intrusions contact zone due to rock competency contrasts; possible NNW-trending fault zone west of

	surficial AQ 205 (strong lineament) within Bonanza Volcanics
Surficial (formation; lithology; thickness)	Primarily Vashon Drift morainal; silt-sand; generally shallow to moderately deep blankets and veneers (> 10 m). Local colluvial veneers on steeper slopes at mid-elevations. Capilano Formation glaciofluvial blankets adjacent to Mill Bay. Capilano glaciolacustrine blanket in northwest corner (northeast of Old Baldy Mountain). Salish Formation fluvial blankets and veneers along Handysen and Hollings Creeks
Surficial designation (1993)	Generally dMb/Cb//R; isolated depressional area in northwest corner (northeast of Old Baldy Mountain) = $LGp
Soils (association; parent; texture; drainage; type; comments)	Mainly SE5v8RJ52/fe (Somenos moraine / Ragbark colluvium). gravelly-sandy loam, DU.DYB / O.DYB.shli; Area around Mill Bay = DD1w/de and QU1w/ce (Dashwood Creek marine / Quamichan fluvial, gravelly-sandy loam, DU.DYB; Area in northwest corner (northeast of Old Baldy Mountain) = CH78AR12/b (Chemainus fluvial), loam, O.DYB, stonefree
Restrictive layers	Yes - surface duric layer in Somenos (morainal) and Dashwood Creek (marine) areas
Estimated permeability	Low - moderate @ surface in duric morainal areas ; higher in colluvial fluvial areas
Hydrology	
GW / SW basin coincidence	No - straddles catchment divide between Shawnigan Creek mainstem & tributaries (including Hollings and handeysen Creeks) and streams flowing direcrtly into Saanich Inlet. Occupies south side of Shawnigan Creek catchment only
Catchments	Shawnigan Creek / Saanich inlet streams
Drainage regime	Dendritic within Shawnigan Creek catchment / radial in hilly areas
Surface waters	Shawnigan Creek (along north border); Hollings and Handysen Creeks (tributaries of Shawnigan Creek), Malahat and Bamberton-John's Creeks (flowing directly flowing into Saanich Inlet at southeast corner of AQ)
Runoff coefficient	~65% cleared-forested / ~20% forested / 15% rural residential / moderate slope = 0.55
Nearest Active EC hydrometric station; distance; type	Shawnigan Creek @ Mill Bay; notheast corner of AQ (inactive); EC 08HA003 Koksilah River @ Cowichan Station; 7.4 km NW; active realtime;
Surface water diversions ; relevance	> 30 licences along Hollings, Handeysen, & Shawnigan Creeks @ north part of AQ / >5 within AQ along unnamed steams; 7 along Malahat & Bamberton-John's Creeks at southeast end of AQ. Moderate to high relevancy due to low-moderate overburden thicknesses
Land Cover	
Vegetation zone	Cgf-wC
Primary land uses	Forestry, rural residential
Degree of development	Extensive forestry clearing / localized rural residential & commercial development at northeast corner at Mill Bay. Generally very low impervious cover, elevated in developed area at Mill Bay
Evapotranspiration potential	Cgf-wC
Relative environmental sensitivity	Moderate in terrestrial areas, high along Hollings/Handeysen/Shawnigan Creek corridors
Hydrogeology	
Groundwater occurrence (primary / secondary)	Void infillings - bedrock fractures & faults
Primary porosity	Low to negligible
Secondary porosity	Moderate in Island Intrusives areas; higher in fracture zones & faults, especially along & south of Shawnigan Fault; low in Bonanza Volcanics areas due to ductile rock
Confinement	Morainal blanket areas locally semi-confined by duric till blankets; WP = 0 - 64.3, avg 4.6 m
Aquifer thickness	Bedrock aquifer / assume < 150 m

Hydraulic anisotropy	High
Hydraulic gradient	Moderate to high based on terrain
Storage potential	Low - secondary voids only
Yield potential	Low-moderate; WP = 0.02 - 12.62 L/s / average 0.25 L/s
Flow velocities	Low - moderate
Flow directions	Northwest half of AQ (i.e. NW of surface water divide) = notheast towards Shawnigan Creek and Mill Bay / Saanich Inlet. Southeast half of AQ (i.e. SE of surface water divide) = radial flow possible to southeast and towards Saanich Inlet
Static water levels	WP = variable 0 - 61 m bgs / avg 7.6 m bgs
Hydraulic connection with surface waters	Generally moderate to high due to shallow overburden cover & deeply incised creeks / lower in areas with thick overburden (near Mill Bay)
Hydraulic connection to adjacent AQ	
Over / Under	North portion overlain by surficial AQ 205 and surficial AQ206
Upgradient	Upgradient contact at northwest corner with bedrock AQ202.Upgradient contact with bedrock AQ203, may receive recharge across sw divide from Shawnigan Fault; cross-gradient? contact along noth border with bedrock AQ204
Downgradient	None - discharge to marine
Vulnerability to surface contamination	Low-moderate due to variably thick overburden cover
Recharge	
Vertical inflow	High recharge from precipitation, subordinate from snowmelt due to high elevations. Moderate to high recharge at north end from overlying surficial AQ 205 & surficial AQ 206. Moderate recharge from Hollings/Handysen/Shawnigan Creek stream losses in deeply incised areas. Low-moderate recharge from irrigation-sewerage return due to low degree of urban / agricultural development
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock sources
Temporal variability	Moderate to high due to vaiable overburden cover
MBR	Moderate - high along south and southwest borders of AQ from Malahat Ridge rocky hills
Discharge	
Evapotranspiration	High
Outflow to marine	Moderate to high due to variable overburden cover & high elevations
Outflow to surface waters	High to Hollings/Handeysen/Shawnigan/Malahat/Bamberton-John's Creeks & tributaries in deeply incised areas
Outflow to other AQ	None
Temporal variability	Moderate to high due to variable overburden cover, low in deep overburden area adjacent to Mill Bay
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #345 = 2.5 km northeast of AQ; completed in surficial materials; irrelevant
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	14,600
Commercial	32,850
Domestic	194,146
Irrigation from GW (MoAg)	100,596
BCMOE Obs	-
Other	40,150
Water Supply Systems	30,715

Table F-2: Direct Recharge Calculation for AQ207.

	Direct Recharge Calculation		
	Hot/Dry	Average	Cold/Wet
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.060	1.060	1.060
Infiltration Coefficient	0.531	0.531	0.531
Area (m^2)	22,530,041	22,530,041	22,530,041
Q (m^3/yr)	6,495,020	9,654,587	16,022,182
Average Infiltration Rate	0.288	0.429	0.711

Table F-3: Annual Summary of AQ207 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 207	22,530,041	0.429	9,654,587
Gain	Leakage down from 205	2,728,692	0.200	545,738
Gain	Leakage down from 206	2,573,511	0.300	772,053
Loss	Lateral Groundwater	--	--	-9,475,572
Gain	Lateral Groundwater	--	--	30,523
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	1,793,768
Loss	Water Usage	--	--	-413,057
Net Gain				**12,796,670**
Net Loss				**-9,888,629**
Net Total (Gain - Loss)				**2,908,040**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 207	22,530,041	0.288	6,495,020
Gain	Leakage down from 205	2,728,692	0.200	545,738
Gain	Leakage down from 206	2,573,511	0.300	772,053
Loss	Lateral Groundwater	--	--	-9,475,572
Gain	Lateral Groundwater	--	--	30,523
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	1,793,768
Loss	Water Usage	--	--	-413,057
Net Gain				**9,637,103**
Net Loss				**-9,888,629**
Net Total (Gain - Loss)				**-251,526**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 207	22,530,041	0.711	16,022,182
Gain	Leakage down from 205	2,728,692	0.200	545,738
Gain	Leakage down from 206	2,573,511	0.300	772,053
Loss	Lateral Groundwater	--	--	-9,475,572
Gain	Lateral Groundwater	--	--	30,523
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	1,793,768
Loss	Water Usage	--	--	-413,057
Net Gain				**19,164,264**
Net Loss				**-9,888,629**
Net Total (Gain - Loss)				**9,275,635**

Table F-4: Monthly Summary of AQ207 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 207	2,427,823	1,581,390	1,141,244	274,071	-329,896	-520,220	-507,532	-228,389	-76,130	834,676	2,560,975	2,496,577	**9,654,587**
Leakage down from 205	44,205	42,568	47,479	46,933	49,116	46,933	47,479	46,388	44,205	44,751	42,568	43,113	**545,738**
Leakage down from 206	62,536	60,220	67,169	66,397	69,485	66,397	67,169	65,625	62,536	63,308	60,220	60,992	**772,053**
Lateral Groundwater Loss	-767,521	-739,095	-824,375	-814,899	-852,801	-814,899	-824,375	-805,424	-767,521	-776,997	-739,095	-748,570	**-9,475,572**
Lateral Groundwater Gain	6,736	5,914	4,272	2,065	732	297	176	57	48	442	3,125	6,658	**30,523**
Surface Water Loss	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Gain	395,850	347,524	251,035	121,376	43,037	17,456	10,367	3,367	2,831	25,985	183,646	391,292	**1,793,768**
Water Usage	-24,783	-26,849	-30,979	-33,045	-37,175	-41,306	-45,436	-47,502	-41,306	-33,045	-28,914	-22,718	**-413,057**
Net Gain	**2,937,150**	**2,037,615**	**1,511,199**	**510,843**	**162,371**	**131,083**	**125,191**	**115,437**	**109,620**	**969,162**	**2,850,534**	**2,998,633**	**14,458,837**
Net Loss	**-792,305**	**-765,943**	**-855,354**	**-847,944**	**-1,219,873**	**-1,376,425**	**-1,377,343**	**-1,081,315**	**-884,957**	**-810,041**	**-768,009**	**-771,288**	**-11,550,797**
Net Total (Gain - Loss)	**2,144,845**	**1,271,672**	**655,845**	**-337,101**	**-1,057,502**	**-1,245,342**	**-1,252,152**	**-965,878**	**-775,336**	**159,121**	**2,082,525**	**2,227,345**	**2,908,040**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 207	1,991,415	1,141,947	1,775,620	106,582	-418,714	-532,909	-456,779	-190,325	-126,883	323,552	1,270,099	1,611,415	**6,495,020**
Leakage down from 205	44,751	41,476	45,842	45,296	47,479	45,842	47,479	46,933	44,751	46,388	44,205	45,296	**545,738**
Leakage down from 206	63,308	58,676	64,852	64,080	67,169	64,852	67,169	66,397	63,308	65,625	62,536	64,080	**772,053**
Lateral Groundwater	-776,997	-720,143	-795,948	-786,472	-824,375	-795,948	-824,375	-814,899	-776,997	-805,424	-767,521	-786,472	**-9,475,572**
Lateral Groundwater	2,503	2,320	2,564	2,533	2,656	2,564	2,656	2,625	2,503	2,594	2,472	2,533	**30,523**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	395,850	347,524	251,035	121,376	43,037	17,456	10,367	3,367	2,831	25,985	183,646	391,292	**1,793,768**
Water Usage	-24,783	-26,849	-30,979	-33,045	-37,175	-41,306	-45,436	-47,502	-41,306	-33,045	-28,914	-22,718	**-413,057**
Net Gain	**2,497,827**	**1,591,943**	**2,139,913**	**339,868**	**160,341**	**130,714**	**127,670**	**119,322**	**113,393**	**464,144**	**1,562,959**	**2,114,617**	**11,362,712**
Net Loss	**-801,780**	**-746,992**	**-826,927**	**-819,517**	**-1,280,264**	**-1,370,163**	**-1,326,590**	**-1,052,725**	**-945,186**	**-838,468**	**-796,435**	**-809,191**	**-11,614,238**
Net Total (Gain - Loss)	**1,696,047**	**844,951**	**1,312,986**	**-479,649**	**-1,119,923**	**-1,239,448**	**-1,198,920**	**-933,403**	**-831,793**	**-374,324**	**766,524**	**1,305,426**	**-251,526**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 207	4,505,617	4,561,685	1,691,771	-203,013	-164,948	-431,402	-558,285	-228,389	-101,506	1,599,995	2,585,876	2,764,781	**16,022,182**
Leakage down from 205	44,205	42,568	47,479	46,933	49,116	46,933	47,479	46,388	44,205	44,751	42,568	43,113	**545,738**
Leakage down from 206	62,536	60,220	67,169	66,397	69,485	66,397	67,169	65,625	62,536	63,308	60,220	60,992	**772,053**
Lateral Groundwater	-767,521	-739,095	-824,375	-814,899	-852,801	-814,899	-824,375	-805,424	-767,521	-776,997	-739,095	-748,570	**-9,475,572**
Lateral Groundwater	2,472	2,381	2,656	2,625	2,747	2,625	2,656	2,594	2,472	2,503	2,381	2,411	**30,523**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	395,850	347,524	251,035	121,376	43,037	17,456	10,367	3,367	2,831	25,985	183,646	391,292	**1,793,768**
Water Usage	-24,783	-26,849	-30,979	-33,045	-37,175	-41,306	-45,436	-47,502	-41,306	-33,045	-28,914	-22,718	**-413,057**
Net Gain	**5,010,680**	**5,014,378**	**2,060,110**	**237,331**	**164,386**	**133,411**	**127,670**	**117,974**	**112,045**	**1,736,542**	**2,874,691**	**3,262,591**	**20,851,809**
Net Loss	**-792,305**	**-765,943**	**-855,354**	**-1,050,957**	**-1,054,925**	**-1,287,607**	**-1,428,096**	**-1,081,315**	**-910,333**	**-810,041**	**-768,009**	**-771,288**	**-11,576,174**
Net Total (Gain - Loss)	**4,218,376**	**4,248,434**	**1,204,756**	**-813,625**	**-890,539**	**-1,154,196**	**-1,300,426**	**-963,341**	**-798,289**	**926,501**	**2,106,683**	**2,491,302**	**9,275,635**

Table F-5: Monthly Coefficients used in Calculations for AQ207.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table F-6: Groundwater Flow Components: Aquifer #0207, Bamberton (Bedrock)

Groundwater Flow	**Direction of Flow**	**Source or Receptor of Water**	**Length (m)**	**Depth (m)**	**Area (m)**	**Hydraulic Conductivity (m/s) - K**	**Distance (m) - dL**	**Hydraulic Head (m) - dh**			**GW Flow (m^3/yr)**		
								Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
$Q_{GW}1$	Zero	AQ 202	952	20	19040	0.00001	1	0			0		
$Q_{GW}2$	Out	AQ 202	286	20	5,712	0.000000001	340	20			-11		
$Q_{GW}3$	Out	AQ 202	143	20	2,856	0.00000001	545	20			-33		
$Q_{GW}4$	Out	AQ 202	524	20	10,472	0.000000001	545	20			-12		
$Q_{GW}5$	Zero	AQ 203	1,333	200	266,560	0.000000001	1	0			0		
$Q_{GW}6$	In	AQ 203	143	200	28,560	0.0000001	--	--			5,459		
$Q_{GW}7$	Zero	AQ 203	809	200	161,840	0.000000001	1	0			0		
$Q_{GW}8$	Zero	AQ 203	143	200	28,560	0.00000001	1	0			0		
$Q_{GW}9$	Zero	AQ 203	666	200	133,280	0.000000001	1	0			0		
$Q_{GW}10$	Zero	AQ 203	95	200	19,040	0.00000001	1	0			0		
$Q_{GW}11$	Zero	AQ 203	1,856	200	371,280	0.000000001	1	0			0		
$Q_{GW}12$	Zero	N/A	952	200	190,400	0.000000001	1	0	-	-	0		
$Q_{GW}13$	In	N/A	238	200	47,600	0.0000001	610	60			14,765		

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Q_{GW}14	In	N/A	1,809	200	361,760	0.000000001	590	100			1,934		
Q_{GW}15	In	N/A	333	200	66,640	0.00000001	640	100			3,284		
Q_{GW}16	In	N/A	619	200	123,760	0.000000001	995	40			157		
Q_{GW}17	In	N/A	143	200	28,560	0.00000001	870	40			414		
Q_{GW}18	In	N/A	2,856	200	571,200	0.000000001	500	60			2,162		
Q_{GW}19	Out	N/A	333	200	66,640	0.0000001	1,280	40			-6,567		
Q_{GW}20	In	N/A	2,142	200	428,400	0.000000001	230	40			2,350		
Q_{GW}21	Out	Ocean	95	100	9,520	0.00000001	335	40			-358		
Q_{GW}22	Out	Ocean	1,142	100	114,240	0.000000001	790	100			-456		
Q_{GW}23	Out	Ocean	95	100	9,520	0.00000001	635	60			-284		
Q_{GW}24	Out	Ocean	619	100	61,880	0.000000001	625	12			-37		
Q_{GW}25	Out	Ocean	4,474	100	447,440	0.000001	545	80			-2,071,261		
Q_{GW}26	Out	Ocean	143	100	14,280	0.0001	570	20			-1,580,120		
Q_{GW}27	Out	Ocean	381	100	38,080	0.00001	75	20			-3,202,376		
Q_{GW}28	Out	Shawnigan Crk	1,047	20	20,944	0.000001	75	20			-1,761,307		
Q_{GW}29	Out	Shawnigan Crk	190	20	3,808	0.0001	145	20			-16,564		
Q_{GW}30	Out	Shawnigan Crk	143	20	2,856	0.00001	130	20			-138,564		
Q_{GW}31	Out	Shawnigan Crk	95	20	1,904	0.00001	370	20			-32,457		
Q_{GW}32	Out	Shawnigan Crk	714	20	14,280	0.000001	205	20	-	-	-43,935		
Q_{GW}33	Out	Shawnigan Crk	95	20	1,904	0.00001	225	20	-	-	-53,373		
Q_{GW}34	Out	Shawnigan Crk	428	20	8,568	0.000001	520	40	-	-	-20,785		
Q_{GW}35	Out	Shawnigan Crk	95	20	1,904	0.0001	240	20	-	-	-500,371		
Q_{GW}36	Out	Shawnigan Crk	1,904	20	38,080	0.000001	260	10			-46,188		
Q_{GW}37	Out	Shawnigan Crk	714	20	14,280	0.000000001	125	20			-72		
Q_{GW}38	Out	Shawnigan Crk	143	20	2,856	0.00000001	320	40			-113		
Q_{GW}39	Out	Shawnigan Crk	381	20	7,616	0.000000001	140	20			-34		
Q_{GW}40	Out	Shawnigan Crk	143	20	2,856	0.00000001	435	20			-41		
Q_{GW}41	Out	Shawnigan Crk	714	20	14,280	0.000000001	85	20			-106		
Q_{GW}42	Out	Shawnigan Crk	238	20	4,760	0.00000001	245	20			-123		
Q_{GW}43	Out	Shawnigan Crk	476	20	9,520	0.000000001	245	20			-25		
Q_{GW}44	In	AQ 205	Leakage from 205	Leakance Factor (m/yr) =	0.200	2,728,692	--	--	--		545,738		
Q_{GW}45	In	AQ 206	Leakage from 206	Leakance Factor (m/yr) =	0.300	2,573,511	--	--			772,053		
Total											-8,127,257		

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Hollings Creek	Unknown	Downward	10%	5000	2	0.00003	946,080			A portion of Hollings Creek runs over a thick layer of overburden therefore those sections are considered to be conveyance features.
Handysen Creek	Unknown	Downward	0%	2200	2	0.00003	0			
Unnamed creek	Unknown	Zero	10%	480	2	0.00003	90,824			Over a thick layer of overburden therefore it is considered a conveyance feature.
Johns Creek	Unknown	Downward	10%	4000	2	0.00003	756,864			
Total							**1,793,768**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	14,600	100%	14,600							100% consumptive
Commercial	32,850	100%	32,850							100% consumptive
Domestic	194,146	100%	194,146							100% consumptive
Irrigation	100,596	100%	100,596							100% consumptive
BCMOE Obs	0	100%	0							100% consumptive
Other	40,150	100%	40,150							100% consumptive
Water Supply Systems	30,715	100%	30,715							100% consumptive
Total			**-413,057**							

APPENDIX G: AQUIFER 0197 (CHERRY POINT)

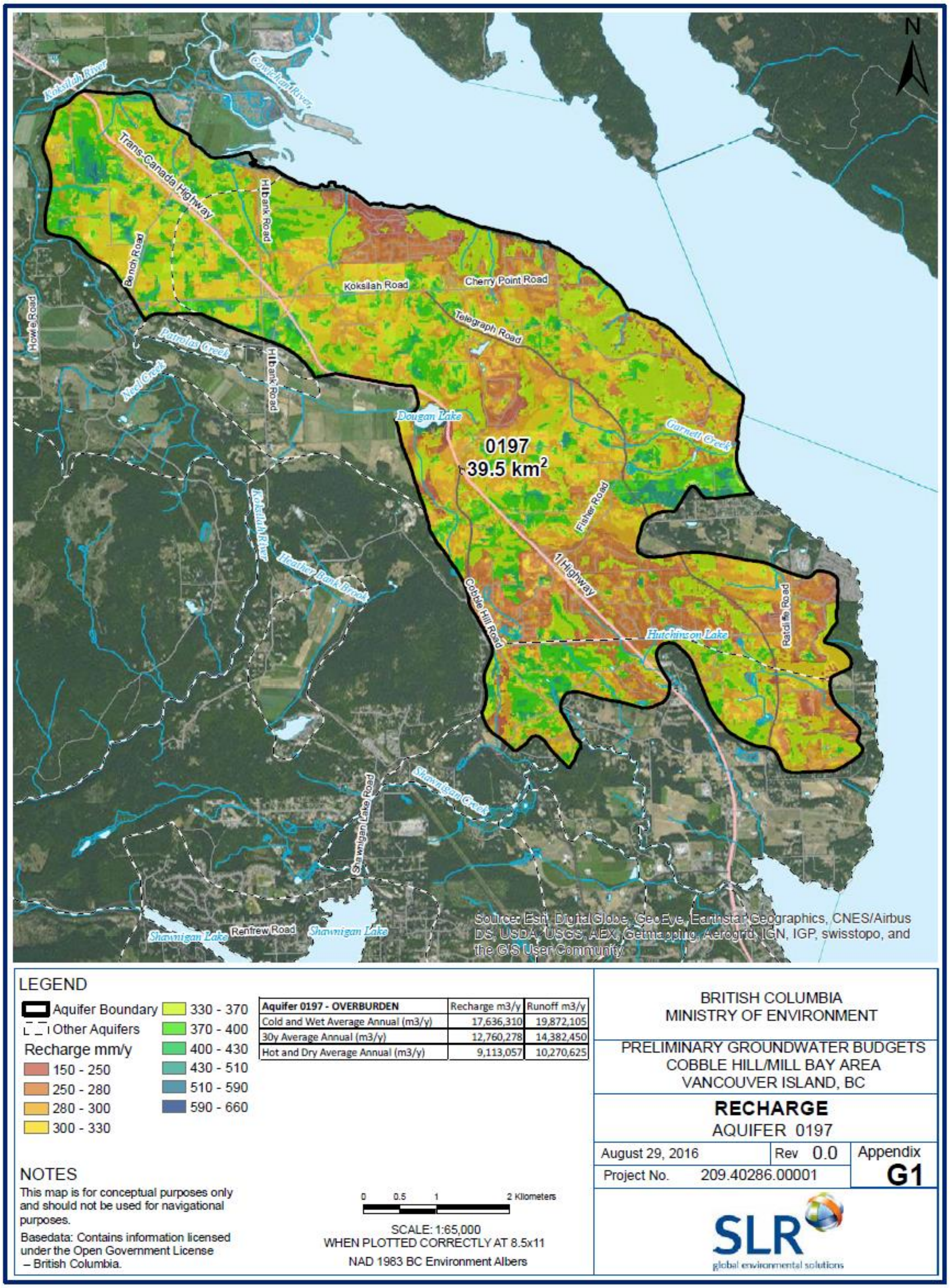


Figure G-1: Recharge distribution for surficial aquifer 0197.

Table G-1: CHM Aquifer Criteria: Aquifer #0197, Cherry Point (Surficial).

BCMOE Criteria	
AQ tag	197 Cherry Point
AQ classification	IIC (11)
AQ type	BCMOE Classification = 4b (SLR Classification = 4a / 4b / 4c)
Location	Cowichan Bay / Cobble Hill
Perimeter (km)	42.05
Area (km^2)	39.48
Aquifer materials	Sand and gravel
Lithostratographic unit	Vashon Drift
Productivity	Moderate
Vulnerability	Low
Demand	Moderate
Use	Multiple
Location	
NTS 50000	Mostly within 092B/12, north end within 092B/13
TRIM 20000	Straddles 092B.062, 092B.063, 092B.072, and 092B.073
Lat / Long (Centre)	48^{o}43'08" / 123^{o}36'09"
UTM Zone 10 (Centre)	455660E / 5396386N
Climate	
Nearest active EC weather station / distance / elevation	EC1012573 Duncan Kelvin Creek / 3.7 km to west (north end of AQ); EC1017230 Shawnigan Lake / 2.8 km to southwest (south end of AQ)
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland
Elevation range (m amsl)	0 - 140 m amsl
Distance to marine	Abuts Cowichan Bay along northeast edge
Geomorphological setting	Plateau-like bench flanked to west and northwest by the west-northwest trending Koksilah River / Dougan Lake valley and Glenora / Kelvin hillslopes, southwest by the Cobble Hill uplands, and northeast-east by steep bluffs along the marine shoreline. Deep, short ravines commonly developed along Cowichan Bay bluffs. Deep, stratigraphically complex morainal / glaciofluvial outwash blanket on south side of the NW-trending Cowichan River regional lineament, contains four subplanar surface depressions aligned roughly northwest within in the southeast corner of the AQ that may be former glacial kettles (lakes)
Topography	Broad, plateau-like, west-northwest trending domed area. Isolated northwest-trending conical hills at south end. Low, chaotic-outline hills at centre east of Dougan Lake (glaciofluvial outwash / kame deposits from Dougan-Koksilah lineament). Local, irregular depressional areas in southeast 1/4 aligned northwest. Short ravines along Cowichan Bay shoreline
Terrain	Generally planar to undulating, hummocky east of Dougan Lake. Irregular, planar depressions southeast of Dougan Lake. Common short ravines along Cowichan bay shoreline
Aspect	Low, west-northwest trending dome, northeast / southeast / southwest, northwest aspects along peripheral flanks
Slope	Generally low to moderate ground slopes, convex & radial apart from east of Dougan Lake (chaotic) and along the Cowichan Bay shoreline (steep, locally incised bluffs)
XS max grade (m/m)	0.046 ENE at south end of AQ from Braithwaite / Gallier Rd area to Cowichan Bay shoreline
Roughness coefficient	0.50 (isolated, open deciduous-coniferous tree stands, extensive cleared agricultural / rural residential areas)
Geology	
Terrane	Overlap / Wrangellia
Bedrock (age ; formation ; lithology)	

Primary	Northern 5/6 of AQ underlain by Upper Cretaceous; Nanaimo Group (uKN); mainly shale + subordinate sandstone
Secondary	Southern 1/6 of AQ underlain by Middle to Upper Devonian Sicker Group Duck Lake Volcanics (muDSiD); basaltic volcanic rocks (80%) / Triassic Karmutsen Volcanics (uTrVK); basaltic (15%) / Carboniferous Buttle Lake Group (PnPBM); limestone (5%)
Tertiary	Southeast tip of AQ underlain by Early to Middle Jurassic Island Plutonic Suite (EMJIgd); granodioritic intrusive rocks (south of San Juan Fault)
Structure	Southern tip of AQ underlain by east-northeast trending San Juan Fault ; Northeast portion of AQ underlain by two southernmost splays of theCowichan Lake Thrust zone
Surficial (formation; lithology; thickness)	Primarily Vashon Drift morainal / glaciofluvial / glaciomarine over basal Quadra Sands glaciofluvial; silt-sand; generally deep blankets (50 - 100 m). Capilano Formation glaciofluvial-glaciolacustrine kame / kettle deposits within an arcuate linear zone east and southeast of Dougan Lake. Salish Formation fluvial veneers along Garnett and Manley Creeks
Surficial designation (1993)	Generally dMbh/$LGp//sgFGf; isolated depressional areas in northeast part of Aq = $LGp and $Op. Unmapped sgFG kame deposits east of Dougan Lake
Soils (association; parent; texture; drainage; type; comments)	Northern 4/5 = FF2 and FF1v8TT71QU1/d (Finlayson & Tagner marine, subordinate Quamichan fluvial), generally silt-clay loam to clay loam, GLE.DYB / O.HG; Southern 1/5 with elevated topographic areas = SE1v8DD1v1QU11/de (Somenos moraine / subordinate Dashwood Creek marine & Quamichan fluvial), generally gravelly-sandy loam, DU.DYB; Small area south of Cherry Point = QU1 (Quamichan fluvial); very gravelly-sandy loam; DU.DYB
Restrictive layers	Yes - low permeability due to near surface silt-clay soils in Finlayson/Tagner soil areas / low permeability due to surface duric layers in Somenos (morainal) and Dashwood Creek (marine) soil areas
Estimated permeability	Generally low throughout AQ
Hydrology	
GW / SW basin coincidence	No - straddles three separate catchments: (1) northeast 1/2 of AQ with streams flowing directly into Cowichan Bay (including Garnett Creek, Manley Creek, and numerous short, unnamed streams; (2) south part of AQ containing Hutchinson Lake & south-flowing tributaries of Shawnigan Creek; and (3) southwest-central part of AQ containing Dougan Lake and headwaters of Patrolas Creek that drain west towards the Koksilah River + northwest border of AQ approximately defined by Koksilah River
Catchments	Cowichan Bay / Shawnigan Creek / Koksilah River
Drainage regime	Generally radial off central topographic dome. Dendretic to trellised within southeast portion and around Dougan Lake
Surface waters	Garnett Creek, Manley Creek, dozens of short streams flowing directly into Cowichan Bay / Dougan lake and Patrolas Creek flowing towards Koksilah River / Hutchinson Lake & northern headwater streams of Shawnigan Creek
Runoff coefficient	~50% cleared-agricultural / ~30% forested / 20% rural residential / moderate slope = 0.55
Nearest Active EC hydrometric station; distance; type	Shawnigan Creek @ Mill Bay 2.04 km south of AQ (inactive); EC 08HA003 Koksilah River @ Cowichan Station adjacent to northwest corner of AQ, active realtime;
Surface water diversions ; relevance	> 50 licences within Cowichan Bay catchment, accessing streams and springs flowing directly into Cowichan Bay; moderate to high relevance for upper AQ zones; > 15 licences within Dougan Lake and Patrolas Creek flowing towards Koksilah River - moderate to high relevance for upper AQ zones
Land Cover	
Vegetation zone	Cgf-wC
Primary land uses	Mainly agricultural and rural residential, subordinate forestry
Degree of development	Extensive agricultural / rural residential clearing. Very low impervious cover
Evapotranspiration potential	High
Relative environmental sensitivity	Moderate in terrestrial areas, high along creeks, lakes, and depressional wetlands

Hydrogeology	
Groundwater occurrence (primary / secondary)	Granular pore space infillings
Primary porosity	Variable: low in morainal & glaciomarine materials, moderate to high in glaciofluvial materials. Suspected multiple stacked AQ zones separated by aquitards, moderate lateral continuity along northwest-southeast axis due to glacial outwash wasting patterns
Secondary porosity	Generally not applicable - surficial AQ; increased secondary porosity in morainal areas with near-surface prismatic structure
Confinement	Suspected variable degrees of confinement based on the composite nature of the AQ: (1) surface and near-surface glaciofluvial and morainal components may be unconfined to semi-confined by duric till blankets; (2) subsurface morainal and glaciofluvial components may be semi-confined to confined due to overlying unstructured, dense moraine and/or glaciomarine-glaciolacustrine aquitards (3) deep morainal and glaciofluvial components may be confined due to their depth below ground (including locations where water-bearing zones are below seas level) WP = 0 - 87.8 m, avg 20.0 m
Aquifer thickness	Thickness of composite AQ highly variable - locally > 100 m. Individual "sub-aquifer" water-bearing zones likely much thinner (<5 m)
Hydraulic anisotropy	Moderate to high due to probable stratigraphic complexity
Hydraulic gradient	Variable, likely low to moderate based on local terrain
Storage potential	Variably low to high due to probable stratigraphic complexity
Yield potential	Variable low-high depending on AQ host materials; WP = 0.01 - 17.35 L/s / average 0.63 L/s
Flow velocities	Variably low to moderate due to probable stratigraphic complexity
Flow directions	Near-surface unconfined / semi-confined AQ zones: flow likely mirrors topography, radially to the south, southwest, and northeast Deeper semi-confined to confined AQ zones: flow direction uncertain, may be driven by upgradient heads northeast towards Cowichan Bay and/or southeast along axis of assumed glacial outwash direction. Deep confined AQ zones at bedrock interface: flow may be influenced by bedrock surface irregularities + regional northwest-trending structural and stratigraphic fabrics
Static water levels	WP = variable 0 - 93 m bgs / avg 27.4 m bgs
Hydraulic connection with surface waters	Near-surface unconfined / semi-confined AQ zones: moderate to high with radial creeks, depending on depths of incision. Historical groundwater "bursts" recorded within Cowichan Bay ravines, resulting in periodic debris flows & flooding of coastal ravine termini areas. Deeper semi-confined to confined AQ zones: low connectivity due to deep overburden cover; Deep confined AQ zones at bedrock interface: negligible due to relative elevation differences (basal AQ zones often positioned below sea level)
Hydraulic connection to adjacent AQ	
Over / Under	AQ is locally overlain by surficial AQ 199 to immediate northwest of Dougan Lake; AQ overlies bedrock AQ 198 (north end), bedrock AQ 204 (southeast end) Central and southwest portions of AQ also underlain by undeveloped extensions of bedrock AQ 198 (Nanaimo Group sedimentary rocks) and bedrock AQ 204 (mixed intrusive / volcanic rocks)
Upgradient	Near-surface unconfined / semi-confined AQ zones, southwest -central area: in contact with higher-elevation portions of bedrock AQ 202 and bedrock AQ 204; Deeper semi-confined to confined AQ zones: likely receiving recharge from upgradient bedrock sources to the northwest (including bedrock AQ 196) , west, and southwest
Downgradient	Near-surface unconfined / semi-confined AQ zones: (1) North end of AQ = surrounded by lower-elevation surficial AQ 186; (2) southwest side of AQ in contact with lower elevation surficial AQ 199 and its undeveloped triangular southeast extension; (3) southeast end of AQ: in contact with lower elevation bedrock AQ 204

Vulnerability to surface contamination	Variable: (1) near-surface unconfined / semi-confined AQ zones = low-moderate based on surficial lithologies and presence of low-permeability surface soil horizons; (2) deeper semi-confined to confined AQ zones - low to negligible based on deep overburden cover
Recharge	
Vertical inflow	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high recharge from precipitation and irrigation-sewerage returns (high levels of rural residential and agricultural development), negligible from snowmelt due to low elevations. Low to negligible from stream losses due to AQ area's domed topography and radial drainage; (2) deeper semi-confined to confined AQ zones: low to negligible from precipitation due to deep overburden cover
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock sources
Temporal variability	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high depending on surficial lithologies and presence of low-permeability surface soil layers (2) Deeper semi-confined to confined AQ zones: negligible due to deep overburden cover
MBR	Low along southwest side from upgradient rocky Cobble Hill (bedrock AQ 202) and exposed areas of bedrock AQ 204 - limited perimeter contact length
Discharge	
Evapotranspiration	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate (2) Deeper semi-confined to confined AQ zones: negligible
Outflow to marine	Moderate to high due to domed topographic setting relative to Cowichan Bay
Outflow to surface waters	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high into radial creek systems (2) Deeper semi-confined to confined AQ zones: negligible
Outflow to other AQ	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to lower elevation aquifers (2) Deeper semi-confined to confined AQ zones: low to moderate outflow to underlying bedrock aquifers
Temporal variability	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high (2) Deeper semi-confined to confined AQ zones: negligible
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	AQ contains Well #233 (northwest end); Well #320 (central area); Well 345 (southeast area); high relevancy
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	401500
Commercial	87600
Domestic	406867
Irrigation from GW (MoAg)	2687689
BCMOE Obs	0
Other	149200
Water Supply Systems	843725

Table G-2: Direct Recharge Calculation for AQ197.

	Direct Recharge Calculation		
	Hot/Dry	**Average**	**Cold/Wet**
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.030	1.030	1.030
Infiltration Coefficient	0.467	0.467	0.467
Area (m^2)	29,351,617	29,351,617	29,351,617
Q (m^3/yr)	7,230,576	10,747,961	17,836,681
Average Infiltration Rate	0.246	0.366	0.608

Table G-3: Annual Summary of AQ197 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 197	29,351,617	0.366	10,747,961
Loss	Leakage down to 204	5,126,386	0.300	-1,537,916
Loss	Leakage down to 198	4,999,983	0.100	-499,998
Loss	Leakage to depth	19,225,248	0.100	-1,922,525
Loss	Lateral Groundwater	--	--	-5,881,466
Gain	Lateral Groundwater	--	--	271,673
Loss	Surface Water	--	--	-741,333
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-4,576,581
Net Gain				**11,019,634**
Net Loss				**-15,159,818**
Net Total (Gain - Loss)				**-4,140,184**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 197	29,351,617	0.246	7,230,576
Loss	Leakage down to 204	5,126,386	0.300	-1,537,916
Loss	Leakage down to 198	4,999,983	0.100	-499,998
Loss	Leakage to depth	19,225,248	0.100	-1,922,525
Loss	Lateral Groundwater	--	--	-5,881,466
Gain	Lateral Groundwater	--	--	271,673
Loss	Surface Water	--	--	-741,333
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-4,576,581
Net Gain				**7,502,249**
Net Loss				**-15,159,818**
Net Total (Gain - Loss)				**-7,657,570**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 197	29,351,617	0.608	17,836,681
Loss	Leakage down to 204	5,126,386	0.300	-1,537,916
Loss	Leakage down to 198	4,999,983	0.100	-499,998
Loss	Leakage to depth	19,225,248	0.100	-1,922,525
Loss	Lateral Groundwater	--	--	-5,881,466
Gain	Lateral Groundwater	--	--	271,673
Loss	Surface Water	--	--	-741,333
Gain	Surface Water	--	--	0
Loss	Water Usage	--	--	-4,576,581
Net Gain				**18,108,354**
Net Loss				**-15,159,818**
Net Total (Gain - Loss)				**2,948,535**

Table G-4: Monthly Summary of AQ197 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 197	2,702,772	1,760,481	1,270,488	305,109	-367,256	-579,135	-565,010	-254,254	-84,751	929,202	2,851,003	2,779,312	**10,747,961**
Leakage down to 204	-124,571	-119,957	-133,799	-132,261	-138,412	-132,261	-133,799	-130,723	-124,571	-126,109	-119,957	-121,495	**-1,537,916**
Leakage down to 198	-40,500	-39,000	-43,500	-43,000	-45,000	-43,000	-43,500	-42,500	-40,500	-41,000	-39,000	-39,500	**-499,998**
Leakage to depth	-155,725	-149,957	-167,260	-165,337	-173,027	-165,337	-167,260	-163,415	-155,725	-157,647	-149,957	-151,879	**-1,922,525**
Lateral Groundwater Loss	-476,399	-458,754	-511,688	-505,806	-529,332	-505,806	-511,688	-499,925	-476,399	-482,280	-458,754	-464,636	**-5,881,466**
Lateral Groundwater Gain	22,006	21,190	23,636	23,364	24,451	23,364	23,636	23,092	22,006	22,277	21,190	21,462	**271,673**
Surface Water Loss	-163,598	-143,625	-103,749	-50,163	-17,787	-7,214	-4,284	-1,392	-1,170	-10,739	-75,898	-161,714	**-741,333**
Surface Water Gain	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-274595	-297478	-343244	-366126	-411892	-457658	-503424	-526307	-457658	-366126	-320361	-251712	**-4,576,581**
Net Gain	**2,724,777**	**1,781,672**	**1,294,124**	**328,473**	**24,451**	**23,364**	**23,636**	**23,092**	**22,006**	**951,479**	**2,872,194**	**2,800,775**	**12,870,041**
Net Loss	**-1,235,387**	**-1,208,772**	**-1,303,238**	**-1,262,693**	**-1,682,707**	**-1,890,411**	**-1,928,964**	**-1,618,515**	**-1,340,774**	**-1,183,902**	**-1,163,927**	**-1,190,937**	**-17,010,225**
Net Total (Gain - Loss)	**1,489,390**	**572,900**	**-9,114**	**-934,220**	**-1,658,256**	**-1,867,047**	**-1,905,328**	**-1,595,423**	**-1,318,768**	**-232,422**	**1,708,267**	**1,609,838**	**-4,140,184**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 197	2,216,942	1,271,272	1,976,707	118,652	-466,133	-593,260	-508,509	-211,879	-141,252	360,194	1,413,937	1,793,906	**7,230,576**
Leakage down to 204	-126,109	-116,882	-129,185	-127,647	-133,799	-129,185	-133,799	-132,261	-126,109	-130,723	-124,571	-127,647	**-1,537,916**
Leakage down to 198	-41,000	-38,000	-42,000	-41,500	-43,500	-42,000	-43,500	-43,000	-41,000	-42,500	-40,500	-41,500	**-499,998**
Leakage to depth	-157,647	-146,112	-161,492	-159,570	-167,260	-161,492	-167,260	-165,337	-157,647	-163,415	-155,725	-159,570	**-1,922,525**
Lateral Groundwater	-482,280	-446,991	-494,043	-488,162	-511,688	-494,043	-511,688	-505,806	-482,280	-499,925	-476,399	-488,162	**-5,881,466**
Lateral Groundwater	22,277	20,647	22,821	22,549	23,636	22,821	23,636	23,364	22,277	23,092	22,006	22,549	**271,673**
Surface Water	-163,598	-143,625	-103,749	-50,163	-17,787	-7,214	-4,284	-1,392	-1,170	-10,739	-75,898	-161,714	**-741,333**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-274595	-297478	-343244	-366126	-411892	-457658	-503424	-526307	-457658	-366126	-320361	-251712	**-4,576,581**
Net Gain	**2,239,219**	**1,291,919**	**1,999,527**	**141,201**	**23,636**	**22,821**	**23,636**	**23,364**	**22,277**	**383,286**	**1,435,942**	**1,816,455**	**9,423,282**
Net Loss	**-1,245,229**	**-1,189,088**	**-1,273,712**	**-1,233,167**	**-1,752,058**	**-1,884,853**	**-1,872,463**	**-1,585,981**	**-1,407,117**	**-1,213,428**	**-1,193,453**	**-1,230,304**	**-17,080,852**
Net Total (Gain - Loss)	**993,990**	**102,831**	**725,815**	**-1,091,966**	**-1,728,422**	**-1,862,032**	**-1,848,827**	**-1,562,617**	**-1,384,840**	**-830,142**	**242,490**	**586,151**	**-7,657,570**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 197	5,015,874	5,078,292	1,883,363	-226,004	-183,628	-480,258	-621,511	-254,254	-113,002	1,781,193	2,878,725	3,077,891	**17,836,681**
Leakage down to 204	-124,571	-119,957	-133,799	-132,261	-138,412	-132,261	-133,799	-130,723	-124,571	-126,109	-119,957	-121,495	**-1,537,916**
Leakage down to 198	-40,500	-39,000	-43,500	-43,000	-45,000	-43,000	-43,500	-42,500	-40,500	-41,000	-39,000	-39,500	**-499,998**
Leakage to depth	-155,725	-149,957	-167,260	-165,337	-173,027	-165,337	-167,260	-163,415	-155,725	-157,647	-149,957	-151,879	**-1,922,525**
Lateral Groundwater	-476,399	-458,754	-511,688	-505,806	-529,332	-505,806	-511,688	-499,925	-476,399	-482,280	-458,754	-464,636	**-5,881,466**
Lateral Groundwater	22,006	21,190	23,636	23,364	24,451	23,364	23,636	23,092	22,006	22,277	21,190	21,462	**271,673**
Surface Water	-163,598	-143,625	-103,749	-50,163	-17,787	-7,214	-4,284	-1,392	-1,170	-10,739	-75,898	-161,714	**-741,333**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-274,595	-297,478	-343,244	-366,126	-411,892	-457,658	-503,424	-526,307	-457,658	-366,126	-320,361	-251,712	**-4,576,581**
Net Gain	**5,037,880**	**5,099,483**	**1,906,998**	**23,364**	**24,451**	**23,364**	**23,636**	**23,092**	**22,006**	**1,803,470**	**2,899,915**	**3,099,353**	**19,987,011**
Net Loss	**-1,235,387**	**-1,208,772**	**-1,303,238**	**-1,488,697**	**-1,499,078**	**-1,791,534**	**-1,985,465**	**-1,618,515**	**-1,369,024**	**-1,183,902**	**-1,163,927**	**-1,190,937**	**-17,038,476**
Net Total (Gain - Loss)	**3,802,493**	**3,890,711**	**603,761**	**-1,465,333**	**-1,474,628**	**-1,768,171**	**-1,961,829**	**-1,595,423**	**-1,347,019**	**619,569**	**1,735,988**	**1,908,416**	**2,948,535**

Table G-5: Monthly Coefficients used in Calculations for AQ197.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table G-6: Groundwater Flow Components: Aquifer #0197, Cherry Point (Surficial)

Groundwater Flow	**Direction of Flow**	**Source or Receptor of Water**	**Length (m)**	**Depth (m)**	**Area (m)**	**Hydraulic Conductivity (m/s) - K**	**Distance (m) - dL**	**Hydraulic Head (m) - dh**			**GW Flow (m^3/yr)**		
								Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
$Q_{GW}1$ (A1)	Out	Ocean	3,000	5	15,000	0.0001	700	30			-2,027,314		
$Q_{GW}2$ (A2)	Out	Ocean	8,700	10	87,000	0.00001	1,900	50			-722,008		
$Q_{GW}3$ (B)	Out	Ocean	3,200	10	32,000	0.00001	1,500	70			-470,938		
$Q_{GW}4$ (C)	Out	AQ 199	2,000	45	90,000	0.0001	3,200	20			-1,773,900		
$Q_{GW}5$ (D)	Out	AQ 198 ($Q_{GW}9$)	5,200	5	26,000	0.00001	400	10			-204,984		
$Q_{GW}6$	In	AQ 202 ($Q_{GW}27$)	143	200	28,560	0.0000001	235	20			7,665		
$Q_{GW}7$	In	AQ 202 ($Q_{GW}28$)	286	200	57,120	0.000000001	235	20			153		
$Q_{GW}8$	In	AQ 202 ($Q_{GW}29$)	1,178	200	235,620	0.0000001	335	100			221,806		
$Q_{GW}9$	In	AQ 202	250	20	5,000	0.000001	525	140			42,048		
$Q_{GW}14$ (F1)	Out	AQ 204	750	10	7,500	0.00001	680	10			-34,782		
$Q_{GW}15$ (F2)	Out	AQ 204	625	10	6,250	0.00001	600	5			-16,425		
$Q_{GW}16$ (F3)	Out	AQ 204	150	10	1,500	0.000001	600	5			-394		
$Q_{GW}17$ (F4)	Out	AQ 204	750	10	7,500	0.0001	1,500	40			-630,720		
Total											**-5,609,793**		

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Granular Sediment Deposit	--	Upward	100%	2,471,109	--	0.3000	-741,333			The creeks within AQ 197 run over soils with low permeability therefore it is assumed that creeks are fed by the water moving through the granular area of the aquifer close to Dugeon's Lake.
Total							**-741,333**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	401,500	100%	401,500							100% consumptive
Commercial	87,600	100%	87,600							100% consumptive
Domestic	406,867	100%	406,867							100% consumptive
Irrigation	2,687,689	100%	2,687,689							100% consumptive
BCMOE Obs	0	100%	0							100% consumptive
Other	149,200	100%	149,200							100% consumptive
Water Supply Systems	843,725	100%	843,725							100% consumptive
Total	**-4,576,581**		**-4,576,581**							

APPENDIX H: AQUIFER 0199 (DOUGAN LAKE)

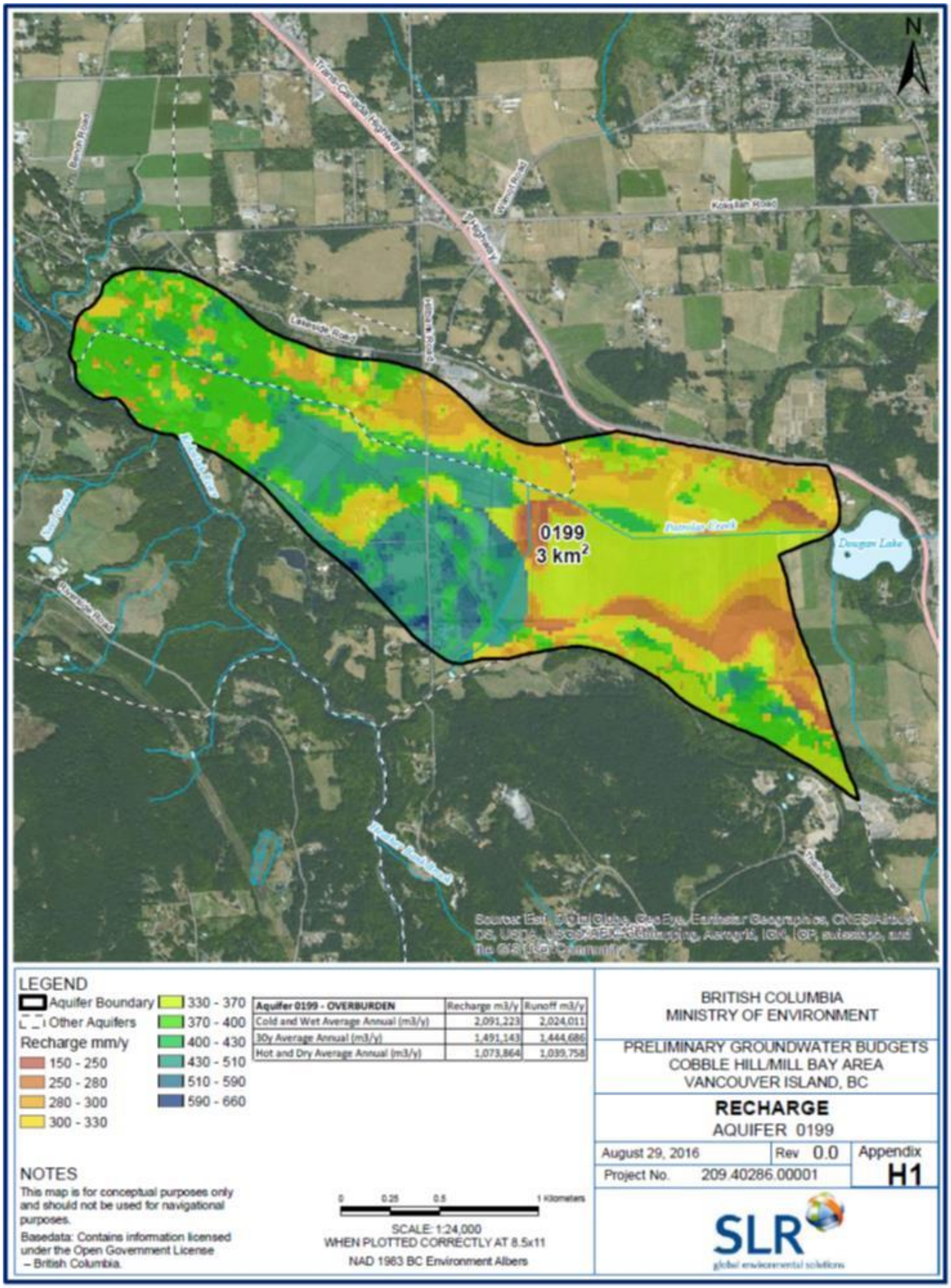


Figure H-1: Recharge distribution for surficial Aquifer 0199.

Table H-1: CHM Aquifer Criteria: Aquifer #0199, Dougan Lake (Surficial).

BCMOE Criteria	
AQ tag	199 Dougan Lake
AQ classification	IIC (9)
AQ type	BCMOE Classification = 4b (SLR Classification = 4a / 4b)
Location	Cowichan Station
Perimeter (km)	9.35
Area (km^2)	3.4
Aquifer materials	Sand and gravel
Lithostratographic unit	Vashon Drift
Productivity	Moderate
Vulnerability	Low
Demand	Moderate
Use	Multiple
Location	
NTS 50000	092B/12
TRIM 20000	092B.072
Lat / Long (Centre)	48^o43'02" / 123^o38'36"
UTM Zone 10 (Centre)	452678E / 5396234N
Climate	
Nearest active EC weather station / distance / elevation	EC1012573 Duncan Kelvin Creek / 4.3 km to west; EC1017230 Shawnigan Lake / 6.4 km to south
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland
Elevation range (m amsl)	60 m (planar area)
Distance to marine	Cowichan Bay is 2.3 km to northeast
Geomorphological setting	Triangular, flat-bottomed bench overlooking Koksilah River to the south. AQ is flanked to the south by Cobble Hill uplands, west by Glenora-Kelvin hillsides, and east/ northeast by Cowichan Bay / Cherry Point domed area
Topography	Generally planar bench overlooking Koksilah River to south
Terrain	Generally planar to gently undulating
Aspect	Generally level, slight slope to the northwest and southwest
Slope	Planar to broadly concave
XS max grade (m/m)	0.005 WNW through centre axis of valley
Roughness coefficient	0.30 (cleared agricultural fields & rural residential properties)
Geology	
Terrane	Overlap
Bedrock (age ; formation ; lithology)	Upper Cretaceous; Nanaimo Group (uKN); shale
Structure	No mapped BCGS structures - possible west / northwest trending thrust faults due to linearity of AQ outline
Surficial (formation; lithology; thickness)	Capilano Formation glaciofluvial-glaciolacustrine ice contact deposit, likely related to Dougan Lake kame/kettle deposits to east
Surficial designation (1993)	$LGp - extends southeast of AQ to south & around Dougan Lake
Soils (association; parent; texture; drainage; type; comments)	East 4/5 = AZ1/b (Azilian organics), moderately decomposed organic materials, T.M; West 1/5 = QU1/c (Quamichan fluvial), very gravelly-sandy loam, DU.DYB;
Restrictive layers	Yes - low permeability organic and/or clay-rich soil layers / subsurface silt-clay aquitards (complex internal stratigraphy) / local surface duric layers in Quamichan soil areas
Estimated permeability	Variable at surface & subsurface due to stratigraphic complexity
Hydrology	
GW / SW basin coincidence	Yes - contained within Koksilah River watershed (north side only)
Catchments	Koksilah River watershed, Patrolas Creek & Dougan Lake catchment
Drainage regime	Rectilinear to trellised, man-made / natural ditching system centred on Patrolas Creek, drains west-northwest into Koksilah River at west end of AQ

Surface waters	Patrolas Creek, northwest corner bordered by Koksilah River
Runoff coefficient	Flat-lying, cleared agricultural & rural residential land = 0.30
Nearest Active EC hydrometric station; distance; type	EC 08HA003 Koksilah River @ Cowichan Station adjacent to northwest corner of AQ, active realtime;
Surface water diversions ; relevance	> 20 licences along Patrolas Creek; moderate to high relevance for upper unconfined AQ zones
Land Cover	
Vegetation zone	Cgf-wC
Primary land uses	Dominantly agricultural and rural residential
Degree of development	Extensive agricultural / rural residential clearing. Very low impervious cover
Evapotranspiration potential	High
Relative environmental sensitivity	Cgf-wC
Hydrogeology	
Groundwater occurrence (primary / secondary)	Granular pore space infillings
Primary porosity	Variable: low in glaciolacustrine materials, moderate to high in glaciofluvial materials. Suspected multiple stacked AQ zones separated by aquitards, moderate lateral continuity along northwest-southeast axis due to glacial outwash wasting patterns
Secondary porosity	Not applicable - surficial AQ
Confinement	Suspected variable degrees of confinement based on the composite nature of the AQ: (1) surface and near-surface glaciofluvial components may be unconfined to semi-confined by silt-clay horizons and duric soil layers; (2) subsurface glaciofluvial components may be semi-confined to confined due to overlying silt-clay aquitards. No WP data - variable aquitard lateral continuities, thicknesses, and depths/ Estimated at 0 - 25 m, avg 10 m
Aquifer thickness	Thickness of composite AQ variable - locally up to 35 m along southwest side, shallows towards northeast and northwest. Individual "sub-aquifer" water-bearing zones likely much thinner (<5 m)
Hydraulic anisotropy	Moderate to high due to probable stratigraphic complexity
Hydraulic gradient	Variable: likely very low based on local terrain / possibly higher at northwest corner adjacent to incised Koksilah River
Storage potential	Variably low to high due to probable stratigraphic complexity
Yield potential	Variable low-high depending on AQ host materials; No WP data, estimated at 0.01 - 3.15 L/s / average 0.63 L/s
Flow velocities	Variable: likely very low based on local terrain / possibly higher at northwest corner adjacent to incised Koksilah River
Flow directions	Near-surface unconfined / semi-confined AQ zones: flow likely mirrors topography towards the west-northwest and southwest towards Koksilah River Deeper semi-confined to confined AQ zones: flow direction uncertain, may be influenced by bedrock surface irregularities + regional northwest-trending structural and stratigraphic fabrics
Static water levels	WP no data / estimated at 0 - 30 m bgs / avg 10 m bgs
Hydraulic connection with surface waters	Near-surface unconfined / semi-confined AQ zones: moderate to high with Patrolas Creek and Koksilah River. Deeper semi-confined to confined AQ zones: negligible connectivity to Patrolas Creek due to deep overburden cover / possible connection to incised portions of Koksilah River at AQ northwest corner.
Hydraulic connection to adjacent AQ	
Over / Under	AQ overlies surficial AQ 197 at its extreme east end / bedrock AQ 198 along much of its northeast side Central, northwest, and southwest portions of AQ also underlain by undeveloped extensions of bedrock AQ 198
Upgradient	AQ in contact with bedrock AQ 198 and surficial AQ 197 along its northwest side. Deeper zones of AQ likely also receive basal recharge from bedrock AQ 196, bedrock AQ 200, and bedrock AQ 202 to the southwest, although BCMOE does not

	indicate their contact with AQ199.
Downgradient	Near-surface unconfined / semi-confined AQ zones: north end of AQ in contact with surficial AQ 186, possible cross-gradient contact with bedrock AQ198
Vulnerability to surface contamination	Variable: (1) near-surface unconfined / semi-confined AQ zones = low-moderate based on surficial lithologies and presence of low-permeability surface soil horizons; (2) deeper semi-confined to confined AQ zones - low to negligible based on deep overburden cover
Recharge	
Vertical inflow	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high recharge from precipitation and irrigation-sewerage returns (high levels of rural residential and agricultural development) and well-documented seasonal flooding, negligible from snowmelt due to low elevations. Low to negligible from stream losses due to AQ area's low-permeability surface soils (2) deeper semi-confined to confined AQ zones: low to negligible from precipitation due to deep overburden cover.
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock and surficial sources, possible lateral surface water inflow from Dougan Lake at east end of AQ
Temporal variability	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high depending on surficial lithologies and presence of low-permeability surface soil layers (2) Deeper semi-confined to confined AQ zones: negligible due to deep overburden cover
MBR	Low to moderate along south side from upgradient rocky Cobble Hill (bedrock AQ 202) - limited perimeter contact length
Discharge	
Evapotranspiration	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high (2) Deeper semi-confined to confined AQ zones: negligible
Outflow to marine	Negligible due to distance from marine shoreline
Outflow to surface waters	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high into Patrolas Creek and Koksilah River (2) Deeper semi-confined to confined AQ zones: low to deeply incised portions of Koksilah River at AQ's west end
Outflow to other AQ	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to lower elevation aquifers (2) Deeper semi-confined to confined AQ zones: low to moderate outflow to underlying bedrock aquifers
Temporal variability	Variable: (1) near-surface unconfined / semi-confined AQ zones: moderate to high (2) Deeper semi-confined to confined AQ zones: negligible
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #233 is 2.1 km to northeast; Well #320 is 3.1 km to southeast; negligible to low relevancy, both wells completed within surficial AQ197
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	109500
Commercial	0
Domestic	16747
Irrigation from GW (MoAg)	161704
BCMOE Obs	0
Other	7300
Water Supply Systems	0

Table H-2: Direct Recharge Calculation for AQ199.

	Direct Recharge Calculation		
	Hot/Dry	Average	Cold/Wet
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.060	1.060	1.060
Infiltration Coefficient	0.511	0.511	0.511
Area (m^2)	3,280,000	3,280,000	3,280,000
Q (m^3/yr)	909,447	1,351,857	2,243,462
Average Infiltration Rate	0.277	0.412	0.684

Table H-3: Annual Summary of AQ199 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 199	3,280,000	0.412	1,351,857
Loss	Leakage down to 198	796,597	0.100	-79,660
Loss	Leakage down to bedrock	2,483,403	0.100	-248,340
Loss	Lateral Groundwater	--	--	-2,056,385
Gain	Lateral Groundwater	--	--	1,778,226
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	0
Loss	Water Useage	--	--	-295,251
Net Gain				**3,130,083**
Net Loss				**-2,679,636**
Net Total (Gain - Loss)				**450,447**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 199	3,280,000	0.277	909,447
Loss	Leakage down to 198	796,597	0.100	-79,660
Loss	Leakage down to bedrock	2,483,403	0.100	-248,340
Loss	Lateral Groundwater	--	--	-2,056,385
Gain	Lateral Groundwater	--	--	1,778,226
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	0
Loss	Water Useage	--	--	-295,251
Net Gain				**2,687,674**
Net Loss				**-2,679,636**
Net Total (Gain - Loss)				**8,037**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 199	3,280,000	0.684	2,243,462
Loss	Leakage down to 198	796,597	0.100	-79,660
Loss	Leakage down to bedrock	2,483,403	0.100	-248,340
Loss	Lateral Groundwater	--	--	-2,056,385
Gain	Lateral Groundwater	--	--	1,778,226
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	0
Loss	Water Useage	--	--	-295,251
Net Gain				**4,021,688**
Net Loss				**-2,679,636**
Net Total (Gain - Loss)				**1,342,052**

Table H-4: Monthly Summary of AQ199 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 199	339,949	221,430	159,799	38,376	-46,193	-72,842	-71,066	-31,980	-10,660	116,873	358,593	349,576	**1,351,857**
Leakage down to 198	-6,452	-6,213	-6,930	-6,851	-7,169	-6,851	-6,930	-6,771	-6,452	-6,532	-6,213	-6,293	**-79,660**
Leakage down to bedrock	-20,116	-19,371	-21,606	-21,357	-22,351	-21,357	-21,606	-21,109	-20,116	-20,364	-19,371	-19,619	**-248,340**
Lateral Groundwater Loss	-166,567	-160,398	-178,906	-176,849	-185,075	-176,849	-178,906	-174,793	-166,567	-168,624	-160,398	-162,454	**-2,056,385**
Lateral Groundwater Gain	144,036	138,702	154,706	152,927	160,040	152,927	154,706	151,149	144,036	145,815	138,702	140,480	**1,778,226**
Surface Water Loss	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Gain	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-17715	-19191	-22144	-23620	-26573	-29525	-32478	-33954	-29525	-23620	-20668	-16239	**-295,251**
Net Gain	**483,986**	**360,131**	**314,505**	**191,303**	**160,040**	**152,927**	**154,706**	**151,149**	**144,036**	**262,688**	**497,295**	**490,056**	**3,362,824**
Net Loss	**-210,850**	**-205,173**	**-229,585**	**-228,677**	**-287,360**	**-307,425**	**-310,985**	**-268,606**	**-233,320**	**-219,140**	**-206,650**	**-204,605**	**-2,912,377**
Net Total (Gain - Loss)	**273,135**	**154,958**	**84,920**	**-37,374**	**-127,320**	**-154,497**	**-156,279**	**-117,457**	**-89,284**	**43,548**	**290,645**	**285,451**	**450,447**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 199	278,842	159,898	248,626	14,924	-58,629	-74,619	-63,959	-26,650	-17,766	45,304	177,842	225,634	**909,447**
Leakage down to 198	-6,532	-6,054	-6,691	-6,612	-6,930	-6,691	-6,930	-6,851	-6,532	-6,771	-6,452	-6,612	**-79,660**
Leakage down to bedrock	-20,364	-18,874	-20,861	-20,612	-21,606	-20,861	-21,606	-21,357	-20,364	-21,109	-20,116	-20,612	**-248,340**
Lateral Groundwater	-168,624	-156,285	-172,736	-170,680	-178,906	-172,736	-178,906	-176,849	-168,624	-174,793	-166,567	-170,680	**-2,056,385**
Lateral Groundwater	145,815	135,145	149,371	147,593	154,706	149,371	154,706	152,927	145,815	151,149	144,036	147,593	**1,778,226**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-17,715	-19,191	-22,144	-23,620	-26,573	-29,525	-32,478	-33,954	-29,525	-23,620	-20,668	-16,239	**-295,251**
Net Gain	**424,657**	**295,043**	**397,997**	**162,517**	**154,706**	**149,371**	**154,706**	**152,927**	**145,815**	**196,454**	**321,878**	**373,227**	**2,929,297**
Net Loss	**-213,235**	**-200,405**	**-222,432**	**-221,524**	**-292,643**	**-304,433**	**-303,878**	**-265,661**	**-242,811**	**-226,293**	**-213,803**	**-214,143**	**-2,921,260**
Net Total (Gain - Loss)	**211,422**	**94,639**	**175,565**	**-59,007**	**-137,938**	**-155,062**	**-149,173**	**-112,733**	**-96,997**	**-29,839**	**108,076**	**159,084**	**8,037**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 199	630,887	638,737	236,886	-28,426	-23,096	-60,406	-78,172	-31,980	-14,213	224,035	362,080	387,131	**2,243,462**
Leakage down to 198	-6,452	-6,213	-6,930	-6,851	-7,169	-6,851	-6,930	-6,771	-6,452	-6,532	-6,213	-6,293	**-79,660**
Leakage down to bedrock	-20,116	-19,371	-21,606	-21,357	-22,351	-21,357	-21,606	-21,109	-20,116	-20,364	-19,371	-19,619	**-248,340**
Lateral Groundwater	-166,567	-160,398	-178,906	-176,849	-185,075	-176,849	-178,906	-174,793	-166,567	-168,624	-160,398	-162,454	**-2,056,385**
Lateral Groundwater	144,036	138,702	154,706	152,927	160,040	152,927	154,706	151,149	144,036	145,815	138,702	140,480	**1,778,226**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-17,715	-19,191	-22,144	-23,620	-26,573	-29,525	-32,478	-33,954	-29,525	-23,620	-20,668	-16,239	**-295,251**
Net Gain	**774,923**	**777,439**	**391,591**	**152,927**	**160,040**	**152,927**	**154,706**	**151,149**	**144,036**	**369,849**	**500,782**	**527,611**	**4,257,982**
Net Loss	**-210,850**	**-205,173**	**-229,585**	**-257,104**	**-264,264**	**-294,988**	**-318,091**	**-268,606**	**-236,873**	**-219,140**	**-206,650**	**-204,605**	**-2,915,930**
Net Total (Gain - Loss)	**564,073**	**572,266**	**162,006**	**-104,176**	**-104,223**	**-142,061**	**-163,386**	**-117,457**	**-92,837**	**150,710**	**294,132**	**323,006**	**1,342,052**

Table H-5: Monthly Coefficients used in Calculations for AQ197.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table H-6: Groundwater Flow Components: Aquifer #0199, Dougan Lake (Surficial)

Groundwater Flow	**Direction of Flow**	**Source or Receptor of Water**	**Length (m)**	**Depth (m)**	**Area (m)**	**Hydraulic Conductivity (m/s) - K**	**Distance (m) - dL**	**Hydraulic Head (m) - dh**			**GW Flow (m^3/yr)**		
								Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
$Q_{GW}1$	In	AQ 197	--	--	90,000	0.0001	3,200	20	--	--	1,773,900		
$Q_{GW}2$	Out	Koksilah River	3,200	6	19,200	0.0001	1,060	36			-2,056,385		
$Q_{GW}4$	In	AQ 202 ($Q_{GW}23$)	107.1	200	21420	0.00000001	510	60	--	--	795		
$Q_{GW}5$	In	AQ 202 ($Q_{GW}24$)	214.2	200	42840	0.000000001	600	80			180		
$Q_{GW}6$	In	AQ 202 ($Q_{GW}25$)	142.8	200	28560	0.00000001	665	100			1,354		
$Q_{GW}7$	In	AQ 202 ($Q_{GW}26$)	1820.7	200	364140	0.000000001	575	100			1,997		
$Q_{GW}8$	Out	Leakage to AQ 198	Leakance Factor (m/yr) =	0.100	796,597	--	--	--	--	--	-79,660		
Total											**-357,819**		

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Patrolas Creek	Yes	Zero	0%	2,600	2	0.00003	0			Conveyance feature
Total							**0**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	109,500	100%	109,500							100% consumptive
Commercial	0	100%	0							100% consumptive
Domestic	16,747	100%	16,747							Assuming 100% percent goes to septic beds
Irrigation	161,704	100%	161,704							100% consumptive
BCMOE Obs	0	100%	0							100% consumptive
Other	7,300	100%	7,300							100% consumptive
Water Supply Systems	0	100%	0							100% consumptive
Total	**-295,251**		**-295,251**							

APPENDIX I: AQUIFER 0201 (KINGBURNE)

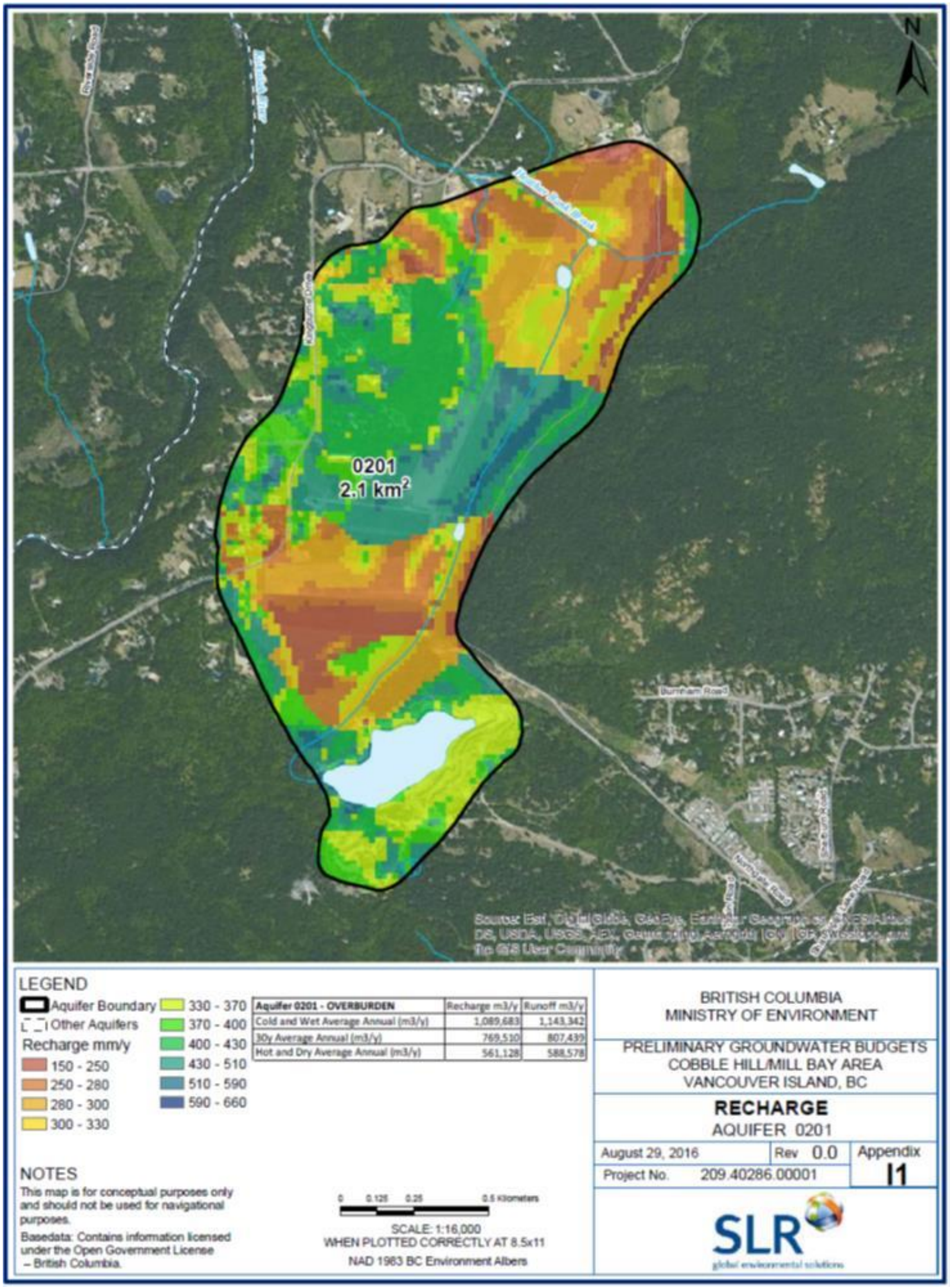


Figure I-1: Recharge distribution for surficial aquifer 0201.

Table I-1: CHM Aquifer Criteria: Aquifer #0201, Kingburne (Surficial).

BCMOE Criteria	
AQ tag	201 Kingburne
AQ classification	IIC (8)
AQ type	BCMOE Classification = 4b - **erroneously includes bedrock quarry area at south end of AQ** (SLR Classification = 4a / 4b / 5b - thin morainal-colluvial overburder in southeast corner only over limestone quarry)
Location	Cobble Hill
Perimeter (km)	6.77
Area (km^2)	2.11
Aquifer materials	Sand and gravel
Lithostratographic unit	Vashon Drift
Productivity	Moderate
Vulnerability	Low
Demand	Moderate
Use	Domestic
Location	
NTS 50000	092B/12
TRIM 20000	092B.062
Lat / Long (Centre)	48^{o}41'05" / 123^{o}38'33"
UTM Zone 10 (Centre)	452725E / 5392602N
Climate	
Nearest active EC weather station / distance / elevation	EC1017230 Shawnigan Lake / 2.6 km to south-southeast; EC1012573 Duncan Kelvin Creek / 7.3 km to northwest
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland
Elevation range (m amsl)	120 m (planar area)
Distance to marine	Cowichan Bay is 5.3 km to northeast
Geomorphological setting	Bean-shaped, flat-bottomed bench overlooking Koksilah River to the northwest. AQ is flanked to the north, east, and south by Cobble Hill uplands
Topography	Generally planar bench overlooking Koksilah River to northwest, with low, northwest-elongated hill in northwest portion
Terrain	Generally planar to gently undulating
Aspect	Generally level, slight slope to the northwest; low, northwest-elongated hill bisected by the AQ's northwest edge
Slope	Planar to broadly concave
XS max grade (m/m)	0.005 NW through centre short axis of valley
Roughness coefficient	0.45 (65% mostly cleared agricultural fields & rural residential properties / 35% forested)
Geology	
Terrane	Wrangellia
Bedrock (age ; formation ; lithology)	
Primary	Northwest & north portions of AQ: Central NE-trending V belt = Devonian Sicker Group Volcanics (muDSiD); basaltic (70%)
Secondary	South & southeast portions of AQ = Triassic Karmutsen Volcanics (uTrVK); basaltic (10%) ; Carboniferous Buttle Lake Group (PnPBM); limestone (10%); Devonian Sicker Group Volcanics (muDSiD); basaltic (10%)
Structure	North splay of northeast-trending San Juan Fault crosses southeast side of AQ
Surficial (formation; lithology; thickness)	Vashon Drift morainal-glaciofluvial-glaciolacustrine ice contact deposit
Surficial designation (1993)	Level areas = $LGp; low hill in northwest part of AQ = Cb/sgFG; quarry area in southeast corner = dMb/Cb/R
Soils (association; parent; texture;	Level areas = Mainly C18AR12/b, subordinate Q1/b (mainly Cowichan "marine"and

drainage; type; comments)	lesser Arrowsmith organics; subordinate Qualicum) mainly silt-clay and organics; O.HG and T.M; Low hill in northwest part of AQ and quarry area in southeast corner = S16RL52D22/fe (Shawnigan morainal / Rosewall colluvium / Dashwood marine), predominantly gravelly-sandy loam, DU.DYB;
Restrictive layers	Yes - low permeability organic and/or clay-rich soil layers in level areas + subsurface silt-clay aquitards (complex internal stratigraphy) / local surface duric layers in Shawnigan soil areas
Estimated permeability	Variable at surface & subsurface due to stratigraphic complexity; generally low due to extent of Cowichan soils
Hydrology	
GW / SW basin coincidence	Yes - contained within Koksilah River watershed (west side only)
Catchments	Koksilah River watershed, small internal stream catchment
Drainage regime	Rectilinear, man-made / natural ditching system centred on a north-flowing, unnamed stream, drains northwest into Koksilah River at north end of AQ
Surface waters	Cobble Hill Quarry Lake, 3 internal unnamed srteams
Runoff coefficient	Genarlly flat-lying, mostly cleared agricultural & rural residential land = 0.40
Nearest Active EC hydrometric station; distance; type	EC 08HA003 Koksilah River @ Cowichan Station; 4.4 km NNW; active realtime; + Shawnigan Creek @ Mill Bay; 6.1 km SE (inactive)
Surface water diversions ; relevance	3 licences along internal unnamed stream and Cobble Hill Quarry Lake; moderate to high relevance for upper unconfined AQ zones
Land Cover	
Vegetation zone	CwH:a
Primary land uses	65% cleared agricultural, 20%rural residential, 20% forested / 5% industrial (quarrying)
Degree of development	Cgf-wC
Evapotranspiration potential	High
Relative environmental sensitivity	Moderate in terrestrial areas, high along internal creeks and Cobble Hill Quarry Lake
Hydrogeology	
Groundwater occurrence (primary / secondary)	Granular pore space infillings
Primary porosity	Variable: low in glaciolacustrine and morainal materials, moderate to high in glaciofluvial materials.
Secondary porosity	Not applicable - surficial AQ
Confinement	Suspected variable degrees of confinement: (1) Level areas = unconfined; (2) elevated hill in northwest part of AQ = semiconfined below a local, low-permeability morainal blanket. WP = 0 - 48.2 m, avg 10.7 m
Aquifer thickness	Thickness of composite AQ (including unconfined and semi-confined zones) variable - generally between 6 m and 20 m thick, locally up to 30 m thick. Irregular underlying bedrock surface = significant aquifer thickness variations over short horizontal distances
Hydraulic anisotropy	Low to moderate due to lack of internal aquitards
Hydraulic gradient	Variable: likely very low based on local terrain / possibly higher along northwest edge adjacent to incised Koksilah River
Storage potential	Variably low to moderate due to elevated proportion of silty glaciofluvial - glaciolacustrine materials
Yield potential	Variable low-moderate depending on AQ host materials; WP = 0.38 - 4.73 L/s / average 0.76 L/s
Flow velocities	Variable: likely very low based on local terrain / possibly higher along northwest edge adjacent to incised Koksilah River
Flow directions	Near-surface unconfined / semi-confined AQ zones: flow likely mirrors topography towards the northwest towards the Koksilah River Deeper semi-confined zones: flow direction uncertain, may be influenced by bedrock surface irregularities and structural fabrics
Static water levels	WP = variable 2.4 - 25.9 m bgs / avg 6.1 m bgs

Hydraulic connection with surface waters	Near-surface unconfined AQ zones: moderate to high with internal unnamed streams and Koksilah River. Deeper semi-confined AQ zones: negligible connectivity to internal; streams due to deep overburden cover / possible connection to incised portions of Koksilah River west and northwest of AQ
Hydraulic connection to adjacent AQ	
Over / Under	AQ overlies, and is entirely underlain by, bedrock AQ 202
Upgradient	AQ in contact with upgradient bedrock AQ 202 along itssoutheast and east sides. Deeper zones of AQ likely also receive basal recharge from bedrock AQ 200 to the west, although BCMOE does not indicate contact
Downgradient	AQ in contact with downgradient bedrock AQ 202 along its west side.
Vulnerability to surface contamination	Variable: (1) near-surface unconfined AQ zones = low to moderate to high based on surficial lithologies and presence of low-permeability surface soil horizons; (2) deeper semi-confined AQ zones - low based on deep overburden cover and overlying morainal aquitard
Recharge	
Vertical inflow	Variable: (1) near-surface unconfined AQ zones: moderate to high recharge from precipitation and irrigation-sewerage returns (high levels of rural residential and agricultural development) and well-documented seasonal flooding, negligible from snowmelt due to low elevations. Low to negligible from stream losses due to AQ area's low-permeability surface soils (2) deeper semi-confined AQ zones: low to negligible from precipitation due to deep overburden cover and overlying morainal aquitard.
Lateral inflow	Low - moderate lateral inflow from upgradient bedrock AQ 202 to the east, south, and southwest. Also upwelling inflow from underlying bedrock AQ 202 - documented bedrock artesian flow conditions along southwest border of AQ.
Temporal variability	Variable: (1) near-surface unconfined AQ zones: moderate to high depending on surficial lithologies and presence of low-permeability surface soil layers (2) Deeper semi-confined AQ zones: low due to deep overburden cover and overlying morainal aquitard
MBR	Moderate to high along southeast, south, and west sides from upgradient rocky Cobble Hill (bedrock AQ 202)
Discharge	
Evapotranspiration	Variable: (1) near-surface unconfined AQ zones: moderate to high (2) Deeper semi-confined AQ zones: low
Outflow to marine	Negligible due to distance from marine shoreline
Outflow to surface waters	Variable: (1) moderate to high along west side of AQ into Koksilah River based on unconfined to semi-confined AQ settings, elevated position relative to Koksilah River, and deeply incised nature of the Koksilah River; (2) low to internal streams due to low-permeability surface soils (streams primarily fed by Cobble Hill Quarry Lake outflow)
Outflow to other AQ	Possible basal outflow to bedrock AQ 202 in areas where artesian bedrock conditions are not apparent
Temporal variability	Variable: (1) near-surface unconfined AQ zones: moderate to high (2) Deeper semi-confined AQ zones: low
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #320 is 3.3 km to east-northeast; negligible relevancy, well completed within surficial AQ197
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	0
Commercial	0
Domestic	15604
Irrigation from GW (MoAg)	28531
BCMOE Obs	0
Other	0
Water Supply Systems	0

Table I-2: Direct Recharge Calculation for AQ201.

	Direct Recharge Calculation		
	Hot/Dry	Average	Cold/Wet
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.080	1.080	1.080
Infiltration Coefficient	0.488	0.488	0.488
Area (m^2)	2,112,633	2,112,633	2,112,633
Q (m^3/yr)	569,675	846,798	1,405,297
Average Infiltration Rate	0.270	0.401	0.665

Table I-3: Annual Summary of AQ201 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 201	2,112,633	0.401	846,798
Loss	Leakage down to 202	2,112,633	0.200	-633,790
Loss	Lateral Groundwater	--	--	-2,759
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	157,680
Losses	Water Usage	--	--	-44,135
Net Gain				**1,004,478**
Net Loss				**-680,684**
Net Total (Gain - Loss)				**323,794**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 201	2,112,633	0.270	569,675
Loss	Leakage down to 202	2,112,633	0.200	-633,790
Loss	Lateral Groundwater	--	--	-2,759
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	157,680
Losses	Water Usage	--	--	-44,135
Net Gain				**727,355**
Net Loss				**-680,684**
Net Total (Gain - Loss)				**46,670**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 201	2,112,633	0.665	1,405,297
Loss	Leakage down to 202	2,112,633	0.200	-633,790
Loss	Lateral Groundwater	--	--	-2,759
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	0
Gain	Surface Water	--	--	157,680
Losses	Water Usage	--	--	-44,135
Net Gain				**1,562,977**
Net Loss				**-680,684**
Net Total (Gain - Loss)				**882,292**

Table I-4: Monthly Summary of AQ201 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 201	212,943	138,703	100,098	24,039	-28,935	-45,628	-44,515	-20,032	-6,677	73,209	224,622	218,973	**846,798**
Leakage down to 202	-51,337	-49,436	-55,140	-54,506	-57,041	-54,506	-55,140	-53,872	-51,337	-51,971	-49,436	-50,069	**-633,790**
Lateral Groundwater Loss	-224	-215	-240	-237	-248	-237	-240	-235	-224	-226	-215	-218	**-2,759**
Lateral Groundwater Gain	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Loss	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Gain	34,797	30,549	22,067	10,670	3,783	1,534	911	296	249	2,284	16,143	34,396	**157,680**
Water Usage	-2,648	-2,869	-3,310	-3,531	-3,972	-4,414	-4,855	-5,076	-4,414	-3,531	-3,089	-2,427	**-44,135**
Net Gain	**247,740**	**169,252**	**122,165**	**34,708**	**3,783**	**1,534**	**911**	**296**	**249**	**75,493**	**240,765**	**253,370**	**1,150,266**
Net Loss	**-54,209**	**-52,520**	**-58,690**	**-58,274**	**-90,197**	**-104,785**	**-104,750**	**-79,214**	**-62,651**	**-55,728**	**-52,740**	**-52,715**	**-826,472**
Net Total (Gain - Loss)	**193,531**	**116,732**	**63,475**	**-23,566**	**-86,413**	**-103,251**	**-103,839**	**-78,918**	**-62,402**	**19,765**	**188,025**	**200,655**	**323,794**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 201	174,666	100,160	155,739	9,348	-36,725	-46,741	-40,064	-16,693	-11,129	28,379	111,400	141,336	**569,675**
Leakage down to 202	-51,971	-48,168	-53,238	-52,605	-55,140	-53,238	-55,140	-54,506	-51,971	-53,872	-51,337	-52,605	**-633,790**
Lateral Groundwater	-226	-210	-232	-229	-240	-232	-240	-237	-226	-235	-224	-229	**-2,759**
Lateral Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	34,797	30,549	22,067	10,670	3,783	1,534	911	296	249	2,284	16,143	34,396	**157,680**
Water Usage	-2,648	-2,869	-3,310	-3,531	-3,972	-4,414	-4,855	-5,076	-4,414	-3,531	-3,089	-2,427	**-44,135**
Net Gain	**209,463**	**130,708**	**177,806**	**20,018**	**3,783**	**1,534**	**911**	**296**	**249**	**30,663**	**127,543**	**175,733**	**878,707**
Net Loss	**-54,845**	**-51,247**	**-56,780**	**-56,364**	**-96,077**	**-104,625**	**-100,298**	**-76,512**	**-67,739**	**-57,637**	**-54,650**	**-55,261**	**-832,037**
Net Total (Gain - Loss)	**154,618**	**79,462**	**121,025**	**-36,347**	**-92,294**	**-103,090**	**-99,387**	**-76,216**	**-67,491**	**-26,975**	**72,893**	**120,472**	**46,670**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 201	395,185	400,103	148,384	-17,806	-14,467	-37,838	-48,967	-20,032	-8,903	140,335	226,806	242,497	**1,405,297**
Leakage down to 202	-51,337	-49,436	-55,140	-54,506	-57,041	-54,506	-55,140	-53,872	-51,337	-51,971	-49,436	-50,069	**-633,790**
Lateral Groundwater	-224	-215	-240	-237	-248	-237	-240	-235	-224	-226	-215	-218	**-2,759**
Lateral Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	34,797	30,549	22,067	10,670	3,783	1,534	911	296	249	2,284	16,143	34,396	**157,680**
Water Usage	-2,648	-2,869	-3,310	-3,531	-3,972	-4,414	-4,855	-5,076	-4,414	-3,531	-3,089	-2,427	**-44,135**
Net Gain	**429,982**	**430,652**	**170,451**	**10,670**	**3,783**	**1,534**	**911**	**296**	**249**	**142,619**	**242,949**	**276,894**	**1,710,990**
Net Loss	**-54,209**	**-52,520**	**-58,690**	**-76,080**	**-75,729**	**-96,995**	**-109,202**	**-79,214**	**-64,877**	**-55,728**	**-52,740**	**-52,715**	**-828,698**
Net Total (Gain - Loss)	**375,773**	**378,132**	**111,762**	**-65,411**	**-71,946**	**-95,460**	**-108,290**	**-78,918**	**-64,628**	**86,891**	**190,209**	**224,179**	**882,292**

Table I-5: Monthly Coefficients used in Calculations for AQ201.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table I-6: Groundwater Flow Components: Aquifer #0201, Kingburne (Surficial)

Groundwater Flow	**Direction of Flow**	**Source or Receptor of Water**	**Length (m)**	**Depth (m)**	**Area (m)**	**Hydraulic Conductivity (m/s) - K**	**Distance (m) - dL**	**Hydraulic Head (m) - dh**			**GW Flow (m^3/yr)**		
								Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
$Q_{GW}1$	Out	Koksilah River	240	5	1,200	0.00001	960	7			**-2,759**		
$Q_{GW}2$	Out	Leakage to AQ 202	Leakance Factor (m/yr) =	0.300	2,112,633	--	--	--	--	--	**-633,790**		
Total											**-636,549**		

Surface Water Contributions	**Cold Water Creek?**	**Observed Vertical Gradient**	**Percent Permeable**	**Length (m)**	**Width (m)**	**Flux (m/s)**	**SW Flow (m^3/yr)**			**Comment**
							Year 1	**Year 2**	**Year 3**	
Heather Bank Brooks	Yes	Downward	10%	2,500	2	0.00001	157,680			Half of the creek sits over impermeable soils, therefore is considered on conveyance feature across those soils.
Total							**157,680**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	0	100%	0							100% consumptive
Commercial	0	100%	0							100% consumptive
Domestic	15,604	100%	15,604							100% consumptive
Irrigation	28,531	100%	28,531							100% consumptive
BCMOE Obs	0	100%	0							100% consumptive
Other	0	100%	0							100% consumptive
Water Supply Systems	0	100%	0							100% consumptive
Total	**-44,135**		**-44,135**							

APPENDIX J: AQUIFER 0205 (CARLTON)

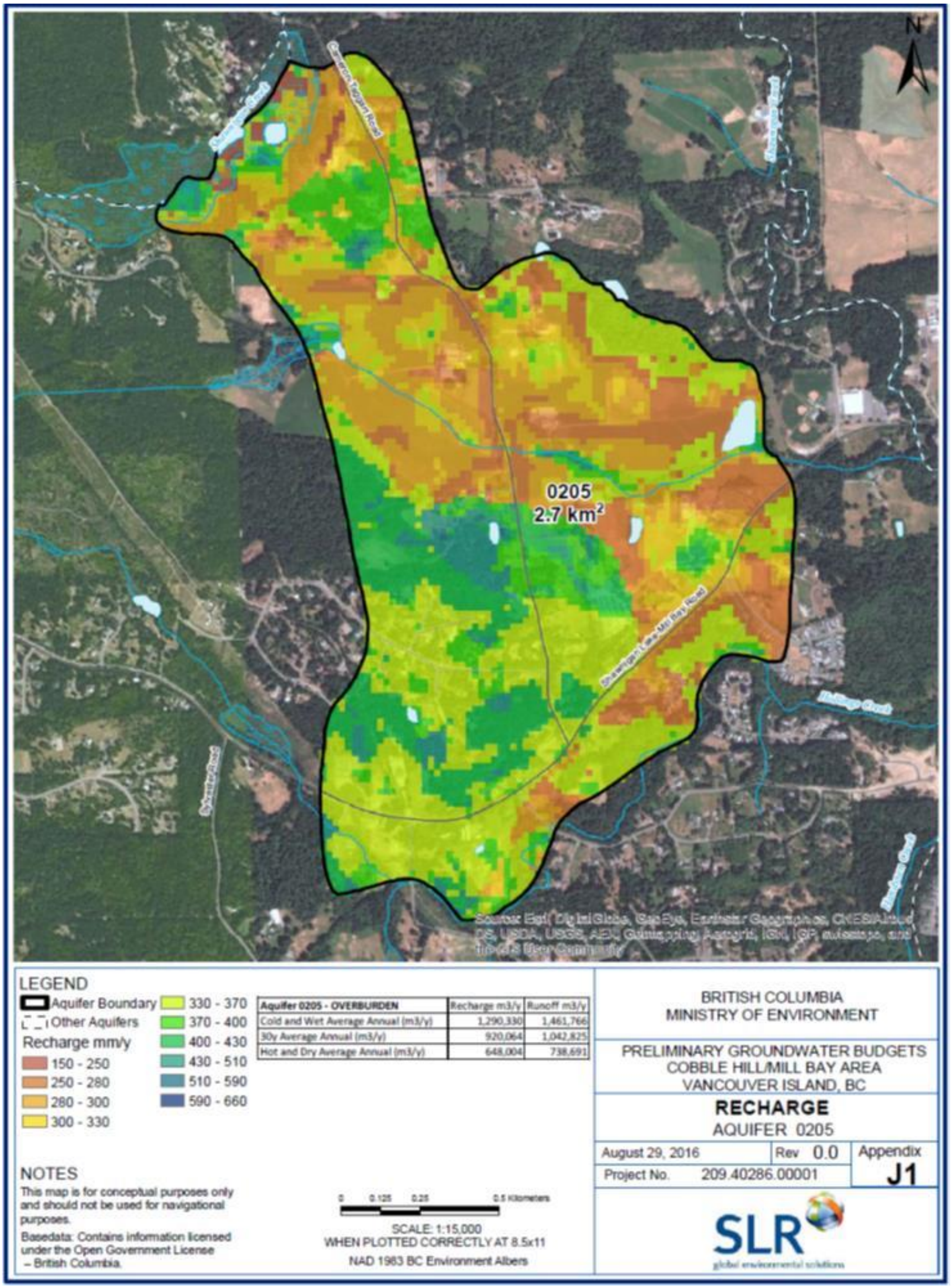


Figure J-1: Recharge distribution for surficial aquifer 0205.

Table J-1: CHM Aquifer Criteria: Aquifer #0205, Carlton (Surficial).

BCMOE Criteria	
AQ tag	205 Carlton
AQ classification	IIC (9)
AQ type	BCMOE Classification = 4b (SLR Classification = 4a / 4b)
Location	Cobble Hill / Shawnigan Lake
Perimeter (km)	8.22 (BCMOE boundary defined by watercourses, not well log AQ lithologies - actual outline is more irregular)
Area (km^2)	2.73 (BCMOE boundary defined by watercourses, does not match well log AQ lithologies - actual area is smaller)
Aquifer materials	Sand and gravel
Lithostratographic unit	Vashon Drift
Productivity	Moderate
Vulnerability	Low
Demand	Moderate
Use	Multiple
Location	
NTS 50000	092B/12
TRIM 20000	092B.063
Lat / Long (Centre)	48°39'26" / 123°35'19"
UTM Zone 10 (Centre)	456654E / 5389517N
Climate	
Nearest active EC weather station / distance / elevation	EC1015136 Mill Bay SW1 570 m to southeast EC1017230 Shawnigan Lake 2.1 km to west
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland
Elevation range (m amsl)	50 - 120 m
Distance to marine	Mill Bay is 1.6 km to the east
Geomorphological setting	East-southeast facing, rolling to hummocky area containing several low, conical hills separated by gently-incised, dendritic streams and depressional areas with small wetlands. Probably represents a variably-thick morainal / glaciofluvial outwash blanket deposited on the east flanks for the Cobble Hill / Old Baldy Mountain upland area. AQ is bounded to the southeast by Hollings Creek & extreme northwest corner by Shawnigan Creek
Topography	Generally rolling to undulating, east-southeast facing convex sidehill with broad, shallow, concave stream valleys
Terrain	Generally rolling to undulating
Aspect	Generally east-southeast facing
Slope	Low concave / convex ground slopes
XS max grade (m/m)	0.056 E through centre short axis of AQ
Roughness coefficient	0.40 (75% mostly cleared agricultural fields & rural residential properties / 25% forested)
Geology	
Terrane	Wrangellia
Bedrock (age ; formation ; lithology)	
Primary	West 2/3 = Jurassic Bonanza Group Volcanics (lJBca); basaltic-andesitic (65%) - suspected more lithologies present than identified by BCGS - (limestone?)
Secondary	East 1/3 = Early to Middle Jurassic Island Plutonic Suite (EMJIgd); granodioritic intrusive rocks (35%)
Structure	None mapped by BCGS. Suspected: northeast-trending trace of Shawnigan Fault approx 250 m southeast of AQ; northeast-trending , high-angle fault crossing extreme southwest corner of AQ
Surficial (formation; lithology; thickness)	Vashon Drift morainal-glaciofluvial outwash deposit with minor glaciolacustrine component

Surficial designation (1993)	Level areas & wetlands = $LGp; low hills between depressions = dMbh/R
Soils (association; parent; texture; drainage; type; comments)	Level areas & wetlands = AR1/b (Arrowsmith organic) T.M; low hills between depressions = FF1V8TT72/DE (Finlayson-Tagner marine) silty-clay, GLE.DYB/O.HG / subordinate S1v6Q5RL51/ef in ele vated areas (Shawnigan morainal & Quamichan fluvial, shallow lithic), gravelly-sandy loam, DU.DYB;
Restrictive layers	Yes, impersistent - low permeability organic and/or clay-rich soil layers in level areas + subsurface silt-clay aquitards (complex internal stratigraphy) / local surface duric layers in Shawnigan soil areas
Estimated permeability	Variable at surface & subsurface due to stratigraphic complexity
Hydrology	
GW / SW basin coincidence	Yes - contained within Shawnigan Creek watershed (south side), but contains several internal tributary subcatchments
Catchments	Shawnigan Creek (south side), North & South Taggart Creeks, Ericson Creek, & unnamed streams
Drainage regime	Dendritic
Surface waters	Shawnigan Creek (south side), North & South Taggart Creeks, Ericson Creek, & several unnamed streams & wetlands + northwest corner = Cameron Wetland (contains Shawnigan Creek mainstem),
Runoff coefficient	Rolling terrain, 75% partly cleared agricultural + 25% subordinate forestry blocks & rural residential land = 0.45
Nearest Active EC hydrometric station; distance; type	Shawnigan Creek @ Mill Bay; 450 m east (inactive) EC 08HA003 Koksilah River @ Cowichan Station; 8.9 km northwest; active realtime
Surface water diversions ; relevance	14 licences along internal Shawnigan Creek tributaries (Taggart Creeks, Ericsopn Creek, and unnamed streams); moderate to high relevance for unconfined AQ zones (recorded low-elevation artesian well flows from unconfined AQ on east border)
Land Cover	
Vegetation zone	CgF-wC in Finlayson-Tagner soils / CwH:a in Arrowsmith-Quamichan-Shawnigan soils
Primary land uses	75% cleared agricultural, 25%rural residential & forested
Degree of development	Cgf-wC
Evapotranspiration potential	High
Relative environmental sensitivity	Moderate in terrestrial areas, high along internal creeks and wetlands
Hydrogeology	
Groundwater occurrence (primary / secondary)	Granular pore space infillings
Primary porosity	Variable: low in glaciolacustrine and morainal materials, moderate to high in glaciofluvial materials.
Secondary porosity	Not applicable - surficial AQ
Confinement	Suspected variable degrees of confinement: (1) unconfined in most areas; (2) semi-confined to confined in south-central area. WP = 0 - 65.5 m, avg 23.5 m
Aquifer thickness	Thickness of composite AQ (including unconfined and semi-confined zones) variable: generally shallow in north half of AQ (10 - 30 m) / thicker in south-central area (up to 66 m deep, although actual AQ thickness below aquitards likely 50% less). Irregular underlying bedrock surface = significant aquifer thickness variations over short horizontal distances
Hydraulic anisotropy	Low to moderate in unconfined areas, elevated in semi-confined to confined areas
Hydraulic gradient	Variable: likely low-moderate based on irregular local terrain / higher in rolling, hilly areas
Storage potential	Locally moderate to high due to elevated proportions of sand-gravel glaciofluvial & morainal materials
Yield potential	Variable low-moderate depending on AQ host materials; WP = 0.19 - 3.16 L/s / average 0.85 L/s
Flow velocities	Variable: likely low to moderate based on irregular local terrain / possibly higher in hilly areas

Flow directions	Regional flow towards the east and Mill Bay / local flow directions likely variable depending on position with stream subcatchments & proximity to Shawnigan Creek. Deeper semi-confined to confined zones: flow direction uncertain, may be influenced by bedrock surface irregularities
Static water levels	WP = variable artesian - 37.8 m bgs / avg 12.8 m bgs
Hydraulic connection with surface waters	Near-surface unconfined AQ zones: moderate to high with internal streams and Shawnigan Creek. Deeper semi-confined to confined AQ zones: low connectivity to internal streams due to deep overburden cover / possible connection to incised portions of creeks along east edge of AQ or where bedrock forces groundwater to surface
Hydraulic connection to adjacent AQ	
Over / Under	AQ overlies an undeveloped portion of bedrock AQ 207
Upgradient	AQ in contact with upgradient bedrock AQ 204 along its northwest corner (also bounded by Shawnigan Creek). AQ likely receives basal and lateral recharge from upgradient portions of surrounding bedrock AQ 204 to the south, west, and north
Downgradient	AQ in contact with downgradient portions of surrounding bedrock AQ 207 along its east and southeast borders . AQ may also locally provide basal recharge to undeveloped portions of bedrock AQ 207, depending on local bedrick AQ hydraulic heads (may be upwelling / artesian in some areas approaching the Shawnigan Fault to the southeast)
Vulnerability to surface contamination	Variable: (1) near-surface unconfined AQ zones = low to high based on variable surficial lithologies and presence of low-permeability surface soil horizons; (2) deeper semi-confined to confined AQ zones - low based on deep overburden cover and overlying morainal aquitard
Recharge	
Vertical inflow	Variable: (1) near-surface unconfined AQ zones: moderate to high recharge from precipitation and irrigation-sewerage returns (high levels of rural residential and agricultural development) and well-documented seasonal flooding, negligible from snowmelt due to low elevations. Variably low to moderate from stream losses, depending on local AQ hydraulic heads (2) deeper semi-confined AQ zones: low to negligible from precipitation due to deep overburden cover and overlying morainal aquitard.
Lateral inflow	Low - moderate lateral inflow from upgradient portions of bedrock AQ 207 to the south, west, and north. Also possible upwelling inflow from underlying undeveloped portion of bedrock AQ 207
Temporal variability	Variable: (1) near-surface unconfined AQ zones: moderate to high depending on surficial lithologies and presence of low-permeability surface soil layers (2) Deeper semi-confined & confined AQ zones: low due to deep overburden cover and overlying morainal aquitard
MBR	Negligible - no adjacent rocky upland areas
Discharge	
Evapotranspiration	Variable: (1) near-surface unconfined AQ zones: moderate to high (2) Deeper semi-confined to confined AQ zones: low
Outflow to marine	Negligible due to distance from marine shoreline
Outflow to surface waters	Variable: (1) moderate to high along east side of AQ into Taggart Creeks / northwest corner into Shawnigan Creek based on unconfined AQ settings & topography; (2) moderate to high to internal streams from unconfined AQ portions or where bedrock forces semi-confined groundwater to surface
Outflow to other AQ	Possible basal outflow to bedrock AQ 207 in areas where artesian bedrock conditions are not apparent
Temporal variability	Variable: (1) near-surface unconfined AQ zones: moderate to high (2) Deeper semi-confined AQ zones: low
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #345 is 3.5 km to the northeast; negligible relevancy, well completed within surficial AQ197
Total Annual Water Use (m^3/yr) as	

reported by Hatfield (2015)	
Industrial	7300
Commercial	10950
Domestic	38011
Irrigation from GW (MoAg)	55601
BCMOE Obs	0
Other	0
Water Supply Systems	20942

Table J-2: Direct Recharge Calculation for AQ205.

	Direct Recharge Calculation		
	Hot/Dry	**Average**	**Cold/Wet**
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.060	1.060	1.060
Infiltration Coefficient	0.468	0.468	0.468
Area (m^2)	2,728,692	2,728,692	2,728,692
Q (m^3/yr)	693,333	1,030,612	1,710,342
Average Infiltration Rate	0.254	0.378	0.627

Table J-3: Annual Summary of AQ205 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 205	2,728,692	0.378	1,030,612
Loss	Leakage down to 207	2,728,692	0.200	-545,738
Loss	Lateral Groundwater	--	--	-413,122
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	-170,294
Gain	Surface Water	--	--	0
Losses	Water Usage	--	--	-132,804
Net Gain				**1,030,612**
Net Loss				**-1,261,958**
Net Total (Gain - Loss)				**-231,347**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 205	2,728,692	0.254	693,333
Loss	Leakage down to 207	2,728,692	0.200	-545,738
Loss	Lateral Groundwater	--	--	-413,122
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	-170,294
Gain	Surface Water	--	--	0
Losses	Water Usage	--	--	-132,804
Net Gain				**693,333**
Net Loss				**-1,261,958**
Net Total (Gain - Loss)				**-568,625**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 205	2,728,692	0.627	1,710,342
Loss	Leakage down to 207	2,728,692	0.200	-545,738
Loss	Lateral Groundwater	--	--	-413,122
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	-170,294
Gain	Surface Water	--	--	0
Losses	Water Usage	--	--	-132,804
Net Gain				**1,710,342**
Net Loss				**-1,261,958**
Net Total (Gain - Loss)				**448,384**

Table J-4: Monthly Summary of AQ205 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 205	259,166	168,811	121,826	29,257	-35,216	-55,533	-54,178	-24,380	-8,127	89,100	273,380	266,506	**1,030,612**
Leakage down to 207	-44,205	-42,568	-47,479	-46,933	-49,116	-46,933	-47,479	-46,388	-44,205	-44,751	-42,568	-43,113	**-545,738**
Lateral Groundwater Loss	-33,463	-32,223	-35,942	-35,528	-37,181	-35,528	-35,942	-35,115	-33,463	-33,876	-32,223	-32,637	**-413,122**
Lateral Groundwater Gain	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Loss	-37,581	-32,993	-23,832	-11,523	-4,086	-1,657	-984	-320	-269	-2,467	-17,435	-37,148	**-170,294**
Surface Water Gain	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-7,968	-8,632	-9,960	-10,624	-11,952	-13,280	-14,608	-15,272	-13,280	-10,624	-9,296	-7,304	**-132,804**
Net Gain	**259,166**	**168,811**	**121,826**	**29,257**	**0**	**0**	**0**	**0**	**0**	**89,100**	**273,380**	**266,506**	**1,208,045**
Net Loss	**-123,217**	**-116,416**	**-117,214**	**-104,609**	**-137,551**	**-152,932**	**-153,192**	**-121,475**	**-99,344**	**-91,718**	**-101,522**	**-120,202**	**-1,439,392**
Net Total (Gain - Loss)	**135,950**	**52,395**	**4,612**	**-75,353**	**-137,551**	**-152,932**	**-153,192**	**-121,475**	**-99,344**	**-2,617**	**171,858**	**146,303**	**-231,347**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 205	212,580	121,901	189,545	11,377	-44,697	-56,887	-48,760	-20,317	-13,545	34,539	135,581	172,016	**693,333**
Leakage down to 207	-44,751	-41,476	-45,842	-45,296	-47,479	-45,842	-47,479	-46,933	-44,751	-46,388	-44,205	-45,296	**-545,738**
Lateral Groundwater	-33,876	-31,397	-34,702	-34,289	-35,942	-34,702	-35,942	-35,528	-33,876	-35,115	-33,463	-34,289	**-413,122**
Lateral Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	-37,581	-32,993	-23,832	-11,523	-4,086	-1,657	-984	-320	-269	-2,467	-17,435	-37,148	**-170,294**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-7,968	-8,632	-9,960	-10,624	-11,952	-13,280	-14,608	-15,272	-13,280	-10,624	-9,296	-7,304	**-132,804**
Net Gain	**212,580**	**121,901**	**189,545**	**11,377**	**0**	**0**	**0**	**0**	**0**	**34,539**	**135,581**	**172,016**	**877,539**
Net Loss	**-124,175**	**-114,498**	**-114,337**	**-101,733**	**-144,156**	**-152,369**	**-147,774**	**-118,371**	**-105,720**	**-94,594**	**-104,399**	**-124,038**	**-1,446,164**
Net Total (Gain - Loss)	**88,405**	**7,403**	**75,207**	**-90,355**	**-144,156**	**-152,369**	**-147,774**	**-118,371**	**-105,720**	**-60,056**	**31,182**	**47,978**	**-568,625**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 205	480,967	486,953	180,594	-21,671	-17,608	-46,052	-59,596	-24,380	-10,836	170,797	276,038	295,136	**1,710,342**
Leakage down to 207	-44,205	-42,568	-47,479	-46,933	-49,116	-46,933	-47,479	-46,388	-44,205	-44,751	-42,568	-43,113	**-545,738**
Lateral Groundwater	-33,463	-32,223	-35,942	-35,528	-37,181	-35,528	-35,942	-35,115	-33,463	-33,876	-32,223	-32,637	**-413,122**
Lateral Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	-37,581	-32,993	-23,832	-11,523	-4,086	-1,657	-984	-320	-269	-2,467	-17,435	-37,148	**-170,294**
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Water Usage	-7,968	-8,632	-9,960	-10,624	-11,952	-13,280	-14,608	-15,272	-13,280	-10,624	-9,296	-7,304	**-132,804**
Net Gain	**480,967**	**486,953**	**180,594**	**0**	**0**	**0**	**0**	**0**	**0**	**170,797**	**276,038**	**295,136**	**1,890,485**
Net Loss	**-123,217**	**-116,416**	**-117,214**	**-126,281**	**-119,943**	**-143,451**	**-158,609**	**-121,475**	**-102,052**	**-91,718**	**-101,522**	**-120,202**	**-1,442,101**
Net Total (Gain - Loss)	**357,751**	**370,536**	**63,380**	**-126,281**	**-119,943**	**-143,451**	**-158,609**	**-121,475**	**-102,052**	**79,079**	**174,516**	**174,934**	**448,384**

Table J-5: Monthly Coefficients used in Calculations for AQ205.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table J-6 Groundwater Flow Components: Aquifer #0205, Carlton (Surficial)

Groundwater Flow	**Direction of Flow**	**Source or Receptor of Water**	**Length (m)**	**Depth (m)**	**Area (m)**	**Hydraulic Conductivity (m/s) - K**	**Distance (m) - dL**	**Hydraulic Head (m) - dh**			**GW Flow (m^3/yr)**		
								Year 1	**Year 2**	**Year 3**	**Year 1**	**Year 2**	**Year 3**
$Q_{GW}1$	Out	AQ 207	1,400	10	14,000	0.00001	1,200	30			-110,376		
$Q_{GW}2$	Out	Shawnigan Creek	1,600	2	3,200	0.00003	--	--	--	--	-302,746		
$Q_{GW}3$	Out	Leakage to AQ 207	Leakance Factor (m/yr) =	0.200	2,728,692	--	--	--	--	--	-545,738		
Total											**-958,860**		

Surface Water Contributions	**Cold Water Creek?**	**Observed Vertical Gradient**	**Percent Permeable**	**Length (m)**	**Width (m)**	**Flux (m/s)**	**SW Flow (m^3/yr)**			**Comment**
							Year 1	**Year 2**	**Year 3**	
Taggart Creek	Yes	Upward	10%	900	2	0.00003	-170,294			Creek feeds into Shawnigan Creek
Total							**-170,294**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	7,300	100%	7,300							100% consumptive
Commercial	10,950	100%	10,950							100% consumptive
Domestic	38,011	100%	38,011							100% consumptive
Irrigation	55,601	100%	55,601							100% consumptive
BCMOE Obs	0	100%	0							100% consumptive
Other	0	100%	0							100% consumptive
Water Supply Systems	20,942	100%	20,942							100% consumptive
Total	**-132,804**		**-132,804**							

APPENDIX K: AQUIFER 0206 (MILL BAY)

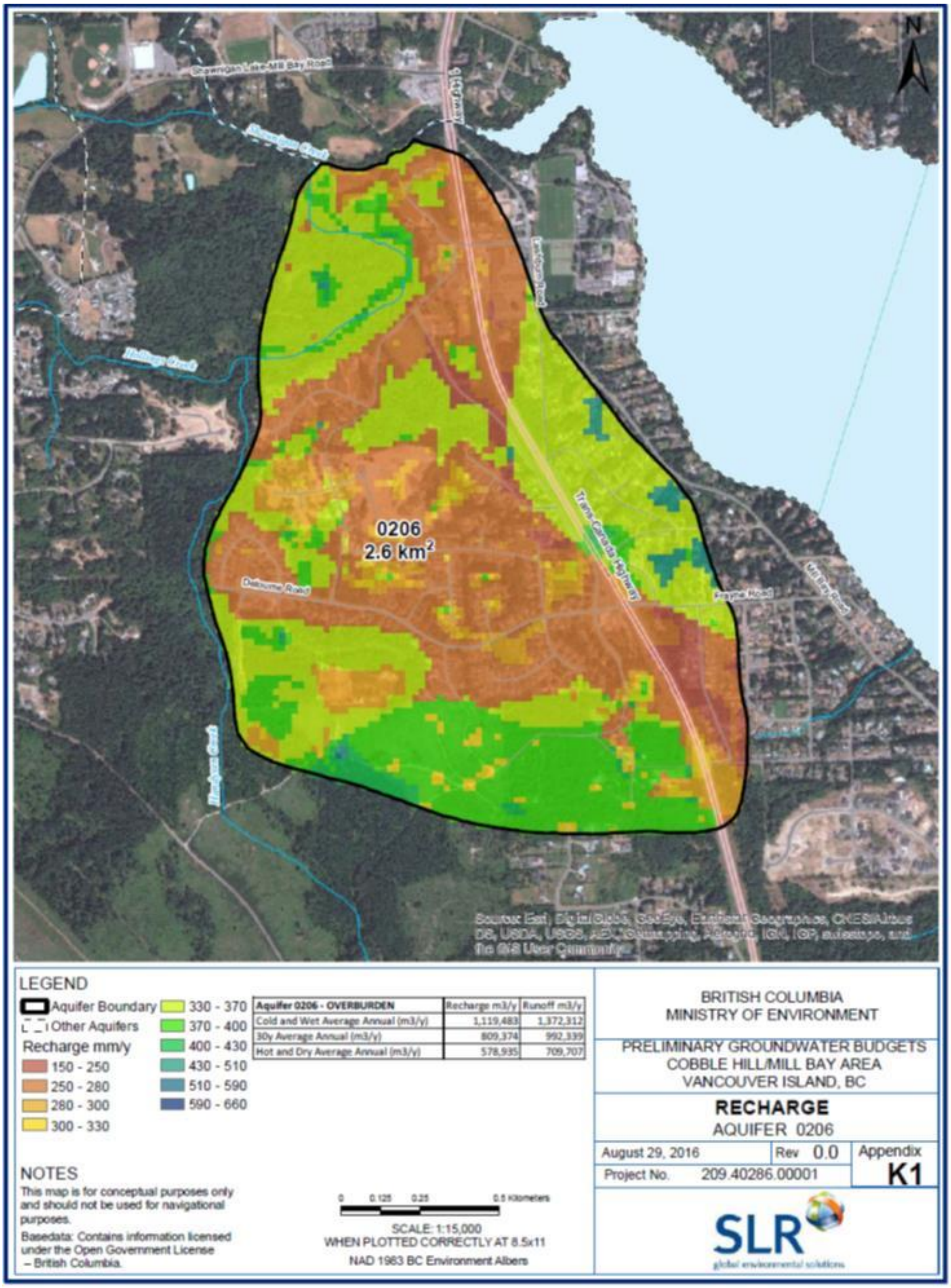


Figure K-1: Recharge distribution for surficial aquifer 0206.

Table K-1: CHM Aquifer Criteria: Aquifer #0206, Mill Bay (Surficial).

BCMOE Criteria	
AQ tag	206 Mill Bay
AQ classification	IIA (11)
AQ type	BCMOE Classification = 4a (SLR Classification = 4a / 4b locally stacked aquifers)
Location	Mill Bay
Perimeter (km)	6.4
Area (km^2)	2.57
Aquifer materials	Sand and gravel
Lithostratographic unit	Vashon Drift
Productivity	Moderate
Vulnerability	High
Demand	Moderate
Use	Multiple
Location	
NTS 50000	092B/12
TRIM 20000	092B.063
Lat / Long (Centre)	48°38'42" / 123°33'42"
UTM Zone 10 (Centre)	458641E / 5388146N
Climate	
Nearest active EC weather station / distance / elevation	EC1015136 Mill Bay SW1 within AQ - northwest corner EC1017230 Shawnigan Lake 3.8 km to west
IDF Curve	Unknown
Physiography	
Physiographic zone	Canadian Cordillera / Western System / Coastal Trough / Georgia Depression / Nanaimo Lowland
Elevation range (m amsl)	20 - 160 m
Distance to marine	Saanich Inlet is 110 m to the northeast
Geomorphological setting	North-northeast to northeast facing, dome-like series of rolling hills on the northeast flank of Malahat Ridge overlooking Mill Bay to the northeast. Probably represents a variably-thick morainal / glaciofluvial outwash blanket deposited on an irregular bedrock surface northeast of Malahat Ridge. AQ is bounded to the west by Handeysen Creek, at its north end by Shawnigan Creek, and to the south-southwest by uplands. Incised at its north end by Hollings Creek & in its central-east portions by unnamed streams
Topography	Generally rolling to undulating, north-northeast to northeast facing, convex hillside with central & north stream valley incisions
Terrain	Generally rolling to undulating
Aspect	Generally north-northeast facing
Slope	Low relief, generally convex ground slopes with subordinate, concave stream incisions & bowl-like areas
XS max grade (m/m)	0.068 north-northeast central long axis of AQ
Roughness coefficient	0.40 (75% rural-residential / 15% forested, 10% cleared & undeveloped)
Geology	
Terrane	Wrangellia
Bedrock (age ; formation ; lithology)	Early to Middle Jurassic Island Plutonic Suite (EMJIgd); granodioritic intrusive rocks
Structure	None mapped by BCGS -uncertain due to overburden masking. Productive bedrock wells in northwest portion suggests locally elevated rock fracturing - could be related to fault swarm adjacent to west AQ boundary within bedrock AQ 207 (intersection area of Shawnigan Fault and north-trending Handysen Creek lineament within Island Intrusive rocks)
Surficial (formation; lithology; thickness)	Vashon Drift morainal-glaciofluvial outwash deposit
Surficial designation (1993)	dMb/Cb//R
Soils (association; parent;	DD1w/de (Dashwood Creek, marine), very gravelly sandy loam, DU.DYB

texture; drainage; type; comments)	
Restrictive layers	Yes, impersistent - low permeability, dense morainal and glaciofluvial silt-clay aquitards, complex internal stratigraphy over an irregular bedrock surface / local surface duric layers in Dashwood Creek soils
Estimated permeability	Variable at surface & subsurface due to stratigraphic complexity
Hydrology	
GW / SW basin coincidence	No - straddles north-trending Shawnigan-Handysen-Hollings Creek / Saanich Inlet watersheds
Catchments	Shawnigan Creek (west side) / Saanich Inlet (east side)
Drainage regime	Radial in central part of AQ, chaotic at north end due to Hollings Creek bedrock-controlled meanders
Surface waters	Shawnigan Creek borders north end. Handysen Creek parallels west side. Northeast and east parts of AQ contain small streams (Wheelbarrow, Bird) & several springs draining towards Saanich Inlet; small, central wetland area
Runoff coefficient	Rolling terrain, 75% rural-residential / 15% forested, 10% cleared & undeveloped = 0.45
Nearest Active EC hydrometric station; distance; type	Shawnigan Creek @ Mill Bay; 400 m northeast of north end (inactive) EC 08HA003 Koksilah River @ Cowichan Station; 11.4 km northwest; active realtime
Surface water diversions ; relevance	> 30 licences along Hollings Creek & internal springs / streams draining towards Saanich Inlet; moderate to high relevance for unconfined AQ zones
Land Cover	
Vegetation zone	CgF-wC
Primary land uses	75% rural-residential / 15% forested, 10% cleared & undeveloped
Degree of development	Extensive agricultural / rural residential clearing. Low impervious cover
Evapotranspiration potential	Cgf-wC
Relative environmental sensitivity	Moderate in terrestrial areas / high along internal creeks, wetlands, springs
Hydrogeology	
Groundwater occurrence (primary / secondary)	Granular pore space infillings
Primary porosity	Variable: low in morainal materials, moderate to high in glaciofluvial materials.
Secondary porosity	Not applicable - surficial AQ
Confinement	Suspected variable degrees of confinement due to aquifer "stacking": (1) most productive wells located in northwest portion of AQ, generally semi-confined to confined; (2) semi-confined to confined surficial aquifer above basal till / bedrock surface & within local bedrock surface embayments; (3) mix of unconfined & semi-confined gw occurrences throughout AQ WP = 0 - ??? m, avg 7.5 m
Aquifer thickness	Thickness of composite AQ (including unconfined and semi-confined zones) highly variable: generally shallow in north half of AQ (< 20 m) / thicker in south-central area (up to 52 m deep, although actual AQ thickness below aquitards likely much less. Irregular underlying bedrock surface = significant aquifer thickness variations over short horizontal distances
Hydraulic anisotropy	Low to moderate in unconfined areas, elevated in semi-confined to confined areas
Hydraulic gradient	Variable: likely low-moderate based on irregular local terrain / higher in rolling, hilly areas & adjacent to incised watercourses
Storage potential	Locally moderate to high due to elevated proportions of sand-gravel glaciofluvial materials; low in areas dominated by morainal materials
Yield potential	Variable low- high depending on AQ host materials; WP = 0.09 - 22.1 L/s / average 0.75 L/s
Flow velocities	Variable: likely low to moderate based on irregular local terrain / possibly higher in hilly areas & adjacent to incised watercourses
Flow directions	Regional flow towards the north-northeast and northeast / local flow directions likely variable depending on positions with stream subcatchments. Deeper semi-confined to confined zones: flow direction uncertain, may be influenced by bedrock surface irregularities

Static water levels	WP = variable artesian - 38.1 m bgs / avg 6.7 m bgs
Hydraulic connection with surface waters	Near-surface unconfined AQ zones: moderate to high with Handeysen Creek to west, Hollings Creek at north, internal streams and springs. Deeper semi-confined to confined AQ zones: low connectivity to internal streams due to deep overburden cover / possible connection to incised portions of creeks along north edge of AQ or where bedrock forces groundwater to surface
Hydraulic connection to adjacent AQ	
Over / Under	AQ overlies bedrock AQ 207
Upgradient	AQ in contact with upgradient portions of bedrock AQ 207 along its south and west sides. AQ in particular may receive considerable lateral & basal recharge from fractured bedrock area to the west (intersection of Shawnigan Fault & Handysen Creek lineament)
Downgradient	AQ in contact with downgradient portions of surrounding bedrock AQ 207 along its west border) & posssibly cross-gradient with bedrock AQ 204 north of Shawnigan Creek (depending on local hydraulic heads)
Vulnerability to surface contamination	Variable: (1) near-surface unconfined AQ zones = low to high based on variable surficial lithologies and presence of low-permeability surface soil horizons; (2) deeper semi-confined to confined AQ zones - low based on deep overburden cover and overlying morainal aquitard
Recharge	
Vertical inflow	Variable: (1) near-surface unconfined AQ zones: moderate to high recharge from precipitation and irrigation-sewerage returns (high levels of rural residential development), negligible from snowmelt due to low elevations. Variably low to moderate from stream losses, depending on local AQ hydraulic heads (2) deeper semi-confined AQ zones: low to negligible from precipitation due to deep overburden cover and overlying aquitards.
Lateral inflow	Low to moderate to high lateral inflow from upgradient portions of bedrock AQ 207 to the south, west, and north. Also possible upwelling inflow from underlying portions of bedrock AQ 207 - particular from the west (intersection of Shawnigan Fault & Handysen Creek lineament)
Temporal variability	Variable: (1) near-surface unconfined AQ zones: moderate to high depending on surficial lithologies and presence of low-permeability surface soil layers (2) Deeper semi-confined & confined AQ zones: low due to deep overburden cover and overlying aquitards
MBR	Negligible to low - adjacent rocky upland area approx 400 m to the south only
Discharge	
Evapotranspiration	Variable: (1) near-surface unconfined AQ zones: moderate to high (2) Deeper semi-confined to confined AQ zones: low
Outflow to marine	Negligible to low - separated from marine shoreline by thin strip iof bedrock AQ 207
Outflow to surface waters	Variable: (1) moderate to high along west (Handysen Ck), north (Hollings and Shawnigan Cks) and east (Bird, Wheelbarrow Cks) sides of AQ based on unconfined AQ settings & topography, or where bedrock forces semi-confined groundwater to surface
Outflow to other AQ	Possible basal outflow to bedrock AQ 207 along east border & in areas where artesian bedrock conditions are not apparent
Temporal variability	Variable: (1) near-surface unconfined AQ zones: moderate to high (2) Deeper semi-confined AQ zones: low
Groundwater Development	
Nearest BCMOE Observation Wells; distance; completion / relevance	Well #345 is 3.6 km to the north-northeast; negligible relevancy, well completed within surficial AQ197
Total Annual Water Use (m^3/yr) as reported by Hatfield (2015)	
Industrial	0
Commercial	18250
Domestic	15250
Irrigation from GW (Hatfield)	43900

BCMOE Obs	0
Other	7300
Water Supply Systems (2014 Mill Bay annual report)	490890

Table K-2: Direct Recharge Calculation for AQ206.

	Direct Recharge Calculation		
	Hot/Dry	**Average**	**Cold/Wet**
Surplus (mm)	512	761	1,263
Station Coefficient Factor	1.040	1.040	1.040
Infiltration Coefficient	0.448	0.448	0.448
Area (m^2)	2,573,511	2,573,511	2,573,511
Q (m^3/yr)	614,175	912,946	1,515,071
Average Infiltration Rate	0.239	0.355	0.589

Table K-3: Annual Summary of AQ206 Water Budgets.

Summary - 30 Year Average				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 206	2,573,511	0.355	912,946
Loss	Leakage down to 207	2,573,511	0.300	-772,053
Loss	Lateral Groundwater	--	--	-373,702
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	-208,138
Gain	Surface Water	--	--	227,059
Losses	Well Water Usage	--	--	-575,590
Net Gain				**1,140,005**
Net Loss				**-1,929,482**
Net Total (Gain - Loss)				**-789,477**
Summary - Hot/Dry (1989)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 206	2,573,511	0.239	614,175
Loss	Leakage down to 207	2,573,511	0.300	-772,053
Loss	Lateral Groundwater	--	--	-373,702
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	-208,138
Gain	Surface Water	--	--	227,059
Losses	Well Water Usage	--	--	-575,590
Net Gain				**841,234**
Net Loss				**-1,929,482**
Net Total (Gain - Loss)				**-1,088,248**
Summary - Wet/Cold (1999)				
Gains and Losses	**Source**	**Area (m^2)**	**Infiltration Rate**	**Q (m^3/yr)**
Gain	Direct Recharge to 206	2,573,511	0.589	1,515,071
Loss	Leakage down to 207	2,573,511	0.300	-772,053
Loss	Lateral Groundwater	--	--	-373,702
Gain	Lateral Groundwater	--	--	0
Loss	Surface Water	--	--	-208,138
Gain	Surface Water	--	--	227,059
Losses	Well Water Usage	--	--	-575,590
Net Gain				**1,742,131**
Net Loss				**-1,929,482**
Net Total (Gain - Loss)				**-187,352**

Table K-4: Monthly Summary of AQ206 Water Budgets.

Average Year													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 206	229,577	149,538	107,917	25,916	-31,195	-49,193	-47,993	-21,597	-7,199	78,928	242,168	236,079	**912,946**
Leakage down to 207	-62,536	-60,220	-67,169	-66,397	-69,485	-66,397	-67,169	-65,625	-62,536	-63,308	-60,220	-60,992	**-772,053**
Lateral Groundwater Loss	-30,270	-29,149	-32,512	-32,138	-33,633	-32,138	-32,512	-31,765	-30,270	-30,644	-29,149	-29,522	**-373,702**
Lateral Groundwater Gain	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water Loss	-45,932	-40,324	-29,129	-14,084	-4,994	-2,025	-1,203	-391	-329	-3,015	-21,309	-45,403	**-208,138**
Surface Water Gain	50,108	43,990	31,777	15,364	5,448	2,210	1,312	426	358	3,289	23,246	49,531	**227,059**
Water Usage	-34,535	-37,413	-43,169	-46,047	-51,803	-57,559	-63,315	-66,193	-57,559	-46,047	-40,291	-31,657	**-575,590**
Net Gain	**279,685**	**193,528**	**139,694**	**41,280**	**5,448**	**2,210**	**1,312**	**426**	**358**	**82,217**	**265,414**	**285,609**	**1,297,181**
Net Loss	**-173,274**	**-167,107**	**-171,979**	**-158,666**	**-191,110**	**-207,312**	**-212,191**	**-185,569**	**-157,893**	**-143,014**	**-150,969**	**-167,575**	**-2,086,658**
Net Total (Gain - Loss)	**106,411**	**26,421**	**-32,285**	**-117,385**	**-185,662**	**-205,102**	**-210,879**	**-185,143**	**-157,534**	**-60,797**	**114,445**	**118,034**	**-789,477**
Hot/Dry (1989)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 206	188,310	107,984	167,904	10,078	-39,594	-50,392	-43,193	-17,997	-11,998	30,595	120,102	152,377	**614,175**
Leakage down to 207	-63,308	-58,676	-64,852	-64,080	-67,169	-64,852	-67,169	-66,397	-63,308	-65,625	-62,536	-64,080	**-772,053**
Lateral Groundwater	-30,644	-28,401	-31,391	-31,017	-32,512	-31,391	-32,512	-32,138	-30,644	-31,765	-30,270	-31,017	**-373,702**
Lateral Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	-45,932	-40,324	-29,129	-14,084	-4,994	-2,025	-1,203	-391	-329	-3,015	-21,309	-45,403	**-208,138**
Surface Water	50,108	43,990	31,777	15,364	5,448	2,210	1,312	426	358	3,289	23,246	49,531	**227,059**
Water Usage	-34,535	-37,413	-43,169	-46,047	-51,803	-57,559	-63,315	-66,193	-57,559	-46,047	-40,291	-31,657	**-575,590**
Net Gain	**238,418**	**151,974**	**199,681**	**25,443**	**5,448**	**2,210**	**1,312**	**426**	**358**	**33,885**	**143,348**	**201,907**	**1,004,409**
Net Loss	**-174,419**	**-164,815**	**-168,541**	**-155,229**	**-196,072**	**-206,220**	**-207,392**	**-183,116**	**-163,838**	**-146,452**	**-154,407**	**-172,158**	**-2,092,658**
Net Total (Gain - Loss)	**63,998**	**-12,841**	**31,140**	**-129,786**	**-190,624**	**-204,011**	**-206,080**	**-182,690**	**-163,479**	**-112,567**	**-11,059**	**29,749**	**-1,088,248**
Cold/Wet (1999)													
Gains and Loses (m^3)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Direct Recharge to 206	426,055	431,357	159,975	-19,197	-15,598	-40,794	-52,792	-21,597	-9,599	151,297	244,523	261,440	**1,515,071**
Leakage down to 207	-62,536	-60,220	-67,169	-66,397	-69,485	-66,397	-67,169	-65,625	-62,536	-63,308	-60,220	-60,992	**-772,053**
Lateral Groundwater	-30,270	-29,149	-32,512	-32,138	-33,633	-32,138	-32,512	-31,765	-30,270	-30,644	-29,149	-29,522	**-373,702**
Lateral Groundwater	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Surface Water	-45,932	-40,324	-29,129	-14,084	-4,994	-2,025	-1,203	-391	-329	-3,015	-21,309	-45,403	**-208,138**
Surface Water	50,108	43,990	31,777	15,364	5,448	2,210	1,312	426	358	3,289	23,246	49,531	**227,059**
Water Usage	-34,535	-37,413	-43,169	-46,047	-51,803	-57,559	-63,315	-66,193	-57,559	-46,047	-40,291	-31,657	**-575,590**
Net Gain	**476,163**	**475,347**	**191,752**	**15,364**	**5,448**	**2,210**	**1,312**	**426**	**358**	**154,586**	**267,769**	**310,971**	**1,901,706**
Net Loss	**-173,274**	**-167,107**	**-171,979**	**-177,863**	**-175,512**	**-198,913**	**-216,990**	**-185,569**	**-160,292**	**-143,014**	**-150,969**	**-167,575**	**-2,089,058**
Net Total (Gain - Loss)	**302,889**	**308,241**	**19,773**	**-162,499**	**-170,065**	**-196,704**	**-215,678**	**-185,143**	**-159,934**	**11,572**	**116,800**	**143,396**	**-187,352**

Table K-5: Monthly Coefficients used in Calculations for AQ206.

30-Year Average												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.251	0.164	0.118	0.028	-0.034	-0.054	-0.053	-0.024	-0.008	0.086	0.265	0.259
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Hot/Dry (1989)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.307	0.176	0.273	0.016	-0.064	-0.082	-0.070	-0.029	-0.020	0.050	0.196	0.248
Leakance/ Lateral Ground Water	0.082	0.076	0.084	0.083	0.087	0.084	0.087	0.086	0.082	0.085	0.081	0.083
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06
Cold/Wet (1999)												
Monthly Factors	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surplus Water	0.281	0.285	0.106	-0.013	-0.010	-0.027	-0.035	-0.014	-0.006	0.100	0.161	0.173
Leakance/ Lateral Ground Water	0.081	0.078	0.087	0.086	0.090	0.086	0.087	0.085	0.081	0.082	0.078	0.079
Surface Water	0.221	0.194	0.140	0.068	0.024	0.010	0.006	0.002	0.002	0.014	0.102	0.218
Water Usage	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.12	0.10	0.08	0.07	0.06

Table K-6: Groundwater Flow Components: Aquifer #0206, Mill Bay (Surficial)

Groundwater Flow	Direction of Flow	Source or Receptor of Water	Length (m)	Depth (m)	Area (m)	Hydraulic Conductivity (m/s) - K	Distance (m) - dL	Hydraulic Head (m) - dh			GW Flow (m^3/yr)		
								Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
$Q_{GW}1$	Out	To Mill Bay	2,100	5	10,500	0.00001	750	60			-264,902		
$Q_{GW}2$	Out	Shawnigan Creek	230	20	4,600	0.00001	400	30			-108,799		
$Q_{GW}3$	Out	Leakage to AQ 207	Leakance Factor (m/yr) =	0.300	2,573,511	--	--	--	--	--	-772,053		
Total											**-1,145,755**		

Surface Water Contributions	Cold Water Creek?	Observed Vertical Gradient	Percent Permeable	Length (m)	Width (m)	Flux (m/s)	SW Flow (m^3/yr)			Comment
							Year 1	Year 2	Year 3	
Handeyson Creek	Unknown	Downward	10%	1,200	2	0.00003	227,059			
Hollings Creek	Unknown	Upward	10%	1,100	2	0.00003	-208,138			
Total							**18,922**	**0**	**0**	

Water Well Usage	Water Well Usage Volume (m^3/yr)									Comments
	Year 1			Year 2			Year 3			
	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	Total Volume Removed	Adjustment Factor	Adjusted Volume Removed	
Industrial	0	100%	0							100% consumptive
Commercial	18,250	100%	18,250							100% consumptive
Domestic	15,250	100%	15,250							100% consumptive
Irrigation	43,900	100%	43,900							100% consumptive
BCMOE Obs	0	100%	0							100% consumptive
Other	7,300	100%	7,300							100% consumptive
Water Supply Systems	490,890	100%	490,890							100% consumptive
Total	**-575,590**		**-575,590**							

APPENDIX L: SUMMARY OF INFLOW AND OUTFLOW OF AQUIFERS

Table L1 Summary of Water Budget Components byAquifer

Aquifer	Infiltration (m^3/yr)			Groundwater to/from Creek (m3/yr)	Groundwater to/from Ocean (m3/yr)	Groundwater Out to other Aquifer (m3/yr)	Groundwater In from other Aquifers (m3/yr)	Surface Water Contribution (m3/yr)	Water Useage (m3/yr)
	Cold, Wet	30 yr Average	Hot, Dry						
Bedrock 198	618,221	618,221	618,221	-37,179	0	-20,236	788,843.98809739	0	238,252
Bedrock 200	23,859,860	14,377,387	9,672,233	-10,990,747	0	-4,135,104	674,169.6	-1,986,768.0	45,230
Bedrock 202	14,606,582	8,801,581	5,921,169	-680,441	0	-12,571,613	633,789.9	1,173,139.2	191,855
Bedrock 203	25,782,231	15,535,762	10,451,518	0	0	-5,852	37,955	-16,339,122	492,906
Bedrock 204	6,874,388	4,142,343	2,786,717	-2,953,636	-4,465,005	-5,070,480	11,921,102	978,247	608,120
Bedrock 207	16,022,182	9,654,587	6,495,020	-2,614,057	-6,854,892	-6,623	1,348,315	1,793,768	413,057
Surficial 197	17,836,681	10,747,961	7,230,576	0	-3,220,260	-2,661,206	271,673	-741,333	4,576,581
Surficial 199	2,243,462	1,351,857	909,447	-2,056,385	0	-79,660	1,778,226	0	295,251
Surficial 201	1,405,297	846,798	569,675	-2,759	0	-633,790	0	157,680	44,135
Surficial 205	1,710,342	1,030,612	693,333	-302,746	0	-656,114	0	-170,294	132,804
Surficial 206	1,515,071	912,946	614,175	-108,799	-264,902	-772,053	0	18,922	575,590
Total	**112,474,317**	**68,020,055**	**45,962,084**	**-19,746,749**	**-14,805,060**	**-26,612,730**	**17,454,074**	**-15,115,762**	**7,613,781**

Based on Leakage from AQ 197 and AQ 199

Table L2 Summary of Water Budget Gains/Losses by aquifer for Wet/Cold Conditions (m3/year)

Aquifer	Cold, Wet	Average Year				Total Useage
		Spreadsheet Check	Gains	Losses	Water Balance	
Surficial 197	17836,681	*2,948,535*	18,108,354	-15,159,818	2,948,535	4,576,581
Bedrock 198	618,221	*531,740*	827,407	-295,667	531,740	238,252
Surficial 199	2,243,462	*1,342,052*	4,021,688	-2,679,636	1,342,052	295,251
Bedrock 200	23,859,860	*7,376,182*	24,534,030	-17,157,848	7,376,182	45,230
Surficial 201	1,405,297	*882,292*	1,562,977	-680,684	FALSE	44,135
Bedrock 202	14,606,582	*2,969,602*	20,109,229	-17,139,627	2,969,602	191,855
Bedrock 203	25,782,231	*8,976,847*	25,814,334	-16,837,487	8,976,847	492,906
Bedrock 204	6,874,388	*6,676,496*	20,290,857	-13,614,360	6,676,496	608,120
Surficial 205	1,710,342	*448,384*	1,710,342	-1,261,958	448,384	132,804
Surficial 206	1,515,071	*-187,352*	1,742,131	-1,929,482	-187,352	575,590
Bedrock 207	16,022,182	*9,275,635*	19,164,264	-9,888,629	9,275,635	413,057
Total	**112,474,317**	***41,240,413***	**137,885,611**	**-96,645,198**	**40,358,121**	**7,613,781**

Table L3 Summary of Water budget Gains/Losses by aquifer for Average Annual Conditions (m3/year)

Aquifer	Ave. Recharge	Average Year				Total Useage
		Spreadsheet Check	Gains	Losses	Water Balance	
Surficial 197	10,747,961	*-4,140,184*	11,019,634	-15,159,818	-4,140,184	4,576,581
Bedrock 198	618,221	*531,740*	827,407	-295,667	531,740	238,252
Surficial 199	1,351,857	*450,447*	3,130,083	-2,679,636	450,447	295,251
Bedrock 200	14,377,387	*-2,106,292*	15,051,556	-17,157,848	-2,106,292	45,230
Surficial 201	846,798	*323,794*	1,004,478	-680,684	323,794	44,135
Bedrock 202	8,801,581	*-2,835,400*	14,304,227	-17,139,627	-2,835,400	191,855
Bedrock 203	15,535,762	*-1,264,163*	15,573,717	-16,837,880	-1,264,163	492,906
Bedrock 204	4,142,343	*3,944,452*	17,558,812	-13,614,360	3,944,452	608,120
Surficial 205	1,030,612	*-231,347*	1,030,612	-1,261,958	-231,347	132,804
Surficial 206	912,946	*-789,477*	1,140,005	-1,929,482	-789,477	575,590
Bedrock 207	9,654,587	*2,908,040*	12,796,670	-9,888,629	2,908,040	413,057
Total	**68,020,055**	***-3,208,390***	**93,437,201**	**-96,645,591**	**-3,208,390**	**7,613,781**

Table L4 Summary of Water budget Gains/Losses by aquifer for Hot - Dry Conditions (m3/year).

Aquifer	Hot, Dry	Average Year				Total Useage
		Spreadsheet Check	Gains	Losses	Water Balance	
Surficial 197	7,230,576	*-7,657,570*	7,502,249	-15,159,818	-7,657,570	4,576,581
Bedrock 198	618,221	*531,740*	827,407	-295,667	531,740	238,252
Surficial 199	909,447	*8,037*	2,687,674	-2,679,636	8,037	295,251
Bedrock 200	9,672,233	*-6,811,445*	10,346,403	-17,157,848	-6,811,445	45,230
Surficial 201	569,675	*46,670*	727,355	-680,684	46,670	44,135
Bedrock 202	5,921,169	*-5,715,811*	11,423,816	-17,139,627	-5,715,811	191,855
Bedrock 203	10,451,518	*-6,328,151*	10,509,729	-16,837,880	-6,328,151	492,906
Bedrock 204	2,786,717	*2,588,826*	16,203,186	-13,614,360	2,588,826	608,120
Surficial 205	693,333	*-568,625*	693,333	-1,261,958	-568,625	132,804
Surficial 206	614,175	*-1,088,248*	841,234	-1,929,482	-1,088,248	575,590
Bedrock 207	6,495,020	*-251,526*	9,637,103	-9,888,629	-251,526	413,057
Total	**45,962,084**	***-25,246,105***	**71,399,486**	**-96,645,591**	**-25,246,105**	**7,613,781**

Table L5 Comparison of Recharge Rate by aquifer and Condition

Aquifer	Infiltration Rate ($m^3/yr/m^2$)		
	Cold, Wet	30 yr Average	Hot, Dry
Bedrock 198	0.100	0.100	0.100
Bedrock 200	0.886	0.534	0.359
Bedrock 202	0.773	0.466	0.314
Bedrock 203	0.831	0.501	0.337
Bedrock 204	0.600	0.362	0.243
Bedrock 207	0.711	0.429	0.288
Surficial 197	0.608	0.366	0.246
Surficial 199	0.684	0.412	0.277
Surficial 201	0.665	0.401	0.270
Surficial 205	0.627	0.378	0.254
Surficial 206	0.589	0.355	0.239

APPENDIX M: SUMMARY OF METEOROLOGICAL CONDITIONS

Shawnigan Lake

Hot/Dry					
Month-Year	**Temp. °C**	**Precipitation (mm)**	**Actual Evapotranspiration (mm)**	**Sum of Surplus Water (mm)**	**Potential Soil Water (mm)**
Jan-87	3.5	214.2	10.3	203.9	150
Feb-87	5.6	70.4	18.3	52.1	150
Mar-87	6.6	120.2	28.6	91.6	150
Apr-87	9.5	65	48.7	16.3	150
May-87	12.4	56	75	-19	131
Jun-87	15.8	6.8	68.8	-62	69
Jul-87	17.3	14.2	48.2	-34	35
Aug-87	17.8	18.4	34.4	-16	19
Sep-87	16.3	5.6	13.6	-8	11
Oct-87	11.6	13.8	15.8	-2	9
Nov-87	7.4	156.8	24.7	132.1	141
Dec-87	2.8	211.2	7.5	203.7	150
Jan-88	2.7	144.2	8.5	135.7	150
Feb-88	5.1	52.4	17.8	34.6	150
Mar-88	6	148.8	27.5	121.3	150
Apr-88	9.2	96	49.3	46.7	150
May-88	11.9	60.6	75.6	-15	135
Jun-88	14.1	38.4	79.4	-41	94
Jul-88	17.4	23.8	67.8	-44	50
Aug-88	17.6	16.8	39.8	-23	27
Sep-88	14.4	80	74.1	5.9	33
Oct-88	11.3	88.4	49.8	38.6	72
Nov-88	6.2	233.4	21.7	211.7	150
Dec-88	4.1	139.4	12.7	126.7	150
Jan-89	2.9	166.1	9.2	156.9	150
Feb-89	-0.7	90	0	90	150
Mar-89	3.9	157.2	17.3	139.9	150
Apr-89	10	62.6	54.2	8.4	150
May-89	12.3	42.2	75.2	-33	117
Jun-89	15.9	28.2	70.2	-42	75
Jul-89	16.7	28	64	-36	39
Aug-89	16.8	30	45	-15	24
Sep-89	16.2	2.6	12.6	-10	14
Oct-89	10.1	69.6	44.1	25.5	39
Nov-89	6.6	123.4	23.3	100.1	140
Dec-89	5	142.8	15.8	127	150

Shawnigan Lake

Cold/Wet					
Month-Year	**Temp. °C**	**Precipitation (mm)**	**Actual Evapotranspiration (mm)**	**Sum of Surplus Water (mm)**	**Potential Soil Water (mm)**
Jan-97	2.7	258.6	8.1	250.5	150
Feb-97	4.7	74.9	15.7	59.2	150
Mar-97	5.4	278	23.8	254.2	150
Apr-97	8.3	107	43.2	63.8	150
May-97	13.5	77	85	-8	142
Jun-97	14.6	85.6	94.6	-9	133
Jul-97	17.6	29.8	88.8	-59	74
Aug-97	18.5	36.4	66.4	-30	44
Sep-97	15.4	113.2	78.9	34.3	78
Oct-97	9.9	215	42.3	172.7	150
Nov-97	6.9	156.4	23.7	132.7	150
Dec-97	4.4	133.6	13.2	120.4	150
Jan-98	3.1	278.6	8.7	269.9	150
Feb-98	5.5	153.8	17.6	136.2	150
Mar-98	6.7	94.6	28.7	65.9	150
Apr-98	8.9	18.2	43.2	-25	125
May-98	13	42.8	70.8	-28	97
Jun-98	16.1	25.6	64.6	-39	58
Jul-98	18.9	60.8	81.8	-21	37
Aug-98	18.8	1.8	21.8	-20	17
Sep-98	16	18.2	24.2	-6	11
Oct-98	10.1	96.2	41.7	54.5	66
Nov-98	7	398	22.9	375.1	150
Dec-98	2.9	299.2	7.6	291.6	150
Jan-99	3.9	369	13.9	355.1	150
Feb-99	3.7	373.2	13.7	359.5	150
Mar-99	4.7	156.2	22.9	133.3	150
Apr-99	7.7	27.2	43.2	-16	134
May-99	9.9	48.4	61.4	-13	121
Jun-99	13.7	44.2	78.2	-34	87
Jul-99	16.5	9.2	53.2	-44	43
Aug-99	18	30.4	48.4	-18	25
Sep-99	14.5	23.8	31.8	-8	17
Oct-99	9.3	168.4	42.3	126.1	143
Nov-99	6.4	227.8	24	203.8	150
Dec-99	4.3	232.4	14.5	217.9	150

Shawnigan Lake

30 Year Average					
Month-#	**Temp. °C**	**Precipitation (mm)**	**Actual Evapotranspiration (mm)**	**Sum of Surplus Water (mm)**	**Potential Soil Water (mm)**
Jan-1	3.1	201.4	10.1	191.3	150
Feb-2	4.3	138.7	14.1	124.6	150
Mar-3	6	117.9	28	89.9	150
Apr-4	8.7	68.5	46.9	21.6	150
May-5	12.1	48.9	74.9	-26	124
Jun-6	15.1	39.5	80.5	-41	83
Jul-7	17.6	23.3	63.3	-40	43
Aug-8	17.8	28.3	46.3	-18	25
Sep-9	14.8	37.4	43.4	-6	19
Oct-10	10	109.7	43.9	65.8	85
Nov-11	5.5	220.9	19	201.8	150
Dec-12	3.1	206.2	9.4	196.8	150

Figure M-1: Temperature

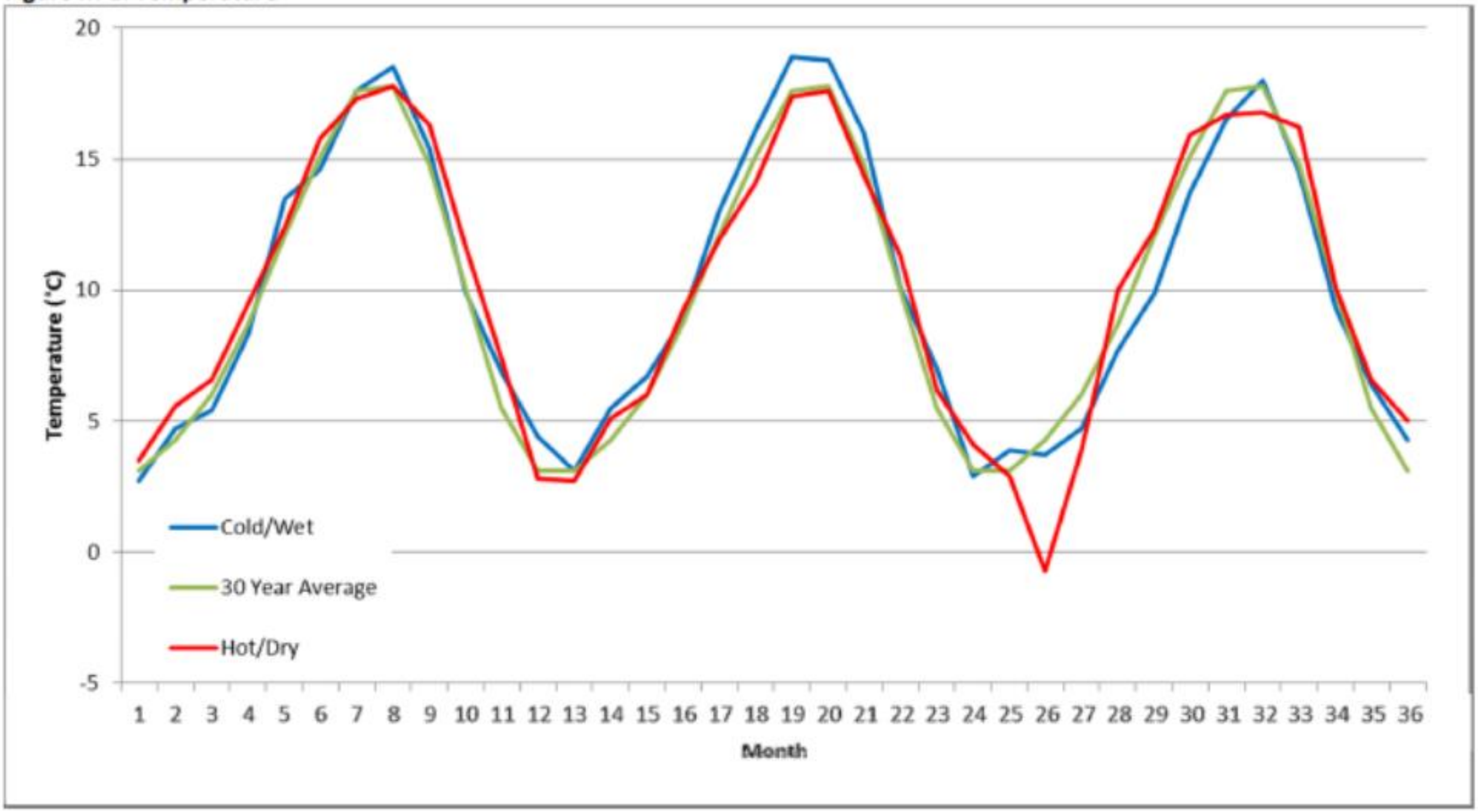


Figure M-2: Actual Evapotranspiration

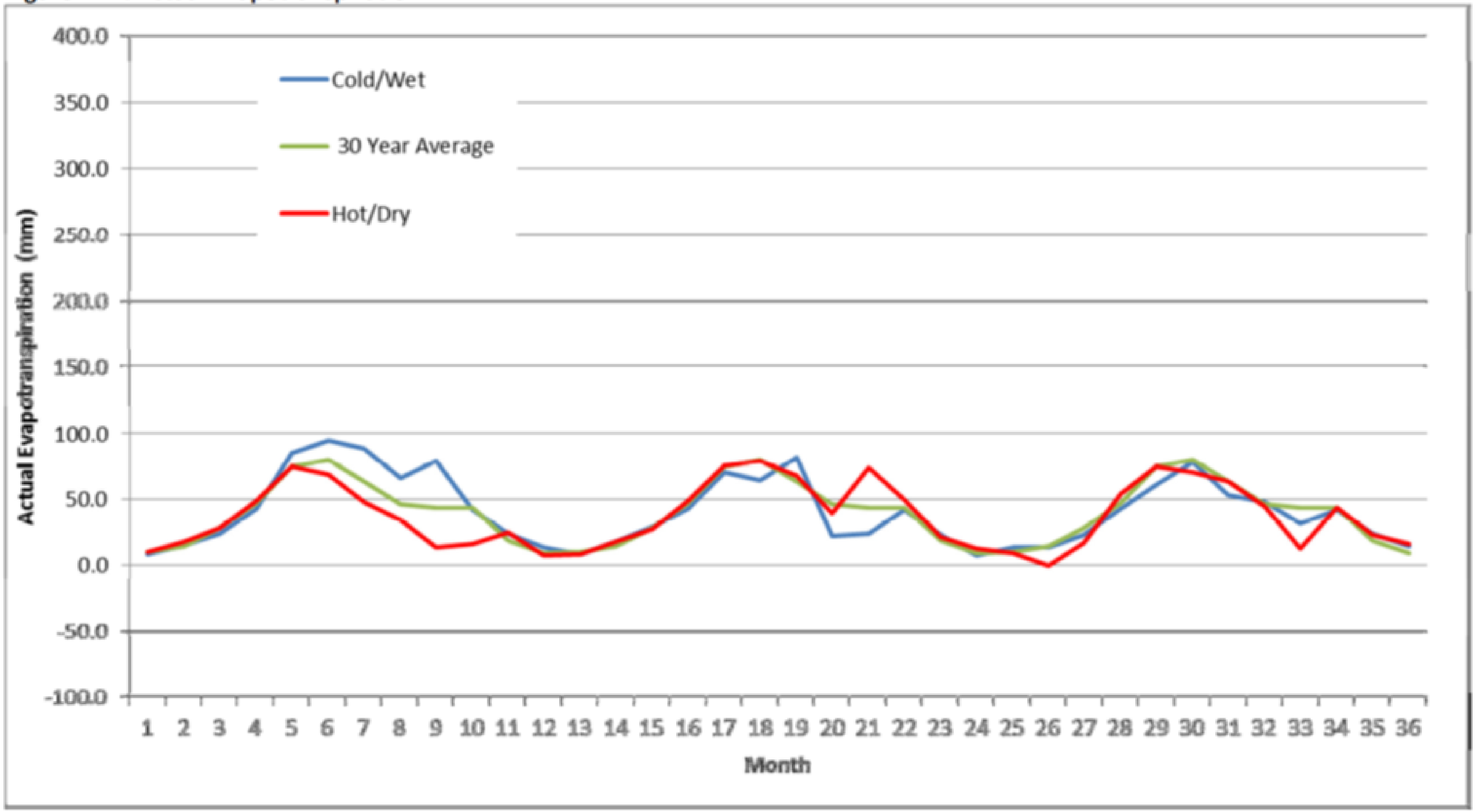


Figure M-3: Potential Soil Water

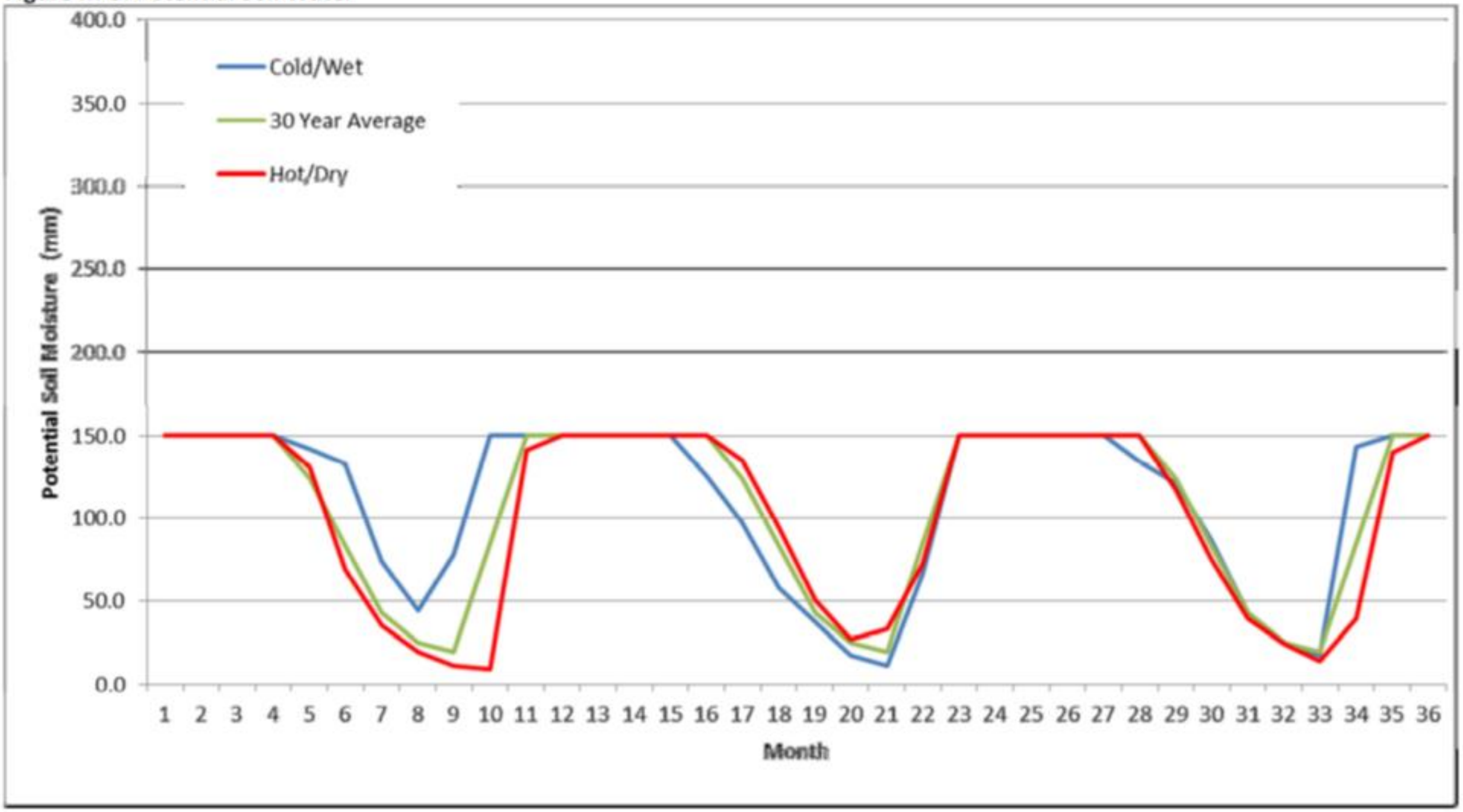


Figure M-4: Precipitation

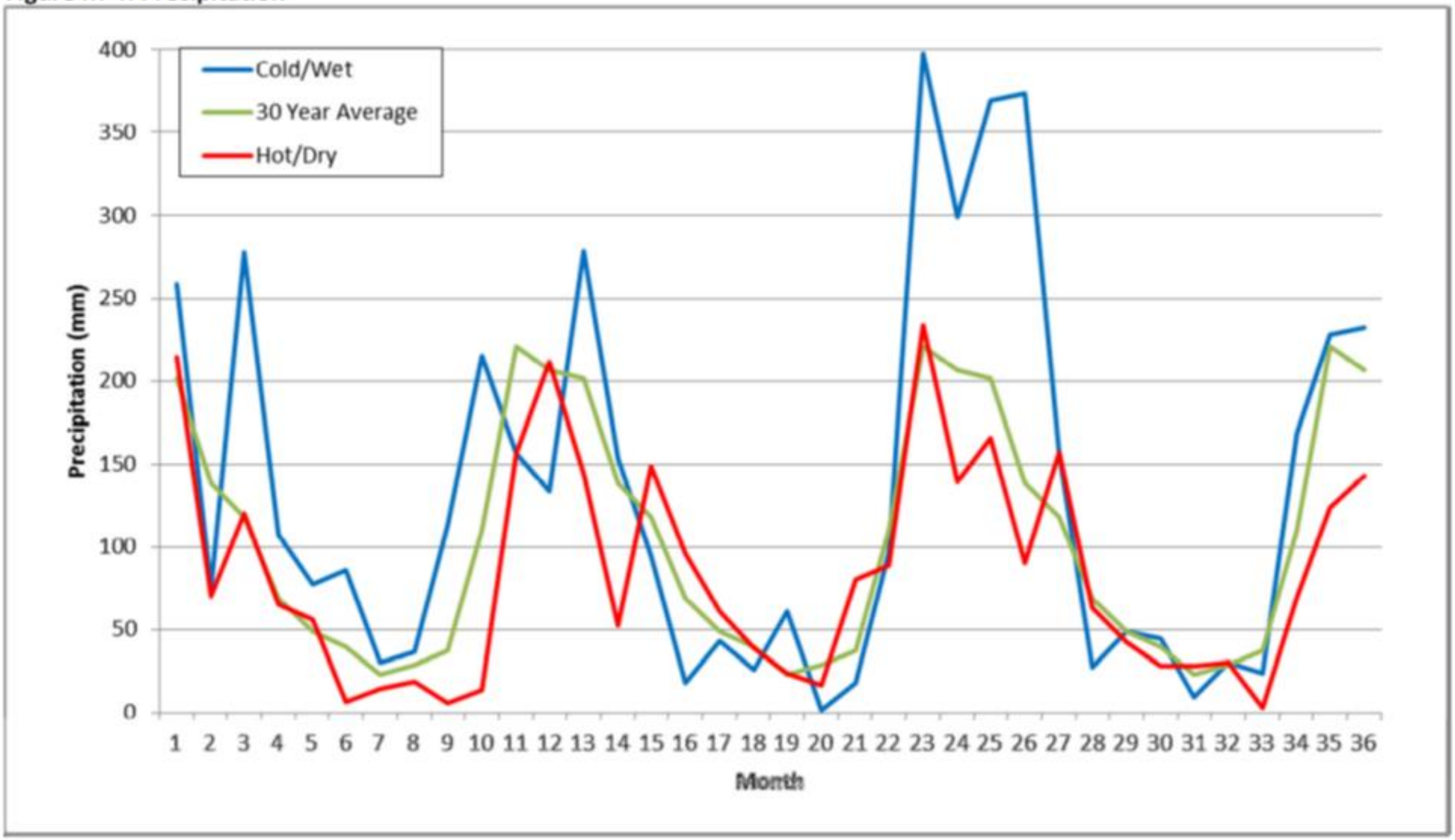


Figure M-5: Sum of Surplus Water

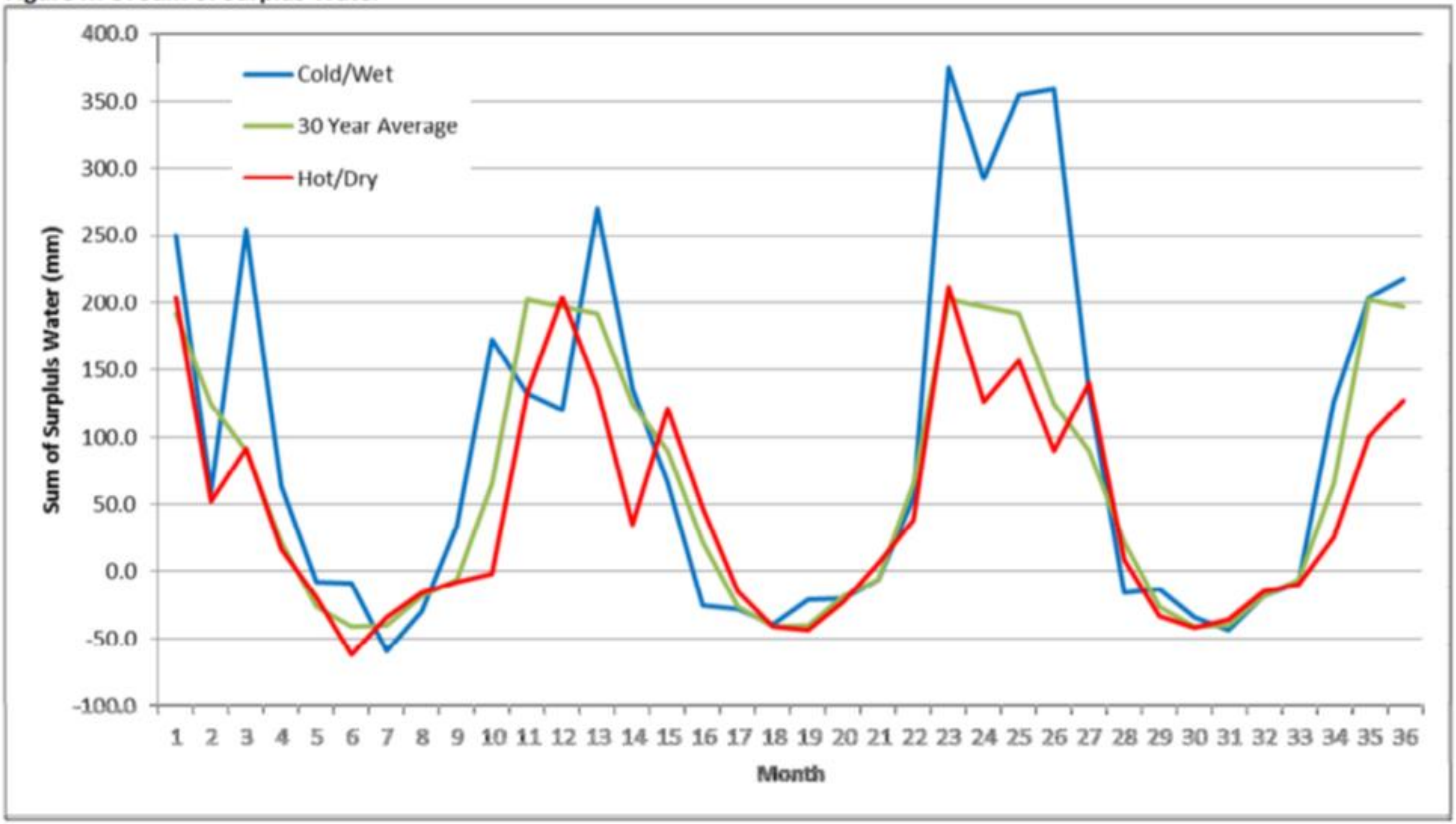


Figure M-6: Conditions during Cold/Wet Year

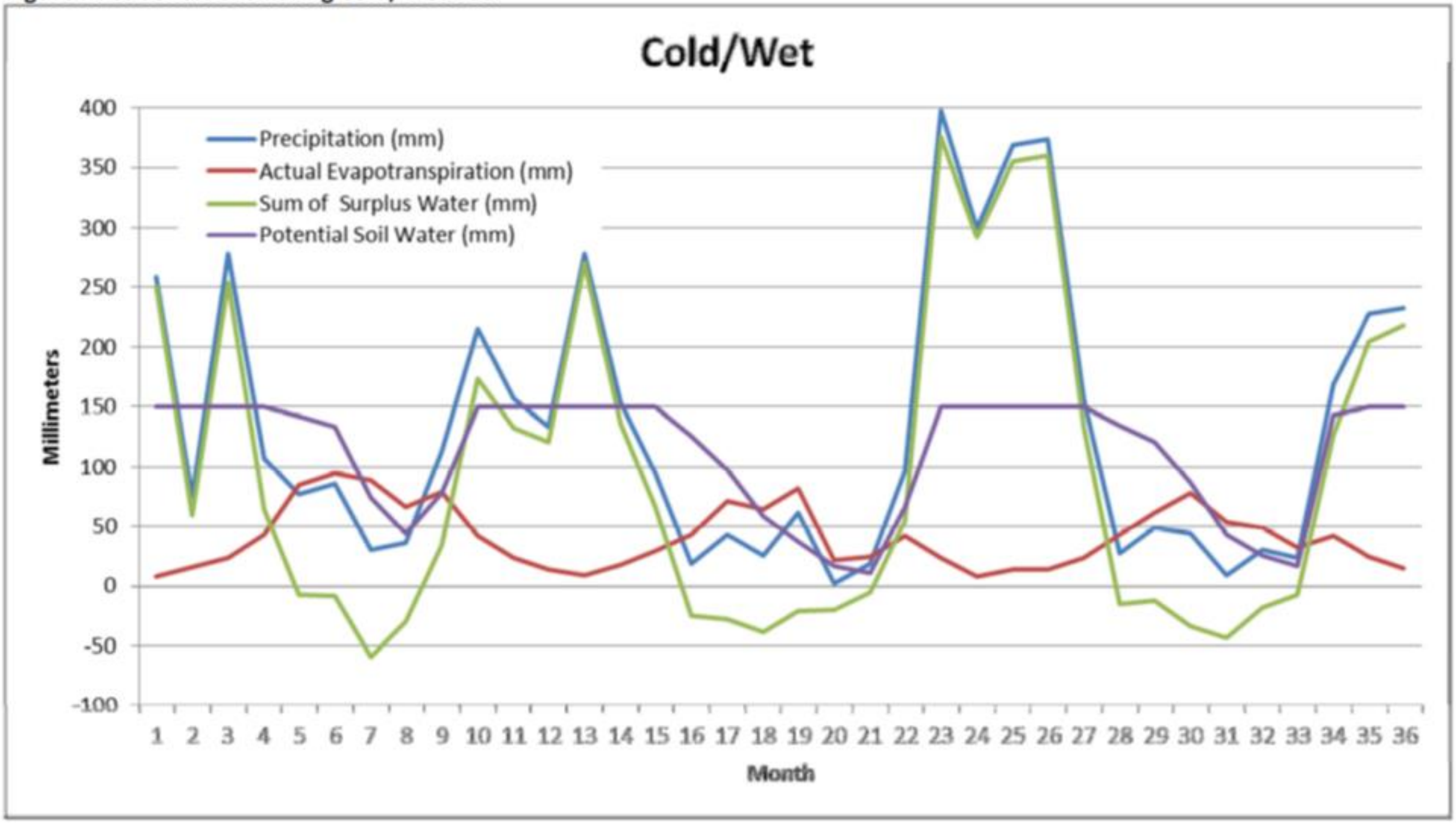


Figure M-7: Conditions during the 30 Year Average

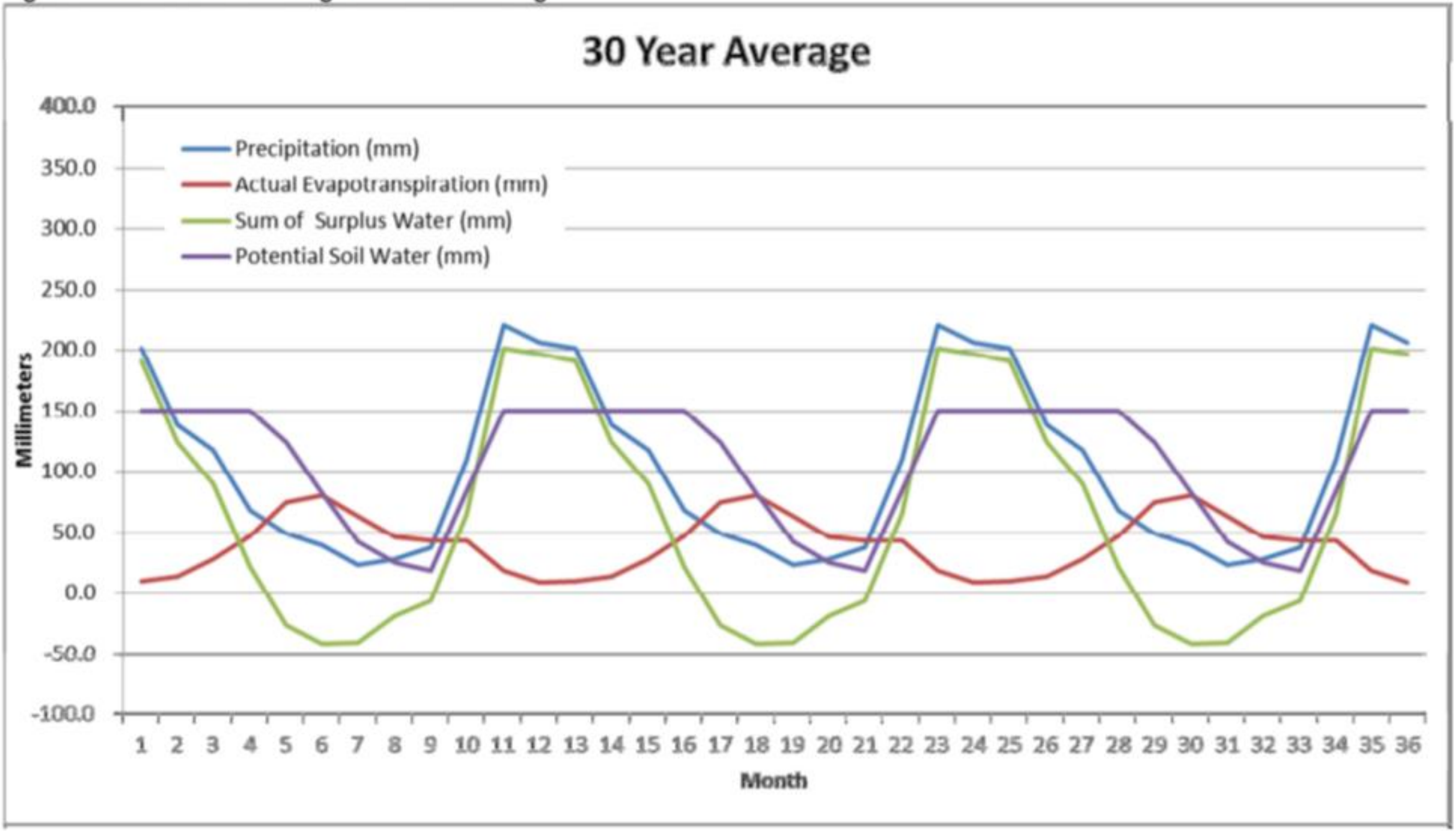
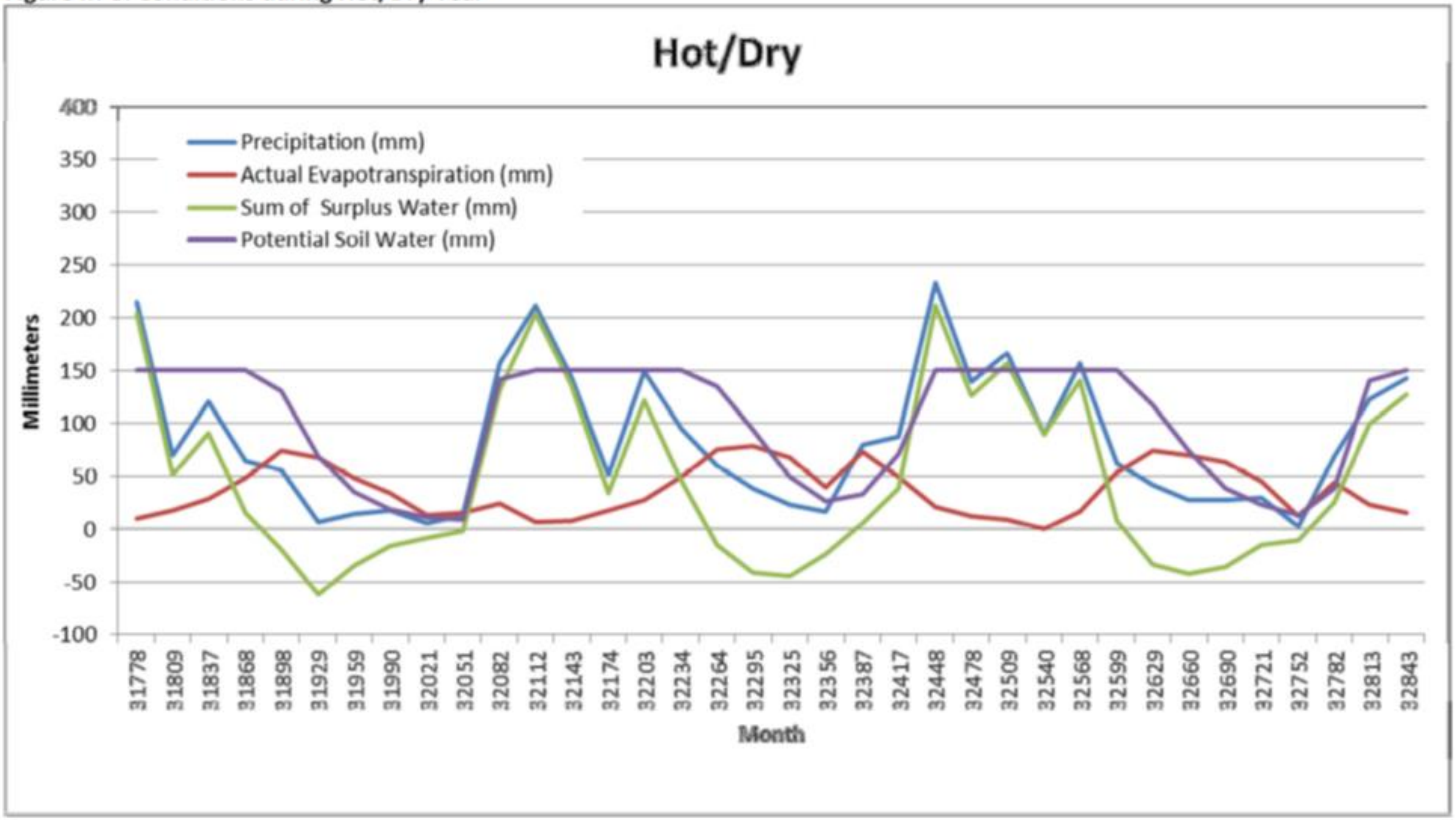
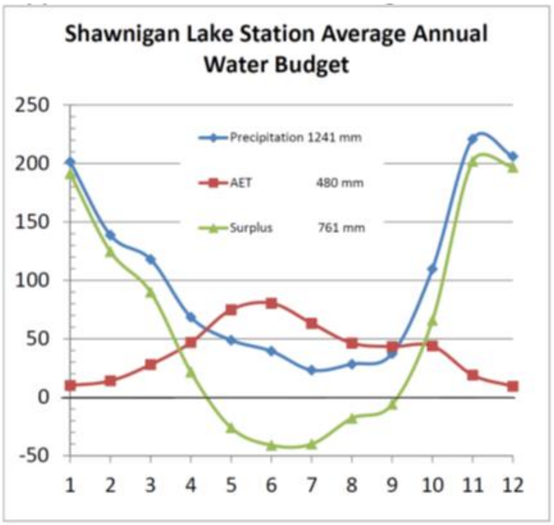
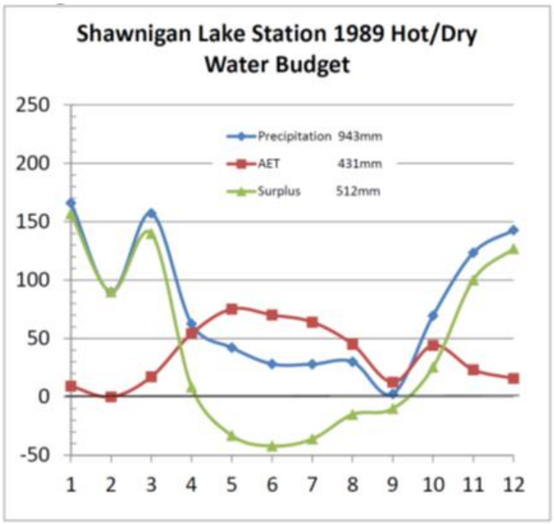


Figure M-8: Conditions during Hot/Dry Year



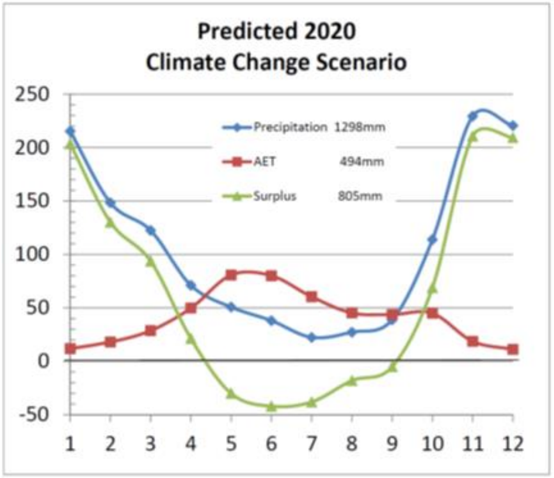
APPENDIX N: ANNUAL WATER BUDGETS FOR CLIMATE CHANGE SCENARIOS

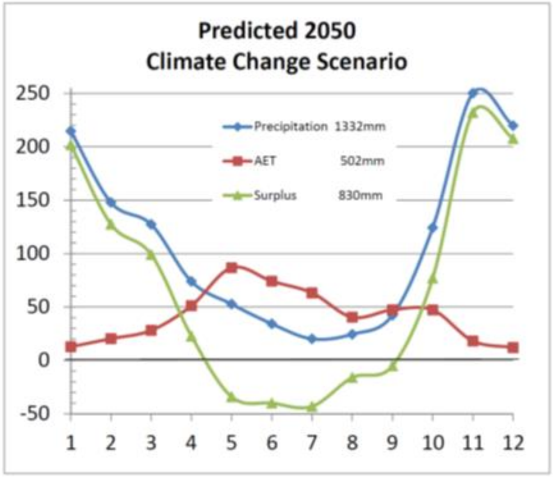


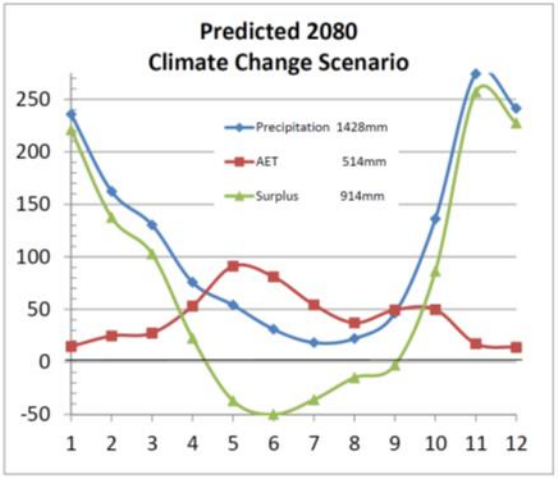


Comparison of Suplus and of Deficit Conditions

Scenario	Surplus	Deficit	Total
30 yr mean	892	-131	761
Hot/Dry (1989)	648	-136	512
2020	938	-133	805
2050	968	-138	830
2080	1055	-141	914







APPENDIX O: LIST OF ACRONYMS

A	Area
AET	Actual Evapotranspiration
amsl	Above the mean sea level
AQ	Aquifer
B.C.	British Columbia
BCMEM	British Columbia Ministry of Energy and Mines
BCGS	British Columbia Geological Survey
BCWRA	British Columbia Water Resource Atlas
bmsl	Below mean sea level
cm	centimetre
CVRD	Cowichan Valley Regional District
°C	Degrees Celsius
DEM	Digital Elevation Model
dh/dL	Hydraulic gradient, where h is the hydraulic head and L is distance
EC	Environment Canada
EPM	Equivalent porous media
ENV	Ministry of Environment & Climate Change Strategy
F_{cover}	Land cover infiltration factor
F_{slope}	Slope infiltration factor
F_{soil}	Soil infiltration factor
GIS	Geographic Information System
ha	Hectare
Hatfield	Hatfield Consultant
IDW	Inverse Distance Weighting
K	Hydraulic conductivity
km	kilometre
km^2	Squared kilometres
K_{mb}	Mountain Block scale bulk hydraulic conductivity
LDZ	Lineament density zone
L/s	Litres per second
m	metres
mm	Millimetres
m^2	squared metres
m^3	cubic metres
m/s	metres per second
m^3 /s	cubic metres per second
m/year	metres per year
mm/year	Millimetres per year
m^3 /year	cubic metres per year
PE	Average Monthly Actual Evapotranspiration
Q	Volumetric flow rate
SLR	SLR Consulting (Canada) Ltd.
TRIM	Terrain Resource Information Management Program
UTM	Universal Transverse Mercator