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Aquifer Mapping and Monthly Groundwater Budget Analysis for Aquifers on Salt Spring Island

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EXECUTIVE SUMMARY

Salt Spring Island is the most populated of British Columbia's southern Gulf Islands. Water supply for its 10,000 residents and an estimated 10,000 annual visitors is derived entirely from the Island's footprint, from community systems utilizing water from surface water and groundwater sources, together with private wells. Groundwater supplies are derived from a complex system of folded sedimentary bedrock in the north Island and volcanic and intrusive bedrock in the south, together with surficial aquifers of limited aerial extent. The Island's groundwater supply faces challenges related to variable yields as a result of aquifer heterogeneity, increased demand due to development pressure, climate change, and saltwater intrusion.

In order to sustainably manage the Island's groundwater resources at present and in the future, the B.C. Ministry of Environment & Climate Change Strategy (ENV), in partnership with the B.C. Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD), Islands Trust, and local partner the Salt Spring Island Watershed Protection Alliance (SSIWPA), commissioned a two phase scientific study to review, revise and update the provincial aquifer mapping and classification for the Island (Phase 1) and conduct a monthly groundwater budget analysis for the updated aquifers (Phase 2).

Aquifer mapping was carried out by integrating available geological mapping, information contained in WELLS database, and other publicly available information into a spatial database and then visualized using Leapfrog Hydro, a commercially available geological and hydrogeological interpretation software. Over 2500 logs from wells completed on the Island were standardized and then used to develop a simplified understanding of subsurface conditions (of the 2667 available well logs for the Island, information from 2538 of the logs was used in the analysis). This information, in combination with the results of hydrogeological testing and Island-wide interpretation of water table elevations was used to delineate key aquifer units. Four bedrock aquifers were delineated based on the hydraulic properties of the differing rock types and formations, geological orientation and structure (folding, deformation and weathering), and an assessment of the influence of geological structures (i.e., faults, contacts) on groundwater movement. Four overburden aquifers of limited extent were delineated in areas where there was evidence of a reasonable thickness of unconsolidated permeable material, evidence (or likelihood) that the permeable material is saturated, and that the permeable material is of sufficient lateral extent to be considered an aquifer.

Monthly groundwater budgets were derived for each aquifer to assess the sustainability of groundwater withdrawals. Groundwater budgets were developed based on available climate data, estimates of groundwater recharge, and an estimate of groundwater demand from domestic, commercial and agricultural users. The results of the water budget analysis show that for the bedrock aquifers on Salt Spring Island, groundwater recharge represents approximately 10% to 12% of the annual average precipitation, surface water runoff represents approximately 54%, and evapotranspiration represents approximately 34% to 36%. Currently, groundwater usage represents a fraction (0.3% to 0.6%) of the average annual precipitation, or 2.4% to 6.1% of the total estimated recharge. Groundwater outflow to local water courses (as baseflow) and groundwater flux to the sea represent components of groundwater recharge estimated to be approximately 9% and 1% to 3%, respectively, of the annual average precipitation. The overall groundwater budgets are subject to considerable uncertainty given the limited surface water data that was used to estimate recharge and direct runoff.

While the results of the water budget analysis suggest that on a regional basis there is potential for further development of bedrock aquifers on Salt Spring Island, insights from the study indicate that future groundwater development will be constrained by the storage capacity and transmissivities of the bedrock aquifers. Hydrographs from local observations wells show that the groundwater regime appears

to be recharged annually on a regional basis, even in years characterized by low rainfall. This indicates that there is not a lack or shortage of available groundwater associated with the Salt Spring Island bedrock aquifers on a regional basis. However, on a local basis, the low transmissivity / hydraulic conductivity of the rock on Salt Spring Island means that groundwater use from individual wells can commonly exceed the capacity of the local rock to bring water to the well when the well is installed in lightly fractured and non-fractured rock or the fracture network intersected by the groundwater well is poorly connected to a larger source. Given variability of groundwater availability at a local level, detailed hydrogeological investigations will be required to assess the feasibility of future groundwater extraction on individual land parcels where development is planned.

Seasonal groundwater shortages in the dry season are also observed across the island due to local exhaustion of groundwater storage. Furthermore, an apparent decline in dry season groundwater levels is noted in some observation wells, suggesting that groundwater resources are coming under increasing stress during the dry season. As a result, groundwater availability and the likelihood of supply problems on Salt Spring Island are likely more sensitive to the overall duration of the dry period as opposed to the amount of precipitation received during that dry period. A prolonged dry period would mean island residents would be drawing from storage earlier in the year, increasing the likelihood of shortages later in the year.

In areas where the unconsolidated aquifers have been mapped, most drillers chose to complete wells in the underlying bedrock aquifers rather than the overlying surficial material. This, combined with the highly variable nature of the surficial material and its glacial origin, suggests that the unconsolidated aquifers may not be particularly productive. Accordingly, while the unconsolidated aquifers may provide a source of minor, local groundwater supply, they should not be targeted for future groundwater development.

Salt water intrusion represents a real concern to groundwater availability in certain areas of Salt Spring Island (particularly in the north part of the Island along the northeast coast and in the Ganges Harbour/Long Harbour area), one which is already observed and managed in some coastal water supply systems (WSS) and which is undoubtedly observed in numerous other private wells across the Island. Saline intrusion in groundwater wells during the dry period is currently observed and does have the potential to impact the amount of available groundwater on a year-to-year basis. Groundwater resources in these incidences must be carefully managed, particularly in coastal wells or high yielding wells with good connectivity to the sea.

Recommendations for improving the hydrogeological understanding of Salt Spring Island include:

- Prioritization of the North Salt Spring Island and North Central Salt Spring Island Aquifers for future work, including the work related to geological and hydrogeological surveys and the hydrometric, meteorological and saline intrusion monitoring described below, as they have the highest population density, local water demand, potential for salt water intrusion and greater risk of supply constraints;
- A geological survey to identify smaller-scale lineaments and faults that could act as potential hydrostructural controls for groundwater flow;
- An island-wide spring survey of likely locations (areas of hydrostructural interest, lowland areas and areas of high topographic relief) to provide insight on the groundwater flow regime and identify areas of potential groundwater supply;
- Field confirmation of high-yielding wells to establish potential presence of high yielding structures, such as faults, fractures and geological contacts;

- Identification and field confirmation of wells that can be incorporated into a community monitoring well network to establish island-wide coverage for reliable hydraulic head monitoring; and
- Compilation of additional pumping test data to confirm well yields and test hydraulic conductivity.

Recommendations for improving groundwater budgeting estimates include:

- Implementation of a hydrometric flow gauging network of major surface water features near their outlet to the sea, particularly in areas of higher groundwater use and population, where recharge estimates are more important. Key streams that could be targets for this monitoring, include Fulford Creek, Cusheon Creek, Bullocks Creek, Ganges Creek, McFadden Creek and Weston Creek. This hydrometric monitoring should be conducted year-round so that estimates of surface water run-off and groundwater recharge can be made; and
- Existing meteorological stations could be supplemented with a higher altitude precipitation gauge at a suitable location on Mount Maxwell or Baynes Peak, for example, or by citizen scientists in order to improve the spatial coverage of precipitation data to improve recharge estimates.

Recommendations for increasing available water and addressing other hydrogeological concerns include:

- General Hydrogeology and Water Use: Establishment of groundwater level monitoring on highly-transmissive, structurally well-connected features in the bedrock that are in areas where groundwater use is comparatively high;
- Potential for Groundwater Supply Expansion: Locations with a larger, undeveloped catchment areas such as the lower slopes of South and Central Salt Spring Island have the best potential for future groundwater supply development without compromising environmental flows. Areas of North Salt Spring Island that are predominantly reliant on surface water for their water supply and which have comparatively less groundwater development may be able to supplement their water supply with additional groundwater expansion. Any future groundwater extraction should be coupled with appropriate hydrogeological monitoring;
- Maintenance of Groundwater Levels: The best strategy to ensure that groundwater levels are not negatively impacted from overuse would be a thoughtfully-designed monitoring system coupled with a multi-pronged approach to increasing the amount of system storage;
- Limiting Saline Intrusion: A critical method for limiting salt water intrusion is to frequently monitor the electrical conductivity or salinity of the groundwater produced from a well and be prepared to make operational adjustments to the pumping scheme or pump setting if salinity increases are observed during the dry period, which survey results show that some coastal WSSs are already doing; and
- Maintenance of Baseflow: Additional data gathering should continue to better characterize the surface water regime both to close the essential loop in the groundwater balance as well as to understand potential baseflow targets for watercourses.

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1. INTRODUCTION

Salt Spring Island (the Island) is the largest and most populous of British Columbia's Gulf Islands, located in the Strait of Georgia, roughly between the cities of Vancouver and Victoria (Figure 1). Located in the rain shadow of Vancouver Island to the west, the climate of the Island is characterized as Cool Mediterranean, with summers that are cool and dry, winters that are humid and mild, with less precipitation in general than surrounding coastal areas. The Island is geologically diverse, with residents relying on an assortment of private and community systems to provide them with their water supply, both from groundwater and surface water sources (Figure 2). Owing to the geography of the Island, the importance of groundwater as a water source is comparatively higher than other areas of the province, with over 2600 water well records for the Island in the provincial database and an estimate of approximately 4000 total wells on the Island based on a provincial assessment of cadastral data.

In order to sustainably manage the Island's groundwater resources at present and in the future, the B.C. Ministry of Environment & Climate Change Strategy (ENV), in partnership with the B.C. Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD), Islands Trust, and local partner the Salt Spring Island Watershed Protection Alliance (SSIWPA), commissioned a two phase scientific study to review, revise and update the provincial aquifer mapping and classification for the Island (Phase 1) and conduct a monthly groundwater budget analysis for the updated aquifers (Phase 2). This Water Science Series report presents the study objective, data sources and methods utilized, analyses conducted, and results for both the aquifer mapping and monthly aquifer groundwater budget analysis phases of the study. The analysis and results of the study benefitted tremendously from the support and engagement of local partners and stakeholders, without whose energy, hard work, and assistance this report would not have been possible.

2. STUDY OBJECTIVES

The sustainable management of BC's groundwater resources has become increasingly important with the adoption of the Water Sustainability Act in B.C. Regulators and water managers require hydrogeological information, data, and tools to inform decision-making related to groundwater licensing and allocation in order to protect groundwater supplies and for ecosystems reliant on groundwater baseflow. To support these initiatives, the provincial ministries have been undertaking numerous aquifer mapping studies both to provide aquifer mapping coverage in areas that have not been previously mapped, or to revise and update aquifer mapping in previously-mapped areas where updated information, data, or records have become available. To provide hydrogeological insight into the concept of "available water" for existing or updated aquifers in the province, preliminary monthly aquifer groundwater budget analyses are conducted that attempt to quantify the major inflows and outflows to the aquifer as a hydrogeological unit, based on a series of prescribed methodologies (Hy-Geo Consulting, 2015). The monthly aquifer groundwater budget analyses provide essential high-level insight into the movement of groundwater in the areas of interest as well as assist in identifying data gaps and limitations to the current conceptual understanding.

The objectives of this study include both an update to the existing aquifer mapping and classification for aquifers on Salt Spring Island (Phase 1) and creation of monthly aquifer groundwater budgets under various scenarios (Phase 2) for the updated aquifer boundaries. Based on the findings and results of the two phases, recommendations to address data limitations are provided.

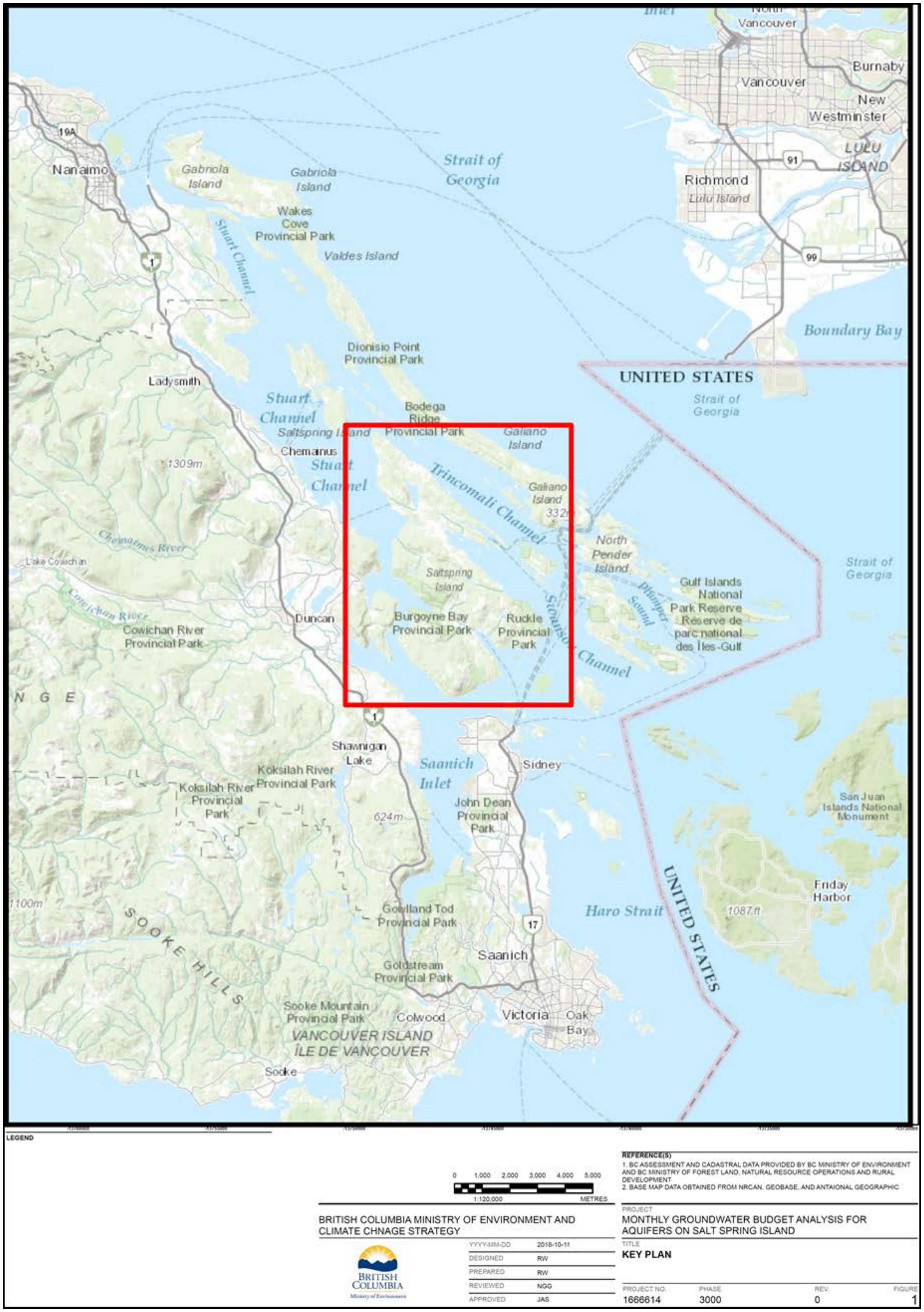

Figure 1: Location of Salt Spring Island in the Strait of Georgia.

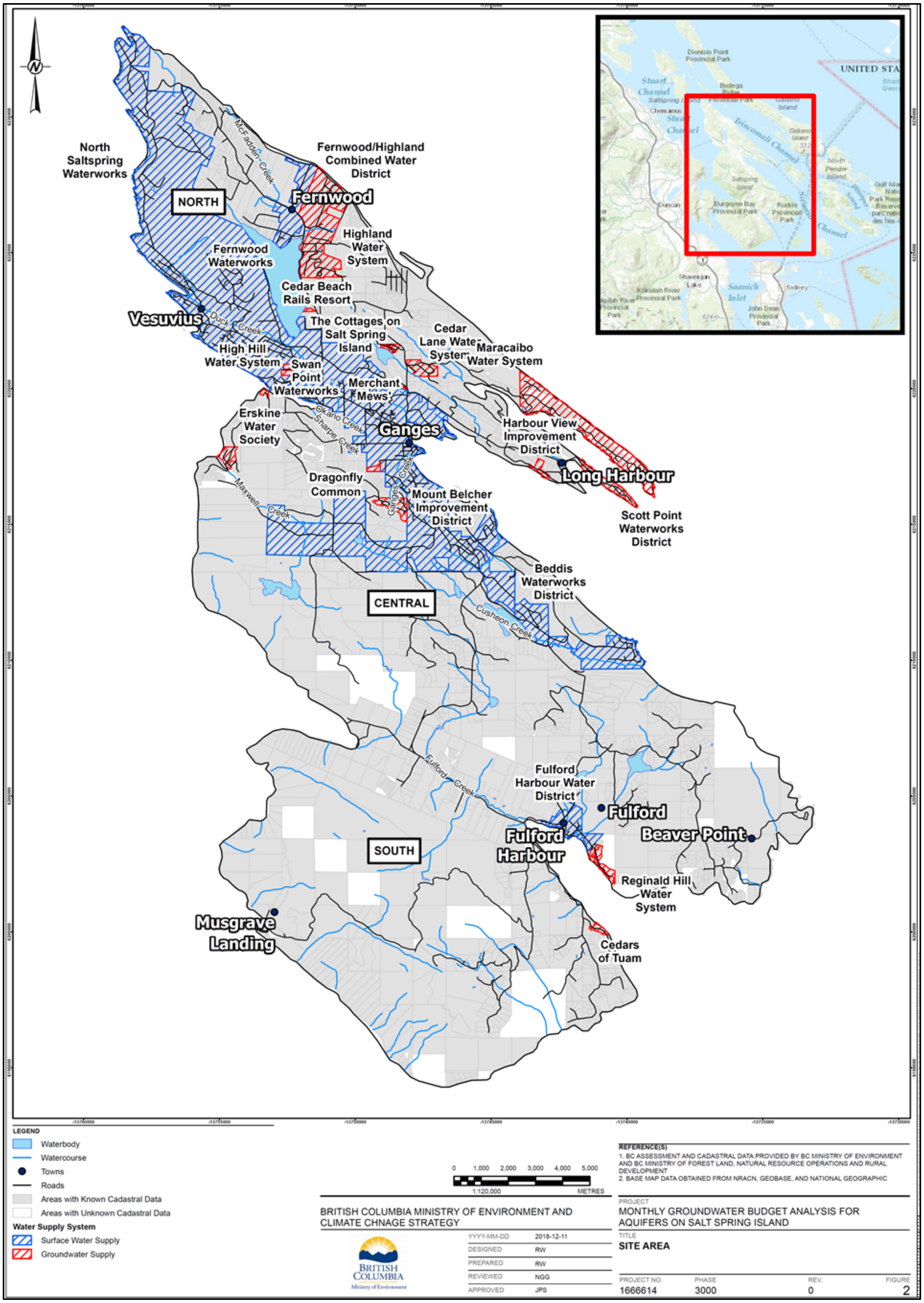

Figure 2: Water supply systems on Salt Spring Island.

3. DATA SOURCES

Data sources for the Phase 1 and Phase 2 of the study are provided in Sections 3.1 and 3.2, respectively. Previous studies are described in Section 3.3.

3.1 Phase 1—Aquifer Mapping and Classification Data Sources

The Salt Spring Island aquifer mapping and classification phase integrates hydrogeological and geological data and information from numerous, diverse sources. Data sources that were utilized to inform the aquifer mapping include the following:

- British Columbia water wells (WELLS) database, with attributes:
  - well locations and UTM accuracy
  - well depths
  - well yields (driller's estimates)
- British Columbia water wells (WELLS) database with lithologies:
  - raw lithological descriptions recorded by depth interval at the time of drilling
  - general drilling remarks by depth interval at the time of drilling
- Previous hydrogeological reports and investigations completed on Salt Spring Island as well as other Gulf Islands;
- Geological mapping for Salt Spring Island;
- Canadian Digital Elevation Model (CDEM) with 20 m resolution from Natural Resources Canada;
- Geological and soil reports for Salt Spring Island and other Gulf Islands;
- Published scientific literature on comparable studies using national, provincial, or regional water well databases for hydrogeological interpretation;
- Discussions with resident geological expert, Dr. Hugh Greenwood; and
- Telephone interviews with local drilling contractors on local hydrogeological conditions and typical water well completions.

Data from these sources were processed and analyzed during the Phase 1—Aquifer Mapping and Classification work described in Section 4.

3.2 Phase 2—Monthly Aquifer Groundwater Budget Analysis Data Sources

The Salt Spring Island monthly aquifer groundwater budget analysis includes land use, meteorological, hydrometric, hydrogeological, and water use data from a variety of sources, including:

- Water production data (groundwater and surface water) and associated reports from community and private Water Supply Systems (WSS) across the Island—obtained and provided by SSIWPA and FLNRORD;
- Groundwater hydraulic head data from WSS observation and production wells and wells from the Provincial Groundwater Observation Well Network (PGOWN)—obtained and provided by ENV/FLNRORD and SSIWPA;
- Meteorological and climatological data from active and discontinued meterological stations from Environment Canada's Climate Data Archive—accessed online;
- Hydrometric data from discontinued Water Survey of Canada (WSC) flow and water level gauging stations—accessed online;
- Hydrometric data (seasonal continuous flow, spot flow, and water level measurements) from 2017 surface water monitoring programs—obtained and provided by FLNRORD and community sources;

- Island-wide “climate surfaces” for monthly meteorological and climatological parameters (i.e., precipitation, evapotranspiration) for climate normals, historical years and climate change model runs—generated by Golder using the ClimateBC interface and database;
- Integrated BC Assessment data, cadastral, land use, actual use geospatial data for Salt Spring Island—provided by FLNRORD;
- Geospatial analysis of primary and secondary water sources per land parcel on Salt Spring Island, including assessment of number of groundwater wells assumed not to be present in the provincial WELLS database—created and provided by FLNRORD;
- Selection of relevant hydrogeological reference reports for Salt Spring Island—provided by Islands Trust, SSIWPA, and FLNRORD;
- Agricultural water demand model (AWDM) and demand estimates under various scenarios for agricultural lands on Salt Spring Island—provided by the Ministry of Agriculture; and
- Results of face-to-face interviews and well surveys between SSIWPA and local WSS operators and well owners—conducted and provided by SSIWPA.

Data from these sources were processed and analyzed during the Phase 2—Monthly Aquifer Groundwater Budget Analysis work described in Section 5.

3.3 Previous Studies

Numerous studies have been conducted on Salt Spring Island and other Gulf Islands to characterize the geology and hydrogeology and to assess groundwater sustainability. Key studies that were evaluated as part of this work are summarized below.

The geology of Salt Spring Island is documented in the following reports:

- Levson, V. and N. Massey, 2011. Geology of Southern Vancouver Gulf Islands and Salt Spring Islands. Field Trip Guidebook for the 5th British Columbia Unconventional Gas Technical Forum;
- Greenwood, H.J. and Mihalynuk, M.G., 2009. Salt Spring Island Geology (Adjoining Quadrants of NTS 93B/11, 12, 13 & 14). Open File 2009-11. BC Ministry of Energy, Mines, and Petroleum Resources, Open File 2009 11, 1:25,000 scale; and
- Greenwood, H.J., 2009. Descriptive notes to accompany Open File 2009-11, Geology of Salt Spring Island. BC Ministry of Energy, Mines and Petroleum Resources.

The general hydrogeology of Salt Spring Island is described in the following reports:

- Hodge, W.S., 1995. Groundwater Conditions on Salt Spring Island. BC Ministry of Environment, Lands and Parks; and
- Larocque, I., D.M. Allen and D. Kirste., 2015. The Hydrogeology of Salt Spring Island. A summary of research conducted by Simon Fraser University as part of a project “Risk Assessment Framework for Coastal Bedrock Aquifers”. January 2015.

Hodge (1995) delineated a bedrock aquifer system and three overburden aquifers on Salt Spring Island. His analysis identified Scott Point as an area where groundwater demand may be exceeding groundwater in storage, and predicted that in the future, concerns may be observed in the Ganges Harbour, Trincomali Channel, Long Harbour and Eleanor Point regions.

Larocque et al. (2015) conducted field studies and analyses to characterize a hydrogeological conceptual model for Salt Spring Island. Their study found that despite the varying rock types on the Island, the estimated hydraulic conductivities of the sedimentary and igneous rocks were similar. The study recognized the uncertainty in estimating recharge to the aquifers and referenced a broad range of recharge estimates based on a variety of methods.

Groundwater quality on Salt Spring Island is described in the following report:

- Lapcevic, P., A. Kingerlee, G. Bickerton and V. Carmichael, 2008. The geochemistry of groundwater on Salt Spring Island, British Columbia, Canada. GeoEdmonton, 2008.

Simon Fraser University, led by Dr. Diana Allen, has conducted numerous studies on Salt Spring Island and the Gulf Islands to characterize groundwater flow within the bedrock regime, together with the potential for salt water intrusion. Fractured groundwater flow in the Gulf Islands has also been examined by the Geological Survey of Canada:

- Klassen, J.K., and D.M. Allen, 2016. Risk of Salt Water Intrusion in Coastal Bedrock Aquifers: Gulf Islands, BC., 2016. An overview of the assessment of risk of saltwater intrusion in bedrock aquifers of the Gulf Islands completed as part of a study conducted by Simon Fraser University and BC Ministry of Forests, Lands and Natural Resource Operations as part of the "Risk Assessment Framework for Coastal Bedrock Aquifers". January 2016;
- Allen, D.M., D. Kirste, J. Klassen, I. Larocque and S. Foster., 2015. Research Monitoring Well on Salt Spring Island. A summary of the drilling, testing, and chemical/isotopic results for the Research Monitoring Well on Salt Spring Island for a study conducted by Simon Fraser University and BC Ministry of Forests, Lands and Natural Resource Operations as part of the "Risk Assessment Framework for Coastal Bedrock Aquifers". September 2015;
- Klassen, J., D.M. Allen and D. Kirste, 2014. Chemical Indicators of Saltwater Intrusion for the Gulf Islands, British Columbia. Final report submitted to the BC Ministry of Forests, Lands and Natural Resource Operations and BC Ministry of Environment. June 2014;
- Surrette, M., D.M. Allen and M. Journeay, 2008. Regional evaluation of hydraulic properties in variably fractured rock using a hydrostructural approach. Hydrogeology Journal 2008. 16: 11-30;
- Allen, D.M. and E. Liteanu, 2006. Long-term Dynamics of the Saltwater Freshwater Interface on the Gulf Islands, British Columbia, Canada. Submitted to the September 2006 Proceedings of SWIM-SWICA Conference, Cagliari, Italy;
- Journeay, M., S. Denny, D. Allen, C.B. Forster, R. Turner and M. Wei, 2004. Integrated Groundwater Resource Assessment of Fractured Bedrock Aquifers in the Gulf Islands, BC;
- Allen, D.M., Liteanu, E., Bishop, T.W., and Mackie, D.C., 2002. Determining the Hydraulic Properties of Fractured Bedrock Aquifers of the Gulf Islands, B.C. Final Report submitted to Al Kohut, BC Ministry of Water, Land and Air Protection. December 2002; and
- Allen, D.M and M. Suchy, 2001. Geochemical evolution of groundwater on Saturna Island, British Columbia. Canadian Journal or Earth Science 38: 1059-1080.

The methodology for groundwater budget analysis in BC and a preliminary regional assessment of groundwater demand in BC are described in the following documents:

- Hatfield Consultants, 2015. Development of a Framework for Licensing Existing Groundwater Users in West Coast Region, BC—Analysis of Current Groundwater Use. Prepared for the BC Ministry of Forests, Lands and Natural Resource Operations; and
- Hy-Geo Consulting, 2014. Preliminary Conceptual Models and Water Budget Methodologies for Aquifers in British Columbia. Submitted to British Columbia Ministry of Environment, March 2014.

Other recent groundwater budget analyses conducted in areas characterized by bedrock aquifers are listed below:

- Harris, M. and S. Usher, 2017. Preliminary Groundwater Budgets, Cobble Hill/Mill Bay Area, Vancouver Island, B.C., Water Science Series No. 2017-01;

- Burgess, R. and Allen, D.M., 2016. Groundwater Recharge Model for Gabriola Island—Final Report. Submitted to Regional District of Nanaimo, December 2016; and
- Hy-Geo Consulting, 2015. Mayne Island water budget in Development of Preliminary Water Budgets for Two Aquifer Areas in British Columbia. Submitted to British Columbia Ministry of Environment, August 2015.

Finally, previous water balance studies completed on Salt Spring Island are listed below:

- Kerr Wood Leidal Consulting Engineers, 2018. St. Mary Lake Watershed – Water Availability and Demand Climate Change Assessment 2017 Update. Prepared for North Salt Spring Waterworks District, 16 May 2018;
- Lam, P. 2010. Salt Spring Island Potable Water Supply and Demand Analysis. Prepared by SSI Water Council, 22 March 2010; and
- Burnett, L., B. Blecic and W. Van Bruggen, 1993. SaltSpring Island Water Allocation Plan. Regional Water Management Vancouver Island Region, Victoria, B.C. 30 November 1993.

4. PHASE 1—AQUIFER MAPPING AND CLASSIFICATION

Phase 1, consisting of the aquifer mapping and classification, was comprised of the following tasks, including:

- Data processing of the extensive data sources identified in Section 3.1, including significant processing of the provincial WELLS database;
- Analysis, 3D visualization and hydrostratigraphic modelling of processed data for hydrogeological interpretation;
- Delineation of new and revised overburden and bedrock aquifers;
- Estimation of hydraulic properties of the newly identified or revised aquifers; and
- Creation of GIS polygons and aquifer classification worksheets for the new and revised aquifers.

4.1 Data Processing

Within the study area, the provincial WELLS database contains 2667 well records, with 2165 well records containing lithological information in over 12000 individual intervals, 2200 estimates of raw well yields, and 570 measurements of depth to water. Lithological descriptions and general remarks are transcribed directly from water well records provided by the drillers and are highly variable in quality and level of detail. Significant pre-processing of data and standardization of lithological descriptors was required to prepare the well records for 3D visualization and interpretation. Data processing routines that were applied include:

- Removal of duplicate records and records missing critical data fields (i.e., depth);
- Standardization of units (feet to meters, USGPM to LPM);
- Keyword scripting of raw lithology fields into broad lithological classifications
- Coarse-grained sedimentary rock terms (sandstone, conglomerate):
    - fine-grained sedimentary rock terms (shale, siltstone, mudstone)
    - igneous rock terms (granite, volcanics, basalt)
    - relatively permeable unconsolidated sediment terms (sand, gravel)
    - relatively impermeable unconsolidated sediment terms (clay, silt, hardpan)
- Calculation of simplified specific capacity, using two methods:
    - well yields divided by the depth of the well
    - well yields divided by the height of the water column (where data were available)

- Calculation of approximate transmissivity and hydraulic conductivity using estimates of simplified specific capacity using formulas provided by Kasenov (2006);
- Keyword scripting of raw lithology and general drilling remarks fields for hydrogeological items of interest:
  - dry, artesian, or flowing well conditions
  - incidence of salt water or saline conditions
- Custom scripts to identify discrete "producing" fractures and zones for the 3D hydrostratigraphic model.

4.2 Data Analysis and 3D Hydrostratigraphic Modelling

Processed data from Section 3.1 was analyzed and used to create a 3D hydrostratigraphic visualization of Salt Spring Island to assist with aquifer mapping and interpretation. Figure 3 presents the 3D study area and ortho-imagery for Salt Spring Island along with topographic elevations. Historical aquifer mapping consisted of three bedrock aquifers and three unconsolidated aquifers. The three bedrock aquifers, previously updated in 2005, were delineated predominantly on topography while the three unconsolidated aquifers, previously updated in 2007, were delineated predominantly based on soil maps and the presence of thicker overburden deposits in local areas.

4.2.1 Hydrogeological / Geological Base Data

Data from the provincial water wells database (WELLS database), together with the geological mapping of Dr. Greenwood (Greenwood and Mihalnyuk, 2009) formed the basis of the hydrostratigraphic interpretation. Figure 4 presents the wellhead locations for the water wells on Salt Spring Island from the WELLS database and Figure 5 presents the bedrock geological mapping. Lithological descriptors contained within the WELLS database are based on records from drillers who utilize drilling methods that can limit high-quality lithological or structural classification. As the lithological descriptors are vague and highly variable, a simplified visual representation of the geology on Salt Spring Island was adopted based on those types of rock more readily identifiable via the water well records. These included the following groupings:

- Cretaceous Period Coarse-Grained Nanaimo Group Rocks (sandstones and conglomerates);
- Cretaceous Period Fine-Grained Nanaimo Group Rocks (siltstone, mudstone, and shale);
- Carboniferous to Permian Rocks (Sicker and Buttle Lake Groups) volcanic and meta-sedimentary rocks; and
- Intrusive Rocks (Salt Spring Intrusions, Mount Hall Gabbro Sills).

4.2.2 Water Well Log Standardization

Over 2600 water wells were contained within the WELLS database for Salt Spring Island. A review of the lithological descriptors in the WELLS database suggested a broad classification of lithologies into four main groupings:

- Descriptors associated with coarse-grained Nanaimo Group (sedimentary) rocks;
- Descriptors associated with fine-grained Nanaimo Group (sedimentary) rocks;
- Igneous / volcanic / metamorphic rock descriptors; and
- Descriptors associated with overburden and unconsolidated deposits.

Iterative, nested keyword scripting together with manual QA/QC was utilized to standardize the borehole logs and results are presented in Figure 6. Note that well log standardization was only conducted on logs with amenable lithological descriptions and only lithological descriptions that were relatively unambiguous were carried forward for comparison to surficial geological mapping.

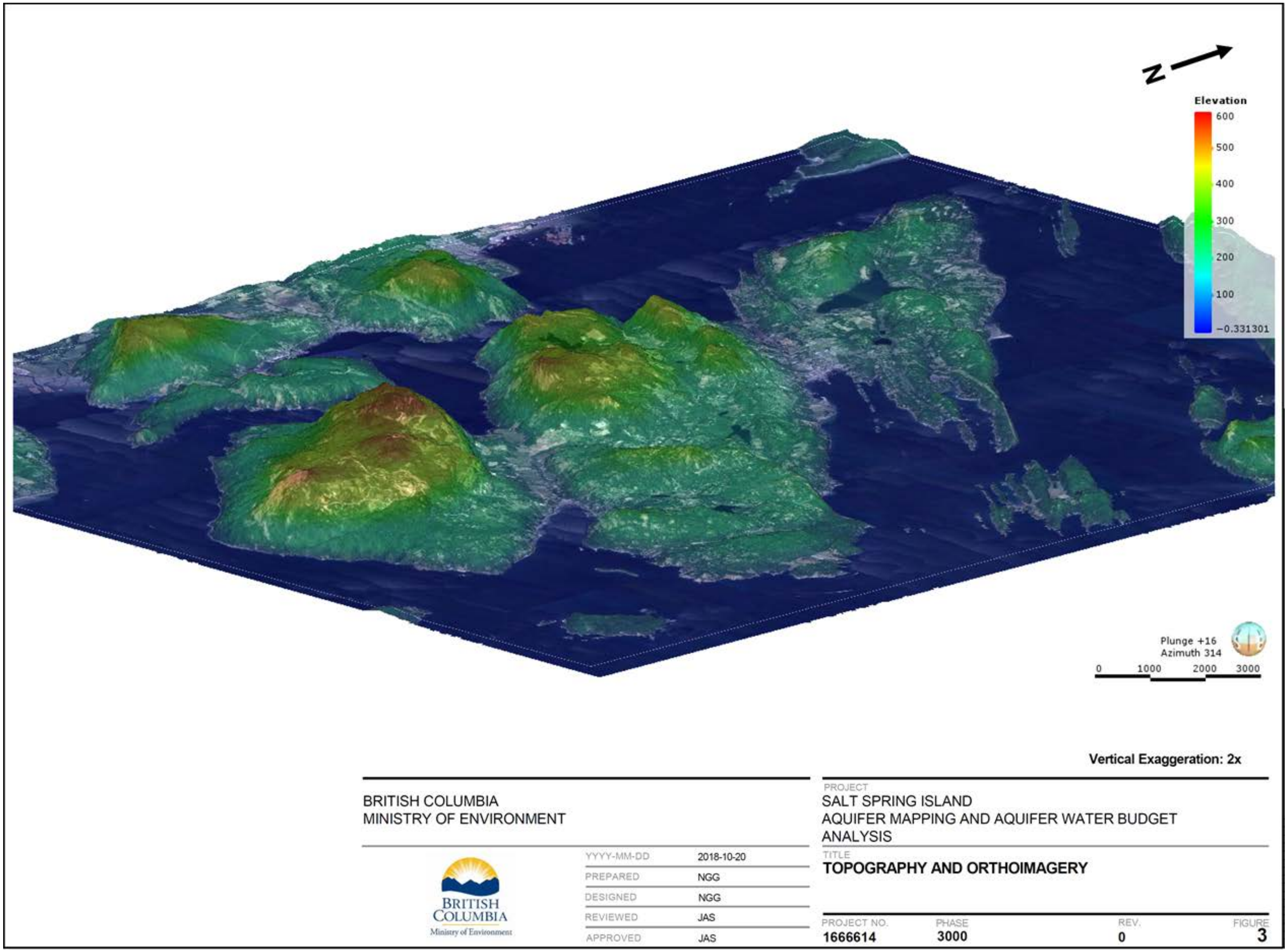

Figure 3: Ortho-image of Salt Spring Island topography.

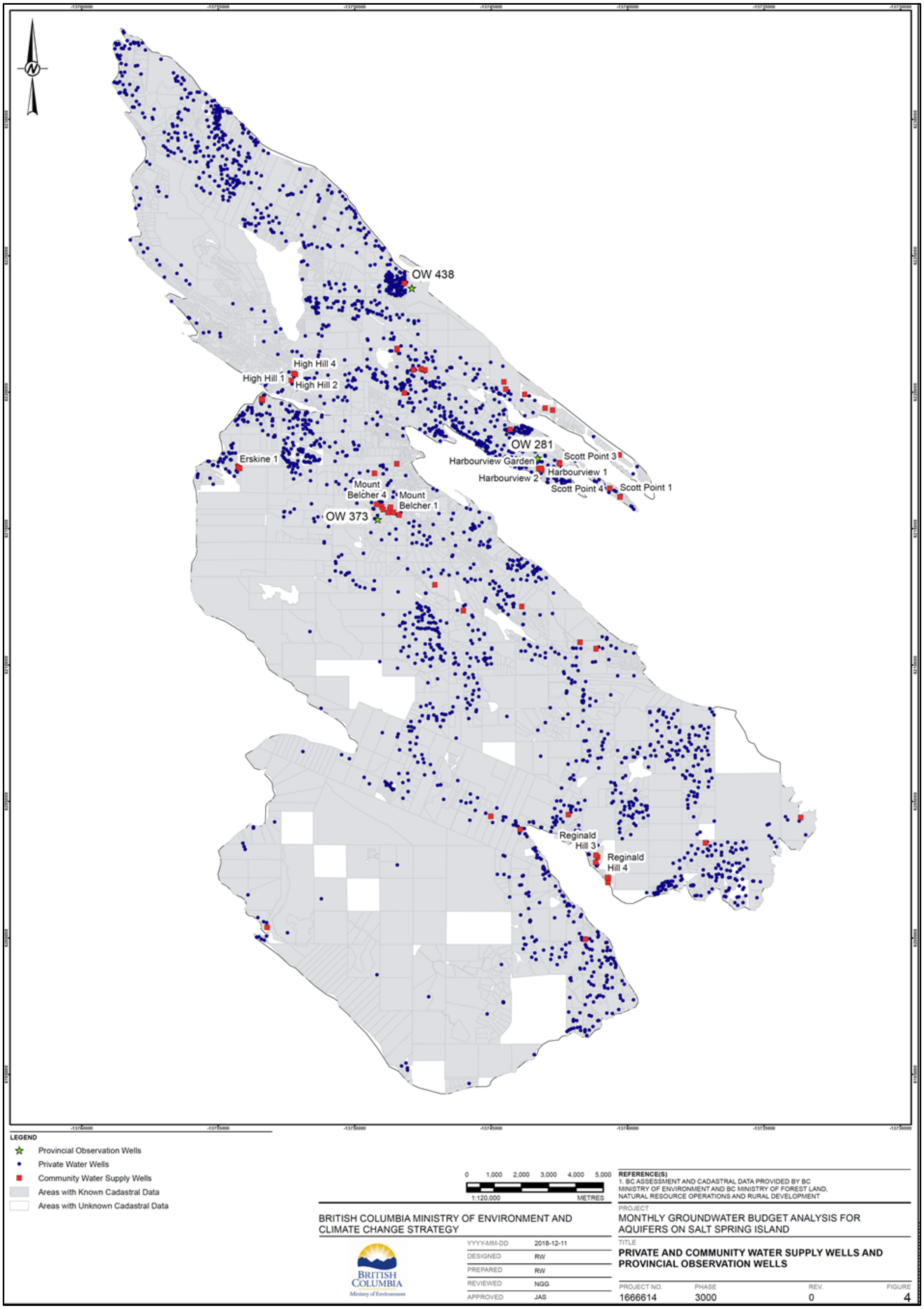

Figure 4: Private and community water supply wells and provincial observation wells.

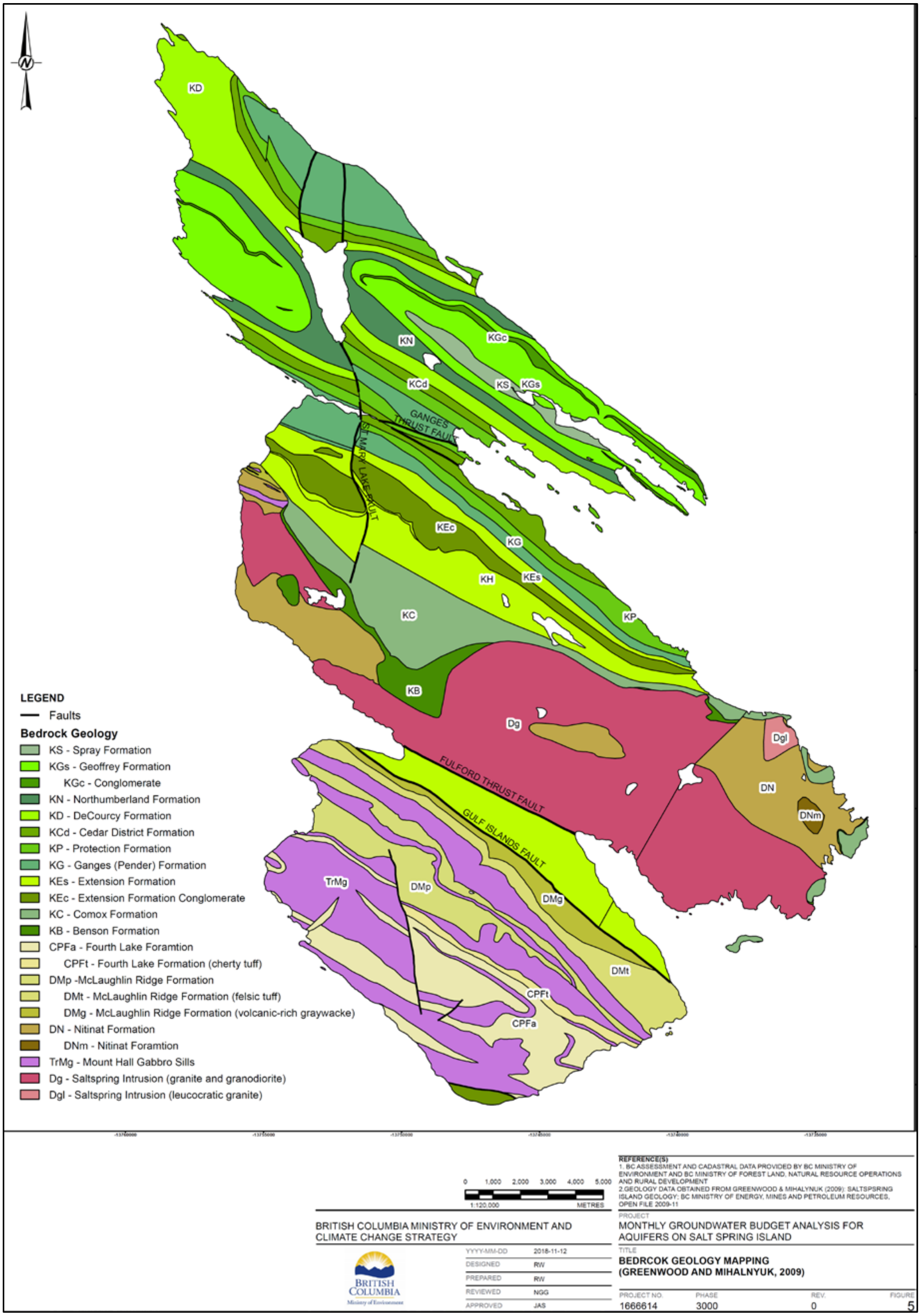

Figure 5: Bedrock geology of Salt Spring Island mapped by Greenwood and Mihalnyuk (2009).

The standardization process to derive simplified groupings was quite successful and general agreement with the geological mapping was obtained. Also of note, is that many of the water well records have a high degree of uncertainty in their lateral coordinates, often owing to the age of the record and means of collection. Isolated intervals of a lithology in an unexpected area were not considered relevant due to spatial uncertainty and interbedded nature of many of the formations unless large clusters of them disagreed with surficial mapping.

4.2.3 Well Yield and Hydraulic Conductivity Analysis

Raw well yields reported from the time of drilling are subject to inaccuracy and error due to, amongst other things, the short term and variable nature of yield testing and relatively poor documentation of test run times. The raw well yields were plotted spatially to assess the potential for correlation between high yields and lithologies (Figure 7) as well as analyzed statistically by formation yield. Well yields and water levels were utilized to estimate simplified specific capacity, transmissivity, and eventually, hydraulic conductivity using the method of Kasenov (2006), assuming a drawdown equal to that of the water column in the well. Hydraulic conductivity values were assumed to be applicable over the entire depth of the well due to the tendency for deep open hole or long screened completions for the domestic wells on Salt Spring Island. Estimated hydraulic conductivity values are presented in Figure 8.

4.2.4 Identification of Saline, Artesian or Dry Conditions

Custom programming scripts were created to identify and flag incidences or remarks of saline, artesian or dry conditions either within the lithology field or the general remarks field of the WELLS database. Results for the reports of saline conditions are presented in Figure 9, with the majority of incidences of saline occurrence being located on North Salt Spring Island. Isolated wells reported saline conditions near St Mary Lake along the St Mary fault. The majority of incidences of artesian conditions are located on the Central and South of Salt Spring Island. Reports of artesian conditions are presented in Figure 10. All results were manually QA/QC'd and incidences visualized over the entire length of the borehole, even though well records may document particular fractures or depths where water is saline.

4.2.5 Construction of 3D Geological Volumes

Three dimensional geological volumes for the Nanaimo Group formations and broader lithological groupings were constructed in Leapfrog using primarily the inferred dip and dip direction from Greenwood and Mihalnyuk's (2009) surficial geological mapping and interpreted cross-sections. Results from the lithological standardization were utilized to query against the interpretation but no major deviances (large clusters of different lithologies) were identified. If minor deviances were identified, it remained unclear whether they were as a result of poor lithological descriptors or poor spatial accuracy so a revision to the geological model was not considered to be necessary.

4.2.6 Interpretation of Groundwater Level and Identification of Producing Fractures

Island-wide groundwater hydraulic heads were obtained from the WELLS database and represent the groundwater level at the time of drilling, which is a source of considerable uncertainty. The hydraulic head within a water well is often a combination of the heads in each producing fracture that the well intersects, making the delineation of a piezometric surface in a fractured bedrock setting more difficult. Smoothing and interpolative techniques in Leapfrog were utilized to obtain a reasonable interpretation but this head distribution is considered to be inferred and subject to uncertainty. Due to the often lightly-fractured nature of Salt Spring Island rock, many of the records in the WELLS database contain detailed information and depths where a producing fracture is intersected. Again, custom scripting was utilized to identify the depths associated with an identified producing feature (where available). These were amalgamated and processed. This could be used to identify likely depths to a water bearing feature or for future groundwater investigations.

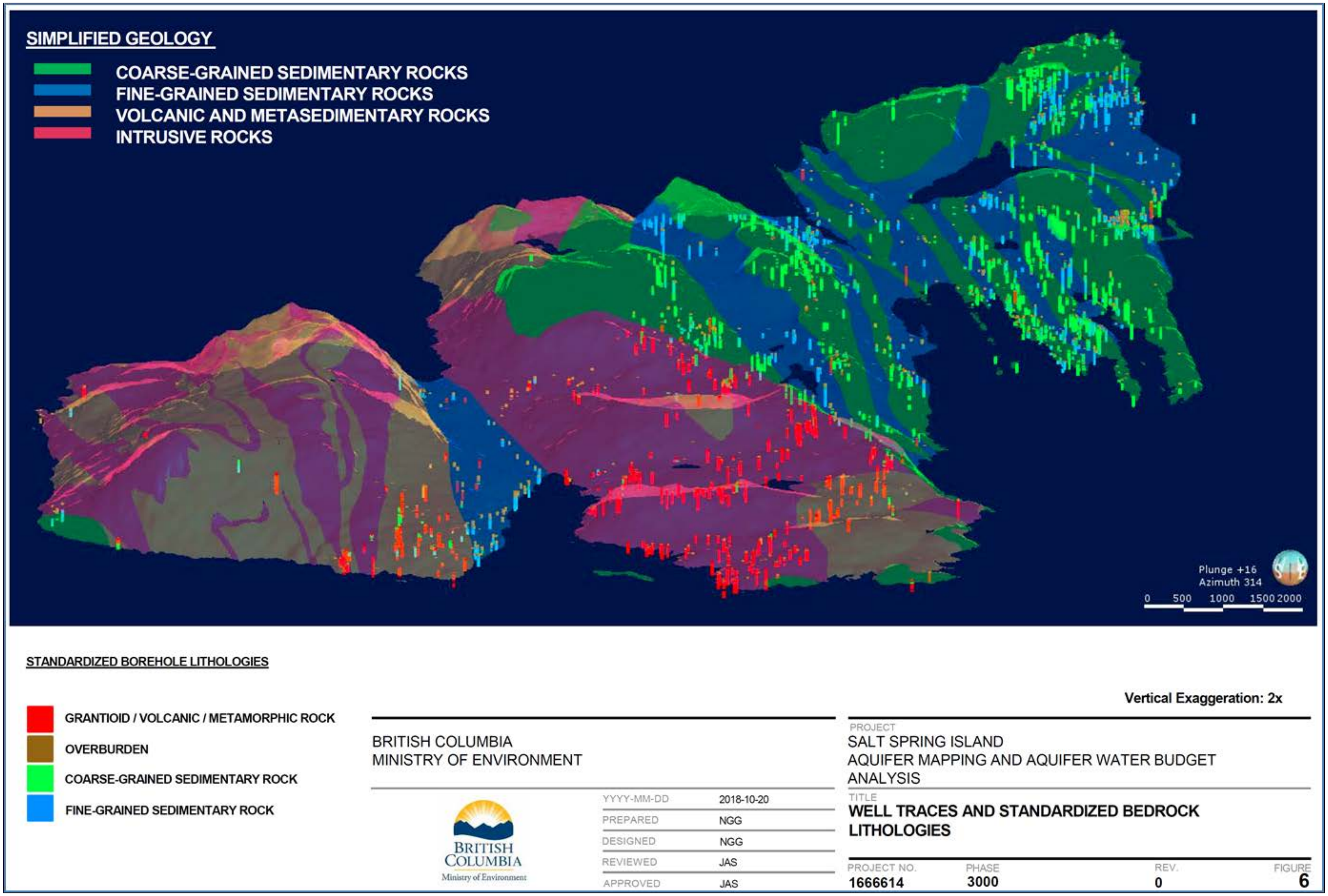

Figure 6: Standardized bedrock lithology and well traces.

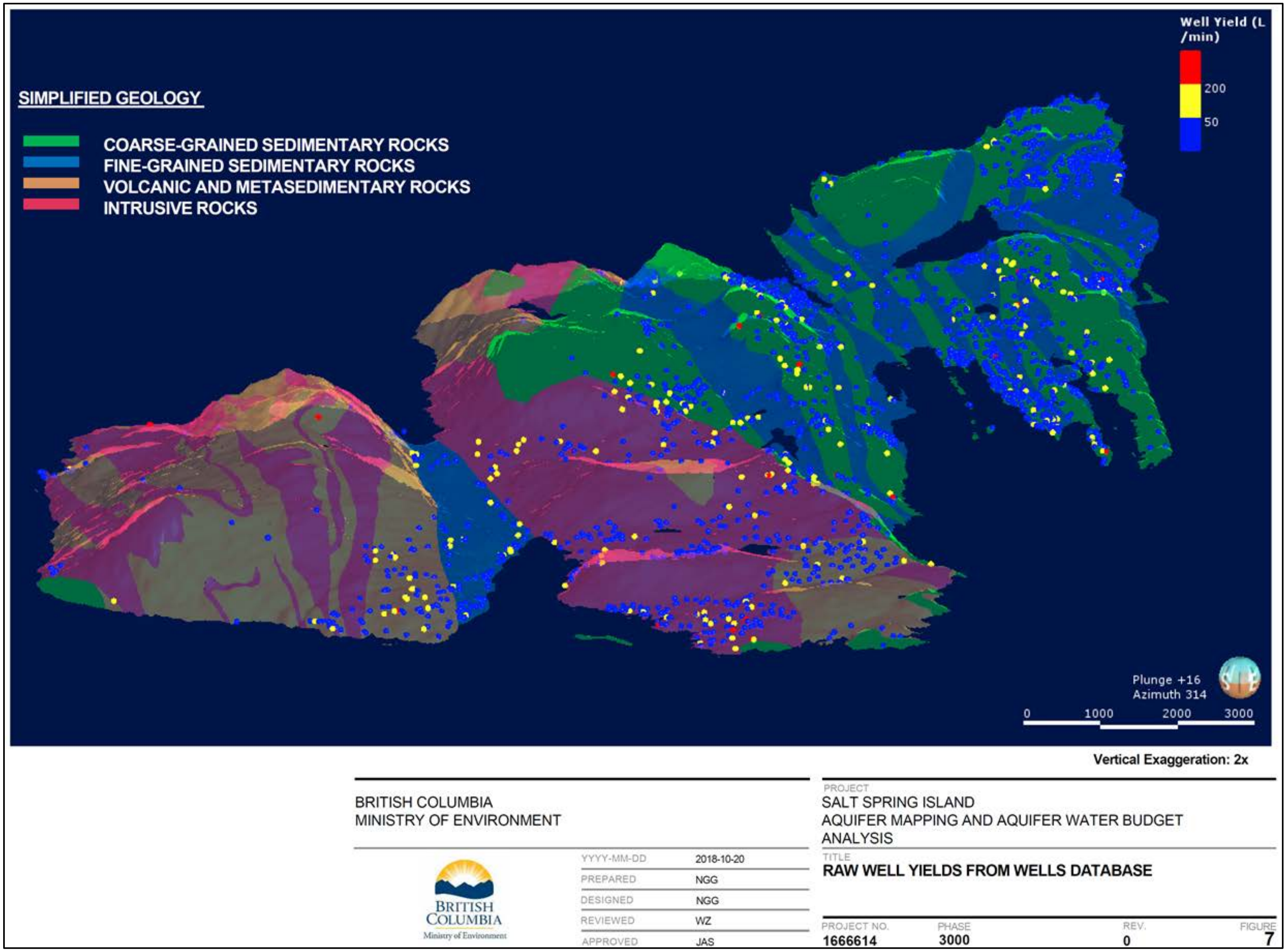

Figure 7: Comparison of reported well yields from the WELLS database and simplified bedrock geology on Salt Spring Island.

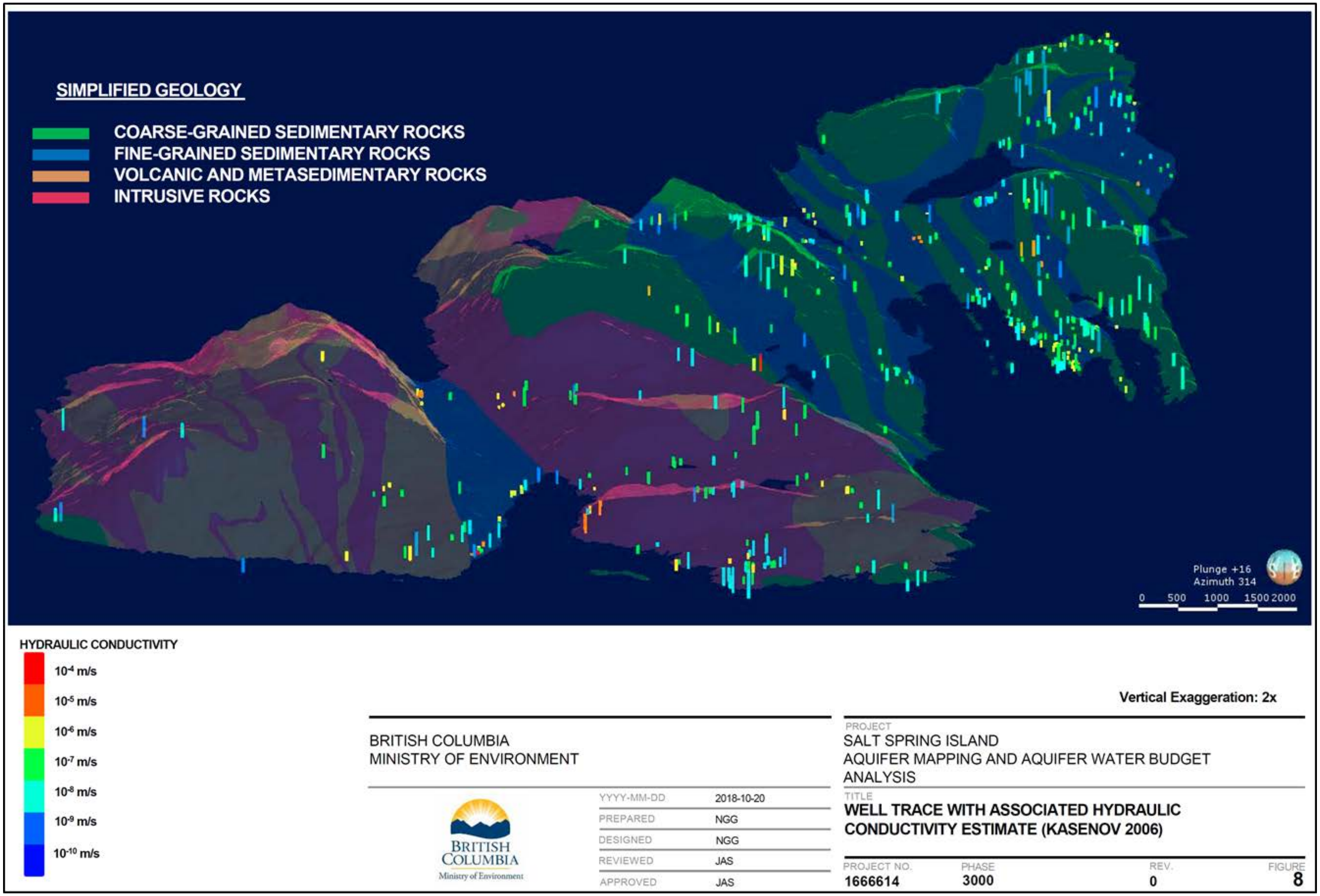

Figure 8: Comparison of estimated hydraulic conductivity and simplified bedrock geology on Salt Spring Island.

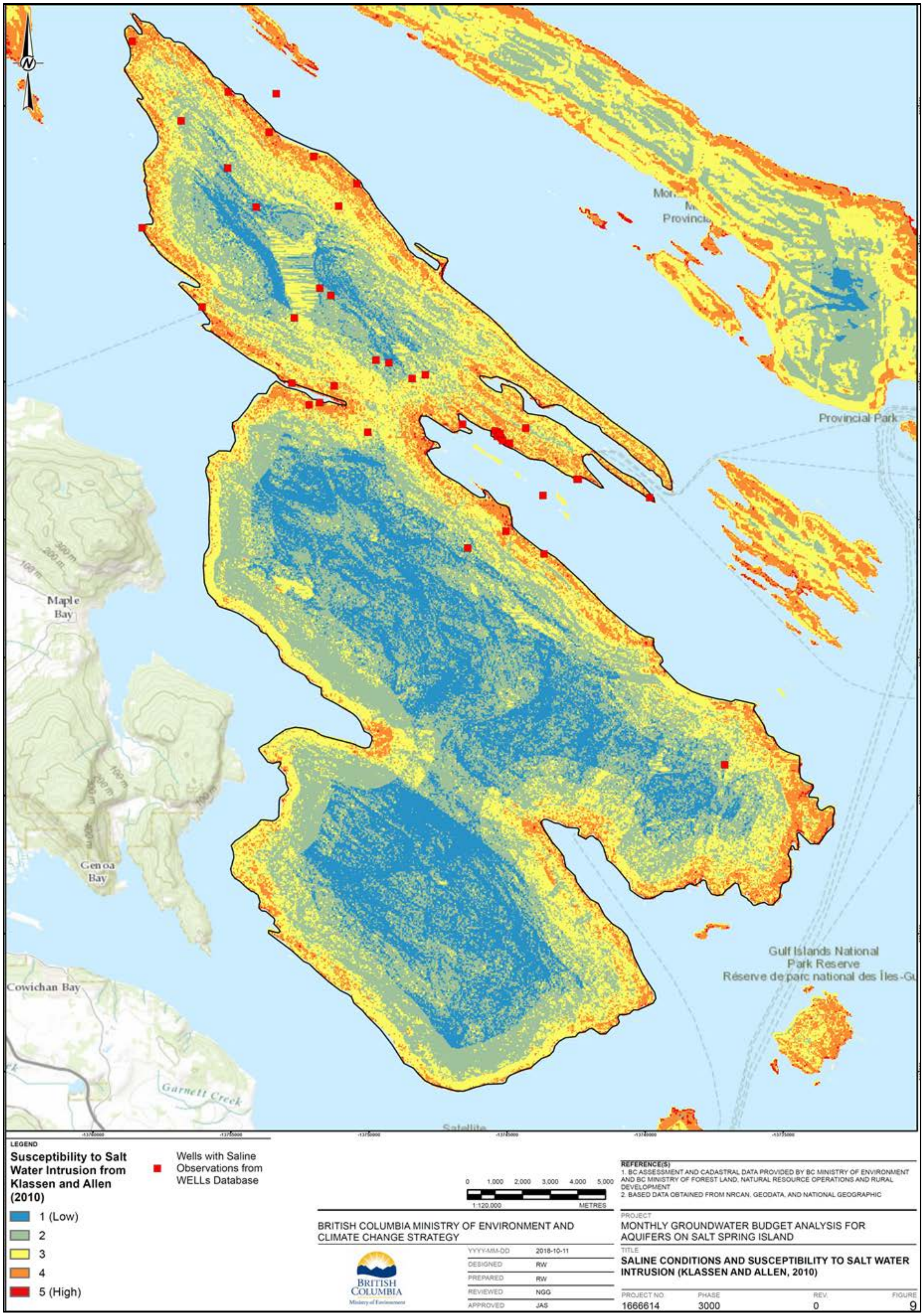

Figure 9: Susceptibility to salt water intrusion and location of wells with saline observations.

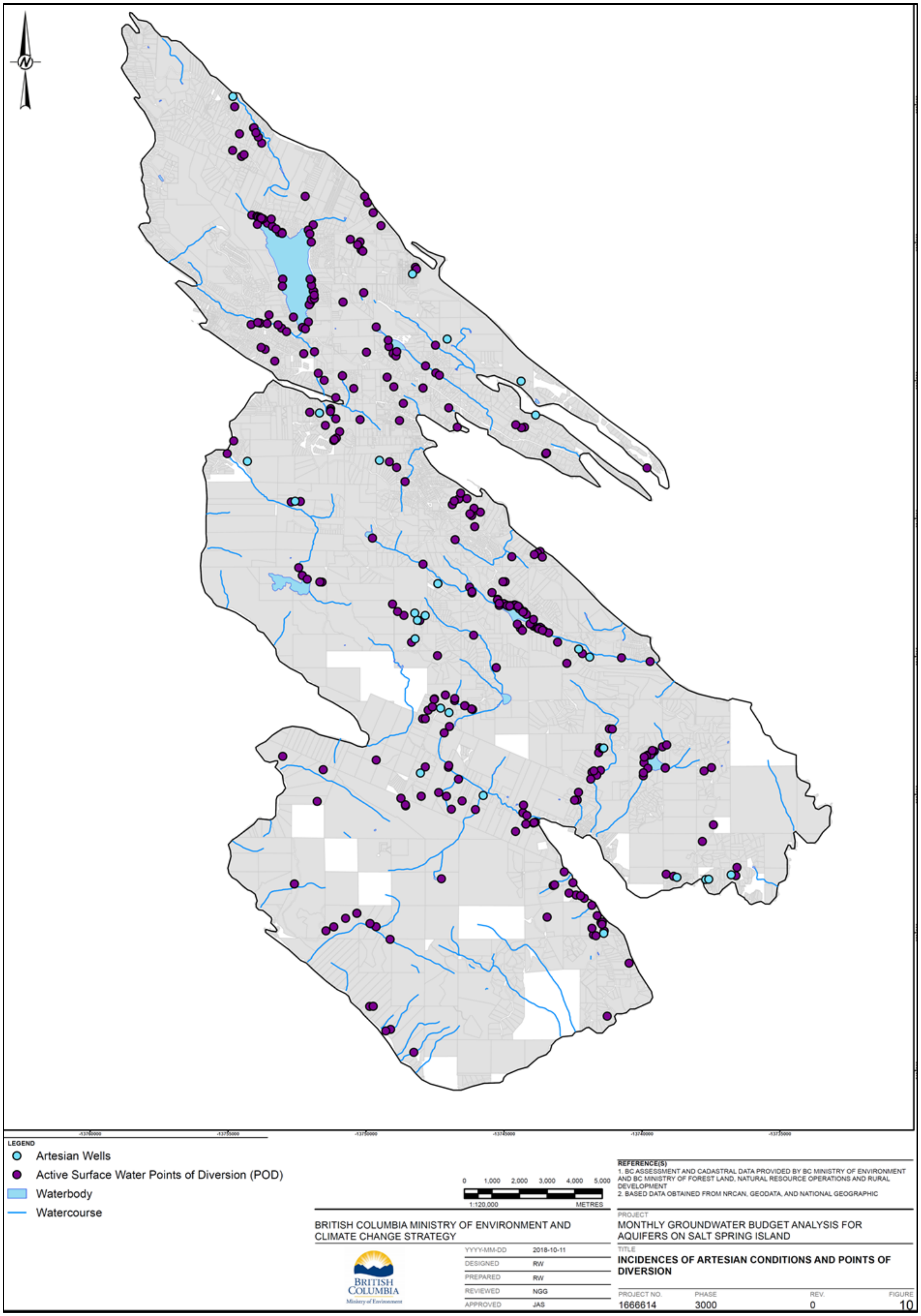

Figure 10: Location of artesian wells and active surface water points of diversion.

4.3 Aquifer Delineation

Based on the results of the data analysis, revisions to the historical aquifer boundaries as well as two new aquifers are proposed for Salt Spring Island. The lateral boundaries of the updated bedrock are presented in Figure 11 whereas lateral boundaries of the updated unconsolidated aquifers are presented in Figure 12. GIS polygons, mapped to provincial standards are provided with this report. Detailed descriptions of the revised and new aquifers are provided in their associated aquifer fact sheets (provided with this report) and a summary of the aquifers and the key rationale for the delineation is described in Table 1 and the following subsections.

Table 1: Summary of revised and new Salt Spring Island aquifers.

Aquifer Type	Previous Aquifer	Revised / New Aquifer	Aquifer Sub Type	Comments
Bedrock Aquifers	North Salt Spring Island Aquifer (AQ 721)	North Salt Spring Island Aquifer (AQ 721)	5a	Similar extent as previous; comprises Cretaceous Nanaimo Group rocks separated from those to the south by the Ganges Thrust Fault.
	Ganges / Central Salt Spring Island Aquifer (AQ 722)	**North Central Salt Spring Aquifer (AQ 722)**	5a	Comprises the Cretaceous Nanaimo Group rocks on North Central Salt Spring Island.
		South Central Salt Spring Aquifer (AQ 1147)	6b	Comprises the Salt Spring Intrusions and Devonian Sicker Group rocks on South Central Salt Spring Island.
	Mt Tuam / South Salt Spring Island Aquifer (AQ 723)	South Salt Spring Island Aquifer (AQ 723)	6b	Includes all of South Salt Spring Island north to the Fulford Thrust and contact with Salt Spring Intrusions.
Unconsolidated Aquifers	Ganges Harbour Aquifer (AQ 156)	Ganges Harbour Aquifer (AQ 156)	4a	Increased extents south of Ganges Harbour and reduced extents along the north of the harbour.
	Fulford Harbour Aquifer (AQ 157)	Fulford Harbour Aquifer (AQ 157)	4a	Increased extent on the south and west of Fulford Harbour and decreased extents along the north of the harbour.
	Walker Hook Aquifer (AQ 155)	Walker Hook Aquifer (AQ 155)	4b	Similar extents as previous though decreased prominence to the northeast.
		Burgoyne Aquifer (AQ 1148)	3a	Small, newly-identified, sand and gravel aquifer located near where Fulford Creek descends into the Fulford Valley.

Bold text—new aquifer.
Aquifer Sub-Type based on Wei et al. (2009).

Figure 11: Lateral extent of revised bedrock aquifers on Salt Spring Island.

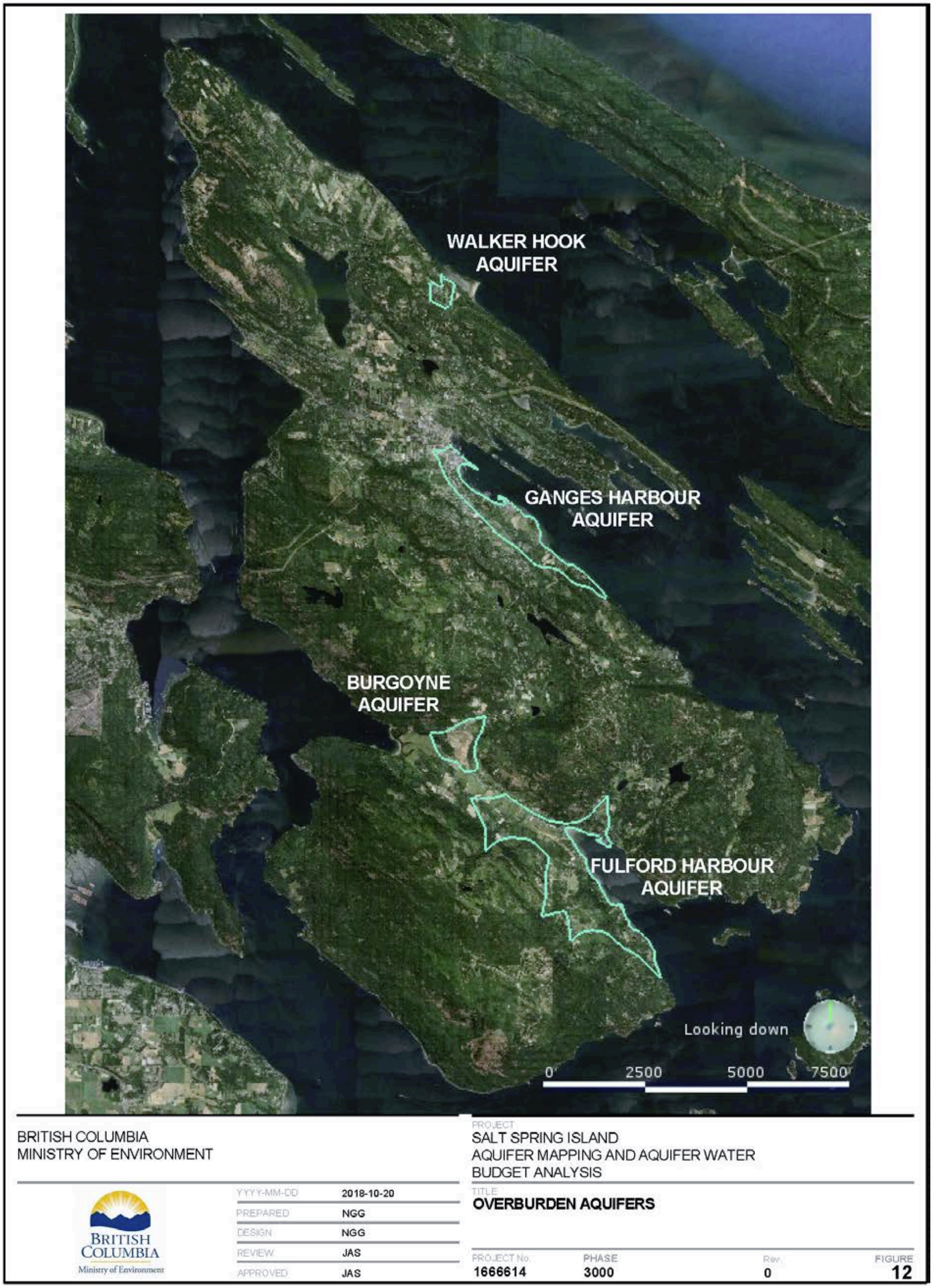

Figure 12: Lateral extent of revised unconsolidated aquifers on Salt Spring Island.

4.3.1 *Bedrock Aquifers*

Key criteria for assessment and delineation of the bedrock aquifers include an analysis of the hydraulic properties of the differing rock types and formations, geological orientation and structure (folding, deformation and weathering), and an assessment of the influence of geological structures (i.e., faults, contacts) on groundwater movement. Bedrock aquifer locations and outlines (GIS polygons) are presented in Figure 11. Detailed aquifer descriptions are provided in the aquifer fact sheets.

- North Salt Spring Island Aquifer: The extent of this aquifer is similar to its previous extent. The delineation was based on the topographic low along the Ganges Valley coincident with the northeast dipping Ganges Thrust Fault, which acts as a hydraulic divide between similar Nanaimo Group (sedimentary) rocks on Central Salt Spring Island. Hydraulic properties of the different Nanaimo Group (sedimentary) rocks, based on available data, do not differ substantially (Allen et al. 2002, Larocque et al., 2015, this study) and the alternating coarse-grained / fine-grained formations together with the complex folding make delineation of separate aquifers based solely on lithology impractical. The St. Mary Lake Fault expresses itself as a spring on the north of Booth Inlet but the lack of hydraulic conductivity information within or in close proximity to the fault means that a separate aquifer based on a hydrostructural domain is not warranted or supported at this time. Formation contacts (Ganges, Protection Formation, Cedar District, DeCourcy, Northumberland, Geoffrey and Spray Formations) may have a higher likelihood of greater hydraulic conductivity;
- North Central Salt Spring Island Aquifer: The previous Ganges / Central Salt Spring Island Aquifer has been subdivided on the basis of lithology as well as differing hydraulic properties and likely hydrostructural controls. The boundary between the two aquifers coincides with the boundary between the Nanaimo Group (sedimentary) rocks to the north and the intrusive rocks to the south. The hydraulic properties of the Nanaimo Group rocks (Benson, Comox, Haslam, Extension, Ganges, Protection and Cedar District Formations) in the north-central portion of Salt Spring Island have similar hydraulic properties as those in the North Salt Spring Aquifer with the exception that there is a greater proportion of conglomerate rock, which has a higher likelihood of having greater hydraulic conductivity;
- South Central Salt Spring Island Aquifer: The granite and granodiorite of the Salt Spring Intrusions and massive and fragmental volcanic rocks of the Nitinat Formation are igneous in nature and hydrogeological controls are likely to differ from the layered, sedimentary rock of the north-central portion of the island. The South-Central Salt Spring Island is delineated along its southern margin by the Fulford Thrust Fault and the contact of the Salt Spring Intrusions with interpreted fine-grained Nanaimo Group (sedimentary) rocks underlying the Fulford Valley. The north-eastern boundary of the aquifer is delineated along the unconformity between the Salt Spring Intrusive Suite / Nitinat Formation (igneous rocks) and the overlying Cretaceous Nanaimo Group (sedimentary) rocks (predominantly Benson and Comox Formations); and
- South Salt Spring Island Aquifer: The South Salt Spring Island Aquifer is comprised of Devonian and Carboniferous rocks of the McLaughlin Ridge and Fourth Lake Formations (volcanic and meta-sedimentary rocks), which have been subsequently intruded by the Mount Hall Gabbroic Sills (intrusive igneous rocks). The south portion of Salt Spring Island has relatively few wells and data points as compared to the remainder of the Island and the lack of sufficient hydrogeological data makes a subdivision of the southern portion of the Island into a number of aquifers impractical. The South Salt Spring Island Aquifer has been delineated on its northeastern boundary by the topographic low corresponding to the likely position of the Fulford Thrust Fault and the inferred contact with the granitic Salt Spring Intrusions (igneous rocks).

4.3.2 Unconsolidated Aquifers

Key criteria for the assessment and delineation of the unconsolidated aquifers include presence of a sizable thickness of unconsolidated permeable material, evidence (or likelihood) that the permeable material is saturated, and that the permeable material is of sufficient lateral extent to be considered an aquifer. Due to the general low permeability of the bedrock on Salt Spring Island, the delineation of the boundary of the unconsolidated aquifers was conducted liberally to include lower permeability sediments (i.e., logged as hardpan or clay) if wells were completed within it or if they are within reasonable local proximity to a permeable unit. This runs counter to aquifer mapping and delineation conducted in areas with thick unconsolidated deposits such as the Fraser Valley but reflects the local hydrogeology as the soil descriptors from the drillers are generally poorer due to the drilling methods utilized on the Island and the fact that a small volume of water can be a suitable groundwater resource on the Island. The properties and composition of the unconsolidated aquifers are expected to vary significantly over their extent, with their relative importance and reliability as a groundwater supply reflected in the fact that most groundwater wells within the unconsolidated aquifer boundaries are still completed in the underlying bedrock aquifers.

Revised unconsolidated aquifers are largely consistent with their previous interpretation with minor adjustments and revisions to the lateral extents. A new unconsolidated aquifer, the Burgoyne Aquifer, was identified near where Fulford Creek decreases in elevation and enters the Fulford valley. Unconsolidated aquifer locations and outlines (GIS polygons) are presented in Figure 12. Detailed aquifer descriptions are provided in the associated aquifer fact sheets.

- <u>Walker Hook Aquifer:</u> The Walker Hook Aquifer is a small unconsolidated aquifer with an area of approximately 0.3 km^2 and comprises a northeast-dipping body of sediments located predominantly above sea level near the northeast shore of Salt Spring Island. Due to the small number of water wells and variable soil descriptions, the stratigraphy and lateral extent of the permeable sand and gravel is poorly understood and the aquifer is mapped to include any fine grained sediments of appreciable thickness that exist within the unconsolidated deposit;
- <u>Ganges Harbour Aquifer:</u> The Ganges Harbour Aquifer is a relatively small, elongate, unconsolidated aquifer located to the south-southwest of Ganges Harbour and oriented northwest-southeast. Due to the small number of water wells and variable soil descriptions, the stratigraphy and lateral extent of the permeable sand and gravel is poorly understood and the aquifer is mapped to include any fine grained sediments of appreciable thickness that exist within the unconsolidated deposit. In general, the aquifer is poorly constrained by available data and the aquifer may be more or less extensive on its margins and throughout, with variable degrees of saturation;
- <u>Fulford Harbour Aquifer:</u> The Fulford Harbour Aquifer is a diverse agglomeration of unconsolidated deposits, predominantly sand and gravel, that underlie the Fulford valley and southern slopes. The aquifer is delineated based on lithological data from water well records, topography, geomorphology, and surficial soil mapping. Due to limited and variable soil descriptions, the aquifer boundaries include any area with sizable thickness of unconsolidated material, including fine-grained, low-permeability sediments. To the south and west, the aquifer roughly follows topography and assumes the presence of permeable materials in alluvial fan-type deposits where surface water features have eroded valley features. The boundary to the northwest is poorly constrained and the aquifer may continue laterally along the orientation of the Fulford Valley. Similarly, the extents near Fulford Harbour are poorly constrained and subject to uncertainty based on bedrock control and topography; and

- Burgoyne Aquifer - The Burgoyne aquifer is a small, unconfined, fan-type sand and gravel aquifer associated with Fulford Creek as it descends from higher topographic elevations downstream of Ford Lake to the lowlands of the Fulford Valley. The aquifer is bounded locally to the northwest and southeast by the bedrock valley walls, to the northeast where the deposits thin near the apex of the fan and higher elevations, and distally to the southwest near the lows of the Fulford Valley. The aquifer is positioned at a higher elevation than the Fulford Harbour Aquifer and interpreted to be a separate permeable unit. However, uncertainty associated with the boundary of Fulford Harbour Aquifer and thicknesses of the distal deposits of the Burgoyne Aquifer mean that some degree of hydraulic connectivity may exist between the two aquifers.

4.4 Aquifer Properties

Information from the WELLS database was used to estimate hydraulic properties for the revised aquifers. Table 2 presents the hydrogeological summary data. Hydraulic conductivity data for unconsolidated aquifers, where presented, are expected to vary strongly across the aquifer due to the variability of sediments and the inclusion of finer-grained deposits within the aquifer.

Table 2: Summary of aquifer hydraulic conductivity using Kasenov (2006).

Aquifer Type	Aquifer	Total Number of Wells	Geometric Mean of Hydraulic Conductivity (m/s)
Bedrock Aquifers	North Salt Spring Island Aquifer	184	2×10^{-7}
	North-Central Salt Spring Island Aquifer	60	2×10^{-7}
	South-Central Salt Spring Island Aquifer	62	2×10^{-7}
	South Salt Spring Island Aquifer	20	1×10^{-7}
Unconsolidated Aquifers	Ganges Harbour Aquifer	Insufficient Data	N/A
	Fulford Harbour Aquifer	5	7×10^{-6}
	Walker Hook Aquifer	Insufficient Data	N/A
	Burgoyne Aquifer	1	1×10^{-5}

4.4.1 Bedrock Aquifers

Bulk hydraulic conductivities of bedrock aquifers on Salt Spring Island can be approximately characterized as a lognormal probability distribution, with the majority of completed wells having a low yield (<0.3 L/s / 5 USGPM) but with a small amount exhibiting much higher yields if the well is completed on a favourable structure in the rock. A comparison of well yields within the Nanaimo Group suggests that a higher percentage of high yielding wells are completed in the coarser-grained sandstone formations than in the finer-grained shale formations. Geometric means of hydraulic conductivity estimated using the simplified specific capacity method described by Kasenov (2006) are broadly consistent (approximately 10^{-7} m/s) with hydraulic conductivities derived from national water well databases from other recently-glaciated, crystalline rock terrains (Banks et al., 2010). The method of Kasenov estimates the simplified specific capacity by dividing the well yield by the saturated thickness of the well and uses an empirical equation to calculate transmissivity based on simple assumptions of hydrogeologic parameters. Hydraulic conductivities for Nanaimo Group rocks estimated from previous studies are provided for comparative purposes. Other lithologies (Sicker Group, Buttle Lake Group, and various intrusive rocks) were not included due to lack of available studies and information in these lithologies.

Table 3: Average bedrock hydraulic conductivities from previous hydrogeological studies.

Location and Study Reference	**Average Hydraulic Conductivity (m/s)**	
	Coarse Grained Nanaimo Group Rocks	**Fine Grained Nanaimo Group Rocks**
Salt Spring Island (Larocque et al., 2015)	2×10^{-7}	4×10^{-7}
Gulf Islands (Allen et al., 2002)	3×10^{-7}	5×10^{-7}

The estimated hydraulic conductivities from other hydrogeological investigations (Table 3) are provided as average hydraulic conductivity as opposed to the geometric mean and will display a degree of bias. However, values do not show a high degree of differentiation between rock types, indicating homogeneity at this scale and reinforcing the influence of structure, i.e. secondary porosity, on the hydraulic conductivity. Of note is the inherent challenge in designing and conducting a pumping test to test the bulk hydraulic conductivity of specific lithologies while achieving a reasonable representative elementary volume (REV) given the inferred structural influence.

4.4.2 Unconsolidated Aquifers

There is more limited information on the hydraulic conductivity of the unconsolidated aquifers due to the relatively small number of well completions and hydrogeological investigations within the unconsolidated aquifers. As a result, the hydraulic conductivity of the aquifer at any one particular location is expected to have a large range. The geometric mean of the five available hydraulic conductivity values for the Fulford Harbour Aquifer is 7×10^{-6} m/s, while the one available hydraulic conductivity value for the Burgoyne Aquifer is 1×10^{-5} m/s. No hydraulic conductivity information is available for the Walker Hook and Ganges Harbour Aquifers (Table 4).

In the areas where the unconsolidated aquifers have been mapped, most drillers chose to complete wells in the underlying bedrock aquifers rather than the overlying surficial material. This, combined with the highly variable nature of the surficial material and its glacial origin, suggests that the unconsolidated aquifers are characterized by a relatively low hydraulic conductivity and may not be particularly productive. As such, representative hydraulic conductivities of the unconsolidated aquifers are inferred to be lower than those referenced above. For the purposes of the groundwater budget analysis, hydraulic conductivities on the order of 10^{-6} m/s were assumed for the overburden aquifers, with values varied slightly for the individual aquifers to close the water balance. These values are representative hydraulic conductivities for silty sand reported by Freeze and Cherry (1979).

Table 4: Inferred hydraulic conductivities for unconsolidated aquifers.

Aquifer	**Geometric Mean Hydraulic Conductivity from Limited Tests (m/s)**	**Representative Value of Hydraulic Conductivity used for Groundwater Budgeting (m/s)**
Walker Hook Aquifer	NA	8×10^{-6}
Ganges Harbour Aquifer	NA	4×10^{-6}
Fulford Harbour Aquifer	7×10^{-6}	1×10^{-6}
Burgoyne Aquifer	1×10^{-5}	5×10^{-6}

4.5 GIS Aquifer Polygons and Aquifer Classification Worksheets

GIS polygons and Aquifer Classification Worksheets were generated according to provincial standards for the new and revised aquifers on Salt Spring Island.

5. PHASE 2—MONTHLY AQUIFER GROUNDWATER BUDGET ANALYSIS

Phase 2, consisting of the monthly aquifer groundwater budget analysis, was comprised of the following tasks:

- Data analysis and study area characterization using the meteorological, climatological, hydrogeological, and hydrometric data for Salt Spring Island, including implications for their representation in the monthly groundwater budgets;
- Characterization of the conceptual hydrogeological model for the Island and parameterization strategy for the major aquifer groundwater budget terms based on the results of the data analysis;
- Monthly aquifer groundwater budget analyses for the Salt Spring Island aquifers;
- Scenario analyses (wet and dry years), climate change scenarios, and sensitivity analyses for the monthly groundwater budget analyses; and
- Estimation and assessment of groundwater availability.

5.1 General Formulation of Groundwater Budget Equations

The general formulation of the groundwater budget equations (Hy-Geo Consulting, 2014) for the bedrock and unconsolidated aquifers present on Salt Spring Island are presented and described in the subsections below.

5.1.1 General Formulation of Groundwater Budget Equations

The bedrock aquifers on Salt Spring Island are characterized as both Type 5a and Type 6b aquifers. The formulation of the groundwater budget equations for these are as follows:

Type 5a Aquifers—Fractured sedimentary rock aquifers (North Salt Spring Island and North-Central Salt Spring Island Aquifers)

$$P + Q^{SW}_{in} + Q^{IRRreturn}_{in} = R + ET + \Delta S^{GW} + \Delta S^{SWlakes} + Q^{SW}_{out} + Q^{GWpump}_{out} + Q^{SWpump}_{out} + Q^{GW}_{out} \quad \text{(Eq. 1)}$$

Type 6b Aquifers—Crystalline granitic, metamorphic, meta-sedimentary, meta-volcanic and volcanic rock aquifers (South-Central Salt Spring Island and South Salt Spring Island Aquifers)

$$P + Q^{SW}_{in} + Q^{GW}_{in} + Q^{IRRreturn}_{in} = R + ET + \Delta S^{GW} + \Delta S^{SWlakes} + Q^{SW}_{out} + Q^{GWpump}_{out} + Q^{SWpump}_{out} + Q^{GW}_{out} \quad \text{(Eq. 2)}$$

Where:

P = precipitation (rain and snow)

ET = evapotranspiration

Q^{SW}_{in} = surface water inflow

Q^{SW}_{out} = surface water outflow

Q^{GW}_{in} = groundwater inflow

Q^{GW}_{out} = groundwater outflow

R = groundwater recharge

ΔS^{SW} = change in surface water storage

ΔS^{GW} = change in groundwater storage

$Q^{IRReturn}_{in}$ = irrigation / septic return flow

Q^{SWpump}_{out} = surface water pumping

Q^{GWpump}_{out} = groundwater pumping

5.1.2 Unconsolidated Aquifers

The unconsolidated aquifers on Salt Spring Island are characterized as Type 3, Type 4a, and Type 4b aquifers. As described in Section 4.3.2 and Section 4.4.2, these aquifers have limited information, a limited number of well completions, and an anticipated high degree of variability and are not expected to be usable as a reliable, long-term groundwater supply. Due to the limitations of the available information, the groundwater budgets were highly simplified as compared to the general formulation of the groundwater budget equation. The formulation of the general groundwater budget equations for these aquifer types are as follows:

Type 3 Aquifers—Predominantly unconfined alluvial fan, colluvial sand and gravel aquifers (Burgoyne Aquifer)

$$P + Q^{SW}_{in} + Q^{GW}_{in} + Q^{IRRreturn}_{in} = R + ET + \Delta S^{GW} + Q^{SW}_{out} + Q^{GWpump}_{out} + Q^{SWpump}_{out} + Q^{GW}_{out} \qquad \text{(Eq. 3)}$$

Type 4a Aquifers—Predominantly unconfined sand and gravel aquifers of glaciofluvial origin (Ganges Harbour and Fulford Harbour Aquifers)

$$P + Q^{SW}_{in} + Q^{GW}_{in} + Q^{IRRreturn}_{in} = R + ET + \Delta S^{GW} + \Delta S^{Lakes} + Q^{SW}_{out} + Q^{GWpump}_{out} + Q^{SWpump}_{out} + Q^{GW}_{out} \qquad \text{(Eq. 4)}$$

Type 4b Aquifers—Predominantly confined / semi-confined sand and gravel aquifers of glacial or pre-glacial origin (Walker Hook Aquifer)

$$Q^{SW}_{in} + Q^{GW}_{in} + Q^{GWLeak}_{in} = R + \Delta S^{GW} + Q^{SW}_{out} + Q^{GWpump}_{out} + Q^{SWpump}_{out} + Q^{GW}_{out} \qquad \text{(Eq. 5)}$$

Where:

P = precipitation (rain and snow)

ET = evapotranspiration

Q^{SW}_{in} = surface water inflow

Q^{SW}_{out} = surface water outflow

Q^{GW}_{in} = groundwater inflow

Q^{GW}_{out} = groundwater outflow

R = groundwater recharge

ΔS^{SW} = change in surface water storage

ΔS^{GW} = change in groundwater storage

$Q^{IRReturn}_{in}$ = irrigation / septic return flow

Q^{GWLeak}_{in} = groundwater leakage through semi-confining units

Q^{SWpump}_{out} = surface water pumping

Q^{GWpump}_{out} = groundwater pumping

5.2 Data Analysis and Study Area Characterization

The monthly aquifer groundwater budget analysis benefited from both a high degree of provincial support as well as local level engagement and, as a result, has a relatively greater amount of data available for analysis in comparison to similar projects. The data analysis and study area characterization task provides an analysis and interpretation of each type of data, followed by an assessment of the implications of the analysis for the conceptual hydrogeological model and, by extension, the monthly aquifer groundwater budget analysis.

5.2.1 General Setting, Topography, and Land Use

Salt Spring Island is the largest of BC's Southern Gulf Islands with an area of approximately 182.7 km^2, located in the Strait of Georgia, roughly between Vancouver and Victoria. The population of the Island, according to Statistics Canada's 2016 Census is 10,577 people, also making it the most populous of the Southern Gulf Islands. The Island is generally comprised of three distinct areas, colloquially referred to in this report as North, Central, and South Salt Spring Island, which are separated on the basis of the two topographic lows of the Ganges and Fulford Valleys. The Central and South areas of the island include several prominent topographic peaks over 500 m, with the largest being Bruce Peak (approximately 709 masl) and Mount Tuam (approximately 602 masl). The population density of the Island is approximately 58 people / km^2, with the majority of the population located on North Salt Spring Island, the largest community being the village of Ganges and the majority of the rest of the Island being lightly inhabited and forested.

The land use of the Island, as defined by the BC Assessment Actual Land use categorization combined with the Integrated Cadastral Fabric for the Island, is predominantly residential (approximately 60%) with agricultural / farming the second largest land use on a proportional basis (approximately 20%). Figure 13 presents the spatial distribution of the various land uses on Salt Spring Island and a summary of the land use by number of lots and area is presented in Table 5. Note that as the cadastral dataset does not provide complete coverage of the Island, the total cadastral area does not equal the total area of the Island stated above.

Table 5: Summary of land use on Salt Spring Island (B.C. Assessment cadastral data).

Land Use	Number of Lots	Area (ha)	Percent of Total Cadastral Area
Civic, Institutional and Recreational	125	2105.6	13%
Commercial	195	128.3	1%
Farm	342	3273.5	20%
Industrial	21	494.8	3%
Residential	5256	9681.3	60%
Transportation, Communication and Utility	29	157.2	1%
Unknown	101	352.4	2%
TOTAL	**6069**	**16193.1**	**100%**

Of the land parcels reported as residential land use, the specific BC Assessment land use codes were used to classify the lots into low density (temporary or single-family housing), medium density (two or three family housing), and high density (multi-family, row housing or condominiums) in order to display the areas of population concentration. As presented in Figure 14 and summarized in Table 6, low-density single family homes comprise the vast majority of the residential lots on Salt Spring Island (approximately 90% on a number of lots basis), with medium and high-density parcels concentrated predominantly within the Ganges Valley area.

Table 6: Summary of the residential density of residential parcels on Salt Spring Island (B.C. Assessment cadastral data).

Residential Density	Number of Lots	Area (ha)	Percentage of Total Residential Land Use
Low Density	4757	9609.3	99.3%
Medium Density	229	61.6	0.6%
High Density	270	10.4	0.1%

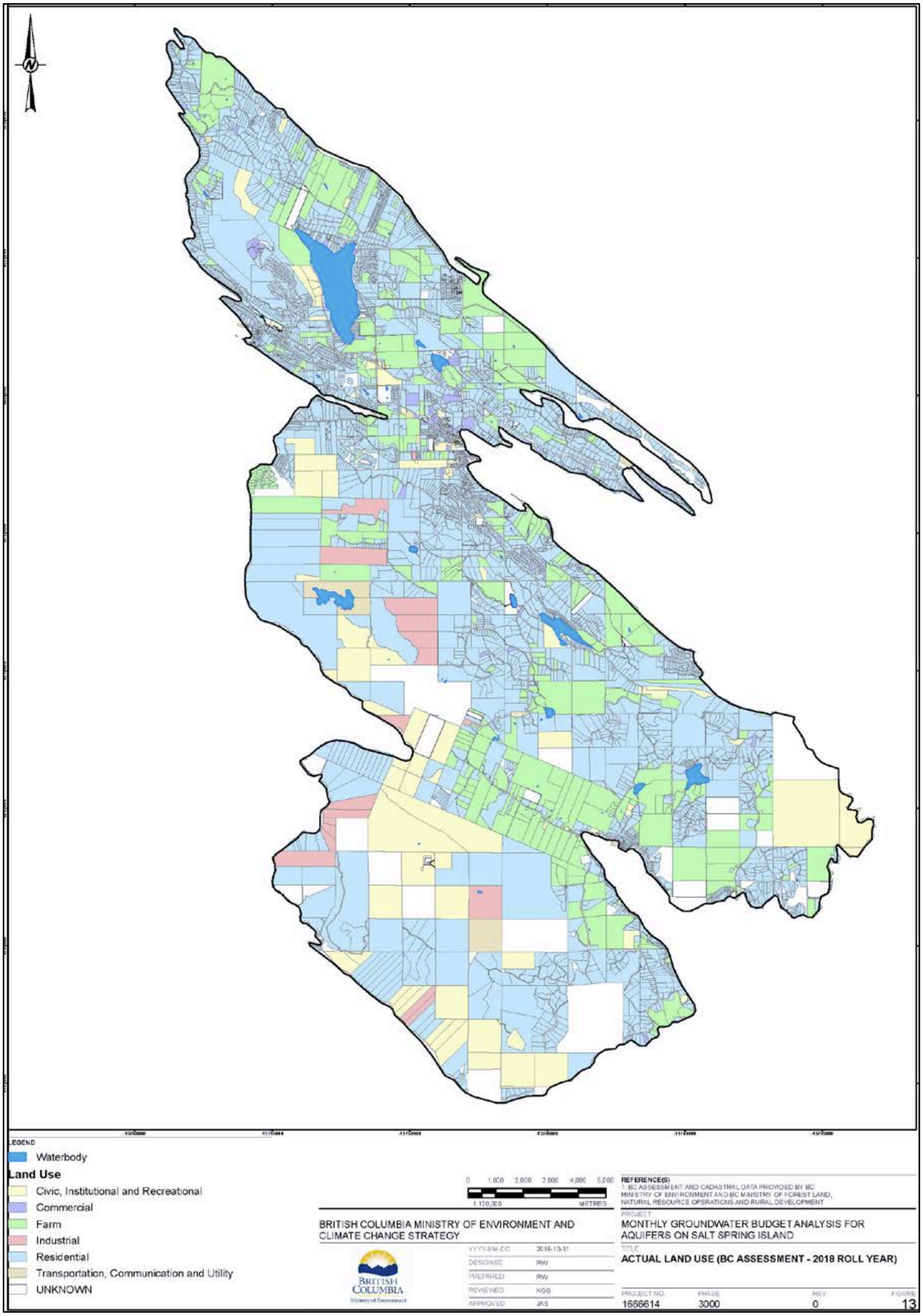

Figure 13: Land use distribution on Salt Spring Island.

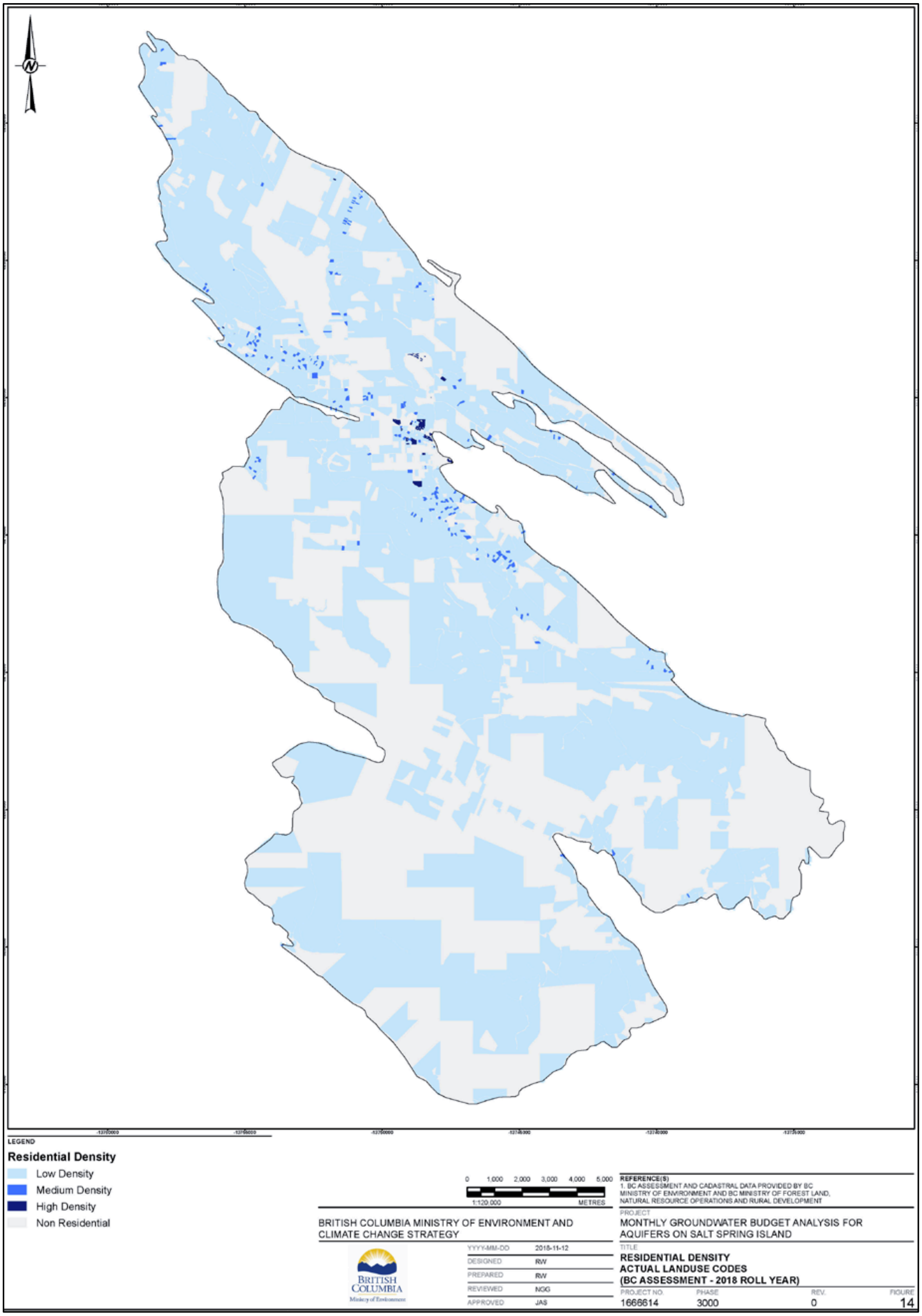

Figure 14: Residential density distribution on Salt Spring Island.

The overall population of Salt Spring Island varies from month to month as an influx of tourists arrive on the Island during the summer months. The exact population and proportional increase over the permanent population during the high tourist season is unknown but increases significantly as stated below.

Implications for Monthly Aquifer Groundwater Budgets

The implications of the general setting, topography and land use data analysis on the monthly aquifer groundwater budgets include:

- As implied by the justification for the delineation of the bedrock aquifers, the topographic lows of the Ganges and Fulford Valleys segment the Island into three relatively independent groundwater flow regimes;
- Analysis of actual land use classification reveals that the majority of land use (by number of lots and proportional area) is residential; and
- Most residential land parcels are low density, single family, or temporary homes, however, the seasonal population of Salt Spring Island (and, by extension, seasonal water demand) increases significantly during the summer months.

5.2.2 Precipitation

The climate of Salt Spring Island is classified as “cool mediterranean”, with dry, cool summers and humid, mild winters. As the Island is located in the orographic rain shadow of Vancouver Island, it also receives comparatively less precipitation than other coastal communities in BC. Salt Spring Island currently has one active Environment Canada (EC) weather station operational, the Salt Spring St. Mary L station (Climate ID# 1016995) located near St. Mary Lake on North Salt Spring Island, though numerous community meteorological stations also exist across the Island (Figure 17). Table 7 presents a summary of the current and discontinued Environment Canada meteorological stations on Salt Spring Island.

Table 7: Current and discontinued Environment Canada meteorological stations on Salt Spring Island.

Station Name	Climate ID	Years Active	Elevation
Salt Spring Is Cusheon Lk	1016992	1976-2001	107.90 m
Salt Spring Island	1016990	1893-1977	73.20 m
Salt Spring St. Mary L	1016995	1975-present	45.70 m
Salt Spring Vesuvius	1017000	1955-1975	7.60 m

Climate normals for 30-year periods of meteorological data only exist for the active St. Mary Lake station. Figure 15 presents the average monthly and annual precipitation amounts (mm) for the 1981–2010 period. From the figure, pronounced “wet” and “dry” periods can be observed in the data, with the ”wet” period (765 mm of precipitation) roughly corresponding to the months of October through to March, inclusive and the ”dry” period (221 mm of precipitation) roughly corresponding to the months of April to September, inclusive. As all water available on Salt Spring Island ultimately comes from precipitation, the total annual amount of precipitation and the monthly distribution of that precipitation represent potentially significant forcings to the overall availability of groundwater for use across the Island. Figure 16 presents total dry and wet season precipitation at the St. Mary Lake station by year for the time span of 2007–2017, together with the total average annual precipitation from the 1981–2010 climate normals. The figure indicates the lack of correlation between total annual precipitation in a given year versus the total precipitation received during the dry period. For example, 2016 is the wettest year in terms of total annual precipitation but also the year where the least amount of precipitation was observed during the dry season, when demands are at their highest. Contrarily, in 2013, where the lowest total annual precipitation was observed, the highest amount of precipitation during the dry period was noted. The implication of this lack of correlation is the importance of considering dry period precipitation when conducting the associated analyses.

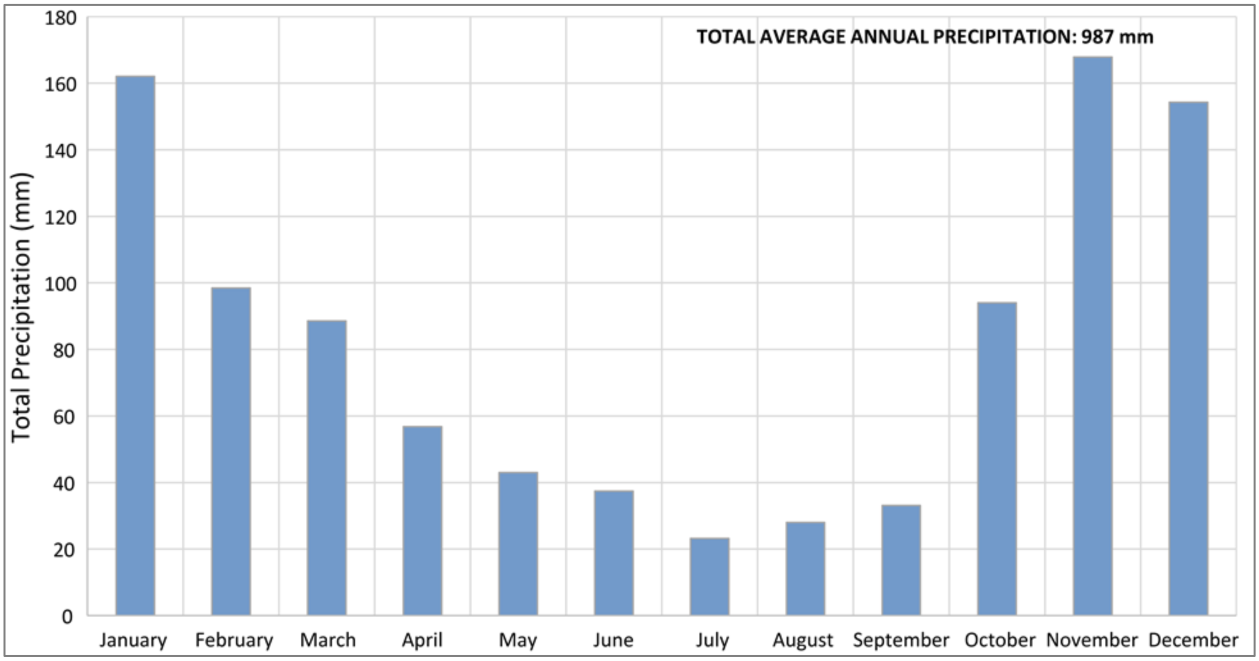

Figure 15: Average total monthly precipitation (mm), St. Mary Lake station, EnvCan Climate Normals, 1981-2010.

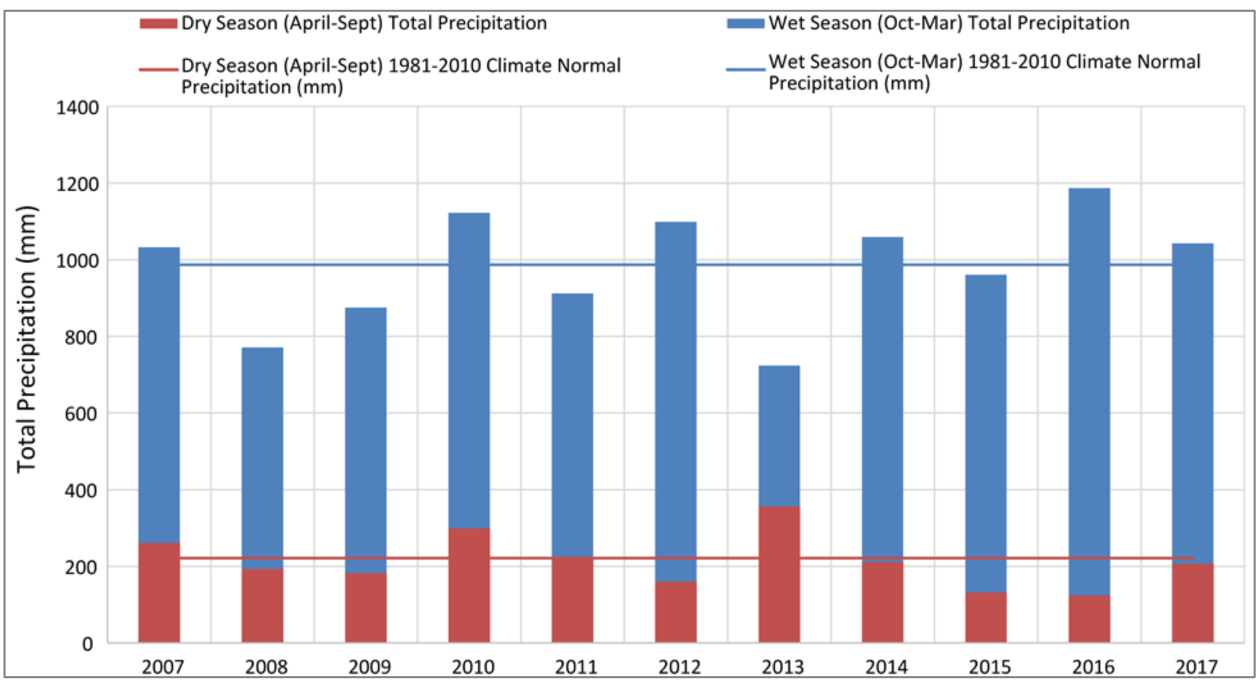

Figure 16: Annual precipitation (mm) wet and dry seasons, St. Mary Lake station, 2007-2017 and 1981-2010 Climate Normals.

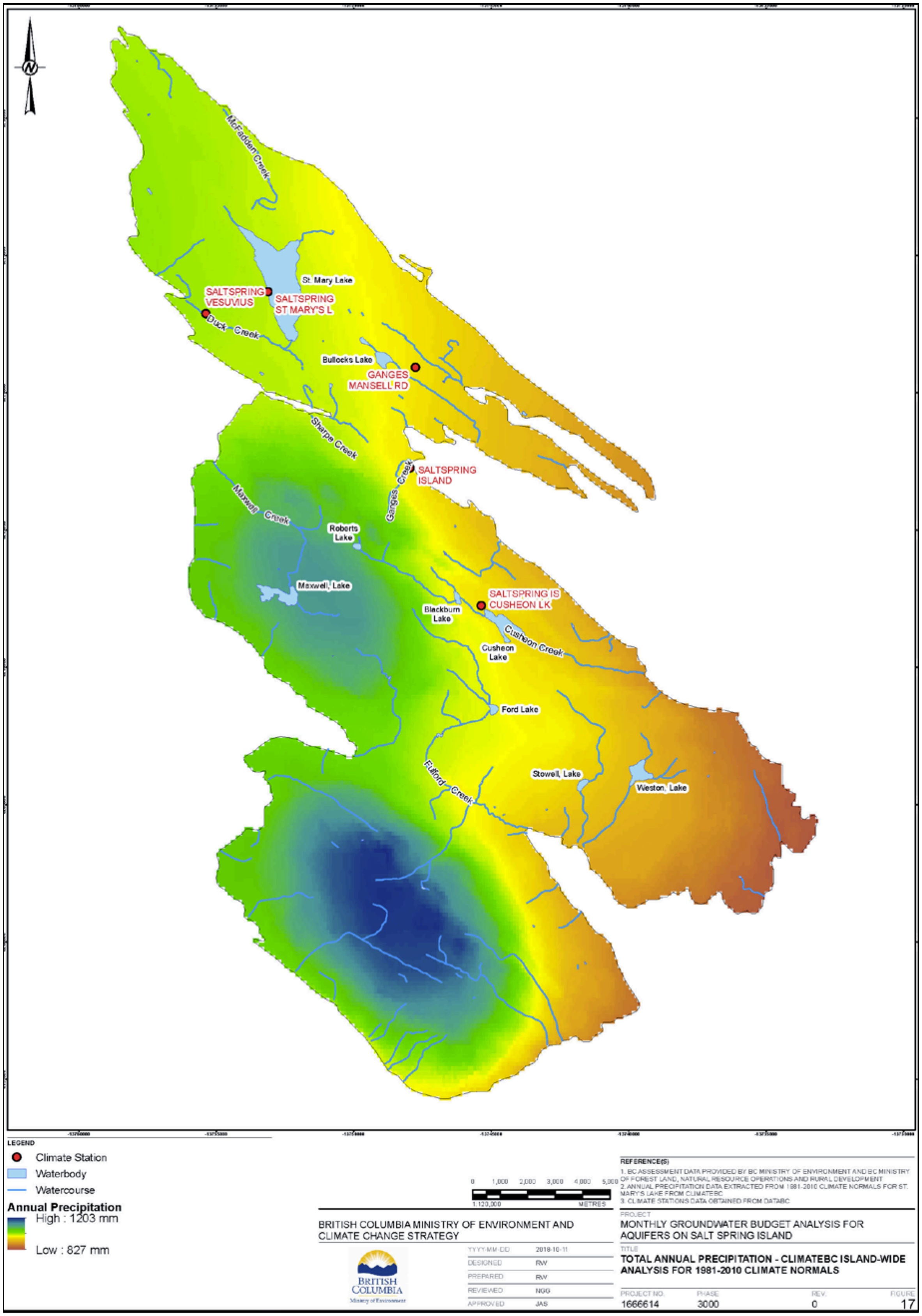

Figure 17: Total annual precipitation (mm), ClimateBC island-wide analysis for 1981-2010.Climate Normals.

Environment Canada's St. Mary Lake meteorological station is located at an elevation of 45.70 masl near the shores of St. Mary Lake on North Salt Spring Island, the section of the Island with the lowest topographical relief (Figure 17). As the Central and South sections of Salt Spring Island have areas of significantly higher elevation, there is the potential that the extrapolation of meteorological data from the lower elevation St. Mary Lake station may not adequately describe meteorological or precipitation conditions at the higher elevations in the southern portions of the Island. Furthermore, Vancouver Island's orographic rain shadow or coastal processes around the Island may also introduce some significant heterogeneities to the precipitation distribution of the Island, resulting in potentially substantial differences in Island-wide aquifer groundwater budgets. This study addresses the potential for spatial heterogeneity and variability in meteorological variables by utilizing the ClimateBC database (Wang et al. 2012) to generate spatially-distributed "climate surfaces" at a high resolution across the Island so as to better account for across-Island variability. ClimateBC utilizes data from the PRISM model (Parameter-elevation Relationships on Independent Slopes Model, Daly et al., 2008) to generate distributed precipitation surfaces that incorporates weather station data, a digital elevation model, and expert knowledge such as rain shadows, coastal effects, orographic lift, and temperature inversions over topographically delineated "facets". By incorporating the effects of a variable topography, results will more closely approximate the heterogeneous distribution of precipitation and meteorological variables in the mountainous regions of Western North America. In addition, ClimateBC allows for downscaling of common climate change general circulation models (GCMs) to the local scale which also take into account local weather station data and topography, providing an accessible means to generate Island-wide climate change simulations using industry standard methods.

Figure 17 presents the total average annual precipitation across the Island based on ClimateBC's sampling of the 1980–2010 climate normals from nearby meteorological stations. From this figure, clear differences in precipitation across the Island are observed in comparison to a uniform application of precipitation data from the EC station at St. Mary Lake. Firstly, increased precipitation is observed at higher topographic elevations, reflecting the effect that orographic lift has on precipitation. Secondly, minor rain shadows are observed in the leeward side of the higher elevation areas. Thirdly, small general gradients in precipitation are observed from west to east, in line with climate normal data from nearby weather stations where wetter conditions are observed on Vancouver Island to the west, and drier conditions observed in weather stations on other Southern Gulf Islands to the east. Quality checks of ClimateBC data versus real world data showed good agreement between simulated and observed values. A comparison of Island-wide monthly and annual precipitation generated from the 1981–2010 climate normals in ClimateBC to the monthly and annual precipitation at EC's St. Mary Lake station is provided in Figure 18.

Annual comparisons of precipitation amounts are often best presented with respect to the "hydrologic year", which is defined here as spanning October to September. By presenting precipitation values in this manner, the total annual precipitation values will include the effects of one full wet period (October to March) and one full dry period (April to September), reducing the likelihood that inter-wet period variability biases the total annual precipitation numbers. Total annual precipitation for the previous ten hydrologic years are presented in Table 8, below.

On the basis of total annual precipitation for a given hydrologic year on Salt Spring Island, the driest year is the 2009 hydrologic year, with only 691.2 mm of precipitation falling between October 2008 and September 2009. The wettest hydrologic year on the basis of total precipitation is 2010, with a total of 1242.6 mm of precipitation falling between October 2009 and September 2010.

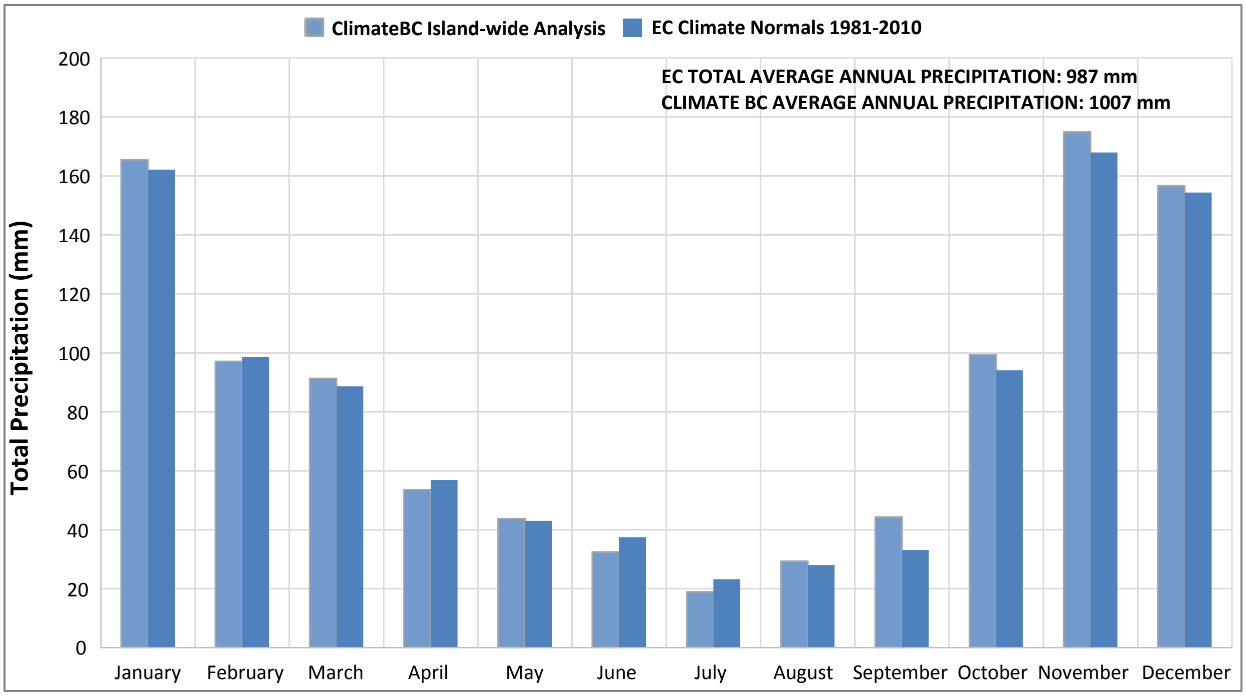

Figure 18: Comparison of average monthly and annual precipitation totals (mm) between EnvCan Climate Normals at the St. Mary station and the ClimateBC island wide analysis.

Table 8: Seasonal and total annual precipitation by hydrologic year

Hydrologic Year (October–September)	Wet Season Precipitation (mm, October–March)	Dry Season Precipitation (mm, April–September)	Total Precipitation (mm)
2008	617.5	193.0	810.5
2009	509.1	182.2	691.2
2010	943.6	299.0	1242.6
2011	772.6	224.6	997.2
2012	680.1	159.6	839.8
2013	830.5	355.9	1186.3
2014	545.4	210.7	756.2
2015	765.3	131.6	896.9
2016	993.9	123.9	1117.8
2017	963.2	206.6	1169.9
1981–2010 Climate Normals [(a)]	765.4	221.5	986.9

(a) 1981–2010 Climate Normals at Salt Spring St. Mary L station (Climate ID# 1016995)

Implications for Monthly Aquifer Groundwater Budgets

The implications of the precipitation data analysis on the monthly aquifer groundwater budgets include:

- The amount, distribution, and timing of precipitation that falls across the Island is ultimately the sole input of water to the hydrologic system of Salt Spring Island and how this input water is partitioned into evapotranspiration, surface water runoff and infiltration (groundwater recharge) represents the major input to the monthly aquifer groundwater budgets;
- Precipitation patterns for Salt Spring Island show marked "wet" and "dry" seasons for the Island, with the dry season (April through September inclusive) also corresponding to the time period of increased seasonal population and water demand;

- A lack of correlation exists between total annual precipitation in a given year versus precipitation that arrives during the April through September dry season, and both the total annual precipitation and dry season precipitation may have important implications for the monthly groundwater budgets;
- ClimateBC modelling of precipitation distribution, which incorporates the complex effects of local station data, elevation and topography on precipitation patterns, is an effective way to account for spatially variable precipitation across Salt Spring Island for the aquifer groundwater budgets;
- ClimateBC also provides readily accessible downscaling of climate change global climate models (GCMs) to high resolution local conditions, which was utilized for the scenario analysis and assessment of climate change impacts; and
- The guidance document for BC aquifer groundwater budgets (Hy-Geo Consulting, 2014) suggests that recharge for bedrock aquifers is governed by infiltration of runoff /surface water into storage of the bedrock aquifer.

5.2.3 Evapotranspiration

Evapotranspiration represents a potential major loss of water for the Island-wide water budget, particularly during the warmer, drier summer months. Accurate estimations of evapotranspiration are complex and typically dependent on a calculated reference evapotranspiration from meteorological variables that are then modified by other factors such as soil type, crop type, or land use and affected by the availability of water in the rooting zone. For the purpose of this study, reference evapotranspiration (ETo) across Salt Spring Island was generated using the Hargreaves and Allen (1985) method which is a temperature only estimation of the reference evapotranspiration more suited for analysis over longer (i.e., monthly) timescales. Table 9 presents the average monthly reference evapotranspiration based on the 1981–2010 climate normals from ClimateBC for the St. Mary Lake station.

Table 9: Average monthly reference evapotranspiration (ClimateBC) for 1981–2010 Climate Normals.

Month	**Reference Evapotranspiration (ET_o, mm)**
January	11.88
February	19.26
March	38.55
April	61.90
May	89.48
June	102.69
July	115.52
August	100.12
September	63.88
October	32.63
November	14.32
December	9.55
TOTAL	**659.78**

Implication for Monthly Aquifer Groundwater Budgets

The implication of the evapotranspiration data analysis on the monthly aquifer groundwater budgets include:

- Direct evapotranspiration from bedrock aquifers is often very limited or negligible due to the small degree of storage in bedrock available for evaporation and a comparatively small degree of rooting depth of plants and trees. As a result, the impact of higher evapotranspiration on groundwater budgets is likely due to the effect ET has on wet or saturated conditions on the Island that would promote groundwater recharge to aquifers.

5.2.4 Surface Water Hydrology

The major surface water and drainage features on Salt Spring Island are presented in Figure 19. Historical hydrometric data (discharge and water levels) for Salt Spring Island streams and lakes is available via the WSC's HYDAT Database, however there are no currently active WSC hydrometric stations on the Island. Numerous private or community sources of hydrometric data exist, including hydrologic monitoring conducted by the NSSWD at St. Mary Lake and Maxwell Lake and community monitoring at Cusheon Lake, amongst others. Seasonal low flow measurements and surface water monitoring was also conducted by FLNRORD staff during the summer and autumn of 2017. A summary of hydrometric gauging stations considered in this study is provided in Table 10.

An understanding of the surface water hydrological regime is integral for the conceptualization of the monthly aquifer groundwater budgets for the aquifers on Salt Spring Island. In the wet season, the measurement of discharge and monitoring of the hydrology of major watercourses on Salt Spring Island provide a directly quantifiable measure of the water (precipitation) which runs off of the Island and, together with estimates of evapotranspiration, provide a mechanism for the indirect measurement of infiltration and groundwater recharge to the Salt Spring Island aquifers. In addition, the occurrence of flowing conditions in watercourses, high water conditions in lakes, ponds and wetlands, and saturated soil conditions are all situations which promote infiltration and recharge into underlying bedrock aquifers and can be a critical indicator of whether recharge is occurring. In the dry season, discharge measurements in the major watercourses can be assumed to be comprised predominantly of baseflow or groundwater discharge from the Salt Spring Island bedrock Aquifers. Recharge to bedrock aquifers in the dry season may be limited to higher elevation lakes and ponds, where flux to underlying aquifers occurs slowly through fractures at the lake / pond bottoms.

Table 10: Summary of hydrometric gauging stations considered in this study.

Station Number	**Station Name**	**Type**	**Period Active**
08HA026 (WSC)	Cusheon Creek at Outlet of Cusheon Lake	Flow (Daily, Year-Round)	1970–1971, 1976–1998
08HA046 (WSC)	Duck Creek at Outlet of St. Mary Lake	Flow (Daily, Apr–Sept)	1980, 1990–1998
08HA055 (WSC)	Fulford Creek on Salt Spring Island	Flow (Daily, Apr–Sept)	1983–1993
08HA038 (WSC)	Cusheon Lake Near Ganges	Lake Level (Monthly, Year-Round)	1976–1998
08HA044 (WSC)	St. Mary Lake at Pumphouse	Lake Level (Monthly, Year-Round)	1979–1985
N/A (FLNRORD)	2017 Fulford Creek	Water Level (Hourly, May–Nov)	2017
N/A (FLNRORD)	2017 Cusheon Creek	Water Level (Hourly, May–Nov)	2017
N/A (FLNRORD)	Bullock, Ganges, McFadden, and Reid Creeks	Water Level / Wetted Width (Weekly, May–Oct)	2017

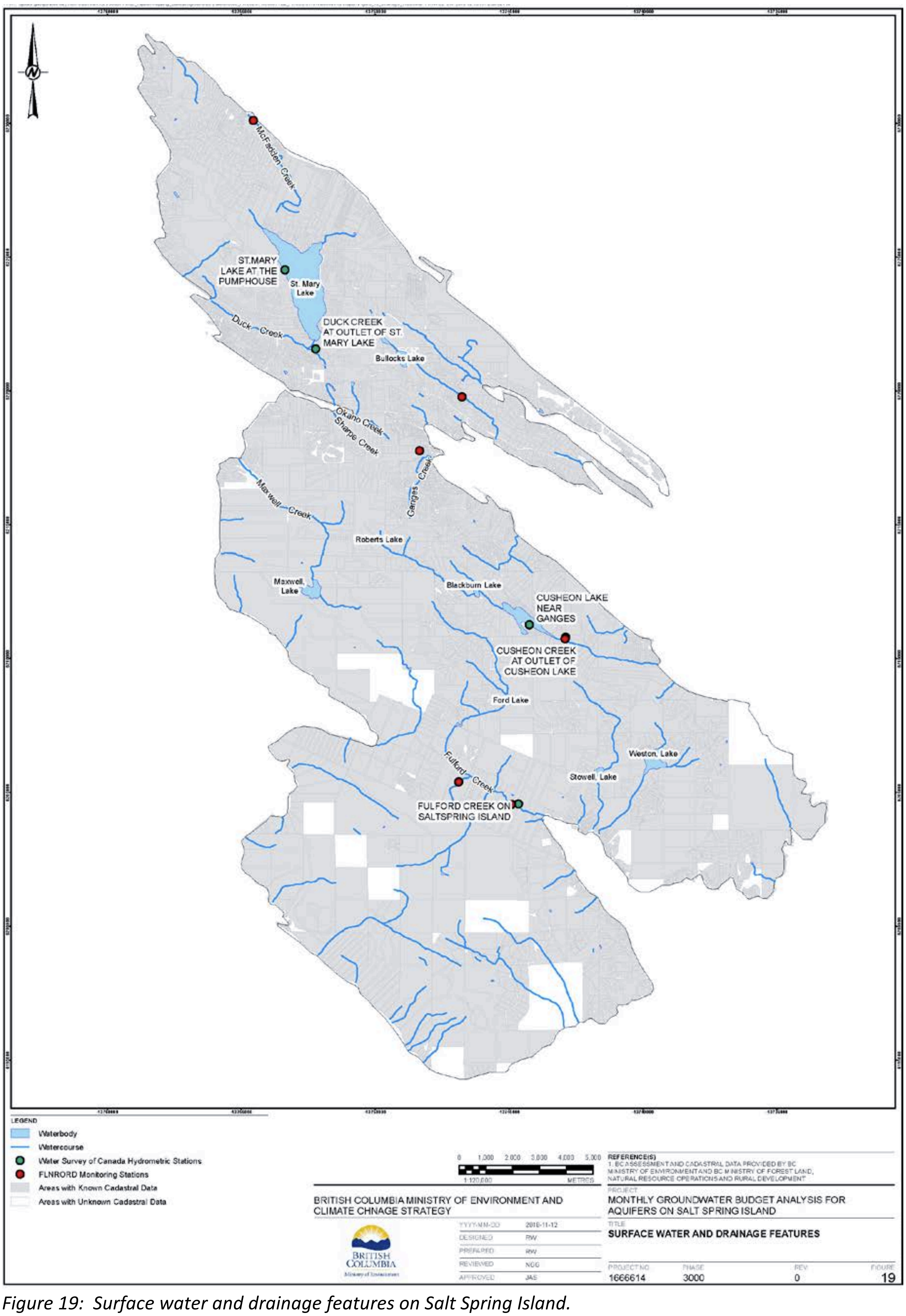

Figure 19: Surface water and drainage features on Salt Spring Island.

Analysis of the surface water regime can provide higher level insight into the conceptual processes of groundwater—surface water interactions across the Island. Figure 20 presents daily discharge time series plots for the three discontinued WSC hydrometric gauges on Salt Spring Island. Discharge observations of the three stations reveal consistent similarities, notably:

- Periods of high flow at all three locations coincident with the higher precipitation of the wet period, or tail end of the wet period where discharge observations are seasonal; and
- Following onset of the drier season in the spring, a marked reduction in discharge with annual periods of no flow at Cusheon Creek and Duck Creek, and annual periods of very low flow in Fulford Creek.

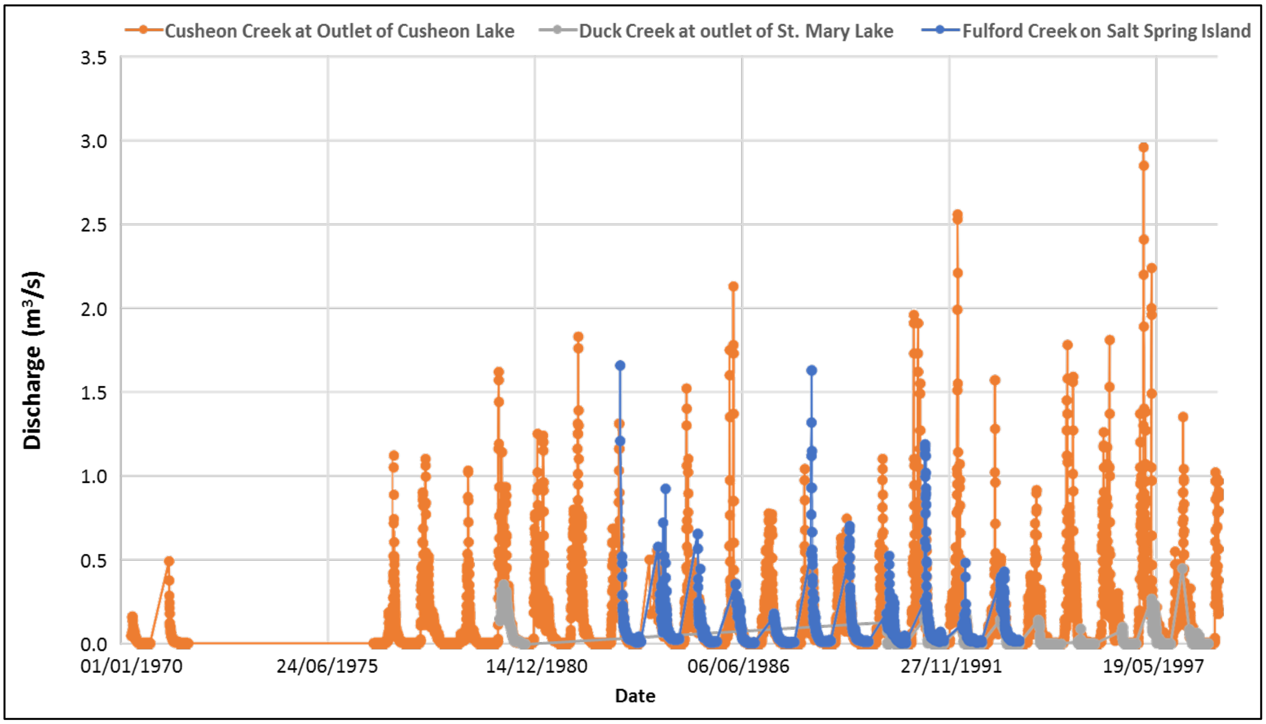

Figure 20: Surface water discharge at discontinued WSC hydrometric gauges on Salt Spring Island.

Figure 21 and Figure 22 present the results of continuous water level monitoring conducted by FLNRORD at Fulford Creek and Cusheon Creek, respectively. To translate measured continuous creek water levels into discharge, a unique stage-discharge relationship must be constructed from manual flow measurements over the expected range of flows at the stream cross-section. For both Fulford Creek and Cusheon Creek, correlation difficulties between measured creek water levels and manual flow measurements precluded the establishment of a unique, reliable stage-discharge relationship. As a result, continuous water levels could not be translated into discharge and both plots are presented as water levels only. Table 11 presents spot discharge observations from FLNRORD's 2017 monthly low flow measurement campaign at Bullock, Ganges, McFadden, and Reid Creeks. These spot flow measurements provide qualitative insight on the hydrologic behaviour of the small creeks and drainage features on Salt Spring Island but, due to the lack of a continuous data record, cannot be utilized to estimate total runoff from these catchments.

Table 11: Discharge observations from FLNRORD 2017 low flow monitoring program.

Monitoring Location	Discharge Observations
2017 Bullock Creek	No flow observed from June 23–September 16
2017 Ganges Creek	Continuous flow observed
2017 McFadden Creek	No flow observed from July 5–September 29
2017 Reid Creek	Continuous flow observed

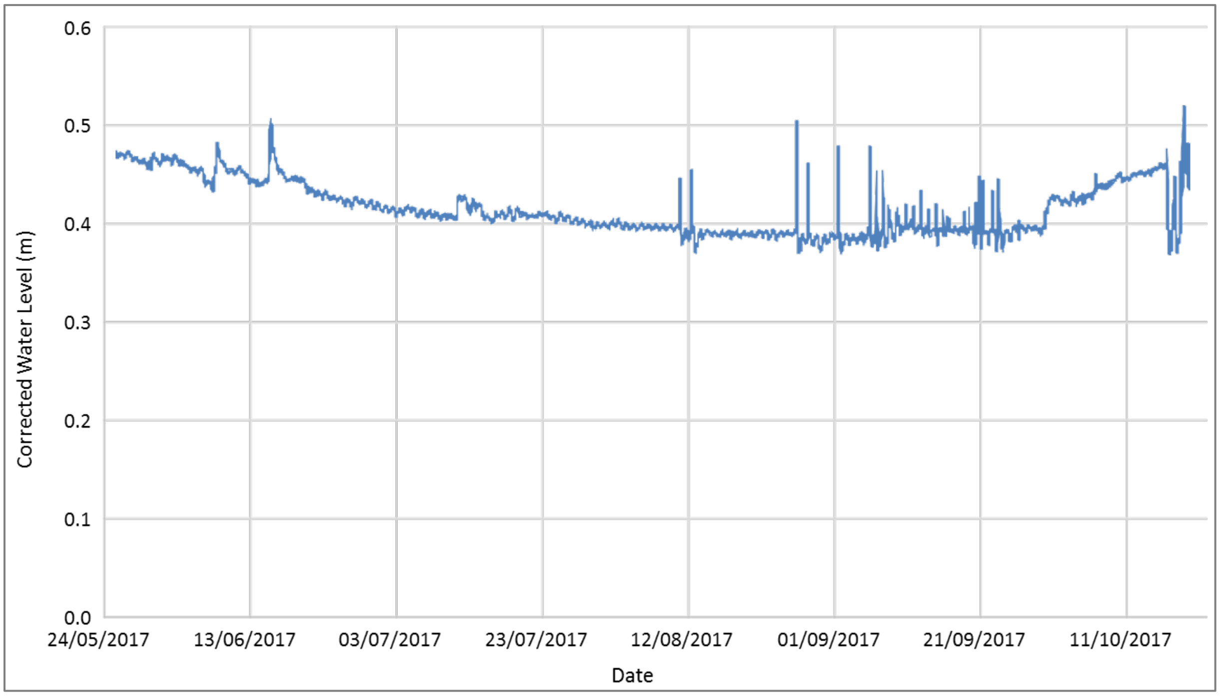

Figure 21: Continuous water level monitoring, Fulford Creek station, 2017.

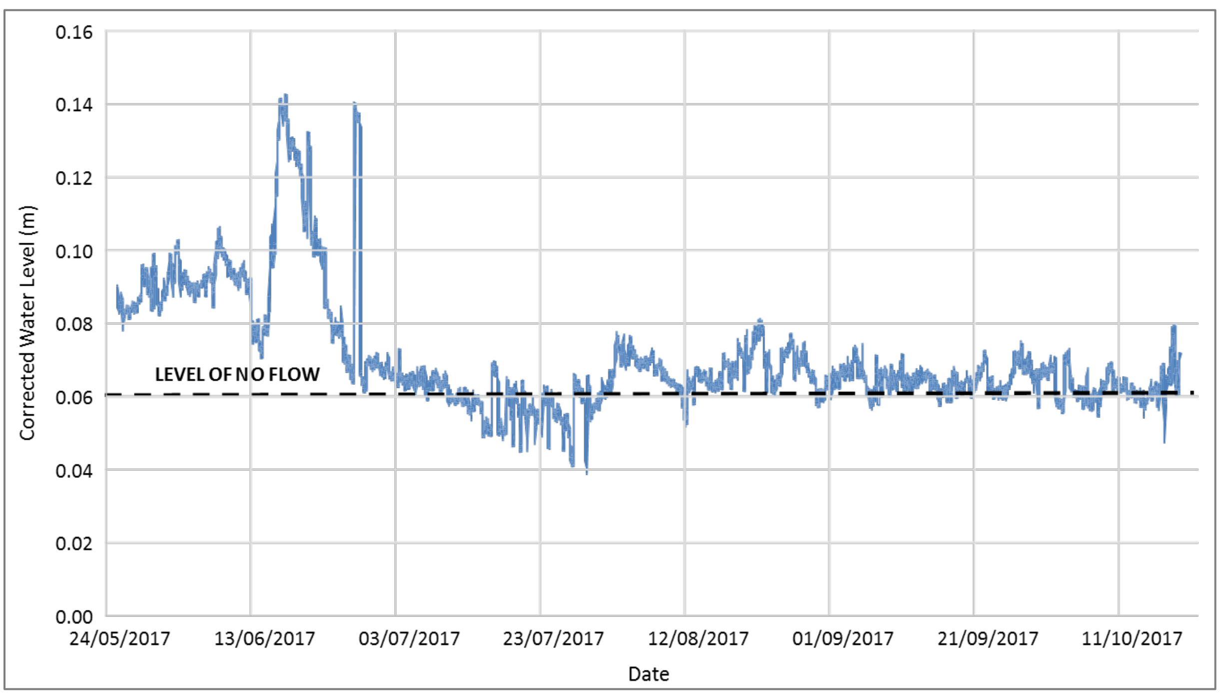

Figure 22: Continuous water level monitoring, Cusheon Creek station, 2017.

Observations from Figure 21 and Figure 22, as well as Table 11, reinforce the conceptual understanding of the hydrology obtained from analysis of the WSC hydrometric data, namely that surface water regime during the drier summer season is characterized by periods of no flow in many of the watercourses or very low flow in some of the larger watercourses with greater contributing area and located at lower elevations.

Figure 23 presents the monthly lake level data for the discontinued WSC hydrometric gauges. Lake levels are also measured by various community monitoring initiatives and by the NSSWD, who use both St. Mary Lake and Lake Maxwell as a water supply source. Lake levels may be regulated by control structures (i.e., weirs) and / or subject to different operational management over time and are predominantly informative as an expression of water storage in a contributing catchment and /or as receivers of groundwater discharge. Numerous small lakes exist across Salt Spring Island but no lake takes on a similar hydrological significance as St. Mary Lake on North Salt Spring Island, which functions as a major drainage basin for North Salt Spring Island as well as a water supply source for a large proportion of the local population in the area. Inputs to St. Mary Lake include surface water runoff from precipitation events as well as groundwater fluxes from local topographic highs surrounding the lake. An assessment of water availability and demand for St. Mary Lake was undertaken on behalf of NSSWD in parallel to this project by Kerr Wood Leidal (2018).

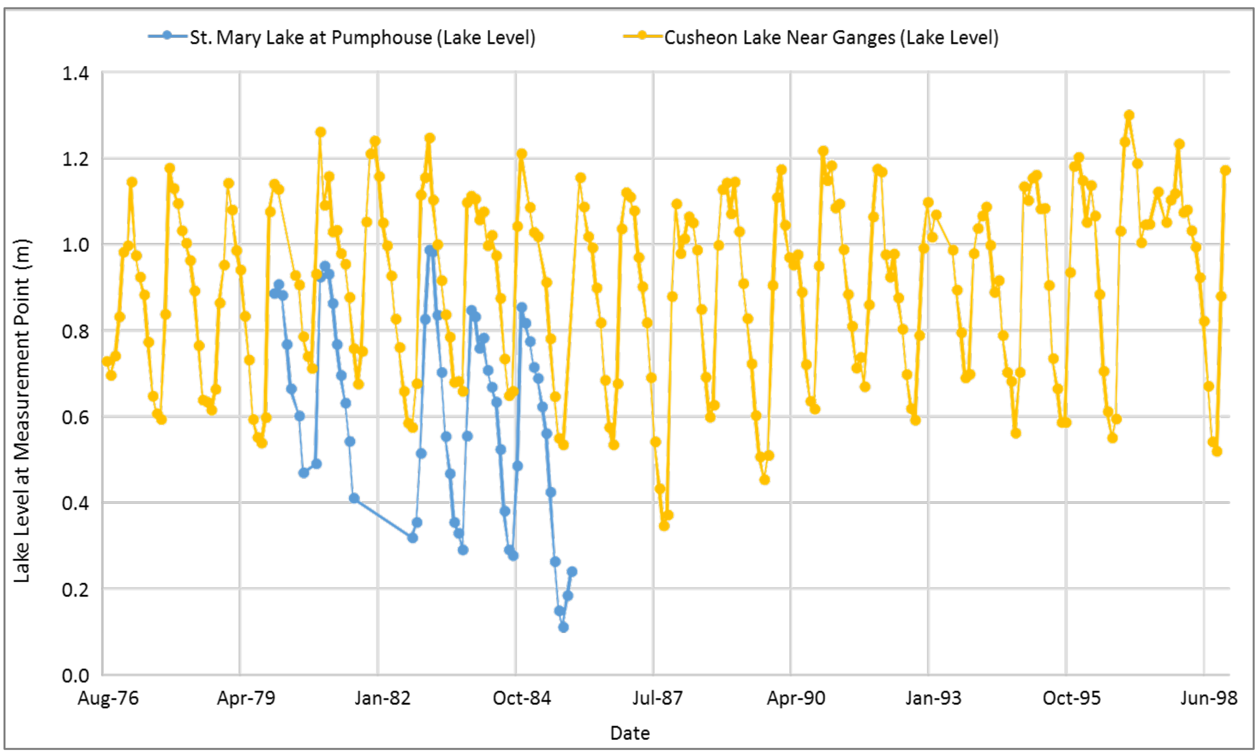

Figure 23: Lake levels measured at discontinued WSC water level stations.

The surface water hydrology represents a critical component of the overall groundwater budget analysis for Salt Spring Island as summer baseflows in watercourses are comprised predominantly of groundwater and because measurement of surface water discharge during the wet period can provide an estimation of the amount of incipient precipitation that recharges the aquifers when conditions are more likely to be saturated. To address the limited surface water data available on the island, monthly flows were estimated in the following manner:

- Average monthly flows for the dry period (April–September) were estimated from historical summer data from the discontinued Fulford Creek on Salt Spring Island (Station 08HA055) WSC gauge on Fulford Creek. A Regional Analysis was then utilized to scale these flows to aquifer-wide monthly runoff values; and
- No existing, unregulated hydrometric data were available during the wet period (October–March), the time when most of the groundwater recharge is expected to occur. To estimate average monthly flows for these months, it was assumed that the regulated Cusheon Creek at the outlet of Cusheon Lake WSC gauge (Station 08HA026) behaved as an unregulated gauge during the wet season months when the lake levels are high. A Regional Analysis, whereby the flow assumed for the area of the individual watershed was scaled up to the area represented by the aquifer, was then utilized to scale these flows to aquifer-wide monthly runoff values.

Implications for Monthly Aquifer Groundwater Budgets

The implications of the surface water hydrology data analysis on the monthly aquifer groundwater budgets include:

- Quantification and measurement of the surface water regime can provide important information on the amount of infiltrating water (groundwater recharge) during the wet winter period and flux out of groundwater aquifers (baseflow) to streams during the dry summer period;
- The hydrologic regime of the major surface water features on the Island generally includes an annual high flow period, coinciding with the wet winter period, and an annual period of very low to no flows that coincides with the dry summer period;
- Recharge to bedrock groundwater aquifers is assumed to take place predominantly during the wet period, where watercourses are flowing, lakes/ponds/depressions have higher water levels and thin veneer soils are saturated. Recharge to bedrock aquifers is likely relatively minor during the dry period and confined to lakes / ponds at higher elevations on the Island; and
- St. Mary Lake is the major drainage basin on North Salt Spring Island, is of particular importance as a water supply for a large proportion of that portion of the Island, and is a receiver of groundwater inputs and runoff from local topographic highs.

5.2.5 Hydrogeology and Groundwater Levels

In general, the potentiometric surface of hydraulic head within the larger Salt Spring Island bedrock aquifers can be considered to be reflective of the topographic relief, with a more subdued expression. The direction of groundwater flow will be from areas of high topographic elevation to areas of low elevation, either discharging to the ground surface as surface water or discharging directly to the ocean. As groundwater flow is structurally controlled, water may not be encountered in a well until a fracture or feature with sufficient permeability is intersected, where after the water level will rise in the borehole or well to its associated hydraulic head. Similarly, due to the structural control of groundwater flow, local flow directions will conform to the orientation of the fracture network and move from areas of high hydraulic head to low hydraulic head along these local features. Where permeable fractures or faults with sufficient hydraulic head intersect the ground surface, the groundwater is expressed as springs. All groundwater recharge to aquifers on Salt Spring Island ultimately comes by way of precipitation within the Island's footprint. This occurs either via direct infiltration into fractures, the rock matrix, or unconsolidated sediments, via major water bodies, or via various other creeks and streams. For the overburden aquifers, groundwater flow is directed from the higher elevations in the southwest (in the northeast for the Burgoyne Aquifer) towards the coast. Figure 24 presents a simplified interpretation of the conceptual hydrogeology of the Island.

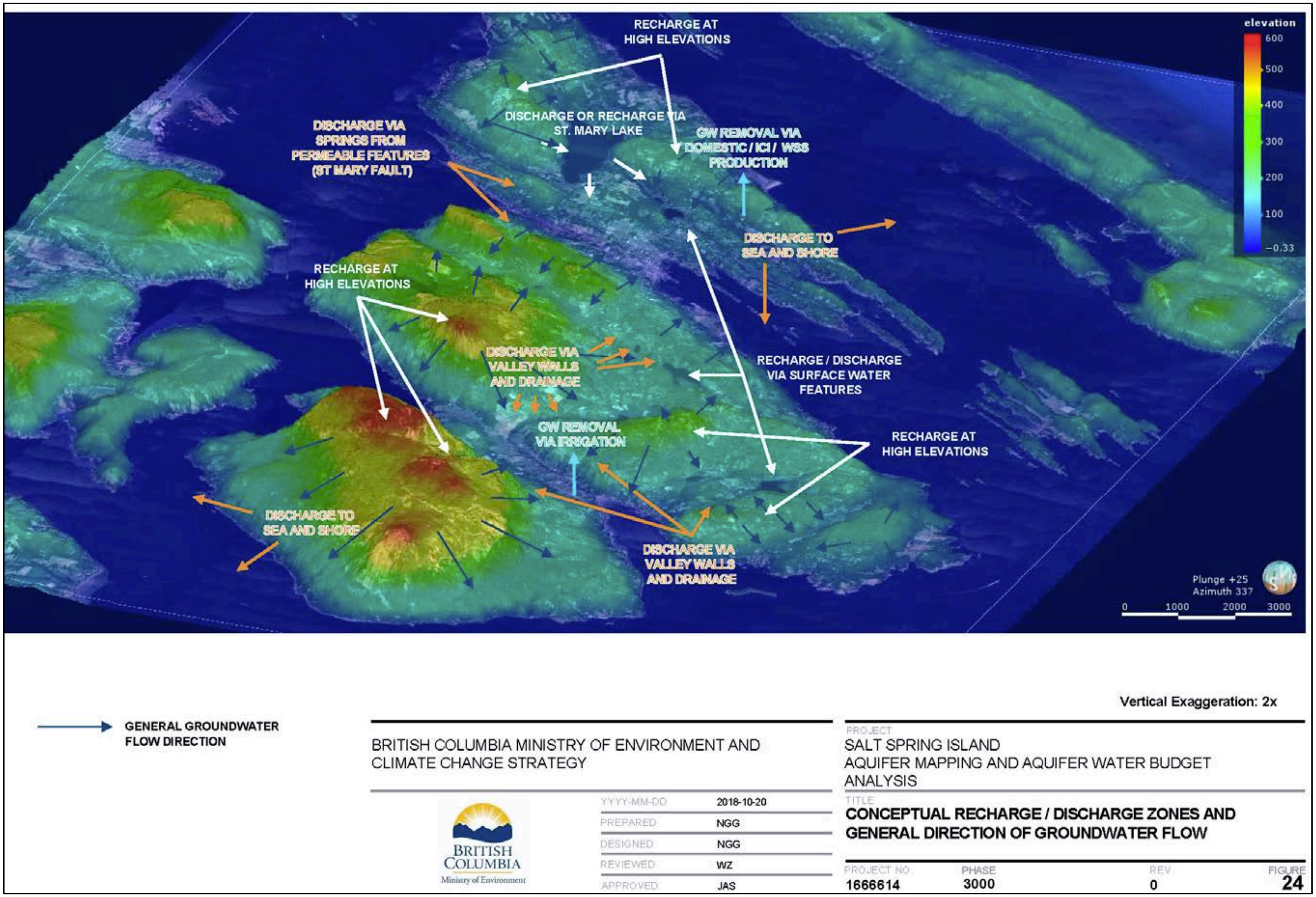

Figure 24: Conceptual model of groundwater flow on Salt Spring Island.

Three provincial observation wells from the Provincial Groundwater Observation Well Network (PGOWN) are active on Salt Spring Island. Table 12 presents a summary of the active PGOWN wells

Table 12: Summary of PGOWN observation wells on Salt Spring Island.

Observation Well #	Location	Years Active
Observation Well #281	Salt Spring Island (Long Harbour Rd)	1983–1986, 1989–Present
Observation Well #373	Salt Spring Island (Mt. Belcher Heights)	2006–Present
Observation Well #438	Salt Spring Island (Ross Rd)	2014–Present

Figures 25, 26 and 27 present the groundwater hydrographs for the PGOWN observation wells, referenced to elevations taken from a 2 m DEM for the Island. Despite the fact that there are only three data points, of particular note is the lack of a significant trend in groundwater levels from year to year, despite the variations in annual and dry season precipitation presented in Section 5.2.2. To quantitatively evaluate trends in the groundwater level data on a year-by year basis, a series of linear regression analyses was performed on the PGOWN Observation wells #281 and #373, which had the longest data records (Figures A-1 and A-2 in Appendix A). The following regression analyses were performed to investigate groundwater trends:

- Regressions of annual groundwater maxima versus precipitation received during the wet period of that year;
- Regressions of annual groundwater minima versus precipitation received during the dry period of that year; and
- Regressions of annual groundwater minima versus precipitation received during the preceding wet period of that year.

In all instances, no significant correlation was observed for any of the regressions (maximum R^2 observed in any regression = 0.20).

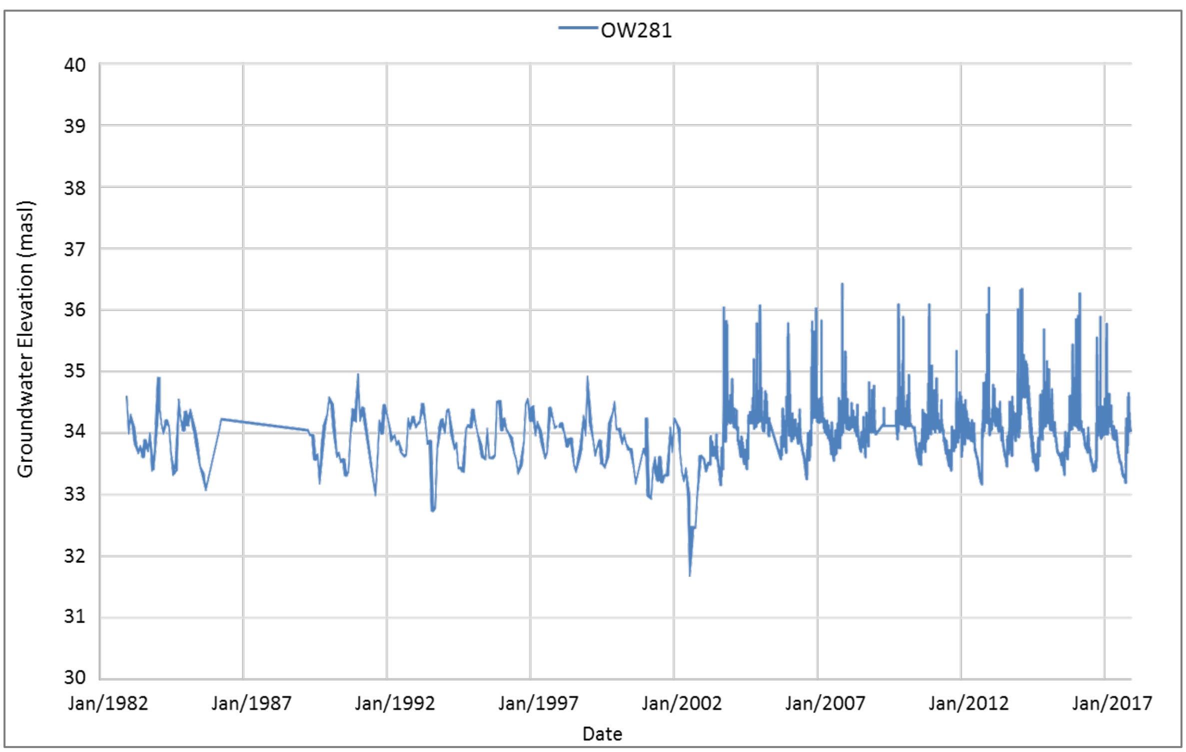

Figure 25: Groundwater hydrograph for PGOWN observation well #281.

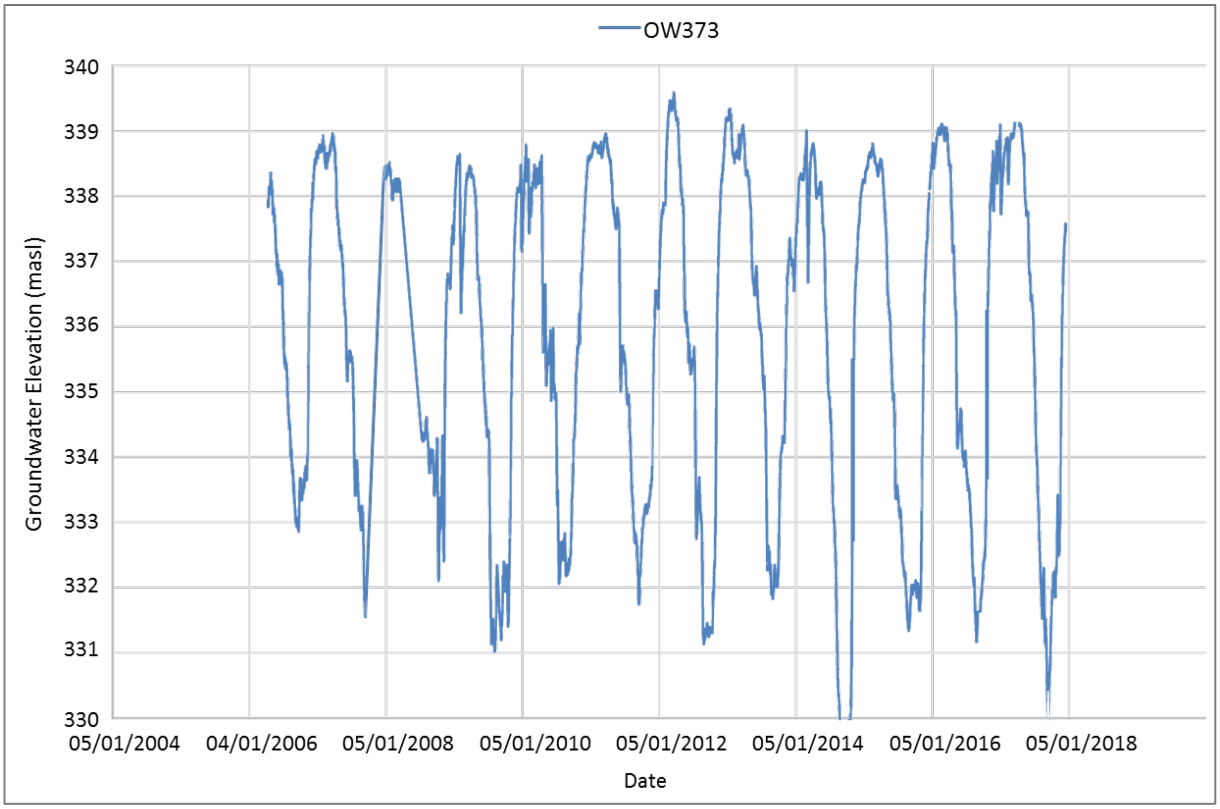

Figure 26: Groundwater hydrograph for PGOWN observation well #373.

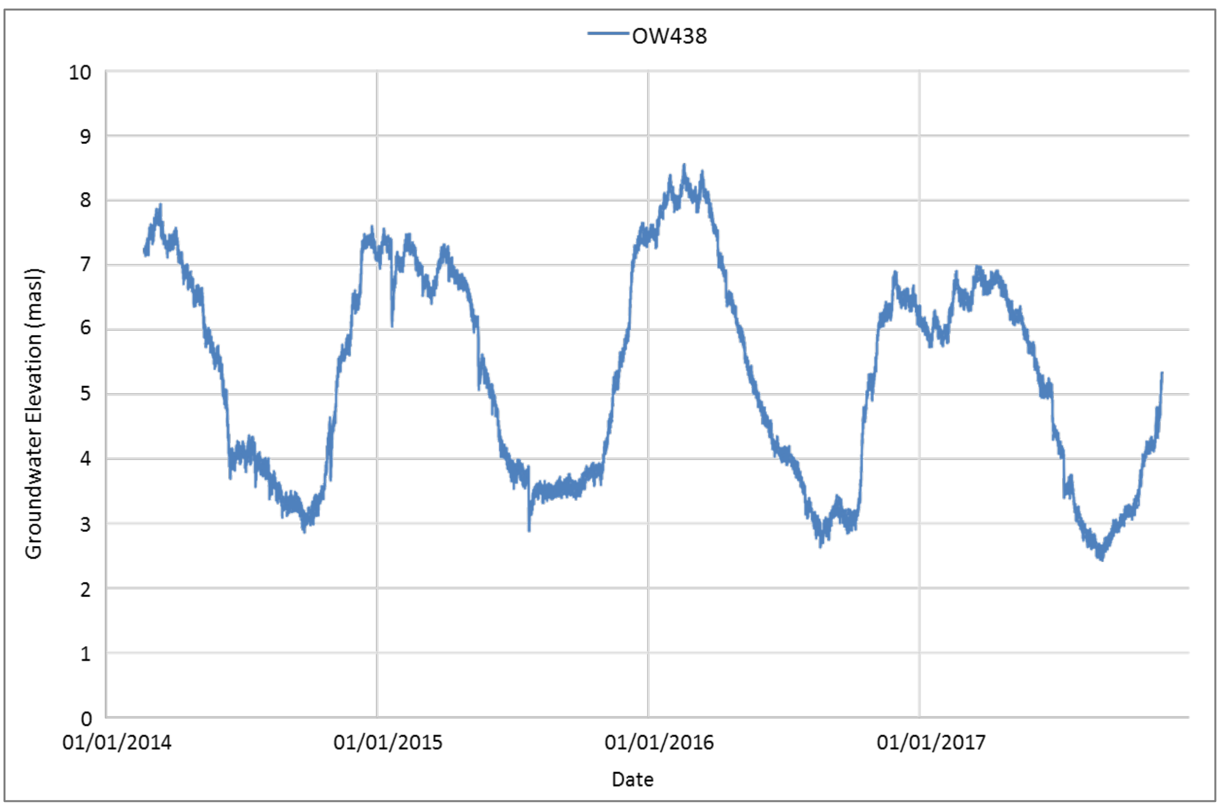

Figure 27: Groundwater hydrograph for PGOWN observation well #438.

Groundwater levels from fifteen community monitoring wells and WSS production and observation wells were obtained by SSIWPA via third-party data sharing agreements, providing valuable insight on groundwater trends and groundwater table fluctuations at distributed locations across the Island (see Figure 4 for locations). Groundwater elevation measurements were taken using a variety of different methods (i.e., datalogger, bubbler tube, manual measurements) in different wells and were also variably affected by pumping for groundwater production. Regardless, the spatial distribution of these groundwater levels across the Island provide robustness and confidence in the conceptualization of the hydrogeological conditions. Selected groundwater hydrographs for various community or WSS wells are presented in Figures 28–33 and a composite plot showing all of the community and WSS wells is presented in Figure 34. These data are further analysed and discussed in Section 5.3.2. An example interpretative analysis of a PGOWN groundwater hydrograph is presented in Figure A-3 in Appendix A. Based on this example, several important observations can be made from the other groundwater hydrographs:

- No obvious annual trend is observed in the groundwater hydrographs and groundwater elevations for most of the wells return to their previous high point at the end of the wet season, regardless of the amount of precipitation received during the wet season or lack of precipitation received during the dry season; and
- Similarly, variations or declining trends observed in dry season groundwater elevations have no correlation to the precipitation received during that year. Assuming no time lag, this suggests that groundwater shortages encountered during the dry season are related to limitations in groundwater storage and the inability for groundwater supply infrastructure to locally draw sufficient water from low permeability rock

Implications for Monthly Aquifer Groundwater Budgets

The hydrogeological and groundwater elevation analysis has important implications on the monthly aquifer groundwater budget analyses:

- The lack of inter-annual trends in the groundwater hydrographs for both the PGOWN and community / WSS wells and the fact that the groundwater elevations tend to reset back to their previous highs after the wet period, irrespective of the amount of wet period precipitation that is received, suggests that aquifers on Salt Spring Island are limited by the ability of the local rock to transmit adequate amounts of groundwater rather than longer term declines in groundwater level and availability (assuming there is no long term time lag effect on aquifer recharge). In addition to the presence or absence of bedrock features capable of transmitting groundwater, well productivity can be dependent on the pumping infrastructure (i.e., well depth, diameter and drilling method);
- Groundwater hydrographs also suggest that, at many locations during the wet season, groundwater levels may reach local maxima based on the storage capacity of the aquifers (Kohut, 2006), whereby additional influx to the aquifer surface is matched by equivalent outflows or runoff. An example groundwater hydrograph analysis is presented in Figure A-3 as a conceptual interpretation in Appendix A; and
- Assuming the lack of inter-annual declines in groundwater level, the question of available groundwater then becomes associated with potential year-round recharge from surface water bodies and managing groundwater storage during the dry season.

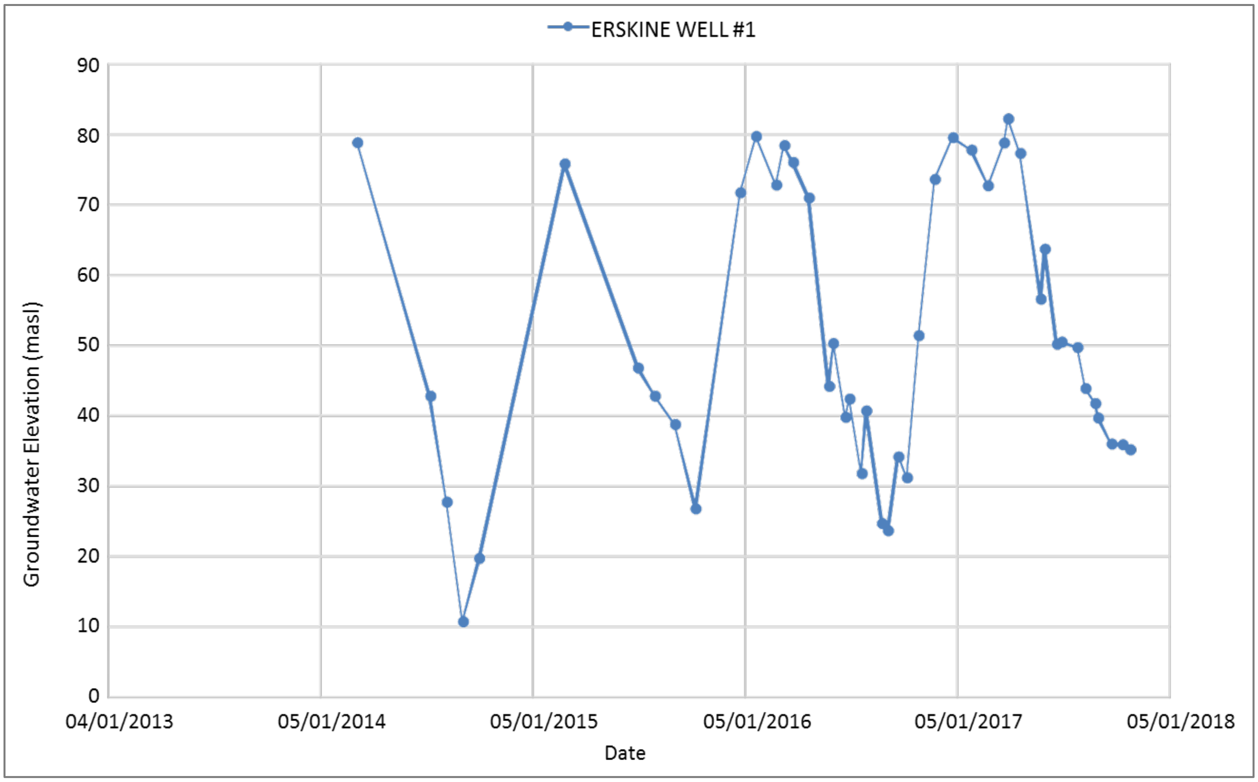

Figure 28: Groundwater hydrograph for Erskine Well #1.

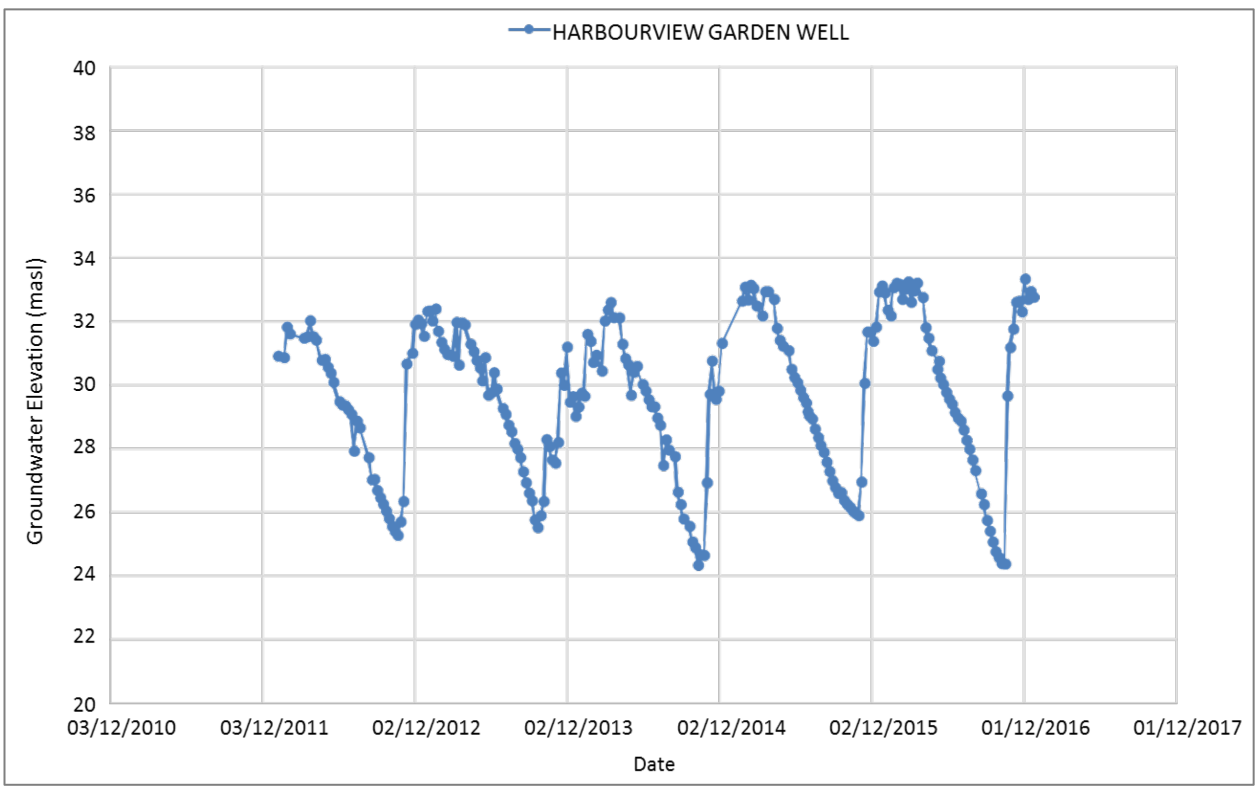

Figure 29: Groundwater hydrograph for Harbourview Garden Well.

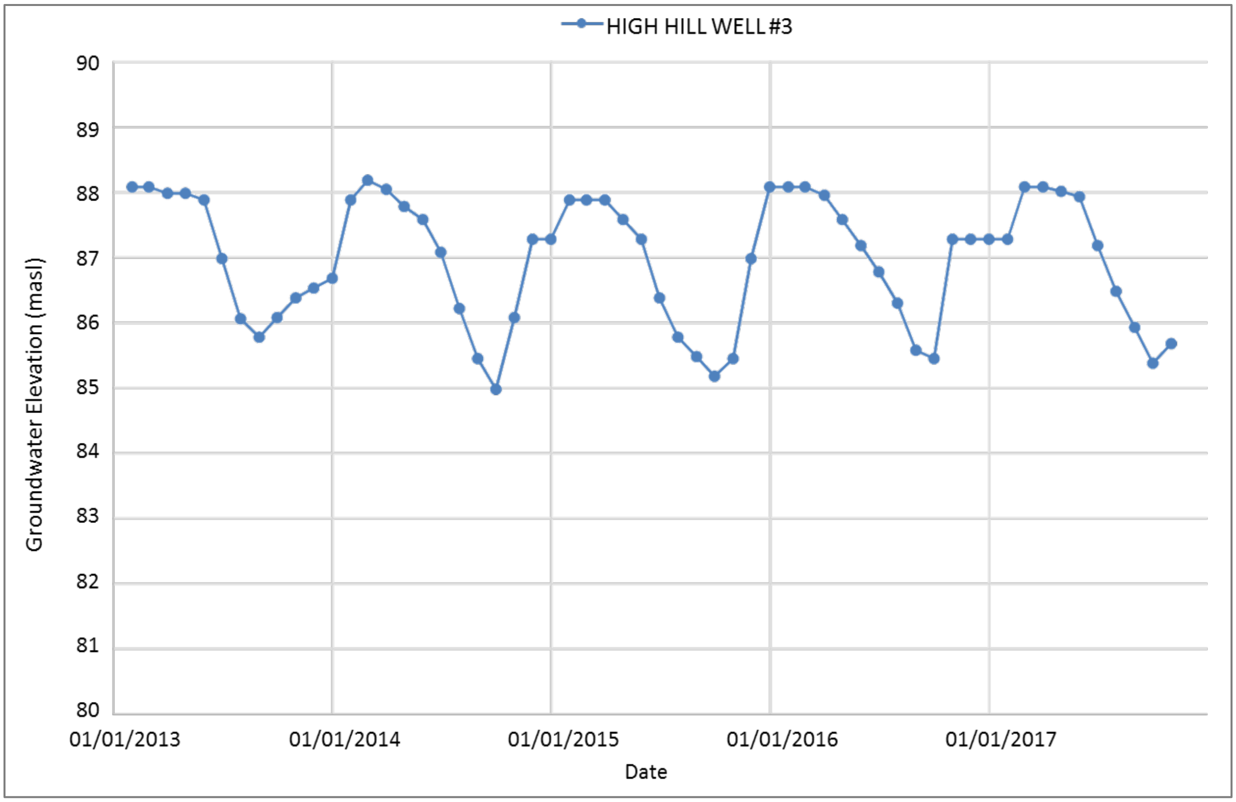

Figure 30: Groundwater hydrograph for High Hill Well #3.

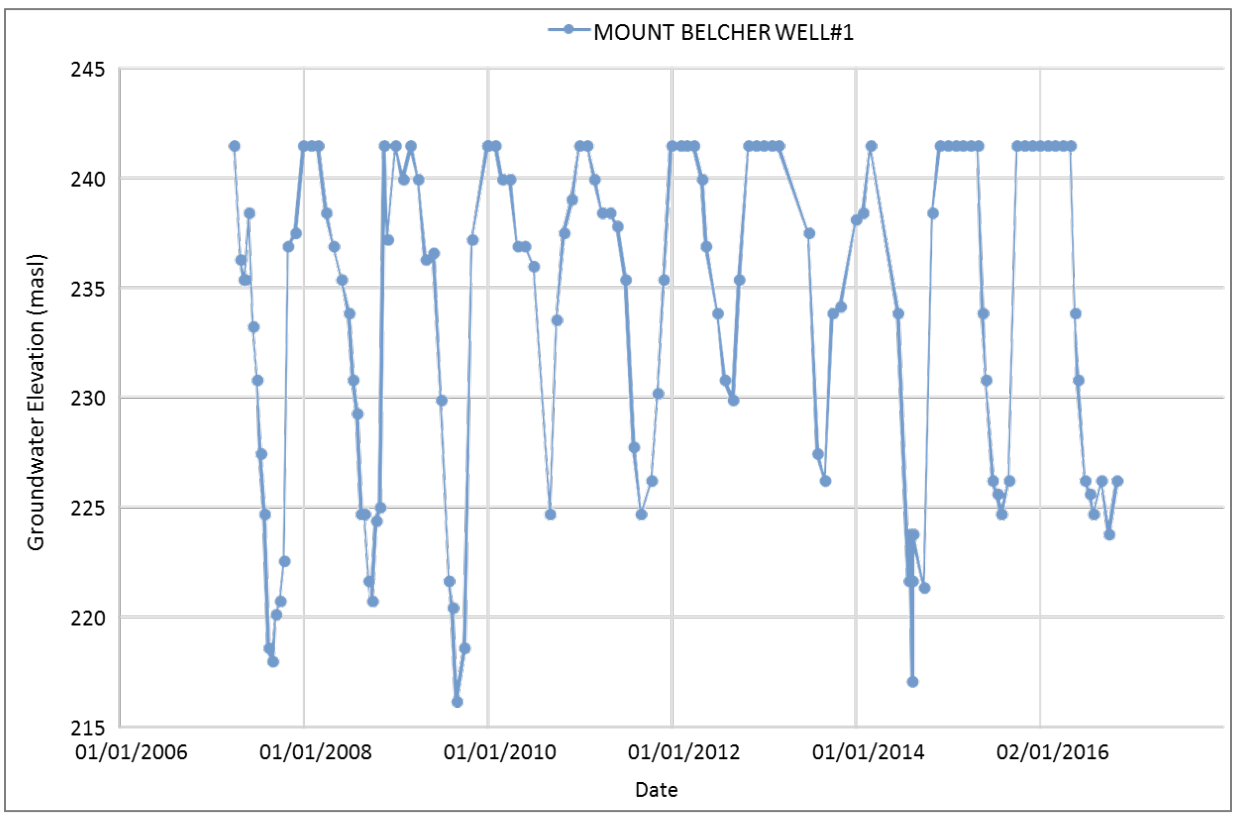

Figure 31: Groundwater hydrograph for Mount Belcher Well #1.

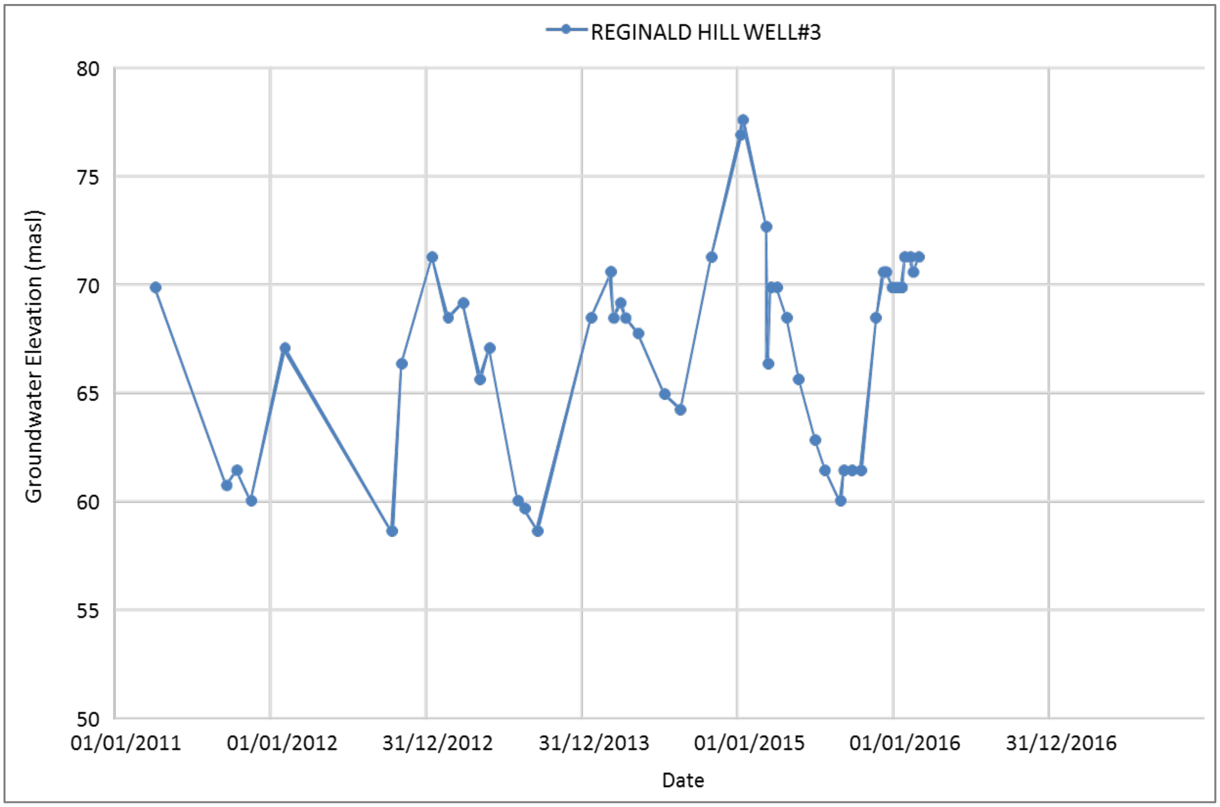

Figure 32: Groundwater hydrograph for Reginald Hill Well #3.

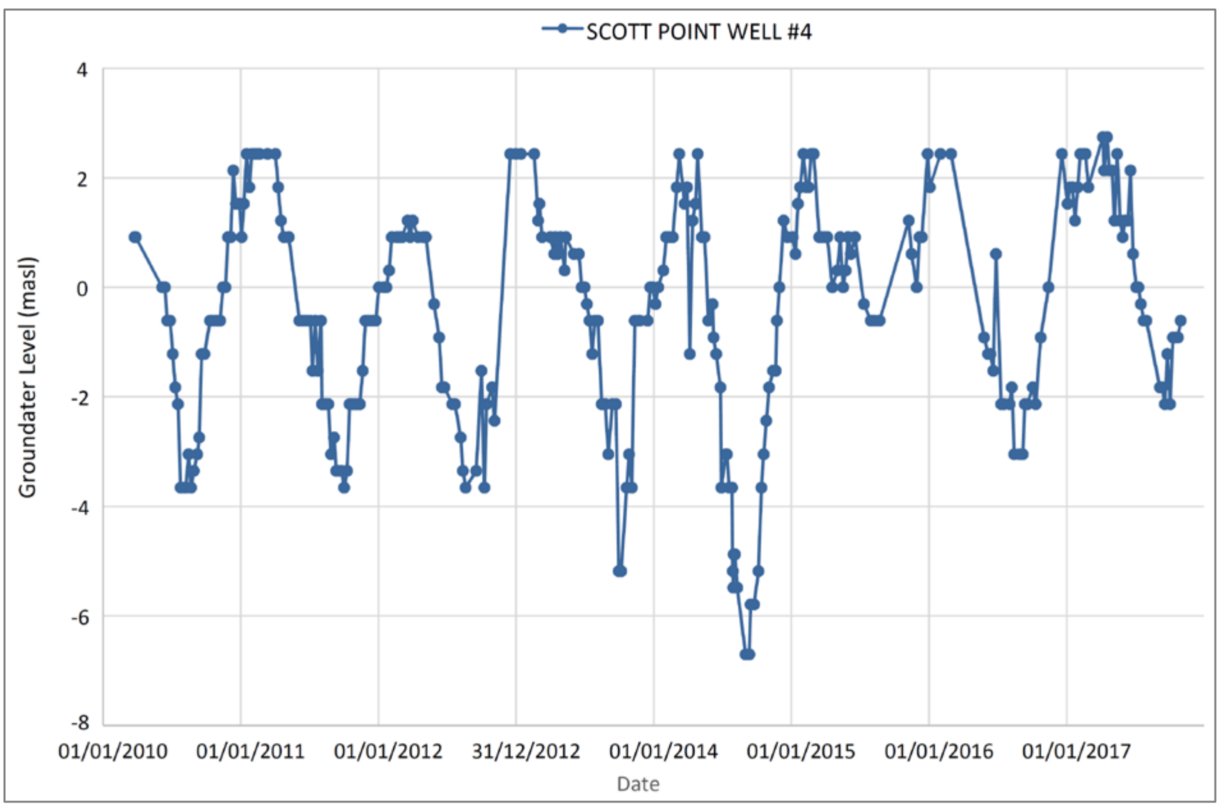

Figure 33: Groundwater hydrograph for Scout Point Well #4.

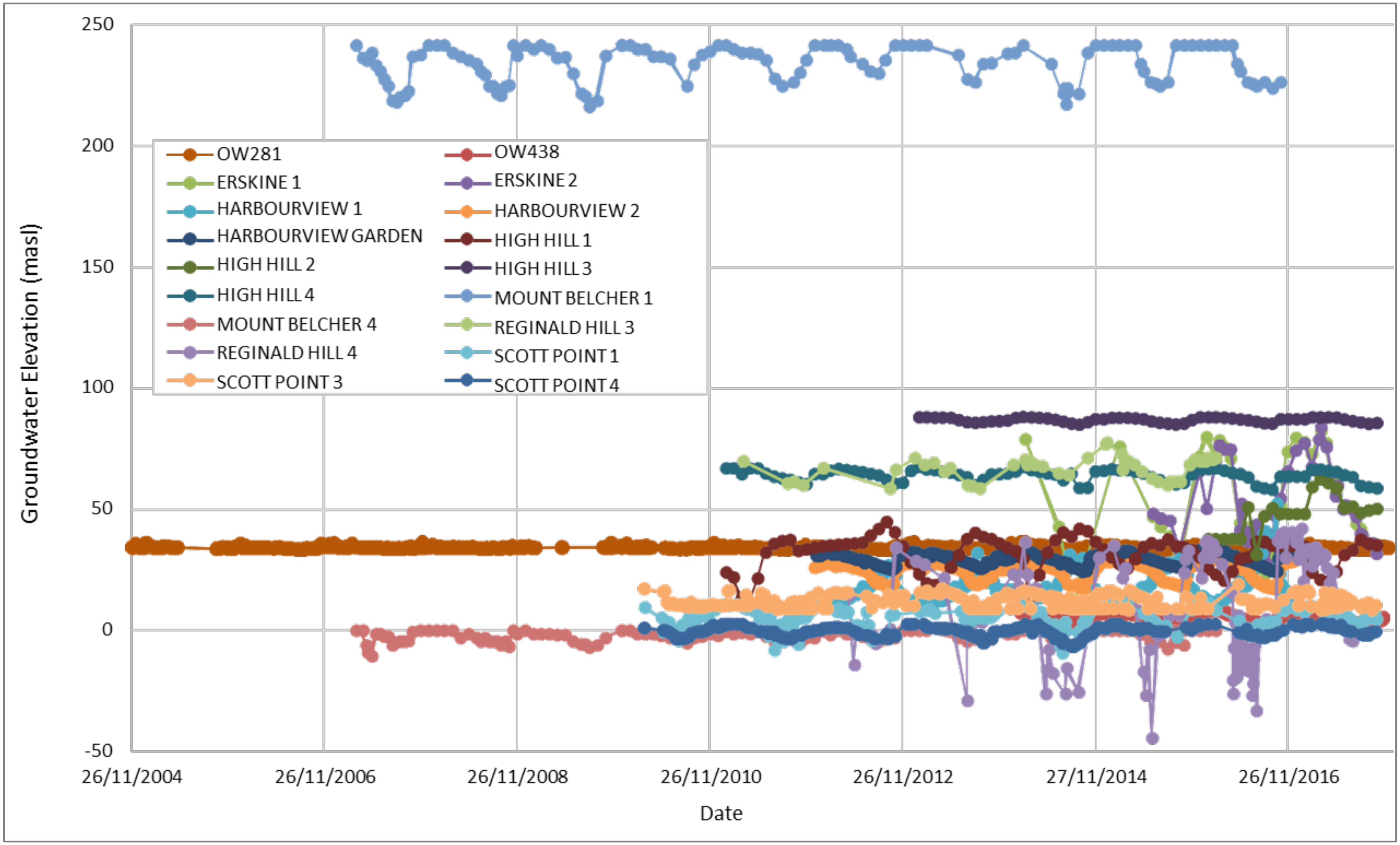

Figure 34: Combined groundwater hydrographs from provincial observation wells and community monitoring wells.

5.2.6 Groundwater Use and Demand

Water is supplied to the Salt Spring residents via private domestic supply wells as well as numerous public Water Supply Systems (WSS), which obtain water either from local surface water or groundwater resources. Figure 2 presents the coverage areas of the Salt Spring Island community WSSs that are listed with the Vancouver Island Health Authority (VIHA), classified as to whether the WSS uses surface water or groundwater as their water supply source. Salt Spring Island is also served by bulk water haulers that service local community members during periods of shortage.

Analysis of Groundwater Use from WSS Areas

The Salt Spring Island Water Protection Alliance (SSIWPA), through extensive community outreach, stakeholder interviews, and data sharing agreements, obtained detailed water production data and survey responses from 12 WSSs on the Island, as well as the Island's sole private water purveyor, the Salt Spring Water Company. Of the 12 WSSs, 11 utilize groundwater as their water supply source and one, the North Salt Spring Water District (NSSWD) which is also the largest water supply system on the Island, utilizes surface water from St. Mary Lake and Lake Maxwell as a water supply source. Table 13 presents the WSSs that provided water production data and survey responses, together with the number of connections associated with each WSS.

Table 13: Summary of WSSs that provided production data and survey responses and actual land use from B.C. Assessment.

Water Supply System (WSS)	Water Source	Number of Connections	Residential	ICI—Industrial/ Commercial/ Institutional [(a)]	Agr/ Farm	Other[(b)]
The Cottages on Salt Spring Island (Bullock Lake Cottages) [(d)]	Groundwater	50	50	0	1	0
Cedar Lane Water System (CRD)	Groundwater	37	42	0	2	2
Cedars of Tuam (CRD)	Groundwater	12	17	0	1	0
Erskine Water Society	Groundwater	33	41	0	0	0
High Hill Water System	Groundwater	9	9	0	0	0
Harbour View Improvement District	Groundwater	21	22	0	1	1
Maracaibo Water System	Groundwater	76	95	0	0	3
Merchants' Mews	Groundwater	25	1	22	0	0
Mt. Belcher Improvement District	Groundwater	52	66	0	0	3
Reginald Hill Water System	Groundwater	20	22	0	0	0
Scott Point Waterworks District	Groundwater	60	58	4	1	0
Swan Point	Groundwater	5	5	0	0	0
North Salt Spring Waterworks District (NSSWD) [(c)]	Surface Water	2418	2147	186	75	43

(a) Includes civic and recreational.

(b) Includes transportation, communication, utility and unknown.

(c) NSSWD and Fernwood/Highland are some of several surface water WSSs on Salt Spring Island; NSSWD was added for reference.

(d) Existing reports were referenced to document number of connections and estimate use.

(e) The last four columns were derived from BC Assessment data.

The NSSWD is, by a large degree, the largest water provider on the Island, both in terms of area (see Figure 2) and number of connections, providing its water from surface water sources. Contrarily, groundwater WSSs tend to be smaller and more local, with fewer connections. The standard industry assumption for the number of people associated with each connection (dwelling or residence) is 2.1 people (CRD 2011). Considerations regarding application of this assumption of water use on Salt Spring are presented below:

- Salt Spring Island has a strong tourism industry, with a sizeable, transient, seasonal increase in population during the summer months;
- In addition to tourism, the Island also has a temporary population, with a number of residences being holiday or second homes;
- Many homes or communities harvest rainwater, have storage cisterns, or activate voluntary water conservation measures during dry periods, which can introduce uncertainty into per capita estimates of water use;
- Many private properties within a WSS area also have a private well on the property that can be utilized as a secondary water supply well, thus reducing the overall per capita estimates of water use for the WSS; and
- The breakdown of water users into residential, commercial, industrial, civic/institutional, and agricultural connections can complicate per capita water use estimation, both within a WSS and external to WSS footprints.

Total monthly water production for all reporting WSSs (surface water and groundwater) for 2016 is presented in Figure 35. A notable increase in monthly water use is observed during the dry summer months, likely owing as mentioned above, to a combination of increased outdoor use and an increase in the summer population of the Island from tourism.

To provide insight on the proportion of various land uses within each WSS that reported production data, a lot-level assessment using the BC Assessment Actual Use cadastral dataset was conducted. The breakdown of the number and type of lots within each WSS is provided in Table 13. Note that the number of lots will not necessarily equal the number of reported connections by WSS, and, due to some minor discrepancies in the cadastral dataset, the intersection between WSS area and lots may not be precise.

The NSSWD, being the largest water supplier, has the greatest diversity in users / connections, with a sizable proportion of Industrial / Commercial / Institutional (ICI), agricultural and other land use lots within its coverage. All of the other smaller groundwater providers are comprised predominantly of residential lots, with the exception of the Merchants' Mews WSS, which services predominantly commercial lots. To understand the range of average daily per capita water use within the various WSSs, monthly production values from multiple wells were aggregated (where possible), divided by the number of connections as provided by the WSS survey and the number of days in the month and then divided by 2.1 people per connection. Figure 36 presents the average daily groundwater use for each month in 2016 for the WSSs. Table 14 presents the average daily water groundwater use for each WSS, together with the monthly "peaking factor", which is the water use during the month with the maximum daily average groundwater use per capita divided by the average daily groundwater use per capita. This monthly interpretation of the peaking factor differs from the peaking factor typically calculated in water demand assessments which often utilize an unaggregated average day demand and maximum day demand for estimation of the peaking factor. As a result, variations in water use within individual months have already been averaged into the peaking factor value and these values will tend to be lower than what may be commonly observed in other reports. This modified peaking factor nevertheless provides a qualitative assessment of the variability in water usage for the associated WSSs.

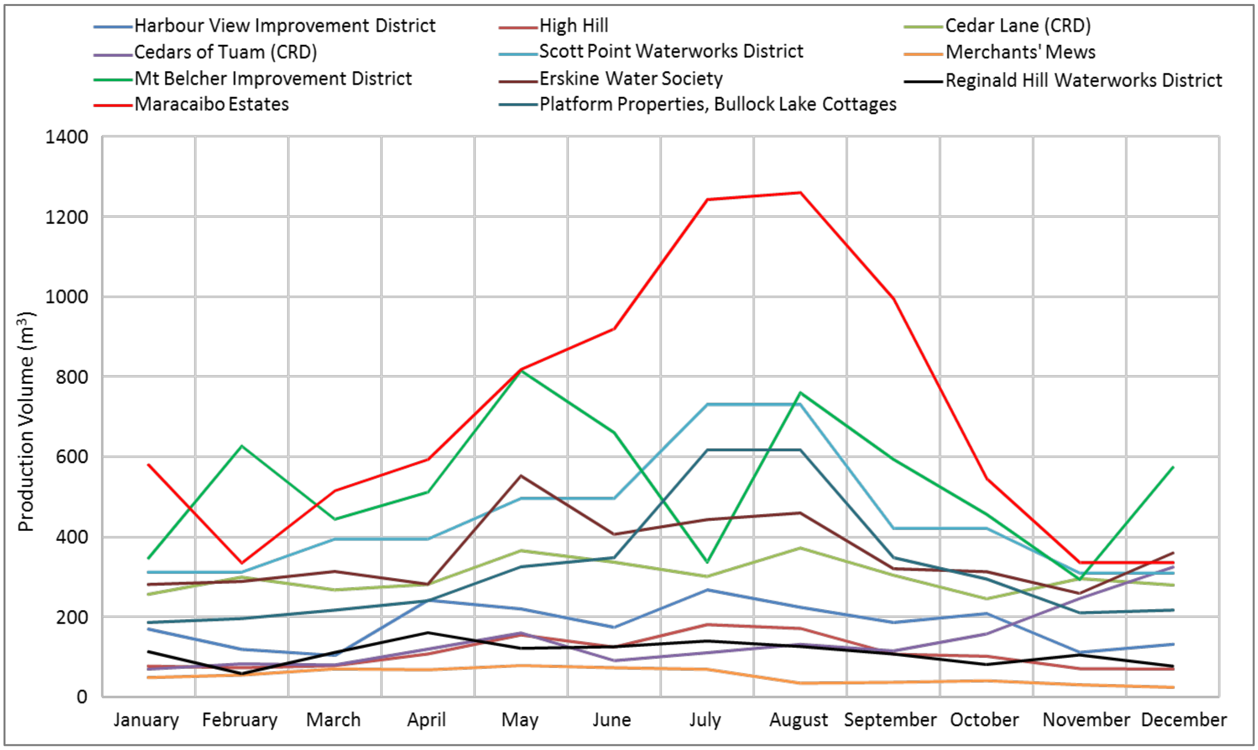

Figure 35: WSS 2016 monthly production volumes.

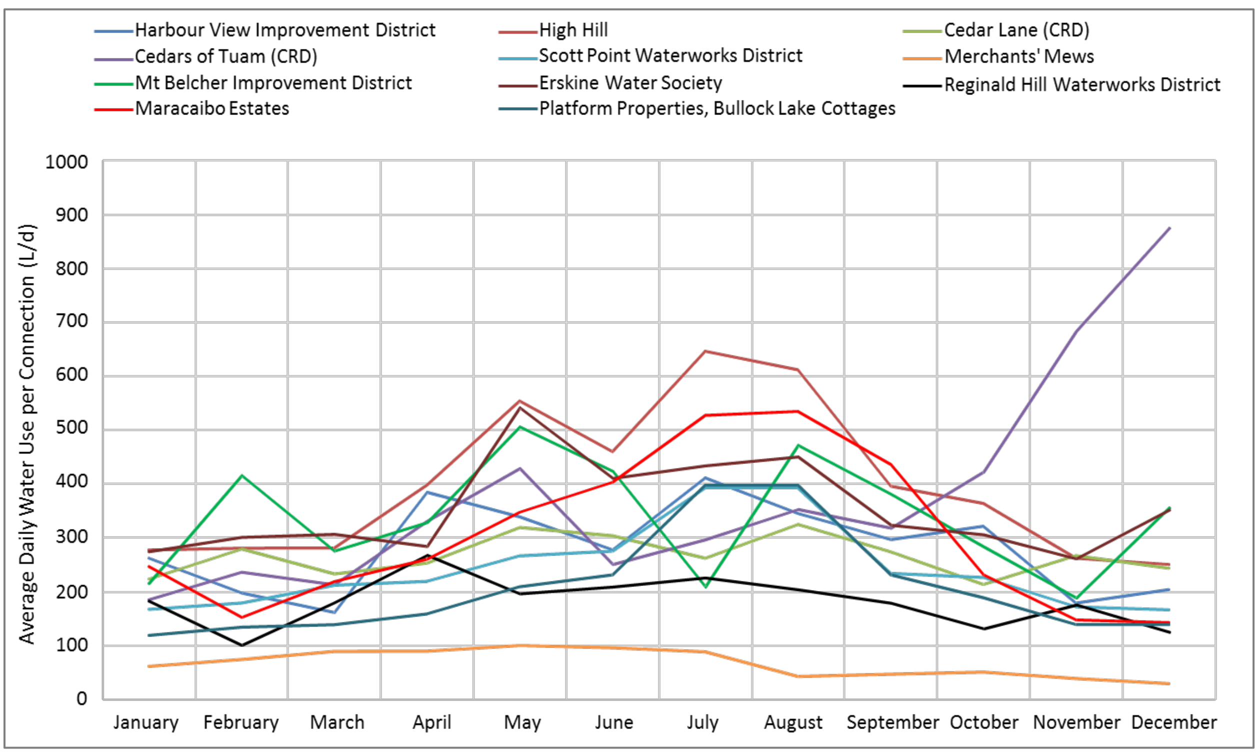

Figure 36: WSS 2016 average daily water use per connection.

Table 14: Summary of per capita groundwater use and monthly "peaking factors" for WSSs.

Water Supply System (WSS) with Available Information	Number of Connections	Average Daily Per Capita Water Use (lpc/d) [a]	Monthly Maximum Average Daily Per Capita Water Use (lpc/d) [a]	Monthly Peaking Factor
The Cottages on Salt Spring Island (Bullock Lake Cottages)	50	99.3	189.5 (July)	1.91
Cedar Lane Water System (CRD)	37	126.9	154.4 (Aug)	1.22
Cedars of Tuam (CRD)	12	182.7	416.8 (Dec) [b]	2.28
Erskine Water Society	33	168.8	257.6 (May)	1.53
High Hill Water System	9	190.0	307.8 (July)	1.62
Harbour View Improvement District	21	134.1	195.7 (July)	1.46
Maracaibo Water System	76	145.2	254.9 (Aug)	1.76
Merchants' Mews (Note: Commercial Use)	25	32.4	47.8 (May)	1.48
Mt. Belcher Improvement District	52	160.6	240.9 (May)	1.50
Reginald Hill Water System	20	86.4	127.5 (April)	1.48
Scott Point Waterworks District	60	115.8	187.3 (Aug)	1.62

(a) lpc/d = litres per capita per day
(b) this value is assumed to be anomalous.

For comparative purposes, average per capita daily metered consumption for the single-family dwellings located in the NSSWD was estimated to be 223 litres per capita per day (lpc/d), the highest of the WSSs that reported production values. It is anticipated that this value is higher than the smaller groundwater-based WSSs as it has a larger proportion of permanent residents and less likely to have its per capita usage numbers affected by the usage confounders mentioned in the bullet points above. The range in the results of the average daily per capita water use for the groundwater-based WSSs highlight the variability in water demand, use, and management across the Island as well as the difficulty in establishing general per capita water use Island-wide in areas where there is no WSS production data to inform estimates. Conversely, the variation in water use also represents an opportunity for water managers on the island, as it can demonstrate potential water use savings that can be accomplished via water conservation, best practices (such as metering and volume-based pricing) and education. A complete understanding of the variation in WSS production volumes is beyond the detail of this study; however, large-scale conceptual factors can be observed in several of the WSSs. For example, residents in many of the water service areas utilize rainwater catchment and storage to offset seasonal use (e.g., Reginald Hill and Scott Point). By disregarding the WSSs that are associated with non-residential land use (Merchants Mews), which have a higher peaking value (i.e., indicator of potential seasonal population, potential errors), as well as the high and low values, the resultant range of average per capita water demand is approximately 115 lpc/d (Scott Point) to 170 lpc/d (Erskine). When taking into account the average per capita water use for single family dwellings from the much larger NSSWD (approximately 225 lpc/d), it is the expected that the actual water use per capita for single family dwellings on a groundwater-based WSS is on the higher side, and potentially higher than the 115–170 lpc/d range due to a combination of seasonal or temporary residents, water conservation, and/or alternate water supply measures.

Analysis of Groundwater Use Outside of WSS Areas

Analysis of groundwater use from users outside of metered WSS areas must consider the following factors:

- Land parcels outside of a WSS may not have an obvious source of water supply associated with it (i.e., point of diversion, groundwater supply well in the database);

- Specific commercial / industrial activities (i.e., bulk water supply, food processing) may utilize comparatively more water than other commercial activities (i.e., shops), making comparisons by commercial land uses challenging; and
- Agricultural water use is highly crop and weather specific and requires detailed information to support its estimation.

In order to address the factors introduced above, analyses were conducted to provide estimates and reduce the associated uncertainty for the groundwater budget terms. Groundwater use from single home domestic supply wells is difficult to quantify because many land parcels that lie outside of WSS service areas do not have a documented well in the provincial database, nor do they have an associated Point of Diversion or surface water source. To address this issue, FLNRORD conducted a geospatial analysis to assign primary and secondary water sources to all land parcels using the methodology adapted from Hatfield (2015) so as to better define the groundwater users on the Island. Table 15 provides a summary of primary and secondary water sources for each land parcel on Salt Spring Island.

Table 15: Summary of primary and secondary water sources for land parcels on Salt Spring Island (Hatfield, 2015).

Water Source	**Number of Lots Designated as Primary Supply**	**Number of Lots Designated as Secondary Supply**
Serviced by a Water Supply System	3308	0
Point of Diversion (surface water license)	344	62
Groundwater Well	2417	505
Other—Bulk Water Purchase/ Rain Water Collection	0	1032
Unknown	0	1599
TOTAL LOTS	6069	6069

Of particular interest to the groundwater budgets from the water source analysis is that it implies the existence of several hundred additional wells than are currently in the provincial WELLS database. Another item of interest is that there are over 500 hundred groundwater wells which may be utilized as a secondary water source, either to a land parcel within a WSS or as a secondary source for lots with a surface water license (Point of Diversion). The implications of both of these observations is that:

- Previously unidentified wells / groundwater sources must be taken into account when estimating per capita or per land parcel groundwater use outside of WSS areas;
- Use of groundwater as a secondary source within WSS areas has the potential to lead to the underestimation of per capita or per land parcel groundwater use within the WSS; and
- To attempt to account for the above, the primary and secondary water source layer, number of lots on the Island, and land use breakdown of those lots outside of WSS areas were used, together with existing information on water use and land use breakdowns within the WSSs where data were available. The assumptions utilized to account for this process are described in further detail below.

In order to extrapolate per capita or per parcel water use from metered WSS areas where the water use is known to areas where the water use is not known (such as areas serviced by WSS that do not meter usage or for parcels outside of serviced areas), the land use must be adjusted. To estimate water use for the different land use parcels external to the WSSs, the assumptions presented in Table 16 were used.

Table 16: Assumptions utilized to estimate water use for different land use classes outside of WSS areas.

Land Use Type	Assumptions Utilized
Residential—Low/Medium Density	Estimate from existing WSS data (NSSWD) with sensitivity analysis
Residential—High Density	Not significant outside of WSS areas
Industrial / Commercial / Institutional (ICI)	Estimate from NSSWD commercial connections
Agricultural	Use Agricultural Water Demand Model (AWDM) from Ministry of Agriculture
Other	Not considered

The use of groundwater for agricultural purposes requires an estimate of crop needs and overall agricultural water demand for farm properties on Salt Spring Island. Concurrent to this study, the British Columbia Ministry of Agriculture undertook an Agricultural Water Demand Modelling (AWDM, Tam and Van der Gulik, 2017) investigation for Salt Spring Island, complete with a lot-by-lot assessment and field-based reconnaissance of the crop type and irrigation method for all agricultural properties on the Island. Agricultural water demand was estimated using a variety of scenarios (wet year, dry year) as well as three future drought years as predicted by climate change runs from standard Canadian GCM runs. Figure 37 presents the agricultural areas where irrigation is in use and where irrigation could be expanded as estimated by the AWDM. Note that crop polygons used for the water demand calculations may not completely encompass the entire area of an agricultural parcel of land and/or may include portions of land on parcels that are not designated as agricultural. This is because the ADWM utilizes aerial photo interpretation and a field-based survey to subdivide land parcels and confirm crop type, providing greater detail into the model. Additional detail on the AWDM model, crop types, and methods used for the agricultural water demand modelling can be found in the associated report (Tam and Van der Gulik, 2017).

Implications for Monthly Aquifer Groundwater Budgets

The groundwater use and demand analysis has the following implications on the monthly aquifer groundwater budget analyses:

- A significant proportion of residents obtain their water from the North Salt Spring Water District (NSSWD) which predominantly sources water from St. Mary Lake and Lake Maxwell. St. Mary Lake, in particular, has a complicated interaction with groundwater, with the lake receiving influx of groundwater from the local topographic highlands and depending on local groundwater hydraulic heads, potentially providing water to the groundwater system. As a major drainage basin, the contributions of surface water / runoff versus groundwater are uncertain;
- Monthly aquifer groundwater budgets rely on per capita estimates to quantify unmetered groundwater use outside of the WSS areas. This is best accomplished by extrapolating per capita estimates from existing WSS production volumes and breakdown of connection numbers / types;
- The FLNRORD geospatial analysis was utilized as an estimate of island-wide primary and secondary groundwater users and is used to extrapolate per capita / per land parcel water demand from WSS areas where the water demand is known to areas outside of the footprint of WSSs; and
- Scenario analyses for the monthly groundwater budget analyses attempts to align climate change years with outputs from the Ministry of Agriculture AWDM in order to increase the reliability of the analyses.

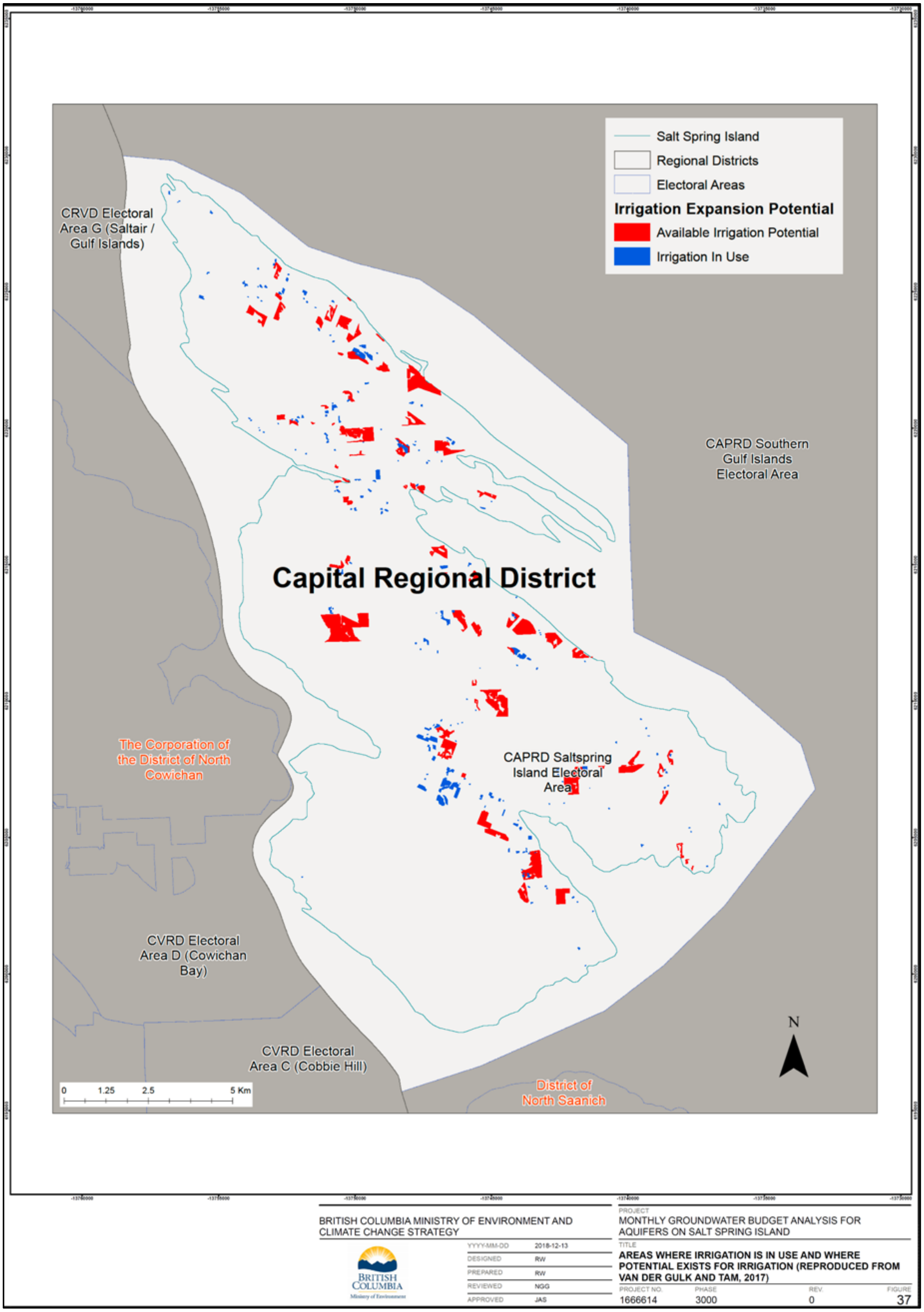

Figure 37: Areas where irrigation is in use and where potential exists for irrigation (Tam and Van der Gulik, 2017).

5.3 Groundwater Budget Equations and Parameterization of Groundwater Budget Terms

5.3.1 Groundwater Budget Terms Excluded from the Analysis

Some of the terms in the groundwater budget equations were excluded from the analysis based on the insights gained from the data compilation and review. A summary of those terms, and the rationale for their exclusion, are presented below.

- Based on the topographic delineation of the bedrock aquifers and the larger-scale delineation of the North-Central and South-Central Salt Spring Island Aquifers, fluxes to aquifers from other bedrock and surficial groundwater does not occur at a significant scale (**Q^{GW}_{in} is negligible**).
- Changes in water elevations associated with large surface water features (lakes, ponds) are not significant enough to affect the magnitude of fluxes to the groundwater regime of the bedrock aquifers at an appreciable level (**ΔS^{SW} and Q^{SWpump}_{out} are negligible**). Major surface water drainage features that are utilized for water supply are assumed to be predominantly influenced by runoff and baseflow inputs from the bedrock aquifers; and
- The contribution of irrigation water **$Q^{IRReturn}_{in}$** and septic returns to groundwater recharge is assumed to be negligible as a conservative assumption for the groundwater balance.

5.3.2 Relationships and Parameterization of Major Groundwater Budget Terms

Parameters that were used as the major groundwater budget terms in the analysis consist of P, Q^{SW}_{in}, R, ET, Q^{SW}_{out}, Q^{GW}_{out}, ΔS^{GW}, Q^{GWpump}_{out}. A discussion of the derivation of each of these terms used in the groundwater budget analysis is presented below.

Groundwater Storage / Water Table Fluctuations

Groundwater in storage was estimated based on possible storativity (storage coefficient) values, estimated aquifer thickness and area of the aquifer using the Water Table Fluctuation, or WTF, method, Healy (2010). The WTF method utilizes the observed variation in groundwater levels from a monitoring well and assumes that these fluctuations are representative of groundwater levels across a given area or aquifer. Under this assumption, the groundwater table fluctuation combined with the assumed storage of the subsurface media constitute the overall change in groundwater volume over a given time.

Selected groundwater level data for wells across Salt Spring Island were presented as part of the hydrogeological analysis in Section 5.2.5. Figure 4 presents the locations of observation wells and WSS wells where groundwater level data is available across Salt Spring Island, understanding that groundwater levels in WSS wells could be impacted by groundwater extraction at that location. Seasonal water table fluctuations associated with these wells were then spatially distributed across the Island and aquifer footprints by creating a set of (four) Thiessen Polygons using well locations where groundwater level data were available.

Utilization of the WTF method / groundwater storage in the groundwater budget analysis requires estimates of the WTF fluctuation as well as estimates on the storage of the bedrock. A generally accepted range of values for interconnected storage of bedrock is considered to be 0.01%–1.0% of the overall volume of the rock, with a value of 0.1% a reasonable average value. Water table fluctuation ranges for wells where groundwater level information data is available and WTFs are observed is presented in Table 17.

Table 17: Annual water table fluctuation ranges for observation and WSS wells.

Groundwater Well	Well Type	Data Range	Approximate Range in Annual WTF (m)[a]
Observation Well #281	PGOWN Well	1983–Current	0.6–3.1 m
Observation Well #373	PGOWN Well	2006–Current	5.9–9.4 m
Observation Well #438	PGOWN Well	2014–Current	4.3–5.9 m
Harbourview Garden Well	Non-Pumping WSS Well	2012–Current	6.1–8.4 m
Erskine Well #1 Well	Pumping WSS Well	2014–Current	53–68 m
Erskine Well #2 Well	Pumping WSS Well	2014–Current	47–52 m
Harbourview #1 Well	Pumping WSS Well	2012–Current	14.2–41.8 m
Harbourview #2 Well	Pumping WSS Well	2012–Current	8.9–12.1 m
High Hill #1 Well	Pumping WSS Well	2012–Current	16.1–30.4 m
High Hill #3 Well	Pumping WSS Well	2012–Current	2.4–3.2 m
High Hill #4 Well	Pumping WSS Well	2012–Current	6.1–8.8 m
Mount Belcher #1 Well	Pumping WSS Well	2007–Current	11.6–25.3 m
Mount Belcher #4 Well	Pumping WSS Well	2007–Current	4.3–10.7 m
Reginald Hill #4 Well	Pumping WSS Well	2012–Current	61.2–79.9 m
Scott Point #1 Well	Pumping WSS Well	2011–Current	4.3–20.5 m
Scott Point #4 Well	Pumping WSS Well	2011–Current	3.0–9.1 m

(a) Maximum and minimum observed WTFs from a year to year basis.

Based on the results presented in Table 17, a clear difference in WTF ranges between the pumping WSS wells and the observation wells / non-pumping WSS wells are observed. The variation in ranges observed in the wells highlights several important conceptual insights:

- Measurements of groundwater levels in pumping WSS wells are usable for conceptual level purposes only (presence / absence of inter-annual or long-term declines, relative degree of seasonal groundwater use) and exact groundwater elevations cannot be relied upon due to effects from pumping; and
- Differences in ranges between pumping WSS wells associated with the same location highlight the locality of the groundwater levels, whereby very large WTFs observed in one pumping well are not observed in nearby pumping wells. This reinforces the heterogeneity in the bedrock aquifers and the uncertainty involved in extrapolating groundwater levels from one location to another, even within the same aquifer.

Due to the variability in pumping WSS wells, Thiessen Polygons were constructed Island-wide and aquifer-wide using only the PGOWN wells and the non-pumping WSS well (Harbourview Garden Well). The Thiessen Polygon method subdivides the areas of the aquifers into polygons based on the closest observation well and then assigns the groundwater level change of that observation well to that area. These Thiessen Polygons are presented in Figure 38 and are used to generate the groundwater storage changes (ΔS^{GW}) for the groundwater budget analysis.

Groundwater Use / Demand

Groundwater use (Q^{GWpump}_{out}) is one of the best characterized processes on Salt Spring Island, owing to the highly detailed data provided by FLNRORD and SSIWPA associated with the WSSs, land use, and geospatial water source assessment. Where WSS groundwater production data were directly available, it was implemented directly into the groundwater budgets for the aquifers. To estimate groundwater use / demand from land parcels outside of the WSS areas, the geospatial analysis of water sources was utilized to identify the number of WSS-external land parcels located in each aquifer where groundwater was estimated to be a primary water source (see Section 5.2.6 for details). For these external parcels, a population of 2.1 people per parcel was assumed and a groundwater use of 225 lpc/d was assigned,

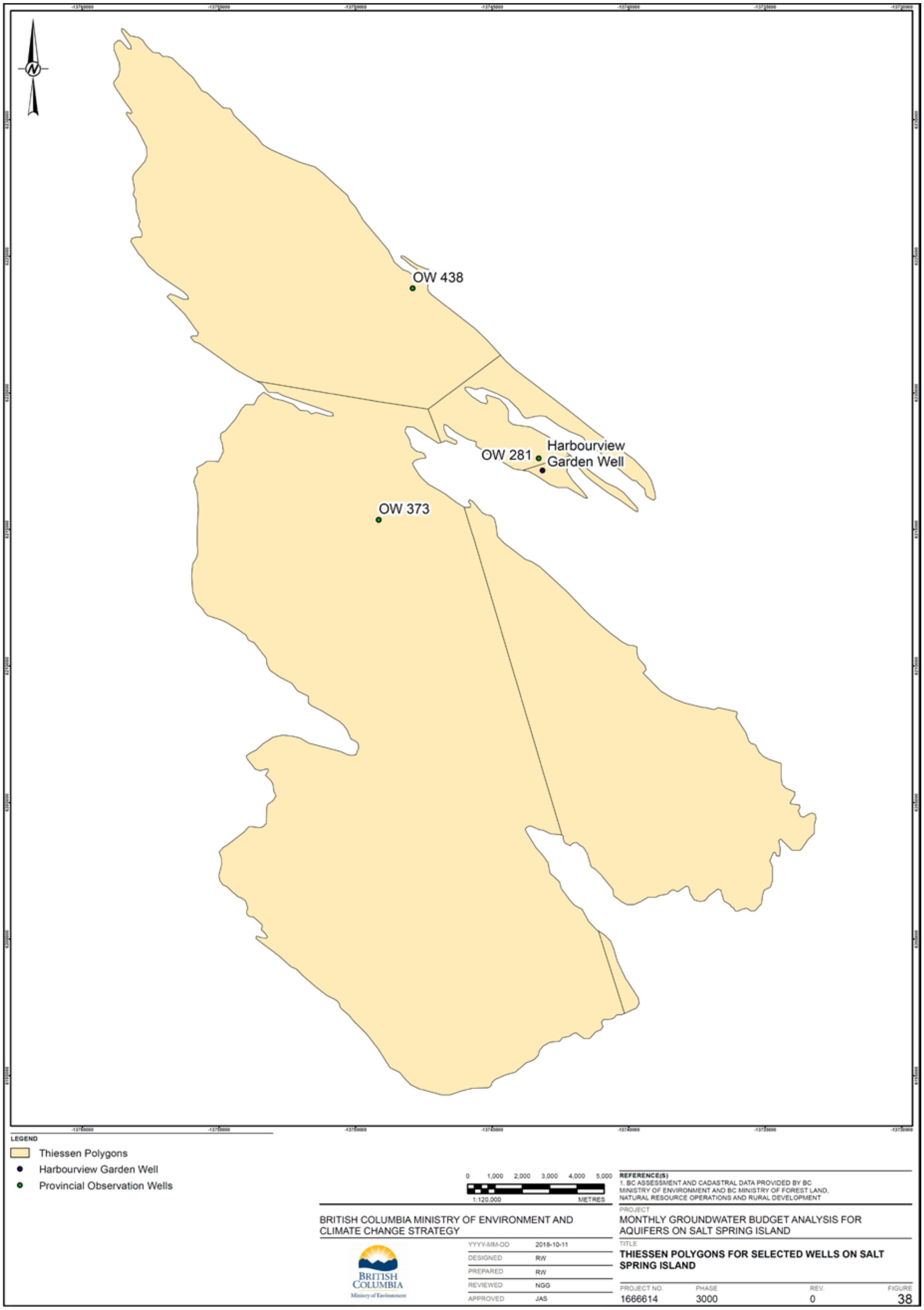

Figure 38: Thiessen polygons for selected wells on Salt Spring Island.

which is based on the average per capita water use of residential parcels in NSSWD in 2016. The NSSWD groundwater use values were selected for external parcels because NSSWD, as the WSS with the largest number of connections, best represented average aggregate demand of year-round residents and, as the largest water use per capita, was more conservative. This value of 225 lpc/d for external parcels is lower than the estimate of 353 lpc/d that was used to estimate regional groundwater licensing requirements by Hatfield (2015) based on Environment Canada's 2011 municipal water use statistics. The 225 lpc/d used in the analysis is considered to be more representative than Environment Canada's estimate given that 1) it was derived from local consumption data, and 2) domestic water usage on the Gulf Islands is typically lower than the national average. Table 18 presents the assumptions used to parameterize groundwater use / demand for the various land use classes.

A summary of the estimated annual groundwater use for each bedrock aquifer, based on the assumptions listed in Table 18, is presented in Table 19.

Table 18: Assumptions utilized for groundwater use / demand estimates.

Groundwater Use /Demand Type	Estimate	Assumptions
Residential / Domestic	115–225 lpc/d averaged annually (225 lpc/d used for parcels external to directly measured WSS production)	Based on WSS production data
Industrial / Commercial / Institutional (ICI)	841 lpd / connection averaged annually over 215 connections	Based on NSSWD 2016 ICI connection data
Agricultural	Direct from AGRI report	Standard AWDM assumptions

Table 19: Estimated annual groundwater use for bedrock aquifers.

Aquifer	Annual Groundwater Use (m^3)			
	Residential	ICI (Indus./Comm./Instit.)	Agricultural	Total
North Salt Spring Island Aquifer	157349	1135	142844	301328
North-Central Salt Spring Island Aquifer	84343	378	60937	145658
South-Central Salt Spring Island Aquifer	83248	675	42930	126853
South Salt Spring Island Aquifer	53941	918	76839	131698

Direct Runoff to Surface Watercourses

Direct runoff from precipitation to surface watercourses was estimated by taking the average monthly surface water discharge estimated using the methods described in Section 5.2.4 and assuming that a percentage contribution of that surface water discharge was sourced from direct runoff. The direct runoff component is also assumed to include shallow subsurface stormflow, a shallow acting component of flow whereby runoff enters the watercourse via the shallow subsurface, but the shallow subsurface is either too shallow or locally saturated for that water to be considered being sourced from the aquifer itself. This type of flow to the watercourse would occur, for example, where the bedrock surface is very high and covered by a thin or discontinuous unconsolidated layer. Water flowing along this contact to the watercourse would enter via the shallow subsurface but would not be considered deep enough to have entered the aquifer proper and be considered baseflow. The relative contributions from the direct runoff and groundwater baseflow components were varied on a monthly basis. During the months of the wet period, surface water discharge was assumed to be comprised mostly of direct runoff or shallow subsurface stormflow (up to a maximum of 90% direct runoff) whereas surface water discharge in the dry period months was assumed to be comprised of mostly groundwater baseflow (up to a maximum of

90% groundwater). To allow the contributions of groundwater baseflow and direct runoff to vary smoothly, the relative contributions were adjusted during the shoulder months.

Natural Groundwater Outflows from Aquifers

Natural outflows from the bedrock aquifers are associated with groundwater outflow to local watercourses which is observed in local streams as baseflow and groundwater flux to the sea ($Q^{GW}{}_{out}$).

For this water balance analysis, groundwater flux to the sea was estimated using Darcy's Law based on estimates of hydraulic gradients, aquifer thicknesses, and aquifer transmissivity / hydraulic conductivity. The hydraulic conductivity values used in the analysis of groundwater flux to the sea are summarized in Section 4.4. Hydraulic gradients were estimated based on the change in topography along the groundwater flow path. For the bedrock aquifers, the groundwater flux to the sea was assumed to occur over a saturated aquifer thickness of 30 m. This value is consistent with the seepage face of groundwater discharge assumed in the Mayne Island groundwater budget analysis (Hy-Geo Consulting, 2015) and similar to the 50 m assumed for the Gabriola Island groundwater budget analysis (Burgess and Allen, 2016). Given the more limited extent of the overburden aquifers, groundwater flux to the sea or to the distal boundary for those aquifers was inferred to occur over a shorter seepage face interval of 5 to 20 m.

Similar to the estimates of direct runoff calculated above, natural groundwater outflows from aquifers to local watercourses were estimated by assuming that a percentage contribution of the surface water discharge estimated in Section 5.2.4 from the aquifer footprint was sourced from groundwater baseflow. As above, the relative contributions from the groundwater and direct runoff components were varied on a monthly basis. During the months of the wet period, surface water discharge was assumed to be comprised mostly of direct runoff or shallow subsurface stormflow (up to a maximum of 90% direct runoff) whereas surface water discharge in the dry period months was assumed to be comprised of mostly groundwater baseflow (up to a maximum of 90% groundwater). To allow the contributions of groundwater baseflow and direct runoff to vary smoothly, the relative contributions were adjusted during the shoulder months.

Recharge

Monthly recharge to the bedrock aquifers was estimated via an analysis and summation of three major components: estimated volume from groundwater storage changes, the estimated volume of baseflow to surface water discharge, and the estimated flux of groundwater to the sea. During the wet period months, changes in groundwater storage were accounted for as recharge, whereas during dry period months changes in groundwater storage were not accounted as part of recharge. The summation of these three components were assumed to comprise the entirety of groundwater recharge.

Precipitation and Evapotranspiration

The total annual average precipitation of 986.9 mm/year from the 1981–2010 Climate Normals (Station #1016995) provides a reference against which the recharge for the various aquifers are compared. Monthly total precipitation values for both the dry (2009) and wet (2010) years were utilized to estimate the impact that the wet and dry year scenarios would have upon the recharge to the aquifers (Section 5.5). Similarly, to estimate the effects of climate change on aquifer recharge (Section 5.6), ClimateBC was utilized to generate monthly precipitation estimates for the year of 2053, which corresponded to a drought year in Ministry of Agriculture's AWDM (Tam and van der Gulik, 2017).

Evapotranspiration was not directly estimated, but was the component used to close the overall water balance by assuming that the remainder of water left over after all of the other components were calculated was equal to the actual evapotranspiration of the area. Note that the warm temperatures and dry conditions experienced during the summer months on Salt Spring Island result in a substantial moisture deficit during this time when the reference / potential evapotranspiration is the highest. As a result, estimates of actual evapotranspiration are expected to be substantially lower than the reference or potential evapotranspiration.

5.4 Monthly Aquifer Groundwater Budget Analysis

5.4.1 Bedrock Aquifers

Based on the site-specific characterization of the hydrogeologic regime, monthly aquifer groundwater budgets were formulated for the bedrock aquifers based on the following assumptions:

- Agricultural demand is not considered during the wet period. During the dry period, agricultural water demand per aquifer as estimated by the AWDM is distributed across the six-month period proportionally to the reference ET for the same time period; and
- ICI water demand for both wet and dry period monthly groundwater budgets is assumed to be constant throughout the months and residential / domestic water demand is distributed based on the monthly peaking factors for the NSSWD which, as the largest provider of water on the Island has the greatest number of connections and best approximates the general domestic monthly use.

Summary level results (precipitation, runoff, recharge, and evapotranspiration) for the monthly aquifer groundwater budget analyses are provided in Tables 20–23, with detailed breakdowns of the various components provided in Appendix B. Results are illustrated in graphic form in Figure A-4 of Appendix A.

Table 20: Groundwater Budget–North Salt Spring Aquifer (AQ 721)—Average Conditions.

Groundwater Budget Term	**Percentage of Average Annual Precipitation (%)** [(a)]	**Volume of Water (m^3)**
Recharge	10.3	4,900,000
Direct Runoff	53.6	25,000,000
Evapotranspiration	36.1	17,700,000
Total		47,600,000
Groundwater Budget Term	**Percent of Estimated Recharge (%)**	**Volume of Water (m^3)**
Estimated Groundwater Use	6.1	301,000

(a) Average annual precipitation is based on 1981–2010 Climate Normals at Salt Spring St. Mary L station (Climate ID# 1016995)

Table 21: Groundwater Budget– North-Central Salt Spring Aquifer (AQ 722)—Average Conditions.

Groundwater Budget Term	**Percentage of Average Annual Precipitation (%)** [(a)]	**Volume of Water (m^3)**
Recharge	11.9	4,300,000
Direct Runoff	53.6	19,200,000
Evapotranspiration	34.4	12,300,000
Total		35,800,000
Groundwater Budget Term	**Percent of Estimated Recharge (%)**	**Volume of Water (m^3)**
Estimated Groundwater Use	3.4	145,000

(a) Average annual precipitation is based on 1981–2010 Climate Normals at Salt Spring St. Mary L station (Climate ID# 1016995)

Table 22: Groundwater Budget– South-Central Salt Spring Aquifer (AQ 1147)—Average Conditions.

Groundwater Budget Term	**Percentage of Average Annual Precipitation (%) [(a)]**	**Volume of Water (m^3)**
Recharge	11.1	5,300,000
Direct Runoff	53.7	25,800,000
Evapotranspiration	35.2	17,000,000
Total		48,100,000
Groundwater Budget Term	**Percent of Estimated Recharge (%)**	**Volume of Water (m^3)**
Estimated Groundwater Use	2.4	127,000

(a) Average annual precipitation is based on 1981–2010 Climate Normals at Salt Spring St. Mary L station (Climate ID# 1016995)

Table 23: Groundwater Budget– South Salt Spring Aquifer (AQ 723)—Average Conditions.

Groundwater Budget Term	**Percentage of Average Annual Precipitation (%) [(a)]**	**Volume of Water (m^3)**
Recharge	10.6	5,400,000
Direct Runoff	53.6	27,200,000
Evapotranspiration	35.8	18,100,000
Total		50,700,000
Groundwater Budget Term	**Percent of Estimated Recharge (%)**	**Volume of Water (m^3)**
Estimated Groundwater Use	2.5	132,000

(a) Average annual precipitation is based on 1981–2010 Climate Normals at Salt Spring St. Mary L station (Climate ID# 1016995)

As shown above, the resultant recharge calculated for the aquifers ranged from 10–12% of mean annual precipitation. In order to calibrate the recharge estimated from the water budget analysis, recharge was estimated with an alternative method using a chloride mass balance analysis developed by Wood and Sanford (1995). The equation for this mass balance analysis is:

$$q = (P)\,(Clwap)/Clgw \qquad \text{(Eq.6)}$$

where:

q = the recharge flux (mm/yr)
P = average annual precipitation (mm/yr)
Clwap = precipitation-weighted mean chloride concentration in precipitation (mg/L)
Clgw = average chloride concentration in groundwater (mg/L)

The method is based on the premise that the mass of chloride in precipitation falling on the area is preserved in recharge; therefore, the increased concentration of chloride in the groundwater system reflects the amount of water that has been evaporated and therefore the amount of recharge. The method is highly simplified in that it assumes there is no overland run-off or other non-evaporative losses of precipitation falling on the area of interest. A precipitation-weighted mean chloride concentration in precipitation data of 1.33 mg/L was obtained from Environment Canada's NatChem/Precipitation Chemistry Database for Saturna Island station (between 2000–2002 and 2005-2007). Representative chloride concentrations for groundwater of 2.89 mg/L to 80 mg/L were derived from a database of 146 private wells that were sampled on Salt Spring Island from 2007 through 2008 as part of a geochemical sampling program conducted by FLNRORD (Lapcevic et. al., 2008). The ratio of chloride concentrations in groundwater relative to those in precipitation results in an estimated recharge ranging from 10-15%. Figure A-5 in Appendix A presents a histogram showing the estimated recharges for the private wells, based on the chloride mass balance, expressed as a percentage of the average annual precipitation.

The estimated recharge of 10–12% of mean annual precipitation is consistent with the 10–15% recharge derived from the chloride mass balance analysis. This recharge falls within the range of 3–45% of mean annual precipitation estimated by Larocque, et al (2014) for Salt Spring Island, but below the 17–26%

referenced for Gabriola Island by Burgess and Allen (2016) and the 15-30% referenced for Mayne Island by Hy-Geo Consulting (2015). In our opinion, 10–12% recharge is considered to be a reasonable estimate of recharge for bedrock aquifers in coastal areas such as Salt Spring Island that are characterized by relatively high relief.

5.4.2 Overburden Aquifers

Recharge to the overburden aquifers is derived from precipitation, with the potential for some groundwater inflow from bedrock aquifers. Monthly water budgets were estimated for the four overburden aquifers by assigning recharge derived from the bedrock water budget analysis to the overburden aquifers based on relative area. Natural outflows were estimated based on the methodology described in Section 5.3 and groundwater usage was assumed to be negligible (based on the limited number of wells). Due to the limited available data and the low use of the overburden aquifers as a water supply, the groundwater budgets for these aquifers are highly simplified. The simplified groundwater budget analyses for the overburden aquifers are presented in Appendix B.

5.5 Scenario and Climate Change Analysis for Monthly Aquifer Groundwater Budgets

Scenario analyses were conducted to evaluate the impact that wet and dry years, as well as climate change, could have on the availability of groundwater on Salt Spring Island. Monthly precipitation values for the wet (2010), dry (2009), and climate change (2053) years were utilized to scale the monthly recharge values of the average year (1981-2010). Tables 24-27 summarizes the estimated changes in recharge as a result of the scenario analyses.

Table 24: Summary of Scenario Analysis Results – North Salt Spring Island Aquifer (AQ 721).

Scenario Year	**Percent Change in Recharge[a]**	**Resultant Recharge**	
		Volume (m^3)	**Percent of Average Annual Precipitation[b] (%)**
Wet Year (2010)	16.4	5,720,000	12.0
Dry Year (2009)	-31.1	3,380,000	7.1
Climate Change (2053)	-13.4%	4,250,000	8.9%

(a) Change in recharge is in comparison to recharge estimates from the groundwater budget for the average year
(b) Percentage change for resultant recharge is expressed as the percentage of the average annual precipitation for the 1981-2010 Climate Normals at Salt Spring St Mary L station (Climate ID# 1016995)

Table 25: Summary of Scenario Analysis Results – North-Central Salt Spring Island Aquifer (AQ 722).

Scenario Year	**Percent Change in Recharge[a]**	**Resultant Recharge**	
		Volume (m^3)	**Percent of Average Annual Precipitation[b] (%)**
Wet Year (2010)	16.8	4,990,000	13.9
Dry Year (2009)	-31.7	2,920,000	8.2
Climate Change (2053)	-13.4%	3,700,000	10.3%

(a) Change in recharge is in comparison to recharge estimates from the groundwater budget for the average year
(b) Percentage change for resultant recharge is expressed as the percentage of the average annual precipitation for the 1981-2010 Climate Normals at Salt Spring St Mary L station (Climate ID# 1016995)

Table 26: Summary of Scenario Analysis Results – South-Central Salt Spring Island Aquifer (AQ 1147).

Scenario Year	Percent Change in Recharge(a)	Resultant Recharge	
		Volume (m^3)	Percent of Average Annual Precipitation(b) (%)
Wet Year (2010)	16.2	6,200,000	12.9
Dry Year (2009)	-32.1	3,630,000	7.5
Climate Change (2053)	-13.4%	4,620,000	9.6%

(a) Change in recharge is in comparison to recharge estimates from the groundwater budget for the average year
(b) Percentage change for resultant recharge is expressed as the percentage of the average annual precipitation for the 1981-2010 Climate Normals at Salt Spring St Mary L station (Climate ID# 1016995)

Table 27: Summary of Scenario Analysis Results – South Salt Spring Island Aquifer (AQ 723).

Scenario Year	Percent Change in Recharge(a)	Resultant Recharge	
		Volume (m^3)	Percent of Average Annual Precipitation(b) (%)
Wet Year (2010)	15.4	6,190,000	12.2
Dry Year (2009)	-32.5	3,630,000	7.1
Climate Change (2053)	-13.4%	4,650,000	9.2%

(a) Change in recharge is in comparison to recharge estimates from the groundwater budget for the average year
(b) Percentage change for resultant recharge is expressed as the percentage of the average annual precipitation for the 1981-2010 Climate Normals at Salt Spring St Mary L station (Climate ID# 1016995)

5.6 Assessment of Available Groundwater

The results of the water budget analysis show that for the bedrock aquifers on Salt Spring Island, groundwater recharge represents approximately 10% to 12% of the annual average precipitation, surface water runoff represents approximately 54%, and evapotranspiration represents approximately 34% to 36% (Table 28). Currently, groundwater usage represents a fraction (0.3% to 0.6%) of the average annual precipitation, or 2.4% to 6.1% of the total estimated recharge. Groundwater outflow to local water courses (as baseflow) and groundwater flux to the sea represent components of groundwater recharge estimated to be approximately 9% and 1% to 3%, respectively, of the annual average precipitation.

Table 28: Summary of groundwater budgets for bedrock aquifers.

Groundwater Budget Term	Percentage of Average Annual Precipitation (%)	Percentage of Estimated Recharge (%)
Recharge	10-12	
Direct Runoff	54	
Evapotranspiration	34-36	
Groundwater Use	0.3-0.6	2.4-6.1

While the results of the water budget analysis suggest that on a regional basis there is potential for further development of bedrock aquifers on Salt Spring Island, insights from the study indicate that future groundwater development will be constrained by the storage capacity and transmissivities of the bedrock aquifers. This storage capacity is highly variable based on the heterogeneity of local geological contacts, fractures and faults.

All available water on Salt Spring Island ultimately comes from precipitation and annual precipitation patterns on the Island are characterized by marked wet (October–March) and dry (April–September) periods. Groundwater level maxima have not been observed to change on a year-to-year basis, regardless of the amounts of wet and dry period precipitation. As inter-annual groundwater levels have not been changing (in those wells shown in Figure 34 for which water-level monitoring data is available), the groundwater regime appears to be recharged annually on a regional basis, even in years characterized by low rainfall. This concept is illustrated in Figure A-6 of Appendix A. This indicates that there is not a lack or shortage of available groundwater associated with the Salt Spring Island bedrock aquifers on a regional basis at this time based on the current observational data. This does not mean that local shortages of available groundwater do not exist; the low transmissivity / hydraulic conductivity of the rock on Salt Spring Island means that groundwater use from individual wells can commonly exceed the capacity of the local rock to bring water to the well when the well is installed in lightly fractured and non-fractured rock or the fracture network intersected by the groundwater well is poorly connected to a larger source. In this case, local groundwater level declines and well capacity issues are observed, together with declines in dry season groundwater levels, in essence a local "hydrogeological drought", which is not indicative of the availability of water in the nearby wells or land parcels. These locally isolated groundwater level declines can also be observed in the high degree of variability in groundwater levels from multiple wells that are installed in the same WSS area or location. This concept is illustrated in Figure A-7 in Appendix A. Given variability of groundwater availability at a local level, detailed hydrogeological investigations will be required to assess the feasibility of future groundwater extraction on individual land parcels where development is planned.

From a hydrogeological perspective, optimal locations for future groundwater supply development would include higher-permeability, persistent structural features with a degree of hydraulic connectivity to areas of higher recharge (i.e. higher elevations or local areas where runoff would collect and infiltrate). This concept is illustrated in Figure A-8 of Appendix A. Locations with a larger, undeveloped catchment area would be comparatively less likely to pull water from environmental flows and cause interference effects and would have a comparatively larger amount of storage. Wells near higher elevations and the topographic break would be expected to benefit from more consistent hydraulic heads, potential flowing artesian conditions, and would be less likely to be impacted by seasonal changes. Based on these criteria, the lower slopes of South and Central Salt Spring Island would be preferential locations for future groundwater development, with the north-facing slopes of the North-Central Salt Spring Island Aquifer being closer to larger population centres.

As the dynamics and connectivity between the larger surface water bodies and the local groundwater systems may be small in comparison to the volumes of water use / demand, it may be possible that additional groundwater development could take place within the footprint of an area that is predominantly serviced by surface water, without negatively impacting the availability of surface water from that source, however further study would be required. Areas of North Salt Spring Island, such as west or north of St Mary Lake, would be potential locations. Parallel efforts to quantify water availability for St. Mary Lake and Lake Maxwell (Kerr Wood Leidal, 2018) are focused on the sections of the hydrological cycle that are less relevant or not well captured as part of this assessment and should be considered complementary to the findings presented in this report. Any potential future groundwater extraction should be coupled with appropriate hydrogeological monitoring.

Though groundwater elevations tend to return to their previous high point at the end of the wet season regardless of precipitation, seasonal groundwater shortages in the dry season are observed across the island due to local exhaustion of groundwater storage. As a result, groundwater availability and the likelihood of supply problems on Salt Spring Island are likely more sensitive to the overall duration of the dry period as opposed to the amount of precipitation received during that dry period. A prolonged dry period would mean island residents would be drawing from storage earlier in the year, increasing the likelihood of shortages later in the year. Estimates of reductions in recharge due to climate change are lower than estimates of reductions in recharge for a representative dry year; however, it is acknowledged that with climate change, the duration of the dry season is expected to increase, together with groundwater demand.

For the overburden aquifers, the water budget analysis demonstrates that the volume of groundwater flowing into the surficial aquifers is largely equivalent to the volume of groundwater flowing out. In areas where the unconsolidated aquifers have been mapped, most drillers chose to complete wells in the underlying bedrock aquifers rather than the overlying surficial material. This, combined with the highly variable nature of the surficial material and its glacial origin, suggests that the unconsolidated aquifers may not be particularly productive. Accordingly, while the unconsolidated aquifers may provide a source of minor, local groundwater supply, they should not be targeted for future groundwater development.

Maintenance of Groundwater Levels

As mentioned in the previous subsection, no evidence of long-term groundwater level declines is observed in the available data. Maintaining existing groundwater levels is important both from the standpoint of sustainability of the resource as well as ensuring that seasonal low groundwater levels do not decline to the degree where baseflow to creeks and watercourses decline and affects the environmental flow and ecological integrity of the watercourse. To this degree, monitoring of groundwater levels near streams and habitat is likely to be less effective than direct monitoring of surface water flows in these features. It should be noted that the recommendation to increase the potential for groundwater storage (by improving groundwater supply infrastructure and promoting infiltration to the subsurface) as mentioned in the previous subsection would also have the dual effect of increasing baseflow to watercourses as a result of the increased groundwater levels. Due to the complexity and heterogeneity of the system, scenario or climate change analysis is unable to predict what level of water use is “sustainable” in the context of groundwater levels.

Salt Water Intrusion

A detailed analysis of groundwater quality was not performed as part of this study; however, particular concern was given to the occurrence and potential for saline intrusion in groundwater wells, in particular coastal wells. As part of the data gathering phase of the project, SSIWPA conducted detailed surveys with WSS managers who operated or had knowledge of the local water supply system. Several WSS contacts, particularly for WSS systems near the coast, noted the presence of elevated electrical conductivity and salinity in some of their water production wells, some of which required operational adjustments to mitigate the potential impact.

The potential for salt water intrusion in Salt Spring Island aquifers has been documented by Klassen and Allen (2016). The SFU study mapped the susceptibility of Salt Spring Island aquifers to salt water intrusion based on proximity to the shoreline and estimates of groundwater flux from topography and inferred hydraulic conductivity. Areas close to the shoreline and where the groundwater flux was inferred to be low were identified as having a high susceptibility to salt water intrusion. Areas where the greatest risk of salt water intrusion were identified are located in the north part of the Island along the northeast coast and in the Ganges Harbour/Long Harbour area.

Well record reports of saline conditions that were extracted from the WELLS database as part of this study confirmed the potential for salt water intrusion in coastal areas. FLNRORD’s Best Practices for the Prevention of Saltwater Intrusion, based on the Klassen and Allen (2016) evaluation of groundwater quality in the Gulf Islands, identifies wells containing groundwater with chloride concentrations greater than 150 mg/L, specific conductivity greater than 1000 µs/cm, or total dissolved solids greater than 700 mg/L to be affected by saltwater intrusion. Operation of wells with groundwater quality above these thresholds may impact adjacent groundwater users in an area and cause long-term or permanent damage to the aquifer. In addition to proximity to the shoreline and groundwater flux, the potential for salt water intrusion increases with well depth and is higher for those bedrock wells where the structures intersected by a given well are well-connected to the sea. Interestingly, the WELLS database contained isolated wells reporting saline conditions located near St. Mary Lake along the St. Mary fault, which raises the question of whether the fault may provide a preferential connection to the sea.

Salt water intrusion represents a real concern to groundwater availability in certain areas of Salt Spring Island, one of which is already observed and managed in some coastal WSS systems and which is undoubtedly observed in numerous other private wells across the Island. Saline intrusion in groundwater wells during the dry period is currently observed and does have the potential to impact the amount of available groundwater on a year-to-year basis. Groundwater resources in these incidences must be carefully managed, particularly in coastal wells or high yielding wells with good connectivity to the sea.

Maintenance of Baseflow

Determining the amount of groundwater that is needed for maintenance of baseflow conditions is contingent on the environmental flow needs and hydrologic regime of a given watercourse. As a result, it is difficult to assess without the proper data and long-term understanding of the watercourses involved. FLNRORD and SSIWPA are taking steps to conduct low flow surveys as well as continuous water level and temperature readings. It should be noted that historical WSC data also noted no flow conditions in the seasonal monitoring of some of the watercourses over a multi-year basis so intermittent streams may be a normal part of the hydrological system of Salt Spring Island.

5.7 Groundwater Budget Uncertainty

Detailed data on groundwater use was made available for this study thanks to the joint efforts of FLNRORD and SSIWPA. Accordingly, there is a relatively high level of confidence (+- 35%) in the water usage data used in this study. Similarly, there is a high level of confidence (+-25%) in the precipitation data obtained from Environment Canada and Climate BC. There is a moderate level of confidence (+-100%) in the estimates of changes in groundwater storage and natural outflows (flow to the sea).

For the components of the groundwater budget related to groundwater recharge and direct runoff, there is a low level of confidence given the limited stream flow data available. The actual volumes of groundwater recharge and direct runoff may differ by an order of magnitude or more from those estimated. Given that recharge and direct runoff represent the largest components of the groundwater budget, the overall groundwater budgets are subject to considerable uncertainty.

6. RECOMMENDATIONS TO ADDRESS DATA LIMITATIONS

Recommendations to address data limitations have been developed based on the results of Phases 1 and 2. Types of recommendations are tailored towards three main objectives: improvement of the hydrogeological understanding of the Island, improvement of groundwater budgeting estimates, and improvement of available water and other hydrogeological concerns.

6.1 Recommendations for Improving the Hydrogeological Understanding of the Island

- It is recommended that the North Salt Spring Island and North Central Salt Spring Island Aquifers be prioritized for future work, including the work related to geological and hydrogeological surveys and the hydrometric, meteorological and saline intrusion monitoring described below, as they have the highest population density, local water demand, potential for salt water intrusion and greater risk of supply constraints;

- Additional insight into the local hydrogeology could be gained through a geological survey by an appropriate mapping authority to identify smaller-scale lineaments and faults that could act as potential hydrostructural controls for groundwater flow. Notes from the geological mapping suggest that numerous smaller scale structural features were mapped or noted but not included on the 1:25,000 scale. Dr. Greenwood hypothesizes that SW-NE oriented faults that cut across several lithologies are of interest as potential conductive features;
- Conduct an island-wide spring survey of likely locations (areas of hydrostructural interest, lowland areas and areas of high topographic relief) to provide insight on the groundwater flow regime and identify areas of potential groundwater supply;
- Field confirmation of high-yielding wells identified in the original well records to establish potential presence of high yielding structures, such as faults, fractures and geological contacts;
- Identification and field confirmation of abandoned wells or wells volunteered by residents that can be incorporated into a community monitoring well network to establish island-wide coverage for reliable hydraulic head monitoring. Preferably, selected wells would be completed across a highly conductive zone as the combination of high conductivity and structural persistence would make the well more likely to be responsive to larger scale variation in groundwater levels and would be more representative of groundwater availability in the local area. These wells would also be expected to be the first wells to exhibit long-term declines in groundwater levels due to climate or local overuse. We understand that Islands Trust, SSIWPA and FLNRORD are in the process of establishing a network of community monitoring wells in strategic locations to complement the existing monitoring network; and
- Compilation of additional pumping test data from water supply assessments and short-term pumping tests on abandoned wells or wells volunteered by residents to confirm well yields and test hydraulic conductivity.

6.2 Recommendations for Improving Groundwater Budgeting Estimates

- In an island setting, groundwater recharge will be controlled in general by the amount of precipitation, proportion of that precipitation that runs off to the ocean via surface water and the amount of water that is lost to evapotranspiration. As such, estimates would be greatly improved via implementation of a hydrometric flow gauging network of major surface water features near their outlet to the sea, particularly in area of higher groundwater use and population, where recharge estimates are more important. Key streams that could be targets for this monitoring, include Fulford Creek, Cusheon Creek, Bullocks Creek, Ganges Creek, McFadden Creek and Weston Creek. This hydrometric monitoring should be conducted year-round so that estimates of surface water run-off and groundwater recharge can be made; and
- Existing meteorological stations could be supplemented with a higher altitude precipitation gauge at a suitable location on Mount Maxwell or Baynes Peak, for example, or by citizen scientists in order to improve the spatial coverage of precipitation data to improve recharge estimates.

6.3 Recommendations for Increasing Available Water and Addressing Other Hydrogeological Concerns

- General Hydrogeology and Water Use: Due to the complexity and heterogeneity of the bedrock groundwater systems, in order to be able to assess the availability of groundwater in the future, efforts should be focused on the observational method, together with a well-conceptualized strategy for monitoring and indications of unsustainability. From a general water use and quantitative groundwater standpoint, this would ideally involve establishment of groundwater level monitoring on highly-transmissive, structurally well-connected features in the bedrock that are in areas where groundwater use is comparatively high. As previously mentioned, these locations would preferentially exhibit signs of longer-term groundwater declines and would also be comparatively important to monitor as features that are more likely to be regional hydrostructural controls. As groundwater storage is important during seasonal dry periods, efforts could be undertaken to increase the groundwater storage "buffer" from year-to-year to provide additional capacity during extended dry periods. Potential examples of this include improvement of groundwater supply infrastructure (i.e., deeper wells, away from coastal areas, and optimization of drilling locations) and utilization of techniques that promote infiltration of additional water to the subsurface (i.e., stormwater infiltration galleries, permeable pavement, or other low impact development strategies);

- Potential for Groundwater Supply Expansion: Areas of North Salt Spring Island that are predominantly reliant on surface water for their water supply and which have comparatively less groundwater development may be able to supplement their water supply with additional groundwater expansion. As during the wet period, groundwater levels in observation wells have been documented to always return to approximately the same elevation each year around December / January, it can be hypothesized that there is groundwater that is available for use. Locations with larger, undeveloped catchment areas, such as the lower slopes of South and Central Salt Spring Island, are also preferred areas for future groundwater development because they are comparatively less likely to pull water from environmental flows. Any groundwater locations for groundwater supply as well as monitoring wells on high conductivity, structurally well-connected features in the bedrock to allow for appropriate monitoring of impacts;
- Maintenance of Groundwater Levels: Strategies to ensure that groundwater levels are not negatively impacted from overuse consist of limiting groundwater extractions and increasing the amount of groundwater storage, coupled with a thoughtfully-designed monitoring system (monitoring of groundwater levels and withdrawals to improve conservation and understanding), with a particular focus on North Salt Spring Island where groundwater is under the greatest stress;
- Limiting Saline Intrusion: A critical method for limiting salt water intrusion is to frequently monitor the electrical conductivity or salinity of the groundwater produced from a well and be prepared to make operational adjustments to the pumping scheme or pump setting if salinity increases are observed during the dry period, which survey results show that some coastal WSSs are already doing. The thresholds identified by FLNRORD as indicators of saltwater intrusion are concentrations in groundwater of greater than 150 mg/L for chloride, 1000 µs/cm for specific conductivity and 700 mg/L for total dissolved solids. Efforts to increase groundwater storage are also advantageous to limiting or mitigating salt water intrusion as the increase in groundwater hydraulic head promotes development of a thicker freshwater lens and deeper fresh water – salt water interface. More involved processes and mechanisms of managing the fresh water – salt water interface, such as barrier wells, stimulated freshwater lens development or so-called "freshkeeper" wells, which involve pumping simultaneously from a deeper well to mitigate saltwater upconing, are more costly and not guaranteed to be completely effective due to the complexity of the hydrogeological setting on Salt Spring Island. Best practices for the prevention of saltwater intrusion are provided in a brochure developed by FLNRORD: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-wells/saltwaterintrusion_factsheet_flnro_web.pdf;

- Maintenance of Baseflow: Additional data gathering should continue to better characterize the surface water regime both to close the essential loop in the groundwater balance as well as to understand potential baseflow targets for watercourses; and
- Water Conservation and Demand Management: Water usage in Gulf Island communities is considerably lower than the national average. Continued water conservation and demand management are critical for the protection of groundwater sustainability.

7. REPORT LIMITATIONS

The factual information, descriptions, interpretations, comments, conclusions and recommendations contained herein are specific to the project described in this report and do not apply to any other project or site. Under no circumstances may this information be used for any other purposes than those specified in the scope of work unless explicitly stipulated in the text of this report or formally authorized by Golder. This report must be read in its entirety as some sections could be falsely interpreted when taken individually or out-of-context. As well, the final version of this report and its content supersedes any other text, opinion or preliminary version produced by Golder.

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Hydrogeological investigations are dynamic and inexact sciences. They are dynamic in the sense that the state of any hydrological system is changing with time, and in the sense that the science is continually developing new techniques to evaluate these systems. They are inexact in the sense that subsurface conditions are not known between the specific investigation locations, and there is invariably a lack of complete information both spatially and temporally about the geological and hydrogeological conditions. A groundwater budget uses the laws of science to draw together the available data into a mathematical representation of the essential features of an existing hydrogeological system. The validity and accuracy of the budget depends on the amount of data available relative to the degree of complexity of the geologic formations, the site hydrogeology, and on the quality and degree of accuracy of the data entered. Therefore, every groundwater budget is a simplification of reality and the budget described in this report is not an exception.

The professional groundwater services performed as described in this report were conducted in a manner consistent with the level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions, subject to the quantity and quality of available data, the time limits and financial and physical constraints applicable to the services. Unless otherwise specified, the results of previous or simultaneous work provided by sources other than Golder and quoted and/or used herein are considered as having been obtained according to recognised and accepted professional rules and practices, and therefore deemed valid. Despite the professional care taken during the construction of the groundwater budgets, their accuracies are bound to the normal uncertainty associated with groundwater budgeting and no warranty, expressed or implied, is made.

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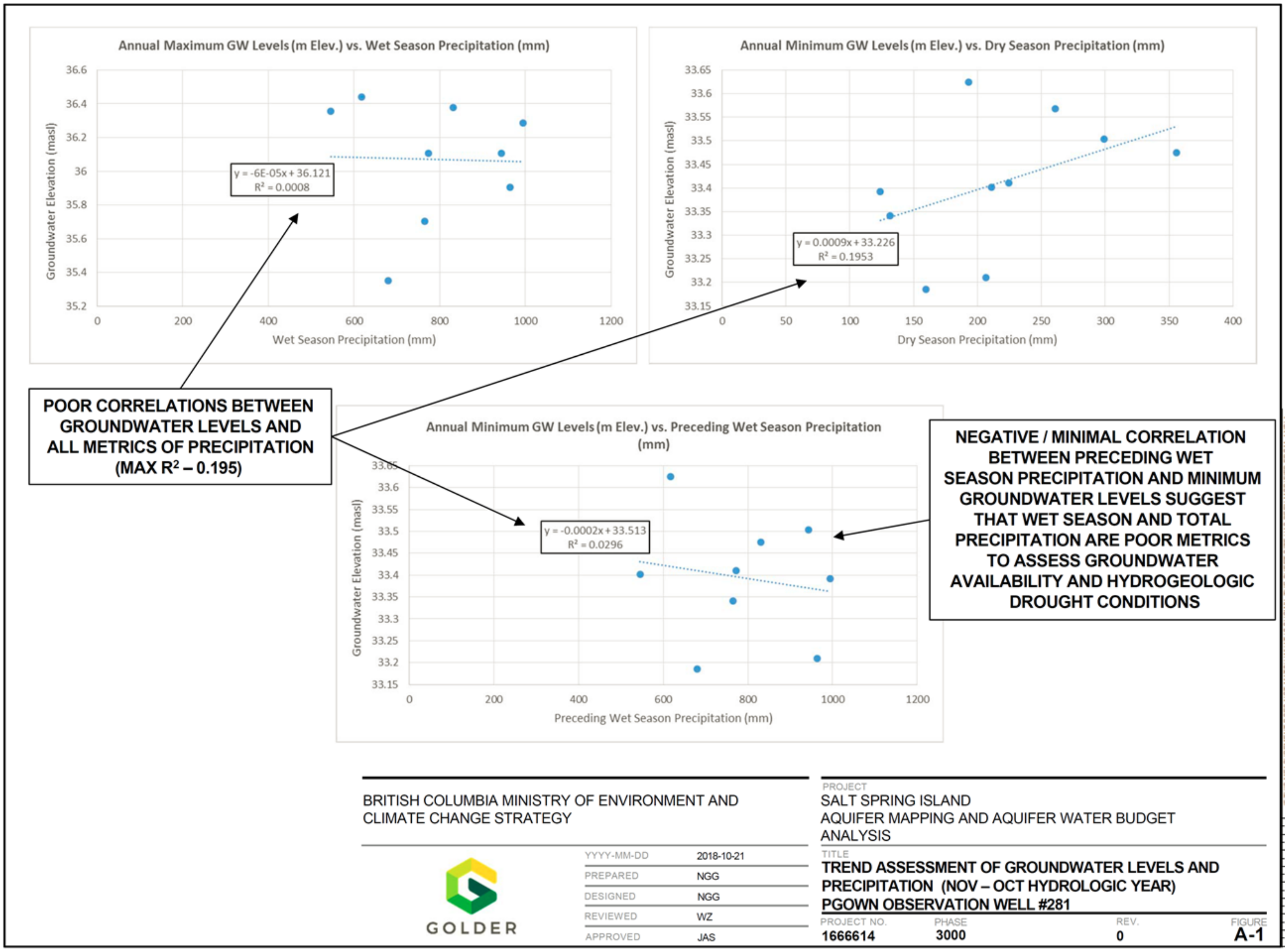
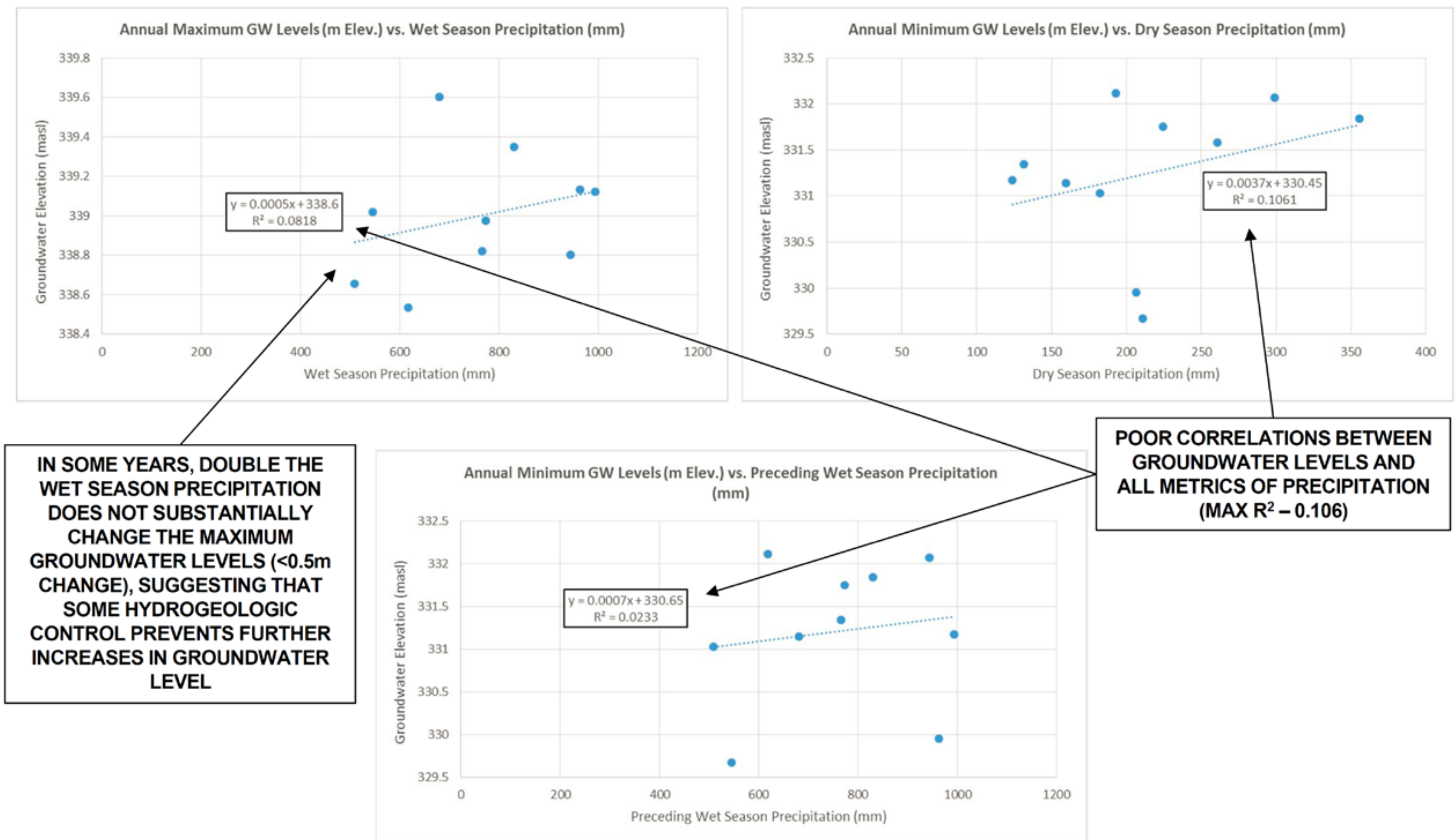
APPENDIX A: INTERPRETIVE FIGURES





BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-03-23
PREPARED	NGG
DESIGNED	NGG
REVIEWED	WZ
APPROVED	JAS

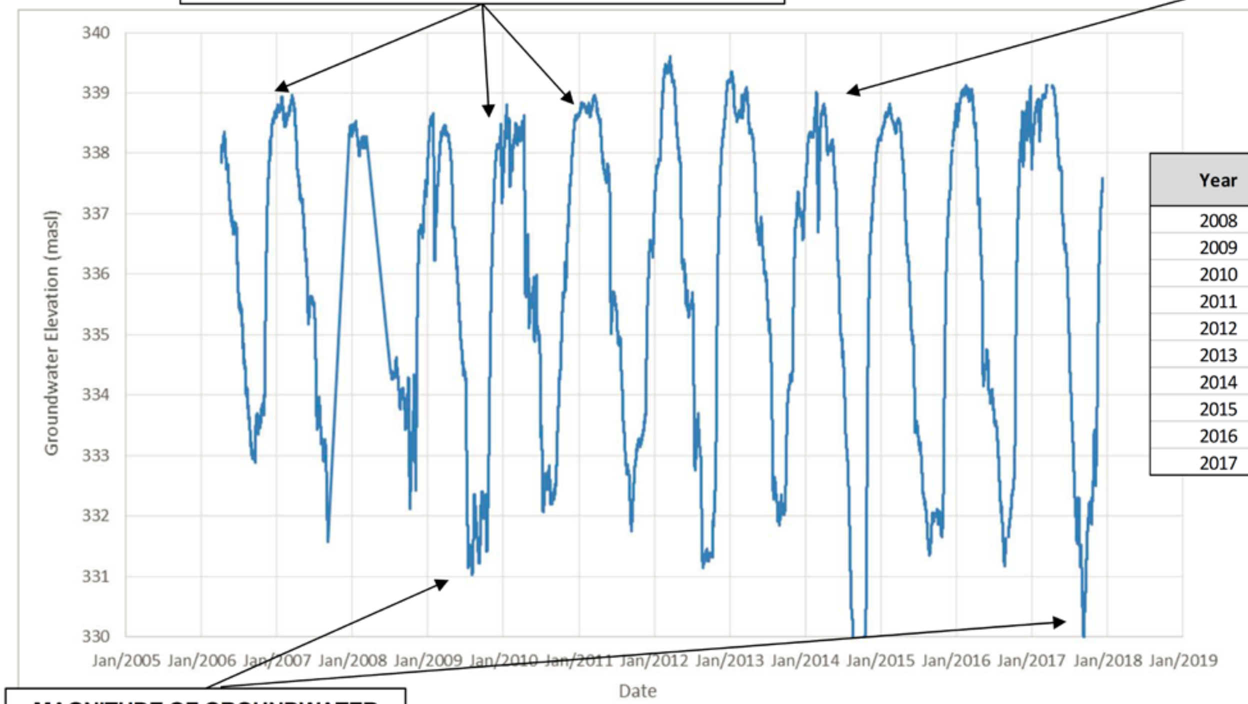
PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
TREND ASSESSMENT OF GROUNDWATER LEVELS AND PRECIPITATION (NOV – OCT HYDROLOGIC YEAR)
PGOWN OBSERVATION WELL #373

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	A-2

X - AXIS LINES INDICATE THE MONTH OF JANUARY. A FLATTENING OF THE GROUNDWATER HYDROGRAPH (ALSO OBSERVED ON OTHER GULF ISLANDS) TENDS TO OCCUR IN THE MIDDLE OF THE WET SEASON WITH GROUNDWATER LEVELS NOT INCREASING DESPITE HIGHER PRECIPITATION IN LATTER PORTION OF THE WET PERIOD

GROUNDWATER LEVEL MAXIMA IN THE WET SEASON ALL TEND TO BE WITHIN 1m OF EACH OTHER DESPITE THE DIFFERENCES IN PRECIPITATION



Year	Wet Season Precipitation (mm)	Dry Season Precipitation (mm)
2008	617.5	193.0
2009	509.1	182.2
2010	943.6	299.0
2011	772.6	224.6
2012	680.1	159.6
2013	830.5	355.9
2014	545.4	210.7
2015	765.3	131.6
2016	993.9	123.9
2017	963.2	206.6

MAGNITUDE OF GROUNDWATER LEVEL MINIMA DO NOT CORRELATE WELL WITH PRECIPITATION. LOCAL SHORTAGES WILL STILL OCCUR AND LENGTH OF THE DRY PERIOD MAY HAVE GREATER IMPACT ON WATER AVAILABILITY AS STORAGE BEGINS GETTING DRAWN DOWN EARLIER.

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

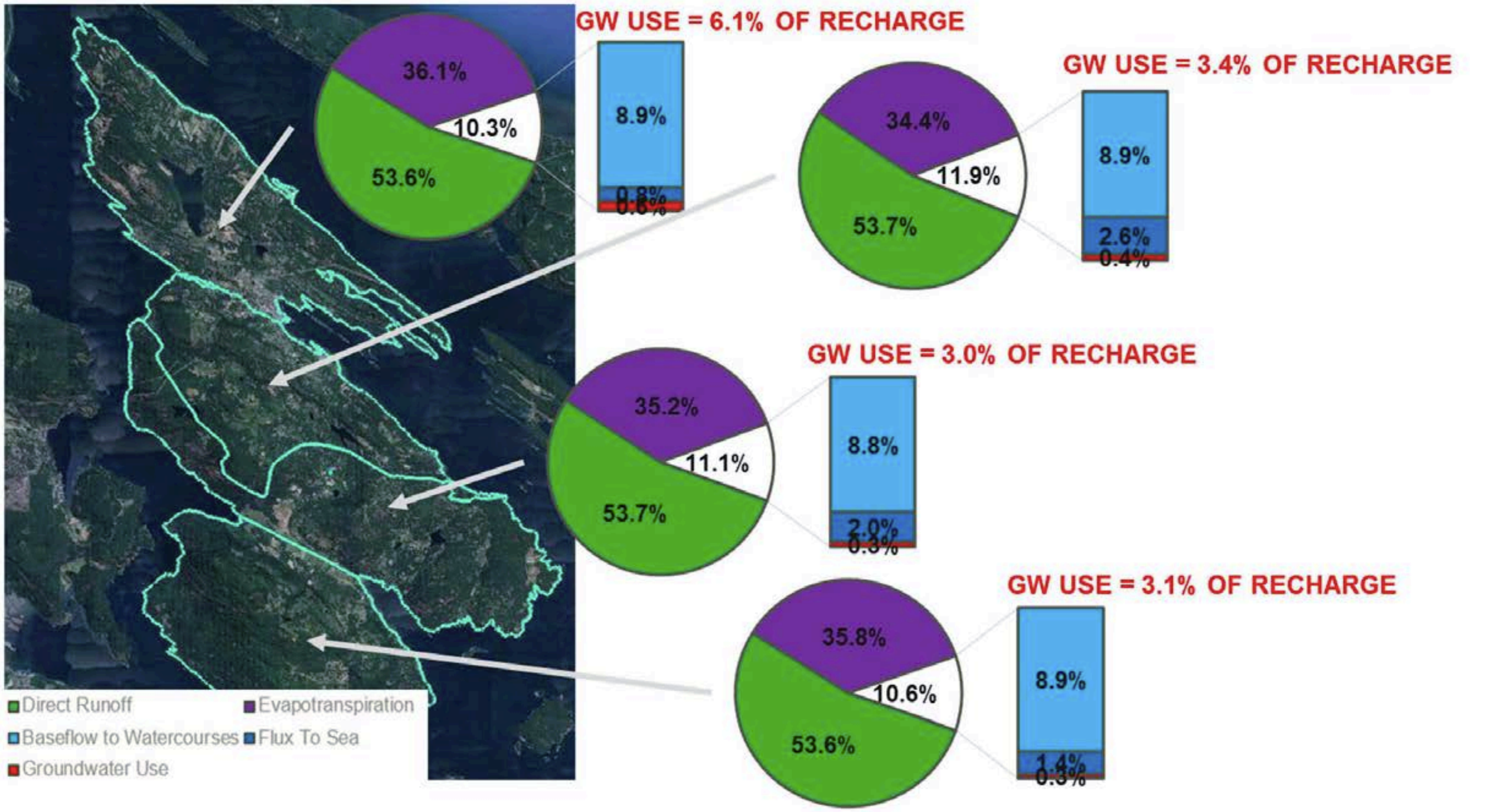
GOLDER

YYYY-MM-DD	2018-03-23
PREPARED	NGG
DESIGNED	NGG
REVIEWED	WZ
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
CONCEPTUAL GROUNDWATER HYDROGRAPH INSIGHTS
PGOWN OBSERVATION WELL #373

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	A-3



BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

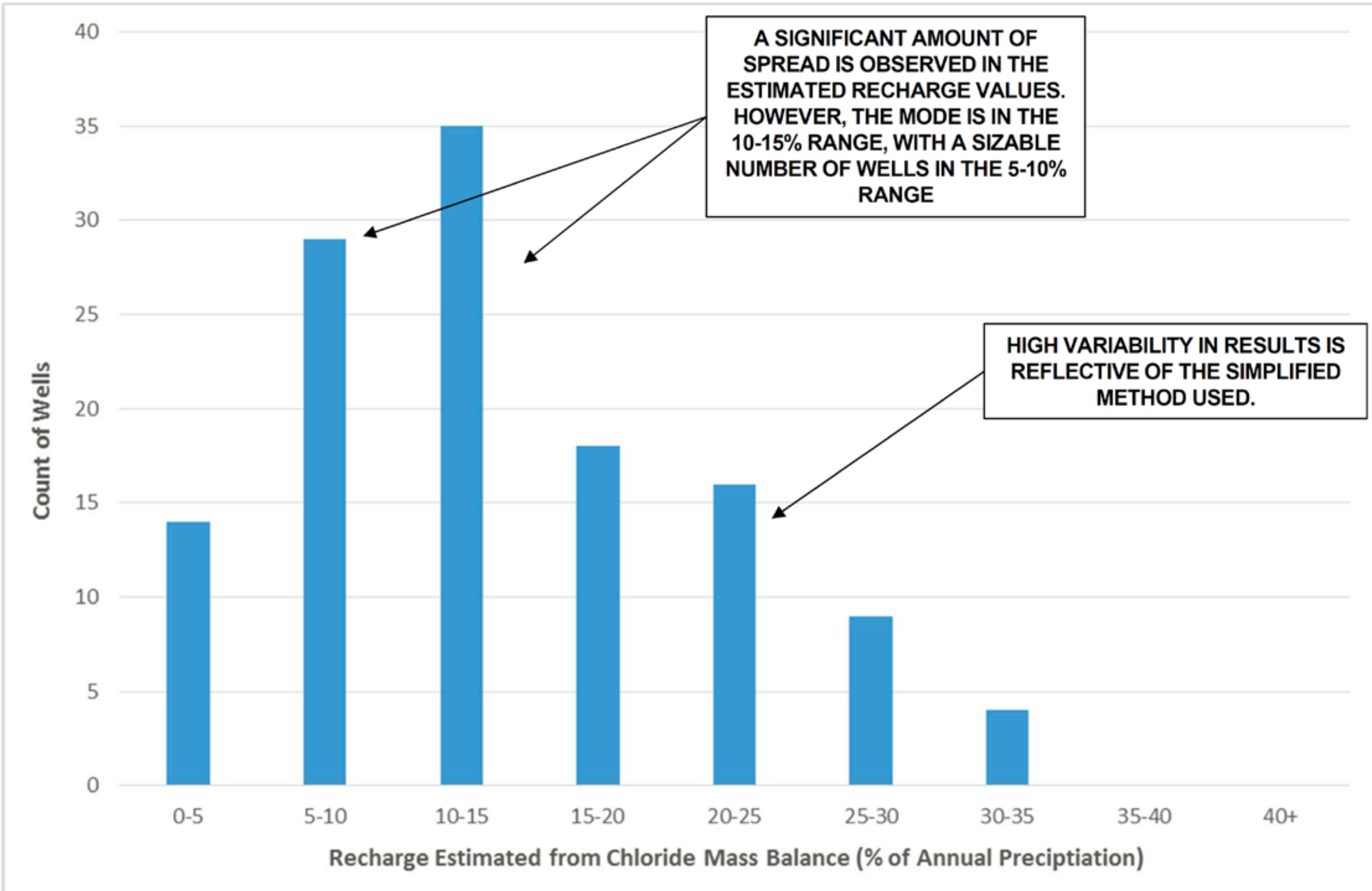
GOLDER

YYYY-MM-DD	2018-12-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
GROUNDWATER BUDGET RESULTS BY AQUIFER

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	A-4



BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

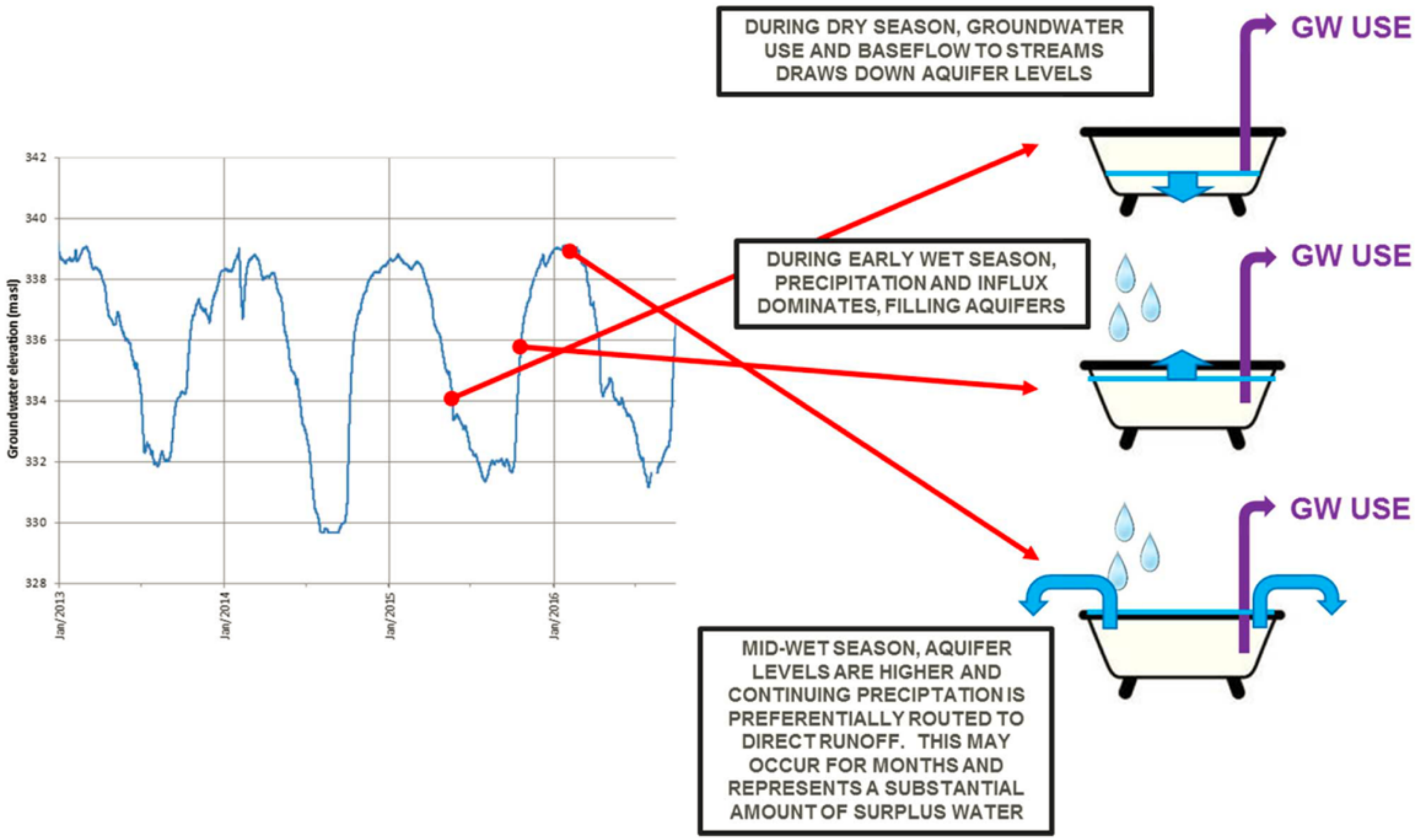
GOLDER

YYYY-MM-DD	2018-10-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	WZ
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
HISTOGRAM OF ESTIMATED RECHARGES FROM PRIVATE WELLS USING CHLORIDE MASS BALANCE METHOD

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	A-5



BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY	PROJECT SALT SPRING ISLAND AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS
YYYY-MM-DD: 2018-12-21 PREPARED: NGG DESIGNED: NGG REVIEWED: JAS APPROVED: JAS	TITLE **INTERPRETATIVE GROUNDWATER HYDROGRAPH ANALYSIS**
GOLDER	PROJECT NO. 1666614 · PHASE 3000 · REV. 0 · FIGURE **A-6**

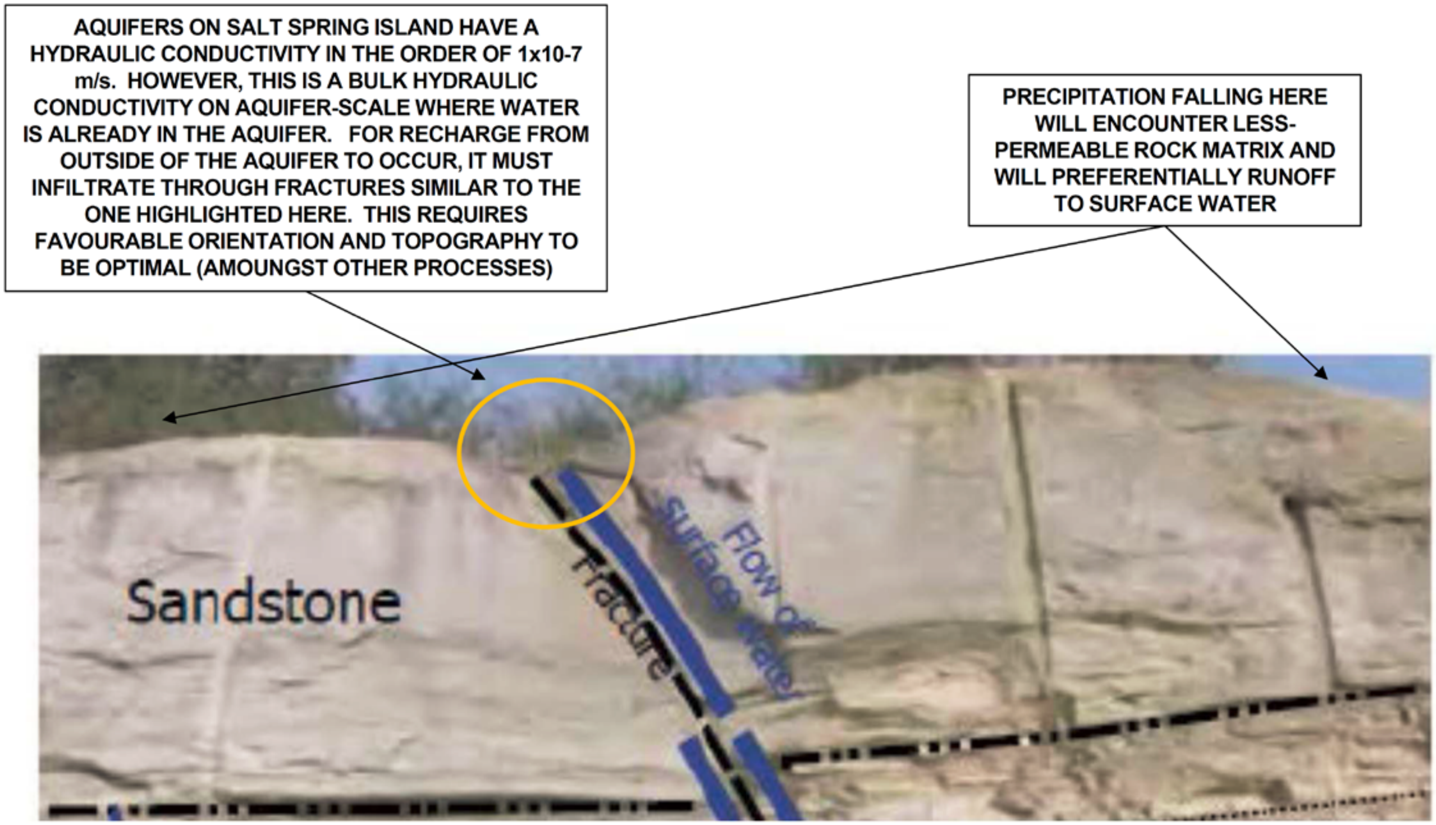


PHOTO CREDIT: CPAWS (2005)

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-03-23
PREPARED	NGG
DESIGNED	NGG
REVIEWED	WZ
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
CONCEPTUAL INSIGHTS ON RECHARGE / INFILTRATION INTO SALT SPRING ISLAND BEDROCK AQUIFERS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	A-7

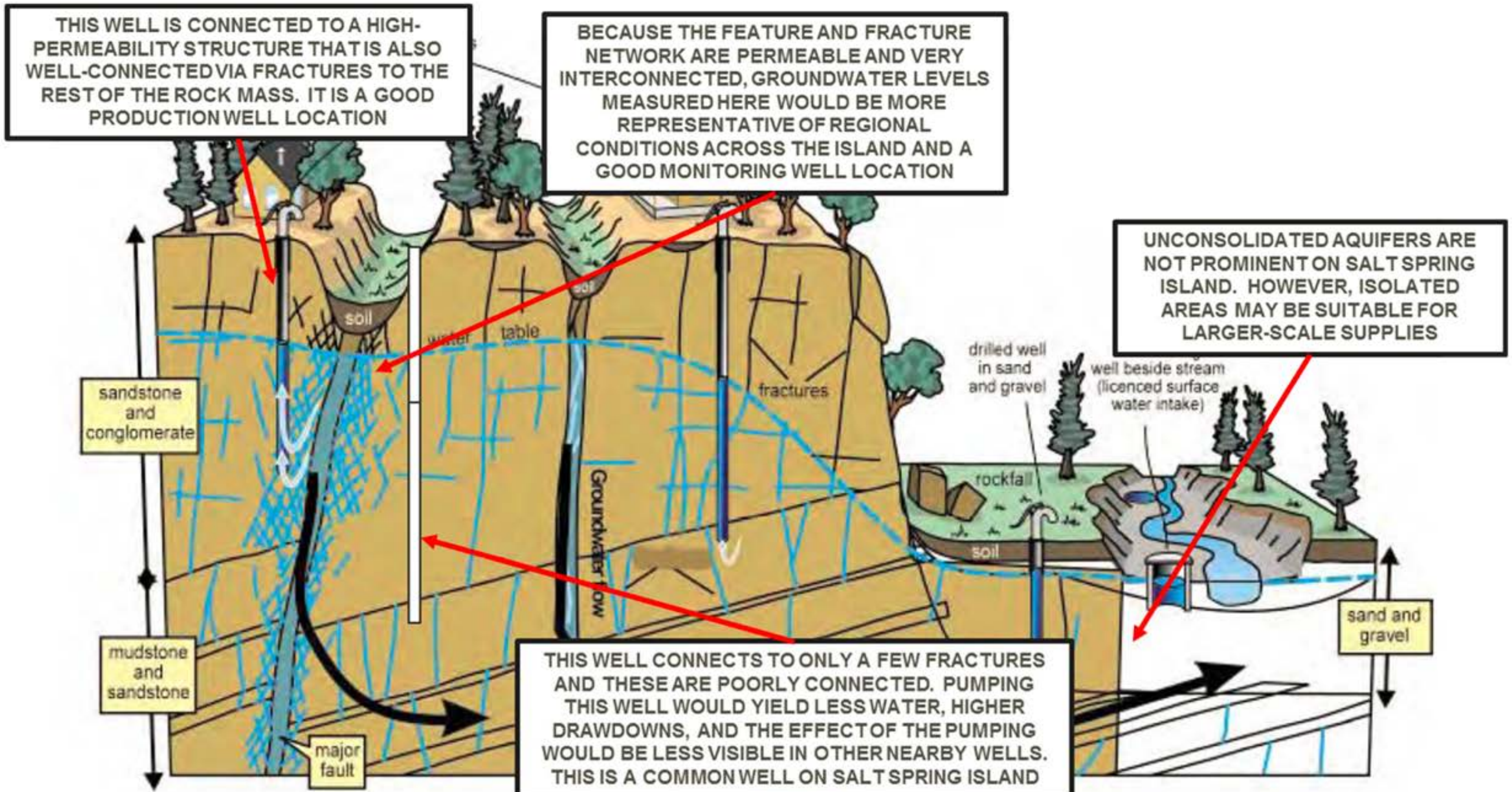


Image: Canadian Parks and Wilderness Society, 2005

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-12-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
CONCEPTUAL HYDROGEOLOGY – WELL LOCATIONS AND YIELDS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	A-8

APPENDIX B: GROUNDWATER BUDGET SHEETS

Input Data				
Storage / Specific Yield	0.001	Unitless		
Area - OW #373	2722559	m2		
Area - OW #281	5111144	m2		
Area - OW #438	38953256.9	m2		
Area - Harbourview Garden	1437033	m2		
ICI Water Use - Per Parcel	2.25	m3		
Res Water Use / Year - Per Ext Parcel	172.46	m3		
QIRReturnIN	0.00	Unitless		
Number of Residential Connections	769			
Number of Commercial Connections	19			
Aquifer Hydraulic Conductivity	2.0E-07	m/s	Assumed Sat Flow Depth	30 m
Hydraulic Gradient	0.05	Unitless	Length of Shoreline	40 km

Distributions						
Total Agricultural Demand	142844	m3				
	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Monthly Distribution of Ag Demand	0.116	0.168	0.192	0.216	0.188	0.120
RefET	61.9	89.48	102.69	115.52	100.12	63.88
Monthly Res Demand - WET	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
	0.073	0.077	0.077	0.060	0.060	0.067
Monthly Res Demand - DRY	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
	0.067	0.104	0.104	0.120	0.120	0.073
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
Wet Season SW Flow (m3)	178000	1740563	6165450	7478933	6938907	4797670
Direct flow composition	0.5	0.9	0.9	0.9	0.9	0.9
Groundwater composition	0.5	0.1	0.1	0.1	0.1	0.1
	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Dry Season SW Flow (m3)	1374278	583527	229879	113607	77459	94950
Direct flow composition	0.6	0.25	0.1	0.1	0.1	0.1
Groundwater composition	0.4	0.75	0.9	0.9	0.9	0.9

WET PERIOD	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	TOTAL
Storage Change							
Change In GW Level - OW 373	0.06	3.52	2.38	0.61	0.40	0.07	
Associated Volume	167.3	9594.7	6489.1	1662.6	1097.2	198.7	19209.7
Change in GW Level - Harbourview	-0.56	4.02	1.76	0.35	0.52	0.26	
Associated Volume	-804.7	5776.9	2529.2	503.0	747.3	373.6	9125.2
Change in GW Level - OW #281	0.2	0.5	0.1	-0.2	-0.1	0.0	
Associated Volume	1242.0	2678.2	746.2	-844.1	-481.1	249.1	3590.3
Change in GW Level - OW #438	0.2	1.4	2.1	0.4	0.5	0.0	
Associated Volume	6711.6	54184.0	81988.8	17396.5	19959.6	1172.5	181413.1
TOTAL ΔSGW (m3)	**7316**	**72234**	**91753**	**18718**	**21323**	**1994**	**213338**
Groundwater Flux Out (QGWout)							
	32141	**31104**	**32141**	**32141**	**29030**	**32141**	**188697.6**
Groundwater Flux to SW (QSWout)							
	89000	**174056**	**616545**	**747893**	**693891**	**479767**	**2801152**
Runoff to SW							
	89000	**1566507**	**5548905**	**6731040**	**6245016**	**4317903**	**24498371**
Groundwater Use							
Residential / Domestic							
External Parcels	9720	10237	10237	7941	7941	8821	54896
Maracaibo Estates WSS	546	336	336	580	335	516	2649
Harbourview WSS	209	112	132	170	120	105	849
Scott Point WSS	422	310	310	312	312	396	2064
High Hill WSS	101	71	70	77	73	78	470
Cedar Lane WSS	246	296	280	258	300	268	1648
The Cottages WSS	295	210	217	186	196	217	1321
Merchants Mews WSS	40	30	24	48	54	70	266
ICI	43	43	43	43	43	43	257
Agricultural	0	0	0	0	0	0	0
SubTotal GWpumpOUT	11622	11645	11649	9616	9374	10512	64419
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	**11622**	**11645**	**11649**	**9616**	**9374**	**10512**	**64419**
Recharge (QGWout + QSWout + deltaS + QGWpump)	**140079**	**289039**	**752088**	**808368**	**753619**	**524414**	**3267607**

DRY PERIOD	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
Storage Change							
Change In GW Level - OW 373	-1.24	-3.59	-0.17	-0.54	-1.61	-0.22	
Associated Volume	-3386.9	-9779.4	-449.2	-1464.5	-4394.3	-585.5	-20059.8
Change in GW Level - Harbourview	-1.48	-1.25	-1.08	-0.87	-1.68	-1.51	
Associated Volume	-2126.8	-1796.3	-1552.0	-1250.2	-2414.2	-2169.9	-11309.5
Change in GW Level - OW #281	-0.3	-0.2	-0.1	0.0	-0.2	0.0	
Associated Volume	-1774.3	-1222.6	-481.1	-22.4	-1157.2	-118.5	-4776.1
Change in GW Level - OW #438	-1.7	-1.2	-1.0	-0.5	-1.0	0.2	
Associated Volume	-68160.4	-45692.2	-37702.9	-20949.1	-38115.8	6026.1	-204594.2
TOTAL ΔSGW	**-75448**	**-58490**	**-40185**	**-23686**	**-46081**	**3152**	**-240740**
Groundwater Flux Out (QGWout)							
	31104	**32141**	**31104**	**32141**	**32141**	**31104**	**189734.4**
Groundwater Flux to SW (QSWout)							
	549711	**437645**	**206891**	**102246**	**69713**	**85455**	**1451662.8**
Runoff to SW							
	824567	**145882**	**22988**	**11361**	**7746**	**9495**	**1022038**
Groundwater Use							
Residential / Domestic							
External Parcels	8821	13735	13735	15859	15859	9720	77728
Maracaibo Estates WSS	594	819	921	1244	1261	995	5834
Harbourview WSS	242	220	175	268	224	187	1316
Scott Point WSS	396	497	497	731	731	422	3274
High Hill WSS	107	155	124	180	171	107	844
Cedar Lane WSS	282	365	337	301	372	304	1961
The Cottages WSS	240	326	348	617	617	348	2495
Merchants Mews WSS	68	78	72	69	34	36	356
ICI	43	43	43	43	43	43	257
Agricultural	16571	23954	27490	30925	26802	17101	142844
SubTotal GWpumpOUT	27362	40191	43741	50236	46114	29263	236909
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	**27362**	**40191**	**43741**	**50236**	**46114**	**29263**	**236909**
Recharge (QGWout + QSWout - deltaS + QGWpump)	**532729**	**451487**	**241552**	**160937**	**101887**	**148974**	**1637566**

Groundwater Budget Term	Percentage of Average Annual Precipitation (%)[1]	Volume of Water (m^3)
Recharge	10.3	4,900,000
Direct Runoff	53.6	25,000,000
Evapotranspiration	36.1	17,700,000
Precipitation Total		47,600,000

[1] – Average annual precipitation is based on 1981 – 2010 Climate Normals at Saltspring St Mary's L station (Climate ID# 1016995)

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-10-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
MONTHLY GROUNDWATER BUDGET
NORTH SALT SPRING ISLAND AQUIFER
AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	B-1

Input Data					
Storage / Specific Yield	0.001	Unitless			
Area - OW #373	28105841.4	m2			
Area - Harbourview Garden	8190938	m2			
ICI Water Use - Per Parcel	2.25	m3			
Res Water Use / Year - Per Parcel	172.46	m3			
QIRReturnIN	0.00	Unitless			
Number of Residential Connections	427				
Number of Commercial Connections	14				
Aquifer Hydraulic Conductivity	2.0E-07	m/s	Assumed Sat Flow Depth	30	m
Hydraulic Gradient	0.10	Unitless	Length of Shoreline	50	km

Distributions						
Total Agricultural Demand	60937	m3				
	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Monthly Distribution of Ag Demand	0.116	0.168	0.192	0.216	0.188	0.120
RefET	61.9	89.48	102.69	115.52	100.12	63.88
Monthly Res Demand Dist - WET	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
	0.073	0.077	0.077	0.060	0.060	0.067
Monthly Res Demand - DRY	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
	0.067	0.104	0.104	0.120	0.120	0.073
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
Wet Season SW Flow (m3)	134054	1310839	4643274	5632474	5225774	3613183
Direct flow composition	0.5	0.9	0.9	0.9	0.9	0.9
Groundwater composition	0.5	0.1	0.1	0.1	0.1	0.1
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
Dry Season SW Flow (m3)	1034986	439461	173125	85559	58336	71508
Direct flow composition	0.6	0.25	0.1	0.1	0.1	0.1
Groundwater composition	0.4	0.75	0.9	0.9	0.9	0.9

WET PERIOD	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	TOTAL
Storage Change							
Change In GW Level - OW 373	0.06	3.52	2.38	0.61	0.40	0.07	
Associated Volume	1727.4	99049.0	66989.2	17163.7	11326.7	2051.7	198307.8
Change in GW Level - Harbourview	-0.56	4.02	1.76	0.35	0.52	0.26	
Associated Volume	-4586.9	32927.6	14416.1	2866.8	4259.3	2129.6	52012.5
TOTAL ΔSGW (m3)	-2859	131977	81405	20031	15586	4181	250320
Groundwater Flux Out (QGWout)							
	80352	77760	80352	80352	72576	80352	471744.0
Groundwater Flux to SW (QSWout)							
	67027	131084	464327	563247	522577	361318	2109581.5
Runoff to SW							
	67027	1179755	4178947	5069227	4703197	3251865	18450018
Groundwater Use							
Residential / Domestic							
External Parcels	5397	5684	5684	4409	4409	4898	30482
Mt. Belcher WSS	457	293	573	347	627	444	2740
Erskine WSS	313	259	360	281	289	314	1815
ICI	32	32	32	32	32	32	189
Agricultural	0	0	0	0	0	0	0
SubTotal GWpumpOUT	6199	6268	6648	5069	5356	5687	35226
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	6199	6268	6648	5069	5356	5687	35226
Recharge (QGWout + QSWout + deltaS + QGWpump)	150718	347088	632733	668699	616096	451538	2866872

DRY PERIOD	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
Storage Change							
Change In GW Level - OW 373	-1.24	-3.59	-0.17	-0.54	-1.61	-0.22	
Associated Volume	-34963.7	-100956.2	-4637.5	-15119.0	-45363.3	-6044.3	-207083.8
Change in GW Level - Harbourview	-1.48	-1.25	-1.08	-0.87	-1.68	-1.51	
Associated Volume	-12122.6	-10238.7	-8846.2	-7126.1	-13760.8	-12368.3	-64462.7
TOTAL ΔSGW	-47086	-111195	-13484	-22245	-59124	-18413	-271547
Groundwater Flux Out (QGWout)							
	77760	80352	77760	80352	80352	77760	474336.0
Groundwater Flux to SW (QSWout)							
	413994	329596	155812	77003	52502	64357	1093264.7
Runoff to SW							
	620991	109865	17312	8556	5834	7151	769709
Groundwater Use							
Residential / Domestic							
External Parcels	4898	7626	7626	8806	8806	5397	43160
Mt. Belcher WSS	512	815	661	337	761	594	3679
Erskine WSS	282	553	407	444	461	321	2467
ICI	32	32	32	32	32	32	189
Agricultural	7069	10219	11727	13193	11434	7295	60937
SubTotal GWpumpOUT	12792	19246	20453	22810	21492	13639	110431
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	12792	19246	20453	22810	21492	13639	110431
Recharge (QGWout + QSWout - deltaS + QGWpump)	457460	317999	240541	157920	95222	137343	1406485

Groundwater Budget Term	Percentage of Average Annual Precipitation (%)[1]	Volume of Water (m^3)
Recharge	11.9	4,300,000
Direct Runoff	53.6	19,200,000
Evapotranspiration	34.4	12,300,000
Precipitation Total		35,800,000

[1] – Average annual precipitation is based on 1981 – 2010 Climate Normals at Saltspring St Mary's L station (Climate ID# 1016995)

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

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DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
MONTHLY GROUNDWATER BUDGET
NORTH-CENTRAL SALT SPRING ISLAND AQUIFER
AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	B-2

Input Data						
Storage / Specific Yield	0.001	Unitless				
Area - OW #373	22505435.1	m2				
Area - Harbourview Garden	26264276	m2				
ICI Water Use - Per Parcel	2.25	m3				
Res Water Use / Year - Per Parcel	172.46	m3				
QIRReturnIN	0.00	Unitless				
Number of Residential Connections	475					
Number of Commercial Connections	25					
Aquifer Hydraulic Conductivity	2.0E-07	m/s		Assumed Sat Flow Depth	30	m
Hydraulic Gradient	0.10	Unitless		Length of Shoreline	50	km

Distributions						
Total Agricultural Demand	42930	m3				
	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Monthly Distribution of Ag Demand	0.116	0.168	0.192	0.216	0.188	0.120
RefET	61.9	89.48	102.69	115.52	100.12	63.88
Monthly Res Demand Dist - WET	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
	0.073	0.077	0.077	0.060	0.060	0.067
Monthly Res Demand - DRY	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
	0.067	0.104	0.104	0.120	0.120	0.073
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
Wet Season SW Flow (m3)	180216	1762230	6242198	7572032	7025283	4857392
Direct flow composition	0.5	0.9	0.9	0.9	0.9	0.9
Groundwater composition	0.5	0.1	0.1	0.1	0.1	0.1
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
Dry Season SW Flow (m3)	1391386	590791	232741	115021	78424	96132
Direct flow composition	0.6	0.25	0.1	0.1	0.1	0.1
Groundwater composition	0.4	0.75	0.9	0.9	0.9	0.9

WET PERIOD							
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	TOTAL
Storage Change							
Change In GW Level - OW 373	0.06	3.52	2.38	0.61	0.40	0.07	
Associated Volume	1383.2	79312.4	53640.8	13743.7	9069.7	1642.9	158792.7
Change in GW Level - Harbourview	-0.56	4.02	1.76	0.35	0.52	0.26	
Associated Volume	-14708.0	105582.4	46225.1	9192.5	13657.4	6828.7	166778.2
TOTAL ΔSGW (m3)	-13325	184895	99866	22936	22727	8472	325571
Groundwater Flux Out (QGWout)							
	80352	77760	80352	80352	72576	80352	471744.0
Groundwater Flux to SW (QSWout)							
	90108	176223	624220	757203	702528	485739	2836021.4
Runoff to SW							
	90108	1586007	5617978	6814828	6322755	4371653	24803330
Groundwater Use							
Residential / Domestic							
External Parcels	6004	6323	6323	4905	4905	5448	33908
Reginald Hill WSS	81	105	77	113	58	111	547
ICI	56	56	56	56	56	56	338
Agricultural	0	0	0	0	0	0	0
SubTotal GWpumpOUT	6142	6484	6456	5074	5019	5616	34792
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	6142	6484	6456	5074	5019	5616	34792
Recharge (QGWout + QSWout + deltaS + QGWpump)	163277	445362	810894	865566	802851	580179	3668129

DRY PERIOD							
	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
Storage Change							
Change In GW Level - OW 373	-1.24	-3.59	-0.17	-0.54	-1.61	-0.22	
Associated Volume	-27996.8	-80839.5	-3713.4	-12106.4	-36324.1	-4839.9	-165820.0
Change in GW Level - Harbourview	-1.48	-1.25	-1.08	-0.87	-1.68	-1.51	
Associated Volume	-38871.1	-32830.3	-28365.4	-22849.9	-44124.0	-39659.1	-206699.8
TOTAL ΔSGW	-66868	-113670	-32079	-34956	-80448	-44499	-372520
Groundwater Flux Out (QGWout)							
	77760	80352	77760	80352	80352	77760	474336.0
Groundwater Flux to SW (QSWout)							
	556554	443093	209467	103519	70581	86519	1469733.3
Runoff to SW							
	834831	147698	23274	11502	7842	9613	1034761
Groundwater Use							
Residential / Domestic							
External Parcels	5448	8484	8484	9796	9796	6004	48011
Reginald Hill WSS	161	122	125	140	126	107	781
ICI	56	56	56	56	56	56	338
Agricultural	4980	7199	8262	9294	8055	5139	42930
SubTotal GWpumpOUT	10645	15861	16927	19286	18033	11307	92060
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	10645	15861	16927	19286	18033	11307	92060
Recharge (QGWout + QSWout - deltaS + QGWpump)	578092	425636	272075	168201	88519	131087	1663610

Groundwater Budget Term	Percentage of Average Annual Precipitation (%)[1]	Volume of Water (m^3)
Recharge	11.1	5,300,000
Direct Runoff	53.7	25,800,000
Evapotranspiration	35.2	17,000,000
Precipitation Total		48,100,000

[1] – Average annual precipitation is based on 1981 – 2010 Climate Normals at Saltspring St Mary's L station (Climate ID# 1016995)

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-03-23
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT

SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE

MONTHLY GROUNDWATER BUDGET
SOUTH-CENTRAL SALT SPRING ISLAND AQUIFER
AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	B-3

Input Data					
Storage / Specific Yield	0.001	Unitless			
Area - OW #373	50750433.5	m2			
Area - Harbourview Garden	647694	m2			
ICI Water Use - Per Parcel	2.25	m3			
Res Water Use / Year - Per Parcel	172.46	m3			
QIRReturnIN	0.00	Unitless			
Number of Residential Connections	303				
Number of Commercial Connections	34				
Aquifer Hydraulic Conductivity	1.0E-07	m/s	Assumed Sat Flow Depth	30	m
Hydraulic Gradient	0.15	Unitless	Length of Shoreline	50	km

Distributions						
Total Agricultural Demand	76839	m3				
	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Monthly Distribution of Ag Demand	0.116	0.168	0.192	0.216	0.188	0.120
RefET	61.9	89.48	102.69	115.52	100.12	63.88
Monthly Res Demand Dist - WET	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
	0.073	0.077	0.077	0.060	0.060	0.067
Monthly Res Demand - DRY	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
	0.067	0.104	0.104	0.120	0.120	0.073
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
Wet Season SW Flow (m3)	189817	1856119	6574774	7975460	7399581	5116188
Direct flow composition	0.5	0.9	0.9	0.9	0.9	0.9
Groundwater composition	0.5	0.1	0.1	0.1	0.1	0.1
	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Dry Season SW Flow (m3)	1465517	622267	245141	121149	82602	101254
Direct flow composition	0.6	0.25	0.1	0.1	0.1	0.1
Groundwater composition	0.4	0.75	0.9	0.9	0.9	0.9

WET PERIOD	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	TOTAL
Storage Change							
Change In GW Level - OW 373	0.06	3.52	2.38	0.61	0.40	0.07	
Associated Volume	3119.2	178851.8	120961.7	30992.4	20452.4	3704.8	358082
Change in GW Level - Harbourview	-0.56	4.02	1.76	0.35	0.52	0.26	
Associated Volume	-362.7	2603.7	1139.9	226.7	336.8	168.4	4113
TOTAL ΔSGW (m3)	**2756**	**181456**	**122102**	**31219**	**20789**	**3873**	**362195**
Groundwater Flux Out (QGWout)							
	60264	**58320**	**60264**	**60264**	**54432**	**60264**	**353808**
Groundwater Flux to SW (QSWout)							
	94909	**185612**	**657477**	**797546**	**739958**	**511619**	**2987121**
Runoff to SW							
	94909	**1670507**	**5917297**	**7177914**	**6659623**	**4604569**	**26124819**
Groundwater Use							
Residential / Domestic							
External Parcels	3830	4033	4033	3129	3129	3475	21630
Cedars of Taum	157	246	326	69	82	79	960
ICI	77	77	77	77	77	77	459
Agricultural	0	0	0	0	0	0	0
SubTotal GWpumpOUT	4064	4356	4435	3274	3288	3631	23049
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	**4064**	**4356**	**4435**	**3274**	**3288**	**3631**	**23049**
Recharge (QGWout + QSWout + deltaS + QGWpump)	**161993**	**429744**	**844279**	**892303**	**818467**	**579387**	**3726173**

DRY PERIOD	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL
Storage Change							
Change In GW Level - OW 373	-1.24	-3.59	-0.17	-0.54	-1.61	-0.22	
Associated Volume	-63133.5	-182295.6	-8373.8	-27300.2	-81912.0	-10914.1	-373929.2
Change in GW Level - Harbourview	-1.48	-1.25	-1.08	-0.87	-1.68	-1.51	
Associated Volume	-958.6	-809.6	-699.5	-563.5	-1088.1	-978.0	-5097.4
TOTAL ΔSGW	**-64092**	**-183105**	**-9073**	**-27864**	**-83000**	**-11892**	**-379027**
Groundwater Flux Out (QGWout)							
	58320	**60264**	**58320**	**60264**	**60264**	**58320**	**355752.0**
Groundwater Flux to SW (QSWout)							
	586207	**466700**	**220627**	**109034**	**74342**	**91128**	**1548038.7**
Runoff to SW							
	879310	**155567**	**24514**	**12115**	**8260**	**10125**	**1089892**
Groundwater Use							
Residential / Domestic							
External Parcels	3475	5412	5412	6249	6249	3830	30626
Cedars of Taum	119	160	90	110	131	115	725
ICI	77	77	77	77	77	77	459
Agricultural	8914	12885	14788	16635	14418	9199	76839
SubTotal GWpumpOUT	12585	18533	20366	23071	20874	13220	108650
QIRReturnIN	0	0	0	0	0	0	0
Total GWpumpOUT	**12585**	**18533**	**20366**	**23071**	**20874**	**13220**	**108650**
Recharge (QGWout + QSWout - deltaS + QGWpump)	**593020**	**362393**	**290240**	**164506**	**72480**	**150777**	**1633414**

Groundwater Budget Term	Percentage of Average Annual Precipitation (%)[1]	Volume of Water (m^3)
Recharge	10.6	5,400,000
Direct Runoff	53.6	27,200,000
Evapotranspiration	35.8	18,100,000
Total		50,700,000

[1] – Average annual precipitation is based on 1981 – 2010 Climate Normals at Saltspring St Mary's L station (Climate ID# 1016995)

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-10-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
MONTHLY GROUNDWATER BUDGET SOUTH SALT SPRING ISLAND AQUIFER AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	B-4

Input Data				
Area of Aquifer	5.7	km2		
Recharge as % of Precipitation	10.6	% of	987 mm	*** Based on 1980-2010 climate normals
Total Recharge	595449.1	m3		
Hydraulic Gradient (towards coast)	0.15	(-)		
Length of Coast	5.5	km		
Assumed Saturated Flow Depth	20	m		
Hydraulic Conductivity	1E-06	m/s		

	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Average Monthly Precip (mm, 81-10 EC normals)	94	167.9	154.3	162.1	98.5	88.6	56.8	43	37.4	23.2	28	33.1	986.9	mm
Distribution of Precipitation	0.095	0.170	0.156	0.164	0.100	0.090	0.058	0.044	0.038	0.024	0.028	0.034	1	
Distribution of Recharge	0.030	0.080	0.157	0.166	0.153	0.108	0.111	0.068	0.054	0.031	0.014	0.028	1	
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Recharge by Month	18055	47748	93719	99045	90857	64343	65855	40279	32277	18333	8128	16811	595449	m3
Discharge to Surface / Sea	44193.6	42768	44193.6	44193.6	39916.8	44193.6	42768	44193.6	42768	44193.6	44193.6	42768	520344	m3

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

YYYY-MM-DD	2018-10-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

GOLDER

TITLE
MONTHLY GROUNDWATER BUDGET
FULFORD HARBOUR AQUIFER
AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	B-5

Input Data				
Area of Aquifer	1	km2			
Recharge as % of Precipitation	11.1	% of	987	mm	*** Based on 1980-2010 climate normals
Total Recharge	109471.1	m3			
Hydraulic Gradient (towards lateral bour	0.04	(-)			
Length of Coast	1.5	km			
Assumed Saturated Flow Depth	10	m			
Hydraulic Conductivity	5E-06	m/s			

	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Average Monthly Precip (mm, 81-10 EC normals)	94	167.9	154.3	162.1	98.5	88.6	56.8	43	37.4	23.2	28	33.1	986.9	mm
Distribution of Precipitation	0.095	0.170	0.156	0.164	0.100	0.090	0.058	0.044	0.038	0.024	0.028	0.034	1	
Distribution of Recharge	0.030	0.080	0.157	0.166	0.153	0.108	0.111	0.068	0.054	0.031	0.014	0.028	1	
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Recharge by Month	3319	8778	17230	18209	16704	11829	12107	7405	5934	3370	1494	3091	109471	m3
Discharge to Surface / Distal Boundary	8035.2	7776	8035.2	8035.2	7257.6	8035.2	7776	8035.2	7776	8035.2	8035.2	7776	94608	m3

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-10-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
MONTHLY GROUNDWATER BUDGET
BURGOYNE AQUIFER
AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	**3000**	**0**	**B-6**

Input Data					
Area of Aquifer	2.5	km2			
Recharge as %age of Precipitation	11.9	% of	987	mm	*** Based on 1980-2010 climate normals
Total Recharge	294439.9	m3			
Hydraulic Gradient (towards lateral bour	0.1	(-)			
Length of Coast	5	km			
Assumed Saturated Flow Depth	5	m			
Hydraulic Conductivity	4E-06	m/s			

	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Average Monthly Precip (mm, 81-10 EC normals)	94	167.9	154.3	162.1	98.5	88.6	56.8	43	37.4	23.2	28	33.1	986.9	mm
Distribution of Precipitation	0.095	0.170	0.156	0.164	0.100	0.090	0.058	0.044	0.038	0.024	0.028	0.034	1	
Distribution of Recharge	0.030	0.080	0.157	0.166	0.153	0.108	0.111	0.068	0.054	0.031	0.014	0.028	1	
	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Recharge by Month	8928	23611	46343	48976	44927	31817	32564	19917	15960	9065	4019	8313	294440	m3
Discharge to Surface / Distal Boundary	26784	25920	26784	26784	24192	26784	25920	26784	25920	26784	26784	25920	315360	m3

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

YYYY-MM-DD	2018-10-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

GOLDER

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
MONTHLY GROUNDWATER BUDGET
GANGES HARBOUR AQUIFER
AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	**3000**	**0**	**B-7**

Input Data					
Area of Aquifer	0.3	km2			
Recharge as %age of Precipitation	10.3	% of	987	mm	*** Based on 1980-2010 climate normals
Total Recharge	30548.7	m3			
Hydraulic Gradient (towards lateral bour	0.05	(-)			
Length of Coast	0.5	km			
Assumed Saturated Flow Depth	5	m			
Hydraulic Conductivity	8E-06	m/s			

	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Average Monthly Precip (mm, 81-10 EC normals)	94	167.9	154.3	162.1	98.5	88.6	56.8	43	37.4	23.2	28	33.1	986.9	mm
Distribution of Precipitation	0.095	0.170	0.156	0.164	0.100	0.090	0.058	0.044	0.038	0.024	0.028	0.034	1	
Distribution of Recharge	0.030	0.080	0.157	0.166	0.153	0.108	0.111	0.068	0.054	0.031	0.014	0.028	1	

	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	TOTAL	
Recharge by Month	926	2450	4808	5081	4661	3301	3379	2066	1656	941	417	862	30549	m3
Discharge to Surface / Distal Boundary	2678.4	2592	2678.4	2678.4	2419.2	2678.4	2592	2678.4	2592	2678.4	2678.4	2592	31536	m3

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT AND CLIMATE CHANGE STRATEGY

GOLDER

YYYY-MM-DD	2018-10-21
PREPARED	NGG
DESIGNED	NGG
REVIEWED	JAS
APPROVED	JAS

PROJECT
SALT SPRING ISLAND
AQUIFER MAPPING AND AQUIFER WATER BUDGET ANALYSIS

TITLE
MONTHLY GROUNDWATER BUDGET
WALKER HOOK AQUIFER
AVERAGE YEAR – 1981-2010 CLIMATE NORMALS

PROJECT NO.	PHASE	REV.	FIGURE
1666614	3000	0	B-8

APPENDIX C: DIGITAL WORK PRODUCTS

Aquifer Well Completions and Well Summary Sheets

Information on the well-aquifer completions is provided in a separate Excel file. The data included in this appendix has been used to update the B.C. GWELLS Database. Well Summary sheet information corresponding to the identified well tag numbers (WTN) is accessible through the GWELLS database (https://apps.nrs.gov.bc.ca/gwells/).

Aquifer Summary Sheets and Shapefiles

Aquifer worksheets and outlines associated with this project are available online from the BC ENV and can be accessed through the B.C. GWELLS Database (https://apps.nrs.gov.bc.ca/gwells/) and iMapBC (https://arcmaps.gov.bc.ca/ess/sv/imapbc/)

Leapfrog Viewer File

Leapfrog Hydro is a commercial geological and hydrogeological interpretation software package that was used to visualize the available aquifer mapping and information from the GWELLS database. A Leapfrog Viewer File is provided as separate files to the report. A free Leapfrog viewer can be downloaded from ARANZ Geo Limited:
http://www.leapfrog3d.com/products/leapfrog-viewer/downloads

Water Budget Spreadsheets

Water budget spreadsheets for each aquifer are provided in a separate Excel file.