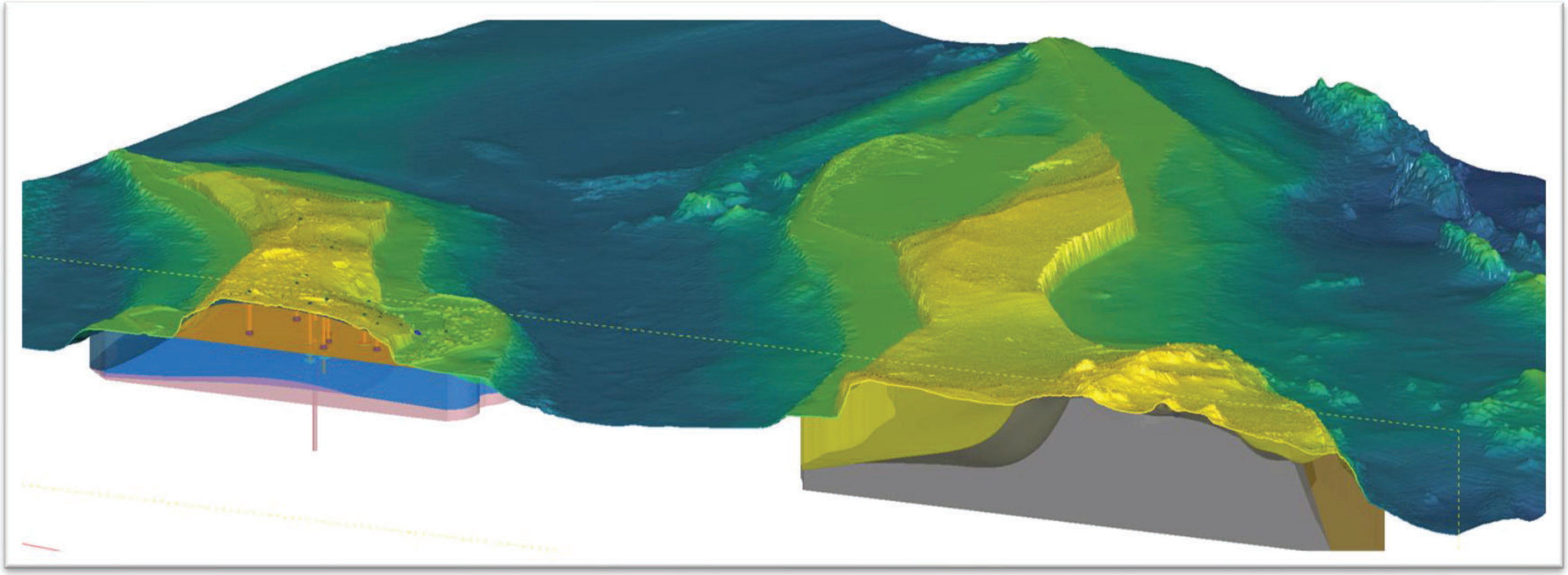
March 31, 2023
Project No. 22-14

Islands Trust Area Aquifer Conceptualization



Prepared for: Islands Trust

Prepared by: GW Solutions Inc.

March 2023

GW Solutions Inc.
Unit 24 – 4800 Island Hwy, Nanaimo, BC, V9T 1W6
Tel. (250) 756-4538 * abarroso@gwsolutions.ca

Table of Contents

FIGURES

TABLES

APPENDICES

1 BACKGROUND AND OBJECTIVES

1.1 Background

A conceptual model is a representation of a groundwater system consisting of concepts used to help people know, understand, or simulate groundwater flow including groundwater system boundaries, hydrogeological units (aquifers and aquitards), and directions of groundwater flow. A conceptual model is a necessary precursor to developing a numerical groundwater model, whereby the groundwater system is modelled under various conditions (e.g., climate change, pumping, land-use).

GW Solutions was retained by the Islands Trust Conservancy (ITC) to conceptualize the groundwater dynamics and aquifers across the ITC Area as part of the *Groundwater Sustainability Science* project. Previous studies included the southern Gulf Islands (Saturna, Pender, Mayne, and Galiano islands), (GW Solutions, 2020); Hornby, Denman, and Gabriola islands (GW Solutions, 2021).

In fiscal year 2022/23, the Study Islands comprised Lasqueti, North Thormanby, South Thormanby, Bowen, Keats, Gambier, Anvil, Valdez, Thetis, Reid, Saltspring, James and Sidney islands. The groundwater conceptual models presented herein are intended to accompany groundwater recharge potential mapping of these islands.

1.2 Objectives and Scope

The objectives of the ITC aquifer conceptualization study are as follows:

1) A geo-spatial data inventory of all Study Islands in a format that can be included in the ITC Freshwater Atlas, and other online mapping services, including:
    a. Compiled geology mapping
    b. Hydrogeological units (aquifers)
    c. Groundwater regions and aquifers
    d. Well yields and producing factures (from GWELLS)
    e. Groundwater levels (from GWELLS)
    f. Seasonal groundwater level variation.
2) Development of 3D conceptual hydrogeologic models for the Study Islands. Deliverables include:

a. 3D models of each study island using the Leapfrog software, including meshes, surfaces, and volumes to be used later for numerical modelling.
b. Conceptual 3D models available in a “viewer” format to be shared publicly.
c. Provide complete models in the ITC Seequent Central, where Leapfrog models and data can be visualised and managed in a centralised environment.

2 AQUIFER CONCEPTUALIZATION

2.1 Well Yields, Fractures, and Data Standardization.

The province maintains a database of wells (GWELLS) where each well is assigned a Well Tag Number (WTN). The database comprises four main data tables relating to well information, screen information, casing information, and lithology information (Figure 1). The lithology of a rock unit is a description of its physical characteristics including colour, texture, grain size, and composition. GWELLS is a valuable source of groundwater and aquifer information, yet it requires a significant amount of data restructuring and cleaning when dealing with a large population of wells (i.e., hundreds to thousands of wells).

To develop the island conceptual models, GW Solutions extracted, cleaned, and standardized the information extracted from GWELLS. The GWELLS “Lithology” table was restructured by grouping the thousands of unique text descriptions recorded by drillers into a codified system of “material classes” which are materials with similar physical characteristics. For example, if a driller recorded encountering “Sand and boulder clay with silt, dense”, this would be interpreted as belonging to the “till” material class.

Unconsolidated materials (e.g., silt, sand, or gravel) store and transmit water in the spaces between the sediment particles. The particle or grain size distribution of unconsolidated sediment governs the material’s capacity to transmit and store groundwater. In the standardized lithologies, unconsolidated materials are grouped into material classes based on textual interpretation of relatively coarse-grained descriptors (typically aquifers) or relatively fine-grained descriptors (typically aquitards). The lithology standardization results in the twelve “material classes” used in the groundwater conceptual models.

Bedrock aquifers, irrespective of rock type, mainly host water in fractures and voids. For this reason, bedrock lithologies from GWELLS descriptions are lumped together. However, in some cases an additional classification is performed where different rock types play a role in aquifer conceptualization and bulk properties. In addition, GW Solutions extracted fracture and yield information from the GWELLS lithology table. The resulting table of the depth and yield of productive fractures in bedrock wells (where reported by drillers) is included in Appendix 2.

Over 4000 wells are listed within the Study Islands with approximately 1710 providing information on both fracture depth and estimated yield per fracture.

To remove outliers in the reported yields, only the interquartile range was analysed, representing 50% of the data. From this subset, the median reported yield was 2 USgpm, with yields above 4 USgpm representing a quarter of the values (75).

Count = 3500	Mean	Standard Deviation	Minimum Value	Percentile: 25%	Median 50%	Percentile: 75%	Maximum Value
Estimated Yield (Usgpm)	3	3	0	1	2	4	11

Water well drillers typically advance through one or more water-bearing bedrock fractures until the cumulative water produced from all the fractures is deemed satisfactory in terms of quantity and quality. While the probability of obtaining a higher cumulative yield increases with depth drilled, so does the potential of encountering poor quality (i.e., saline) water. This is especially of concern throughout the Gulf Islands where the freshwater-salt water interface is near the shoreline. The completed well depths recorded in GWELLS indicate the depths where sufficient, cumulative yields were reached. From a total of over 4050 wells, the median bedrock well depth is approximately 50% of the recorded total depth.

Count = 4050	Mean	Standard Deviation	Minimum Value	Percentile: 25%	Median: 50%	Percentile: 75%	Maximum Value
Well Depth (m)	64	38	0	37	61	91	171

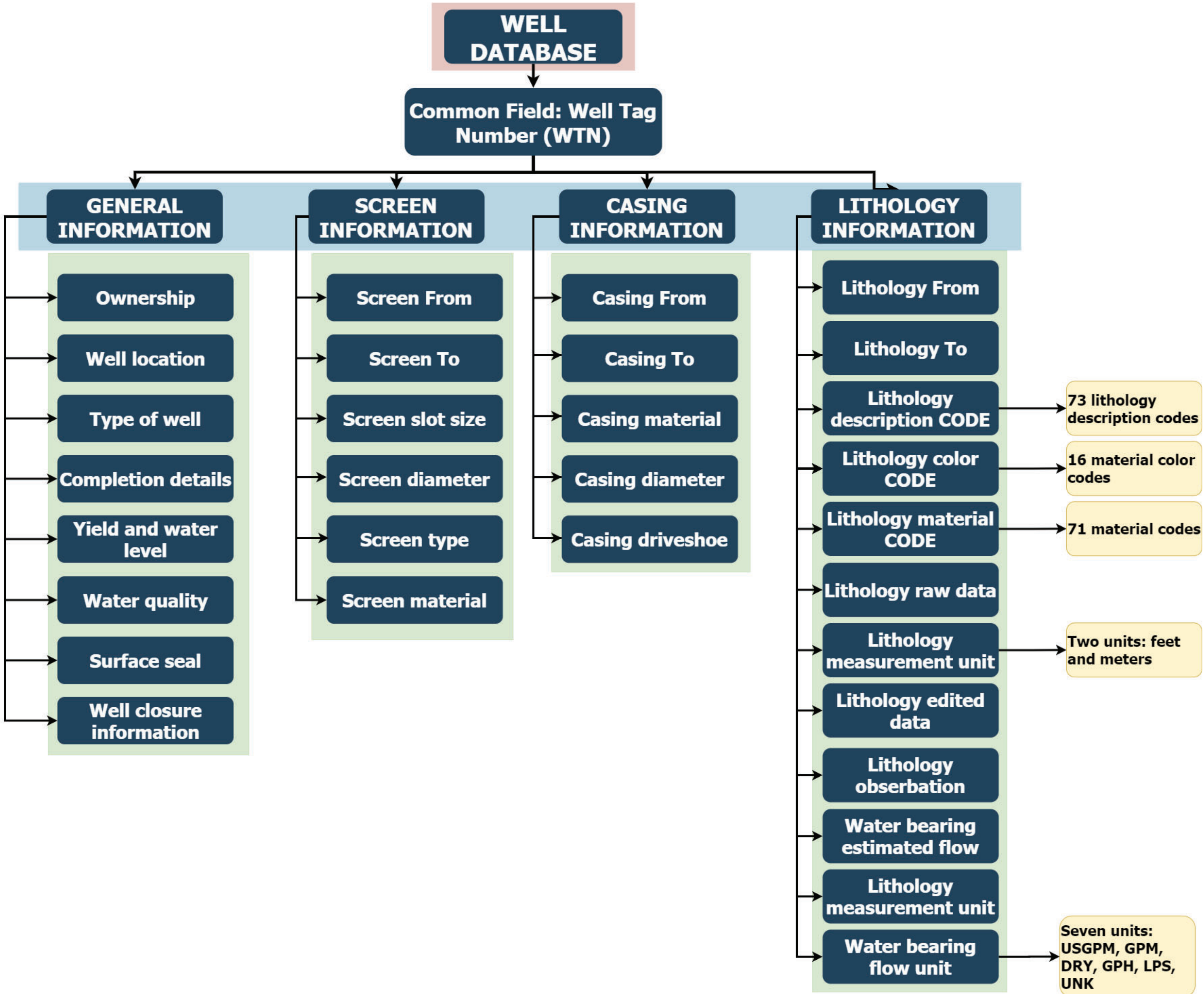


Figure 1 : BC Water Well Database (GWELLS) tables

2.2 Mapped aquifers, observation wells and groundwater fluctuations

Bedrock aquifers are the most common source of groundwater throughout the Study Islands. Mapped bedrock aquifers in the Study Islands are predominantly volcanic rock, intrusive crystalline rock, and sedimentary rocks. The Provincial mapped aquifers for the Study Islands are shown in Figure 2 and Figure 3.

Many shallow or “dug” wells exist throughout the Study Islands, and these rely on shallow groundwater from the surficial veneer of glacial sediments. Dug wells may experience seasonal water shortages and tend to be more vulnerable to surficial sources of contamination (e.g. septic systems, agrochemicals, road salt). Thicker accumulations of glacial or unconsolidated sediment exist on North Thormanby Island (Aquifer 973), James Island (unnamed), Sidney Island (Aquifer 786), and Saltspring Island (Aquifers 155, 156, 157, and 1048). Overburden aquifers on Salt Spring Island are not extensive. In contrast, North Thormanby, James and Sidney islands have overburden aquifers that cover most of the islands.

Monitoring of groundwater levels (depth to water below ground or groundwater elevation above sea level) is an important part of monitoring aquifer health. There are six wells of the provincial groundwater observation network (PGOWN) throughout the Study Islands. Water level plots for each observation well are presented in Figure 4. Key findings are summarized below:

- Groundwater level minima occur in August and September, depending on the well type and depth (deep or shallow).
- Groundwater levels rise as aquifers are recharged starting in October with the onset of the rainy season. Groundwater level maxima occur in the winter months, typically, December and January.
- No discernable trends in groundwater levels are observed over the last decade of data from Saltspring, Bowen, and Keats islands. A decreasing trend in groundwater levels could indicate either increased aquifer discharge (e.g. pumping wells) or decreased aquifer recharge (e.g. climate change, land use change,).
- The amplitude of annual groundwater fluctuation in the provincial observation wells is 2-10 m on Saltspring Island, 2 m on Bowen Island, and 10 m on Keats Islands.

Observation Well 281 on Saltspring Island has a level pattern that is similar to precipitation (ie. spikes in groundwater level correspond closely with major rain events. The other observation wells on Saltspring Island indicate that recharge is precipitation dependent, however, the response is much more muted than Well 281. The groundwater response to precipitation in the observation wells on Bowen and Keats islands is more muted still.

Table 1. Provincial Groundwater Observation Well Network (PGOWN)

Island	Observation Well (PGOWN)		Timespan of Record
Saltspring Island	438	Simon Fraser University research well completed in sandstone/mudstone (bedrock aquifer 721)	February 20, 2014 to present
	281	Scott Point Water Works well completed in shale (bedrock aquifer 721)	January 06, 1983 to present
	373	Monitoring well completed in sandstone/conglomerate (bedrock aquifer 722)	April 10, 2006 to present
Bowen Island	473	Completed in bedrock aquifer 747.	April 01, 2019 to present
	495	Located in an unconfined bedrock aquifer identified as aquifer 746.	May 24, 2018 to January 24, 2022
Keats Island	480	Completed in crystalline bedrock aquifer 548.	June 19, 2018 to present

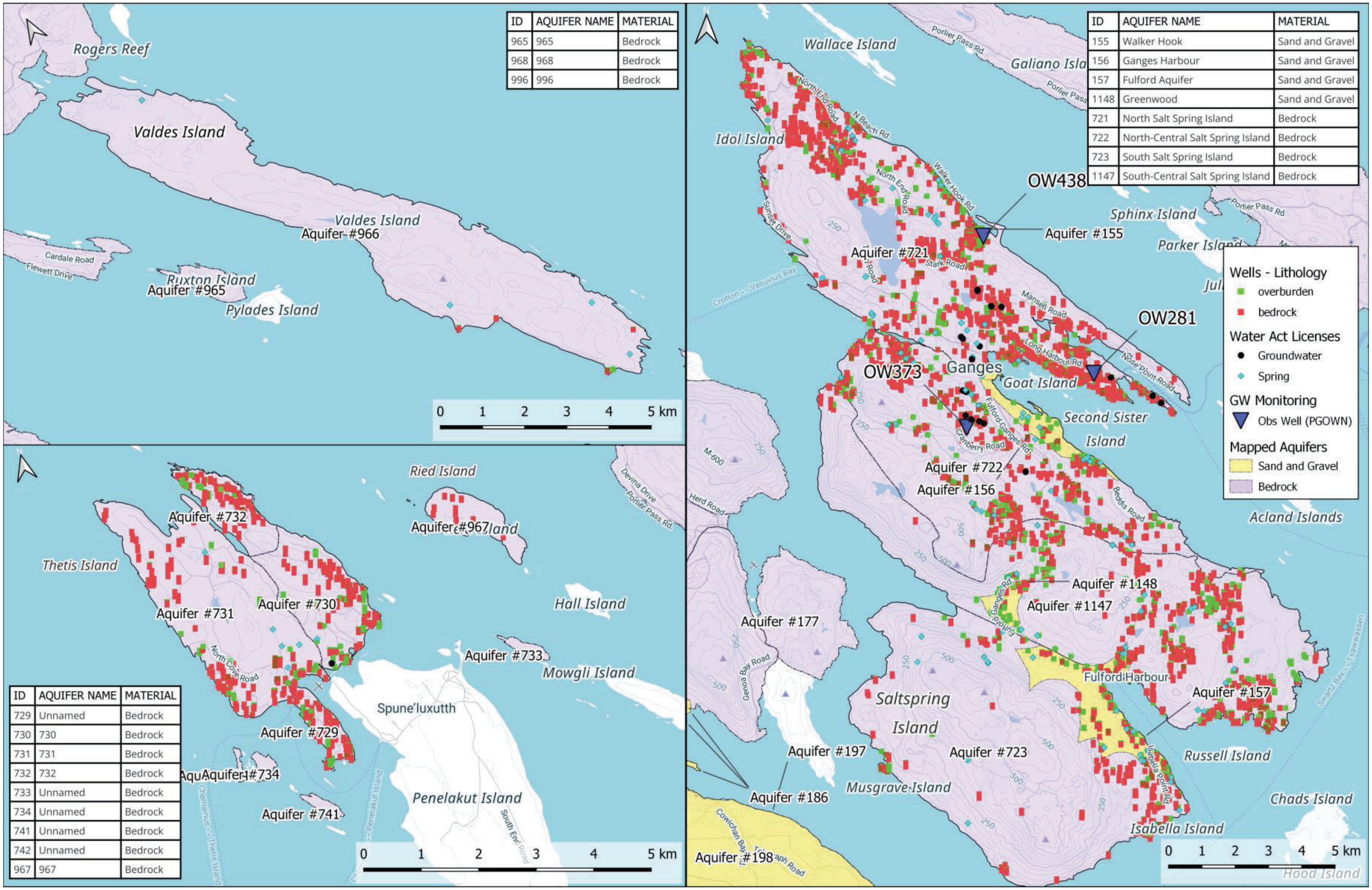


Figure 2. Valdes, Thetis, Reid, and Salt spring islands; Mapped Aquifers and provincial observation wells (PGOWN)

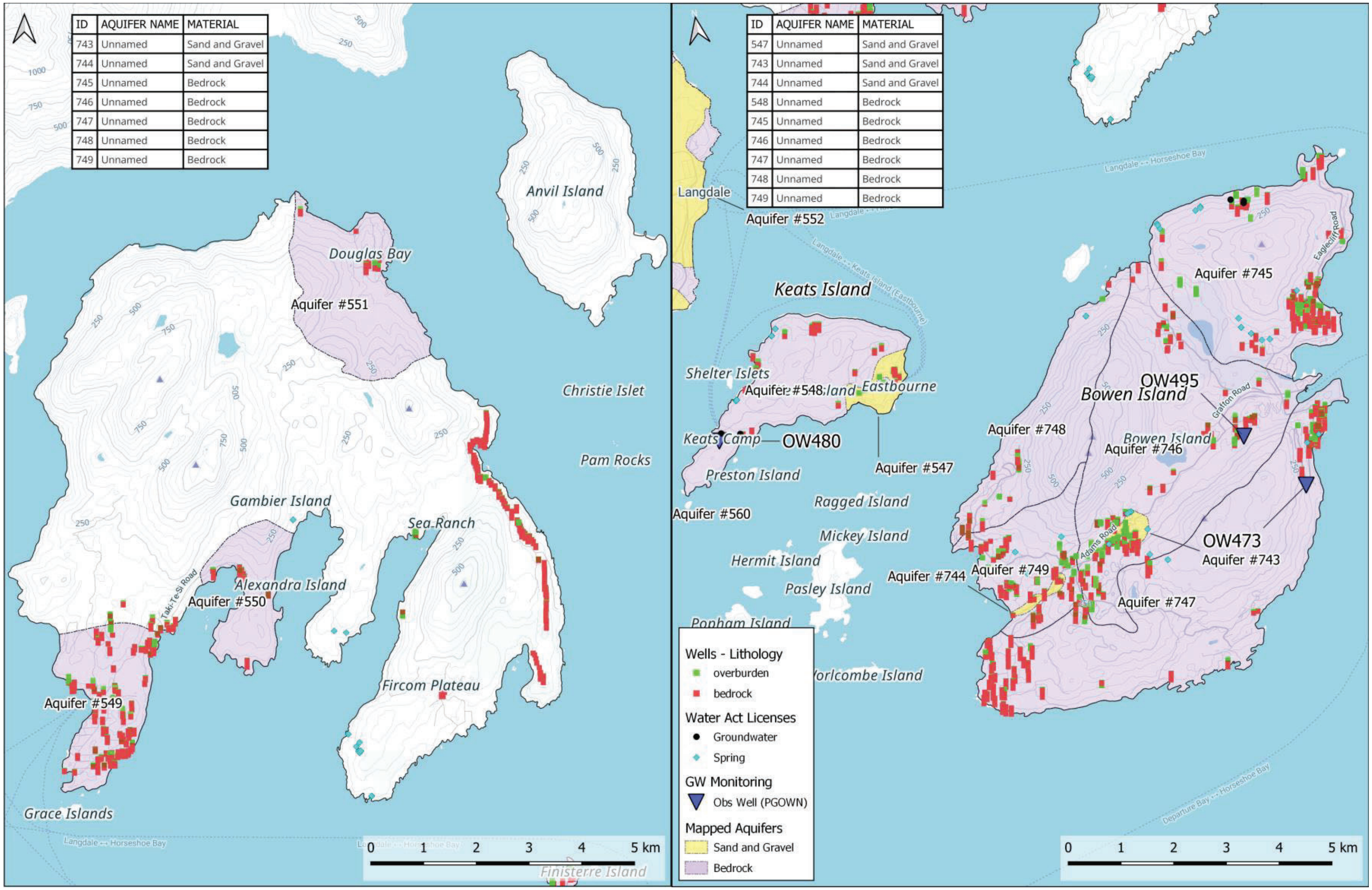


Figure 3. Gambier, Anvil, Bowen, and Keats islands; Mapped Aquifers and provincial observation wells (PGOWN)

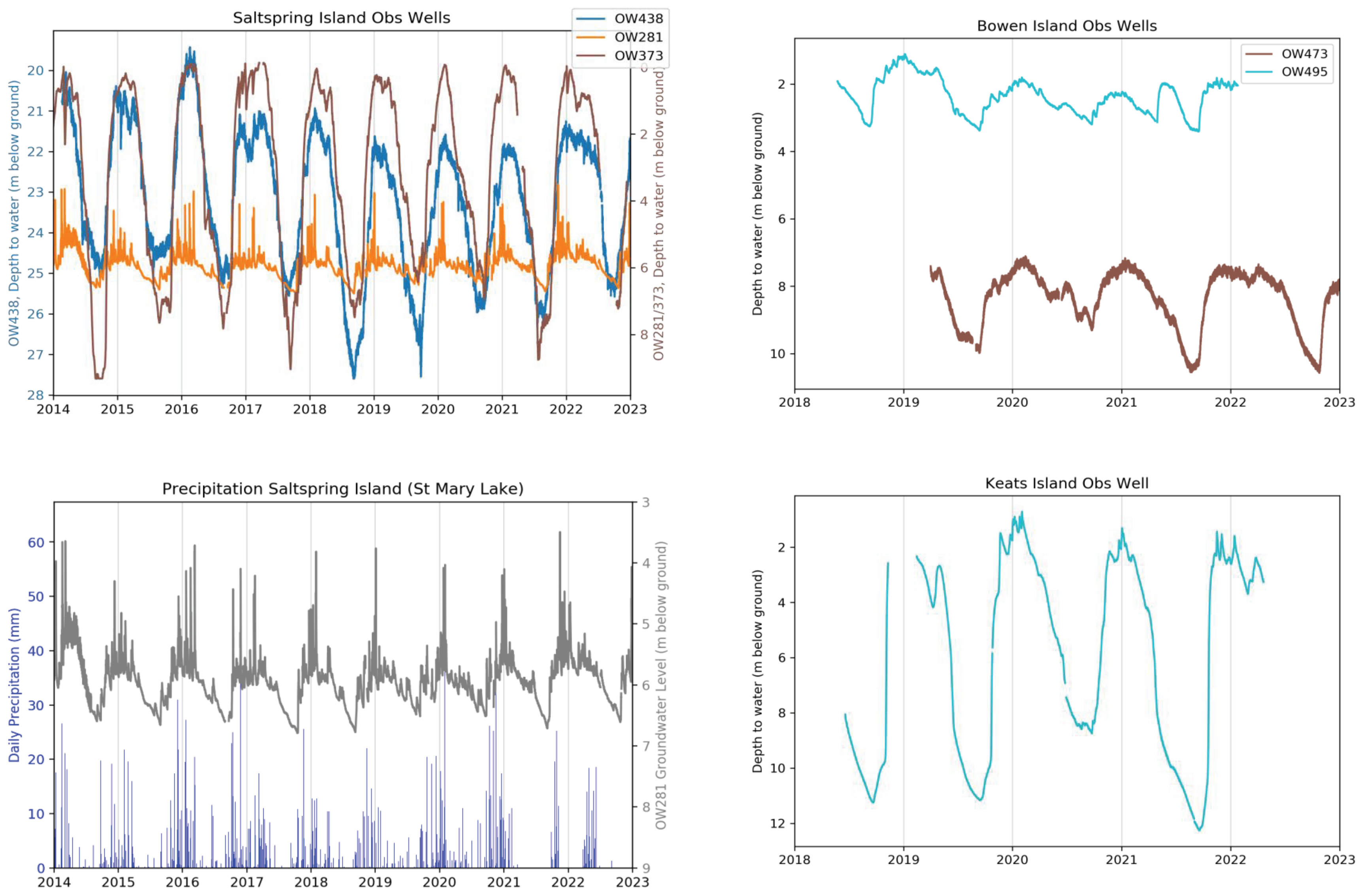


Figure 4: Groundwater fluctuation in existing observation wells within the study area, And daily precipitation at the St Mary Lake station in Saltspring Island

2.3 3D Conceptual Models

The conceptual models of the Study Islands are three-dimensional representations of the groundwater systems. The models include system boundaries (e.g., topography, ocean), hydrogeological units (bedrock and overburden aquifers and aquitards), and indicators of groundwater flow (e.g., groundwater levels and piezometric contours). GW Solutions built 3D conceptual models for the Study Islands using Leapfrog Works (Seequent Ltd.) software. The primary inputs for the models include:

- LiDAR “Bare Earth” topography (2 m resolution)
- Standardized GWELLS tables (collar, lithology, screens, water levels)
- Well yields and static water levels.
- Bedrock geology mapping (Table 2)

Table 2. Geology maps and sources used in the development of the 3D models.

Island	Information Sources
Sidney, James	**Thurber (2008)**
Lasqueti, Thormanby	Cui et al., (2017)
Bowen-Keats	GSC (1965), Cui et al., (2017)
Gambier-Anvil	GSC (1965), Cui et al., (2017)
Thetis-Reid	England (1989), ITC (2020)
Valdes	England (1989), ITC (2020)
Saltspring	England (1989), Greenwood & Mihalynuk (2009), Golder Associates (2019), ITC (2020)

Three distinct hydrogeologic material types can be distinguished among the Study Islands, depending on the dominant geological and groundwater character of the island:

1. Quaternary/Unconsolidated sediments
2. Sedimentary rocks (Nanaimo Group)

3. Crystalline or volcanic rocks

2.3.1 Quaternary/Unconsolidated Sediment Dominant Islands

A veneer of unconsolidated sediment exists even on bedrock dominant islands, and thicker accumulations in low-lying areas can even play an important role in groundwater storage. However, most groundwater users on the Study Islands rely on the fractured bedrock systems for water. Quaternary sediments are only dominant on the islands of James, Sidney, and North Thormanby. Here, the main aquifers are composed of an assemblage of Quadra and Vashon sediments, like those typically found on eastern Vancouver Island and the coastal mainland.

The conceptual models developed for the unconsolidated sediment dominant islands are represented by hydrogeological units interpreted from the standardized lithologies of GWELLS. The locations of wells were adjusted as required in the models based on the scanned original drilling records, where available (Thurber, 2008).

The James Island conceptual model comprises six hydrogeological units (Figure 5). The main James Island aquifer is the saturated portion of Quadra sediment which are comprised of sand, silty sand, and minor gravel. The Quadra sediment form the prominent sand cliffs of James Island. The dry portion of the Quadra unit is locally exposed at ground surface or is overlain by marine deposits and glacial till (Vashon Drift). Underlying units comprise silt, stoney clay, and till of the Dashwood Drift and granitic bedrock.

Sidney Island hosts a sand and gravel aquifer throughout the northern half of the island that is likely composed of Quadra and Vashon glacial sediment. Bedrock dominates the southern part of the island and is composed of Island Plutonic Suite (intrusive diorites) and shale and sandstone of the Nanaimo Group.

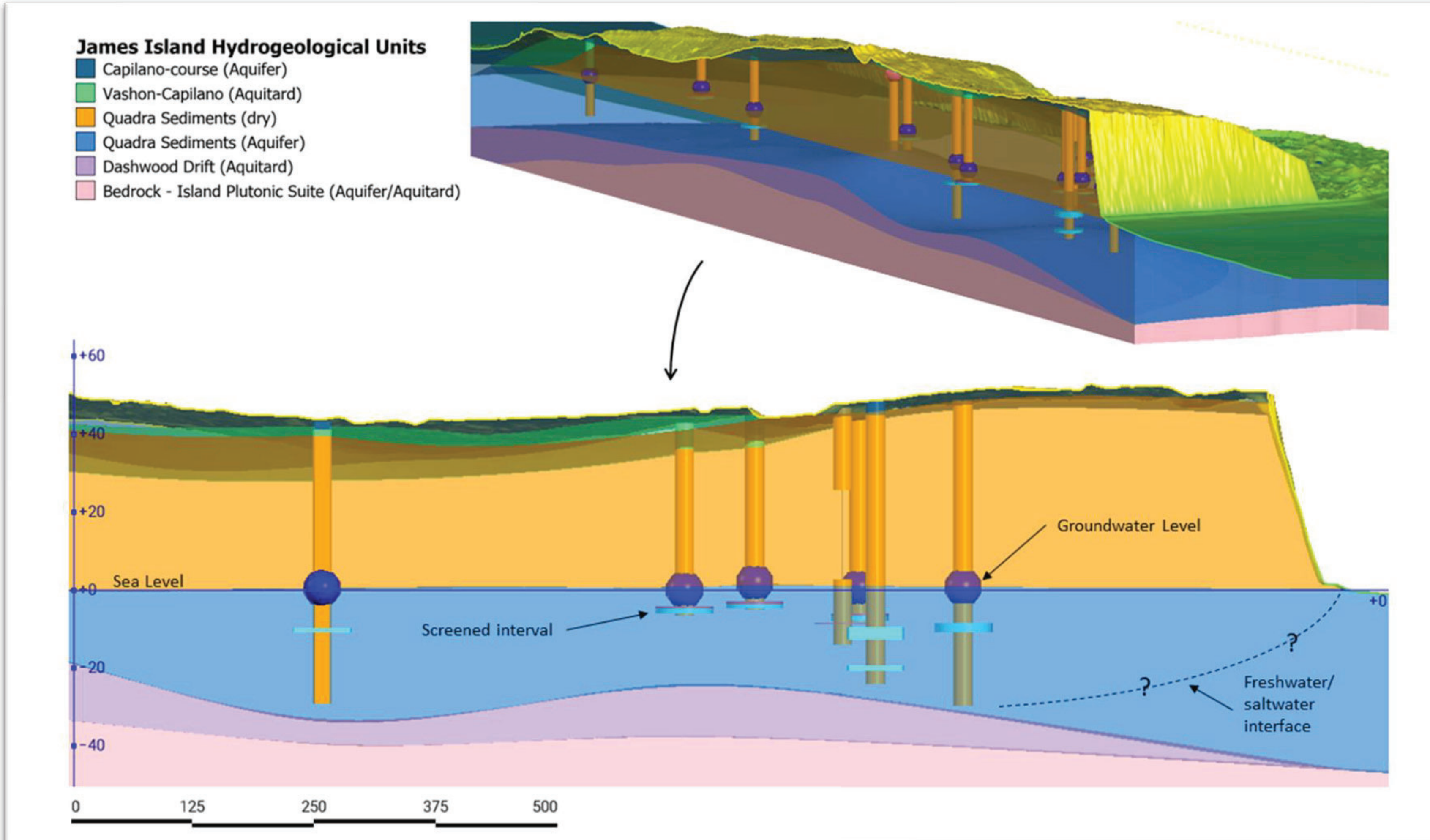


Figure 5. James Island conceptual model cutaway.

2.3.2 Sedimentary Rock Dominant Islands

The sedimentary rock dominant islands of Valdes, Thetis, and Reid are underlain by bedrock of the Cretaceous Nanaimo Group (Figure 6). Saltspring Island is underlain by all three major rock types: intrusive and extrusive igneous rocks, sedimentary units, and metasedimentary rocks. However, roughly two thirds of groundwater users on Saltspring Island rely on sedimentary rocks of the Nanaimo Group (Golder Associates, 2019).

The Nanaimo Group consists of ten formations each comprising alternating strata of sandstone, conglomerate, mudstone, and shale (Table 3). Interbedding or alternating sequences of rock types is common throughout the Group. These strata were tectonically folded and faulted, resulting in bedding dip (tilt) angles that range from horizontal to vertical. Local topography, together with the dip of the strata, and the relative orientation of bedding planes likely influence local recharge conditions and groundwater flow (Allen & Suchy, 2001). The porosity of Nanaimo Group rocks is low, and permeability is likely tied to fractures, bedding planes, and geologic contacts between the formations. Water-bearing zones are more often associated with shale beds where fractures and bed partings are abundant, than with less fractured sandstone and conglomerate units (Allen & Suchy, 2001).

The conceptual models developed for the sedimentary rock dominant islands focused on modelling the stratigraphy and structures of the Nanaimo Group (Figure 7). Bedrock mapping compiled from England (1989), Greenwood & Mihalynuk (2009), and ITC (2020) was used in conjunction with LiDAR (ITC, 2022) to interpolate the stratigraphic contacts and surface expression of geological structures. Strike and dip information from England (1989) and Greenwood and Mihalynuk (2009) was used to generate the large-scale structure of bedrock strata in the models. Bedrock lithologies from the standardized version of GWELLS were used to refine geological contact surfaces, where possible. Static water levels and the fracture and yield data also illuminate the dynamics of groundwater flow.

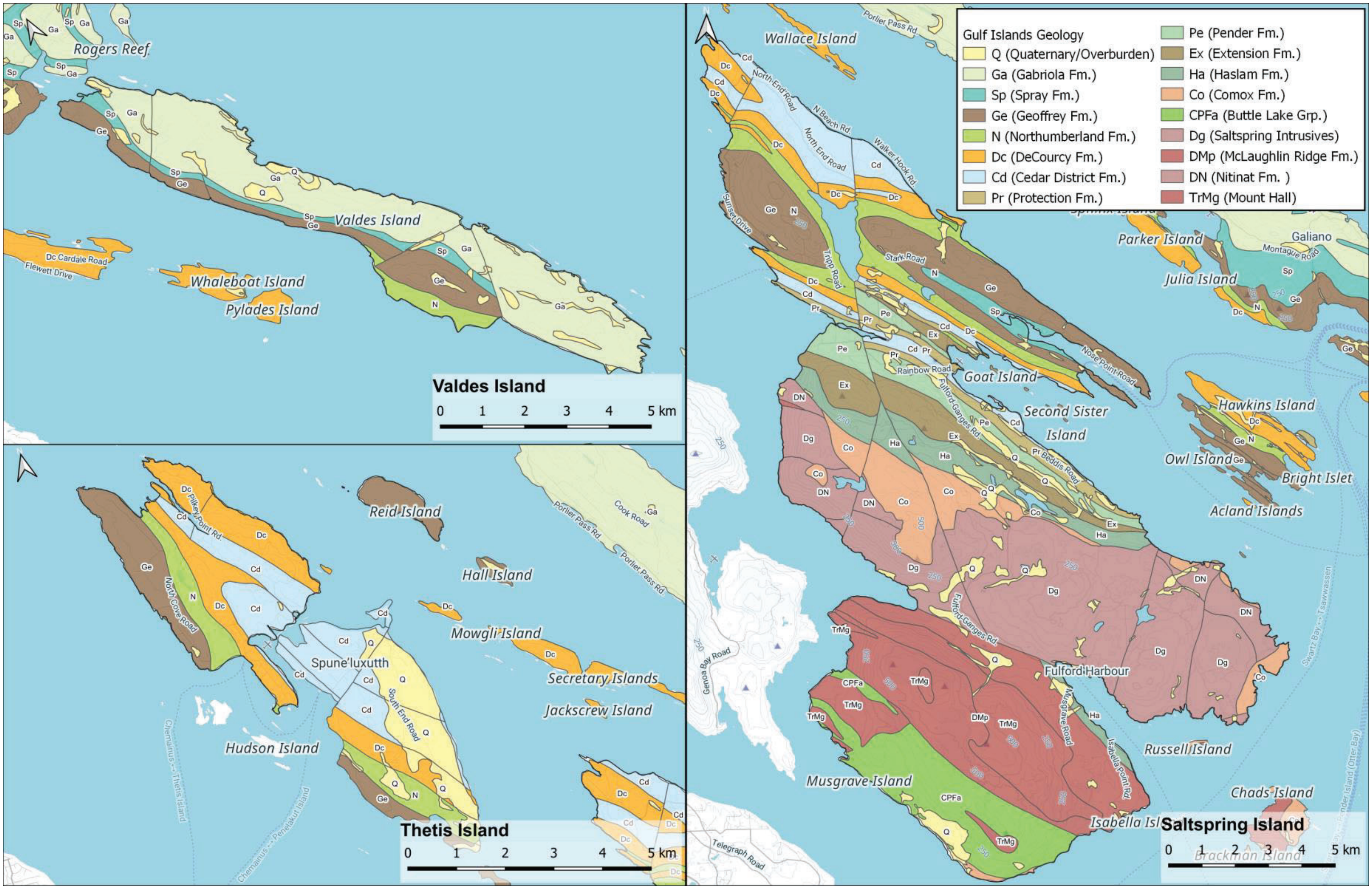


Figure 6. Sedimentary rock dominant geology compiled from England (1989), Greenwood & Mihalynuk (2009), ITC (2020).

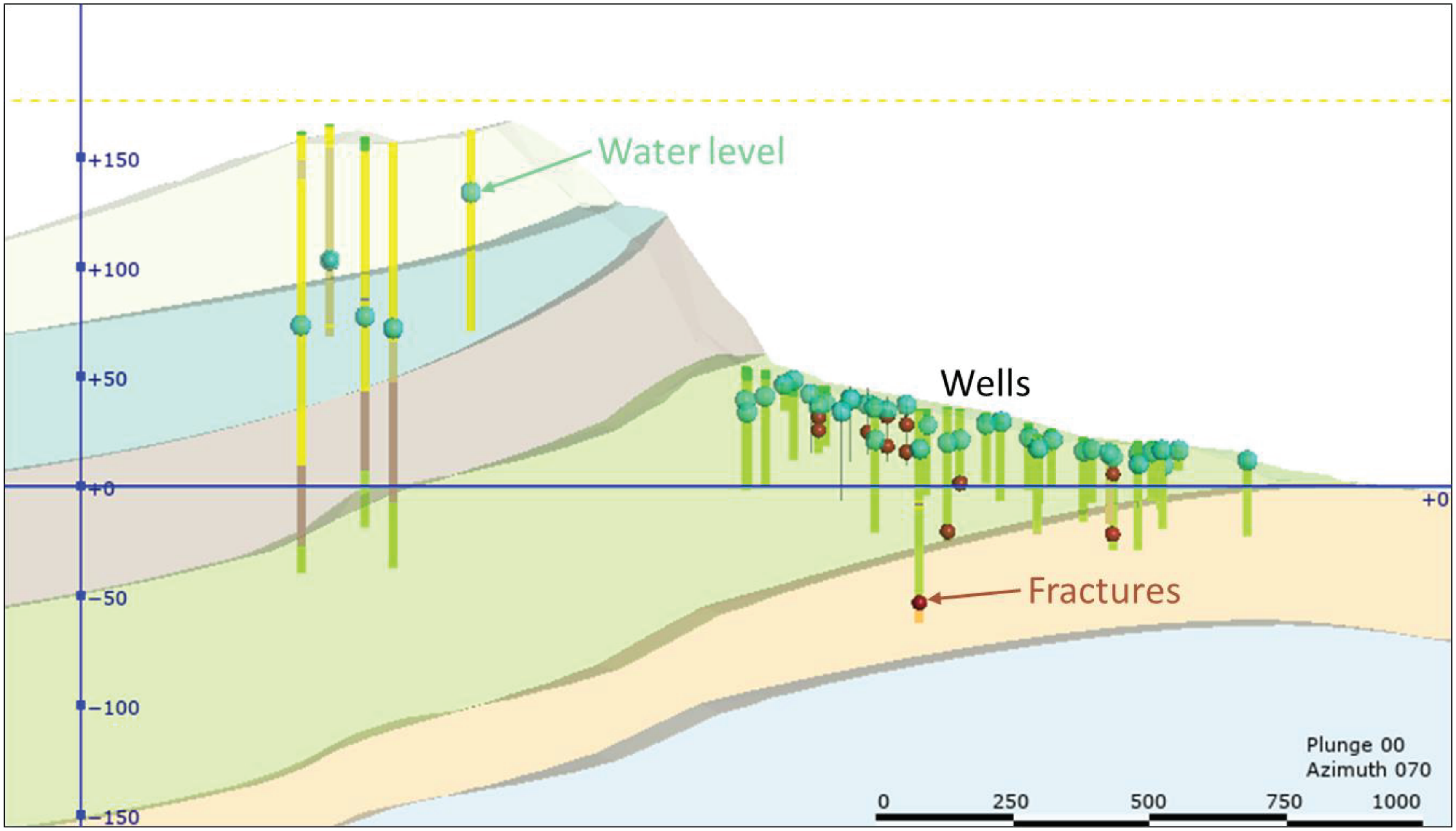
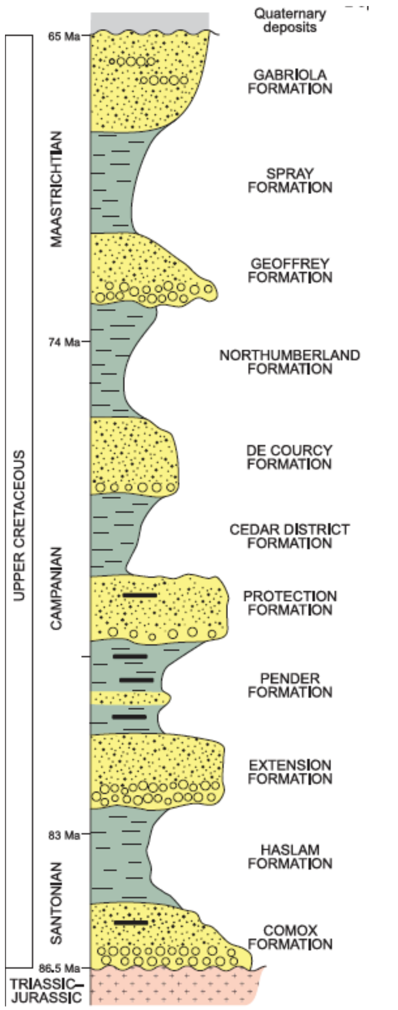


Figure 7. 3D Geological model showing the wells data and subsurface structure of Nanaimo Group strata.

Table 3. Nanaimo Group strata and simplified geology from Hamblin, (2012) (* indicates the islands included in this study).

Simplified Geology	Map Code	Hornby	Denman	Gabriola/ Valdes*	Thetis*/ Reid*	Galiano	Mayne/ Saturna	Pender	Saturna	Saltspring*
	Ga									
	Sp									
	Ge									
	N									
	Dc									
	Cd									
	Pr									
	Pe									
	Ex									
	Ha									
	Co									

Each island is comprised of a different sequence of Nanaimo Group formations (Table 3**Error! Reference source not found.**). The structural character varies across the islands in terms of bedrock bedding plane orientations (strike and dip), folding and faulting. All islands, however, display a characteristic pattern of coarse-grained strata (e.g., conglomerate or sandstone) producing topographic features at higher elevations, with fine-grained rocks (e.g., mudstone or shale) at lower elevations. The interplay of bedrock type, structure and topography likely controls the relative amounts of surface water runoff versus infiltration (i.e. groundwater recharge).

The conceptual models of the sedimentary rock dominant islands comprise the following geological units:

1. **Gabriola Formation - Ga**: Thick-bedded, river-channelized conglomerate interbedded with sandstone. The unit forms the prominent ridges along the south coast of Gabriola and Valdes islands.
    - Although the Gabriola Formation provides prominent topographic features, the underlying Spray Formation is likely the main source of groundwater.
    - The Gabriola Fm. is the major source of groundwater for most of Galiano Island.
2. **Spray Formation - Sp**: Massive, olive-grey mudstone interbedded with thin-bedded (or locally thick-bedded), massive sandstone.
    - The Spray Fm. is a heterogenous unit (in contrast to the overlying Gabriola Formation) and is notable for its mixed interbedding of sandstone and shale in driller's logs. This unit is a major source of groundwater in the more densely developed areas of southern and northeastern Hornby Island.
    - The Spray Fm. is a significant source of groundwater on Gabriola and Mayne islands, and likely the source of water for many wells along southeast Galiano Island.
3. **Geoffrey Formation - Ge**: Thick-bedded, channelized conglomerate interbedded with massive, olive-grey sandstone, and minor mudstone. The Geoffrey Formation conglomerate is the resistive capstone of Mt Geoffrey, the most prominent topographic feature of Hornby Island. Similar promontories composed of Geoffrey Formation can also be seen on Thetis, Valdes, and north Saltspring islands. On Reid Island, it is the only mapped unit and the likely source of all groundwater users there.
    - The unit is identified as conglomerate, sandstone/conglomerate, and massive sandstone from driller's logs. The conglomerate and sandstone are likely not major water-bearing units; however, the inclined bedding planes may direct runoff to areas where infiltration to the subsurface can occur.

4. **Northumberland Formation - N**: This dominantly fine-grained unit is characterized by massive dark grey mudstone, locally interbedded with siltstone and sandstone. In well logs, this unit is typically described as shale or mixed sandstone/shale.
    - The Northumberland Formation is interpreted as the dominant source of groundwater for north and northwestern Denman Island, and significant areas of Gabriola Island, especially along the coast.
5. **De Courcy Formation - Dc**: The De Courcy Formation is characterized by massive, light grey, thick-bedded sandstone, locally interbedded with thick-bedded conglomerate. This unit forms topographic ridges and the intervening valleys are dominated by shale units of the overlying Northumberland Fm or underlying Cedar District Fm. The shale units have preferentially eroded to form small surface water catchments.
    - The De Courcy Formation is a prominent ridge-forming unit on Pender, Mayne, Saturna, and Saltspring islands. Many wells are drilled through the massive sandstone/conglomerate of the ridge tops and terminate in underlying fine-grained Cedar District Formation.
6. **Cedar District Formation – Cd**: Massive dark grey mudstone (shale), locally interbedded with siltstone and sandstone.
    - The unit is likely the dominant source of groundwater for wells drilled along the central axis of Denman Island.
    - The Cedar District Formation is a locally important groundwater source on Pender Island and north Saltspring Island.
7. **Protection, Pender, Extension, Haslam & Comox Formations – Pr, Pe, Ex, Ha, Co**: These formations represent a sequence of alternating coarse- or fine-grained rocks. The resistive sandstone/conglomerate formations (Protection, Extension, and Comox formations) make up topographic ridges and the intervening valleys are dominated by mudstone/shale units (Pender and Haslam formations).
    - The mudstone-dominant units are important sources of groundwater on Pender and central Saltspring islands. Many wells were drilled through the massive sandstone/conglomerate of the ridge tops and terminate in underlying fine-grained units.

2.3.3 Crystalline and Volcanic Rock Dominant Islands

The third group of islands is dominated by crystalline and volcanic rock and includes six study islands. These include the islands of Lasqueti, South Thormanby, Bowen, Keats, Gambier, and Anvil. The fracturing of crystalline and volcanic rocks is disordered and complex. Groundwater flow is influenced by various factors, including the degree of fracturing, the presence of faults and joints, and the characteristics (hydraulic conductivity, porosity/storativity) of the bedrock itself. In general, crystalline bedrock is relatively impermeable, meaning that water moves through it slowly and is often confined to fractures or other pathways. Groundwater flow in crystalline bedrock can be influenced by topography, with flow often directed toward valleys or other low-lying areas.

Lasqueti and South Thormanby islands are underlain by mafic volcanic rocks of the Karmutsen Formation (Upper Triassic Vancouver Group). The formation consists of a thick package of basaltic volcanic rocks formed by pillowed flows and pillow breccias. The rocks of Lasqueti are heavily fractured and produce a variable topography. Fracture zones have preferentially eroded and form deeply incised valleys between prominent uplands. A small area on the northern tip of Lasqueti Island features basal conglomerates of the Nanaimo Group, likely associated with the Comox Formation.

Bowen and Keats islands form part of the Coast Plutonic Complex of the Coast Range. Keats Island hosts metamorphosed volcanics and lesser interbedded sedimentary rocks of the Bowen Island Group, along with Coast Plutonic granitic rocks. Bowen Island comprises intrusive and extrusive igneous rocks, metasedimentary rocks, and minor sedimentary units. A small number of groundwater users on Bowen and Keats islands rely on sand and gravel aquifers of limited extent, located in the central island valleys.

Most of Gambier Island and all of Anvil Island is underlain by mafic volcanic and associated sedimentary strata of the Lower Cretaceous Gambier Group. Granitic rocks of the Coast Plutonic Complex underlie the southern part of Gambier Island (like Bowen Island).

The conceptual models developed for the crystalline and volcanic rock dominant islands focused on differentiating the broad scale rock types (where mapped) and modelling areas of thicker unconsolidated sediments (Figure 8). Isolated pockets of glacial and post-glacial deposits of sufficient thickness to host groundwater exist on Bowen, Keats, and Saltspring islands. Few wells are reported from Lasqueti Island and virtually none are recorded in South Thormanby and Anvil Islands. As a result, the conceptual groundwater models for these islands lack the level of information available from other islands in this study.

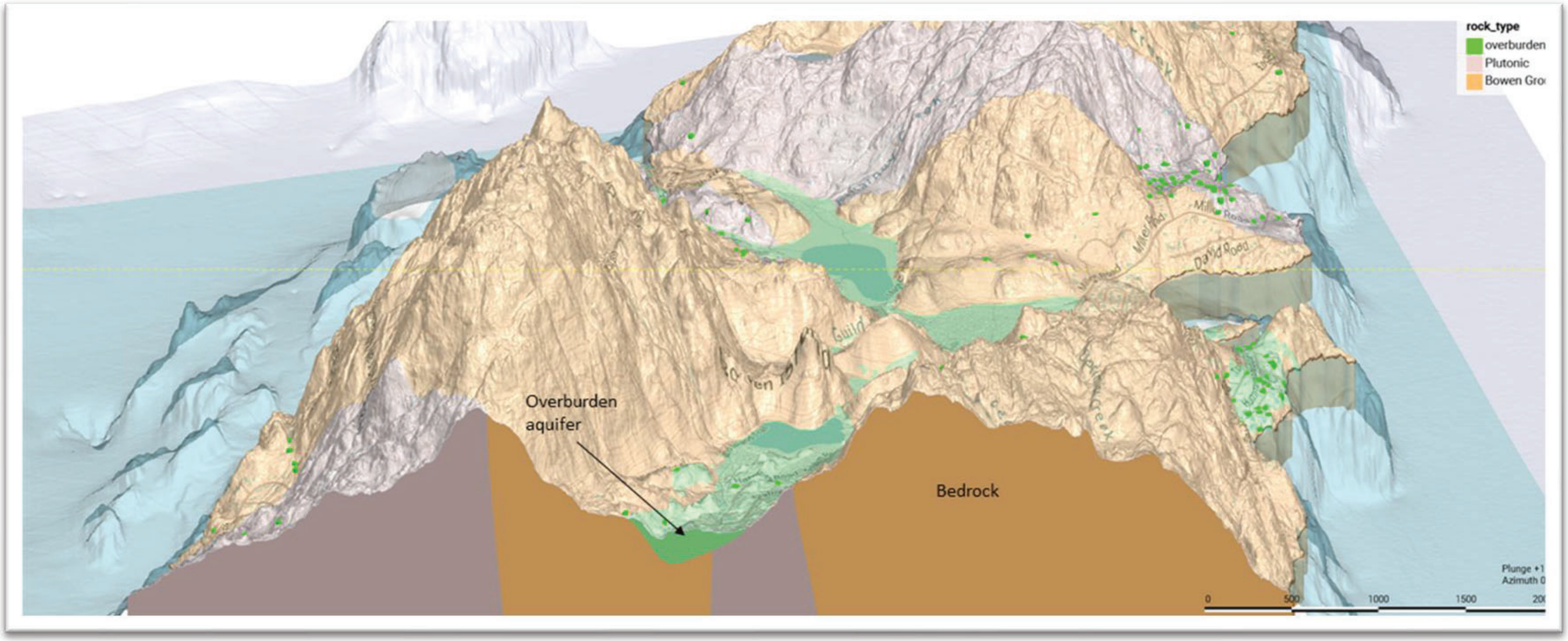


Figure 8. Vertical slice through Bowen Island 3D model.

3 CONCLUSIONS

Based on the completed work, GW Solutions draws the following conclusions:

1. 3D conceptual groundwater models have been developed for the following islands: Bowen, Keats, Gambier, Valdez, Thetis, Reid, Saltspring, James, and Sidney. Anvil, Lasqueti, North Thormanby, South Thormanby islands lacked sufficient groundwater information, resulting in simple 3D models composed of topography, broad-scale geology.

2. Geospatial datasets generated from this work include:
    - Compiled geology mapping for all Study Islands;
    - Hydrogeological Units;
    - Groundwater Regions and Aquifers;
    - Well Yields and Producing Factures (from GWELLS);
    - Groundwater Levels (from GWELLS); and

      Seasonal Groundwater Level Variation.

3. Three distinct hydrogeologic material types can be distinguished among the Study Islands, depending on the dominant geological and groundwater character of the island; 1) Quaternary/Unconsolidated sediments, 2) Sedimentary rocks (Nanaimo Group), and 3) Crystalline or volcanic rocks

4. There are six wells of the provincial groundwater observation network (PGOWN) throughout the Study Islands; three wells (all completed in bedrock) in Saltspring Island, two well (one completed in unconsolidated and one in bedrock) in Bowen Island, and one well (completed in bedrock) in Keats Island.

5. Based on the available groundwater level data in the observation wells:
    - Groundwater level minima occur in August and September, depending on the well type and depth (deep or shallow).
    - Groundwater levels rise as aquifers are recharged starting in October with the onset of the rainy season. Groundwater level maxima occur in the winter months, typically, December and January.
    - No discernable trends in groundwater levels are observed over the last decade of data from Saltspring, Bowen, and Keats islands. A decreasing trend in groundwater levels could indicate either increased aquifer discharge (e.g. pumping wells) or decreased aquifer recharge (e.g. climate change, land use change,).

- The amplitude of annual groundwater fluctuation in the provincial observation wells is 2-10 m on Saltspring Island, 2 m on Bowen Island, and 10 m on Keats Islands.

4 RECOMMENDATIONS

GW Solutions makes the following recommendations:

1. Review, expand and update the Leapfrog models as new information becomes available.

2. Develop a comprehensive model of the freshwater-saltwater interface and risk of saltwater intrusion due to excessive well pumping using the 3D models as a framework to model the spatial variability of groundwater chemistry data across the islands.

3. Increase the number of community groundwater monitoring locations on each Study Island to better understand the seasonal, annual and multi-year fluctuations in groundwater levels. This could be achieved through a community-based network of privately-owned wells that are equipped with devices that automatically measure water level and electrical conductivity (a proxy for salinity). The Regional District of Nanaimo's Volunteer Observation Well Network includes private wells on Gabriola Island and could provide a good model for the Islands Trust Council to expand to other islands.

5 REFERENCES

Allen, D.M., Suchy, M. (2001). Geochemical evolutions of groundwater on Saturna Island, British Columbia. Canadian Journal of Earth Science. 38, 1095-1080.

Cui, Y., Miller, D., Schiarizza, P., and Diakow, L.J., 2017. British Columbia digital geology. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 2017-8, 9p. Data version 2019-12-19.

England, T. J. 1989. Late Cretaceous to Paleogene evolution of the Georgia Basin, Southwestern British Columbia. PhD thesis, Memorial University of Newfoundland.

Golder Associates (2019). Aquifer Mapping and Monthly Groundwater Budget Analysis for Aquifers on Salt Spring Island. Gorski, N. G. and J. P. Sacre. Available from Ecocat: https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=56660

GSC 1965, Geology of North Vancouver. Geological Survey of Canada. Memoir 335. Map 1152A

Greenwood, H.J. and Mihalynuk, M.G. 2009. Salt Spring Island Geology; (Map, GIS files, and notes); BCGS Open File 2009-11. BC Ministry of Energy Mines and Petroleum Resources.

Hamblin, A.P. 2012. Upper Cretaceous Nanaimo Group of Vancouver Island as a potential bedrock aquifer zone: summary of previous literature and concepts. Geological Survey of Canada. Open File 7265.

ITC, 2020. Islands Trust, Digital Data. URL http://mapfiles.islandstrust.bc.ca/DATA/IT/

Mustard, P. S. 1994. The Upper Cretaceous Nanaimo Group, Georgia Basin. Geology and geological hazards of the Vancouver region, southwestern British Columbia. Edited by JWH Monger. Geological Survey of Canada, Bulletin 481, 27–95.

Thurber, (2008). James Island Project - Phase 1 Groundwater Supply Report to J.I. Properties Inc. SRK Job No. 1CTO10_002. April 2008.

Province of British Columbia, 2020. DataBC - Data Catalogue, URL https://catalogue.data.gov.bc.ca/dataset?download_audience=Public

Province of British Columbia, 2020. Groundwater Level Data. URL https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=b53cb0bf3f6848e79d66ffd09b74f00d

Province of British Columbia, 2020. Groundwater Wells and Aquifers. URL https://apps.nrs.gov.bc.ca/gwells/

6 STUDY LIMITATIONS

This document was prepared for the exclusive use of Islands Trust (the client). The inferences concerning the data, site and receiving environment conditions contained in this document are based on information obtained during investigations conducted at the site by GW Solutions and others and are based solely on the condition of the site at the time of the site studies. Soil, surface water and groundwater conditions may vary with location, depth, time, sampling methodology, analytical techniques and other factors.

In evaluating the subject study area and water data, GW Solutions has relied in good faith on information provided. The factual data, interpretations and recommendations pertain to a specific project as described in this document, based on the information obtained during the assessment by GW Solutions on the dates cited in the document, and are not applicable to any other project or site location. GW Solutions accepts no responsibility for any deficiency or inaccuracy contained in this document as a result of reliance on the aforementioned information.

The findings and conclusions documented in this document have been prepared for the specific application to this project, and have been developed in a manner consistent with that level of care normally exercised by hydrogeologists currently practicing under similar conditions in the jurisdiction.

GW Solutions makes no other warranty, expressed or implied and assumes no liability with respect to the use of the information contained in this document at the subject site, or any other site, for other than its intended purpose. Any use which a third party makes of this document, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. GW Solutions accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or action based on this document. All third parties relying on this document do so at their own risk. Electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore no party can rely upon the electronic media versions of GW Solutions' document or other work product. GW Solutions is not responsible for any unauthorized use or modifications of this document.

GW Solutions makes no other representation whatsoever, including those concerning the legal significance of its findings, or as to other legal matters touched on in this document, including, but not limited to, ownership of any property, or the application of any law to the facts set forth herein.

If new information is discovered during future work, including excavations, sampling, soil boring, water sampling and monitoring, predictive geochemistry or other investigations, GW Solutions should be requested to re-evaluate the conclusions of this document and to provide amendments, as required, prior to any reliance upon the information presented herein. The validity of this document is affected by any change of site conditions, purpose, development plans or significant delay from the date of this document in initiating or completing the project.

The produced graphs, images, and maps have been generated to visualize results and assist in presenting information in a spatial and temporal context. The conclusions and recommendations presented in this document are based on the review of information available at the time the work was completed, and within the time and budget limitations of the scope of work.

The Islands Trust may rely on the information contained in this report subject to the above limitations.

7 CLOSURE

Conclusions and recommendations presented herein are based on available information at the time of the study. The work has been carried out in accordance with generally accepted engineering practice. No other warranty is made, either expressed or implied. Engineering judgement has been applied in producing this letter-report.

This letter report was prepared by personnel with professional experience in the fields covered. Reference should be made to the General Conditions and Limitations attached in Appendix 1.

GW Solutions is pleased to produce this document. If you have any questions, please contact us.

Yours truly,

GW Solutions Inc.

2023/03/31

PROFESSIONAL PROVINCE OF K.A. BARROSO CHULVE # 49456 BRITISH COLUMBIA ENGINEER

PROVINCE OF Dr. D. N. BETHUNE # 53150 BRITISH COLUMBIA GEOSCIENTIST

Antonio Barroso, M.Sc, P.Eng
Project Hydrogeologist

Matt Vardal, M.Sc.
in Geology and GIS Expert

David Bethune, Ph.D., P.Geo.
Senior Hydrogeologist

APPENDIX 1

GW SOLUTIONS INC. GENERAL CONDITIONS AND LIMITATIONS

This report incorporates and is subject to these "General Conditions and Limitations".

1.0 USE OF REPORT

This report pertains to a specific area, a specific site, a specific development, and a specific scope of work. It is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site or proposed development would necessitate a supplementary investigation and assessment. This report and the assessments and recommendations contained in it are intended for the sole use of GW SOLUTIONS's client. GW SOLUTIONS does not accept any responsibility for the accuracy of any of the data, the analysis or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than GW SOLUTIONS's client unless otherwise authorized in writing by GW SOLUTIONS. Any unauthorized use of the report is at the sole risk of the user. This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of GW SOLUTIONS. Additional copies of the report, if required, may be obtained upon request.

2.0 LIMITATIONS OF REPORT

This report is based solely on the conditions which existed within the study area or on site at the time of GW SOLUTIONS's investigation. The client, and any other parties using this report with the express written consent of the client and GW SOLUTIONS, acknowledge that conditions affecting the environmental assessment of the site can vary with time and that the conclusions and recommendations set out in this report are time sensitive. The client, and any other party using this report with the express written consent of the client and GW SOLUTIONS, also acknowledge that the conclusions and recommendations set out in this report are based on limited observations and testing on the area or subject site and that conditions may vary across the site which, in turn, could affect the conclusions and recommendations made. The client acknowledges that GW SOLUTIONS is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the client.

2.1 INFORMATION PROVIDED TO GW SOLUTIONS BY OTHERS

During the performance of the work and the preparation of this report, GW SOLUTIONS may have relied on information provided by persons other than the client. While GW SOLUTIONS endeavours to verify the accuracy of such information when instructed to do so by the client, GW SOLUTIONS accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

3.0 LIMITATION OF LIABILITY

The client recognizes that property containing contaminants and hazardous wastes creates a high risk of claims brought by third parties arising out of the presence of those materials. In consideration of these risks, and in consideration of GW SOLUTIONS providing the services requested, the client agrees that GW SOLUTIONS's liability to the client, with respect to any issues relating to contaminants or other hazardous wastes located on the subject site shall be limited as follows:

(1) With respect to any claims brought against GW SOLUTIONS by the client arising out of the provision or failure to provide services hereunder shall be limited to $10,000, whether the action is based on breach of contract or tort;

(2) With respect to claims brought by third parties arising out of the presence of contaminants or hazardous wastes on the subject site, the client agrees to indemnify, defend and hold harmless GW SOLUTIONS from and against any and all claim or claims, action or actions, demands, damages, penalties, fines, losses, costs and expenses of every nature and kind whatsoever, including solicitor-client costs, arising or alleged to arise either in whole or part out of services provided by GW SOLUTIONS, whether the claim be brought against GW SOLUTIONS for breach of contract or tort.

4.0 JOB SITE SAFETY

GW SOLUTIONS is only responsible for the activities of its employees on the job site and is not responsible for the supervision of any other persons whatsoever. The presence of GW SOLUTIONS personnel on site shall not be construed in any way to relieve the client or any other persons on site from their responsibility for job site safety.

5.0 DISCLOSURE OF INFORMATION BY CLIENT

The client agrees to fully cooperate with GW SOLUTIONS with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The client acknowledges that in order for GW SOLUTIONS to properly provide the service, GW SOLUTIONS is relying upon the full disclosure and accuracy of any such information.

6.0 STANDARD OF CARE

Services performed by GW SOLUTIONS for this report have been conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Engineering judgement has been applied in developing the conclusions and/or recommendations provided in this report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of this report.

7.0 EMERGENCY PROCEDURES

The client undertakes to inform GW SOLUTIONS of all hazardous conditions, or possible hazardous conditions which are known to it. The client recognizes that the activities of GW SOLUTIONS may uncover previously unknown hazardous materials or conditions and that such discovery may result in the necessity to undertake emergency procedures to protect GW SOLUTIONS employees, other persons and the environment. These procedures may involve additional costs outside of any budgets previously agreed upon. The client agrees to pay GW SOLUTIONS for any expenses incurred as a result of such discoveries and to compensate GW SOLUTIONS through payment of additional fees and expenses for time spent by GW SOLUTIONS to deal with the consequences of such discoveries.

8.0 NOTIFICATION OF AUTHORITIES

The client acknowledges that in certain instances the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by GW SOLUTIONS in its reasonably exercised discretion.

9.0 OWNERSHIP OF INSTRUMENTS OF SERVICE

The client acknowledges that all reports, plans, and data generated by GW SOLUTIONS during the performance of the work and other documents prepared by GW SOLUTIONS are considered its professional work product and shall remain the copyright property of GW SOLUTIONS.

10.0 ALTERNATE REPORT FORMAT

Where GW SOLUTIONS submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed GW SOLUTIONS's instruments of professional service), the Client agrees that only the signed and sealed hard copy versions shall be considered final and legally binding. The hard copy versions submitted by GW SOLUTIONS shall be the original documents for record and working purposes, and, in the event of a dispute or discrepancies, the hard copy versions shall govern over the electronic versions. Furthermore, the Client agrees and waives all future right of dispute that the original hard copy signed version archived by GW SOLUTIONS shall be deemed to be the overall original for the Project. The Client agrees that both electronic file and hard copy versions of GW SOLUTIONS's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except GW SOLUTIONS. The Client warrants that GW SOLUTIONS's instruments of professional service will be used only and exactly as submitted by GW SOLUTIONS. The Client recognizes and agrees that electronic files submitted by GW SOLUTIONS have been prepared and submitted using specific software and hardware systems. GW SOLUTIONS makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.