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Consultants in Hydrogeology and Environmental Science

Cowichan Estuary Restoration Seawater Intrusion Assessment



Prepared for:

The Nature Trust of British Columbia
500-888 Dunsmuir Street
Vancouver, BC V6C 3K4

August 13, 2025
Project: 25-050-01VC

Prepared by:

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Executive Summary

The Nature Trust of British Columbia (NTBC) is leading an initiative to restore the natural processes in the Cowichan Estuary near Cowichan Bay, BC through removal of barriers to estuarine marsh development (NHC, 2022). Western Water Associates Ltd. (WWAL) was retained by NTBC to conduct a hydrogeological assessment of seawater intrusion (SWI) potential for the Cowichan Estuary that could occur as a result of marsh restoration. The purpose of the study was to assess SWI impacts for area wells after the proposed removal of Dike 49 located within the Cowichan Estuary (the project).

The study area was defined using the boundary of the Cowichan River Floodplain, extending 2 km inland from the coastline. WWAL completed a systematic review of available reports and datasets in the study area to gain understanding of the hydrogeology, historical water quality concerns, and potential mechanisms for SWI into the aquifers.

Three mapped sand and gravel (unconsolidated) aquifers were identified to be located in the study area:

- A shallow, unconfined aquifer (Aquifer 186),
- A deeper, confined aquifer (Aquifer 188),
- Another deeper, confined aquifer that underlies only the southern boundary of the floodplain and the upland beyond (Aquifer 197).

Underlying all the unconsolidated aquifers is the Nanaimo Group sedimentary bedrock aquifer (Aquifer 198). There were no bedrock wells identified within the study area, and therefore Aquifer 198 was not considered in any further assessment of potential SWI impact.

WWAL carried out fieldwork in June 2025 to complete an inventory of active wells and collect groundwater samples from accessible locations in the study area. No active wells completed in upper Aquifer 186 could be accessed during the site visits. Based on the limited available data, salinity of the groundwater in Aquifer 188 does not appear to have changed much over the past four decades.

WWAL assessed potential impacts from SWI to active wells within a smaller portion of the study area, referred to as the SWI assessment area, that was defined as the floodplain area to the south and upgradient of Dike 49, extending approximately 2 km inland from the coast. The analysis was completed only on two, six, and five active wells completed in Aquifers 186, 188, and 197, respectively, located within the SWI assessment area.

The assessment of SWI in this study followed the GIS-based methodology used by WWAL (2021) to assess Aquifer Susceptibility, Pumping Threat, and Aquifer Vulnerability from Pumping along the entire BC coast. Values for these aspects of the assessment were considered independent of dike removal and flood mitigation activities. They are summarized as follows:

- All wells within the study area had Aquifer Susceptibility values of 5 (high) because of the generally shallow static water elevations (<10 m above sea level) and proximities to coast (<1.5 km).
- Pumping Threat values up to 2, 3, and 1 were assessed for Aquifers 186, 188, and 197, respectively. These are lower than the Pumping Threat values for the SWI assessment area from WWAL (2021), which were overestimated because WWAL (2021) assumed all reported wells were active.

- Aquifer Vulnerability to Pumping values up to 3, 4 and 2 were assessed for Aquifers 186, 188, and 197, respectively. Aquifer Vulnerability from Pumping was lower for Aquifers 186 and 197 compared to the results from WWAL (2021) because there were fewer active wells completed in these aquifers within the study area. The Aquifer Vulnerability from Pumping for Aquifer 188 initially appeared similar to results from WWAL (2021). This similarity arose because the former approach did not account for WTN 54536 (Kidd Well) being used only intermittently as a backup supply source. Under normal conditions, when WTN 54536 is not pumping, the Aquifer Vulnerability from Pumping near the well would decrease to 3, which is lower than the value reported in WWAL (2021).

Coastal Hazards were not analyzed using the methodology from WWAL (2021). Instead, they were evaluated qualitatively using data and information from hydrology work done by Northwest Hydraulic Consultants (NHC) to determine how the active wells may be impacted by the project. Modelling from NHC showed appreciable surface water level increases on the Dinsdale Field property for some joint riverine and ocean-level flood conditions, which is a desired outcome of the project (NHC, 2025a). Flood Hazard mapping indicated that the project will either reduce or maintain existing flood hazards for the present climate condition for Cowichan Bay Road and the properties west of the road after Dike 49 is decommissioned (NHC, 2025a). Assessment of Coastal Hazards pre and post dike removal indicated 0.01 m change to water levels and maximum wave heights in the vicinity of the active wells from the project which were within NHC's modelling uncertainty limits (NHC, 2025a).

The Cowichan Estuary Marsh Restoration Project is not expected to result in significant impacts to active groundwater users within the SWI study area upgradient of Dike 49. Most of the wells in the SWI assessment area were completed in Aquifer 188. The presence of an overlying confining unit and the lack of hydraulic connection between Aquifers 188 and 197 and the distributary channels of the Cowichan River in the SWI study area indicate Aquifers 188 and 197 should not be vulnerable to infiltration of any brackish or saline water that may be occasionally present in the distributary channels. Removal of Dike 49 should have a negligible affect on Aquifers 188 and 197, provided that the integrity of the wells (e.g., proper casing stick-up and mounding around the wellhead, secure and flood-proofed well cap, adequate surface seal) drilled into these aquifers are maintained such that they do not allow any shallow water to enter into the aquifer directly from the upper portion of the well.

There were only two wells within the SWI assessment area completed in Aquifer 186. Infiltration of brackish or saline water from the distributary channels into Aquifer 186 can occasionally occur under current conditions. Well WTN 53193 is more susceptible to SWI given its proximity to the distributary channel and to the coast, regardless of removal of Dike 49. The potential of infiltration of brackish or saline water affecting the use of well WTN 53193 can be mitigated, if necessary, by deepening the well and completing it in Aquifer 186 or into Aquifer 188.

Based on the results of the assessment, the following recommendations are provided:

- Conduct groundwater sampling at the following wells to monitor groundwater quality specific to SWI. The samples should be tested for specific conductance, total dissolved solids, and chloride, which are key indicator parameters for seawater intrusion.
    - WTN 53913, completed in Aquifer 186.

  - The South Cowichan Lawn Tennis Club well (WTN 48582), WTN 52512, the Kidd Well (WTN 54536), and former observation well 297 (WTN 56954), completed in Aquifer 188.

The annual sampling should be completed before, during and for several years after the project is completed. Sampling frequency and schedule should then be reevaluated to determine if it is still needed.

- Complete well head improvements at former Provincial Observation Well 297 (WTN 56954) (now used for domestic purposes) to control annular flow and improve drainage around the well.
- Properly decommission any wells that are no longer in use to mitigate the potential for them to be used as preferential pathways for seawater to migrate into the aquifers below Cowichan Estuary.
- Encourage well owners in the study area to properly maintain their wells and not use them beyond their authorized quantities.
- Forward the errors in GWELLS identified and summarized in this report to the Province of BC.

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Consultants in Hydrogeology and Environmental Science

August 13, 2025 FILE: 25-050-01VC

The Nature Trust of British Columbia
500-888 Dunsmuir Street
Vancouver, BC V6C 3K4
Attention: Thomas Reid

Re: Cowichan Estuary Restoration Seawater Intrusion Assessment

Dear Mr. Reid:

Western Water Associates Ltd. (WWAL) is pleased to provide this report assessing the potential seawater intrusion impacts on area wells following the proposed removal of Dike 49, located within the Cowichan Estuary. WWAL's original proposal for this work was provided on April 23, 2025. Approval to proceed was given on April 30, 2025, and a Service Contract from Nature Trust of British Columbia was signed.

We trust that the professional opinions and advice presented in this document are sufficient for your current requirements. Should you have any questions, or if we can be of further assistance in this matter, please contact the undersigned.

Western Water Associates Ltd.
(EGBC Permit to Practice 1001419)

Aug 13 2025

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List of Abbreviations

ags - above ground surface
AGWQM&A - Ambient Groundwater Quality Monitoring and Assessment
bgs – below ground surface
btoc – below top of casing
DFL – Designated Flood Level
ETIF – Elevation Tie-In Feature
FCL – Flood Construction Level
FWA – Freshwater Atlas
GIS – Geographic Information System
HEC-RAS - Hydrologic Engineering Center's River Analysis System
HHWLT – Higher High Water Large Tide
NTBC – The Nature Trust of British Columbia
NHC – Northwest Hydraulic Consultants
SCLTC – South Cowichan Lawn and Tennis Club
SLR – Sea Level Rise
SWAN – Simulating WAves Nearshore
WAF - Wave Attenuation Feature
WRA – Water Resources Atlas
WSA – Water Sustainability Act
WWAL – Western Water Associates Ltd.

1. INTRODUCTION

The Nature Trust of British Columbia (NTBC) is leading an initiative to restore the natural processes in the Cowichan Estuary near Cowichan Bay, BC through removal of barriers to estuarine marsh development (NHC, 2022). Western Water Associates Ltd. (WWAL) was retained by NTBC to conduct a hydrogeological assessment of seawater intrusion (SWI) potential for the Cowichan Estuary that could occur as a result of marsh restoration. The purpose of this study was to assess SWI impacts for area wells after the proposed removal of Dike 49 located within the Cowichan Estuary.

Figure 1.1 below shows the locations of Dikes 49 and 88 in the Cowichan Bay Estuary. NTBC is proposing to decommission Dike 49 as part of the Cowichan Estuary Restoration project. The restoration initiative includes removing barriers located within the mapped boundaries of Dike 49 to enable the natural development of marshes in the estuary. We understand that Dike 88 will not be removed as part of the project.

Dike 49 is located within the Cowichan Estuary approximately 5 km southeast of Duncan, BC. The dike has two sections, a northern section and a southern section, that extend east from Cowichan Bay Road and converge at the coastline. Dike 88 extends west from the northern section of Dike 49 for approximately 0.6 km toward the junction of Cowichan Bay Road and Lochmanetz Road. According to the BC Water Resource Atlas (WRA), Dike 49 has a total length of approximately 1.9 km (ENV, 2025a).

Figure 1.1. Locations of Dike 88 and 49 in Cowichan Bay Estuary (source: Water Resources Atlas BC)



As part of the provincial dike decommissioning guidelines, dike removal projects must not transfer flood risk to other properties (MFLNRORD, 2022). According to the guidelines, properties affected by the dike removal must be protected to their existing level against flood hazards or to withstand the 10-year flood, whichever is greater.

Northwest Hydraulic Consultants (NHC) has completed various hydraulic and wave modelling studies for the project. The data provided by NHC were used to define the study area and identify potential impacts to active wells from the Cowichan Estuary Marsh Restoration Project.

2. SCOPE OF SERVICES

We completed the following scope of work for this report, as outlined in our proposal dated April 23, 2025:

- Conducted a literature search on EcoCat and our internal records and identified and reviewed relevant hydrogeological reports within the area.
- Compiled hydrogeological data and information on wells, aquifer mapping, groundwater use, aquifer properties, and groundwater quality.
- Developed a conceptual hydrogeological model based on the compiled data, LiDAR mapping and other available hydrogeological information in the area.
- Completed a site reconnaissance to document existing site features, observe wellheads and validate well locations, well stickup, and other details relevant to SWI for each accessible well.
- Evaluated the SWI potential within the defined study area for conditions before and after proposed dike removal and identified the wells with the highest potential for SWI.
- Evaluated existing groundwater quality data and provided input on potential sampling locations and tested parameters.
- Summarized the results in this report, which included:
    - Information on methodology, results, summary of geological and hydrogeological setting, descriptions of each well;
    - Evaluation of vulnerability of SWI for each well and aquifer; and,
    - A summary of data gaps and recommendations for additional study.

3. COWICHAN ESTUARY MARSH RESTORATION PROJECT

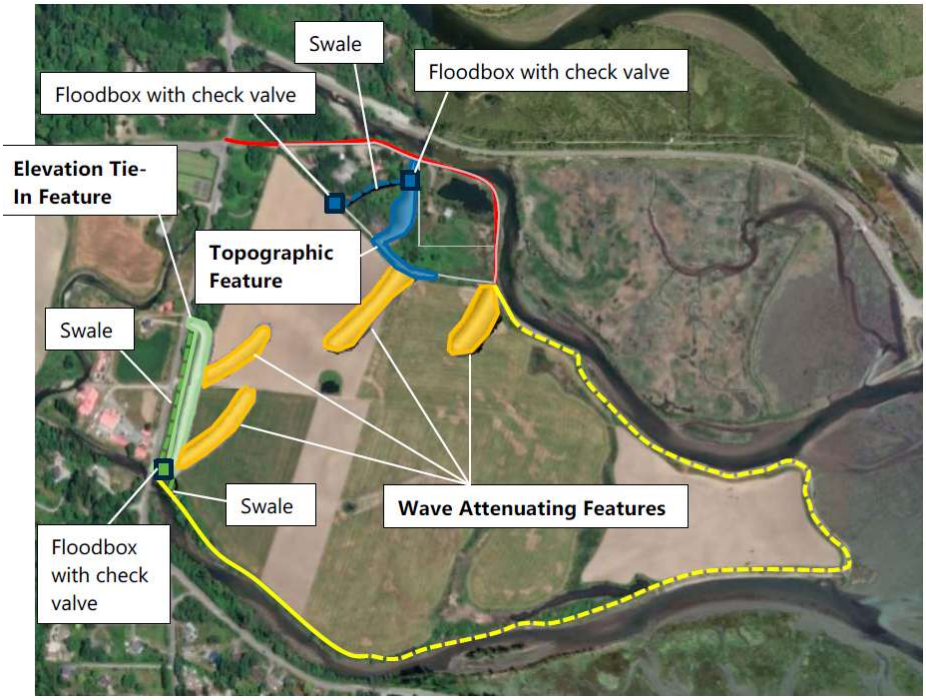
WWAL reviewed the following reports from NHC regarding coastal hazard assessment and proposed flood mitigation works for the Cowichan Estuary Marsh Restoration Project:

- Assessment of Physical Processes and Restoration Opportunities (NHC, 2022);
- Dinsdale Field Flood Mitigation Features Design Summary (NHC, 2025a);
- Flood Mitigation Design Summary (NHC, 2025b); and,
- Dinsdale Field Marsh and Tidal Channel Design (NHC, 2025c).

During initial phases of the work, NHC (2022) determined that dike removal and the proposed mitigation structures were expected to reduce maximum flood depths in the estuary through improved flow conveyance. The project will either reduce or maintain existing flood hazard conditions for present climate conditions for Cowichan Bay Road and properties west of the road after Dike 49 is decommissioned (NHC, 2022).

Figure 3.1 below shows the locations of the flood mitigation features presented in the Issued-for-Review designs from NHC (2025b). According to NHC (2025a), the proposed design includes four wave attenuation features (WAFs) in Dinsdale Field and an Elevation Tie-In Feature (ETIF) along Cowichan Bay Road.

Figure 3.1. Proposed flood mitigation works prepared by NHC in 2025 (NHC, 2025b)



The proposed ETIF comprises compacted soil and runs parallel to Cowichan Bay Road, with a crest elevation of 2.45 m along its full length (NHC, 2025a). The purpose of the ETIF is to prevent high tides from overtopping a low point along Cowichan Bay Road while minimizing impacts to overland flow from river flooding and stormwater runoff (NHC, 2025a).

The proposed WAFs were designed to dissipate wave energy and reduce wave propagation off Dinsdale Field (NHC, 2025a). The crest elevation of the WAFs is 2.5 m and the wave heights were reduced to less than 0.2 m for areas of the property adjacent to Cowichan Bay Road for present day water levels excluding sea level rise. Additional information on the proposed design can be found in the NHC reports.

NHC (2025a, 2025b, 2025c) completed hydraulic modelling in HEC-RAS[1] and wave modelling in SWAN[2] to support designing the flood mitigation features for decommissioning of Dike 49 (NHC, 2025a). Appreciable surface water level increases were predicted on the Dinsdale Field property for some joint riverine and ocean-level flood conditions, which is a desired outcome of the project (NHC, 2025a). The modelling indicated that the project will either reduce or maintain existing flood hazards for the present climate condition for Cowichan Bay Road and the properties west of the road after Dike 49 is decommissioned (NHC, 2025a). Water level increases of <0.05 m were simulated in three of the 11 joint riverine and tide flood scenarios modelled by NHC (2025a), which were inferred by NHC to be within model uncertainty limits. The model simulations also indicated that dike removal would result in lower water levels on Cowichan Bay Road and the properties west of the road (NHC, 2025a).

4. DATA SOURCES, ANALYSIS, AND LIMITATIONS

In completing the analysis, we incorporated a series of spatial datasets in various data formats and scales, as summarized in Table 4.1 below.

Table 4.1. Summary of spatial dataset used in this study

Dataset	Format	Scale	Purpose	Reference
GWELLS	Shapefile	-	Used to identify well locations, aquifer type, well depth, lithology and create the conceptual models	ENV (2025b)
Water Rights	Shapefile	-	Used to determine licensed volumes for Pumping Thread Analysis	ENV (2025a)
B.C. Coastline	Shapefile	-	Used as a basis for determining parameters to calculate Aquifer Susceptibility	GeoBC (2020)
NHC Model Terrain Existing & Restoration	GeoTIFF	1 m resolution	Used to extract well elevations to well points	NHC (2025d)
NHC Higher High Water Large Tide Existing & Restoration	GeoTIFF	1 m resolution	Used to evaluate change in high water levels from project near active wells in SWI assessment area	NHC (2025e)
Wave Effect Existing & Restoration	GeoTIFF	15 m resolution	Used to evaluate change in maximum wave heights from project near active wells in SWI assessment area	NHC (2025f)
Orthophotos	Georeferenced Image	-	Used as a base map for the figures	CVRD (2015)

[1] HEC-RAS is a software program supported by the US Army Corps of Engineers used for hydraulic modelling studies (U.S Army Corps of Engineers, 2025).
[2] SWAN is Simulating WAves Nearshore, which is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters (Delft University of Technology, 2024).

A large amount of geospatial data previously compiled by others formed the basis of this desktop study. The scope of work did not include validation or quality control checks on the spatial datasets provided; unless otherwise stated, the spatial datasets were taken at face value for analysis and interpretation. Combining geospatial datasets generated at different scales can also produce errors in positional accuracy and precision.

The GIS-based approach was objective and systematic, relying on regionally available information supported by data collected in brief site visits.

As noted above, GWELLS formed our main hydrogeological data source. A limitation of the well dataset was that it contained incomplete records and/or missing or erroneous data, including inexact well locations, incomplete or missing well construction details, and/or incorrect or missing well-aquifer correlations. Errors found in GWELLS included:

- Well Tag Number (WTN) 62971 was a duplicate of McLeod Well (WTN 63966).
- WTN 65021 was correlated to Aquifer 197 in GWELLS however, according to the well log and WWAL's hydrogeological cross sections, it was interpreted that WTN 65021 is completed in Aquifer 186.
- The following wells statuses were classified as 'New' but were field verified or verified by landowners as abandoned or decommissioned:
    - WTN 4057
    - WTN 19518
    - WTN 29401
    - WTN 34325
    - WTN 44174
    - WTN 44176
    - WTN 44178
    - WTN 44871
    - WTN 64138
    - WTN 64139
    - WTN 64140

5. LITERATURE REVIEW

A literature review, comprising a total of eight reports, was carried out to gain an understanding of the hydrogeology of the aquifers in the estuary, the historical water quality concerns, and the potential mechanisms for SWI into the aquifers. The review, while not exhaustive, focused on reports most relevant to our assessment of the potential for impact of SWI. A literature review template was developed that summarized the following aspects of the studies:

- Brief synopsis;
- Scale;
- Key take-aways;
- Findings;
- Recommendations; and,
- Relevance (and methodology)

The review summaries for the eight reports are provided in Appendix B.

The earliest reporting of SWI in the area was by Zubel (1978), who looked at wells WTN 33488, WTN 33892, WTN 31885, and WTN 31887 at the former Doman Industries site where saline water was encountered in the initial 24 m (80 ft) below ground surface (bgs) during drilling. Zubel (1978) also identified three unconsolidated aquifers in the estuary: an upper, middle and lower aquifer. Zubel's initial work in 1978 was incorporated into the Cowichan Estuary Task Force – Preliminary Groundwater Study (Zubel, 1978).

The province received complaints about intrusion of salt water in three shallow wells (WTN 518, WTN 44174, and WTN 44176) in the summer of 1980 in the Cowichan Estuary (Chwojka, 1981). Kohut (1981) concluded that shallow dug wells (completed into the shallow aquifer – Aquifer 186) and located close to the distributary channels, historically experienced impacts from SWI due to:

1. lower than normal river flows and higher than normal tides, and
2. changes in river morphology (e.g., erosion, sedimentation, blockage by woody debris) due to flooding.

The impact of water quality from infiltration of saline or brackish water present in the distributary stream channels is different and distinct from the more textbook scenarios of SWI laterally from the ocean or from up-coning as a result of heavy pumping.

In 1985, the Province initiated the Ambient Groundwater Quality Monitoring and Assessment (AGWQM&A) Program in the Cowichan Estuary, based on reported water quality concerns regarding SWI. Wei (1985) summarized the initial water quality sampling in the of Fall, 1985, which showed that most shallow wells completed into Aquifer 186 had been abandoned at that time and were not in use. Figures 6 and 8 in Wei (1985) also showed his conceptual understanding of the occurrence of seawater in the stacked aquifers. Wei (1985) hypothesized that the groundwater salt content (NaCl) in the shallow aquifer (Aquifer 186) was highly influenced by infiltration of saline or brackish water in the stream distributary channels (as interpreted by Kohut (1981)), while the NaCl content in the lower aquifer (Aquifer 188) was influenced by the fresh water-saltwater interface in the aquifer as groundwater discharging to the ocean flows up against the seawater from the ocean. Wei (1985) also identified water chemistry differences between water in the distributary channel and that in the shallow and deeper aquifers. Zimmerman (1989) delved into the chemical differences of the groundwater in the upper and lower aquifers (Aquifers 186 and 188). Chwojka (1997) completed a review of over 10 years of ambient monitoring in the estuary and concluded that the AGWQM&A program could be terminated; although some shallow wells in Aquifer 186 experienced elevated levels of saline water in the past, monitoring of wells in the lower aquifer (Aquifer 188) showed stable trends and SWI was not a concern.

Between 2002 and 2011, Barroso et al. (2013) collected water samples from six municipal supply wells and observation wells. The results showed there was no chemical difference in the groundwater between the upper aquifer (Aquifer 186) and a formerly mapped middle aquifer (Aquifer 187), and no evidence of SWI into either aquifer (this may be one of the reasons Aquifers 186 and 187 were merged into one aquifer (186)).

Finally, Foster and Allen (2015) developed a coupled surface water-groundwater model of the entire watershed. While the model was regional in nature and not directly applicable to our study, the results predicted that changing climate will result in higher winter and spring flows and lower summer flows in the Cowichan River.

6. SETTING

6.1 Physiography, Climate, and Surrounding Land Use

Figure A1 in Appendix A provides an overview of the study area that shows the project location and relevant features. The study area is defined as the Cowichan River Floodplain, extending approximately 2 km inland from the Cowichan Bay Estuary. Dike 49 is located within the Cowichan Estuary approximately 5 km southeast of Duncan, BC approximately 800 m northeast of the Trans-Canada Highway and extends approximately 1.1 km inland of the coastline near Cowichan Bay Road.

WWAL evaluated the vulnerability of wells from removal of Dike 49 within the SWI assessment area, also shown in Figure A1. The SWI assessment area focused on wells upgradient of Dike 49 that could potentially be impacted by dike removal. The SWI assessment area is bounded to the north and south by the two distributary channels of the Koksilah River, and the northwest boundary of the study area.

Based on Environment Canada Climate Normals between 1981 and 2010 for the Duncan Kelvin Creek station (Climate ID 1012573) located approximately 6 km southwest of the study area, the average annual temperate and precipitation are 10.1°C and 1361.2 mm, respectively (Environment Canada, 2025). Typical of this region, most of the precipitation falls as rain between the months of November and March, followed by relatively warm dry summers. Table 6.1 below provides an overview of the climate normal data for the Duncan Kelvin Creek Station. The majority of the Cowichan Estuary is located at an elevation lower than the Duncan Kelvin Creek climate station. Therefore, Cowichan Estuary may experience a slightly different climate (e.g. warmer temperatures and less snow) than what is reported in Table 6.1.

Table 6.1. 1981-2010 Climate Normal Data for Duncan Kelvin Creek Station (Climate ID 1012573)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rain (mm)	225.2	125.9	125.9	82.6	49.1	36.7	22.3	33.2	31.6	119.1	219.7	218.0	1289.2
Snow (cm)	23.0	13.2	9.6	0.1	0.0	0.0	0.0	0.0	0.0	0.4	8.3	17.6	72.0
Total Precip. (mm)	248.3	139.1	135.4	82.6	49.1	36.7	22.3	33.2	31.6	119.4	227.9	235.6	1361.2
Daily Avg Temp (°C)	3.6	4.4	6.3	9.1	12.4	15.3	17.9	17.8	15.2	10.1	5.8	3.3	10.1

Climate change is an ongoing process, and among the forecasted outcomes for the region is warming temperatures across seasons in addition to longer, drier summers and wetter winters with more precipitation falling as rain at lower elevations. There is also a predicted overall hydrologic transition from snowmelt-dominant watersheds to rainfall-dominant, increasing the need for water conservation and storage (PCIC, 2013).

6.2 Hydrogeology

6.2.1 Aquifers in the Cowichan Estuary

Four mapped aquifers occur in the Cowichan Estuary:

- A shallow, unconfined sand and gravel (unconsolidated) aquifer (Aquifer 186),
- A deeper, confined unconsolidated aquifer (Aquifer 188),
- Another deeper, confined unconsolidated aquifer that underlies only the southern boundary of the floodplain and the upland beyond (Aquifer 197), and
- Underlying all the unconsolidated aquifers is the Nanaimo Group sedimentary bedrock aquifer (Aquifer 198).

Figure A1 (Appendix A) shows the locations of the mapped aquifers in the study area. Figures A2 and A3 (Appendix A) are hydrogeological cross-sections that show the aquifers with depth. The aquifers are discussed in further detail below. Major aquifer characteristics are summarized in Table 6.2 on Page 10 of this report.

Aquifer 186

The areal extent of Aquifer 186 is limited to within the Cowichan River floodplain. It was formed by deposition of sand, gravel, silt and clay associated with the Cowichan and Koksilah Rivers. This aquifer extends from the ocean upstream to the City of Duncan where it is the source of water supply for the City. The aquifer is highly productive with reported transmissivity values ranging from 918 to 201,832 m^2/day (with a geomean and median transmissivity of 20,127 m^2/day and 28,060 m^2/day, respectively) (Carmichael, 2014).

Foweraker (1976) was first to identify three aquifers in the local Duncan area. Zubel (1978) and Wei (1985) also described three aquifers in the estuary, including a middle aquifer – Aquifer 187. In 2020, Aquifer 187 and Aquifer 186 were combined and referred to as Aquifer 186 because the confining unit separating Aquifer 186 and Aquifer 187 appeared discontinuous and the lower aquifer was therefore not highly confined.

Aquifer 188

Aquifer 188 is also contained entirely within the Cowichan River floodplain but only occurs in the estuary. Cross sections in Figure A2 (across the estuary) and Figure A3 (from the estuary to inland) show both Aquifers 186 and 188 extend across the entire estuary. A semi-confining aquitard separates the aquifers. The fact that the aquitard separating Aquifers 186 and 188 pinches out upstream of the estuary suggests that the Cowichan River system deposited the fluvial sediments to fill the floodplain to form Aquifers 186 and 188 and the aquitard may reflect a period of transgression of the ocean farther inland (and deposition of finer sediments). This also means that upstream of where the aquitard pinches out, Aquifer 188 merges with the overlying Aquifer 186. An inspection of the correlation of wells to mapped aquifers suggests Aquifer 188 may not even extend as far up-gradient as currently mapped.

Aquifer 188 also has a high productivity with reported transmissivity values ranging from 146 to 242,295 m^2/day (with a geomean and median transmissivity of 2,995 m^2/day and 2,155 m^2/day, respectively) (Carmichael, 2014).

Aquifer 197

Aquifer 197 is older than Aquifer 186 and 188 because it occurs underneath till, the confining unit. The till unit is associated with the deposition of a mixture of sediments from glaciers during the last ice age. Aquifer 197 underlies much of the upland area at Cobble Hill. The portion of Aquifer 197 underneath the Cowichan River floodplain represents the northern edge of the aquifer. The hydraulic relationship between Aquifers 197, 186 and 188 is not clear and is beyond the scope of this study. However, groundwater in Aquifer 197 that flows north into the Cowichan River floodplain either discharges to the land surface as springs (where Aquifer 197 is exposed), into Aquifer 186 or, more likely, into Aquifer 188 where the confining unit is absent.

Aquifer 197 has reported transmissivity values ranging from 2.5 to 4,042 m^2/day (with a geomean and median transmissivity of 142 m^2/day and 167 m^2/day, respectively) (Carmichael, 2014).

Aquifer 198

Fractured bedrock Aquifer 198 underlies the Cowichan River floodplain. Aquifer 198 is comprised of the Nanaimo Group of sedimentary bedrock and extends from Cobble Hill to Duncan. Aquifer 198 is much less productive than the other three unconsolidated aquifers; transmissivity values are not reported for the local area of the aquifer but may only be a few m^2/day or less, based on our experience test pumping the Nanaimo Group bedrock elsewhere. Only three wells belonging to Aquifer 198 are plotted as being within the estuary (WTN 64138, WTN 64139, and WTN 64140). These wells were not found during WWAL's site visit and there is no record of licences or licence applications associated with the wells (indicating any significant usage). Therefore, Aquifer 198 has not been considered in this assessment of potential SWI impact.

Table 6.2. Summary of Major Aquifer Characteristics

Aquifer ID	Primary lithology	Degree of confinement	Inferred groundwater flow direction	Hydraulic connection to Cowichan River	Reported geomean transmissivity (m^2/day)	Potential mechanisms for SWI	Comment
186	Sand & Gravel	Unconfined	Down-valley	Likely	20,127	Infiltration of salty or brackish water from distributary channels; lateral intrusion or up-coning under heavy pumping conditions	-
188	Sand & Gravel	Confined at the estuary	Down-valley	Only likely upgradient of the estuary	2,995	Lateral intrusion or up-coning under heavy pumping conditions	-
197	Sand & Gravel	Confined	North, into the floodplain area	Less likely	142		-
198	Fractured Sedimentary Bedrock	Confined	East, toward Cowichan Bay	Less likely	Not reported; likely only a few m^2/day or less		Not considered in assessment as there are no wells in the aquifer within the study area

6.2.2 Groundwater Flow and Sources of Recharge and Discharge

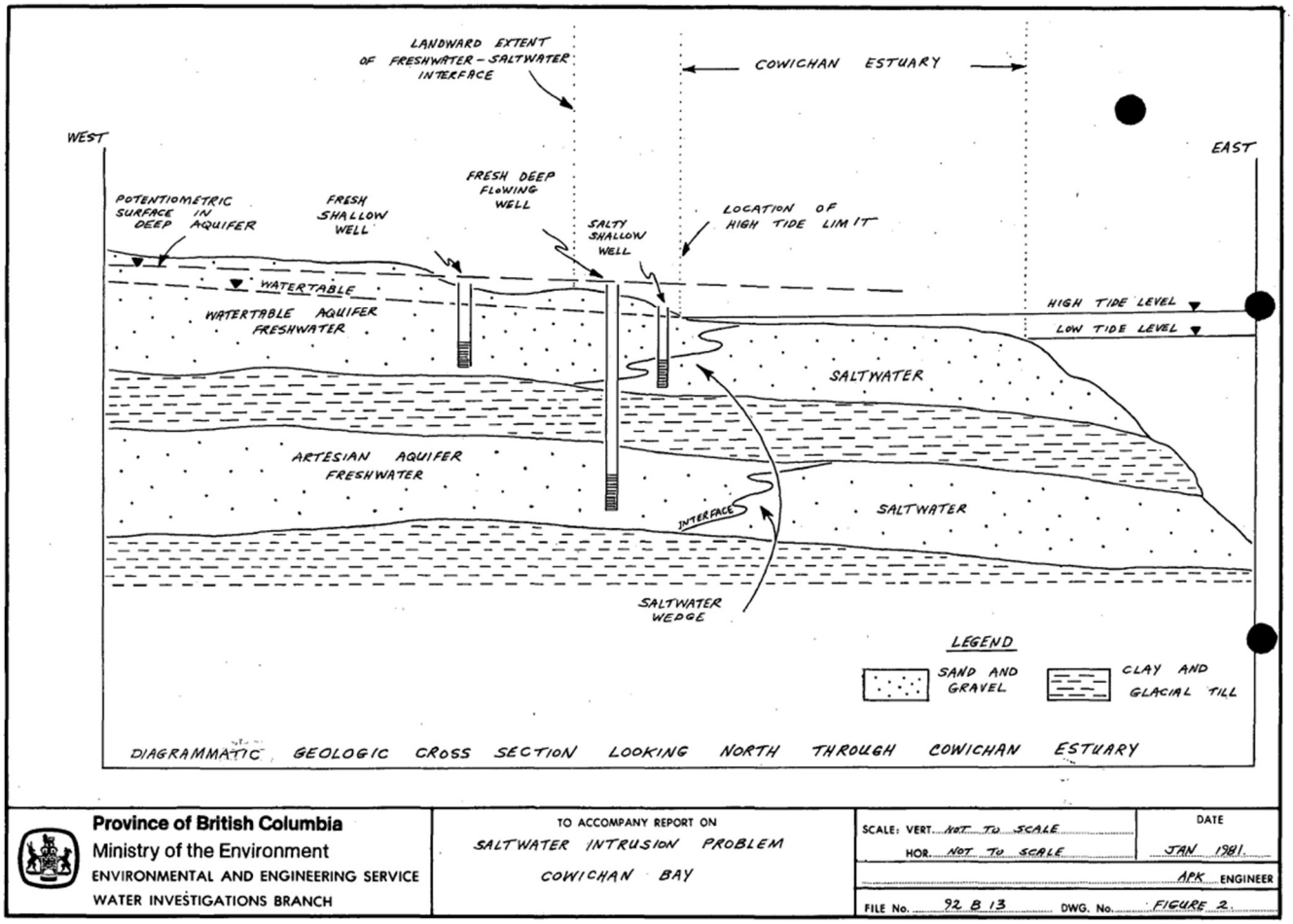
Groundwater flow in the estuary has not been well mapped due to limited data from available wells. Additionally, because the terrain is flat, desktop mapping without accurate ground-level elevation data could be misleading. Despite the low relief, groundwater flow is still expected to be topographically driven to the east-southeast along the general down-valley direction.

The conceptual understanding is that the source of groundwater is principally derived from the Cowichan River flow system, and that groundwater and river water generally flow downstream along the floodplain. Aquifer 186 may also be recharged by infiltration of precipitation and groundwater flow may also come laterally from the margins of the floodplain and vertically, for example, from Aquifer 197 and upward from Aquifer 198.

Hydraulic connection between Aquifer 186 and the Cowichan River and Koksilah River is likely. Direct hydraulic connection between Aquifer 188 and the Cowichan River is expected only upgradient of where the aquitard pinches out. Downgradient, the aquitard likely limits hydraulic connection between Aquifer 188 and the Cowichan and Koksilah Rivers.

The presence of flowing artesian conditions associated with some wells drilled into Aquifer 188 at the estuary (WTN 34325, WTN 56954) suggests that there is also an upward hydraulic gradient between Aquifer 188 and Aquifer 186 (see Figure 6.1 on the following page).

Figure 6.1. Schematic cross-section of Aquifer 186 and Aquifer 188 at the Cowichan Estuary from Kohut (1981)



6.2.3 Potential Mechanisms for SWI into Aquifers in the Estuary

The potential mechanisms for SWI differ between Aquifer 186 and Aquifer 188. Based on the interpretation of Zubel (1978), Kohut (1981) and Wei (1985), any intrusion of seawater into Aquifer 188 is expected to be by lateral intrusion or by up-coning (due to pumping, if wells only partially penetrate the aquifer) referring to the freshwater-saltwater interface advancing inland or upward into the aquifer.

Lateral SWI can also occur in Aquifer 186, for example under significant pumping. The other potential mechanism of SWI in Aquifer 186 was identified by Kohut (1981) where saline or brackish water present in the distributary channels infiltrates locally into the sand and gravel. This mechanism can occur regardless of any pumping and impacts would be greatest near the stream channel, diminishing with distance away from the stream channel. This understanding is reflected in Figure 6.2 and Figure 6.3 (on the following page) from Wei (1985), that illustrate the NaCl concentration contours in Aquifer 186 and Aquifer 188. NaCl concentration contours in Aquifer 186 is interpreted to be heavily influenced by the distributary channels where brackish water may be present, whereas the NaCl contours for Aquifer 188 are independent of the distributary channels (i.e., lateral intrusion comes from the coast).

Figure 6.2. Sodium-Chloride (NaCl) Concentration Contours in Aquifer 186 from Wei (1985)

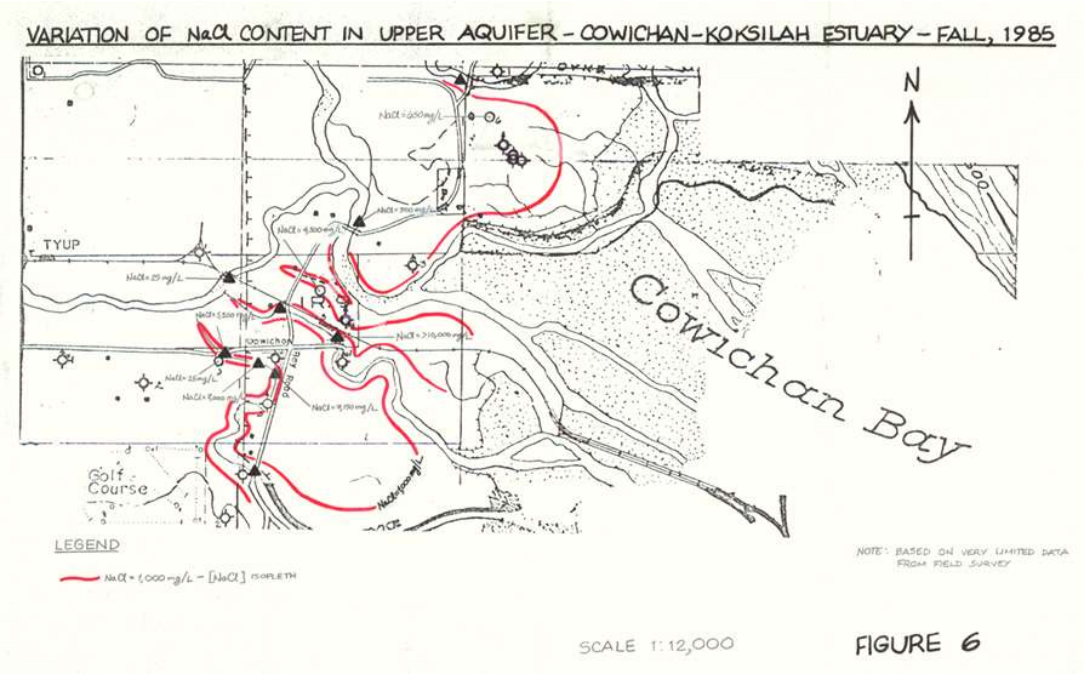
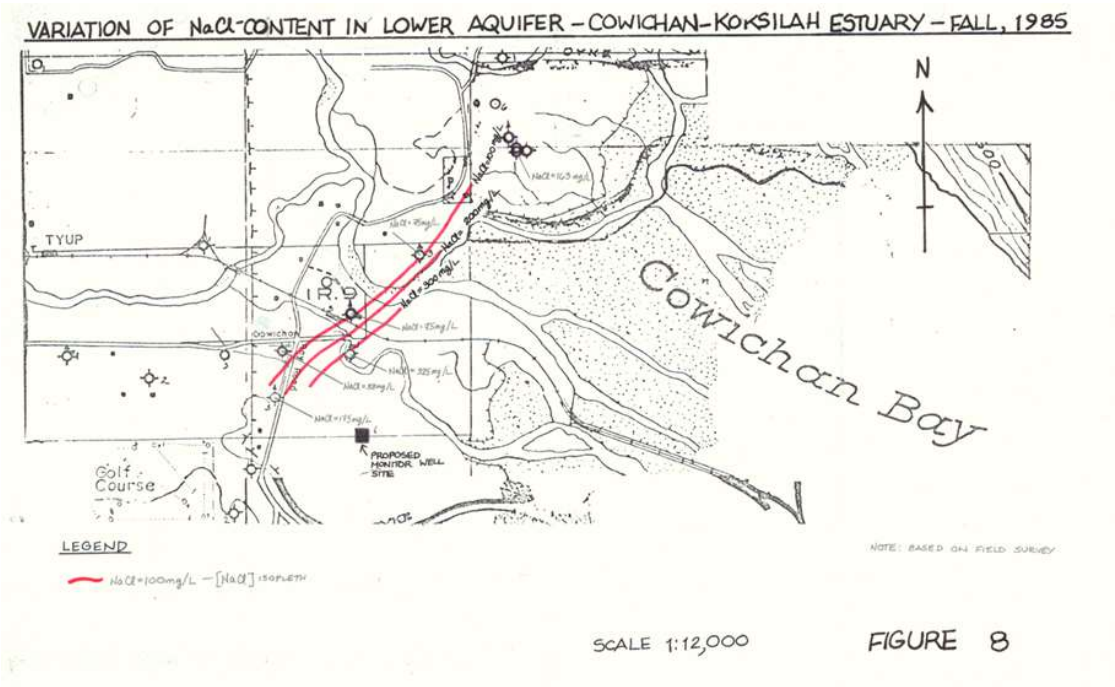


Figure 6.3. Sodium-Chloride (NaCl) Concentration Contours for Aquifer 188 from Wei (1985)



6.3 Surface Water

Based on Provincial mapping, distributaries of the Koksilah River intersect the study area in and around Dike 49. The Koksilah River originates southeast of Duncan, B.C. and flows northeast until it discharges into the Cowichan River. Small distributaries of the Koksilah River meander within the study area west of Dike 49. According to Water Resource Atlas (WRA), there are approximately 19 streams with Water Allocation Notations within the study area. The Koksilah River and surrounding tributaries are Fully Recorded (NO32788) indicating a possible water shortage for additional authorized use. The Cowichan River and distributaries of the Koksilah River discharge into Cowichan Bay.

6.4 Existing Wells and Water Rights

To assess the local geology and the potential impact of the dike removal on nearby groundwater supplies, WWAL reviewed information for wells located within the study area from the Province's GWELLS database (ENV, 2025b). The locations of registered wells by WTN are shown in Figure A1. Table 6.3 below summarizes average well depths, water levels, and yields by aquifer within the study area.

Table 6.3. Summary Statistics for Wells Within the Study Area by Aquifer

Aquifer ID	Number of Wells	Average Final Well Depth		Average Static Water Level		Average Reported Well Yield	
		(m)	(ft)	(m btoc)	(ft btoc)	(L/s)	(USgpm)
186	8	8.04	26.4	2.3	7.5	18	278
188	8	42.8	140	2.6	14	8.3	131
197	6	19.4	63.6	3.8	16	6.9	110
198	3	152	500	-	-	0.33	5.3

According to the GWELLS database there are 25 registered wells within the study area. The reported wells completed in Aquifer 186 had depths ranging from 3.1 to 22 m (10 to 73 ft) below ground surface (bgs) with an average depth of 8.0 m (26 ft) bgs. Of those wells, four static water levels (SWLs) were reported, the average being 2.3 m (7.5 ft) below top of casing (btoc). For reported wells completed in Aquifer 188, final depths ranged from 36 to 51 m (119 to 167 ft) bgs and the SWL ranged from 0.6 to 41 m (2.0 to 137 ft) btoc. There were six wells within the study area completed in Aquifer 197 with a range of depths from 18 to 175 m (59 to 575 ft) bgs. Two SWL were reported for the wells in Aquifer 197, 2 m (6 ft) and 15 m (49 ft) btoc. For the three wells located in bedrock Aquifer 198, the depths range from 130 to 175 m (425 to 575 ft) bgs. No SWL was reported for any of these wells.

Table 6.4 on the following page summarizes select well construction and water rights details for the wells within the study area. Registered wells were located within four aquifers: eight in the shallow unconsolidated Aquifer 186, eight in the deeper unconsolidated Aquifer 188, six in unconsolidated Aquifer 197 and three in bedrock Aquifer 198. Two wells in Aquifer 186 were assumed to be active based on GWELLS records, as their status was not field-verified, while six wells in Aquifer 188 and all five wells in Aquifer 197 were assumed to be active. The three wells in Aquifer 198 within the study area were assumed to be inactive or abandoned.

Table 6.4. Summary of Select Well Construction Details and Water Rights Information for Reported Wells Within Study Area

Well Tag Number (WTN)	Aquifer ID	Inferred Well Status	Licence Status	Licence Number	Primary Licensee	Priority Date (MM/DD/YYYY)	Licensed Quantity (m^3/day)	Season of Use	Intended Water Use	Final Well Depth		Static Water Level		Reported Well Yield	
										(m bgs)	(ft bgs)	(m bgs)	(ft bgs)	(L/s)	(US gpm)
4057	186	Inactive	Unlicensed	-	-	-	-	-	Unknown	7.9	26	1.8	6	2.2	35
19518	186	Inactive	Unlicensed	-	-	-	-	-	Unknown	13	43	2.1	7	25	400
29401	186	Inactive	Unlicensed	-	-	-	-	-	Unknown	6.1	20	-	-	-	-
44174	186	Inactive	Unlicensed	-	-	-	-	-	Unknown	4.3	14	-	-	-	-
44176	186	Inactive	Unlicensed	-	-	-	-	-	Domestic	4.6	15	-	-	-	-
44178	186	Inactive	Unlicensed	-	-	-	-	-	Domestic	3.1	10	-	-	-	-
44871	186	Inactive	Unlicensed	-	-	-	-	-	Unknown	22	73	2.7	9	25	400
53193	186	Active	Unlicensed	-	-	-	-	-	Unknown	3	10	2.4	8	-	-
65021	186	Active	Licensed	506471	Cowichan Golf and Country Club	7/12/1984	249	May 1 to September 30	Irrigation	9.1	30	2.1	7	14.2	225
518	188	Inactive	Unlicensed	-	-	-	-	-	Unknown	51.1	168	3	10	-	-
34325	188	Inactive	Unlicensed	-	-	-	-	-	Water supply	48.8	160	-	-	25	396
48582	188	Active	Licensed	506310	The South Cowichan Lawn Tennis Club	7/14/1981	12	May 1 to September 30	Irrigation	41.6	137	0.6	2	1.9	30
52512	188	Active	Unlicensed	-	-	-	-	-	Domestic	36.3	119	4.3	14	1.9	30
54536	188	Active	Licensed	506624	Cowichan Bay Waterworks District	9/1/1957	735	January 1 to December 31[1]	Water supply	43	141	-	-	16	250
56954	188	Active	Unlicensed	-	-	-	-	-	Observation	42.7	140	-	-	6.6	104
63965	188	Active	Unlicensed	-	-	-	-	-	Domestic	37.2	122	12	39	0.6	10
63966	188	Active	Unlicensed	-	-	-	-	-	Irrigation	41.8	137	0.9	3	6.3	100
26262	197	Active	Unlicensed	-	-	-	-	-	Unknown	18	59	0	0	0.4	6
32166	197	Active	Unlicensed	-	-	-	-	-	Unknown	20	66	15	49	0.9	15
48489	197	Active	Unlicensed	-	-	-	-	-	Domestic	21	70	-	-	1.1	18
48997	197	Active	Unlicensed	-	-	-	-	-	Domestic	28	93	1.8	6	0.6	10
131150	197	Active	Licensed	506634	Cowichan Golf and Country Club	3/5/1974	2	January 1 to December 31	Commercial	-	-	-	-	-	-
64138	198	Abandoned	Unlicensed	-	-	-	-	-	Unknown	152	500	-	-	0.2	3
64139	198	Abandoned	Unlicensed	-	-	-	-	-	Unknown	175	575	-	-	0.4	7
64140	198	Abandoned	Unlicensed	-	-	-	-	-	Unknown	130	425	-	-	0.4	6

[1] According to Cowichan Bay Waterworks District, the Kidd Well (WTN 54536) is only used as a backup well during emergencies.

Detailed water licence information is also summarized in Table 6.4. Within the study area, there were four active water licences: groundwater licences for The South Cowichan Lawn Tennis Club, Cowichan Bay Waterworks District (CBWD)and the Cowichan Golf and Country Club and one surface water licence for Ducks Unlimited (Canada). The water licences are summarized as follows:

- The water licence for the Cowichan Golf and Country Club permits the seasonal withdrawal of up to 249 m^3/day from Aquifer 186 between May and September.

- The water licences for the South Cowichan Lawn Tennis Club (SCLTC) and the CBWD both draw from Aquifer 188, at rates of 12 m^3/day between May to September and 735 m^3/day year-round, respectively. However, the CBWD licence is only used as a backup during emergencies.

- The Cowichan Golf and Country Club also holds a separate groundwater licence for Aquifer 197, which allows for the diversion of 2 m^3/day year-round, from January to December.

7. SITE VISITS

WWAL completed two site visits to the study area as part of this work, which involved documenting well locations, confirming well construction details and water use, measuring field water quality parameters, and collecting groundwater samples. WWAL measured field parameters, which included pH, electrical conductivity (EC), chloride and salinity, using an APERA Instruments PC60 Premium Pocket Tester during each sampling event.

The first site visit was conducted by Jackie Van der Vlugt, GIT of WWAL and Mike Wei, P.Eng. on June 6, 2025. Three wells were identified during the site visit: WTN 56954, WTN 34325, and WTN 54536. WTN 56954, formerly Provincial Observation Well No. 297, was being used to supply 2289 Lochmanetz Road, WTN 34325 had been decommissioned and the Kidd Well (WTN 54536), was only being used as a backup well for the CBWD. A water sample was collected during the site visit from the Kidd Well which was sent for laboratory analysis for Total Dissolved Solids (TDS), EC and chloride.

Based on discussion with Nature Trust and review of the well log, WTN 56954 is a flowing artesian well. WWAL inspected the well head on June 6, 2025. It was comprised of 200 mm (10”)-diameter casing and 150 mm (6”)-diameter casing extending 0.50 m and 0.66 m above ground surface (ags). WWAL observed spray foam had been used to seal the annulus between the well casings and flow was not observed from the annulus during the site visit.

A second site visit was conducted by Jackie Van der Vlugt, GIT and Tim Sivak, P.Geo. on June 17, 2025. WTN 48582 supplying the SCLTC was located south of the clubhouse surrounded by a concrete enclosure. The well had a stick up of 0.17 m ags but no Well Plate Identification Number (WPID) was visible on the casing. Based on the depth and additional information provided by the owner, the well was confirmed in the field to be WTN 48582. WWAL collected a sample from WTN 48582 from a spigot located in an outbuilding several meters away from the wellhead, after flushing the well for five minutes.

The property directly south of the SCLTC, 2288 Cowichan Bay Road, had three provincially registered wells according to the WRA. One well, the McLeod well (WTN 63966), was located in a pumphouse on the property. The well head was 0.13 m above the concrete pad. According to the property owner, the concrete pad was

approximately 0.2 m thick. WWAL collected a groundwater sample at the time of the site visit from WTN 63966 from a hose located approximately 30 m south of the pump house after flushing the well for several minutes.

Based on the site visits and discussions with Natures Trust, we understand that Cowichan Tribes properties located on Tzouhalem Road and Cowichan Bay Road are connected to municipal water. Therefore, the reported wells located on these properties (WTN 19518 and WTN 29401) are likely not in use and likely abandoned.

WTN 48489 may have been mislocated in the GWELLs database as there was no evidence of the well at the location provided in GWELLS. The location is also along the shoulder of Cowichan Bay Road where the ground drops steeply into the Cowichan River floodplain. Shallow wells WTN 44176 and WTN 44178 were also not located during the second site visit. According to the WRA, WTN 44176 and WTN 48582 are mapped on the SCLTC. WTN 44178 was a dug well that was constructed in 1981 and has been replaced by a drilled well, WTN 48582. We infer that these shallow wells have been abandoned. Well WTN 62971 appears to be a duplicate of WTN 63966. The current status of the wells (whether active, inactive, or abandoned) based on our review of the well logs and field review from site visits, is summarized in Table 6.4.

No active wells completed in upper Aquifer 186 could be accessed during the site visits in June 2025. WWAL attempted to locate a number of shallow wells that were previously sampled but they were either not found or have since been abandoned.

8. WATER QUALITY

Lab reports from the June sampling events are included in Appendix C. Table 8.1 and Figure 8.1 below compares the recent well sampling results for chloride and EC with historical results from the Province's AGWQM&A program for the SCLTC (deep) well, the Kidd well and the former Observation Well 297.

No lab results from the AGWQM&A program were available for McLeod well (WTN 63966). The June 2025 results for the McLeod well (WTN 63966) fall within the range of values of the other three wells (EC of 200 µS/cm and chloride of 21.8 mg/L, well below the levels thought to be impacted by sea water intrusion (specific conductance >1000 µS/cm, chloride >150 mg/L) (Province of BC, 2016).

Based on comparison of recent and historical water quality for the wells in which data were available, EC and chloride concentrations do not appear to have risen over the intervening decades as the June 2025 results were close to or below the historical median and average values for these parameters. From the limited well sampling carried out in June 2025 due to the few wells located during the site visits, the salinity of the groundwater in Aquifer 188 does not appear to have changed considerably over the past four decades.

Figure 8.1. Chloride (top) and specific conductance (bottom) from June 2025 and historical lab results for the South Cowichan Lawn and Tennis Club, Kidd Well and the former Observation Well 297

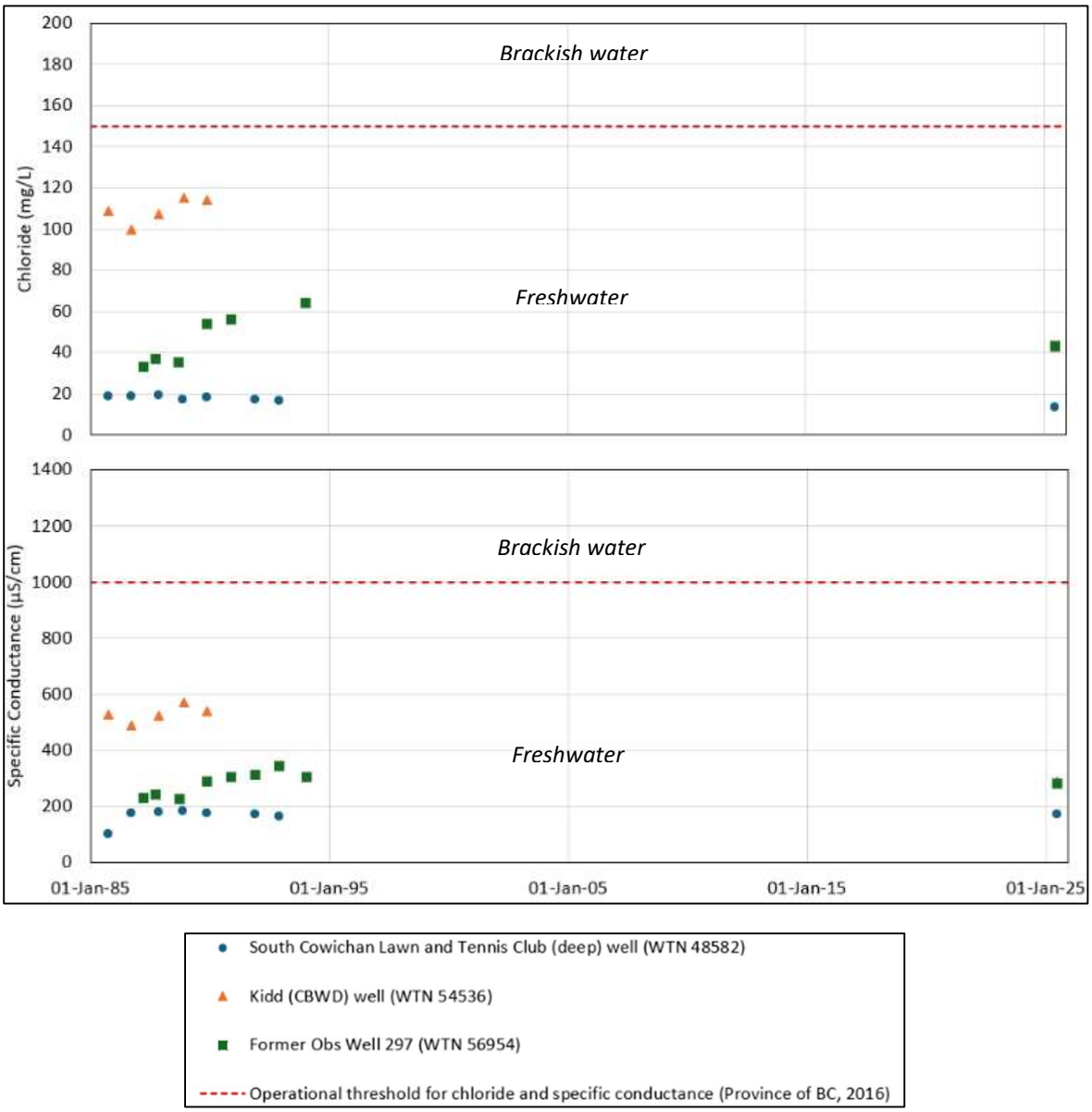


Table 8.1. Comparison of the lab results for three of the wells sampled in June 2025 with statistical summary of lab results from the Province's AGWQM&A Program

Statistical Measure or Sample Date	SCLTC (deep) WTN 48582	Kidd WTN54536	Former Obs. Well 297 WTN 56954	SCLTC (deep) WTN 48582	Kidd WTN 54536	Former Obs. Well 297 WTN 56954
	Specific Conductance (µS/cm)			Chloride (mg/L)		
AGWQM&A Program						
Range	85	80	120	2.4	15.0	30.9
Maximum	185	570	345	19.3	115.0	64.1
Average	165	531	282	18.1	109.0	46.6
Median	176	530	297	18.1	109.0	45.5
Minimum	100	490	225	16.9	100.0	33.2
Recent Sampling						
June 2025	173	288	282	13.6	42.5	43.4

9. SEAWATER INTRUSION ASSESSMENT

The overall objective of the SWI assessment was to evaluate impacts to existing groundwater users from removal of Dike 49. This was done on a well-by-well basis. As discussed in Section 3, dike removal and the design flood mitigation structures are expected to result in water level increases of less than 0.05 m based on the simulations from NHC (2025a).

As shown in Figure A1 in Appendix A, the SWI assessment area was defined as the floodplain area immediately surrounding Dike 49 and extending upgradient approximately 2 km inland from the coast.

The well inventory and site visits completed by WWAL indicated the following active wells within the SWI assessment area:

- WTN 53193 and WTN 65021, completed in Aquifer 186;
- WTN 48582, WTN 52512, WTN 54536, WTN 56954, WTN 63965, and WTN 63966 completed in Aquifer 188; and,
- WTN 26262, WTN 32166, WTN 48489, WTN 48997, and WTN 131150, completed in Aquifer 197.

The assessment was only completed on unconsolidated Aquifers 186, 188, and 197. As discussed in Section 6.4, the reported three bedrock wells within the study area were not found during the site visit and there was no record of licences or licence applications (indicating any significant usage) for these wells. Therefore, fractured bedrock Aquifer 198 was excluded from the SWI assessment and the three reported bedrock wells were assumed abandoned.

To evaluate the potential of SWI under current conditions and upon dike removal, the GIS-based methodology used by WWAL (2021) to assess SWI risk along the entire BC coast was updated to reflect local conditions. This approach looked at the following defined properties related to SWI: Aquifer Susceptibility, Pumping Threat, and Aquifer Vulnerability from Pumping. Additional details on the approach can be found in WWAL (2021). Loss and Risk were not required to assess impacts to active wells in the SWI assessment area and therefore were not determined for this study.

Aquifer Susceptibility, Pumping Threat, and Aquifer Vulnerability from Pumping values reflect severity of pumping in the study area and are independent of dike removal and flood mitigation. In this study, the same grid cell size was used because it was appropriate for this more local scale of mapping and provided a basis of comparing mapped results to the WWAL (2021) study. Mapping in this study included only wells that were active which better reflected actual local conditions than the WWAL (2021) study which assumed all reported wells were in use. Furthermore, for Pumping Threat and Aquifer Vulnerability from Pumping, mapping in this study was determined individually for each of the three unconsolidated aquifers (Aquifers 186, 188, and 197), as opposed to the WWAL (2021) study which combined pumping from all three aquifers. Finally, this study utilized parameters (e.g., transmissivity) specific to the local aquifers, as opposed to the typical parameter values used in WWAL (2021).

WWAL relied on data and information from the NHC reports to qualitatively evaluate how the active wells may be impacted from tides and waves resulting from the flood mitigation features. WWAL assessed impacts from high tides and storm surge by mapping Flood Hazards using local site specific data from NHC (2022), and validated the parameters and results by comparing them with WWAL (2021).

Results for Aquifer Susceptibility, Pumping Threat, and Aquifer Vulnerability from Pumping are summarized in Sections 9.1 to 9.3. Results for high water levels, wave height and sea level rise on the active wells (Coastal Hazards) are summarized in Section 9.4.

9.1 Aquifer Susceptibility

Aquifer Susceptibility is an aquifer's natural susceptibility to intrusion of sea water, regardless of pumping. In WWAL (2021), Aquifer Susceptibility was defined (for each grid cell) based on the aquifer's static water level elevation (inferred from reported static water levels in nearby wells) and distance of the grid cell from the coast (see Table 9.2). In this study, only the wells that were currently active were considered; wells that had been decommissioned or abandoned were excluded from the assessment because we were not able to confirm their locations

Figure 9.1, on the following page, shows the Aquifer Susceptibility values from WWAL (2021) and for the current study. Aquifer Susceptibility values from WWAL (2021) for the SWI assessment area ranged between 3 and 5 (inclusive). Aquifer Susceptibility values of 3 from WWAL (2021) located along the west end of the SWI assessment area were from contouring well data from outside of the SWI assessment area. Aquifer Susceptibility values of 4 located in the center of the SWI assessment area were due to erroneous well records and artifacts of contouring.

Because of limited data for the regional study by WWAL (2021), it was necessary to assess Aquifer Susceptibility for all three unconsolidated aquifers (186, 188, and 197) together. For the current study, all grid cells in the SWI study area had Aquifer Susceptibility values of 5 because of the generally shallow static water elevations ($\leq$10 m above sea level), proximity to coast (<1.5 km) and because the interpolation did not include wells located to the west and outside the SWI Assessment area.

Figure 9.1. Aquifer Susceptibility for the SWI assessment area from WWAL (2021) and from the current study

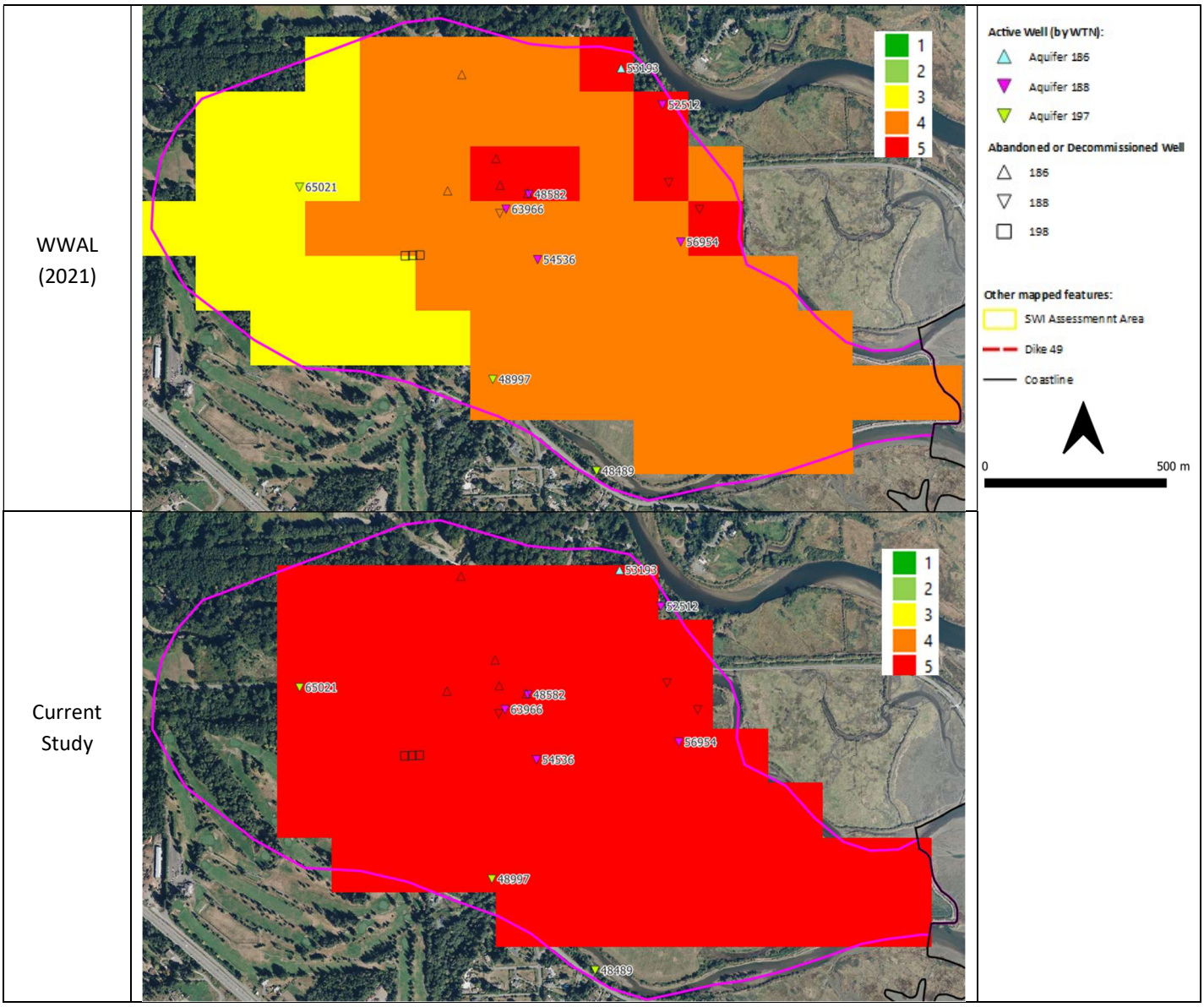


Table 9.1. Susceptibility rating scheme for unconsolidated aquifers from WWAL (2021)

		Distance from coast (m)				
		< 500	500-1000	1000-1500	1500-2000	2000-3000
Static Water Level Elevation (m above sea level)	≥40	2	1	1	1	1
	40 -> 30	3	2	2	1	1
	30 -> 20	4	3	3	2	1
	20 -> 10	5	4	4	3	2
	≤10	5	5	5	4	3

9.2 Pumping Threat

Pumping Threat values were estimated using Equation 9.1 as follows:

Equation 9.1. Pumping Threat

$$Pumping\ Threat\ = \left(\log\left(\frac{\sum Q}{T \times i \times cell\ width}\right)\right) + 4$$

where Q is the pumping rate (m^3/day) for a given well within the grid cell, T is the aquifer transmissivity (m^2/day), i is the horizontal flow gradient (unitless), and 4 is the empirical scaling factor applied by WWAL (2021) that shifts the rating values to within a range of between 1 and 5.

For this study, WWAL mapped Pumping Threat separately for each of the three unconsolidated aquifers: Aquifer 186, Aquifer 188, and Aquifer 197. Pumping Threat values were not assigned for wells that were confirmed to no longer be in use by landowners or reported as decommissioned or abandoned.

The transmissivity and flow gradient values used to calculate Pumping Threat are found in Table 9.2 below, compared with values from WWAL (2021). The geomean transmissivity values used for each unconsolidated aquifer in the current study were from a compendium of re-evaluated pumping tests in the Cowichan Valley Regional District completed by Carmichael (2014). The horizontal flow gradient was assigned as the local topographic slope value within the SWI assessment area for each aquifer, because there were insufficient water level data to contour the groundwater table. The same topographic slope value was used for all three aquifers. This differs from WWAL (2021), where transmissivity values were selected based on typical values reported in Wei et al. (2009) and flow gradients were based on average topographic gradients of the mapped aquifer types along the entire BC coast.

Table 9.2. Aquifer types and their transmissivity and flow gradient values to inform Pumping Threat ratings

Aquifer (Type)	Transmissivity (m^2/day)		Horizontal groundwater gradient (-)	
	Current Study	WWAL (2021)	Current Study	WWAL (2021)
Aquifer 186 (1b)	20,127	2,000	0.007	0.01
Aquifer 188 (4b)	2,995	200	0.007	0.03
Aquifer 197 (4b)	142	200	0.007	0.03

Figure A4 in Appendix A shows the results for Pumping Threat from WWAL (2021) (see top left) compared with Pumping Threat results from the current study for Aquifers 186, 188, and 197. The results from the current study are summarized as follows:

- There were only two active wells completed in Aquifer 186, since most of the wells drilled in Aquifer 186 were either confirmed by property owners to be no longer in use or were inferred to be abandoned or decommissioned. Therefore, Pumping Threat values for Aquifer 186 of up to 2 (out of 5) were only identified in the western, upgradient end of the SWI assessment area near WTN 65021. Pumping Threat values decreased away from this well to <1 toward WTN 53193 and the coastline because pumping in this area was considered negligible.

- Pumping Threat values for Aquifer 188 of up to 3 were concentrated in the central portion of the SWI assessment area, associated with pumping of wells WTN 58582, WTN 54536, and WTN 63966. Pumping Threat decreased to <1 toward the northwest and southeast where wells in this aquifer were absent.

- Pumping Threat values of up to 1 were assessed for Aquifer 197 due to the low density of wells and their pumping rates. Most of the wells completed in Aquifer 197 in the SWI study area were domestic and the pumping rates were assumed to be 2 m^3/day.

These results for Pumping Threat differed significantly from those of WWAL (2021). Mapping from WWAL (2021) showed that Pumping Threat values of 4 were located near the center of the SWI assessment area, where the most wells were concentrated, with values decreasing to the north, west, east and southeast. In the southwest section of the SWI assessment area, one cell had a Pumping Threat value of 5 (due to the assumed pumping rate of WTN 131150 and other wells beyond the SWI assessment area boundary).

The Pumping Threat for the SWI study area was over-estimated in the WWAL (2021) study because it assumed that all reported wells in GWELLS were active and pumping at the reported well yield rate, which is not the case. Additionally, pumping from all three unconsolidated aquifers was combined in the previous study, whereas in this study, Pumping Threat was mapped separately for each aquifer.

9.3 Aquifer Vulnerability from Pumping

Aquifer Vulnerability from Pumping values were calculated for each unconsolidated aquifer using the geometric mean of the product of Pumping Threat and Aquifer Susceptibility (see Equation 9.2 below). The rating scheme for Aquifer Vulnerability from Pumping is summarized in Table 9.3.

Equation 9.2. Aquifer Vulnerability from Pumping

$$Aquifer\ Vulnerability\ from\ Pumping\ = \sqrt{Pumping\ Threat\ \times Aquifer\ Susceptibility}$$

Table 9.3. Rating scheme for Aquifer Vulnerability to Pumping Threat

Susceptibility	Pumping Threat 1	2	3	4	5
1	1	1	2	2	2
2	1	2	2	3	3
3	2	2	3	3	4
4	2	3	3	4	4
5	2	3	4	4	5

Figure A5 (Appendix A) shows the Aquifer Vulnerability to Pumping Threat from WWAL (2021) and for the current study. The results from the current study are summarized as follows:

- Aquifer Vulnerability from Pumping values for Aquifer 186 of up to 3 were mapped in the northwest part of the SWI assessment area where WTN 65021 is located. It decreased to <1 to the east of WTN 65021 toward Dinsdale Field and the coastline.

- Aquifer Vulnerability from Pumping values for Aquifer 188 of up to 4 were concentrated near WTN 48582, WTN 54536, and WTN 63966, decreasing to <1 to the northwest and the southeast where there were no wells in the aquifer.

- Aquifer Vulnerability from Pumping values for Aquifer 197 of up to 2 were present in the west and southwest part of the SWI assessment area which is most of the portion of the assessment area in which the aquifer is mapped. Aquifer 197 pinched out west of Cowichan Bay Road and north of the floodplain boundary.

Similar to the results for Pumping Threat, Aquifer Vulnerability from Pumping was significantly lower for Aquifers 186 and 197 compared to the results from WWAL (2021) because groundwater use from those aquifers was lower than what was assumed in WWAL (2021).

The Aquifer Vulnerability from Pumping for Aquifer 188 appeared similar to the results from WWAL (2021). As noted previously, WTN 54536 is a backup supply well operated by the CBWD only on an emergency basis, whereas Figure A5(c) assumes WTN 54536 is pumping continuously. When WTN 54536 is not pumping (which is normally the case), the Aquifer Vulnerability from Pumping for Aquifer 188 would decrease to 3 near WTN 54536 which is less than the values from WWAL (2021).

9.4 Coastal Hazards

WWAL reviewed modelling results from NHC (2025a) to assess Coastal Hazards related to potential impacts to active wells from the estuary restoration project. NHC provided raster layers representing joint high tide and riverine conditions (simulated high water levels) and wave heights for existing condition and with flood mitigation features in place. These raster layers did not consider sea level rise. Our reviews of the modelling done by NHC with respect to well impacts are discussed in Sections 9.4.1 and 9.4.2.

WWAL evaluated Flood Hazard using data and information from WWAL (2021) and NHC (2022). Flood Hazard considers future sea level rise, storm surge, and extreme tides which did not depend on dike removal and the proposed flood mitigation features. Flood Hazard is discussed in Section 9.4.3.

9.4.1 Water Level Modelling

NHC (2025e) provided the following raster layers depicting joint combinations of riverine and ocean levels under existing conditions and post-dike removal with flood mitigation features in place:

- Koksilah River 1.5-year flow combined with 200-year ocean levels;
- Koksilah River 200-year flow combined with 1.5-year ocean levels; and,
- Koksilah River mean annual discharge (MAD) combined with Higher High Water Large Tides (HHWLT).

We reviewed the raster layers provided by NHC and determined that Koksilah River MAD and HHWLT was a reasonable approximation of simulated high water levels under current conditions. Although the raster layers did not consider sea level rise and storm surge, these factors were evaluated and validated against the WWAL (2021) study in Section 9.4.3.

The left column in Figure A6 (Appendix A) shows the simulated distribution of Koksilah River MAD combined with HHWLT under existing and flood mitigated conditions. With proposed dike removal and flood mitigation measures in place, NHC (2025e) showed that water elevations of 1.6 m were simulated to occur on the low-lying areas adjacent to the coastline, including the area east of Cowichan Bay and Tzouhalem Roads. The active wells within this area included:

- WTN 53193 and WTN 52512, located north of Dike 88 and completed in Aquifers 186 and 188, respectively;
- WTN 56954, completed in Aquifer 188; and,
- WTN 48489 (located south of Dike 49) completed in Aquifer 197.

All active wells appeared to be above the simulated high water levels from NHC (2025e). The ground elevation near WTN 56954 was approximately 1.7 m above sea level (m asl), which does not account for casing stickup (well WTN 56954 also has a casing stick-up of 0.50 m above ground), and above the simulated high water level condition from NHC (2025e) of 1.6 m asl.

There were no abandoned wells located within the low-lying areas in Dinsdale Field where inundation may occur. Abandoned wells that were not properly decommissioned would serve as preferential pathways for brackish or saline groundwater to flow into the subsurface.

9.4.2 Wave Height Modelling

NHC provided a SWAN output depicting simulated maximum wave heights under the present day scenario with dikes and the flood mitigation condition with dikes removed for a 200-year ocean level circumstance (NHC, 2025f). The right column in Figure A6 shows the results from the simulated wave distribution compared with locations of active wells within the SWI assessment area.

Under existing conditions, the modelling shows wave heights up to 0.4 m occurred near WTN 56954. Wave heights near WTN 56954 post-dike removal and with flood mitigation features in place were reduced to approximately 0.2 m. Otherwise, there did not appear to be significant differences in simulated wave height in the vicinity of the active wells between existing conditions and post-dike removal with flood mitigation features in place.

9.4.3 Flood Hazard

Equation 9.3 below summarizes Designated Flood Level (DFL) which was used by WWAL (2021) to map Flood Hazard. DFL considered future sea level rise, storm surge, and extreme tides (HHWLT). Table 9.4 below summarizes the parameters that were used in the assessment.

Equation 9.3. Designated Flood Level from WWAL (2021)

$$DFL = HHWLT + Sea\ Level\ Rise\ (SLR) + Storm\ Surge$$

Table 9.4. Summary of parameters used in Flood Hazard analysis

Parameter	Southern Gulf Islands (WWAL, 2021)	Cowichan Bay Estuary (NHC, 2022)
HHWLT	1.57 m [(1)]	1.56 m[(2)]
Storm Surge	95th percentile: 0.49 m [(1)] Maximum: 0.92 m [(1)]	95th percentile: 0.43 m[(2)] Maximum: 0.68 m[(2)]
SLR	Mean: 0.87 m [(1)] Maximum: 1.17 m [(1)]	Mean: 0.71 m[(2)] 95th percentile: 0.78 m[(2)]
Regional Adjustment	-0.119 m [(1)]	-

Notes:
[1]from WWAL (2021)
[2]from NHC (2022)

HHWLT was defined as the average of the annual maximum HHWLT (extreme tides) from 19 years of predicted tide data, and was used to represent the average annual high tide level. Storm surge values were determined using predicted and observed tide levels and extreme value analyses[3], converted to the Cowichan Bay area by NHC (2022). Sea Level Rise (SLR) was based on local values from published reports from Smart Shores Inc. (2020) reported by NHC (2022). For the Cowichan Bay area, Smart Shores Inc. (2020) estimated a local relative SLR of 0.74 m (90% confidence interval of 0.54 to 0.96 m), which included adjustment for regional effects such as land subsidence or tectonic uplift.

Combinations of HHWLT, storm surge, and SLR from WWAL (2021) and NHC (2022) were used to update the Flood Hazard ranking scheme based on the more recent and local data. Table 9.5 compares the Flood Hazard ranking scheme from WWAL (2021) with the updated scheme determined in the current study.

Table 9.5. Flood Hazard rating scheme

Rating	Sea Level Rise (SLR)	Storm Surge	Updated Flood Hazard ranking scheme	Flood Hazard ranking scheme from WWAL (2021)
5	Mean	95th percentile	<3.0	<2.8 m
4	Max	95th percentile	3.0 – 3.1 m	2.8 – 3.1 m
3	Mean	Max	3.1 – 3.2 m	3.1 – 3.2 m
2	Max	Max	3.2 – 3.3 m	3.2 – 3.5 m
1	Max	Max	>3.3 m	>3.5 m

[3]Extreme value analysis is a statistical method used to understand the behaviour of extreme values in hydrological datasets, particularly those that are very small or large.

Figure 9.2 shows the Flood Hazard mapping from WWAL (2021) clipped to the SWI assessment area, compared with Flood Hazard mapping using the updated ranking scheme from the current study. Overall, the results from the current study were fairly similar to those from WWAL (2021).

High Flood Hazard values (5) were primarily constrained to low-lying areas adjacent to the coastline, and near the north and south distributaries of the Koksilah River. There were five wells with high Flood Hazard values located within the SWI assessment area:

- WTN 53193, completed in Aquifer 186;
- WTN 48582, WTN 52512, and WTN 56954, completed in Aquifer 188; and
- WTN 48489[4] completed in Aquifer 197.

The remaining eight active wells within the SWI assessment area had low Flood Hazard values of 1 which occurred away from the distributary channels. There were no wells with Flood Hazard ratings of 2 to 4 (inclusive).

[4] The high (5) Flood Hazard value for this well is based on the well's mapped location. As mentioned in Section 0, this well could not be found and may actually be located elsewhere.

Figure 9.2. Comparison of Flood Hazard mapping from WWAL (2021) and current study

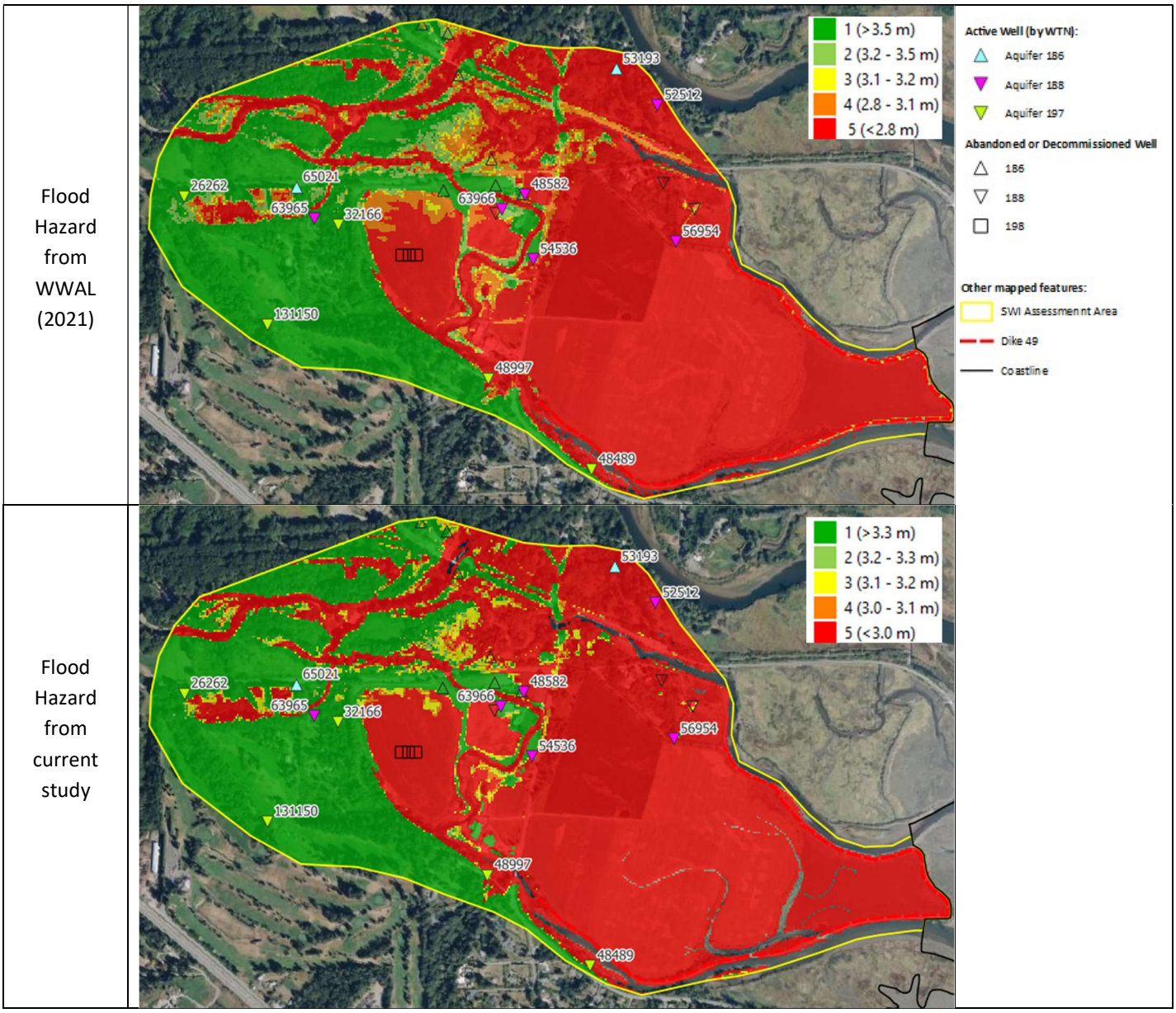


Table 9.6 summarizes simulated wave heights at the active wells within the SWI assessment area under existing conditions and post-dike removal with flood mitigation features in place. There were five wells with simulated wave heights ranging between 0.11 m and 0.26 m. Modelling by NHC indicated that Dike 49 removal combined with the proposed flood mitigation features would result in changes in wave heights of ± 0.01 m at the active wells which was within the range of modelling uncertainty of 0.05 m from NHC (2025a).

Table 9.6. Simulated wave heights, and Flood Hazard values at active wells in SWI assessment area

WTN	Aquifer ID	Simulated Wave Height (m)		Flood Hazard
		Existing Condition	Post-dike removal with flood mitigation features	
53193	186	0.11	0.12	5
65021	186	-	-	1
48582	188	-	-	5
52512	188	0.26	0.26	5
54536	188	-	-	1
56954	188	0.17	0.16	5
63965	188	-	-	1
63966	188	-	-	1
26262	197	-	-	1
32166	197	-	-	1
48489	197	0.24	0.25	5
48997	197	-	-	1
131150	197	-	-	1

10. DISCUSSION AND CONCLUSION

The presence of an overlying confining unit and the lack of hydraulic connection between Aquifers 188 and 197 and the distributary channels of the Cowichan River in the SWI study area indicate these aquifers should not be vulnerable to infiltration of any brackish or saline water that may occasionally be present in the distributary channels. Removal of Dike 49 should therefore have a negligible effect on the wells in Aquifers 188 and 197, provided that their integrity are maintained (e.g., proper casing stick-ups and mounding around the wellheads, secure and flood-proofed well caps, adequate surface seals) such that they do not allow any brackish or saline water to enter into the aquifer directly from the upper portion of the well.

Infiltration of brackish or saline water from the distributary channels into Aquifer 186 can occasionally occur under current conditions. However, there are only two active wells completed into this aquifer within the SWI study area: wells WTN 65021 and WTN 53193. SWI impacts to WTN 65021 are not expected because it is located more than 1.8 km from the coast. WTN 53193 is more susceptible given its proximity to a distributary channel and to the coast, regardless of removal of Dike 49. However, the potential of infiltration of brackish or saline water affecting the use of WTN 53193 can be mitigated, if necessary, by deepening the well and completing it in Aquifer 186 or Aquifer 188.

Lateral intrusion of sea water into Aquifers 186, 188 and 197 also appears to be of limited concern at this time because of the limited pumping from these aquifers within the SWI study area, regardless of removal of Dike 49. A comparison of SWI indicator parameters to historical ones (from 1985-1994) for wells WTN 48582, WTN 54536, and WTN 56954 shows that specific conductance and chloride concentrations do not appear to have risen over the intervening decades despite on-going groundwater use.

More refined mapping of Aquifer Susceptibility, Pumping Threat, and Vulnerability to Pumping Threat based on local data shows a more realistic and less vulnerable picture of lateral SWI within the study area than originally depicted by WWAL (2021), which focused on the entire BC coast.

Assessment of coastal hazards pre and post dike removal indicated no significant change to water levels and maximum wave heights in the vicinity of the active wells. Simulated high water levels of 1.6 m (based on joint combined MAD from Koksilah River and HHWLT) occurred on the low-lying areas adjacent to the coastline east of Cowichan Bay and Tzouhalem Roads, which was below the elevation of active wells in the area The modelling showed that the proposed flood mitigation features reduced maximum wave height near WTN 56954. Flood Hazard (which considers high tides, storm surge, and sea level rise) mapped using local data compiled from NHC (2022) indicated no significant differences between Flood Hazard mapped by WWAL (2021).

Overall, the Cowichan Estuary Marsh Restoration Project is not expected to result in significant impact to active groundwater users within the SWI study area upgradient of Dike 49. Monitoring groundwater quality data from active wells completed in Aquifer 186 (where limited water quality data were available) (i.e., WTN 53913) and in the most susceptible wells (i.e., WTN 53193, WTN 48582, WTN 52512, and WTN 56954) would help verify actual SWI potential.

11. RECOMMENDATIONS

Based on the results of this study, we provide the following recommendations:

- Conduct groundwater sampling at the following wells to monitor groundwater quality specific to SWI. The samples should be tested for specific conductance, TDS, and chloride, which are key indicator parameters for seawater intrusion.
    - WTN 53913, completed in Aquifer 186 (because groundwater quality in Aquifer 186 was poorly characterized); and,
    - The SCLTC well (WTN 48582), WTN 52512, the Kidd Well (WTN 54536), and former Observation Well 297 (WTN 56954) (the most susceptible wells), completed in Aquifer 188.

  All of these wells were identified as having Flood Hazard ratings of 5. WTN 48489 was excluded because it could not be located in the site visits. The annual sampling should be completed before, during and for several years after the project is completed. Sampling frequency and schedule should then be reevaluated to determine if it is still needed.
- Complete well head improvements at former Provincial Observation Well 297 (WTN 56954) (now used for domestic purposes) to control annular flow and improve drainage around the well.
- Properly decommission any wells that are no longer in use, to mitigate the potential for them to be used as preferential pathways for seawater to migrate into the aquifers below Cowichan Estuary.
- Encourage well owners in the study area to properly maintain their wells, and not use them beyond their authorized quantities.
- Forward the errors in GWELLS identified and summarized in Section 4 of this report to the Province of BC.

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13. GLOSSARY OF TERMS

Term	Definition
Aquifer	A geological deposit that is permeable and saturated that allows a sufficient supply of water to flow to wells and to springs.
Aquitard	A geological deposit that is made up of mainly low permeability sediments like till, silt or clay. Also sometimes referred to as a confining layer.
Artesian	Means the same as confined (see below) in reference to an aquifer. In reference to a well, a flowing artesian well is under pressure greater than the surface of the land or top of casing.
Confined aquifer	An aquifer that is overlain by confining sediments or confining layer; groundwater in a confined aquifer is commonly under pressure.
Confining sediments	Sediments composed of typically low permeability sediments like till, silt or clay.
Deltaic sediments	Unconsolidated sediments (mostly permeable sandy sediments) deposited at the mouth of a river or stream.
Down-gradient	The direction of maximum decrease in the groundwater elevation; often inferred as the direction of groundwater flow.
Fluvial sediments	Unconsolidated sediments (mostly sandy, gravelly sediments) deposited by stream (moving) water.
Freeboard	The remaining vertical height between the water level and level where submergence occurs.
Fully recorded	An operational term meaning there is insufficient unrecorded (unlicensed) water in the stream or aquifer for any additional authorizations.
Glaciofluvial sediments	Unconsolidated sediments deposited by meltwater streams from glaciers
Glaciolacustrine sediments	Unconsolidated sediments deposited in glacial lakes
Hydraulic connection	The existence of flow between distinct sources of water such as between an aquifer and a stream or ocean.
Hydraulic gradient	The amount the groundwater level decreases over a specific distance in a specific direction (e.g., vertical hydraulic gradient; horizontal hydraulic gradient). Hydraulic gradient is usually expressed as a dimensionless fraction (e.g., 0.0005).
Hydrostratigraphic unit	A geologic unit or grouping of units exhibiting similar water-bearing characteristics.
Lacustrine sediments	Sand, silt and clay deposited in stillwater lakes and ponds.
Lateral intrusion (of seawater)	When well pumping (of fresh groundwater) occurs within a coastal aquifer, the equilibrium that exists between a body of fresh groundwater and salt water is disturbed such that the freshwater-saltwater interface moves inland, towards the pumping well.
Morainal sediments	Primarily a mixture of clay, silt, sand, gravel and boulders ranging widely in size and shape deposited directly by and underneath a glacier.
Recharge	Process where water (from rain, snow, surface water) percolates to the aquifer.
Seawater intrusion	The incursion of saltwater into freshwater aquifers located in coastal areas. While seawater intrusion occurs seasonally as a natural process, well pumping,

Term	Definition
	sea level rise from climate change and from storm surges can cause significant incursion of saltwater into freshwater aquifers to occur.
Stacked aquifers	An informal term meaning there is a vertical sequence of two or more distinct aquifers, typically separated by aquitards or confining units.
Static water level (SWL)	Distance (in metres or feet) from the top of the production casing or the surface of the ground to the groundwater level in the well, when the groundwater level is not affected by pumping activities in the well (legal definition from the Water Sustainability Act).
Storativity (S)	Volume of water stored or released from a column of aquifer with unit cross-section under unit change in groundwater level. Storativity determines how quickly (or slowly) an aquifer responds to hydraulic changes and is reported as a dimensionless number (e.g., 0.0001).
Streamflow depletion	In relation to well pumping, it is the capture of water from a stream by a pumping well. Water can be captured by the pumping well intercepting water that would otherwise flow to the stream (process called interception) or by inducing infiltration of water from the stream into the underlying aquifer to the pumping well (process called induced infiltration).
Storativity (S)	Volume of water stored or released from a column of aquifer with unit cross section under unit change in groundwater level. Storativity determines how quickly (or slowly) an aquifer responds to hydraulic changes and is reported as a dimensionless number (e.g., 0.0001).
Total Dissolved Solids (TDS)	The total weight of all minerals dissolved in water, usually expressed in mg/L; represents the mineral content of the water.
Transmissivity (T)	The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is commonly expressed as metres squared per second or day, feet squared per second or day, or gallons per day per foot. Transmissivity reflects the permeability of the aquifer integrated over the thickness of the aquifer.
Unconfined aquifer	An aquifer where the top of the aquifer is the water table.
Unconsolidated sediments	A geological material comprising loose sediments, e.g., sand and gravel. Synonymous with “Surficial sediments”.
Up-coning (of fresh water/saltwater interface)	When well pumping (of fresh groundwater) occurs within a coastal aquifer above where a freshwater-saltwater interface occurs at depth, the equilibrium that exists between a body of fresh groundwater and salt water is disturbed such that the freshwater-saltwater interface will move upward, bringing the body of saltwater closer to the pumping well.
Water Allocation Notation	Operational notations used in B. C. to indicate the potential lack of water availability on a stream or an aquifer to alert staff and prospective applicants to current or potential water allocation concerns.
Wave Effect	Height of the ocean level accounting for height of waves.

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Groundwater Supply Development and Management

Source Water Assessment and Protection

Well Monitoring & Maintenance

Environmental & Water Quality Monitoring

Storm & Wastewater Disposal to Ground

Groundwater Modeling

Aquifer Test Design and Analysis

Geothermal / Geoexchange Systems

Policy and Guideline Development

Applied Research

Rural Subdivision Services

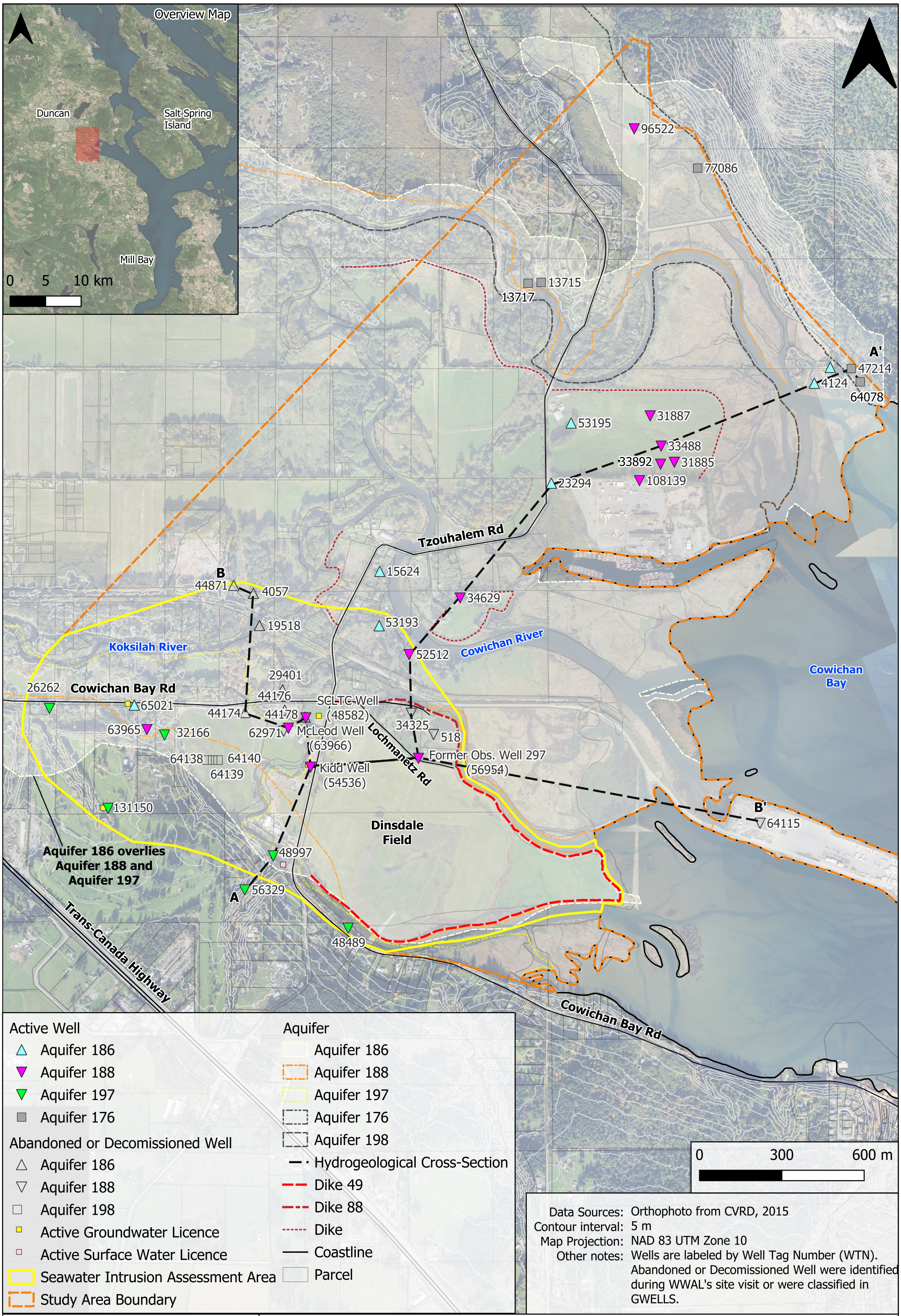
Environmental Assessment & Permitting

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Appendix A

Figures

Nature Trust of British Columbia
Cowichan Estuary Restoration Seawater Intrusion
Assessment WWALL Ref: 25-050-01VC



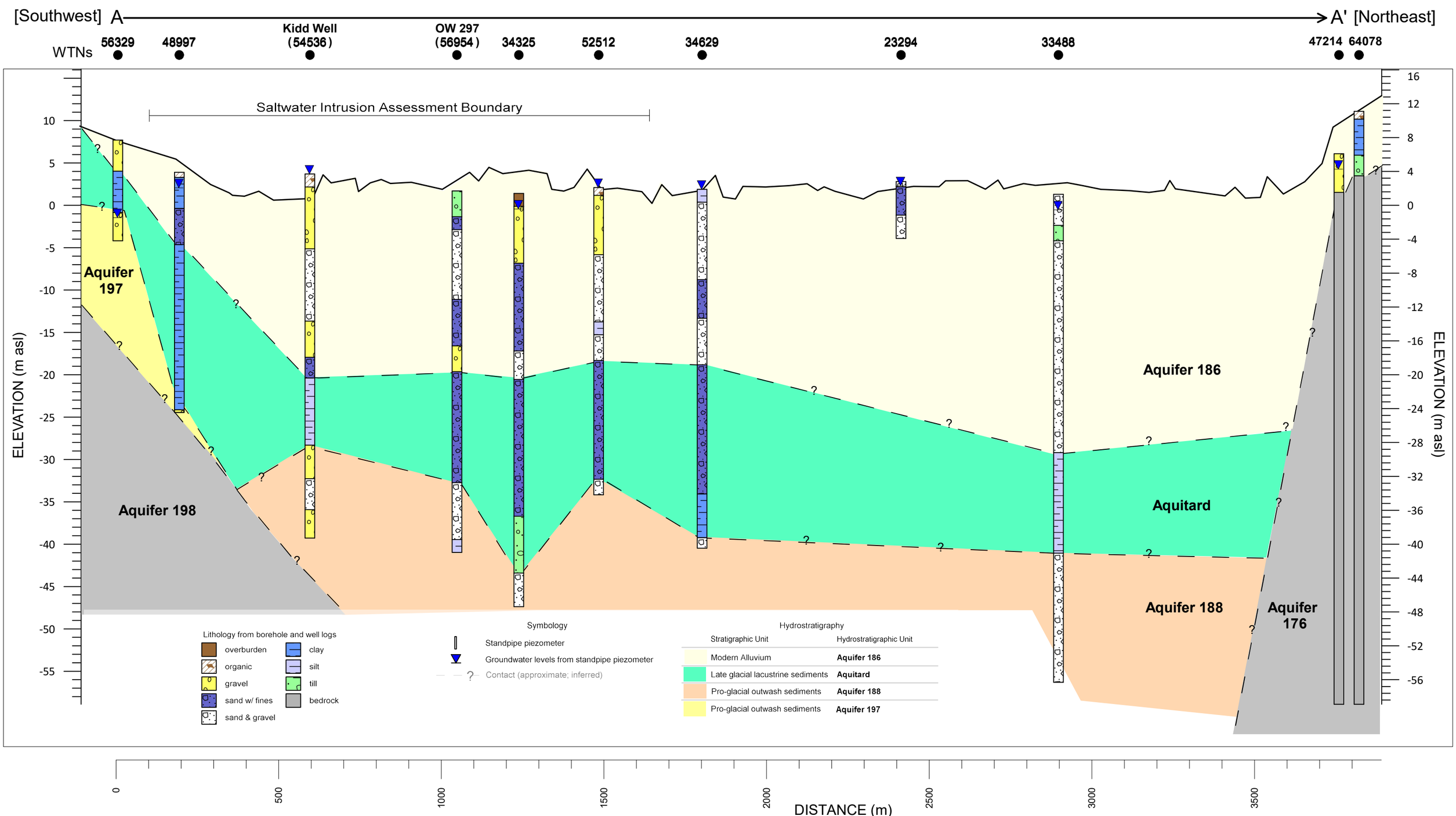
Data Sources: Orthophoto from CVRD, 2015
Contour interval: 5 m
Map Projection: NAD 83 UTM Zone 10
Other notes: Wells are labeled by Well Tag Number (WTN). Abandoned or Decomissioned Well were identified during WWAL's site visit or were classified in GWELLS.

Cowichan Estuary Seawater Intrusion Assessment

western water ASSOCIATES LTD

TITLE **Figure A1:** Site Overview

DRAWN	DATE	CLIENT
Jackie Van der Vlugt, GIT	August 7, 2025	Nature Trust of British Columbia
REVIEWED	PROJECT NO.	REVISION NO.
Tim Sivak, P.Geo	25-050-01VC	D



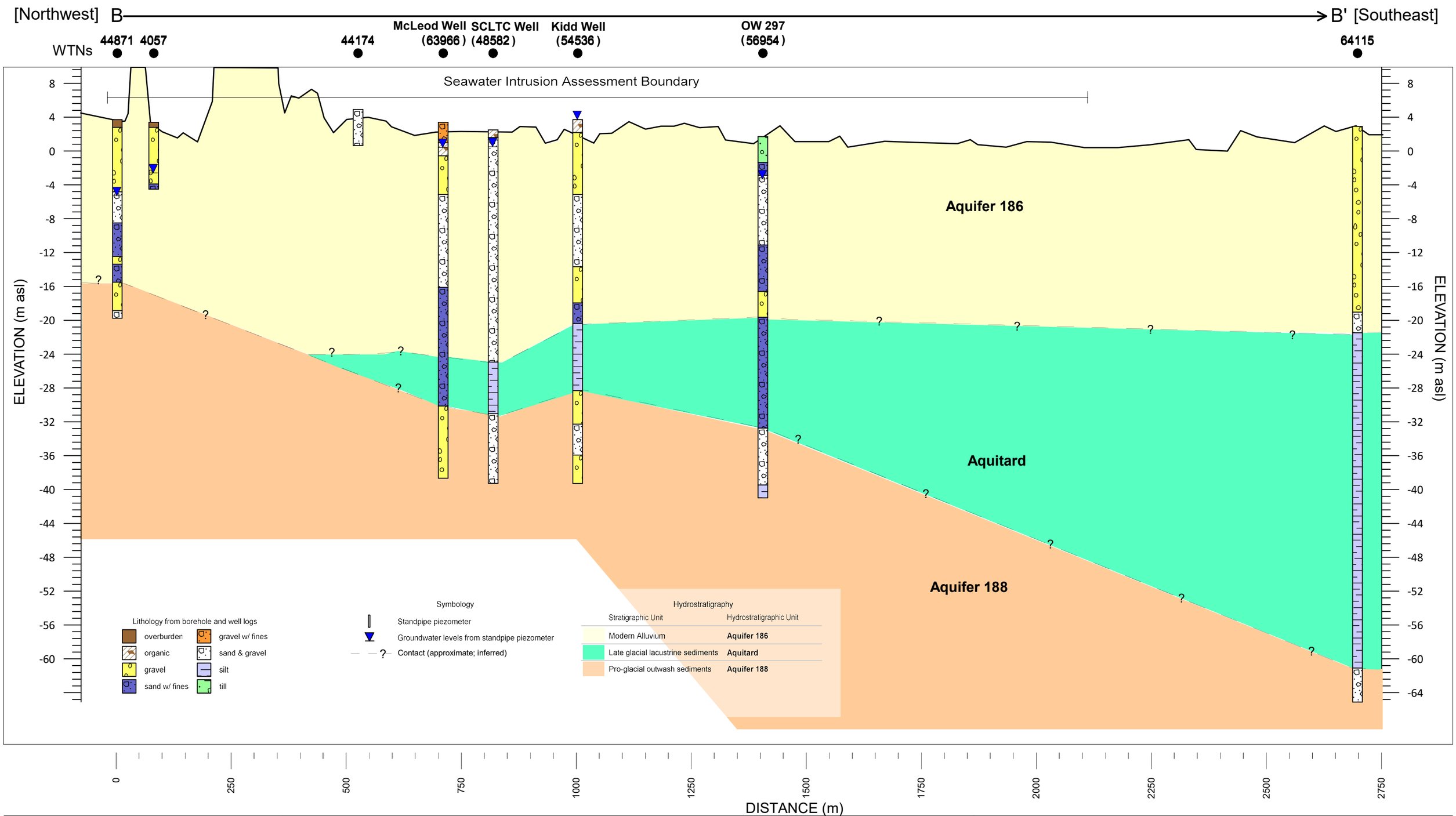
Cowichan Estuary Restoration Seawater Intrusion Assessment

Figure A2. Cross-Section A-A' Looking Northwest

western water ASSOCIATES LTD

Drawn:	Jackie Van der Vlugt, GIT	**Client:**	Nature Trust of British Columbia
Reviewed:	Mike Wei, P.Eng	**Project Number:**	25-050-01VC
Revision:	D	**Date:**	August 7, 2025

Notes:
1) Map Projection: NAD83 UTM Zone 10
2) Lithology descriptions from GWELLS;
3) Topography from Google Earth (2025);
4) The hydrostratigraphy shown on this drawing are interpreted from well data. Actual hydrostratigraphy may vary from that indicated on this drawing;
5) Wells are labelled by common name and/or Well Tag Number (WTN).
6) Vertical Exaggeration: 22.71



Cowichan Estuary Restoration Seawater Intrusion Assessment	**Figure A3. Cross-Section B-B' Looking Northeast**		**Notes:** 1) Map Projection: NAD83 UTM Zone 10 2) Lithology descriptions from GWELLS; 3) Topography from Google Earth (2025); 4) The hydrostratigraphy shown on this drawing are interpreted from well data. Actual hydrostratigraphy may vary from that indicated on this drawing; 5) Wells are labelled by common name and/or Well Tag Number (WTN). 6) Vertical Exaggeration: 18.03
western water ASSOCIATES LTD	**Drawn:** Jackie Van der Vlugt, GIT	**Client:** Nature Trust of British Columbia	
	Reviewed: Mike Wei, P.Eng	**Project Number:** 25-050-01VC	
	Revision: D	**Date:** August 7, 2025	

Figure A4. Pumping Threat values for the SWI assessment area from (a) WWAL (2021), and from the current study for (b) Aquifer 186, (c) Aquifer 188, and (d) Aquifer 197

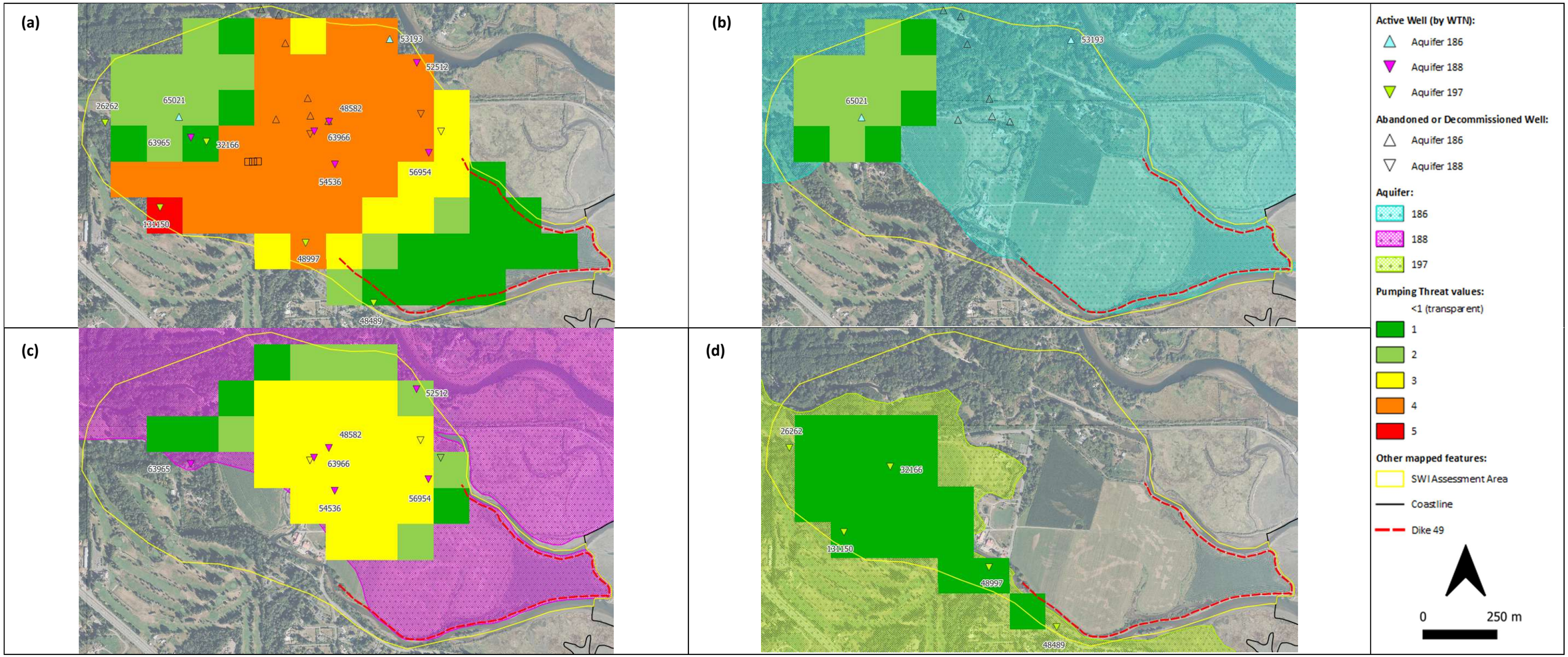


Figure A5. Aquifer Vulnerability from Pumping for the SWI assessment area from (a) WWAL (2021), and from the current study for (b) Aquifer 186, (c) Aquifer 188, and (d) Aquifer 197

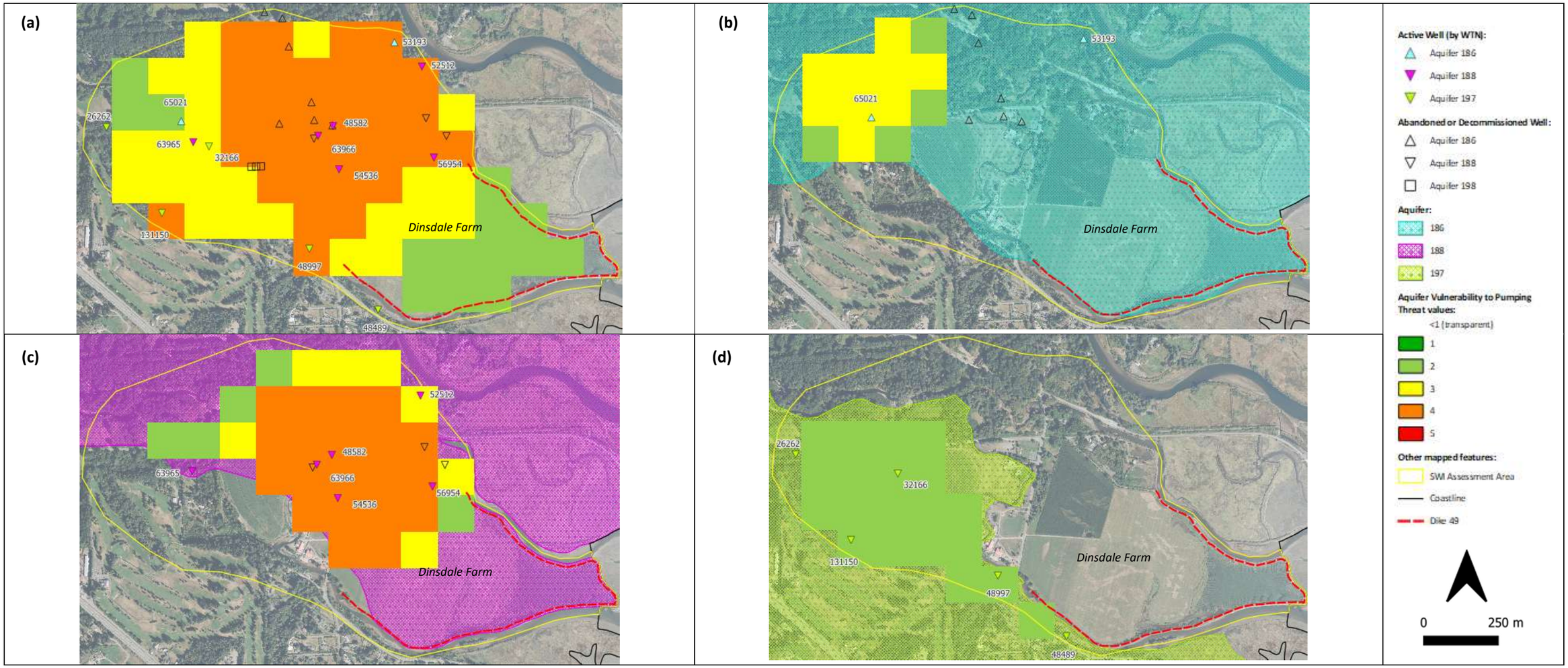
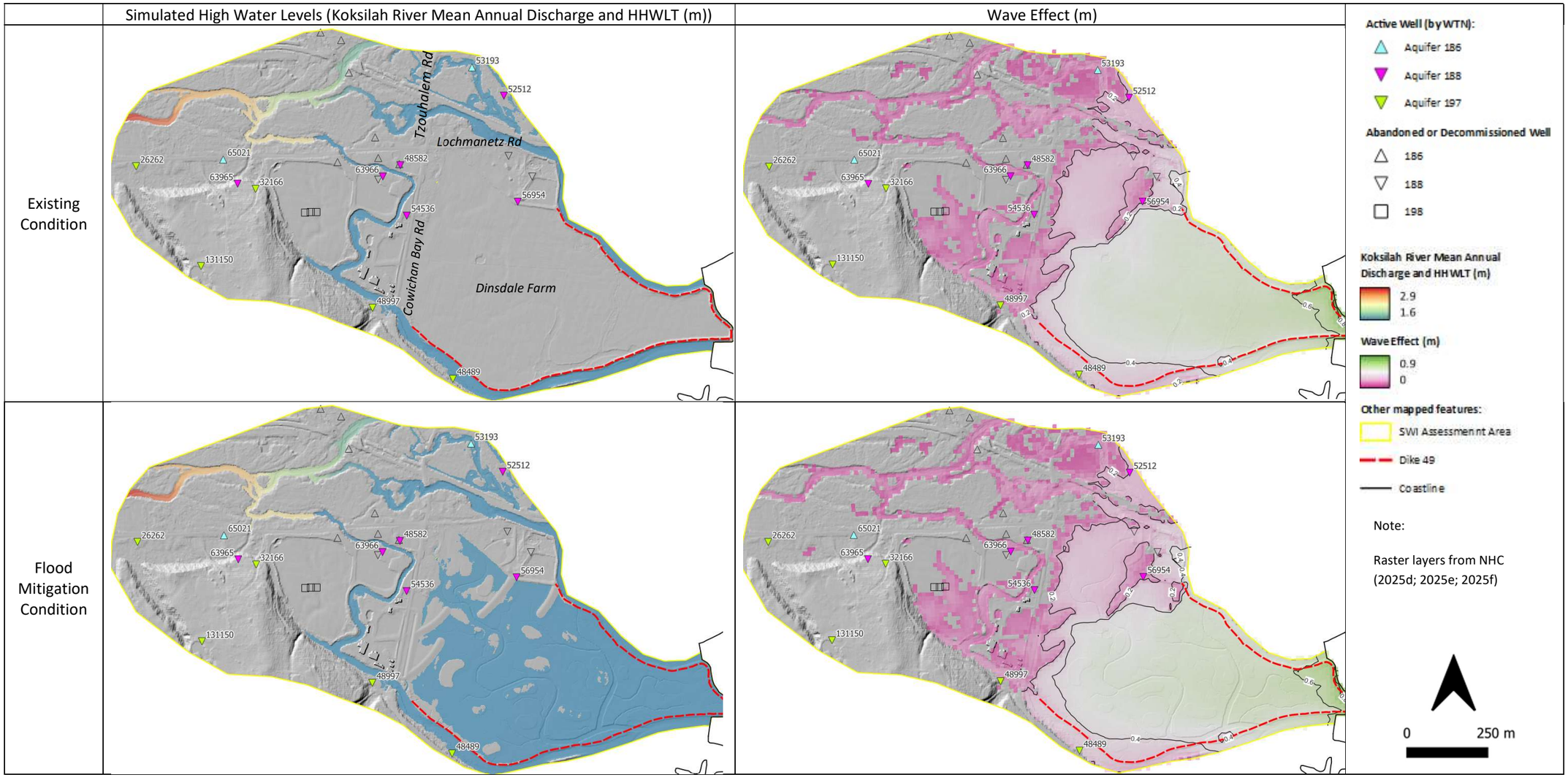


Figure A6. Simulated high water levels and wave effect for existing conditions and after dike removal with flood mitigation features in place



Appendix B

Literature Review

Nature Trust of British Columbia
Cowichan Estuary Restoration Seawater Intrusion Assessment
WWALL Ref: 25-050-01VC

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LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Barroso, S., Ormond, R., Henderson, G., Lapcevic, P. 2013. Groundwater Quality in the Lower Cowichan River Aquifer Complex. Ministry of Forests, Lands and Natural Resource Operations. April 2013.

Brief Synopsis: What is it about?

To establish a baseline of ambient groundwater chemistry in the Lower Cowichan River aquifer complex, focusing on wells in the uppermost aquifers (Aquifers 186 and 187). The data and information should be used to evaluate future changes, seasonal variability, and temporal trends in groundwater quality.

Relevance to Project: **Yes** or No

How is it Relevant?

Groundwater quality
Intrinsic aquifer properties

Scale of Study:

Well-scale, aquifer scale

Key Nuggets

- The study focused on Aquifers 186 and 187 (upper and middle aquifers), and there was less emphasis on the deeper aquifer (Aquifer 188).
- Analysis indicated that there is no evidence of seawater intrusion in Aquifers 186 and 187.
- Limited water quality data for the deeper aquifer (Aquifer 188) are available.
- The reported transmissivity values for aquifers 186, 187 and 188 are $1.9E^3$ to $3.6E^4$ m^2/day, 124 to $1.2E^4$ m^2/day, and 277 to 584 m^2/day, respectively. Selected aquifer parameters are summarized in the table on the following page. Aquifer 188 is inferred to be the least productive of the three aquifers although previous work by others indicates uncertainty in this regard.

Parameter		Aquifer 186	Aquifer 187	Aquifer 188
Level of development		I (Heavy)	II (Moderate)	III (Low)
Level of vulnerability		A (High)	B (Moderate)	C (Low)
Productivity		High	High	High
Ranking		14	12	10
Area (km^2)		17.0	11.4	8.7
Well Depth Range (Median)	m	2.4 – 22.3 (7.9)	9.4 – 38 (23)	29 – 61 (43)
	ft	8 – 73 (26)	31 – 125 (75)	94 – 200 (140)
	N=	88	17	15
Well yield range (Median)	L/s	0.44 – 143 (1.6)	2.2-189 (30)	0.63 – 32 (6.6)
	USgpm	7 – 2260 (25)	35 – 3000 (478)	10 – 500 (104)
	N=	66	16	13
Depth to Static Water Level (Median)	m bgs	0.5 – 6.4 (2.4)	0.30 – 4.9 (2.1)	0.6 – 12 (1.4)
	ft bgs	1.5 – 21 (8.0)	1.0 – 16 (7.0)	2.0 – 39 (4.5)
	N=	67	17	10
Transmissivity	(m^2/d)	1.9×10^3 – 3.6×10^4	124 – 1.2×10^4	277 – 584
	USgpd/ft	1.5×10^5 – 2.9×10^6	1.0×10^4 – 1.0×10^6	2.2×10^4 – 4.7×10^4
Specific Capacity	(L/s/m)	9.3 – 80	1.3 – 38	2.9
	USgpm/ft	45 – 386	6.3 – 182	14

Report Findings/Conclusions:

- Samples were collected biannually from 2002 to 2007, and once in 2011 at six municipal wells, and at varying degrees in two provincial observation wells.
- Groundwater in the upper and middle aquifers was determined to be immature, calcium-bicarbonite type with no evidence of seawater intrusion.
- Water chemistry is representative of recently recharged groundwater from shallow unconsolidated sand and gravel aquifers.
- There were no significant differences in quality between aquifers 186 and 187.

Report Limitations:

Report Recommendations:

WWAL Recommendations:

References:

LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Chwojka, F. 1997. Assessment of Water Quality and Identification of Water Quality Concerns and Problem Areas Cowichan – Koksilah Estuary, Cowichan Bay, B.C. Ministry of Environment, Water Management Branch, Groundwater Section. 43 pp.

Brief Synopsis: What is it about?

This is a review of the Quality Assessment Programin the Cowichan Bay Estuary from its initiation in 1985 to 1997.

Relevance to Project: **Yes** or No

How is it Relevant?

The study speaks to the water chemistry over the 10 years of sampling and if changes were present in the upper and lower aquifer. Upper aquifer exhibited salt water encroachment whereas the lower aquifer remained unchanged over 10 years of sampling. The middle aquifer had no monitoring wells and therefore observations were not recorded.

Scale of Study:

Local study for the Cowichan Bay Estuary.

Key Nuggets

- The upper aquifer (Aquifer 186) exhibited saltwater intrusion in some shallow dug wells.
- Lower aquifer (Aquifer 188) showed no high levels of chloride over the 10 years of sampling suggesting seawater encroachment is not a concern in the lower aquifer.
- Observation Well #298 (Upper aquifer) had field conductivity range is 1520 umhos/cm with a maximum of 1600 umhos/cm and a minimum of 80 umhos/cm
- Observation Well #297 (lower aquifer) had field conductivity range is 170 umhos/cm with a maximum of 390 umhos/cm and a minimum of 220 umhos/cm. The field chloride range is 114 mg/L with a maximum of 152 mg/L and a minimum of 38 mg/L.
- Cowichan Bay Water Works Well field conductivity range is 145 umhos/cm with a maximum of 540 umhos/cm and a minimum of 395 umhos/cm. The field chloride range is 87 mg/L with a maximum of 182 mg/L and a minimum of 95 mg/L.

- Doman's No.2 Well field conductivity range is 370 umhos/cm with a maximum of 650 umhos/cm and a minimum of 280 umhos/cm. The field chloride range is 258 mg/L with a maximum of 303 mg/L and a minimum of 45 mg/L.

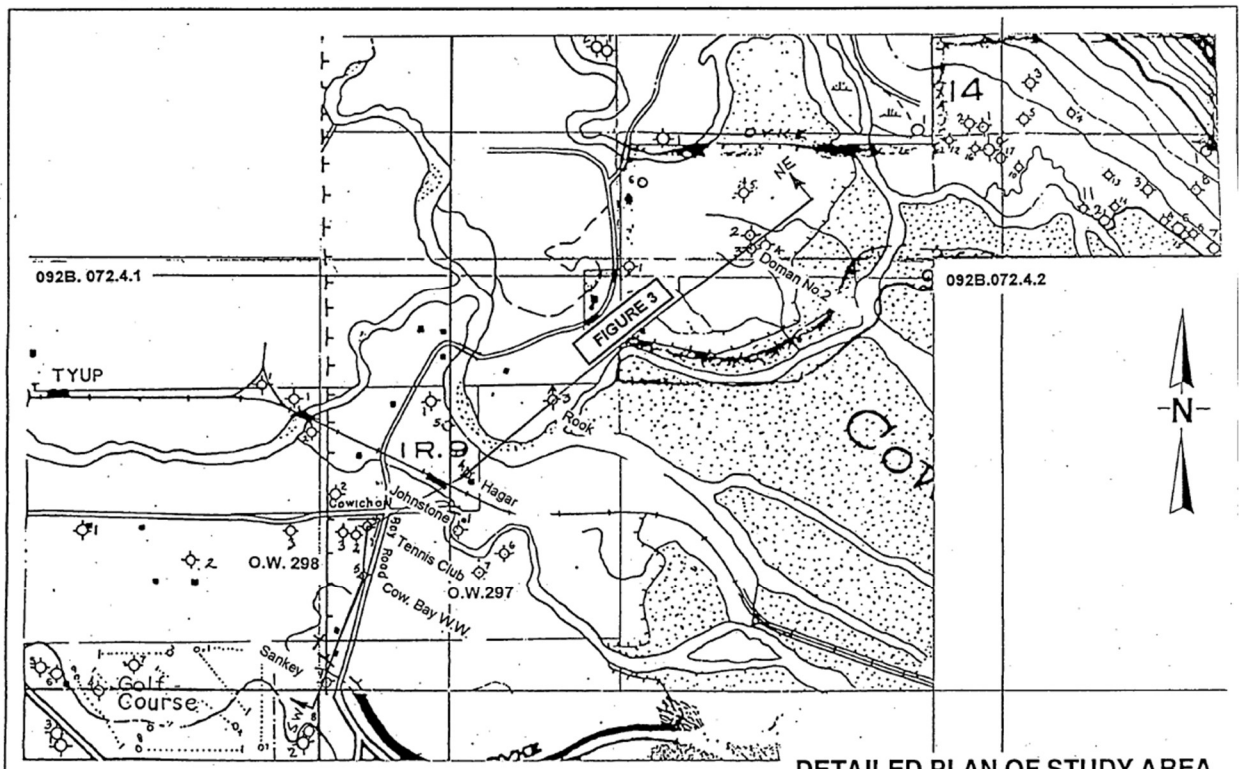
- Hagar's Well field conductivity range is 240 umhos/cm with a maximum of 460 umhos/cm and a minimum of 220 umhos/cm. The field chloride range is 76 mg/L with a maximum of 91 mg/L and a minimum of 15 mg/L.

- Johnstone's Well field conductivity range is 935 umhos/cm with a maximum of 1150 umhos/cm and a minimum of 215 umhos/cm. The field chloride range is 288 mg/L with a maximum of 303 mg/L and a minimum of 15 mg/L.

- Rook's Well field conductivity range is 60 umhos/cm with a maximum of 300 umhos/cm and a minimum of 240 umhos/cm. The field chloride range is 68 mg/L with a maximum of 91 mg/L and a minimum of 23 mg/L.

- The Tennis Club Well field conductivity range is 1075 umhos/cm with a maximum of 1220 umhos/cm and a minimum of 145 umhos/cm. The field chloride range is 167 mg/L with a maximum of 182 mg/L and a minimum of 15 mg/L.

- Deeper wells in the lower aquifer show no high levels of chloride over the ten years of sampling, suggesting seawater encroachment is not a concern in the deeper aquifer.

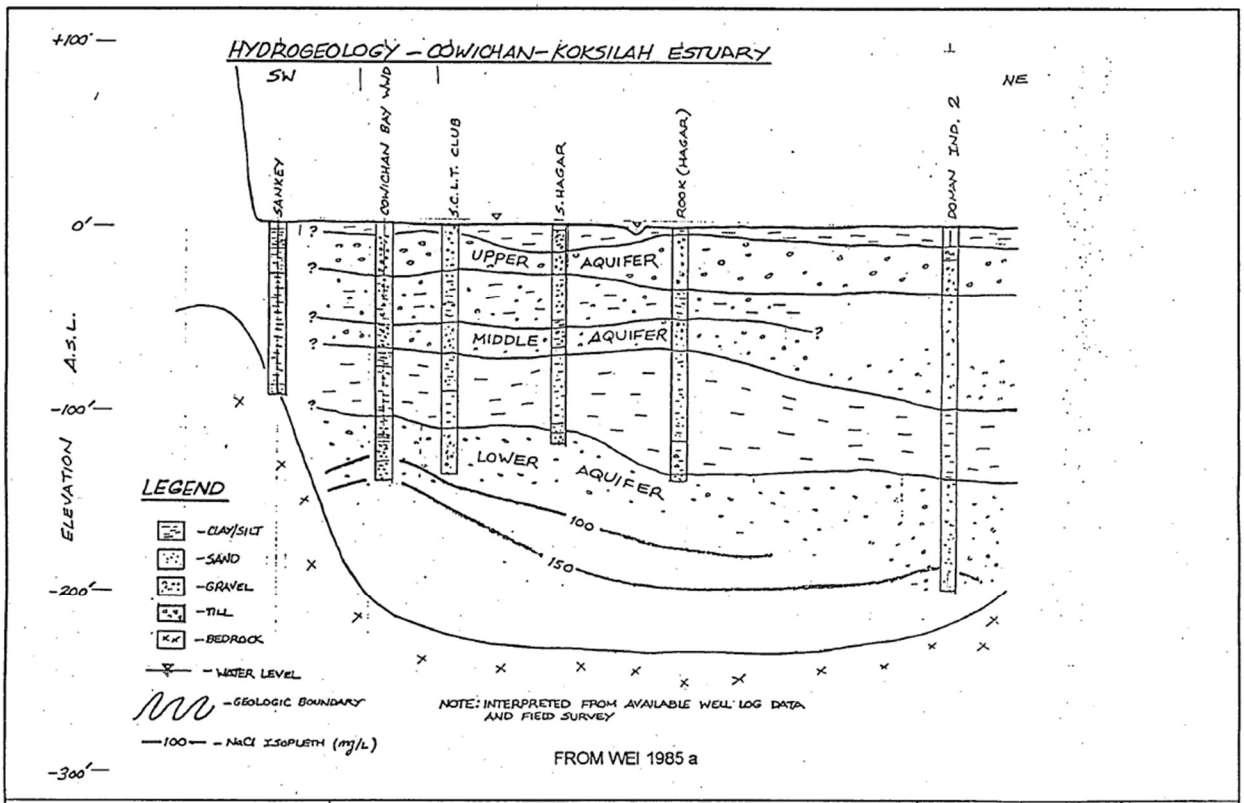


DETAILED PLAN OF STUDY AREA

Province of British Columbia
Ministry of Environment, Lands and Parks
Water Management Division
Hydrology Branch
Groundwater Section

TO ACCOMPANY REPORT ON
GROUNDWATER QUALITY MONITORING
AND ASSESSMENT PROGRAM
COWICHAN - KOKSILAH ESTUARY

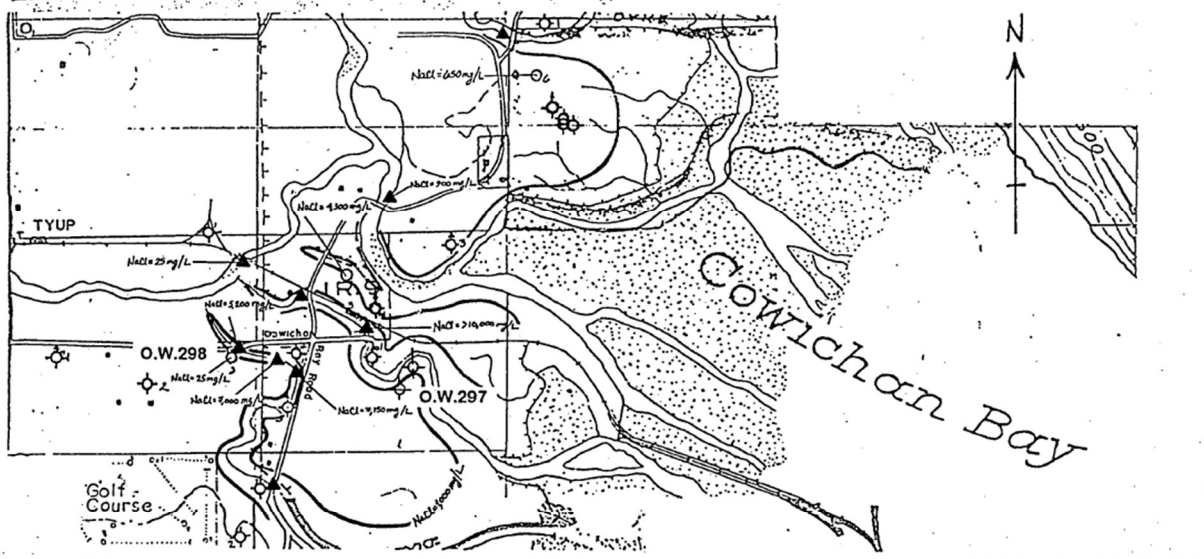
SCALE : VERT.	DATE
SCALE : HOR. 1 : 15360	MARCH 1995
PRODUCED BY :	F. CHWOJKA
FILE NO. 0329563-A	FIGURE 2



FROM WEI 1985 a

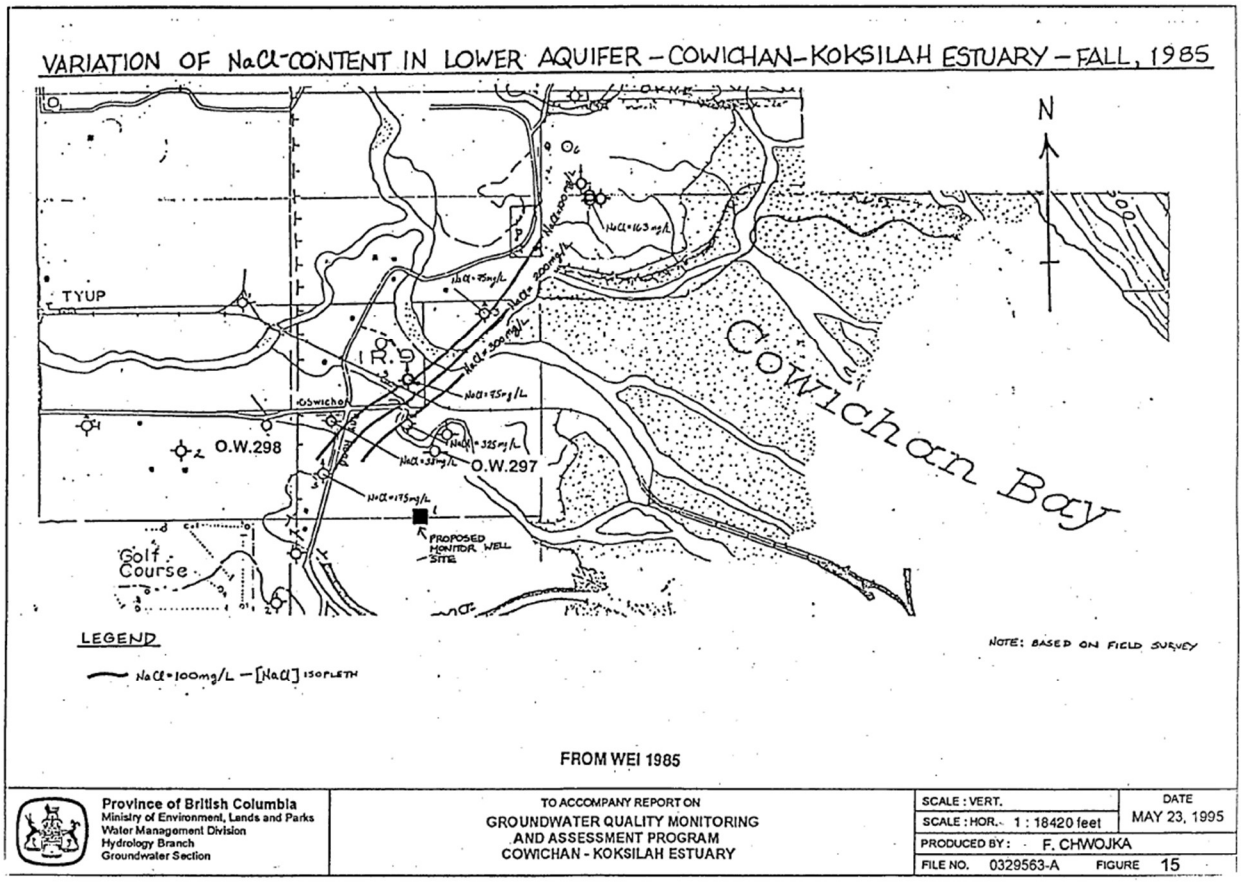
Province of British Columbia Ministry of Environment, Lands and Parks Water Management Division Hydrology Branch Groundwater Section	TO ACCOMPANY REPORT ON GROUNDWATER QUALITY MONITORING AND ASSESSMENT PROGRAM COWICHAN - KOKSILAH ESTUARY	SCALE : VERT. AS SHOWN SCALE : HOR. 1 : 15360 PRODUCED BY : F. CHWOJKA FILE NO. 0329563-A FIGURE 3	DATE MAY 23, 1995

VARIATION OF NaCl CONTENT IN UPPER AQUIFER - COWICHAN-KOKSILAH ESTUARY - FALL, 1985



FROM WEI 1985

Province of British Columbia Ministry of Environment, Lands and Parks Water Management Division Hydrology Branch Groundwater Section	TO ACCOMPANY REPORT ON GROUNDWATER QUALITY MONITORING AND ASSESSMENT PROGRAM COWICHAN - KOKSILAH ESTUARY	SCALE : VERT. N/A SCALE : HOR. 1 : 18420 PRODUCED BY : F. CHWOJKA FILE NO. 0329563-A FIGURE 12	DATE MAY 23, 1995



FROM WEI 1985

Province of British Columbia Ministry of Environment, Lands and Parks Water Management Division Hydrology Branch Groundwater Section	TO ACCOMPANY REPORT ON GROUNDWATER QUALITY MONITORING AND ASSESSMENT PROGRAM COWICHAN - KOKSILAH ESTUARY	SCALE : VERT. SCALE : HOR. 1 : 18420 feet PRODUCED BY : F. CHWOJKA FILE NO. 0329563-A FIGURE 15	DATE MAY 23, 1995

TABLE 1 (1 of 2)
COWICHAN - KOKSILAH WELL RECORDS

	Location			Owner's	Depth		Water	Well	Water	Aquifer	Year	Remarks	SC	Aquifer	Sampling
BCGS No	Sec	Rge	No	Name	in feet		Level	Capacity	use	Lithology	compl.		gpm/ft		Point
					dug	drilled	in feet	gpm							
92B.072.4.1.2.1	11	2	1	I.R. No.9		26	9	10		Gravel/Fn.Sand	1958		0.8	upper	
92B.072.4.1.2.2	9	2	1	J. Sankey		93	6	10	Domestic	Gravel				lower	
92B.072.4.1.2.3	12	1	1	Domans		73	9	400	Irrigation	Sand/Gravel	1980			middle	
92B.072.4.1.2.4	11	1	1	Indian Dept.		26	6	35		Gravel			35	upper	
92B.072.4.1.2.5	10	1	1	L.J. Bernard		59	G.L.	6		Sand/Gravel	1972			upper	
92B.072.4.1.2.6	11	2	2	Indian Department		20						Field Chem.		upper	
92B.072.4.1.2.7	10	2	2	Tennis Club-Shallow	10				Domestic			Field Chem.		upper	
92B.072.4.1.2.8	11	1	2	C.N. Railway		43	6.7	400		Gravel/Sand	1965	Pump test	22.9	upper	
92B.072.4.1.2.9	10	1	2	Foxall		66	49	15		Sand/Gravel				upper	
92B.072.4.1.2.12	10	2	3	L. McLeod	15				Domestic			Field Chem.		upper	
92B.072.4.1.2.13	**10**	**1**	**3**	**OW 298**	**14**				**Domestic**			**Field Chem.**		**upper**	well
92B.072.4.1.2.14	**10**	**2**	**4**	**Tennis Club-Deep**		**136.5**	**2**	**30**	**Domestic**	**Gravel/Sand**	**1981**	**Field & Lab**	**56**	**lower**	outside tap
92B.072.4.1.2.15	10	2	5	Cow.Bay W.W.D.		141	Flows	466	Waterworks	Gravel	1985			lower	
92B.072.4.1.2.16	9	1	5	C. Cameron		92	72	20		Gravel	1972		1.3	upper	
92B.072.4.1.2.17	9	1	6	Cow Golf Club		74	40	75		Gravel	1973	Field Chem.		upper	
92B.072.4.1.2.18	9	1	7	Cow Golf Club		80		60						upper	
92B.072.4.2.1.1	**10**	**2**	**1**	**Johnstone**		**160**	**-6**	**396**		**Sand/Gravel**	**1976**	**Field Chem.**		**lower**	outside tap
92B.072.4.2.1.2	**11**	**2**	**3**	**Rook (Hagar)**		**139**	**-6**	**40**		**Sand/Gravel**				**lower**	outside tap
92B.072.4.2.1.3	**11**	**2**	**4**	**Hagar (Windsor)**		**119**	**14**	**30+**		**Gravel/Sand**	**1983**	**Field & Lab**		**lower**	outside tap
92B.072.4.2.1.4	11	2	5	Hagar	10		8.02		Not used					upper	
92B.072.4.2.1.5	**10**	**2**	**6**	**Johnstone**		**167.6**	**9.51**		**Not used**			**Abandoned**		**lower**	well
92B.072.4.2.1.6	**10**	**2**	**7**	**OW 297**		**140**	**Flowing**	**104**	**Obs.Well**	**Sand/Gravel**	**1987**	**Field & Labs**		**lower**	well
92B.072.4.2.3.1	13	4	16	Croy		274		3		Granite,Clay					
92B.072.4.2.3.2	14	4	1	Schurkeby		150		4		Bedrock	1976	140'			
92B.072.4.2.3.3	13	3	1	I.R.No.1		30								upper	
92B.072.4.2.3.4	13	4	17	Trevor Cole		310	20	2	Domestic	Black Shale	1986				
92B.072.4.2.3.5	14	3	1	Schiffcano	12					Sand				upper	
92B.072.4.2.3.6	12	3	1	Slegg Bros. Lumber		21.5	2 to 6	100 +		Sand/Gravel	1970	Pump test	17	upper	
92B.072.4.2.3.7	14	2	1	Dept. of Ind. Affairs		200		10	Abandoned	Bedrock	1952	Salt W@200'			
92B.072.4.2.3.8	14	2	2	Dept. of Ind. Affairs		100			Abandoned	Bedrock	1952	Salt W@85'			
92B.072.4.2.3.9	**13**	**3**	**2**	**Doman's No.2**		**200**	**6**	**35**		**Sand/Gravel**	**1975**	**Field & Lab**		**lower**	Inside tap
92B.072.4.2.3.10	14	4	2	Sutherland		270		6		Bedrock	1975	30',210'			

TABLE 1 (2 of 2)
COWICHAN - KOKSILAH WELL RECORDS

	Location			Owner's	Depth		Water	Well	Water	Aquifer	Year	Remarks	SC	Aquifer	Sampling
BCGS No	Sec	Rge	No	Name	in feet		Level	Capacity	use	Lithology	compl.		gpm/ft		Point
					dug	drilled	in feet	gpm							
92B.072.4.2.3.11	13	3	3	Doman Ind.		160	2.28	1500	Industrial	Gravel/Sand	1975	Field, Lab, Pump test	33	lower	
92B.072.4.2.3.12	13	3	4	Doman Ind.		166	5.02	1865	Industrial			Pump test	100	lower	
92B.072.4.2.3.13	13	3	5	Doman Ind.		146	Flows					Field, Lab, Pump test	27	lower	
92B.072.4.2.3.14	**13**	**3**	**6**	**Blackeley**	**8**			**25**	**Irrigation**			**Field & Lab**		**upper**	**well**
92B.072.4.2.3.15	13	4	9	Gilles		330	100	1.5		Bedrock	1979				
92B.072.4.2.3.16	13	4	12	James Robert		230	6	3		Bedrock	1981				
92B.072.4.2.4.3	13	4	2	Morford		104	37.83	4		Bedrock	1968				
92B.072.4.2.4.4	13	4	3	Greenwood		100	22	3.5		Bedrock					
92B.072.4.2.4.5	14	4	3	Tzouhalem		230		8		Bedrock	1976	130',170',210',230'			
92B.072.4.2.4.6	14	4	4	Lee Rodert		120		5	Domestic	Bedrock	1980	115'			
92B.072.4.2.4.7	13	4	4	Hartley		114	35	20		Bedrock	1973				
92B.072.4.2.4.8	14	4	5	Payne J.		480		1	Domestic	Bedrock	1985	370',480'			
92B.072.4.2.4.9	13	4	7	Clayton		160	10	3		Bedrock	1975	82',114',156'			
92B.072.4.2.4.10	13	4	8	Holden		120		12		Bedrock	1976	75',115'			
92B.072.4.2.4.11	13	4	10	Underhill E.H.		430	15	1.75	Domestic	Bedrock	1985				
92B.072.4.2.4.12	13	4	11	Spence Dennis		250		6	Domestic	Bedrock	1985				
92B.072.4.2.4.13	13	4	13	Chase David		320		4.5	Domestic	Bedrock	1982	150',200',290'			
92B.072.4.2.4.14	13	4	14	Chase David		230	12	6	Domestic	Bedrock					
92B.072.4.2.4.15	13	4	15	Allen R. Wayne		170	Flows	20	Domestic	Bedrock	1982	167'			
92B.072.4.2.4.16	13	4	6	Orr		118				Bedrock	1971				
92B.072.4.2.4.17	13	4	5	Skinner		78	6	5		Bedrock	1969				
92B.072.4.2.4.18	13	4	1	Fairweather	Spring				Waterworks		1963				
92B.072.4.2.4.19	14	4	?	Holden		310	120	1.5		Bedrock	1979				
92B.072.3.4.6	9	1	1	Wilson & Cox		154	138	8 +		Gravel	1957	17',31',50'			
92B.072.3.4.12	9	1	2	D. Roe		60		3		Bedrock	1961				
92B.072.3.4.20	9	1	3	Duncan Zoo		134	103	10		Gravel	1965				
92B.072.3.4.27	9	1	4	Cow Golf Club		103	78	40		Gravel	1965	Field Chem.	100		
92B.072.3.4.43	9	1	8	Lane Stephen		50	30	10+	Domestic	Silty gravel	1986				
92B.072.4.1.4.1	13	1	1	Indian Coop.	15 - 20			135				Field Chem.			
Note: Wells shown in bold are monitor wells.															

Report Findings/Conclusions:

Figure 5 shows the spike in field specific conductance and chloride in fall of 1989 in Observation Well No. 198 (upper aquifer) was responsible for the large range in specific conductance and chloride observed over the period of monitoring. This suggests periodic inundation of brackish or saline water into the upper aquifer does occasionally occur but is short-lived (lasts no more than a month or so). Similar frequency of sampling of Observation Well No, 197 (deep aquifer) showed no spikes.

Report Limitations:

Water chemistry results are over 25 years old. Some of the more frequent analyses are field analyses.

Report Recommendations:

It is recommended that the Cowichan - Koksilah Estuary Monitoring Program be discontinued. Observation Well 297 and 298 should however be retained for water level monitoring and field testing for conductivity and chloride and complete laboratory water quality analysis on a yearly basis.

WWAL Recommendations:

References:

LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Chwojka, F., 1981. Salt Water Intrusion Problem - Cowichan Bay.

Brief Synopsis: What is it about?

The memo summarizes a field investigation of 3 wells (South Cowichan Lawn Tennis Club Well, McLeod Well, and Dinsdale Well) along Cowichan Bay Road after a reported saltwater problem began in the summer of 1980. Water quality results are provided for the three wells for samples collected on December 17, 1980.

Relevance to Project: **Yes** or No

How is it Relevant?

Talks about saltwater intrusion for three of our potential well locations and provides water quality samples from December 1980 for conductivity and sodium chloride.
This memo could provide hints if we are having issues locating the wells in the field.

Scale of Study:

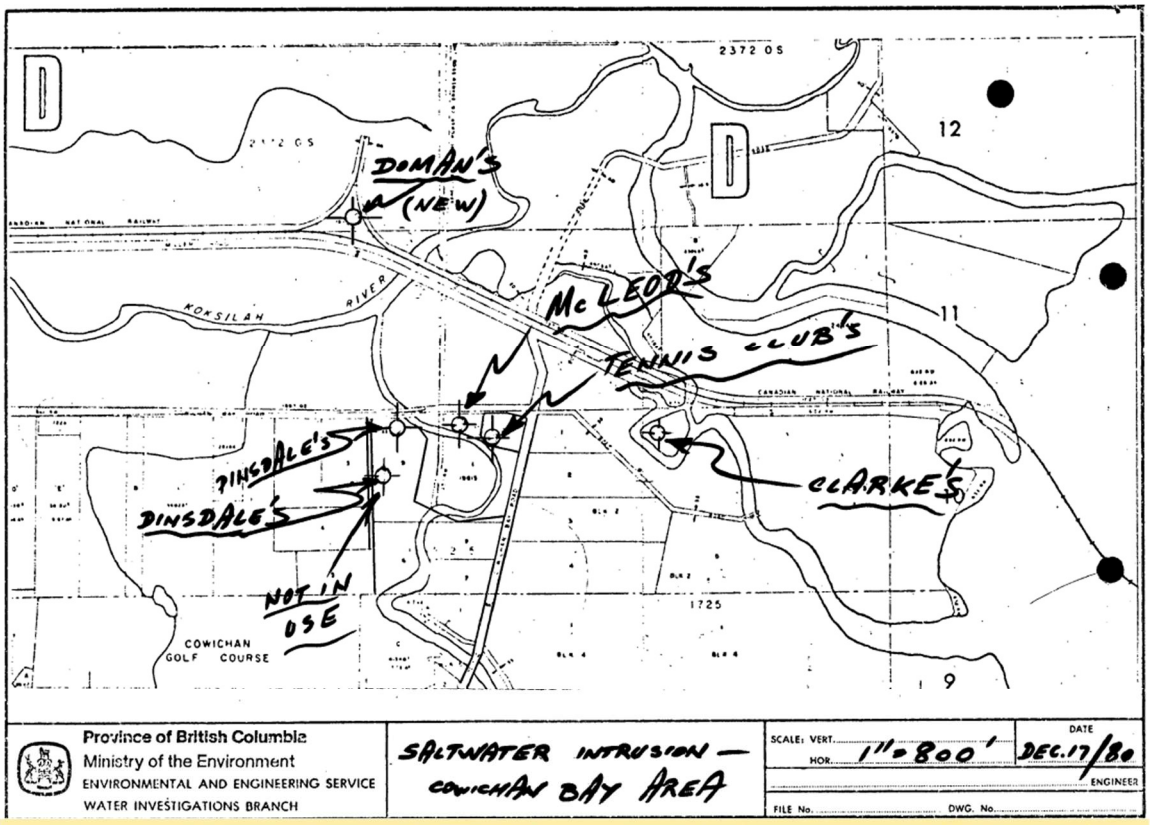
Local scale of the Cowichan Estuary.

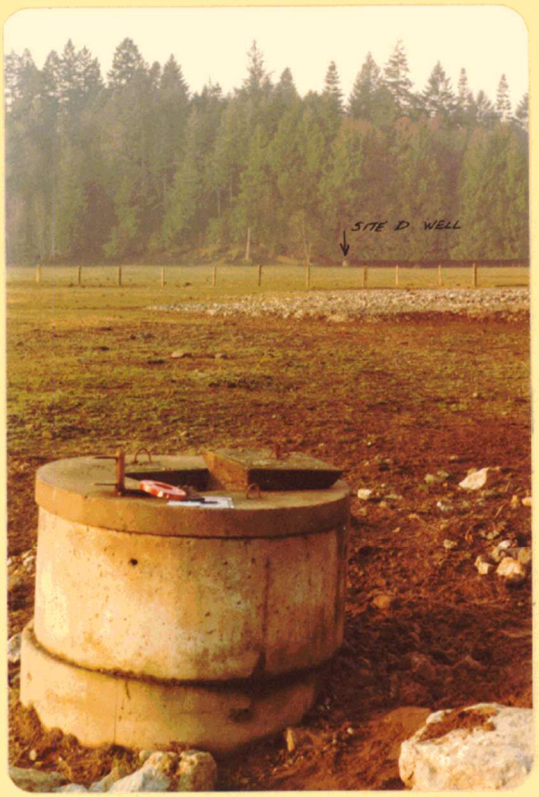
Key Nuggets

Dinsdale Well: specific conductance of 200 micromhos/cm at 10°C and a sodium chloride content of 62.5 mg/l
McLeod Well: specific conductance of 800 micromhos/cm at 20°C and a sodium chloride content of 400 mg/l
South Cowichan Lawn Tennis Club Well: specific conductance of 1130 micromhos/cm at 150°C and a sodium chloride content of 650 mg/l

The Tennis Club is closest to the coastline and reported the highest conductivity values then followed by the McLeod Well and lastly the Dinsdale Well.

A map and photos showing the wells and their locations are found on page 3 and 4 of the memo.





DINSDALE WELL SITE C LOOKING WEST TOWARDS WELL SITE D.



SOUTH COWICHAN LAWN TENNIS CLUB WELL SITE A. WELL 8 m. from CHANNEL LOOKING SOUTH

Report Findings/Conclusions:

Wells closest to the coastline experienced the highest conductivity and sodium chloride values. Concentrations decreased with distance from the coastline.

Report Limitations:

Historical (field) water chemistry is good to know but it won't be able to be used as baseline data.

Report Recommendations:

WWAL Recommendations:

References:

LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Foster, S.B., Allen, D.M., 2015. Results of Coupled Groundwater-Surface Water Model of the Cowichan Valley Watershed. Prepared for BC Ministry of Forests, Lands and Natural Resource Operations and Cowichan Valley Regional District. Final Report June 2015.

Brief Synopsis: What is it about?

The report describes how the Cowichan Watershed Model (CWM) was designed and used to simulate various factors that comprise the hydrological system (including evapotranspiration, GW recharge/discharge, surface water routing, GW/SW interaction, and overland flow).

Relevance to Project: **Yes** or No

How is it Relevant?

Describes how the watershed and aquifers are modelled, but not at a scale that is relevant to our study.

Scale of Study:

Well to aquifer scale

Key Nuggets

- The model was creating using numerical modelling code MIKE SHE, which is a coupled land surface-subsurface code.
- The scale of the study is relatively coarse. Aquifers 186 and 187, located near the estuary, are grouped together for the purpose of this study, and assigned a hydraulic conductivity of 1E-2 m/s. Flow between both of these aquifers is not accounted for in the modelling.
- The report notes that there are several large groundwater users near the estuary, including the Cowichan River Hatchery. The large groundwater users do not appear to be directly on the floodplain.

Report Findings/Conclusions:

- The Cowichan River transitions to losing near the coast where groundwater extraction is focused.
- Climate change is projected to alter temperature and precipitation patterns, with the largest effects being noted on the snow pack. Less snowpack accumulation is projected to occur in the high alpine, with consequent alteration of snowmelt timing, resulting in higher winter and spring river flows and lower summer flows in the Cowichan River.

Report Limitations:

Report Recommendations:

WWAL Recommendations:

References:

LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Kohut, A. P., 1981. Salt Water Intrusion Problem - Cowichan Bay. Unpublished memorandum, Ministry of Environment, Inventory and Engineering Branch, Groundwater Hydrology Section. File 92B13. 6 pp.

Brief Synopsis: What is it about?

The memo summarizes a preliminary investigation on 3 wells (South Cowichan Lawn Tennis Club Well, McLeod Well, and Dinsdale Well) along Cowichan Bay Road after a reported saltwater problem began in the summer of 1980. All three subject wells are shallow dug wells.

Relevance to Project: **Yes** or No

How is it Relevant?

Speaks of historical saltwater intrusion issues in 1980 on three wells that are [likely] within our study area.

Scale of Study:

Local scale of the Cowichan Estuary.

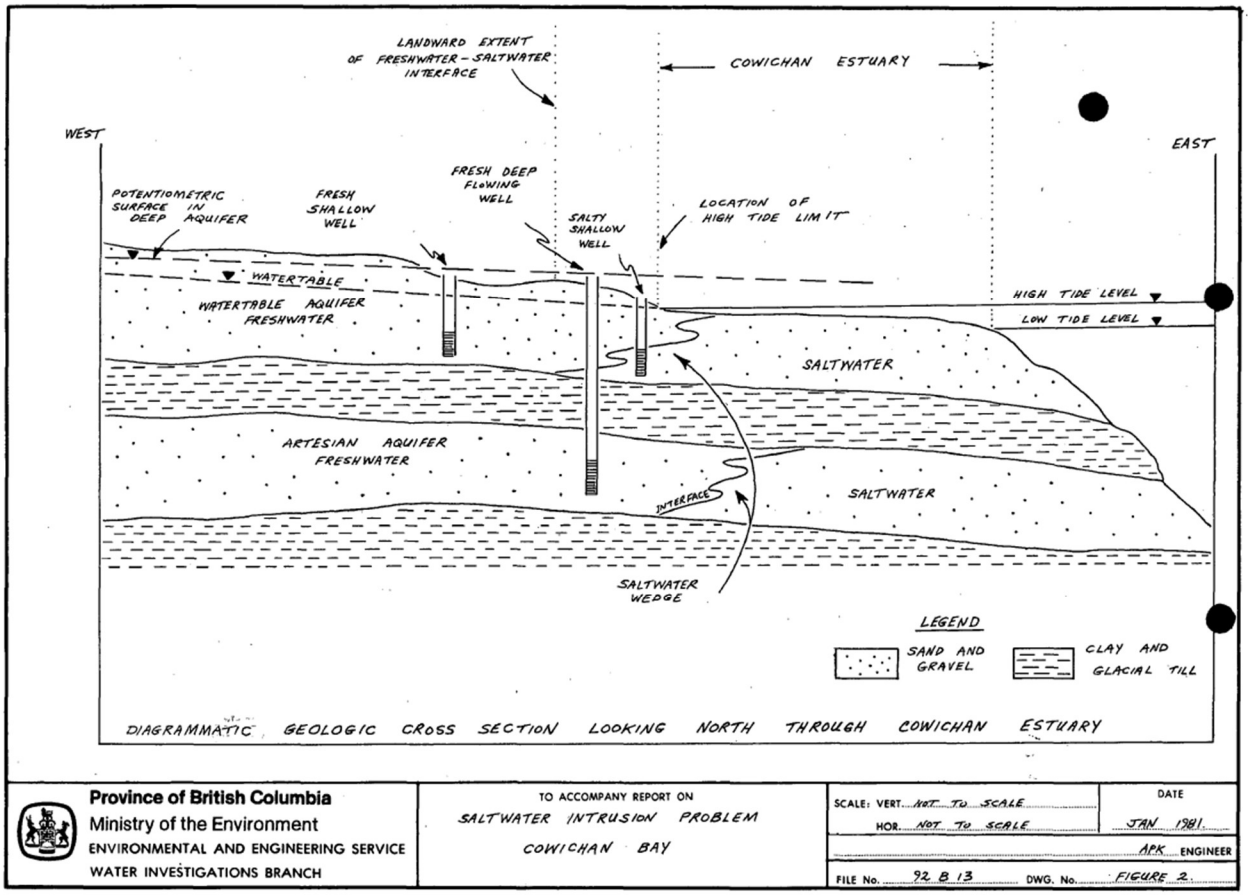
Key Facts and Analyses

South Cowichan Lawn Tennis Club Well: 10 ft deep dug well
McLeod Well: 15 ft deep dug well
Dinsdale Well: 14 ft deep dug well

- All three wells were sampled and field tested for conductivity and chloride by the Ministry of Environment on December 17, 1980.
- All wells showed salinity increasing seawards from the Dinsdale well (Cl: 62.5 mg/L and conductivity: 200 μS/cm) to the Tennis Club well (Cl: 390 mg/L and conductivity: 1130 μS/cm).
- Presence of sea water was evident in the distributary channel (sampled January 13, 1981) opposite the Dinsdale well. Conductivity values of 1200 μS/cm were measured upstream of the Dinsdale well.
- The likely source of increased chloride concentration is due to the well's proximity to the distributary channels, particularly when the wells are pumping.
- Potential causes of deterioration in water quality:
    - Heavy pumping (unlikely in this situation)
    - Reduction in freshwater surface flows (most likely)

- Erosion, sedimentation, dredging and diking of other channels in the estuary (most likely)
- Higher than normal tides and lower than normal river flows (most likely)

Includes a cross section of the wells (page 5).



Report Findings/Conclusions:

- Shallower wells, especially dug wells, have historically seen seawater intrusion impacts due to lower than normal river flows and changes in river morphology due to flooding.

Report Limitations:

It is an older study so the river morphology has likely changed somewhat.
Water quality parameters were from field, not laboratory, analyses.

Report Recommendations:

Recommendations were to do more work or to abandon wells and

- drill deeper wells[1] (150 – 200 ft deep) with an adequate surface casing to enable any artesian flow to be controlled or
- Construct new shallow dug wells but as far west of the distributary channel as possible.

It will be interesting to see if the highest tide model we get from NHC will show seawater occurrences inland of the Dinsdale well as shown in the figure on page 4 of this report.

WWAL Recommendations:

References:

[1] Note the South Cowichan Lawn Tennis Club drilled a 136.5-foot deep well on July 14, 1981.

LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Wei, M., 1985. Groundwater Quality Monitoring and Assessment Program 1985/86 Cowichan-Koksilah Estuary - Fall 1985 Field Survey. Unpublished memorandum, Ministry of Environment, Water Management Branch, Groundwater Section, File 0329563. 55 pp.

Brief Synopsis: What is it about?

This report mostly discusses the field survey completed in Fall 1985. It discussed the three aquifers present at the time the report was written and the distinguishing water chemistry characteristics of the upper and lower aquifers. The extent of the upstream seawater flow in distributaries is discussed as it varies with the tide and stream discharge. Seawater presence upstream was observed to be the highest in later summer during low stream discharge. Conductivity was observed to be low in the fall/winter (November). The report recommends a monitoring plan for the upper and lower aquifers with a focus on the lower aquifer as it is more heavily used.

Relevance to Project: **Yes** or No

How is it Relevant?

It provides a bit of water quality history for the study area and provides a cross-section oriented NE/SW across the floodplain.

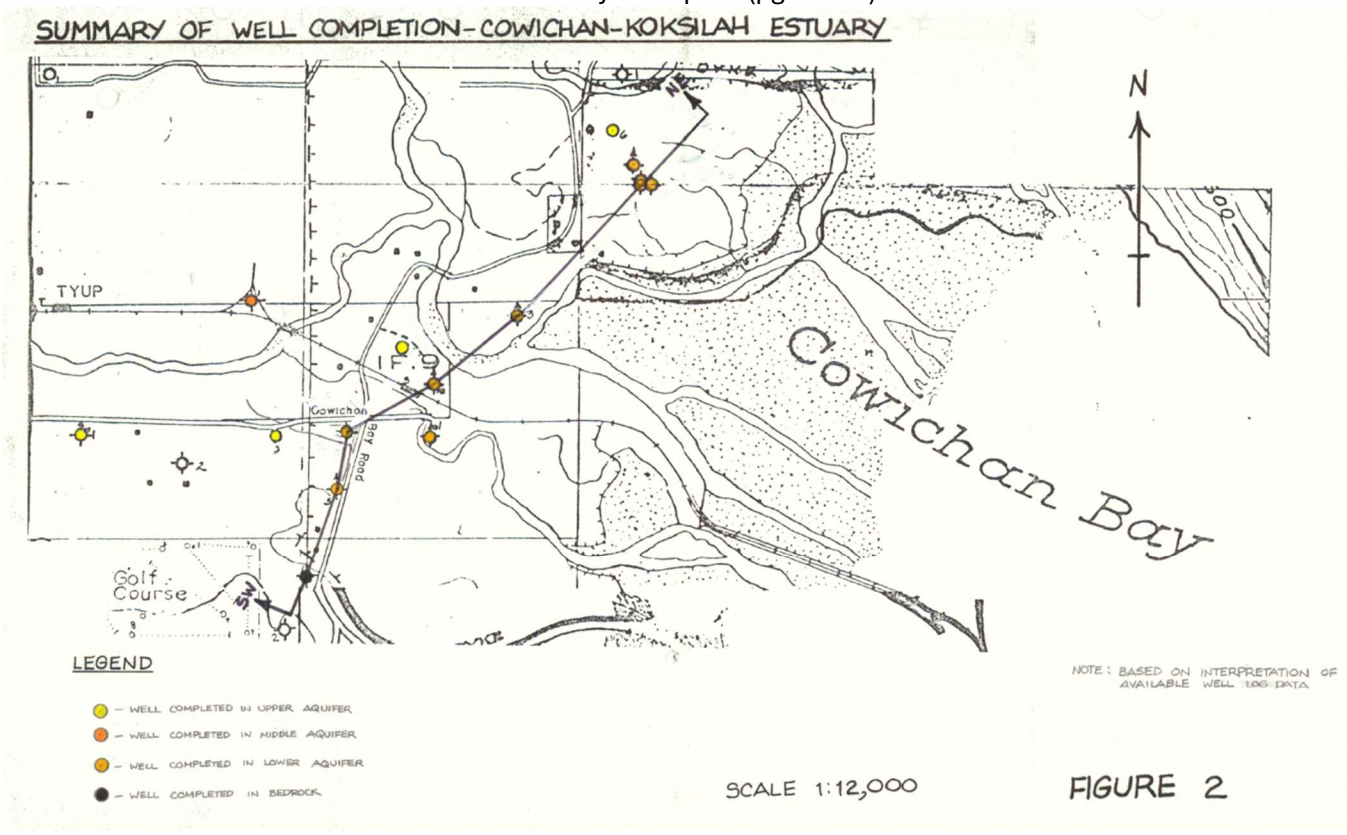
Scale of Study:

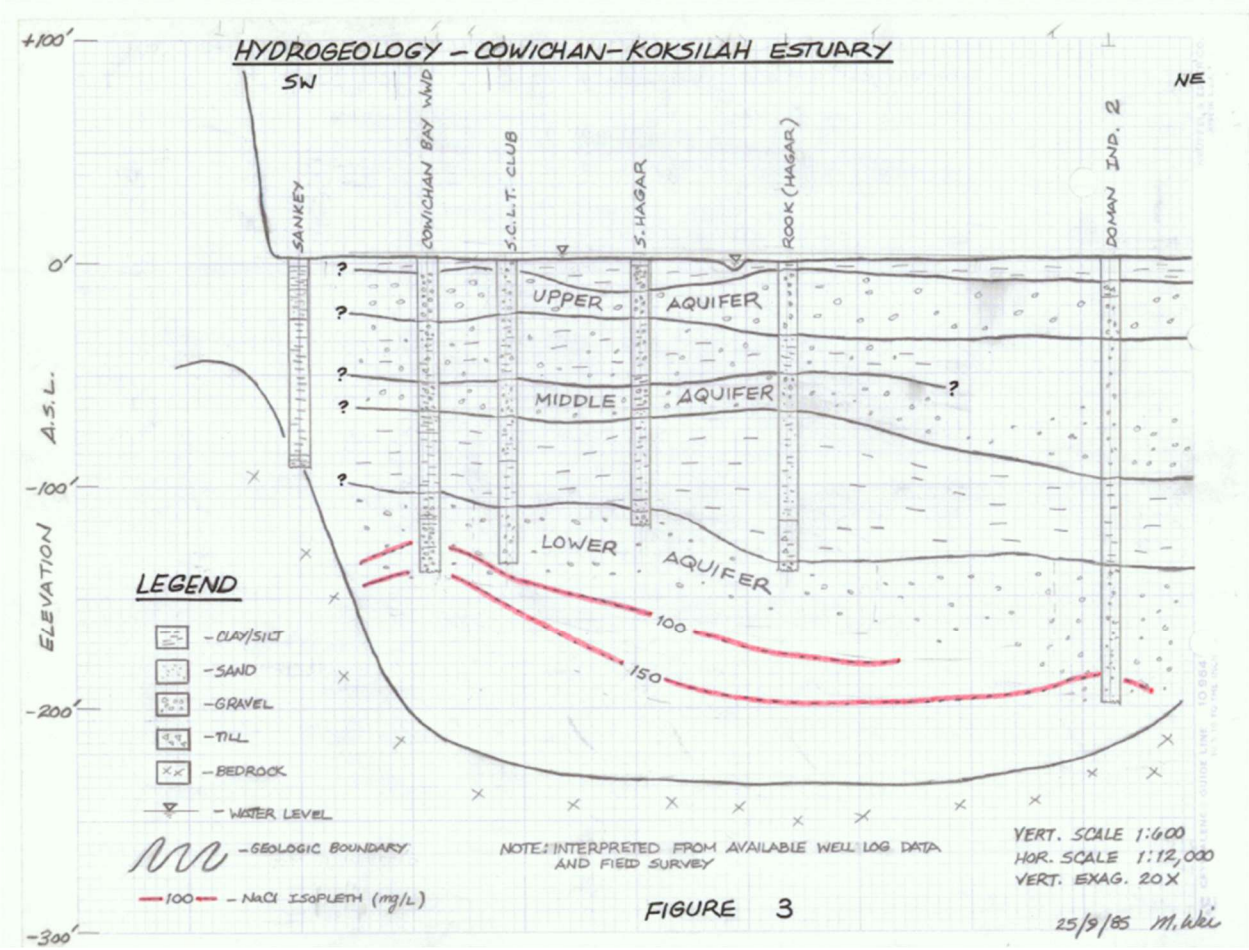
Local scale of the Cowichan Estuary.

Key Nuggets

- Most shallow wells have been reported abandoned due to poor water quality or limited yield.
- Wells on indigenous land have been replaced by city water EXCEPT for the Blackeley Well (upper aquifer)
- the extent of upstream seawater flow in distributary channels varies with the tide and stream discharge.
    - Greatest seawater presence upstream during high tides in late summer and low stream discharge
- Most site shows low conductivity values in fall/winter (November)
- It is noted that the freshwater-saltwater interface appears to be moving inland whereas it appears to be constant in other areas (near Doman Mill)

- Cross section oriented NE/SW in Cowichan Estuary Floodplain (pg. 48-49)



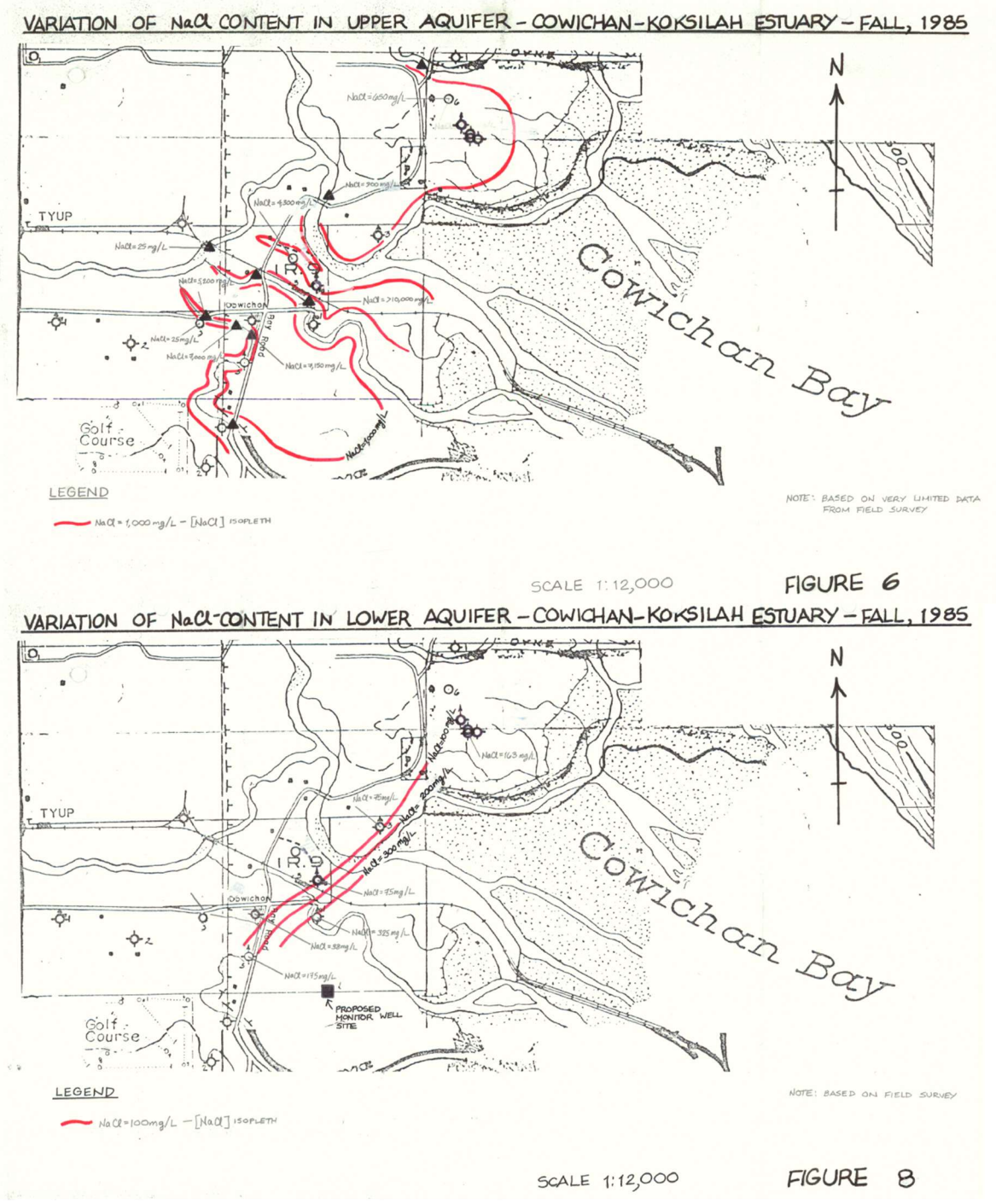


Report Findings/Conclusions:

Groundwater in upper, mid (not present any longer) and lower aquifers can be distinguished by water chemistry:

- River surface water: Sodium chloride (NaCl) concentrations ~ 75 mg/L
- Upper aquifer – lower pH ~ 6 to 6.5
- Mid to lower aquifer – pH ~ 8.5 – 9.5 with a sulphur smell – hydrogen sulphide presence

See figures 6 and 8 for variation of NaCl in upper and lower aquifers. Note Wei (1985)'s interpretation (influenced by conceptual understanding in Kohut (1981)) that the NaCl concentration (and seawater-freshwater interface) in the upper aquifer (Aquifer 186) is heavily influenced by presence of seawater in the distributary channels. Conversely, the NaCl concentration in the lower aquifer (Aquifer 188) is not influenced by the distributary channels.



Recommends a monitoring plan for the upper aquifer and the lower aquifer. The recommended monitoring focuses on the lower aquifer since it is more heavily used.

Report Limitations:

The NaCl concentration contours were based on limited water chemistry data.

Report Recommendations:

WWAL Recommendations:

References:

LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Zimmerman, R., 1989. Water Chemistry Differences of the Upper and Lower Aquifers near the Cowichan-Koksilah Estuary. Unpublished memorandum, Ministry of Environment, Water Management Branch, Groundwater Section. 27 pp.

Brief Synopsis: What is it about?

Presents Piper Plots for groundwater chemistry for 9 wells located in the Cowichan Bay estuary, and interprets difference in chemistry between the upper and lower aquifers, and spatial evolution of chemistry for the lower aquifer.

Relevance to Project: **Yes** or No

How is it Relevant?

Water Quality

Scale of Study:

Well to Aquifer scale

Key Nuggets

Findings that are of direct benefit to current project.

Report Findings/Conclusions:

The author uses piper plots to classify and compare groundwater chemistry from samples collected from 10 wells completed in the upper, middle, and lower unconsolidated aquifers within Cowichan Bay. The report has the following findings:

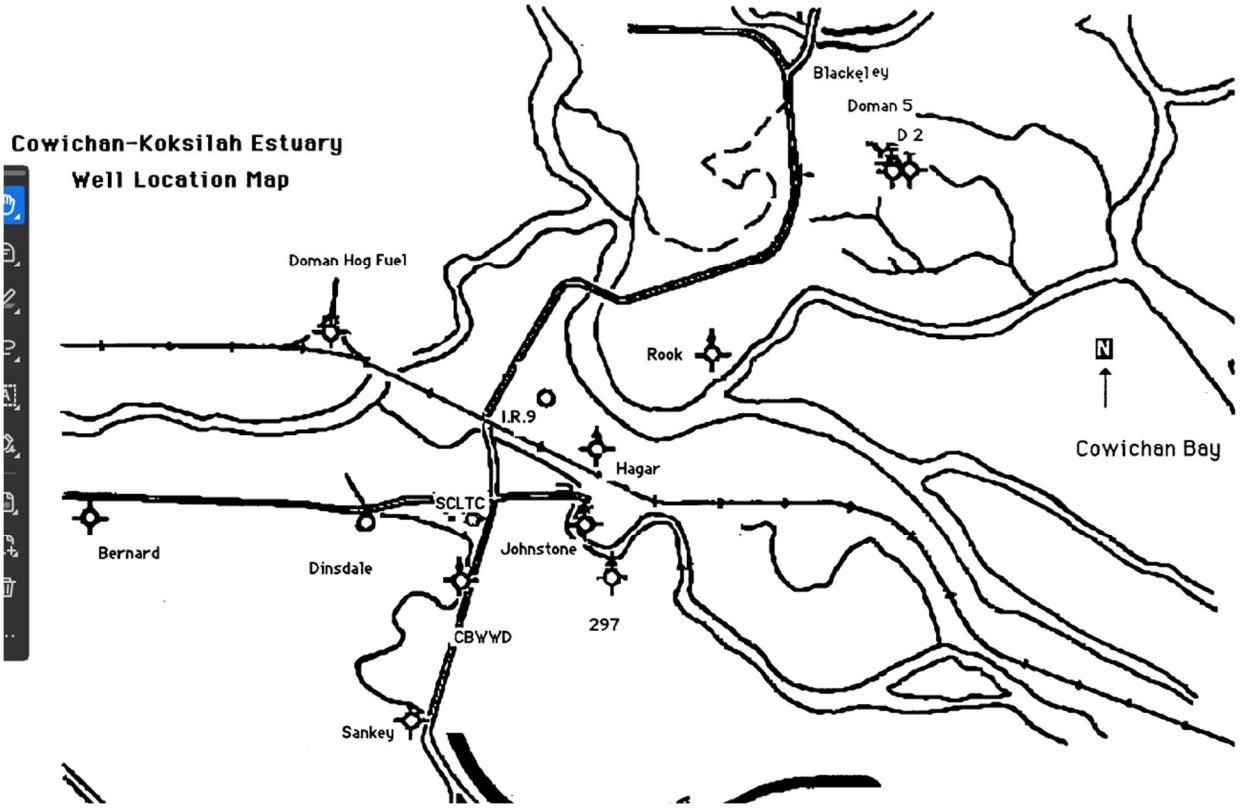
- Conductivity and hardness in estuary aquifers are proportional to NaCl concentrations. Groundwater from bedrock aquifer can be distinguished from estuary aquifers based on high total alkalinity, and high conductivity despite low NaCl content

- Groundwater from the upper aquifer (Aquifer 186) can be distinguished from middle and lower aquifer (Aquifer 188) by lower pH (6 to 6.5 vs 8.5 to 9.4), and odour (lower aquifer has rotten egg odor possibly due to presence of hydrogen sulphide).

- Groundwater samples produced from wells completed in the lower aquifer increase in salinity based on proximity to the coast and the volume of water pumped from the aquifer.

- Groundwater chemistry in the lower aquifer evolves from being dominated by alkaline earths (Ca and Mg) and weak acids (secondary alkalinity) (HCO_3) to being dominated by alkalies (Na) and strong acids (primary salinity) (i.e., HCl) (as groundwater moves downstream towards the coast).

- Groundwater from the upper and lower aquifers is occurring in the estuary area of the Cowichan and Koksilah watersheds.



Well	EMS ID	Aquifer	Groundwater classification type
Blackely Well	E206486	Upper	Sodium-Chloride-Bicarbonate
CBWWD Well	E206484	Lower	Sodium-Chloride-Bicarbonate
Doman 2 Well	E1400132	Lower	Sodium-Chloride-Bicarbonate
Doman's Hog Fuel Well	E206487	Middle	Magnesium-Calcium-Bicarbonate
Hagar Well	E206485	Lower	Sodium-Magnesium-Chloride-Bicarbonate
Johnstone Well	E206488	Lower	Sodium-Magnesium-Chloride
Observation Well 297	E206919	Lower	Sodium-Magnesium-Calcium-Bicarbonate-Chloride
Rook Well	E206479	Lower	Sodium-Magnesium-Chloride-Bicarbonate
SCL/TC Well	E206483	Lower	Calcium-Sodium-Magnesium-Bicarbonate-Chloride

Report Limitations:

N/A

Report Recommendations:

N/A

WWAL Recommendations:

- Correlate the wells in the table above to GWELLs
- Review the EMS for each well in the above table to see if there have been any additional samples collected at these locations since 1989.

References:

LITERATURE REVIEW SUMMARIES

Note: references listed are for referenced material in the literature review summary. An extensive list of references can be found in the applicable document.

Report Citation:

Zubel, M. 1978. Cowichan Estuary Task Force – Preliminary Groundwater Study. Memorandum to A.P. Kohut, March 16, 1978.

Brief Synopsis: What is it about?

This report is a preliminary review of available groundwater reports, existing well data from the groundwater section files, geological reports, aerial photos and 1-day site visit. An approximate transmissivity value (620-2484 m^2/d) was calculated for the lower aquifer based on a pumping test completed in one of the Doman Industry wells. It also is a preliminary hydrogeological assessment completed on the Cowichan Bay aquifers.

Relevance to Project: **Yes** or No

How is it Relevant?

Groundwater
water quality
Source protection
Transmissivity value for the lower aquifer
Detailed Cross-Sections oriented NE/SW

Scale of Study:

Well-scale, aquifer scale

Key Nuggets

- Preliminary background on water quality monitoring program objectives
- Preliminary background on environment of deposition and hydrogeological setting

Report Findings/Conclusions:

The author identifies three aquifers (upper, middle, and lower) within the Cowichan Bay estuary, and describes a preliminary hydrogeological conceptual model for the site.

Description and estimated yields of the upper, middle (non-existent anymore?) and lower aquifers (Yield are from individual wells and may not be accurately represented).

- Upper: 100 US gpm
- Middle: 400 US gpm
- Lower: up to 1,500 US gpm

Aquifer Productivity:

- Lower confined aquifer is most productive, capable of supplying yield of 1500 USgpm (well no. X3-Y13-3) (Doman Industries wells). From pumping test data, the transmissivity was calculated to be approximately 50,000 to 200,000 USgpd/ft. Source of recharge is likely the Cowichan River.
- Middle confined aquifer is 50 ft thick, capable of providing up to 400 USgpm (well no. X1-Y11-2).
- Upper unconfined aquifer is capable of supplying 100 USgpm (well no. X3-Y12-1).
- Transmissivity of upper (possibly middle aquifer as well, report is not specific) is 26,000 to 900,000 USgpd/ft.
- Upper and middle aquifers are hydraulically connected to Cowichan River.
- Artesian wells are present in the area, and the author infers that aquifers in the estuary are recharged at higher elevations, possibly upstream along the Cowichan Valley near Duncan.

Water quality:

- Moderately soft and low in mineralization
- Salty water in the area occur in wells X12-Y14-1,2 drilled into fractured bedrock. Drilling of the Doman Industries wells (X3-Y13-2,3,4,5) indicate salt water was encountered in the first 80 ft of drilling. Water quality tests performed on well no. X3-Y13-3 (Doman Industries Well) in 1975 and 1978 indicated chloride content was 71.6 mg/L and 106 mg/L, respectively. The author infers that chloride concentrations have increased over this period.

TABLE 1

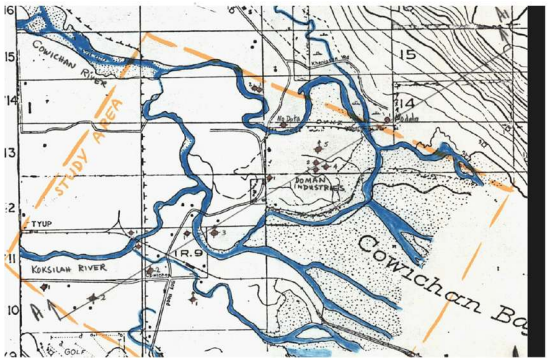
SUMMARY OF WELL CARD DATA FOR STUDY AREA

LOCATION	WELL NO.	YIELD (gpm)	DEPTH OF HOLE (ft.)	AQUIFER MATERIAL[1]	DEPTH TO WATER (ft.)[2]	WATER QUALITY DATA[3]			
						Fe	Cl	$CaCO_3$	pH
X1-Y10	1	6	59	S+G	0				
	2	15	66	S+G	49				
X1-Y11	1	35	26	G(SILTY)	6				
	2	400	43	S+G	6.7				
X2-Y10	1	396	160	S+G	+6 (F)	<0.5	45	86	7.9
X2-Y11	1	10	26	S+G	9				
	2	?	23	S+G	7	<0.5	15	34	6.5
	3	40	139	S+G	+6 (F)				
X2-Y14	1	10	200	SST	?	Fresh at 167 ft., salty at 200'.			
	2	2	100	SST	?	Salty.			
X3-Y12	1	100	21.5	S+G	2-6				
X3-Y13	2	35	200	S+G+C	6	10.4	105	45	8.3
	3	1,500	160	S+G	2	0.2	72	39	8.0
	4	1,500	166	S+G	5				
	5	135	146	S+G	+5 (F)	0.1	75	40	8.5

[1]Aquifer Material: S = SAND, G = GRAVEL, C = CLAY.

[2]Depth to Water: With respect to ground, (F) = flowing well.

[3]Water Quality: Fe, Cl, $CaCO_3$ figures in mg/L.



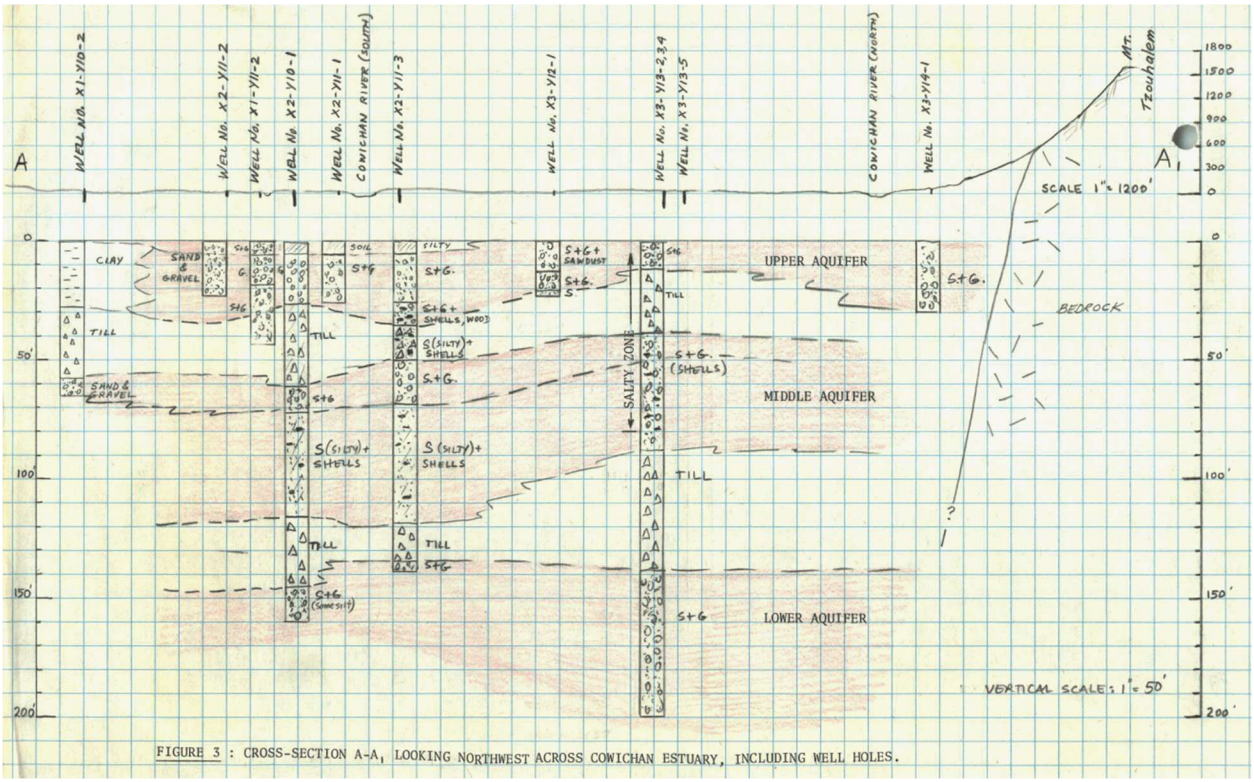


FIGURE 3 : CROSS-SECTION A-A, LOOKING NORTHWEST ACROSS COWICHAN ESTUARY, INCLUDING WELL HOLES.

Report Limitations:

-

Report Recommendations:

-

WWAL Recommendations:

-

References:

-

Appendix C

Caro Analytical Services

Water Quality Results

Nature Trust of British Columbia
Cowichan Estuary Restoration Seawater Intrusion Assessment
WWALL Ref: 25-050-01VC

CERTIFICATE OF ANALYSIS

REPORTED TO	Western Water Associates Ltd. (Victoria) 301-1095 McKenzie Ave. Victoria, BC V8P 2L5		
ATTENTION	Jackie Van der Vlugt	**WORK ORDER**	25F1068
PO NUMBER		**RECEIVED / TEMP**	2025-06-06 11:58 / 11.3°C
PROJECT	25-050-01VC	**REPORTED**	2025-06-12 10:00
PROJECT INFO		**COC NUMBER**	No COC #

Introduction:

CARO Analytical Services is a testing laboratory full of smart, engaged scientists driven to make the world a safer and healthier place. Through our clients' projects we become an essential element for a better world. We employ methods conducted in accordance with recognized professional standards using accepted testing methodologies and quality control efforts. CARO is accredited by the Canadian Association for Laboratories Accreditation (CALA) to ISO/IEC 17025:2017 for specific tests listed in the scope of accreditation approved by CALA.

Big Picture Sidekicks

You know that the sample you collected after snowshoeing to site, digging 5 meters, and racing to get it on a plane so you can submit it to the lab for time sensitive results needed to make important and expensive decisions (whew) is VERY important. We know that too.

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It's simple. We figure the more you enjoy working with our fun and engaged team members; the more likely you are to give us continued opportunities to support you.

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If you have any questions or concerns, please contact me at bwhitehead@caro.ca

Authorized By:

Brent Whitehead
Account Manager

TEST RESULTS

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F1068
PROJECT	25-050-01VC	**REPORTED**	2025-06-12 10:00

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
56954 (25F1068-01) | Matrix: Water | Sampled: 2025-06-05 09:24						
Anions						
Chloride	**43.4**	AO ≤ 250	0.10	mg/L	2025-06-10	
General Parameters						
Conductivity (EC)	**282**	N/A	2.0	µS/cm	2025-06-10	
Solids, Total Dissolved	**135**	AO ≤ 500	10	mg/L	2025-06-10	

APPENDIX 1: SUPPORTING INFORMATION

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F1068
PROJECT	25-050-01VC	**REPORTED**	2025-06-12 10:00

Analysis Description	Method Ref.	Technique	Accredited	Location
Anions in Water	SM 4110 B (2020)	Ion Chromatography	✓	Richmond
Conductivity in Water	SM 2510 B (2021)	Conductivity Meter	✓	Richmond
Solids, Total Dissolved in Water	SM 2540 C* (2020)	Gravimetry (Dried at 103-105C)		Richmond

Note: An asterisk in the Method Reference indicates that the CARO method has been modified from the reference method

Glossary of Terms:

RL	Reporting Limit (default)
AO	Aesthetic Objective
mg/L	Milligrams per litre
µS/cm	Microsiemens per centimetre
SM	Standard Methods for the Examination of Water and Wastewater, American Public Health Association

Guidelines Referenced in this Report:

Guidelines for Canadian Drinking Water Quality (Health Canada, September 2022)

Note: In some cases, the values displayed on the report represent the lowest guideline and are to be verified by the end user

General Comments:

The results in this report apply to the received samples analyzed in accordance with the Chain of Custody document. This analytical report must be reproduced in its entirety. CARO is not responsible for any loss or damage resulting directly or indirectly from error or omission in the conduct of testing. Liability is limited to the cost of analysis. Caro will dispose of all samples within 30 days of sample receipt, unless otherwise agreed.

Results in **Bold** indicate values that are above CARO's method reporting limits. Any results that are above regulatory limits are highlighted **red**. Please note that results will only be highlighted red if the regulatory limits are included on the CARO report. Any Bold and/or highlighted results do not take into account method uncertainty. If you would like method uncertainty or regulatory limits to be included on your report, please contact your Account Manager:bwhitehead@caro.ca

Please note any regulatory guidelines applied to this report are added as a convenience to the client, at their request, to help provide some initial context to analytical results obtained. Although CARO makes every effort to ensure accuracy of the associated regulatory guideline(s) applied, the guidelines applied cannot be assumed to be correct due to a variety of factors and as such CARO Analytical Services assumes no liability or responsibility for the use of those guidelines to make any decisions. The original source of the regulation should be verified and a review of the guideline(s) should be validated as correct in order to make any decisions arising from the comparison of the analytical data obtained to the relevant regulatory guideline for one's particular circumstances. Further, CARO Analytical Services assumes no liability or responsibility for any loss attributed from the use of these guidelines in any way.

APPENDIX 2: QUALITY CONTROL RESULTS

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F1068
PROJECT	25-050-01VC	**REPORTED**	2025-06-12 10:00

The following section displays the quality control (QC) data that is associated with your sample data. Groups of samples are prepared in "batches" and analyzed in conjunction with QC samples that ensure your data is of the highest quality. Common QC types include:

- **Method Blank (Blk)**: A blank sample that undergoes sample processing identical to that carried out for the test samples. Method blank results are used to assess contamination from the laboratory environment and reagents.
- **Duplicate (Dup)**: An additional or second portion of a randomly selected sample in the analytical run carried through the entire analytical process. Duplicates provide a measure of the analytical method's precision (reproducibility).
- **Blank Spike (BS)**: A sample of known concentration which undergoes processing identical to that carried out for test samples, also referred to as a laboratory control sample (LCS). Blank spikes provide a measure of the analytical method's accuracy.
- **Matrix Spike (MS)**: A second aliquot of sample is fortified with a known concentration of target analytes and carried through the entire analytical process. Matrix spikes evaluate potential matrix effects that may affect the analyte recovery.
- **Reference Material (SRM)**: A homogenous material of similar matrix to the samples, certified for the parameter(s) listed. Reference Materials ensure that the analytical process is adequate to achieve acceptable recoveries of the parameter(s) tested.

Each QC type is analyzed at a 5-10% frequency, i.e. one blank/duplicate/spike for every 10-20 samples. For all types of QC, the specified recovery (% Rec) and relative percent difference (RPD) limits are derived from long-term method performance averages and/or prescribed by the reference method.

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
Anions, Batch B5F2739										
Blank (B5F2739-BLK1)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Chloride	< 0.10	0.10	mg/L							
Blank (B5F2739-BLK2)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Chloride	< 0.10	0.10	mg/L							
LCS (B5F2739-BS1)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Chloride	2.78	0.10	mg/L	3.00		93	85-115			
LCS (B5F2739-BS2)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Chloride	2.80	0.10	mg/L	3.00		93	85-115			
Duplicate (B5F2739-DUP2)		**Source: 25F1068-01**		Prepared: 2025-06-10, Analyzed: 2025-06-10						
Chloride	42.8	0.10	mg/L		43.4			1	20	
General Parameters, Batch B5F2862										
Reference (B5F2862-SRM1)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Conductivity (EC)	48.3	2.0	µS/cm	50.0		97	90-110			
General Parameters, Batch B5F2869										
Blank (B5F2869-BLK1)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Solids, Total Dissolved	< 10	10	mg/L							
Blank (B5F2869-BLK2)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Solids, Total Dissolved	< 10	10	mg/L							BLK
LCS (B5F2869-BS1)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Solids, Total Dissolved	225	10	mg/L	200		112	85-115			
LCS (B5F2869-BS2)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Solids, Total Dissolved	28	10	mg/L	50.2		55	85-115			SPK1
LCS (B5F2869-BS3)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Solids, Total Dissolved	205	10	mg/L	200		102	85-115			

APPENDIX 2: QUALITY CONTROL RESULTS

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F1068
PROJECT	25-050-01VC	**REPORTED**	2025-06-12 10:00

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
General Parameters, Batch B5F2869, Continued										
LCS (B5F2869-BS4)				Prepared: 2025-06-10, Analyzed: 2025-06-10						
Solids, Total Dissolved	55	10	mg/L	50.2		110	85-115			
Duplicate (B5F2869-DUP2)			**Source: 25F1068-01**	Prepared: 2025-06-10, Analyzed: 2025-06-10						
Solids, Total Dissolved	158	10	mg/L		135			15	20	

QC Qualifiers:

BLK Analyte concentration in the Method Blank is above the Reporting Limit (RL).

SPK1 The recovery of this analyte was outside of established control limits. The data was accepted based on performance of other batch QC.

CERTIFICATE OF ANALYSIS

REPORTED TO	Western Water Associates Ltd. (Victoria) 301-1095 McKenzie Ave. Victoria, BC V8P 2L5		
ATTENTION	Jackie Van der Vlugt	**WORK ORDER**	25F2618
PO NUMBER		**RECEIVED / TEMP**	2025-06-18 13:06 / 12.1°C
PROJECT	25-050-01VC	**REPORTED**	2025-06-25 11:27
PROJECT INFO		**COC NUMBER**	NO#

Introduction:

CARO Analytical Services is a testing laboratory full of smart, engaged scientists driven to make the world a safer and healthier place. Through our clients' projects we become an essential element for a better world. We employ methods conducted in accordance with recognized professional standards using accepted testing methodologies and quality control efforts. CARO is accredited by the Canadian Association for Laboratories Accreditation (CALA) to ISO/IEC 17025:2017 for specific tests listed in the scope of accreditation approved by CALA.

Big Picture Sidekicks

You know that the sample you collected after snowshoeing to site, digging 5 meters, and racing to get it on a plane so you can submit it to the lab for time sensitive results needed to make important and expensive decisions (whew) is VERY important. We know that too.

We've Got Chemistry

It's simple. We figure the more you enjoy working with our fun and engaged team members; the more likely you are to give us continued opportunities to support you.

Ahead of the Curve

Through research, regulation knowledge, and instrumentation, we are your analytical centre for the technical knowledge you need, BEFORE you need it, so you can stay up to date and in the know.

By engaging our services, you are agreeing to CARO Analytical Service's Standard Terms and Conditions outlined here: https://www.caro.ca/terms-conditions

If you have any questions or concerns, please contact me at efex@caro.ca

Authorized By:

Echo Fex
Junior Account Manager

TEST RESULTS

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F2618
PROJECT	25-050-01VC	**REPORTED**	2025-06-25 11:27

Analyte	Result	Guideline	RL	Units	Analyzed	Qualifier
Mclead Well (25F2618-01) | Matrix: Water | Sampled: 2025-06-17 09:55						
Anions						
Chloride	**21.8**	AO ≤ 250	0.10	mg/L	2025-06-19	
General Parameters						
Conductivity (EC)	**200**	N/A	2.0	µS/cm	2025-06-24	
Solids, Total Dissolved	**125**	AO ≤ 500	10	mg/L	2025-06-19	
Tennis Club WTN 48582 (25F2618-02) | Matrix: Water | Sampled: 2025-06-17 09:27						
Anions						
Chloride	**13.6**	AO ≤ 250	0.10	mg/L	2025-06-19	
General Parameters						
Conductivity (EC)	**173**	N/A	2.0	µS/cm	2025-06-24	
Solids, Total Dissolved	**112**	AO ≤ 500	10	mg/L	2025-06-19	
WTN 54536 (25F2618-03) | Matrix: Water | Sampled: 2025-06-17 10:57						
Anions						
Chloride	**42.5**	AO ≤ 250	0.10	mg/L	2025-06-19	
General Parameters						
Conductivity (EC)	**288**	N/A	2.0	µS/cm	2025-06-24	
Solids, Total Dissolved	**182**	AO ≤ 500	10	mg/L	2025-06-19	

APPENDIX 1: SUPPORTING INFORMATION

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F2618
PROJECT	25-050-01VC	**REPORTED**	2025-06-25 11:27

Analysis Description	Method Ref.	Technique	Accredited	Location
Anions in Water	SM 4110 B (2020)	Ion Chromatography	✓	Richmond
Conductivity in Water	SM 2510 B (2021)	Conductivity Meter	✓	Richmond
Solids, Total Dissolved in Water	SM 2540 C* (2020)	Gravimetry (Dried at 103-105C)		Richmond

Note: An asterisk in the Method Reference indicates that the CARO method has been modified from the reference method

Glossary of Terms:

RL	Reporting Limit (default)
AO	Aesthetic Objective
mg/L	Milligrams per litre
µS/cm	Microsiemens per centimetre
SM	Standard Methods for the Examination of Water and Wastewater, American Public Health Association

Guidelines Referenced in this Report:

Guidelines for Canadian Drinking Water Quality (Health Canada, September 2022)

Note: In some cases, the values displayed on the report represent the lowest guideline and are to be verified by the end user

General Comments:

The results in this report apply to samples received by CARO and analyzed in accordance with the Chain of Custody document. This analytical report must be reproduced in its entirety and must not be modified. CARO is not responsible for losses or damages resulting directly or indirectly from errors or omissions in the conduct of the testing. Any liability is limited to the cost of analysis. CARO will dispose of all samples within 30 days of sample receipt, unless otherwise agreed.

Results in **Bold** indicate values that are above CARO's method reporting limits. Results in **red** indicate values above the regulatory limits where these have been included. Any Bold and/or highlighted results do not take into account method uncertainty. If you would like method uncertainty or regulatory limits to be included on your report, please contact your Account Manager: efex@caro.ca

Regulatory limits are added to test reports on request and are as a convenience only. While CARO makes every effort to ensure accuracy of regulatory limits, CARO assumes no liability for the use of this information. It remains the client's responsibility to ensure that regulatory limits are correct for their circumstances.

APPENDIX 2: QUALITY CONTROL RESULTS

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F2618
PROJECT	25-050-01VC	**REPORTED**	2025-06-25 11:27

The following section displays the quality control (QC) data that is associated with your sample data. Groups of samples are prepared in "batches" and analyzed in conjunction with QC samples that ensure your data is of the highest quality. Common QC types include:

- **Method Blank (Blk)**: A blank sample that undergoes sample processing identical to that carried out for the test samples. Method blank results are used to assess contamination from the laboratory environment and reagents.
- **Duplicate (Dup)**: An additional or second portion of a randomly selected sample in the analytical run carried through the entire analytical process. Duplicates provide a measure of the analytical method's precision (reproducibility).
- **Blank Spike (BS)**: A sample of known concentration which undergoes processing identical to that carried out for test samples, also referred to as a laboratory control sample (LCS). Blank spikes provide a measure of the analytical method's accuracy.
- **Matrix Spike (MS)**: A second aliquot of sample is fortified with a known concentration of target analytes and carried through the entire analytical process. Matrix spikes evaluate potential matrix effects that may affect the analyte recovery.
- **Reference Material (SRM)**: A homogenous material of similar matrix to the samples, certified for the parameter(s) listed. Reference Materials ensure that the analytical process is adequate to achieve acceptable recoveries of the parameter(s) tested.

Each QC type is analyzed at a 5-10% frequency, i.e. one blank/duplicate/spike for every 10-20 samples. For all types of QC, the specified recovery (% Rec) and relative percent difference (RPD) limits are derived from long-term method performance averages and/or prescribed by the reference method.

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
Anions, Batch B5F3924										
Blank (B5F3924-BLK1)				Prepared: 2025-06-19, Analyzed: 2025-06-19						
Chloride	< 0.10	0.10	mg/L							
Blank (B5F3924-BLK2)				Prepared: 2025-06-19, Analyzed: 2025-06-19						
Chloride	< 0.10	0.10	mg/L							
LCS (B5F3924-BS1)				Prepared: 2025-06-19, Analyzed: 2025-06-19						
Chloride	3.35	0.10	mg/L	3.00		112	85-115			
LCS (B5F3924-BS2)				Prepared: 2025-06-19, Analyzed: 2025-06-19						
Chloride	3.40	0.10	mg/L	3.00		113	85-115			
Duplicate (B5F3924-DUP2)		**Source: 25F2618-02**		Prepared: 2025-06-19, Analyzed: 2025-06-19						
Chloride	13.4	0.10	mg/L		13.6			2	20	
Matrix Spike (B5F3924-MS2)		**Source: 25F2618-02**		Prepared: 2025-06-19, Analyzed: 2025-06-19						
Chloride	16.9	0.10	mg/L	3.00	13.6	109	75-125			
General Parameters, Batch B5F4086										
Blank (B5F4086-BLK1)				Prepared: 2025-06-19, Analyzed: 2025-06-19						
Solids, Total Dissolved	18	10	mg/L							BLK
LCS (B5F4086-BS1)				Prepared: 2025-06-19, Analyzed: 2025-06-19						
Solids, Total Dissolved	55	10	mg/L	50.2		110	85-115			
LCS (B5F4086-BS2)				Prepared: 2025-06-19, Analyzed: 2025-06-19						
Solids, Total Dissolved	220	10	mg/L	200		110	85-115			
General Parameters, Batch B5F4574										
Blank (B5F4574-BLK1)				Prepared: 2025-06-24, Analyzed: 2025-06-24						
Conductivity (EC)	< 2.0	2.0	µS/cm							
Duplicate (B5F4574-DUP1)		**Source: 25F2618-01**		Prepared: 2025-06-24, Analyzed: 2025-06-24						
Conductivity (EC)	196	2.0	µS/cm		200			2	4	

APPENDIX 2: QUALITY CONTROL RESULTS

REPORTED TO	Western Water Associates Ltd. (Victoria)	**WORK ORDER**	25F2618
PROJECT	25-050-01VC	**REPORTED**	2025-06-25 11:27

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
General Parameters, Batch B5F4574, Continued										
Reference (B5F4574-SRM1)				Prepared: 2025-06-24, Analyzed: 2025-06-24						
Conductivity (EC)	48.8	2.0	µS/cm	50.0		98	80-120			

QC Qualifiers:

BLK Analyte concentration in the Method Blank is above the Reporting Limit (RL).