Water Quality and Quantity Risk Assessment for RDN Electoral Area F

Prepared for:

Regional District of Nanaimo

Prepared by:

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Executive Summary

GW Solutions has been retained by the Regional District of Nanaimo (RDN) to complete a water quality/ quantity risk assessment for groundwater and surface water resources within the RDN Electoral Area F (Area F) in support of the RDN Area F Official Community Plan (OCP) update. In order to characterize the issues and risks associated with both water quality and quantity the following objectives were addressed:

Water quantity:

- Gather, review and integrate information, including topography, geology, soils, streamflow and surface water levels within the study watersheds, and wells, groundwater levels, mapped aquifers; and
- Identify the concerns for surface water flows, groundwater levels, aquifers, and surface water and groundwater interaction.

Water quality:

- Gather, clean, standardize and integrate available water quality data for surface water and groundwater;
- Analyze the spatial and temporal evolution of water quality, and exceedances when compared to water quality guidelines;
- Characterize the existing and potential hazards and threats to water quality; and
- Evaluate the vulnerability of water resources.

The study area includes the RDN Electoral Area F and significant portions of three water regions: WR2- Little Qualicum, WR3- French Creek and WR4- Englishman River. This includes the following watersheds: Little Qualicum River, Grandon Creek, French Creek, Morningstar Creek, Englishman River, and Carey Creek.

The RDN Area F relies strongly on groundwater as the main water supply as shown by the available information including service areas, water wells, and water supply systems. Additionally, there is surface water usage in the area from licensed Points of Diversion (PODs) for purposes such as domestic, irrigation, industrial, commercial, and institutional use and water supply systems.

From 2011 to 2016 the population has grown within Area F at a rate of 4.1% and the number of dwellings has increased at a similar proportion (3.9%). Based on regional growth, water demand in the area is also predicted to increase.

There are approximately 1,000 known wells within Area F of which 66% are completed in overburden (sand and gravel) aquifers and 30% within fractured bedrock. The remaining 4% of wells are not defined.

The study watersheds for RDN Area F overlie 14 mapped aquifers from which only five overburden aquifers (209, 662, 663, 216, and 217) and one bedrock aquifer (220) are within or intercept the Area F boundary. Complementary information will be available in the BC Water Science Series document for the French Creek watershed where surface water and groundwater connections were studied in more detail. GW Solutions through Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) is in the process of finalizing a study called “French Creek Area Hydraulic Connectivity and Aquifer Mapping Study” to be published in the BC Water Science Series. We recommend to refer to this study to further assist the RDN on the development of an Aquifer Protection Development Permit Area in areas where connections between aquifers and surface water are more prevalent

Based on the completed work, we draw the following conclusions:

For water quantity:

1. Five overburden aquifers (209, 662, 663, 216, and 217) and one bedrock aquifer (220) are partly or fully within the Area F boundary.

2. The thickness of overburden material within Area F was refined based on the GSC Nanaimo Lowlands project (Benoit et al, 2015). It ranges from less than 2 m (or exposed bedrock) to up to 120 m. Overburden aquifers are present where the overburden is thicker. Bedrock aquifers are predominant where overburden sediments are less than 2 m thick. They also underly overburden aquifers.

3. The regional groundwater flow is from ridges at high elevation towards the ocean. The flow directions in overburden Aquifers 209, 216, and 217 were determined with a higher level of detail based on a good definition of the piezometric level.

4. Minimum flows have historically been recorded in August, when groundwater discharge to the streams is responsible for sustaining the flow. However, in recent years minimum flows have been observed over a longer period, from July to September. This could possibly be attributed to the effects of climate change and increased groundwater usage. Additionally, land modification such as forest loss over time might also be a modifying factor.

5. Declines in groundwater levels in bedrock aquifers were observed with the exception of wells near Little Mountain and the Englishman River where localized groundwater recharge has been identified. These water level declines are attributed to a combination of factors including climatic conditions, water usage, and land modification (e.g., forest loss, surface impermeabilization).

6. Groundwater levels in overburden aquifers are relatively stable after declining levels were observed in Aquifer 216 (until 2015) and 217 (until 2010), likely resulting from over-extraction from well fields.

7. The fluctuation of groundwater levels has been compared to the cumulative precipitation departure (CPD) for some wells, for which data was available for a sufficient length of time (i.e., more than 10 years). This was done for OW287 (bedrock Aquifer 220), and OW314 (overburden Aquifer 216). If groundwater level trends follow a similar trend to the CPD then this suggests that the groundwater level trend is being influenced by climatic factors.

8. Precipitation trends can partly explain the decline in groundwater level in Aquifer 220. From 1984 to 1990, the CPD decreased and groundwater levels also indicate a drop of the water table. However, after 1990, the CPD started to increase indicating that average precipitation within that period was higher than the long-term average, and groundwater levels appear to have stabilized. A decline in CPD from 2008 to present corresponds to a decline in groundwater levels. Other factors, such as land use (e.g., increased percentage of land covered by impermeable surfaces), and population rise have also likely contributed to the long-term decline observed in groundwater levels over the last 35 years.

9. For OW314, installed in Aquifer 216, groundwater levels drastically declined between 1992 and 2003. The dropping trend was decoupled from the CPD curve which indicated a series of wet years. The decline in groundwater level likely resulted from the influence of nearby production wells managed by EPCOR water services at the time. Apparently, EPCOR started regulating pumping in the production wells after 2003. Since then, the groundwater level trend has stabilized and even slightly increased.

10. Unfortunately, there is not enough information (both in time and spatially) to describe the fluctuation of the water table for all the aquifers in Area F. Therefore, it is critical to increase the number of monitoring wells and cover as thoroughly all the aquifers so that, gradually, enough information is collected to adequately monitor the status of aquifers.

11. It is predicted, due to climatic conditions, that snow accumulation will decrease. This will directly impact aquifers and wells that have a snow dominant recharge regime (e.g., Aquifer 216).

For water quality:

12. The surficial overburden aquifers have each their own water quality, as indicated by their own clouds on the Piper plot. For example, Aquifer 663 shows a higher proportion of Chloride. Some of the points (e.g., samples from Aquifer 209 showing higher concentrations of sodium and potassium) may represent locations where impact to groundwater quality due to surface activity is observed.

13. Groundwater in bedrock is predominantly HCO_3-Ca, suggesting young water (i.e., the aquifer is recharged by rain and snowmelt and groundwater flows relatively fast through the fractured bedrock). However, there are some wells reporting a Cl-Na water type suggesting that groundwater has been affected by anthropogenic sources such as septic fields, farming activities, or road salting.

14. The presence of saline waters is also possibly associated with mature groundwaters and/or connate relict marine water from past periods of higher sea level, particularly within areas of limited recharge. Wells that fall into this group (Cl-Na) correspond to surficial Aquifer 216, 217, 262 and bedrock Aquifer 220.

15. Coliforms are present in groundwater, both in the bedrock and surficial aquifers. There are no spatial or temporal trends. Coliforms could be attributed to natural sources or a combination of poorly maintained wells and the absence of surface seals.

16. For metals, for Area F and the area north of it, only five samples show concentrations above guidelines with arsenic (in bedrock Aquifer 220 – one sample), barium, lead (one sample in overburden Aquifer 217), zinc (four samples, Aquifer 217 and 664), and copper (five samples in Aquifer 217). Therefore, the presence of these metals does not appear to be a dominant issue.

17. Both arsenic and boron are often associated in the Nanaimo group bedrock deposits. Maximum concentrations of boron are reported in the 1 mg/L range (the drinking water guideline being 5 mg/L). However, higher concentrations of arsenic are present within Area F in the range of 0.02 to 0.08 mg/L (the guideline is 0.01 mg/L). Arsenic is assumed to be naturally present in the groundwater in the area.

18. Nitrate, sulfate, chloride, and TDS are the main parameters with concentrations exceeding the guidelines for drinking water. This is predominantly observed in bedrock wells (Aquifer 220). This is also observed for wells located along the Alberni Highway and in small clusters (Little Mountain area, Errington). Therefore, the presence of these parameters likely results from anthropogenic activities. We do not observe increasing or decreasing trends with time.

19. Nitrates are locally present at concentrations that are not of natural sources. Nitrate is present at concentrations that could have health impacts. Some cancers, thyroid problems, and negative birth consequences have been linked with concentrations of nitrate in drinking water even significantly below the drinking water guidelines (Temkin, et al., 2019). The relatively high concentrations of nitrate in groundwater within Area F could be attributed to the use of fertilizers and/or failing septic fields and/or animal farming practices.

20. Only two samples exceeded the nitrate drinking water quality guideline (10 mg/l); however, many wells are showing increasing trends and nitrate concentrations are slowly approaching the guideline. Higher concentrations of nitrate are observed after 2011 in the Alberni Highway and Church Road area, with recent concentrations in the 2 to 8 ppm range. It may be related to an increased presence of nitrate in groundwater and/or to an increase in sampling and analyses. The medium and 75th percentiles of samples collected from wells within 300 m from medium and large animal farms show higher concentration for both nitrate and sodium suggesting the animal farms might be affecting the groundwater quality.

21. Nitrate management has been presented in case studies such as for the Abbotsford Aquifer (Chesnaux, et al., 2007). It demonstrates that nutrient management practices can be adopted and implemented to reduce the risks of nitrogen loading to groundwater without compromising agricultural productivity and activity.

22. Chloride appears to be present due to both natural and anthropogenic sources. No spatial or temporal trends are observed. Concentrations in the 250 ppm to 600 ppm range in the last 10 years, reaching values in a 1 to 3 ppm range. However, this trend may be due to the fact that more samples have been collected in the last six years. We observe a larger amplitude of concentration covered by a larger set of samples. This observation also applies to fluoride.

23. GW Solutions has drafted best management practices to reduce the risks of groundwater contamination from a variety of anthropogenic sources.

And, we make the following recommendations:

1) The RDN should work in cooperation with all the water purveyors to better monitor the effects of using aquifers for water supply in Area F. Working towards developing modeling tools to forecast the long-term effects of extracting groundwater from the aquifers should be a priority.

2) The network of monitoring wells should be reviewed in light of the improved definition of aquifers to identify areas needing monitoring.

3) The creation of new impermeable areas should be prevented to minimize the reduction of groundwater recharge.

4) The RDN should consider Aquifer Protection Development Permit Areas in particular in areas where connections between aquifers and surface water are more prevalent.

5) In addition to the application of the BC Riparian Areas Protection Act and the requirements listed in the RDN Freshwater and Fish Habitat Development Permit Area, we recommend that land protection measures be developed and implemented within a distance (i.e. 50 to 100 m) from top of banks (Beacon Environmental Ltd., 2012). Measures should consider both water quantity (e.g., no increase of impermeable areas) and water quality (e.g., no release of elements that would negatively affect water quality). A full review of the Freshwater Protection DPA regarding riparian buffers was outside the scope of this study.

6) Agricultural best management practices to reduce the risks of surface and groundwater contamination from fertilizers and farming activities need to be enforced. For instance, adequate setbacks from farming components (i.e., application of fertilizers, management of manure, wastewater lagoons, fertilizer storage) should be required. This could be promoted by the RDN through an education and awareness outreach program to farmers and also achieved by working with the Ministry of Agriculture to modify regulations, and to implement nitrate management plans.

7) The presence and types of coliforms need to be better characterized and monitored. The RDN should work closely with Island Health to assess the human health and ecological risks associated with coliforms.

8) The RDN should design and implement a nitrate monitoring and management program. It may include:

    a) Sampling of wells with highest nitrate concentrations (e.g., network of a dozen wells, quarterly sampling);

    b) Detailed mapping of septic fields and agricultural activities at proximity (i.e., within 500 m radius);

c) Detailed hydrogeological characterisation;

d) Simultaneous tracking of other parameters (e.g., chloride, sodium, sulfate).

9) A water quality assessment within Area F is recommended to be repeated no later than 10 years from this assessment; it should include septic field mapping and characterization to better characterise the potential correlation between the presence of coliforms, nitrate, and chloride in groundwater and the proximity to septic fields.

10) The water quality assessment was completed based on data from various sources. We recommend continuing monitoring and reporting on groundwater quality and facilitating the access and sharing of results. Private-domestic well owners are recommended to sample their wells for bacterial analysis and nutrients (i.e. nitrate) once a year, and metals (every three years).

11) Well inspections were not part of the project; however, it is well documented that contamination of groundwater could also occur due to the lack of an adequate well surface seal and poor completion of wellheads. It is recommended to encourage residents to upgrade their wells if they do not comply with the new Water Sustainability Act and Groundwater Protection Regulation. This is already encouraged via the RDN Wellhead Upgrade Rebate Program[1].

12) The RDN should continue its effort of education and outreach to the public for the proper operation and maintenance of septic fields.

13) The RDN should design and implement a program to locate wells which have been omitted from GWELLS. This should be accompanied by a well upgrade or closure plan, to meet the WSA requirements.

For wells exceeding iron, manganese and arsenic, treatment technologies such as reverse osmosis, chlorine injection, or specialized filters might be considered to reduce the concentrations to potability standards. Well owners are recommended to contact a certified water treatment specialist or qualified pump installer.

[1] https://rdn.bc.ca/well-protection-upgrades-rebate

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1 BACKGROUND AND OBJECTIVES

1.1 Background

GW Solutions has been retained by the Regional District of Nanaimo (RDN) to complete a water quality and quantity risk assessment for groundwater and surface water resources within the RDN Electoral Area F (RDN Area F) in support of the RDN Area F Official Community Plan (OCP) update.

GW Solutions has characterized issues and risks associated with both water quality and quantity based on area-specific data and outlined mitigation measures to reduce the risks.

1.2 Objectives

The objectives of the analysis are to spatially understand and identify where water quality and quantity concerns and risks exist within the RDN Area F. This includes analyzing:

Water quantity:

- Define study watersheds that intersect RDN Area F boundary;
- Define the boundary of aquifers that intersect RDN Area F boundary;
- Gather, review and integrate information, including topography, geology, soils, streamflow and surface water levels within the study watersheds and wells, groundwater levels, mapped aquifers; and
- Identify the concerns for surface water flows, groundwater levels, aquifers, and surface water and groundwater interaction.

Water quality:

- Gather, clean, standardize and integrate available water quality data for surface water and groundwater;
- Analyse the spatial and temporal evolution of water quality, and exceedances when compared to water quality guidelines;
- Characterize the existing and potential hazards and threats to water quality; and

- Evaluate the vulnerability of water resources.

Reporting:

- Report on the methodology and findings;
- Outline recommendations and management strategies.

2 STUDY AREA

The study area shown in Figure 1 includes the RDN Electoral Area F and significant portions of three water regions: WR2- Little Qualicum, WR3- French Creek and WR4- Englishman River. This includes the following watersheds: Little Qualicum River, Grandon Creek, French Creek, Morningstar Creek, Englishman River, and Carey Creek.

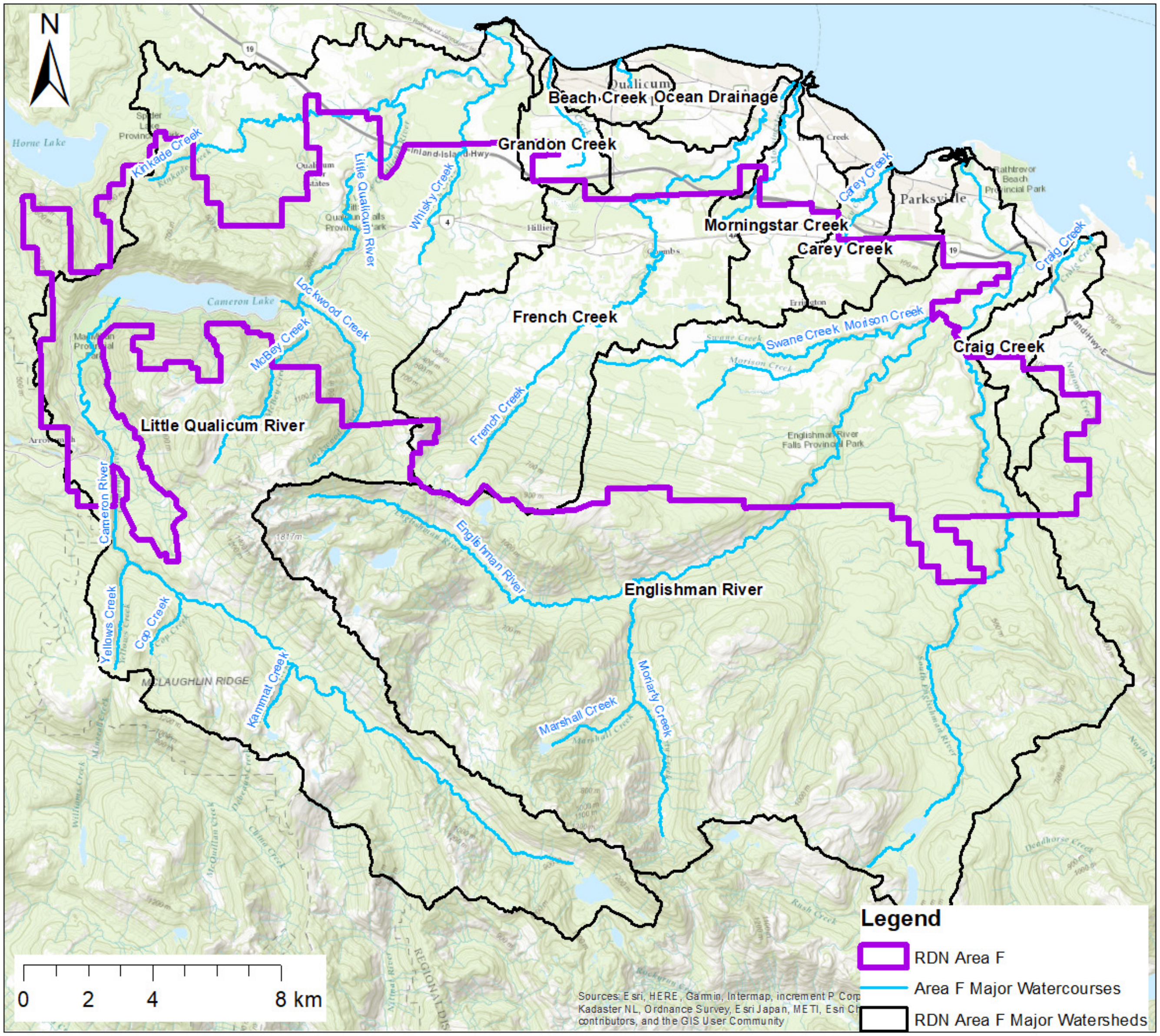

Figure 1. Study area

3 DATA COLLECTION, REVIEW, AND INTEGRATION

3.1 Data Type and Sources of Information

GW Solutions and the RDN worked collaboratively to access, share and compile the information summarized in Table 1.

Table 1. Data type and source of information used in the study

Data Type	Data Source	Provided by/obtained from
Groundwater levels	Observation Well Network (water levels) from the Province	Ministry of Environment and Climate Change Strategy (PGWOWN Aquarius Database)
	Observation wells from volunteers used for the Englishman River Project	GW Solutions
	RDN State of our aquifers (RDN-Regional District of Nanaimo)	RDN/ GW Solutions
	RDN Volunteer Observation Wells	RDN
Surface water levels and flows	Streamflow and water level data from Water Survey of Canada	Water Survey of Canada (HYDAT database)
	Water level data from Pacfish-Hydromet (sponsored by First Nations, Regional Districts, Provincial and Federal Government)	Hydromet Stations through Pacfish
	Englishman River water monitoring (flow and level)	Englishman River project (MVIHES)

Data Type	Data Source	Provided by/obtained from
	BC Real-time Water Data	BC Real-time data (BC Aquarius)
Potential Risk	Contaminated sites	Environmental Remediation Sites
	Active and Abandoned Mines (include rock quarries)	BC Mine Sites
	Effluent discharge permits (Landfills, industry, etc.)	BC Waste Discharge Authorizations
	Forest loss in the last 10 to 18 years	Completed by the University of Maryland
	Land Use	RDN
	RDN Agricultural Land Use Inventory (ALUI) completed in 2012	RDN
General; Soil, geology and land	1:50,000 scale Digital Elevation Model (DEM) available from Natural Resources Canada (NRCAN).	Environment and Natural Resources Canada (NRCAN)
	Soil, geology and land	Environment and Natural Resources Canada (NRCAN)
	Geology	Geological Survey of Canada
	Regional and local geology and soils information	British Columbia Soil Information Finder Tool and BC Soil Database

Data Type	Data Source	Provided by/obtained from
	BC Land Cover, circa 2000-Vector Data	BC Province and government of Canada
Wells, aquifer properties and mapped aquifers	BC GWELLS database	BC Province
	Aquifer boundaries and map sheets	BC Province
	Aquifer properties and mapped aquifers	Geological Survey of Canada 2015 – Nanaimo Lowlands Aquifer Characterization – FEFLOW (numerical model)
	Aquifer properties and mapped aquifers	RDN Water Budget Phase 1 (Waterline, 2013)
	Aquifer properties and mapped aquifers	Geological Survey of Canada 2015 – Nanaimo Lowlands Aquifer Characterization – FEFLOW (numerical model)
	Aquifer properties and mapped aquifers	BC Well database (GWELLS)
	Aquifer properties and mapped aquifers	EcoCat Ecological Reports Catalogue
	Aquifer properties and mapped aquifers	BC Data Catalogue

Data Type	Data Source	Provided by/obtained from
Water Quality	RDN Water Service Areas and water systems (Melrose, Westurne, Whiskey Creek, and French Creek)	RDN
	B.C. Environmental Monitoring System (EMS). Surface water and groundwater quality	EMS Web Reporting
	RDN Water Trax program – voluntary submissions of well water quality data	RDN
	RDN Area F Water Purveyors (EPCOR Water Services)	RDN
	Island Health Authority Water Quality Data	RDN/Vancouver Island Health
	Other Studies; Englishman River Project	GW Solutions/MVIHES
	Other Studies; Englishman River Water quality data (Thesis)	University of Calgary
	Other Studies; Whiskey Creek Groundwater Source Assessment by Elanco Enterprises LTD	RDN

3.2 Data Description and Integration

GW Solutions used Tableau and GIS software for data integration, display and analysis. Tableau is a program for data management, analysis and display that can integrate geospatial data as well as time-series information (i.e., water level, water quality monitoring data).

4 WATER QUANTITY ANALYSIS

4.1 Topography and Hydrology

Elevation data were processed with the open source QGIS software, using the 1:50,000 scale digital elevation model (DEM) available from Natural Resources Canada (NRCAN). The DEM was scaled to 20 m x 20 m. Figure 2 presents the topography and the hydrology of the study area. Additionally, the RDN provided the 2 m DEM which was used to estimate the elevation of the wellhead of observation wells.

4.2 Land Cover, Soils and Surficial Geology

GW Solutions used Land Cover, circa 2000-Vector Data-polygons to derive land cover classes. We have also used updated land cover based on current satellite imagery and based on work presented in Nanoose Bay – Deep Bay Area, and Nanaimo Lowland Groundwater Study Atlas (Geological Survey of Canada, OPEN FILE 7877).

The available soils information and surficial geology for the study watersheds have been acquired from BC Environment-Ecosystem branch and from the Ministry of Natural Resources Canada (NRCAN Bednarski, 2015).

Figure 3 shows the derived land cover classes and the resulting soils and surficial geology for the study watersheds. Most of the soils within Area F consist of glacio-fluvial, marine deposits, and moraine sediments.

4.3 Climate

4.3.1 **Climate monitoring stations (precipitation, temperature, snow melt, soil moisture, humidity, wind)**

The main sources of information for climate monitoring data on Vancouver Island are listed below:

- Environment Canada (EC);

- Agricultural and Rural Development Act Network (ARDA);
- BC Hydro (BCH);
- BC Ministry of Environment - Automated Snow Pillow Network (ENV-ASP);
- BC Ministry of Environment - Air Quality Network (ENV-AQN); and
- BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development - Wild Fire Management Branch (FLNRO-WMB);

This information has been gathered and standardized by the Pacific Climate Impacts Consortium (PCIC). Climate data for the study watersheds came predominantly from two sources (EC and ARDA) as shown in Figure 4. Climate monitoring stations mainly record precipitation and temperature (hourly, daily, monthly).

Daily precipitation information was used to assess groundwater level variations with precipitation events.

4.3.2 **Precipitation and Temperature**

Monthly total precipitation and maximum and minimum temperature gridded data were obtained from the Pacific Climate Impact Consortium (PCIC). The information corresponds to climate normal data 1981-2010. Total annual precipitation and average annual temperature were inferred from the monthly gridded averages. The information was verified using the compiled climate stations presented in Figure 4.

Figure 5 shows the distribution of monthly total precipitation in mm. The wettest months occur between October to March, and the driest months are usually July and August. There are considerably higher precipitation events from November to January.

Average temperatures for the study watersheds are shown in Figure 6 where warmer months correspond to drier months.

Figure 7 shows the inferred average total annual precipitation and average annual temperature.

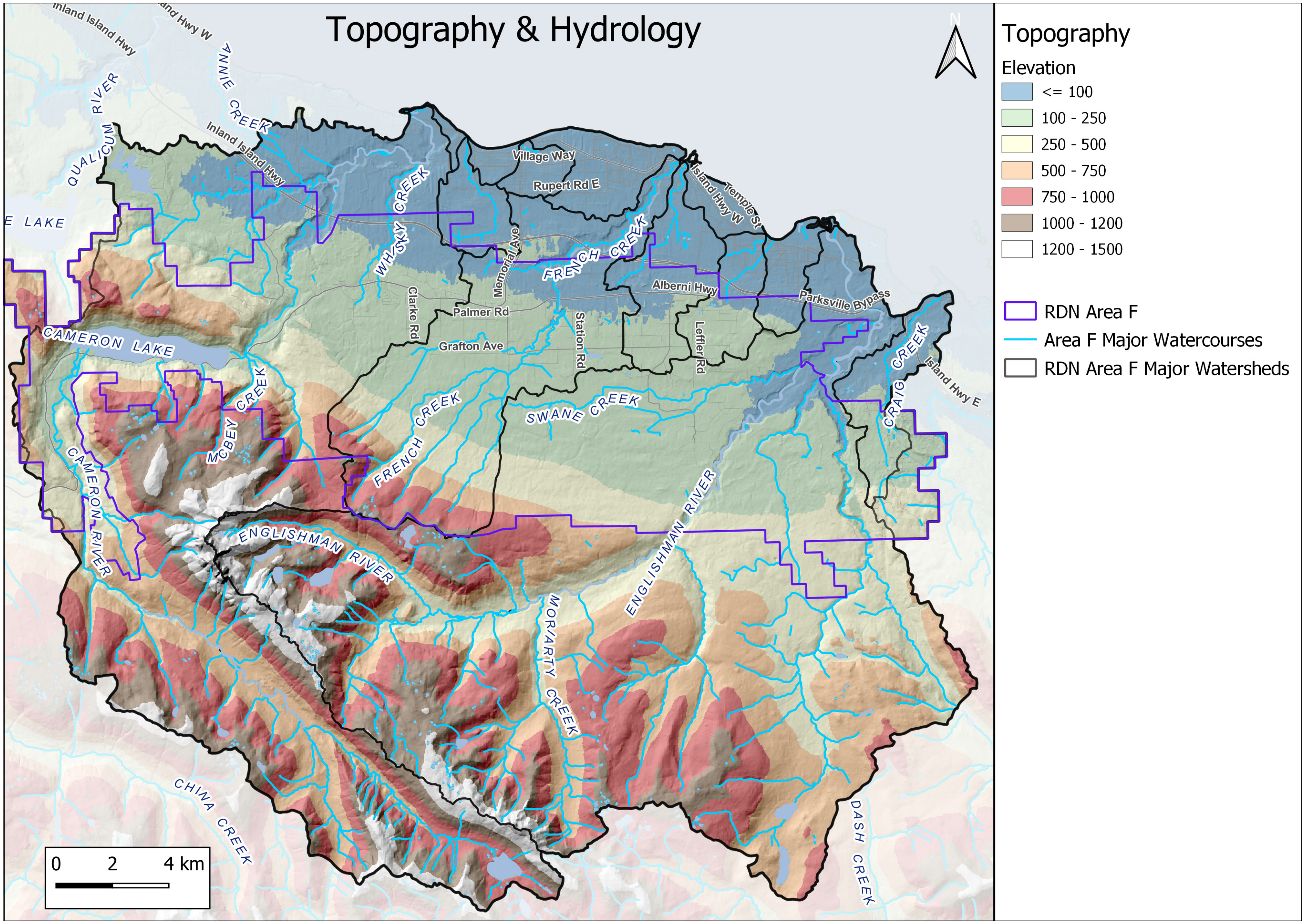

Figure 2: Hydrology and Topography

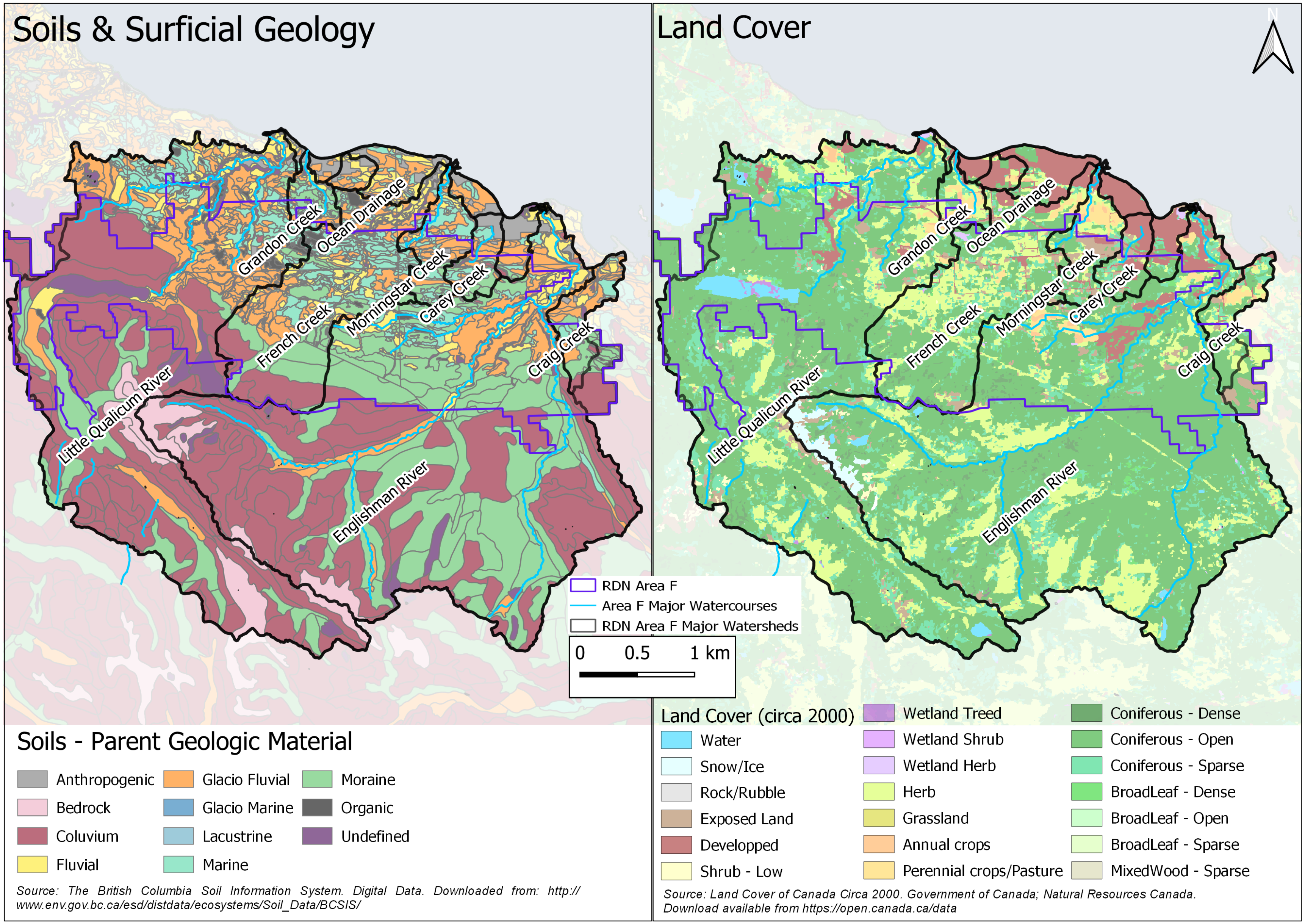

Figure 3: Land cover and surficial geology / soil

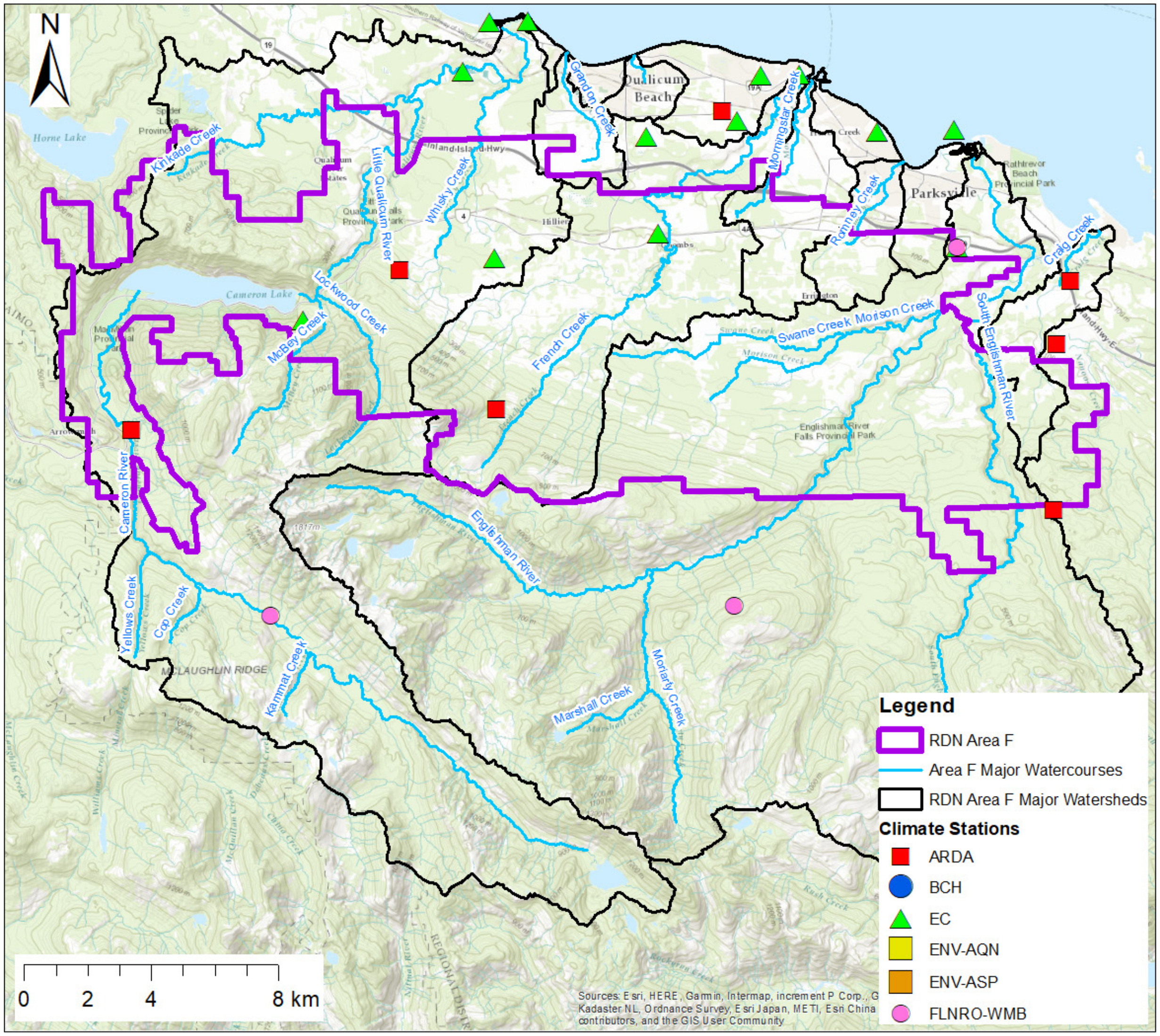

Figure 4: Climate monitoring stations

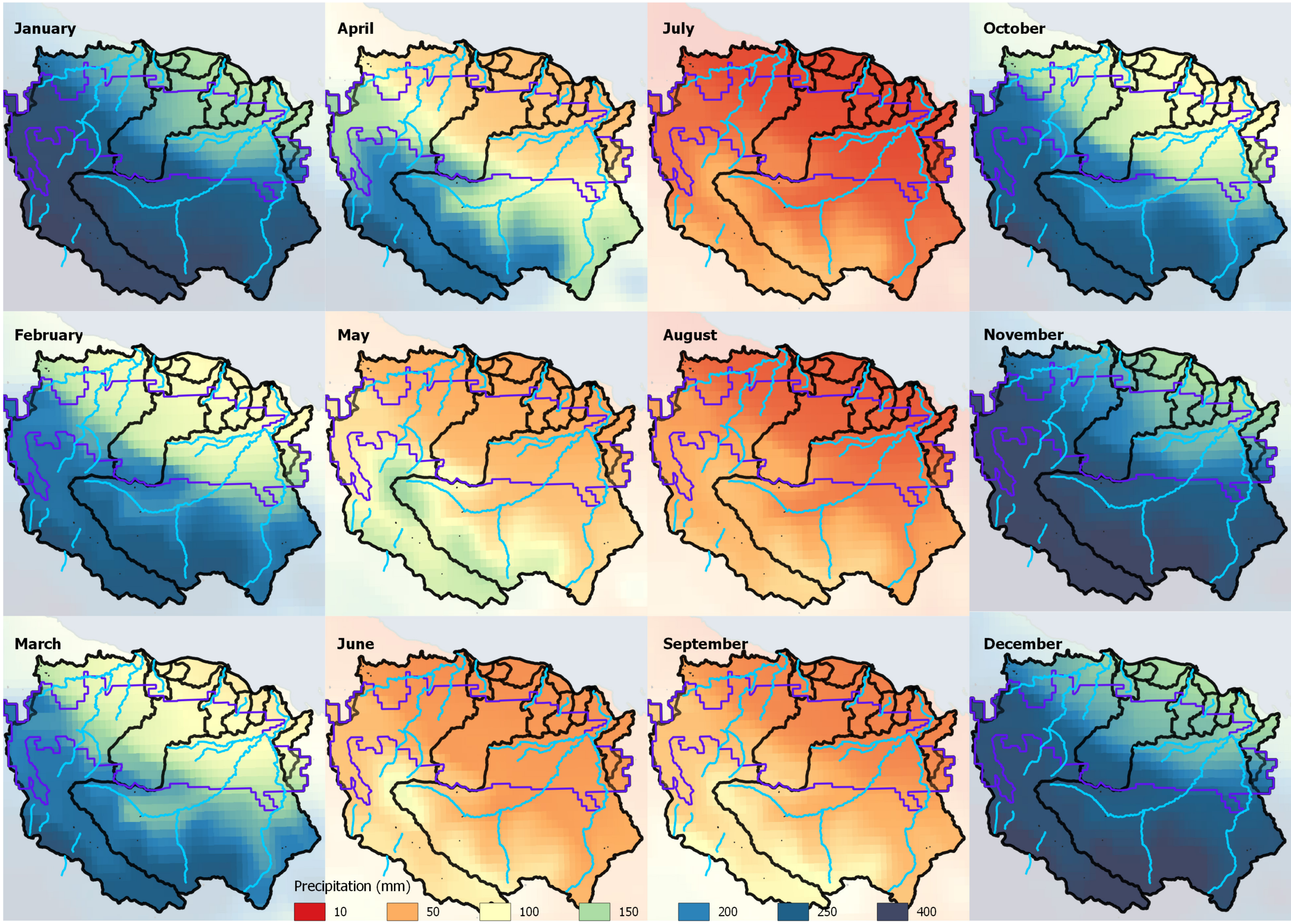

Figure 5: Average monthly total precipitation

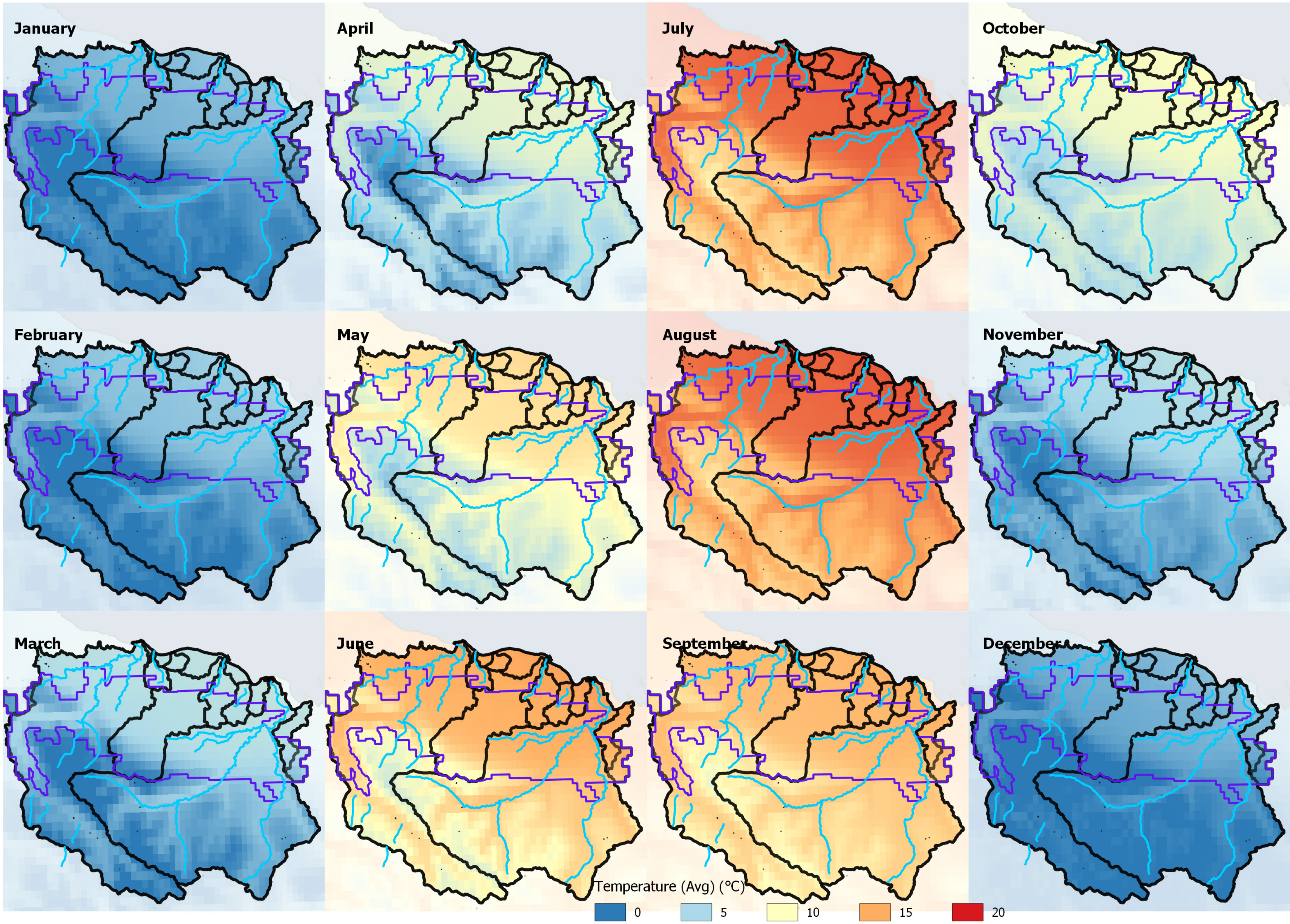

Figure 6: Average monthly temperature

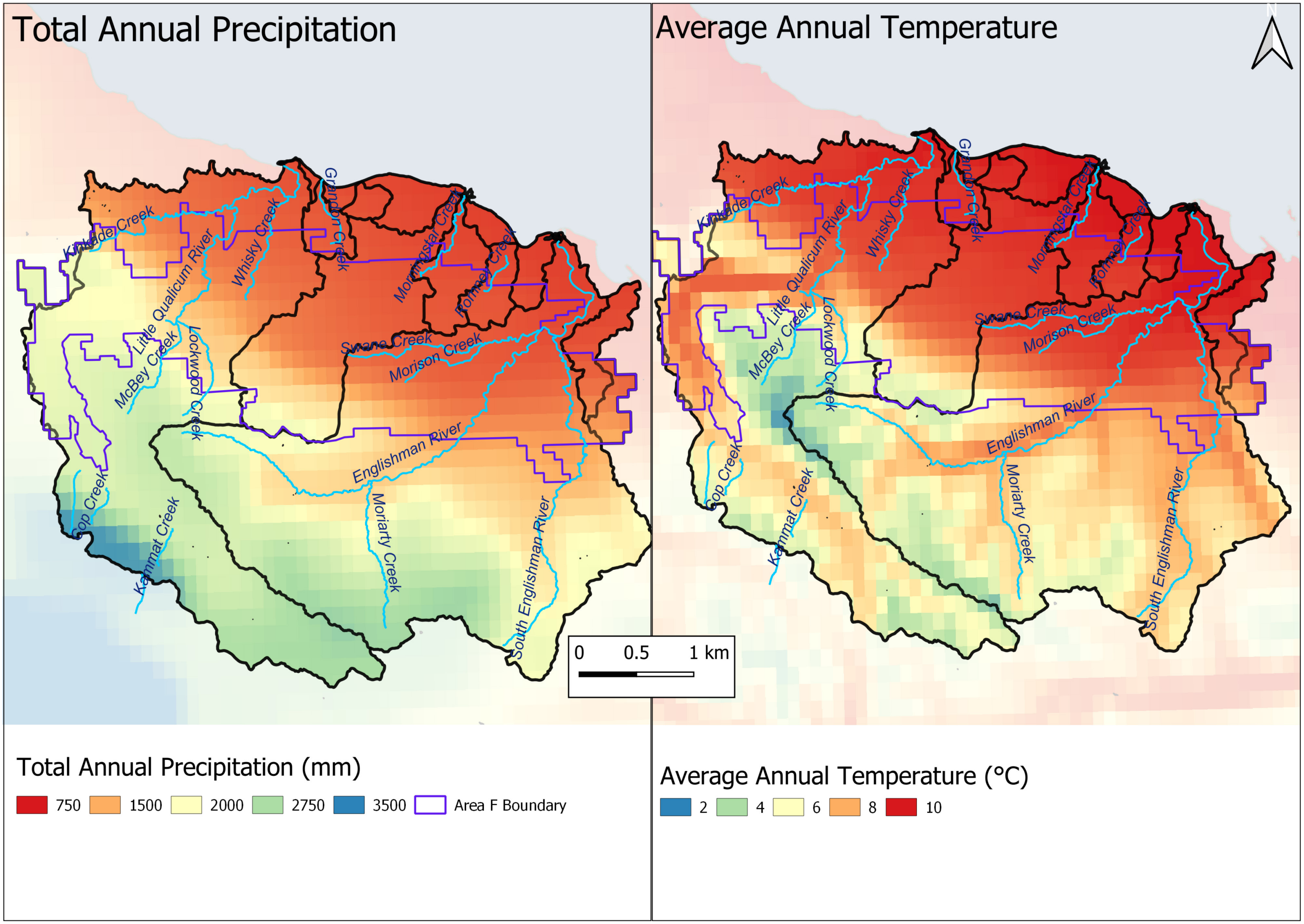

Figure 7: Average annual total precipitation and annual average temperature gridded data

4.4 Current Water Supply Sources

4.4.1 Surface Water Licenses of Points of Diversion (POD)

The BC Points of Diversion (POD) database which includes Water License information for surface water and springs is presented in Figure 8. Generally, this database contains a record for each water license associated with each Point of Diversion in the Province (each Point of Diversion can have multiple licenses). For each record, basic information about the water license is provided such as license status (refused applications, pending, expired, current, cancelled, active applications, abandoned, and abandoned applications), expiry date, granted volume and its corresponding unit and purpose (there are 60 types of “purpose” for current licenses on Vancouver Island).

The current licensed Points of Diversion for the study watersheds, limited to consumptive uses, were classified by type of usage including: domestic, irrigation, industrial, commercial, institutional and water supply systems (Figure 8).

4.4.2 Groundwater Supply Source

Two databases provide information about drinking water suppliers relying on groundwater: Island Health (IH) and the RDN. Figure 9 presents the water supply systems regulated by IH under the Drinking Water Protection Regulation and the RDN production wells.

Figure 10 shows the areas which are supplied by RDN water supply systems. Three systems provide water to small areas including: Melrose Terrace Community Water, Westurne Heights Water and Whiskey Creek Water. They are all located within the Little Qualicum watershed.

Groundwater usage data are not available for the water supply systems listed under IH.

4.4.3 Future Water Demand

According to the 2016 national census data the following comments can be made:

- In 2016, the population of RDN Area F was 7,724. This represents an increase in population of approximately 4.1% from 2011, comparable to the provincial growth average (5.6%), and the national growth average (5.0%).
- The area of RDN Area F is 264.36 km^2 and the population density was 29.2 people per km^2. Figure 11 shows the population density according to the 2016 census.

- In 2016, there were 3,373 private dwellings, which represents an increase of 3.9% from 2011.

Based on this information, it is anticipated that water usage and demand will increase as population increases. Although, the improvement in technology might positively reduce water demand, there are also other factors that might increase water usage such as water losses due to old water supply water works (i.e. the Whiskey Creek distribution system constructed in the 1970s by a developer and inherited by the RDN in 2011), greater irrigation for agricultural purposes during longer and warmer summers resulting from climate change, etc.

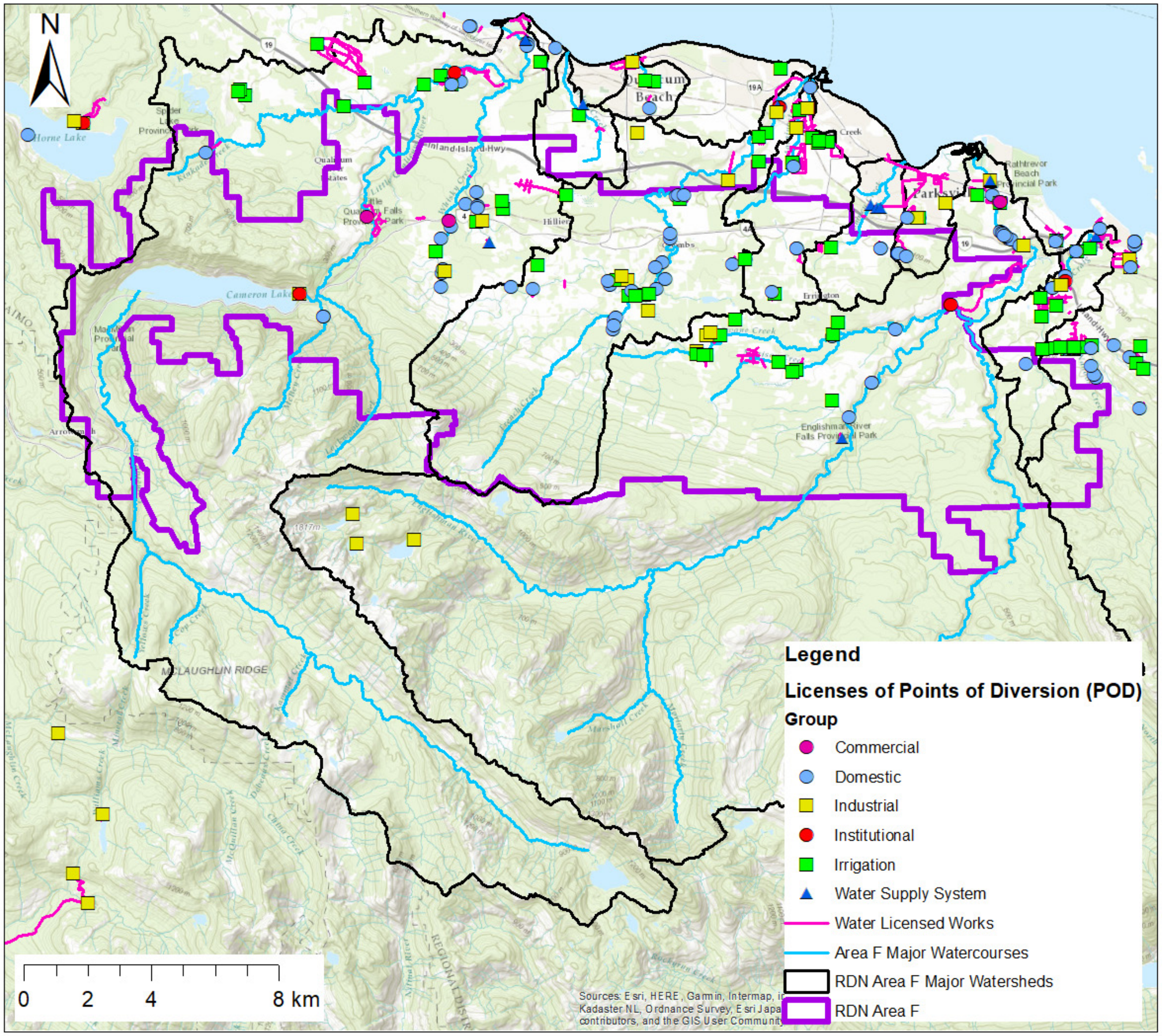

Figure 8: BC Points of Diversion (surface water and spring water licences)

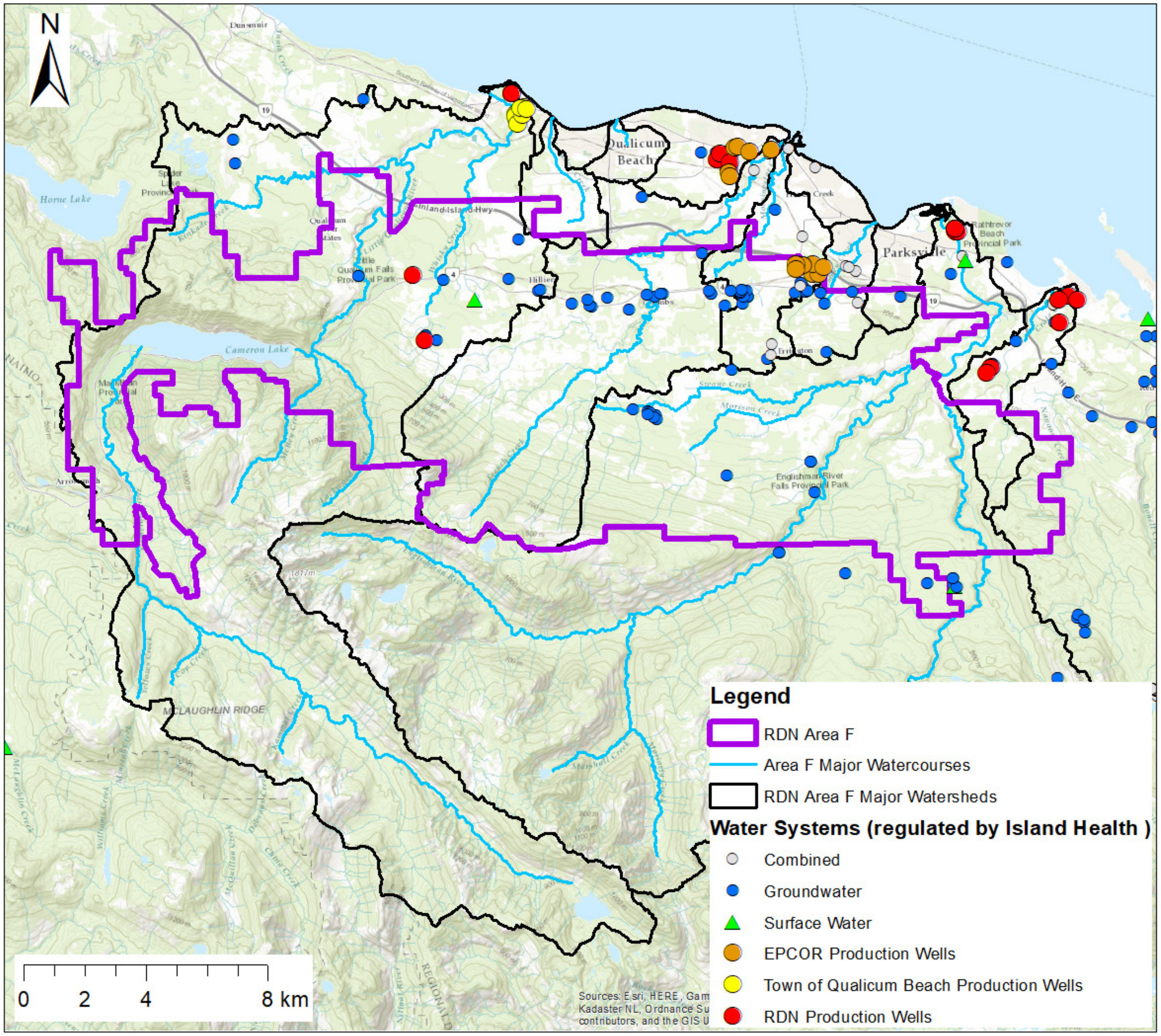

Figure 9: Island Health and RDN Regulated Systems

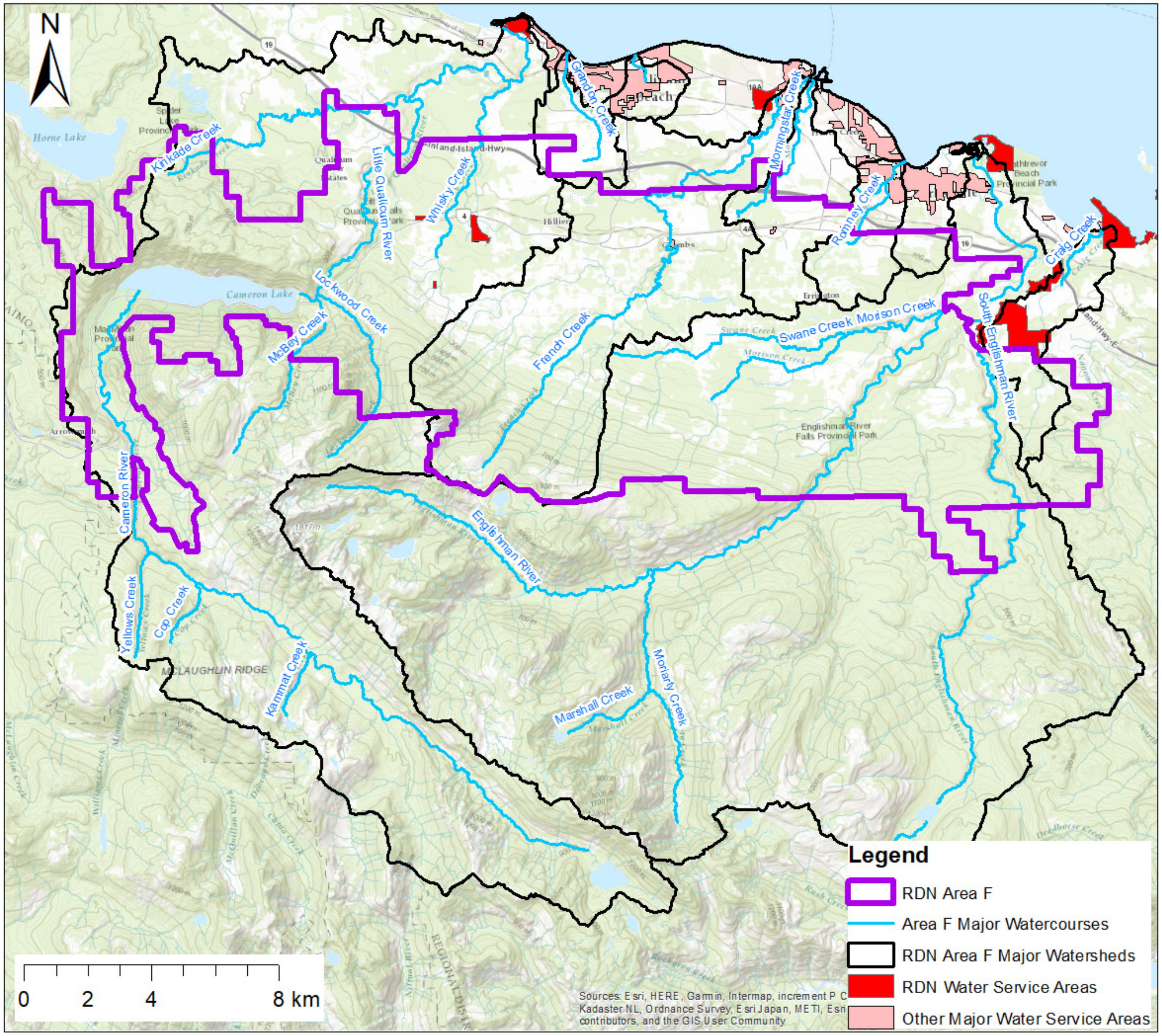

Figure 10: Areas supplied by RDN Water Supply Systems

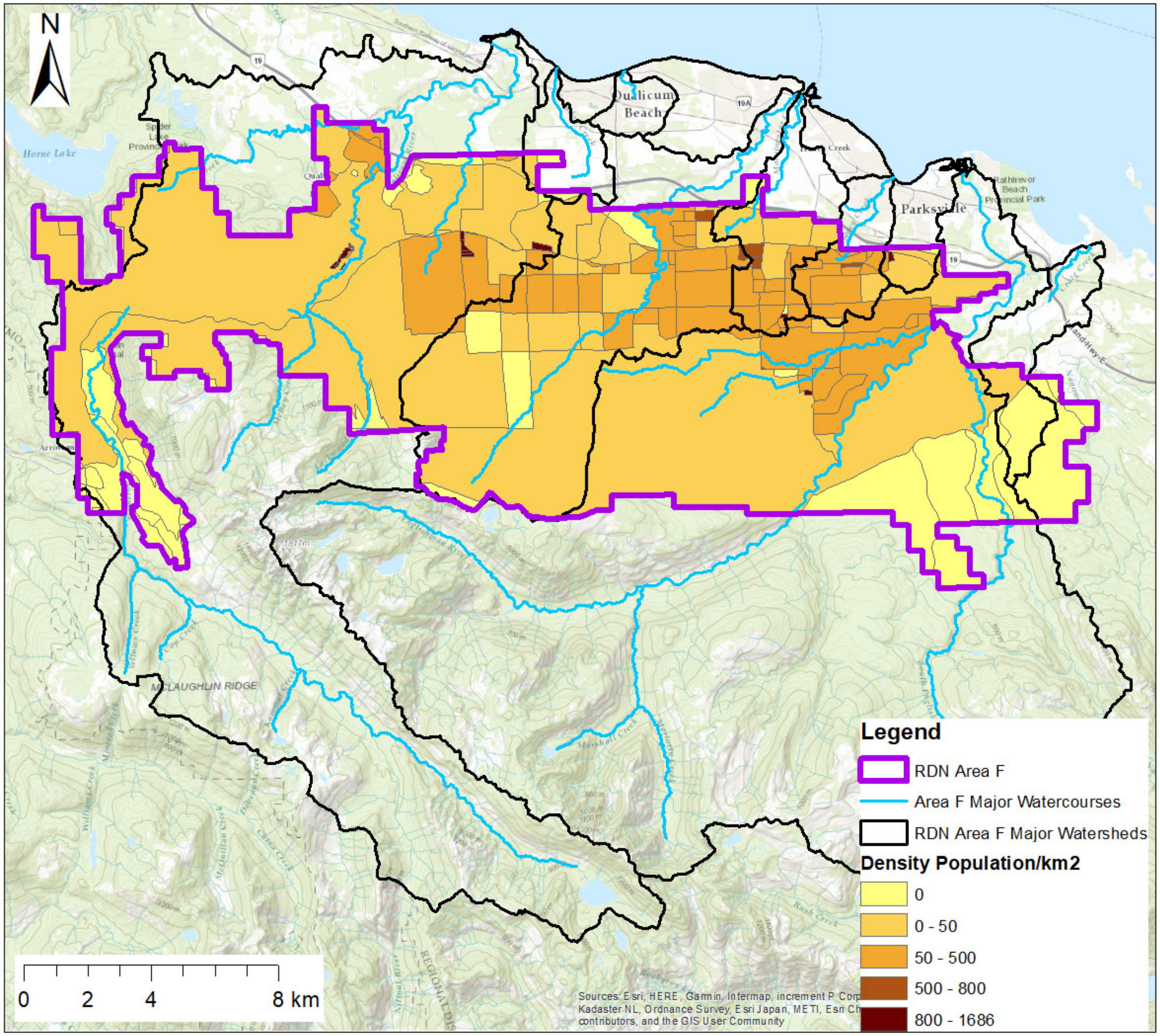

Figure 11: Population density according to 2016 Census

4.5 Groundwater Wells (Type, Lithology)

GW Solutions uses the Groundwater Wells and Aquifers (GWELLS) database maintained by the BC Ministry of Environment and Climate Change Strategy (BC MoE). The database contains four main data tables listing general well information, screen, casing, and lithological intervals.

Figure 12 shows the location of the water wells in GWELLS classified based on their completion type as bedrock or overburden (sand and gravel) wells.

GW Solutions has further cleaned and standardized the GWELLS database and extracted relevant information for data analysis including hydrogeological conceptual modeling (thickness of overburden, hydrogeological cross-sections), aquifer delineation, and groundwater usage. Figure 13 shows the resulting refined water wells classified by their completion type (overburden and bedrock). Additionally, this map shows the location of water wells classified as monitoring wells for which GW Solutions has compiled water level information.

Figure 14 shows the number of wells from GWELLS within Area F classified by completion type and depth. There are approximately 1,000 known wells within Area F from which 66% are completed in overburden (sand and gravel) aquifers and 30% within fractured bedrock. The remaining 4% of wells are not defined.

4.6 Mapped Aquifers and Aquifer Conceptualization

The Province of BC maintains and manages a provincial aquifer database. The provincial aquifer classification was developed in 1994 and provides information on the regional extent, level of development, productivity, and vulnerability of mapped aquifers. The aquifer extents are delineated based partly on available well logs at the time the mapping was carried out, and likely extend beyond the limits shown on the map. The BC mapped aquifers for Area F are depicted in Figure 12.

Table 2 summarizes the aquifers' properties such as location, size, materials and type, productivity, lithology and stratigraphy, vulnerability, the type of water use, and water demands for each aquifer within the study area. Some mapped aquifers underlie more than one watershed in the study area. The study watersheds for RDN Area F overlie fourteen mapped aquifers; however, only five overburden aquifers (Aquifers 209, 662, 663, 216, and 217) and one bedrock aquifer (Aquifer 220) are within or intercept the Area F boundary.

The Little Qualicum Water Region overlays five mapped aquifers:

- Aquifer 661, Kame feature (Unconfined sand and gravel);

- Aquifer 662, Quadra (Confined sand and gravel);
- Aquifer 663, Kame terrace and delta, glacio-fluvial deposits (Unconfined sand and gravel);
- Aquifer 664, Salish sediment (Unconfined sand and gravel); and
- Part of Aquifer 220 (Haslam Formation of Nanaimo Group- Fractured bedrock).

There are four aquifers underlying the French Creek Water Region:

- Part of Aquifer 216, Quadra Sand (Confined sand and gravel);
- Part of Aquifer 217, Quadra Sand (Confined sand and gravel);
- Aquifer 212 (Nanaimo Group - Fractured sedimentary Bedrock); and
- Part of Aquifer 220 (Haslam Formation of Nanaimo Group - Fractured bedrock).

Eight aquifers extend beneath the Englishman River Water Region:

- Aquifer 221, Salish Sediments (Unconfined sand and gravel);
- Aquifer 219, Quadra Sand (Confined sand and gravel);
- Part of Aquifer 216, Quadra Sand (Confined sand and gravel);
- Aquifer 209, Likely Quadra Sand (Confined sand and gravel);
- Aquifer 1098 (sand and gravel);
- Aquifer 210 (Fractured Bedrock: sedimentary rocks, Fourth Lk. Formation, Intrusive rocks and Mount Hall Gabbro)
- Aquifer 214 (Fractured Bedrock: Nanaimo Group: Extension Formation and Comox Formation); and
- Part of Aquifer 220 (Haslam Formation of Nanaimo Group- Fractured bedrock).

A cursory examination of the location of wells in relation to mapped aquifers within the study area indicates that the aquifer polygons (mapped aquifer boundaries) need to be updated by the Province (Figure 12). For instance, there is no mapped aquifer along the McBey Creek and Little Qualicum River even though a high concentration of drilled wells in both overburden and bedrock aquifers exists there. GW Solutions understands the Province is presently undertaking this task.

GW Solutions understands that mapping bedrock aquifers is complex and requires an understanding of the network of fractures, and piezometric data.

Hydrogeological cross-sections were prepared and are presented in Figure 15 though Figure 17 to understand the aquifer extent, thickness and location relative to main streams. Aquifer 220 (bedrock), and overburden Aquifers 209, 216 and 217 are presented in three hydrogeological cross-sections. Additionally, water levels obtained from drilling records are included (GWELLS). Generally, water levels in wells completed in bedrock aquifers are higher than in overburden aquifers, suggesting an upward gradient from the bedrock system to the overburden aquifers.

4.6.1 Overburden Thickness

Natural Resources Canada (NRCAN) provided the Leapfrog model for the Nanaimo Lowlands (Russell, H.A.J. and Benoit, N., 2016). GW Solutions refined the model to include additional information from wells drilled since 2014. Based on the aquifer conceptual model, GW Solutions has mapped the thickness of overburden materials, presented in Figure 18. Large variability exists in the thickness of overburden material ranging from less than 2 m (or exposed bedrock) to up to 120 m. Areas of limited overburden thickness or exposed bedrock include the headwaters of Swane Creek and Whisky Creek, Cameron Lake area, the banks of upper French Creek (south of Highway 19), most of the Englishman River, areas of Errington/Coombs, and the urban area of lower French Creek. Areas of thick overburden deposits include Qualicum Beach near the shore and areas along the Inland Island Highway. Thicker overburden sediments correspond with the mapped overburden aquifers whereas exposed bedrock or overburden sediments less than 2 m corresponds with areas of mapped bedrock aquifers.

4.6.2 Groundwater Flow Direction

Groundwater flows regionally from the mountains towards the ocean (east to west). GW Solutions estimated the flow directions of overburden Aquifers 209, 216, and 217 based on reported water levels in GWELLS and compiled observation well data. Groundwater in Aquifer 209 flows in the same direction as Morison Creek, northeastward towards the Englishman River. Groundwater in Aquifers 216 and 217 flows along and towards major water courses (i.e. French Creek) and towards the Ocean. Groundwater flows in these aquifers are complex and require further analysis and data collection to locally characterize them in detail.

Table 2: Mapped Aquifers' properties

Aquifer ID	Aquifer Number and Classification	Aquifer Type	Productivity	Vulnerability	Demand	Classification	Description	Lithology and Stratigraphy	Size (km^2)	Type of water use
209	209 IIC (9)	Sand and Gravel	Moderate	Low	Low	IIC	Errington; Morison Creek area	Confined glaciofluvial sand and gravel - likely Quadra Sand	10.7	Multiple
210	210 IIB (10)	Bedrock	Low	Moderate	Moderate	IIB	Nanoose Bay	Sedimentary Rks, Fourth Lk. Form.; Intrusive Rk., Mount Hall Gabbro	5.4	Multiple
212	212 IIIC (6)	Bedrock	Low	Low	Low	IIIC	Parksville	Nanaimo Group	5.9	Domestic
214	214 IIB (10)	Bedrock	Low	Moderate	Low	IIIB	Madrona Point / Parksville	Nanaimo Group: Extension Form. & Comox Form.	30.4	Domestic
216	216 IB (14)	Sand and Gravel	Moderate	Moderate	Moderate	IB	Parksville	Quadra Sand	25.5	Multiple
217	217 IB (14)	Sand and Gravel	Moderate	Moderate	Moderate	IB	Qualicum	Quadra Sand	42	Multiple
219	219 IIC (9)	Sand and Gravel	Moderate	Low	Low	IIC	Nanoose Creek	Quadra Sand	27.4	Multiple
220	220 IIB (11)	Bedrock	Low	Moderate	Low	IIB	Errington	Haslam Formation of the Nanaimo Group	59.2	Multiple
221	221 IIA (11)	Sand and Gravel	High	High	Moderate	IIA	Parksville	Salish Sediments	4	Domestic

Aquifer ID	Aquifer Number and Classification	Aquifer Type	Productivity	Vulnerability	Demand	Classification	Description	Lithology and Stratigraphy	Size (km^2)	Type of water use
661	661 IIIA (10)	Sand and Gravel	Moderate	High	Moderate	IIIA	Spider Lk nr Horne Lk	Kame Feature	3.8	Domestic
662	662 IIC (12)	Sand and Gravel	Moderate	Low	Moderate	IIC	Between Big & Little Qualicum Rivers	Quadra	53	Multiple
663	663 IIIA (12)	Sand and Gravel	Moderate	High	Low	IIIA	Upper reaches of Whisky Creek	Kame terrace and delta glacio-fluvial deposits	9.8	Multiple
664	664 IA (13)	Sand and Gravel	High	High	High	IA	Little Qualicum R. valley & delta	Salish sediments	5	Multiple
1098	1098 IIC (12)	Sand and Gravel	Moderate	Low	Moderate	IIC	East of Englishman River		17	Multiple

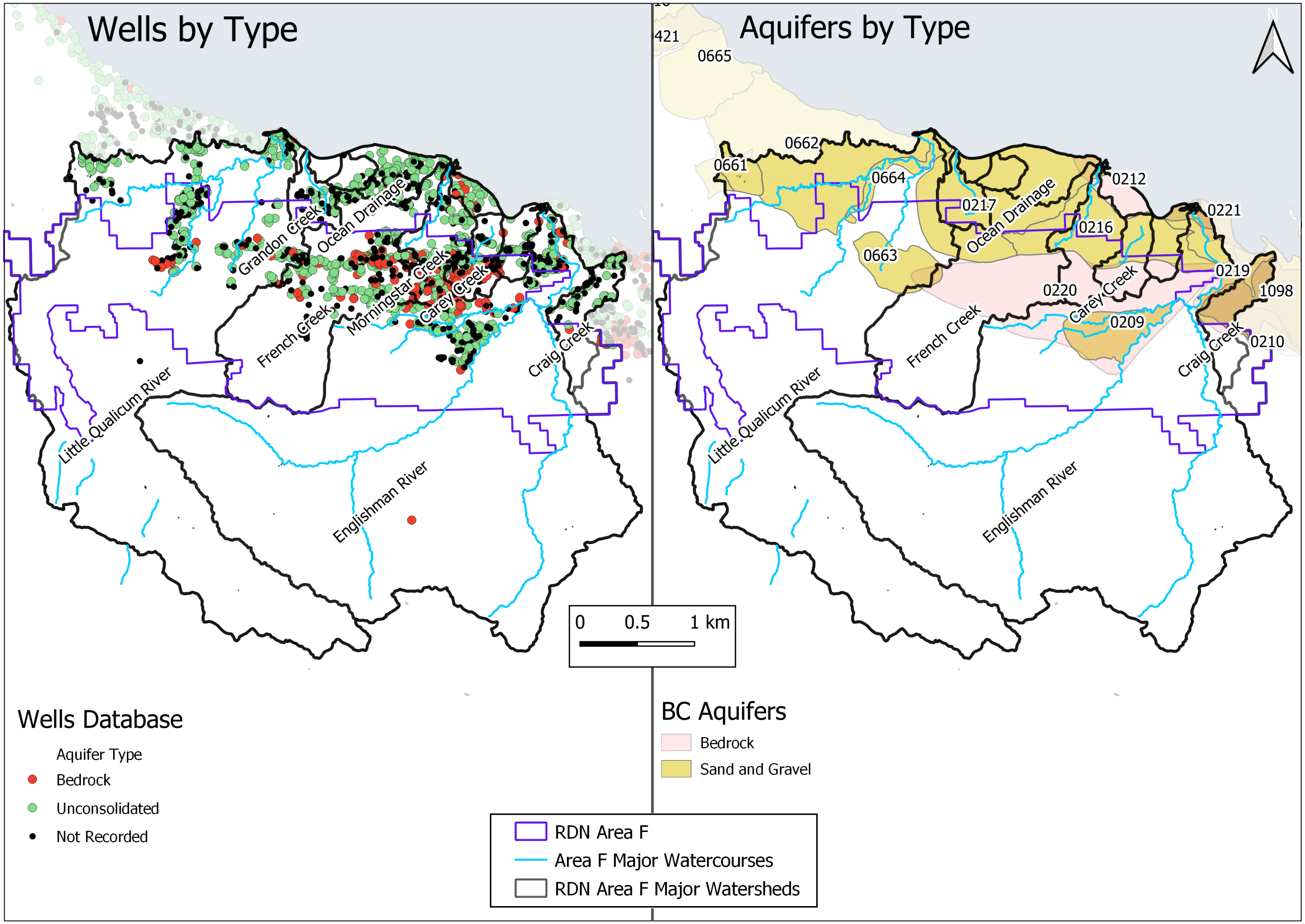

Figure 12: Mapped aquifers and water wells

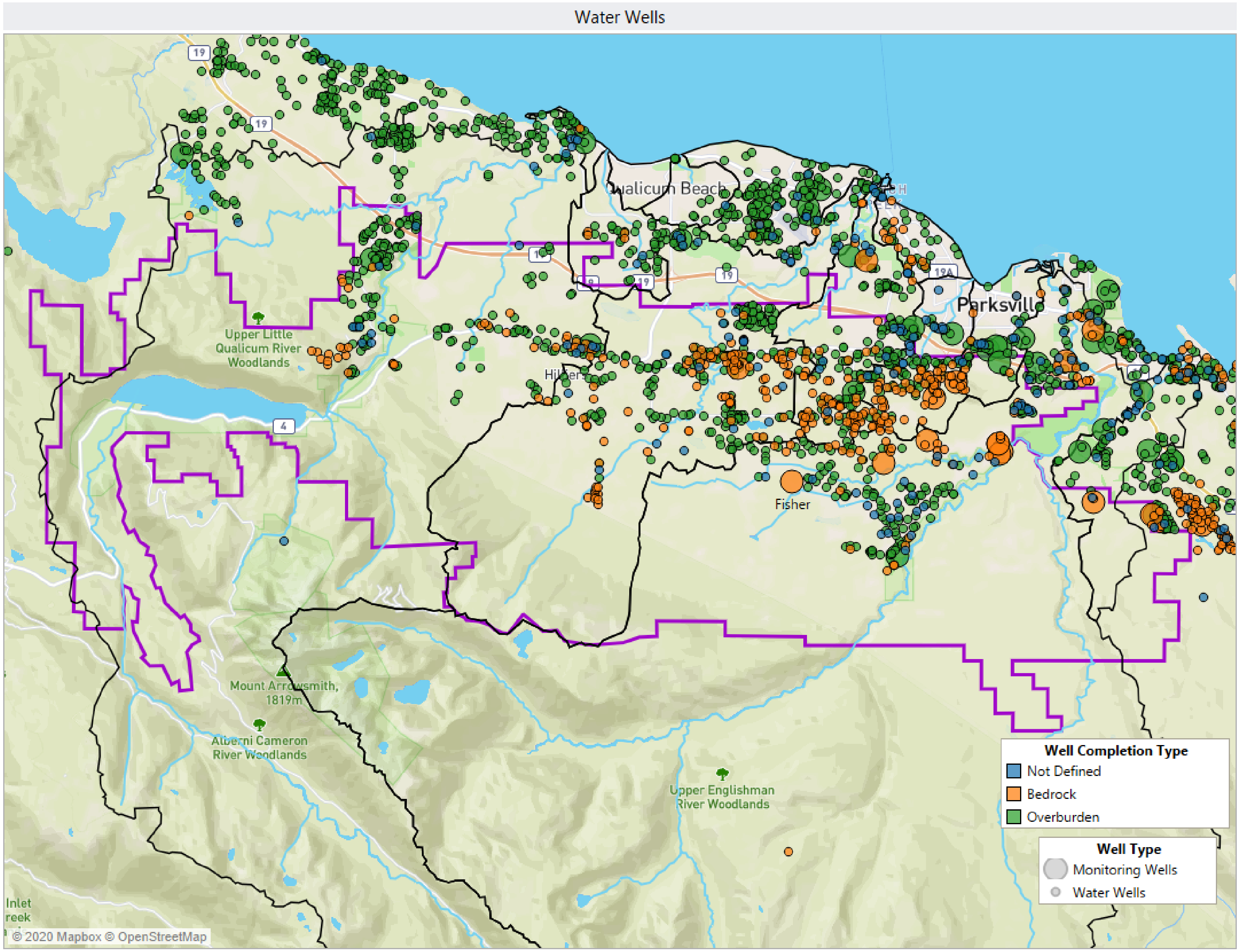

Figure 13: Water wells and Observation wells within Area F

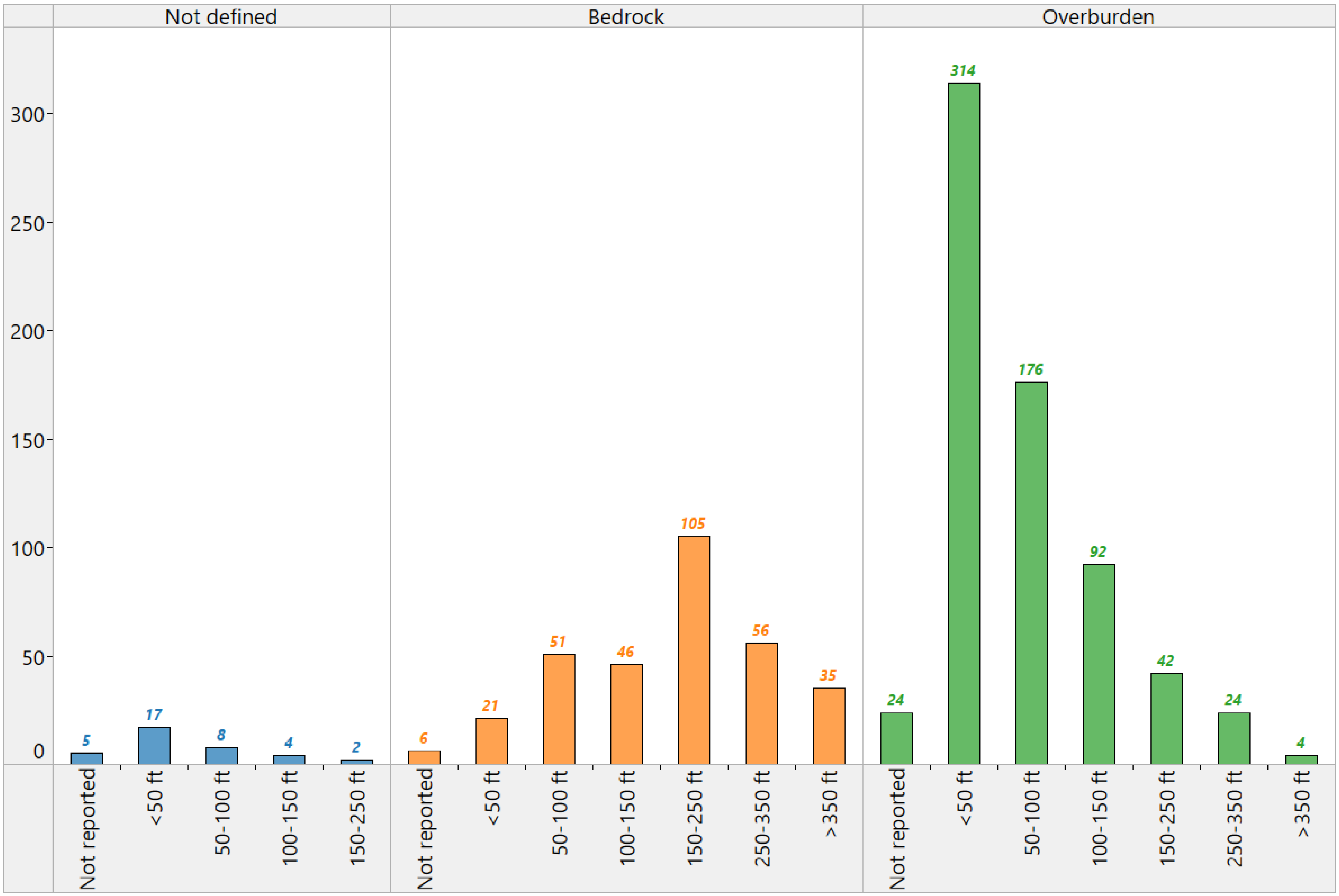

Figure 14: Number of wells present in the GWELLS database classified by completion type and depth

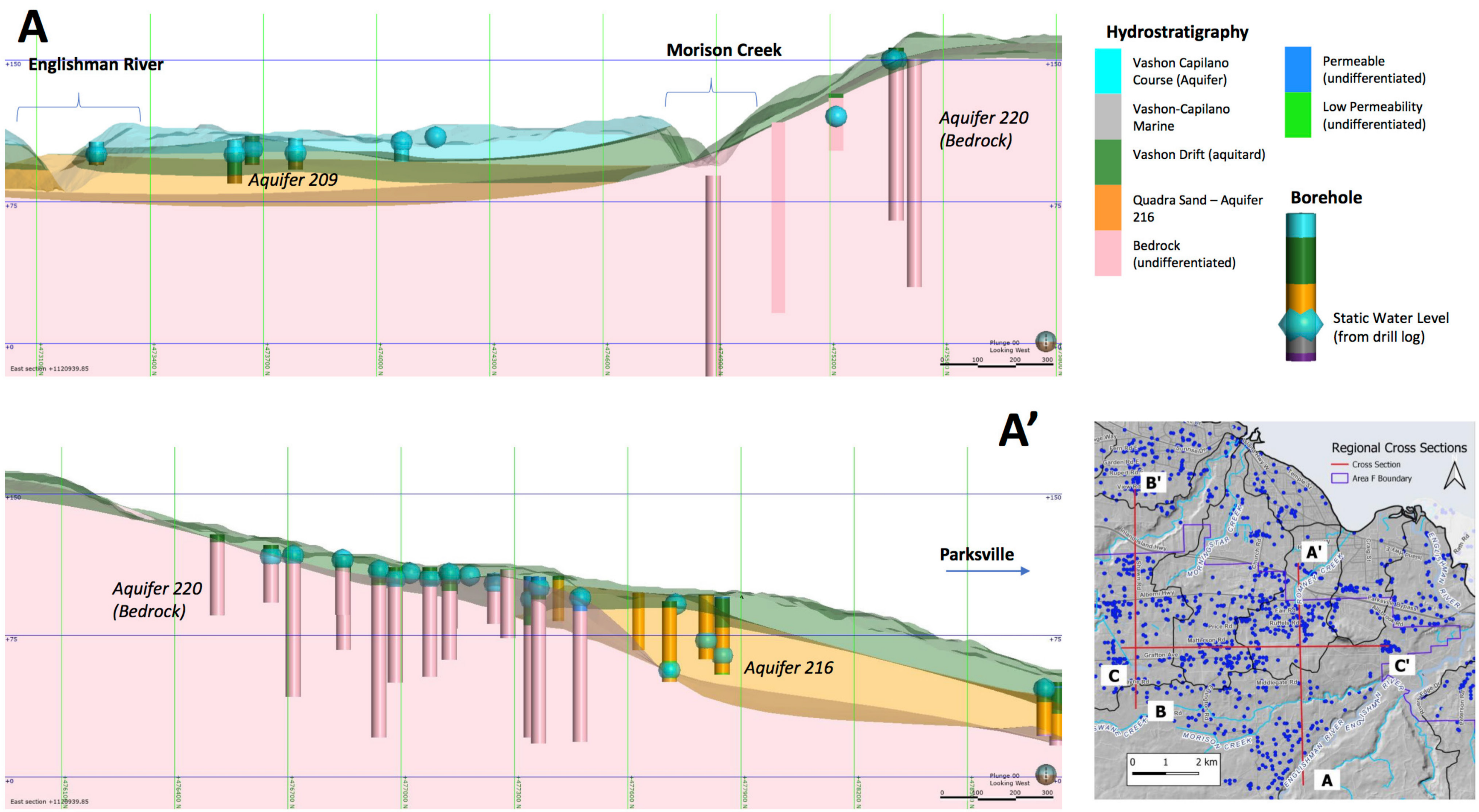

Figure 15: Hydrogeological Cross-section A-A' South-North through Englishman River and Morison Creek

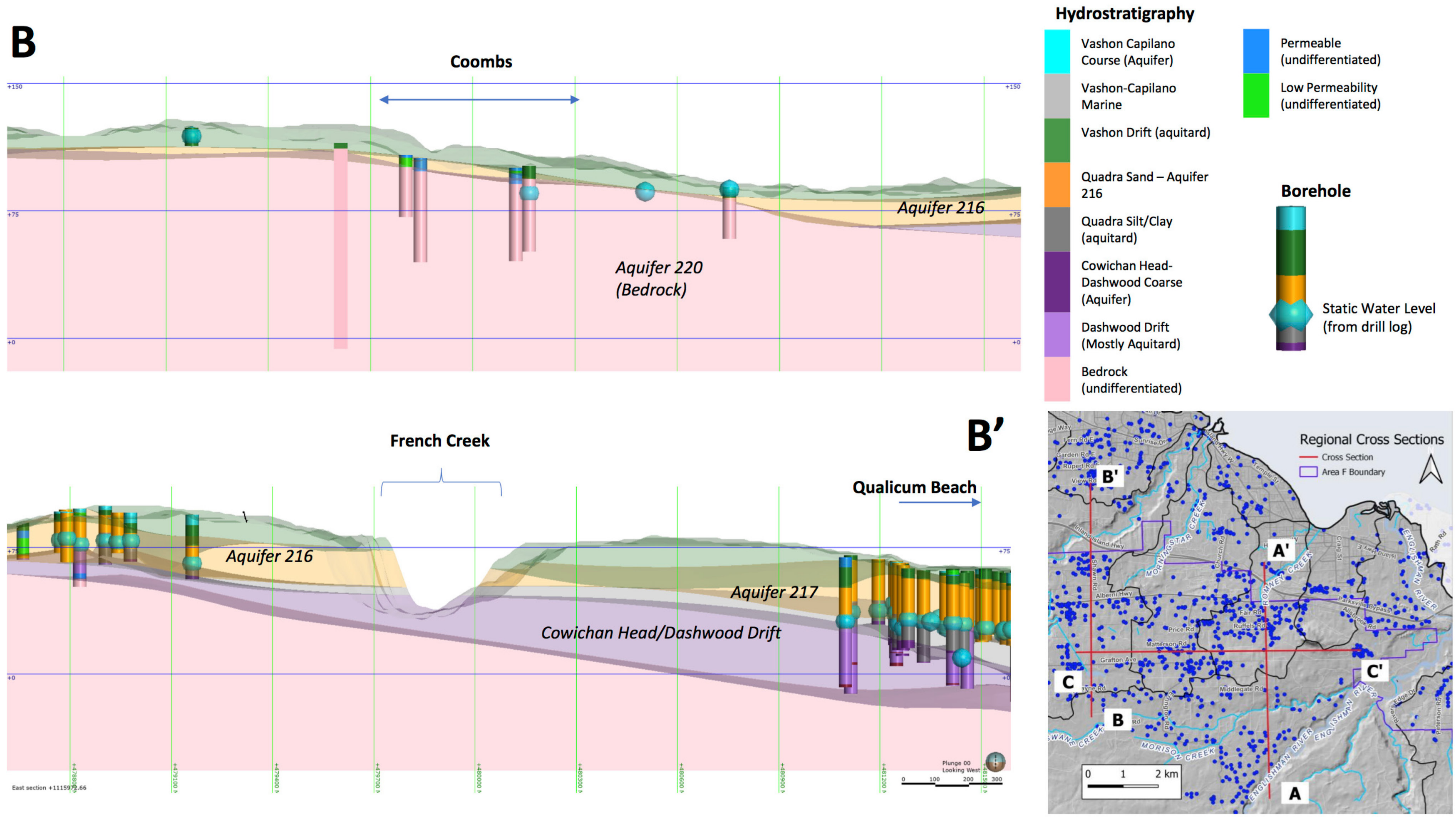

Figure 16: Hydrogeological Cross-section B-B' South-North through French Creek

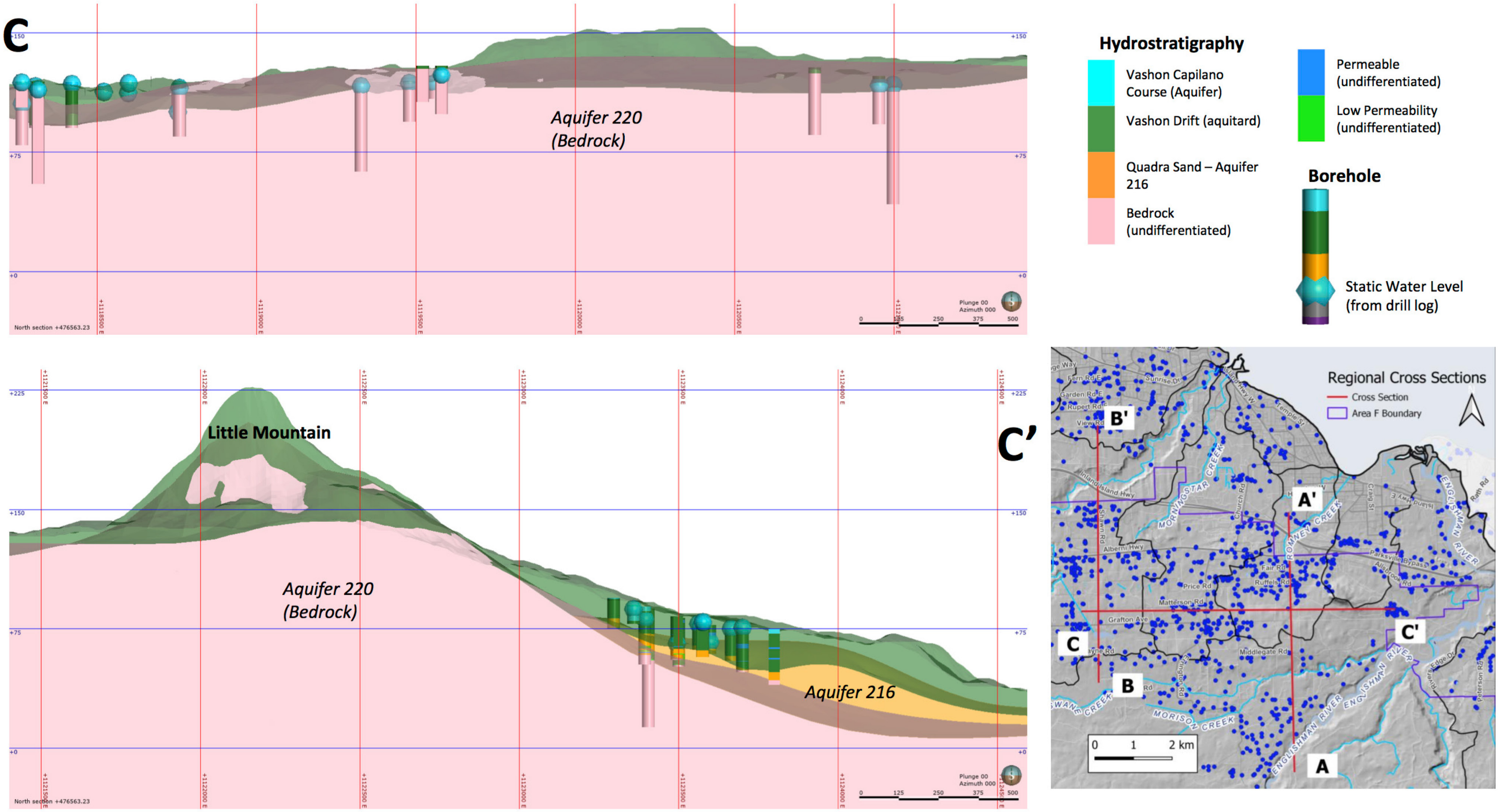

Figure 17: Hydrogeological Cross-section C-C' West-East through Little Mountain

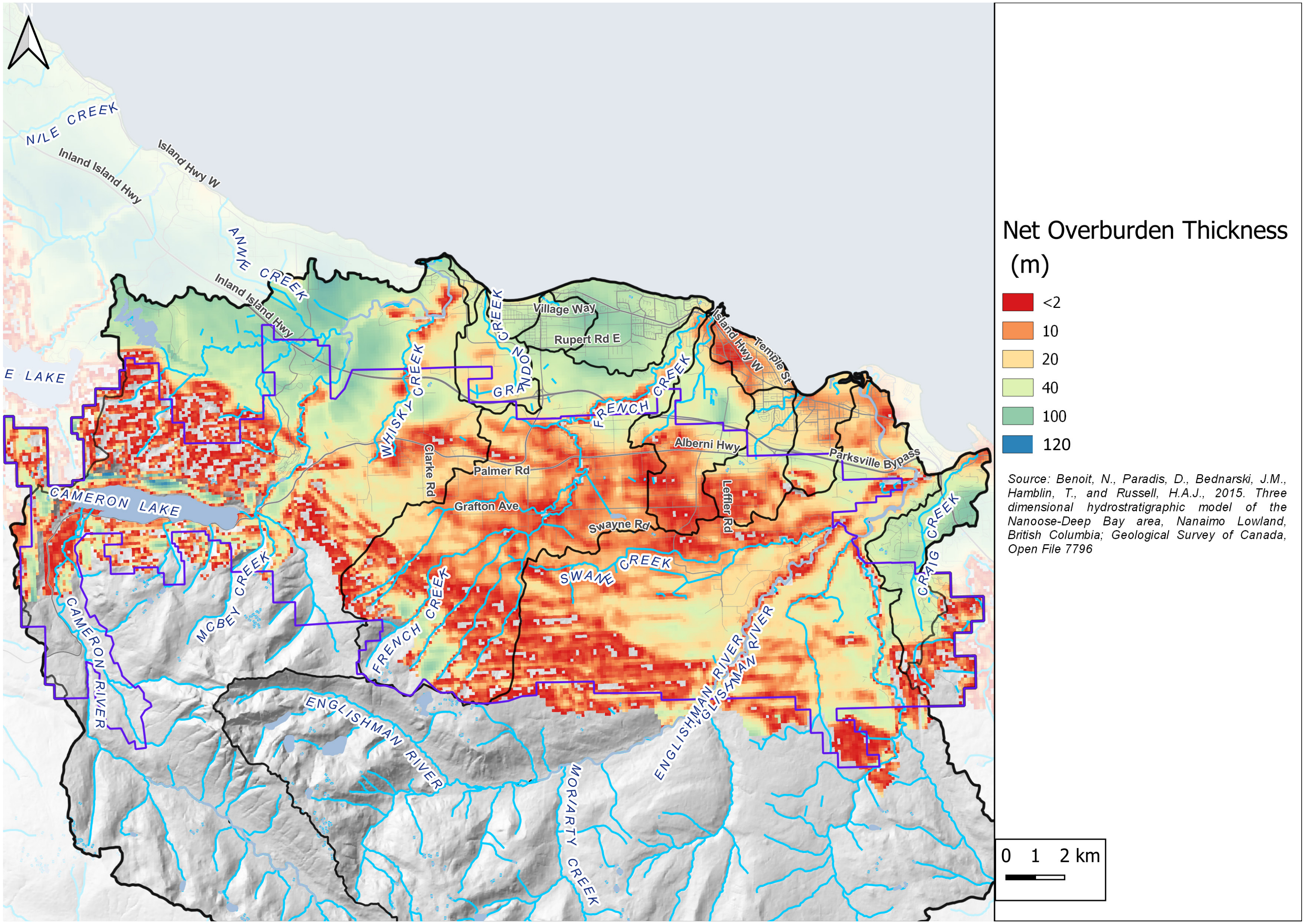

Figure 18: Thickness of overburden material

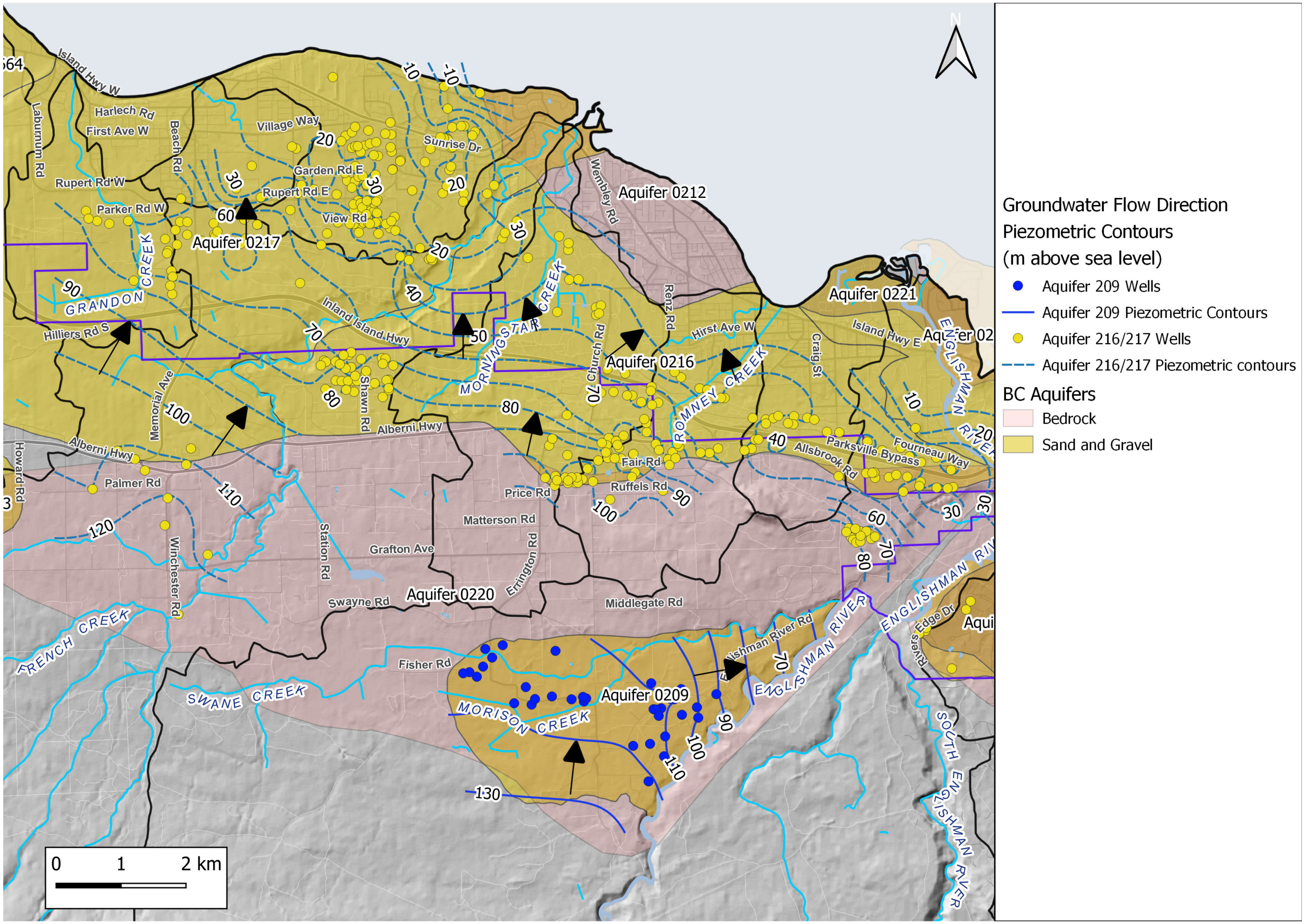

Figure 19: Groundwater flow direction in overburden aquifers

4.7 Observation Wells and Groundwater Levels

4.7.1 Data Compilation

In this report, an observation well refers to a well where groundwater level is regularly monitored. Three sources of information have been included in the assessment of groundwater levels: BC Provincial Government Observation Well Network (PGOWN), RDN volunteer Observation Wells, and wells monitored in the Englishman River Project (Figure 20).

Table 3 summarizes the 49 wells with available groundwater level information from which 19 wells are located within Area F. PGOWN wells OW287 (Aquifer 220 - Bedrock) and OW314 (Aquifer 216 - Overburden) have the largest data set with 36 and 28 years of data, respectively.

4.7.2 Water Level Analysis

Water level trend analysis, monthly and yearly summaries and level and precipitation analysis are presented in Figure 21 through Figure 28 for OW287 and OW314.

OW287, installed in Aquifer 220, records groundwater level data from 1984 to 2020 (Figure 21). High water levels usually occur in January and the lowest levels occur in September (Figure 22). Seasonal variation of water level is about 2.5 m. Groundwater level is clearly declining, with an approximate rate of decline of more than 1 m per decade (Figure 21). Over the last five years, depth to water varied between 4.5 and 8 m below ground in winter and 6.5 m and 9.5 m below ground in summer.

Figure 24 shows an analysis of the cumulative precipitation departure (CPD) versus groundwater levels in OW287. The cumulative precipitation departure from average (CPD) is a derivative of precipitation data (Weber, K., and M. Stewart, 2004). The CPD is calculated by determining the mean monthly precipitation over the groundwater level monitoring period and summing the cumulative difference between the actual monthly precipitation and the mean monthly precipitation for each month in the monitoring period. A decreasing CPD indicates that precipitation in a particular year or period is less than the long-term average. If groundwater level trends follow a similar trend to the CPD then this suggests that the groundwater level trend is being influenced by climatic factors.

Precipitation trends can partly explain the decline in groundwater level in Aquifer 220: From 1984 to 1990, the CPD decreased and groundwater level trend also decreased. However, after 1990, the CPD started to increase indicating that average precipitation within that period was higher than the long-term average, and groundwater levels appear to have stabilized. A decline in CPD from 2008 to present corresponds to a decline in groundwater levels. Other factors, such as land use (e.g., increased percentage of land covered by impermeable surfaces), and population rise have also likely contributed to the long-term decline observed in groundwater levels over the last 35 years.

OW314, installed in Aquifer 216, records groundwater level data from 1992 to 2020 (Figure 25). High water levels usually occur in April and the lowest occur in September (Figure 26). Seasonal variation in the water level is on average about 1 m. Groundwater levels drastically declined between 1992 and 2003. Following this, the groundwater level trend stabilized and even increased slightly up to present (Figure 25). We can also observe that over the last 5 years, groundwater levels were lower in 2015 and 2016 and higher from 2017 to 2019. Depth to water varies between 5.1 and 6.2 m below ground in spring (April) and 6.3 m and 6.9 m below ground in summer (September).

Figure 28 shows analysis of the cumulative precipitation departure (CPD) versus groundwater levels in OW314. The CPD increased between 1992 and 2008 and decreased between 2008 and 2019. Observed groundwater levels in OW314 are decoupled from a rising CPD from 1992 to 2003, likely as a result of the influence of nearby production wells managed by EPCOR water services. Apparently, EPCOR started regulating pumping in the production wells after 2003, which explains the stabilization of water level in OW314 after that year.

Unfortunately, there is not enough information (both in time and spatially) to describe the fluctuation of the water table for all the aquifers in Area F. However, based on the limited information, GW Solutions completed a preliminary trend analysis for the observation wells listed in Table 3. Data included in the trend analysis corresponds from January 01, 2010 to December 31, 2019 (10 years' time frame). Five trend categories were defined based on the estimated slope of water level: Stable (less than ±0.03 m per year), moderate rate of decline (slope between -0.03 to -0.10 m per year), large rate of decline (< -0.10 m per year), moderate rate of increase (slope between +0.03 to +0.10 m per year) and large rate of increase (>+0.10 m per year). The resulting trend analysis map is presented in Figure 29. Further analysis and discussion regarding groundwater level trends are provided in section 4.8 Groundwater Quantity - Discussion . Appendix 2 provides the water levels trend analysis for wells with data between 2010 and 2019.

Table 3. Compiled groundwater observation wells

Station ID	Station Name	Parameter	Source of Information	Status	Data From	Data To	Years of Data	Electoral Area F	Aquifer Number	Aquifer Type
OW287	OW287	Level	BC Gov	ACTIVE	3/12/1984	1/21/2020	35.9	Yes	220	Bedrock
OW295	OW295	Level	BC Gov	ACTIVE	11/26/1986	1/21/2020	33.2		217	Overburden
OW303	OW303	Level	BC Gov	ACTIVE	9/8/1988	11/13/2019	31.2		217	Overburden
OW304	OW304	Level	BC Gov	ACTIVE	10/3/1988	11/26/2019	31.2		216	Overburden
OW313	OW313	Level	BC Gov		1/8/1992	12/9/1992	0.9	Yes	216	Overburden
OW314	OW314	Level	BC Gov	ACTIVE	1/25/1992	1/21/2020	28.0	Yes	216	Overburden
OW321	OW321	Level	BC Gov	ACTIVE	12/15/1992	11/13/2019	26.9		217	Overburden
OW389	OW389	Level	BC Gov	ACTIVE	8/6/2010	1/21/2020	9.5		664	Overburden
OW391	OW391	Level	BC Gov	ACTIVE	4/11/2011	6/16/2019	8.2	Yes	662	Overburden
OW392	OW392	Level	BC Gov	ACTIVE	3/29/2011	7/8/2019	8.3		1098	Overburden
OW393	OW393	Level	BC Gov	ACTIVE	3/29/2011	1/21/2020	8.8		219	Overburden
OW395	OW395	Level	BC Gov	ACTIVE	4/20/2012	11/20/2019	7.6		1098	Overburden
OW396	OW396	Level	BC Gov	ACTIVE	4/27/2012	1/21/2020	7.7		219	Overburden
OW398	OW398	Level	BC Gov	ACTIVE	2/19/2013	11/26/2019	6.8		216	Overburden
OW424	OW424	Level	BC Gov	ACTIVE	1/4/2013	1/21/2020	7.0	Yes	216	Overburden
OW433	OW433	Level	BC Gov	ACTIVE	9/3/2013	11/13/2019	6.2			Overburden
OW434	OW434	Level	BC Gov	ACTIVE	4/3/2013	11/13/2019	6.6		217	Overburden
Bellevue	Bellevue (Private/volunteer)	Level	Englishman River Project	ACTIVE	12/13/2013	11/18/2016	2.9	Yes	220	Bedrock
Benzon	Benzon (Private/volunteer)	Level	Englishman River Project		8/18/2009	8/12/2010	1.0	Yes		Bedrock
Butler	Butler (Private/volunteer)	Level	Englishman River Project		8/31/2010	1/31/2014	3.4			Overburden
ERR Deep	ERR Deep (Private/volunteer)	Level	Englishman River Project	ACTIVE	7/18/2013	11/23/2016	3.4	Yes	220	Bedrock
ERR Shallow	ERR Shallow (Private/volunteer)	Level	Englishman River Project		7/18/2013	3/18/2014	0.7	Yes		Bedrock
Errington	Errington (Private/volunteer)	Level	Englishman River Project		8/18/2009	6/25/2013	3.9	Yes		Overburden
Fire Centre	Fire Centre (Private/volunteer)	Level	Englishman River Project		10/1/2010	1/31/2014	3.3	Yes		Overburden

Station ID	Station Name	Parameter	Source of Information	Status	Data From	Data To	Years of Data	Electoral Area F	Aquifer Number	Aquifer Type
Fisher	Fisher (Private/volunteer)	Level	Englishman River Project	ACTIVE	7/6/2013	11/18/2016	3.4	Yes	220	Bedrock
Grieg	Grieg (Private/volunteer)	Level	Englishman River Project	ACTIVE	6/26/2013	11/17/2016	3.4			Bedrock
Highway Scale	Highway Scale (Private/volunteer)	Level	Englishman River Project		8/31/2010	1/31/2014	3.4			Overburden
IT Yard	IT Yard (Private/volunteer)	Level	Englishman River Project		10/1/2010	2/11/2014	3.4		1098	Overburden
Lana	Lana (Private/volunteer)	Level	Englishman River Project	ACTIVE	12/13/2013	2/16/2016	2.2		210	Bedrock
Leffler	Leffler (Private/volunteer)	Level	Englishman River Project	ACTIVE	6/26/2013	11/23/2016	3.4	Yes	220	Bedrock
Lt. Mountain	Lt. Mountain (Private/volunteer)	Level	Englishman River Project	ACTIVE	8/31/2010	11/18/2016	6.2	Yes	220	Bedrock
Maple	Maple (Private/volunteer)	Level	Englishman River Project		8/31/2010	12/12/2013	3.3			Overburden
Margot	Margot (Private/volunteer)	Level	Englishman River Project	ACTIVE	8/18/2009	11/23/2016	7.3	Yes		Bedrock
Martindale	Martindale (Private/volunteer)	Level	Englishman River Project	ACTIVE	10/25/2011	11/17/2016	5.1			Bedrock
Matthew Deep	Matthew Deep (Private/volunteer)	Level	Englishman River Project	ACTIVE	2/12/2014	11/23/2016	2.8			Bedrock
Matthew Shallow	Matthew Shallow (Private/volunteer)	Level	Englishman River Project		8/13/2010	12/11/2013	3.3		1098	Overburden
Paradise	Paradise (Private/volunteer)	Level	Englishman River Project		8/18/2009	12/11/2013	4.3			Overburden
Peterson	Peterson (Private/volunteer)	Level	Englishman River Project		6/26/2013	1/31/2014	0.6	Yes		Bedrock
Rascal	Rascal (Private/volunteer)	Level	Englishman River Project		7/12/2011	6/25/2013	2.0			Overburden
Rathtrevor Maint Yd	Rathtrevor Maint Yd (Private/volunteer)	Level	Englishman River Project		9/25/2010	1/31/2014	3.4			Overburden
Rathtrevor Nature House	Rathtrevor Nature House (Private/volunteer)	Level	Englishman River Project		9/25/2010	6/25/2013	2.8			Overburden
TH4	TH4 (Private/volunteer)	Level	Englishman River Project		7/12/2011	6/25/2013	2.0			Overburden
Wildgreen	Wildgreen (Private/volunteer)	Level	Englishman River Project		8/18/2009	7/22/2011	1.9			Overburden

Station ID	Station Name	Parameter	Source of Information	Status	Data From	Data To	Years of Data	Electoral Area F	Aquifer Number	Aquifer Type
VOW01	VOW01 (RDN private/volunteer)	Level	RDN	ACTIVE	4/23/2013	6/20/2019	6.2		216	Overburden
VOW14	VOW14 (RDN private/volunteer)	Level	RDN	ACTIVE	8/24/2017	6/20/2019	1.8		216	Overburden
VOW15	VOW15 (RDN private/volunteer)	Level	RDN	ACTIVE	8/24/2017	6/20/2019	1.8		212	Bedrock
VOW16	VOW16 (RDN private/volunteer)	Level	RDN	ACTIVE	8/24/2017	6/5/2019	1.8	Yes	217	Overburden
VOW17	VOW17 (RDN private/volunteer)	Level	RDN	DISCONTINUED	8/24/2017	4/24/2018	0.7	Yes	209	Overburden
VOW18	VOW18 (RDN private/volunteer)	Level	RDN	ACTIVE	8/24/2017	6/20/2019	1.8	Yes	220	Bedrock

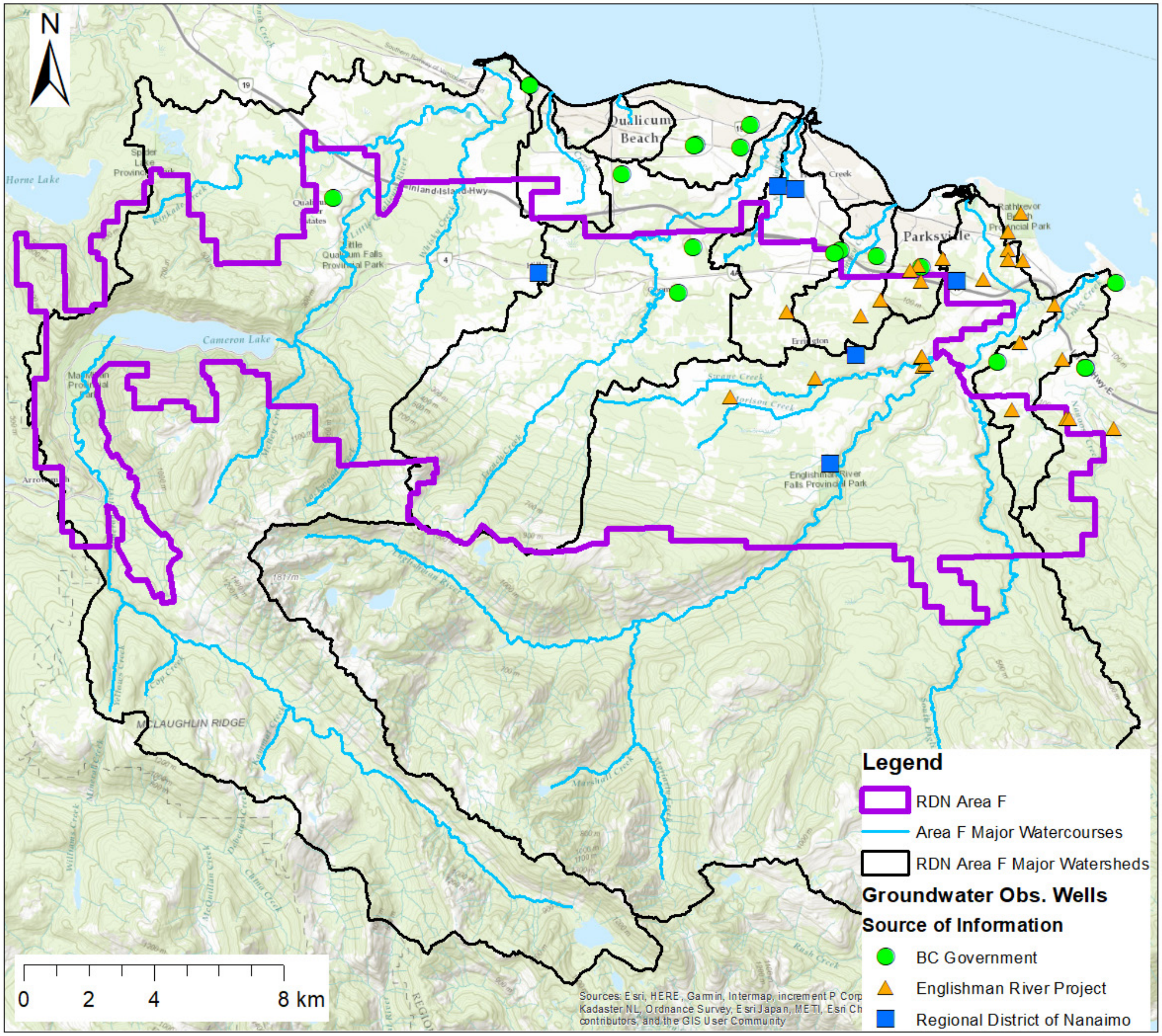

Figure 20. Observation wells classified by source of information

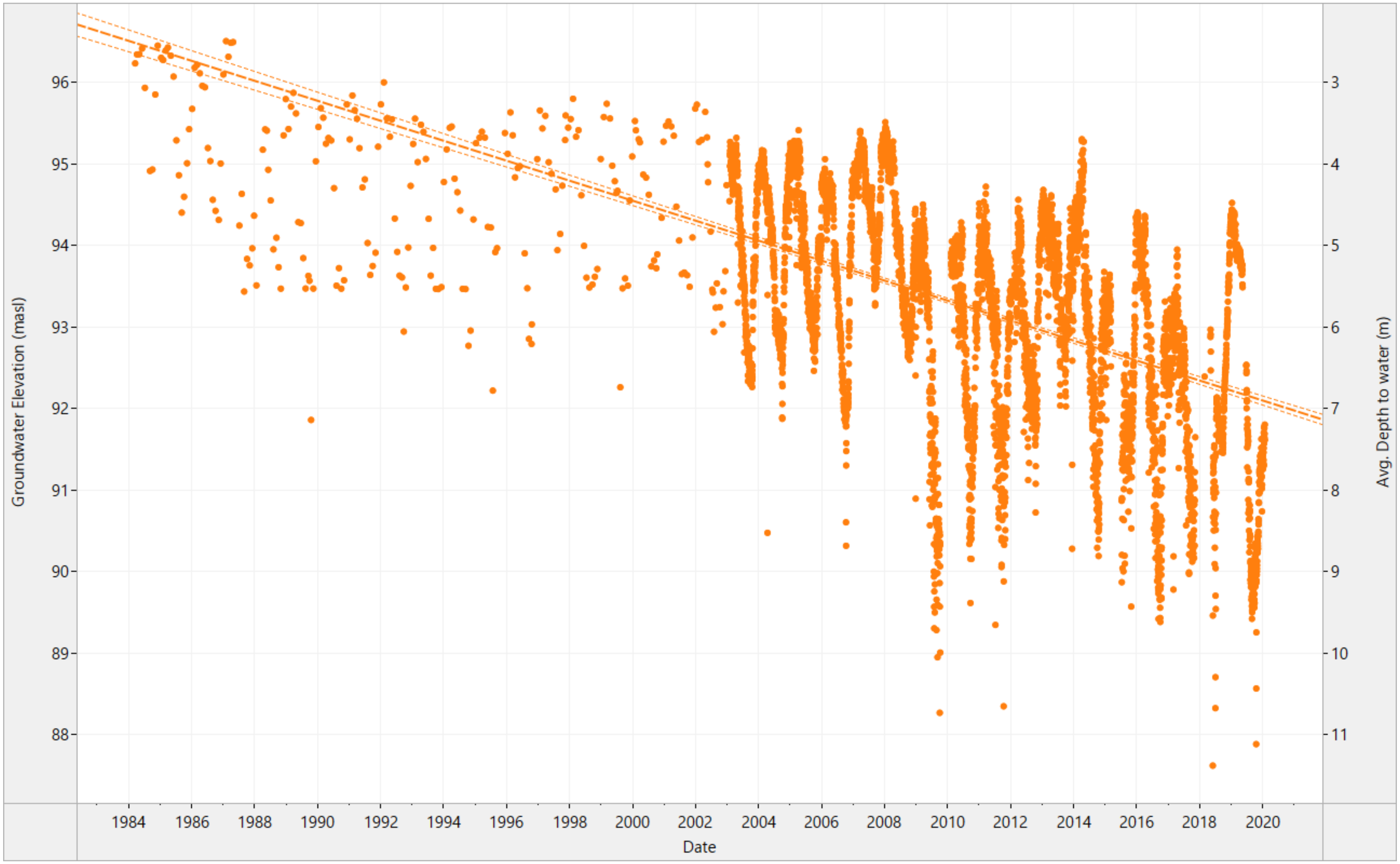

Figure 21. Groundwater elevation and depth to water in OW287 completed in Bedrock Aquifer 220.

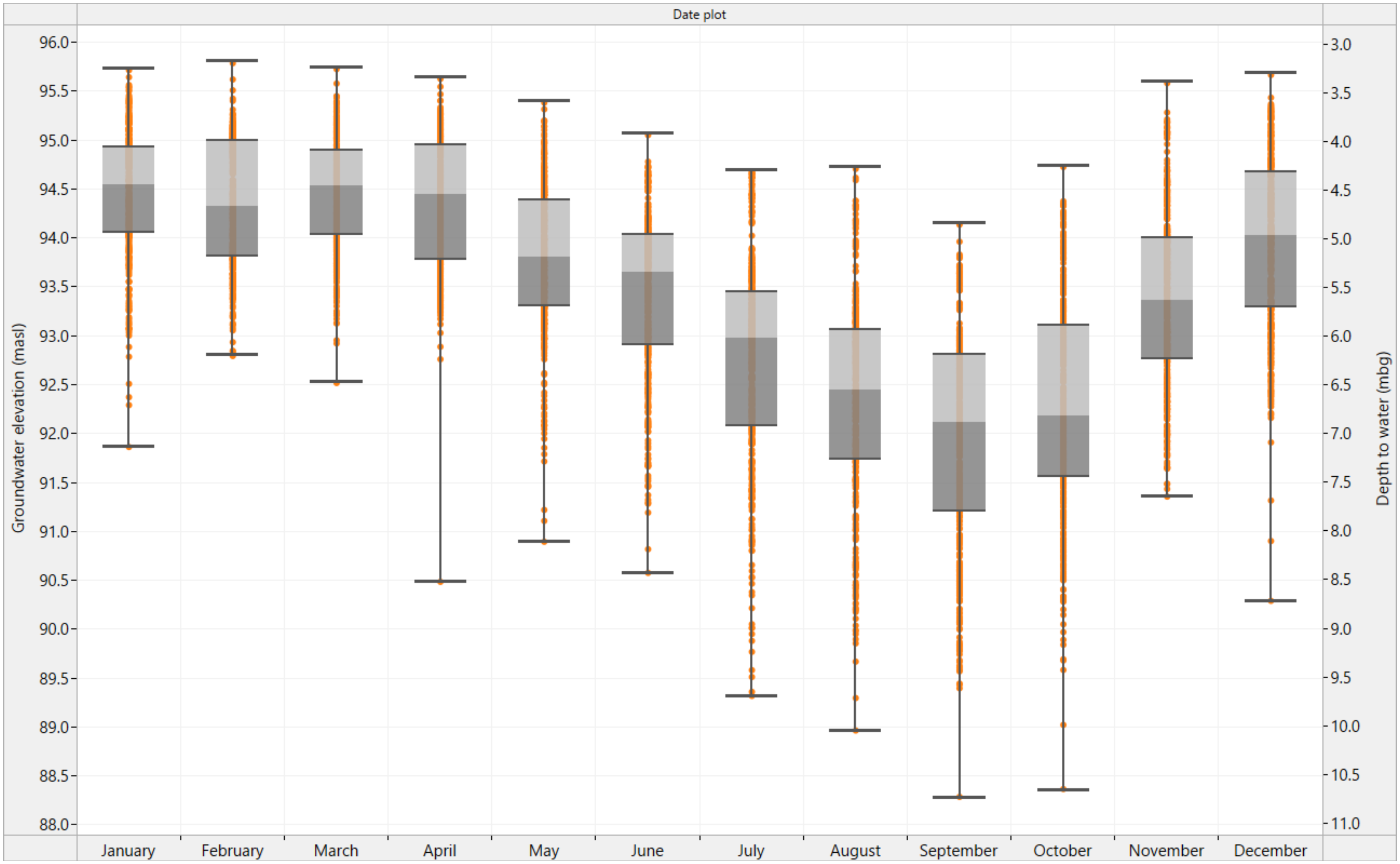

Figure 22. Monthly variation in groundwater elevation and depth to water (OW287)

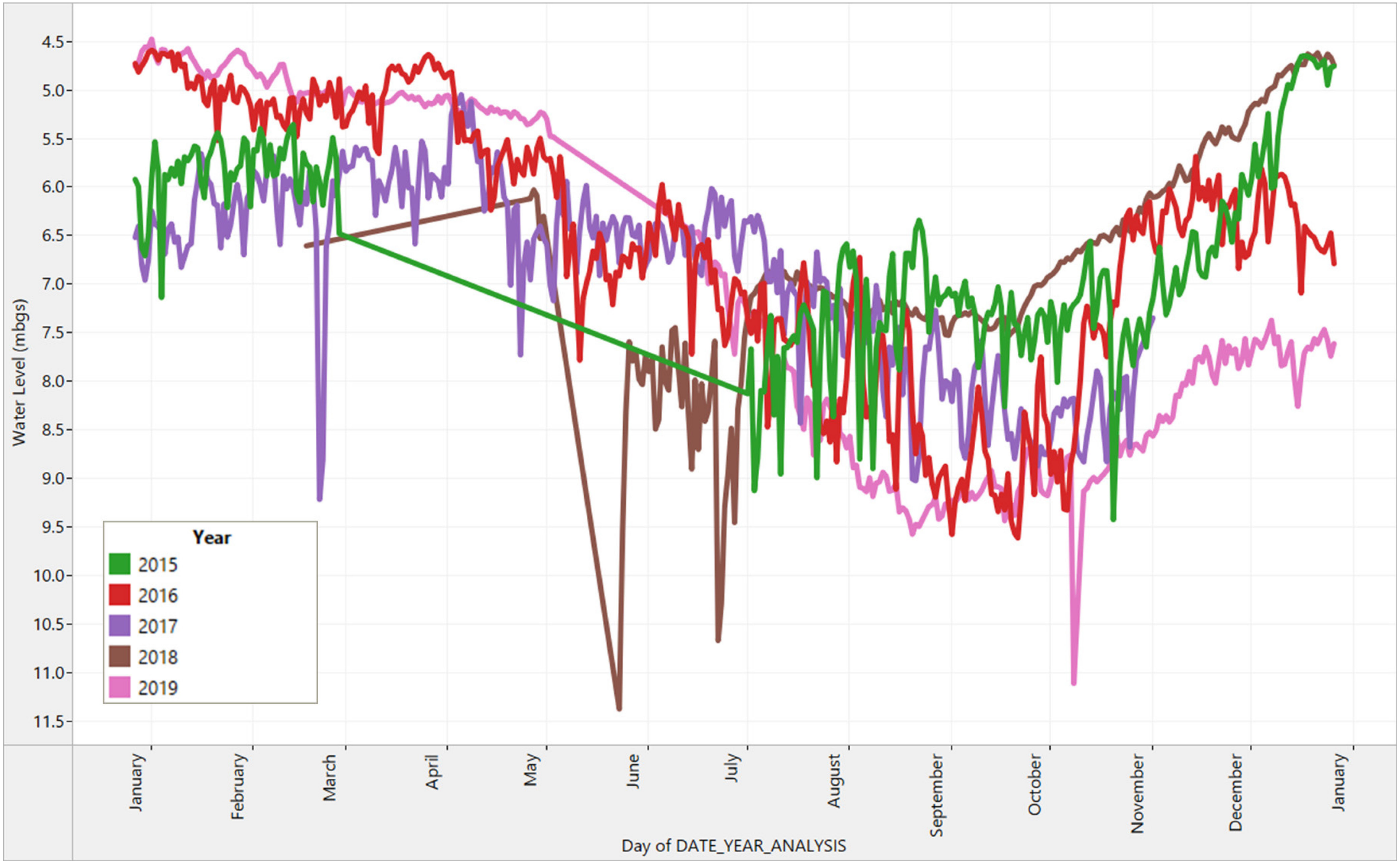

Figure 23. Variation of water level in OW287 for the last five years (2015-2019)

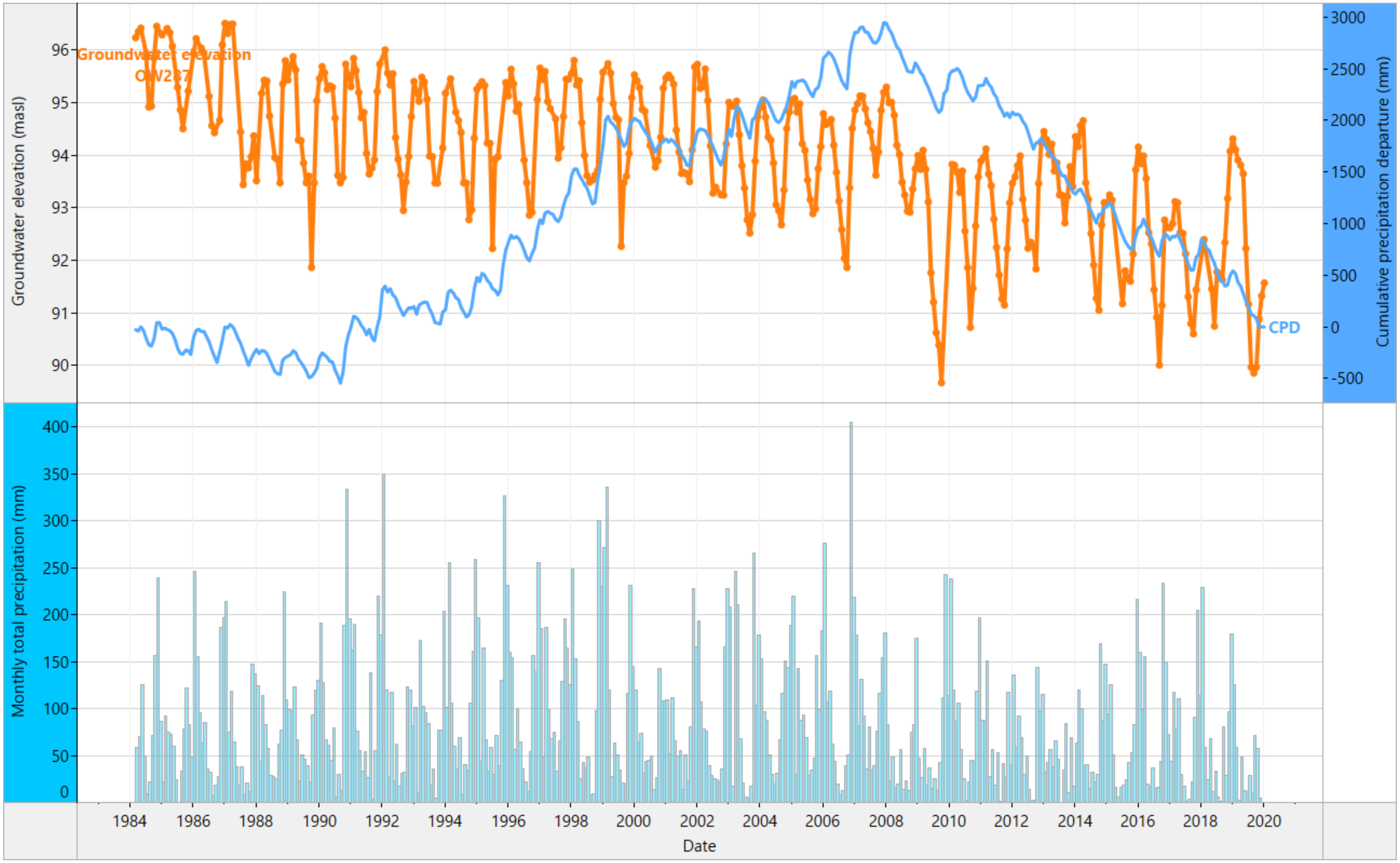

Figure 24. OW287: Groundwater levels (orange) compared to cumulative precipitation departure curve (blue) and total monthly precipitation (2010-2016)

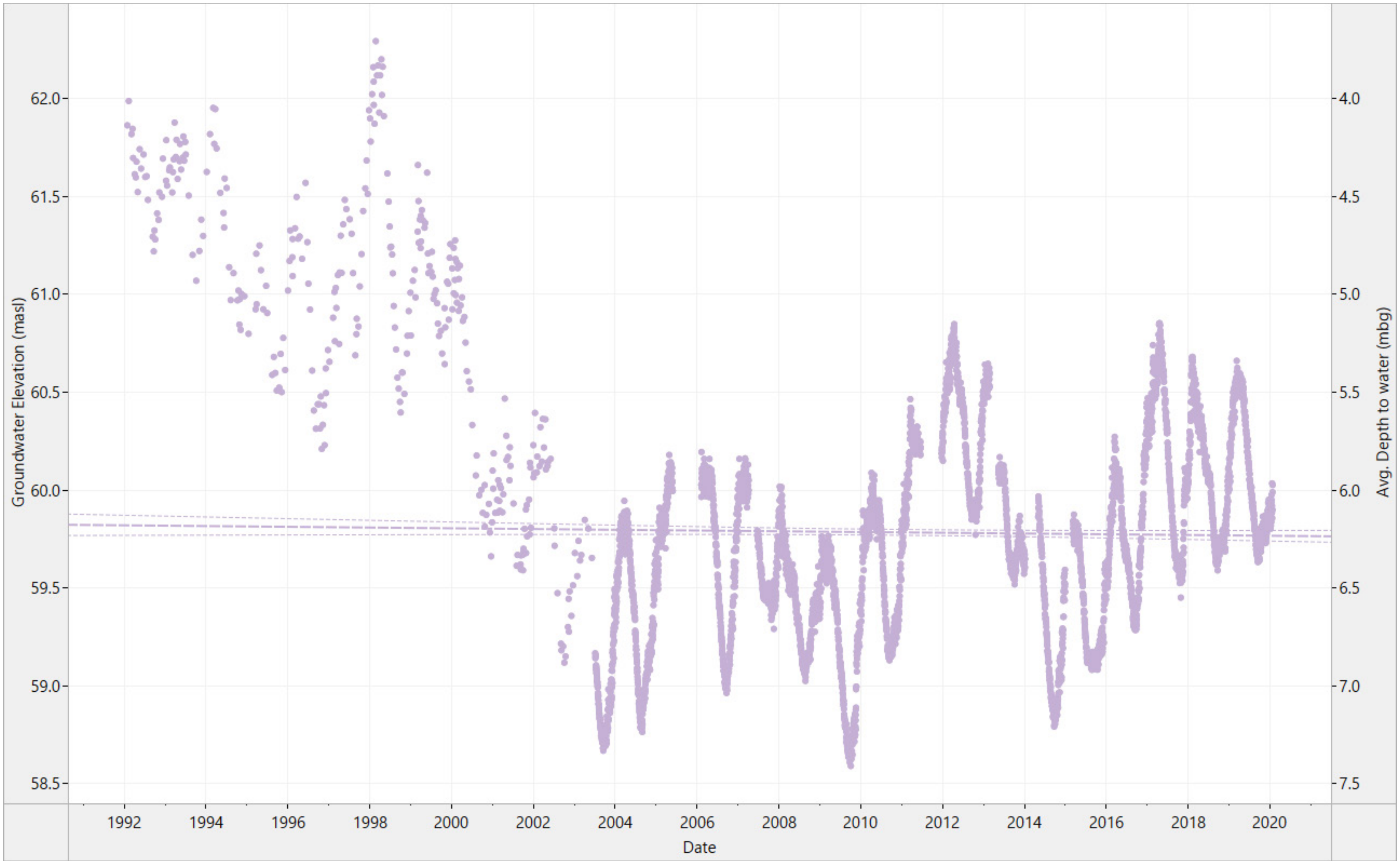

Figure 25. Groundwater elevation and depth to water in OW314 completed in Overburden Aquifer 216.

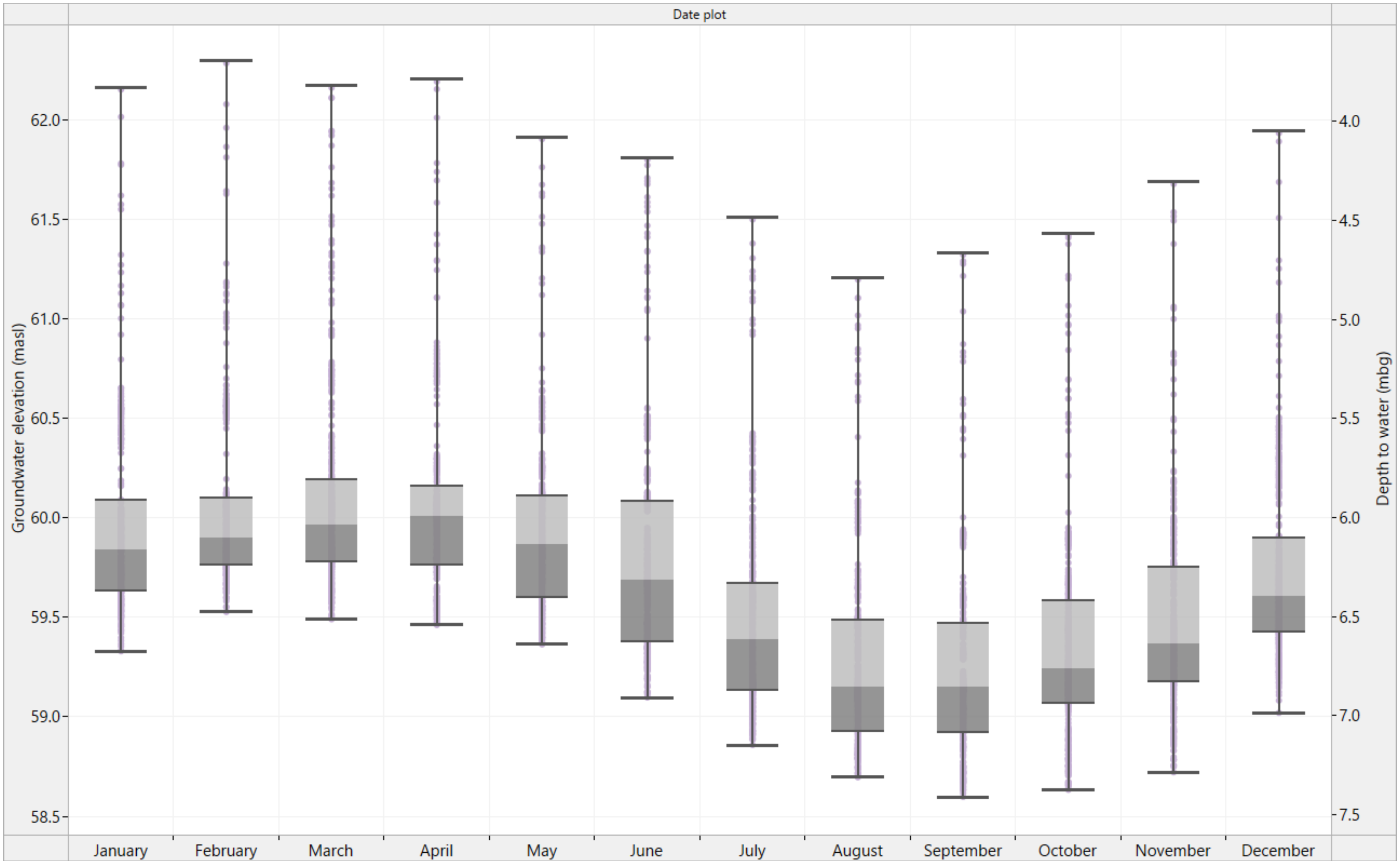

Figure 26. Monthly variation of groundwater elevation and depth to water (OW314)

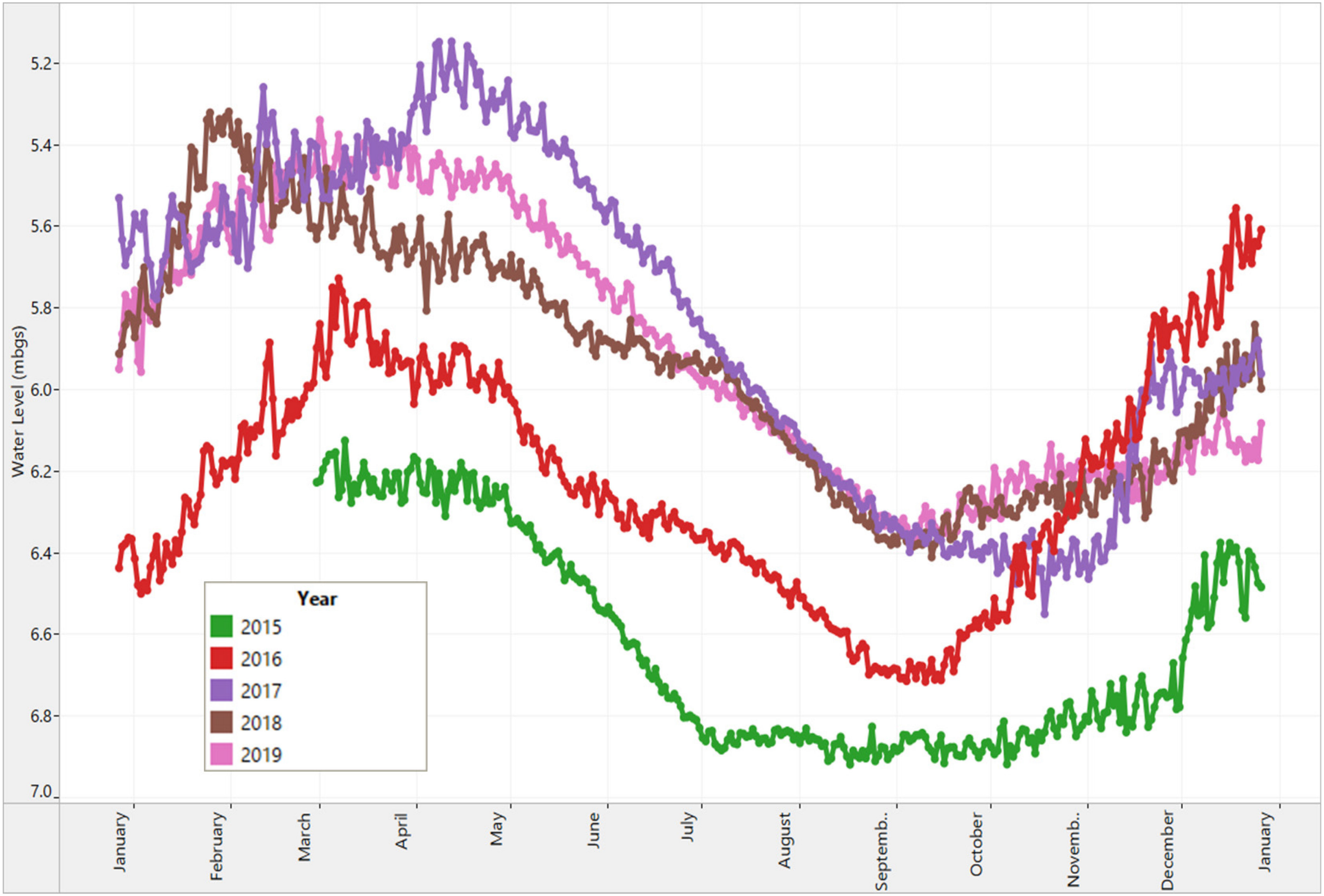

Figure 27. Variation of water level in OW314 for the last five years (2015-2019)

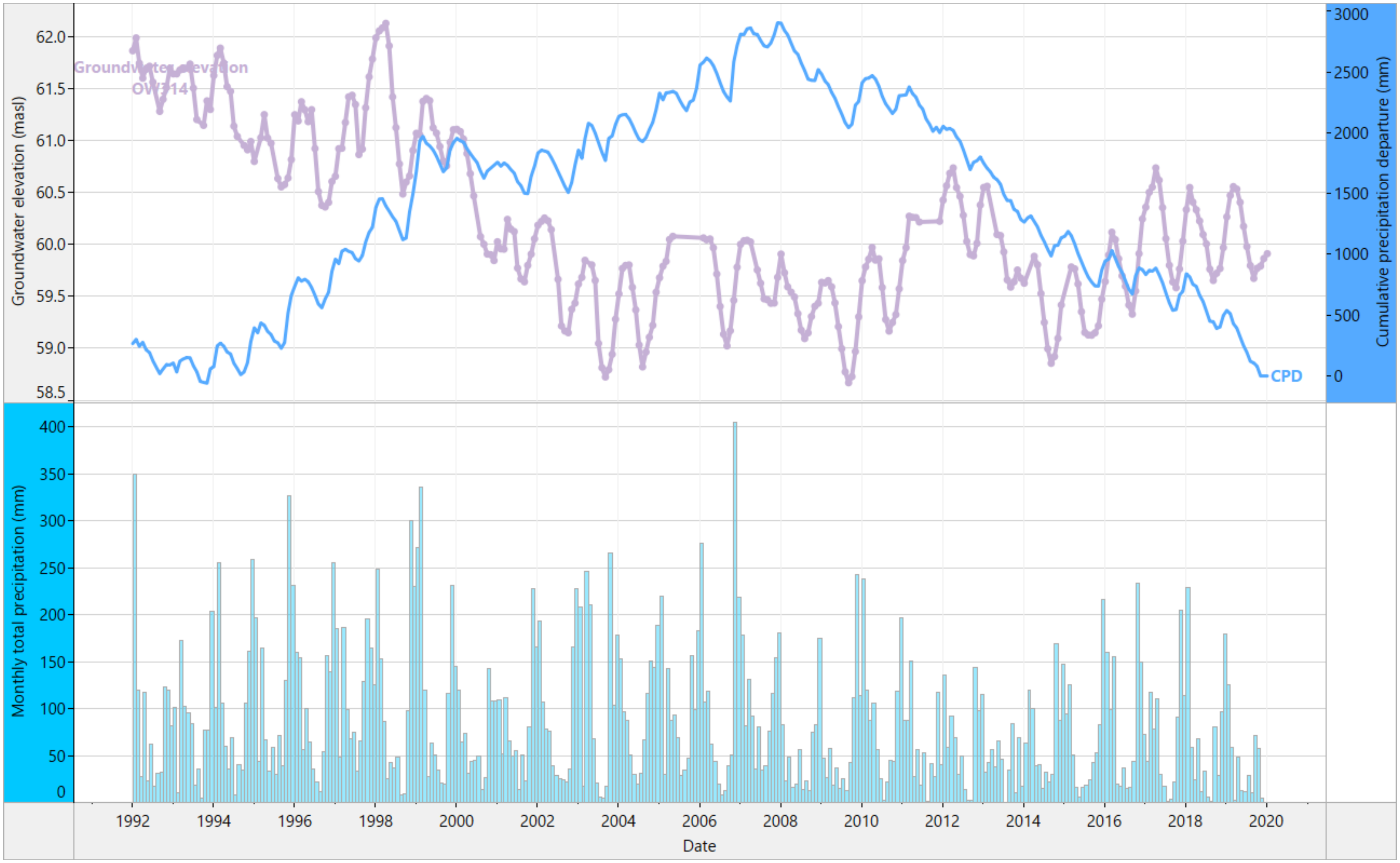

Figure 28. OW314: Groundwater levels compared to cumulative precipitation departure curve and total monthly precipitation (2010-2016)

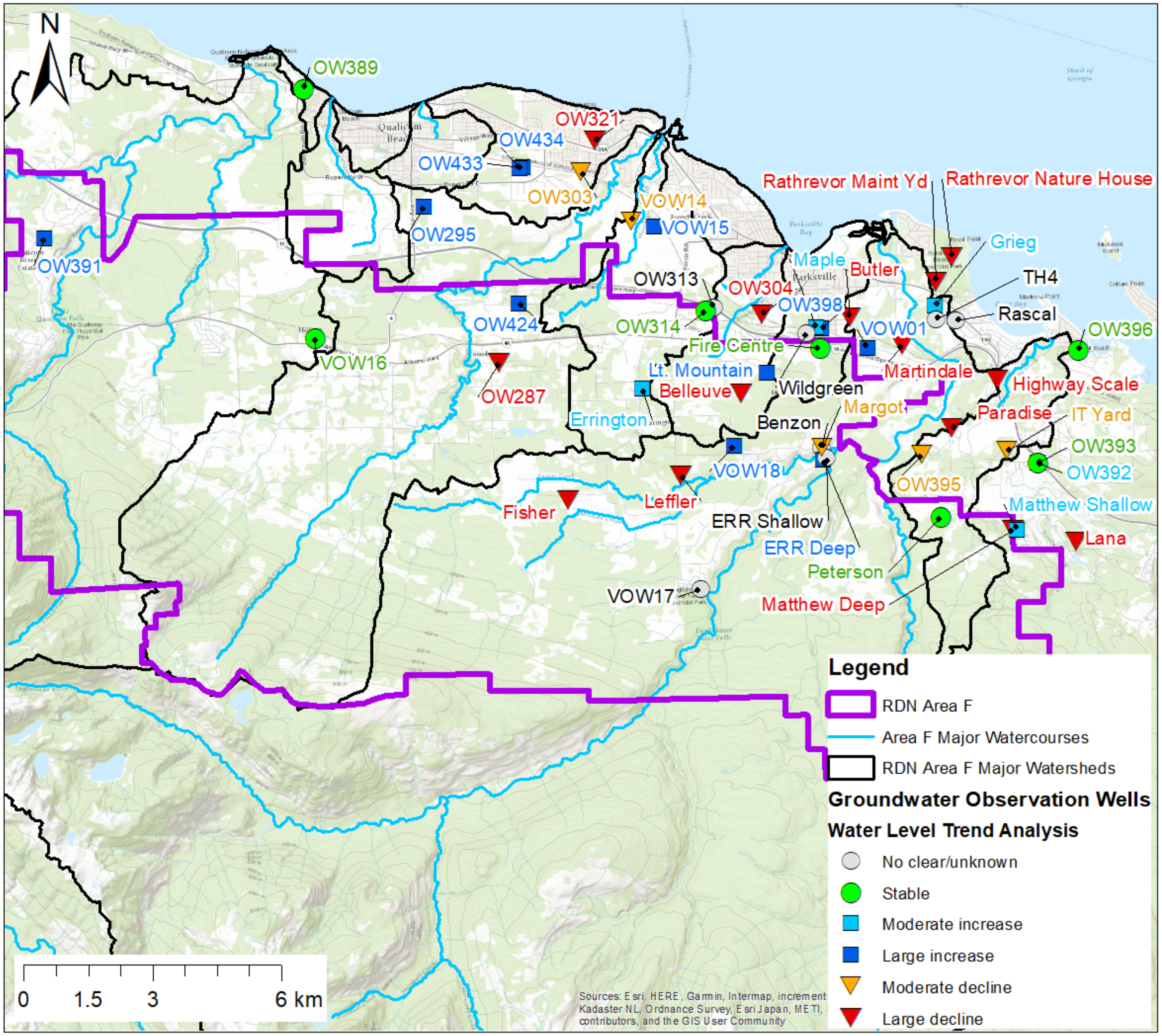

Figure 29. Water level trend analysis

4.8 Groundwater Quantity - Discussion

4.8.1 Groundwater in Bedrock

Only one monitoring well (OW287) provides a long-term trend (since 1984) in bedrock. The annual high water level appears to have dropped by about 2 m from approximately 96 m to 94 m. The annual low water level (summer conditions) appears to have dropped by about 6 m from approximately 94 m to 88 m. The decline is more noticeable after 2000.

The CPD curve shows a wetting trend from 1990 through 2007, and since then a drying trend, indicative of a general water deficit of approximatively 3 m over the last 13 years. The effect on the drying trend is not observed in its early phase (2008-2014), but is noticed in the last five years, with an observed 3 m drop of the high water level.

We also observe that the lowest levels were observed in 2018 and 2019, and the largest amplitude of fluctuation (over 6 m) was observed during the same period (Figure 23).

Of the set of bedrock wells with shorter monitoring time spans (since 2010), Bellevue, Leffler, and Martindale private wells indicate a decreasing trend, with a more noticeable drop of the annual low water levels, in the order of 2 m. It appears that these monitoring wells are connected to the regional groundwater flow in the fractured bedrock associated with the mountain block recharge.

Some wells indicate a general increasing trend: ERR Deep (0.5 m over 2013-2016) and Little Mountain (2 m over 2010-2016). The ERR Deep well appears to be connected to the Englishman River. Little Mountain is a large bedrock hill where groundwater recharge is taking place, as revealed by groundwater mounding observed within its footprint. The Little Mountain well illustrates the local groundwater regime on Little Mountain.

Figure 30 shows the groundwater water level trend analysis results summarized in extrapolated polygons (Thiessen). To determine these polygons only bedrock wells were included. These interpolated groundwater level trend regions will assist the RDN in further developing Aquifer Protection Development Permit Areas.

Groundwater in bedrock: Drop in water levels observed, except near Little Mountain (having its own recharge), and near the Englishman River.

4.8.2 Groundwater in Overburden Aquifers

More monitoring information is available in the overburden aquifers. In this section, comments on the aquifers encountered in Area F or north of it, from west to east are provided. However, the comments are still very limited because of the lack of data.

Aquifer 661: Data is only available from one well (Shayla) for a relatively short period (2013 – 2015). The amplitude of the fluctuation is relatively small (1 m). There is not enough information to discuss the status of this aquifer.

Aquifer 662: Data is only available from one well (OW391) for approximately nine years (2011 – 2019). The amplitude of the fluctuation of the groundwater level is approximately 2 m. The recent rise of the water level from 2014 to 2019 by about 2 m, following an observed water level drop between 2011 and 2014 is encouraging.

Aquifer 664: Data is only available from one well (OW389) for approximately ten years (2010 – 2019). The amplitude of the water level fluctuation is approximately 2 m, and the levels have been constant, with no sign of stress on the aquifer. However, on its eastern side, towards French Creek, a gradual decrease of the water level has been observed in the last 30 years.

Aquifer 217: In its central part, as shown by data collected at OW295 since 1988, a drop of approximately 3 m has been recorded, indicative of aquifer mining. However, the levels appear to have stabilized in the last 10 years. This stabilization might be a result of changes in groundwater use from the aquifer in the area of the observation well (production well management).

Aquifer 216: The water levels appear to be stable in the western part of this aquifer as indicated by OW424. In its central part, several wells (OW304, OW314) indicate a gradual drop until 2004 (OW314) and 2015 (OW304). Since then, the levels have stabilized or recovered. This more recent behaviour is also observed in its eastern part (VOW01).

Aquifer 209: Data are only available from one well (VOW17) for a very short period (2017 – 2018). The amplitude of the fluctuation is relatively small (1 m). There is not enough information to discuss the status of this aquifer.

Aquifer 1098: Based on data covering approximately 10 years, the conditions appear stable in the up-gradient and southern part of the aquifer. More data is required to comment on the status of the aquifer in its northeast part.

Figure 31 shows the interpreted groundwater level regions for the overburden aquifers within the Area F. Groundwater levels within the overburden aquifers are relatively stable with the exception along the Englishman River for which moderate declining trends of groundwater levels are observed.

Groundwater in surficial aquifers: Conditions are relatively stable, after declining trends were observed in Aquifer 216 (until 2015) and 217 (until 2010).

4.8.3 Concerns

Bedrock Aquifer 220 within Area F has shown a declining trend of water levels mainly due to a combination of climatic effects since 2008 and likely groundwater and surface water extraction in the area.

Water purveyors operating in Area F, including the RDN, rely heavily on groundwater; therefore, use and monitoring of the aquifers should be completed in concert to prevent over pumping and stressing of the aquifers.

Extraction of water from surface water bodies will directly impact wells connected to streams, especially wells completed in surficial sediments adjacent to waterbodies. This depends on whether the stream is gaining, loosing, or disconnected to the aquifer.

It is anticipated, due to climatic conditions, that snow accumulation will decrease. This will directly impact aquifers (e.g., Aquifer 216) and wells that have a snow dominant recharge regime.

The head water of the Little Qualicum River, French Creek and Englishman River watersheds have experienced extensive tree loss over the last 18 years. This may result in a deterioration of water quality during times of high flow and potential reduction in quantity during times of low flow.

A summary of water quantity concerns to groundwater availability is presented in Table 4. The rating or level of concern is based on a professional opinion.

Table 4. Water quantity concerns and rating

Potential concerns	Rating	Rationale	Comments
Water usage (from water supply systems and points of diversion)	High	Increase in population, water usage, combined with longer dry season	An increase in water usage due to growth in the area is predicted. (potentially mitigated by more efficient water management). Water demand for irrigation will very likely increase in response to climate change.
Climate change	High	Shift in precipitation pattern, less snow, and longer and dryer summers	It is predicted to negatively affect groundwater recharge particularly in aquifers with snow dominant recharge regime.
Forestry (forest loss)	Moderate	Based on the slope, morphology and percentage of area affected by forest loss	The loss of forest cover modifies water flows and water levels. Complexity of effects function of many factors (stage of canopy, etc.)
Land use (increase in impermeable surface)	Low-moderate	Increase in population will likely result in increase of impermeable areas	Impermeable surfaces impede groundwater recharge. However, Area F is still predominantly rural and increase in impermeable area is anticipated to be small.

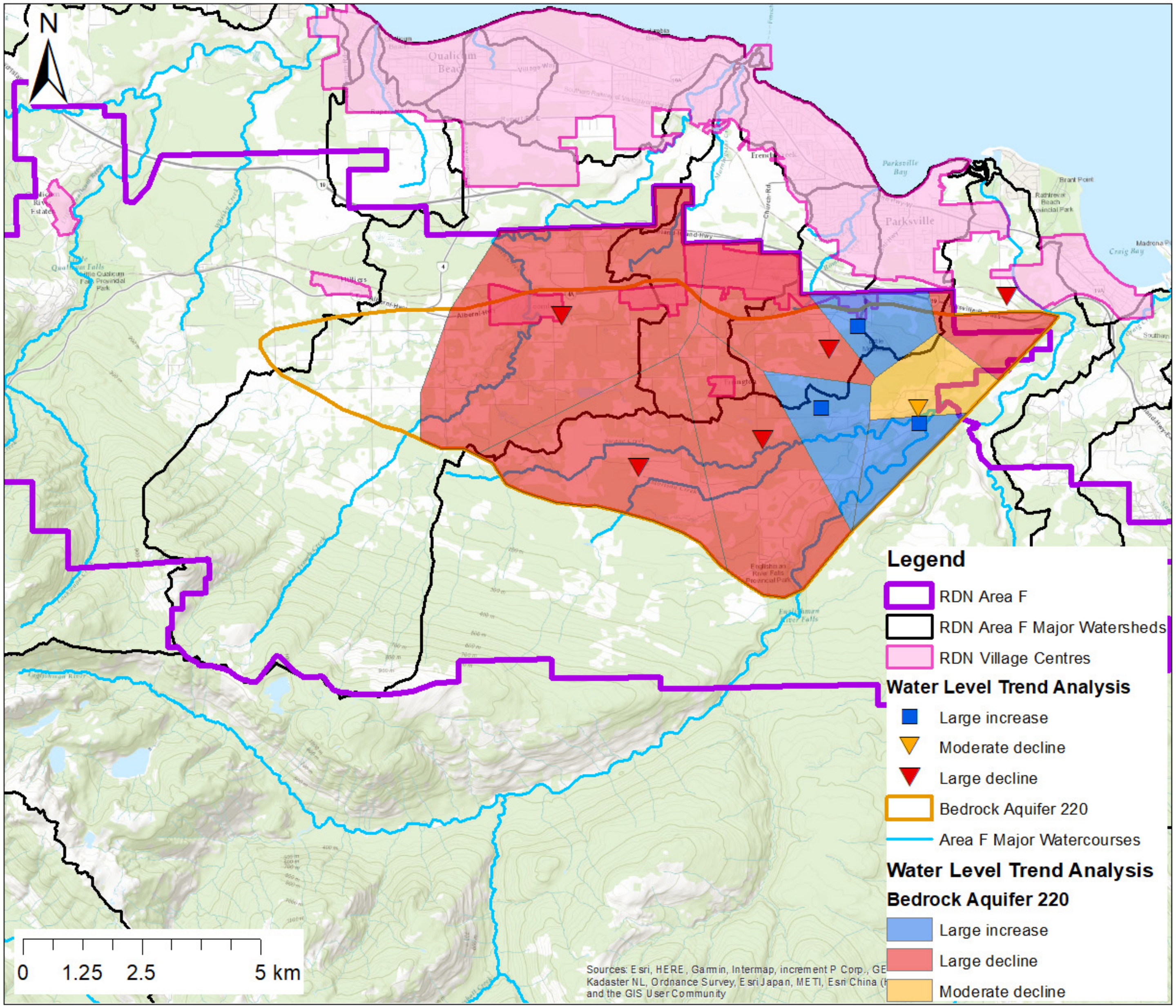

Figure 30. Interpreted groundwater level trend regions for bedrock aquifer 220

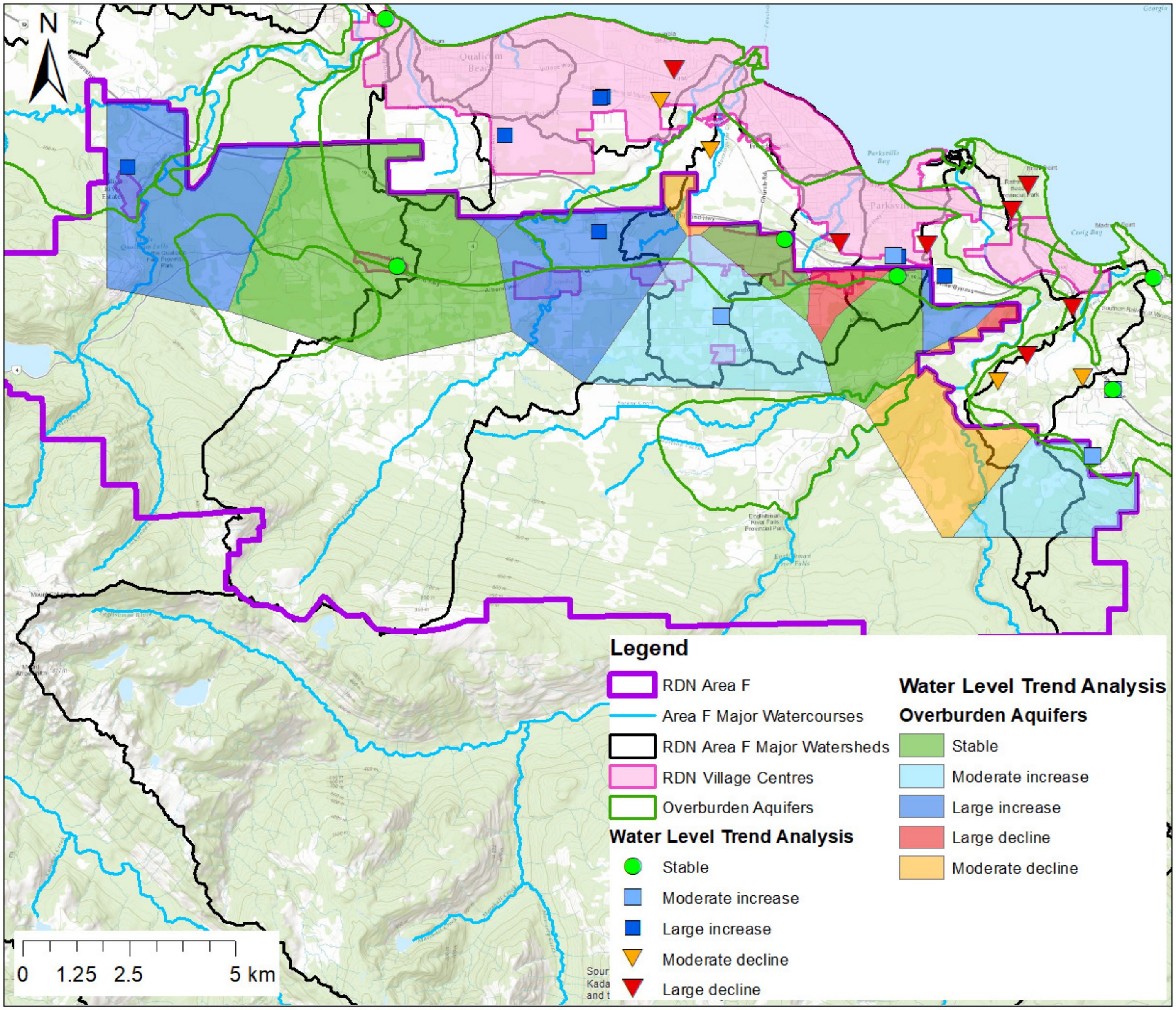

Figure 31. Interpreted groundwater level trend regions for unconsolidated aquifers (sand and gravel material)

4.9 Stream Flows and Levels

4.9.1 Data compilation

GW Solutions compiled streamflow and stream level information from BC Real Time Water Data Portal (Aquarius Web Portal, February 2020), Water Survey of Canada (WSC) and the Englishman River Project. The resulting maps with the hydrometric stations classified by source of information and available monitoring data are shown in Figure 32 and Figure 33, respectively.

Table 5 summarizes information available from the hydrometric stations. Four WSC stations present the largest datasets (08HB002-Englishman River near Parksville, 08HB004-Little Qualicum River at Outlet of Cameron Lake, 08HB029-Little Qualicum River near Qualicum Beach, and 08HB038-French Creek at Coombs).

4.9.2 Data analysis

Historical flow and level data for four stations located in Little Qualicum River (08HB004-active and 08HB029-discontinued), French Creek (08HB0021-active) and Englishman River (08HB002-active) are presented in Figure 34 through Figure 37. The stations in Little Qualicum River and Englishman River are maintained and operated by Water Survey Canada and the station in French Creek is operated by the Department of Fisheries and Oceans Canada (DFO) partnered with the Regional District of Nanaimo and thr Ministry of Forest, Lands, Natural Resource Operations and Rural Development.

Mean annual discharge (MAD) in Little Qualicum River near Cameron Lake is estimated at 8.5 m^3/s and near Qualicum Beach (14 km downstream) 11.8 m^3/s suggesting an increase of approximately 3.0 m^3/s (Figure 34 and Figure 35). The increase in flow downstream could be mainly attributed to contribution of flow from Kinkade Creek, Whisky Creek, Lockwood Creek and McBey Creek. However, when comparing MAD to August conditions, the August mean monthly flow is 1.7 m^3/s near Cameron Lake and 2.0 m^3/s near Qualicum Beach suggesting an increase of 0.3 m^3/s mainly attributed to groundwater contribution at the watershed scale since very little to no precipitation is observed during August.

The mean annual discharge (MAD) based on two years (2018-2019) of data in French Creek near the river mouth (08HB0021) is approximately 0.8 m^3/s (Figure 36) and August monthly average discharge is estimated at 0.01 m^3/s. There is a discontinued WSC hydrometric station in French Creek at Coombs (08HB038) located 9 km upstream of 08HB0021 with an incomplete data set from 1969 to 1989. The August mean monthly discharge in French Creek at Coombs was approximately 0.008 m^3/s. When comparing the August mean monthly discharge at these two stations, the stream flow in August has remained constant based on the partial data set. The stream flow in August is largely groundwater discharge.

The historical MAD considering 12 months in Englishman River (Figure 37) is estimated as 13.1 m^3/s and the historical monthly average discharge for August is 1.4 m^3/s.

Flow analysis in the Little Qualicum River, French Creek and Englishman River are presented in Figure 38 to Figure 40, respectively.

4.9.3 Surface Water flows - Discussion

Unfortunately, only two stream gauges provide information about the change in river flows. One located on the Little Qualicum River (since 1960) and the other on the Englishman River (1913-1917, and 1970-present). The active hydrometric station on French Creek does not have enough data yet (data collection started in 2018) to properly assess the change in flow at this location.

In the last 10 years, low water levels have been recorded for longer periods (July to September) compared to what was observed historically, when low flows were predominantly recorded in August. This could possibly be attributed to the effects of climate change and increase in groundwater usage.

According to climate change models, wetter winters and drier summers are expected in the near future. Combined with a reduction of the snowpack, this will also affect stream flows. Freshet will happen sooner, and snow will melt sooner; therefore, late spring flows will be smaller compared to historical data, and low flows can be expected to be lower and to occur for longer periods of time.

Table 5. Compiled hydrometric station with stream flow and/or level data

Station ID	Station Name	Parameter	Source of Information	Status	Latitude	Longitude	Data From	Data To	Years With Data	Within Electoral Area F
08HB0005	Craig Creek near NW Bay Rd	Flow and Level	BC Aquarius	UNKNOWN	49.2990	-124.2463	7/19/2016	11/13/2019	3.3	
08HB0011	Grandon Creek at Crescent Rd W	Level	BC Aquarius	UNKNOWN	49.3572	-124.4673	8/17/2012	11/10/2015	3.2	
08HB0014	French Creek Near Miller Rd	Level	BC Aquarius	UNKNOWN	49.3408	-124.3759	8/10/2012	10/24/2017	5.2	
08HB0021	French Creek ds of Barclay Cres	Flow and Level	BC Aquarius (DFO,RDN,FLNRORD)	ACTIVE	49.3442	-124.3709	1/24/2018	1/13/2020	2.0	
08HB0027	Shelley Creek upstream of Hamilton Avenue	Flow and Level	BC Aquarius	UNKNOWN	49.3069	-124.3038	6/19/2018	11/26/2019	1.4	

Station ID	Station Name	Parameter	Source of Information	Status	Latitude	Longitude	Data From	Data To	Years With Data	Within Electoral Area F
Control	Control (Surface water stations)	Flow and Level	Englishman River Project	ACTIVE	49.2057	-124.4516	5/20/2015	10/7/2016	1.4	
DS Falls	DS Falls (Surface water stations)	Flow and Level	Englishman River Project	ACTIVE	49.2474	-124.3490	5/29/2015	10/11/2016	1.4	RDN Area F
DS Hatchery	DS Hatchery (Surface water stations)	Flow and Level	Englishman River Project	ACTIVE	49.2796	-124.2959	5/19/2015	10/11/2016	1.4	
US Falls	US Falls (Surface water stations)	Flow and Level	Englishman River Project	ACTIVE	49.2284	-124.3711	6/12/2015	10/11/2016	1.3	
US Hatchery	US Hatchery (Surface water stations)	Flow and Level	Englishman River Project	ACTIVE	49.2814	-124.3000	5/29/2015	10/11/2016	1.4	
08HB002	ENGLISHMAN RIVER NEAR PARKSVILLE	Flow and Level	Water Survey of Canada	ACTIVE	49.3161	-124.2853	2/1/1913	12/31/2018	47.0	
08HB004	LITTLE QUALICUM RIVER AT OUTLET OF CAMERON LAKE	Flow	Water Survey of Canada	DISCONTINUED	49.2908	-124.5833	3/1/1913	12/31/2001	48.0	RDN Area F
08HB019	CAMERON RIVER NEAR ALBERNI	Flow	Water Survey of Canada	DISCONTINUED	49.2458	-124.6569	8/1/1958	9/30/1959	1.2	RDN Area F
08HB029	LITTLE QUALICUM RIVER NEAR QUALICUM BEACH	Flow and Level	Water Survey of Canada	ACTIVE	49.3546	-124.4834	10/1/1960	12/31/2017	33.0	
08HB038	FRENCH CREEK AT COOMBS	Flow	Water Survey of Canada	DISCONTINUED	49.3047	-124.4250	4/1/1969	10/31/1989	10.0	RDN Area F
08HB078	FRENCH CREEK ABOVE PUMPHOUSE	Flow	Water Survey of Canada	DISCONTINUED	49.3400	-124.3747	3/1/1990	3/31/1996	6.1	
08HB080	ARROWSMITH CREEK AT OUTLET OF ARROWSMITH LAKE	Flow	Water Survey of Canada	DISCONTINUED	49.2211	-124.5347	9/1/1990	8/31/1997	7.0	

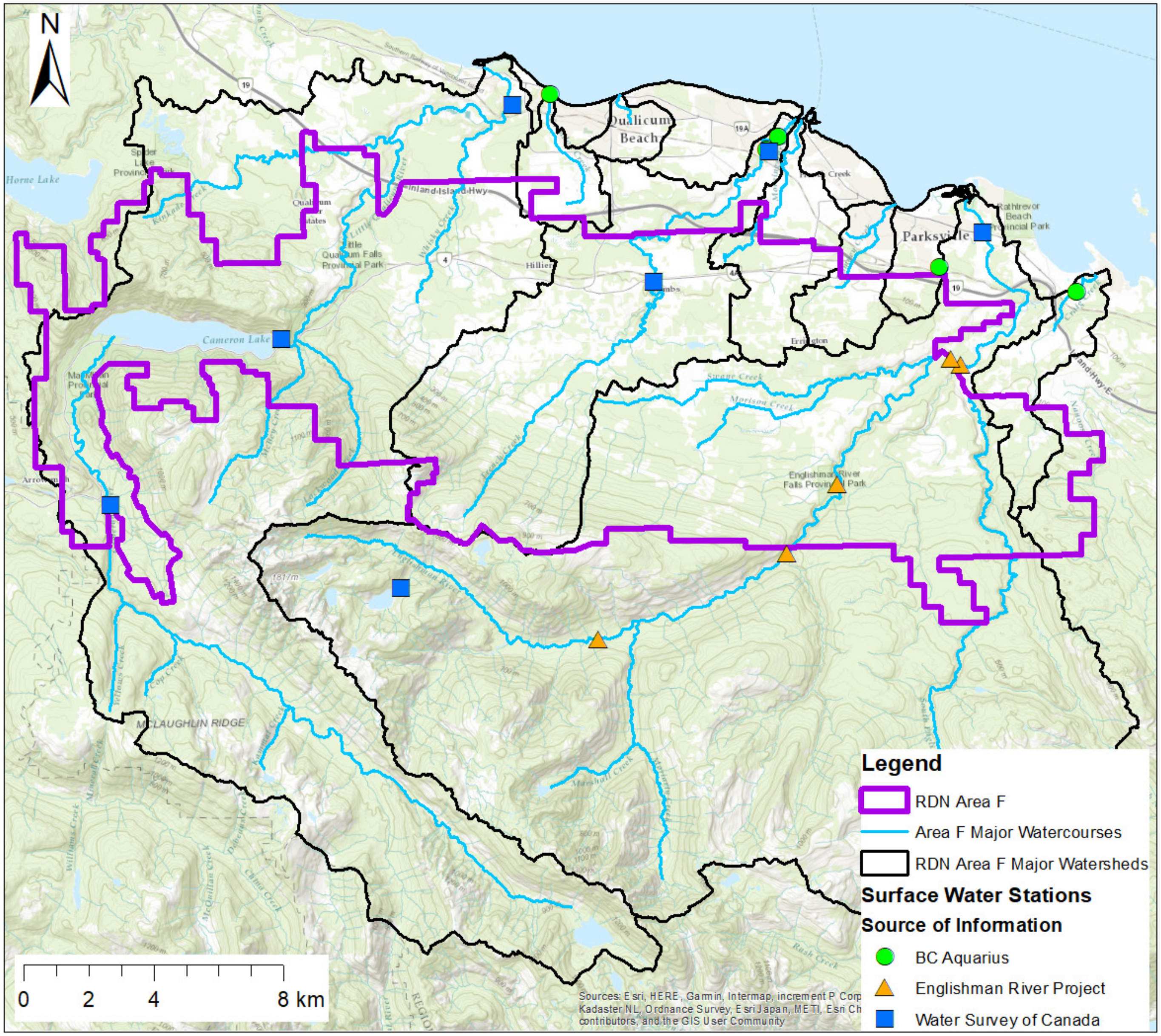

Figure 32. Hydrometric stations classified by source of information

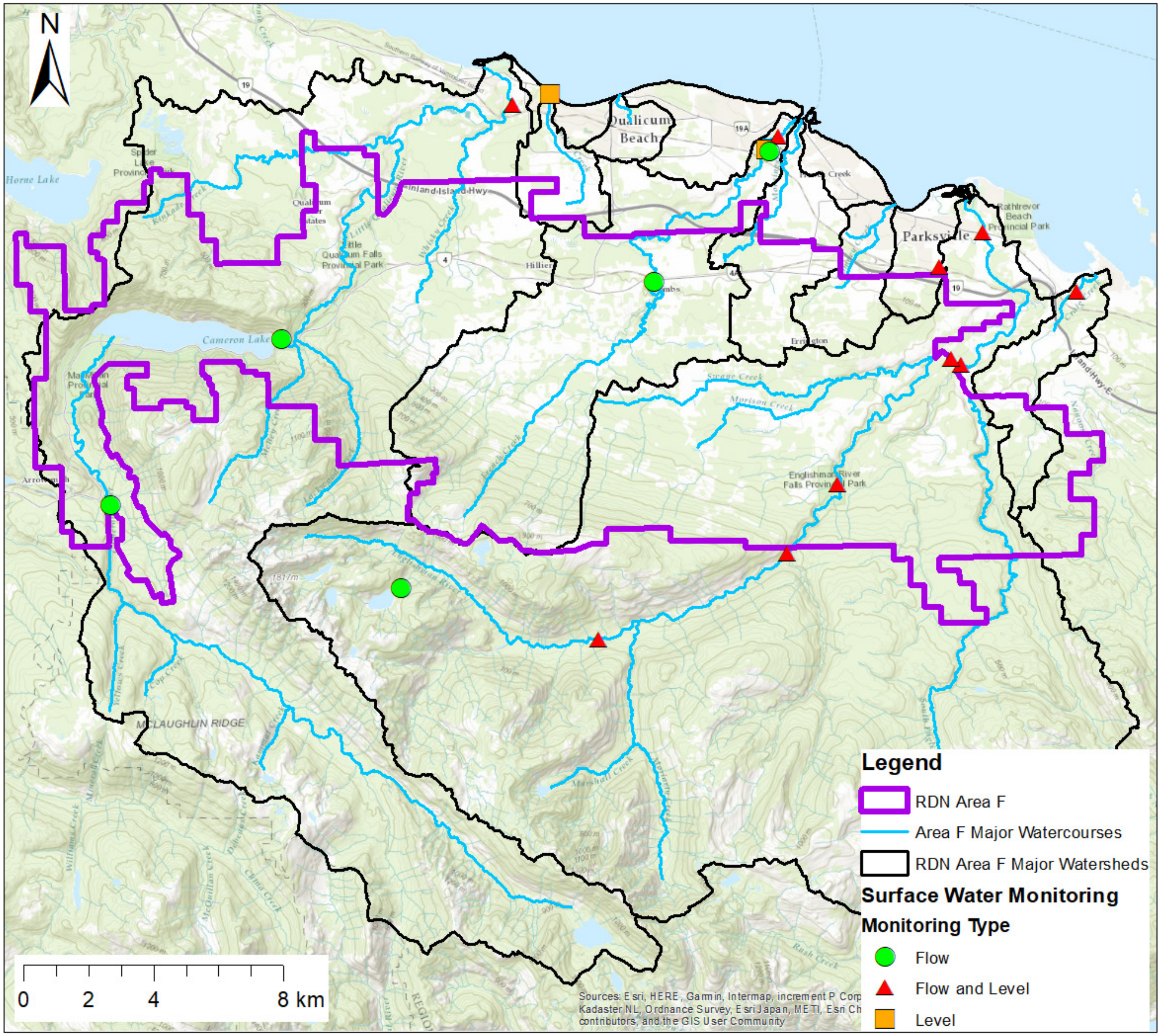

Figure 33. Hydrometric stations classified by monitoring data type (flow, level or both)

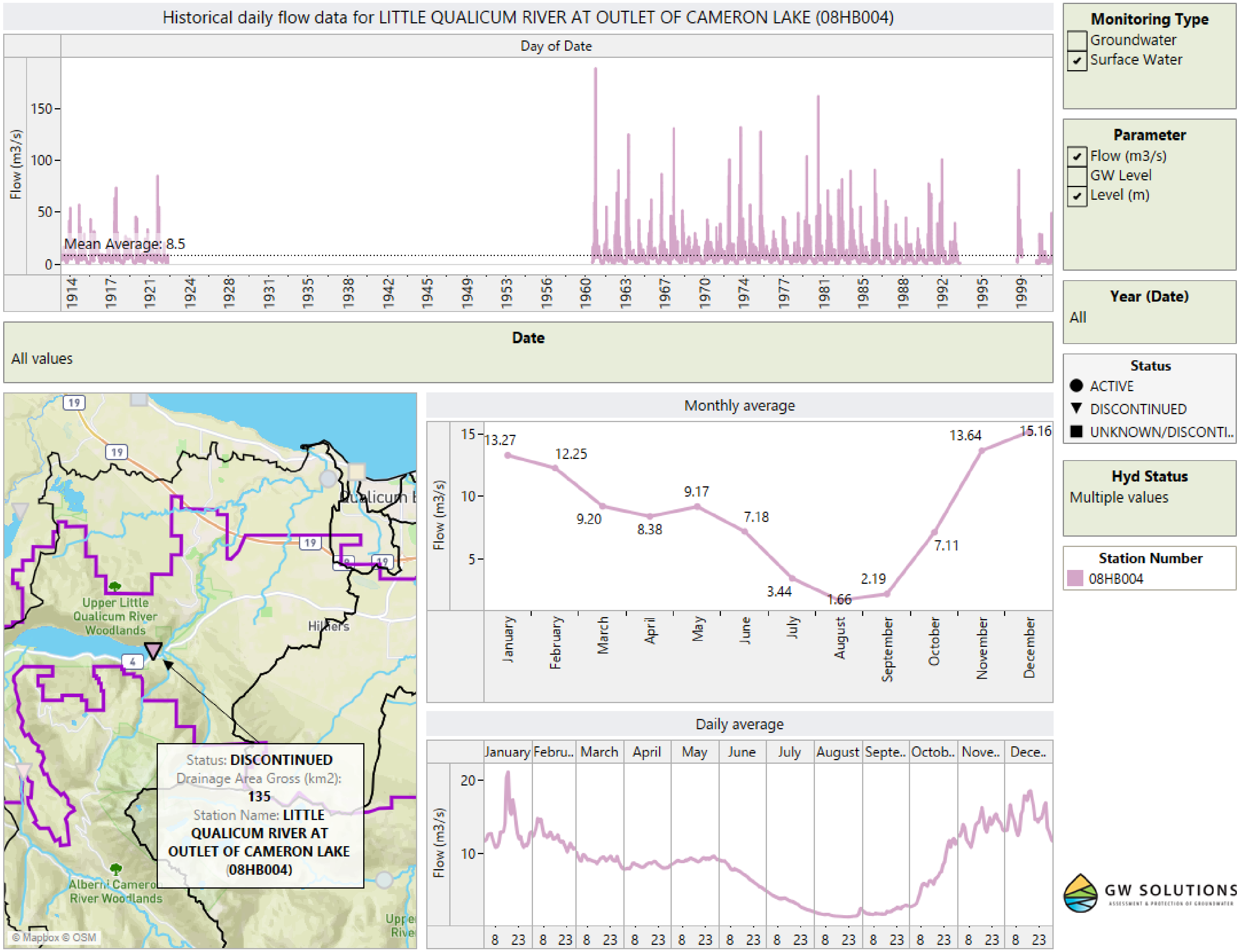

Figure 34. Historical flow data for the Little Qualicum River station at the outlet of Cameron Lake (08HB004)

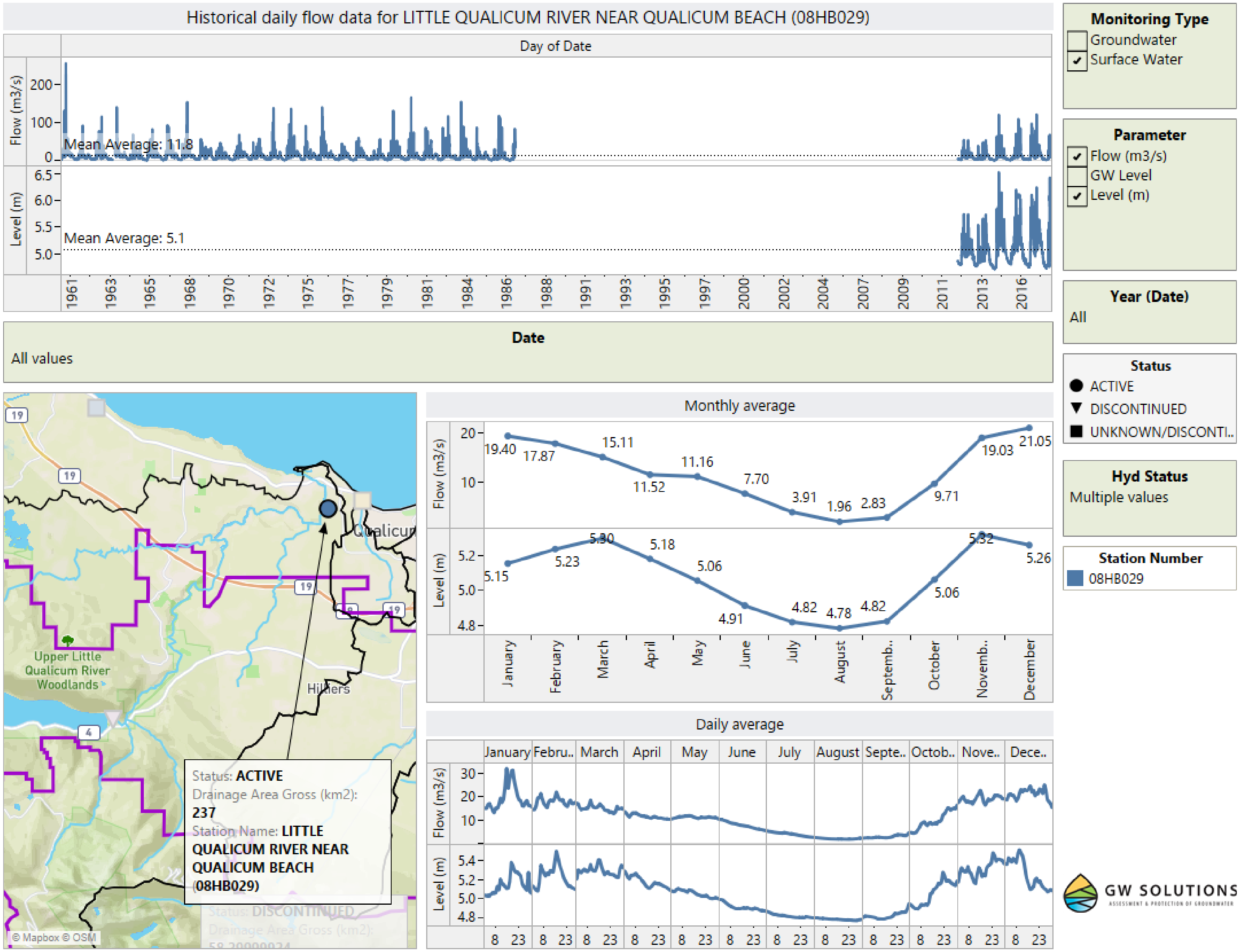

Figure 35. Historical flow and level data for the Little Qualicum River station near Qualicum Beach (08HB029)

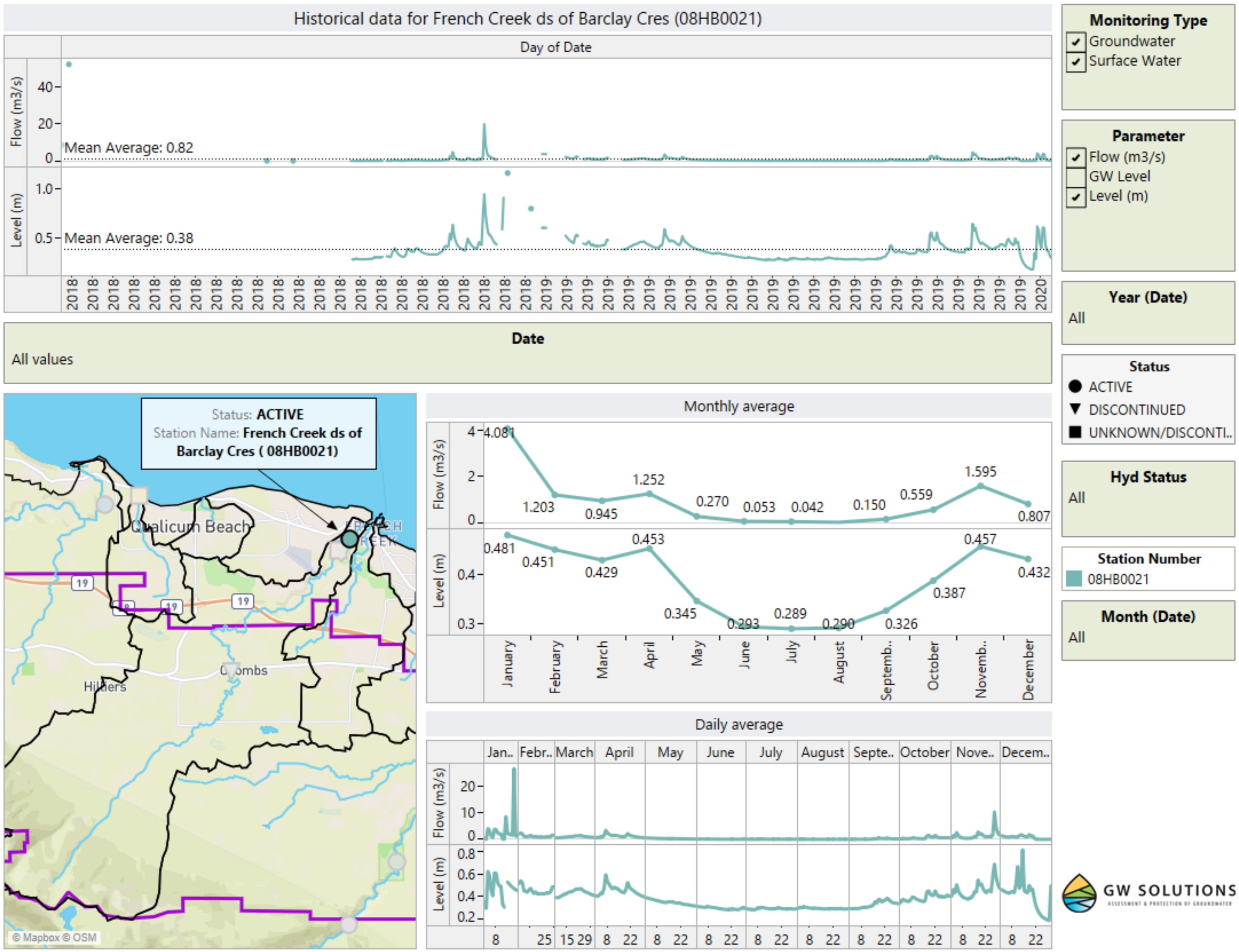

Figure 36. Historical flow data for French Creek downstream of Barclay Crescent near the discharge to the ocean (08HB0021)

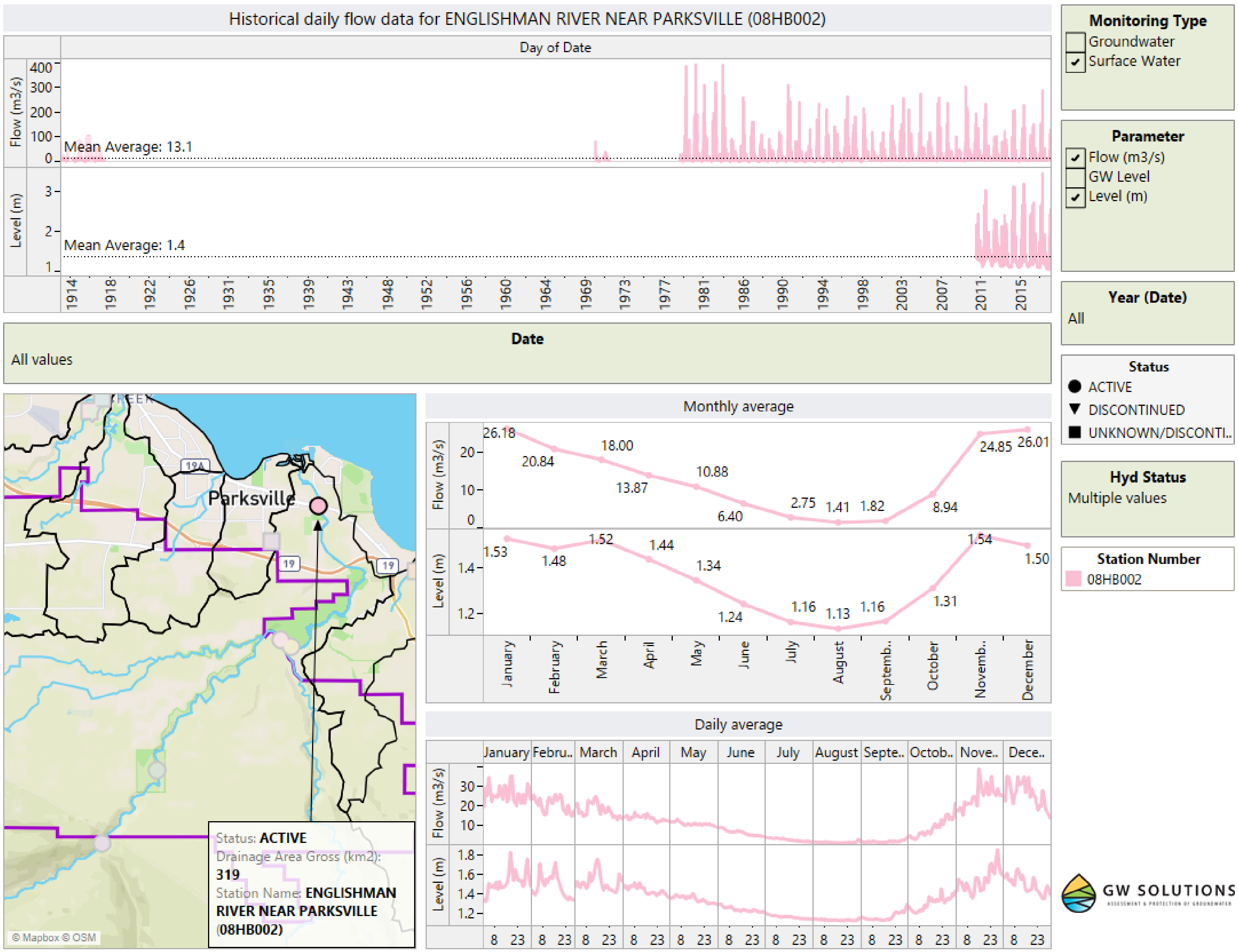

Figure 37. Historical flow and level data for the Englishman River station near Parksville (08HB002)

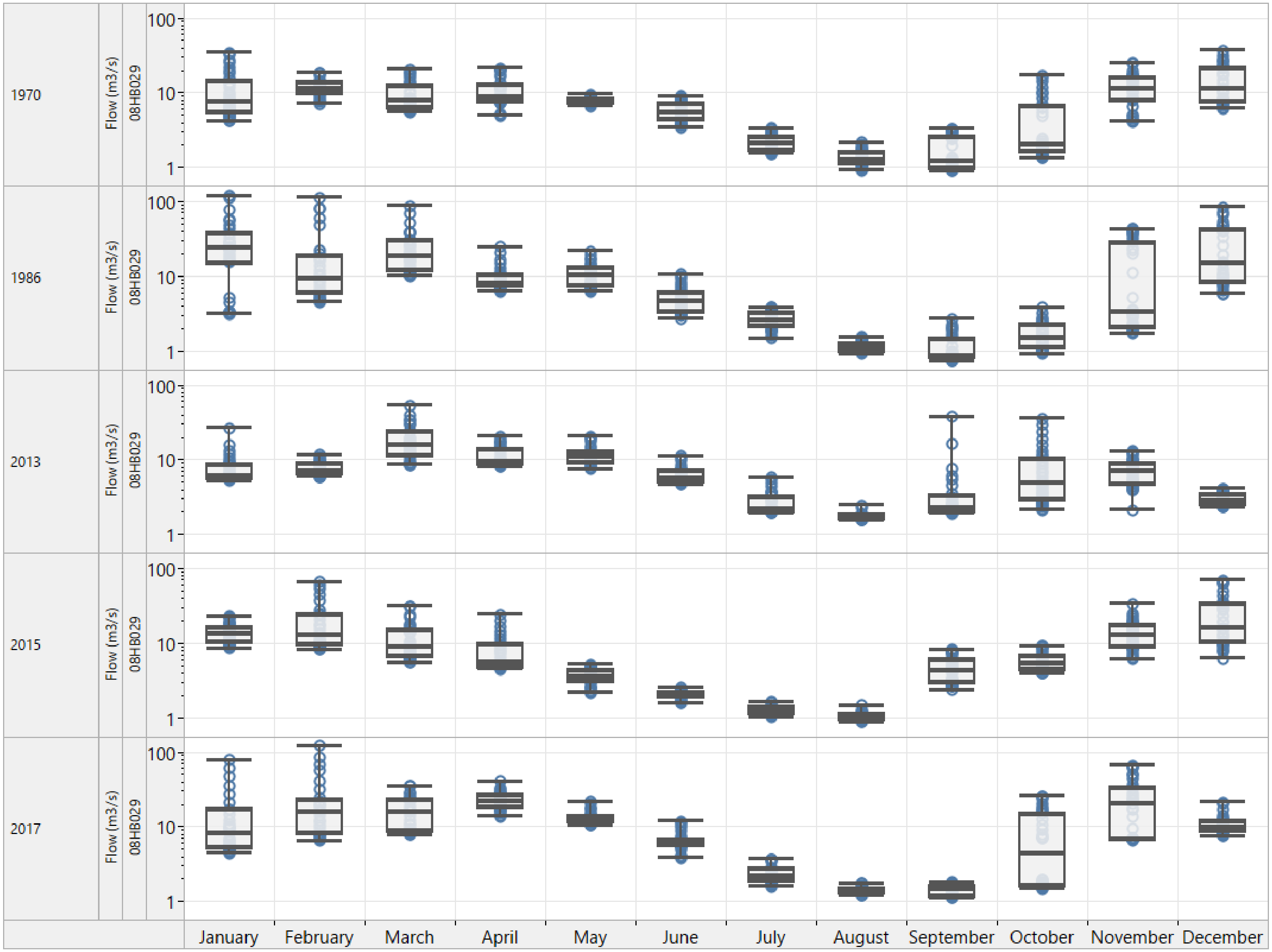

Figure 38. Flow analysis for the Little Qualicum River station near Qualicum

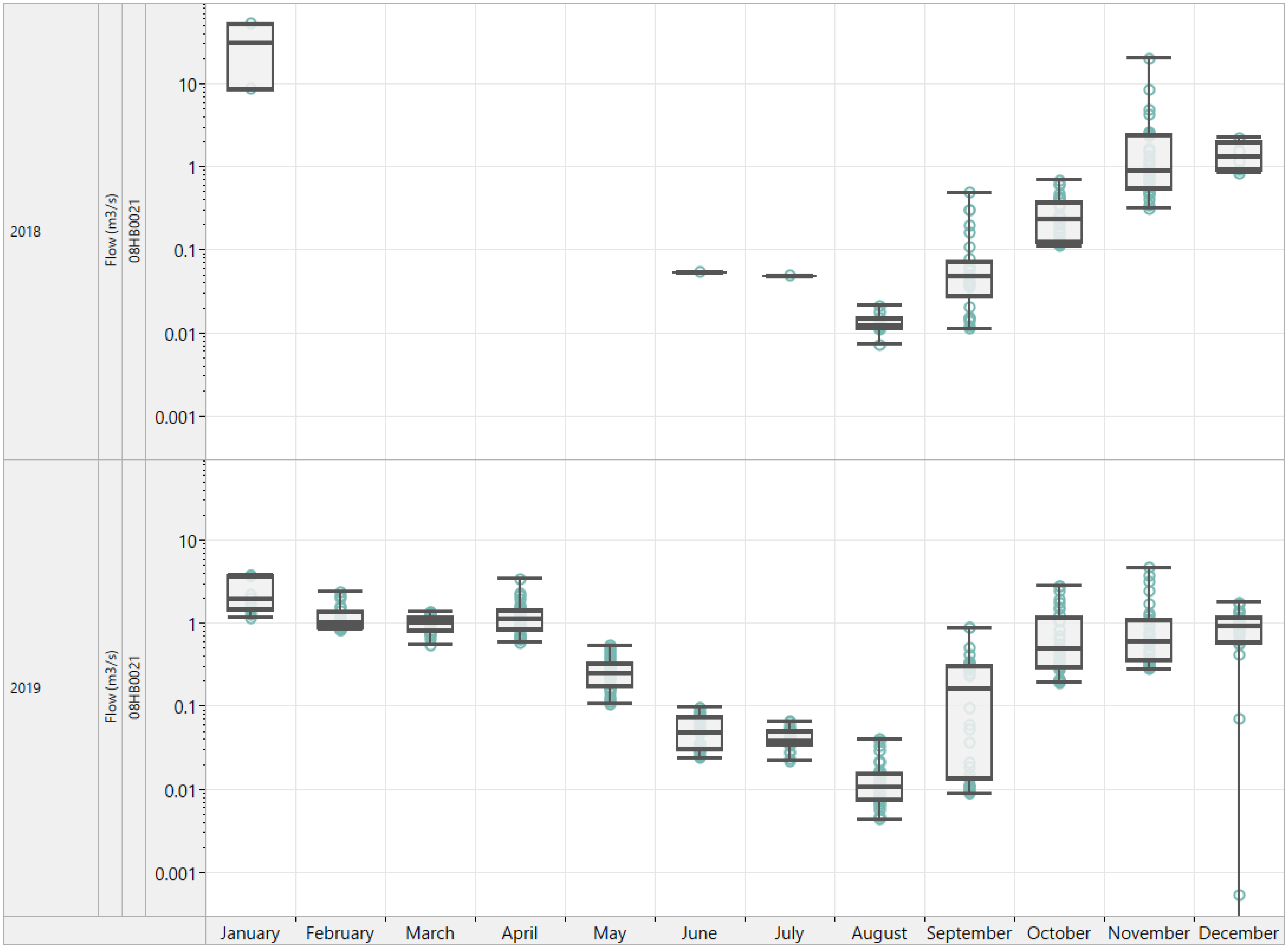

Figure 39. Flow analysis for the station at French Creek

Figure 40. Flow analysis for the station at Englishman River near Parksville

4.10 Groundwater-Surface Water Interaction

In order to understand the connection between groundwater and surface water, hydrographs showing water levels in observation wells and water levels in rivers and streams were plotted and presented in Figure 41 to Figure 45. The following observations were made:

- Both flow and water level information are available for the Englishman River, French Creek and Little Qualicum River.
- Wells completed in bedrock aquifers present a larger amplitude of groundwater level fluctuations such as observed in OW287 (aquifer 220) and VOW15 (aquifer 212). The response of groundwater levels in bedrock systems at the site follows precipitation events.
- Groundwater levels from observation wells completed in overburden sediments located adjacent to streams follow the same trend as the stream levels, as observed in OW303 which is completed in overburden Aquifer 217 (Figure 44). This group of wells are likely connected to surface water courses.
- Groundwater level minima occur in the summer to early fall, i.e. August or September, depending on the well type and depth (bedrock, overburden, deep or shallow). Typically, groundwater level maxima occur in the winter months when precipitation is predominantly rain.
- Observation wells for which groundwater level minima occur during winter months and maxima coincide with snow melt (March), are classified as mountain recharge and snow melt dependant. Examples of this group are presented in Figure 42 (VOW01) and Figure 43 (VOW16).

Complementary information will be available in the BC Water Science Series document[2] for the French Creek watershed where surface water and groundwater connections were studied in more detail. GW Solutions through Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) is in the process of finalizing a study called "French Creek Area Hydraulic Connectivity and Aquifer Mapping Study" to be published in the BC Water Science Series. The study area is located along the east coast of Vancouver Island, BC within the Nanaimo Lowland physiographic region. It extends from the Englishman River to Deep Bay and includes the following major watersheds: Englishman River, Little Qualicum River,

[2] French Creek Area Hydraulic Connectivity and Aquifer Mapping Study, by Antonio Barroso, Sandra Richard, Matt Vardal, and Gilles Wendling, BC Water Science Series, 2020

Qualicum River, French Creek, Cook Creek, Nile Creek, Thames Creek and Morningstar Creek. The deliverables of the study includes:

- Updating the extent and information for existing mapped aquifers within the study area;
- Mapping and describe new aquifers within the study area. A total of six aquifers has been mapped
- Correlate wells in the GWELLS database to the mapped aquifers;
- Identify and characterize where hydraulic connections occur between surface water (e.g. stream, rivers, lake) and aquifers to support the application of the WSA.

The relevant findings of this study includes:

- Bedrock aquifers provide important baseflow to major streams such as French creek, Englishman River, Little Qualicum River, Whisky Creek and Swane Creek.

- In the lowlands, streams are mostly gaining flow from Quadra aquifers either directly (gaining) or perched above the streams providing seepage (e.g. French Creek).

- Locally, aquifers formed by glacio-fluvial deposits of a kame terrace and kame delta deposits (part of Vashon-Capilano sediments) are connected to overlying streams (mostly gaining), including Whisky Creek (Aquifer 663), Spider Lake (Aquifer 661), and tributaries of Kinkade Creek and Little Qualicum River.

- Major rivers, including the Englishman River, French Creek, Little Qualicum River and Qualicum River, are connected to their respective delta and river valley unconfined Capilano-Salish aquifers

We recommend to refer to this study to further assist the RDN on the development of an Aquifer Protection Development Permit Area in areas where connections between aquifers and surface water are more prevalent.

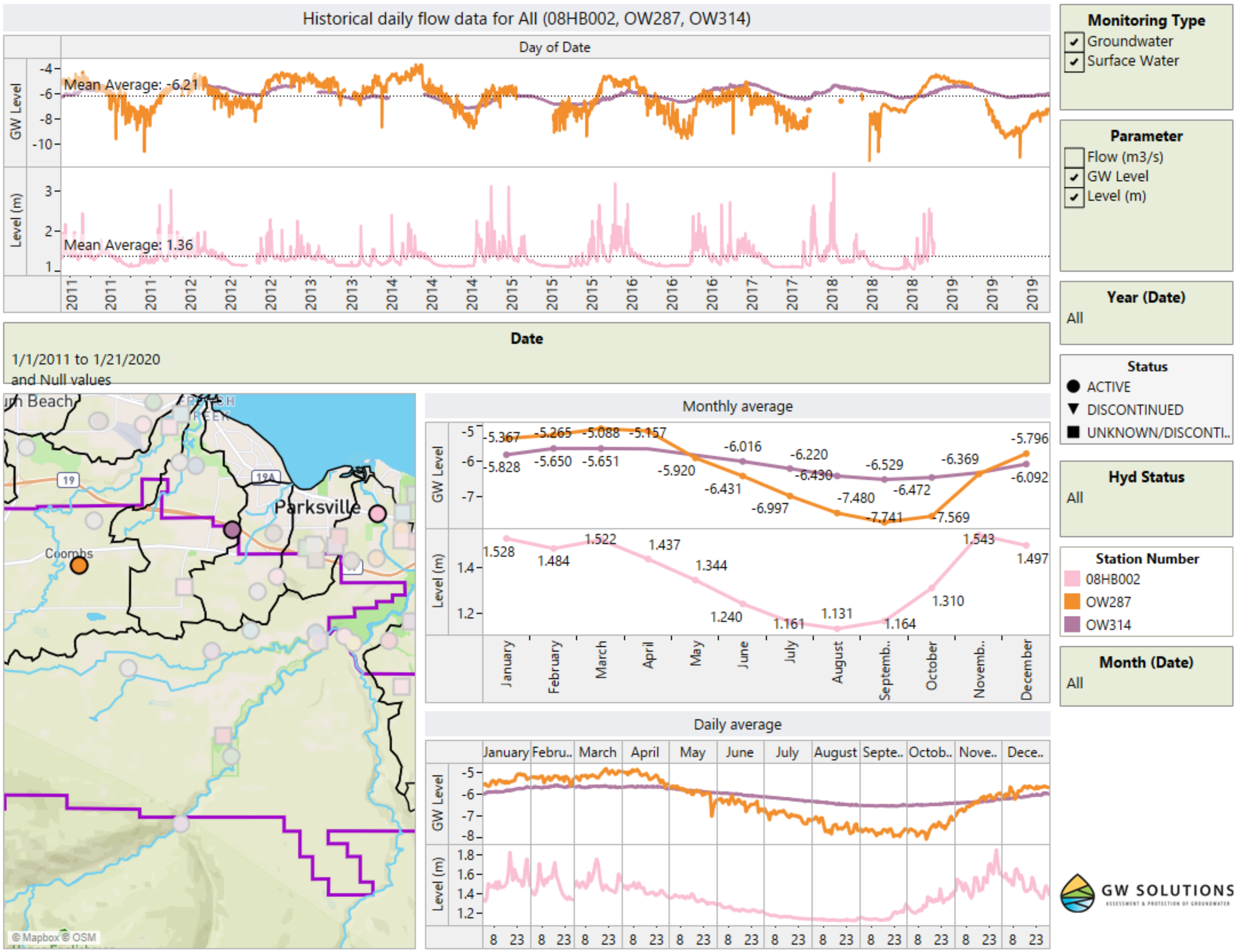

Figure 41. Level in OW287 (bedrock Aquifer 220), OW314 (overburden Aquifer 216) and level in the Englishman River (from 2011)

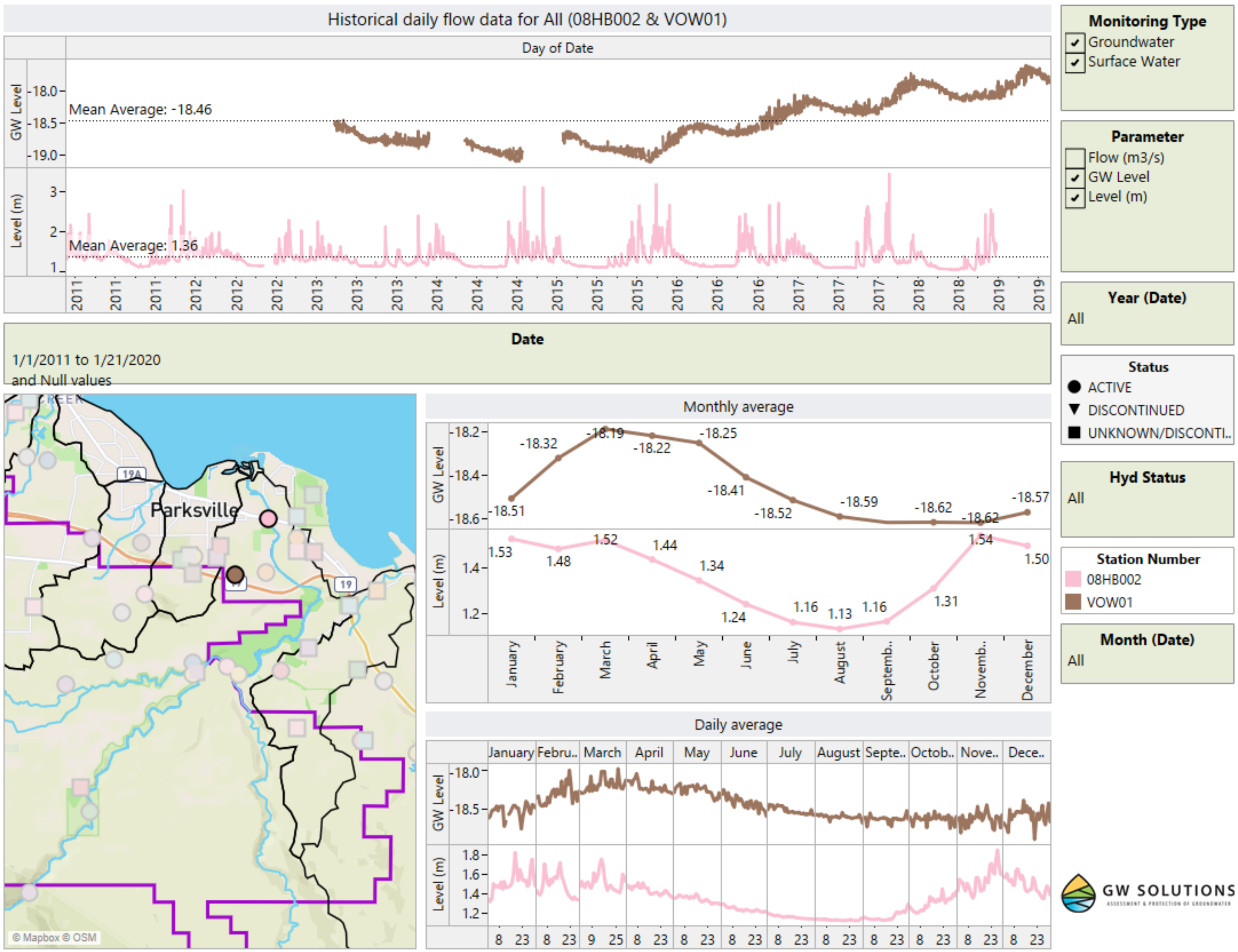

Figure 42. Level in VOW01 (overburden Aquifer 216), and level in the Englishman River (from 2011)

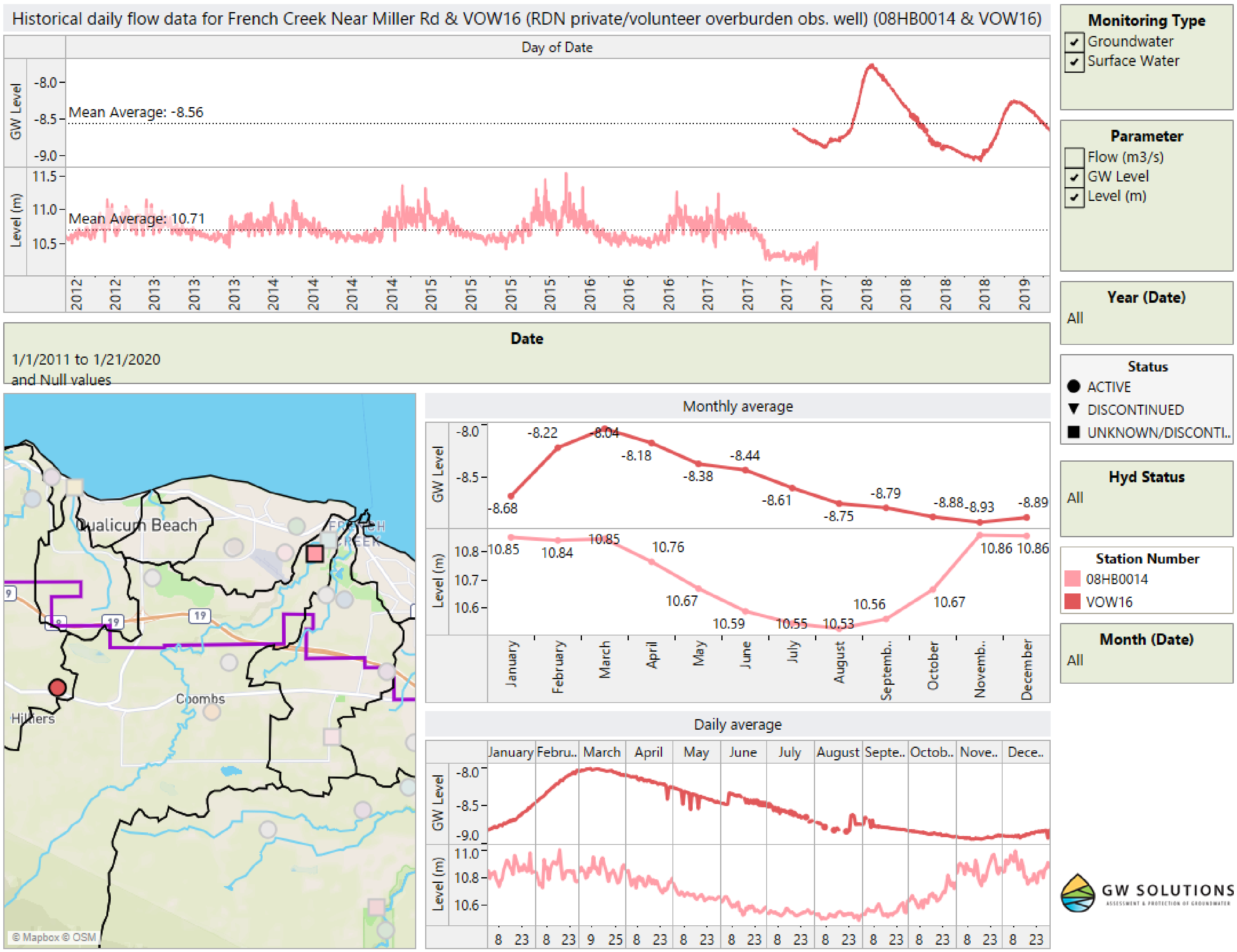

Figure 43. Level in VOW16 (overburden Aquifer 217), and level in French Creek (from 2011)

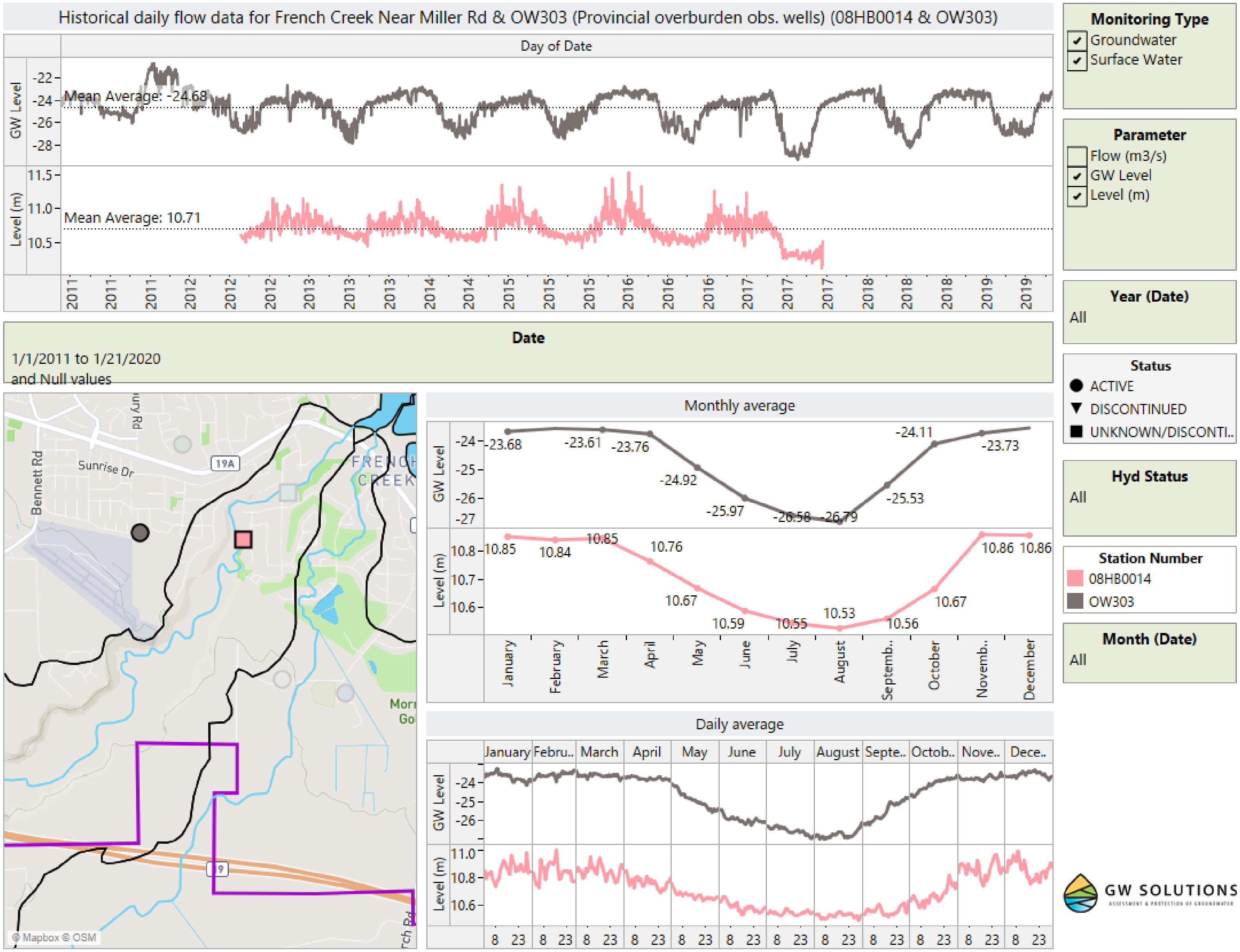

Figure 44. Level in OW303 (overburden Aquifer 217), and level in French Creek (from 2011)

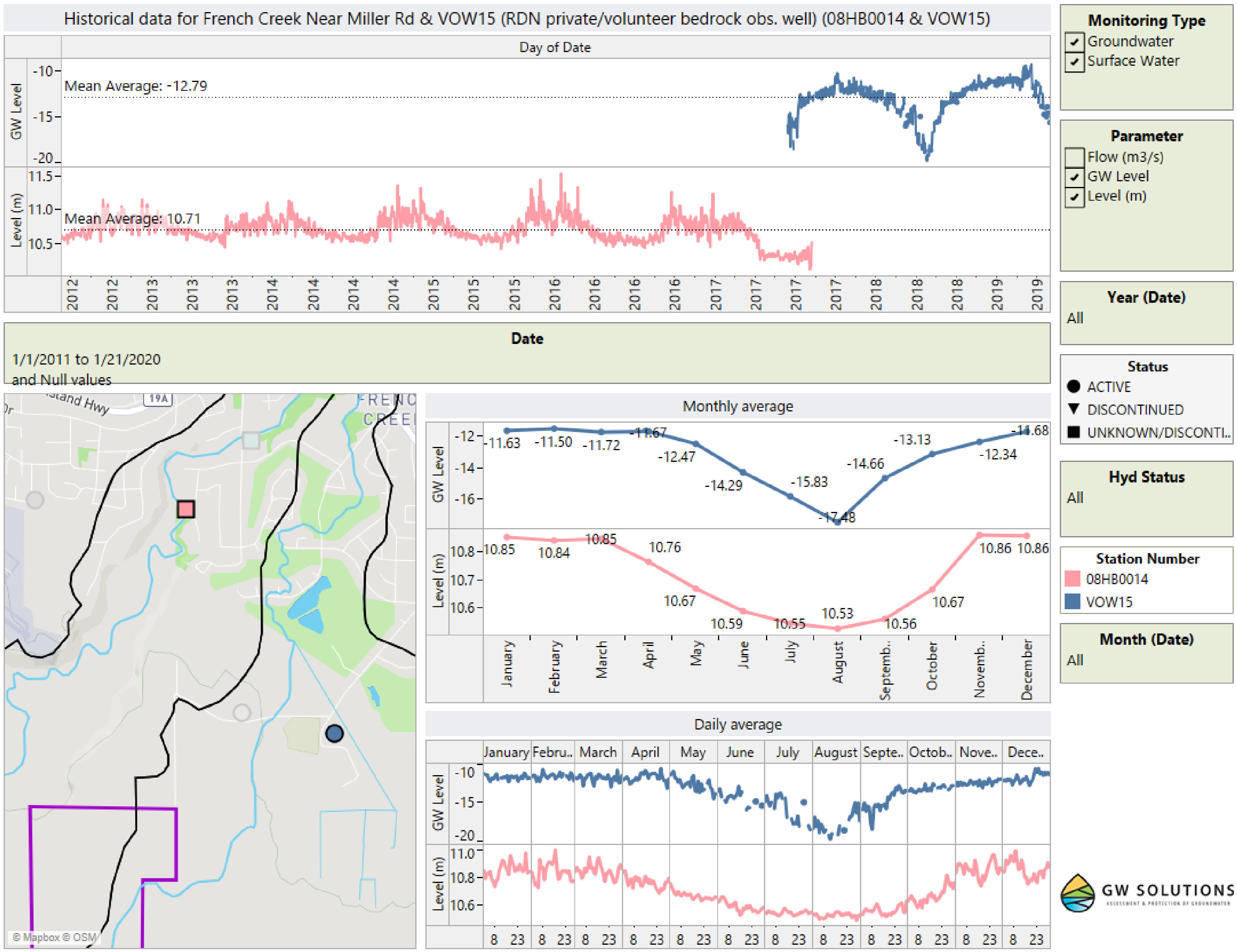

Figure 45. Level in VOW15 (bedrock Aquifer 212), and level in French Creek (from 2011)

4.11 Climate Change Concerns

GW Solutions has completed climate change analysis for the Te'mexw Treaty Association (TTA) including Nanoose and Malahat sites and had permission from TTA to use the results of the analysis in this study. GW Solutions selected *CanESM* Model (the Canadian Center for Climate Modeling and Analysis) among the available General Circulation Models (GCMs) in the package and ran it considering the *RCP8.5 scenario* for future projection. This GCM predicts the climate variables more conservatively for future time series and it effectively replicates the historical data trends for Vancouver Island. We used ClimateBC package version 6.21 (Wang et al, 2019) to predict monthly specific climate variables for 2025, 2055 and 2085.

Based on our analysis of the effect of climate change on the east coast of Vancouver Island, the following comments applicable to the RDN Area F are made:

- Higher precipitation is predicted to occur from October to February and less precipitation is projected from May to September, compared to historic averages (1981-2010);
- Precipitation as snow is predicted to decrease between October to March;
- Higher temperatures are anticipated throughout the year with the highest increase in July, August and September.

The potential impacts of climate change on water resources are described below:

- Longer dry intervals combined with an increase in temperature will likely lead to lower water levels (both surface water and groundwater). Groundwater contribution to surface water bodies and base flow will be reduced;
- Greater amounts of precipitation over shorter time frames will not necessarily lead to more recharge, especially if they occur when soils have been dry for longer periods. Rainwater at the surface needs time to infiltrate into the ground, and percolation is greater through saturated or partially saturated soil. This will lead to greater runoff and consequently a greater risk of flooding; and
- In general, it is expected that groundwater recharge will decrease, affecting the water level in the aquifers.

4.12 Forest Loss

According to Global Forest Watch, the RDN has experienced a forest loss of 23%, with a decrease in tree cover since 2000 equivalent of 41,700 hectares (Figure 46). In this data set, “tree cover” is defined as all vegetation greater than 5 meters in height. “Forest Loss” indicates the removal or mortality of tree cover and can be due to a variety of factors, including mechanical harvesting (deforestation), fire, disease, and storm damage. It does take into account the area where tree planting has been undertaken following harvesting. Additionally, Figure 46 displays forest gain for the period 2000-2012. Forest gain is considered the inverse of forest loss where a non-forest area changes to forest entirely (gain of tree cover).

Forests loss can impact both the quantity and quality of water. The mechanisms involved are complex because they depend on multiple factors including meteorological conditions, soil type, slope, terrain, plant species and their stage of development, etc. The potential concerns of forest loss for the study watersheds are the following:

- When forest cover is removed, two scenarios can happen (Lachassagne, 2016):
    - excess water (not used by the trees anymore) will move faster horizontally as subsurface flow or surface runoff (depending on slope, soil type, surface disturbance and rainfall intensity); this will not only increase streams flows but also sediment yield (e.g. turbidity) in water courses; or,
    - excess water will infiltrate deeper and recharge aquifers, which then feeds streams, lakes or ponds. This triggers a rise in surface water and groundwater levels.
- When trees are replanted after harvest, the growth of newly planted trees requires more water which translates into an increase in evapotranspiration for several years. This can translate into a deficit in water reaching the ground and a resulting drop of the groundwater and surface water levels. Small surface water features such as ponds or wetlands can be lost. Pre-harvesting water conditions may come back when trees reach maturity.
- If forest harvesting is replaced by urbanized area and not sustainably managed, then groundwater recharge (thus groundwater levels) will decrease due to an increase in impermeable surfaces. Runoff from impermeable surfaces, collected by storm water network, discharges directly to a receiving surface water body, without providing the benefits of gradual release of flow.

The actual impacts of forest loss on water quantity within the RDN have not been studied and are out of the scope if this study.

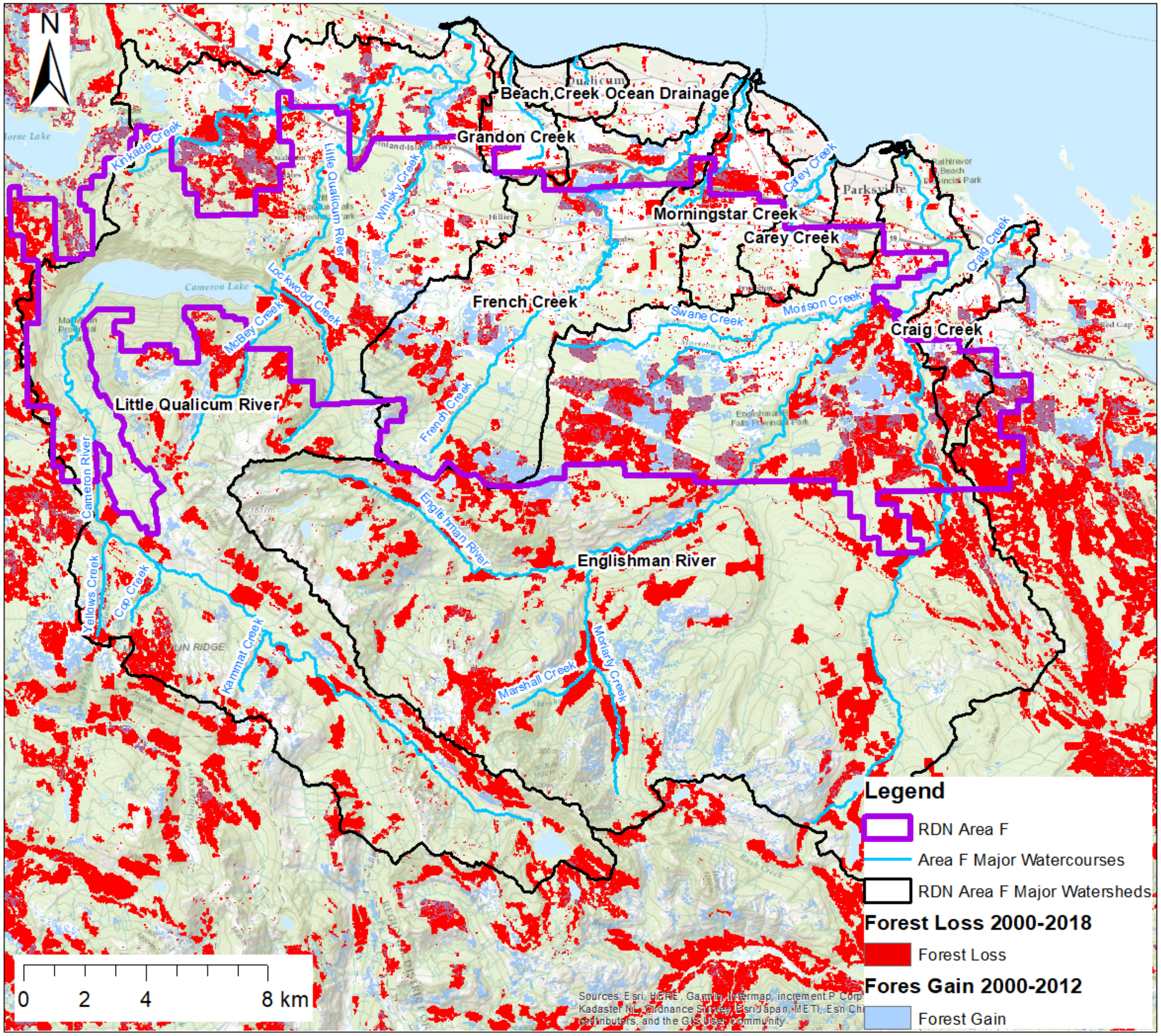

Figure 46: Forest loss within study watersheds - Global Forest Watch

5 WATER QUALITY ANALYSIS

5.1 Data Collection, Review and Integration

GW Solutions and the RDN worked collaboratively to access information. GW Solutions then reviewed, cleaned and standardized the available information. Data was obtained from:

- BC Environmental Monitoring Systems (EMS);
- Island Health (IH);
- RDN Water Supply Systems;
- RDN Volunteer Observation Wells Water Quality - Water Trax;
- RDN Area F Water Purveyors (Parksville, Qualicum and EPCOR);
- Other studies: MVIHES Englishman River project, the Englishman River water quality data completed by University of Calgary, and Whiskey Creek Groundwater Source Assessment by Elanco Enterprises LTD.

Table 6 summarizes the compiled water quality data. GW Solutions has built a data integration and visualization platform to easily view the results and compare concentrations to various guidelines (e.g., drinking water and aquatic life).

Figure 49 and Figure 50 show the groundwater and surface water stations and/or data points classified by water source (groundwater and surface water) and source of information, respectively. Figure 51 shows the surface water stations classified by name of waterbody and Figure 52 shows the groundwater stations classified by aquifer type and number. Aquifer numbers were reported in some water samples; however, many groundwater samples did not refer to an aquifer. GW Solutions assigned groundwater quality stations to aquifers based on Well Tag Number, well completion details, well location and mapped aquifer boundaries.

5.2 Sources of Information for Water Quality Data

5.2.1 BC Environmental Monitoring System (EMS)

GW Solutions used the BC Environmental Monitoring System (EMS) database, which is a repository of water quality sampling results for British Columbia. The water quality data within the EMS was grouped into three categories based on water source sampled: i.e. groundwater, surface water, and “other”. Only surface water and groundwater samples were used for the data analysis.

Samples of groundwater sources have been taken from 29 locations within the study watersheds, including from monitoring wells, observation wells, and groundwater source wells. The groundwater dataset includes 4,524 tests (ions, physical properties, nutrients, and metals) between 1985 and 2019.

The surface water samples have been collected at 45 locations including lakes, ponds, rivers, streams and/or creeks. The surface water database is the larger dataset, and includes 62,308 tests (ions, physical properties, nutrients, and metals) for samples taken between 1986 and 2019. Samples from 21 locations are included in the EMS surface water database sampled within the RDN Community Watershed Monitoring Network (CWMN) program.

5.2.2 Island Health Water Authority Water Supply System

Island Health (IH) routinely inspect, sample and assess community water systems for the purpose of protecting the public’s health and for monitoring compliance with the Drinking Water Protection Act (DWPA) and Drinking Water Protection Regulation (DWPR).

The RDN provided a copy of water quality results obtained from IH through a freedom of information request. Data from this source underwent further cleaning and standardization.

The IH database includes samples taken from 100 groundwater sources (water wells) and three surface water sources (streams/creeks). The dataset includes 5,753 tests (ions, physical properties, nutrients, and metals) between 2007 and 2019 for groundwater, and 2012 and 2018 for surface water sources.

5.2.3 Regional District of Nanaimo and Water Purveyors

The RDN provided groundwater and surface water quality information from the RDN Water Supply System (Productions Wells), from the RDN Volunteer Observation Wells Water Quality Program (WaterTrax - Well Testing Rebate Program Voluntary Submissions) and Water Purveyors (EPCOR).

Approximately 4,012 tests from 90 wells have been included within the WaterTrax data source, 2,147 tests from 18 water wells from EPCOR water supply system and 4,484 tests from eight production wells and one surface water source from the RDN Water Supply Systems (Whiskey Creek).

5.2.4 Other studies

Other sources of water quality information include MVIHES Englishman River project (35 tests from one well), Thesis Study (Shannon Provencher, 2014) from University of Calgary (851 tests from 50 wells and 1,390 tests from 79 locations along Englishman River), and Whiskey Creek Report Test Well completed by Elanco Enterprises LTD (50 tests from a test well and 49 tests from surface water source).

Table 6. Compiled water quality data based on source of information

Source	Type	From	To	Parameters	Monitoring Stations	Tests	Samples	Data Range
BC Environmental Monitoring System (EMS)	Groundwater	7/2/1985	8/27/2019	110	29	4,524	76	1985-2019
	Other	5/9/2011	1/20/2015	6	1	86	38	2011-2015
	Surface water	3/10/1986	11/12/2019	246	45	62,308	2760	1986-2019
Englishman River Project	Groundwater	10/31/2008	10/31/2008	35	1	35	1	2008-2008
EPCOR Water Purveyor RDN Area F	Groundwater	8/10/2004	10/17/2018	62	18	2,147	48	2004-2018
Island Health Water Supply Systems	Groundwater	11/22/2007	12/3/2019	62	100	5415	165	2007-2019
	Surface water	10/16/2012	12/12/2018	52	3	338	8	2012-2018
RDN Volunteer Observation Wells Water Quality-Water Trax	Groundwater	2/5/2014	5/28/2019	60	90	4,012	91	2014-2019
RDN Water Supply Production Wells	Groundwater	10/16/2000	11/8/2018	48	7	4,053	102	2000-2018
	Surface water	10/26/2011	10/25/2018	49	1	431	9	2011-2018
University of Calgary Englishman River Thesis Study	Groundwater	7/1/2011	7/1/2011	19	50	851	50	2011-2011
	Surface water	8/1/2010	9/1/2011	19	79	1,390	85	2010-2011
Whiskey Creek Report Test Well	Groundwater	7/20/2017	7/20/2017	49	1	49	1	2017-2017
	Surface water	7/20/2017	7/20/2017	50	1	50	1	2017-2017
				Total	**426**	**85,689**	**3,435**	**1985-2019**

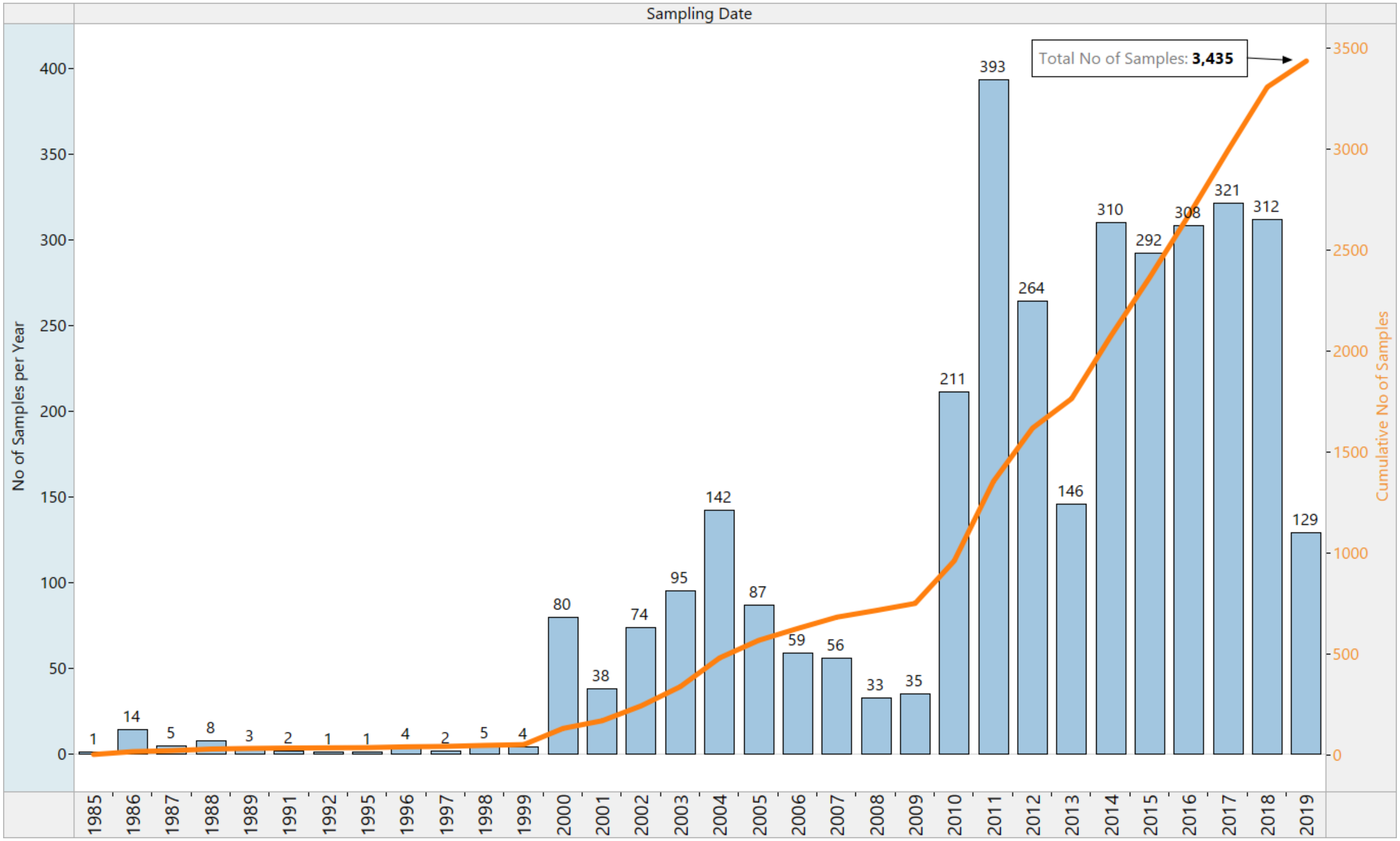

Figure 47. Number of samples per year

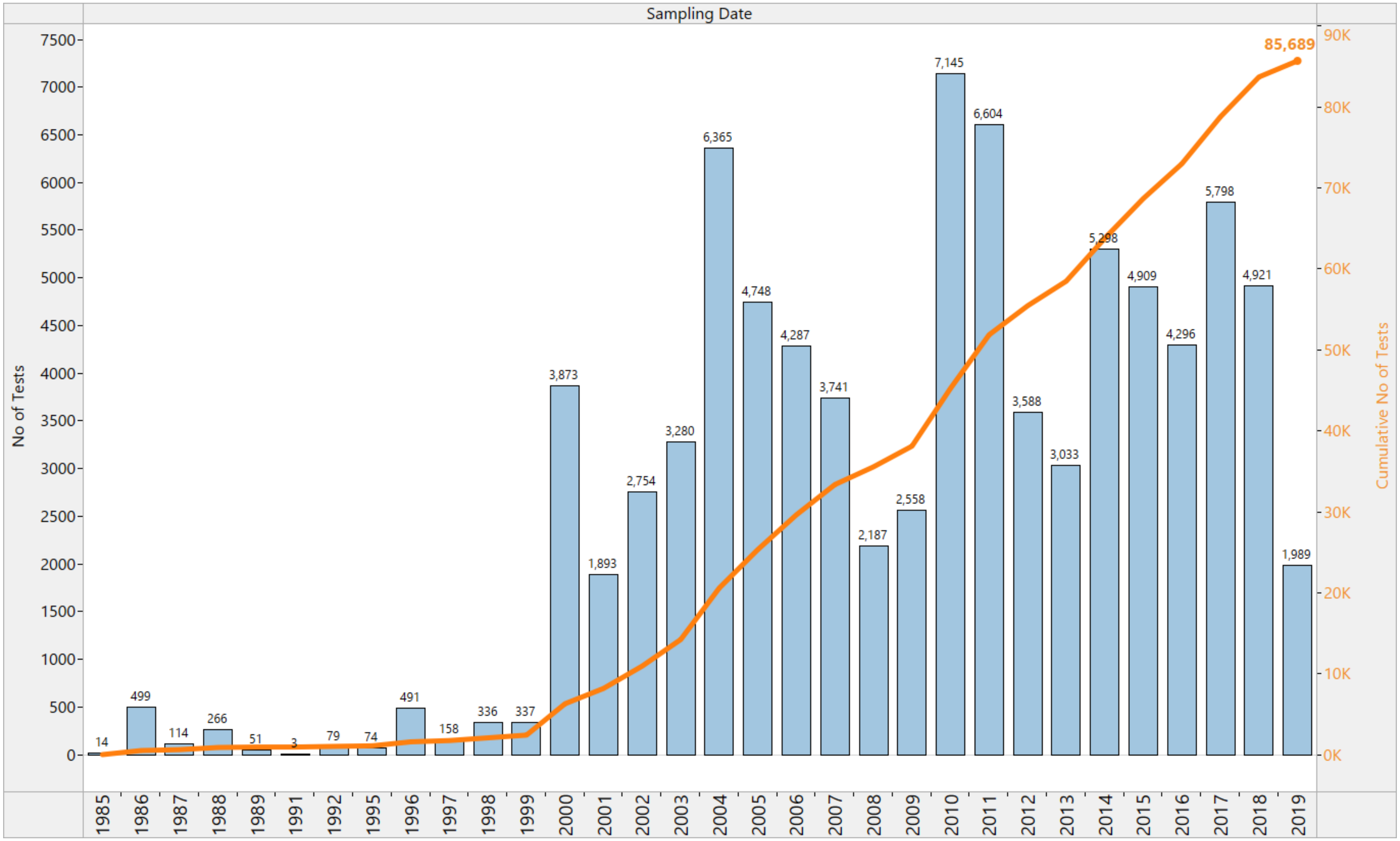

Figure 48. Number of tests per year

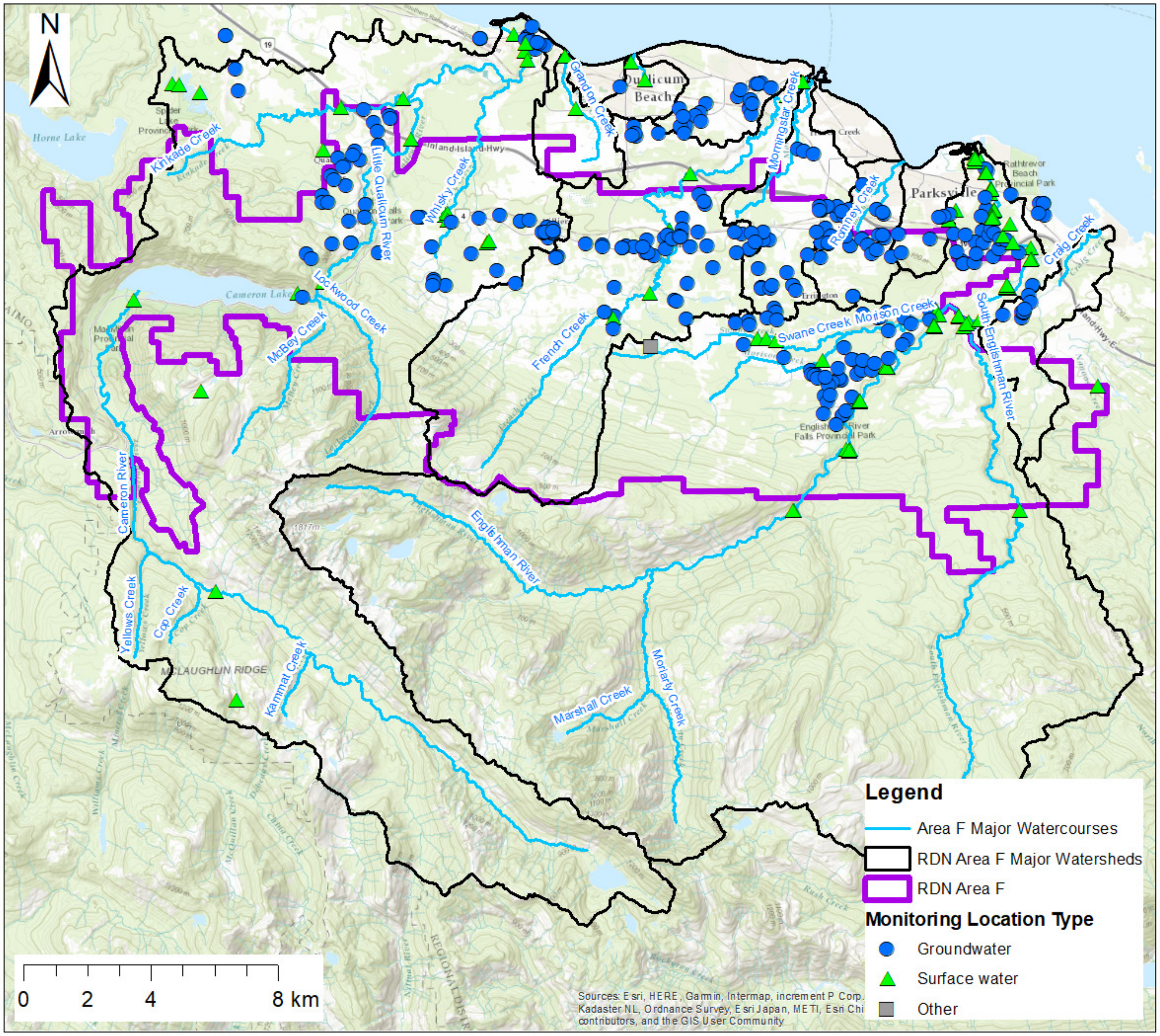

Figure 49. Groundwater and surface water quality stations

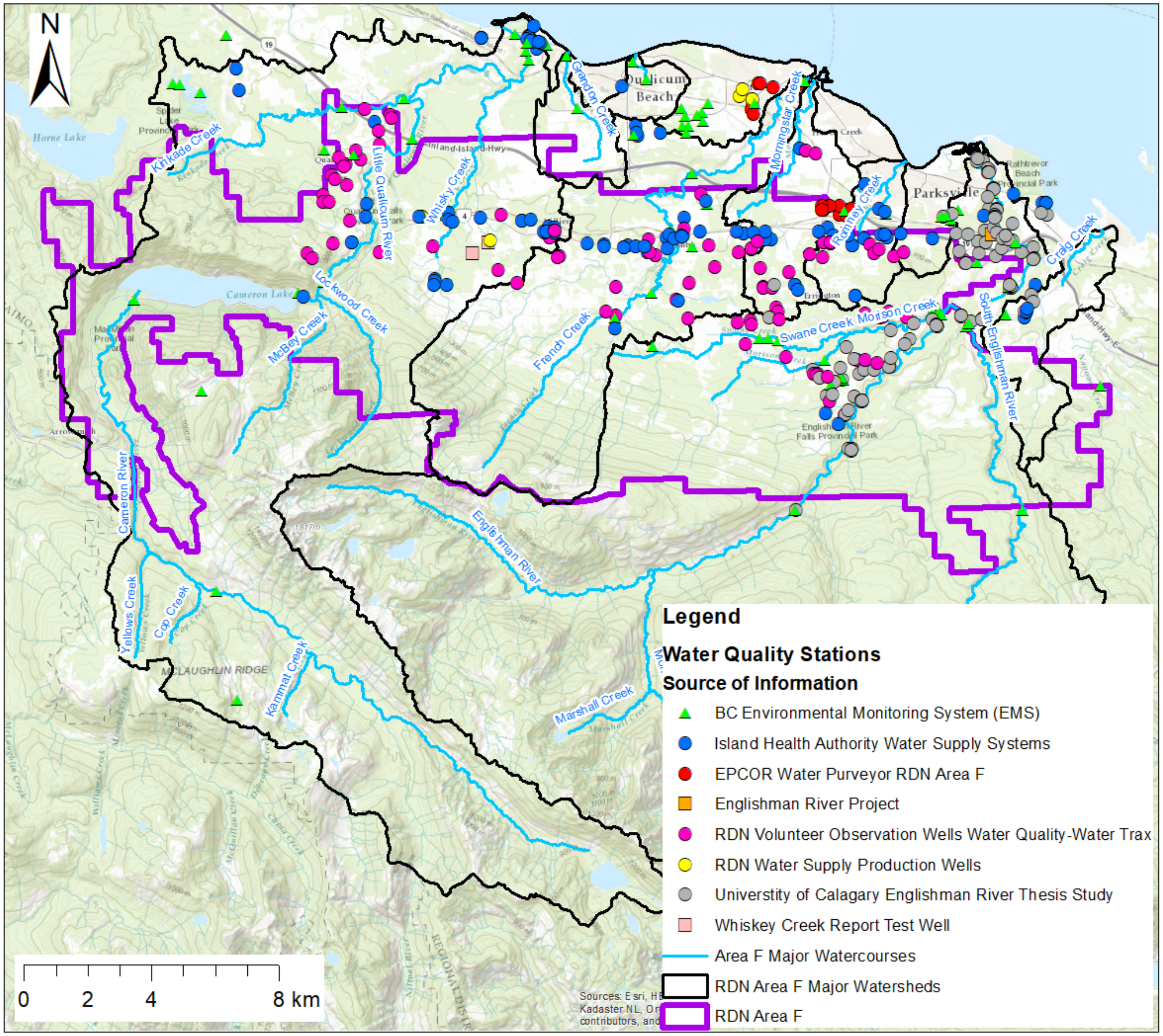

Figure 50. Groundwater and surface water quality stations classified by source of information

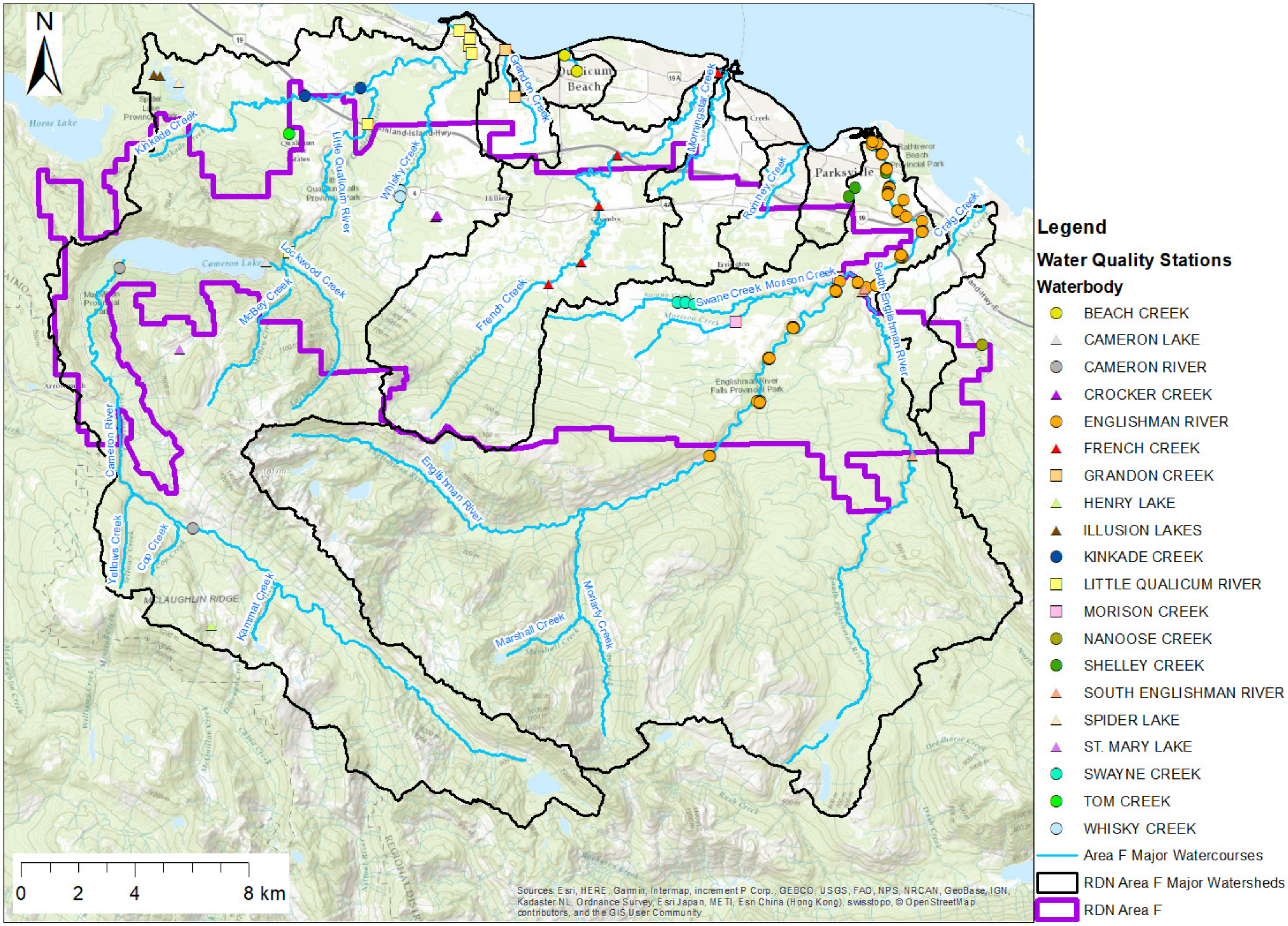

Figure 51. Surface water quality stations classified by watercourse

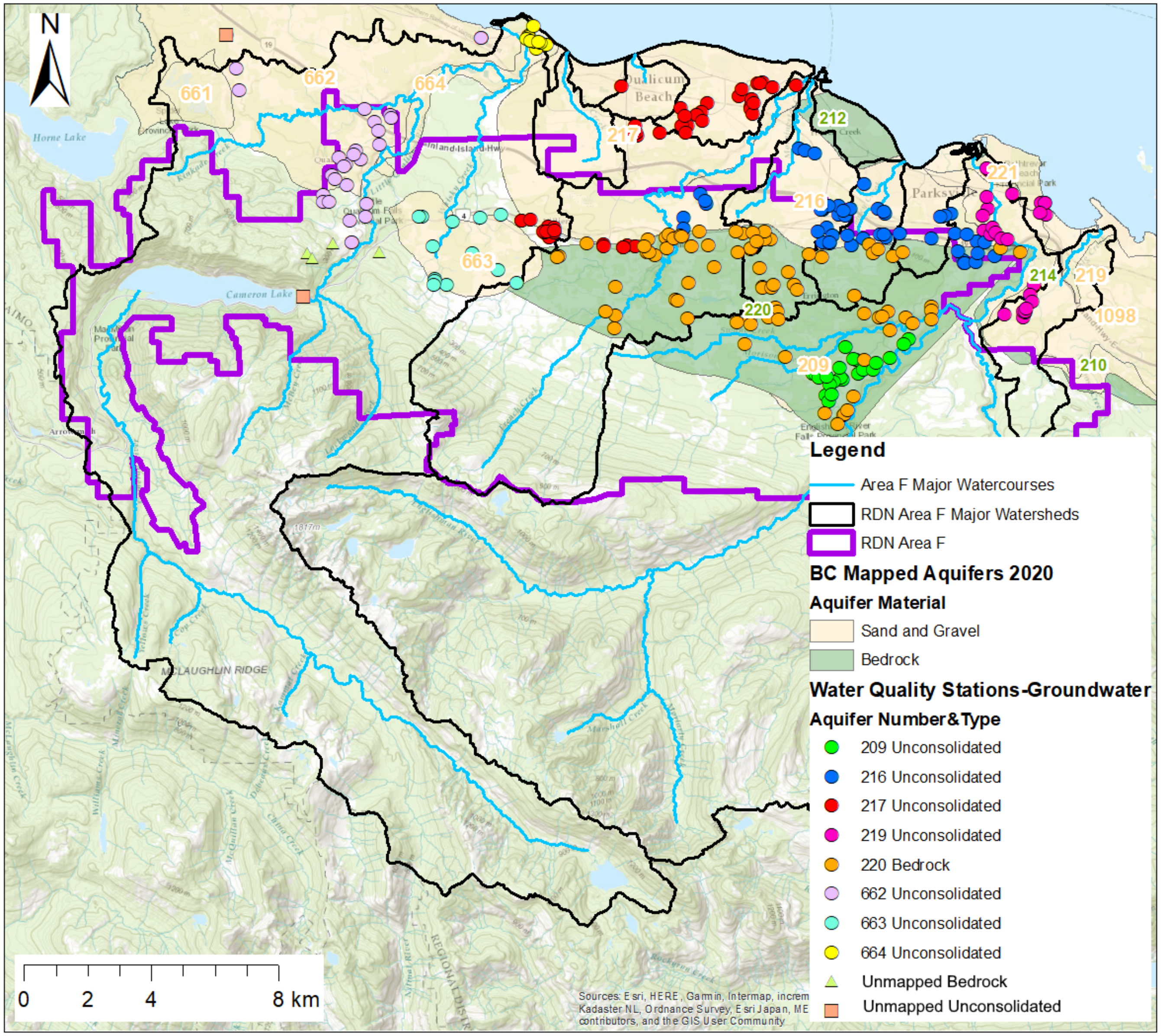

Figure 52. Groundwater quality stations classified by aquifer

5.3 Spatial and Temporal Changes of Water Quality

5.3.1 Water type determination to assess water quality change

5.3.1.1 *Methodology*

The main anions and cations constituting the water chemistry analysis are used to determine the water type, or hydrochemical facies. Piper diagrams are commonly used to represent and visualize the key ions present in water, to compare water samples, and to illustrate changes in water quality. The major ions in water are usually calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg) for the cations, and sulfate (SO_4), chloride (Cl), bicarbonate (HCO_3), carbonate (CO_3) and nitrate (NO_3) for the anions.

The concept of hydrochemical facies has been used to describe the effects of complex hydrochemical chemical processes in the subsurface occurring between geological materials and the groundwater passing through them. The water type has been used to illustrate the spatial variability of groundwater chemistry and its evolution through time.

Only the major ions (Ca, Na, K, Mg, SO_4, HCO_3, CO_3, Cl and NO_3) were included for water type analysis.

5.3.1.2 *Water Type - Surface Water*

The Piper diagram presented in Figure 53 shows samples from all waterbodies within Area F. Figure 54 shows the spatial distribution of the dominant water type in surface water samples. All the samples are characterized as being of the Bicarbonate-Calcium (HCO_3-Ca) type, which is typical for fresh, surface water with an exception of samples collected in waterbodies close to the ocean.

The water from both French Creek and the Englishman River was further analysed.

French Creek (Figure 55):

- There are three sampling stations for this water body within Area F. Spatial trends were not observed for this segment of French Creek. Variations in water type are likely explained by temporal or seasonal variations in water chemistry.

Englishman River (Figure 56):

- The data indicates a downstream increase in sodium, potassium and chloride. This likely results from the increased contribution of groundwater derived from the bedrock.

5.3.1.3 *Water Type - Groundwater*

For wells installed in bedrock, groundwater falls mainly into three types: Bicarbonate-Calcium (HCO_3-Ca), Bicarbonate-Sodium (HCO_3-Na), and Chloride-Sodium (Cl-Na) (Figure 57 and Figure 58). This is typically related to the time water was in contact with the bedrock and the nature of the bedrock. A Bicarbonate-Calcium (HCO_3-Ca) water type would reflect a younger water flowing through a poorly reactive rock.

There is no clear spatial trend in groundwater type for wells installed in Aquifer 220; however, we observe that groundwater in the headwaters of the aquifer shows a predominance of type HCO_3-Ca, indicative of a water which had little time to interact with the bedrock (Figure 58). Reasons for spatial variability in water type may be factors such as well depth, land use, or hydraulic connectivity with streams and/or overlying aquifer.

Figure 59 shows the water types for wells installed in overburden aquifers and Figure 60 shows the spatial distribution of the dominant water type in groundwater samples completed in the overburden aquifer. The results for aquifers within Area F are summarized as:

- Aquifer 209 shows a dominant HCO_3-Ca type with the exception of two wells falling under the HCO_3-Na type.
- Aquifer 216 also shows mostly HCO_3-Ca type, with one sample showing HCO_3-Mg type, one sample showing Na-Cl type and two samples with HCO_3-Na type.
- Aquifer 217 shows mostly HCO_3-Ca-Mg type. We observe that the closest samples to the road tend to have a higher content of sodium and chloride.
- Aquifer 262 reports mostly HCO_3-Ca type. We also observe a tendency of some samples to indicate a higher content of Na and Cl.
- For Aquifer 663, we can distinguish two groups: One with HCO_3-Ca type and the other having a high chloride concentration that increased over time. This last group includes the wells located along the Alberni Highway.

The presence of saline waters at depth is possibly associated with mature groundwaters and/or connate relict marine water from past periods of higher sea level, within areas of limited recharge.

Piper plots for each overburden aquifer, separately, are provided in Appendix 3.

5.3.1.4 *Water Type by zoning and land use*

Most wells are used for domestic purposes according to the zoning within Area F. Figure 61 shows that wells with higher chloride concentration are predominantly domestic with some being used for commercial purposes. A possible reason for higher chloride concentrations for this type of land use is the use of pesticides for lawns and gardens and/or mature groundwaters and/or connate relict marine water from past periods of higher sea level.

- Aquifers reporting bicarbonate calcium water type (HCO_3-Ca) represents young water (not mature) such us overburden Aquifers 209, 216, 217, 262 and 663 and bedrock Aquifer 220
- Aquifers reporting bicarbonate sodium water type (HCO_3-Na) represents more mature groundwater that has undergone some cation exchange or alternatively have been affected by anthropogenic activities such as some wells in overburden Aquifer 209, 216 and some wells in the bedrock Aquifer 220.
- Groundwater type chloride sodium (Cl-Na) represents groundwater affected by anthropogenic activities (e.g., septic fields and/or farming activities) or likely associated with mature groundwaters and/or connate relict marine water from past periods of higher sea level, within areas of limited recharge. Wells that falls into this group corresponds to surficial Aquifer 216, 217, 262 and bedrock Aquifer 220
- Groundwater samples classified as bicarbonate magnesium type (HCO_3-Mg) reflects the dissolution or cation exchange with magnesium containing rocks such as those reported in overburden Aquifers 216 and 217 suggesting that these aquifers might be partially recharged from the bedrock system.

- Aquifers reporting bicarbonate calcium water type (HCO_3-Ca) represents young water (not mature) such us surficial aquifers 209, 216, 217, 262 and 663 and bedrock aquifer 220
- Aquifers reporting bicarbonate sodium water type (HCO_3-Na) represents more mature groundwater that has undergone some cation exchange or alternatively have been affected by anthropogenic activities such as some wells in surficial aquifer 209, 216 and some wells in the bedrock aquifer 220.
- Groundwater type chloride sodium (Cl-Na) represents groundwater affected by anthropogenic activities such road salting and/or septic fields and/or farming activities. Wells that falls into this group corresponds to surficial aquifer 216, 217, 262 and bedrock aquifer 220
- Groundwater samples classified as bicarbonate magnesium type (HCO_3-Mg) reflects the dissolution or cation exchange with magnesium containing rocks such as those reported in surficial aquifers 216 and 217 suggesting that these aquifers might be partially recharged from the bedrock system.

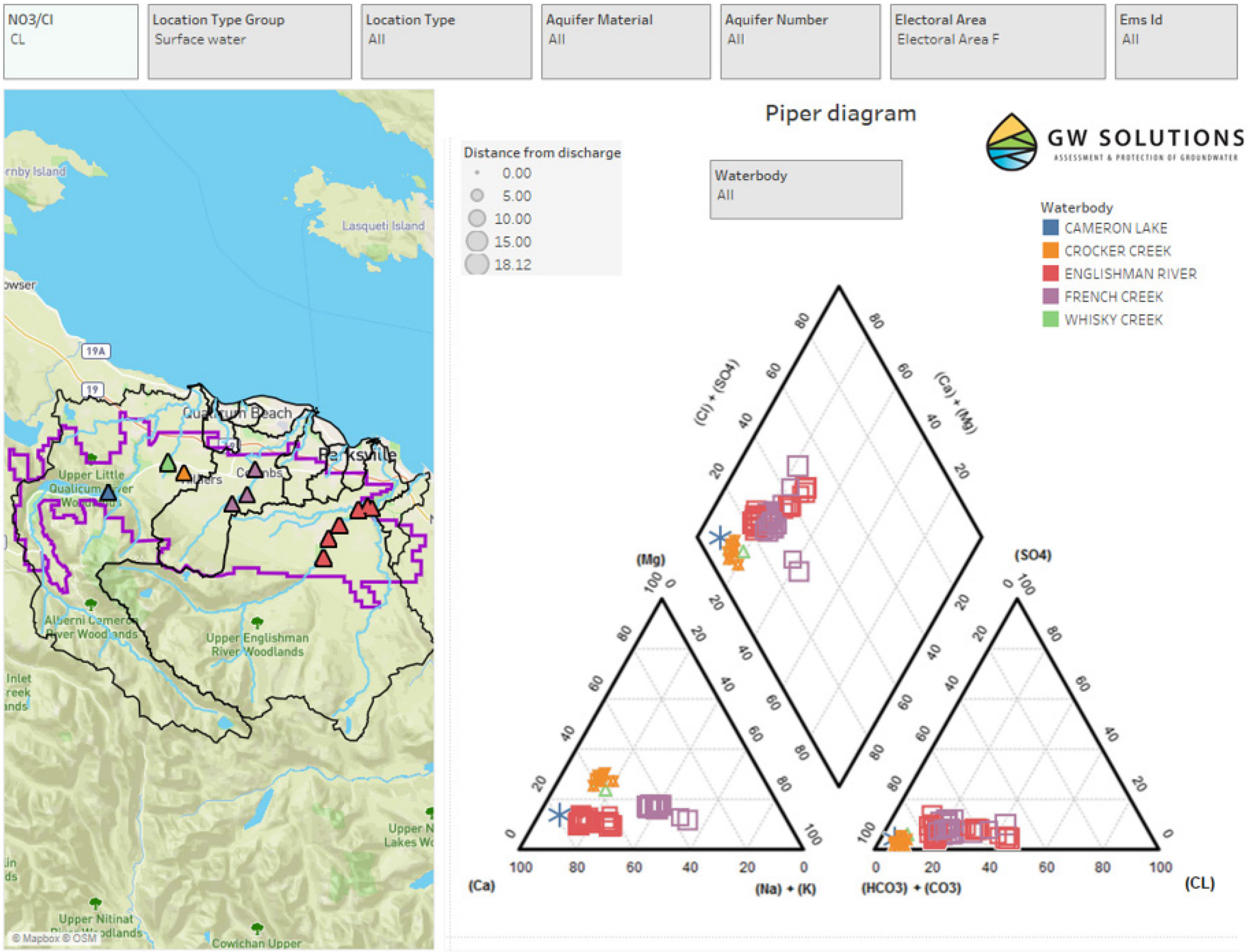

Figure 53. Water type analysis for surface water

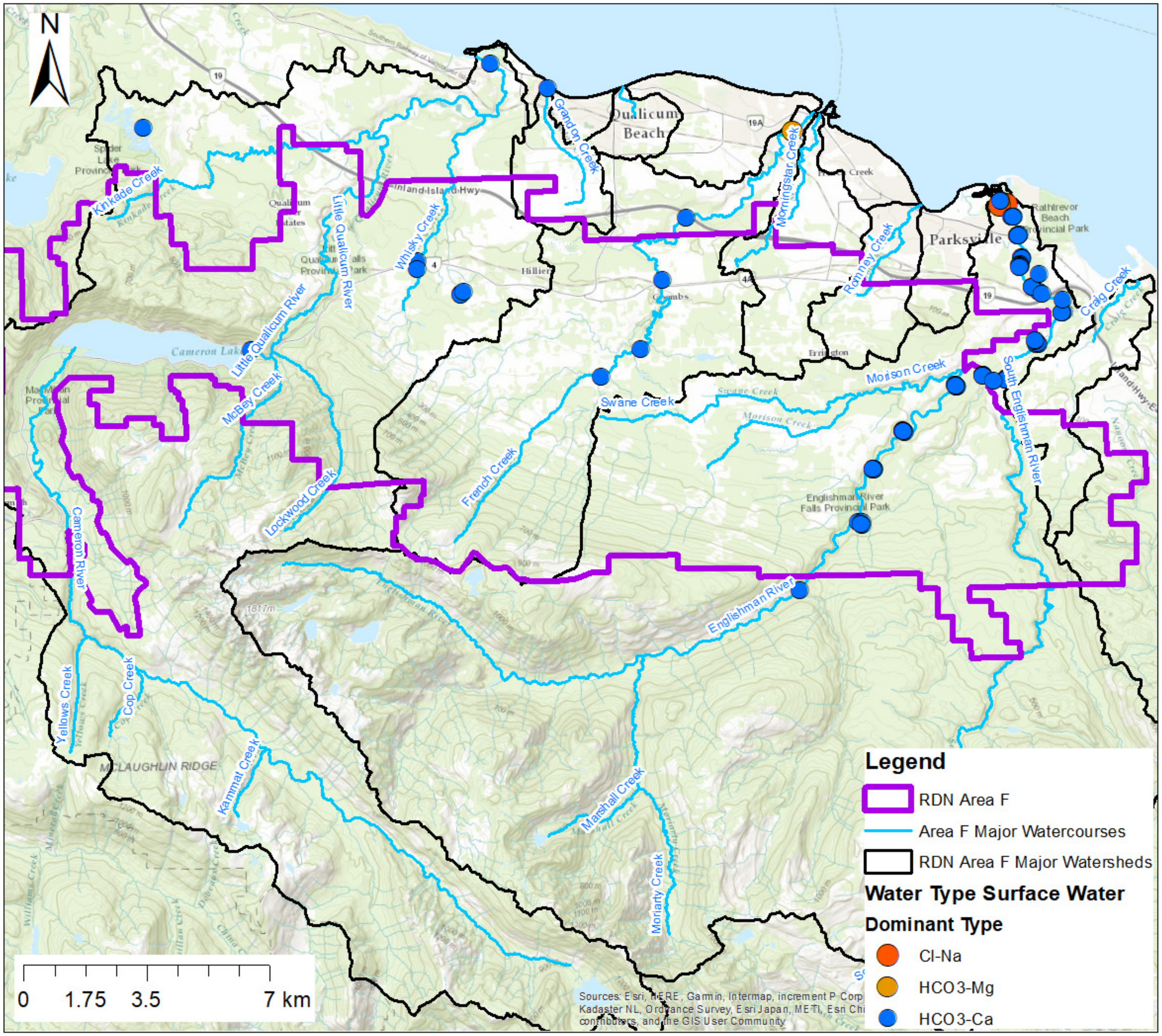

Figure 54. Spatial distribution of dominant water type for surface water samples

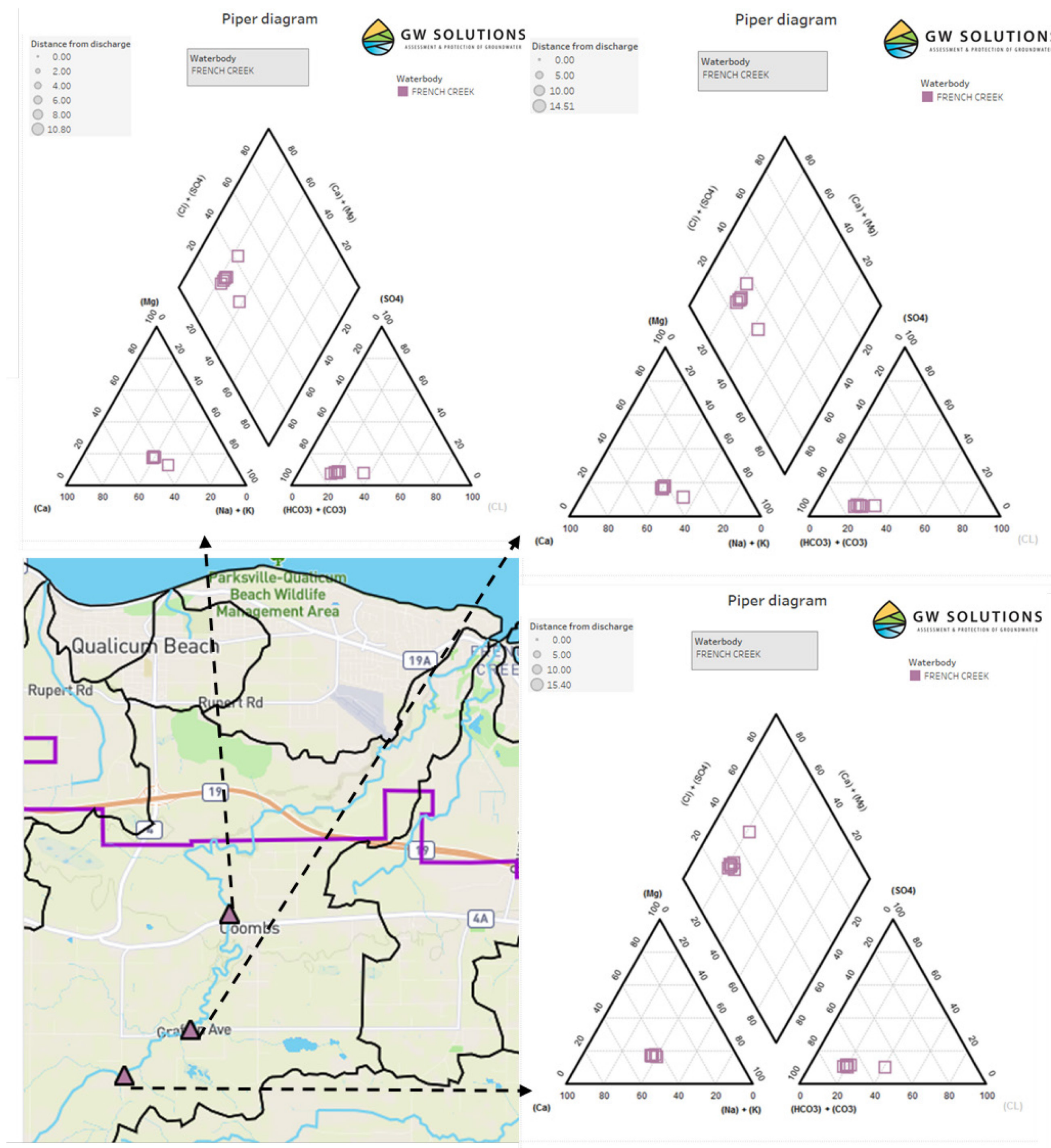

Figure 55. Water type analysis along French Creek (samples within Area F)

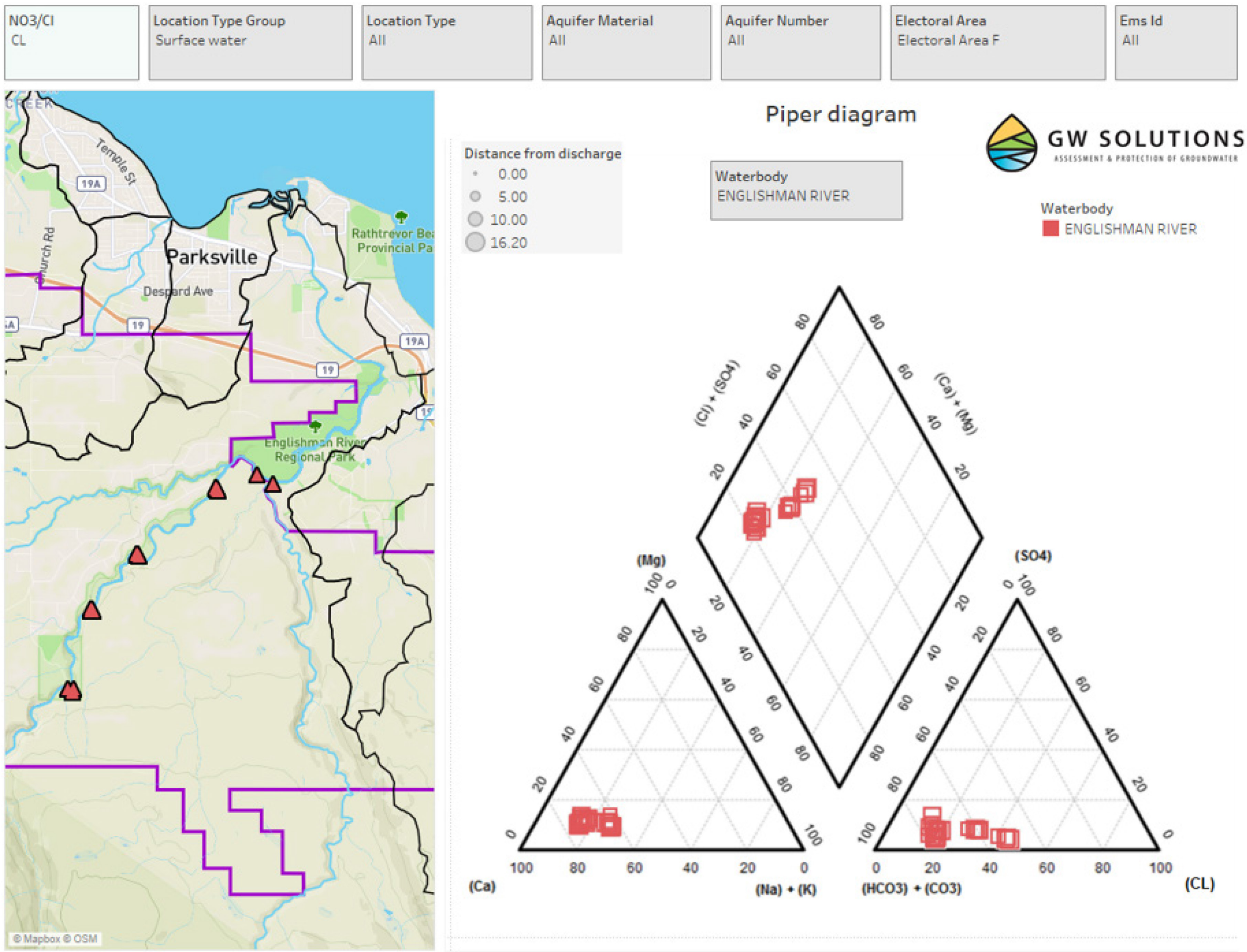

Figure 56. Water type analysis along the Englishman River (samples within Area F)

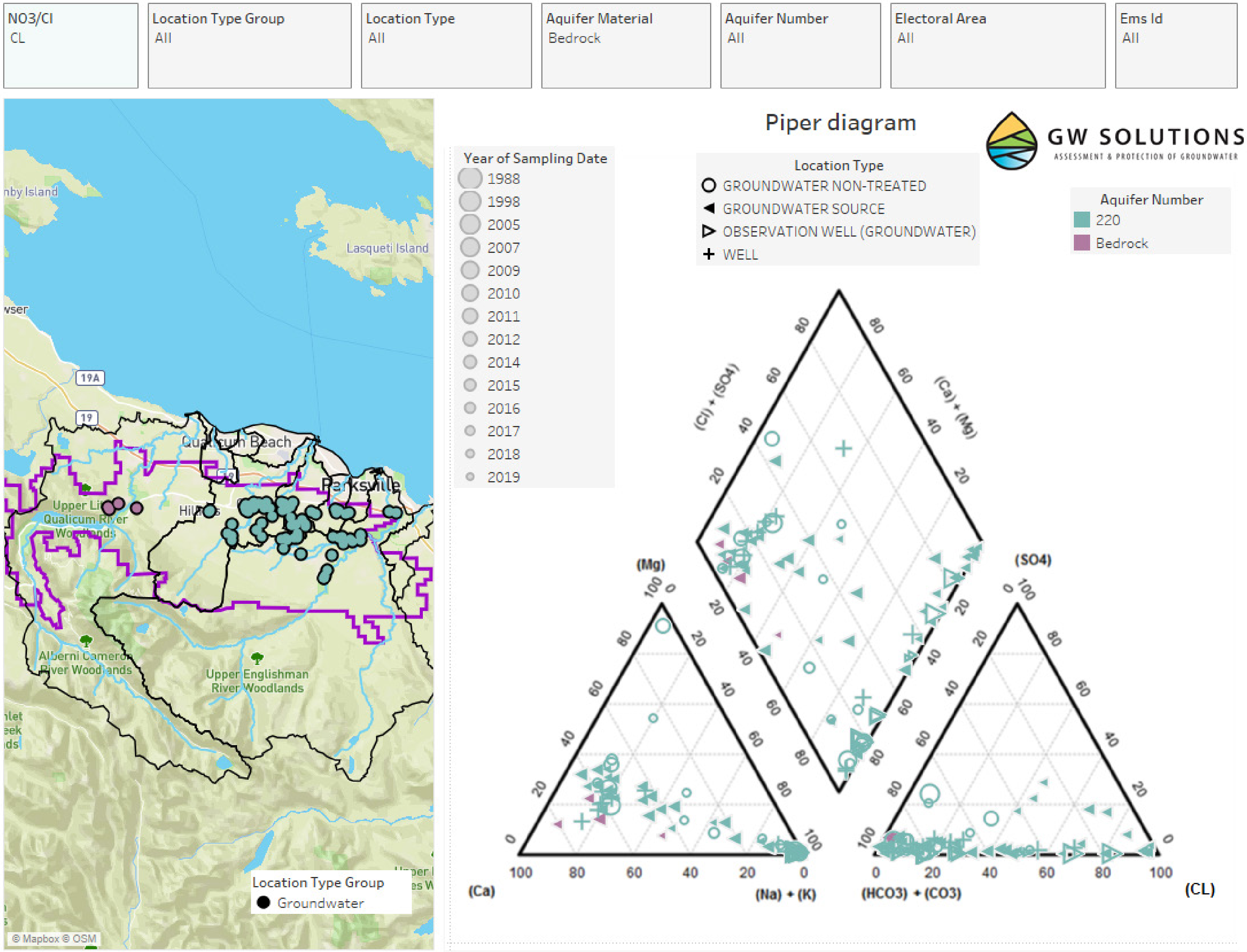

Figure 57. Water type analysis for bedrock aquifers

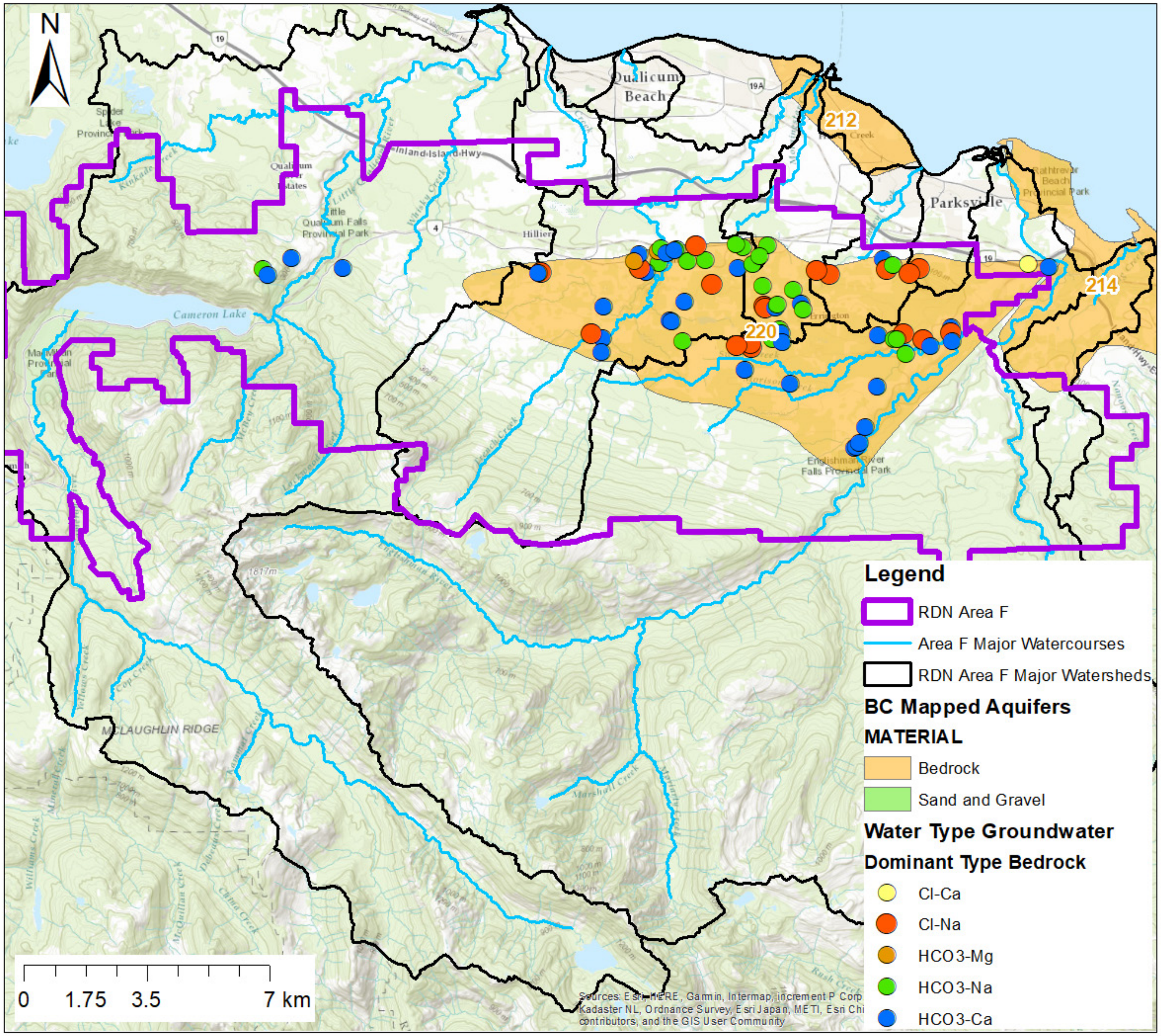

Figure 58. Spatial distribution of dominant water type for groundwater samples in bedrock wells

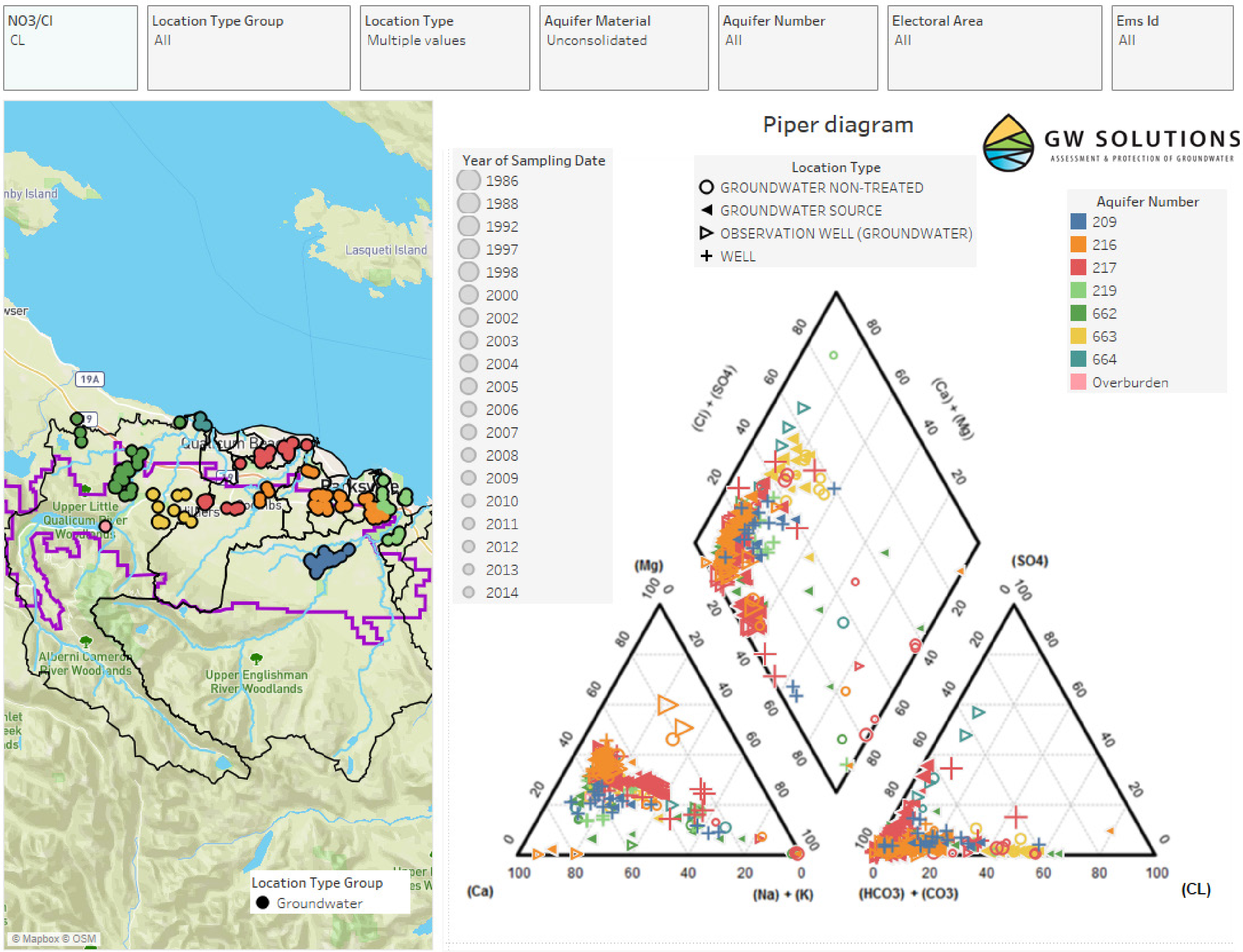

Figure 59. Water type analysis for overburden aquifers

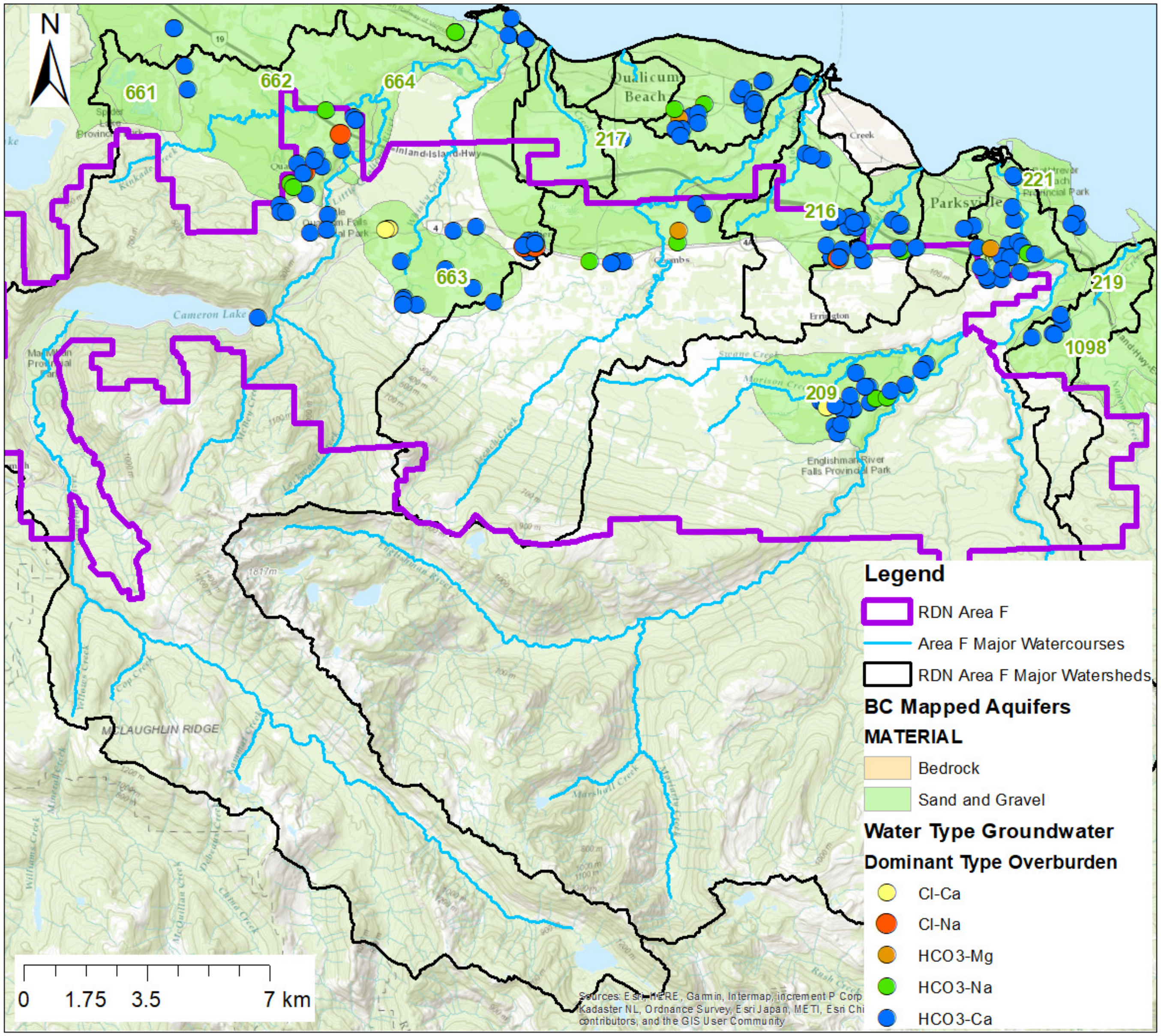

Figure 60. Spatial distribution of dominant water type for groundwater samples in overburden wells

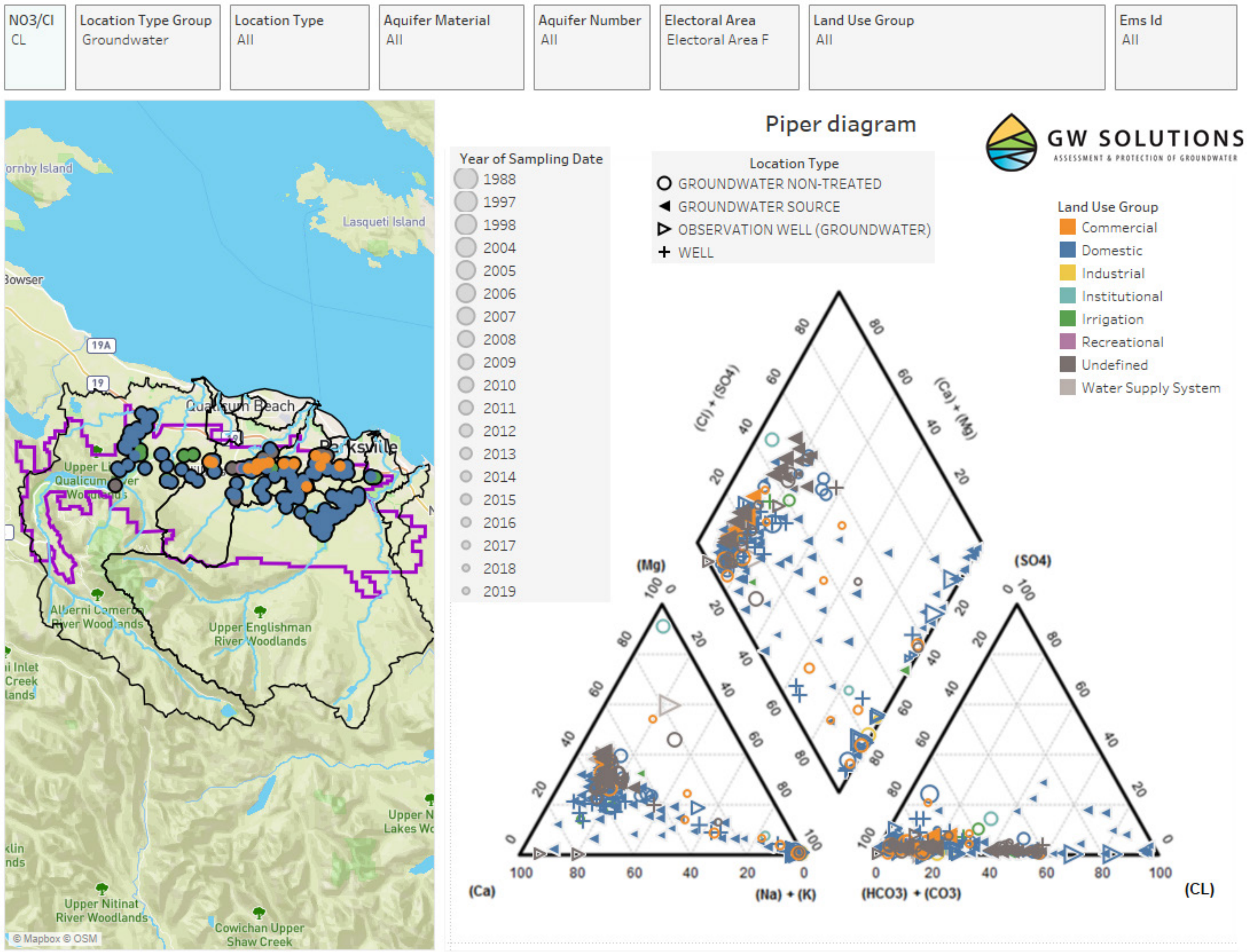

Figure 61. Water type analysis for groundwater classified by land use (samples within Area F)

5.4 Guidelines and Exceedance Analysis

Two sets of guidelines were considered for the exceedance analysis: The Guidelines for Canadian Drinking Water Quality and the BC Fresh Water Aquatic Life Guidelines for both acute and chronic exposure.

5.4.1 Guidelines for Canadian Drinking Water Quality (GCDWQ)

The Guidelines for Canadian Drinking Water Quality are published by Health Canada on behalf of the Federal-Provincial-Territorial Committee on Drinking Water (CDW) (Health Canada 2012; Health Canada 2017). The guidelines are based on current, published scientific research related to health effects, aesthetic effects, and operational considerations. Health-based guidelines are established on the basis of comprehensive review of the known health effects associated with each contaminant, on exposure levels and on the availability of treatment and analytical technologies. As of June 2019, limits for 107 parameters are provided including bacteriological, physical, metals, hydrocarbons and radiological parameters.[3]

The guidelines are established based on the following assumptions:

1. Exposure to the contaminant could lead to adverse health effects;
2. The contaminant is frequently detected or could be expected to be found in a large number of drinking water supplies throughout Canada; and
3. The contaminant is detected, or could be expected to be detected, at a level that is of possible health significance.

Exceedance analysis reports using this guideline (GCDWQ) for groundwater samples are presented in Figure 62 through Figure 69. These figures indicate:

- For Area F and north to the coast: Parameters such as coliforms, ions (sodium, fluoride and chloride), metals (arsenic, copper, cadmium, lead, zinc, manganese, chromium, iron, aluminum and barium), nitrates, and physical properties (pH, TDS, color and sulfide) have exceedances to the guideline. Iron and manganese reported a large number of exceedance (48% and 24% of samples exceeded guidelines, respectively), followed by aluminum (5%), lead (4%), and arsenic (3%) (Figure 62);

[3] (https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/water-eau/sum_guide-res_recom/sum_guide-res_recom-eng.pdf).

- For Area F: Groundwater samples show similar series of parameters exceeding guidelines. However, the list of metals is smaller and includes arsenic, copper, lead, zinc, manganese, iron, aluminum and barium (Figure 63);

- Nitrate, TDS, sulfide, sodium, fluoride, chloride and aluminum are found exceeding the guidelines more often for samples collected within Area F than samples collected outside of Area F (Figure 64);

- Only three metals (aluminum, manganese and iron), and pH, color and bacteria are reported as exceeding the GCDWQ for surface water samples within the Area F (Figure 68);

- When comparing surface water samples collected within Area F to samples collected downstream of Area F we observe an increase in exceedance for iron from 2% to 10% of samples (Figure 69) suggesting more groundwater discharging to streams as we move downstream along the streams.

The exceedance analysis report by aquifer is presented in Appendix 4. Examples of exceedance analysis reports for aquifers 209, 220 and 663 are presented in Figure 65, Figure 66, and Figure 67, respectively.

5.4.2 **Provincial Acute Fresh Water Aquatic Life Guidelines**

The BC Ministry of Environment (BC MoE) has developed several guidelines to protect water users including drinking water, recreation, aquatic life, wildlife, and agriculture. For most of the parameters, the most stringent provincial guideline corresponds to the protection of aquatic life. The aquatic life guideline includes both chronic and acute limits. The guidelines are updated periodically to incorporate new information and represent the best guidance.

Although the guidelines do not have a strong legal status, once approved, they must be considered in any decision affecting water quality. The guidelines are used to assess water quality and may be used as the basis for determining the allowable limits in waste discharge authorizations. Exceeding a water quality guideline does not imply that unacceptable risks exist, but rather that the potential for adverse effects may be increased and additional investigation may be required.

Only surface water samples were compared to the acute aquatic life guideline. The results are presented in Figure 70. Samples collected within Area F present exceedances for aluminum and cadmium-dissolved concentrations. Samples collected downstream of Area F show exceedances for copper, lead, zinc, aluminum, cadmium, and iron concentrations.

5.4.3 Aquatic Life Freshwater Chronic (30-Day Mean) Guideline

The guidelines applying to long-term exposure (further referred to as "chronic" guidelines) can be used when at least five tests (results) within 30 days are available. As they refer to toxicity under chronic exposure, they are more stringent than the guidelines corresponding to short-term exposure (i.e., single event or "acute"). Therefore, the number of stations for which the conditions are met to calculate and compare to the chronic guideline are fewer than the number of stations for which we can compare to the acute guideline.[4]

Exceedance analysis reports for surface water stations with chronic data are presented in Figure 71. We observe exceedances for aluminum-dissolved, and copper-total in surface water samples collected within and downstream of Area F. Additionally, zinc is reported exceeding the guideline for chronic exposure at one location downstream of Area F (Englishman River at Highway 19A). The reasons are presently unknown.

[4] The guideline limits can be accessed through the link (https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines).

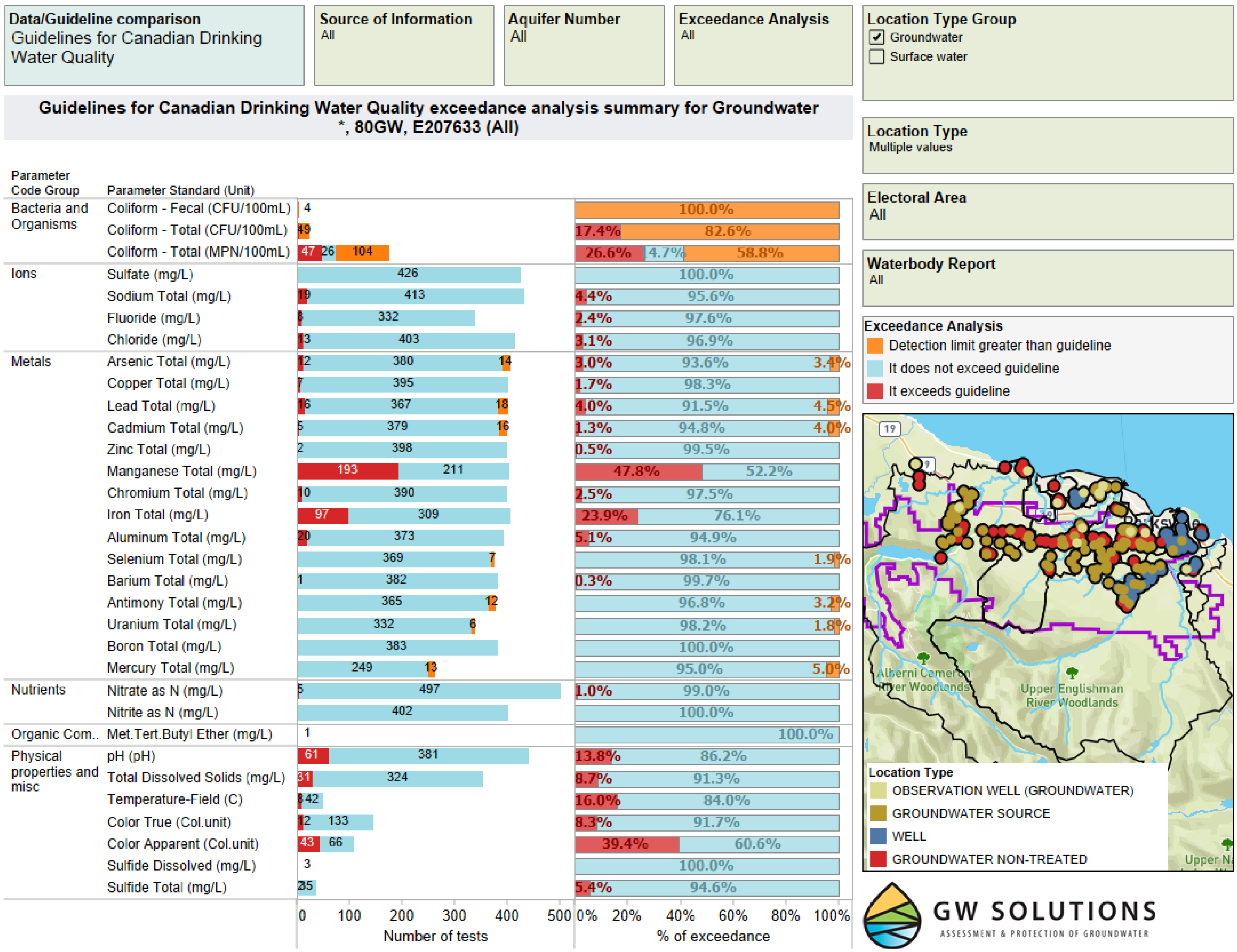

Figure 62. Exceedance Analysis (%) - GCDWQ – Groundwater samples

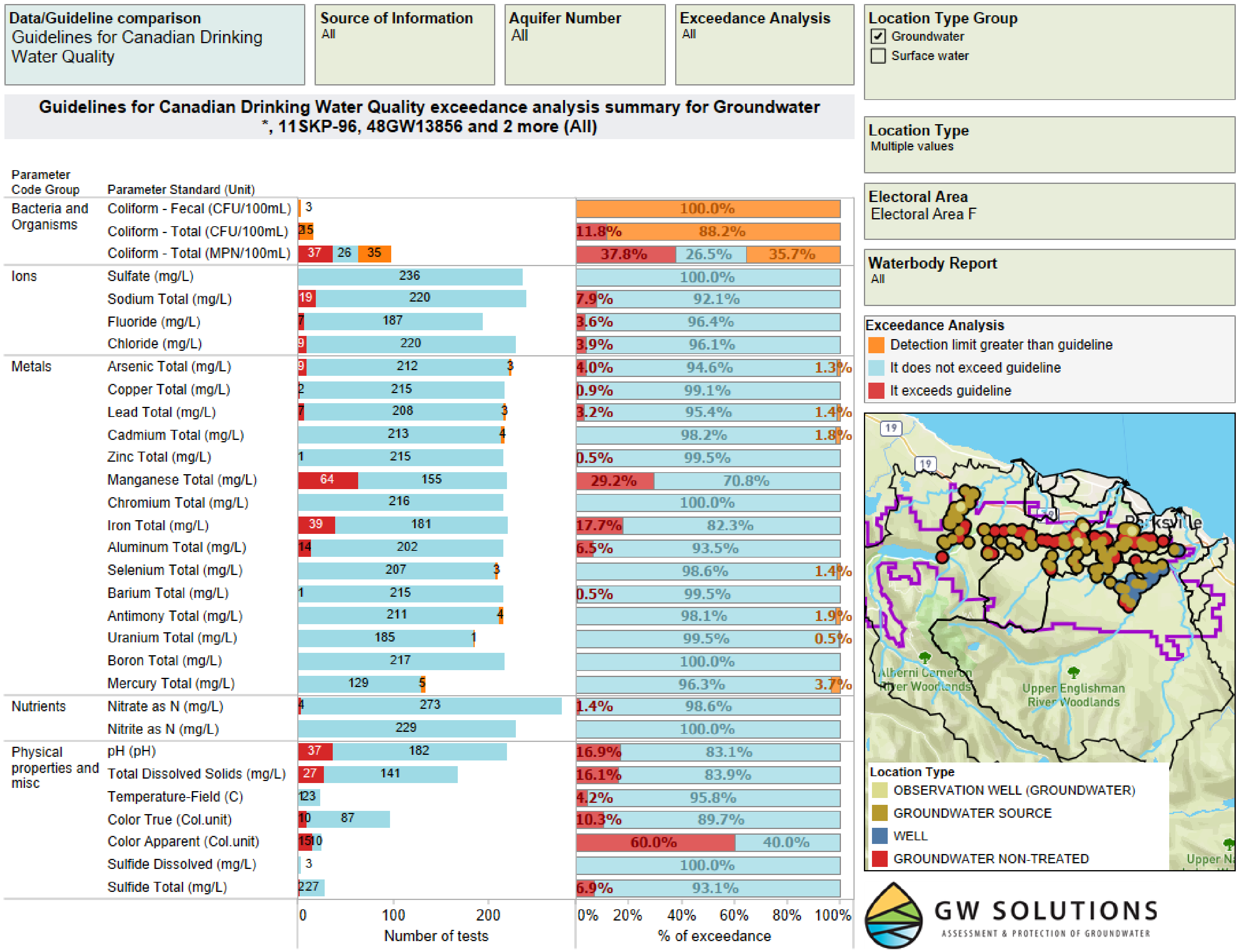

Figure 63. Exceedance Analysis (%) - GCDWQ – Groundwater samples within Area F

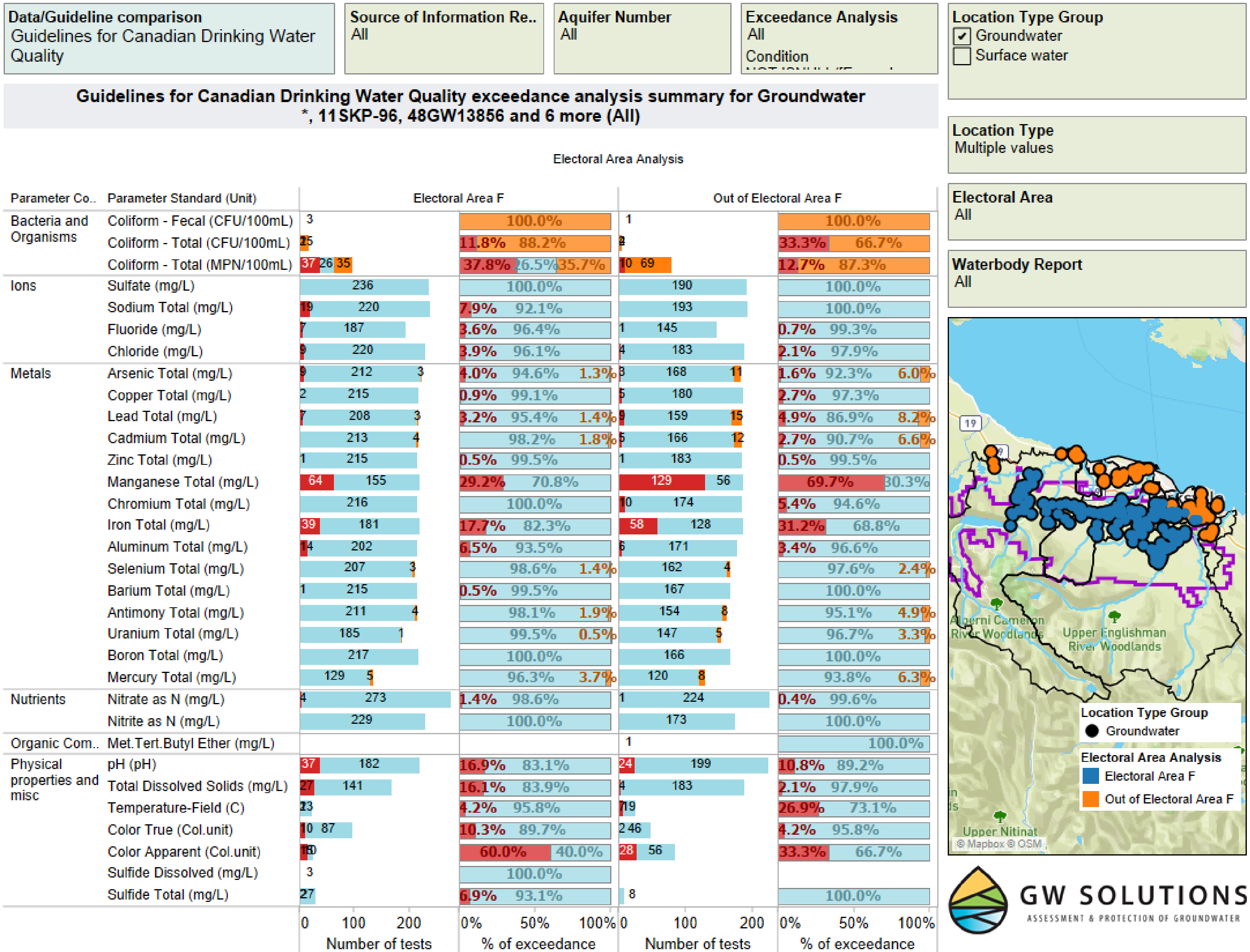

Figure 64. Exceedance Analysis (%) - GCDWQ – Groundwater samples within and out of boundary of Area F

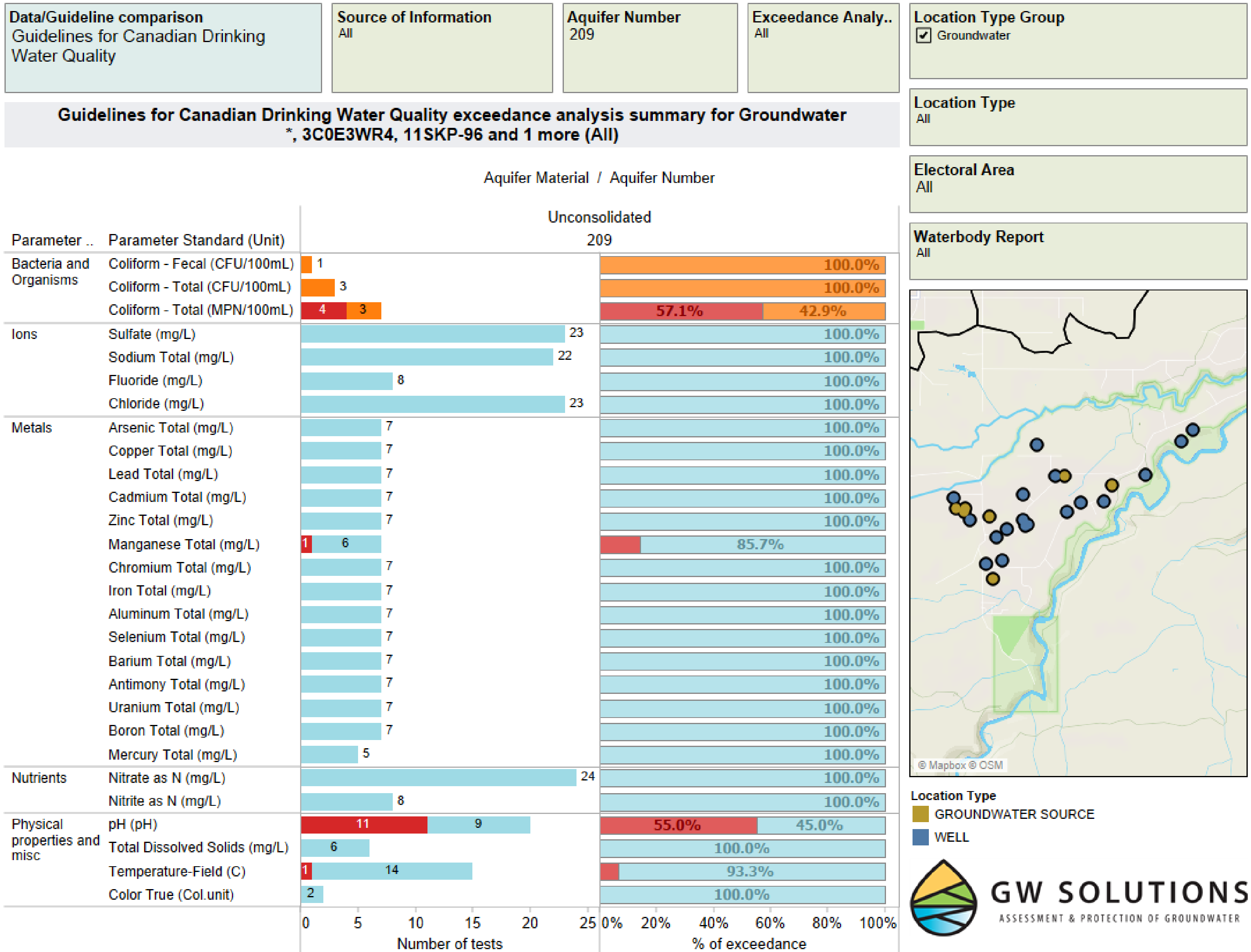

Figure 65. Exceedance Analysis (%) - GCDWQ – Groundwater samples collected from overburden Aquifer 209

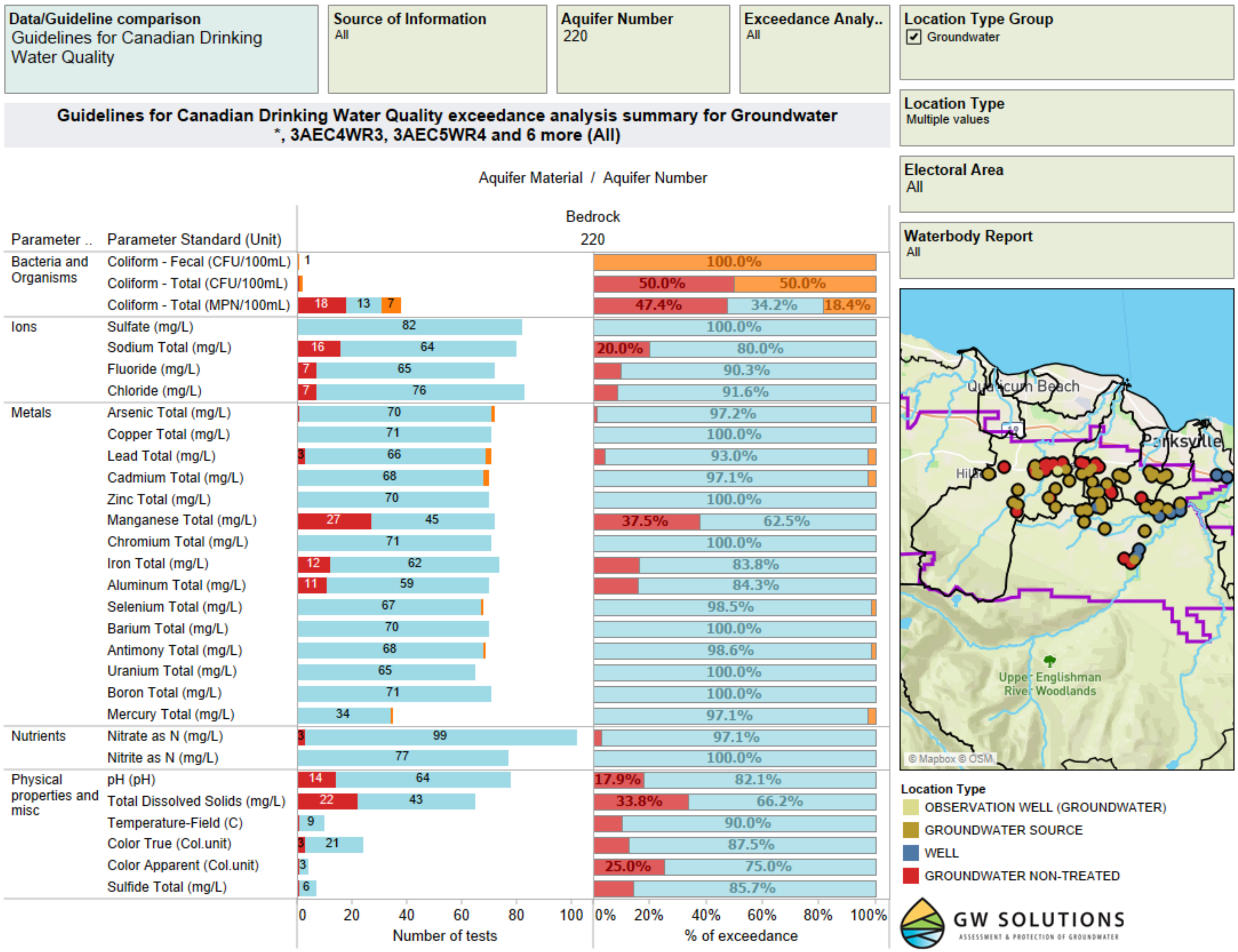

Figure 66. Exceedance Analysis (%) - GCDWQ – Groundwater samples collected from bedrock Aquifer 220

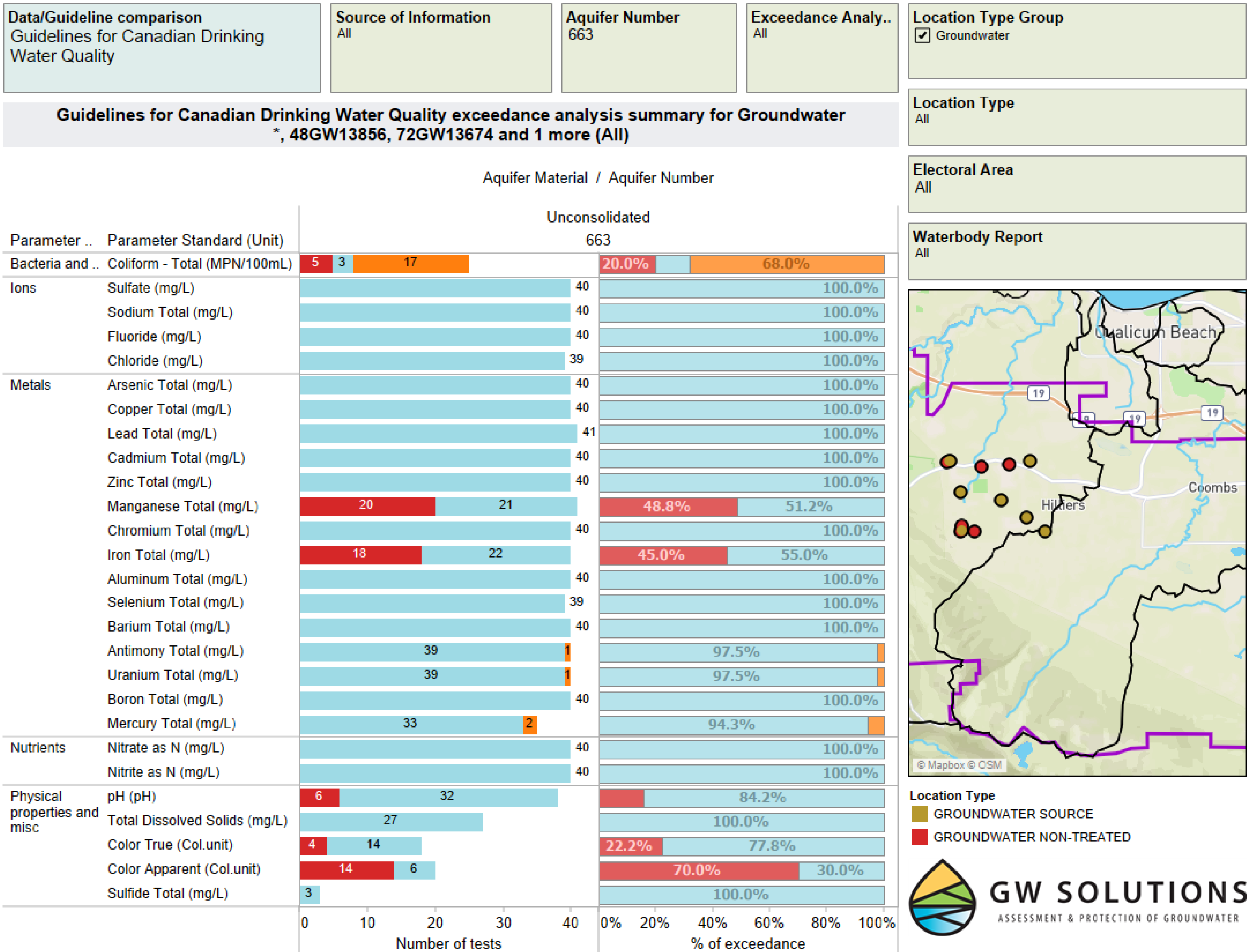

Figure 67. Exceedance Analysis (%) - GCDWQ – Groundwater samples collected from overburden Aquifer 663

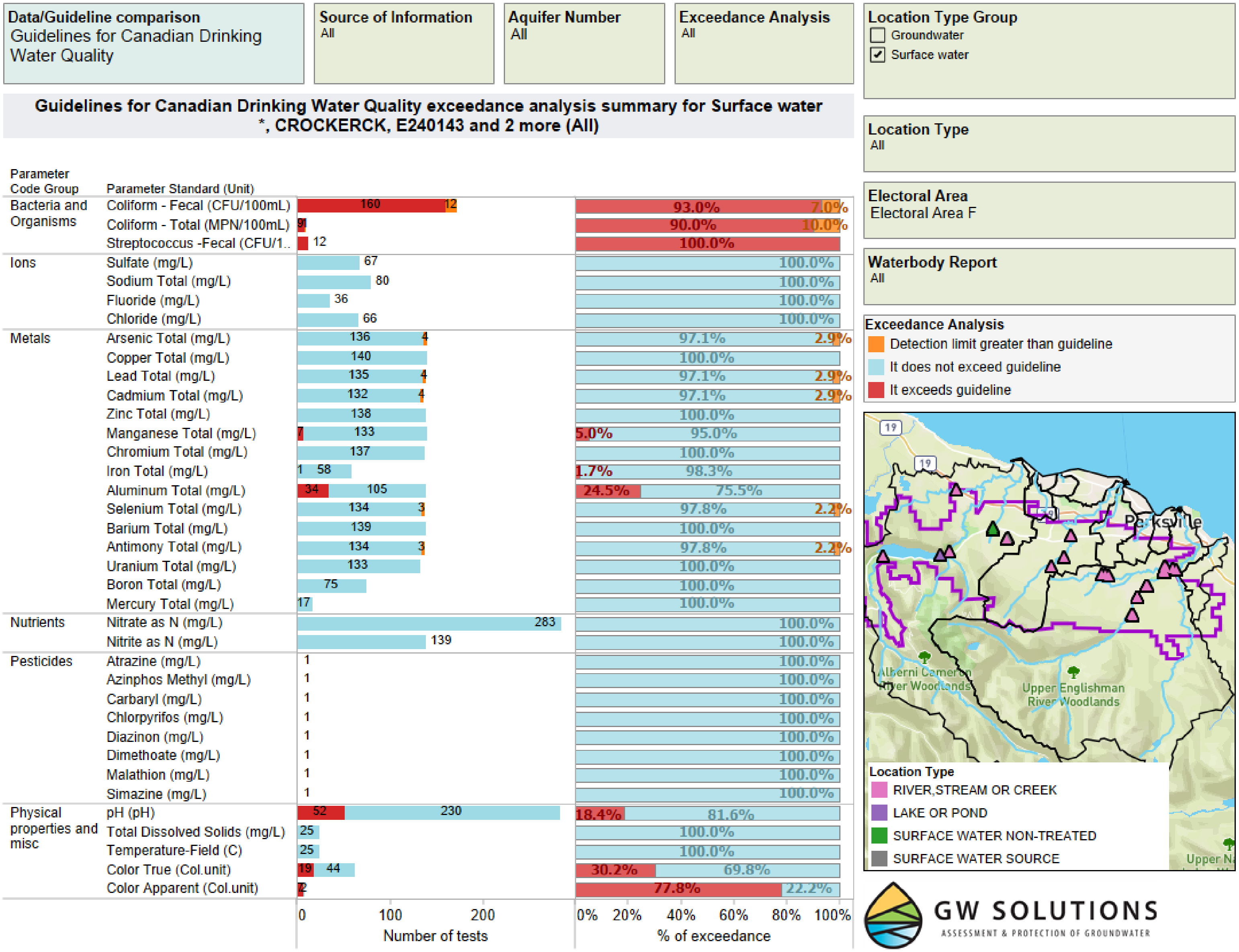

Figure 68. Exceedance Analysis (%) - GCDWQ – Surface water samples within Area F

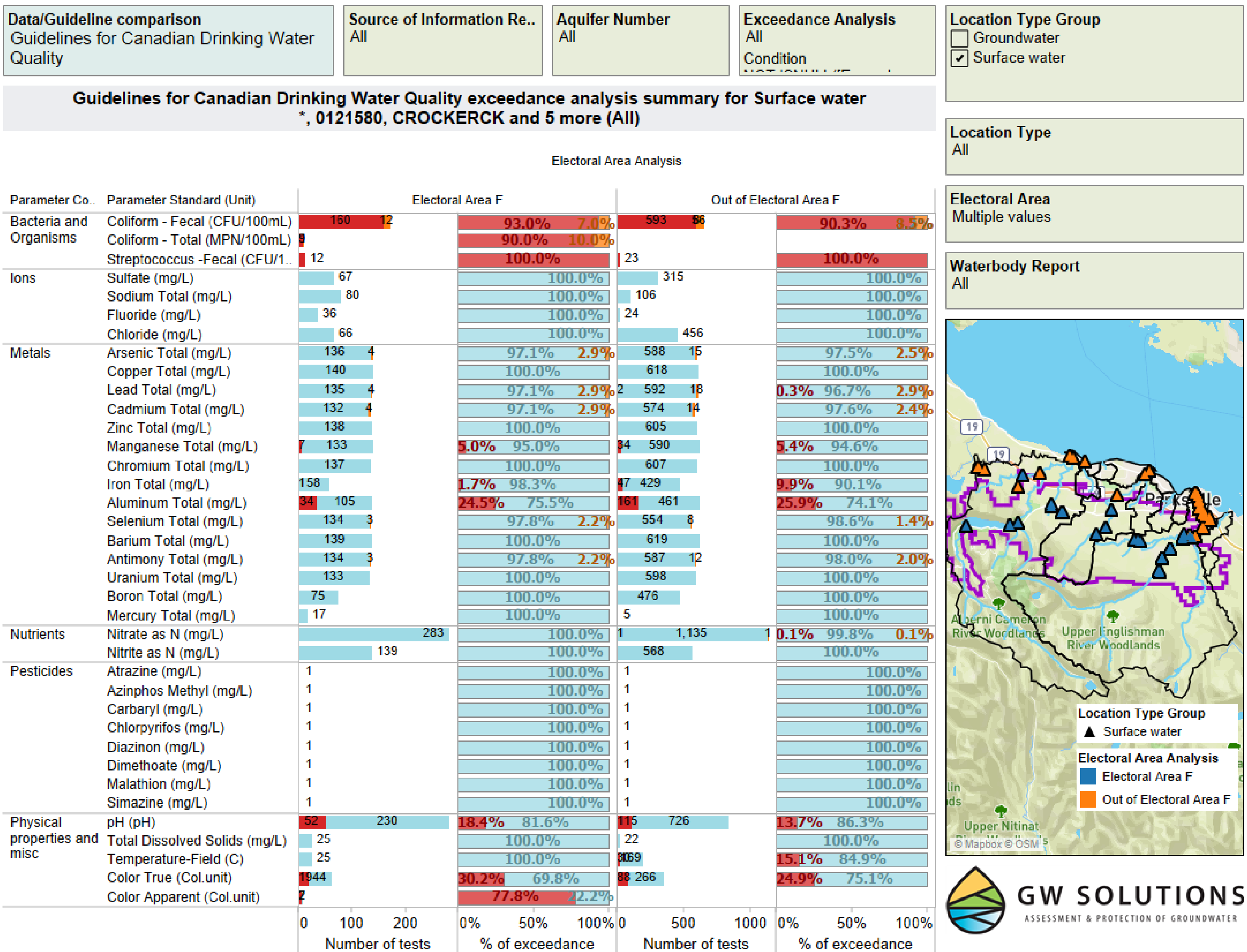

Figure 69. Exceedance Analysis (%) - GCDWQ – Surface water samples within and downstream of Area F

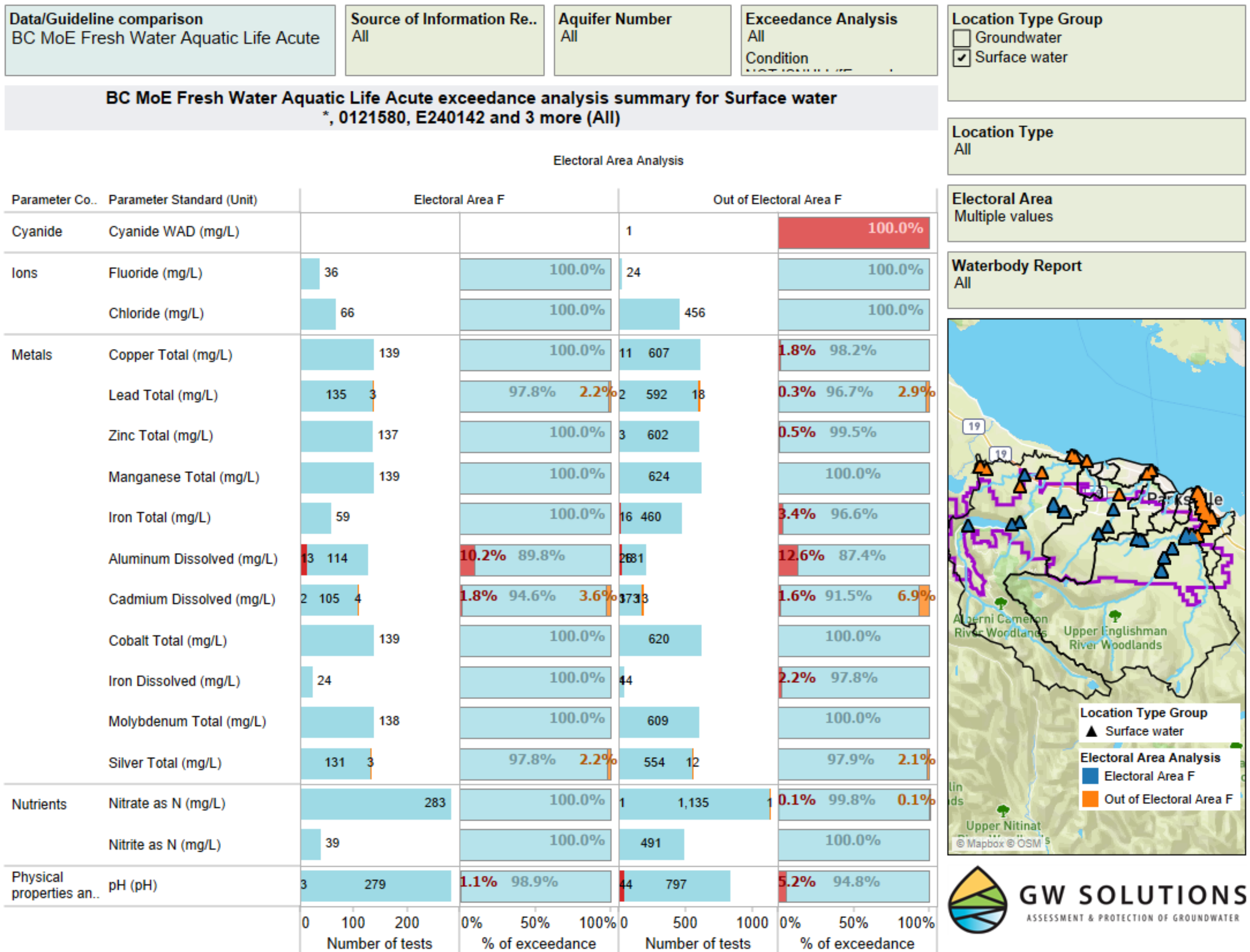

Figure 70. Exceedance analysis - BC FWAL - Acute Guideline – Surface water samples collected within and downstream of Area F

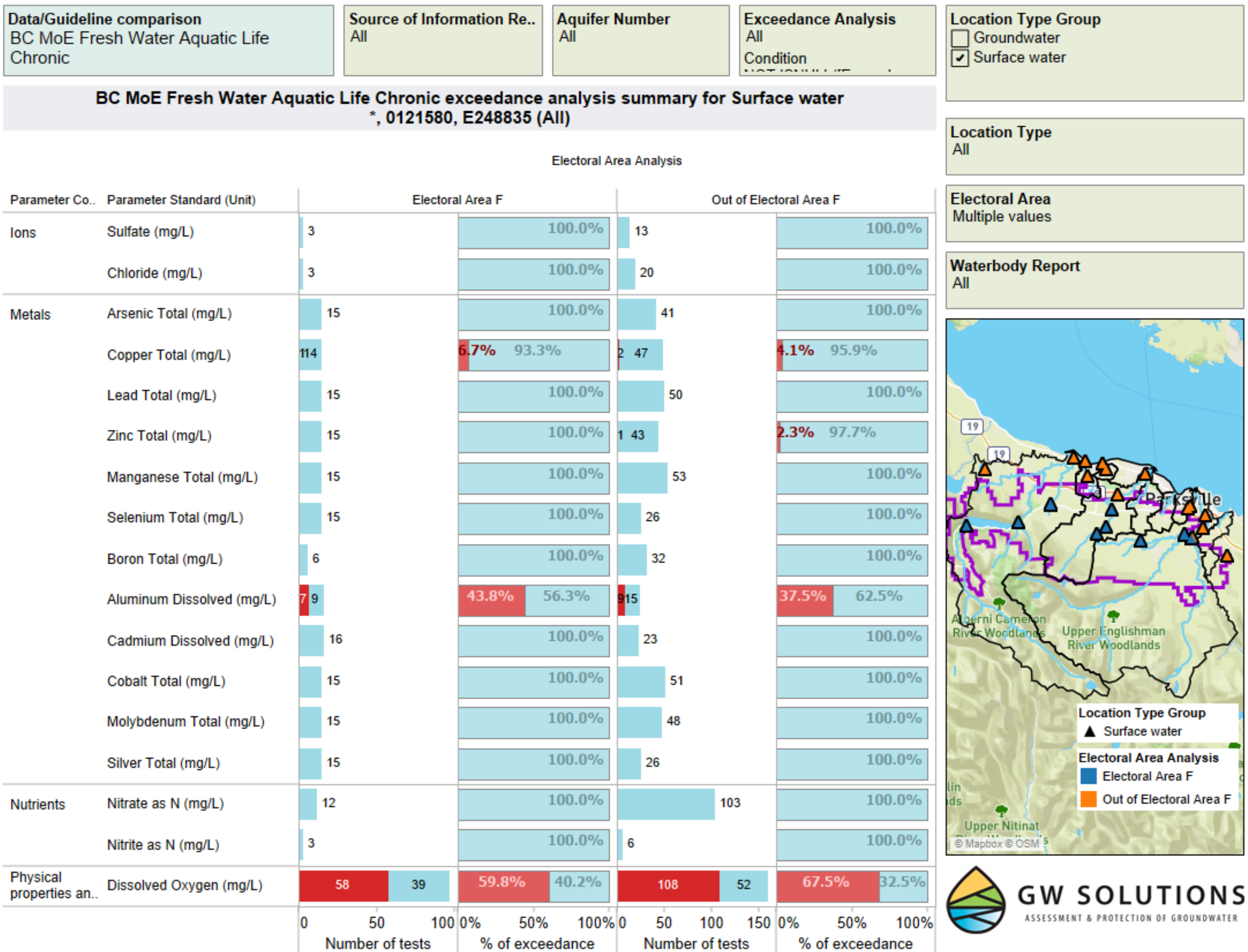

Figure 71. Exceedance analysis – BC FWALCG - Chronic Guideline – Surface water samples collected within and downstream of Area F

5.5 Assessment of Potential Link between Water Quality and Land Use

Several information sources have been studied to assess the potential adverse impacts of land activities on water quality. These resources were used in our study to infer the level of concerns and rate the associated hazards on water quality.

5.5.1 **Water Quality Hazards**

5.5.1.1 *Contaminated sites and Discharge authorizations*

- *Contaminated Sites*

“In British Columbia, a contaminated site is defined as an area of land in which the soil or underlying groundwater or sediment contains a hazardous waste or substance in an amount or concentration that exceeds provincial environmental quality standards[5]”. Based on this definition, a specific area is considered as a contaminated site if it is inappropriate for a certain use of land, water and its soils.

Based on the Ministry of Environment and Climate Change Strategy Database, there are many sites within the study area which have become contaminated due to past or current industrial or commercial activities.

Appendix 5 provides the list (common name) of registered contaminated sites along with their types, addresses, geographic locations and file numbers.

- *Waste Discharge*

Waste Discharge is regulated by the Province. The regulation defines what industries, activities and operations require authorizations to discharge or release waste to the air, water, and land under the Environmental Management Act in BC.

Waste discharge (e.g. factories effluents, hazardous sewage and wastewater discharge) is a potential source of contamination which could have an adverse impact on groundwater through seepage, or on surface water bodies through runoff to water ways.

Appendix 6 presents the list of the discharge types, their facilities, permit status and other properties.

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[5] https://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation

Figure 72 illustrates the existing contaminated sites based on the Ministry of Environment and Climate Change Strategy Database and BC Wastewater Discharge Licences within the study area.

5.5.1.2 *Land Use Activities and Zoning*

The current actual land use and zoning (land use regulations[6]) information were provided by RDN. Figure 73 and Figure 74 present the current land use (BC Assessment data) and the regulated land use, respectively. Table 7 summarizes the type of land uses and their corresponding potential contaminants based on published literature.

Figure 75 summarizes the RDN Agricultural Land Use Inventory (ALUI) completed in 2012. This map shows the land use for farming, highlighting the lands that fall into medium and large-scale animal farming activities. The farming lands are considered as a potential source of nutrients (i.e. nitrates) to the groundwater. Further analysis has been completed for nitrate and sodium concentrations in samples collected within 300, 500, 1000 and greater than 1000 m distance from medium and large-scale animal farming lands. The results, as box and whiskers diagrams, are presented in Figure 76. The medium and 75th percentiles of samples collected from wells within 300 m from medium and large animal farms show higher concentration for both nitrate and sodium suggesting the animal farms might be affecting the groundwater quality.

5.5.1.3 *Forest Loss*

The potential effects of forest loss on water quality are presented as follows:

- Contamination of water by nitrate, phosphate and/or bacteria in heavily logged watersheds before forest is re-established and/or where harvesting or pile burning occur too close to surface water bodies (Neary et al., 2005, Hubbert et al., 2013, Rouquet et al. 2016).
- In streams directly receiving urban drainage, various contaminants can be present depending on the type of land use (refer to Table 7 for potential contaminants). Generally, forests act as a buffer to contamination, they protect water resources.

The actual impacts of forest loss on water quality within the RDN have not been studied and are out of the scope if this study.

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[6] zoning and subdivision bylaw no. 1285, 2002 for RDN Area F

Zoning bylaw no. 500 for the study watersheds area, outside of RDN Area F

Table 7. Land use and potential water quality contaminants based on literature review

Land Use Category	Potential Contaminants	Comment
Agricultural	Pesticides, herbicides, fertilizers (nitrate and phosphorus), phenols, chloride, pathogens (bacteria, viruses), pharmaceuticals	
Industrial and Commercial	Hydrocarbons; solvents; pesticides, herbicides, fertilizers; metals; cyanide (jewelry shops and photo lab); potassium, bromide, sodium, sulfate (X-Ray clinics); PCBs; phenols, glycols, pathogens; pharmaceuticals and personal care products (PPCPs), TDS.	
Residential (urban and rural)	Hydrocarbons, solvents, pesticides, herbicides, fertilizers, metals, pathogens, PPCPs	Garden spaces, oil tanks, cars, septic systems, cleaning products
Forestry/Resource	Turbidity, fertilizers, phosphate, pathogens, hydrocarbons	due to soil erosion and runoff and loss of leaf litter
Recreational and Parks	Pesticides, herbicides, fertilizers, pathogens, PPCPs	

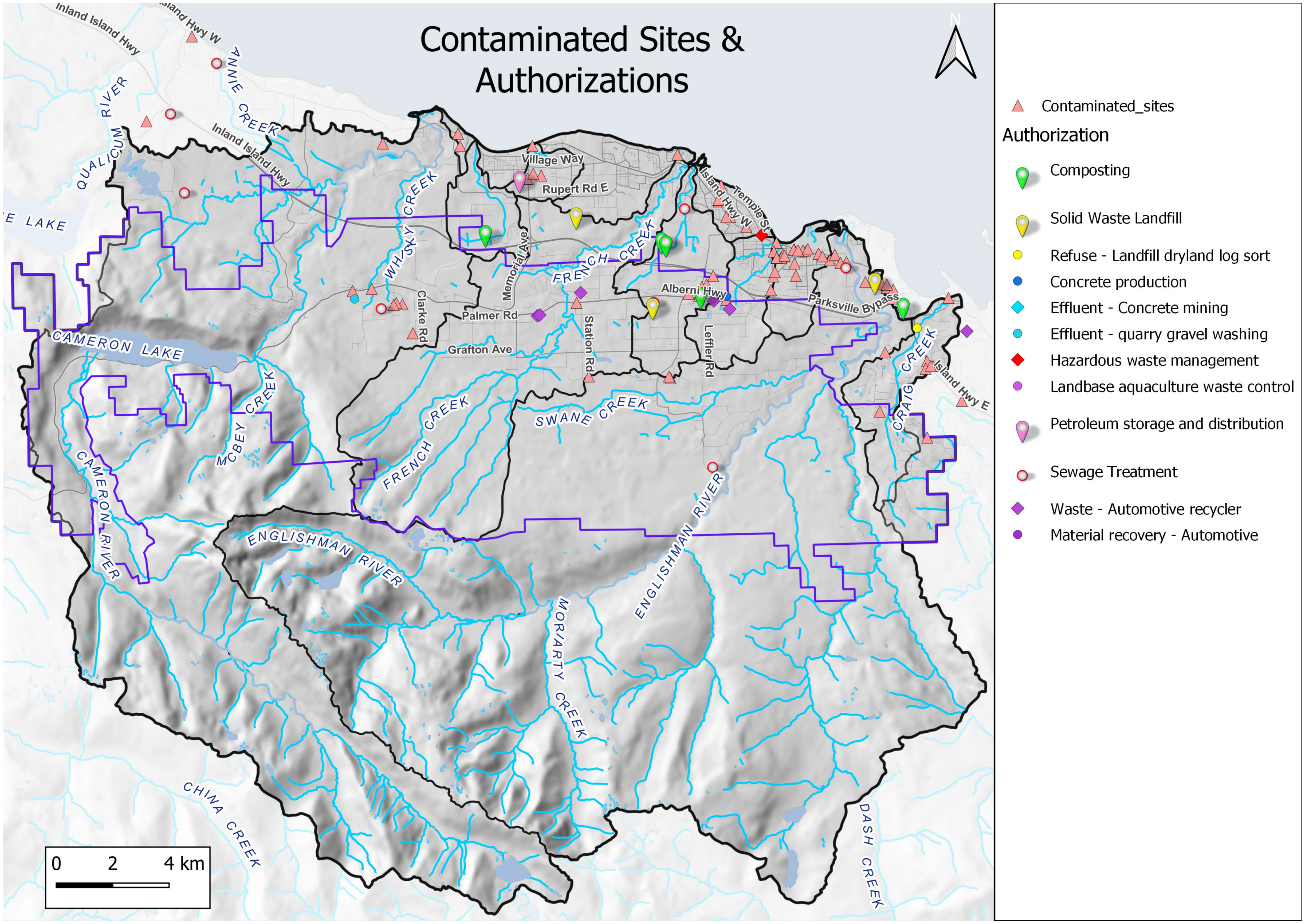

Figure 72. Contaminated sites and discharge effluent authorizations

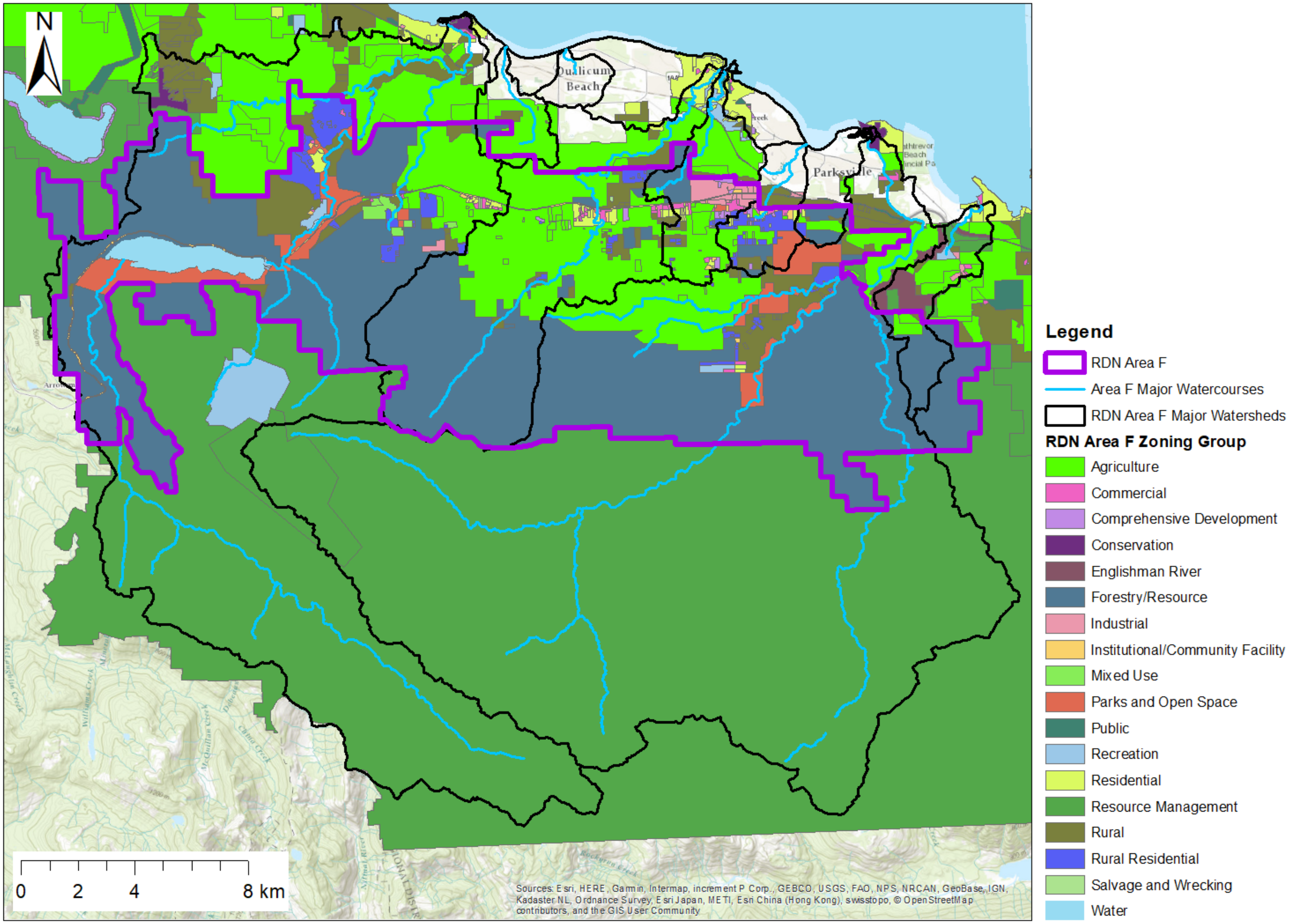

Figure 73. RDN Area F zoning

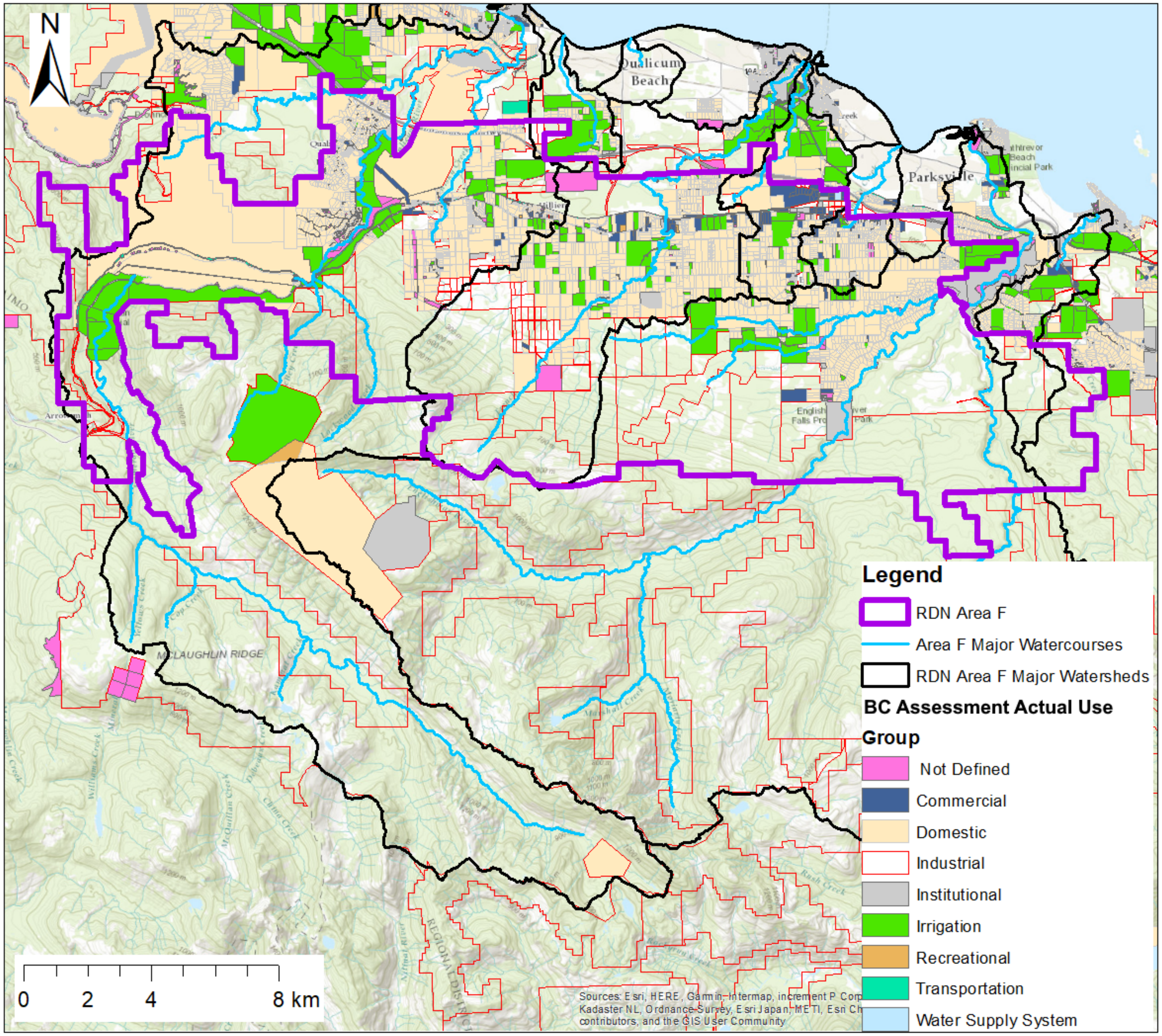

Figure 74. RDN Area F Land Actual Use (BC Assessment Data)

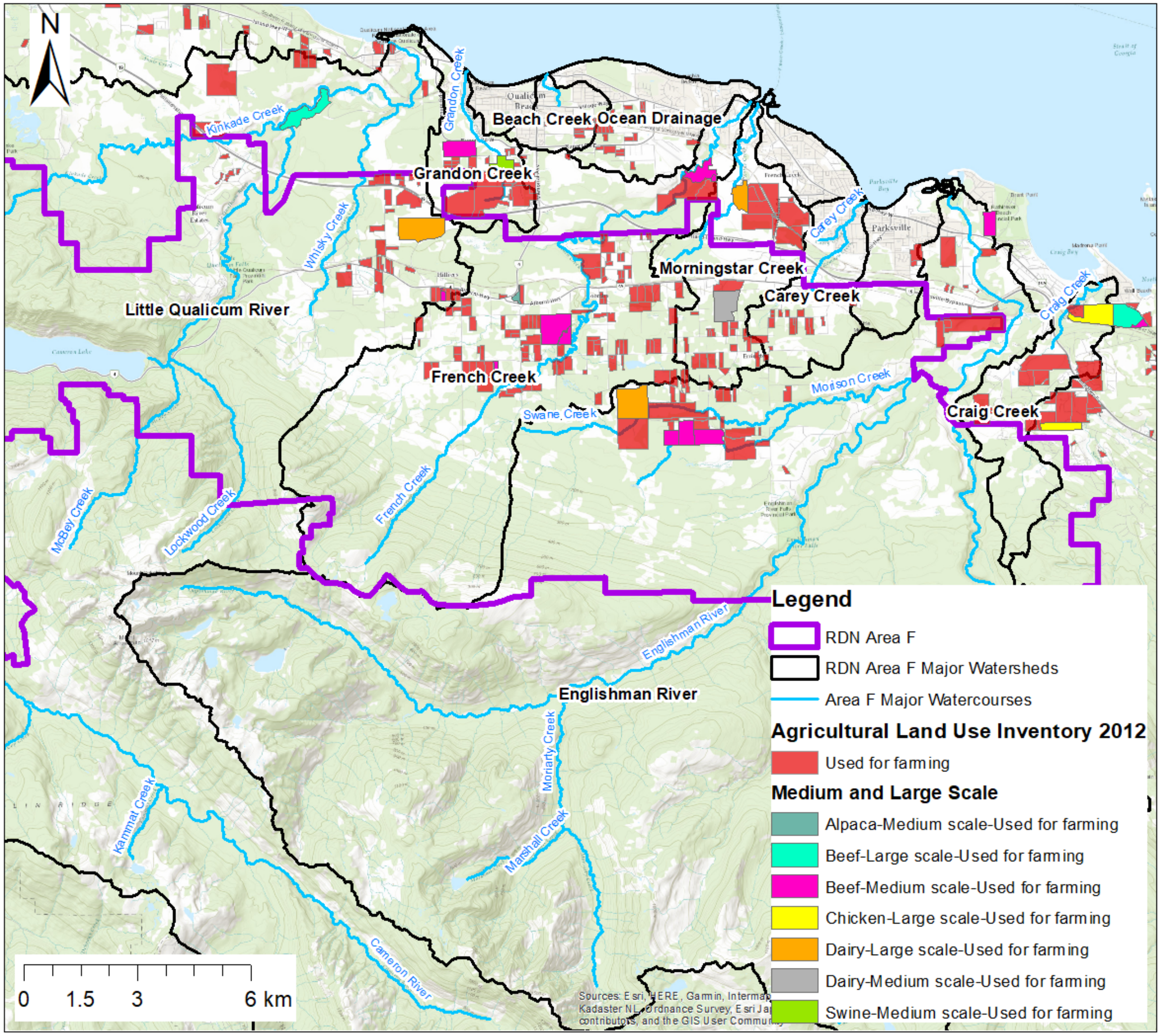

Figure 75. RDN Area F Agriculture Land Use Inventory (2012) limited to lands used for farming and lands with medium and large-scale animal farming activities

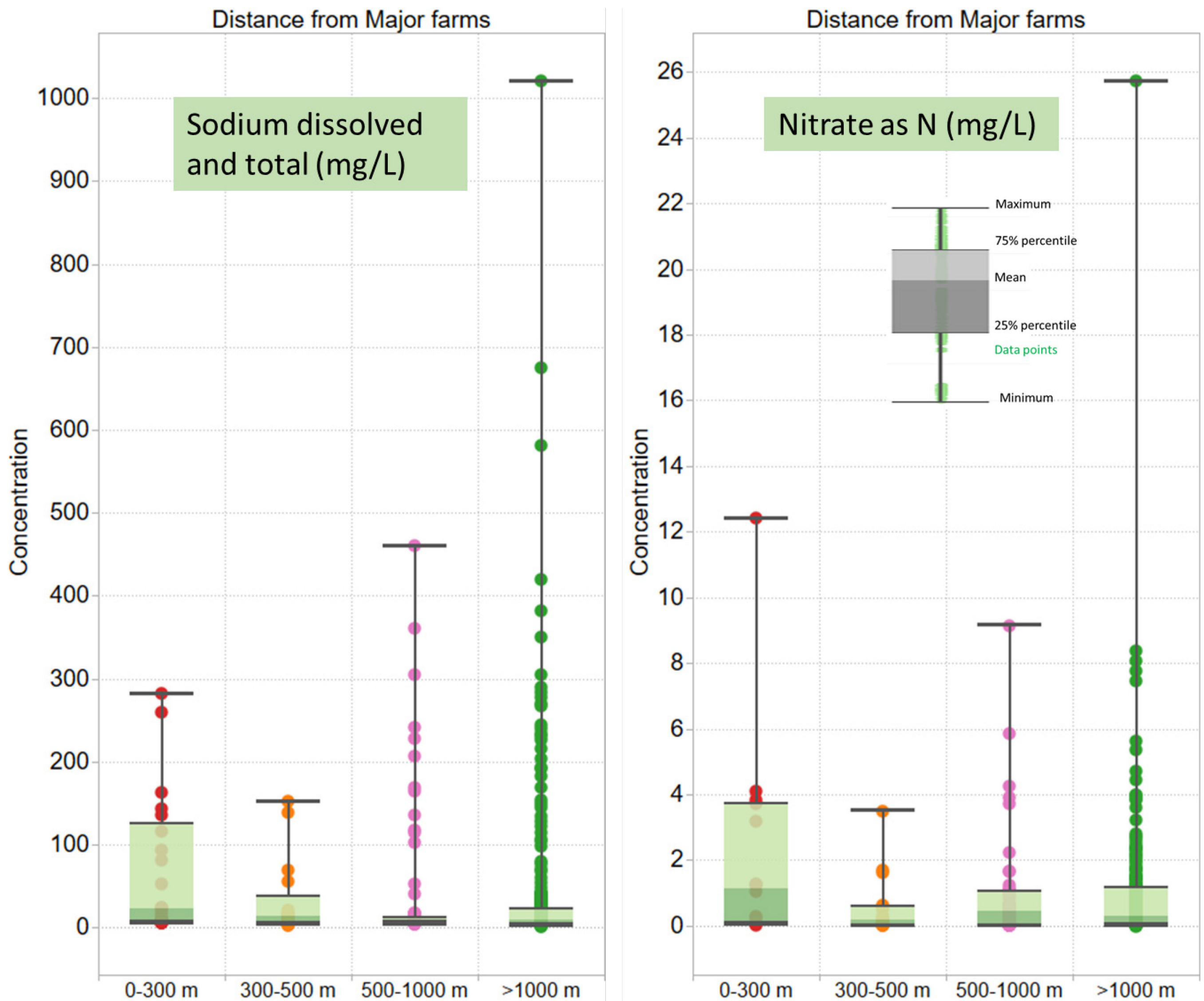

Figure 76. Nitrate and sodium concentration for wells located within distances of 300, 500, 1000 and greater than 1000 m from medium to large animal farming lands

5.5.2 Estimation of Background Concentrations

Background concentration is defined as the concentration of a parameter/substance in a particular environment that is indicative of a minimal influence of anthropogenic activities (human sources). GW Solutions used the probabilistic approach (S.V. Panno et al, 2016) in order to determine background concentrations of parameters of concern within Area F.

5.5.2.1 *Nitrates (NO3)*

Nitrate concentration in precipitation is presented in Figure 77. The data was obtained from Environment and Climate Change Canada Data (http://donnees.ec.gc.ca/data/air/monitor/?lang=en). The precipitation sample corresponds to a station located on Saturna Island, the nearest station for which data is available. Nitrates in precipitation varies seasonally. A process called denitrification occurs when precipitation recharges the aquifer and water moves through the porous media; therefore, a very low concentration of nitrates is expected in aquifers.

Figure 78 illustrates the nitrate/nitrogen cycle and agricultural land effects to nitrate concentration in groundwater. Possible sources of nitrate include disruption of soils and oxidation of organic matter and inputs from fertilizer and livestock waste and septic effluents.

Only two samples from groundwater wells within Area F exceeded the nitrate drinking water quality guideline (10 mg/l); however, many wells are showing increasing trends and nitrate concentrations are slowly approaching the guideline.

Figure 79 shows the resulting analysis of nitrates for groundwater samples collected within Area F. The following observations are made:

- Nitrate concentration of 0.03 mg/L corresponds to background concentration with the assumption that denitrification has occurred and there are no other sources of nitrate;
- Nitrate concentrations between 0.03 and 1.6 mg/L, indicate groundwater affected by natural phenomena (e.g., loss of wetlands);
- Concentrations greater than 1.6 mg/L indicate the influence of anthropogenic sources. Figure 80 shows the wells for which a nitrate concentration greater than 1.6 mg/l have been observed. Most of the wells with concentrations greater than 1.6 mg/L are located within Area F.

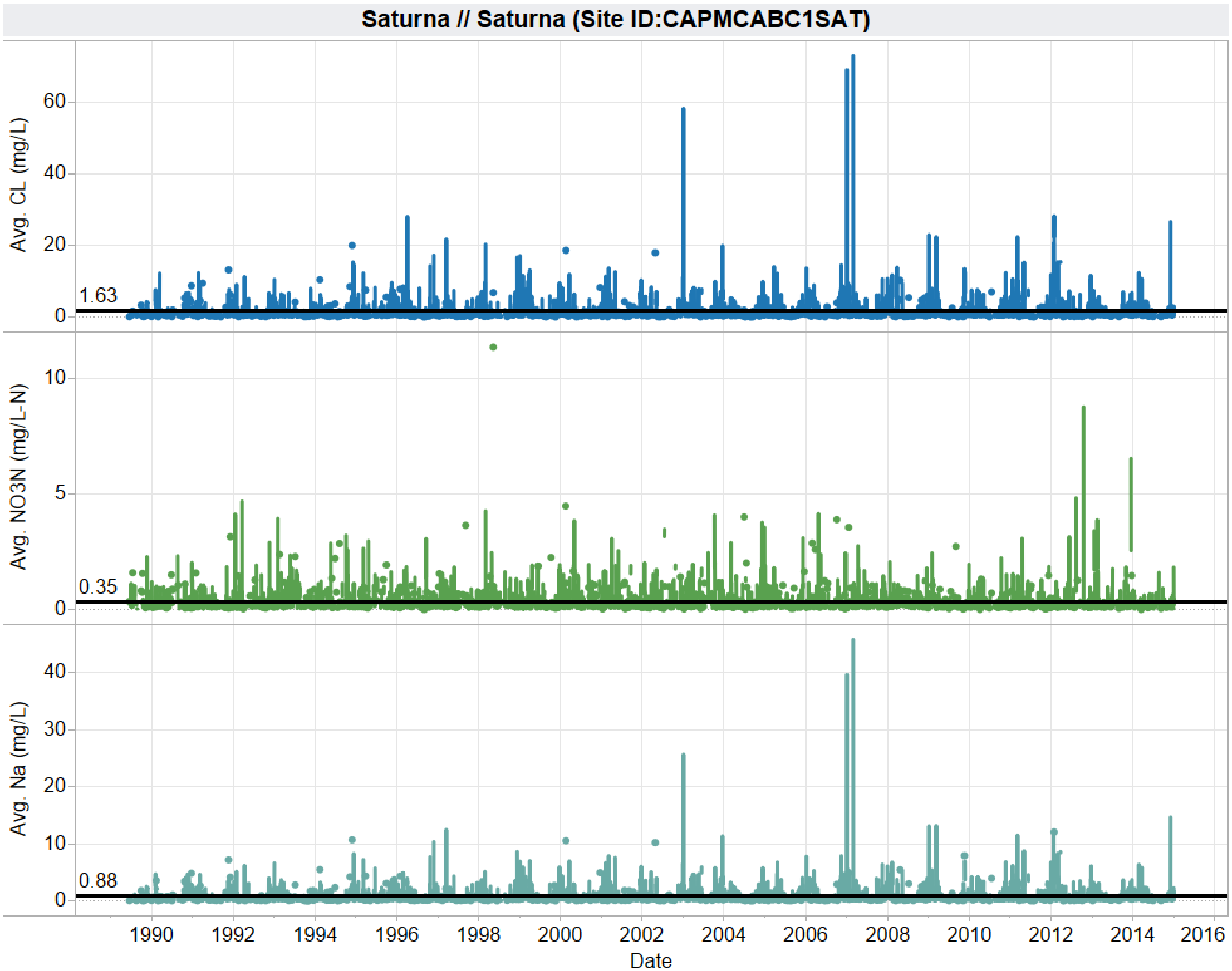

Figure 77. Chloride, nitrate, and sodium concentrations in rainfall from Saturna Island.

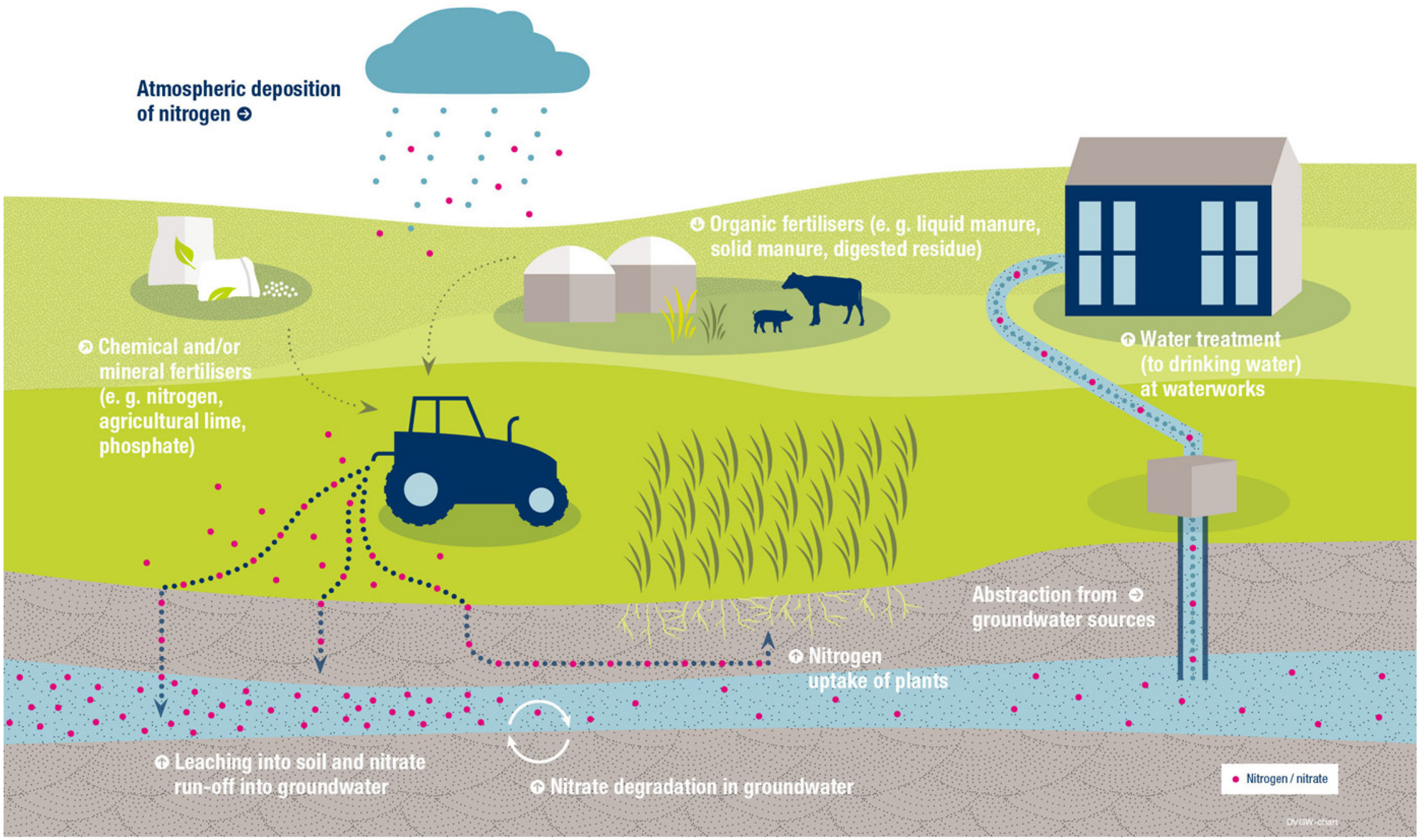

Figure 78. Nitrate process in agricultural lands (obtained from https://www.dvgw.de/english-pages/topics/water/nitrates-and-drinking-water/)

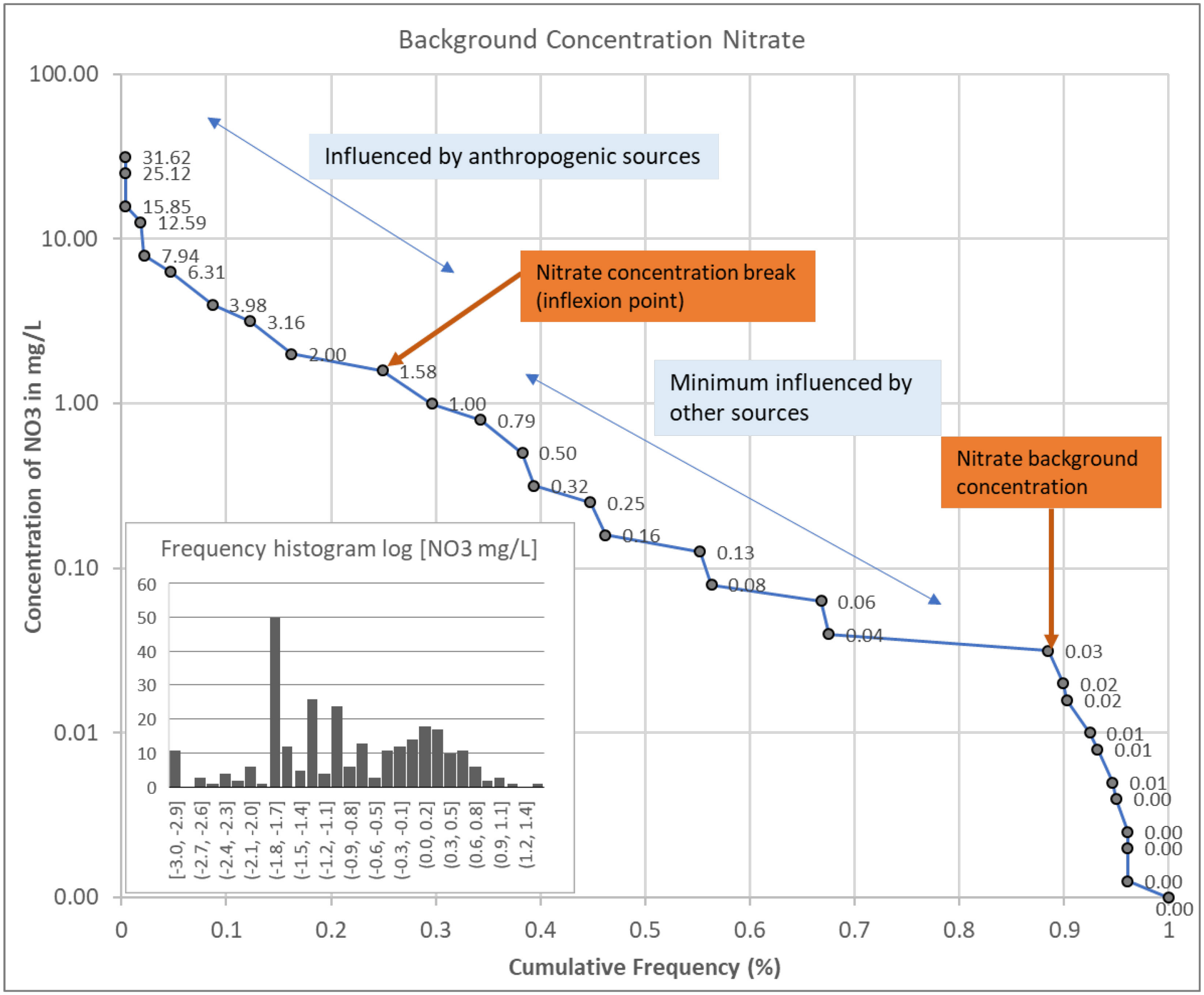

Figure 79. Cumulative probability graph for groundwater water samples showing threshold values for nitrate.

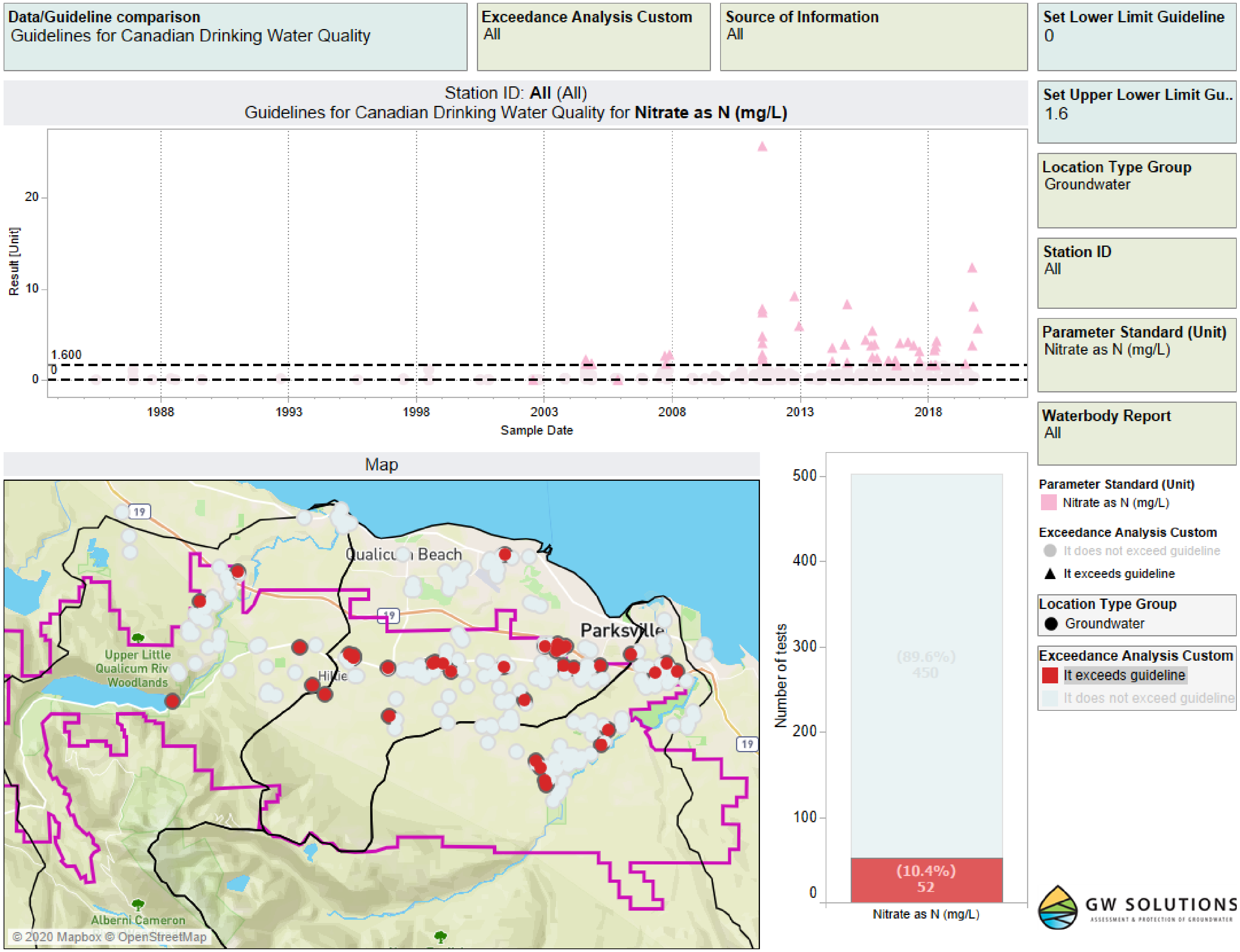

Figure 80. Groundwater wells for which concentration of nitrate has been reported greater than 1.6 mg/L

5.5.2.2 *Chloride (Cl)*

Concentration of chloride in rainfall also varies seasonally (Figure 77). The average chloride concentration in precipitation is estimated at 1.6 mg/L (Saturna Island).

Possible anthropogenic sources of chloride in groundwater includes rocks formation containing chlorides, agricultural runoff, wastewater from industries, leakage of septic fields, effluent wastewater from wastewater treatment plants, and road salting.

Based on the probabilistic method displayed in Figure 81, using chloride concentration in groundwater wells within Area F, the following conclusions are drawn:

- Chloride concentration of 1.7 mg/L corresponds to average rainfall. Water wells with concentrations lower than 1.7 mg/L suggest direct recharge from precipitation to the aquifer. This is typical in shallow aquifers with very little anthropogenic influence.

- Chloride concentrations between 1.7 to 54 mg/L indicate an influence by aquifer geological processes and/or anthropogenic sources. It is difficult to differentiate between natural sources and anthropogenic because of the shape of the probabilistic curve.

- Concentrations greater than 54 mg/L indicate a strong influence of geology and/or anthropogenic sources. Figure 82 shows the wells in red reporting chloride concentrations greater than 54 mg/L. The wells located close to the ocean are likely influenced by saltwater intrusion[7]. Most of the wells with chloride concentrations greater than 54 mg/L are located within agricultural, residential and residential rural zones (The results may be biased because sampling was predominantly completed by and for people living on parcels with this zoning).

To further understand the natural conditions of chloride vs anthropogenic impact, chloride concentration is plotted against reported well depth as presented in Figure 83. The presence of chloride in deep wells might be an indication of connate water in the fractures from the periods of higher sea level that is still present in the deeper groundwater system, and/or mature

[7] Within groundwater sampled from wells in coastal aquifers, chloride >150 mg/L is considered impacted by saltwater intrusion. "Best Practices for Prevention of Saltwater Intrusion " can be found at: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-wells/saltwaterintrusion_factsheet_flnro_web.pdf and Klassen, Allen and Kirste SWI indicators report found at: http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=50327

groundwater that is influenced from dissolution of minerals from marine sedimentary rocks. This older mineralization or marine signal may be more dominant where recharge is limited. The presence of salty groundwater in some areas of Errington is known. Additionally, the surficial aquifers are partially recharged from the bedrock aquifers containing chloride. However, within Area F, shallow wells (<30 m) also contain chloride concentrations greater than 54 mg/l that could partially be attributed to anthropogenic sources described above.

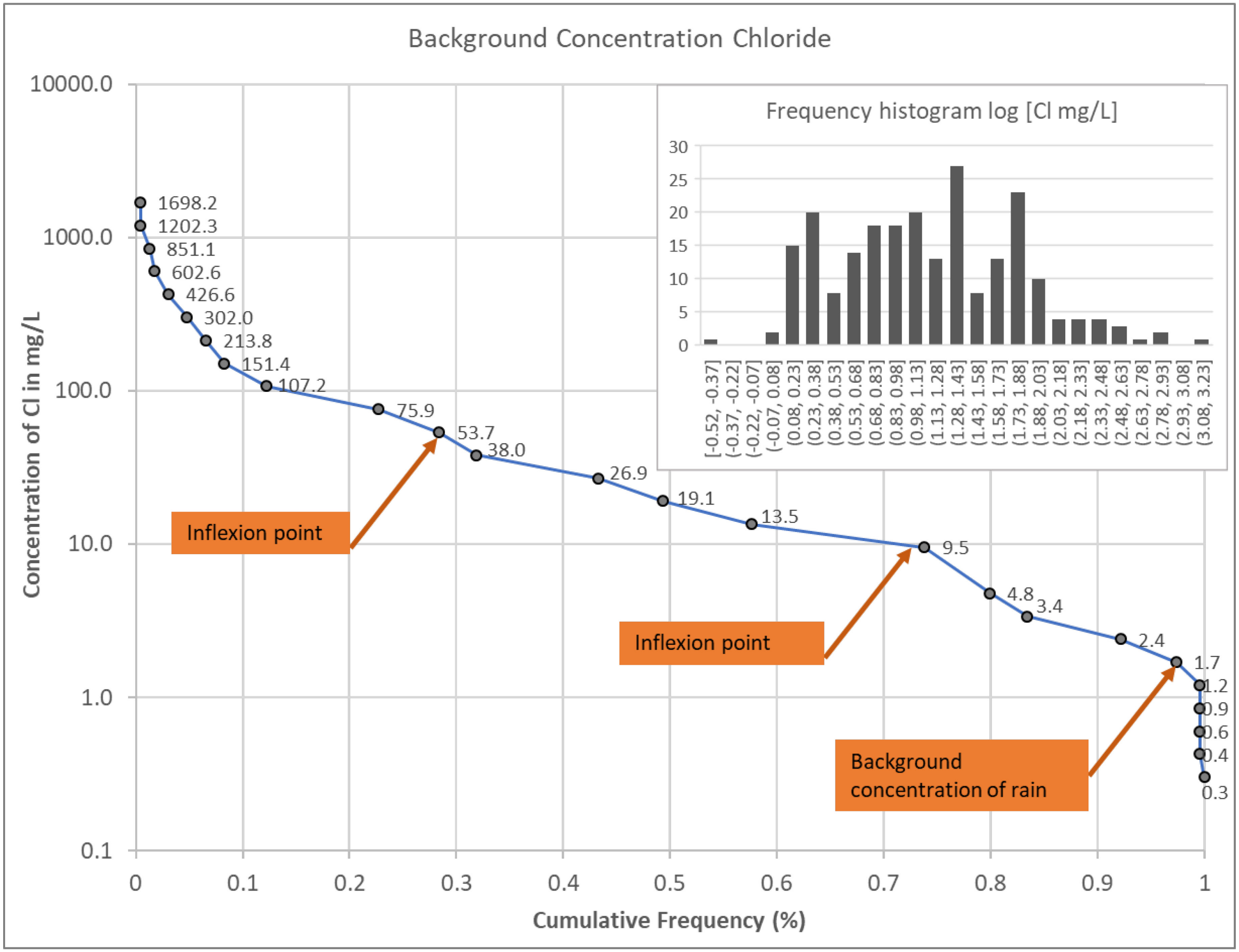

Figure 81. Cumulative probability graph for groundwater water samples showing threshold values for chloride

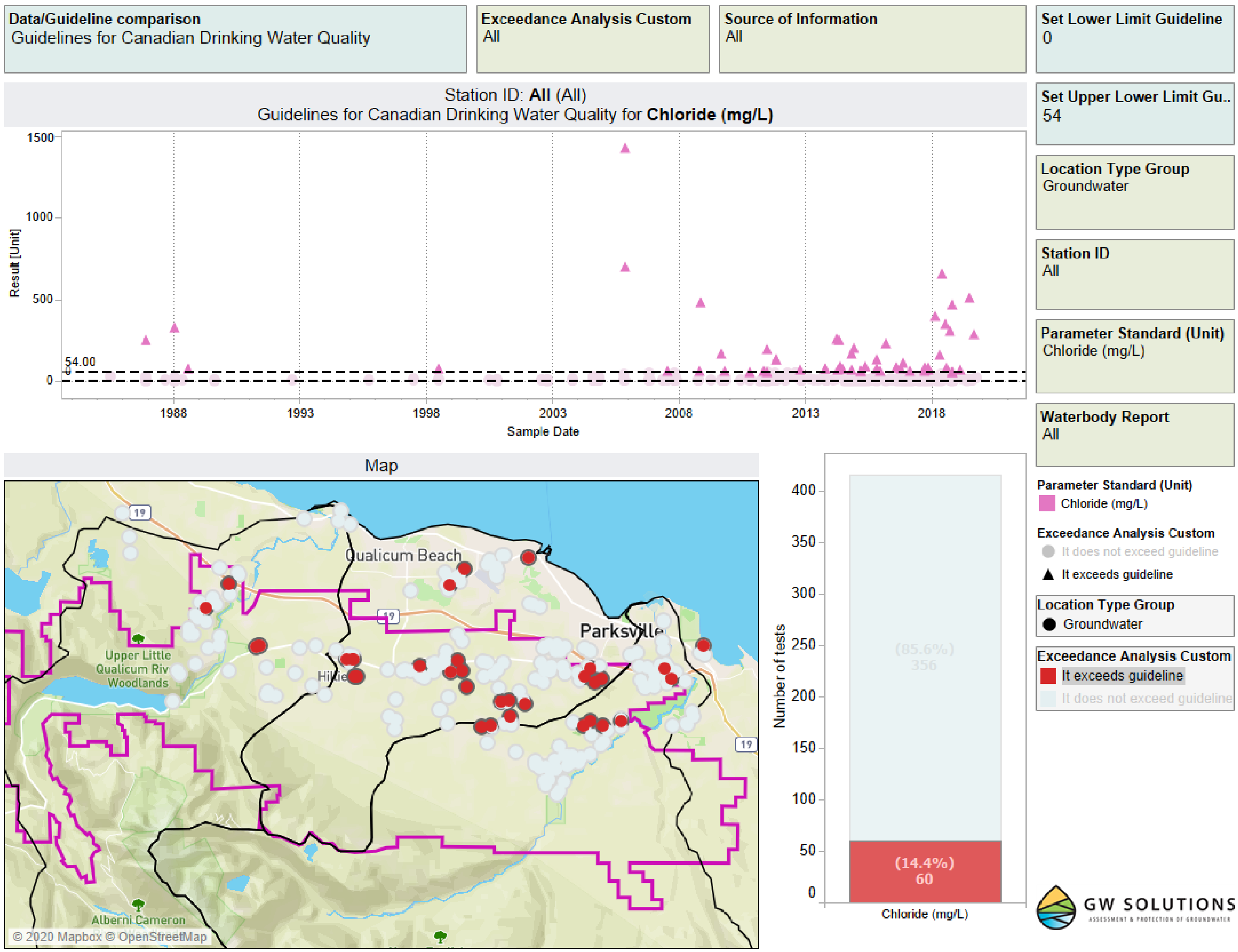

Figure 82. Groundwater wells for which concentration of chloride has been reported greater than 54 mg/L

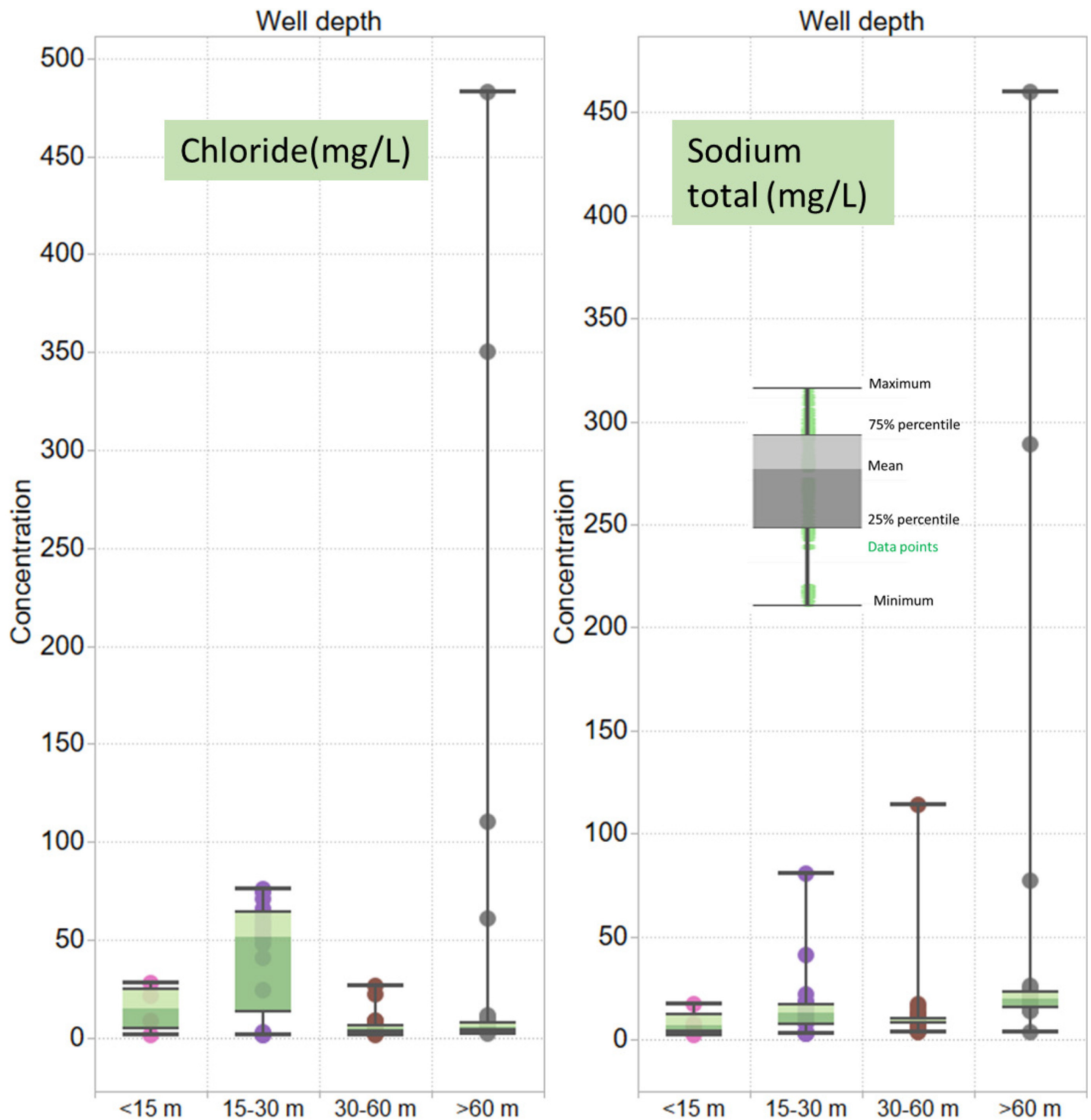

Figure 83. Chloride concentration variability in groundwater wells with reported depth

5.5.2.3 *Sodium (Na)*

The average concentration of sodium in rainfall is estimated at 0.9 mg/L (Figure 77 - Saturna Island). Although sodium is naturally found in groundwater, there are a number of anthropogenic sources of sodium that can contribute significantly to groundwater, including water treatment chemicals, domestic water softeners, sewage effluents, and road salt.

Figure 84 shows the results of the sodium probabilistic concentration. The following comments can be made:

- Concentrations of sodium below 8 mg/L suggest direct groundwater recharge typical of shallow systems with little to no anthropogenic influence.

- Concentrations between 8 and 170 mg/L suggest that the groundwater has been influenced by natural sources (geological) and anthropogenic sources.

- Concentrations greater than 170 mg/L suggests groundwater is likely strongly influenced by anthropogenic sources. Figure 85 shows the location of wells where sodium concentrations exceed 170 mg/L. These wells are located within the agricultural, commercial, residential and rural residential RDN zones. Wells within the agricultural zone presents the highest percentage (15% of samples) with concentrations greater than 170 mg/L.

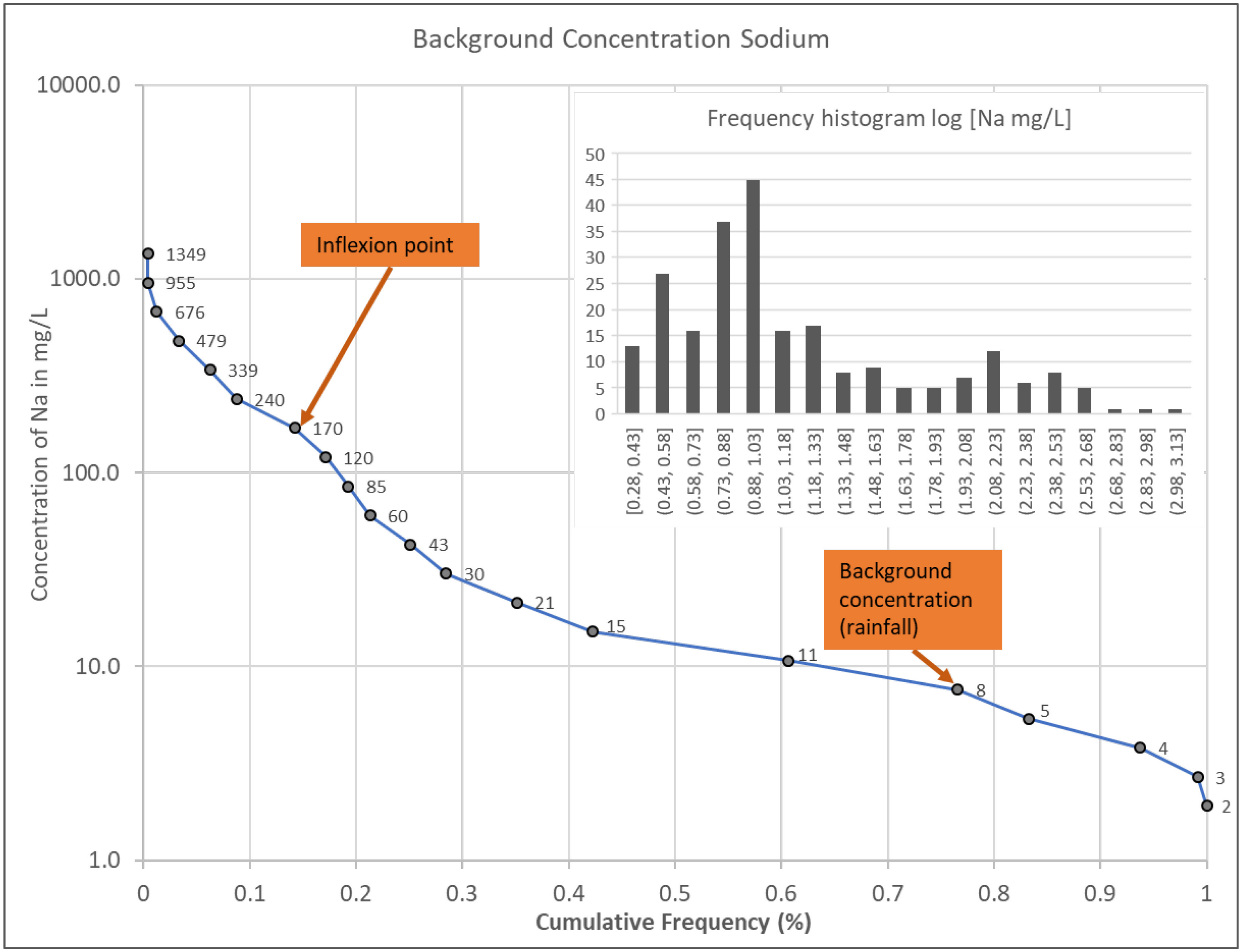

Figure 84. Cumulative probability graph for groundwater water samples showing threshold values for sodium

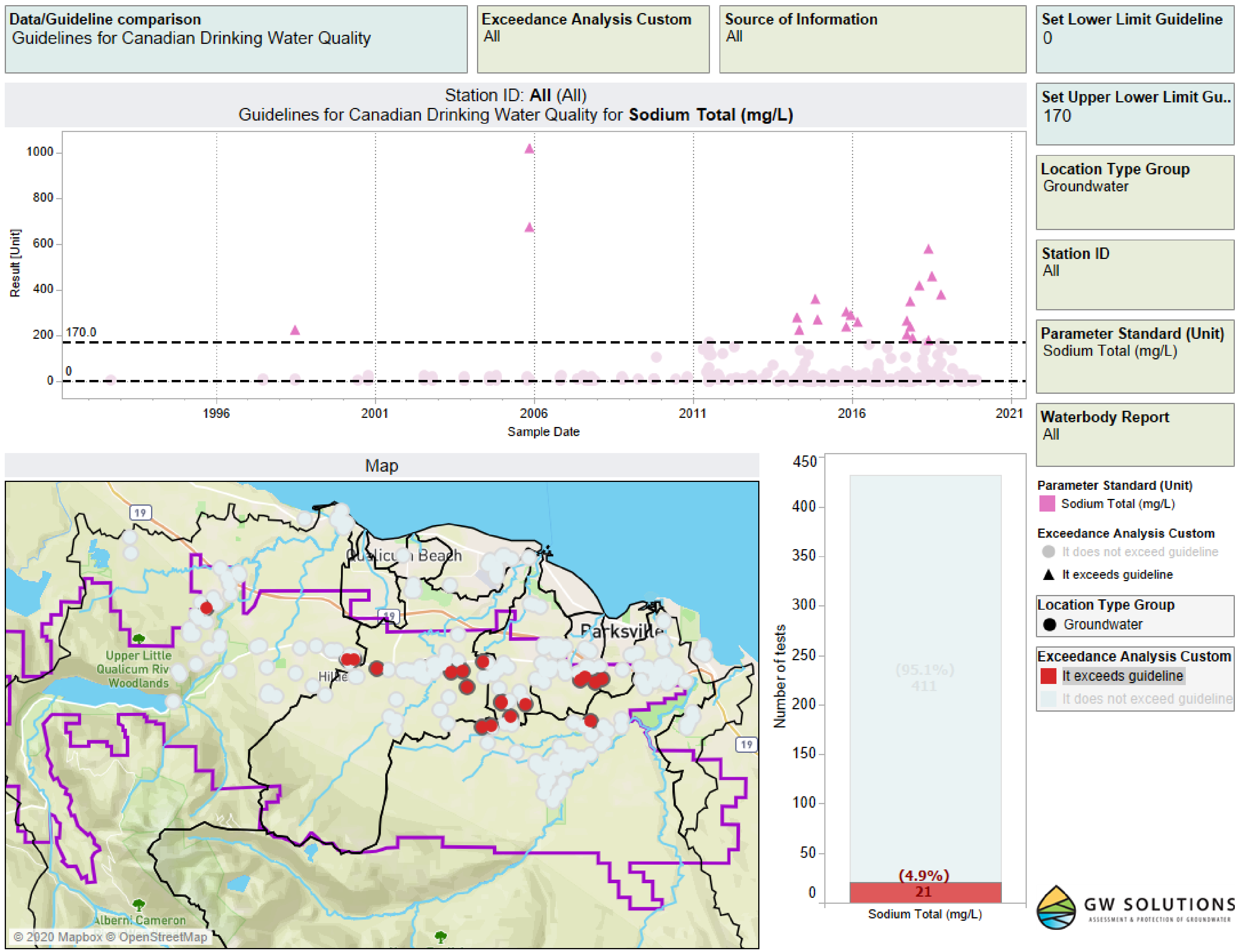

Figure 85. Groundwater wells for which concentration of sodium has been reported greater than 170 mg/L

5.6 Aquifer Vulnerability Assessment

Vancouver Island University (VIU) in collaboration with the Province, Natural Resources Canada, and Island Health (IH) completed the vulnerability mapping for Vancouver Island.

Figure 86 shows the vulnerability map for the Electoral Area F, with all levels (low, medium and high) present within Area F.

Figure 87 shows the exceedance analysis taking into account the vulnerability class and the drinking water quality guideline. There is no clear tendency or distinct difference in percentage exceedance between low, moderate and high vulnerability class. Figure 88 shows box and whiskers diagrams for sodium and chloride concentrations classified by the vulnerability class (high, moderate and low).

This analysis was completed to confirm the following assumption:

1. Are higher concentrations or more parameters present in more vulnerable areas? This would have potentially been a source of concern. In addition, it could have confirmed that more vulnerable areas were more susceptible to having their groundwater quality affected.

The completed analysis and comparison of results for wells located within the three classes of vulnerability do not indicate specific trends. So, the assumption is not confirmed.

Similarly, when focusing on specific parameters (sodium and nitrate), there is no clear indication that more vulnerable areas have been more negatively impacted. For nitrate, wells located in the high vulnerability zone show higher concentrations (illustrated by the top whisker), but when considering the mean or 25% to 75% percentile, the concentrations are comparable or less than for the wells located in low and moderate vulnerability zones.

Therefore, vulnerability mapping should be considered as a tool providing general information with limitations related to the methodology it is based on.

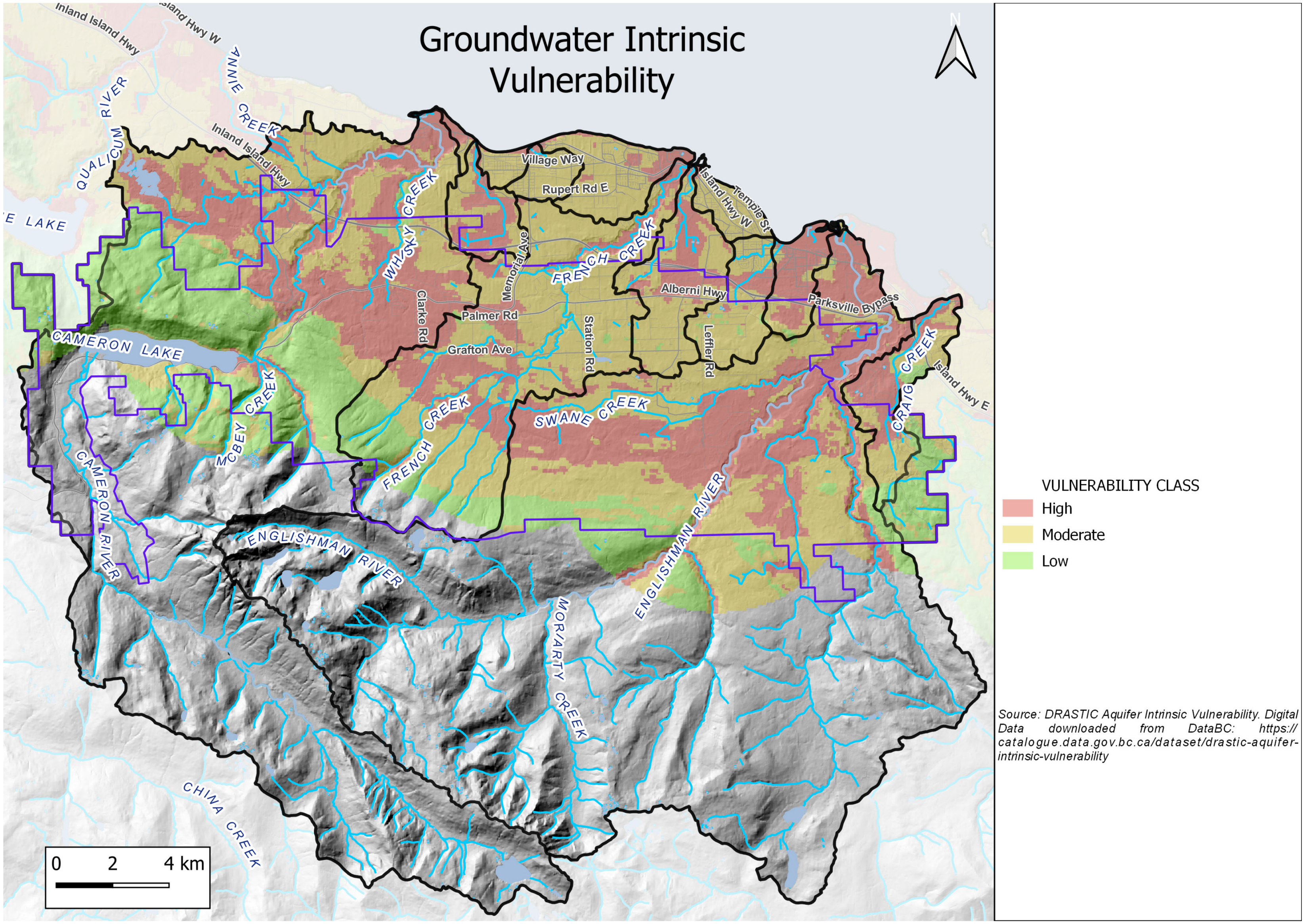

Figure 86. Drastic aquifer vulnerability for the study area

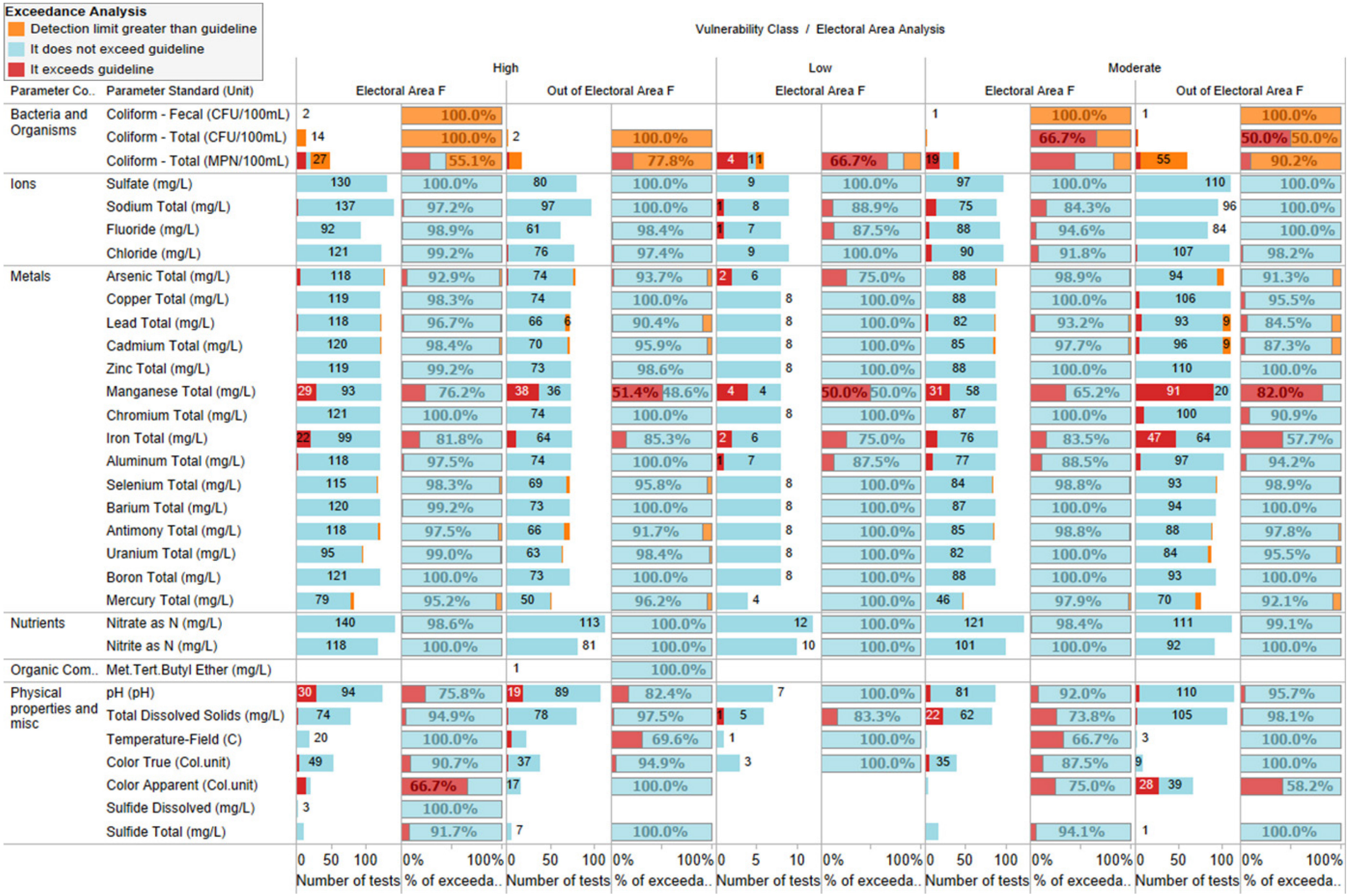

Figure 87. Drinking water quality guideline exceedance analysis based on aquifer vulnerability

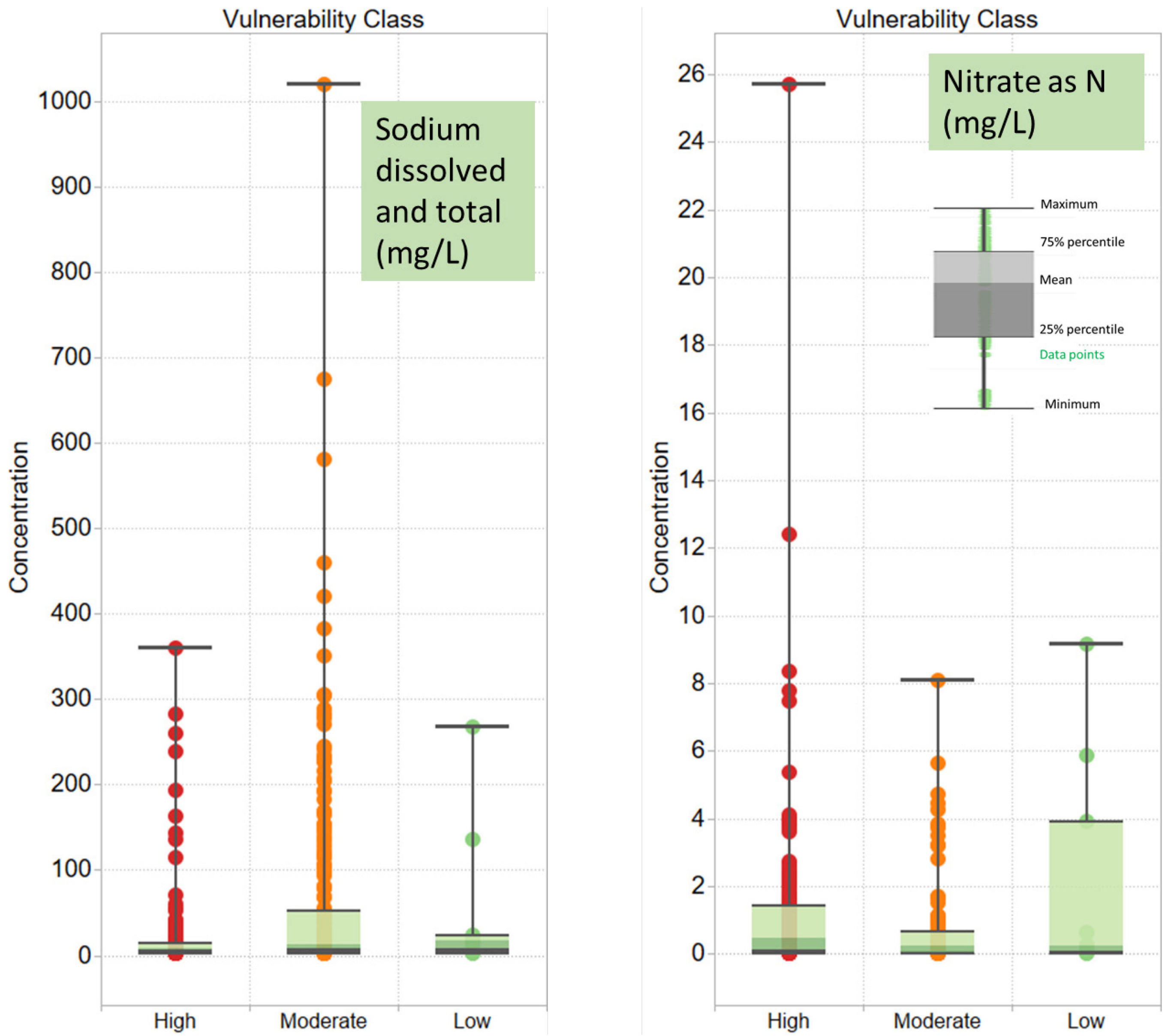

Figure 88. Sodium and chloride concentration represented by the vulnerability class

5.7 Water Quality Discussion

Groundwater in bedrock clearly shows an absence of sulfate (SO_4), with a predominance of HCO_3-CO_3 combined with either Ca or Na or K ions. In bedrock Aquifer 220, which is best representative of mountain block recharge, the water type is HCO_3-CO_3 and Ca dominant; that typically reflects a relatively young water. The groundwater in Aquifer 220 is recharged by rain and snowmelt and flows relatively fast through the fractured bedrock.

The overburden aquifers appear to each have their own water quality, as indicated by their own clouds on the Piper plot (Fig. 56). Aquifer 663 shows a higher proportion of chloride. Some of the outlier points (e.g., samples from Aquifer 209 showing higher concentrations of Na and K) may represent locations where impact to groundwater quality due to surface activity is observed.

The main parameters for which concentrations exceed the guidelines for drinking water are nitrate, sulfate, chloride, and TDS. This is predominantly observed in bedrock wells (Aquifer 220). This also appears to be located along the Alberni Highway and in small clusters (Little Mountain area, Errington). Therefore, the presence of these parameters could be enhanced by fertilizers, septic fields, animal farming practices, and road salts. We do not observe specific increasing or decreasing trends with time.

For metals, for Area F and the area north of it, only five samples show concentrations above guidelines with arsenic (in bedrock aquifer 220 – one sample), barium, lead (one sample in overburden Aquifer 217), zinc (four samples, Aquifer 217 and 664), and copper (five samples in Aquifer 217). Therefore, the presence of these metals does not appear to be an issue at the regional scale.

Coliforms are widely present in groundwater, both in the bedrock and surficial aquifers. There are no spatial or temporal trends. This is very likely of natural sources or a combination of poorly maintained wells and absence of surface seals.

Sodium seems to indicate an increasing trend, although this may be due to the fact that more samples have been collected in the last six years and therefore a larger amplitude of concentration is covered by a larger set of samples.

We observe an increase in concentration after 2011, as seen in the Alberni Highway and Church Road area, with recent concentrations in the 2 to 8 ppm range. It may be related to an increased presence of nitrate in groundwater and/or to an increase in sampling and analyses. We also note this observation is based on a limited number of samples.

Concentrations of fluoride appear to increase in the last 10 years, in a 1 to 3 ppm range. We observe a similar pattern with nitrate, both in terms of spatial distribution and concentrations.

No spatial or temporal trends are observed for chloride. A few samples report chloride in the 250 ppm to 600 ppm range in the last 10 years (the aesthetic guideline is 250 ppm). The water quality on the Englishman River indicates a slight shift with chloride being more present as the water flows downstream.

Both arsenic and boron are often associated in the Nanaimo group bedrock deposits. Maximum concentration of boron is reported in the 1 ppm range (the drinking water guideline being 5 ppm). However, higher concentrations of arsenic are measured in the 0.02 to 0.08 ppm range (the guideline is 0.01 ppm).

No observable spatial or temporal trends are observed for sulfate. Higher concentrations are in the 20 ppm range (Drinking water guideline, aesthetic, is 500 ppm).

Figure 89 shows locations of groundwater samples for which exceedances have been observed of either chloride, aluminum, iron, manganese, zinc and TDS or a combination of these parameters. Iron and manganese have shown exceeding in most locations.

Figure 90 summarizes the locations at which groundwater quality might have been affected based on the analysis of background concentrations discussed in section 5.5.2. The map shows location for which nitrate concentration is greater than1.6 mg/L, chloride greater than 54 mg/L and sodium greater than 170 mg/L.

- The concentrations of metals (excluding iron and manganese) do not appear to be an issue, except for arsenic in some bedrock wells. The source of arsenic is natural.
- Increasing trends that would require immediate actions have not been identified.
- Nitrate and chloride are locally present at concentrations that are not of natural sources. Nitrate is present at concentrations that could have health impact. It is possibly related to the use of fertilizers or failing septic fields or animal farming practices.

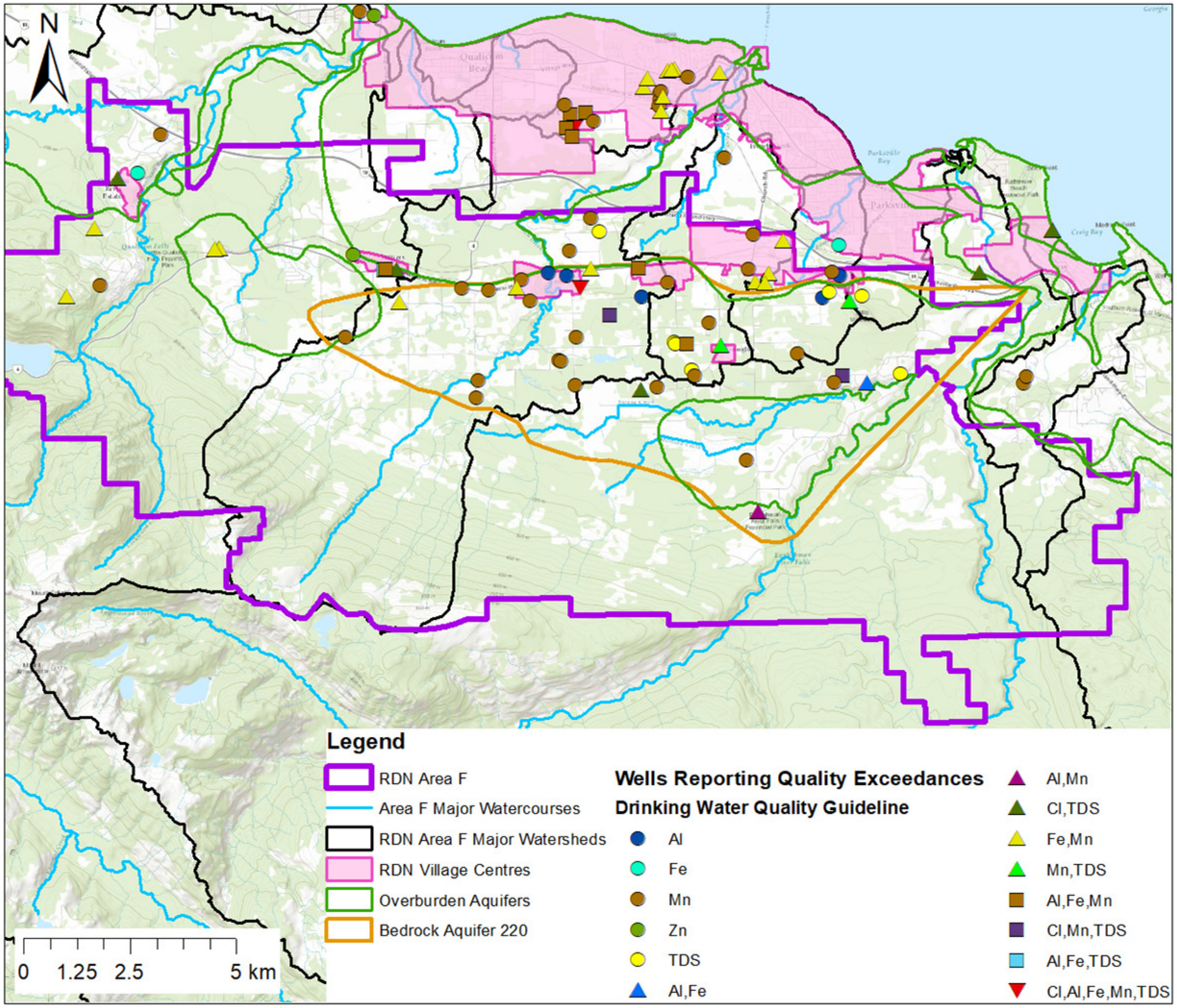

Figure 89. Canadian drinking water quality exceedance analysis summary for chloride, aluminum, iron, manganese, zinc and TDS

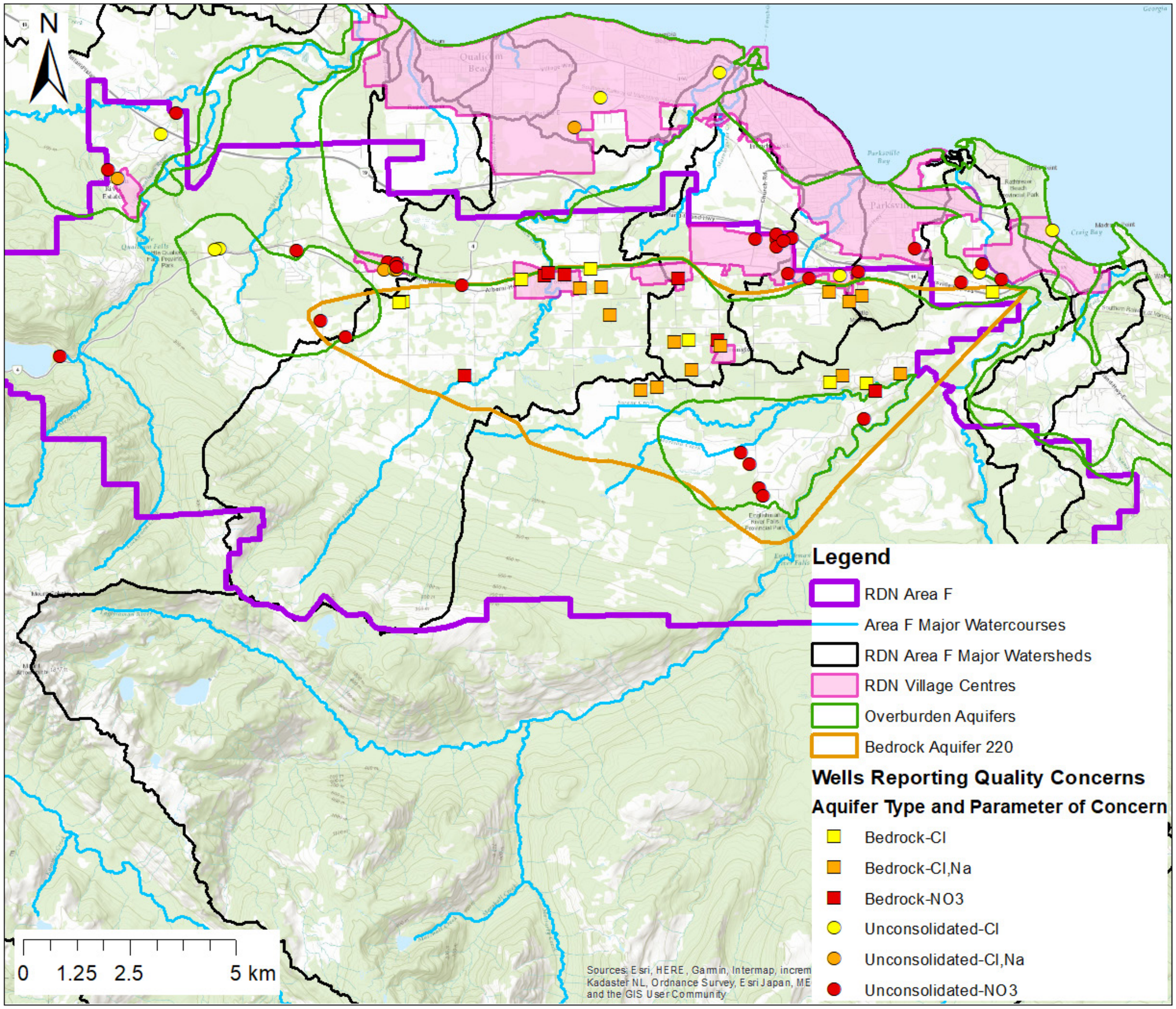

Figure 90. Groundwater well locations potentially impacted by anthropogenic sources based on analysis of concentrations of nitrate, chloride and sodium

5.7.1 Water Quality Concerns

Table 8 summarizes identified elements that could potentially affect the water quality within Area F. Septic systems, industrial effluent, livestock, landfills and gas stations are rated as high concern, based on professional opinion.

Table 8. Water quality concerns identified within Area F and hazard rating

Hazard Type (based on land use, discharges authorizations, contaminated sites)	Hazard Rating	Comments	Potential Contaminants
Gravel pit	Moderate	Some gravel pits in the area are registered as contaminated sites	Hydrocarbons, metals
Sewage/septic system (commercial or residential)	Moderate-high	Depending on septic density and proximity to streams	Pathogens, nutrients (phosphorous, nitrogen), BOD, pharmaceuticals and personal care products (PPCPs).
Industrial effluent	High	If not treated or inadequately treated	TDS, nitrogen, chloride, metals, hydrocarbons, cyanides, PCBs, radionuclides
Farming and residential use of pesticides and fertilizers	Moderate to high	Depending on type of pesticides/fertilizers and amount used	Fertilizers, pesticides, herbicides, phenols, chloride, hydrocarbons
Forestry (wood waste and logging sites)	Low/ Moderate	Low for groundwater and moderate for surface water	Turbidity, NO3, phosphate, pathogens, hydrocarbons
Gas station / fuel storage	High	Some registered as contaminated site	Hydrocarbons
Composting facilities	Low		Micro-plastics
Landfills	High		Nitrogen compounds, metals, hydrocarbons
Livestock	Moderate-High		Pathogens, nitrate-nitrogen, phosphates, chloride
Recycling facilities (automotive)	Moderate		Metals, organic and inorganic chemicals
Transportation Corridors	Moderate		Hydrocarbons, salts, herbicides
Concrete plant	Moderate		Hydrocarbons

6 BEST MANAGEMENT PRACTICES RECOMMENDATIONS

Table 9 summarizes the different potential sources of groundwater contamination within Area F and proposes Best Management Practices (BMPs) which should be applied depending on the type of land use. The aim of the BMPs is to prevent or to reduce the risk of causing groundwater contamination.

Appendix 7 details the rationales for Best Management Practices (BMPs) with respect to the various sources of contamination described in Table 9.

Table 9. Best Management Practices for the potential sources of contamination within Area F

Sources of Contamination		Best Management Practices
Agricultural	*Animal wastes*	Low density livestock activity is allowed. If manure is spread, implement groundwater and surface water quality monitoring. Livestock activity not allowed within capture zone of municipal water supply systems.
	Pesticide application	Ban toxic classes of pesticides. Promote use of organic and natural pesticides, in collaboration with farmers. Pesticides and fertilization are allowed combined with groundwater and surface water quality monitoring. Pesticides are not allowed within capture zone of regulated production wells or near streams (100m buffer).
	Fertilizer application	Nitrate management plans to be designed and implemented.
	Irrigation return flows	Assessment of potential impact on the quality of groundwater. Groundwater quality monitoring.
Residential / municipal (urban and rural)	*Sewer leakage and sewer outfall*	2 to 10 year inspections depending on vulnerability of the aquifer the sewer is situated above. Strict monitoring of treated wastewater before introduction to the environment (e.g. streams) and alarm system in place.
	Septic tanks and cesspools	Keep promoting and implementing maintenance of private septic fields (e.g., rebate program, “kitchen” meeting, etc.). 2 to 10 year inspections depending on vulnerability of the aquifer.
	Liquid wastes (Land application of municipal effluent)	Untreated effluent not allowed. Monitoring of treated effluent before application.

Sources of Contamination		Best Management Practices
	Solid wastes	Properly constructed landfill/composting facility permitted only in/above low permeability soil layer combined with proper groundwater quality monitoring. Detailed hydrogeological assessment required.
	Roadway de-icing	Use of sand recommended. Road de-icing is allowed on main roads.
	Borehole leakage (wells)	Design and implement program to locate wells not listed in GWELLS. Abandoned wells to be closed. Operating wells to be inspected and upgraded (surface sealed, secure well caps and covers, stick-up length and integrity, upgrade wells in pit).
Industrial and Commercial	*Liquid wastes*	Untreated effluent not allowed. Monitoring of treated effluent before disposal.
	Tank and pipeline leakage	Tanks and pipelines are allowed, with strict groundwater monitoring and maintenance plan.
	Spills	Containment and spill response plan required.
	Stockpiles	Containment is required.
Forestry / Resources	*Harvesting*	Apply conservative riparian zones buffer near streams, in particular where aquifers are directly connected to streams (100 m riparian buffer from top of bank recommended).
	Mining activities	Detailed definition of aquifers and monitoring of both surface water and groundwater.

7 CONCLUSIONS

Based on the completed work, we draw the following conclusions:

7.1 Water Quantity

1. Five overburden aquifers (209, 662, 663, 216, and 217) and one bedrock aquifer (220) are partly or fully within the Area F boundary.

2. The thickness of overburden material within Area F was refined based on the GSC Nanaimo Lowlands project (Benoit et al, 2015). It ranges from less than 2 m (or exposed bedrock) to up to 120 m. Overburden aquifers are present where the overburden is thicker. Bedrock aquifers are predominant where overburden sediments are less than 2 m thick. They also underly overburden aquifers.

3. The regional groundwater flow is from ridges at high elevation towards the ocean. The flow directions in overburden Aquifers 209, 216, and 217 were determined with a higher level of detail based on a good definition of the piezometric level.

4. Minimum flows have historically been recorded in August, when groundwater discharge to the streams is responsible for sustaining the flow. However, in recent years minimum flows have been observed over a longer period, from July to September. This could possibly be attributed to the effects of climate change and increased groundwater usage. Additionally, land modification such as forest loss over time might also be a modifying factor.

5. Declines in groundwater levels in bedrock aquifers were observed with the exception of wells near Little Mountain and the Englishman River where localized groundwater recharge has been identified. These water level declines are attributed to a combination of factors including climatic conditions, water usage, and land modification (e.g., forest loss, surface impermeabilization).

6. Groundwater levels in overburden aquifers are relatively stable after declining levels were observed in Aquifer 216 (until 2015) and 217 (until 2010), likely resulting from over-extraction from well fields.

7. The fluctuation of groundwater levels has been compared to the cumulative precipitation departure (CPD) for some wells, for which data was available for a sufficient length of time (i.e., more than 10 years). This was done for OW287 (bedrock Aquifer 220), and OW314 (overburden Aquifer 216). If groundwater level trends follow a similar trend to the CPD then this suggests that the groundwater level trend is being influenced by climatic factors.

8. Precipitation trends can partly explain the decline in groundwater level in Aquifer 220. From 1984 to 1990, the CPD decreased and groundwater levels also indicate a drop of the water table. However, after 1990, the CPD started to increase indicating that average precipitation within that period was higher than the long-term average, and groundwater levels appear to have stabilized. A decline in CPD from 2008 to present corresponds to a decline in groundwater levels. Other factors, such as land use (e.g., increased percentage of land covered by impermeable surfaces), and population rise have also likely contributed to the long-term decline observed in groundwater levels over the last 35 years.

9. For OW314, installed in Aquifer 216, groundwater levels drastically declined between 1992 and 2003. The dropping trend was decoupled from the CPD curve which indicated a series of wet years. The decline in groundwater level likely resulted from the influence of nearby production wells managed by EPCOR water services at the time. Apparently, EPCOR started regulating pumping in the production wells after 2003. Since then, the groundwater level trend has stabilized and even slightly increased.

10. Unfortunately, there is not enough information (both in time and spatially) to describe the fluctuation of the water table for all the aquifers in Area F. Therefore, it is critical to increase the number of monitoring wells and cover as thoroughly all the aquifers so that, gradually, enough information is collected to adequately monitor the status of aquifers.

11. It is predicted, due to climatic conditions, that snow accumulation will decrease. This will directly impact aquifers and wells that have a snow dominant recharge regime (e.g., Aquifer 216).

7.2 Water Quality

12. The surficial overburden aquifers have each their own water quality, as indicated by their own clouds on the Piper plot. For example, Aquifer 663 shows a higher proportion of Chloride. Some of the points (e.g., samples from Aquifer 209 showing higher concentrations of sodium and potassium) may represent locations where impact to groundwater quality due to surface activity is observed.

13. Groundwater in bedrock is predominantly HCO_3-Ca, suggesting young water (i.e., the aquifer is recharged by rain and snowmelt and groundwater flows relatively fast through the fractured bedrock). However, there are some wells reporting a Cl-Na water type suggesting that groundwater has been affected by anthropogenic sources such as septic fields, farming activities, or road salting.

14. The presence of saline waters is also possibly associated with mature groundwaters and/or connate relict marine water from past periods of higher sea level, particularly within areas of limited recharge. Wells that fall into this group (Cl-Na) corresponds to surficial Aquifer 216, 217, 262 and bedrock Aquifer 220.

15. Coliforms are present in groundwater, both in the bedrock and surficial aquifers. There are no spatial or temporal trends. Coliforms could be attributed to natural sources or a combination of poorly maintained wells and the absence of surface seals.

16. For metals, for Area F and the area north of it, only five samples show concentrations above guidelines with arsenic (in bedrock Aquifer 220 – one sample), barium, lead (one sample in overburden Aquifer 217), zinc (four samples, Aquifer 217 and 664), and copper (five samples in Aquifer 217). Therefore, the presence of these metals does not appear to be a dominant issue.

17. Both arsenic and boron are often associated in the Nanaimo group bedrock deposits. Maximum concentrations of boron are reported in the 1 mg/L range (the drinking water guideline being 5 mg/L). However, higher concentrations of

arsenic are present within Area F in the range of 0.02 to 0.08 mg/L (the guideline is 0.01 mg/L). Arsenic is assumed to be naturally present in the groundwater in the area.

18. Nitrate, sulfate, chloride, and TDS are the main parameters with concentrations exceeding the guidelines for drinking water. This is predominantly observed in bedrock wells (Aquifer 220). This is also observed for wells located along the Alberni Highway and in small clusters (Little Mountain area, Errington). Therefore, the presence of these parameters likely results from anthropogenic activities. We do not observe increasing or decreasing trends with time.

19. Nitrates are locally present at concentrations that are not of natural sources. Nitrate is present at concentrations that could have health impacts. Some cancers, thyroid problems, and negative birth consequences have been linked with concentrations of nitrate in drinking water even significantly below the drinking water guidelines (Temkin, et al., 2019). The relatively high concentrations of nitrate in groundwater within Area F could be attributed to the use of fertilizers and/or failing septic fields and/or animal farming practices.

20. Only two samples exceeded the nitrate drinking water quality guideline (10 mg/l); however, many wells are showing increasing trends and nitrate concentrations are slowly approaching the guideline. Higher concentrations of nitrate are observed after 2011 in the Alberni Highway and Church Road area, with recent concentrations in the 2 to 8 ppm range. It may be related to an increased presence of nitrate in groundwater and/or to an increase in sampling and analyses. The medium and 75th percentiles of samples collected from wells within 300 m from medium and large animal farms show higher concentration for both nitrate and sodium suggesting the animal farms might be affecting the groundwater quality.

21. Nitrate management has been presented in case studies such as for the Abbotsford Aquifer (Chesnaux, et al., 2007). It demonstrates that nutrient management practices can be adopted and implemented to reduce the risks of nitrogen loading to groundwater without compromising agricultural productivity and activity.

22. Chloride appears to be present due to both natural and anthropogenic sources. No spatial or temporal trends are observed. Concentrations in the 250 ppm to 600 ppm range in the last 10 years, reaching values in a 1 to 3 ppm range. However, this trend may be due to the fact that more samples have been collected in the last six years. We observe a larger amplitude of concentration covered by a larger set of samples. This observation also applies to fluoride.

23. GW Solutions has drafted best management practices to reduce the risks of groundwater contamination from a variety of anthropogenic sources.

8 RECOMMENDATIONS

We make the following recommendations:

14) The RDN should work in cooperation with all the water purveyors to better monitor the effects of using aquifers for water supply in Area F. Working towards developing modeling tools to forecast the long-term effects of extracting groundwater from the aquifers should be a priority.

15) The network of monitoring wells should be reviewed in light of the improved definition of aquifers to identify areas needing monitoring.

16) The creation of new impermeable areas should be prevented to minimize the reduction of groundwater recharge.

17) The RDN should consider Aquifer Protection Development Permit Areas in particular in areas where connections between aquifers and surface water are more prevalent.

18) In addition to the application of the BC Riparian Areas Protection Act and the requirements listed in the RDN Freshwater and Fish Habitat Development Permit Area, we recommend that land protection measures be developed and implemented within a distance (i.e. 50 to 100 m) from top of banks (Beacon Environmental Ltd., 2012). Measures should consider both water quantity (e.g., no increase of impermeable areas) and water quality (e.g., no release of elements that would negatively affect water quality). A full review of the Freshwater Protection DPA regarding riparian buffers was outside the scope of this study.

19) Agricultural best management practices to reduce the risks of surface and groundwater contamination from fertilizers and farming activities need to be enforced. For instance, adequate setbacks from farming components (i.e., application of fertilizers, management of manure, wastewater lagoons, fertilizer storage) should be required. This could be promoted by the RDN through an education and awareness outreach program to farmers and also achieved by working with the Ministry of Agriculture to modify regulations, and to implement nitrate management plans.

20) The presence and types of coliforms need to be better characterized and monitored. The RDN should work closely with Island Health to assess the human health and ecological risks associated with coliforms.

21) The RDN should design and implement a nitrate monitoring and management program. It may include:

a) Sampling of wells with highest nitrate concentrations (e.g., network of a dozen wells, quarterly sampling);

b) Detailed mapping of septic fields and agricultural activities at proximity (i.e., within 500 m radius);

c) Detailed hydrogeological characterisation;

d) Simultaneous tracking of other parameters (e.g., chloride, sodium, sulfate).

22) A water quality assessment within Area F is recommended to be repeated no later than 10 years from this assessment; it should include septic field mapping and characterization to better characterise the potential correlation between the presence of coliforms, nitrate, and chloride in groundwater and the proximity to septic fields.

23) The water quality assessment was completed based on data from various sources. We recommend continuing monitoring and reporting on groundwater quality and facilitating the access and sharing of results. Private-domestic well owners are recommended to sample their wells for bacterial analysis and nutrients (i.e. nitrate) once a year, and metals (every three years).

24) Well inspections were not part of the project; however, it is well documented that contamination of groundwater could also occur due to the lack of an adequate well surface seal and poor completion of wellheads. It is recommended to encourage residents to upgrade their wells if they do not comply with the new Water Sustainability Act and Groundwater Protection Regulation. This is already encouraged via the RDN Wellhead Upgrade Rebate Program[8].

25) The RDN should continue its effort of education and outreach to the public for the proper operation and maintenance of septic fields.

26) The RDN should design and implement a program to locate wells which have been omitted from GWELLS. This should be accompanied by a well upgrade or closure plan, to meet the WSA requirements.

27) For wells exceeding iron, manganese and arsenic, treatment technologies such as reverse osmosis, chlorine injection, or specialized filters might be considered to reduce the concentrations to potability standards. Well owners are recommended to contact a certified water treatment specialist or qualified pump installer.

[8] https://rdn.bc.ca/well-protection-upgrades-rebate

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10 STUDY LIMITATIONS

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

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

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

The Regional District of Nanaimo (RDN) may rely on the information contained in this report subject to the above limitations.

11 CLOSURE

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

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

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

Yours truly,

GW Solutions Inc.

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APPENDIX 1

GW SOLUTIONS INC. GENERAL CONDITIONS AND LIMITATIONS

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

1.0 USE OF REPORT

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

2.0 LIMITATIONS OF REPORT

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

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

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

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

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

4.0 JOB SITE SAFETY

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

5.0 DISCLOSURE OF INFORMATION BY CLIENT

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

6.0 STANDARD OF CARE

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

7.0 EMERGENCY PROCEDURES

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

8.0 NOTIFICATION OF AUTHORITIES

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

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

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