Wetland Classification and Geologic Assessment Report:

French Creek Water region (WR3-FC)

Prepared for:

Regional District of Nanaimo's Drinking Water and Watershed Protection Program

Prepared by:

Mount Arrowsmith Biosphere Region Research Institute

Acknowledgments

This research has been conducted under the supervision and guidance of MABRRI Research Director, Dr. Pamela Shaw PhD MCIP RPP FRCGS.

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Abstract

Significant data gaps exist within the Regional District of Nanaimo (RDN) in regards to wetland locations, classifications, and what role they have in groundwater recharge. While there has been recent interest in regional freshwater resources within the RDN's watersheds, there are relatively few studies that have inventoried wetlands, and investigated their localized connection to groundwater resources. Our objectives in this study were to: 1) groundtruth predictive mapping that showed the distribution of potential wetland sites in the RDN; 2) create an inventory of wetlands in the French Creek water region based on their classification; 3) evaluate the hydrogeological position of each site to gain a better understanding of water storage, discharge, and potential flow pathways at each site; and 4) identify priority wetland sites for long-term monitoring and installation of instruments to identify potential hydraulic connections to groundwater systems. Researchers found that many of the wetlands in the region were behaving as swamp ecosystems with secondary classifications that were unique to each site, based on localized conditions. The majority of swamp systems were situated in Vashon Drift glaciomarine sediments and appeared to have reduced levels of water. One study site was identified as a priority site within the French Creek water region and was chosen based on its unique geology and location in the headwaters of the watershed. The study site is located in a region that contains unmapped aquifers, therefore further subsurface investigations will be needed. By investigating subsurface conditions through desktop analysis and by installing instrumentation, it should be possible to identify any connections between the water budget and runoff. It should be noted that wetlands were mapped based on accessibility and proximity to vulnerable aquifer systems and that these findings may not be representative of all wetlands that exist across the entire water region. Overall, results from this study may provide a framework for understanding how localized wetland systems may contribute to both local and regional groundwater flow systems.

1.0 Introduction

The French Creek water region (FCWR) is located within the Regional District of Nanaimo (RDN) on Vancouver Island, British Columbia (Figure 1). Geographically, the RDN contains four member municipalities: City of Nanaimo, District of Lantzville, City of Parksville and Town of Qualicum Beach. The RDN stretches along the coast of Vancouver Island from Deep Bay to Cassidy, extends upwards into the headwaters of the Cameron River, and reaches the Mount Arrowsmith Massif Regional Park (RDN Water Budget, 2016). There are more than 140,000 residents living within the RDN and the seven major basins that it encompasses, which are referred to as water regions for the purpose of this report. These water regions include Big Qualicum, Little Qualicum, French Creek, Englishman River, South Wellington to Nanoose, Cedar Yellow-Point, and Gabriola. The French Creek water region is situated in between the Little Qualicum and Englishman River water regions, encompassing approximately 121 km^2 (Waterline Resources Inc., 2013) (Figure The FCWR contains five major watersheds within its boundaries, with the French Creek system being the largest at 69.7 km^2 (Waterline Resources Inc., 2013). The region has the third largest number of wells within the RDN, with 895 reported; however, it is believed that there are likely many more wells currently in use (Waterline Resources Inc., 2013). This water region report will discuss in-field observations and classifications of the six wetlands that were mapped within the FCWR, as well as interpret their geologic position to better understand their potential connection to groundwater recharge. The report will highlight field methods used to map wetlands, as well as the physiography and regional geology of the FCWR. Increasing our understanding of wetland ecology and geology will be a critical component to the project as we try to understand how these systems are connected to regional hydrological and hydrogeological processes, more specifically, groundwater recharge.

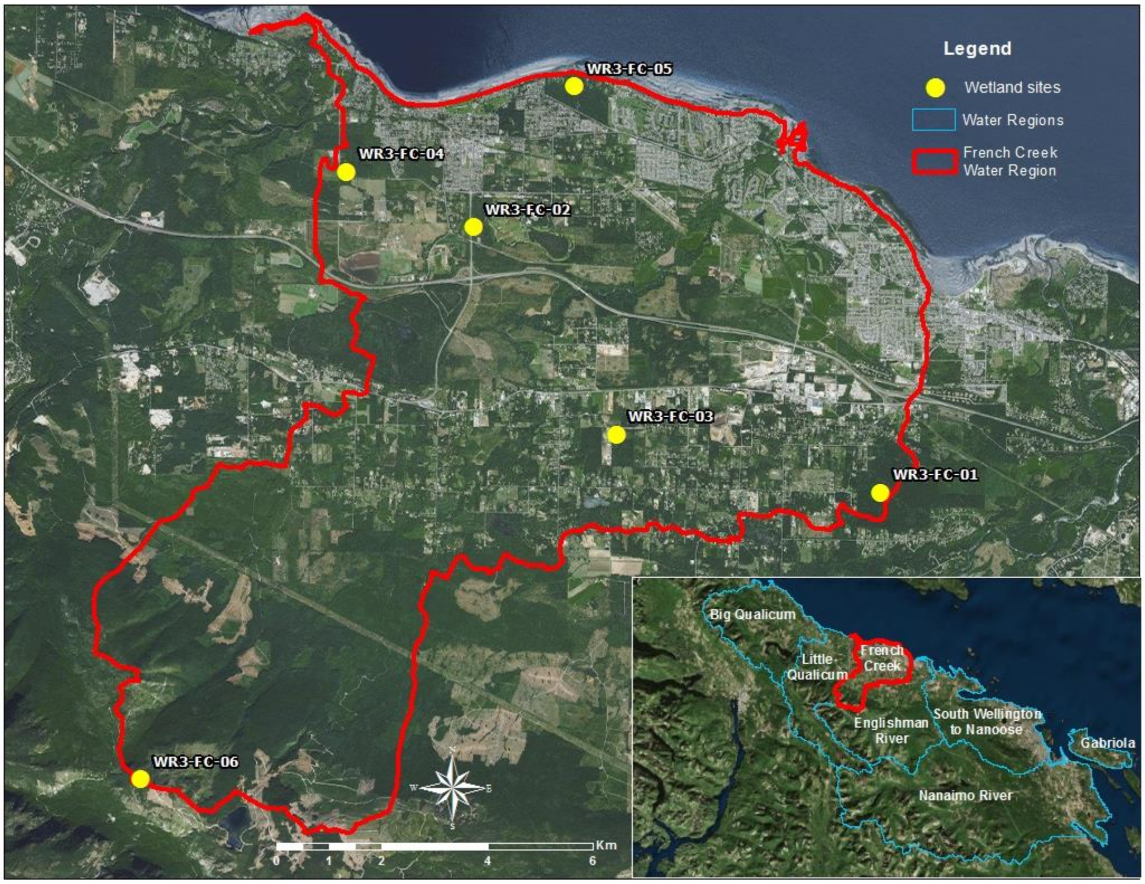

Figure 1: Wetland sites within the French Creek water region.
Source: Imagery obtained from Esri's online basemap database and water region perimeters were obtained from the Regional District of Nanaimo.

2.0 Methods

2.1 Preliminary Research Steps

Prior to mapping a wetland in the field the following preliminary research steps were taken:

1. Review predictive wetland maps that were created using Geographic Information Systems (GIS) and remote sensing; these maps were created using existing data from Ducks Unlimited Workflow (2014) that combines the Sensitive Ecosystem Inventory (SEI), Pacific Estuary Conservation Program (PECP) polygons, and the Fresh Water Atlas (FWA) to determine location and classification of each site.

2. Determine which water region each wetland is located in using ArcMap GIS software and associated RDN water region layers (RDN, 2017).

3. Determine which aquifer each study site is proximal to, as well as their classification number, type, level of demand, productivity, and vulnerability. This was completed using GIS software and associated groundwater layers provided by British Columbia's Ministry of Environment (2016).

4. Review topographic maps, surficial deposit maps, well drilling data, satellite imagery, and GIS data to establish drainage basins, as well as localized inflows and outflows at wetland sites, which provides an aerial perspective of the physical traits of each wetland.

5. Review satellite imagery to determine adjacent land uses to each wetland site.

6. Review Parcel Identification numbers provided by the RDN to determine property ownership, which will be used to establish accessibility to the wetland sites.

7. Create field maps of each wetland site using a determined scale and Universal Transverse Mercator (UTM) coordinate system.

8. Determine points of access on field map and potential wetland boundaries prior to visiting each site.

Once the preliminary research was completed and permission had been granted from property owners, allowing researchers access to their land, the team would enter the field to map and classify each site. Upon entering the field, researchers used the methods and standards that were previously established by the BC Wildlife Federation's (BCWF), specifically the WetlandKeeper's long form survey (BC Wildlife Federation [BCWF], 2015).

2.2 Field Steps

When entering the field, the following steps were taken to ensure data was accurately recorded:

1. Data recorded on the BCWF (2015) wetland long form survey includes: weather, wetland coordinates, wetland size and dimensions, site classification, functionality, dominant adjacent land use, hydrology, surrounding vegetation, surficial deposit composition, impacts/disturbances, wetland management, photographs, wetland sketches, vegetation transect surveys with quadrats, and soil observations taken from samples that were collected using a 30 cm auger. The number of transects completed at each site varied; they were dictated by the complexity of vegetation at each location. The more complicated sites had an increased number of transect lines to ensure vegetation data was

representative. Along transect lines, quadrats were placed in the middle of each wetland zone to identify shrubs, herbs, and tree cover.

2. Identify sites where bedrock or surficial deposits are exposed and record compositional characteristics to understand how water may infiltrate into groundwater. Researchers would also attempt to constrain if and where seepage may be occurring at localized sites. This was done using surficial geology maps created by Jan Bednarski (2013).

3. Ground truth where inflows and outflows may be at each wetland site and record waypoints at these locations using GPS units.

4. Record GPS track of wetland perimeter which can be compared to the Ducks Unlimited data (2015) and predictive mapping (2016) to interpret any observable changes in wetland shape and size. The lines of the perimeter were smoothed in some cases due to accessibility of some times. The wetland dimensions were also measured by using both the perimeter data and ArcGIS software.

3.0 Regional Description

3.1 Physiography

The French Creek water region is one of the smallest water regions in the RDN, but it is geographically diverse, ranging from the high rugged mountains of the Beaufort Mountain Range to the Nanaimo Lowlands -- a 280 km strip of relatively low-lying land that extends along the eastern coast of Vancouver Island. The Nanaimo Lowlands in the FCWR are characterized by the coastal beaches and urban areas found around Parksville, Qualicum Beach, and Coombs (Waterline Resources Inc., 2013). The climate in the French Creek water region is similar to the rest of the RDN, experiencing cool, wet winters and mild, dry summers; in the lower regions, such as Coombs, the area has an annual average precipitation of 1,126.3 mm, but can experience as much as 2,500 mm in the upper regions (Waterline Resources Inc., 2013). Additionally, four biogeoclimatic subzones constitute the FCWR, including Mountain Hemlock moist maritime (MHmm1), Coastal Western Hemlock moist maritime (CWHmm2), Coastal Western Hemlock very dry maritime (CWHxm1), and Coastal Douglas Fir moist maritime (CDFmm).

3.2 Regional Geology of the Nanaimo Lowlands

3.2.1 Bedrock Geology

Vancouver Island resides to the west of the Georgia Depression, as a part of the Insular Belt that is mostly comprised of Wrangellia Terrane (Bednarski, 2015). The Buttle Lake and Sicker Groups are the oldest rock formations, while the Karmutsen Formation is the youngest of the Wrangellia Terrane. On Vancouver Island, it is observed that Karmutsen bedrock has been intruded by granodioritic plutons of the Island Plutonic Suite (Bednarski, 2015). Bedrock geology, for most of the Nanaimo Lowlands, is typically underlain by upper Cretaceous sedimentary, known as the Nanaimo Group. The Nanaimo Group rocks are the basement of the eastern portion of Vancouver Island, deposited between North America and Wrangellia (Bednarski, 2015). They were formed by fluvial processes and deposited as a sedimentary gradation of conglomerate, sandstone, shale, and coal (Bednarski, 2015). Extensive areas of the coastal lowland are also mantled by unconsolidated material that is suggested to be over 100 m thick (Bednarski, 2015). However, the thickness of surficial materials is variable in the region and bedrock outcrops are commonly found throughout (Bednarski, 2015).

3.2.2 Stratigraphic Framework

The Nanaimo Lowlands are extensively covered in unconsolidated materials that were deposited during the last two glaciation events (Bednarski, 2015). Many of the coarser deposits act as groundwater reservoirs for many municipalities within the Nanaimo Lowlands (Waterline Resources Inc., 2013). Understanding their distribution is imperative when considering the relationship between wetlands and groundwater recharge. Below highlights the most recent glaciation and deglaciation events, and the associated lithostratigraphic deposits that are found in the Nanaimo Lowlands.

- *Penultimate Glaciation*

The Penultimate glacial period deposited extensive deposits of till approximately 3 to 9 m thick within the Nanaimo Lowlands region; these units are most commonly known as Dashwood Drift (Bednarski, 2015). In many regions, these till packages are bound by glaciofluvial, ice-contact, glaciomarine or marine sediments, and are overlain by fossiliferous glaciomarine silt and silty sand (Bednarski 2015).

- *Olympia Non-glacial Interval*

Sediments such as marine, estuarine, and fluvial materials overlying the Dashwood Drift till packages are interpreted to have originated from non-glacial processes and are designated as the

Cowichan Head Formation of the Olympia non-glacial interval (Bednarski, 2015). These represent a period of post Penultimate Glaciation and are followed by sediments deposited during the formation of the Fraser Glaciation, known as Quadra Sand (Bednarski, 2015). During climatic cooling, there was an increase in the amount of precipitation that lead to a large amount of sediment production from the Coast Mountains of BC (Bednarski, 2015). The sediment deteriorated streams and river channels, and flowed into the Georgia basin depositing a sandy outwash approximately 100 m thick (Clague *et al*. 1983).

- *Fraser Glaciation*

The most recent glacial period that was experienced by Vancouver Island was the Fraser Glaciation, which originated from the Vancouver Island mountain range as an alpine glacier that was met by the Cordilleran Ice Sheet advancing from the Coast Mountains of BC (Bednarski, 2015). Retreat of the ice sheets caused deposition of till blankets, as well as glaciofluvial terraces and deltas along the ice-margin as Vashon Drift materials (Bednarski, 2015). Complete deglaciation of the area led to isostatic rebound and a decrease in sea level, leaving glaciofluvial deposits along mountain flanks (Bednarski, 2015).

- *Postglacial Period*

During deglaciation, Vashon Drift sediments transitioned into post-glacial Capilano sediments (Bednarski, 2015). Even though the sediments are considered to be post-glacial, they were influenced by rapid glacial meltwaters; they consisted of glaciofluvial outwash, such as sands and gravels, with some diamicton present, and are generally a maximum of 25 m thick (Bednarski, 2015).

Following the deposition of Capilano sediments are Salish sediments (Bednarski, 2015). Their deposition occurred as intertidal marine sediments, beach sediments, lacustrine organic sediments, alluvial terraces, alluvial delta terraces, and alluvial flood plains (Bednarski, 2015). Along the shorelines, intertidal sediments were deposited by waves into tidal flats, while beach sediments were deposited by waves and currents at the present shoreline (Bednarski, 2015).

4.0 French Creek Water region Study Sites

4.1 Coastal Lowlands of French Creek

The area we will be discussing as the coastal lowlands in this section refers to the geographical area that is located below the marine limit which was interpreted by Jan Bednarski (2015 (Figure 2). Wetlands in this area are located within both Capilano and Vashon Drift sediments and fall between 0 and 200 meters above sea level. In total, five wetlands were mapped within the coastal lowlands area, including WR3-FC-01, WR3-FC-02, WR3-FC-03, WR3-FC-04, and WR3-FC-05; they are situated within either the Coastal Douglas Fir moist maritime (CDFmm) or Coastal Western Hemlock (CWHmm) biogeoclimatic (BEC) subzones. BEC zones incorporate ecosystems with similar vegetation, soils, and animal diversity that reflect the climate of that region (Mackenzie & Moran, 2004).

Coastal lowland study sites were situated on either unconsolidated or bedrock aquifers including: aquifer 212, 216, 217, and 220 (Appendix B: Figures 9-12). Aquifers 216 and 217 are both unconsolidated sand and gravel aquifers (Quadra sands), and are moderately productive with moderate to high vulnerability, while aquifers 212 and 220 are bedrock with low productivity and moderate vulnerability (Waterline Resources Inc., 2013). Many of these aquifers are considered to be at risk due to their partial confinement and recent declining water levels (GW Solutions Inc., 2017). Wetland sites were chosen based on their proximity to at-risk aquifer systems and unique hydrogeological position.

4.1.1 Surficial Materials of Coastal Lowlands

The largest control over the distribution of surficial deposits in the FCWR is the marine limit at approximately 200 m above sea level, represented by the red line in Figure 2; the marine limit is the maximum sea level during the last glacial period. Extensive glaciomarine sediments exist below the marine limit and their extent is highly variable. The marine deposits, which are Capilano and Vashon in origin, typically consist of silt, sand, and minor gravel units between 1 and 10 m in thickness (Bednarski, 2015). These units are typically understood to be stratified with various intermittent layers of clay, marine muds, and gravel. Drilling data from wells 50007 and 51233 show that these glaciomarine sediments are variable in terms of thickness and sediment size. The area near WR3-FC-01 has a relatively thin layer, 0 to 11 m, of glaciomarine deposits above bedrock units; this is likely due to the higher elevation of Little Mountain, which is 135 m above sea level. Drilling data from wells 96862, 803, and 32242 show surficial deposits that extend upwards of 30 m into the subsurface and do not encounter bedrock; these wells were drilled approximately 75 m above sea level, near WR3-FC-03. Regions that are lower lying typically have thick deposits of glaciomarine sediments, which extend 1 to 35 m in thickness, and have interbedded units of clay and silt that often separate water bearing sand and gravel units. Deposits that are proximal to primary watercourses, such as French Creek and smaller tributaries, have an abundance of alluvial terrace, fan, floodplain, and delta terrace deposits. Surrounding these channel margins are glaciofluvial delta and kame terrace deposits. Quadra Sands and till blankets are exposed extensively along channel margins due to river-incision.

Overall, the surficial geology of the French Creek water region can be subdivided into two primary physiographic regions that correlate with the chronological order of environmental changes. Highlands above the marine limit represent the highest topography that has been least affected by the Cordilleran Ice Sheet, which will be discussed below, and the coastal lowlands below the marine limit describe the post-glacial marine environment during high sea level. The river regions represent the sequence of changing environments from marine to glaciofluvial to fluvial.

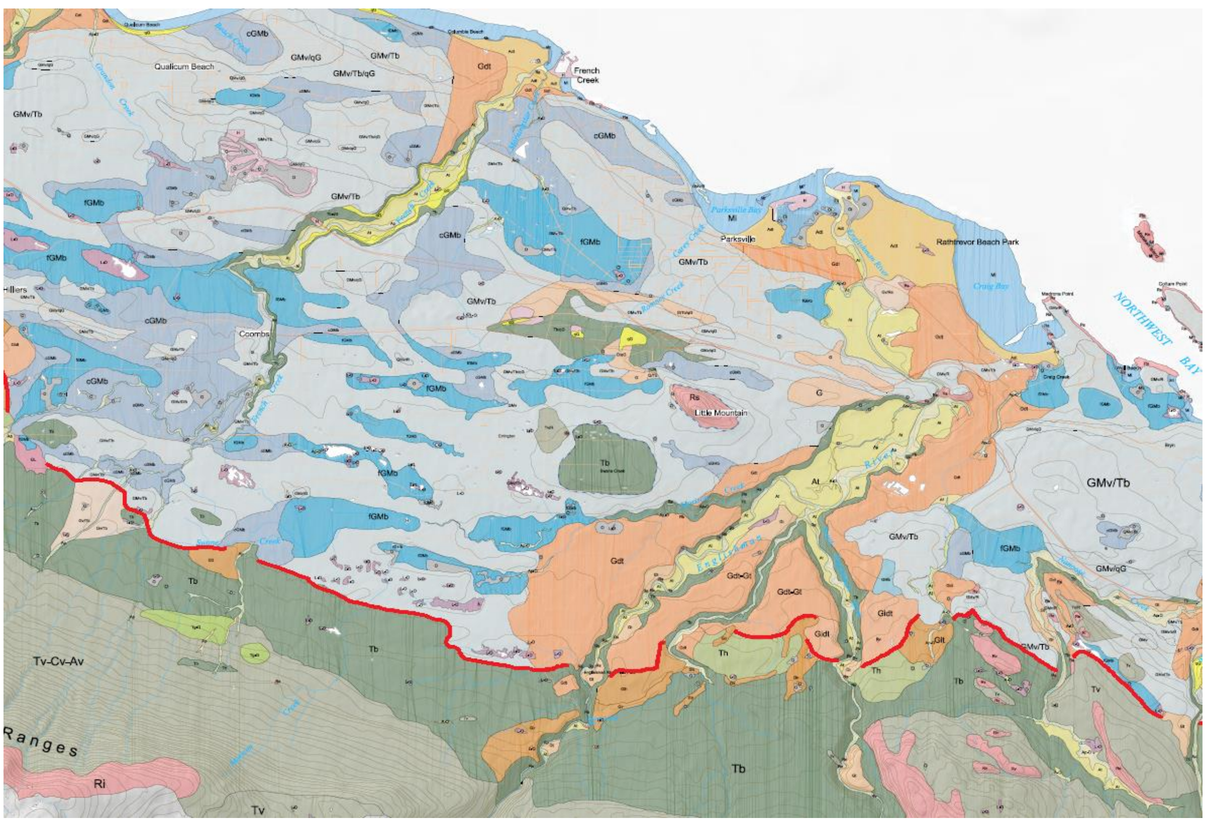

Figure 2: Detailed surficial geology map of the study area. Yellow units represent fluvial sediments, orange units represent glaciofluvial sediments; blue units represent marine and glaciomarine sediments, and green represents till. The red line represents the marine limit.
Source: Bednarski, 2015.

4.1.2 WR3-FC-01 Wetland Observations and Classifications

WR3-FC-01 was mapped on June 21, 2016 on Little Mountain, a rural area located between Errington and Parksville, British Columbia. The site sits at an elevation of 135 m above sea level in the Coastal Douglas Fir moist maritime biogeoclimatic zone and encompasses an area of approximately 1.8 ha (Figure 3). The study area is situated in a low-density residential area that is surrounded by undeveloped forested park. Recreational activities dominate the surrounding land, as much of this area is undeveloped. It was noted that near Little Mountain there has been extensive litter and dumping observed, which can contaminate ecologically sensitive areas, such as wetlands. WR3-FC-01 is situated on top of bedrock aquifer 220 that is known to be under localized stressed due to consumptive demand. The dimensions of the wetland were approximated to be 80 m long and 50 m wide using ArcMap software.

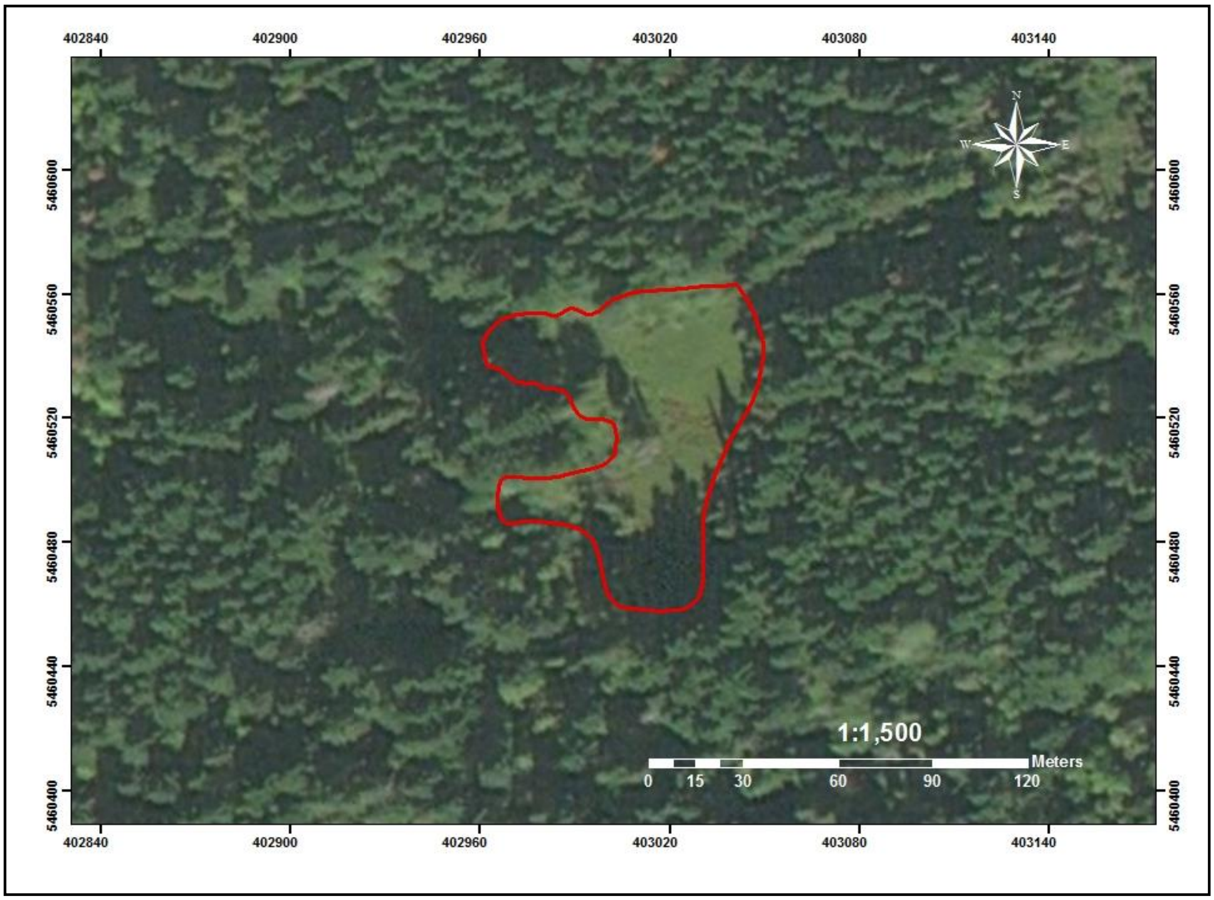

Figure 3: WR3-FC-01
Source: Imagery obtained from Esri’s online basemap database.

The wetland was situated in a shallow basin and was classified as a swamp due to its characteristic vegetation. Hardhack (*Spiraea douglasii)* was the dominant plant species found within the wetland, with a dense, uniform distribution throughout the entire site. The outer edges contained slough sedge (*Carex obnupta)* that transitioned into a mixed forest dominated by Douglas fir (*Pseudotsuga menziesii),* lodgepole (shore) pine (*Pinus contorta* var. *contorta),* big-leaf maple (*Acer macrophyllum),* Western red cedar (*Tjuja plicata*), and red alder (*Alnus rubra).* Centralized surface water, approximately 0.15 m in depth, was found within the swamp and was a turbid green-brown in colour. In central regions of the swamp, water samples were collected to determine pH (4.7) and water temperature (14°C). The pH of the water sample indicates a slightly acidic environment.

Soil samples were taken along transect one and two and contained 19 cm of rich organic soil on the surface that transitioned into a lens of sand and clay. The last 6 cm of the auger contained high clay content with some sand and pebble clasts. It was also noted that along the sides of the public trail there were exposed surficial deposits; samples collected from these areas were significantly different from the sites surveyed adjacent to transects. The organic soil layer here was approximately 7.5 cm in thickness and transitioned into a 10 cm sand layer, followed by an 8.5 cm layer of clay. Further field observations can be reviewed in Appendix A (Table 1). Overall, the system appeared to be a functioning wetland that did not have any observable inflow or outflow sites. Observational analysis suggests that the wetland likely retains much of its water in central sections, as hardhack and aquatic species appeared healthy and undisturbed.

4.1.3 WR3-FC-02 Wetland Observations & Classifications

The second wetland site, WR3-FC-02, is located along Memorial Road in Qualicum Beach, British Columbia 75 m above sea level and in the CDFmm. WR3-FC-02 was mapped on June 22, 2017 and was approximately 200 m long and 110 m wide. The study site had a unique distribution of vegetation, containing both wetland and terrestrial plant species that are not typically observed in many of the systems that the researchers mapped. Predictive mapping had an unknown classification for the wetland; therefore, researchers thought it would be important to ground-truth the site. WR3-FC-02 had one inflow adjacent to Memorial Road, which was a culvert that directed surface runoff into a field that is associated with the wetland system. There was no visible standing water on the field during the site visit, but this likely occurs during precipitation events. Surrounding this area, heading east towards the Pheasant Glen Golf Course, plant species transitioned into more dominant swamp species. Species that were observed during the site visit included: salmonberry (*Rubus spectabilis*), red alder, shore pine, red osier dogwood (*Cornus stolonifera),* Western red cedar, hardhack, black twinberry (*Lonicera involucrate*), red elderberry (*Sambucus racemose*), nootka rose (*Rosa Nutkana*), common horsetail

(*Equisetum arvense*), goat's beard (*Aruncus dioicus*), stinging nettle (*Urtica dioica*), bracken fern (*Ptderidium aquilinum*), lady fern (*Athyrium filix-femina*), bitter cherry (*Prunus emarginata*), creeping buttercup (*Ranunculus repens*), grand fir (*Abies grandis*), small flowered forget-me-not (*Myosostis laxa*), orchard grass (*Dactylis glomerata*), and Canada thistle (*Cirsium arvense*). The mosaic of vegetation made this site ecologically unique.

WR3-FC-02 is situated on top of Aquifer 217 and near wells 96862, 803, and 32242, which have higher-than-normal pumping rates (Ministry of Environment, 2017). These wells have pumping rates between 200 and 300 gallons per minute, indicating the aquifer may be vulnerable to over-pumping and high demand (Waterline, 2013). Aquifer 217 is understood to be confined; recent studies on localized water budgets indicate the aquifer is under a high degree of stress; water levels in observation wells have been experiencing substantial water level declines since the mid 2000's (Waterline, 2013). Soil samples were collected at various locations at the site and contained dark brown to black soil with distinct plant structures. For further information regarding classification and field observations, see Appendix A (Table 1).

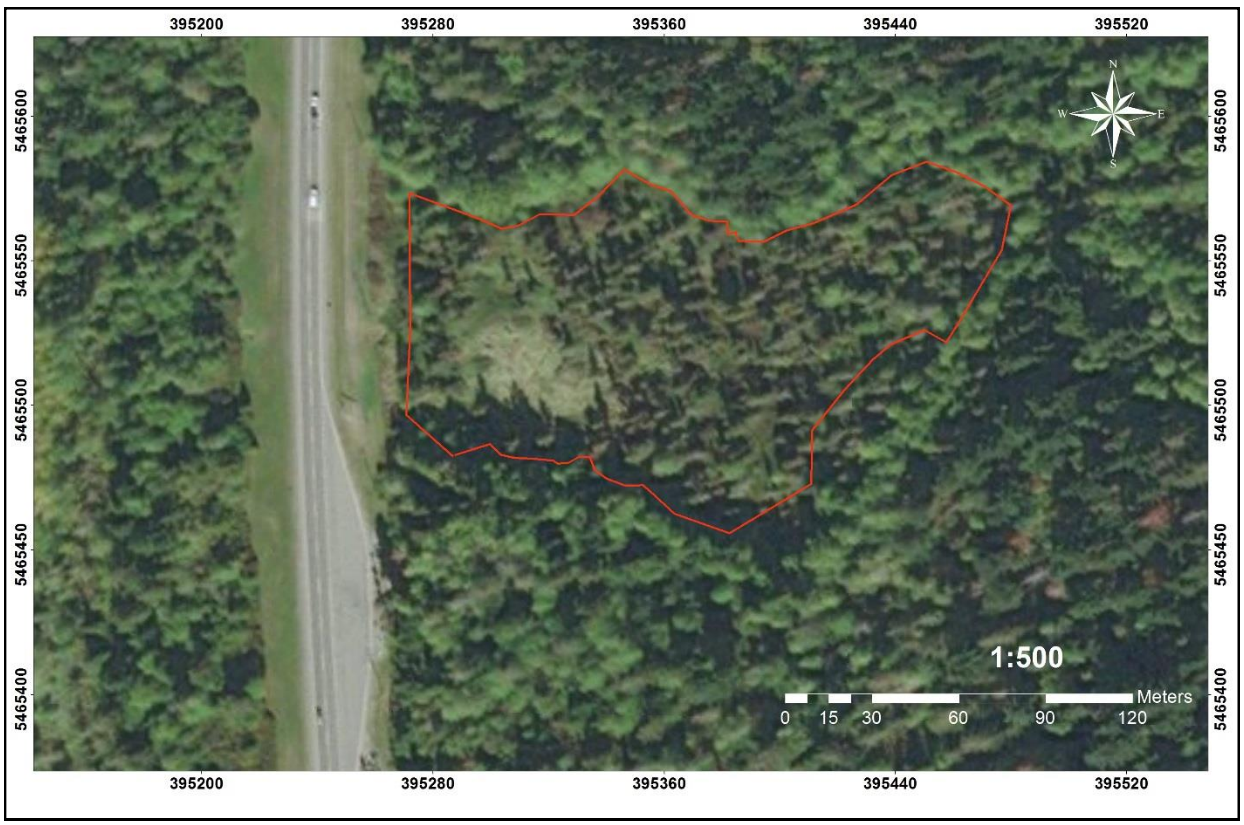

Figure 4: WR3-FC-02
Source: Imagery obtained from Esri's online basemap database.

4.1.4 WR3-FC-03 Wetland Observations & Classifications

WR3-FC-03 was mapped on November 28, 2016 and determined to be 320 m long and 125 m wide. This wetland is located 105 m above sea level in the CDFmm biogeoclimatic zone; it was within a shallow basin that contained hardhack and shore pine as the dominant plant species. Unfortunately, due to the density of hardhack, entering the wetland system was not possible. Researchers took a general plant inventory to better discern the classification of the system. The non-dominant species observed included trailing blackberry (*Rubus ursinus*), grand fir, step moss (*Hylocomium splendens*), slough sedge, yellow moss (*Homalothecium fulgescens*), rough moss (*Claopodium crispifolium*), Oregon beaked moss (*Kindbergia oregana*), Western red cedar, red alder, salal (*Gaultheria shallon*), and English holly (*Llex aquifolium*). Water samples at the time of the visit were clear and colourless, with a temperature of 3°C and a pH of 6.5. An official soil sample using a soil auger was not taken due to site conditions, however, a hand sample was taken. The result of this test indicated a fibric peat soil with very weak decomposition, and distinct plant structures. The surrounding land-uses include agriculture, industrial gravel pits, and new residential developments. Overall, from observational analysis the wetland site appeared to be functional, but due to the dense hardhack it was difficult to tell if the wetland had a central distribution of water with any inflows or outflows. There were diffuse patches of water surrounding the wetland indicating there may have been water pooling in central sections. Further in-field analysis may need to be conducted to better understand the system's behavior.

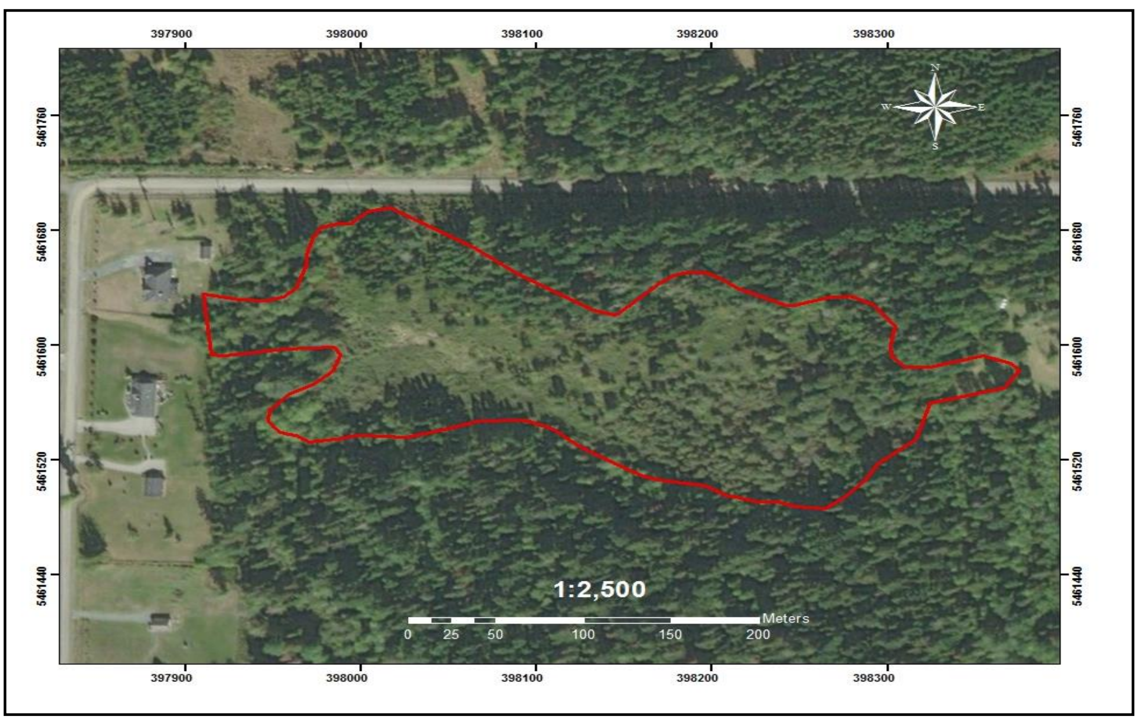

Figure 5: WR3-FC-03
Source: Imagery obtained from Esri's online basemap database.

4.1.5 WR3-FC-04 Wetland Observations & Classifications

WR3-FC-04 was mapped on August 2, 2017 and was classified as a wet forest system and resides within a CDFmm BEC zone. The study site is situated 85 m above sea level and is approximately 275 m long and 75 m wide. The polygon in Figure 5 shows the perimeter of the wetland system that was generated by predictive mapping. Unfortunately, the perimeter was not collected in the field as the site was not a typical forested swamp ecosystem. Wetland vegetation was diffuse and was not consistent throughout, which may have been a result of limited water availability. Researchers surveyed the site to understand dominant plant species and the type of soil that existed within the system. WR3-FC-04 was dominated by Douglas fir and Western red cedar trees, while the understory was largely composed of sword fern (*Polystichum munitum)*, skunk cabbage (*Lysichiton americanus)*, slough sedge, lady fern, salal, salmonberry, red huckleberry (*Vaccinium parvifolium)*, and Mexican hedge nettle (*Stachys mexicana).* Soil was classified as humic peat with almost complete decomposition, leaving plant structures nearly unrecognizable. Standing water was not observed at the site, thus a pH and temperature profile could not be completed. Overall, the study site did not appear to be functioning as a typical swamp system and was not representative of typical wetland systems in the region.

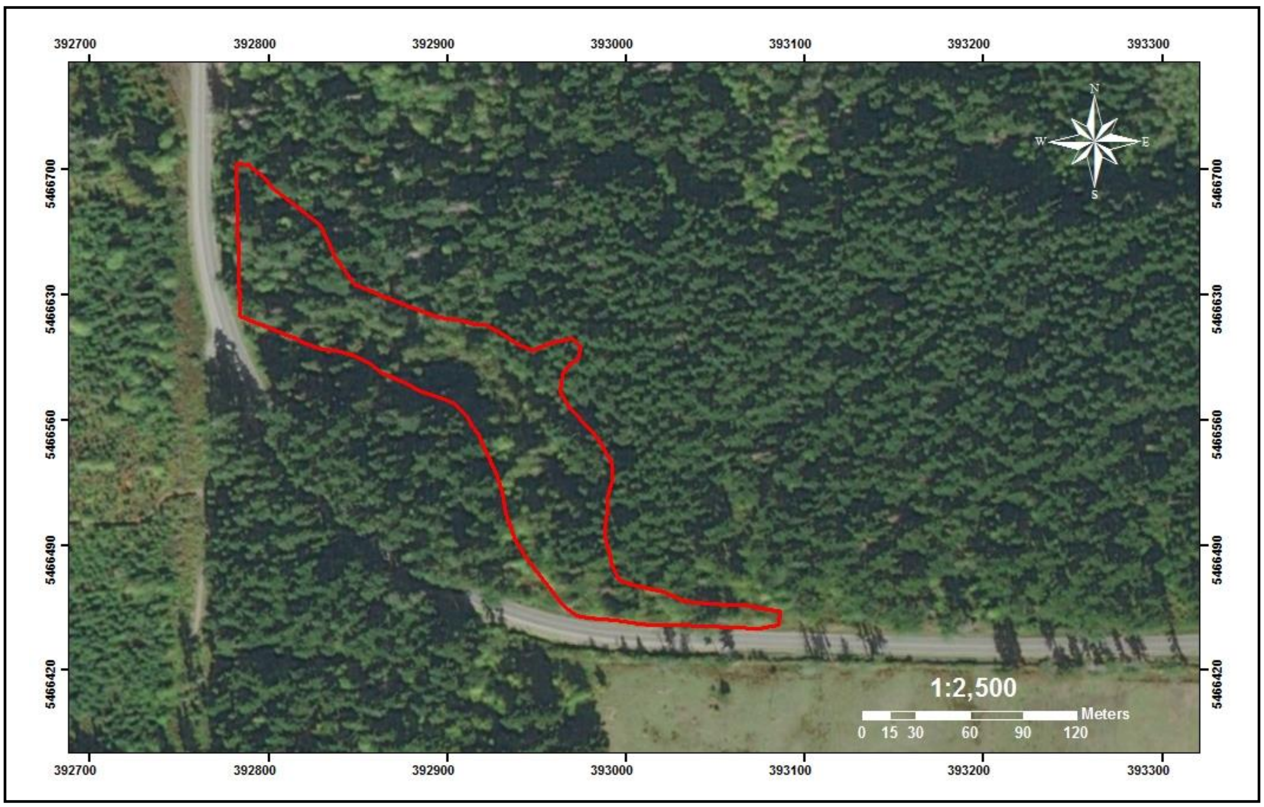

Figure 6: WR3-FC-04
Source: Imagery obtained from Esri's online basemap database

4.1.6 WR3-FC-05 Wetland Observations and Classifications

WR3-FC-05 is situated amongst dense forest cover (Figure 7) and was not identified as a potential wetland site through analysis of predictive mapping; instead, researchers found it on a previous visit to Milner Gardens. The wetland is approximately 0.0018 ha in area and was classified as a swamp wetland with a secondary shallow water region. Although the surrounding area is highly developed with urban and residential uses, this site is a managed forest by VIU's Milner Gardens and Woodlands. The forest is dominated by Douglas fir, Western red cedar, red alder, and salal. Whereas, within the swamp transition zone the wetland species such as sword fern, skunk cabbage, and slough sedge were identified. The transition zones within the wetland and surrounding areas are dictated by soil, water quantity, and vegetation. The study site appeared to be a functioning swamp wetland that contained shallow surface water centrally, approximately 7 cm in depth. The water was very clear and brown, with a temperature of 11°C and a pH of 6.5. There was no visible fluvial inflow and outflow sites, as a result water appeared fairly stagnant.

During our field study in June 2017, the central wetland area contained approximately 55% open water, although the wetland may be dry seasonally. Visible surface deposits found near the wetland site were composed of clay and organic materials. Three soil samples were taken along the transect lines during the survey. The first sample was collected within the treed swamp and had a 12 cm layer of fibric organics followed by a thick layer of clay. The second sample was taken within the shallow water section and contained dark organic soil with some plant structures present from 0 to 4 cm; the rest of the sample contained a thick sand layer. The last sample was consistent with the first, having fibric soil from 0 to 7 cm, which transitioned into a much higher clay content profile from 7 to 13 cm. Overall, FC-03-05 appeared to be a healthy functioning system.

Figure 7: WR3-FC-05
Source: Imagery obtained from Esri's online basemap database.

4.2 Uplands Region of French Creek

The uplands region extends from the catchment of the FCWR, 1,080 m above sea level, and extends down towards the marine limit that was determined by Bednarski (2013). Water flows to the east from the Beaufort Mountains along the steep forested terrain and out into the Strait of Georgia. Vegetation in the uplands is characteristic of the Coastal Western Hemlock moist maritime montane BEC subzone (CWHmm2). This subzone experiences cooler temperatures, heavier snowfall, and shorter growing seasons in comparison to the lower, submontane variant (Green & Klinka, 1994). Additionally, these ecosystems, similar to the submontane variant, have water deficits during the growing season due to the rain shadow effect of the Vancouver Island Mountains (Green & Klinka, 1994). The uplands receive significant precipitation during winter months, with an annual average of 2,000 to 2,500 mm (Waterline Resources Inc., 2013). In total, one wetland, WR3-FC-06, was mapped in the uplands region due to limited accessibility of private forestlands. Wetland systems were prioritized in this region due to their unique hydrology and relationship to unmapped aquifers. Groundwater recharge modelling created by

Waterline Resources Inc. suggests that these upland regions contribute to groundwater recharge for the FCWR.

4.2.1 Geology of the French Creek Water Region Uplands

Above the marine limit is defined as the topographic high area that is made up of till, bedrock, and glaciofluvial deposits. Surficial materials within the uplands region are largely Vashon Drift in origin and consist of bouldery diamictons that were deposited in subglacial and ice marginal environments (Bednarski, 2015). The sediments are typically sand to clay with clasts of various lithologies and can range between 1 and 3 m in thickness. Capilano sediments are also found within the uplands region and typically found where major watercourses flow out of the mountainous valleys, near the marine limit (Bednarski, 2015). In these areas, sediments are often course and appear as large terraces and ridges that have been reworked by modern day fluvial processes. Unfortunately, in the upper reaches of the FCWR, minimal drilling information is available to interpret the sedimentology of the entire region. In-field observations match that of Bednarski's 2013 study, showing exposed bedrock outcrops that are granodioritic intrusive rocks of the Jurassic Island Plutonic suite. In other sections bedrock is covered by till units that have varying composition. Further in-field analysis will need to be conducted to confirm literature on these areas but will be done at a localized, site-specific scale.

4.2.2 *WR3-FC-06 Wetland Classification and Observations*

WR3-FC-06, situated near the headwaters of the FCWR, has a small tributary that connects to French Creek in lower elevation areas. The study site is located to the east of Mount Arrowsmith, near Rowbotham Lake, and was accessed on June 20, 2017. The wetland is within the CWHmm2 BEC zone, at an elevation of 1,027 m. The study site appeared to be within an area of old growth forest, dominated by yellow cedar (*Chamaecyparis nootkatensis*), Amabalis fir (*Abies amabilis*), Western hemlock (*Tsuga heterophylla*), mountain hemlock (*Tsuga mertensiana*), Western white pine, and lodgepole pine. The study site was approximately 115 m long and 60 m wide, covering an area of 0.37 ha. The alpine wetland system appeared to behave different than many of the shallow water wetlands in the lowlands. The site had central pooling water with emergent vegetation and transitioned into a bog zone before changing into a forested ecosystem (Figure 8). The site was classified as a shallow water wetland with a secondary bog zone along the shoreline. Shallow water wetlands are dominated by rooted, submerged, and floating aquatic plants and are linked to permanent still or slow-moving waterbodies (MacKenzie & Moran, 2004). Midsummer, they are usually permanently flooded and maintain water levels less than 2 m (MacKenzie & Moran, 2004). The wetland contained a variety of emergent aquatic plant species, including buckbean (Menyanthes *trifofiata)* and yellow pond lily (*Nuphar polysepalum)*. The bog transition zone was dominated by a variety of species, including a variety of peat moss species (*Sphagnum* spp.), pink mountain heather (*Phyllodoce empetriformis*), Western bog-laurel *(Kalmia microphylla* spp. *Occidentalis)*, round-leaved sundew (*Drosera rotundifolia*), false azalea (*Menziesia ferruginea*), Indian hellebore (*Veratrum viride*), dwarf dogwood (*Cornus canadensis*), ribbed bog moss (*Aulacomnium palustre*) and lodgepole pine. In addition, while in the field, over 50 Roughskin Newts (*Taricha granulosa)* were observed within the wetland, likely using it for breeding and laying eggs (Ministry of Environment, n.d.).

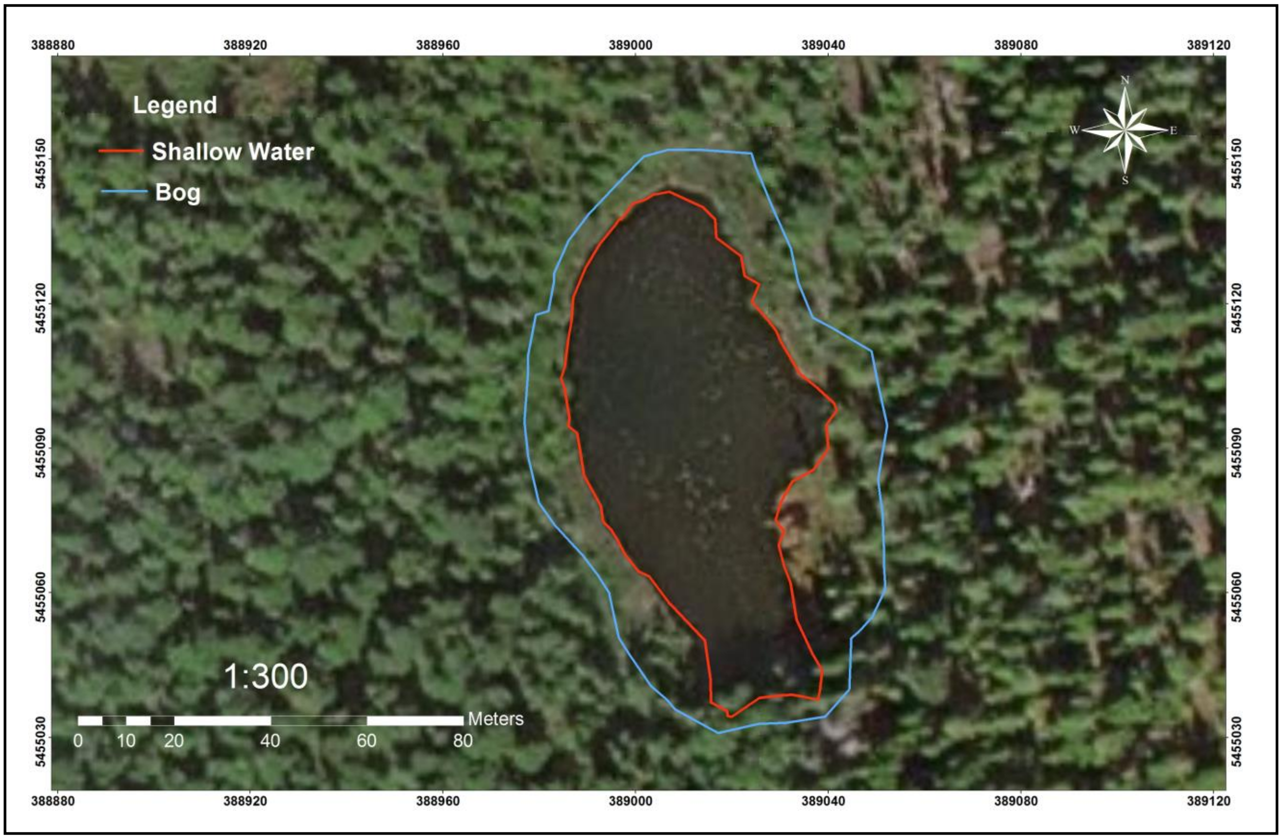

Figure 8: WR3-FC-06
Source: Imagery obtained from Esri's online basemap database

The hydrogeomorphic position of the wetland is in a natural bedrock depression on an unmapped aquifer. One main outflow was found, on the north side of the wetland, joining the system to French Creek. Additionally, a smaller outflow was found on the south side, flowing in the opposite direction. There was no observable inflow at the study site. As the wetland is important habitat for Roughskin Newts, the open water section was not surveyed to determine depth or plant composition; however, the depth along the perimeter was estimated to be approximately 1 to 1.5 m. The water was clear and had a surface temperature of 16°C and a pH of 8.

5.0 Discussion

5.1 Hydrostratigraphy

The study area located in the French Creek water region has undergone a series of geologic deformation events, including a number of glacial intervals (as mentioned above in section 3.0). These events have had a large impact on how hydrologic and hydrogeological systems behave on a local and regional scale (Bednarski, 2015). The main bedrock units observed in the area are either Karmusten Basalt or Nanaimo Group origin including: Protection Formation (Fm), De Courcy Fm, Cedar District FM, Comox Fm, Haslam Fm, Extension Fm, and Pender Fm (Hamblin, 2012). These units have been exposed at the surface in certain areas as a result of tilting, faulting, and folding from accretionary processes (Hamblin, 2012). These deformation events have led to extensive fracturing of all major bedrock units in the area allowing for a dramatic increase in fracture porosity, permeability, aperture size hydraulic conductivity, and transmissivity (Hamblin, 2012). These fractures have allowed relatively impermeable bedrock units to have moderate to high aquifer potential. Well descriptions indicate that sandstone and shale units are water-bearing in some areas, typically without fractures and acting as aquitards due to low permeability and porosity (e.g. Aquifer 211).

Surficial sediments in the FCWR reflect the glacial and post-glacial processes that took place during the Quaternary period. During periods of isostatic uplift, glaciofluvial processes dominated the region, resulting in the deposition of coarse sand and gravel units that act as modern day aquifers. The majority of the study area was composed of Capilano glaciomarine mud and clay veneer that act as localized aquitard units above water bearing sand and gravel outwash deposits. Outwash deposits were deposited intermittently during postglacial isostatic uplift and sea level rise. Veneer units may be disconnected due to variable thickness as a result of modern day marine limit erosional processes. These units likely reflect a low energy, deep marine environment where sea level was significantly higher than pre-glacial periods. Fluctuating sea levels and variable marine environments were responsible for depositing these aquitard and aquiclude units. Additionally, these units are spatially variable in thickness and may be disconnected at a localized scale. Locations that are proximal to French Creek likely represent glaciofluvial and fluvial processes, as thick packages of sand and gravel are seen on either side of the river with interbedded lenses of clay. Further subsurface investigations will need to be conducted to better understand the extent of aquiclude and aquitard units at a local scale.

5.2 Wetland Characteristics

Swamps were the most dominant wetland systems identified within the FCWR along with two unique sites, one that was classified as “wet forest ecosystem” and the other as a shallow water wetland with a secondary bog zone. In total, four of the study sites within the region were classified as dominant swamp wetland systems with secondary classifications that were more specific to each site. Swamp systems are characterized by distinct vegetation that reflect high cover of tall shrubs and trees, with a well-developed herb layer (MacKenzie & Moran, 2004). There are typically two distinct types of swamps found in British Columbia, which are characterized by: [1] a tall shrub physiognomy and [2] forested (MacKenzie & Moran, 2004). Wetlands characterized by tall shrub species are often related to fen ecosystems, but are distinguished by vigorous shrub growth and a poorly developed moss layer, which is due to shade and abundant litter. Wetland study sites 01, 02, 03, and 05 were classified as dominant swamp systems with tall shrubby vegetation species, while study site 04 was classified as a wet forested ecosystem that contained some forested swamp species. The classification and distinction between these two types of swamps was based on the quantity of water that encouraged vegetation change. Within the wet forest ecosystem, swamp vegetation was diffuse with smaller shrubs such as skunk cabbage and various sedge species. These systems typically had significantly less water available and appeared to be seasonally damp.

In contrast, study sites classified as swamps contained shallow water where hardhack and shrub species thrived. Water levels typically ranged between 0.2 and 0.5 m in these areas and had poorly decomposed plant matter with lenses of mud and clay. Additionally, these sites appeared to experience seasonal water fluctuations. WR3-FC-06 was classified as a shallow water wetland with a bog zone on the outer portions of the system. Bogs are characterized by wet, spongy, poorly drained peaty soil; WR3-FC-06 met these vegetation parameters, in addition to being dominated by sphagnum bog moss (Encyclopaedia, 2017). Upland lakes or shallow water systems in glaciated regions have also been understood to develop into bogs if they were not drained (Encyclopaedia, 2017). These “lake” systems begin to fill as a result of the development of a floating mat of vegetation next to the shore, which was observed at WR3-FC-06 (Encyclopaedia, 2017). In the uplands section there were a series of shallow water systems that had outer bog sections; it is likely that in these areas wetland systems behave more like the “lake” systems, that have characteristic floating mats situated on pooling water. Pooling water is typically on top of on thin till veneers that directly mantle bedrock.

5.2.1 *Hydrology of WR3-FC-06*

During field visits to WR3-FC-06, it was observed that the site had unique hydrological characteristics that may be indicative of its position on fractured bedrock units. The wetland had significant surface water storage during the site visit and had two visible outflow sites. It is generally understood that upland sections of the FCWR contribute to regional groundwater recharge but it is likely that these sites act to redistribute water to lower lying areas and actually have limited water storage in shallow bedrock aquifers (Waterline, 2013). Locally, it is likely that water infiltrates through cracks, fissures and, faults to redistribute water into other subsurface systems that exist in lower areas (Lesemann, 2017). At WR3-FC-06, a thin blanket of discontinuous till veneer of variable thicknesses was visible over granodioritic bedrock units; therefore their ability to confine upland groundwater systems was reduced. During verbal communication, Lesemann (2017) suggested that the bedrock aquifers in these areas are typically shallow and do not contribute significantly to groundwater recharge, due to the steep topography in the region. Lesemann suggested that understanding surface to groundwater interactions would be complex in these areas, and that it is likely beneficial to start by monitoring surface water to create a water budget which will allow researchers to quantify how much water exits the system through surface runoff (2017).

Overall, the majority of the study sites visited were classified dominantly as swamps, which may not be representative of the region. The study sites visited were done so based on proximity to vulnerable aquifer units and accessibility of the property. In many cases the study sites were located on publicly accessible lands or private forestlands. Moving forward it would be beneficial to map more wetlands proximal to major fluvial systems to better understand how these systems differ from low-lying wetland systems situated in glaciomarine deposits.

5.3 Recommendations

The purpose of the study was to map and classify wetland systems across the FCWR, while highlighting the stratigraphic framework of the region to better understand how study sites may be contributing to groundwater recharge. In order to move forward with developing an accurate groundwater flow model, understanding how wetlands are connected to groundwater systems, in the FCWR it will be necessary to conduct further desktop analysis and in field research, including cross-sectional analysis, well observation analysis, geophysical surveys, and installation of data loggers to understand localized water level fluctuations. Further research and analysis will also need to be conducted to understand the functionality of particular wetlands and how surrounding land uses can affect these systems.

5.3.1 *Cross-Sectional Analysis*

To date, field visits have been undertaken to gain an initial understanding of wetland classifications, potential sediment and bedrock types, and local topography within the FCWR. In order to determine the subsurface geology at a local scale, further research will need to be conducted using well locations and tag numbers in the area from the BC Water Resource Atlas. By using well tag numbers, researchers will be able to retrieve detailed descriptions of the selected wells from the Ministry of Environment's WELLs Database, used to understand what stratigraphic units were encountered during drilling. Moving forward, researchers will need to draw multiple cross-section lines across each study site to best capture the subsurface variability. By using wells located proximal to the cross section lines, researchers will be able to draw both stratigraphic and hydrostratigraphic logs of the area, which capture the geologic setting of deposits and bedrock, as well as aquifer, aquiclude, and aquitard potentials, respectively. These qualitative findings will make it possible for researchers to develop a working stratigraphic and hydrostratigraphic interpretation of each study site that can be used to hypothesize where water may be infiltrating into the subsurface. It is these qualitative findings and hypotheses that will lead to the quantification of groundwater recharge.

5.3.2 *Installation of Instrumentation*

The study of groundwater involves many complex disciplines and principles, and is considered to be a quantitative science. For this reason, it is critical to install instrumentation to better understand qualitative data that has been collected by researchers. Wetland sites will be prioritized based on their geologic frameworks, proximity to vulnerable aquifers, potential for surficial deposits to have high hydraulic conductivity values, and overall position within regional groundwater flow systems. In order to understand the amount of water entering and exiting each study site, researchers will need to create a localized water budget. A water budget accounts for the inputs, outputs, and changes in the amount of water by breaking the water cycle down into components (USGS, 2017). Researchers will need to start by installing simplistic weather stations to gather basic information regarding annual precipitation, temperature, evapotranspiration, wind speed and direction, and elevation. It will also be necessary to install level loggers at these sites to monitor water level fluctuations overtime. Data collected from level loggers will be compared against water table fluctuations from nearby observation wells in order to identify any correlations between the systems. Installing low-cost instrumentation as discussed will be the first step towards understanding the local hydrology of each site.

Although mapping and classification of wetlands in the FCWR has not been completed, researchers will be able to begin investigating the hydrostratigraphy of wetlands in glaciomarine sediments, as these sediments typically act as aquitard units. Further investigations will also need to be conducted to better understand the functionality of particular wetlands and how surrounding land uses can affect these systems. Furthermore, funding will need to be secured to ensure that preliminary groundwater analysis can begin.

6.0 Conclusion

Two methods of interpretation were used to better understand wetland systems within the French Creek water region: preliminary desktop analysis and in-field analysis. These methods were established early in the development of the project and have guided researchers through the mapping and classifying of wetland systems. Based on predictive mapping, six wetlands were mapped and classified for the FCWR. Wetlands were classified based on their soil, hydrology, and vegetation characteristics. One important implication of using predictive mapping to identify wetland sites is the lack of accuracy associated with remote sensing. Many of the wetland sites could not simply be classified as one dominant wetland system as they had various transition zones associated with secondary classifications. Moving forward, it should be noted that predictive mapping is only a tool that can be used to guide researchers in identifying potential wetland sites. While in-field ground-truthing of predictive mapping, researchers also had the opportunity to analyze each site's local physiography and hydrogeologic position. Throughout this process it was evident that many of the wetlands within the lowland regions were behaving as swamp ecosystems, with secondary classifications that were unique to each site. Researchers identified one wetland of particular interest and suggest further investigations should be conducted at WR2-FC-06, as the hydrology of the area is quite unique based on its location in the headwaters of the watershed. As discussed above, it will be very important to move forward with further subsurface investigations to better understand existing hydraulic connections at WR3-FC-06 by using data gathered from instrumentation, desktop and cross-sectional analysis

7.0 References

Bednarski, J.M. 2015. *Surficial Geology and Pleistocene stratigraphy from Deep Bay to Nanoose Harbour, Vancouver Island, British Columbia*. Geological Survey of Canada [Internet]. [cited 2015 Nov 30]. Available from: http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=295609 doi: 10.4095/295609.

Benoit, N., Paradis, D., Bednarski, J.M., Hamblin,T., Russell, H.J.A. 2015. *Three dimensional hydrostratigraphic model of the Nanoose – Deep Bay Area, Nanaimo Lowland, British Columbia*. Geological Survey of Canada [Internet]. [cited 2015 Nov 30]. Available from: http://www.rdn.bc.ca/dms/documents/dwwp-reports/region-wide-reports/nrcan_gsc_three_dimensional_model_aquifer_characterization_of_nanaimo_lowlands_wr1-5_-_2015.pdf doi: 10.4095/296302.

Clague J, Luternauer J. 1983. *Trip 6 Late Quaternary Geology of Southwestern British Columbia*. Geological Association of Canada [Internet]. [cited 2015 Nov 30]. Available from: http://www.gac-cs.ca/publications/Field%20trips/FieldTrip%206%20-%20Late%20Quaternary%20Geology%20of%20SW%20BC.pdf

Green, R.N. & Klinka, K. (1994). *A field guide to site identification and interpretation for the Vancouver forest region*. Res. BR., B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 28.

GW Solutions Inc. (2017, Aug 10). *State of our aquifers.* Retrieved from http://www.rdn.bc.ca/dwwpreports

Lowen, D., Kohut, A., Hodge, B. (January 25, 2010). Arrowsmith Water Service Englishman river water intake study groundwater management. Lowen hydrogeology consulting Ltd. Retrieved from: http://www.englishmanriverwaterservice.ca/aws_documents/aws_dp5-1.pdf

Ministry of Environment. (n.d.). *B.C. frogwatch program: Roughskin newt*. Retrieved from the Ministry of Environment website: http://www.env.gov.bc.ca/wld/frogwatch/publications/factsheets/salamanders/roughskin.htm

Oram, B. (n.d.). The ph of water. Retrieved from the Water Research Center website: http://www.water-research.net/index.php/ph

Waterline Resources Inc. (2013). *Water budget project: RDN phase one (vancouver island).* Retrieved from http://www.mvihes.bc.ca/images/pdfs/Waterline2014.pdf

Appendix A
Wetland Classification Summary

Table 1: Summary of Wetland Classifications and Aquifer Characteristics

Wetland Name	Wetland Location	Wetland Classification	Dominant Plant Species	Wetland Size (ha)	Wetland Elevation (masl)	Wetland Water Temperature (°C)	Wetland Water pH	Wetland Soils	Aquifer Classification Code	Aquifer Type	Aquifer Confinement
WR3-FC-01	49° 17' 22" N 124° 20' 01"W	Swamp	Hardhack	1.8	135	14	4.7	Dark organic layer, transitioning to sand and clay lens	220 llb (11)	Bedrock	Confined
WR3-FC-02	49° 20' 00" N 124° 26' 24" W	Swamp	Orchard grass, red alder, salmonberry, red oiser dogwood, western red cedar	1.66	75	n/a	n/a	Dark /black brown in color, high organic material, plant structure not fully decomposed, thick mud with little water	217 IIB (14)	Sand and gravel	Partially confined to confined
WR3-FC-03	49° 17' 54" N 124° 24' 10" W	Swamp	Hardhack, shore pine	4.6	105	3	6.6	Fibric peat; very weak decomposition with distinct plant structures	220 IIB (11)	Bedrock	Confined
WR3-FC-04	49° 20' 32" N 124° 28' 30" W	Wet forest	Douglas fir, slough sedge, Sword fern, red alder, Skunk cabbage	1.8	85	n/a	n/a	Humic peat with almost complete decompostion	217 lB (14)	Sand and gravel	Partially confined to confined
WR3-FC-05	49° 17' 24" N 124° 24' 53" W	Swamp; shallow water wetland	Red alder, sword fern, skunk cabbage, western red-cedar	0.0018	30	11	6.5	Fibric peat with no decomposition. Underlying clay and sand layer	217 lB (14)	Sand and gravel	Partially confined to confined
WR3-FC-06	49° 14' 19" N 124° 31' 28" W	Shallow water wetland; bog	Yellow pond lily, buckbean, sphagnum spp	0.37	1027	16	8	n/a	Unmapped	Bedrock	Unknown

Appendix B

Aquifers in the French Creek Water region

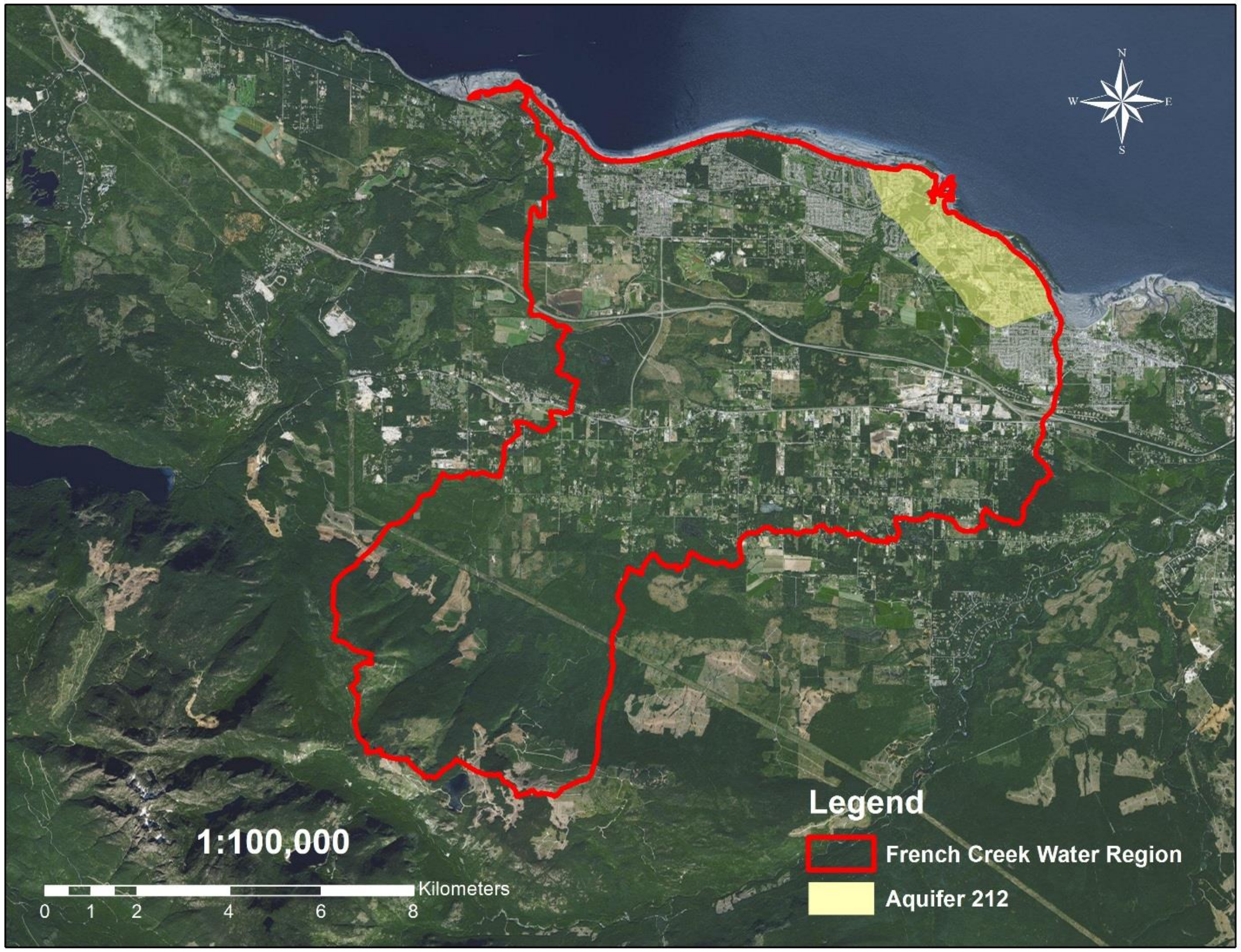

Figure 9: Aquifer 212
Source: Imagery obtained from Esri's online basemap database.

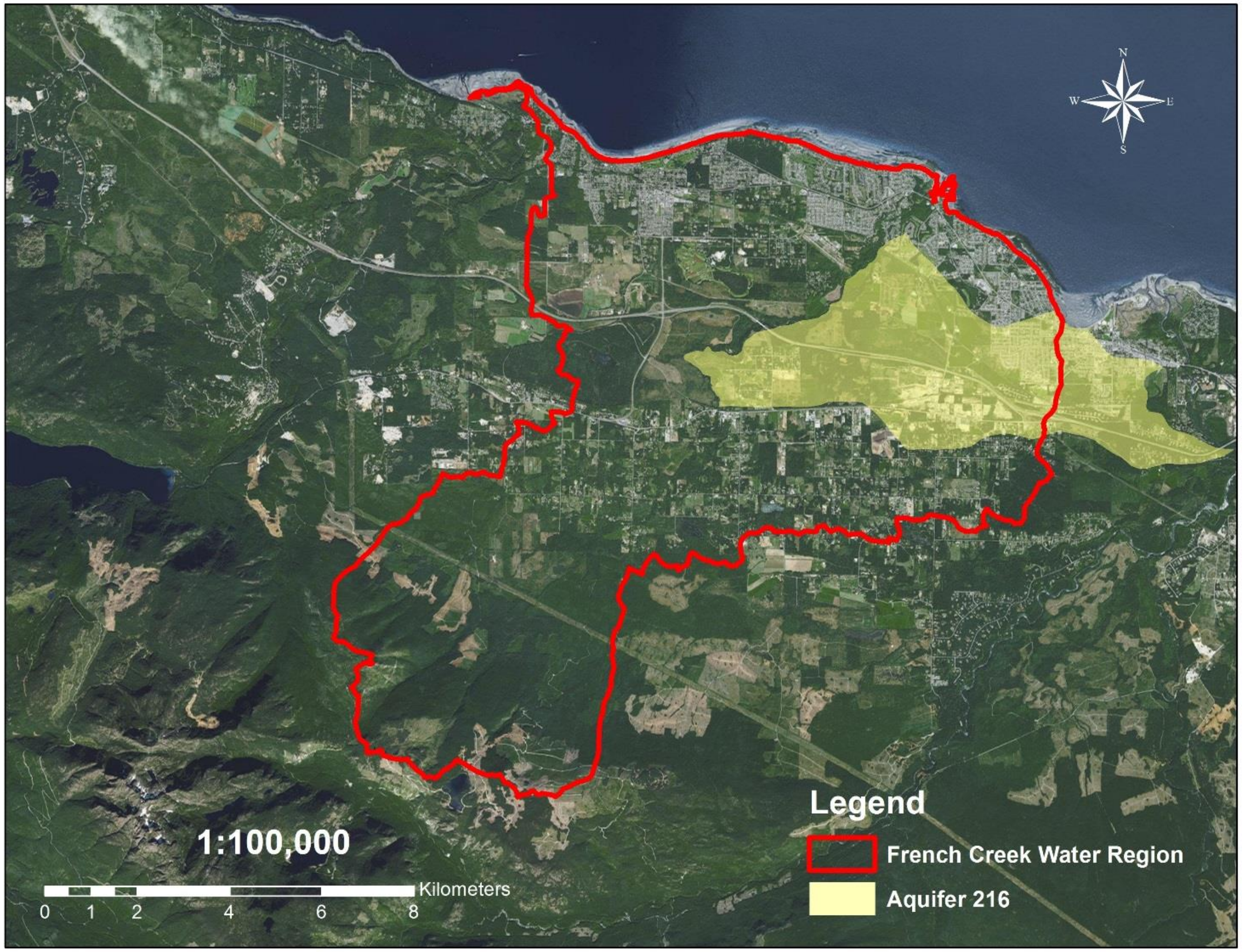

Figure 10: Aquifer 216
Source: Imagery obtained from Esri's online basemap database.

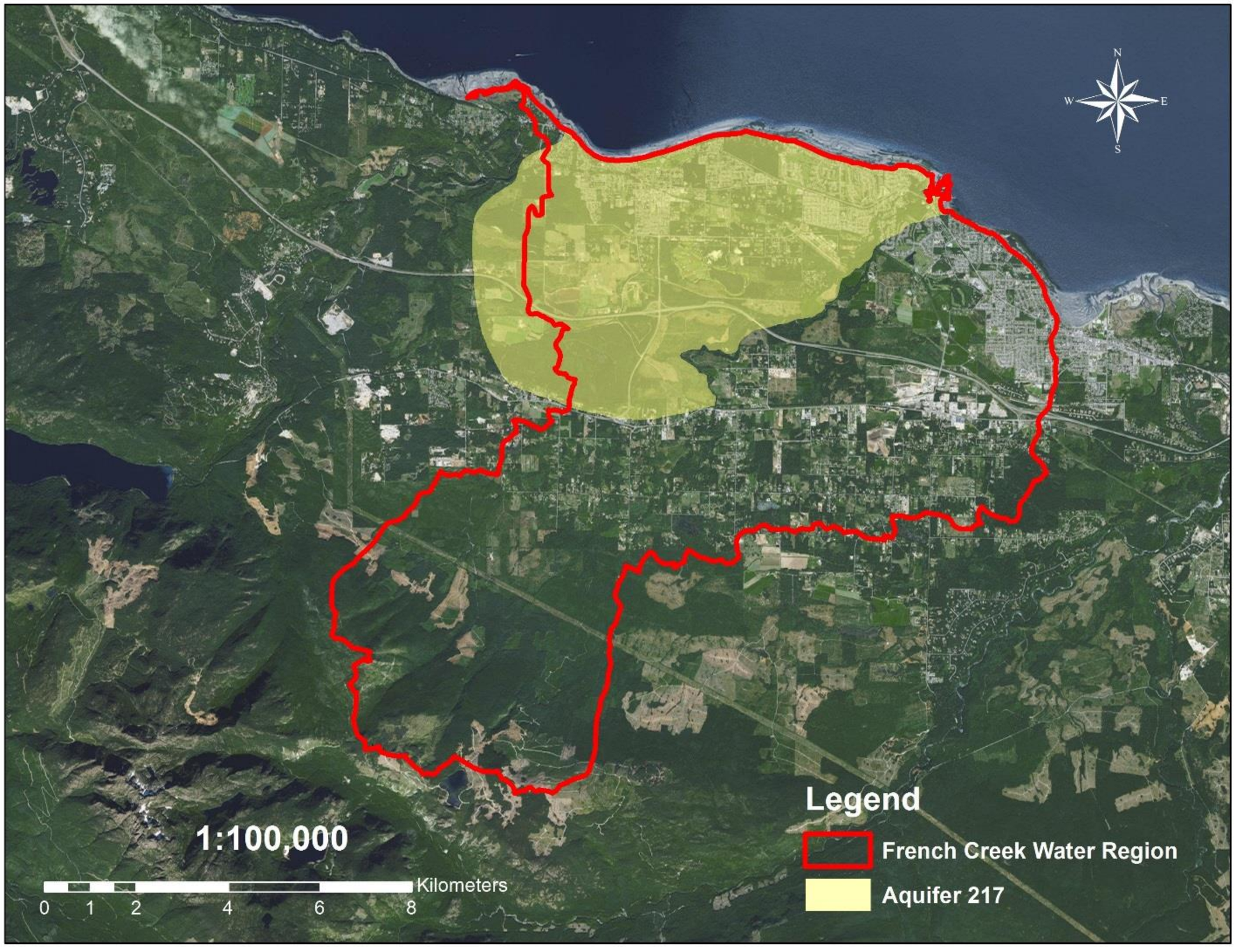

Figure 11: Aquifer 217
Source: Imagery obtained from Esri's online basemap database.

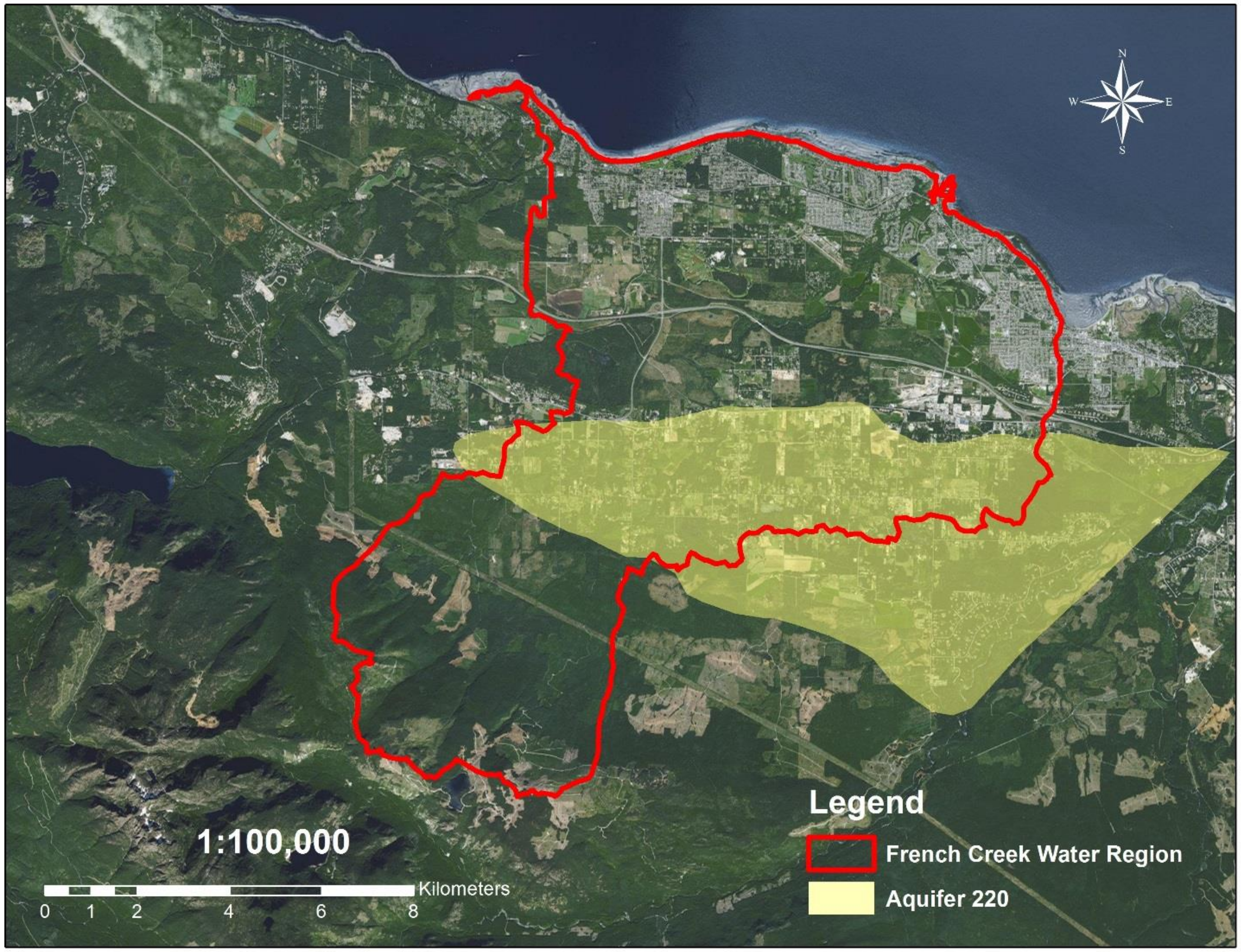

Figure 12: Aquifer 220
Source: Imagery obtained from Esri's online basemap database.