Wetland Classification and Geologic Assessment Report:

South Wellington to Nanoose Water Region (WR5-SW-N)

Prepared for:

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

Prepared by:

Mount Arrowsmith Biosphere Region Research Institute

Acknowledgments

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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 have been 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 South Wellington to Nanoose water region based on their classification; 3) evaluate the hydrogeological position to gain a better understanding about water storage, discharge, and potential flow pathways at each site; and 4) identify priority wetland sites that have potential hydraulic connection 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 and based on localized conditions. 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 South Wellington to Nanoose water region (SW-NWR) is the fifth water region (WR5) and is located within the Regional District of Nanaimo (RDN) on Vancouver Island, British Columbia (Figure 1). Geographically, the RDN encompasses four member municipalities: City of Nanaimo, District of Lantzville, City of Parksville, and Town of Qualicum Beach. Geographically, the RDN stretches along the coast from Deep Bay to Cassidy, extends into the headwaters of the Cameron River, and reaches the Mount Arrowsmith Massif Regional Park (RDN Water Budget, 2016). The RDN is home to more than 140,000 people and includes seven major basins, each composed of several watersheds and sub-watersheds (RDN, 2017). These seven major basins will be referred to as water regions for the purpose of this report and include: Big Qualicum water region, Little Qualicum water region, French Creek water region, Englishman River water region, South Wellington to Nanoose water region, Cedar Yellow-Point water region and Gabriola water region. WR5 contains 1,685 water wells, which is the second greatest number of recorded wells across the seven RDN water regions (RDN Water Budget, 2016). To date, a total of 6 wetlands have been mapped within the SW-NWR. The purpose of this report is to discuss infield observations and classifications of wetlands that were mapped within WR5-SW-N, 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, the physiography, and regional geology of the South Wellington to Nanoose water region. Increasing our understanding of wetland ecology and geology will be a critical component of the project as we aim to understand how these ecosystems are connected to regional hydrological and hydrogeological processes, and more specifically, groundwater recharge.

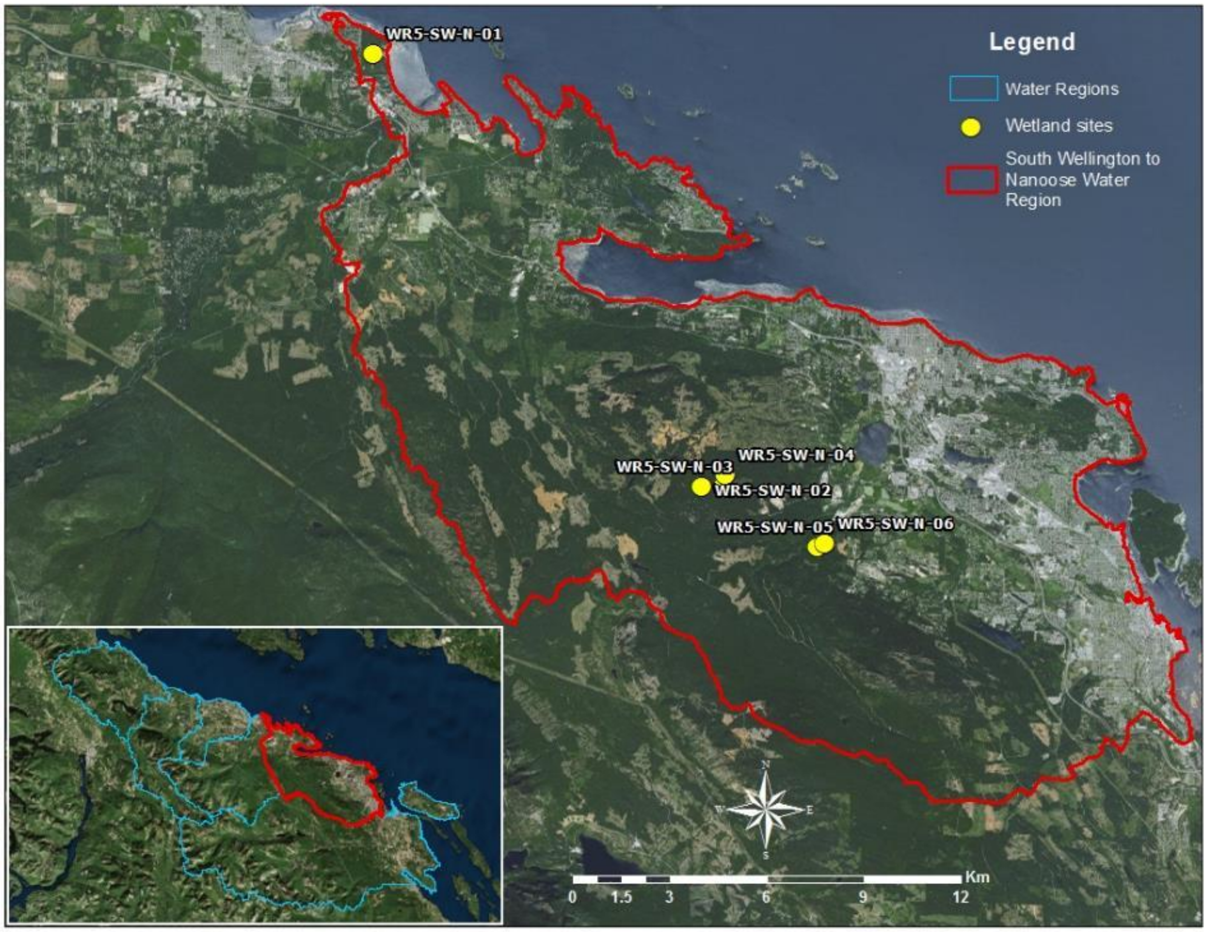

Figure 1: Wetland Sites within the South Wellington to Nanoose Water Region
Source: Imagery obtained from Esri's online basemap database; water region perimeters obtained from the Regional District of Nanaimo.

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 that 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 South Wellington to Nanoose water region is split into two sub regions: Nanoose (5a) and Lantzville to South Wellington (5b). Together, this water region encompasses an area of 315 km^2, making it the third largest in the RDN. SW-NWR has a dense population with the City of Nanaimo, District of Lantzville, and the Nanoose Peninsula residing within the boundary. There are seventeen small subwatersheds and six major watersheds within SW-NWR; the six major watersheds are Craig Creek, Nanoose Creek, Bonnell Creek, Millstone River, Chase River, and Beck Creek (Waterline Resources Inc., 2013). Mount Benson, the highest peak in the region with an elevation of 1,023 m, is the headwaters to the major watersheds in the region, which flow generally north and south (Waterline Resources Inc., 2013). Similar to the rest of the RDN, cool, wet winters and mild, dry summers characterize WR5's climate. There are two Environment Canada weather stations in Nanaimo, both at low elevations. The stations are located at the Nanaimo City Works Yard and Departure Bay, they have reported the average total annual precipitation to be 937.8 mm and 1,140.9 mm, respectively (Waterline Resources Inc., 2013).

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 Lowland, is typically underlain by upper Cretaceous sedimentary, 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 3-9 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 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, it 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 (Bednarski, 2015). They consist 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 was 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 South Wellington Water Region Study Sites

4.1 Coastal Lowlands of South Wellington-Nanoose

For the purpose of this study, the Coastal Lowlands will be used to describe regions that fall within the marine limit, which was the maximum sea level during the last glacial period. The marine limit encompasses sites that are at elevations of 0 to 200 m above sea level. It was through research conducted within the Nanaimo Lowlands study area, from Deep Bay to Nanoose, that this boundary was determined (Bednarski, 2015). It is crucial to note that the Coastal Lowlands are not to be used interchangeably with the Nanaimo Lowlands, which refers a geologic area of low relief that is 10 km wide and 150 km long, running along the southeastern coast of Vancouver Island (Beniot, et al., 2015). The Coastal Lowlands fall within the Nanaimo Lowlands boundaries but also extend beyond the study area boundaries. Based on our understanding of the surficial geology research conducted by Bednarski (2015), wetlands that are 200 metres above sea level or greater are not within the marine limit and are therefore not within the Coastal Lowland region for this the purpose of this study. To date, only one wetland has been mapped in the Coastal Lowlands, within the SW-NWR; it is located within an area of relatively flat topography and is less than 0.5 km inland of Rathtrevor Beach Provincial Park.

4.1.1 Surficial Materials of the Coastal Lowlands

The marine limit, approximately 200m above sea level and represented by the red line in Figure 2, is the most influential property controlling the distribution of surficial deposits in the SW-NWR. Extensive glaciomarine sediments exist below the marine limit and have a highly variable extent. 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. Regions that are located proximal to the coast typically have Salish sediments that are from modern marine processes. Well 55857, near Rathtrevor Provincial Park, show sand and gravel deposits extending from 0 to 22 m, which are likely Quadra Sands in origin (Ministry of Environment, 2017). In most areas along the coast, glaciomarine deposits were eroded and Salish sediments sit directly on bedrock (Ministry of Environment, 2017).

In Nanoose, moving inland, drilling data from wells 67171 and 44442 show that glaciomarine sediments are variable in terms of thickness and sediment size. Well 44442 hits bedrock nearly immediately, showing that the glaciomarine cover in this area is thin as a result of erosion from post glacial processes. In contrast, well 67171, has a 17 m thick layer of glaciomarine sediment that mantles a sand and gravel aquifer, extending from 26 to 36 metres. Deposits that are proximal to primary watercourses, such as the Englishman River and smaller tributaries, have an abundance of alluvial terrace, fan, floodplain, and delta terrace deposits (Bednarski, 2015). Surrounding the channel margins are glaciofluvial delta and kame terrace deposits (Bednarski, 2015). Quadra Sands and till blankets are exposed extensively along channel margins due to river-incision (Bednarski, 2015). These deposits can be seen in Figure 2 and are represented by the orange and yellow regions.

Overall, the surficial geology of the SW-NWR can be subdivided into three 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, this will be discussed below in further detail. Further, 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.

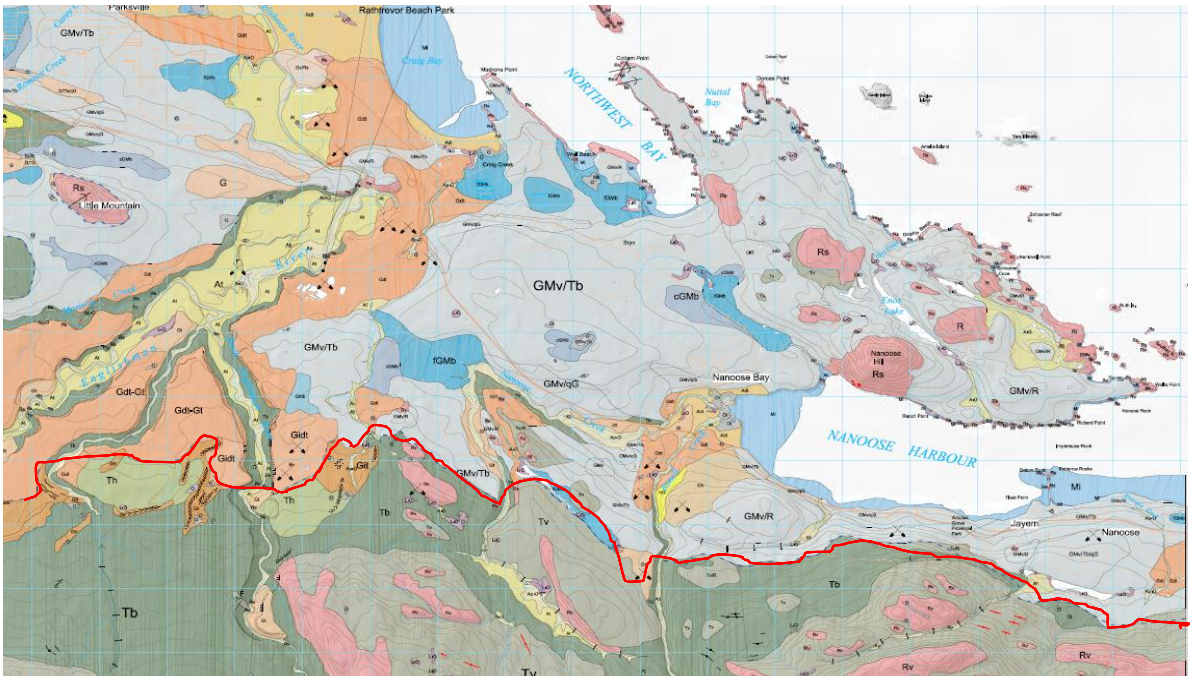

Figure 2: Detailed surficial geology map, captures part of the South Wellington to Nanoose water region. Yellow units represent fluvial sediments, organge units represent glaciofluvial sediments; blue units represent marine and glaciomarine sediments and green represents till. The red line represents the marine limit.
Source: Bednarski, 2015

4.1.2 WR5-SW-N-01 Wetland Observations & Classification

WR5-SW-N-01 was mapped on July 6, 2016 and is located within Rathtrevor Beach Provincial Park, at 3 m above sea level. The study area resides within the Coastal Douglas Fir moist maritime (CDFmm) subzone as determine by the Biogeoclimatic Ecosystem Classification (BEC) system; this BEC zone hosts a moderate climate, where summers are warm and dry, and winters are cool and wet (MacKenzie & Moran, 2004). Additionally, this BEC zone encompasses ecosystems with uniform macroclimates, as well as a characteristic mosaic of vegetation, soils, and particular animal life that reflect the climate (MacKenzie & Moran, 2004). Using ArcMap software and perimeter data collected using a handheld GPS unit, the wetland is approximated to be 322 m long, 29 m wide, and 1.3 hectares (Figure 3). The hydrogeomorphic position of the wetland is in a shallow depression, located in an area of flat topography.

The wetland was classified as a dominant marsh with a secondary surrounding forested swamp. Central sections of the site experience significant changes in water levels due to seasonal changes. Vegetation within the wetland was dominated by lyngsby sedge (*Carex lyngbyei*), Pacific crab apple (*Malus fusca*), and baldhip rose (*Rosa gymnocarpa*). Within the central marsh zone of the wetland, algal mats dominated and invasive yellow flag iris (*Iris pseudacorus*) was observed. Transition zones within the wetland were dictated by changes in soil and vegetation. Three soil samples were observed: (1) at the first site the soil texture was sandy-loamy with an organic layer from 0 to 7 cm, whereas from 7 to 12 cm the sample consisted almost entirely of sand; (2) the second sample consisted of a 4 cm thick rich, dark, organic soil, which transitioned into a thick sand layer with minimal clay; (3) sample three was highly organic and fibrous from 0 to 7 cm, followed by a significant increase in clay content from 7 to 13 cm. The soils of the Rathtrevor Beach Provincial Park are Salish sands and fine gravels that have been reworked by modern marine processes (Bednarski, 2015). The soils are generally well drained, although some locations are saturated from a high water table (Province of British Columbia, 1987).

The study site appears to be a functioning wetland that may be at risk to sea water intrusion, as well as pollution from runoff. The inflow appears on the south-west side of the wetland and a stable man-made culvert acts as an outflow on the north-east side. Based on observations during several site visits, the wetland appears to be dry seasonally and has varying water depths throughout the year. During our field study, the central marsh area contained less than five percent open water. This was likely due to seasonal fluctuations and a lack of precipitation events.

WR5-SW-N-01 is situated on top of aquifers 214, 219, and 221, which are highly vulnerable to seawater intrusion. Aquifer 214 (Appendix B, Figure 9) is situated in fractured bedrock of the Nanaimo Group, and is considered to be moderately vulnerable. The quantity concern for this aquifer entails dry wells for surrounding residents, whereas quality concerns include elevated manganese and iron (Lowen, 2010). Productivity of the aquifer is classified as low and there are only 28 reported drilled wells. Aquifer 219 (Appendix B, Figure 10) is moderately developed (128 domestic wells) with low vulnerability to pollution from surface sources (Lowen, 2010). The partially confined aquifer is situated within sand and gravel of the Quadra Sands and has no reported quantity or quality concerns (Lowen, 2010). Aquifer 221 (Appendix B, Figure 11) is situated within unconsolidated Salish sediments and is considered highly vulnerable to pollution from surface sources. This unconfined aquifer hasn't had any quantity or quality concerns but the depth of water is extremely shallow, leaving it susceptible to contamination. See Table 1 in Appendix A for other parameters and the classification summary.

Figure 3: WR5-SW-N-01
Source: Imagery obtained from Esri's online basemap database.

4.2 Uplands Region of South Wellington-Nanoose

For the purpose of this study the uplands region of the SW-NWR will be used to describe regions that extend above the marine limit from elevations of 200 m to 1,023 m, the peak of Mount Benson. Study sites are located between 221 m and 386 m above sea level (Appendix A, Table 1). To date, five wetlands have been mapped in the uplands region of the SW-NWR and are located in an area of irregular topography with steep slopes, hills, and depressions near Benson Creek Falls Regional Park and Benson Meadows. These wetland sites are situated in the Coastal Western Hemlock very dry maritime subzone (CWHxm) as classified by the Biogeoclimatic Ecosystem Classification (BEC) system. The climate of a

CWHxm subzone has relatively warm, dry summers and moist, mild winters with little snowfall. Growing seasons are often long and there are only minor water deficits (Green & Klinka, 1994, p. 47).

4.2.1 Geology of the South Wellington to Nanoose Uplands

Above the marine limit is defined as the topographic high area, which is made up of till, bedrock, and glaciofluvial deposits. Surficial materials within the uplands region are largely Vashon Drift in origin and consist of course 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 SW-NWR, minimal drilling information is available to interpret the sedimentology of the entire region. In the field, it was common to see exposed bedrock outcrops that were granodioritic intrusive rocks of the Jurassic Island Plutonic suite. In other sections bedrock was 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 WR5-SW-N-02 Wetland Observations & Classification

WR5-SW-N-02 was mapped on July 4, 2017 and is located at an elevation of 386 m above sea level, in an undeveloped area that is primarily used for forest harvesting, research, as well as recreational trail use. The wetland size is approximately 80 m long and 45 m; using ArcMap software, it was approximated that the wetland was 0.24 ha (Figure 4). The wetland was classified as a swamp that is dominated by hardhack (*Spiraea douglasii*). The study site is a natural wetland positioned within a shallow depression. There was no water present in the wetland during the site visit; therefore, hydrological measurements for temperature, pH, turbidity, water depth, on-site colour, and clarity were not recorded. Soil samples were taken along transect lines in the wetland. The profile of the sample showed a distinct 15 cm thick layer of organics that were moderately decomposed with distinct plant fibers and woody debris. Soils within the wetland were red in colour indicating high levels of iron within the deposits. Surficial materials surrounding the wetland consisted of sands and silt. See Table 1 in Appendix A for other wetland parameters and the classification summary.

WR5-SW-N-02 is located in an area where aquifers are not mapped. The nearest mapped aquifer to the wetland site is aquifer 213 (Figure 16), which is a bedrock aquifer that shows moderate responses to precipitation events, indicating higher than typical recharge rates (GW Solutions, 2017). Groundwater extraction rates are not well known for this system but vulnerability rates are low. Further subsurface investigations will need to be carried out to better understand the surface – groundwater interactions in the area.

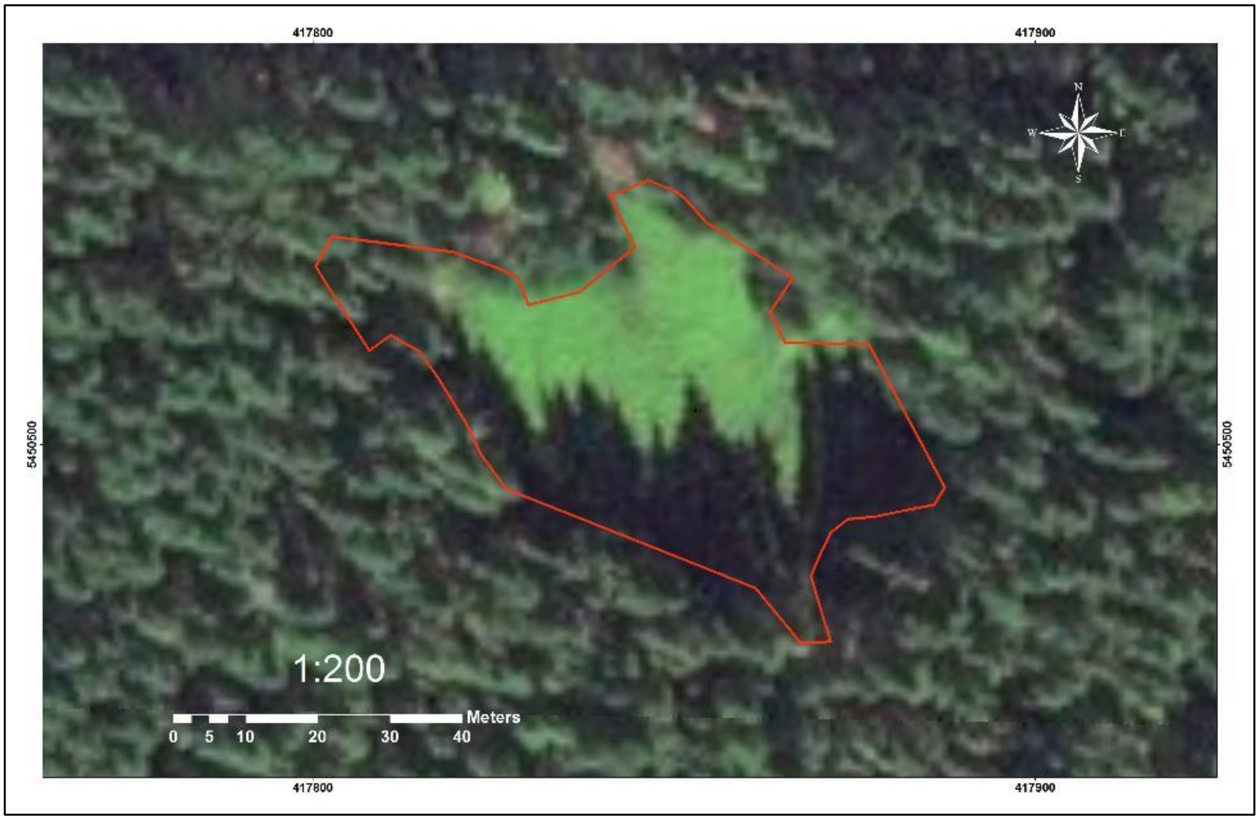

Figure 4: WR5-SW-N-02
Source: Imagery obtained from Esri's online basemap database.

4.2.3 WR5-SW-N-03 Wetland Observations & Classification

The third wetland study site, WR5-SW-N-03, was mapped by student researchers on June 29, 2017. This site is a natural wetland, situated within a topographic depression at an elevation of 383 m above sea level. ArcMap software was used to approximate the wetland to be 100 m long, 60 m wide, and 0.23 ha (Figure 5). The wetland was mapped and classified as a swamp, dominated by hardhack; it was surrounded by a forest dominated by a canopy of shore pine (*Pinus contorta*) and Douglas fir (*Pseudotsuga menziesii*), as well as a dense understory of salal (*Gaultheria shallon*). The wetland appears to be functioning with no signs of impact or disturbance from surrounding forestry activity or nearby recreational trail use. Within the wetland there is no central distribution of standing water; however, there was an inflow and an outflow of water visibly flowing through the wetland. The wetland overflow stability was determined to be stable with no signs of erosion or evidence of recent flooding. Surface water measurements were taken where hardhack was dominating, water temperature was 14°C and pH was 5.5. Further, the on-site clarity of the water sample was clear and colourless. Soils observed in the center of the wetland contained silt and clay with moderate decomposition as plant structures were becoming indistinct. The wetland had a thick layer of peat, greater than 1 m in thickness. WR5-SW-N-03 was also located in an area where aquifers have not been mapped. The nearest mapped aquifer to the wetland site was also aquifer 213 (Figure 12). Overall, the system appeared to be a healthy functioning system, more data on the wetland site can be seen in Appendix A, Table 1.

Figure 5: WR5-SW-N-03
Source: Imagery obtained from Esri's online basemap database.

4.2.4 WR5-SW-N-04 Wetland Observations & Classification

The fourth wetland site, WR5-SW-N-04, was mapped on June 27, 2017 and is located at an elevation of 374 m above sea level. The size of the wetland is 0.15 ha and is 94 m long and 65 m wide, which was approximated using ArcMap software (Figure 6). The wetland is classified as a swamp and is largely dominated by hardhack, red alder (*Alnus rubra*), and slough sedge (*Carex obnupta*). The wetland's hydrogeomorphic position is within a shallow depression, surrounded by sand and gravel slopes. Pooling water was observed within areas where hardhack dominated; surface water temperatures were 13°C with a pH of 6.0. There were no visible inflows or outflows at this site. Wetland soils were dominated by clay with an organic layer that was approximately 10 cm thick and almost completely decomposed with nearly unrecognizable plant structures throughout. The wetland appears to be functioning and no impacts from surrounding land use were observed with regards to erosion or water levels. Based on observations during the site visit, it appears this wetland dries seasonally, in the summer months. The wetland site is also located in a region where aquifers are unmapped and is proximal to aquifer 213. See Table 1 in Appendix A for other wetland parameters and the classification summary.

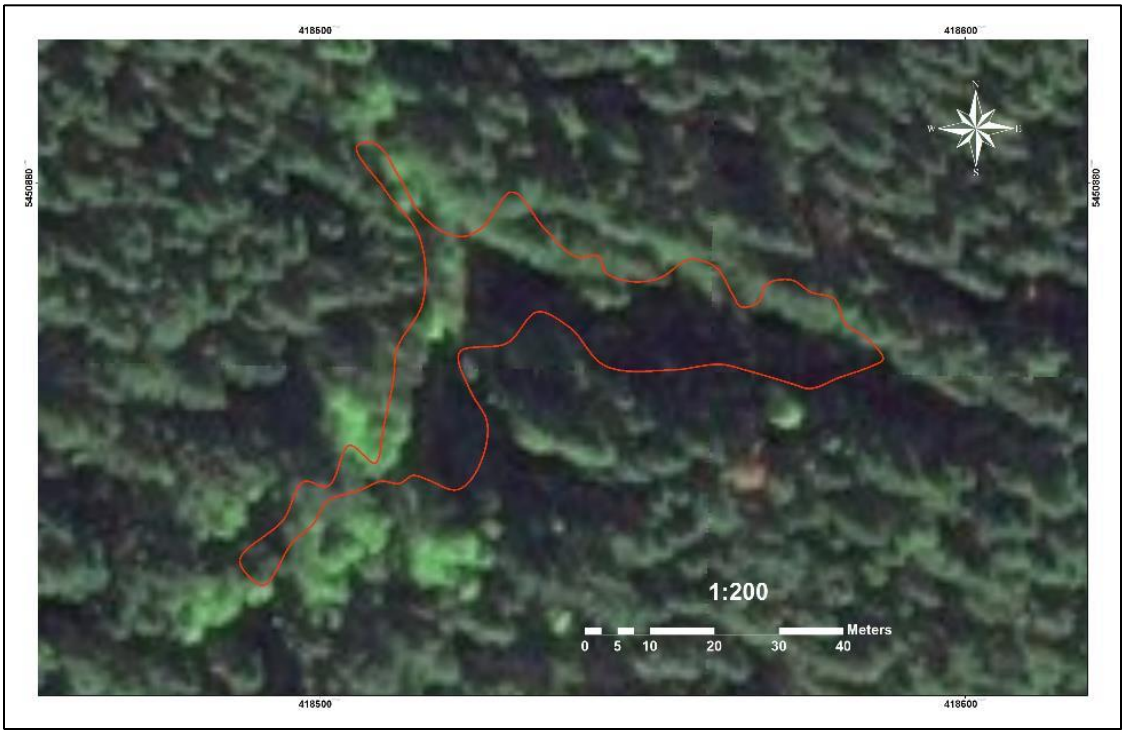

Figure 6: WR5-SW-N-04
Source: Imagery obtained from Esri's online basemap database.

4.2.5 WR5-SW-N-05 Wetland Observations & Classification

WR5-SW-N-05 was mapped on July 13, 2017, it is 230 m above sea level, located in a depression that is nestled topographically between steep slopes. The size of the wetland is approximately 105 m long, 25 m wide, and 0.34 ha (Figure 7). Since Benson Creek Falls Regional Park is quite proximal to the wetland, recreational land use dominates the surrounding area. Other land uses in the area include forestry research and harvesting, as well as residential development. WR5-SW-N-05 appears to be a natural system that is situated adjacent to sand and gravel slopes; it was classified dominantly as a swamp and is surrounded by a forest riparian area. Overflow structure stability appeared to be stable as the wetland is situated within a depression and was surrounded by banks on the south, north, and eastern sides. The wetland appears to be functioning with a large central section of standing water, the centre of the wetland had approximately 50 to 75 percent open water with depths of 40 cm or greater; this area also contained emergent vegetation. Dominant species within the wetland were beaked sedge *(Carex rostrata)*, hardhack, and Pacific willow *(Salix lucidida).* The riparian forest surrounding the wetland was dominated by Douglas fir, Western red cedar (*Thuja plicata*), and salal.

In-field observations determined there is one inflow on the western side of the swamp, it is a tributary from Benson Creek. Water samples were taken from the swamp's open water and on-site surface water clarity was very turbid and yellow-brown in colour. The yellow-brown colour is an indicator of the wetland's soil nutrient regime, suggesting relatively poor nutrient conditions. The water sample was 17°C and had a pH of 6.8. Soil samples had very strong decomposition and any remnants of plant material were identified to be resistant to decomposition, such as roots and woody debris. Plant structures were very indistinct and below the organic layer the sample contained a high concentration of clay and silt, acting as a lens beneath the bed of the wetland.

Figure 7: WR5-SW-N-05
Source: Imagery obtained from Esri's online basemap database.

WR5-SW-N-05 is located in an area where aquifers are not mapped. The nearest mapped aquifer to the wetland site is aquifer 211 (Figure 13), which is a bedrock aquifer that has been experiencing declining water rates (GW Solutions, 2017). Aquifer 167, an unconsolidated sand and gravel aquifer, overlies aquifer 211. This system was evaluated to have a low vulnerability but showed very rapid responses from precipitation events and is believed to be directly connected to Benson Creek and the Millstone River (GW Solutions, 2017). The connection between aquifer 211 and 167 is unknown but further subsurface investigations will need to be conducted by the RDN to determine any relationship between the two systems.

4.2.6 WR5-SW-N-06 Wetland Observations & Classification

Wetland WR5-SW-N-06 was mapped on July 25, 2017 and is located 221 m above sea level, situated within a depression adjacent to a forest service road and recreational park trails for Benson Creek Falls Regional Park. The wetland size is approximately 50 m long, 30 m wide, and 0.11 ha (Figure 8). WR5-SW-N-06 was classified as a swamp that is largely dominated by hardhack, and slough sedge and is surrounded by a second growth forest dominated by Western red cedar, shore pine, with a thick understory of salal. During the time of the site visit, there was no sign of standing water within the wetland; therefore, surface hydrology data was not able to be collected. Soil samples were dominated by clay and silt, with a thin layer of organics on top. The organic layer had very weak decomposition and most plant structures remained distinct. Further samples within the study site revealed a layer of peat that was approximately 15 cm deep. Unfortunately the wetland was located in an area where aquifers have not been mapped, but is most proximal to aquifers 211 and 167. Overall, the system was healthy and functioning.

Figure 8: WR5-SW-N-06
Source: Imagery obtained from Esri’s online basemap database.

5.0 Discussion

5.1 Hydrostratigraphy

The SW-NWR study area 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 (Hamblin, 2012). The main bedrock units observed in the area are either Karmusten Basalt or Nanaimo Group in origin; these bedrock units include: 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, like aquifer 211 that is typically without fractures, acting as aquitards due to low permeability and porosity.

Surficial sediments in the SW-NWR reflect the glacial and post glacial processes that took place during the Quaternary period. During times of isostatic uplift, glaciofluvial processes dominated the region, resulting in the deposition of coarse sand and gravel units that act as modern day aquifers (Bednarski, 2015). 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 (Bednarski, 2015). Outwash deposits were deposited intermittently during postglacial isostatic uplift and sea level rise (Bednarski, 2015). 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 (Bednarski, 2015). 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 fluvial systems likely represent glaciofluvial and fluvial processes, as thick packages of sand and gravel are seen on either side of rivers with sections of exposed fractured bedrock. 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 and marshes were the two distinct wetland systems identified within the SW-NWR. Five of the six study sites within WR5 were classified as dominant swamp wetland systems. Swamp wetland systems are characterized by a high cover of tall shrubs and trees, as well as a well-developed herb layer (MacKenzie & Moran, 2004). There are typically two distinct types of swamps found in British Columbia, characterized by either: 1) tall shrub physiognomy, or 2) being forested (MacKenzie & Moran, 2004). Wetlands characterized by tall shrub species are often related to fen ecosystems, but are distinguished by vigorous shrub growth; in these sections the moss layer is poorly developed due to shade and abundant litter. Wetland study sites 02, 03, 04, 05, and 06 within WR5-SW-N were classified as dominant swamp systems with tall shrubby vegetation species, whereas study site 01 was classified as a secondary forested swamp ecosystem with central marsh and shallow water sections. The classification and distinction between these two types of swamps was based on the quantity of water that encouraged vegetation changes. Within the forested swamp study site at WR5-SW-N-01, water was less abundant throughout the year due to seasonal fluctuations and vegetation was dominated by water tolerant tree species. These systems typically had significantly less water available and are commonly associated with wetland ecosystems that are seasonally dry.

Wetland sites 02, 03, 04, and 05 in WR5-SW-N were all located on forest lands and appeared to host an abundant diversity of species and wildlife, including birds, deer, and bears. Fortunately, there were no visible signs of impact or disturbance to the site; however, both WR5-SW-N-03 and WR5-SW-N-04 contained invasive species: daphne (*Daphne odora*) was documented at WR5-SW-N03 along the roadways and trail paths and English holly (*Llex aquifolium*) was found at WR5-SW-N-04. Invasive species management practices may need to be implemented over time. It is recommended that these sites be visited again between late fall and early spring when there is an increase in precipitation throughout the region. It is also possible that over time there may be visible impacts from forestry.

5.3 Recommendations

The purpose of the study was to map and classify wetland systems across the SW-NWR, 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 region 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 SW-NWR. 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 SW-NWR 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 SW-NWR: 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, in total, were mapped and classified for the SW-NWR. 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 groundtruthing 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. As discussed above, it will be very important to move forward with further subsurface investigations to better understand existing hydraulic connections at prioritized sites.

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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
WR5-SW-N-01	49° 19’ 14” N 124° 16’ 13” W	Marsh; secondary shallow water and forested swamp	Pacific crab apple; baldhip rose; lingsby sedge	1.3	3	18	6.3	Organic overlaying sandy loam; transitioning to sand and organic; transitioning to sands to clay mix	219 IIC (9), 214, and 221	Sand and gravel & Bedrock	Unconfined to Partially Confined
WR5-SW-N-02	49° 12’ 06” N 124° 07’ 40” W	Swamp	Hardhack	0.24	386	n/a	n/a	Moderately decomposed organic layer with underlying clay dominated soil	n/a	n/a	n/a
WR5-SW-N-03	49° 12’ 07” N 124° 07’ 08” W	Swamp	Hardhack and shore pine	0.23	383	14	5.5	Mesic peat with moderate decomposition	n/a	n/a	n/a
WR5-SW-N-04	49°12’18” N 124°07’05” W	Swamp	Hardhack, red alder, slough sedge	0.15	374	13	6	10 cm organic layer; underlain by clay dominated soil	n/a	n/a	n/a
WR5-SW-N-05	49° 11’ 08” N 124° 04’ 43” W	Swamp	Beaked sedge, hardhack, pacific willow	0.34	230	17	6.8	Humic with very strong decomposition; largely clay and silt mixture	n/a	n/a	n/a
WR5-SW-N-06	49° 11’ 12” N 124° 04’ 31” W	Swamp	Hardhack, slough sedge, western red-cedar	0.11	221	n/a	n/a	Weak decomposition; clay dominant mixed with silt	n/a	n/a	n/a

Appendix B

Aquifers in the South Wellington-Nanoose Water Region

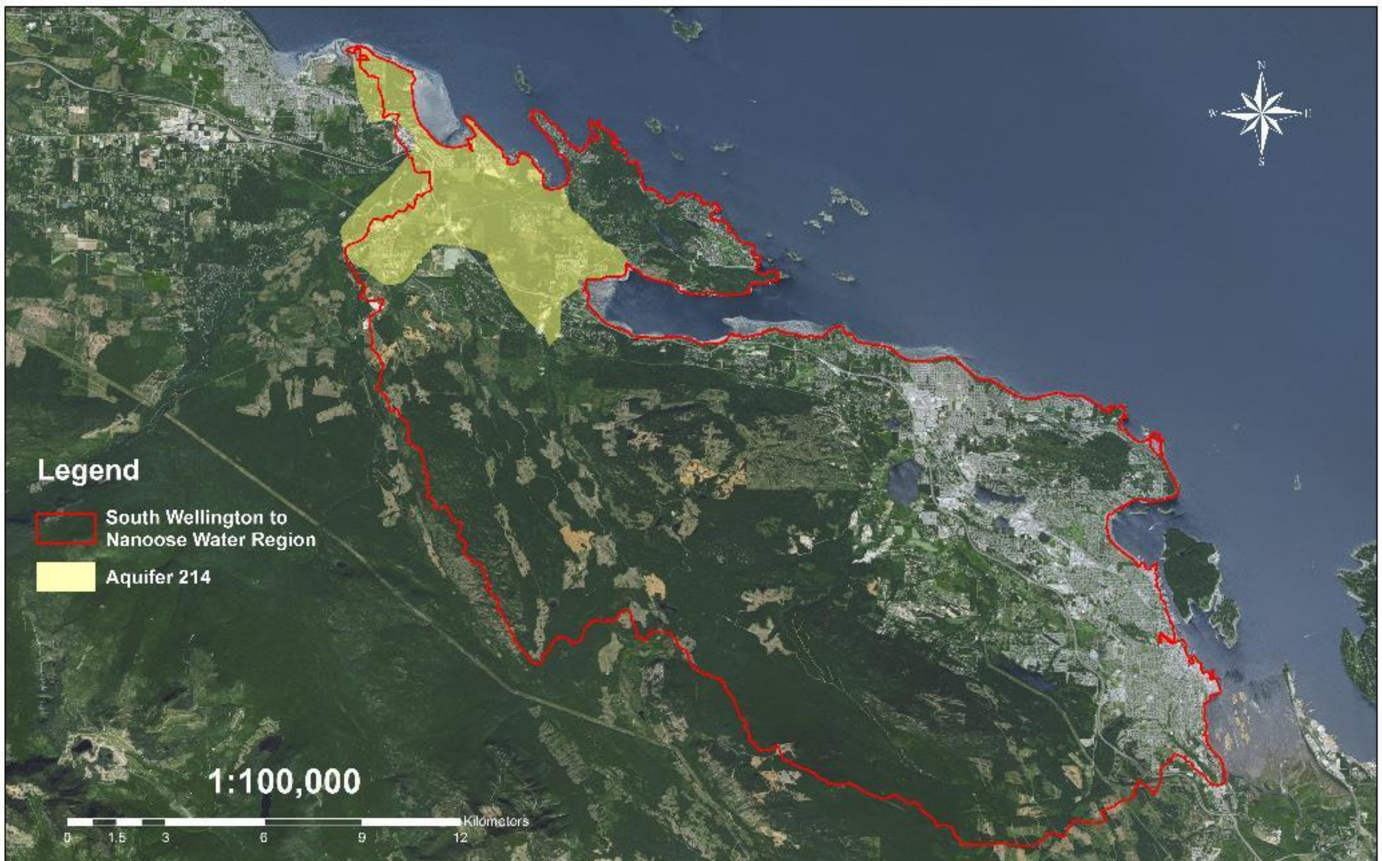

Figure 9: Aquifer 214
Source: Imagery obtained from Esri's online basemap database.

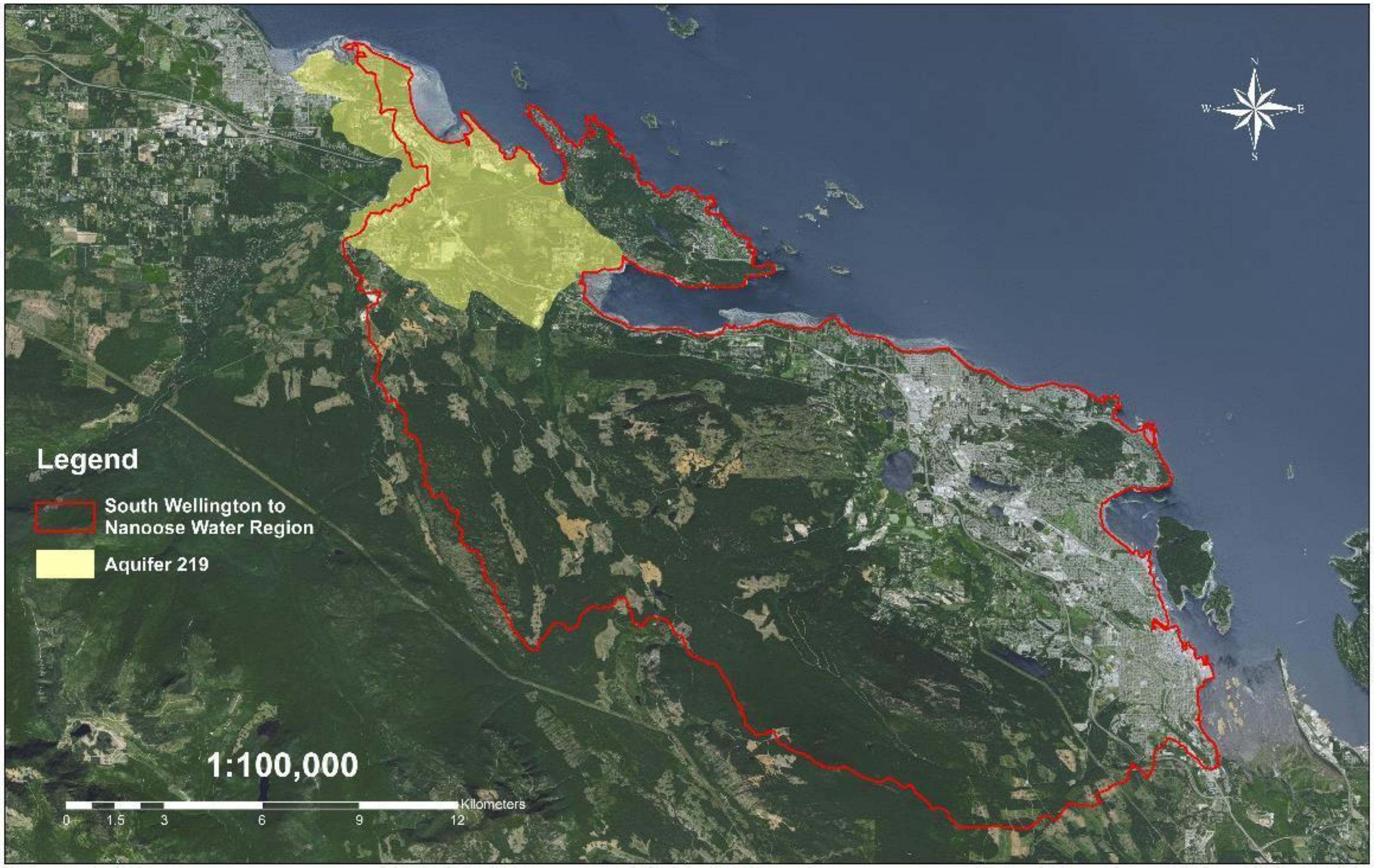

Figure 10: Aquifer 219
Source: Imagery obtained from Esri's online basemap database.

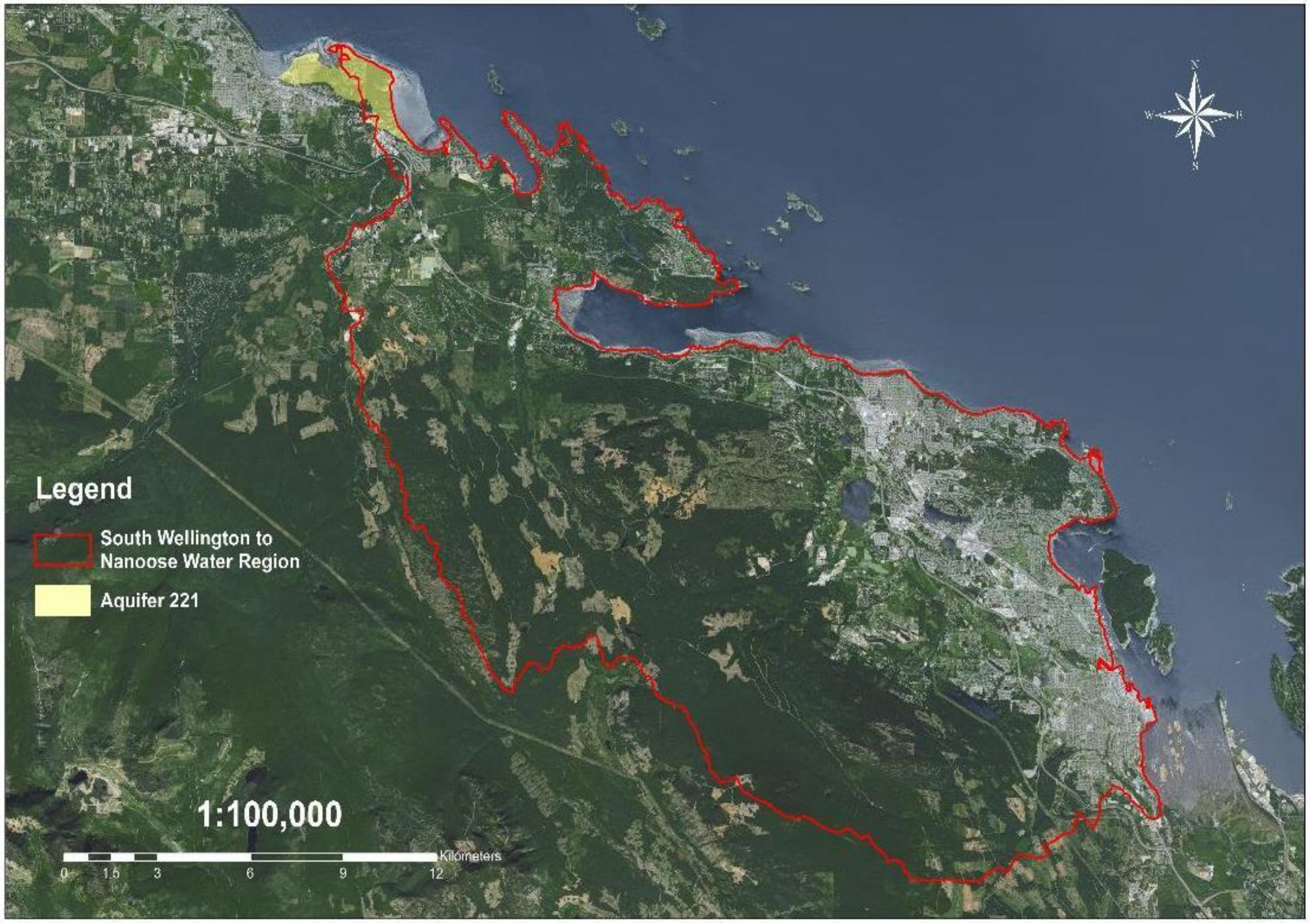

Figure 11: Aquifer 221
Source: Imagery obtained from Esri's online basemap database.

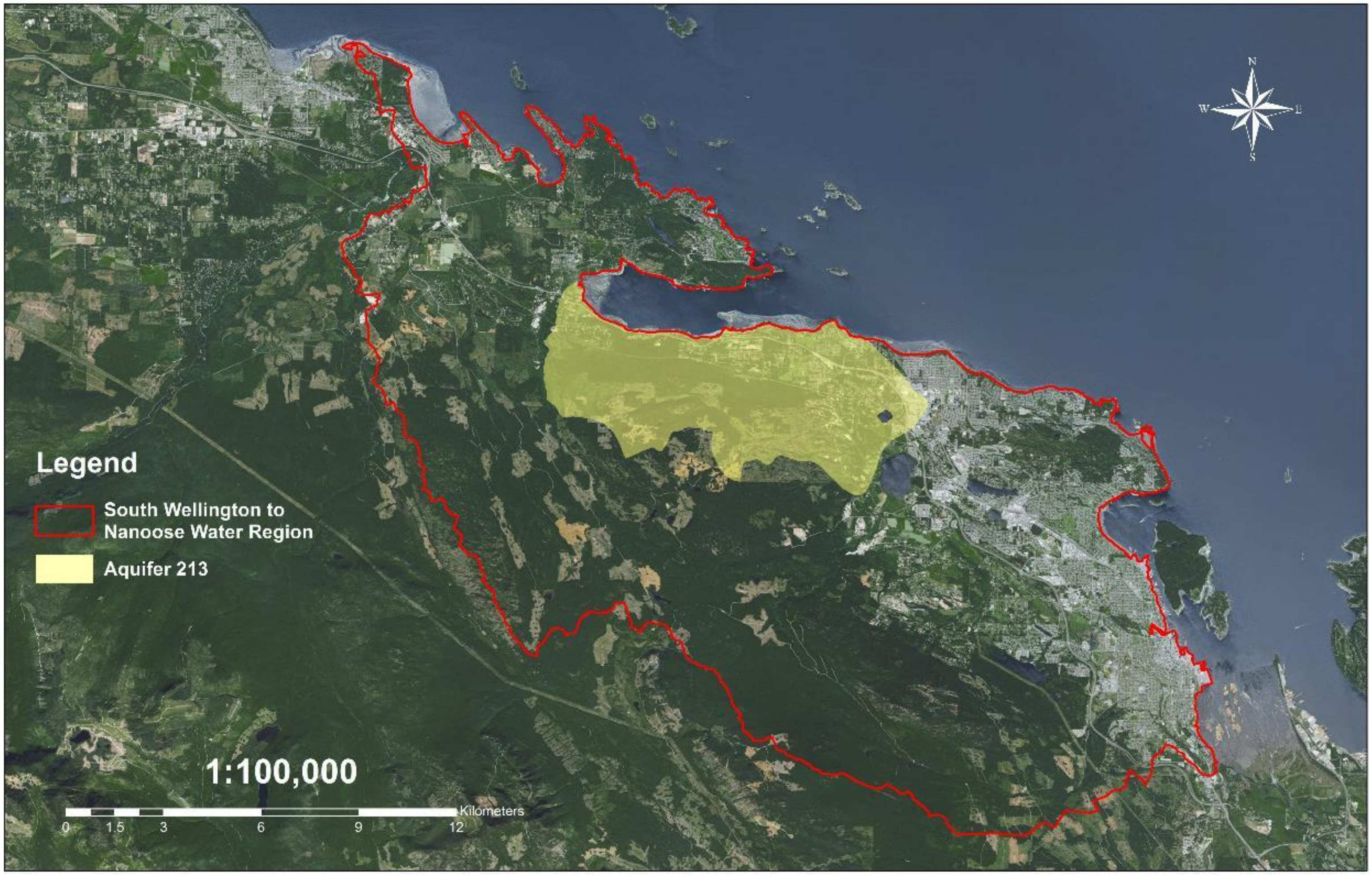

Figure 12: Aquifer 213
Source: Imagery obtained from Esri's online basemap database.

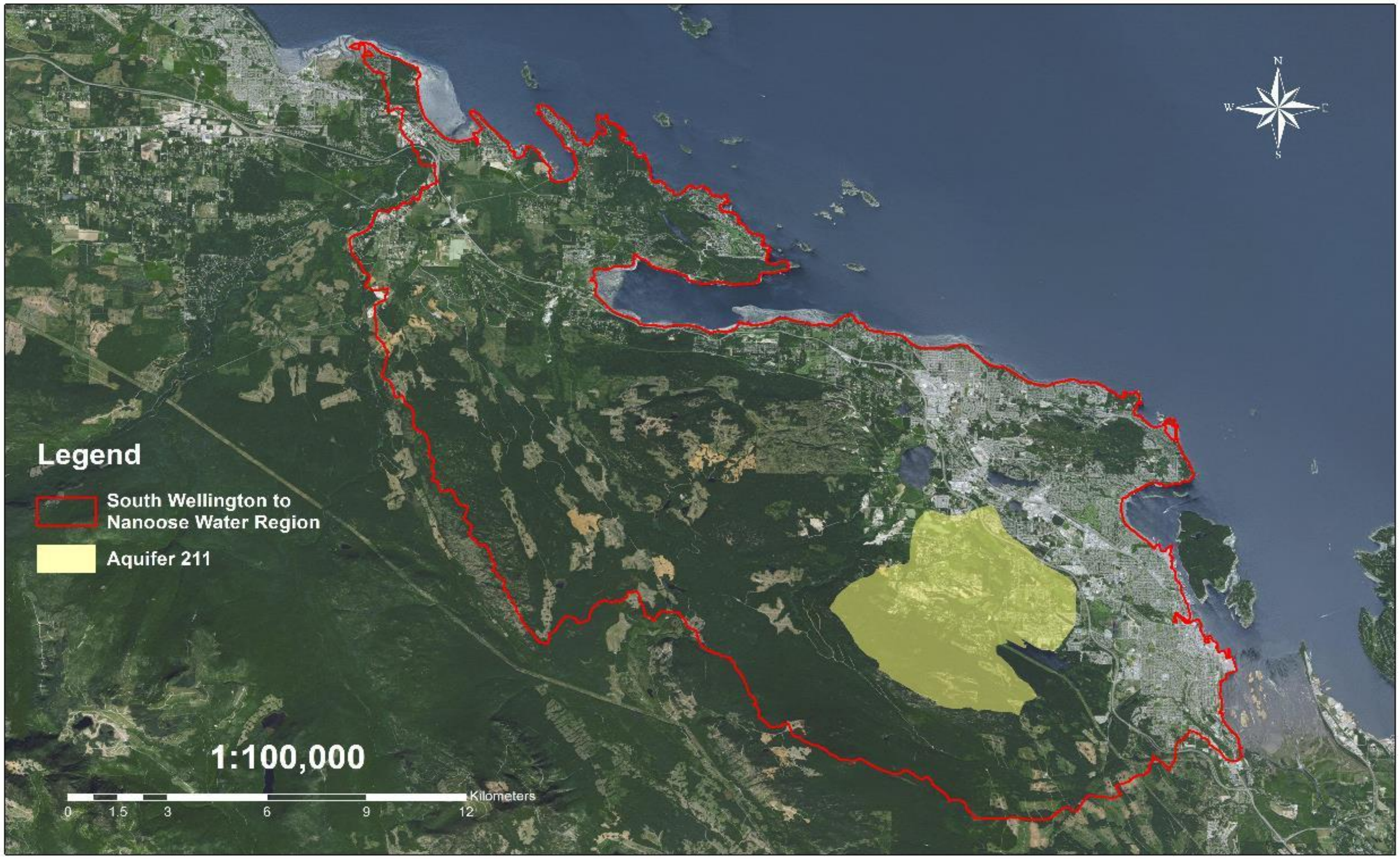

Figure 13: Aquifer 211
Source: Imagery obtained from Esri's online basemap database.

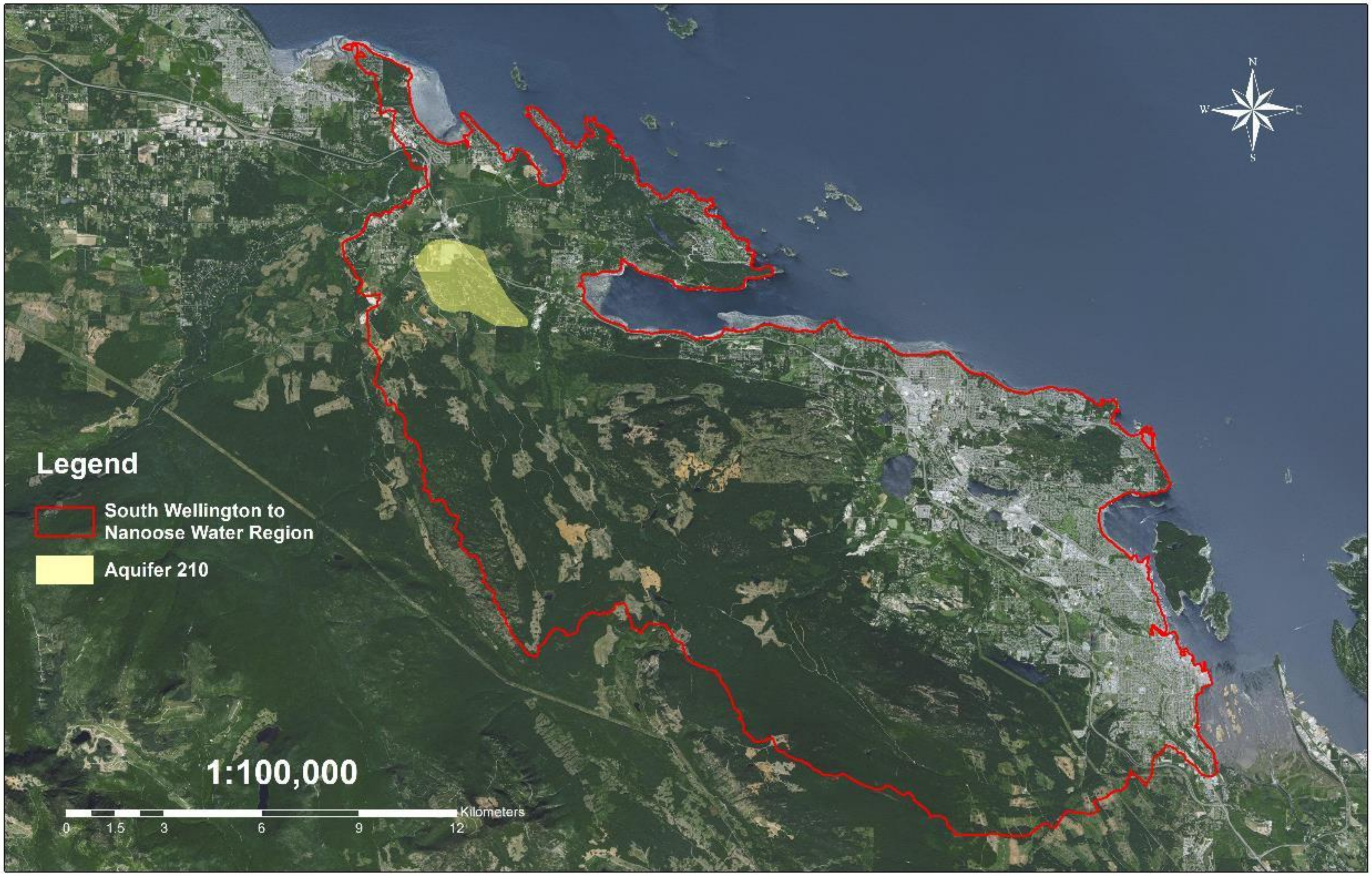

Figure 14: Aquifer 210
Source: Imagery obtained from Esri's online basemap database.