Wetland Classification and Geologic Assessment Report:

Little Qualicum Water Region (WR2-LQ)

Prepared for:

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

Prepared by:

Mount Arrowsmith Biosphere Region Research Institute

United Nations
Educational, Scientific and
Cultural Organization

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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 Little Qualicum water region based their classification; 3) evaluate the hydrogeological position 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. Swamp systems that were located proximal to either fluvial systems or water bodies typically contained central portions of pooled water. These wetlands were situated within Vashon Drift glaciofluvial deposits which are composed of highly porous materials that have high hydraulic conductivities. The hydraulic properties of sediments or bedrock act to connect surface water and groundwater systems. Study sites that weren't situated near fluvial systems or surface water bodies typically had reduced water levels and were situated in Vashon Drift glaciomarine materials. Two study sites were identified as priority sites within the Little Qualicum water region and were chosen based on their unique lithology, hydrology and hydrogeologic position. Both in field observations and aerial photographs revealed that WR2-LQ-02 and WR2-LQ-03 experience significant fluctuations in water levels that should be investigated further. By investigating subsurface conditions through desktop analysis, geophysical surveys, and by installing instrumentation it should be possible to identify any connections between surface water and groundwater systems. 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 Little Qualicum water region (WR2 (LQ)) 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, extending into the headwaters of the Cameron River, and reaching 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. WR2 contains only 387 water wells, making it the third lowest for wells within the seven water regions of the RDN (RDN Water Budget, 2016). Overall, ten wetlands were mapped within the Little Qualicum Water Region. The purpose of this report is to discuss infield observations and classifications of wetlands that were mapped within LQWR2, 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 Little Qualicum Water Region. 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, and more specifically, groundwater recharge.

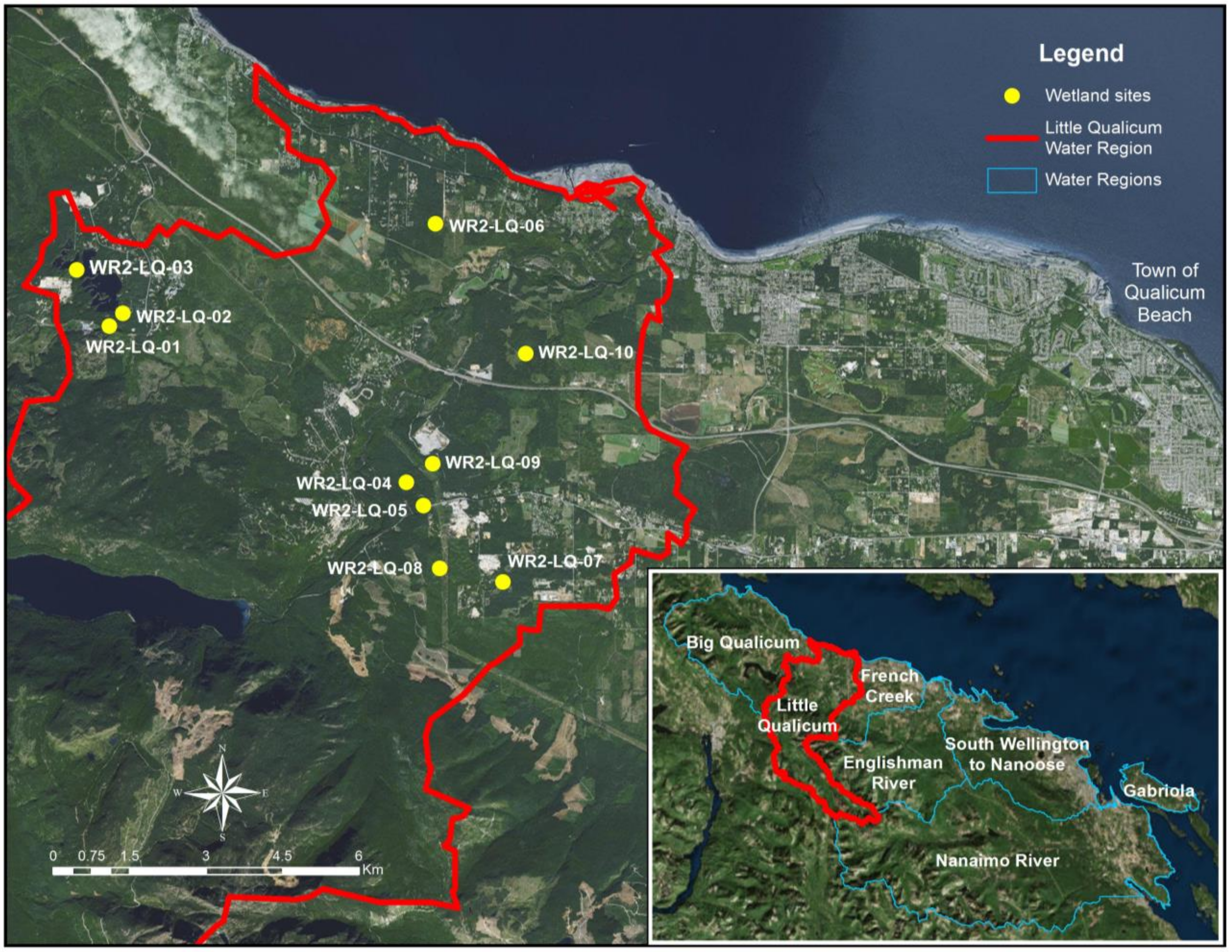

Figure 1: Wetland Sites within the Little Qualicum Water Region
Source: Imagery obtained from Esri’s online basemap database; water region perimeters obtained from the Regional District of Nanaimo.

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 based on 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 to provide 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 in order to determine accessibility to wetland sites.
7. Create field maps of each wetland site with 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, specifically the WetlandKeeper's long form survey (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 centimeter (cm) auger. The number of transects completed at each site varied, it was dictated by the complexity of vegetation at each system. 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 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 to allow for a more representative track that follows the wetland boundary between vegetation zones. The wetland dimensions were also measured by using both the perimeter data and ArcGIS software.

3.0 Regional Description

3.1 *Physiography*

The Little Qualicum Water Region is located within the northern section of the RDN boundaries, slightly south of the Big Qualicum Water Region. The geographically diverse area extends from the Salish Sea to the headwaters of the Cameron River (Waterline Resources Inc., 2013). Half of the Little Qualicum Water Region is set within the Nanaimo lowlands, a 280-kilometer strip of relatively low-lying land that extends along the eastern coast of Vancouver Island. The other half lies within the Vancouver

Island mountain range. As is the case with the rest of the RDN, WR2 experiences cool, wet winters and mild, dry summers; however, the climate differs significantly from the lowlands to the mountainous regions (Waterline Resources Inc., 2013). Low-lying areas receive much less precipitation than the high elevation areas (Waterline Resources Inc., 2013). For example, in the lowlands, the Little Qualicum Hatchery receives on average 1,098.5 mm of precipitation annually, while areas in the mountainous headwaters on Mt. Arrowsmith may receive up to 5,000.0 mm annually (Waterline Resources Inc., 2013). As a result of the variable climate conditions, there are six different biogeoclimatic ecosystem classification (BEC) zones within the Little Qualicum Water region, which include Coastal Douglas Fir moist maritime (CDF mm), Coastal Western Hemlock very dry maritime eastern (CWH xm1), Coastal Western Hemlock very dry maritime western (CWH xm2), Coastal Western Hemlock moist maritime montane (CWH mm2), Mountain Hemlock moist maritime windward (MH mm 1), and Coastal Mountain Heather Alpine undifferentiated and parkland (CMA unp) (MABR, n.d.).

3.2 *Regional Geology of the Nanaimo Lowlands*

3.2.1 *Bedrock Geology*

Vancouver Island resides to the west of the Georgia Depression, it is part of the Insular Belt which is mostly comprised of Wrangellia Terrane (Bednarski, 2015). Of the Wrangellia Terrane, the Buttle Lake and Sicker Groups are the oldest rock formations, while the Karmutsen Formation is the youngest. 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, 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 three to nine meters thick within the Nanaimo lowlands region; these units are more 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, ultimately flowed into the Georgia basin depositing a sandy outwash approximately 100 m thick (Clague et al. 1983).

- *Fraser Glaciation*

The most recent glacial period experienced by Vancouver Island was the Fraser Glaciation, which originated on the Vancouver Island mountain range; an alpine glacier was met by the advancing Cordilleran Ice Sheet, which was coming 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 were 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 onto tidal flats, while beach sediments were deposited by waves and currents at the present shoreline (Bednarski, 2015).

4.0 Little Qualicum Water Region Study Sites

4.1 *Spider Lake Provincial Park & Illusion Lakes*

Spider Lake Provincial Park and Illusion Lakes are located in Qualicum Beach, BC and contain three wetland sites of interest. The wetlands are located within an area of very irregular topography consisting of small hills and depressions, best described as kame and kettle topography (Livingston & Badry, 1992). The provincial park is situated within the Coastal Douglas-fir moist maritime biogeoclimatic (BEC) zone, indicating the region has a moderate climate, where summers are warm and dry, while winters are wet (MacKenzie & Moran, 2004). This BEC zone encompasses ecosystems with uniform macroclimates, a characteristic mosaic of vegetation, soils and particular animal life that reflect the climate (MacKenzie & Moran, 2004). Each wetland study site is situated within either Spider Lake Provincial Park or Illusion Lakes, and are atop the unconfined aquifer 661(Appendix B, Figure 12), which is situated in glaciofluvial sand and gravel sediments of the Vashon Drift (Bednarski, 2015). Literature is not available for water quality and quantity but it is noted that the site is at risk to contamination (i.e. surface pollution), as aquifer 661 is considered to be unconfined in most regions (Waterline Resources Inc., 2014).

4.1.1 *Surficial Materials of Spider Lake Provincial Park & Illusion Lakes*

Surficial materials surrounding Spider Lake and Illusion Lakes are largely Capilano and Vashon drift in origin, and were deposited through both glacial and deglacial processes (Bednarski, 2015). Spider Lake and Illusion Lakes are situated in a thick glaciofluvial delta terrace that contains gravel, sand, and minor diamictons (Bednarski, 2015). These units are typically between 2 and 50 m thick and can be poorly to well sorted, depending on the proximity to fluvial systems (Bednarski, 2015). Well records from wells 96842 and 87225, near Illusion Lakes, show that these units extend 75 to 106 m into the subsurface and do not intersect bedrock (Ministry of Environment, 2017). On the eastern portion of Spider Lake, sediments range between 2 and 50 m thick without intersecting bedrock units, complimenting Bednarski's study. Well drilling data changes significantly once slightly outside the Provincial Park boundaries. Drilling records from 107033 show that surficial deposits are only shallowly deposited between 0 and 14 m and then hit "red and black bedrock units" from 14 to 91 meters (Ministry of Environment, 2017, no page). Field observations confirmed data collected through desktop analysis, as surficial outcrops were visible and showed extensive sand and gravel materials.

4.1.2 *WR2-LQ-01 Wetland Observations & Classification*

WR2-LQ-01 was mapped on July, 12th 2016 and is situated 144 meters above sea level, near a series of gravel pits and active recreational trails. The wetland is 87 m long and 45.5 m wide on average, which was approximated using ArcMap software and perimeter data collected by GPS units. Figure 2 illustrates the extent of the 0.28 ha swamp with secondary marsh sections, which is situated in a shallow depression. Central regions of the wetland contained shallow water, 0.3 m deep, where dense and uniform hardhack (*Spiraea douglasii)* flourished. In regions where water was minimal, sedges, various mosses, trailing blackberry (*Rubus ursinus)*, and false lily-of-the-valley (*Maianthemum dilatatum)* thrived. Coniferous forest species dominated the regions around the study site and consisted of Douglas fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), and grand fir (*Abies grandis)*. The transition zones within the wetland and surrounding areas were dictated by changes in soil and vegetation. Soil samples at the site were taken at two different sites along transect lines to better understand the change in materials within each zone. At the first sample site, the soil texture was fibrous with minimal sand. The soil profile started with an organic layer from 0 to 18 cm and transitioned into a clay lens approximately 13 cm in thickness. The second sample consisted of a similar profile. Overall the soil was a rich dark red, which contained poorly decomposed matter, see Table 1 in Appendix A for other parameters and the classification summary.

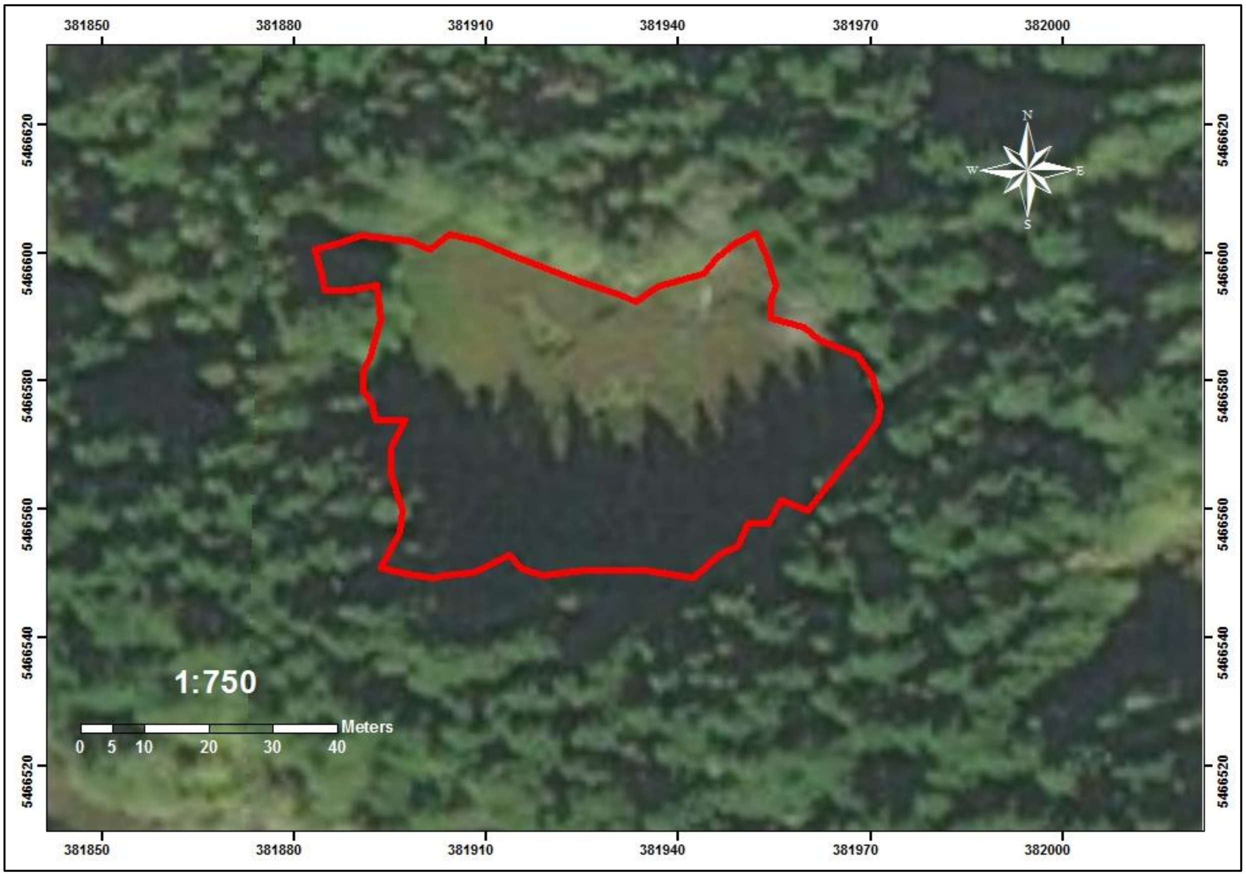

Figure 2: WR2-LQ-01
Source: Imagery obtained from Esri's online basemap database.

4.1.3 *WR2-LQ-02 Wetland Observations & Classification*

The second study site, WR2-LQ-02, was mapped on October 2, 2016, it is approximately 120m above sea-level and is situated adjacent to the main entrance of Spider Lake. The area is primarily used by recreational users and industrial vehicles entering nearby gravel pits.Using ArcMap software, the dimensions of the wetland were approximated as 202 m long and 113 m wide, on average. The study site was also situated in a shallow depression and was classified dominantly as a shallow water wetland with a secondary forested swamp section that was located on the outer edges (Figure 3). During our analysis of the study site, central portions of the wetland were relatively dry but contained extensive amounts of clay and silt. While in the field, researchers observed motion within the clay deposits with each step they took, the ground rolled and moved indicating water storage deeper within the clay deposits. Soil samples were collected and showed no transition of materials, the profile was dominated by dark grey clay and silt with very minimal amounts of fine organics.

Through the summer, researchers frequented Spider Lake and observed the wetland site to have deep open water sections through the majority of the site. As of October 2016, water appeared to have drained from the system into the subsurface. This was interpreted based on the fact that there were no evident inflows or outflows connected to the system during that time. Where water once dominated in the wetland, emergent vegetation, and in particular yellow pond-lily (*Nuphar polysepalum),* was observed to be dying due to reduced water levels. On the outer portions of the wetland, sedges, grasses, field mint (*Mentha arvensis),* northern starwort (*Stellaria calycantha),* and big leaved sandwort (*Moegringia macrophylla)* dominated. Surrounding the study site were steep gravel terraces that contained hardhack, red alder (*Alnus rubra),* Douglas fir, lodgepole (shore) pine (*Pinus contorta* var. *contorta)* and various tall grass. Due to the woody vegetation, this section was classified as a forested swamp. Further field observations can be reviewed in Appendix A, Table 1.

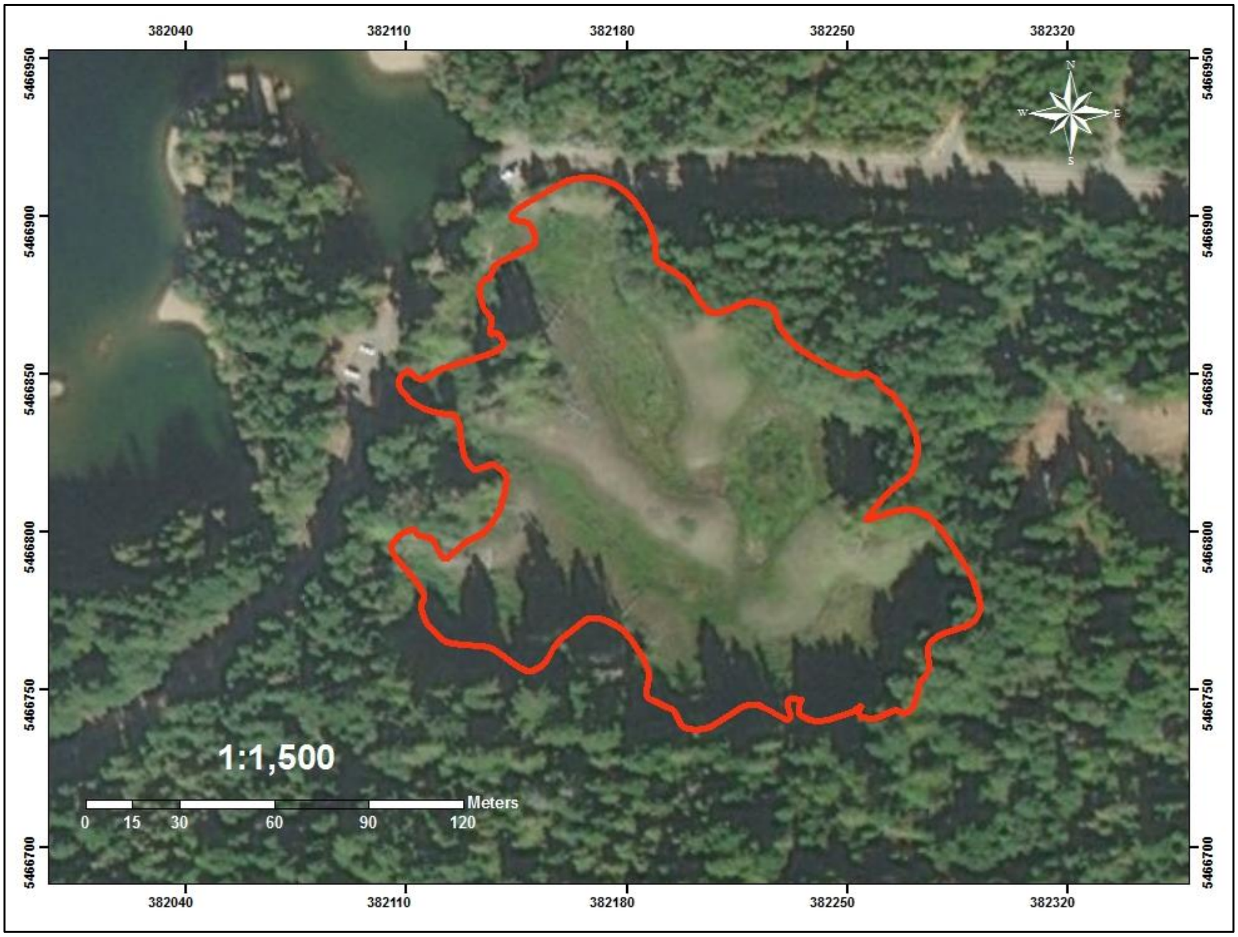

Figure 3: WR2-LQ-02
Source: Imagery obtained from Esri's online basemap database.

4.1.4 *WR2-LQ-03 Wetland Observations & Classification*

On October 5th,2016 researchers mapped the third wetland site, WR2-LQ-03, which was located at Illusion Lakes, approximately 120 m above sea-level and just north of Spider Lake (Figure 4). The wetland is approximately 0.25 ha and sits adjacent to steep sand and gravel slopes. Land use in the area is consistent with the other study sites and is dominated by industrial gravel pits and recreational activities. Dimensions of the study site were approximated using ArcMap software and were, on average, 201 m long and 34 m wide. WR2-LQ-03 was situated within a shallow depression and was classified dominantly as a forested swamp with a small central marsh section that experienced seasonal flooding where shallow water pooled. The site was classified dominantly as a forested swamp with central sections that appeared to be transitioning into a marsh as water levels were reduced. Marsh sections of the wetland contained sparse sections of new vegetation, which included field mint, slough sedge (*Carex obnupta)*, Sitka sedge (*Carex aquatilis*), grasses, and common rush (*Juncus effusus)*. The forested swamp region contained sedges, dense hardhack, red alder, lodge pole pine, Nootka Rose (*Rosa nutkana)*, trailing blackberry, and ocean spray (*Holodiscus discolor*). The study site contained dense hardhack in the northeast corner of the wetland, limiting accessibility.

Through air photo analysis it was observed that water levels were once much higher and the study site once connected with Illusion lake. This was confirmed in the field as natural levees were visible in the surrounding surficial deposits. There were no visible inflows or outflows to the study site other than observable levees indicating the wetland likely acts as an overflow outlet when water levels rise within the lake during winter months. The water temperature was 14°C and was recorded in the central portions of the study site. Surficial deposits were visible around the wetland site and contained coarse sands and gravel. Seepage was observed out of some of the eroded slopes indicating the high permeability and hydraulic conductivity of the surficial deposits. Soil samples were taken with a 30 cm soil auger and showed two zones of materials. The profile contained a thin 2 cm inch layer of organics while the rest of the sample was dominated by coarse sand and gravel with no visible organics.

Figure 4: WR2-LQ-03
Source: Imagery obtained from Esri's online basemap database.

4.2 *Little Qualicum Falls Provincial Park*

Little Qualicum Falls Provincial Park is located within the LQWR off of the Alberni Highway in Qualicum Beach, BC. The Provincial Park is situated within the Coastal Western Hemlock Dry Maritime BEC zone, which indicates a moderate regional climate with warm, dry summers and wet winters (MacKenzie & Moran, 2004). Both WR-LQ-04 and WR2-LQ-05 were mapped within the Provincial Park and were chosen based on their unique relationship to aquifer 663 (Appendix B, Figure 13). WR2-LQ-09 was also added to this section as it lies adjacent to Little Qualicum Falls Provincial Park and has a similar geologic framework as the other two study sites. All three sites overlay aquifer 663, which is a unique kame feature that is highly vulnerable to contamination. Aquifer 663 is considered unconfined and situated in glaciofluvial sand and gravel sediments of the Vashon Drift (Bednarski, 2015). Currently there are no observation wells for this aquifer along with no quantity concerns; but quality concerns arise regarding elevated iron and manganese levels (Lowen, 2010). Overall, the moderately developed aquifer is highly vulnerable to pollution from the surface (Lowen, 2010).

4.2.1 *Surficial Materials of Little Qualicum Falls Provincial Park*

Surficial materials surrounding Little Qualicum Falls Provincial Park are very similar to the Spider Lake region. The Provincial Park contains sediments that are Capilano and Vashon drift in origin, and were deposited through both glacial and deglacial processes (Bednarski, 2015). Areas closer to Little Qualicum River and Cameron Lake have extensive units of poorly sorted sand and gravel that are often 0 to 20 m in thickness (Bednarski, 2015). Drilling data from wells in the region (96506, 96503, and 108109) indicate that these poorly sorted materials extend from 0 to 43 m into the subsurface (Ministry of Environment, 2017). Furthermore, this changes significantly the further you move from the Little Qualicum River. In these areas, granitic bedrock is encountered almost immediately between 0 and 5 m (Ministry of Environment, 2017). Within the provincial park, Bednarski (2015) has recorded sand and gravel deposits to be between 2 and 50 m thick. Drilling data collected from wells within the park support this understanding. Data collected from wells 33967, 26039, 39011 illustrate significant variability in terms of surficial deposit thickness (Ministry of Environment, 2017). Well 33967 has only a 6 m thick gravel and silt layer deposited above granitic bedrock, whereas 26039 has a 40 m thick deposit of sand, gravel and silt overlying the Island Plutonic suite (Ministry of Environment, 2017). Furthermore, well 39011, near well 26039, has a 17 m thick deposit of gravel, sand, and silt above bedrock units (Ministry of Environment, 2017). Field observations were similar to data that was collected through literature analysis. Although no bedrock outcrops were observed, extensive sand and gravel deposits were seen when entering the study area.

4.2.2 *WR2-LQ-04 Wetland Observations & Classification*

WR2-LQ-04 was mapped on July 19th, 2016 and is situated approximately 123 m above sea level within the Little Qualicum Falls Provincial Park. The study area is situated near several gravel pits and low-density residential development. Recreational activities dominate the surrounding land, as much of this area is left undeveloped. Figure 5 (below) illustrates the two distinct wetland zones of the study site. WR2-LQ-04 was classified dominantly as a swamp wetland with a secondary shallow water wetland region within. Central regions of the wetland contained shallow water where rooted, submerged, and floating aquatic plants thrived. The dominant species within the shallow water wetland ecosystem were beaked sedge (*Carex rostrata)*, buckbean *(Menyanthes trifoliate)*, cat tail (*Typha latifolia)*, yellow pond lily (*Nuphar lutea)*, and dagger leaved rush (*Juncus ensifolius*). The swamp region varied significantly, in the outer regions water was in patches and the species that dominated were Douglas fir, red cedar, Nootka rose, slough sedge, and Pacific crab apple (*Malus fusca)*. Moving away from the forest, towards the wetland, water levels increased and became more consistent, at approximately 0.3 m deep. Further, there was an observable shift in vegetation, with uniform dense hardhack dominating. The transition zones within the wetland and surrounding areas were dictated by soil, water quantity and vegetation. The outer swamp region is on average 144.5 m long and 244 m wide, which was approximated using ArcMap software. The central shallow water wetland region (Figure 5) was approximately 82.5 m in length and 94 m wide, which was also calculated using ArcMap software.

There were no visible surficial deposit outcrops found near the wetland site. Soil samples were taken at five different sites within open water patches and the soil profiles at each sample site were consistent. Soil texture was fibrous indicating weak decomposition. The soil profile contained dark brown-black organics and transitioned into coarse sand and clay. The transition zone was consistent with minor differences in the thickness of organic content. Soil samples were fibric and dark brown-black containing poorly decomposed matter.

Overall, the system appeared to be a functioning wetland that had two potentially inactive inflow sites located in the north and southwest regions of the wetland. One outflow site was located on the eastern side of the wetland and was filled with deep, still water. By analyzing the air photos, it was determined that this outflow site may be a small tributary that is connected to the Little Qualicum River. Replenishment of surface water in the study site is likely from numerous sources, water table fluctuations, precipitation, and a potential infrequent connections to the two inflow tributaries. Observational analysis suggests that the wetland likely retains much of its water during summer months as aquatic species in the shallow water appear healthy and undisturbed.

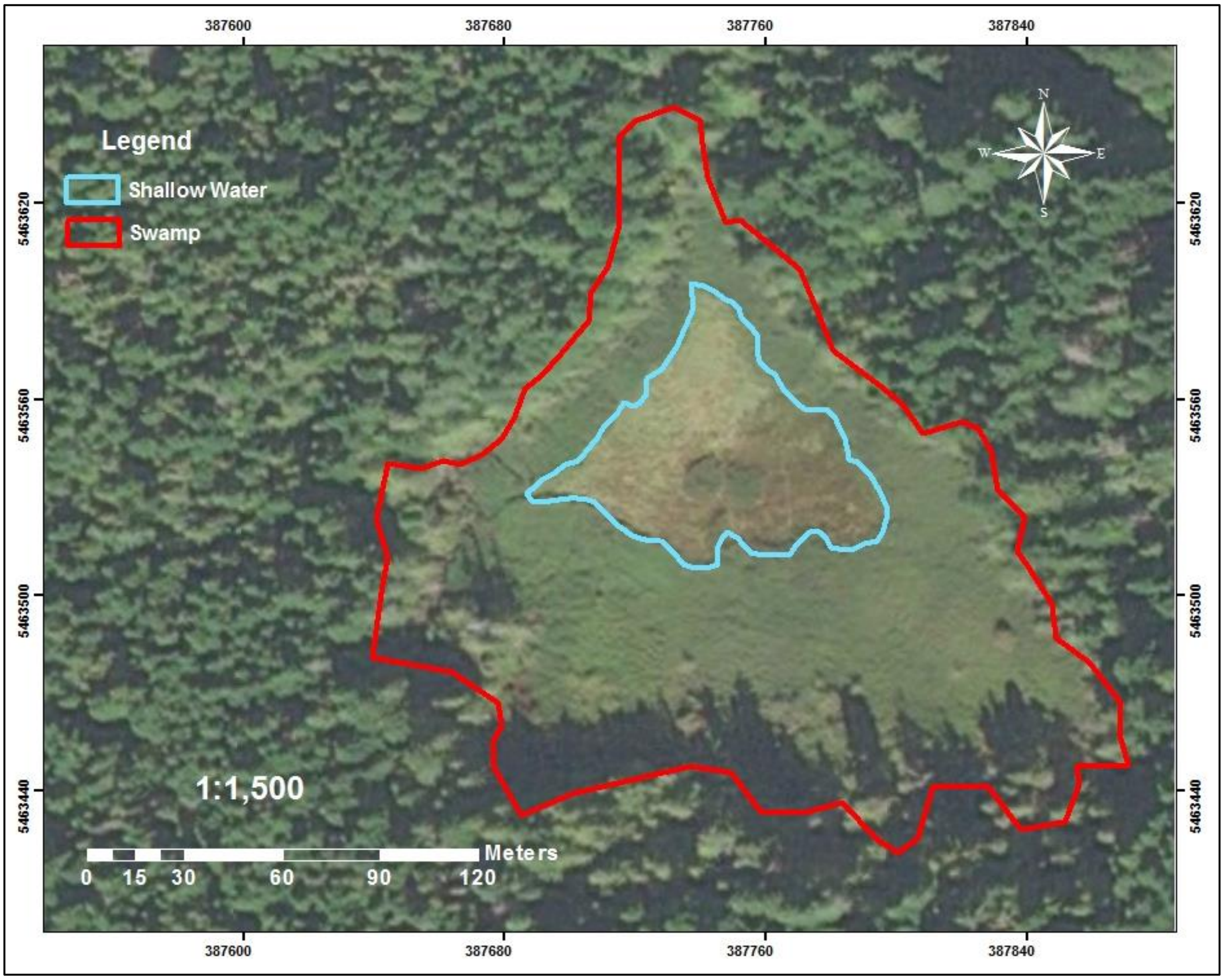

Figure 5: WR2-LQ-04
Source: Imagery obtained from Esri's online basemap database.

4.2.3 *WR2-LQ-05 Wetland Observations & Classification*

WR2-LQ-05 was mapped on July 26th, 2016 (Figure 6) and while surrounding land use was consistent with the other study sites, its elevation was slightly higher at 135 m. Researchers classified WR2-LQ-05 as a swamp, surrounded by a healthy, coniferous forest ecosystem. The outer regions of the wetland contained shallow water where emergent aquatic plants thrived. The dominant species within the swamp were hardhack, big leaved sandwort, common water moss *(Fontinalis antipyretica)*, and slough sedge. Vegetation within the forested ecosystem, along the outer edges, consisted of Oregon beaked moss *(Kindbergia oregano)*, salal, Nootka rose, Pacific crab apple, Douglas fir, and western red cedar. The study site appears to be a well-functioning wetland that has a unique hydrologic distribution. The swamp regions contain diffuse shallow water pockets filled with very clear and colorless water; they were 18° C and had a pH of 6.1. Temperature and pH readings were taken on both transects with no observable changes. There were no visible inflow or outflow sites, but surrounding the wetland were steep sand and gravel slopes. The wetland likely retains much of its water on the outer sections as aquatic species in the area appear healthy and undisturbed. During the field visit, it was determined that the central wetland area contained less than 5% of open water, as the entire pool contained hardhack. Soil samples were collected and contained high organic humic peat content with decomposed plant structures, which when squeezed, brown turbid water escaped. Overall, the soil transition was consistent in the other samples with minor differences in the thickness of organic content. In conclusion, the wetland soil samples was considered to be well decomposed with some coarse gravel inclusions.

Figure 6: WR2-LQ-05
Source: Imagery obtained from Esri’s online basemap database.

4.2.4 *WR2-LQ-09 Wetland Observations & Classification*

The wetland site WR2-LQ-09 is located adjacent to Little Qualicum Falls Provincial Park on Melrose Road in Qualicum Beach, British Columbia (Figure 7). The surrounding land uses are dominantly rural residential development, forestry, specifically a Christmas tree farm, and off road recreational activity, as well as hiking and biking activity. The site is located at an elevation of 127 m above sea level and is approximately 114 m long and 71 m wide. Researchers visited the study site on

July 11th, 2017. Upon entering the field, researchers found that the wetland was populated by dense hardhack, willows, and coniferous tree species. These conditions made it challenging to run transects into the wetland, therefore the researchers surveyed vegetation around the entire site to gain a better understanding of the wetlands ecology.

Along the edges of the wetland, vegetation was dominated by western red cedar, deer fern (*Blechnum spicant*), skunk cabbage (*Lysichiton americanus*), slough sedge, hardhack, bitter cherry (*Prunus emarginata*), western hemlock (*Tsuga heterophylla*), western white pine (*Pinus monticola*), and Douglas fir. Understory species consisted of salal, common horsetail (*Equisetum fluviatile*), common tree moss (*Climacium dendroides*), witches hair (*Alectoria sarmentosa*), and step moss. The wetland then transitioned into the dominant swamp ecosystem, which housed black cottonwood (*Populus balsamifera ssp. Trichocarpa*), hardhack, slough sedge, bitter cherry, hooker's willow (*Salix hookeriana*), hairy lantern moss (*Rhizomnium magnifolium*), yellow moss (*Homalothecium fulgescens*), ribbed bog moss (*Aulacomnium palustre*), and western red cedar. Soil samples were collected during vegetation surveys and showed that the majority of the site had a thick layer, 7 cm, of reddish organic peat that transitioned into a thick clay lens of 23 cm. At the site there was no visible standing water, but when soil samples were collected, water pooled in the subsurface void. Researchers collected water samples at these sites and determined the water temperature to be 11°C and have a pH of 5.5. In summary, the study site appeared to be a functioning wetland with stable overflow structures on all sides.

Figure 7: WR2-LQ-09
Source: Imagery obtained from Esri's online basemap database.

4.3 *Dashwood & Whiskey Creek*

The community of Dashwood and Whiskey Creek are both rural areas that lie to the north of Qualicum Beach and to the south of Qualicum Bay. Dashwood is situated in the Coastal Douglas Fir moist maritime BEC zone, which is characterized by warm, dry summers and mild, wet winters and is restricted to elevations below 150 m (MacKenzie & Moran, 2004). Aquifer 662 exists within the majority of the Dashwood region and is a sand and gravel aquifer with an unknown confinement status (Appendix B, Figure 14). According to GW Solutions (2017), aquifer 662 is considered to be moderately in demand and moderately productive.

Although Whiskey Creek and Dashwood are proximal to one another, the BEC zones are slightly different. Whiskey Creek is situated in both the CDFmm and CWHdm BEC zones, containing three wetlands: WR2-LQ-07, WR2-LQ-08, and WR2-LQ-09. Whiskey Creek is situated above aquifer 663 IIIA (12), an unconfined sand and gravel aquifer consisting of glaciofluvial sediments of the Vashon Drift

(Bednarski, 2015). Aquifer 663 is considered to be highly vulnerable to contamination, has moderate to high relative stress levels, and is moderately productive. These wetlands were identified and mapped due to their position above aquifer 663.

4.3.1 *Surficial Geology of Dashwood & Whiskey Creek*

Dashwood and parts of Whiskey Creek are located in relatively low-lying regions, near the eastern shoreline of central Vancouver Island. Within these low-lying areas surficial deposits have been recorded as Capilano and Vashon Drift in origin. These units are considered glaciomarine and include coarse marine blankets with sand and gravel that are underlain by clay between 1 and 10 m thick (Bednarski, 2015). In other sections, the glaciomarine blanket is significantly finer with silt, fine sands, and clay (Bednarski, 2015). According to Bednarski (2015), glaciomarine sediments are often deposited by floating glaciers and melt water from retreating glaciers. Drilling data from wells 96451, 87930, 96325 and 107382 show that these coarse and fine marine deposits extend significantly deeper, up to 98 m (Ministry of Environment, 2017). In many of the drilling logs, there are inter-bedded units of clay and silt above and below sand and gravel deposits (Ministry of Environment, 2017).

The upper sections of Whiskey Creek, and along the water course, typically contain surficial deposits that reflect both glacial and non-glacial processes. Many of the glaciomarine deposits have been eroded away by modern day fluvial processes and are reflective of thick glaciofluvial delta terraces that contain gravel, sand and minor diamictons (Bednarski, 2015). These units are typically between 2 and 50 m thick and can be poorly to well sorted, depending on the proximity to fluvial systems (Bednarski, 2015). Furthermore, these units can typically range between 1 and 20 m thick and are believed to have been in contact with the retreating glacier (Bednarski, 2015). Well data was collected from three drilling reports on iMaps BC (2017) to better understand the distribution of these lithostratigraphic units. Drilling information confirmed Bednarski’s (2015) surficial deposits map and showed that between 0 and 12 m there are extensive sand and gravel deposits with discontinuous clay layers separating these packages (Ministry of Environment, 2017). In the field there were no visible outcrops showing local surficial deposit; therefore, using data from past drilling reports was necessary to understand the stratigraphic framework in the area.

4.3.2 *WR2-LQ-06 Wetland Observations & Classification*

The study site located on Larkedowne road was mapped on October 20th, 2016 and was a unique wetland system that was identified as another wet forest. Predictive mapping indicated that the site was a swamp wetland; however, this was not representative of the actual system. In-field observations determined a random distribution of wetland vegetation with no defined boundary for the wetland area, as vegetation and water patches were diffuse. Vegetation consisted of a variety of mosses, salal, sedges, grasses, bracken fern, blackberry, Nootka rose, and very dense western red cedar, spruce, and Douglas fir tree cover throughout. There were many snags and wildlife trees within the study area, and the outer property line contained a man-made ditch that runs adjacent to farmland. The site did not have any significant standing water, although there were random patches of mud that might have contained water at some point. The wetland did not appear to be productive during our site visit. It may be beneficial to revisit this site during the fall and winter to gain a better understanding of how much water pools. Soils within the man-made trench consisted primarily of clay. There was high sand content on the forest floor with red color indicating high iron content. Overall, the predictive mapping was inaccurate and does not represent the true size or perimeter of the wetland as mud depressions and sedge patches are diffuse and continue throughout the property.

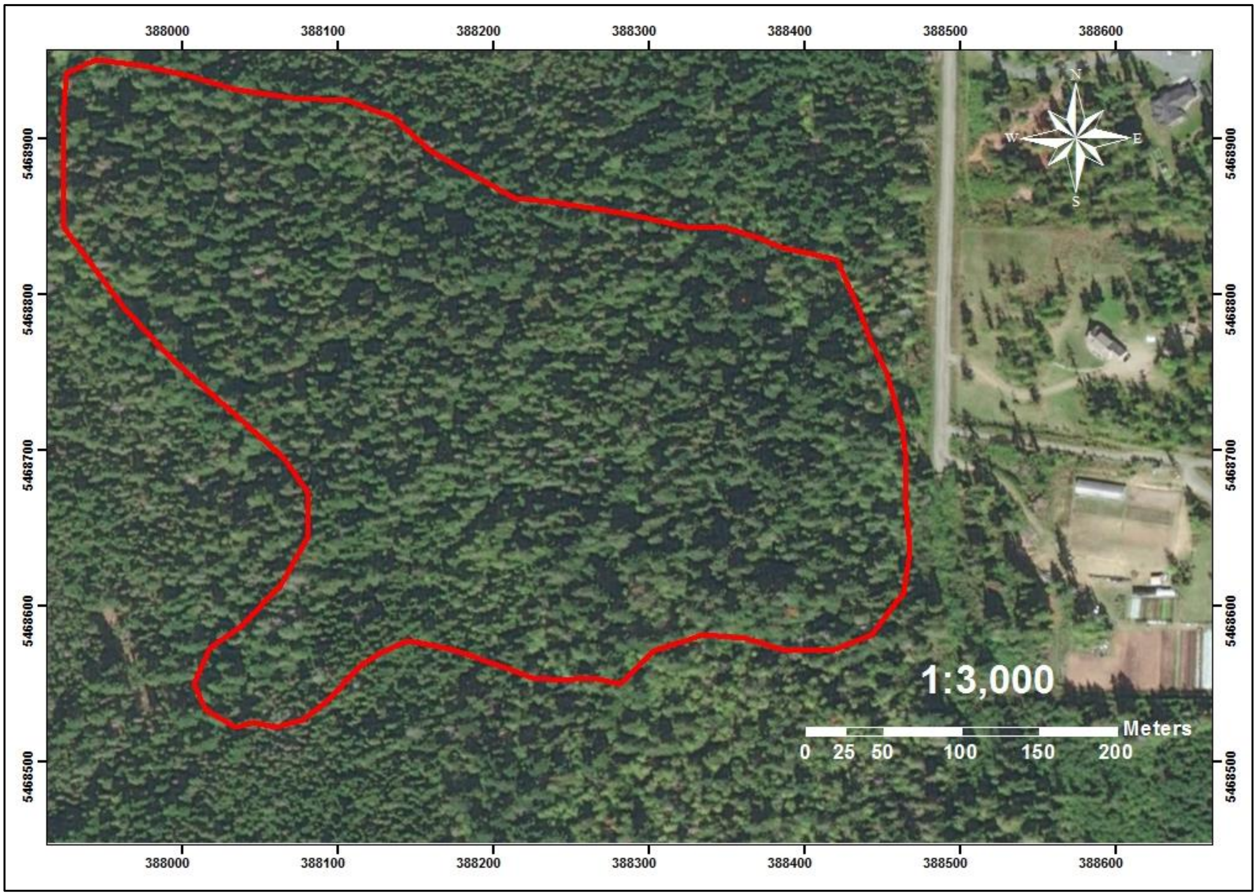

Figure 8: WR2-LQ-06
Source: Imagery obtained from Esri’s online basemap database.

4.3.3 *WR2-LQ-07 Wetland Observations & Classification*

WR2-LQ-07 was mapped on November 10th, 2016 and was located in Qualicum Beach, British Columbia (Figure 9). The study site was 174 m above sea level and had vegetation that was indicative of the CDFmm biogeoclimatic subzone, it contained Douglas fir, western red cedar, grand fir, dull Oregon grape *(Mahonia nervosa),* salal, trailing blackberry, Oregon beaked moss, witches hair lichen, hardhack, red huckleberry *(Vaccinium parvifolium),* step moss, and small red peat moss *(Spagnum capillifolium).* It was also noted that there was a large percentage of sedge species that were unidentifiable due to the time of year, as they had begun to decompose. Through vegetation surveys, researchers identified the system to be a marsh wetland due to its neutral pH, emergent vegetation in central water sections, and presence of sedges and various grass species. Soil samples were taken along transect lines and revealed that there was a 2.5 to 5 cm layer of organic material that was moderately decomposed with plant structures that were clear but becoming indistinct. The upper portion of the soil profile contained sand mixed with organic material, which transitioned into the dominant layer of silt and clay that was slate grey in color.

The wetland appeared to be a healthy, functioning system with central sections of water that supported emergent vegetation plant life. It is unknown if the system dries seasonally, but during the field visit, there was approximately 30 cm of standing water throughout the wetland. There were no visible inflows; however, preliminary research showed that the wetland feeds directly into Whisky Creek (GW Solutions Inc., 2011). Overall, water appeared fairly turbid and was red-brown in color with pH measurements of 6.1 near the banks of the wetland and 7.0 in central water sections.

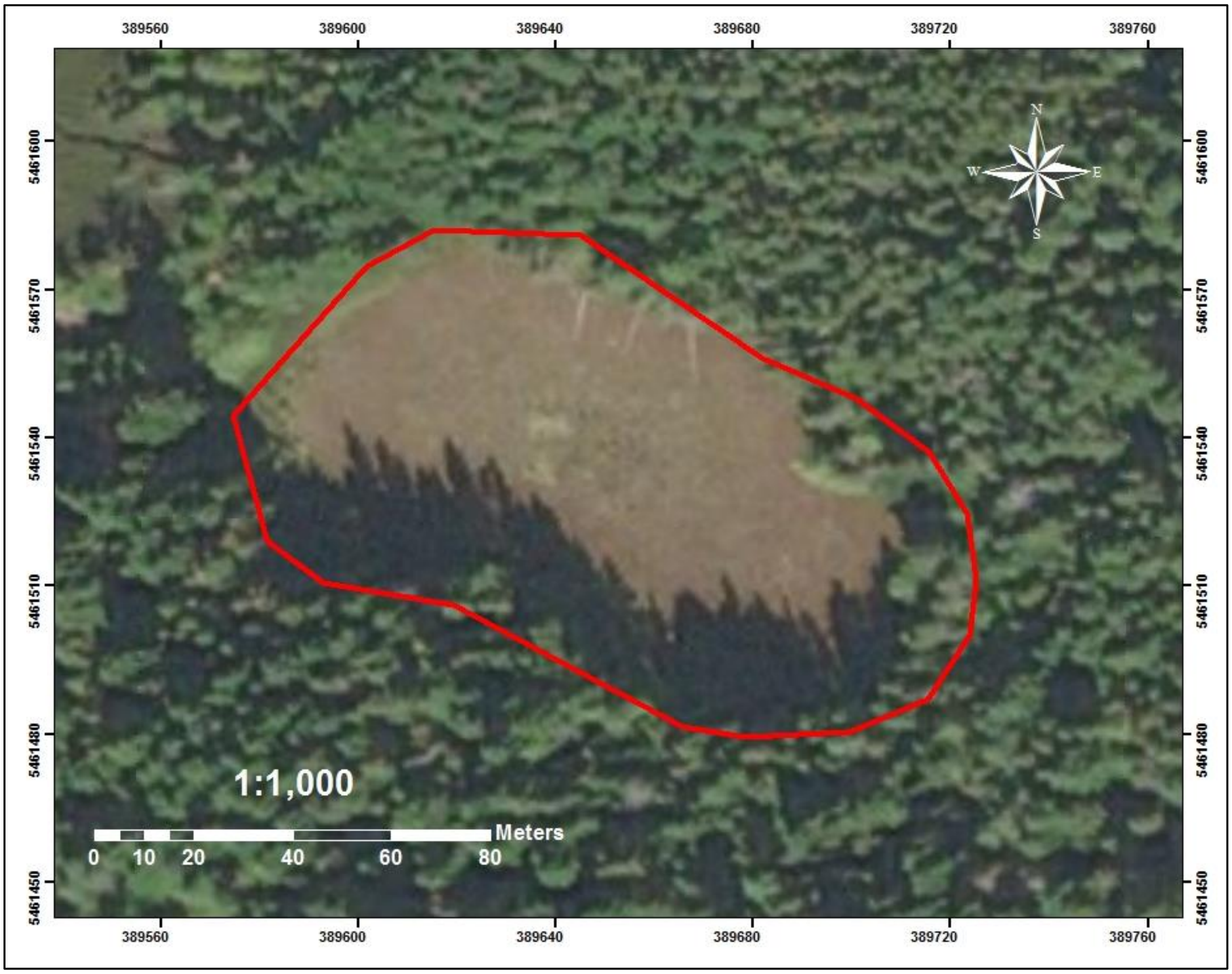

Figure 9: WR2-LQ-07
Source: Imagery obtained from Esri's online basemap database.

4.3.4 *WR2-LQ-08-Wetland Observations & Classification*

Researchers entered the upper reaches of Whiskey Creek on May 11th, 2017 to map and classify WR2-LQ-08. The study site is surrounded by various forestry activities and nearby rural residential land. Located at 190 m above sea level, WR2-LQ-08 is situated in CWHmm. Figure 10 (below) illustrates the wetland and its mapped GPS perimeter track. The wetland dimensions are approximately 130 m in length and 76 m wide.

Researchers classified the study site as a swamp wetland with a densely forested perimeter. Common species observed are water tolerant species such as western red cedar, skunk cabbage, slough sedge, hardhack, and Pacific crab apple. The forested vegetation zone was dominated by bitter cherry, western hemlock, western white pine, red alder, Douglas fir, and western red cedar. The understory was dominated by common tree moss, witches hair, step moss, dragon cladonoia (*Cladonia squamosal*), British soldier lichen (*Cladonia cristatella)*, antlered perfume or Oakmoss (*Evernia prunastri*), tree ruffle liverwort (*Porella navicularis*), goose neck moss (*Rhytidiadelphus triquetrus*), Lyell's bristle moss (*Orthotrichum lyellii*), scotch broom (*Cytisus scoparius)*, and curly hipnum (*Hypnum subimponens*). The swamp zone was dominated almost entirely by hardhack, slough sedge, bitter cherry and Pacific crab apple and contained highly fibrous soils. Soil samples showed very distinct plant structures, suggesting low decomposition rates. Unfortunately, soil samples were difficult to obtain at the study site as subsurface materials were compact and impenetrable; therefore, samples may not be representative of the entire site. There were no visible inflows or outflows at the study site but brief hydrological data was recorded in areas where water pooled (Appendix A, Table 1).

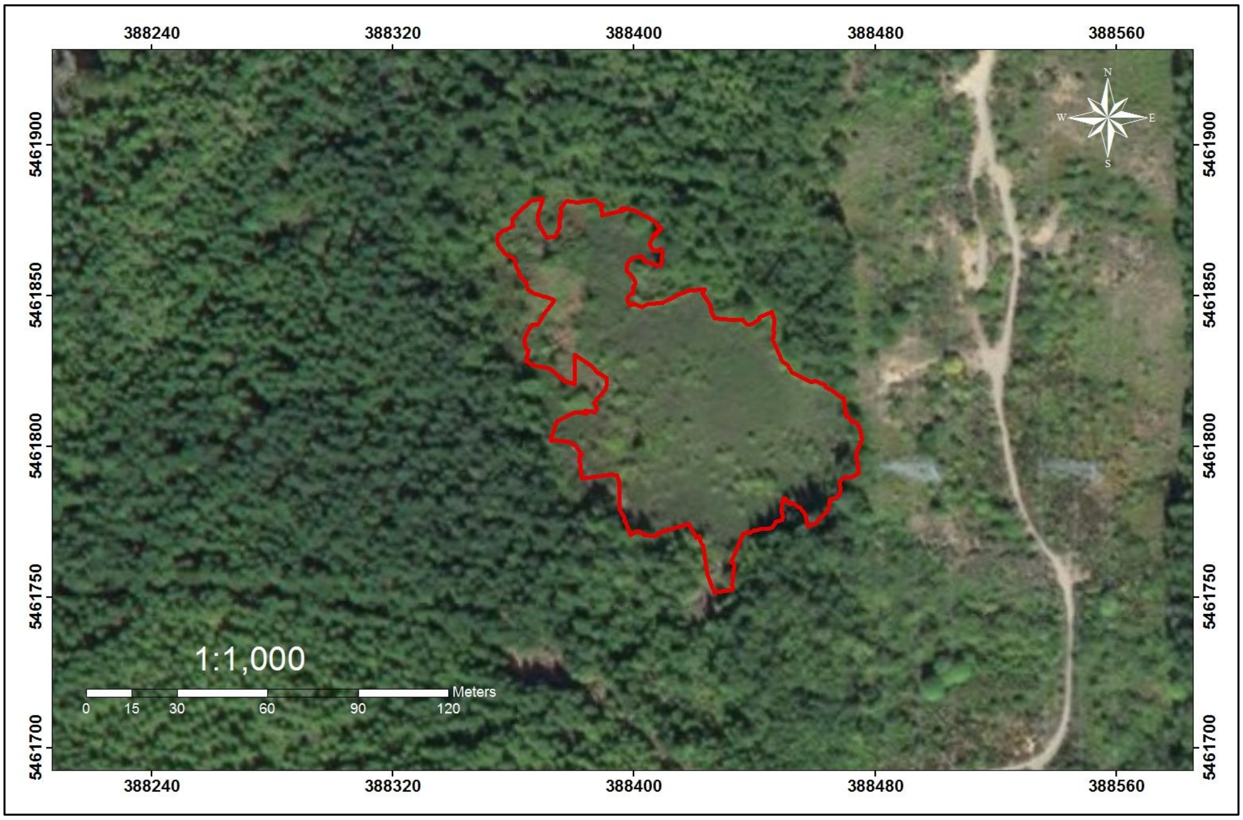

Figure 10: WR2-LQ-08
Source: Imagery obtained from Esri's online basemap database.

4.3.5 *WR2-LQ-10 Wetland Observations & Classification*

WR2-LQ-10 was accessed and groundtruthed on August 2nd, 2017; it is located off of Melrose Road in Qualicum Beach, British Columbia (Figure 11). This study site was close in proximity to Whiskey Creek and was therefore added to this section. Although predictive mapping classified the study site as a swamp wetland, air photo analysis showed the site to be dominated by coniferous forests, with no indication of a wetland site. Upon entering the field, it was clear that the site behaves as a wet forest ecosystem with some characteristic wetland species. The wetland was located 71 m above sea level within the CDFmm BEC zone and was classified as a forested swamp ecosystem. The dominant plant species for this site included Douglas fir, skunk cabbage, salmon berry (*Rubus spectabilis*), Sitka spruce (*Picea sitchensis*), lady fern (*Athyrium filix-femina),* deer fern , bracken fern , red huckleberry, foamflower (*Tiarella trifoliata),* hardhack, common horsetail, small-flowered bulrush (*Scirpus microcarpus)*, step moss, and pipe cleaner moss (*Rhytidiopsis robusta).* The study was not representative of forested swamp ecosystems therefore available data was limited.

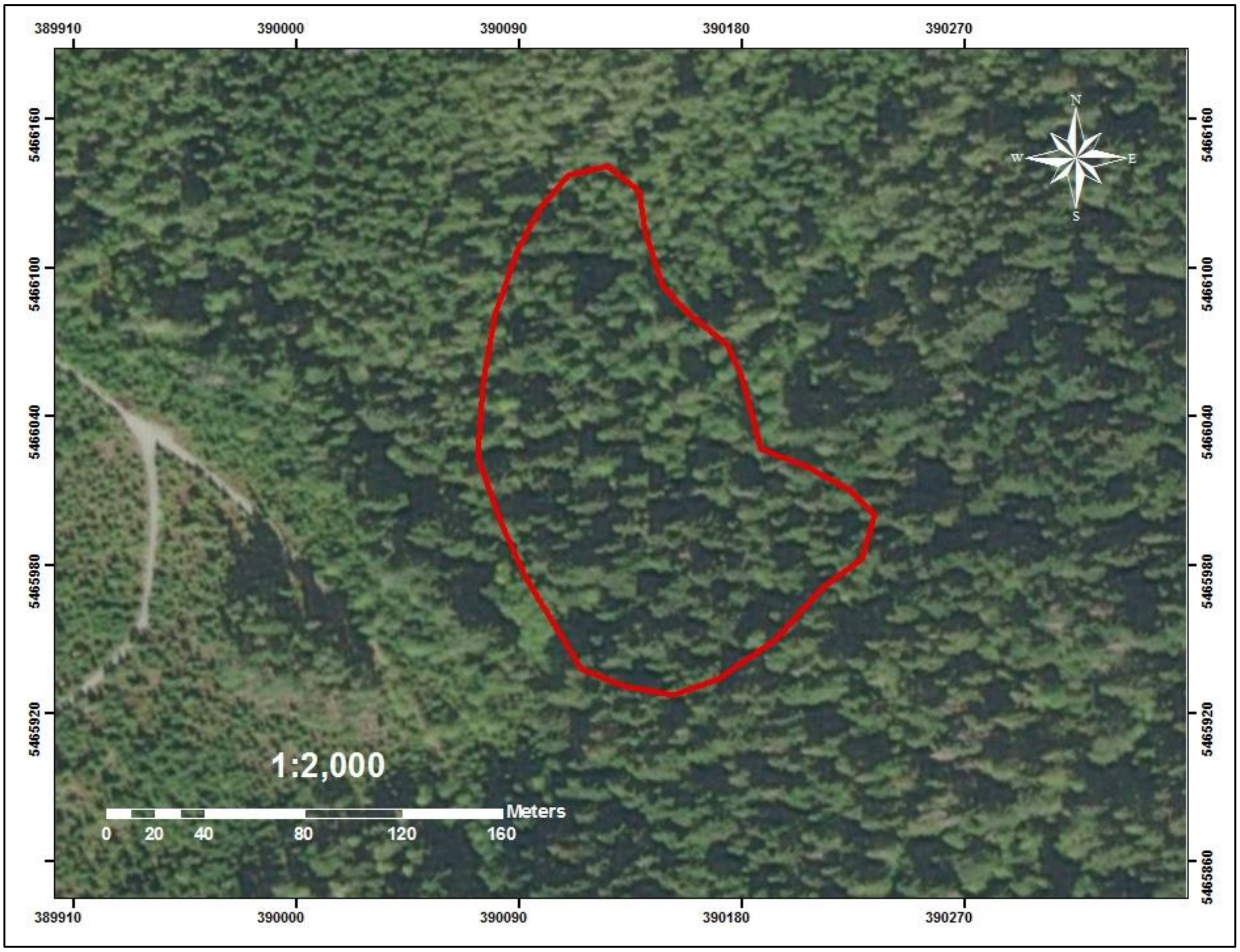

Figure 11: WR2-LQ-10
Source: Imagery obtained from Esri’s online basemap database.

5.0 Discussion

5.1 *Hydrostratigraphy*

The study area in the Little Qualicum Water Region has undergone a series of climatic changes that has led to a number of glacial intervals, as discussed above in section 3.2. These events have had a large impact on how hydrologic and hydrogeologic systems behave both on a regional and local scale. Surficial deposits in the LQWR reflect the glacial and postglacial processes that took place during the Quaternary Period. During periods of isostatic uplift glaciofluvial processes dominated the region resulting in the deposition of coarse sands and gravel units that often act as modern day aquifers. These units are typically coupled with alternating layers of clay and mud, as sea-levels rose and istocity remained relatively constant. These glaciofluvial sediments were exposed in many of the study areas and typically consist of water bearing sands and gravels at depth, with overlying till or clay packages that act to partially or fully confine aquifer units. Glaciofluvial packages were typically located near major river courses, such as Qualicum River or Little Qualicum River, or directly surrounding smaller fluvial systems, like Whiskey Creek.

The central sections of the LQWR, which were not proximal to major river courses, were typically overlain by Capilano glaciomarine veneers that had variable coarseness. These glaciomarine deposits can often act as localized aquitard units above sand and gravel outwash deposits. 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. These units are spatially variable in thickness and may be disconnected at a localized scale. Overall, bedrock units were not prominent at localized study sites but the three main bedrock units observed within in the study area are the Nanaimo Group, Island Plutonic Suite, and Karmutsen Formation (Ministry of Environment, 2017). In many regions of the LQWR these bedrock units are not entirely exposed, except in regions where fluvial processes have eroded away surficial materials. The connection between bedrock and unconsolidated aquifer units is not well understood in the region, including within this study. Moving forward, further investigations will need to be pursued at a localized scale.

5.2 *Wetland Characteristics*

Swamps and marshes were the two distinct wetland systems identified within the LQWR along with two unique sites that were classified as "wet forest ecosystems". Seven of the study sites within the LQWR were classified as dominant swamp wetland systems with secondary classifications that were more specific to each site. The other two were classified as either a marsh wetland or wet forest.

Swamp wetland systems are characterized by high cover of tall shrubs, trees and a well-developed herb layer (MacKenzie & Moran, 2004). There are typically two distinct types of swamps found in British Columbia: one that is characterized by a tall shrub physiognomy and the other 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 01, 04, 05, 08, and 09, within WR2-LQ, were classified as dominant swamp systems with tall shrubby vegetation species, while study site 03 was classified as a dominant forested swamp ecosystem with central marsh sections. The classification and distinction between these two types of swamps was based on the quantity of water that encouraged vegetation changes, which aid to differentiate these different systems. Within the forested swamp study sites water patches were diffuse and vegetation was dominated by water tolerant species, such as western red cedar and willows, along 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 pooling water and were dominated by hardhack and shrub species. Water levels typically ranged between 0.2 and 0.5 meters in these areas and had poorly decomposed plant matter. Only WR2-LQ-07 was classified as a dominant marsh, which is characterized by permanent to seasonal flooding in a non-tidal area and are typically dominated by simple plant communities with low species diversity, and strong dominance by one or two species (MacKenzie & Moran, 2004). WR2-LQ-07 had shallow water in central sections of the site and was dominated by peat moss, ferns and step moss. Two "wet forest" ecosystems were identified at both WR2-LQ-06 and 10. These sites appeared to experience seasonal water table fluctuations that allowed the forest to contain wetland vegetation species, such as willows trees, sedges and skunk cabbage.

5.2.1 *Hydrology of WR2-LQ-02 & WR2-LQ-03*

During field visits to WR2-LQ-02 and WR2-LQ-03 it was observed that these sites had unique hydrological characteristics that may be indicative of local and regional hydraulic connections. These study sites had significant surface water storage during the months of June to mid-August, in both 2016 and 2017. It was observed that during the latter half of August and into the fall surface water drained from these sites. These study sites do not contain any points of inflow or outflow other than a few seepage sites from the surrounding sand and gravel terraces. Winter (1998) suggests that in most cases surface water bodies have hydraulic connections to groundwater or other surface water systems. Through air photo analysis (Appendix C Figures 15 to 30), there is an evident seasonal transition where water levels in the lake systems and wetland sites are high during winter and early summer months and low from the mid-summer into late fall. The drastic transition, between periods of high water and low water levels, between both surface water bodies, is consistent; the water levels in the wetland systems mimic those of the lake, with rising and falling water levels occurring simultaneously (Appendix C Figures 15-30). This observational trend indicates a shallow hydraulic connection between Spider Lake and LQ-WR2-02, as well as WR2-LQ-03 and Illusion Lakes. An existing subsurface connection between these two sites is very likely as the hydraulic properties of medium to coarse grained outwash deposits support the flow of water through porous materials (Freeze & Cherry, 1979). The followability of water between multiple systems through these pore spaces or fractures is called hydraulic conductivity (K). Glaciofluvial sediments are known to have high K values which indicates permeable materials that allow water to easily pass (Freeze & Cherry, 1979). Although this has not been quantified with instrumentation, it is clear that due to the lithology of sediments in the area there is likely a shallow subsurface connection between the two systems. In order to identify any relationship between surface water and groundwater complexes, these two sites should be prioritized and additional subsurface investigations will need to be conducted to better understand the distribution of these sediments and the seepage conditions between deeper sections of the wetland sites and lake systems.

Overall, majority of the study sites visited were classified dominantly as swamps which may not be representative of the region. The study sties that were visited were based on proximity to vulnerable aquifer units and ability to access the property. In many cases the study sites were located on publicly accessible lands which were either Provincial or RDN parks. Moving forward it would be beneficial to map more wetlands in the headwaters of the Little Qualicum water region to better understand how these systems differ from the low lying wetland systems. Two sites within the LQWR, WR2-LQ-02 and WR2-LQ-03, were identified as priority sites based on their unique hydrologic characteristics.

5.3 *Recommendations*

The purpose of the study was to map and classify wetland systems across the LQWR, 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 and understanding how wetlands are connected to groundwater systems in the LQWR 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 LQWR. 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 *Geophysical Surveys*

Geophysics is an interdisciplinary physical science that applies the knowledge and techniques of physics, mathematics, and chemistry to understand the structure, subsurface, and dynamic behavior of the earth and environment. Geophysical techniques will be a tool that researchers can use to better understand the distribution of surficial materials within study sites in the LQWR. There are three potential geophysical techniques that can be used to understand subsurface materials, including ground-penetrating radar (GPR), seismic refraction, and electrical resistivity. Each of these methods requires the establishment of survey lines, their locations will be determined based on surficial deposits, proximity to surface water, and the ability to run a straight line in a safe manor. GPR data will be used to determine the location of the water table within the upper unconfined aquifer and will help determine its saturated thickness and extent. Seismic refraction can be used to determine the structure of the subsurface, including the location and extent of sediment aquifers, clay aquicludes and any present bedrock aquitards. Electrical resistivity will determine the presence of water in sediment aquifers and is beneficial when assessing any regions that have confining layers situated above and below stacked aquifers. Although subsurface geophysical techniques cannot replace test drilling to understand surficial deposit distributions, they may lead to a better interpretation of stratigraphic units within a localized context. This understanding will contribute to understanding how water is able to flow from the surface into the subsurface.

5.3.3 *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. Water budgets account 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 LQWR has been completed, 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. Funding will also need to be secured to ensure that groundwater analysis can happen as discussed above.

6.0 Conclusion

Two methods of interpretation were used to better understand wetland systems within the Little Qualicum 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, ten wetlands, in total, were mapped and classified for the LQWR. 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. Researchers identified two swamps of particular interest and suggest further investigations should be conducted at WR2-LQ-02 and WR2-LQ-03, as the hydrology of the area is quite unique based on their hydrogeologic position. As discussed above, it will be very important to move forward with further subsurface investigations to better understand existing hydraulic connections at these two sites by using data gathered by instrumentation, cross-sectional analysis, and geophysics.

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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
WR2-LQ-01	49° 20' 25" N 124° 37' 26" W	Swamp;marsh	Hardhack, false lily of the valley, slough sedge, sphagnum spp.	0.28	144	14	5.3	Fibrous, with minimal sands, poorly decomposed plant matter	661 lllA (10)	Sand and gravel	Partially Confined
WR2-LQ-02	49° 20' 33" N 124° 37' 19" W	Shallow water/Marsh wetland; secondary forested swamp	slough sedge, grass spp., field mint, hardhack	1.5	120	14	7.1	Clay and silt dominated; minimal organics	661 lllA (10)	Sand and gravel	Partially Confined
WR2-LQ-03	49° 21' 07" N 124° 38' 08" W	Forested swamp; secondary marsh	Hardhack, grass spp.	0.25	120	11.2	8.2	Thin organic layer with underlying coarse sand and gravels	661 lllA (10)	Sand and gravel	Partially Confined
WR2-LQ-04	49° 18' 51" N 124° 32' 39" W	Swamp; secondary shallow water wetland	Hardhack, slough sedge	3.31	123	17	6.1 (5.9 in shallow water wetland)	Organic, transitioning into coarse sands and clay	663 lllA (12)	Sand and gravel	Unconfined
WR2-LQ-05	49° 18' 34" N 124° 32' 20" W	Swamp	Hardhack	0.7	135	18	6.1	Humic peat with almost complete decomposition and some gleying	663 lllA (12)	Sand and gravel	Unconfined
WR2-LQ-06	49° 21' 30" N 124° 32' 13" W	Wet forest	Western red cedar, Douglas fir, slough sedge, salal	n/a	90	n/a	n/a	n/a	662 IIIC (12)	Sand and gravel	Confined
WR2-LQ-07	49° 17' 47" N 124° 31' 03" W	Marsh;swamp	Hardhack, sphagnum spp., sedge spp.	1	166	n/a	6.1 (center of wetland 7.1)	Thin moderately decomposed organic layer mixed with sands transitioning to silty clay	663 lllA (12)	Sand and gravel	Unconfined

WR2-LQ-08	49° 17' 55" N 124° 32' 05" W	Swamp	Hardhack, slough sedge	1.05	190	11	9.1	Thick organic layer transitioning to sand and silts	663 lllA (12)	Sand and gravel	Unconfined
WR2-LQ-09	49° 19' 03" N 124° 32' 14" W	Swamp	Hardhack	0.69	127	11	5.5	Poorly decomposed organic matter, clays and very little sand	663 lllA (12)	Sand and gravel	Unconfined
WR2-LQ-10	49° 20' 13" N 124° 30' 40" W	Wet Forest	Douglas fir, skunk cabbage	2	71	n/a	n/a	High organic content; silty clay loam	Unmapped aquifer	n/a	n/a

Appendix B

Aquifers in the Little Qualicum Water Region

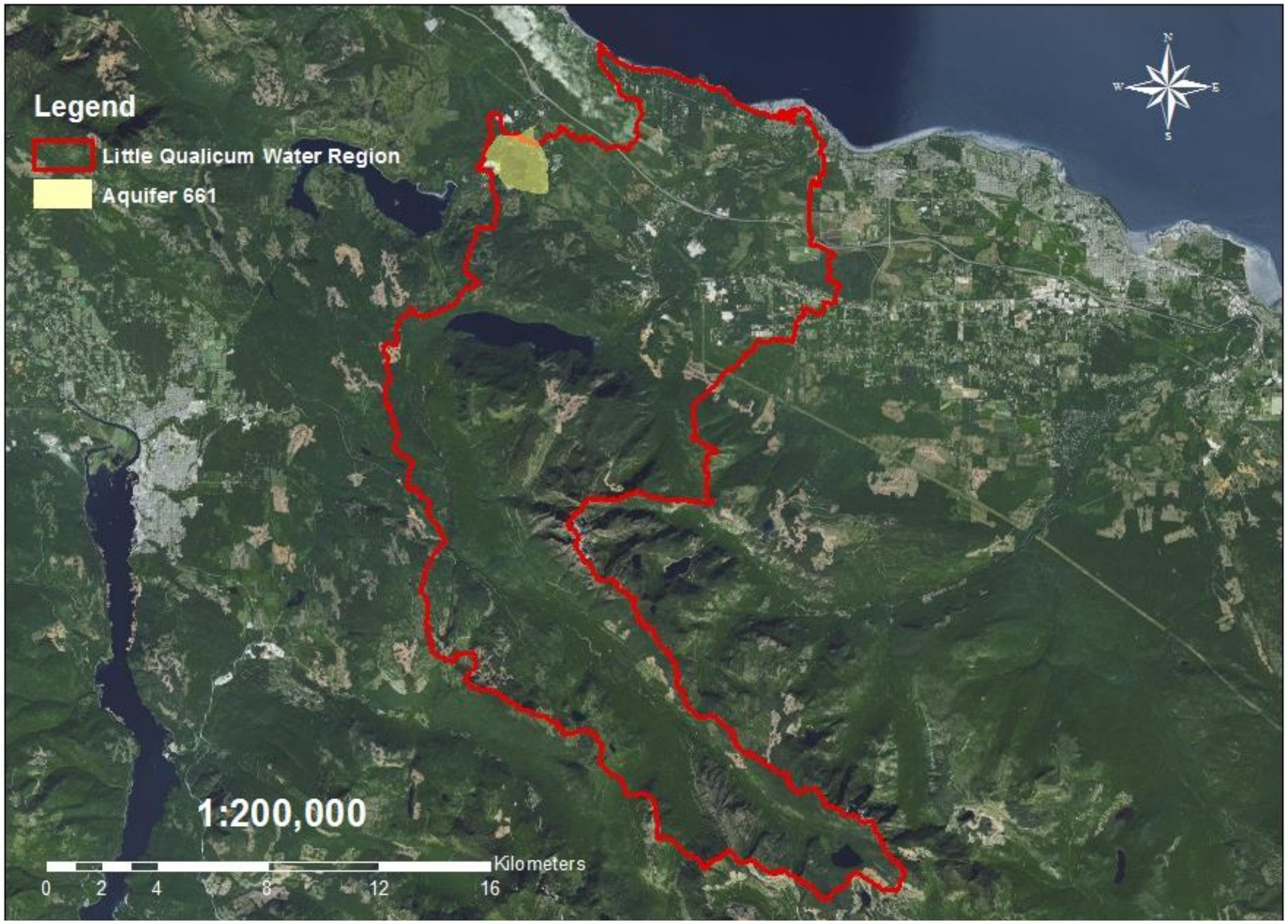

Figure 12: Vashon Drift Aquifer 661
Source: Imagery obtained from Esri's online basemap database.

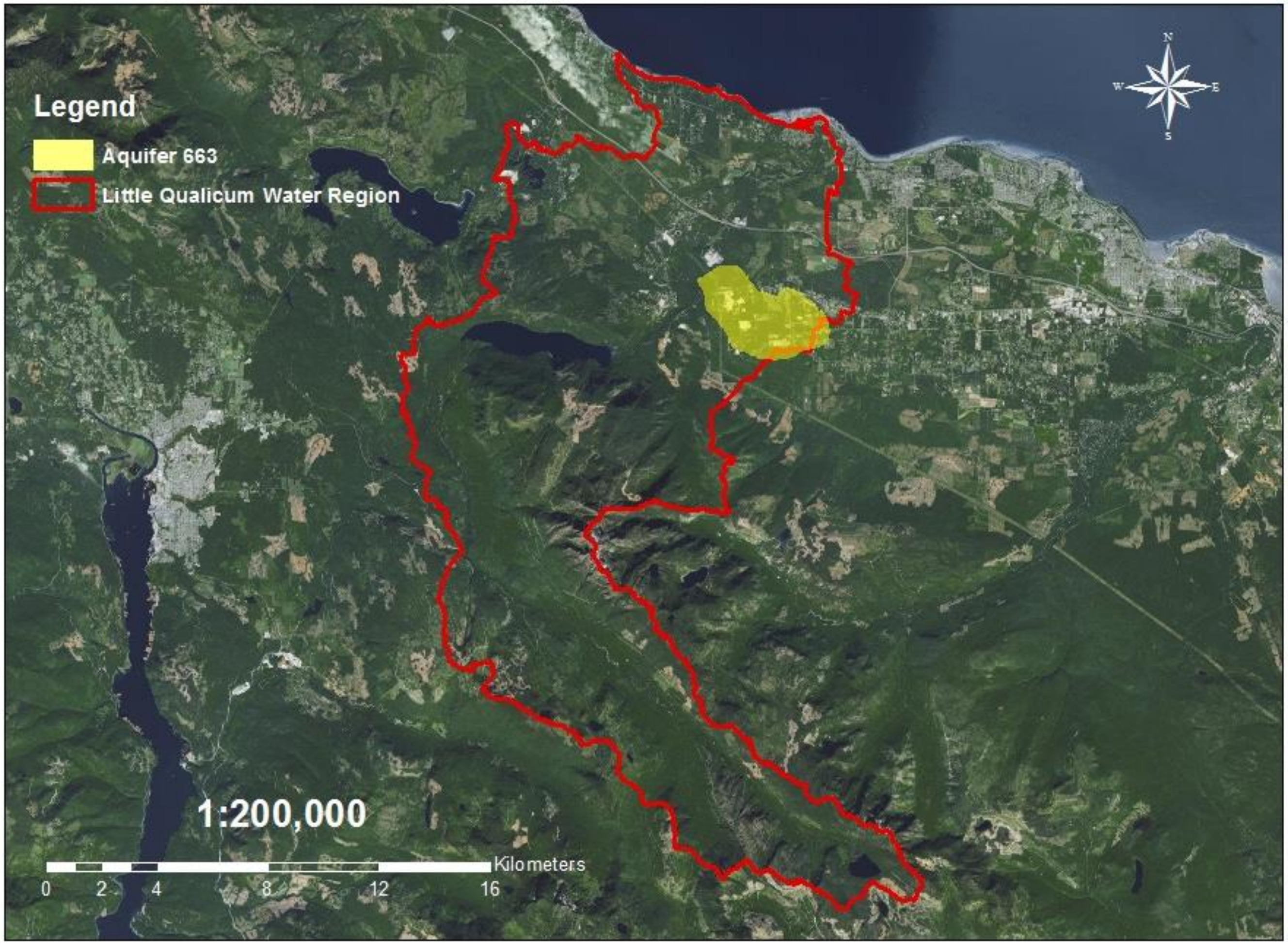

Figure 13: Vashon Drift Aquifer 663
Source: Imagery obtained from Esri’s online basemap database.

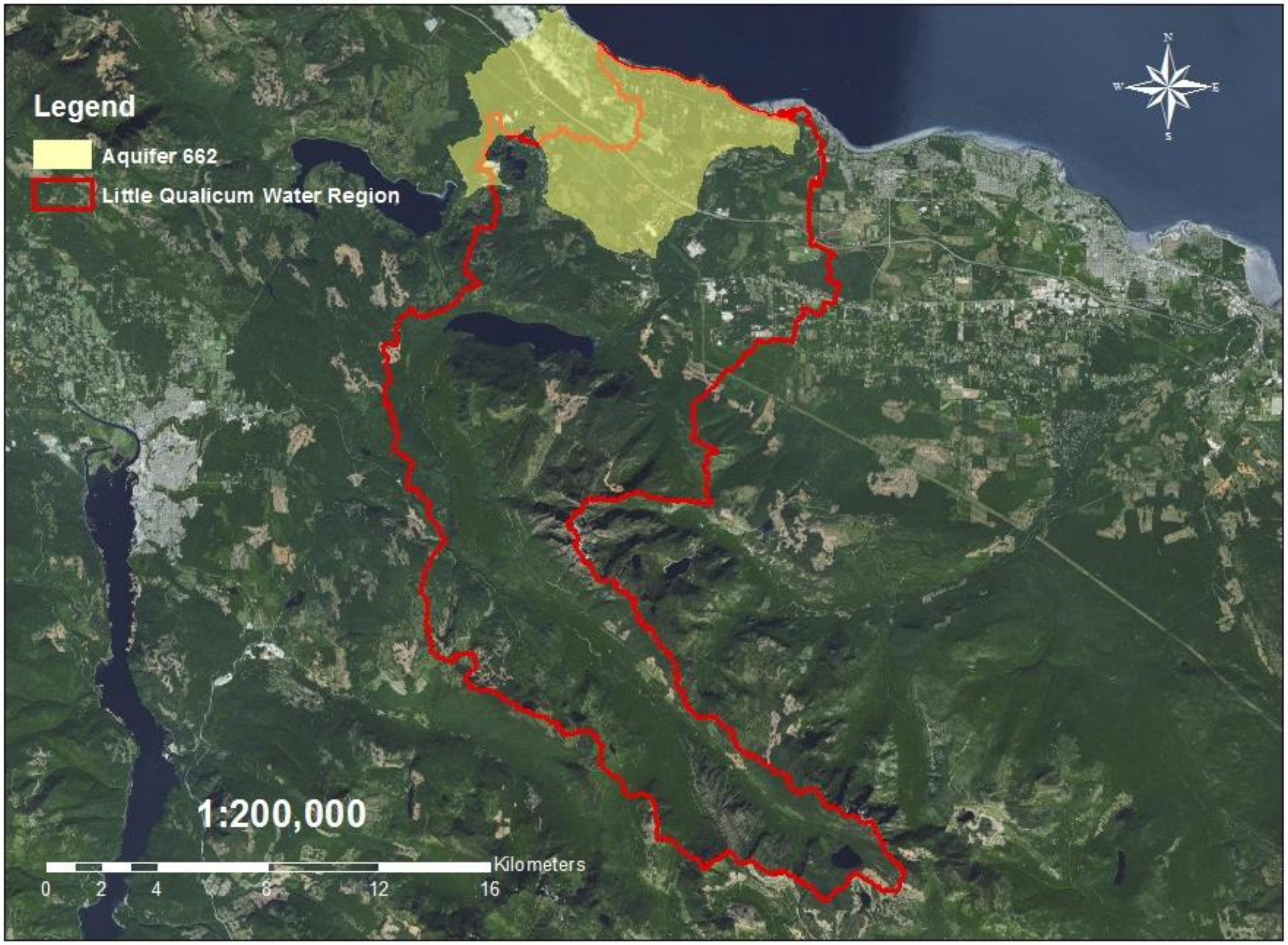

Figure 14: Quadra Sands Aquifer 662
Source: Imagery obtained from Esri’s online basemap database.

Appendix C

Aerial Photographs of WR2-LQ-02 & WR2-LQ-03 in the Little Qualicum Water Region

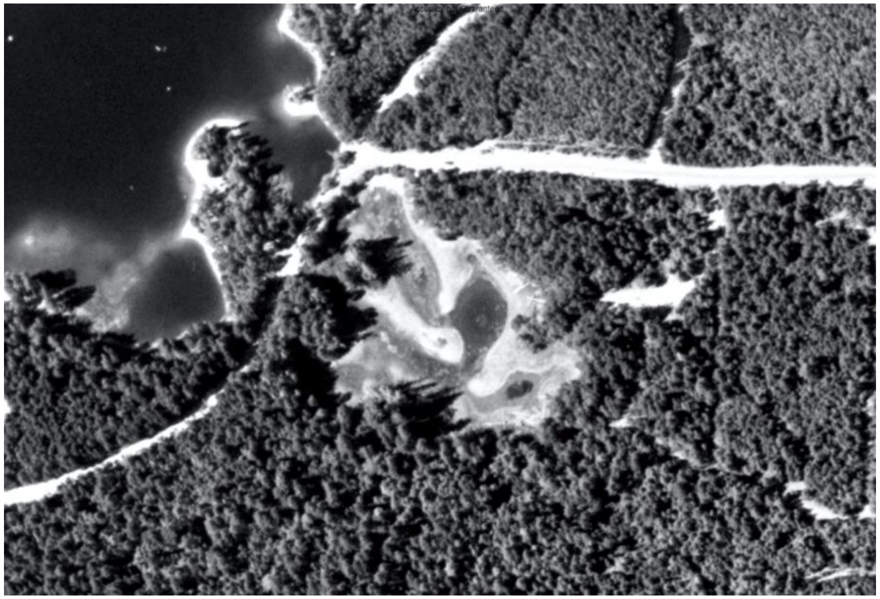

Figure 15: WR2-LQ-02, 2002
Source: Imagery obtained from Esri's online basemap database.

Figure 16: WR2-LQ-02, 2005
Source: Imagery obtained from Esri's online basemap database.

Figure 17: WR2-LQ-02, 2007
Source: Imagery obtained from Esri's online basemap database.

Figure 18: WR2-LQ-02, 2009
Source: Imagery obtained from Esri's online basemap database.

Figure 19: WR2-LQ-02, 2011
Source: Imagery obtained from Esri's online basemap database.

Figure 20: WR2-LQ-02, 2012
Source: Imagery obtained from Esri's online basemap database.

Figure 21:WR2-LQ-02, 2014
Source: Imagery obtained from Esri’s online basemap database.

Figure 22: WR2-LQ-02, 2016
Source: Imagery obtained from Esri’s online basemap database.

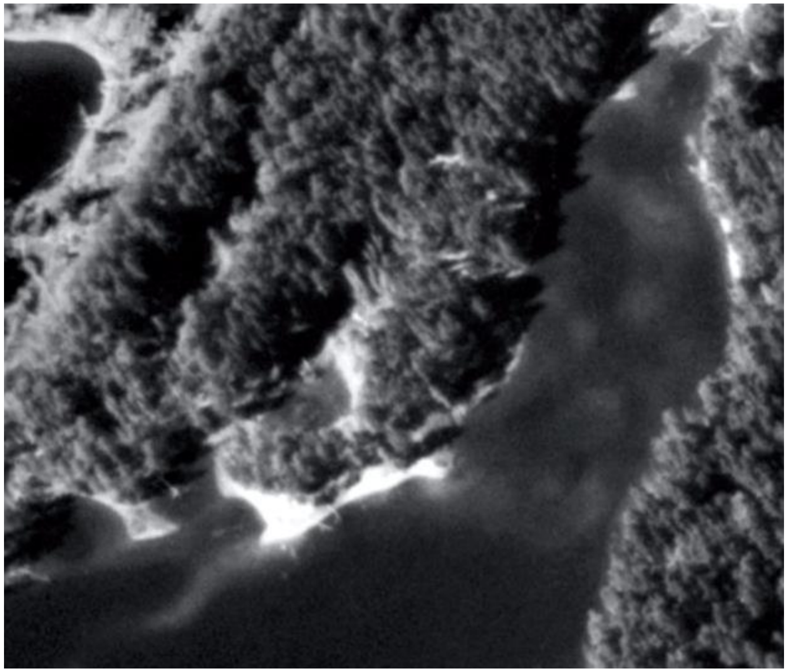

Figure 23: WR2-LQ-03, 2002
Source: Imagery obtained from Esri's online basemap database.

Figure 24: WR2-LQ-03, 2005
Source: Imagery obtained from Esri's online basemap database.

Figure 25: WR2-LQ-03, 2007
Source: Imagery obtained from Esri's online basemap database.

Figure 26: WR2-LQ-03, 2009
Source: Imagery obtained from Esri's online basemap database.

Figure 27: WR2-LQ-03, 2011
Source: Imagery obtained from Esri’s online basemap database.

Figure 28: WR2-LQ-03, 2012
Source: Imagery obtained from Esri’s online basemap database.

Figure 29: WR2-LQ-03, 2014
Source: Imagery obtained from Esri’s online basemap database.

Figure 30: WR2-LQ-03, 2016
Source: Imagery obtained from Esri’s online basemap database.