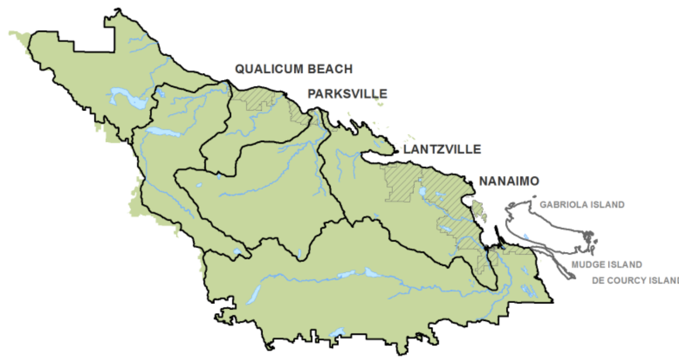
Water Budget Project: RDN Phase One (Vancouver Island)



Submitted To:

REGIONAL DISTRICT OF NANAIMO

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Submitted By:

Waterline Resources Inc.
Nanaimo, BC
June 17, 2013

Project No.: 1924-11-001

ACKNOWLEDGEMENTS

The RDN Phase One Water Budget Study (Vancouver Island) was a joint effort completed by the Waterline Resources Inc., KerrWood Leidal and Associates, and Regional District of Nanaimo staff. Waterline wishes to thank the RDN for their assistance and support throughout this very interesting and challenging project. Special thanks to Christina Metherall, Tom Sohier, Maury Scott, and Pam Newton for providing historical water-related data and assistance in coordinating the project. Waterline also wish to extend our gratitude to Mike Donnelly, Dawn Keim, and Pat Lapsevic, as well as other TAC committee members for a thorough review of a rough first draft and providing valuable comments which greatly improved the final report. We also wish to acknowledge and thank staff at the GSC and the Ministry of Agriculture for their contributions to the geological and the water demand aspects of the water budget project.

On behalf of Waterline management we wish to also acknowledge all Waterline staff who worked tirelessly on the RDn project and came up with innovative ways to deal with the often poor quality and challenging data. Key Waterline staff who helped deliver the project include Matt Skinner, Spring McCaskill, and David van Everdingen. Without their extra effort and dedication which at times went beyond the call of duty, it would not have been possible to complete the project.

EXECUTIVE SUMMARY

The Regional District of Nanaimo is a rapidly growing region on Vancouver Island where the land base is primarily rural, with several expanding urban areas. Projections indicate that the population in the RDN will increase 49% by the year 2031. During this time, climate change is predicted to cause irregular weather patterns that include longer, hotter and drier summers. Present data indicates that water levels may already be dropping in some water supply aquifers, causing reduced flows in rivers and associated ecosystem impacts. The RDN has initiated a Drinking Water and Watershed Protection Program (DWWP) in an attempt to ensure sufficient, safe and sustainable supply of water exists for present and future residents. As part of its mandate, the DWWP was seeking to develop an understanding of the current water demands, the stresses placed on rivers/creeks and aquifers by human activities, as well as long-term effects of changing climate conditions within the RDN. The water budget project was initiated as a preliminary assessment of water use practices within each of the six water regions and to develop water management and monitoring strategies that will help ensure sustainability of water resources for future generations.

The primary objective of the RDN Water Budget Project was to develop a better understanding of the surface and groundwater flow systems within the RDN. In order to meet the intent of the study, compilation of available information into a comprehensive electronic geodatabase was completed by Waterline. The electronic information was used to develop conceptual models of the hydrogeology within each of the six water regions within the RDN. This information was needed in order to assess the water movement and exchange between various watershed elements including rivers/creeks, lakes, and groundwater aquifers.

The Phase one water budget assessment was an initial attempt to consider the inputs and outputs from the surface water and groundwater systems using existing data on a water region basis. The geodatabase developed by Waterline was used to construct two and three dimensional hydrological and hydrogeological images in order to visualize and understand how surface features and activities relate to subsurface aquifers. The compiled data, in conjunction with water use data developed by the RDN, was used to assess the level of stress on each of the six water regions and 28 mapped aquifers across the Vancouver Island area of the RDN. The following table provides a summary of the results of the conceptual water budget assessments completed as part of the study.

Water Region		Watershed or Aquifer Tag No.	Aquifer Material	Aquifer Location	Relative Stress Level
Big Qualicum (BQ)	WR1	Nile Creek	NA	NA	Low
		Big Qualicum River	NA	NA	Low
		416	Quadra	North of Thames Creek	Low
		421	Quadra	Between Nile and Thames	Moderate to High
		665	Capilano	Over Quadra between BQ and Thames	Low to Moderate
		662	Quadra	South of BQ and into LQ	Low to Moderate
Little Qualicum (LQ)	WR2	Little Qualicum River	NA	NA	Moderate
		662	Quadra	North of LQ to BQ	Low
		661	Kame	South of LQ at upper Kinkade Creek	Moderate
		664	Salish	Along LQ River Valley to ocean	Low
		663	Kame	Upper Whiskey Creek	Moderate to High
		217	Quadra	South of LQ and into WR3	Moderate to High
French Creek (FC)	WR3	French Creek	NA	NA	High
		220	Bedrock	Upper FC, Coombs/Errington and area	Low to Moderate
		216	Quadra	Upper Parksville, North/South of Hwy 1	High
		217	Quadra	Qualicum Beach, between LQ and FC	High
		212	Bedrock	Along the coast in Parksville to FC	Moderate
Englishman River (ER)	WR4	Englishman River	NA	NA	Moderate
		209	Quadra	Upper ER near Morison/Swan Creeks	Low to Moderate
		220	Bedrock	Upper ER under Aq. 209	High
		216	Quadra	Lower Parksville to ER	Moderate to High
		219	Quadra	East of ER and extends into WR5	Low to Moderate
		214	Bedrock	East of ER along coast	Low
		221	Salish	ER Valley to Ocean	Moderate
South Wellington to Nanoose (SW-N)	WR5	Nanoose Creek	NA	NA	High
		Millstone River	NA	NA	Low to Moderate
		Chase River	NA	NA	Moderate to High
		219	Quadra	Nanoose area	Low
		214	Bedrock	Nanoose underlying Quadra Aq. 219	Low
		210	Bedrock	Nanoose Creek	Moderate to High
		218	Bedrock	Nanoose Penninsula	V. High
		213	Bedrock	Lantzville underlying Quadra Aq. 215	Low
		215	Quadra	East Lantzville, North Nanaimo	Moderate to High
		166	Bedrock	Stephenson Point, North Nanaimo	Low
		211	Bedrock	Benson Meadows	V. High
		167	Quadra	Westwood to Divers Lake above Hwy 1	Low to Moderate
Nanaimo River (NR)	WR6	Nanaimo River	NA	NA	Moderate to High
		160	Vashon	Lower Cassidy Aquifer	Moderate to High
		161	Capilano	Cassidy Aquifer-Nanaimo River Valley	Moderate to High
		162	Bedrock	Cedar and Yellowpoint	High
		163	Quadra	East of Holden Lake	V. High
		164	Bedrock	South of Extension	Moderate to High
		165	Bedrock	South Wellington	Moderate

Notes: Aquifer stress color codes: blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high, NA means not applicable.

Major watersheds within the RDN exhibiting moderately high to high apparent stress include the following:

- French Creek,
- Nanoose Creek,
- Chase River, and
- The Nanaimo River.

Mapped aquifers exhibiting moderately high to high or very high apparent stress include the following:

- Quadra Sand Aquifer 421 located in WR1 (BQ) adjacent to Nile Creek,
- Haslam Formation Bedrock Aquifer 220 which extends across 3 regions including WR1 (BQ), WR2 (LQ), and WR3 (FC),
- Vashon (Kame) Aquifer 663 at the top of Whisky Creek in WR2 (LQ),
- Quadra Sand Aquifer 217 extending from WR2 (LQ) to WR3 (FC),
- Quadra Sand Aquifer 216 in WR3 (FC) and extending into WR4 (ER),
- Buttle Lake Group Bedrock Aquifer 210 in upper Nanoose Creek,
- Benson Formation bedrock Aquifer 218 located on the Nanoose Peninsula,
- Quadra Sand Aquifer 215 beneath the District of Lantzville,
- Vancouver Group and Nanaimo Group bedrock aquifer 211 located at Benson Meadows,
- Upper Cassidy (Capilano) Aquifer 161,
- Nanaimo Group bedrock Aquifer 162 located in the Cedar-Yellow Point Area, and
- Quadra Sand Aquifer 163 located in an isolated pocket in the Cedar area.

Due to the regional nature of the study and the limited monitoring data available only qualitative water budget assessments could be completed at this time. The water budget estimates provide a relative comparison from region to region or aquifer to aquifer, rather than actual values of water availability or water use which are needed for quantitative land use planning and design. In addition, it should also be noted that local issues cannot be fully addressed at the regional scale of assessment and the enclosed report should therefore not be relied upon for determining the suitability or future sustainability of new projects or developments with respect to surface water or groundwater supply.

Waterline recommends that the RDN select one or two water regions to complete more detailed water budget assessments in accordance to the Ontario Ministry of Natural Resources Tier 1 or Tier 2 level assessment which was used by Waterline as a guide for the RDN project. This will allow the RDN to further develop the geodatabase for future quantitative water planning in all water regions across the RDN. Waterline recommends that the RDN select a water region within the Nanaimo Lowland area so that numerical modelling currently underway by the Geological Survey of Canada can be used to further refine aquifer water budget estimates in this area. Given the stress assessment for both surface and groundwater, the French Creek Water Region may be a suitable candidate for a pilot study which is recommended by Waterline.

The geodatabase structure developed by Waterline is intended for use by the RDN to develop a secure web application where surface water and groundwater information can be made available to the public. This will allow water managers and practitioners to have current and consistent data for use in water and environmental-related projects within the RDN which should allow for the advancement of knowledge with respect to water management and protection. It is anticipated that the web-based user interface would initially be similar to the RDN Water Map where key reports, maps and datasets are made available on-line. As the web interface is further developed, it should be possible for users to upload electronic groundwater and surface water data on-line. The data could include monthly/annual water use, water levels, water chemistry, aquifer properties interpreted from pumping test analysis, cross-sections, time-series data, hyperlinks to raw data, and a geo-referenced copy of any final reports. The RDN will likely need to develop guidelines, policies, and templates for data collection and submission as part of their planning and watershed management initiatives.

Surface and groundwater are renewable resources but a balance must be struck between water needed to maintain healthy ecosystems and the demand for water by humans. Although the Phase One Water Budget project sets the framework for assessing water availability versus water demand, considerable gaps in the data exists which need to be filled in order to provide a more accurate picture of current and future surface water and groundwater conditions. The objective in water management is to achieve “sustainability" of water resources. This is simply not possible in the absence of accurate monitoring data (measured surface and groundwater use, stream flow, water levels, aquifer hydraulic parameters, water quality, etc.). The geodatabase developed as part of the project represents a fundamental first step to establishing a “living” data system in order to improve water management planning practices for each water region within the RDN. The cooperation of residents, water purveyors, drillers, water practitioners, corporations, municipal/provincial/federal regulatory officials is now needed to move towards a sustainable water future.

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1.0 INTRODUCTION

1.1 Background and Scope

The Regional District of Nanaimo (RDN) is located on the east coast of Vancouver Island and extends from about Cedar in the south to Deep Bay in the north (Figure 1). The RDN is divided into seven water regions, one of which includes Gabriola, Mudge, and DeCourcy Islands which is the subject of another study. The enclosed document focuses on the development of a water budget for the six regions located on Vancouver Island defined by watershed drainage rather than political boundaries.

The Vancouver Island portion of the RDN includes City of Nanaimo which has a population of approximately 80,000 people. Several towns, districts, and smaller unincorporated communities with the RDN have an aggregate population of approximately 25,000 people. The total population of the RDN is estimated to be approximately 146,574 (RDN, 2011). Most of the residents live and work within the Nanaimo Area Lowlands, typically at elevations less than 250 metres above sea level (mASL). The uplands are primarily private forest land with active logging operations.

The RDN is a rapidly growing area where the land base is primarily rural, with several expanding urban areas. Projections indicate that the population in the RDN will increase 49% by the year 2031 (HB Lanarc, 2010). During this time, climate change is predicted to cause irregular weather patterns that include longer, hotter and drier summers. Present data indicates that water levels may already be dropping in some water supply aquifers, causing reduced flows in rivers and associated ecosystem impacts (HB Lanarc, 2010). As a result, the RDN has initiated a Drinking Water and Watershed Protection Program (DWWP) in an attempt to ensure sufficient, safe and sustainable supply of water exists for present and future residents (RDN Website: www.rdn.ca).

The RDN's DWWP program has a mandate to protect drinking water and watershed health by developing an understanding of local water resources and using this information to make informed land use decisions and to promote community stewardship. To accomplish the DWWP mandate, it is important to understand how much water is available within the six water regions and mapped aquifers identified over the Vancouver Island portion of the RDN. There is also a need to understand the current and future demand for water, how land use and climate change will impact water resources and the general health of watersheds within the RDN.

In February 2012, Waterline Resources Inc. (Waterline) was retained to complete the Phase 1 Water Budget study for Vancouver Island. Kerr Wood Leidal and Associates Limited (KWL) have been sub-contracted to Waterline to assess surface water for this project. A water budget assessment is an attempt to consider all the inputs and outputs from the surface water and groundwater systems to assess if water is being used sustainably, or being overused. As all water inputs to both surface and groundwater systems within the RDN comes from precipitation, either as rain or from the mountain snowpack, climate data is very important to complete accurate water budget estimates. The interaction between different systems, i.e. exchanges between aquifers and rivers, and both natural and anthropogenic discharges from the system must be understood to facilitate a preliminary water budget. The enclosed report summarizes the results and conclusions of the Waterline study.

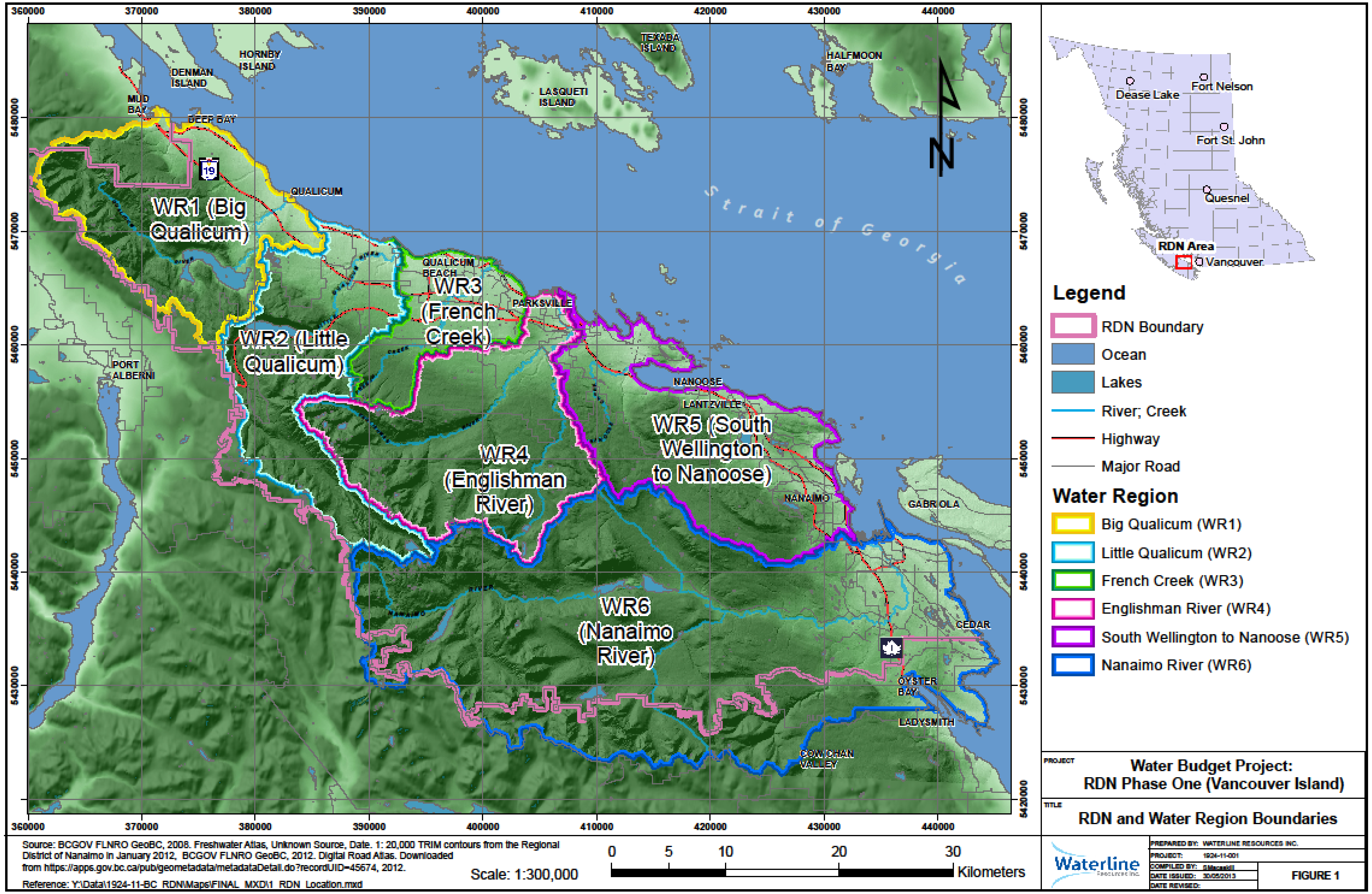


Figure 1: RDN and Water Region Boundaries

1.2 Study Objectives and Goals

The primary objective of the RDN Phase 1 Water Budget Project was to develop a better understanding of the interactions between rivers/creeks, lakes, and groundwater aquifers across the RDN. In order to meet the objective of the study, compilation of available hydrology[1] and hydrogeology[2] information into a comprehensive electronic geodatabase was completed by Waterline. The electronic information was then used to develop an up-to-date conceptual model of each region to assess water movement and exchange between various watershed elements including rivers and creeks, lakes, and aquifers. An important aspect of the study was to assess environmental controls on surface water and groundwater availability such as climate, topography, soil/geology, land cover, aquifer geometry, etc. and how they affect the water balance in each region.

As part of the water budget assessment, the determination of the availability of water needed to maintain natural ecosystems and community water supplies was also required. The study aimed to develop an understanding of the current water demands, the stresses placed on rivers/creeks and aquifers by human activities, as well as long-term effects of changing climate conditions. The ultimate goal of the project was to determine the sustainability of current and possibly future water use practices in each water region and to identify uncertainties and data gaps in the analysis. Recommendations are also included to improve input parameters for water budget estimates and to develop surface water and groundwater monitoring strategies that will help ensure sustainability of water resources for future generations.

1.3 Scale of Assessment - Conceptual Water Budget

In order to complete the RDN's Phase 1 Water Budget project, Waterline followed the approach previously applied by the Ontario Ministry of Natural Resource (OMNR) for water budget assessment in that province which requires increasing level of complexity with each tier of assessment (OMNR, 2011). The following lists the approach and the level of analysis required at each Tier level:

1. Conceptual Water Budget (RDN Project):
   - Characterization and visualization;
   - Watershed or Water Region Scale.
2. Tier 1 Water Budget RDN Project (Partially):
   - GIS-based Water Budget
   - Supply, Demand, Stress Assessment (RDN Project but preliminary)
   - Subwatershed Scale
3. Tier 2 Water Budget:
   - 3D GW Flow or continuous SW Flow Model;
   - Subwatershed scale
4. Tier 3 Water Budget:
   - 3D GW Flow or continuous SW Flow Model;
   - Water Quantity Risk Assessment;
   - Local scale (well capture, GW protection zones).

[1] The study of surface water
[2] The study of subsurface water or groundwater

It must be cautioned that the RDN Water Budget project is a regional study intended as a high level water budget assessment for many of the watersheds and aquifers within the six water regions on Vancouver Island. As a result, calculations presented herein are conceptual in nature and only serve to provide an assessment of the linkages between various water resource elements. Local issues may not be fully addressed at the current scale of assessment. However, these will be considered in the future as the RDN progresses through each Tier level (OMNR 2011) from the water region scale (100’s of watersheds), to individual watersheds, and finally to the subwatershed scale where more detailed and complex water budget calculations can be completed.

Although water budget and stress calculations presented herein may appear quantitative, they should only be considered as qualitative. The water budget estimates provide a relative comparison from region to region or aquifer to aquifer, rather than actual values of water availability or water use which are needed for quantitative land use planning and design.

1.4 Report Terminology and References

Wherever possible, Waterline has attempted to use non-technical language in the enclosed report. However, where this may not have been possible, a footnote has been added to the bottom of the page to further describe the term and a glossary of terms provided in Appendix A. Data and references provided by the RDN and used in the water budget analysis are summarized in the bibliography provided in Appendix B.

2.0 METHODOLOGY AND APPROACH TO WATER BUDGET STUDY

2.1 ARC-GIS Geodatabase Development

The first task for the RDN Phase One Water Budget project was to assemble existing surface water and groundwater data previously collected across the RDN into a single, centralized Geodatabase. The data was compiled in a consistent format that would allow the Waterline team to complete water budget assessments. The intent was to develop a “living system” whereby the state of knowledge on surface and groundwater systems within the RDN could be expanded with every new study. With this tool, data and water management guidelines may be developed to elevate the accuracy of water budget estimates that will ultimately be used for making land use decisions.

Numerous groundwater-related studies have been completed in each region in relation to the existing well fields and mapped aquifers in the region. However, the data existed in various formats (mostly paper) and needed to be synthesized and integrated into a consistent electronic format by Waterline so that surface and subsurface information could be considered concurrently as part of the Phase One Water Budget Project. Files were reviewed by Waterline and data extracted as required for use in the analysis (E.g.: aquifer transmissivity/storativity values (Carmichael 2012), water levels, information on groundwater flow, etc.). As a result, individual sources of data could not all be referenced in the body of this report but are listed in the attached bibliography provided in Appendix B.

The bibliography provides a complete list of reports and files on individual projects completed by the RDN, consultants, land developers, and commercial operations over many years. The information was used by Waterline wherever possible to complete the water budget analysis. Although Waterline made every effort within the scope of the study to compile the data provided in our ARC GIS Geodatabase, it was not always possible to capture all of the data given the amount and condition of the information. Waterline's main focus was to construct the ARC GIS Geodatabase so that it could accommodate any future data that should be requested by the RDN in a consistent electronic format. The database was then populated with the critical datasets needed to complete the conceptual water budget estimates at the current regional scale of assessment.

The database developed by Waterline was used to construct two and three dimensional hydrological and hydrogeological images so that both scientific and non-scientific readers can visualize and understand how surface features and activities relate to subsurface aquifers. The compiled data, in conjunction with water use and demand data developed by the RDN, was used to assess the level of stress on each of the six water regions and 28 mapped groundwater aquifers across the Vancouver Island area of the RDN. The mapped aquifers within the six water regions are shown on Figure 2.

The RDN Water Budget project is expected to greatly benefit the people who live and/or work within the RDN as it forms the foundation for understanding the present and future availability and demand for fresh water. The project outcome allows the RDN to plan for future development in a way that contributes to protection and management of groundwater and surface water resources not previously available. The Phase 1 project provides the RDN with the ability to electronically update hydrologic/hydrogeologic data as it becomes available. Although more work is required to make this information available to the general public and water practitioners through an on-line secure user interface, the framework has been established and will require the future cooperation of all water providers and users to allow for sustainable management of fresh water resources within the RDN.

2.2 Available Information and Concurrent Projects

A significant amount of groundwater and surface water information exists within the six defined water regions within the Vancouver Island area of the RDN. However, the data was in various formats and needed to be synthesized and integrated into a consistent electronic format so that surface and subsurface information could be considered concurrently. Over 750 water-related studies/reports/files previously completed by the RDN, consultants, land developers, and commercial operations were provided to Waterline as part of the Water Budget project (see list in Appendix B).

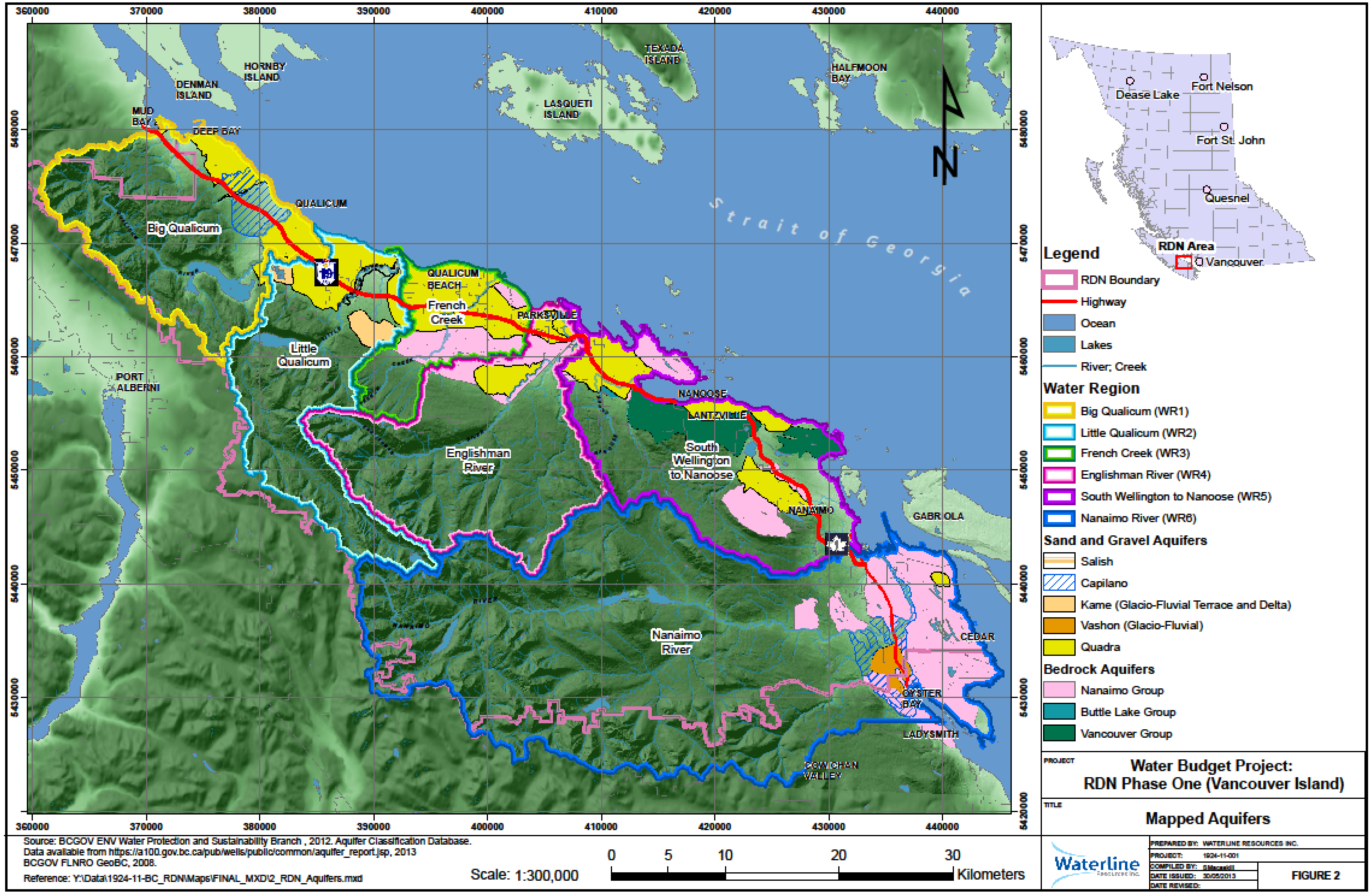


Figure 2: Mapped Aquifers

The RDN and other groups have undertaken concurrent activities relating to the collection of water data through the installation of new observation wells, geological mapping, aquifer mapping, monitoring of private wells, and stream flow monitoring as part of an outreach program with local stewardship and community groups. Some additional studies that could significantly impact the outcome of the water budget project include the following:

- The Geological Survey of Canada (GSC) has initiated an assessment of the groundwater resources as part of their Nanaimo Lowlands Project (Metherall, Pers. Comm. 2011). This project will update the Parksville area surficial geology mapping (Fyles 1963), conduct geophysical surveys to assess subsurface geology, complete a drilling and well installation program, and develop a numerical groundwater model of the Quadra Sand aquifer(s) in the area extending from the Englishman River to Deep Bay.
- The BC Ministry of Agriculture and Lands (MAL) is also working on a project for the RDN to establish an agricultural water demand model previously developed for the Okanogan Region for use in estimating agricultural water requirements within the RDN.
- In 2011, BC Ministry of Environment (MOE) retained Worley Parsons (Ronneseth, Pers. Comm. 2012), Pers.to update all the aquifer maps across the RDN; however, the updates were not released by MOE until late in the fall of 2012.
- Waterline understands that MOE in partnership with the RDN are also in the process of expanding its observation well network across the RDN.

Waterline has made every effort to include available information from these relevant projects into the Phase 1 Water Budget project. However, as of the writing of this report, all studies were on-going and incomplete, or Waterline's work was too far advanced and not all data could be integrated into the project. However, results of the studies indicated should be incorporated into the Waterline Geodatabase once the investigation phase is complete.

Another important project within the RDN is being undertaken by Englishman River Water Service (ERWS) who is currently investigating the suitability of an Aquifer Storage and Recovery (ASR) concept (Lowen Hydrogeology, 2010). The ASR project involves surface water diversion from the Englishman River during high flow periods in the winter, treatment, and re-injected into an underlying sand and gravel aquifer (Aquifer # 219) to the east of the Englishman River. The intent of the ASR project is to provide temporary storage of fresh water for later recovery and use during the drier season when rivers and aquifers may be under greater stress. This study is specific to one aquifer and, although important from a water supply perspective, it does not significantly affect the outcome of the Phase Water Budget project. The ASR Study results should be incorporated into the Waterline Geodatabase once the investigation phase is complete.

For surface water hydrology, several data sources have been used to develop estimates of surface water runoff, aquifer recharge and surface water demand including:

- Climate Data from stations operated by Environment Canada;
- Gridded climate data from the Climate NWA model developed by the UBC Faculty of Forestry;
- Continuous stream flow and water level data from stations operated by Water Survey of Canada, and Ministry of Environment;

- Discrete summer low-flow stream flow data from Ministry of Environment and BC Conservation Foundation;
- Surface water license information from the BC Ministry of Forest, Lands and Natural Resource Operations;
- Surface water withdrawal data from water license holders including City of Parksville, City of Nanaimo, and Harmac;
- Water Allocation Reports prepared by Ministry of Environment; and
- Other reports pertaining to surface water hydrology for watersheds within the NRD.

Details of the climate and hydrometric stations for each of the water regions are outlined in each of the specific sections below. A listing of all reports is available in the references section.

2.3 Data Compilation

A considerable amount of data was compiled to produce the maps needed to complete water budget calculations. It should be noted that any data received and compiled by Waterline as part of the present study were assumed to be correct and have not otherwise been verified by for quality or accuracy other than what could be assessed as part of the development of conceptual models for each region. There may be a need for further verification of the data used to develop the conceptual models if interpretations and analysis conflict with other information, or interpretations not considered as part of the study. In addition, as new data becomes available and a more comprehensive understanding of surface water and groundwater flow systems is developed, the enclosed conceptual models will need to be updated accordingly.

2.4 Conceptual Water Budget Model Development

2.4.1 The Water Cycle

The water cycle is fundamental to the understanding of how water exchange occurs between surface water features and subsurface aquifers. Figure 3 shows the various natural elements of the water cycle which must be considered in the water budget analysis.

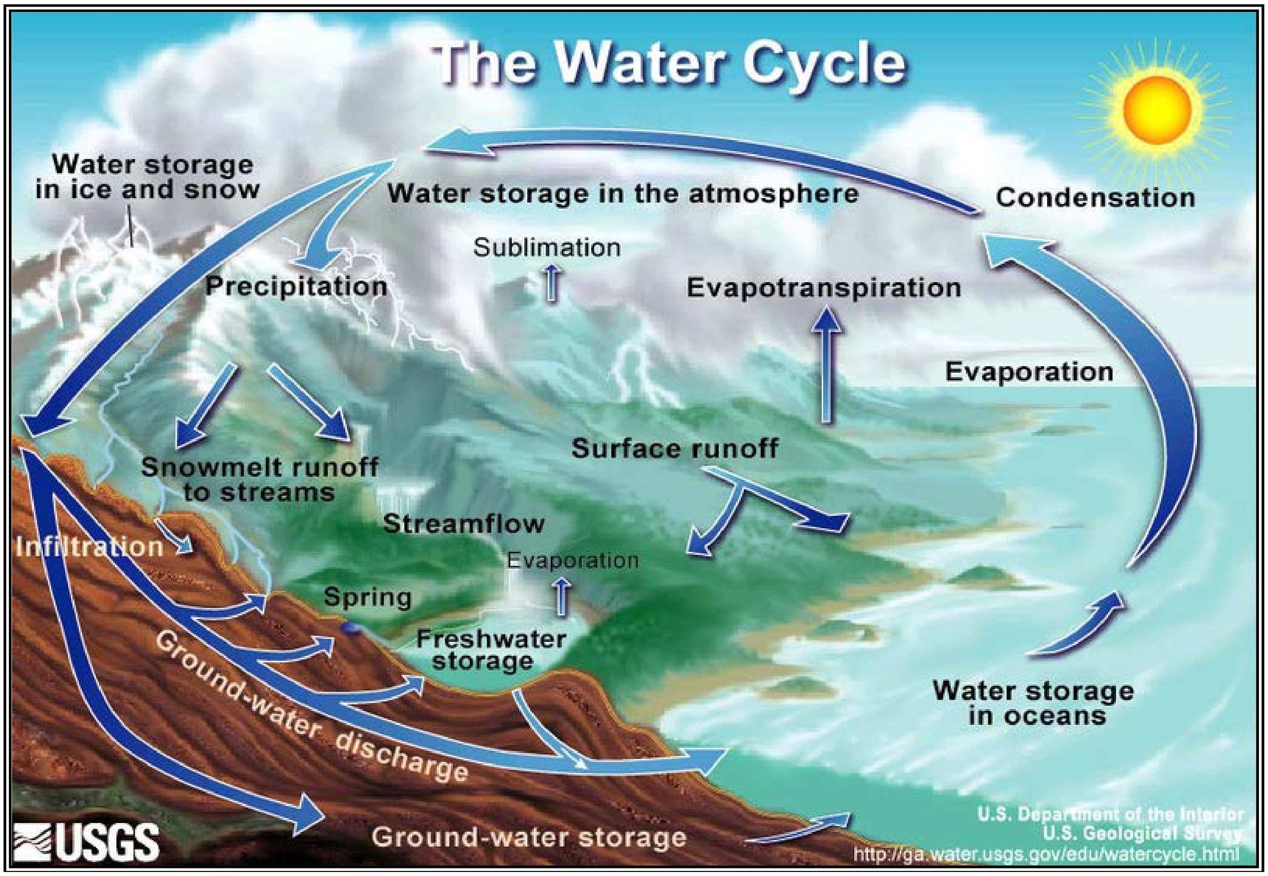


Figure 3: Water Cycle Schematic.

The water or hydrologic cycle illustrates how water moves from the land, to the atmosphere, and back to the land. Figure 3 shows how water evaporates from the ocean and other surface water bodies (rivers, creeks, lakes, ponds, and ocean) into the atmosphere forming clouds which eventually condense and fall back to the earth as rain or snow. Sublimation is when solid-phase snow or ice evaporate directly to water vapor (gas phase) with no intermediary liquid phase. Transpiration is a process whereby plants take up water directly for growth. Rain or snow that falls to the earth then moves from one reservoir to another, such as from snow and ice stored in the mountains, percolating into the subsurface to become groundwater and then discharges back to the surface feeding rivers and lakes and ultimately flows down slope and discharges into the ocean.

The water cycle purifies the water and replenishes freshwater sources on the land, and in the process transports nutrients and minerals from one part of a watershed to another which is vital for maintenance of natural ecosystems. In the process, water flow over the land reshapes geological features by processes such as erosion and sediment deposition. Elements of the water cycle need to be understood in order to develop water budgets for surface and groundwater (aquifer) systems which exist within the RDN.

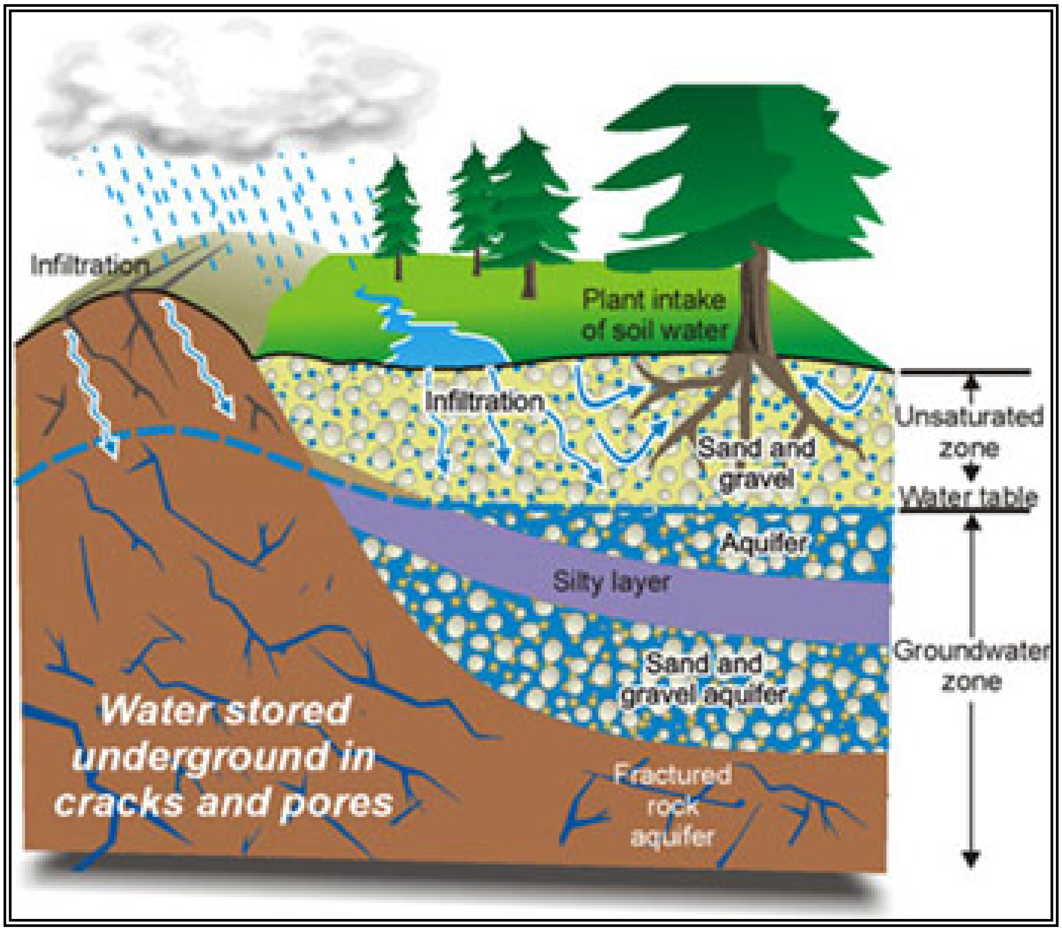
2.4.2 Surface Water

Using existing information, the Waterline team developed conceptual models to help describe the overall water flow system dynamics for each water region in the RDN. A basin wide approach was taken where the surface and groundwater basins were initially characterized by prominent drainage features (watersheds). Figure 1 shows that the actual RDN boundary in the northernmost and southernmost water regions (Big Qualicum and Nanaimo River) does not extend to the water region boundary. Although the RDN has no jurisdiction over these areas, the water budget assessment needed to be completed at the basin scale which extends beyond the RDN boundaries in the north and the south.

Using available stream flow and climate data, estimates of monthly and annual runoff from each of the major watersheds was completed to assess the seasonality of water availability. Stream flow estimates were developed using a regional hydrology approach in which naturalized stream flow records were adjusted to account for water withdrawals and/or storage in the watersheds. Estimates of stream flows in un-gauged watersheds were developed based on physical watershed characteristics. The summer stream flow estimates were verified wherever possible using available base flow measurements in creeks and rivers. This approach is similar to the approach used to develop the BC MOE Water Allocations Plans (Boom and Bryden, 1994; Braybrook et. al., 1995; Bryden et. al., 1994; Pirani and Bryden, 1996; Bryden et. al., 1994; and MoELP, 1993) and provides an assessment of surface water availability in the major watersheds and allows for completing watershed stress assessment.

2.4.3 Groundwater Aquifers

Figure 4 shows a cross-section schematic through the earth were various types of subsurface aquifers may be developed as the water cycle (Figure 3) replenishes groundwater systems through a process known as infiltration either into permeable bedrock or permeable sediment exposed at the ground surface. An aquifer is described as a geologic unit that can transmit useable quantities of groundwater to a well. A fractured bedrock aquifer is formed when a series of interconnected fractures exists that can store and transmit water. Unconsolidated, sand and gravel aquifers store water between the sediment grains (blue color between white sand and gravel, Figure 4) and coarse sand and gravel deposits can form high water yield aquifers as is observed across the RDN. The unsaturated zone occurs above the water table and aquifers that are in direct contact with the atmosphere are known as unconfined aquifers. If a layer of silt or clay (purple layer, Figure 4) covers the saturated sand and gravel or fractured bedrock aquifer then the aquifer is considered to be confined (or semi-confined) from the atmosphere and referred to as a confined aquifer.



Source: RDN

Figure 4: Cross-Section Schematic Ilustrating Groundwater and Aquifers.

A significant amount of groundwater and surface water information exists within the six defined water regions that make up the RDN study area. The RDN has made considerable progress in assembling this information into an ARC-GIS system which is now available on-line in the RDN Water Map. However, the data had not been full synthesized and integrated, with respect to subsurface geology and/hydrogeology and assessment of linkages to surface water resources.

In addition to the numerous individual water-related studies that have been completed, the RDN was undertaking concurrent activities relating to collection of water data in partnership with the six local stewardship groups, which includes community development and outreach programs. The Geological Survey of Canada is also conducting an assessment of the groundwater resources including a numerical groundwater model for the area from the Englishman River to Deep Bay which is referred to as the Nanaimo Lowlands Aquifer study (Metherall, Pers. Comm., 2011). In addition, the Englishman River Water Service (ERWS) is investigating geology in the Nanoose area for an Aquifer Storage and Recovery (ASR) project. The BC Ministry of Agriculture and Lands has also developed a Water Demand Model similar to the one for the Okanagan Water Supply and Demand Project (MAL, 2013). Wherever possible, Waterline attempted to integrate concurrent activities being conducted by the RDN, the GSC, ERWS, and BC MAL with the Water Budget Project. However; it was not always possible to accomplish this as study schedules and objectives were not necessarily aligned by the RDN at the outset.

Developing a conceptual hydrogeological model of subsurface aquifers is a complex exercise that involves integrating numerous key datasets including, but not limited to, the following existing information:

- Topography/digital elevation maps,
- Climate data,
- Land cover information,
- Surficial and bedrock geology maps,
- Borehole geology and water level information,
- Aquifer mapping and vulnerability data,
- Aquifer properties including permeability and storage parameters,
- Long-term water level monitoring data, and
- Groundwater use (pumping) data where available.

All of these datasets were processed electronically so they could be entered into Waterline's Geodatabase. These data were then used to develop other maps and to profile the subsurface geology to facilitate an understanding of how the surface features interact with the subsurface geology. Key GIS layers produced as part of the project are presented in Appendix C. Using these and other datasets, it was then possible to develop three dimensional views of the subsurface, which form the conceptual aquifer models for each region. As there are 28 mapped aquifers across the RDN, over 6,000 water wells, and numerous water levels identified in the BC MOE WELLS database (BCGOV ENV Water Protection and Sustainability Branch, 2008), it was not possible to develop a continuous model for each water region. However; key areas were selected for 3D visualization in order to illustrate some of the more important inter-connections between surface water and groundwater systems across the RDN.

2.4.4 Regional Geology

Most of the landscape and landforms observed across the RDN resulted from glacial and interglacial processes operating during the last 50,000 years. The latest and largest glaciation was the Fraser Glaciation which started approximately 29,000 year before present (BP) due to a deteriorating (colder) climate. In southwestern BC, mountain glaciers formed between 19,000 and 30,000 BP before they advanced, coalesced, and thickened to create the maximum extent of the ice sheet that covered Georgia Strait nearly 15,000 BP. At this time, the ice surface was at about 2300 mASL and towered over 1000 m above the present-day peak of the Coast Mountain Range. After about 14,500 BP, the regional climate began to warm causing ice to melt and glaciers to retreat over the next 5,000 years (Clague, 1994).

During the advancement phase, glaciers from Vancouver Island flowed towards and coalesced with ice flowing south along the Salish Sea (present day Strait of Georgia), producing a large glacier lobe that extended down into the Puget Lowlands in Washington, USA. Quaternary sediments up to 300 m thick underlay the lowlands bordering the Strait of Georgia. Throughout this region, sediments were deposited during the glacial advance and retreat and in some areas during older glacial and intervening interglacial cycles. Loading and unloading of the ice sheet caused significant land rebound and sea level fluctuations. Along the Strait of Georgia, sea level rose up to almost 200 m above present-day sea level, leaving various marine deposits observed across the Nanaimo Lowlands and the Sunshine Coast at elevations up to 180 mASL (McCammon, 1975).

A description of the regional geology based on Fyles (1963) defines the overburden[3] geology and is shown in Appendix C (Maps C3 and C4). All geology data has been compiled electronically in Waterline's geodatabase and was considered in the construction of the conceptual hydrogeological model.

The main unconsolidated[4] deposits with the RDN include the following:

1. **Salish:** Recent shore, deltaic, and fluvial[5] deposits laid down by rivers and creeks and by wave action along coastal areas. These are colored very light yellow/cream on Fyles (1963) map shown in Appendix C (Map C3). The deposits contain gravel, sand, silt, clay and form local aquifers along river/creek and lake.
2. **Capilano:** Deltaic[6], and marine veneer deposits laid down during glacial retreat and ocean ingress over the Nanaimo Lowlands and coastal areas. These are colored light green and blue on Fyles (1963) map shown in Appendix C (Map C3). The extent of marine ingress can be seen across the RDN and generally is below 200 m ASL. The deposits contain sand, gravel, clay; and stoney clay, clay and silt and the coarser fractions form local unconfined[7] aquifers, whereas the finer clays and silts form aquitards[8].
3. **Vashon:** Glacial[9] fluvial material deposited during glaciation by surface and/or subsurface rivers and creeks formed with the retreat of ice sheets. The areas are colored orange on Fyles (1963) map shown in Appendix C (Map C3). The deposits contain sand, gravel, clay; and dense clay till. The coarser fractions form local unconfined aquifers, whereas the finer clays and silts form aquitards.
4. **Quadra:** Pro-glacial fluvial outwash materials deposited during glacial advance at the leading edge of the ice sheet. The areas are colored bright yellow on Fyles (1963) map shown in Appendix C (Map C3). The Quadra sand deposits form regionally significant aquifers in the Nanaimo Lowland are very important from a water supply perspective within the RDN.

Most of Vancouver Island is made up of what is referred to as the Wrangellia Terrane which collided with the west coast of North America around 100 million years ago (m.y.a.) (Earle, 2012). The Nanaimo Group rocks were deposited on top of the Wrangellia rocks from about 85 to 65 m.y. ago.

The Vancouver Island mountain range occurs in the western portion of the water region. The structural geology in this area is complex and comprises northwest striking[10] faults[11] that

[3] Refers to material that lies above bedrock (typically used in mining applications to describe waste above mineral deposit).
[4] A term used when referring to sediment that has not been lithified into a rock (i.e.: not cemented).
[5] Formed or deposited by running water including rivers, creeks, and the ocean.
[6] A fan-like feature where sediments are deposited at mouth of a river.
[7] Having no overlying low permeability confining layer and connected to the atmosphere.
[8] Low permeability geologic unit that cannot easily transmit water
[9] Deposited during glaciation 20,000 to 30,000 years ago.
[10] Geological measurement that indicates orientation from north.
[11] A planar break, fracture or discontinuity in rock which may exhibit displacement or movement.

subdivide the different bedrock types into narrow structural and geology units. Within these narrow units, the rocks may be folded, and block or thrust faulted. Bedrock geology mapping completed by the BC Geological Survey (Muller and Jeletzky, 1970) is provided in Appendix C (Map C4). The primary bedrock types within RDN include the following:

1. **Nanaimo Group:** The Nanaimo Group sedimentary rocks were deposited into the basin between Wrangellia and North the American plate. Most of the Nanaimo Group sediments were deposited under marine conditions, largely as submarine fans offshore from coastal shelf deposits. Comprises clastic[12] sedimentary conglomerates, sandstones, and mudstones. The Nanaimo Group rocks are situated along the coastal areas and typically are overlain by Quadra or Quadra equivalent sediments.
2. **Vancouver Group - Karmutsen Formation:** The Karmutsen Formations is part of the Vancouver Group and comprises volcanic basalt flows and pillow basalt deposited on the sea-floor. The Karmutsen is the most common rock type exposed on Vancouver Island and within the RDN.
3. **Sicker Group - Nitnat Formation:** These are the oldest rocks of Vancouver Island and are Devonian in age (ca. 370 m.y.). They are composed of calc-alkaline [13]volcanic rocks and include sea-floor and terrestrial volcanic rocks.
4. **Buttle Lake Group; Mount Mark Formation:** Comprises limestone formed as part of an ancient reef deposit.
5. **Buttle Lake Group - Fourth Lake Formation:** Sedimentary bedrock composed of chert,[14] siliceous argillite[15], silici-clastic rocks.
6. **Island Plutonic Suite:** Igneous[16] intrusive rocks dominantly quartz diorite[17] to granodiorite[18] but with considerable lithological variation observed across the RDN.
7. **Mount Hall Gabbro:** Igneous intrusive rocks composed of gabbroic[19] to dioritic.

2.5 Surface Water Assessment and Water Budgets

2.5.1 Regional Hydrological Model

A regional hydrological model has been developed for the RDN to assess surface water balance and estimate contributions to groundwater. It is a GIS-based distributed conceptual model which uses physical parameters of the watersheds to calculate runoff for each one square kilometre grid cell.

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[12] Composed predominantly of broken pieces or clasts of older weathered and eroded rocks.
[13] Rich in alkaline earths (magnesia and calcium oxide) and alkali metals and make up a major part of the crust of the continents.
[14] Variety of quartz mineral
[15] Fine grained, lithified sedimentary rock composed predominantly of clay.
[16] Igneous rocks form as liquid magma cools, forming crystal structured rocks.
[17] Grey to dark grey intermediate intrusive igneous rock.
[18] Intrusive igneous rock similar to granite.
[19] Refers to a large group of dark, coarse-grained, intrusive mafic igneous rocks chemically equivalent to basalt.

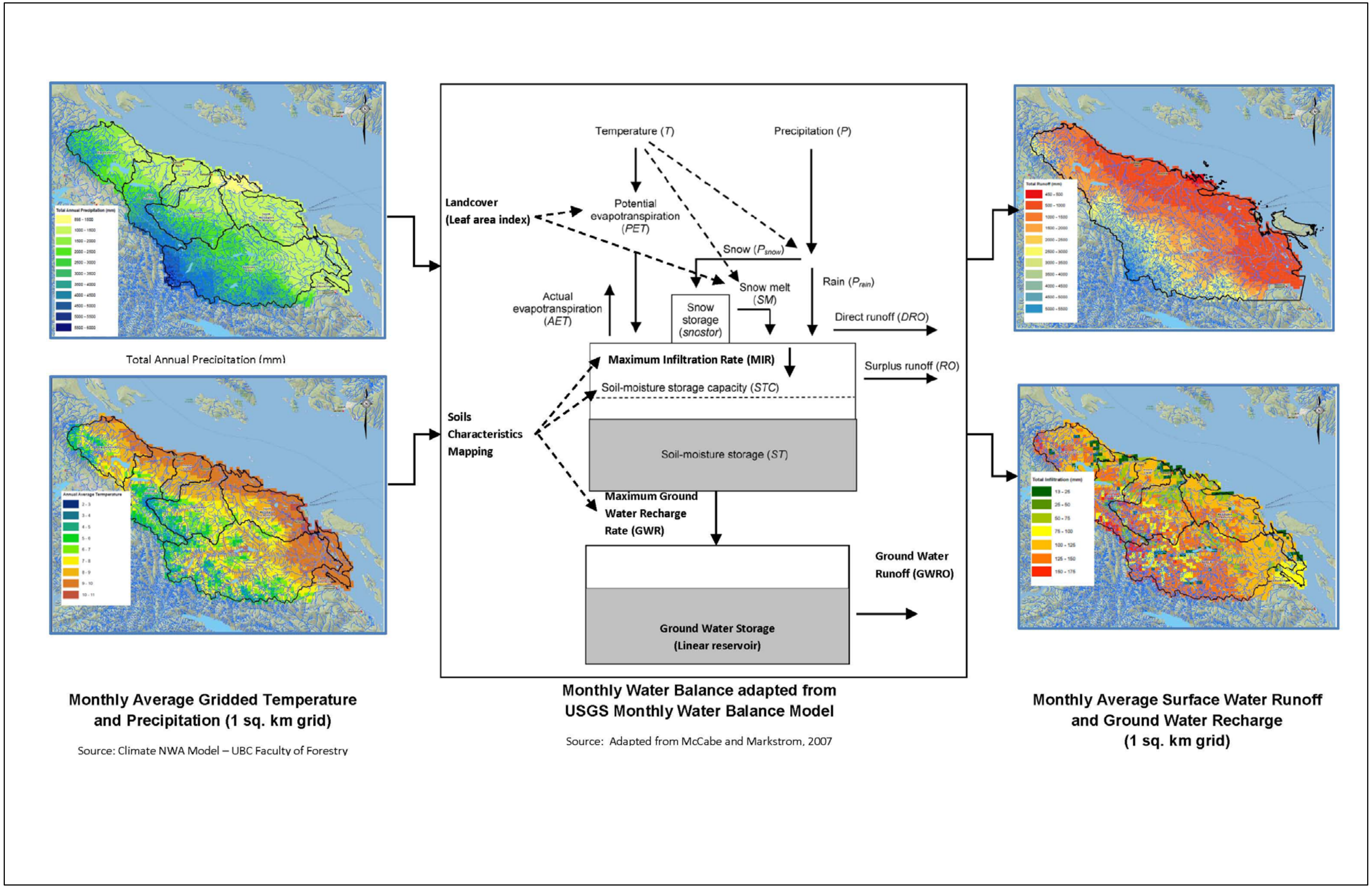


Figure 5: Regional Hydrology Model Schematic

The physical parameters considered in the water balance for each square kilometre include:

1. Average ground elevation
2. Surficial Soil Types
3. Ground Cover; and
4. Leaf Area Index

Once calculated at a grid-scale, the surface runoff is then routed to watercourses using a flow accumulation routine to estimate surface water discharges for entire watershed. Through the surface water balance process the model also estimates groundwater recharge on a 1 sq. km grid across the region. The inputs to the model include gridded average monthly precipitation and temperature data from the ClimateBC and Climate NWA models (Wang et. al., 2006 and Wang et. al. 2012) and the model calculates average monthly stream flow. A schematic of the model process is shown in Figure 5.

The Climate BC Model down scales climate variables (temperature, precipitation, etc.) from larger scale data sources (with grid cells larger than 1 sq. km), such as; historical climate data from the PRISM data set as well as forecast future climate from Global Circulation Models (GCMs) or Regional Climate Models (RCMs). Climate BC model uses temperature and precipitation lapse rates (rate of change of climate with elevation) to adjust the larger scale data to take account of topography not captured in the larger grid sizes of the larger scale datasets.

Runoff for each grid-cell is calculated using a water budget which accounts for snowpack accumulation and melt, potential and actual evapotranspiration, soil moisture, transfer to ground water storage and runoff from the surface and ground water. The runoff model is based on the Monthly Water Balance Model developed by the US Geological Service (McCabe and Markstrom, 2007), with some changes to reflect local conditions. These changes include:

- Adjustments to Potential Evapotranspiration based on land cover data and leaf area index;
- Spatially variable soil infiltration parameters based on surficial soils data; and
- Adjustment to snow accumulation and melt routine using a temperature range ($2^{o}C$ to $-2^{o}C$) to represent partial rain/snow mix throughout the month.

The model generates monthly runoff for each grid square, which is then used to develop a set of gridded runoff data for the entire region. These monthly runoff surfaces are then used to generate stream flows using a GIS stream-flow accumulation routine. The result is an estimate of average monthly stream flows along the length of the water courses in the region. Using precipitation and temperature from the Climate BC model for future climate change conditions, an estimate of future stream flows have also been made. A detailed outline of the surface water assessment methodology is provided in Appendix D.

2.5.2 Surface Water Budgets and Stress Analysis

Surface Water Budgets for each of the major watersheds has been completed as part of the assessment. A water budget is used to assess the relative stress of each of the watersheds by comparing water availability with water demand. The water budget considers all inflows and discharges from the surface water component of the water cycle including rainfall and snowmelt as inflow; evaporation/evapotranspiration, canopy storage and human consumption as losses; transfer to and from soil moisture storage, surface storage in lakes and reservoirs; and ground water recharge and exfiltration. It should be noted that some amount of water extracted for human consumption returns can return to the surface water or ground water components of the water cycle either through treated waste-water effluent, septic fields or irrigation runoff. However, the larger municipal and industrial users on Vancouver Island discharge treated effluent directly to the ocean and is therefore lost to the surface and ground water budgets. For this study, we have considered all consumptive water demands as a permanent loss to the surface and ground water budgets which is considered to be a conservative assumption. A diagram of the surface water budget is shown in Figure 6.

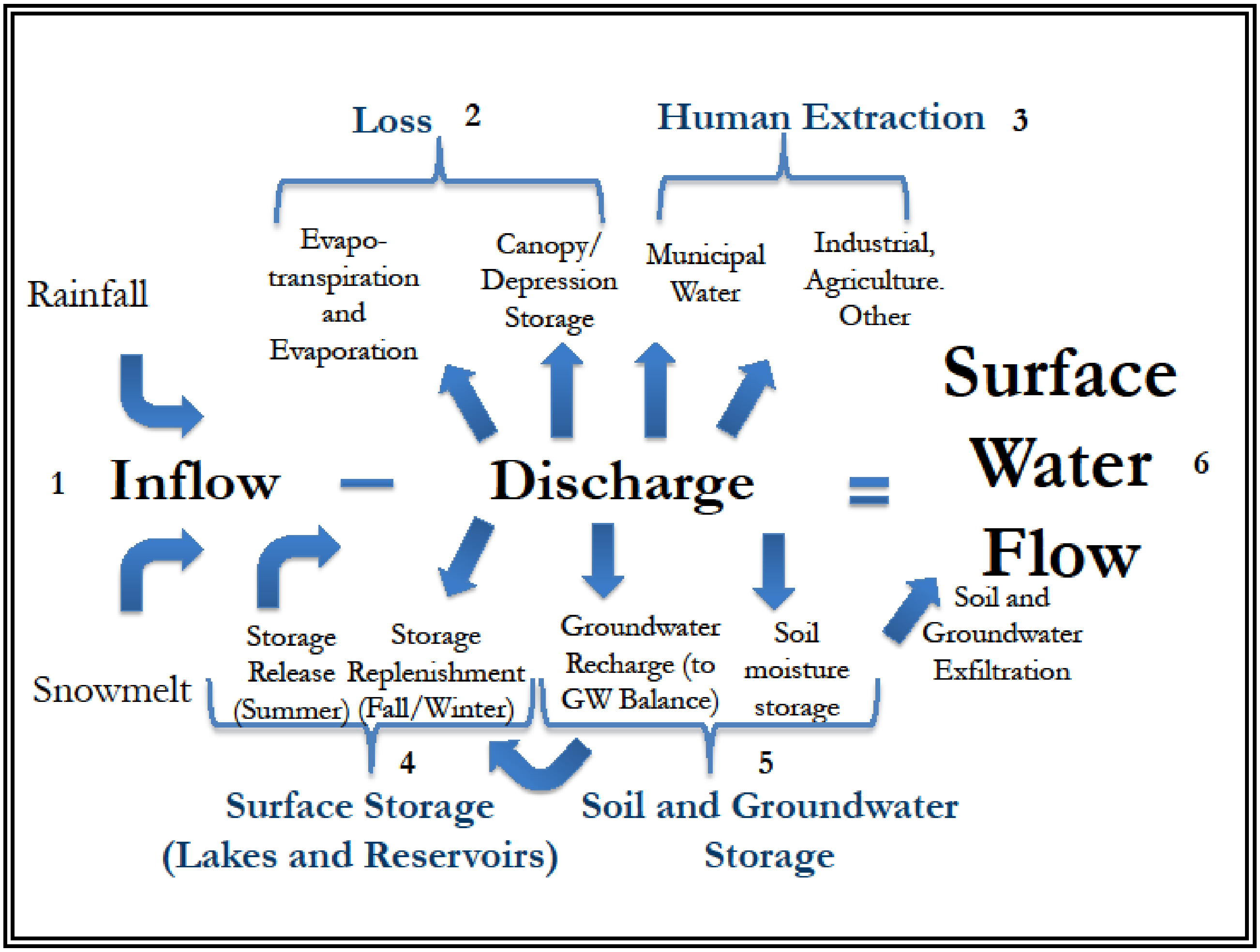


Figure 6: Surface Water Budget Components

Each parameter is described as follows:

1. Inflow to the surface water budget comes from either precipitation in the form of rainfall or from snowmelt from snow pack

2. Losses from the surface water budget include evapotranspiration from vegetated areas and evaporation from lake and other open water surface which is calculated using average monthly temperatures and the Hamon (1961) equation;
3. Surface water extraction amount have been assumed to be equal to the volumes allocated under water license unless recorded values are available. The licenses have been classified based on water use including municipal water supply which is assumed to follow an annual cycle with lower winter indoor water use base demands, and higher summer demands which includes irrigation and outdoor water use, agricultural demands which are assumed to only occur during the summer months for irrigation, except for stock watering which occurs year-round, and other demands such as industrial or institutional demands which are considered to be constant year round;
4. Surface water storage is considered to be lakes and managed reservoirs which capture winter and spring runoff to release during the summer and the early fall low flow period. Surface water storage within a watershed is assumed to be the total of the licensed storage volume for managed reservoirs and 0.5 m of storage on natural lakes and wetlands (the assumed average natural water level variation). To simplify the water balance, water release from surface water storage is assumed to only occur between July to September, unless specific operating rules are provided for the reservoir which provide different criteria;
5. Soil and ground water storage are accounted for within the water balance using the USGS water balance model which is based on the Thorntwaite (1948) method and linear reservoir for ground water storage;
6. Finally, surface water runoff is assumed to be the remaining component of the water balance not accounted for in the components outlined above which is calculated based on mass balance equation such that inflow minus outflow is equal to the change in storage over the time period.

During most of the year, the availability of surface water far exceeds demands. However, during the summer dry period water demand increases and water availability decreases to a point where water stress may occur. Therefore, the stress analysis has been carried out for the summer months which typically extend from July to September each year.

The surface water stress is calculated using the following formula:

$$\text{Surface Water Stress (\%)} = \frac{\text{Consumptive Demand} + \text{Minimum Conservation Flow}}{\text{Natural Water Supply} + \text{Storage}} \text{ x } 100$$

Consumptive Demand is the total allocated or licensed demand for all consumptive water uses including industrial, municipal waterworks, domestic, agricultural, etc. Where appropriate, the annual average licenced amounts have been adjusted to account for seasonal variation in demand such as agricultural, domestic and municipal waterworks demands. Where records of surface water demands are available, they have been used to estimate actual demands to prepare a recorded Water Stress Analysis. This provides a current snapshot of water stress for certain watersheds.

The Minimum Conservation Flow is assumed to be 10% of Mean Annual Discharge (MAD). This is the current FLNRO Policy for water licencing on the east coast of Vancouver Island as outlined in the BC MOE Water Allocation Plans (Boom and Bryden, 1994; Braybrook et. al., 1995; Bryden et. al., 1994; Pirani and Bryden, 1996; Bryden et. al., 1994; and MoELP, 1993). Any new water licence which results in residual flows in the river being less than 10% MAD on a monthly basis, requires storage to support the demand.

The natural water supply is either the recorded flows where available or the results of the regional hydrological model in ungauged watersheds. It is considered to be the unregulated natural flow available in the river. Finally, storage includes all licenced storage in the watershed including conservation storage and land improvement storage.

The results of the Surface Water Stress Analysis have been assigned a relative stress scale and aquifer color code as follows:

- 0-25% = Low Stress Blue
- 25-50% = Low to Moderate Stress Green
- 50-75% = Moderate Stress Yellow
- 75-100% = Moderate to High Stress Brown
- 100-150% = High Stress Red
- >150 % = Very High Stress Red

It should be noted that the water stress analysis is based on average monthly water availability and demands and does not take into account inter-annual variations in stream flow or demand, in particular drought periods. It assumes that water licences reflect actual water demands and that all storage in the watershed is available to support the consumptive demands and minimum conservation flow requirements for the 90 day period through July to September. The water stress has been assessed on a watershed scale and does not consider relative stress within sub-watersheds or river reaches.

2.6 Groundwater Assessment and Aquifer Water Budgets

The following describes the overall rationale for Waterline's approach to aquifer water budget calculations. A more technical discussion of the methodology is presented in Appendix D.

2.6.1 Approach Used For Water Budget Calculations

Waterline used aquifer mapping layers available from the BC Water Resources Atlas at the time of data compilation in February of 2012 (BCGOV ENV Water Protection and Sustainability Branch 2012). As previously indicated, aquifer mapping updates were made available from the MOE in late 2012. The RDN should consider updating the project to reflect the newer map boundaries/areas in conjunction with the work completed by Waterline.

As indicated, all fresh water resources in rivers/creek/lakes and water supply aquifers originate as rain or snow melt. As shown in Figure 3, a portion of precipitation returns to the atmosphere by direct evaporation[20] from the ocean and lakes and streams, or is taken up by trees and vegetation (evapotranspiration[21]). Some portion will runoff the land as a function of land cover,

[20] Vaporization of liquid from a surface to the atmosphere.
[21] Loss of water as vapor from plant leaves to the atmosphere,

soil texture (fine clay, silt, or coarse sand and gravel, or fractured bedrock) and slope, and a small portion (about 10%) will percolate into the subsurface and recharge the aquifers.

The RDN is bounded to the west by mountains and to the east by Georgia Strait. Surface water and groundwater drain from high to low elevations, thus the steep coastal profile creates a natural gravity-driven system with relatively high hydraulic gradients to the ocean. Fresh water resources that do not evaporate or transpire will eventually flow to the ocean, unless intercepted by wells or surface intakes for water supply use. The groundwater flow paths in aquifers across the RDN tend to mimic the topography of the land (Appendix C, Maps C8 and C9).

Surface water and groundwater systems are dynamic systems and constantly in a state of flux in accordance to the changing seasons and longer term climate variability on the Pacific Coast of North America. Both surface and groundwater systems in the RDN are expected to have short residence times resulting in relatively young groundwater (10’s to 100’s of years old) from the point of recharge at higher elevations to discharge points in local creeks, or near the coast. Rivers and creeks exchange water with shallow aquifers through the watershed. Over time, rivers and creeks erode away surficial materials and cut down into underlying aquifers causing direct exchange between the surface water and groundwater systems. As groundwater flows from areas of high topographic elevation to areas of lower elevation, aquifers can also receive lateral recharge from adjacent, up gradient aquifers, or from bedrock fractures in contact at higher elevations on the coastal mountains, also termed ‘mountain block recharge’.

Aquifer recharge characteristics and groundwater extraction practices in a region will significantly affect groundwater levels in and availability in RDN aquifers. Therefore, it is important that properly located observation wells are monitored over the long term in order to gauge the aquifer performance and response to pumping. Monitoring therefore provides an early-warning system which allows private and public users to maintain a balance between aquifer recharge and groundwater use. These data are critical to help determine if groundwater extraction activities are negatively impacting aquifers and whether such practices can be sustained into the future. At present, the level of groundwater monitoring being conducted in many aquifers across the RDN is insufficient to allow for proper aquifer and watershed management. It should be noted that the RDN in partnership with the MOE and GSC have recently added several additional observation wells to the network (Donnelly, Pers. Comm., 2013) within the RDN which will to develop a better understanding of aquifer response to environmental and human impacts in those areas.

The following generalized equation shown in Figure 7 was used to assess aquifer water budgets and the groundwater demand (stress) on each mapped aquifer:

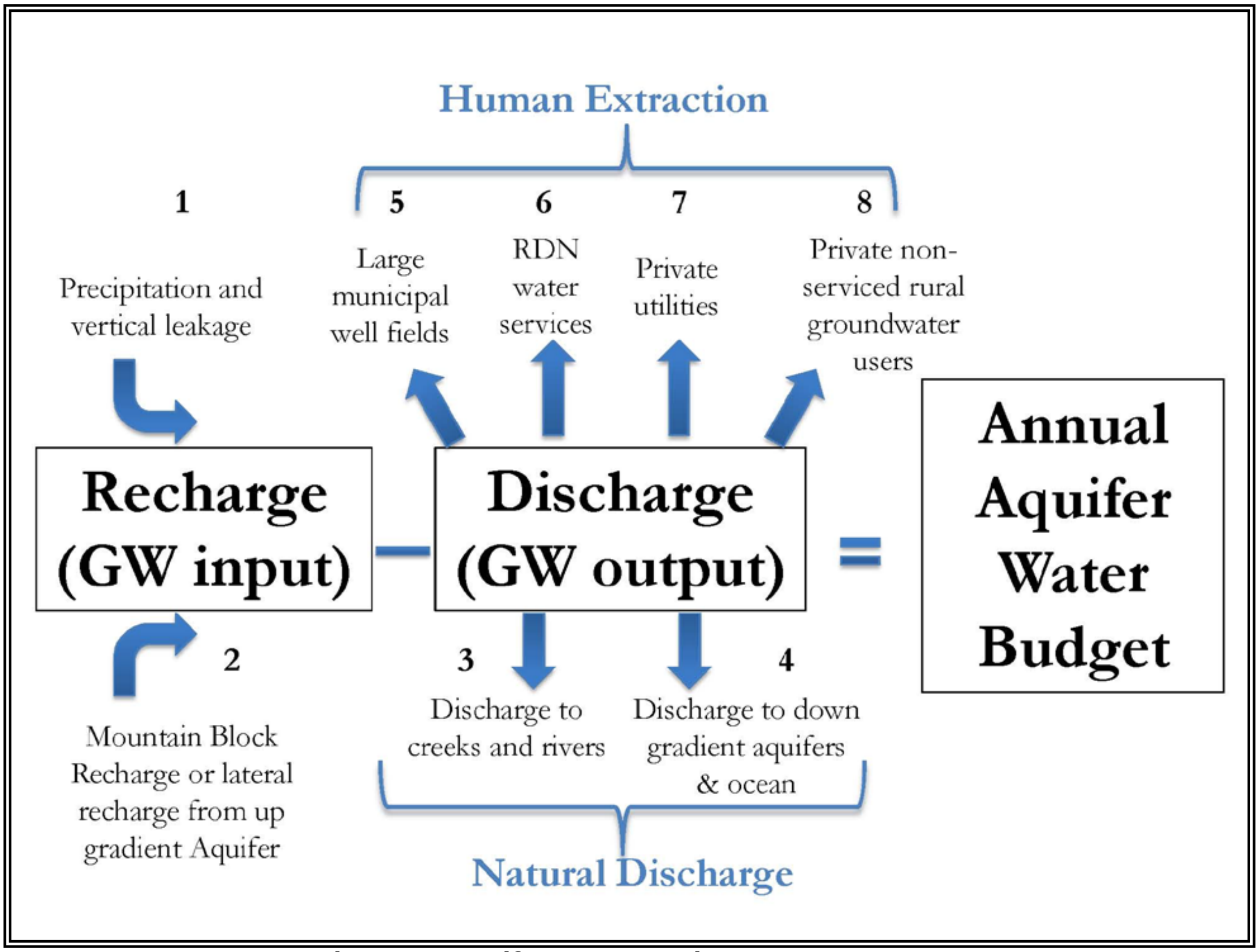


Figure 7: Aquifer Water Budget Components.

Each parameter is described as follows:

1. Precipitation and vertical leakage is rainwater or snowmelt that recharges the subsurface or water that moves from an overlying aquifer to an underlying aquifer through vertical leakage,
2. Lateral through-flow and mountain block recharge is an important source of aquifer recharge. Aquifers that have been mapped at the higher elevations tend to receive recharge directly from the upgradient mountain block and will also then feed aquifers at lower elevation located near the coast and is referred as lateral recharge from upgradient;
3. Some of the creeks are in direct hydraulic communication with the various creeks and rivers within each water region. There is a certain amount of groundwater that discharges to these creeks and it is important that this is maintained in an effort to preserve a healthy ecosystem. This volume of groundwater was estimated for aquifers that were considered to be connected to a local creek or river and factored into the aquifer water budget analysis;
4. All aquifers mapped in each water region will discharge to an adjacent down gradient aquifer which maintains the health and water balance in the system. The volume of groundwater moving out of one aquifer (discharge) and into a down gradient aquifer (recharge) was also considered in the aquifer water budget assessment;

5. Human extraction of groundwater by pumping was also considered wherever data was available. Annual extraction from large municipal wells that service communities such as Parksville and Qualicum Beach were consider in the Aquifer Water budget assessment;
6. Similarly, RDN has a number of water service wells located in various aquifers and locales across the RDN. Annual water abstraction data for each system was used to assess aquifer water budgets in each respective area;
7. In areas not serviced by a community system, the water use was estimated by assigning water use parcels based on zoning and land use. For instance, agricultural parcels were assign a groundwater use based on the BC Ministry of Agriculture and Lands water demand model previously developed for the RDN. Other land use parcels such as residential, commercial, and industrial were assigned water use values in accordance to estimates provided by the RDN for water service areas where the water use was metered. The estimates were applied to non-service areas where groundwater was thought to be in use based on the existence of water wells in those respective areas.
8. The final aquifer water budget (surplus or deficit) was determined by adding the summing the recharge components (inputs) and subtracting the sum of all discharge components (outputs). A negative number would indicate that there is less water recharging the aquifer than is discharging from the aquifer in which case one would expect declining water levels in the aquifer. Where available, the long-term water levels trends were considered in the final aquifer stress assessment.

Detailed water budget calculations are provided in Appendix D.

2.6.2 Aquifer Stress Assessment – Relative Ranking

A stress assessment for an aquifer is a function of the amount of water available versus that which is needed to maintain lateral recharge to down-gradient aquifers, to maintain baseflow to creeks/rivers, and to service the existing demand for groundwater supply. Although aquifer stress analysis may only consider the anthropogenic stress on an aquifer, for the purpose of the RDN Phase One project the final stress ranking factors in both natural stressors on water availability (reduced precipitation and recharge, the need to maintain groundwater discharges to creeks and rivers, etc.) and anthropogenic stressors (groundwater abstraction, land development and its effects on aquifer recharge, etc..).

The following simplified equation was used to assign a relative stress ranking to each aquifer mapped within the RDN:

$$\text{Aquifer Stress } (\%) = \frac{\text{GWout}}{\text{GWin}} \text{ x } 100$$

Where:

- GWout is the calculated discharge to down-gradient aquifers plus discharge to any creek/rivers based on the geological model and measured or estimated groundwater pumping for water supply purposes.

- GWin is the estimated recharge to aquifers either directly from precipitation in the case of unconfined aquifers, or from vertical leakage in the case of confined aquifers plus any lateral recharge from adjacent upgradient aquifers, or mountain block recharge.

The final calculations were then assigned a relative stress scale and aquifer color code as follows:

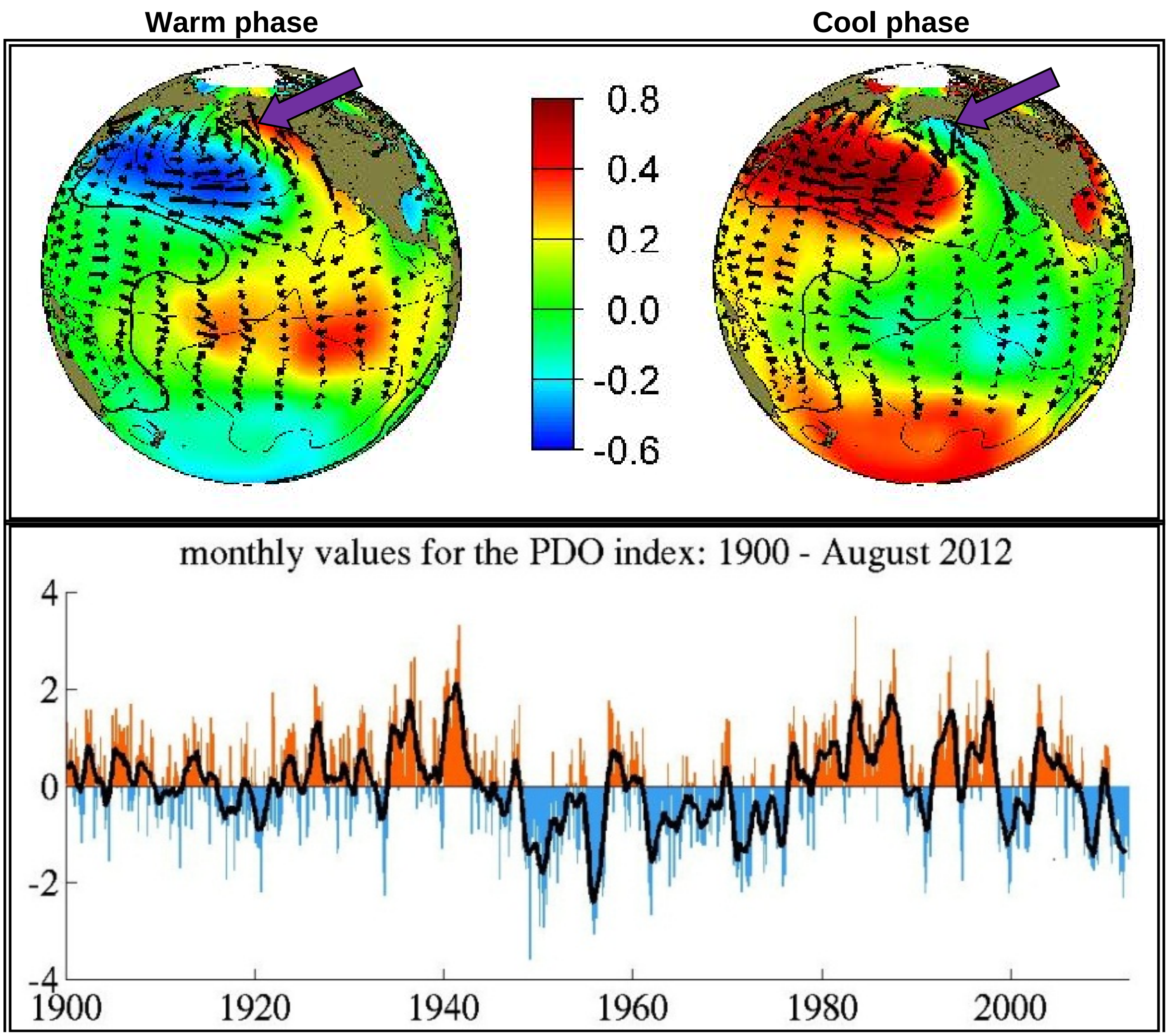
- 0-25% = Low Stress Blue
- 25-50% = Low to Moderate Stress Green
- 50-75% = Moderate Stress Yellow
- 75-100% = Moderate to High Stress Brown
- 100-150% = High Stress Red
- >150 % = Very High Stress Red

The analytical method used provides a crude approximation of stress to a particular aquifer. It should be noted that by using this method of assessment it is possible for an aquifer to be classified as being under some level of stress even though there is no significant anthropogenic use (i.e.: groundwater pumping). In this case the aquifer stress is natural and it may mean that the aquifer is vulnerable to pumping and development resulting from generally reduced recharge due to assessed ground/soil conditions or perhaps due to natural climate variability causing declining precipitation and recharge. The following section briefly discusses climate variability and potential implications to the assessment and prediction of aquifer recharge.

More detailed aquifer data and complex computer simulations (numerical modelling) would be required to fully couple surface and groundwater systems, which would allow for a more accurate and quantitative assessment. As indicated previously, the stress assessment provided herein should be used for comparison purposes only and should not be considered as a quantitative assessment for design or detailed watershed management purposes.

2.6.3 Climate Variability Indicator and Implications for Aquifer Recharge

The Pacific Decadal Oscillation (PDO) is a long-lived El Niño-like pattern of Pacific climate variability. It is a measure of the variability of sea surface temperature (SST) in the North Pacific Ocean (Figure 8). Combined with an understanding of atmospheric circulation patterns has been used to assess the regional/global effects on weather patterns along the coast of North America.



Source: University of Washington (Mantua and Hare 1997)

Figure 8: Pacific Decadal Oscillation Schematic and Graph

It has been recognized by researchers that the SST oscillation causes warming and cooling trends with periods ranging from 15 to 25 years, and 50-75 years (Minobe 1997) which can dramatically affect weather patterns along the north pacific coast. The current PDO trend over the last 35 years appears to be in a warm phase, which generally means drier climate along the coast and less water available for recharging water supply aquifers. Water level hydrographs in wells completed in aquifers along the BC coast tend to follow the PDO pattern/trend and have generally shown declining water levels over the same period.

Local precipitation data may provide information on short-term events and correlate strongly to water level trends in unconfined aquifers and some confined aquifer systems across the RDN. However, as the precipitation gauges are often located at lower elevations and recharge may occur at higher elevations for some aquifers, comparing water level hydrographs to the PDO anomaly provides a more direct correlation in some cases. The stronger correlation with PDO may be more representative of the overall recharge characteristics of regional aquifer systems that will tend to follow long-term climate trends.

PDO provides an indication of the long-lived climate variability cycle and therefore may be of greater value in predicting long-term groundwater availability. Comparing water level hydrograph trends to the PDO anomaly can also help to determine the vulnerability of aquifers to drought and the availability of fresh water supply as the land across the RDN continues to be developed. Pumping activities can impact aquifers relatively quickly in hydrogeological terms (several years or decades), whereas; natural aquifer recharge processes can take decades, centuries, and in some cases even millennia. Waterline believes that understanding climate variability and climate change impacts early will allow proper management of the water resources within the RDN. PDO can be used as a proxy to predicting climate change/variability trends which can be factored into future water allocation and water management plans.

It should be cautioned that the causes of PDO are not entirely understood and the predictability of climate oscillation may be uncertain. However, long-term climate variability will need to be considered as part of land use planning strategies and water budget analysis. The current practice in BC for confirming groundwater supply for new developments is to conduct predictive analysis over 100 days. Although this approach may be appropriate to address short-term (seasonal) effects, it is likely not appropriate for long-term planning and watershed management. More will be presented on this subject later in the document as provincial observation well hydrographs are presented along with the PDO anomaly data.

3.0 WATER REGION # 1 - BIG QUALICUM

3.1 Regional Overview

The Big Qualicum water region (WR1-BQ) is defined as the area extending from Mud Bay in the north, to the Qualicum River in the south, and from the coast to the Beaufort Mountain Range in the west (Figure 9). It should be noted that the actual water region boundary in the northernmost part of WR1 (BQ) was extended beyond the RDN boundary to coincide with the drainage basin. Although the RDN has no jurisdiction over this area, the water budget assessment needed to be completed at the basin scale and water resource management of this area will need to be a joint effort with the Comox Valley Regional District.

WR1 (BQ) is the fourth largest water region within the RDN covering an area of approximately 292 km^2. The region includes several major watersheds as listed in the Table 1. The largest watershed is associated with the Big Qualicum River itself. Horne Lake is a major surface water feature within WR1 (BQ). Four hydrometric stations, three climate stations, and approximately 37 surface water diversion licenses exist within the region (Figure 9, and Table 1). Not all 37 surface water diversions licenses locations can be seen on Figure 9 as the scale of the drawing is such that numerous points plot on top of each other due to their close proximity.

Table 1: WR1 (BQ) - Watersheds, Wells and Surface Water Licenses

Total Water Region Area	***292 km^2**
Major Watersheds	**Drainage Area[1] (km^2)**
Rosewall Creek (including Roaring Creek)	44.1
McNaughton Creek	9.0
Cook Creek (including Chef Creek)	27.0
Sandy Creek	2.7
Thames Creek	8.5
Nile Creek	18.3
Big Qualicum River (including Hunts Creek and Horne Lake)	146.0
Annie Creek	8.2
Wells and Surface Water Diversion Points	**No.**
# Water Wells listed in MOE DB	221
Surface water diversion licenses	37

Note: Drainage Areas are based on 1:50,000 BC Watershed Atlas. * Total water region area includes areas that drain directly to the ocean and are not part of a major watershed.

According to the MOE Wells Database (BCGOV ENV Water Protection and Sustainability Branch, 2008), WR1 (BQ) has the lowest number of water wells (221 wells) of the six water regions in the RDN. The MOE database likely only represents a fraction of the actual wells currently in use. Many well records may not have been entered into the database and some wells may simply not be in use or have been abandoned. As there is no mandatory requirement for submitting well logs or well abandonment records, it is not possible to determine the groundwater demand from private wells with any degree of certainty, nor is it possible to assess the vulnerability that may exist with improperly abandoned or standing water wells.

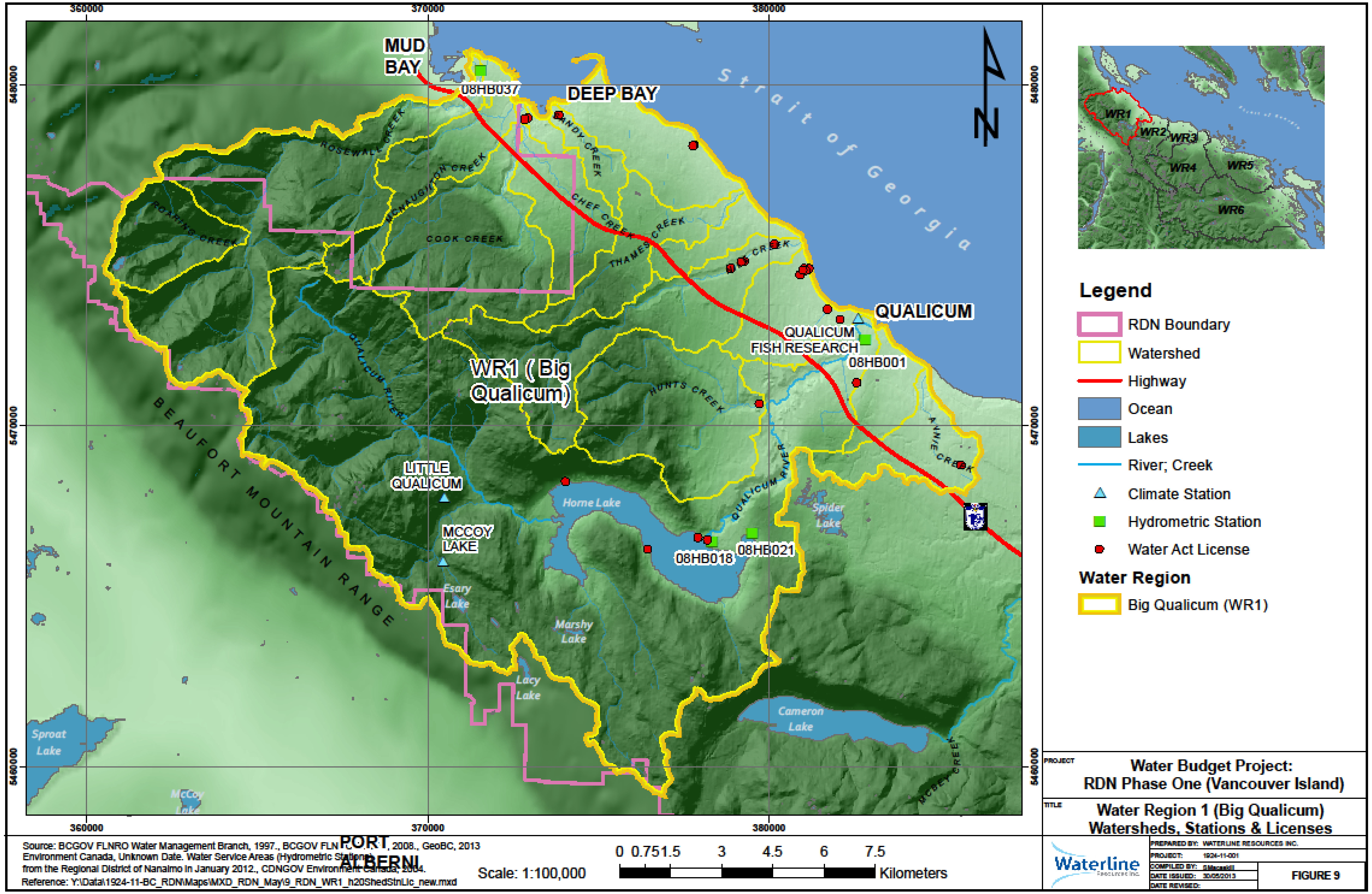


Figure 9: WR1 (BQ) – Watersheds, Hydrometric/Climate Stations & Licenses

3.2 Surface Water Assessment

3.2.1 Terrain, Topography and Land Use

WR1 (BQ) water region covers the northern section of the RDN. The region lies mostly within the Nanaimo Lowlands with the Beaufort Mountains defining the western boundary of the area. Elevations in the region range from sea level up to 1,306 m at Mount Irwin near the headwaters of the Big Qualicum River.

The majority of the lands within the water region are privately owned forest lands with some small areas of crown forest land in the northern portion of the region within the Rosewall Creek, McNaughton Creek, Cook Creek, and Thames Creek watersheds. The lower reaches of the region are rural development with agricultural lands, and low density residential. Some light industrial and commercial development is located in Bowser and Qualicum Bay.

Most of the watersheds in the region drain the east to north east facing slopes of the Beaufort Mountains towards Baynes Sound and the Strait of Georgia. The most significant water feature in the region is the Big Qualicum River and Horne Lake. The major watersheds in the region from North to South are listed in Table 1.

3.2.2 Climate

The climate for the Big Qualicum Water Region is similar to the rest of the RDN with cool wet winters and mild dry summers. In general, climate records indicate that this region tends to be wetter than the other water regions with average total annual precipitation for the 1971 to 2000 Climate Normal Period of 1704.9 mm and 1314.2 mm for the Mud Bay and Qualicum Fish Research Climate Stations, respectively (see Figure 10 and Figure 11 for average monthly climate conditions). This compares with recorded average total annual precipitation of 1,162.7 mm at the Nanaimo Airport. Figure 12 shows the distribution of total annual precipitation across WR1 (BQ) as modelled by KWL. Figure 13 shows the distribution of average annual air temperature across WR1 (BQ) as modelled by KWL. Climate station locations are shown on Figure 9.

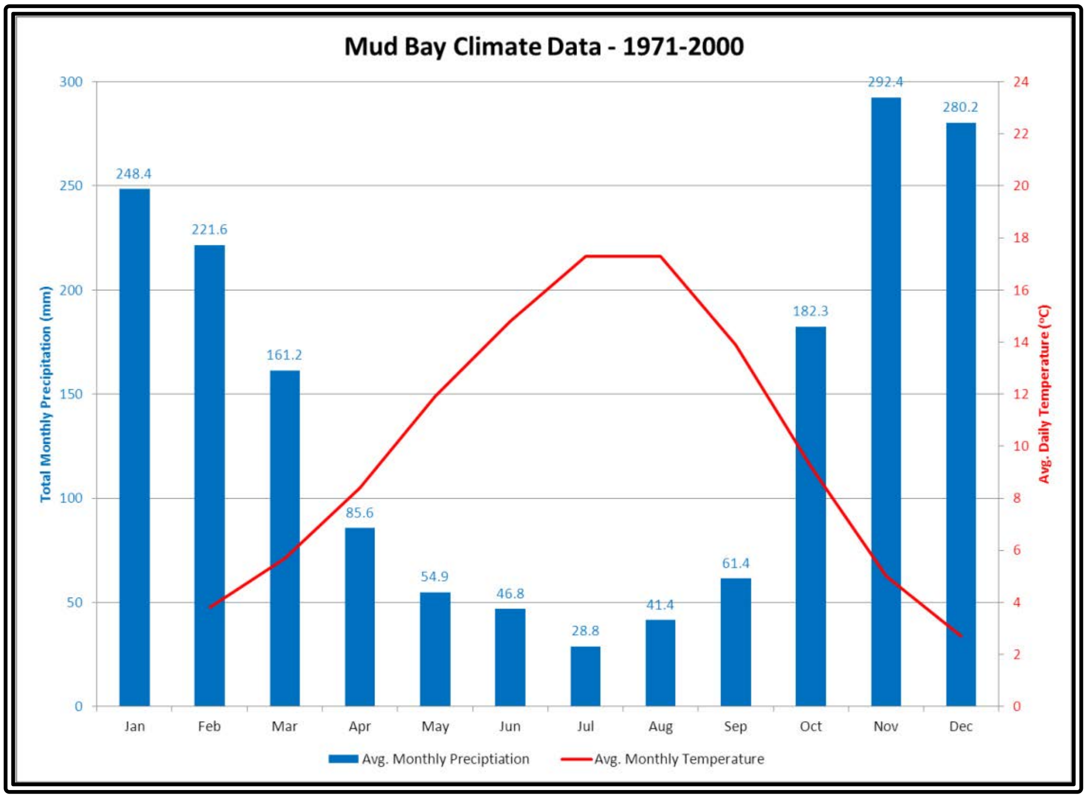


Figure 10: WR1 (BQ) - Mud Bay Monthly Climate (1971 to 2000 Normal Period)

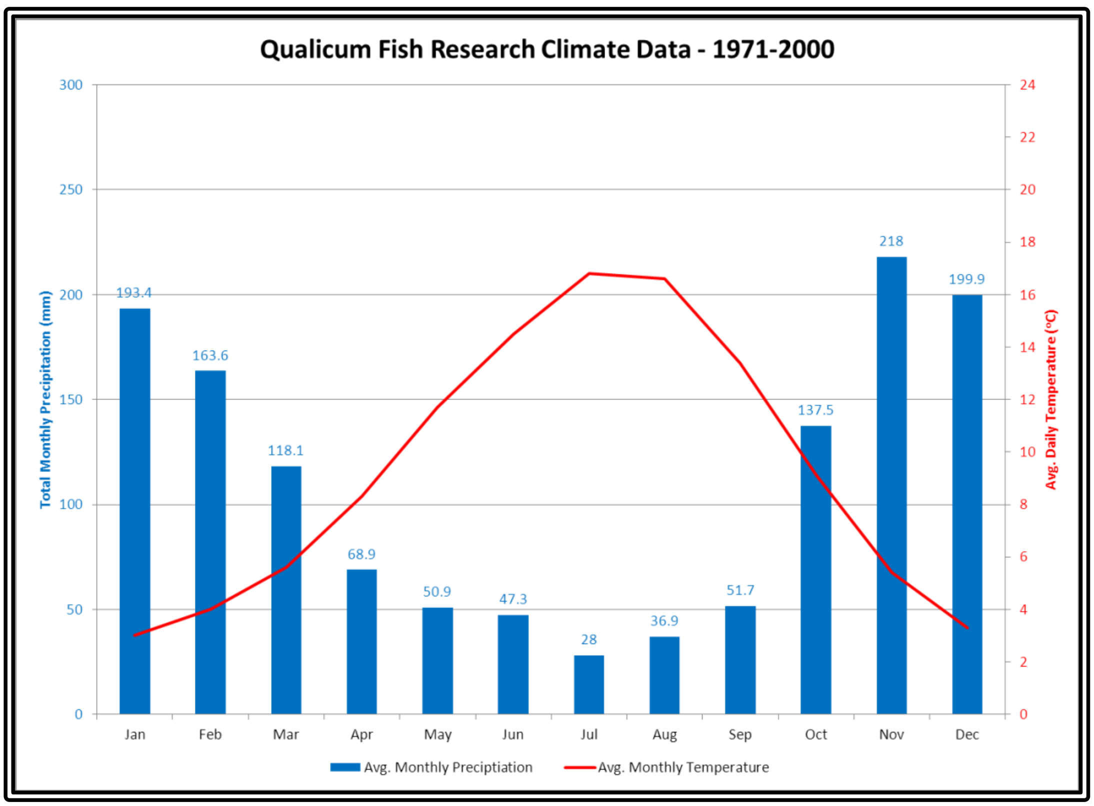


Figure 11: WR1 (BQ) - Qualicum Fish Research Monthly Climate (1971 to 2000 Normal)

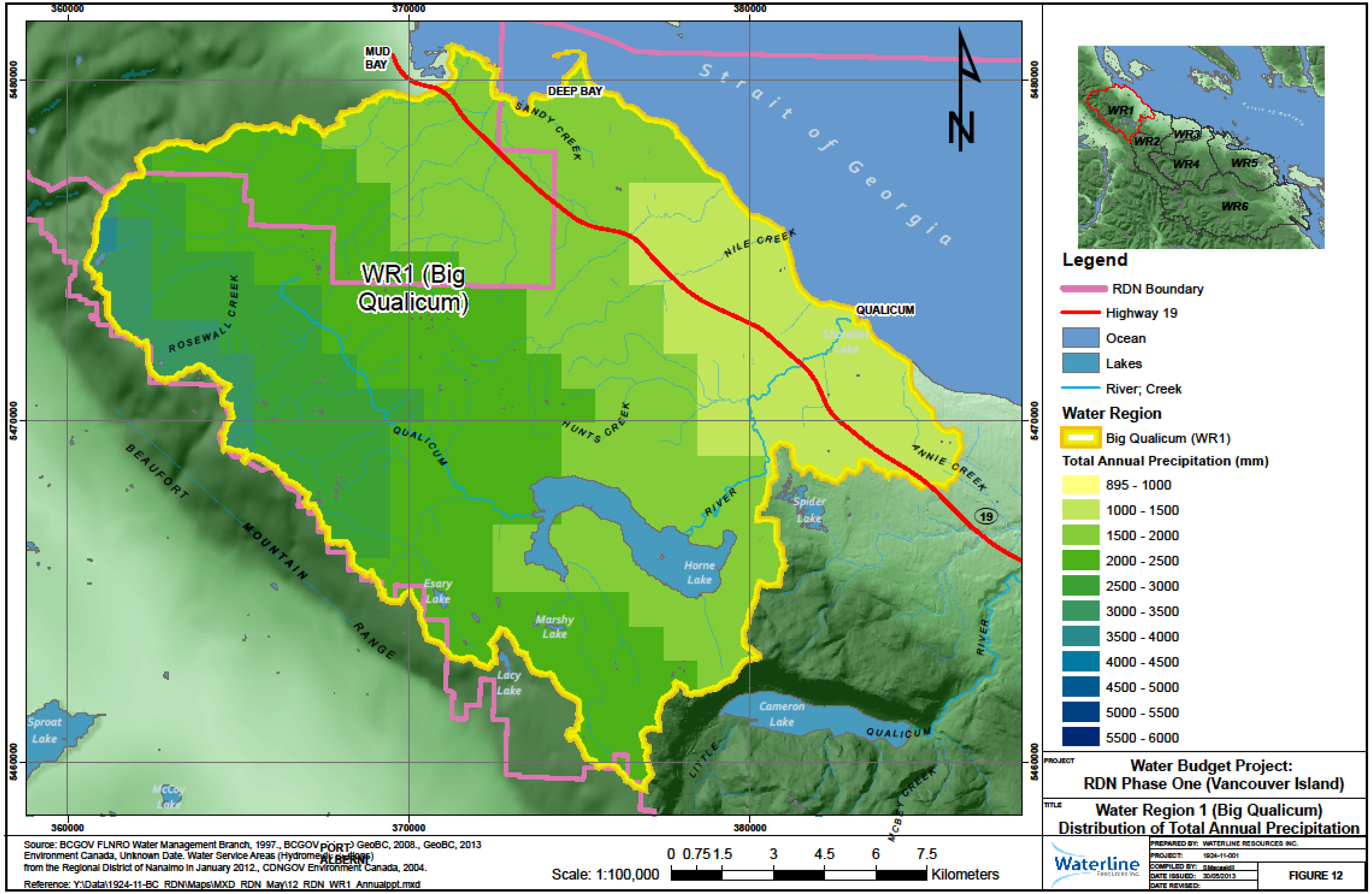


Figure 12: WR1 (BQ) - Distribution of Total Annual Precipitation

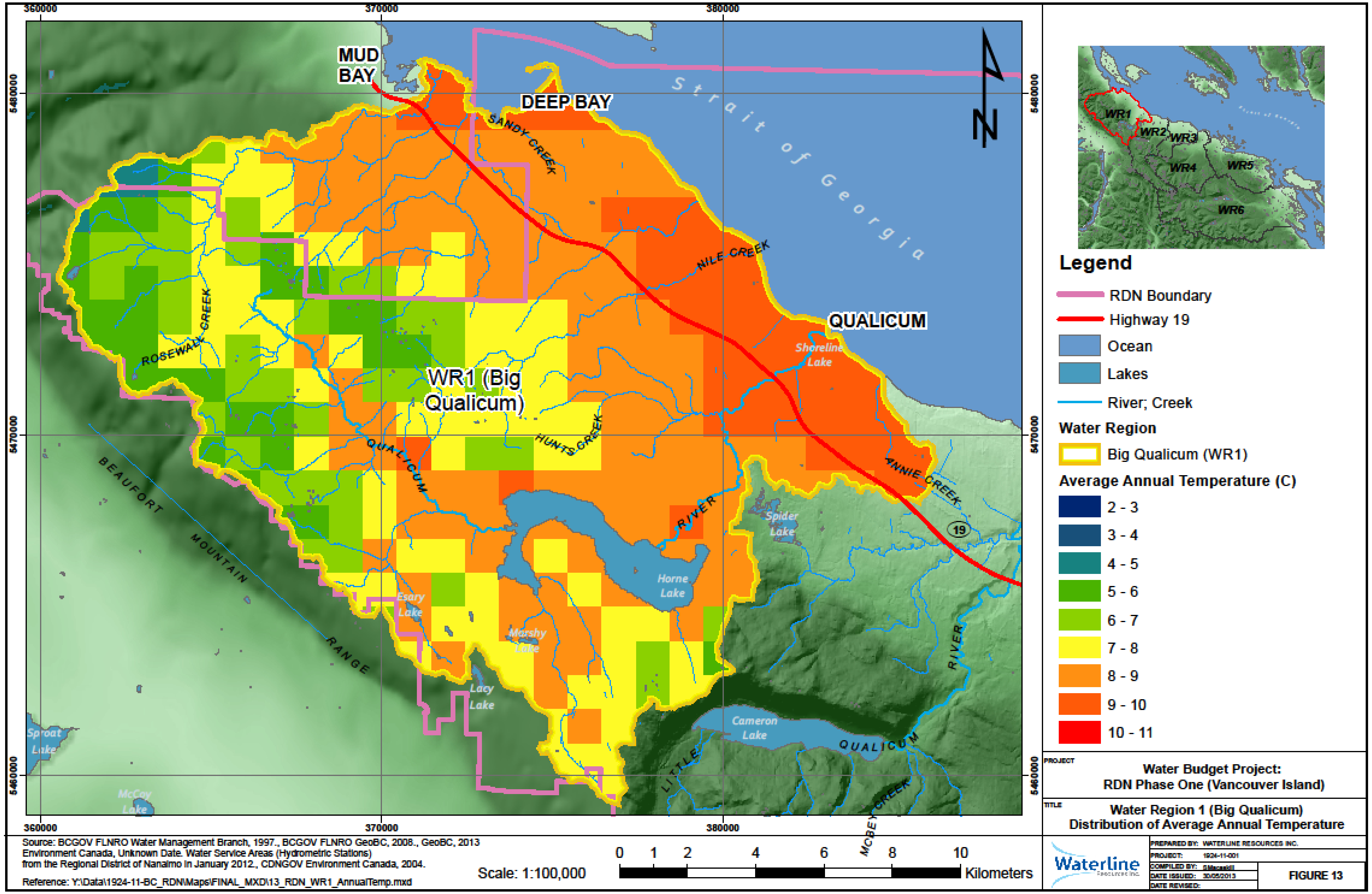


Figure 13: WR1 (BQ) - Distribution of Average Annual Temperature

3.2.3 Stream Gauging and Monitoring

Table 2 lists the names of the hydrometric stations are located in the WR1 (BQ) and they are shown in Figure 9.

Table 2: WR1 (BQ) – Water Survey of Canada Records

Station Name (WSC Number)	Period of Record	Natural or Regulated	Drainage Area to Gauge (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)
Big Qualicum at Bowser (08HB001)	1956 to 1974	Regulated	146	7.5 m^3/s 236 million m^3	3.07 m^3/s 24.4 million m^3
Nile Creek at Bowser (08HB002)	1960 to Present	Natural	15	1.0 m^3/s 31.5 million m^3	0.24 m^3/s 1.9 million m^3
Rosewall Creek at the Mouth (08HB037)	1968 to 1978	Natural	43.3	2.62 m^3/s 82.6 million m^3	0.85 m^3/s 6.76 million m^3

Note: 1 – Summer Period July to September (three lowest average months)

The monthly average discharge for Nile Creek is shown in hydrograph in Figure 14.

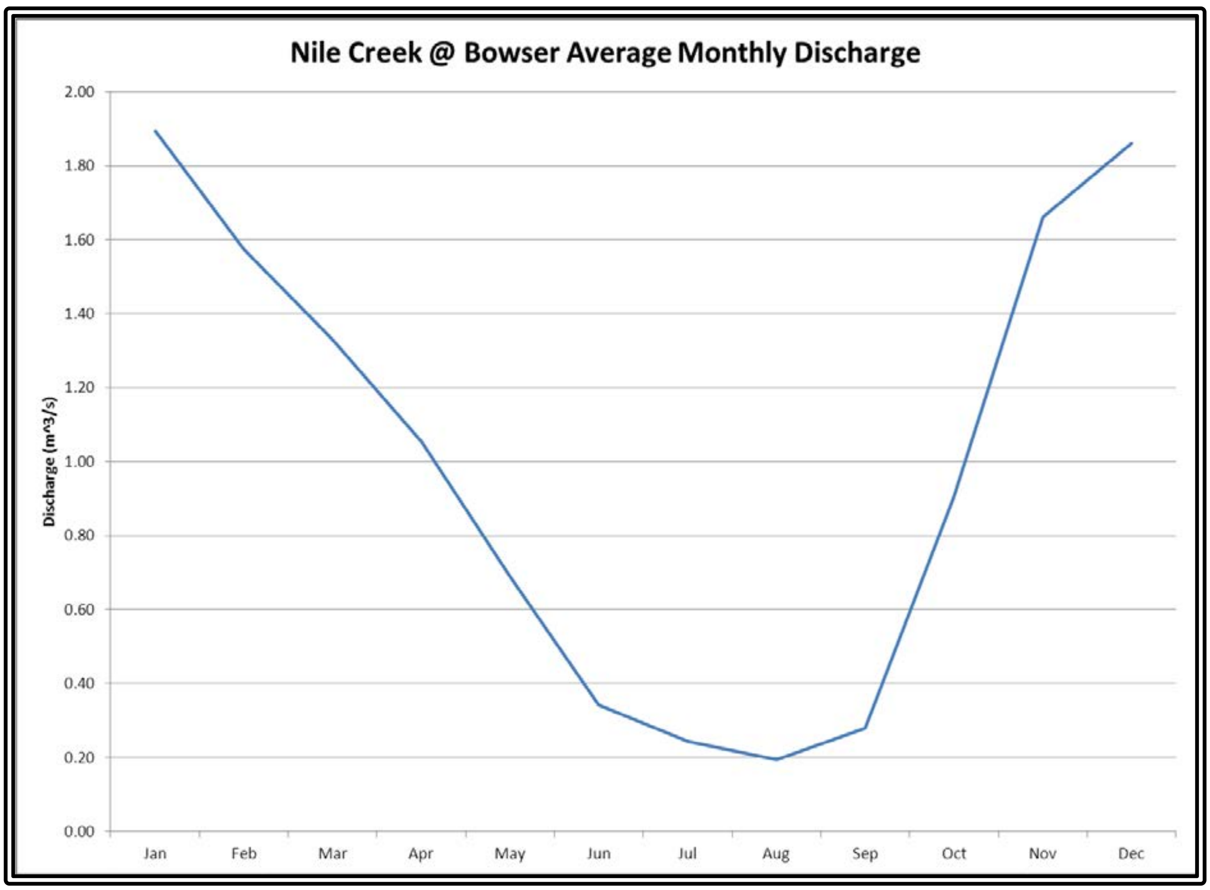


Figure 14: WR1 (BQ) - Nile Creek Monthly Discharges

3.2.4 Hydrology and Surface Water Resources

The hydrological model has provided estimates of average available surface water resources for the major watersheds in the region for the year and the summer (Table 3).

Table 3: WR1 (BQ) – Available Surface Water Resources (Avg. for 1971 to 2000 period)

Watershed	Drainage Area (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)	Previous Estimate of MAD (m^3/s)
Rosewall Creek (including Roaring Creek)	43.3	2.93 m^3/s 432.9 million m^3	0.26 m^3/s 2.1 million m^3	
McNaughton Creek	9.0	0.42 m^3/s 13 million m^3	Less than 0.01 m^3/s	0.6
Cook Creek (including Chef Creek)	27.0	1.3 m^3/s 40 million m^3	0.034 m^3/s 0.27 million m^3	1.3
Sandy Creek	2.7	0.08 m^3/s 2.7 million m^3	Less than 0.01 m^3/s	0.24
Thames Creek	8.5	0.28 m^3/s 8.8 million m^3	Less than 0.01 m^3/s	0.56
Nile Creek	18.3	1.0 m^3/s 31.5 million m^3	0.24 m^3/s 1.9 million m^3	1.0
Qualicum River (including Hunts Creek and Horne Lake)	146 km^2	7.5 m^3/s 236 million m^3	3.07 m^3/s 24.4 million m^3	7.3
Annie Creek	8.2	0.22 m^3/s 7.0 million m^3	Less than 0.01 m^3/s	0.14

Notes: Drainage Areas are based on 1:50,000 BC Watershed Atlas. Previous estimates from the BC Ministry of Environment Water Allocation Plans (Braybrook et. al., 1995; Pirani and Bryden, 1996) have been included for reference.

3.2.5 Surface Water Demand

Table 4 summarizes the surface water licences in WR1 from the BC Surface Water Licence Database. A summary of the licensed storage in the water region is included in Table 5. The locations of some of the surface water licences for WR1 (BQ) are shown on Figure 9. The actual geo-reference locations will be provided in the ARC GIS Geodatabase and will not be presented here.

Table 4: WR1 (BQ) - Surface Water Demand

Type of Demand	Monthly (m^3/month)	Annual (m^3)	Summer (Jul-Sept) (m^3)
Consumptive Demand			
Agriculture	154	1,850	1,390
Domestic	28,800	345,700	114,100
Industrial	136	1,640	410
Institutional	-	-	-
WaterWorks	17,300	207,300	68,400
Total Consumptive	46,400	556,500	184,300
Non- Consumptive Demand			
Power	-	-	
Conservation	18,400,000	221,300,000	55,300,000
Total Non-Consumptive	18,400,000	221,300,000	55,300,000

Table 5: WR1 (BQ) - Licenced Surface Water Storage

Type of Storage	Total Storage (Million m^3)
Storage	175.2
Conservation Storage	0
Other Storage	0.04
Total Storage	175.2

The largest licensed water user in WR1 (BQ) is the Department of Fisheries and Oceans to maintain conservation flows in the Big Qualicum River and to supply the Qualicum Fish Hatchery. These flows are supported by storage at Horne Lake which is controlled by a dam and outlet tunnels. The total licensed storage on Horne Lake is 175,154,160 m^3. It is interesting to note that private domestic surface water license amounts in the area exceed the total annual licensed municipal water withdrawals. The largest domestic surface water license in the region is held by the owners of Strata Plan VIS5160 (Horne Lake Recreation Strata) located on Horne Lake and totals 331,900 m^3 per year for privately owned and managed water systems for recreational properties around Horne Lake.

3.2.6 Surface Water Stress Analysis

As outlined in Section 2.5.2, a surface water stress analysis for some of the major watersheds within each water region has been completed. The results of the stress analysis which could be reasonably assessed for watersheds in WR1 (BQ) are shown in Table 6. Water budget analysis for other smaller ungauged subwatersheds within WR1 (BQ) should be completed when data is available and as part of a more detailed Tier 1 or Tier 2 water budget assessment (OMNR 2011). A map showing the relative stress for each watershed is shown in Figure 15.

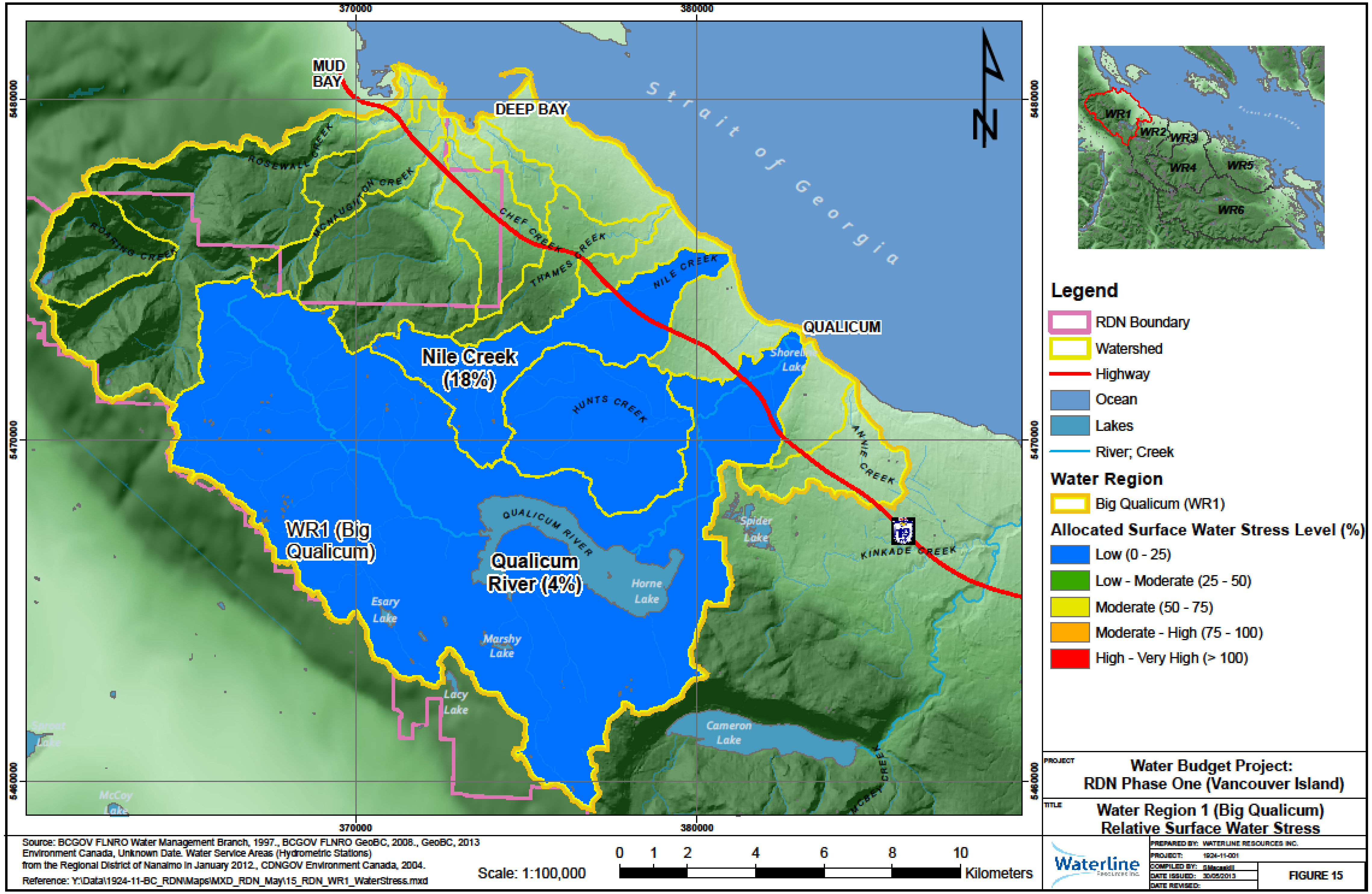


Figure 15: WR1 (BQ) - Relative Surface Water Stress

Table 6: WR1 (BQ) - Surface Water Stress Analysis

Watershed	Average Natural River Flow Supply (million m^3)	Storage (million m^3)	Conservation Flow (10% of MAD) (million m^3)	Licensed Demand (million m^3)	Allocation Stress	Stress Level
Nile Creek	1.90	0.00	0.26	0.07	18%	Low
Big Qualicum River	3.7	175.2	6.2	0.1	4%	Low

Notes: Volumes indicated in the table are average volumes for summer period (Jul to Sep). Average natural river flow is the estimated or recorded unregulated flow in the watershed. Total storage is based on licenced storage volume and assumes all storage is available to support conservation flow and licenced demand for the Jul to Sep period. The 10% of Mean Annual Discharge (MAD) conservation flow is based on current Ministry of Forest, Lands and Natural Resource Operations (BC MELP, 1996) minimum conservation flow policies for the east coast of Vancouver Island. Licenced demand is the total licenced volume for summer based on consumptive water licences. Allocation stress = (Average Natural supply + storage) / (Conservation Flow + Licenced Demand) Surface water stress color codes: blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high. Values reflect average flow conditions and do not consider drought years.

3.3 Groundwater Assessment

3.3.1 Existing Groundwater Studies and Data – WR1 (BQ)

Given the regional scale of the Phase One Water Budget Assessment, the most important data compiled and geo-referenced by Waterline was the water well information, elevation data, soil and geology maps, land cover, aggregate resource map, mapped aquifers, and water service areas. Other maps were generated using the input data as part of Waterline's work and some samples are provided in Appendix C for illustration purposes (Eg: overburden thickness (Map C7), piezometric contour maps (Maps C8 and C9), air temperature (Map C14), precipitation (Map C15), runoff (Map C16 and C17), evapotranspiration (Map C18), infiltration (Map C19), Water Service Areas (Map C20), and Water Demand Assessment in Non-service areas (Map C21). All of these maps are provided in Appendix C for the entire RDN study area with an explanation of how the map was geo-reference or created by Waterline. These data and layers are now available in the ARC GIS Geodatabase at the RDN Scale, water region scale, watershed scale, on other local scale needed for site specific assessments. These data will be provided to the RDN in electronic format as part of the ARC GIS Geodatabase system which was constructed by Waterline for use by the RDN. These regional datasets form the framework for construction of the conceptual hydrogeologyical model.

Although only some of the data in certain reports may have been incorporated into Waterline's Geodatabase, the primary studies in the region were used in Waterline's water budget assessment to provide the local hydrogeological are provided in Table 7.

Table 7: WR1 (BQ) – Hydrogeology Reference Reports

Author	Year	Study Title
Pacific Hydrology Consultants Ltd.	1997	Completion Report: Installation and Testing of Well 8-97 and Re-evaluation of Groundwater Supply Potential of Quadra Sand Aquifer at Deep Bay
Pacific Hydrology Consultants Ltd.	2007	Groundwater Study at Deep Bay Waterworks District
Pacific Hydrology Consultants Ltd.	2007	Completion Report: Groundwater Study at Deep Bay Waterworks District

3.3.2 Description of Aquifers and Water Wells

A total of four unconsolidated aquifers have been mapped within WR1 (BQ) (Figure 16). Table 8 provides a summary the aquifer ID, lithology, location, potential interactions with the surface water and other aquifers, aquifer area, vulnerability, and aquifer yield/productivity according to BC MOE aquifer classification. Quadra sand aquifers (416 & 421) in the north are variable in terms of productivity and are generally confined[22] to semi-confined[23] with low vulnerability and light to moderate use indicated. Based on Waterline's conceptual model, Quadra Aquifer 421 and Capilano Aquifer 665 appear to be connected to Nile Creek and likely provide needed base flow during the summer and fall seasons to the creek.

Table 8: WR1 (BQ) – Summary of Mapped Aquifers

Aquifer Tag No.	Aquifer Lithology	Location Within Water Region	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	Developed Aquifer surface Area	Confined, Semi, or unconfined, Aquifer Classification Code	Yield
				(km^2)		(L/M/H)
416	Quadra	North of Thames Creek	Ocean	14.2	Confined, IIB	H
421	Quadra	Between Nile and Thames	Ocean, Nile	61.6	Semi-confined, IIIB	L
665	Capilano	Overlies Quadra between BQ to Thames	Ocean, Nile Creek, BQ	22.8	U, IIIB	M
662	Quadra	South of BQ and into LQ	Ocean (Quadra Exposed)	28.4	C, IIC	M

Notes: A/B/C is high/moderate/low vulnerability, I/II/III is heavy/moderate/light use, H/M/L means high/medium/low productivity/yield. All aquifer classification parameters, codes and yield are defined at the following MOE web address http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/Aq_Classification/Aq_Class.html#class.

[22] Aquifer is capped by a low permeability or impermeable layer.
[23] Aquifer is partially capped by a low permeability or impermeable layer.

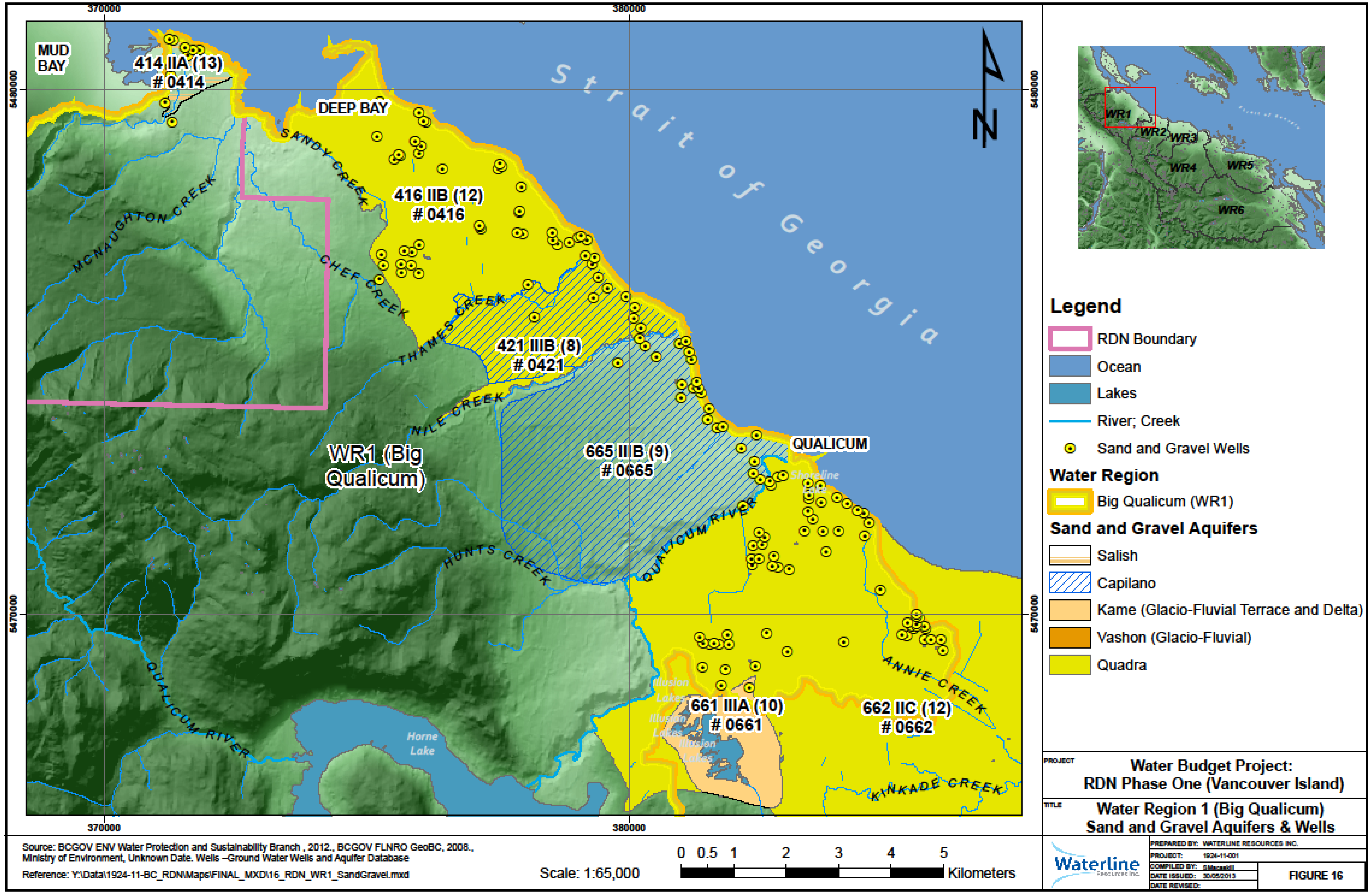


Figure 16: WR1 (BQ) – Sand and Gravel Aquifers & Wells

The majority of supply wells are completed along the coast in unconsolidated Quadra and Capilano sand and gravel aquifers (Figure 16). There are a total of 221 overburden and bedrock wells listed in the MOE data base (Table 1). As there are no regulatory requirements in BC to submit wells logs to MOE for capture in the BC Wells Database (reference), the water wells shown on Figure 16 likely represent only a fraction of wells actually drilled and represents a source of uncertainty in the water budget calculations.

3.3.3 Groundwater-Surface Water Interaction - Conceptual Hydrogeological Model

A conceptual hydrogeological model of each aquifer with WR1 (BQ) was developed in order to understand the key elements and linkages between surface water and groundwater systems required to complete the water budget assessment. Although the conceptual hydrogeological model developed by Waterline includes numerous cross-sectional views developed within the Waterline Geodatabase, only one 3D view into the subsurface is presented for WR1 (BQ).

Figure 17 shows a 3D block diagram illustrating the relationship between surface and subsurface geology in the area of WR1 (BQ) where major water supply aquifers have been mapped. The schematic shows how the Quadra sand aquifer (662) is exposed in the Big Qualicum River valley and likely contributes important base flow to the creek during the summer and fall season. The model also shows the considerable thickness of overburden in the region and possible interactions between the unconfined Capliano aquifer (665) and the underlying Quadra Aquifer (662).

View 1 shows the unconfined and perched Vashon aquifer (661) in the Spider Lake area situated in the adjacent water region (WR2 (LQ)) and how the deposit extends towards the Big Qualicum River in WR1 (BQ). Water levels in wells completed in the deeper confined Quadra sand aquifer (662) are considerably lower (deeper) than water levels in the overlying Vashon aquifer (661) suggesting disconnected flow systems and a strong downward gradient between the two aquifers.

View 2 shows that the unconfined Vashon aquifer (661) does not extend far into WR1 (BQ) and therefore is not expected to contribute baseflow to the Big Qualicum River in WR1 (BQ). The underlying Quadra Sand Aquifer (662) is considerably deeper and appears to cross into the adjacent water region (WR2 (LQ)) and likely also discharges groundwater to the base of the Big Qualicum River Valley. Water levels in wells completed in the deeper confined Quadra sand aquifer (662) are considerably lower (deeper) than water levels in the overlying Vashon aquifer (665) suggesting poor connection between the two flow systems. It appears that aquifer 661 likely only flows toward the Little Qualicum River, whereas the underlying Quadra sand aquifer may be interacting with both the Big Qualicum and the Little Qualicum Rivers.

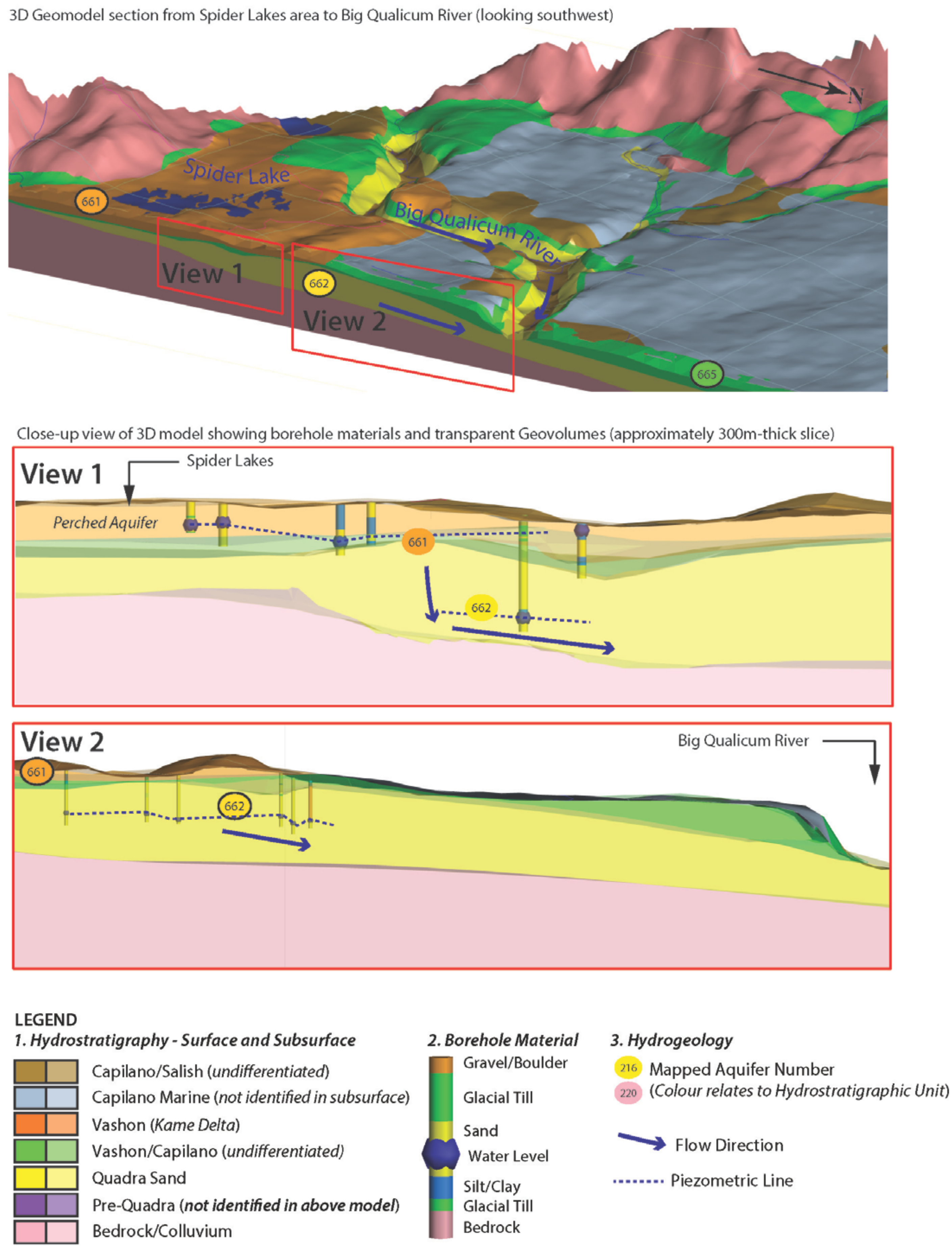


Figure 17: WR1 (BQ) – Hydrogeological Conceptual Model – Big Qualicum River

3.3.4 Significant Recharge Areas

Significant recharge areas within WR1 (BQ) were determined as part of the assessment of infiltration across the region by Waterline and KWL. The analysis was based on existing topography, mapped textural soil characteristics, land cover (bare land, vegetation, impermeable surfaces), and leaf area index obtained from NRCAN Remote Sensing data (Appendix C, Map C11). These areas are important for maintaining recharge to aquifers and base flow to creeks and rivers. The preliminary assessment presented herein is based on the integration of numerous datasets which may be incomplete and therefore will require further field verification. Figure 18 shows areas where high infiltration capacity is indicated within WR1 (BQ) based on data integration into the USGS distributed watershed model run by KWL.

Significant recharge areas in extend to the upper reaches of WR1 (BQ) (Roaring Creek, Rosewell Creek, Qualicum River) and into the upper reaches of and Thames Creek. Many of the areas indicated are not well developed. Better definition of these areas should be completed as the current modelling completed by Waterline and KWL was done on a 1 km square grid. Future development planning needs to consider these areas to ensure aquifer recharge continues to be maintained. There is a need to develop protection zones around areas contributing recharge to underlying aquifers to ensure the future sustainability of groundwater resources in this region.

3.3.1 Groundwater Level Monitoring - BCMOE Observation Well Network

Long-term water level monitoring data provides an indication of an aquifer’s response to global, regional, and local environmental changes in climate, groundwater pumping, and the impacts (if any) of other activities related land development. Long-term records also allow for establishing hydraulic linkages between the groundwater and surface water systems.

Figure 19 shows the locations of MOE observation wells and long-term water level monitoring records (MOE 2012b) in relation to community water supply wells identified from the MOE Wells Database (E.g.: large municipal users, the RDN, private utilities wells). Although numerous community wells are listed in the database, Waterline understands that not all of these wells shown on Figure 19 are currently active and need to be reconciled through field verification. In addition, many of the community service wells have been given local names by the owners and could not be cross-referenced with those listed in the MOE Database used to create the conceptual model. It is strongly recommended that reconciliation with the database be completed so that a more accurate water budget accounting can be complete when the RDN moves to a full Tier 1 or Tier 2 water budget assessment (OMNR 2011).

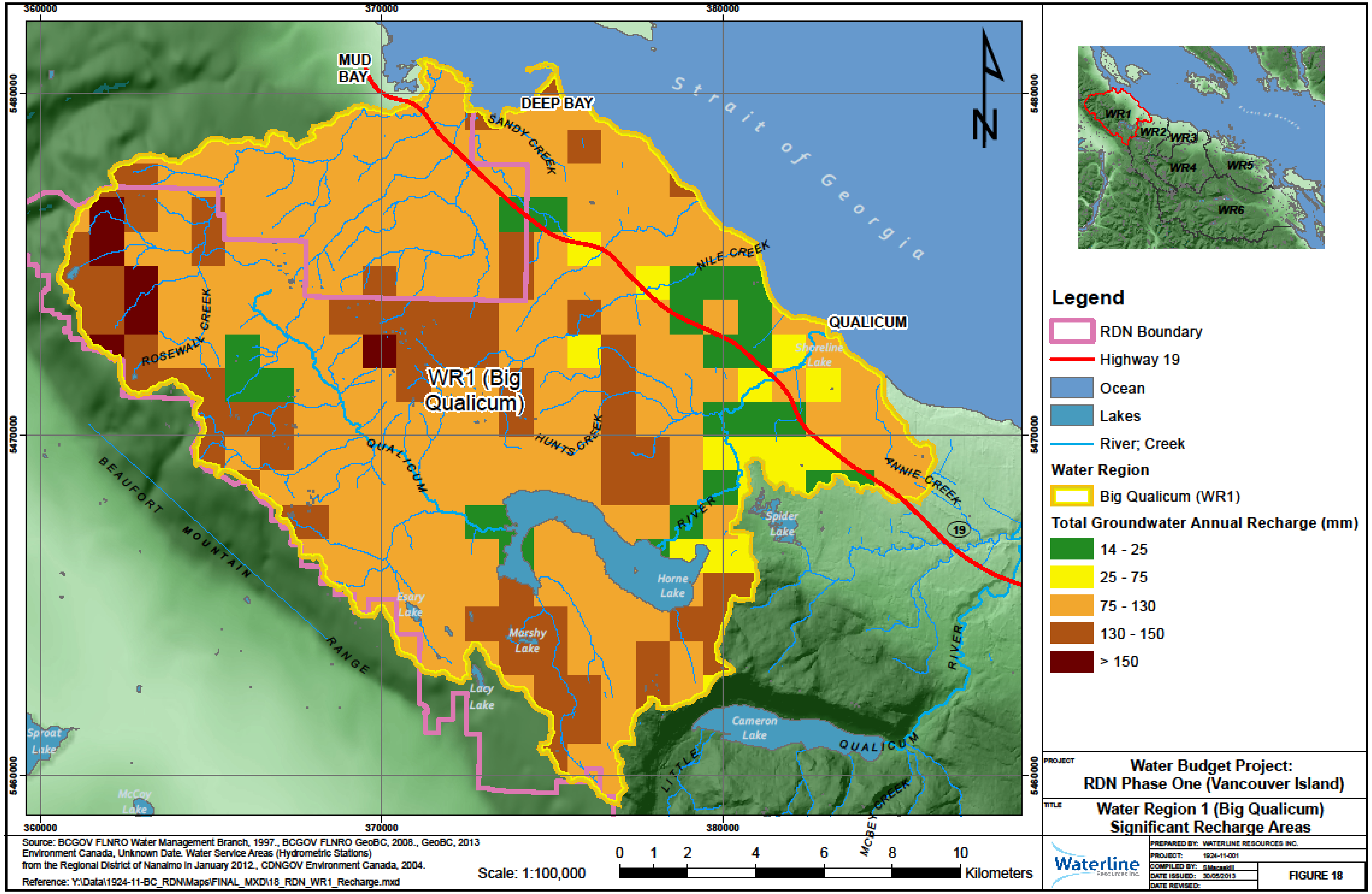


Figure 18: WR1 (BQ) – Significant Recharge Areas

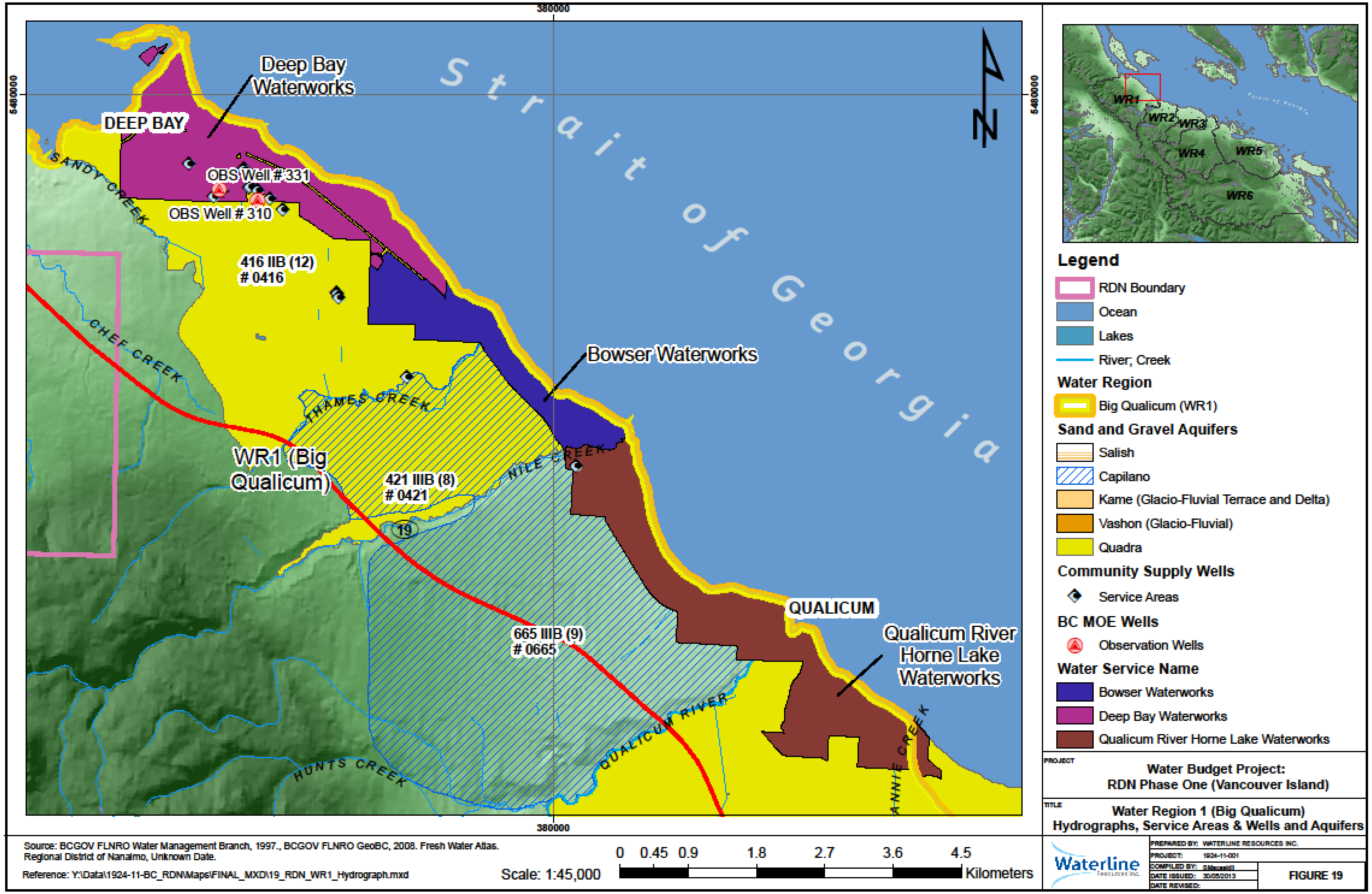


Figure 19: WR1 (BQ) – MOE Well Hydrographs, Service Areas & Wells, and Aquifers.

Figure 20 and Figure 21 show water level hydrographs for MOE Observation Wells 310 and 331. Water level data was along with the Qualicum River Research Station precipitation record and the PDO trend (Mantua and Hare, 1997)

Both MOE wells are completed in Quadra sand aquifer 416 near Bowser Waterworks District production wells. The wells both show a slight declining trend starting in 1999-2000 with some recovery indicated by 2003. The decline may be related to water extraction practices in the Bowser area combined with lower total cumulative precipitation. When Deep Bay Improvement District introduced metering, usage decreased by about 50% which is thought to be related to the observed increasing water levels in MOE Well 331 after 2003 (Lapsevic 2013).

The record for MOE well 310 (Figure 20) is about 22 years and the water level trend follows the precipitation record. The record for MOE Well 331 (Figure 21) is a bit longer and shows that the water level in the aquifer follows precipitation with a 2-5 day delay.

There is some indication that long-term climate variability (PDO graph) related to changes in sea surface temperature in the North Pacific (explained in Section 2.6.3) may result in a decline in precipitation and corresponding decline in aquifer recharge. This is indicated in both water level hydrograph for MOE wells 310 and 331 where the water level trend appears to generally follow the PDO trend.

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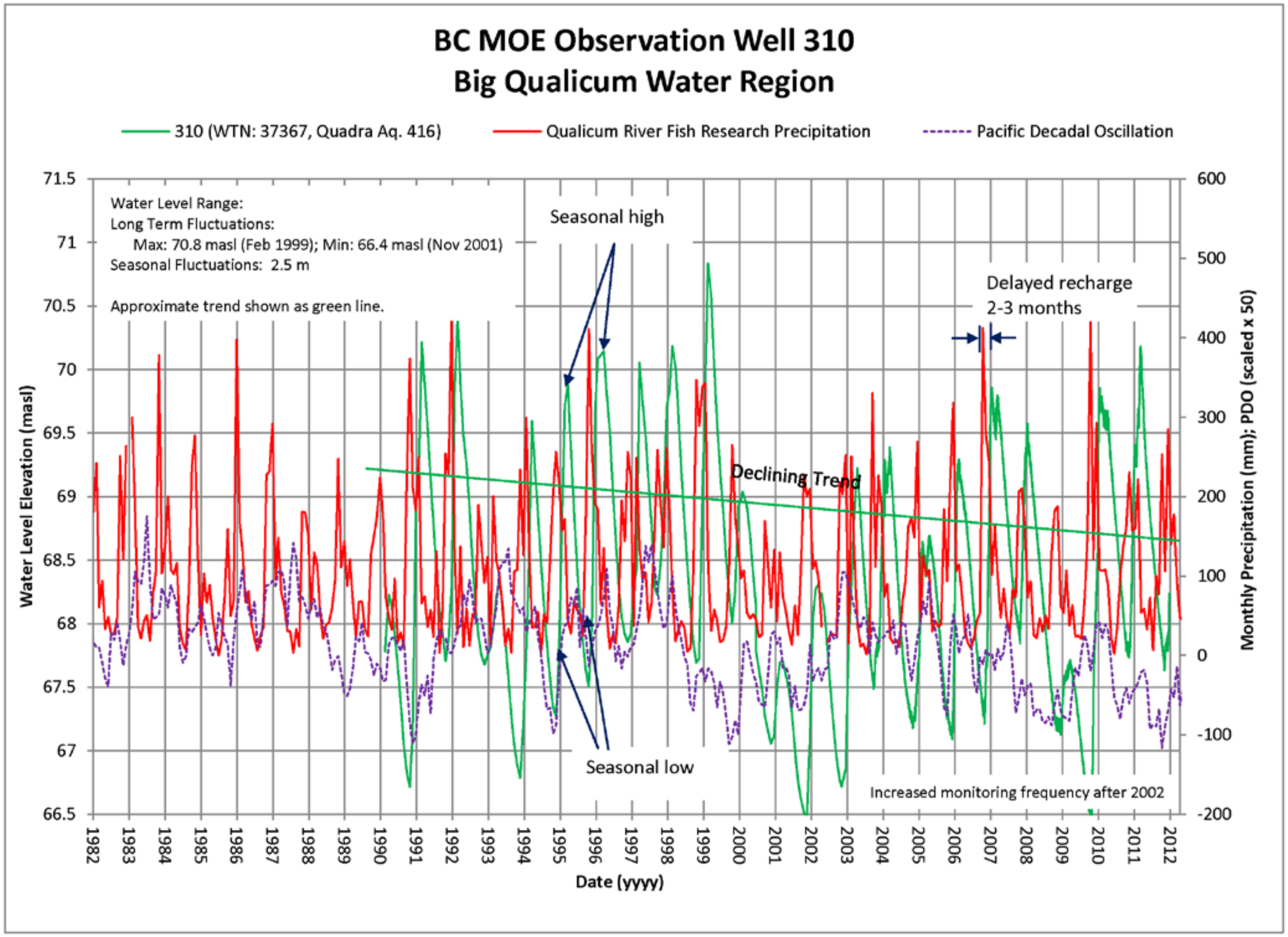


Figure 20: WR1 (BQ) – Water Level Hydrograph BCMOE 310.

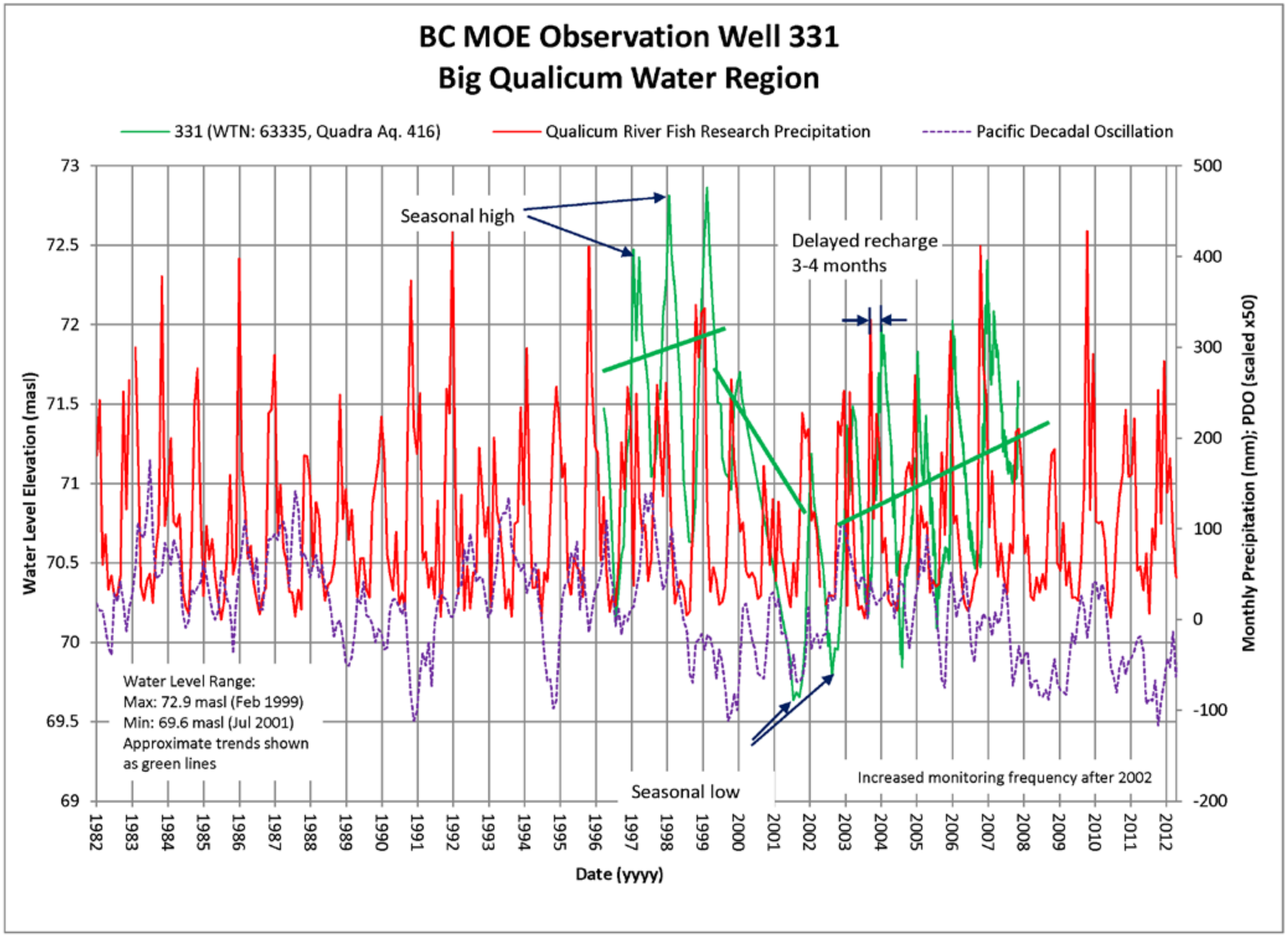


Figure 21: WR1 (BQ) – Water Level Hydrograph BCMOE 331.

3.3.2 Anthropogenic[24] Groundwater Demand

Table 9 summarizes the available groundwater demand data available for WR1 (BQ).

Table 9: WR1 (BQ) – Summary of Anthropogenic Groundwater Demand Analysis

Aquifer Tag No.	Qualicum Bay & Horne Lake WWD @ Nile Creek	Qualicum Bay & Horne Lake WWD @ Thames Creek	Bowser WWD	Deep Bay ID	Other Private Wells (From RDN Water Use Est. based on Zoning compiled on GIS)	Total Ground Water Use Estimate (ANTHout)
	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)
416	NA	?	9.2E+04	1.7E+05	5.4E+04	3.1E+05
421	?	NA	NA	NA	0.0E+00	0.0E+00
665	NA	NA	NA	NA	7.0E+00	7.0E+00
662	NA	NA	NA	NA	6.7E+05	6.7E+05

Notes: NA means not applicable,? Means not known or unavailable, ANTHout means anthropogenic water extraction from aquifer, WWD means Waterworks District, ID means Improvement District.

The annual water use for serviced areas within the RDN (large municipal users, RDN wells, and private utilities) is typically measured and was provided by the RDN, or taken from annual reports for 2010. The groundwater demand estimate for non-service areas was calculated from water use data provided by the RDN for serviced areas, and then applied to non-serviced areas based on civic addresses and zoning classification. The method of assessment is further described in Appendix C and D.

There may also be groundwater discharging from aquifers that is required for conservation of flow in creeks and rivers based on the physical model developed by Waterline. In addition, Waterline understands that Qualicum Bay and Horne Lake WWD may also be discharging water to Nile Creek for river level conservation measures (Donnelly, Pers. Comm., 2012). The total groundwater demand for each aquifer, including conservation flow requirements, was compared against the estimated aquifer recharge to assess the stress on each aquifer. The results are presented in the following section.

3.3.3 Aquifer Water Budgets and Stress Analysis

Table 10 provides a summary of the final water budget calculations for each aquifer mapped within WR1 (BQ). Detailed water budget calculations are provided in Appendix D (Tables D7 and D8). Water budgets for aquifers that extend from one water region to an adjacent water region (E.g.: Aquifer 662, Figure 16) were completed on the portion of the aquifer which lies within each region. The water budget calculations were also designed to be additive so that a complete water budget of an entire mapped aquifer that extends across a water region boundary could be easily developed.

[24] Human induced

Table 10: Summary of Water Budget and Stress Analysis - WR1 (BQ)

Aquifer Tag No.	Aquifer Lithology	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	MOE Obs Well	Seas. Fluc.	Long-Term Fluc.	WL Trend (up or down)	Total Est. AQ. Rec. (TRin) (Rp/l + Rmb)	Est. Ann. Disch to Cr. & Down Grad Aquifer (Tc out)	Ground Water Use Estimate (ANTHout)	Total Out [TcOut + $ANTH_{out}$]	Stress Anal. % GW Use of the avail. AQ. Rec.	Relative Stress Assess.
			ID	(m)	(m)	U/D	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(%)	Lo, Mod, Hi
416	Quadra	Ocean	310, 331	2.5	4.4	U	5.1E+06	0.0E+00	3.1E+05	3.1E+05	6	Lo
421	Quadra	Ocean, Nile	NA	NA	NA	NA	1.7E+06	1.3E+06	0.0E+00	1.3E+06	78	Mod-Hi
665	Capilano	Ocean, Nile Creek, BQ	NA	NA	NA	NA	9.8E+08	3.3E+08	7.0E+00	3.4E+08	33	Lo-Mod
662	Quadra	Ocean (Quadra Exposed)	NA	NA	NA	NA	1.2E+07	4.1E+06	6.7E+05	4.8E+06	41	Lo-Mod

Notes: BQ means Big Qualicum, NA means not applicable, AQ means aquifer, Seas. Fluc. means seasonal fluctuation, PDO means Pacific Decadal Oscillation, WL means water level, Est means estimated, Disch. means discharge, Rec. means recharge ,Cr. Means creek, TRin means total recharge into aquifer, Rp/l means total recharge from precipitation and/or leakage from overlying aquifer, Rmb means total lateral recharge from upgradient aquifer or mountain block, Tc out means total aquifer groundwater discharge to creek, assess. means assessment , Total out means total discharge from aquifer (not including discharge to ocean), ANTH out mean total groundwater Anthropogenic groundwater extraction from aquifer, aquifer stress color codes: : blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high.

Based on the water budget estimates for mapped aquifers within WR1 (BQ), overall conditions appear to be stable with low to moderate stress indicated. Some concerns existed in the Bowser area where a 4.4 m water level drop in the MOE observation well completed in Aquifer 416 was noted from 1999 to 2003 but the declining trend appears to have reversed after 2003.

The water budget assessment for Aquifer 421 indicates a moderate to high stress, which is due to the assessed groundwater discharge to Nile Creek. This is supported by conceptual model where the Quadra sand appears exposed in the creek bed, and also supported by the surface water budget developed for Nile Creek.

More accurate water budget and aquifer stress estimates could only be accomplished using a computer modelling approach, but again the lack of aquifer data would likely render this exercise inconclusive as well. Rigorous testing requirements and complete aquifer test analysis by groundwater practitioners to determine aquifer transmissivity and storativity properties, in addition to long-term groundwater monitoring data in each aquifer would be required to fully assess the actual stress on each aquifer in this region.

3.4 Water Management Planning Within WR1 (BQ)

General guidance on water management planning for all water regions is provided in later sections of this document. Specific to WR1 (BQ), the following recommendation are presented for consideration by RDN to improve the state of knowledge in the water region:

- At least one observation well should be installed in each mapped aquifer. Aquifers that currently do not have observation wells include 421, 665 and 662;
- Well owners should identify the MOE well plate and tag numbers for each of their active water wells. In this manner, water use and monitoring data can be easily cross-referenced with the BC MOE well records. These include the Qualicum Bay & Horne Lake Waterworks District (WWD) well at Nile Creek and Thames Creek, and the Bowser WWD wells, and Deep Bay Improvement District (ID) wells;
- Major water users should be requested to provide RDN with annual operations records (i.e.: water levels, water use, chemistry);
- The significant recharge area map needs to be updated by further processing of the NRCAN remote sensing data and by field verification;
- Further mapping of the groundwater surface water interactions is also required in Nile Creek to confirm the preliminary assessment; Waterline recommends specialized analysis (E.g.: isotopes[25], noble gases) of groundwater samples in this region to assist in determining groundwater age and origin. Thermal imaging of the river during high and low flow many help to quickly pinpoint areas where more detailed studies may be required;
- Big Qualicum River Flow and Horne Lake Level data collected by DFO should be obtained at regular intervals and included in the Regional Water Database; and
- Weekly or bi-weekly summer low flow measurements should be collected for Nash Creek, Sandy Creek, Cook Creek, Thames Creek, McNaughton Creek and Annie Creek as part of the Regional Community Watershed Monitoring Network project to better understand summer low flows in these smaller watersheds.

[25] Elements of the same family but with different atomic weights. Technique is used to assess recharge elevation and age of water.

4.0 WATER REGION # 2 - LITTLE QUALICUM

4.1 Regional Overview

The Little Qualicum water region (WR2 (LQ)) is defined as the area extending from the coast to the headwaters of the Cameron River in the southeast of the water region (Figure 22). It is the fourth largest water region within the RDN covering an area of approximately 259 km^2. The region includes major watersheds as listed in Table 11. The largest watershed is associated with the Little Qualicum River with an estimated drainage area of 251.7 km^2. Cameron Lake is also a major surface water feature within WR2 (LQ). Two hydrometric stations, six climate stations, and approximately 42 surface water diversion points exist within the region (Figure 22 and Table 11).

Table 11: WR2 (LQ) - Watersheds, Wells and Surface Water Licenses

Total Water Region Area	*** 259 km^2**
Major Watersheds	**Drainage Area[1] (km^2)**
Kinkade Creek (tributary to Little Qualicum River)	39.6
Whisky Creek (tributary to Little Qualicum River)	26.8
McBey Creek (tributary to Little Qualicum River)	11.5
Lockwood Creek (tributary to Little Qualicum River)	14.3
Cameron Lake/River (tributary to Little Qualicum River)	111.8
Little Qualicum River (including tributaries)	251.7
Wells and Surface Water Diversion Points	**No.**
# Water Wells listed in MOE DB	387
Surface water diversion licenses	42

Note: Drainage Areas are based on 1:50,000 BC Watershed Atlas. *The total water region area includes area that drains directly into the ocean and is not part of a major watershed. Little Qualicum Watershed Drainage Area is the area to the mouth and includes all tributary areas.

According to the MOE Wells Database (BCGOV ENV Water Protection and Sustainability Branch, 2008) WR2 (LQ) has the 3rd lowest number of water wells (387 wells) of the six water regions in the RDN. The MOE database likely only represents a fraction of the actual wells currently in use. Many well records may not have been entered into the database and some wells may simply not be in use or have been abandoned. As there is no mandatory requirement for submitting well logs or well abandonment records, it is not possible to determine the groundwater demand from private wells with any degree of certainty, nor is it possible to assess the vulnerability that may exist with improperly abandoned or standing water wells.

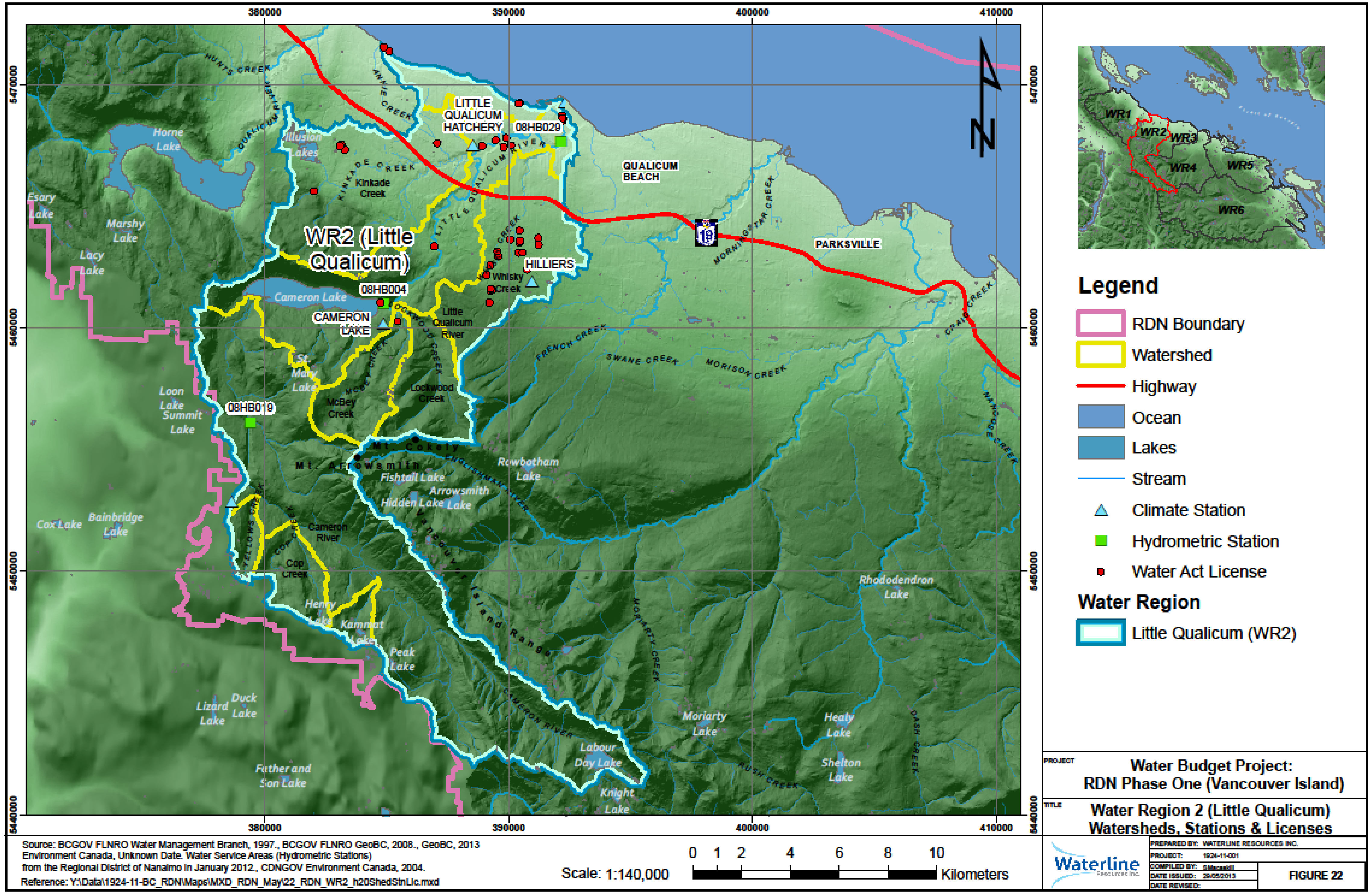


Figure 22: WR2 (LQ) – Watersheds, Hydrometric/Climate Stations & Licenses

4.2 Surface Water Assessment

4.2.1 Topography and Land Use

The Little Qualicum Water Region (#2) is located in the northern section of the Regional District of Nanaimo, between Big Qualicum and French Creek. Approximately half of the region is within the Nanaimo Lowlands, the other half lies within the Vancouver Island mountain range.

The region lies along the course of the Englishman River which rises up to Mount Arrowsmith (1,819) near the headwaters. Mount Arrowsmith lies within a UNESCO Biosphere Reserve and Mt. Arrowsmith Regional Park. The majority of the watershed lies within privately managed forest lands with the headwaters in Crown Forest Lands. The lower portion of the water region is rural development with agricultural and low density residential development. A small commercial/light industrial area is located near Hilliers within the Whiskey Creek watershed.

The most significant water feature in the region is the Little Qualicum River and Cameron Lake. Most of the mountainous watersheds in the water region drain to the northwest towards Cameron Lake. The Little Qualicum River flows to the north east from Cameron Lake into the Strait of Georgia. Two smaller lakes in the Kinkade Creek watershed, Ilusion Lakes and Spider Lake, do not have outflow and are thought to flow into the Kinkade Creek watershed through groundwater paths. The major watersheds in the region from north to south are shown in Figure 22.

4.2.2 Climate

The climate for the Little Qualicum Water Region is similar to the rest of the RDN with cool wet winters and mild dry summers. The climate varies significantly between the mountainous and low-lying areas of the region. The low-lying area has a typical rainfall record as the other coastal with an average total annual precipitation for the 1971 to 2000 Climate Normal Period of 1098.5 at the Little Qualicum Hatchery (Figure 23). This compares with recorded average total annual precipitation of 1,162.7 mm at the Nanaimo Airport. The mountain regions typically get precipitation as snow during the winter, providing snowmelt in the late spring. A snow course at Mt. Cokely (03B02A) (Figure 22), operated by the River Forecast Centre, has a long period of manual snowpack records between February and May (1980-Present). The average April 1st SWE recorded at Mount Cokley is 864 mm and the maximum recorded SWE is 2,100 mm on April 1st 1999. Climate station locations are shown on Figure 22.

Maps showing the distribution of annual precipitation and average annual temperature over the water region are shown in Figure 24 and Figure 25, respectively. These maps show the influence of the Mount Arrowsmith and Vancouver Island mountains on precipitation and temperatures compared to the warmer, low-lying coastal areas of Little Qualicum. Total precipitation amounts in coastal areas are typically between 1,000 to 1,500 mm per year while up to 5,000 mm of precipitation per year is likely in the mountainous headwaters near Mt. Arrowsmith.

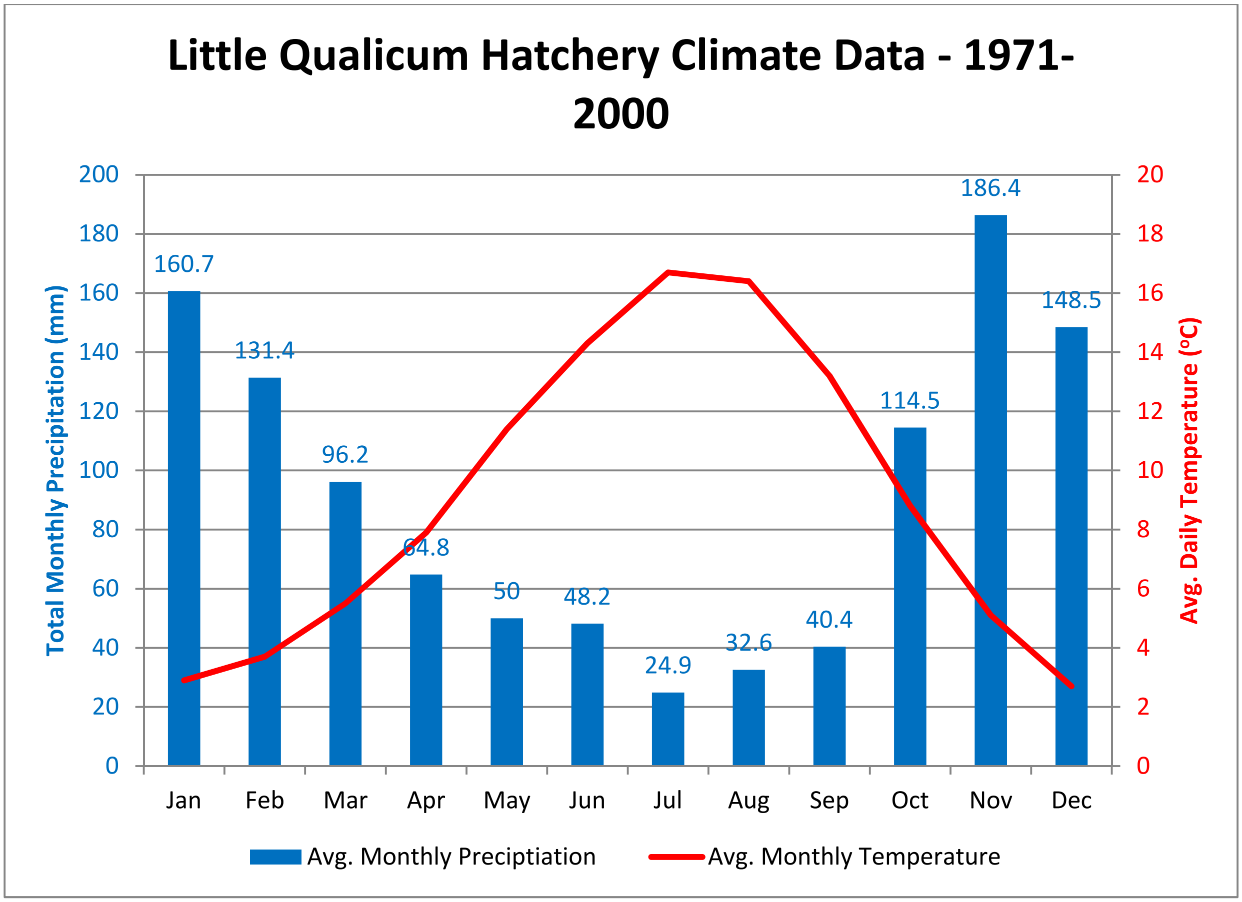


Figure 23: WR2 (LQ) – Little Qualicum Hatchery Monthly Climate (1971-2000 Normal)

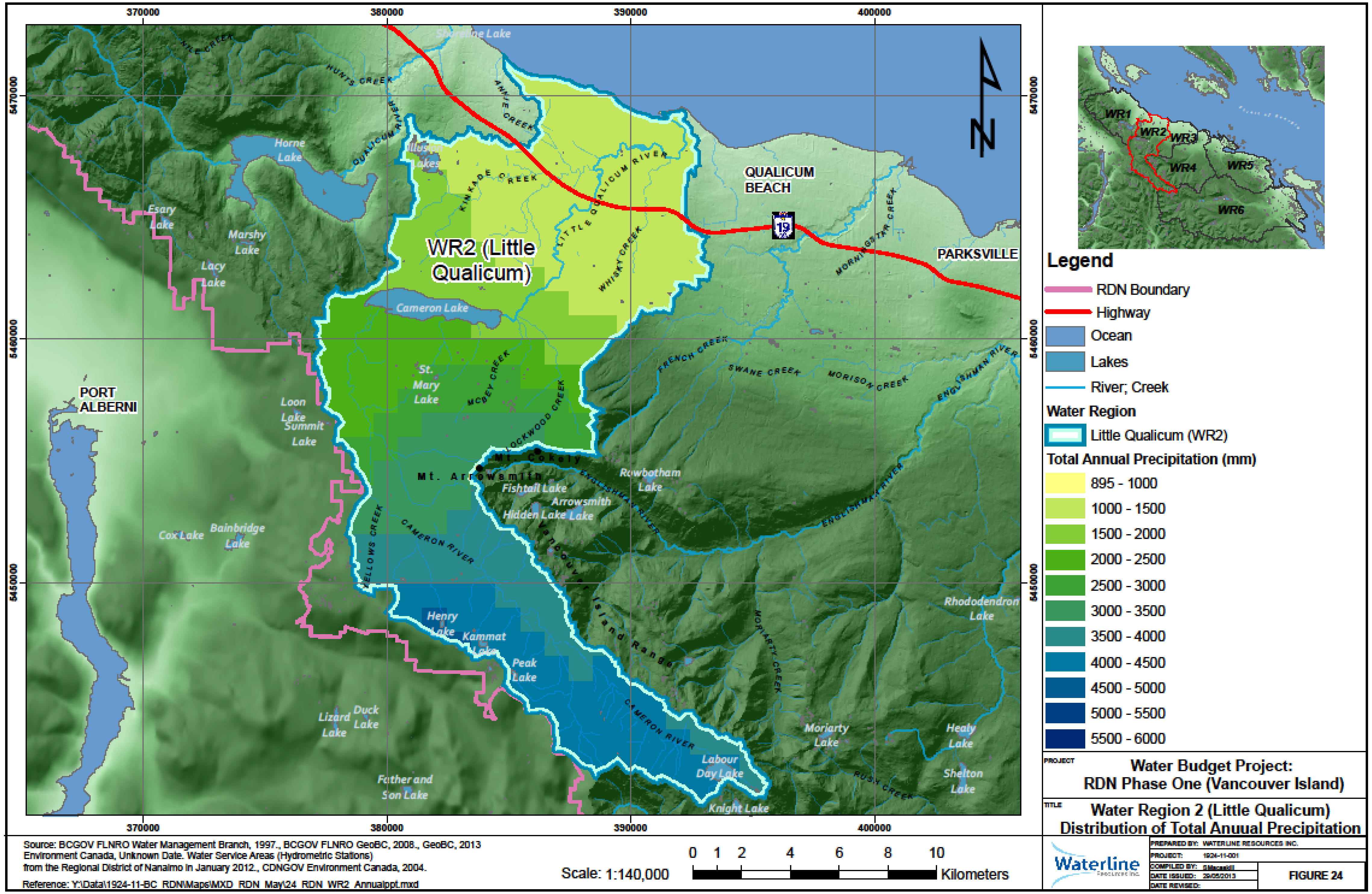


Figure 24: WR2 (LQ) – Distribution of Total Annual Precipitation

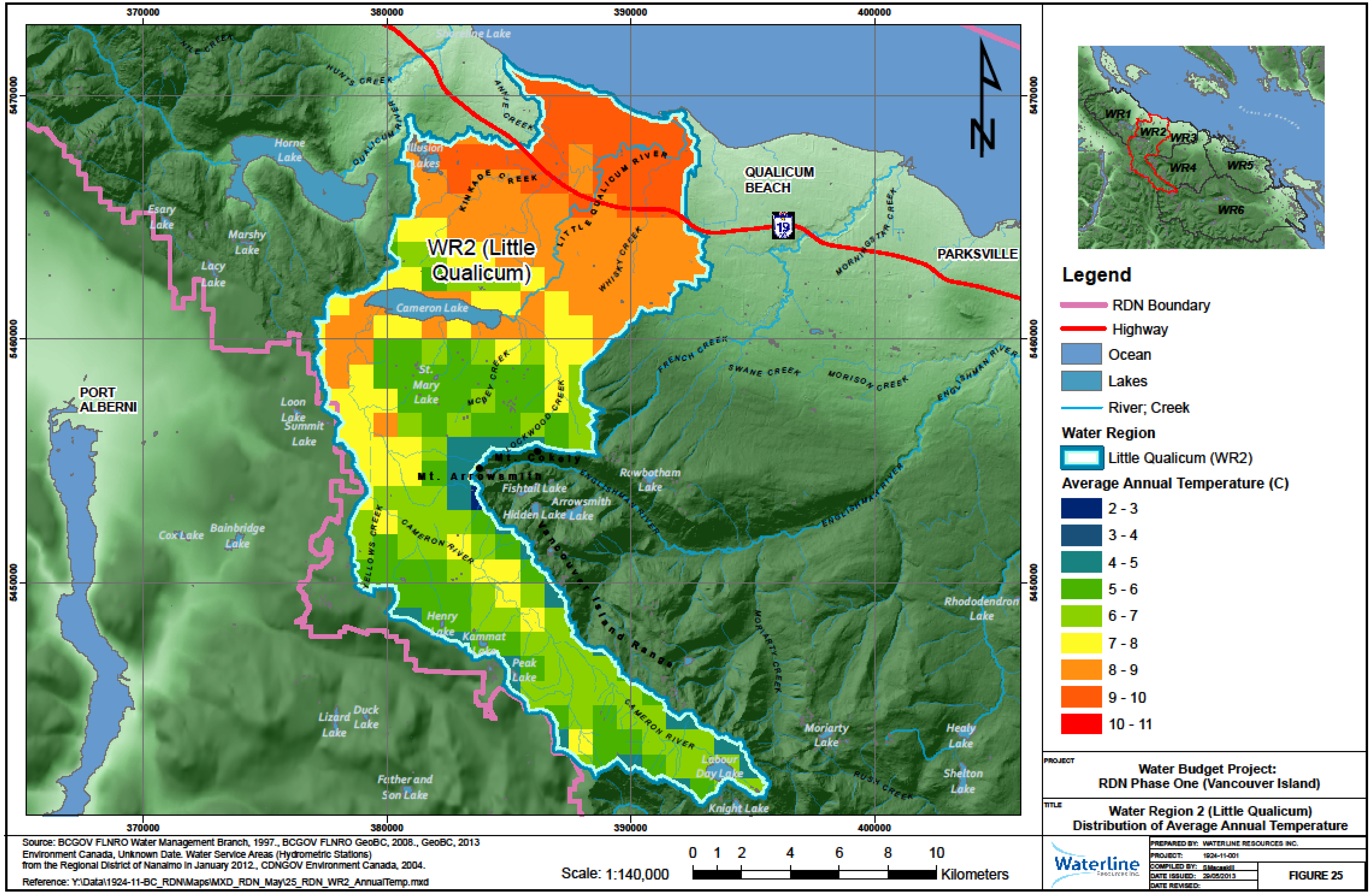


Figure 25: WR2 (LQ) – Distribution of Average Annual Temperature

4.2.3 Stream Gauging and Monitoring

Two Water Survey of Canada stations are located within the Little Qualicum Water Region. Table 12 lists the names of the hydrometric stations are located in the WR 2 (LQ) and they are shown on Figure 22.

Table 12: WR2 (LQ) – Water Survey of Canada Records

Station Name (WSC Number)	Period of Record	Natural or Regulated	Drainage Area to Gauge (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)
Little Qualicum River (08HB029)	1960 to 1986	Regulated since 1978	237	11.9 m^3/s 375.7 million m^3	3.1 m^3/s 24.4 million m^3
Little Qualicum at Cameron L. (08HB004)	1913 to 2001	Regulated since 1978	135	8.8 m^3/s 276.6 million m^3	2.4 m^3/s 19.0 million m^3

Note: 1 – Summer Period Jul to Sep (three lowest average months)

In addition to the records outlined above, a lake level gauge has been operated on Cameron Lake since 1978. The records indicate that lake levels fluctuate approximately about 1.0 m on average but have a maximum recorded range of 3.4 m.

Flows in the Little Qualicum River are controlled by a weir at the outlet of Cameron Lake. Hydrographs showing monthly average flows in the river before and after regulation are shown in Figure 26 and Figure 27.

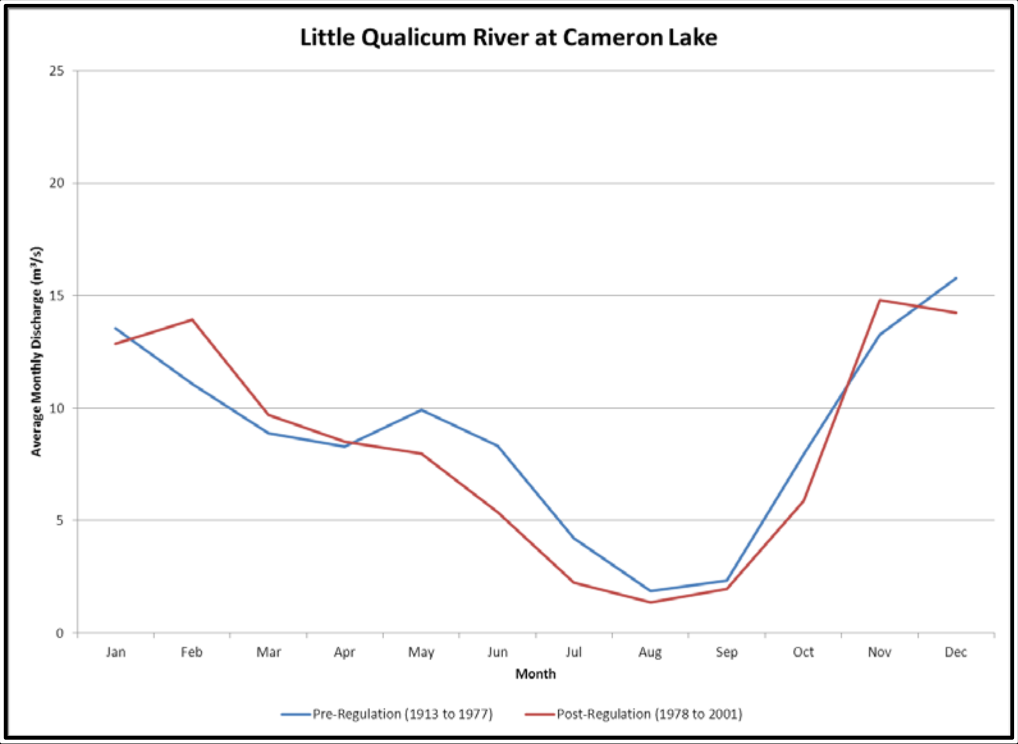


Figure 26: WR2 (LQ) – Little Qualicum River at Cameron Lake

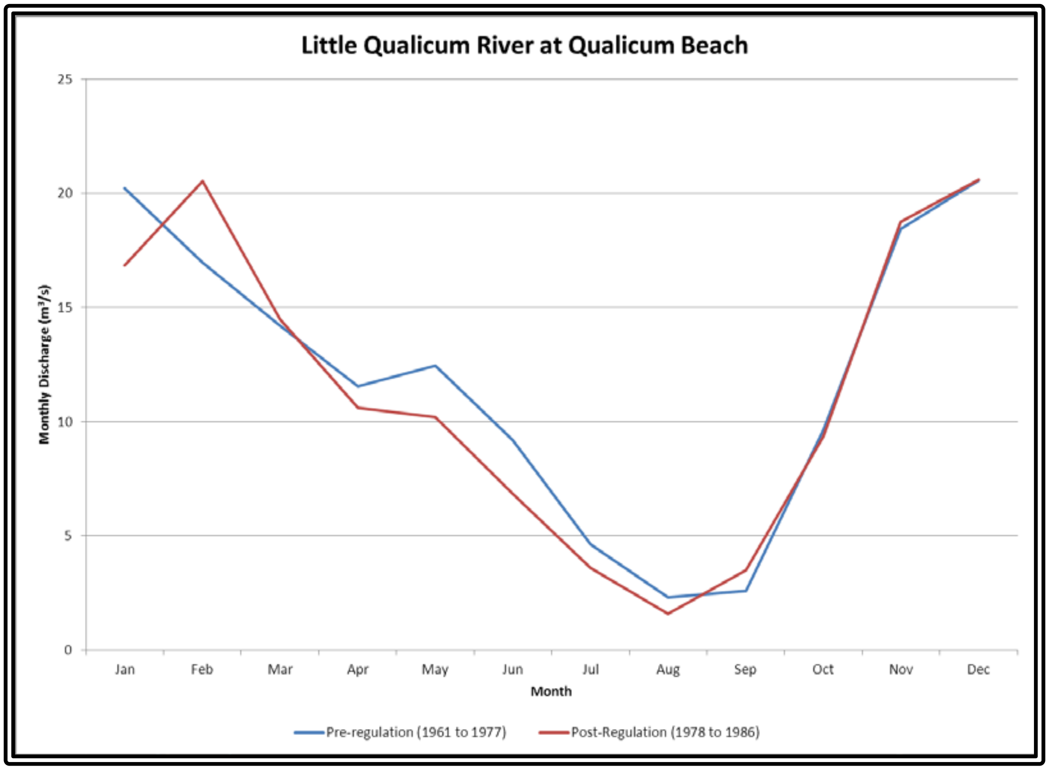


Figure 27: WR2 (LQ) – Little Qualicum River at Qualicum Beach

4.2.4 Hydrology and Surface Water Resources

The hydrological model has provided estimates of average available surface water resources for the major watersheds in the region for the year and the summer (Table 13).

Table 13: WR2 (LQ) – Available Surface Water Resources (Avg. for 1971 to 2000 period)

Watershed	Drainage Area[1] (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)	Previous Estimate of MAD (m^3/s)
Kinkade Creek	39.6	1.1 m^3/s 35.2 million m^3	0.04 m^3/s 0.3 million m^3	
McBey Creek	11.5	0.9 m^3/s 27.9 million m^3	0.2 m^3/s 1.2 million m^3	
Lockwood Creek	14.3	0.9 m^3/s 29.9 million m^3	0.1 m^3/s 0.8 million m^3	
Whisky Creek	26.8	0.8 m^3/s 24.1 million m^3	Less than 0.1 m^3/s	0.7 m^3/s
Cameron River	111.8	11.5 m^3/s 362.6 million m^3	1.8 m^3/s 14.5 million m^3	
Little Qualicum River	251.7	17.2 m^3/s 543.2 million m^3	2.4 m^3/s 18.9 million m^3	11.8 m^3/s

Note: Drainage Areas are based on 1:50,000 BC Watershed Atlas.

4.2.5 Surface Water Demand

Table 14 summarizes the surface water licences in WR2 (LQ) from the BC Surface Water Licence Database. The locations of the surface water licences for WR2 (LQ) are shown on Figure 22. Not all license locations can be seen at this scale as many are in close proximity and plot over each other.

Table 14: WR2 (LQ) – Surface Water Demand (m^3)

Type of Demand	Monthly	Annual	Summer (Jul-Sept)
Consumptive Demand			
Agriculture	8,446	101,352	76,010
Domestic	1909	22,912	7,561
Industrial	477	5,728	1,432
Institutional	-	-	-
WaterWorks	41,414	496,967	163,999
Total Consumptive	52,246	626,954	249,002
Non- Consumptive Demand			
Power	-	-	
Conservation	3,439,584	41,275,008	10,318,752
Total Non-Consumptive	3,439,584	41,275,008	10,318,752

Table 15: WR2 (LQ) – Licensed Surface Water Storage (m^3)

Type of Storage	Annual
Storage	1,233
Conservation Storage	4,631,717
Other Storage	215,378
Total Storage	4,848,329

The largest licensed water user in WR2 (LQ) is the Department of Fisheries and Oceans to maintain conservation flows in the Little Qualicum River and to supply the Little Qualicum Fish Hatchery. These flows are supported by storage at Cameron Lake which is controlled by a dam. The total licensed storage on Cameron Lake is 6,280,229 m^3.

4.2.6 Surface Water Stress Analysis

As outlined in Section 2.5.2, a surface water stress analysis for the Little Qualicum River watershed has been completed. Water budget analysis for other smaller ungauged subwatersheds within WR2 (LQ) should be completed when data is available and as part of a more detailed Tier 1 or Tier 2 water budget assessment (OMNR 2011). The results of the stress analysis for the watersheds in WR2 (LQ) are shown in Table 16. A map showing the relative stress for each watershed is shown in Figure 28.

Table 16: WR2 (LQ) – Surface Water Stress Analysis

Watershed	Average Natural River Flow Supply (million m^3)	Storage (million m^3)	Conservation Flow (10% of MAD) (million m^3)	Licensed Demand (million m^3)	Allocation Stress	Stress Level
Little Qualicum River	18.89	4.85	13.46	0.20	58%	Moderate

Notes: Volumes indicated in the table are average volumes for summer period (Jul to Sep). Average natural river flow is the estimated or recorded unregulated flow in the watershed. Total storage is based on licenced storage volume and assumes all storage is available to support conservation flow and licenced demand for the Jul to Sep period. The 10% of Mean Annual Discharge (MAD) conservation flow is based on current Ministry of Forest, Lands and Natural Resource Operations (MELP 1996) minimum conservation flow policies for the east coast of Vancouver Island. Licenced demand is the total licenced volume for summer based on consumptive water licences. Allocation stress = (Average Natural supply + storage) / (Conservation Flow + Licenced Demand) Surface water stress color codes: : blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high. Values reflect average flow conditions and do not consider drought years.

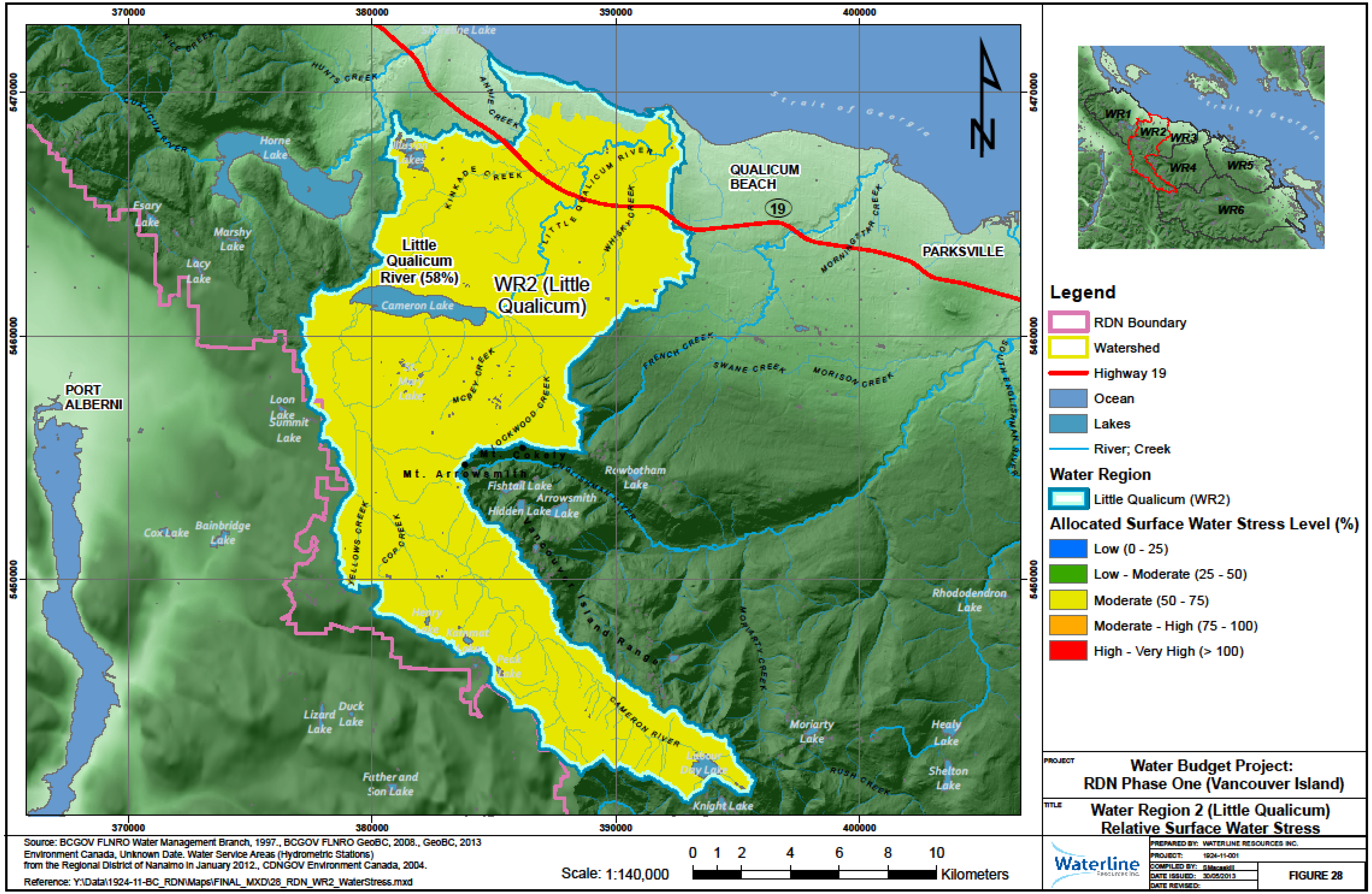


Figure 28: WR2 (LQ) – Relative Surface Water Stress

4.3 Groundwater Assessment

4.3.1 Existing Groundwater Studies and Data

Given the regional scale of the Phase One Water Budget Assessment, the most important data compiled and geo-referenced by Waterline was the water well information, elevation data, soil and geology maps, land cover, aggregate resource map, mapped aquifers, and water service areas. Other maps were generated using the input data as part of Waterline's work and some samples are provided in Appendix C for illustration purposes (Eg: overburden thickness (Map C7), piezometric contour maps (Maps C8 and C9), air temperature (Map C14), precipitation (Map C15), runoff (Map C16 and C17), evapotranspiration (Map C18), infiltration (Map C19), Water Service Areas (Map C20), and Water Demand Assessment in Non-service areas (Map C21). All of these maps are provided in Appendix C for the entire RDN study area with an explanation of how the map was geo-reference or created by Waterline. These data and layers are now available in the ARC GIS Geodatabase at the RDN Scale, water region scale, watershed scale, on other local scale needed for site specific assessments. These data will be provided to the RDN in electronic format as part of the ARC GIS Geodatabase system which was constructed by Waterline for use by the RDN. These regional datasets form the framework for construction of the conceptual hydrogeologyical model.

Although only some of the data in certain reports may have been incorporated into Waterline's Geodatabase, the primary studies in the region were used in Waterline's water budget assessment to provide local hydrogeological context are provided in Table 17.

Table 17: WR2 (LQ) – Hydrogeology Reference Reports

Author	Year	Study Title
EBA Engineering Consultants Ltd	2003	Drinking Water Protection Plan – Mt. Arrowsmith Watersheds
EBA Engineering Consultants Ltd	2005	Mt. Arrowsmith Final Aquifers Modeling Projects, Parksville Area
Lowen Hydrogeology Consultants	2010	Arrowsmith Water Service Englishman River Water Intake Study Groundwater Management. Discussion Paper 5-1. Existing Groundwater Supply Evaluation and Aquifer Yield Assessment, Prepared by Dennis Lowen, Alan Kohut and Bill Hodge, January 25, 2010.

4.3.2 Description of Aquifers and Water Wells

Four unconsolidated aquifers have been mapped within WR2 (LQ) (Figure 29). Table 18 provides a summary of information on mapped aquifers within WR2 (LQ). Quadra sand and Kame Delta aquifers (662, 661, & 663) have been mapped as moderate productivity, whereas the Salish Aquifer 664 has been mapped as highly productive (BCGOV ENV Water Protection and Sustainability Branch, 2012). The Quadra sand aquifers (662 and 217) are confined with low vulnerability, while the unconfined Salish (664) and Kame Delta (661 and 663) aquifers are described as highly vulnerable. Kame aquifer 661 in the vicinity of Spider Lake appears to be hydraulically connected to the lake and experiences up to 5 m seasonal fluctuations in water level. The GSC drilling program conducted in March 2013 has confirmed that the Kame Delta aquifer (661) is perched and limited in extent (Paradis, Pers. Comm., 2013).

The majority of supply wells are completed along the coast in unconsolidated Quadra sand and gravel aquifers (Figure 29). As there are no regulatory requirements in BC to submit wells logs to MOE for capture in the Wells Database, the water wells shown on Figure 29 likely represents only a fraction of wells actually drilled.

Table 18: Summary of Mapped Aquifers in WR2 (LQ)

Aquifer Tag No.	Aquifer Name/ Lithology	Location Within Water Region	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	Developed Aquifer surface Area	Confined, Semi, or unconfined, Aquifer Vulnerability Code	Yield
				(m^2)		(L/M/H)
662	Quadra	Extends from BQ, connected to Kame 661	Ocean, LQ, Aq. 661	2.84E+07	Confined , IIC	M
661	Kame	Along LQ, Springs towards Kinkade Creek	Spider LK, Horne?	9.63E+06	Unconfined, IIIA	M
664	Salish	Lower LQ	Ocean, LQ	4.96E+06	Unconfined, IA	H
663	Kame (Vashon Gf) top of Whiskey Creek	Upper Whisky Creek at border with WR3 (FC)	Whiskey Creek, LQ	9.63E+06	Unconfined, IIIA	M
217	Quadra	Below Kame and Above Haslam 220	LQ and Ocean	6.02E+06	Confined , IB	M

Notes: A/B/C is high/moderate/low vulnerability, I/II/III is heavy/moderate/light use, H/M/L means high/medium/low productivity/yield. All aquifer classification parameters, codes and yield are defined at the following MOE web address http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/Aq_Classification/Aq_Class.html#class

4.3.3 Groundwater-Surface Water Interaction - Conceptual Hydrogeological Model

A conceptual hydrogeological model of each aquifer with WR2 (LQ) was developed in order to understand the key elements and linkages between surface water and groundwater systems required to complete the water budget assessment. Although conceptual hydrogeological model developed by Waterline includes numerous cross-sectional views developed within the Waterline Geodatabase, only one 3D view into the subsurface is presented for WR2 (LQ).

Figure 30 shows a 3D block diagram illustrating the relationship between surface and subsurface geology in WR2 (LQ) where major water supply aquifers have been mapped. The schematic shows two cross-sectional views: one in the Spider Lakes area and one where mapped overburden aquifers intercept the Little Qualicum River.

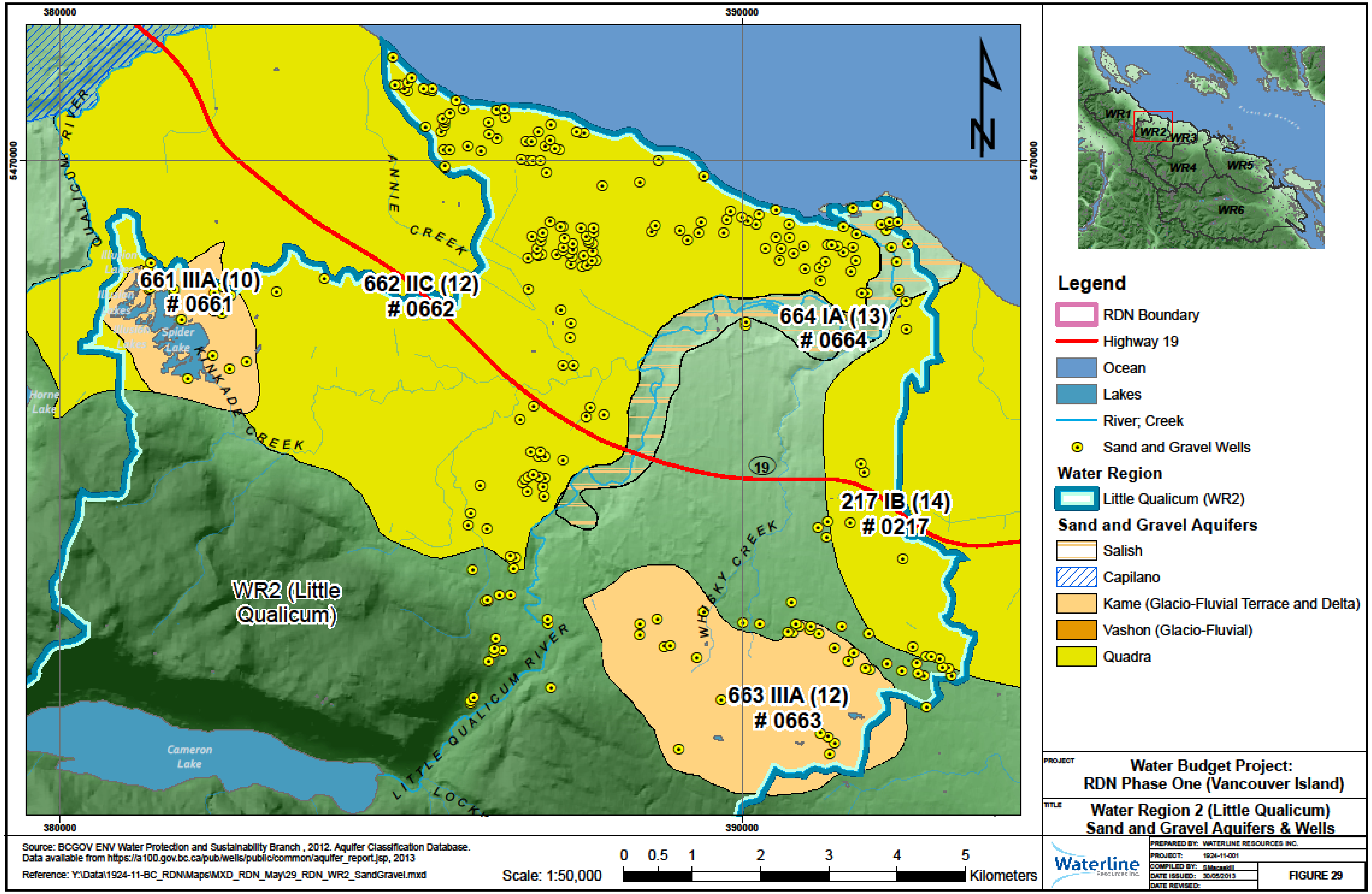


Figure 29: WR2 (LQ) – Sand and Gravel Aquifers and Wells

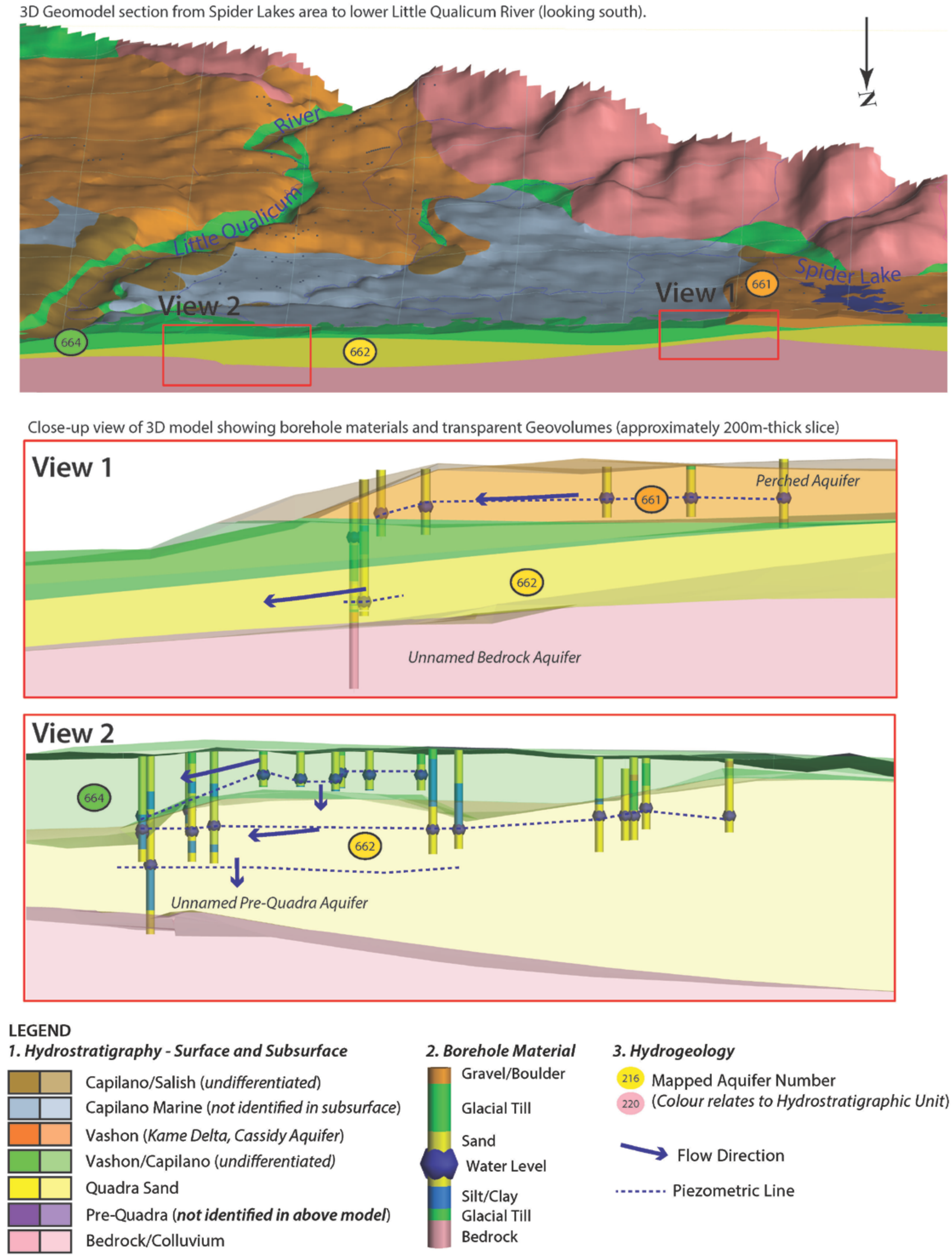


Figure 30: WR2 (LQ) – Hydrogeological Conceptual Model – Little Qualicum River

View #1 shows the subsurface view of the unconfined and perched Vashon aquifer (661) which is known to be directly connected to Spider Lake. Water levels in wells completed in the deeper confined Quadra sand aquifer (662) are considerably lower (deeper) than water levels in the overlying Vashon aquifer (661) suggesting disconnected or poorly connected flow systems.

View 2 shows the unconfined Capilano aquifer (664) overlying Quadra Sand Aquifer (662), overlying an unnamed bedrock aquifer (likely 220 found in the adjacent WR3). Water levels in wells completed in the deeper confined Quadra sand aquifer (662) are considerably lower (deeper) than water levels in the overlying Capilano aquifer (664) suggesting poor connection between the two flow systems. A component of groundwater flow in both the shallow and deep aquifers appears to be towards the Little Qualicum River Valley which illustrates the potential interaction with the river.

4.3.4 Significant Recharge Areas

Significant recharge areas within WR2 (LQ) were determined as part of the assessment of infiltration across the region base on topography, mapped textural soil characteristics, land cover (bare land, vegetation, impermeable surfaces), and leaf area index. These areas are important for maintaining recharge to aquifers and base flow to creeks and rivers. The preliminary assessment presented herein is based on the integration of numerous datasets which may be incomplete and therefore will require further field verification. Figure 31 shows significant recharge areas mapped in WR2 (LQ) as part of the water budget project.

Significant recharge areas extend to the upper reaches of WR2 (LQ) and into the upper reaches of Kinkade Creek. Many of the areas indicated are not well developed and others around Kinkade Creek are moderately developed. Spider Lake likely also represents a substantial recharge source for the Kame Delta aquifer (661). Future development planning needs to consider these areas to ensure that recharge continues to be maintained. There is a need to develop protection zones around critical areas contributing recharge to underlying aquifers to ensure the future sustainability of groundwater resources in this region. Better definition of these areas should be completed as the current modelling completed by Waterline and KWL was done on a 1 km square grid.

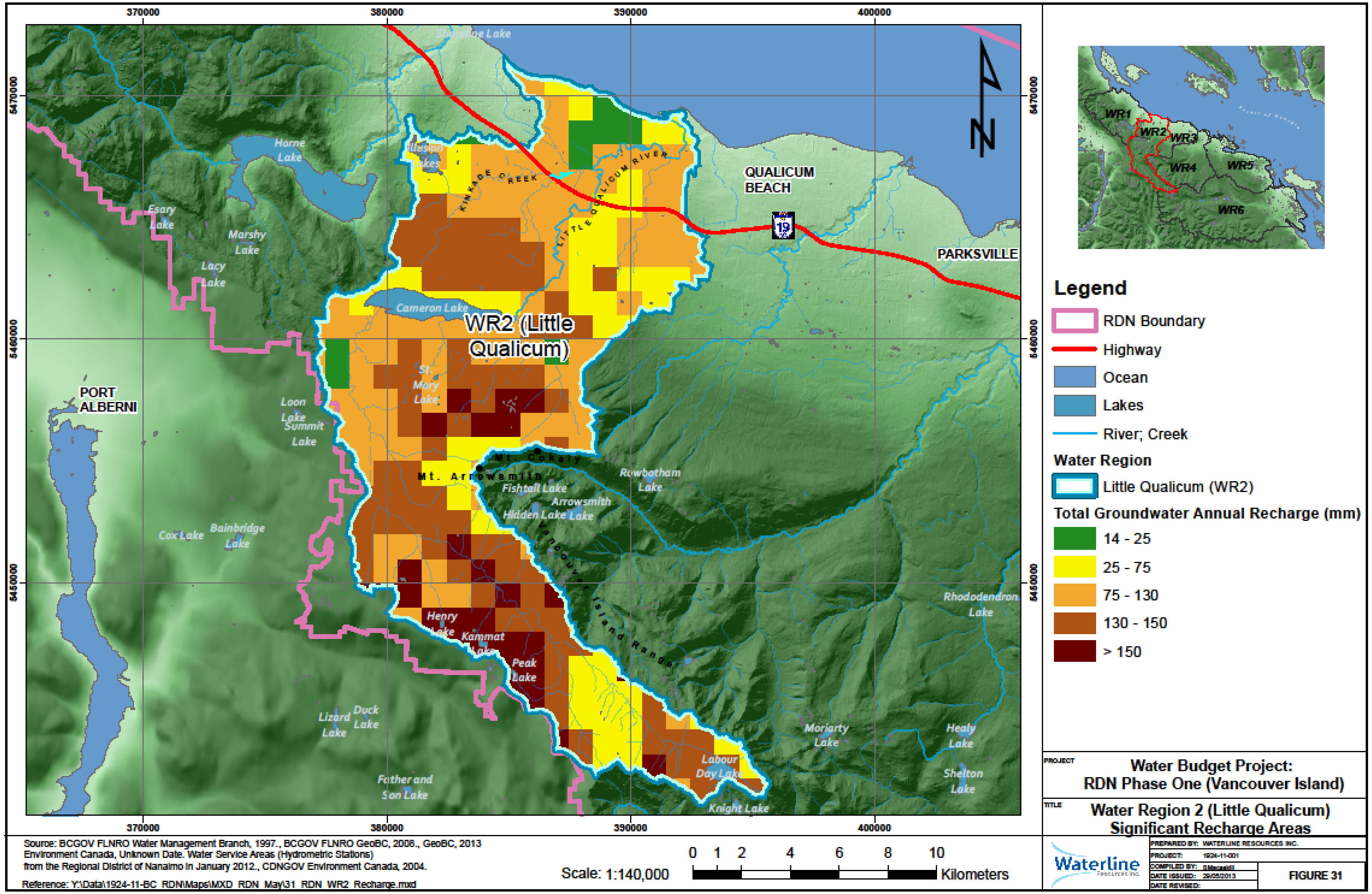


Figure 31: WR2 (LQ) – Significant Recharge Areas

4.3.5 Groundwater Level Monitoring – BC MOE Observation Well Network

Long-term water level monitoring data provides an indication of an aquifer's response to global, regional, and local environmental changes in climate, groundwater pumping, and the impacts (if any) of other activities related land development. Long-term records also allow for establishing hydraulic linkages between the groundwater and surface water systems.

Figure 32 shows the locations of MOE observation wells and long-term water level monitoring records in relation to community water supply wells identified from the MOE Wells Database (E.g.: large municipal users, the RDN, private utilities wells). Although numerous community wells are listed in the database, Waterline understands that not all of these wells shown on Figure 32 are currently active.

One of the problems encountered by Waterline during the water budget project was that community well owners generally do not cross reference active production wells to respective well logs in the MOE database. Often wells are referred to by local names (E.g.: RDN well # 1, #2, etc…). As water budget calculations require that production wells be assigned to specific aquifers, it is important that cross-referencing with the MOE well logs be done. Well owners are encouraged to report the MOE Well tag number so that accurate water level and groundwater extraction volumes can be allocated to the corresponding MOE well log and mapped aquifer.

Figure 33 and Figure 34 show water level hydrographs for MOE Observation Wells 391 completed in Quadra aquifer 662, and 389 completed in the Salish aquifer 664 near the coast. Water levels in MOE Wells were plotted along with the Qualicum Beach Middle School precipitation record and the PDO trend where appropriate.

The record for MOE well 391 (Figure 33) is about one year and the water level trend follows the precipitation record. The record for MOE Well 389 (Figure 34) is a bit longer and shows that the water level in the aquifer follows precipitation with a 2-5 day delay.

There is some indication that long-term climate variability (PDO graph) related to changes in sea surface temperature in the North Pacific (explained in 2.6.3) may result in a decline in precipitation and corresponding decline in aquifer recharge as the water level hydrograph for MOE well 389 generally follows the PDO trend (Figure 34).

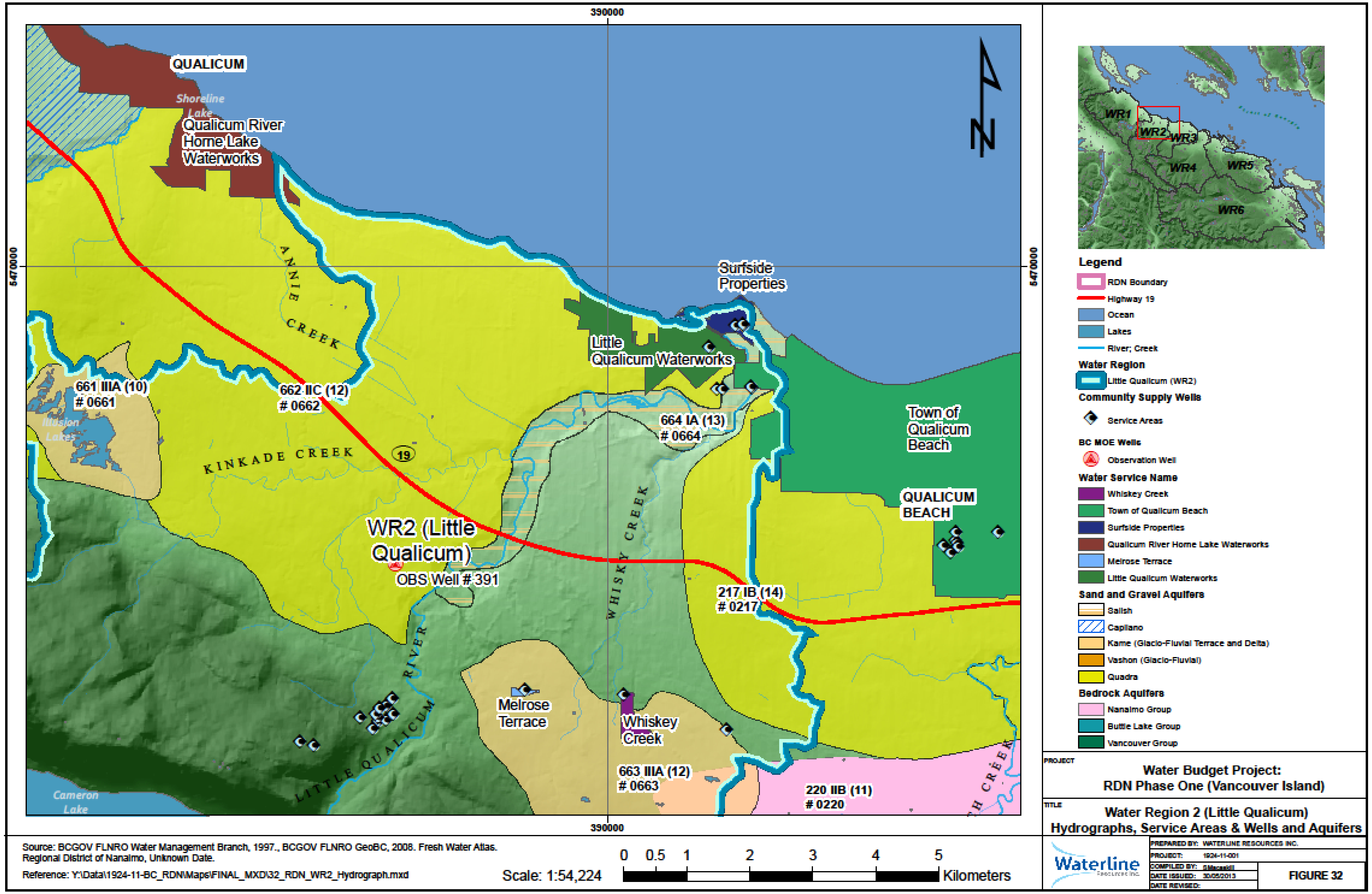


Figure 32: WR2 (LQ) – MOE Well Hydrographs, Service Areas & Wells, and Aquifers.

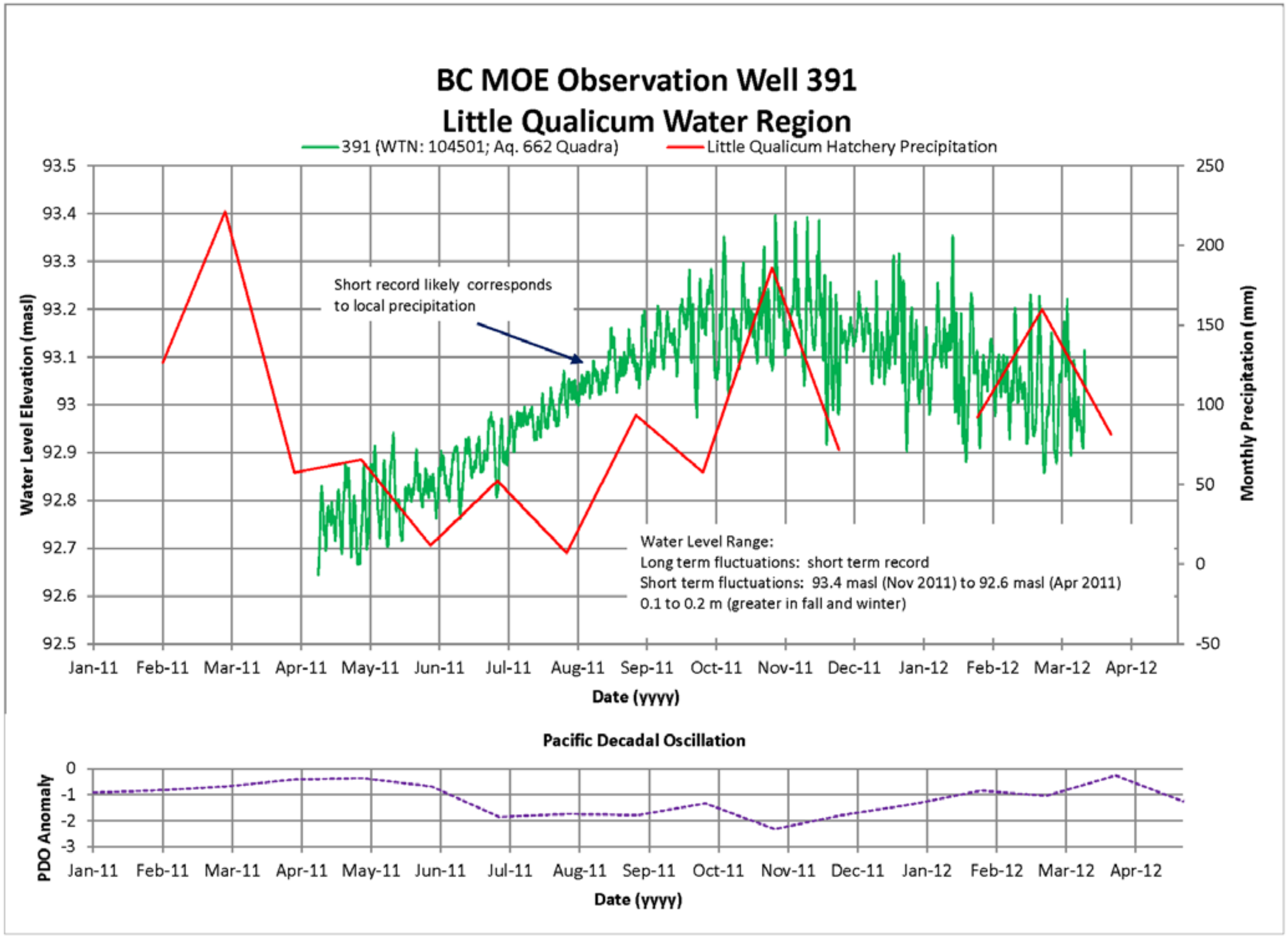


Figure 33: WR2 (LQ) – Water Level Hydrograph BCMOE 391.

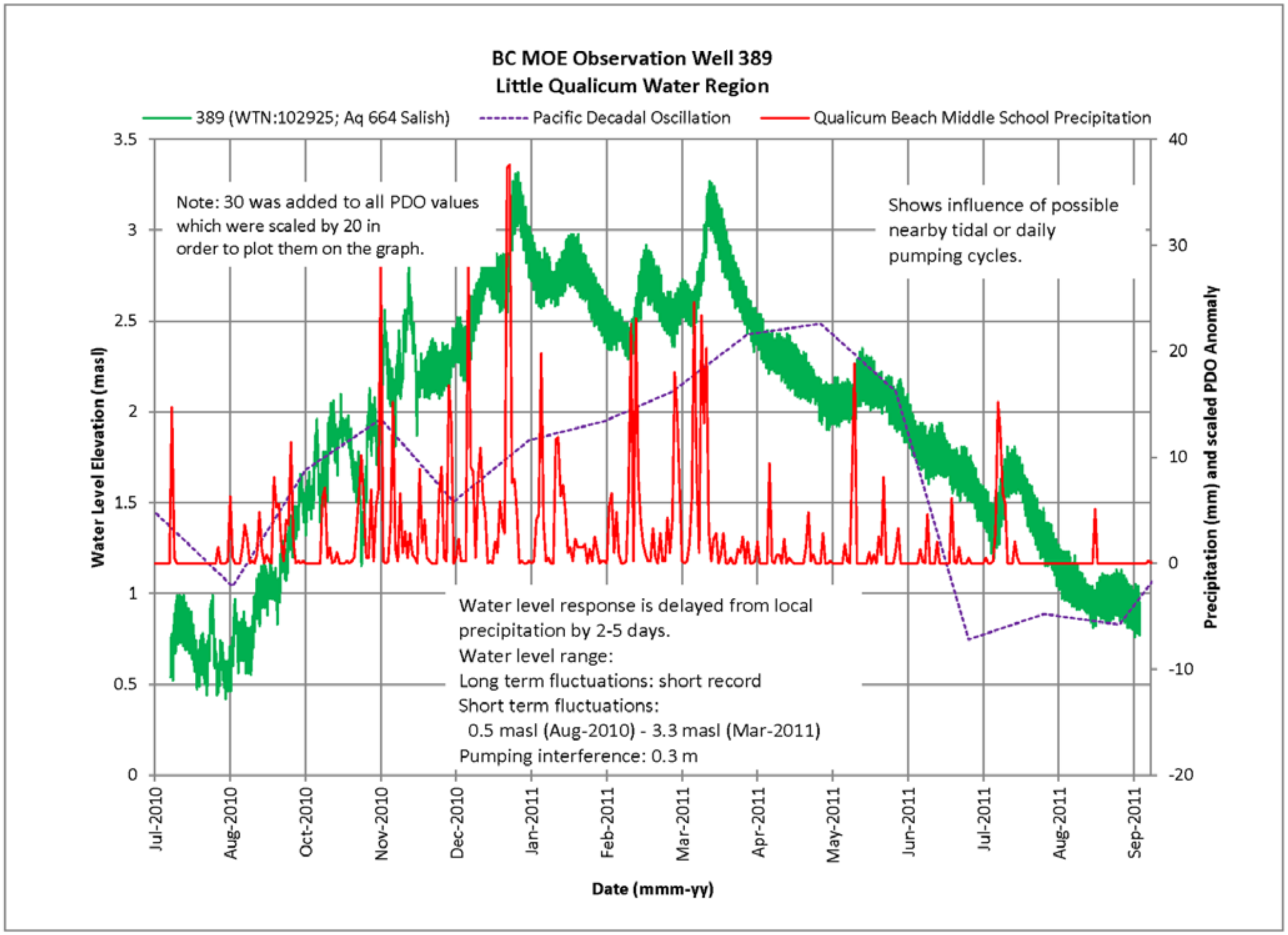


Figure 34: WR2 (LQ) – Water Level Hydrograph BC MOE 389.

4.3.6 Anthropogenic Groundwater Demand

Table 19 summarizes the available groundwater demand data available for WR2 (LQ).

Table 19: WR2 (LQ) – Summary of Anthropogenic Groundwater Demand Analysis

Aquifer Tag No.	Town of Qualicum Beach	RDN Surfside	RDN Melrose System	Whiskey Creek Water System	LQ River Village	Westerly Estates	Other Private Wells (From RDN Water Use Est. based on Zoning compiled on GIS)	Total Ground Water Use Estimate (ANTHout)
	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)
662	NA	NA	NA	NA	NA	NA	1.2E+06	1.22E+06
661	NA	NA	NA	NA	NA	NA	4.1E+04	4.13E+04
664	8.2E+05	1.1E+04	NA	NA	NA	NA	5.7E+05	1.39E+06
663	NA	NA	8.0E+03	8.0E+03	3.44E+04	NA	5.8E+04	1.08E+05
217	NA	NA	NA	NA	NA	?	4.4E+05	4.42E+05

Notes: NA means not applicable, ? Means not known or unavailable, ANTHout means anthropogenic water extraction from aquifer.

The annual water use for serviced areas within the RDN (large municipal users, RDN wells, and private utilities) is typically measured and was provided by the RDN or taken from annual reports for 2010. The groundwater demand estimate for non-service areas was calculated from water use data provided by the RDN for serviced areas, and then applied to non-serviced areas based on civic addresses and zoning classification. The method of assessment is further described in Appendix C (Map C21) and Appendix D.

There may also be groundwater discharging from aquifers that is required for conservation of flow in creeks and rivers based on the physical model developed by Waterline. The total groundwater demand for each aquifer, including conservation flow requirements, was compared against the estimated aquifer recharge to assess the stress on each aquifer. The results are presented in the following section.

4.3.7 Aquifer Water Budgets and Stress Analysis

Table 20 provides a summary of the final water budget calculations for each aquifer mapped within WR2 (LQ). Detailed water budget calculations are provided in Appendix D (Tables D7 and D8). Water budgets for aquifers that extend from one water region to an adjacent water region (E.g.: Aquifer 0662, Figure 29) were completed on the portion of the aquifer which lies within each region. The water budget calculations were also designed to be additive so that a complete water budget of an entire mapped aquifer that extends across a water region boundary can be developed as required.

As indicated above, there are a total of 387 overburden and bedrock wells listed in the MOE data base in WR2 (LQ) which represents the third lowest number of wells in all of the 6 water regions across the RDN on Vancouver Island. It is also recognized that this number may only represent as little as 50% of water wells actually in operation in this region. This generally agrees with the moderate demand for groundwater in WR2 (LQ) in comparison to other regions. Nevertheless, there is a need to better manage groundwater extraction as the population increases in this region.

Based on the water budget estimates for mapped aquifers within WR2 (LQ), overall conditions appear to be mixed, ranging from low to high stress indicated. Some concerns exist in the Spider Lake area (HB Lanarc, 2010) although the water budget assessment indicates only moderate stress. No observation well water level data is available for the Spider Lake area to confirm or refute these concerns.

The stress assessment for Quadra aquifer (662) appears to indicate low stress which agrees with water levels data from MOE well 391 which appears to be trending up. Moderate to high stress is indicated in the sand and gravel aquifers 663 and 217.

More accurate water budget and aquifer stress estimates could only be accomplished using a computer modelling approach. However, the lack of aquifer data would likely render this exercise inconclusive as well. Rigorous testing requirements and complete aquifer test analysis by groundwater practitioners to determine aquifer transmissivity and storativity properties, in addition to long-term groundwater monitoring data in each aquifer would be required to fully assess the actual stress on each aquifer in this region.

Table 20: Summary of Water Budget and Stress Analysis – WR2 (LQ)

Aquifer Tag No.	Aquifer Lithology	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	MOE Obs Well	Seas. Fluc.	Long Term Fluc. (PDO)	WL Trend (up or down)	Total Est. AQ. Rec. (TRin) (Rp/l + Rmb)	Est. Ann. Disch to Cr. & Down Grad Aquifer (Tc out)	Ground Water Use Estimate (ANTHout)	Total Out [TcOut + $ANTH_{out}$]	Stress Anal. % GW Use of the avail. AQ. Rec.	Relative Stress Assess.
			ID	(m)	(m)	U/D	(m^3/yr)		(m^3/yr)	(m^3/yr)	(%)	Lo, Mod, Hi
662	Quadra	Ocean, LQ	391	2.50	0.80	U	3.2E+07	0.0E+00	1.22E+06	1.22E+06	4	Lo
661	Kame	Spider LK, Horne?	?	?	?	?	1.9E+07	1.2E+07	4.13E+04	1.17E+07	65	Mod
664	Salish	Ocean, LQ	389	3.00	?	D	3.7E+07	0.0E+00	1.39E+06	1.39E+06	4	Lo
663	Kame (Vashon Gf) top of Whiskey Cr.	Whiskey Cr., LQ	?	?	?	?	3.8E+07	2.9E+07	1.08E+05	2.92E+07	81	Mod-Hi
217	Quadra	LQ and Ocean	?	?	?	?	7.2E+06	4.9E+06	4.42E+05	5.32E+06	87	Mod-Hi

Notes: LQ means Little Qualicum, NA means not applicable, AQ means aquifer, Seas. Fluc. means seasonal, fluc. means fluctuation, PDO means Pacific Decadal Oscillation, WL means water level, Est. means estimated, Disch. means discharge, Rec. means recharge ,Cr. Means creek, TRin means total recharge into aquifer, Rp/l means total recharge from precipitation and/or leakage from overlying aquifer, Rmb means total lateral recharge from upgradient aquifer or mountain block, Tc out means total aquifer groundwater discharge to creek, assess. means assessment , Total out means total discharge from aquifer (not including discharge to ocean), ANTH out mean total groundwater Anthropogenic groundwater extraction from aquifer, aquifer stress color codes: blue=low, green =low to moderate, yellow =moderate, brown=moderate to high, red=high to very high.

4.4 Water Management Planning Within WR2 (LQ)

General guidance on water management planning for all water regions is provided in later sections of this document. Specific to WR2 (LQ), the following recommendation are presented for consideration by RDN to improve the state of knowledge in the water region:

- At least one observation well should be installed in each mapped aquifer. Aquifers that currently do not have MOE observation wells include 661, and 663. Waterline understands that MOE/RDN has recently installed an observation well in Aquifer 217 (Lapsevic, Pers. Comm., 2013);
- Well owners should identify the MOE well plate and tag numbers for each of their active water wells. In this manner, water use and monitoring data can be easily cross-referenced with the BC MOE well records. These include the Town of Qualicum Beach wells, RDN Melrose System well, Whiskey Creek Water System wells, Little Qualicum River Village wells, and Westerly Estates wells;
- The significant recharge area map needs to be further updated by further processing of the NRCAN remote sensing data and by field verification;
- Further mapping of the groundwater surface water interactions is also required in the Little Qualicum River to confirm the preliminary assessment. Waterline recommends specialized analysis (E.g.: isotopes[26], noble gases) of groundwater samples in this region to assist in determining groundwater age and origin. Thermal imaging of the river during high and low flow many help to quickly pinpoint areas where more detailed studies may be required;
- Reactivation of WSC surface water gauge on Little Qualicum at Qualicum Beach is recommended;
- River discharge and lake level data collected for Little Qualicum River below Cameron Lake and Cameron Lake levels be obtained at regular intervals from the Department of Fisheries and Oceans and be included in the Regional Water Management database;
- A hydrometric gauge be established on Kinkade Creek to investigate potential influence of groundwater recharge from Illusion Lake and Spider Lake on summer base flows; and
- Lake levels be recorded on Illusion Lake and Spider Lake to investigate any interaction between ground water levels and lake levels; and
- Weekly or Bi-weekly flow measurements during the summer period (June to Sept) be collected as part of the Community Watershed Monitoring Network program for McBey Creek, Lockwood Creek and Whiskey Creek to better understand summer low flows in these smaller watersheds.

[26] Elements of the same family but with different atomic weights. Technique is used to assess recharge elevation and age of water.

5.0 WATER REGION # 3 - FRENCH CREEK

5.1 Regional Overview

The French Creek water region (WR3 (FC)) is defined as the area extending from Qualicum Beach to Parksville along the coast to the top of the French Creek catchment in the southwest (Figure 35). It is one of the smallest water regions within the RDN covering an area of approximately an area of approximately 121 km^2. The region includes several major watersheds as listed in the Table 21. The largest watershed is associated with French Creek. Two hydrometric stations, five climate stations, and approximately 68 surface water diversion licenses exist within the region (Figure 35, and Table 21). Not all 68 points are visible on the figure since many plot over each other at this scale. The locations however are included in the ARC GIS Geodatabase which will be provided to the RDN.

Table 21: WR3 (FC) - Watersheds, Wells and Surface Water Licenses

Total Water Region Area	***121 km^2**
Major Watersheds	**Drainage Area[1] (km^2)**
Grandon Creek	7.2
French Creek	69.7
Morningstar Creek	15.1
Carey Creek (including Romney Creek)	8.9
Romney Creek (Tributary of Carey Creek)	6.4
Wells and Surface Water Diversion Points	**No.**
# Water Wells listed in MOE DB	895
Surface water diversion licenses	68

Note: Drainage Areas are based on 1:50,000 BC Watershed Atlas. *Total Water Region area includes areas that drain directly to the ocean and are not part of a major watershed.

According to the MOE Wells Database (BCGOV ENV Water Protection and Sustainability Branch, 2008) WR3 (FC) has the 3rd largest number of water wells (895 wells) of the six water regions in the RDN. Although this may provide a qualitative sense of groundwater use in the region, the MOE database likely only represents a fraction of the actual wells currently in use. Many well records may not have been entered into the database and some wells may simply not be in use or have been abandoned. As there is no mandatory requirement for submitting well logs or well abandonment records, it is not possible to determine the groundwater demand from private wells with any degree of certainty, nor is it possible to assess the vulnerability that may exist with improperly abandoned or standing water wells.

5.2 Surface Water Assessment

5.2.1 Terrain, Topography and Land Use

The French Creek Water Region (#3) covers the North-Central section of the Regional District of Nanaimo. The west part region of the region runs along the edge of the Beaufort Mountains and consists of steep forested terrain. The rest of the region consists of the mild topography of the Nanaimo lowlands.

Water flows to the east in the region from its highest point in the French Creek catchment (1,080m) and out to the Strait of Georgia. The most significant water feature in the region is

French Creek and Hamilton Marsh. The major watersheds in the region from north to south are shown in Figure 35.

The majority of the land use in the upper water region is privately managed forest lands. The coastal sections of the water region are a mixture of rural development with agriculture and low density residential. Some commercial and light industrial development is located in Coombs. Both the Town of Qualicum Beach and the north-western potion of the City of Parksville, lie within this water region. These areas consist of high density development.

5.2.2 Climate

The climate for the Little Qualicum Water Region is similar to the rest of the RDN with cool wet winters and mild dry summers. In general, climate records indicate that this region tends to follow the average precipitations totals of the other low-lying regions due to the lack of influence of the mountain range. The total annual precipitation for the 1971 to 2000 Climate Normal Period of Coombs is 1126.4 (see Figure 36 for monthly distributions). This compares with recorded average total annual precipitation of 1,162.7 mm at the Nanaimo Airport.

Climate station locations are shown as green squares on Figure 35. Maps showing the distribution of annual precipitation and average temperature over the water region are shown in Figure 37 and Figure 38, respectively. Maximum total annual precipitation amounts are approximately 2,500 mm in the upper reaches of French Creek.

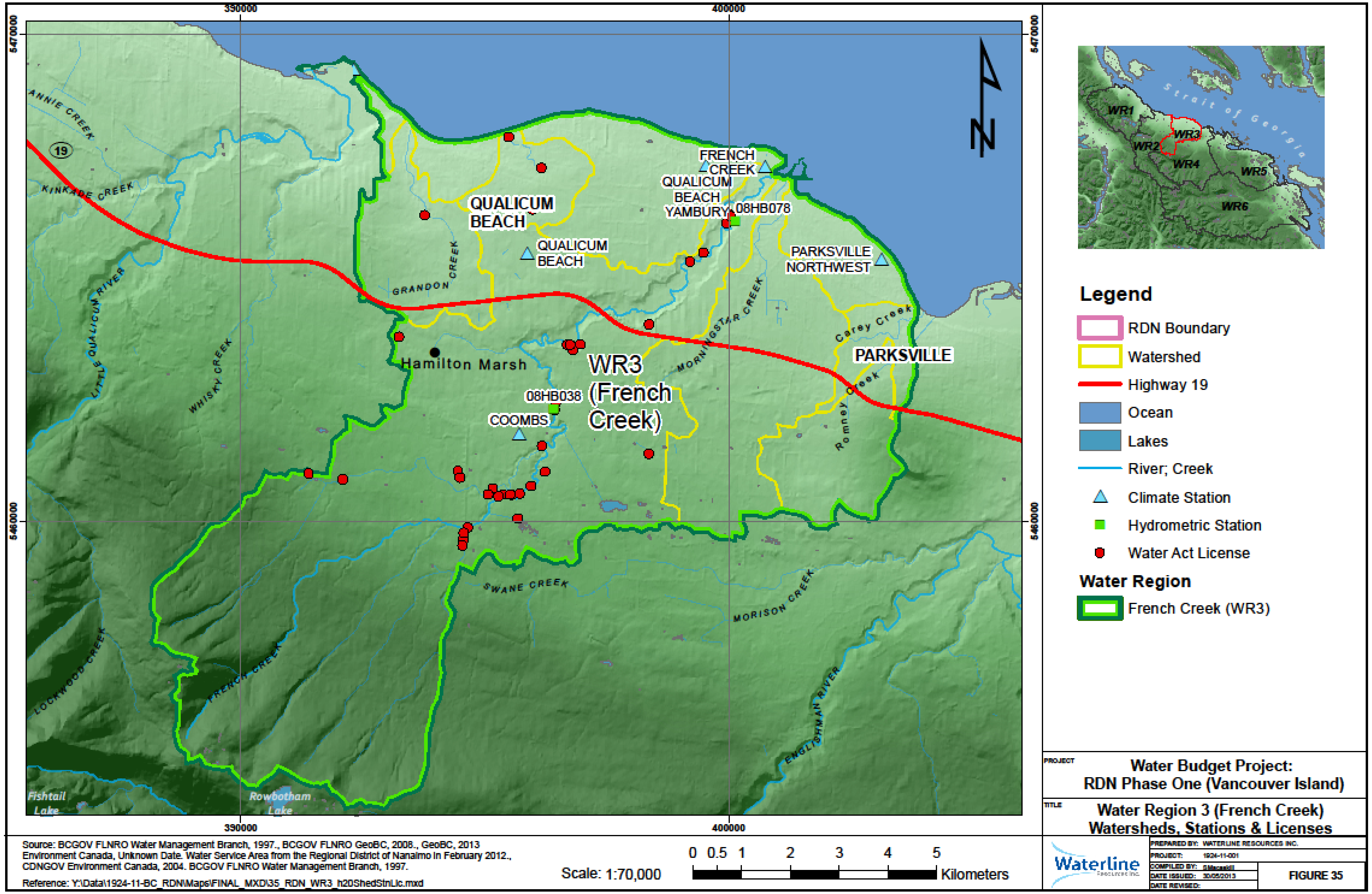


Figure 35: WR3 (FC) – Watersheds, Stations & Licenses.

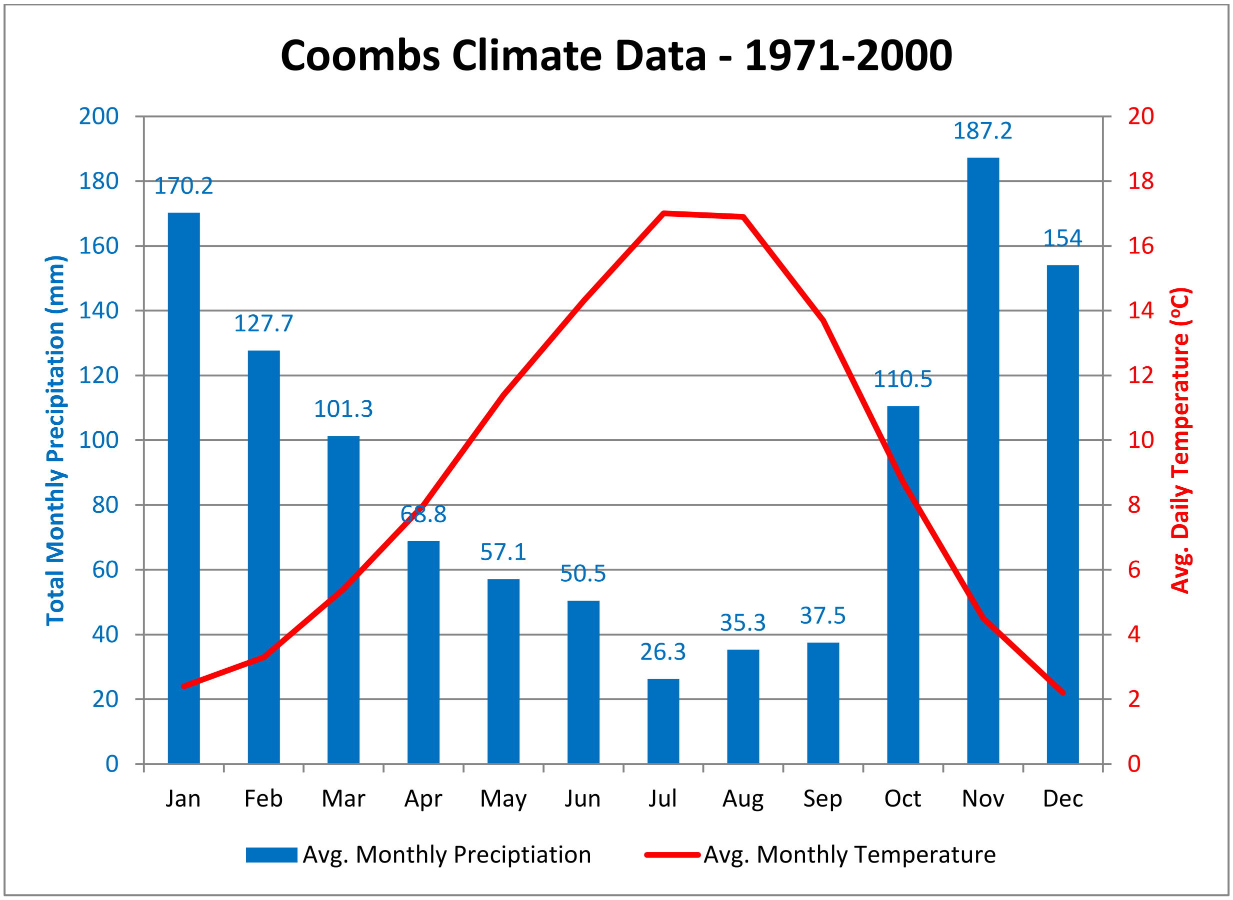


Figure 36: WR3 (FC) – Coombs Monthly Climate (1971 to 2000 Normal Period)

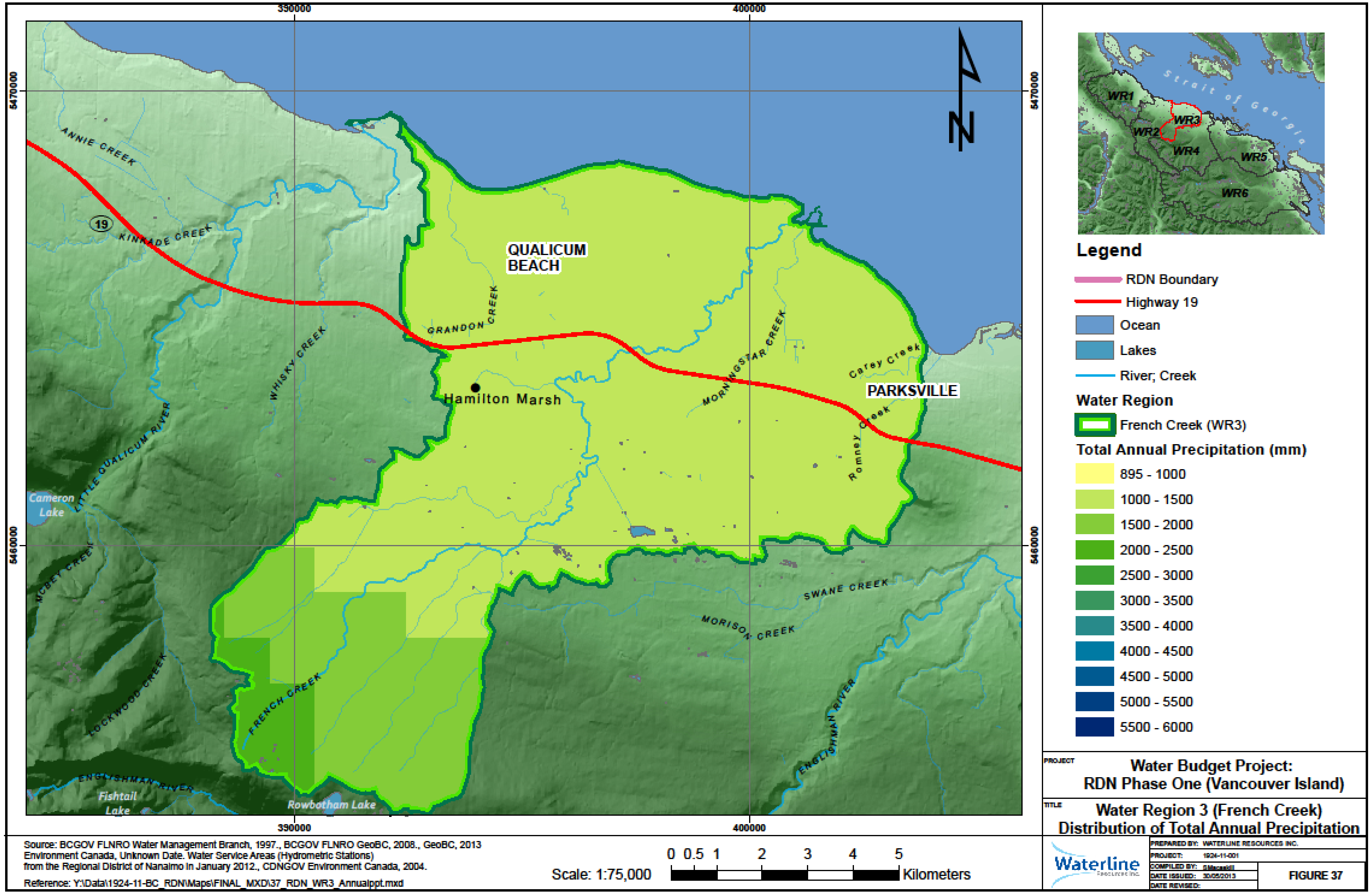


Figure 37: WR3 (FC) – Distribution of Total Annual Precipitation

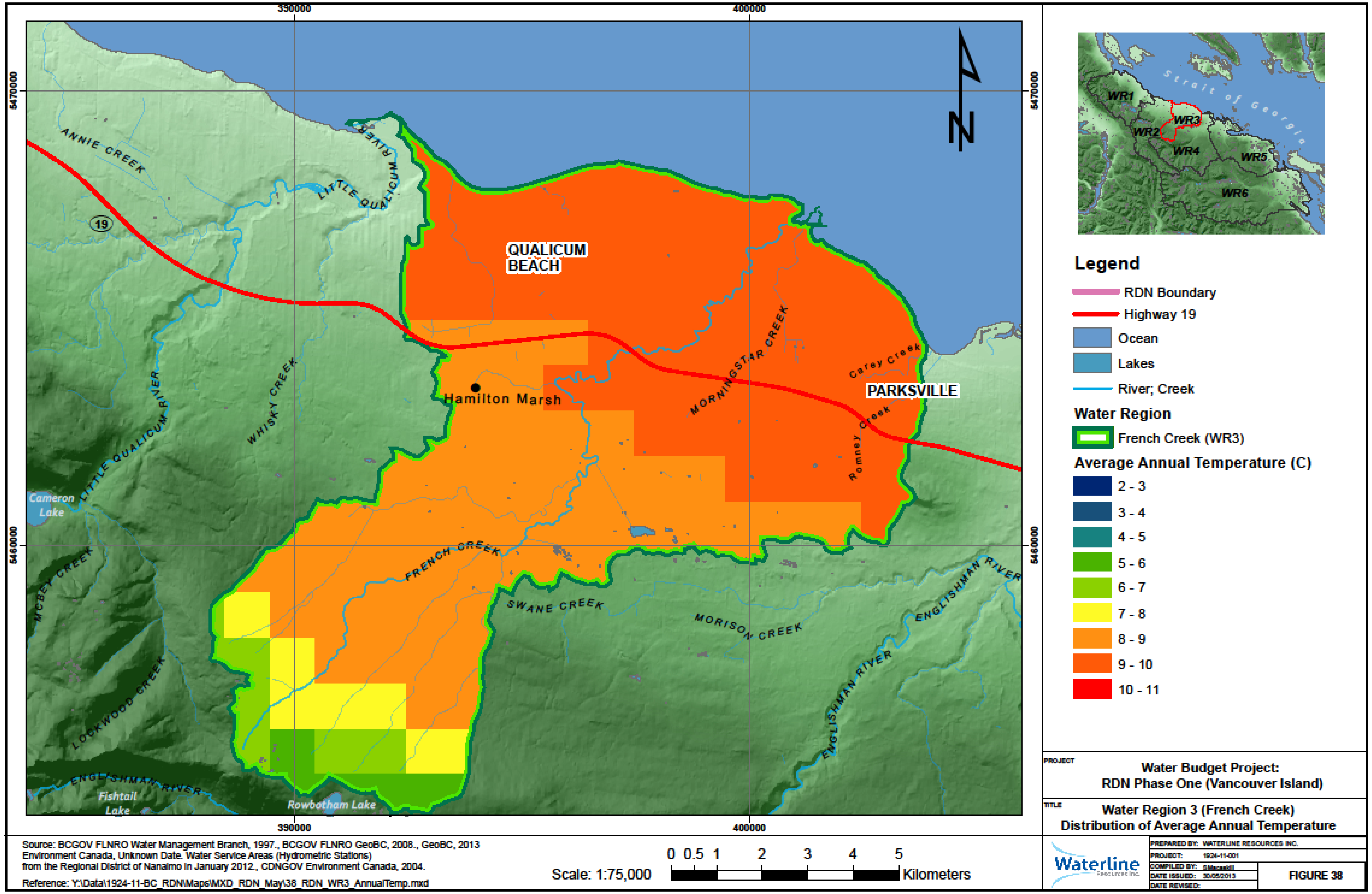


Figure 38: WR3 (FC) – Distribution of Average Annual Temperature

5.2.3 Stream Gauging and Monitoring

Table 22 lists the names of the hydrometric stations are located in the WR 3 (FC) and they are shown on Figure 35.

Table 22: WR3 (FC) – Water Survey of Canada Records

Station Name (WSC Number)	Period of Record	Natural or Regulated	Drainage Area to Gauge (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume[1] (million m^3)
French Creek above Pump house (08HB078)	1990 to 1996	Natural	79.1	2.35 m^3/s 74.2 million m^3	0.06 m^3/s 0.5 million m^3
*French Creek at Coombs[2] (08HB038)	1969-1971 1983-1989	Natural	58.3	Summer Only	0.04 m^3/s 0.4 million m^3

Notes: 1 – Summer Period Jul to Sep (three lowest average months). MAD for French Creek above the Pump House are based on only Records for French Creek at Coombs are summer only (April to September) so MAD cannot be determined.

5.2.4 Hydrology and Surface Water Resources

The hydrological model has provided estimates of average available surface water resources for the major watersheds in the region for the year and the summer (Table 23).

Table 23: WR3 (FC) – Available Surface Water Resources (Avg. for 1971 to 2000 period)

Watershed	Drainage Area (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)	Previous Estimate of MAD (m^3/s)
Grandon Creek	7.2	0.16 m^3/s 5.1 million m^3	0.00 m^3/s 0.0 million m^3	0.251 m^3/s
French Creek	69.7	2.25 m^3/s 71.0 million m^3	0.18 m^3/s 1.4 million m^3	2.167 m^3/s
Morningstar Creek	15.1	0.31 m^3/s 9.7 million m^3	Less than 0.1 m^3/s	0.216 m^3/s
Carey Creek	8.9	0.18 m^3/s 5.6 million m^3	Less than 0.1 m^3/s	0.095 m^3/s
Romney Creek (Tributary of Carey Creek)	6.4	0.12 m^3/s 3.6 million m^3	Less than 0.1 m^3/s	0.179 m^3/s

Notes: Previous estimates of MAD from the BC Ministry of Environment Water Allocation Plans (Bryden et. al., 1994) have been included for reference.

5.2.5 Surface Water Demand

Table 24 summarizes the surface water licences in WR3 (FC) from the BC Surface Water Licence Database. Table 24 summarizes the surface water storage in WR3 (FC. The locations of the surface water licences for WR3 (FC) are shown on Figure 35.

Table 24: WR3 (FC) – Surface Water Demand (m^3)

Type of Demand	Monthly	Annual	Summer (Jul-Sept)
Consumptive Demand			
Agriculture	8,437	101,240	75,930
Domestic	4,848	58,177	19,198
Industrial	-	-	-
Institutional	-	-	-
WaterWorks	17,285	207,415	68,447
Total Consumptive	30,569	366,833	163,576
Non- Consumptive Demand			
Power	-	-	
Conservation	36,288	435,456	108,864
Total Non-Consumptive	36,288	435,456	108,864

Table 25: WR3 (FC) – Surface Water Storage (m^3)

Type of Storage	Total
Storage	617
Conservation Storage	109903
Other Storage	9435
Total Storage	119955

The largest licensed water user in WR3 (FC) is the Parksville-Qualicum is Epcor Water Inc. for the French Creek water system. It is understood that Epcor plan to abandon the surface water intake in the near future and rely on new production wells. There is only a relatively small amount of surface water storage within the water region.

5.2.6 Surface Water Stress Analysis

As outlined in Section 2.5.2, a surface water stress analysis for French Creek has been completed. Water budget analysis for other smaller ungauged subwatersheds within WR3 (FC) should be completed when data is available and as part of a more detailed Tier 1 or Tier 2 water budget assessment (OMNR 2011). The results of the stress analysis for the watersheds in WR3 (FC) are shown in Table 26. A map showing the relative stress for French Creek is shown in Figure 39.

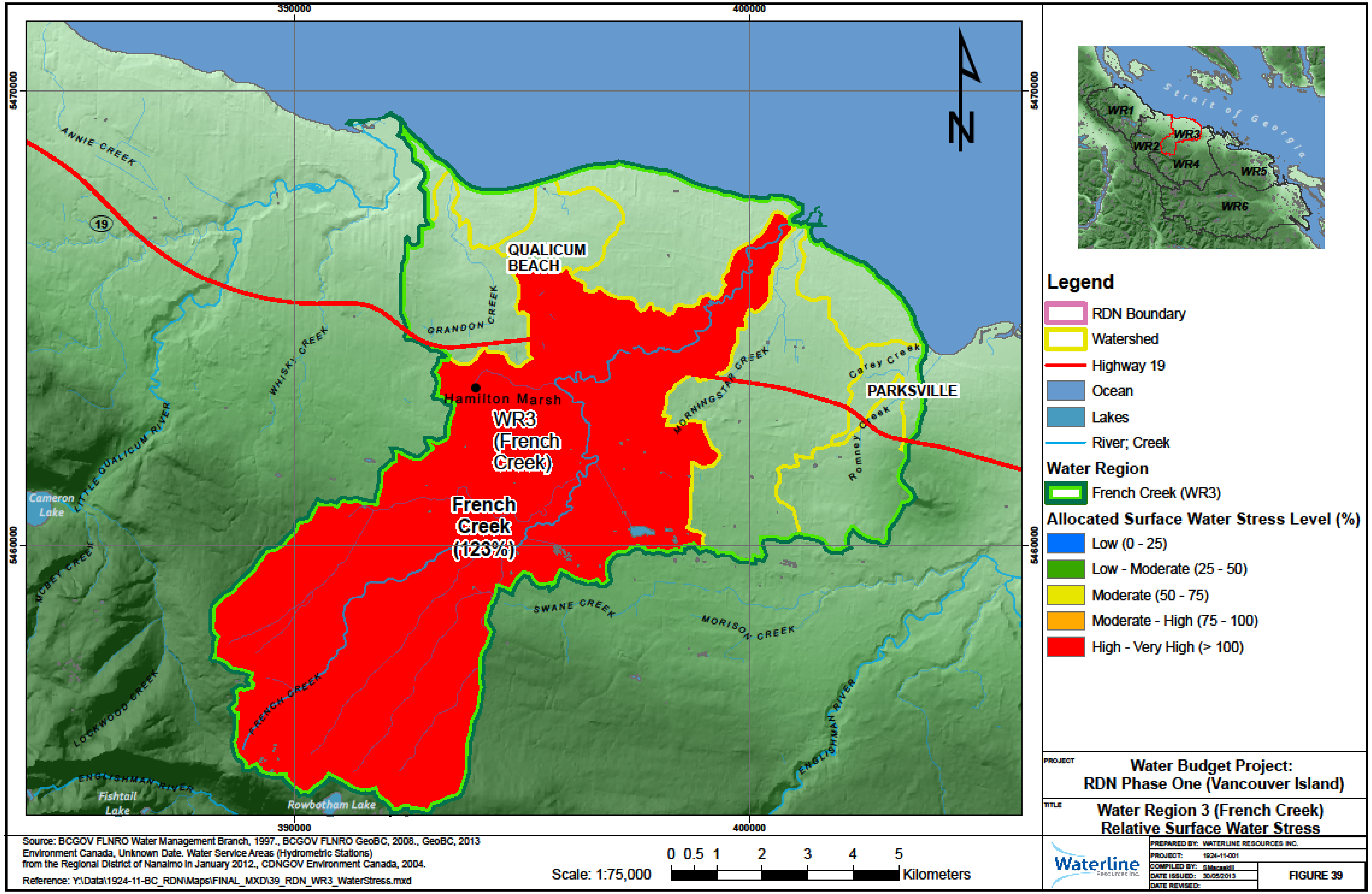


Figure 39: WR3 (FC) – Relative Surface Water Stress

Table 26: WR3 (FC) – Relative Surface Water Stress Assessment Results

Watershed	Average Natural River Flow Supply (million m^3)	Storage (million m^3)	Conservation Flow (10% of MAD) (million m^3)	Licensed Demand (million m^3)	Allocation Stress	Stress Level
French Creek	1.40	0.11	1.75	0.10	123%	High

Note: Volumes indicated in the table are average volumes for summer period (Jul to Sep). Average natural river flow is the estimated or recorded unregulated flow in the watershed. Total storage is based on licenced storage volume and assumes all storage is available to support conservation flow and licenced demand for the Jul to Sep period. The 10% of Mean Annual Discharge (MAD) conservation flow is based on current Ministry of Forest, Lands and Natural Resource Operations (MELP, 1996) minimum conservation flow policies for the east coast of Vancouver Island. Licenced demand is the total licenced volume for summer based on consumptive water licences. Allocation stress = (Average Natural supply + storage) / (Conservation Flow + Licenced Demand) Surface water stress color codes: : blue=low, green =low to moderate, yellow =moderate, brown=moderate to high, red=high to very high. Values reflect average flow conditions and do not consider drought years.

5.3 Groundwater Assessment

5.3.1 Existing Groundwater Studies and Data – WR3 (FC)

Given the regional scale of the Phase One Water Budget Assessment, the most important data compiled and geo-referenced by Waterline was the water well information, elevation data, soil and geology maps, land cover, aggregate resource map, mapped aquifers, and water service areas. Other maps were generated using the input data as part of Waterline's work and some samples are provided in Appendix C for illustration purposes (Eg: overburden thickness (Map C7), piezometric contour maps (Maps C8 and C9), air temperature (Map C14), precipitation (Map C15), runoff (Map C16 and C17), evapotranspiration (Map C18), infiltration (Map C19), Water Service Areas (Map C20), and Water Demand Assessment in Non-service areas (Map C21). All of these maps are provided in Appendix C for the entire RDN study area with an explanation of how the map was geo-reference or created by Waterline. These data and layers are now available in the ARC GIS Geodatabase at the RDN Scale, water region scale, watershed scale, on other local scale needed for site specific assessments. These data will be provided to the RDN in electronic format as part of the ARC GIS Geodatabase system which was constructed by Waterline for use by the RDN. These regional datasets form the framework for construction of the conceptual hydrogeologyical model.

Although only some of the data in certain reports may have been incorporated into Waterline's Geodatabase, the primary studies in the region were used in Waterline's water budget assessment to provide local hydrogeological context are provided in Table 27.

Table 27: WR3 (FC) – Hydrogeology Reference Reports

Author	Year	Study Title
AGRA Earth & Environmental Ltd.	1998	Well and Aquifer Evaluation for Surfside Well
EBA Engineering Consultants	2001	Aquifer Identification – Parksville Area
EBA Engineering Consultants Ltd.	2005	Final Mt. Arrowsmith Modeling Project Parksville Area, BC
Gilles Wendling, Sr. Hydrogeologist	1998	Aquifer Management Breakwater Enterprises Ltd. – Public Utility
Koers & Associates Engineering Ltd.	1994	Town of Qualicum Beach - Water Study Update
Kohut, A.P.	2003	Long Term Sustainability of Groundwater Sources, French Creek and Breakwater
Levelton	1997	Pumping Test Review Pintail Estates Wells 1-94 & 2-95 Qualicum Beach, B.C.
Lowen Hydrogeology	2011	Observation Well Drilling Program 2011 Phase 1
Ministry of the Environment	1994	French Creek Water Allocation Plan
Pacific Hydrology Consultants Ltd.	1990	Pump Testing and Capacity of Hills of Columbia Well No 7
Pacific Hydrology Consultants Ltd.	1994	Construction and Testing of New Test Wels R-1 and R-4 and Testing of Existing Anderson Test Well I-88 for French Creek Estates in the French Creek Area of Vancouver island
Pacific Hydrology Consultants Ltd.	1994	Completion Report: Test-Production Drilling/Well Construction and Capacity Testing of Hills of Columbia Well 11-94 in the French Creek Area of Nanoose District
Pacific Hydrology Consultants Ltd.	1994	Construction and Testing of Test Wells R-5 and R-8 for French Creek Estates in the French Creek Area of Vancouver Island
Pacific Hydrology Consultants Ltd.	1995	Construction and Testing of Test Wells R-7 and R-7A for French Creek Estates in the French Creek Area of Vancouver Island
Ministry of Water, Land and Air Protection Ministry of Sustainable Resource Management Nanaimo Regional Office	2002	French Creek Watershed Study
Lowen Hydrogeology Consultants	2010	Arrowsmith Water Service Englishman River Water Intake Study Groundwater Management. Discussion Paper 5-1. Existing Groundwater Supply Evaluation and Aquifer Yield Assessment, Prepared by Dennis Lowen, Alan Kohut and Bill Hodge, January 25, 2010.

5.3.2 Description of Aquifers and Water Wells

Two unconsolidated, sand and gravel aquifers, and two bedrock aquifers have been mapped within WR3 (FC) (Figure 40 and Figure 41, respectively). Table 28 provides a summary of information on mapped aquifers within WR3 (FC). Quadra sand aquifers (216 & 217) are moderately productive are generally confined to semi-confined with moderate vulnerability and heavy use. Bedrock aquifers 220 and 212 are low productivity aquifers and are generally confined with moderate vulnerability. Aquifer 220 has heavy use while Aquifer 212 along the coast is only lightly used (BCGOV ENV Water Protection and Sustainability Branch, 2012). It is important to note that there are many well records missing (unmapped) in aquifers 217 and 209 as they were mapped in the mid-nineties and a lot of well records were added to the WELLS database after 2005 (Pat Lapsevic, Pers. Comm., 2013). This illustrates the limitation of the aquifer classification designation for this area.

Table 28: WR3 (FC) – Summary of Mapped Aquifers

Aquifer Tag No.	Aquifer Lithology	Location Within Water Region	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	Developed Aquifer surface Area	Confined, Semi, or unconfined, Aquifer Vulnerability Code	Yield
				(m^2)		**(L/M/H)**
220	Haslam	FC and Alberni Hwy.	FC	3.35E+07	Confined, IB	L
216	Quadra	Daylights in FC below Albernie Hwy	FC	1.84E+07	Semi-Confined, 1B	M
217	Quadra	Lower FC	FC and Ocean	3.79E+07	Confined, IB	M
212	NG	FC Mouth	Ocean	5.90E+06	Confined, IIIC	L

Notes: A/B/C is high/moderate/low vulnerability, I/II/III is heavy/moderate/light use, H/M/L means high/medium/low productivity/yield. All aquifer classification parameters, codes and yield are defined at the following MOE web address http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/Aq_Classification/Aq_Class.html#class. NG means Nanaimo Group.

The majority of supply wells are completed along the coast in unconsolidated Quadra sand aquifers (Figure 40). Aquifer 212 and 220 appear to be less developed (Figure 41). There are a total of 895 overburden and bedrock wells listed in the MOE data base in WR3 (FC) (Table 21), however; aquifer 220 is a low yield aquifer as indicated in Table 28 and is under some stress locally. As there are no regulatory requirements in BC to submit wells logs to MOE for capture in the BC Wells Database, the water wells shown on Figure 40 and Figure 41 likely represents only a fraction of wells actually drilled.

5.3.3 Groundwater-Surface Water Interaction - Conceptual Hydrogeological Model

A conceptual hydrogeological model of each aquifer with WR3 (FC) was developed in order to understand the key elements and linkages between surface water and groundwater systems required to complete the water budget assessment. Although conceptual hydrogeological model developed by Waterline includes numerous cross-sectional views developed within the Waterline Geodatabase, only one 3D view into the subsurface will be presented here. Figure 42 shows a 3D block diagram illustrating the relationship between surface and subsurface geology in WR3 (FC). The Quadra sand deposit extends across the French Creek Valley and is mapped as aquifer 217 to the north and aquifer 217 to the south.

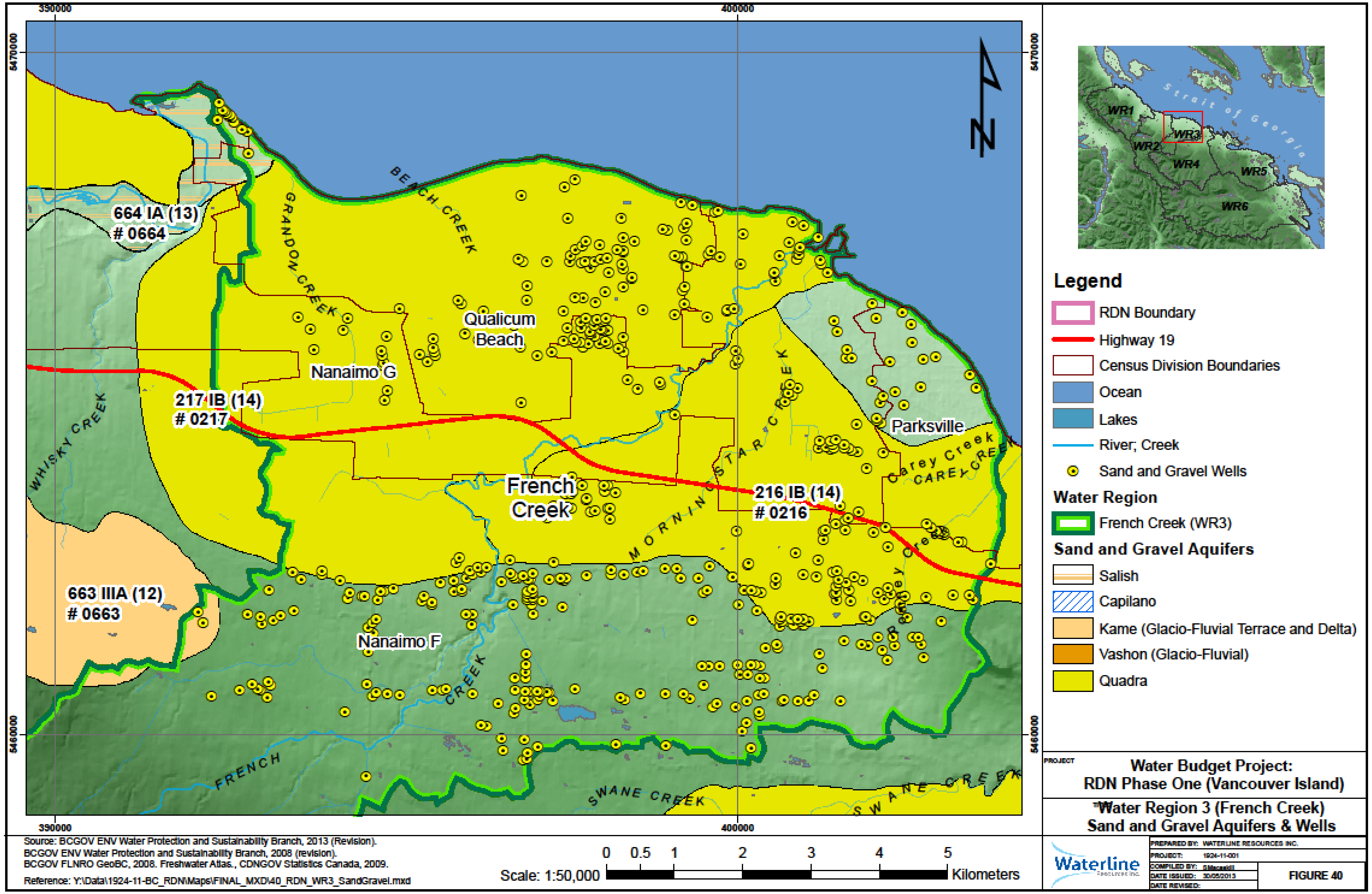


Figure 40: WR3 (FC) – Mapped Sand and Gravel Aquifers & Wells

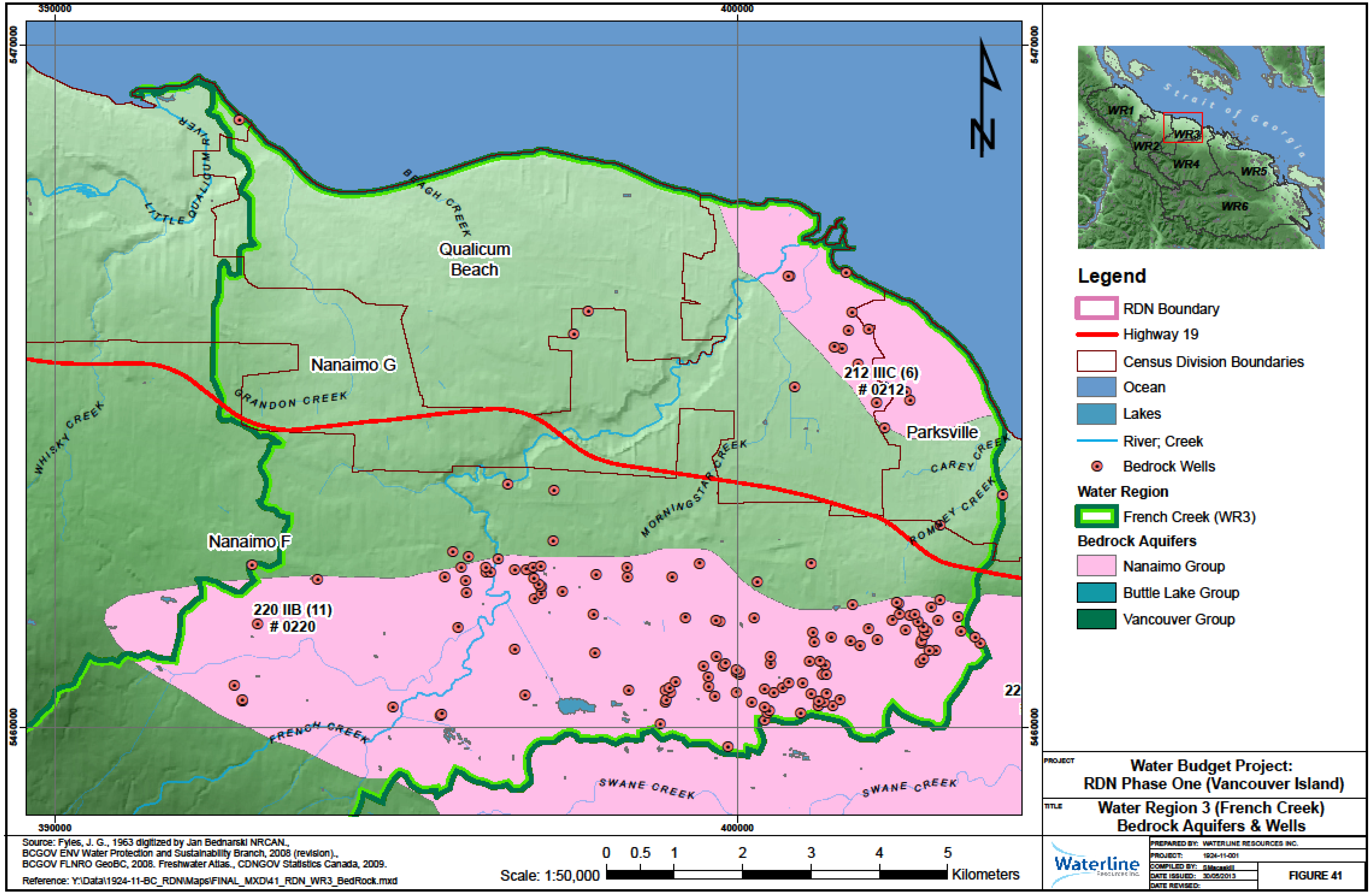


Figure 41: WR3 (FC) – Mapped Bedrock Aquifers & Wells

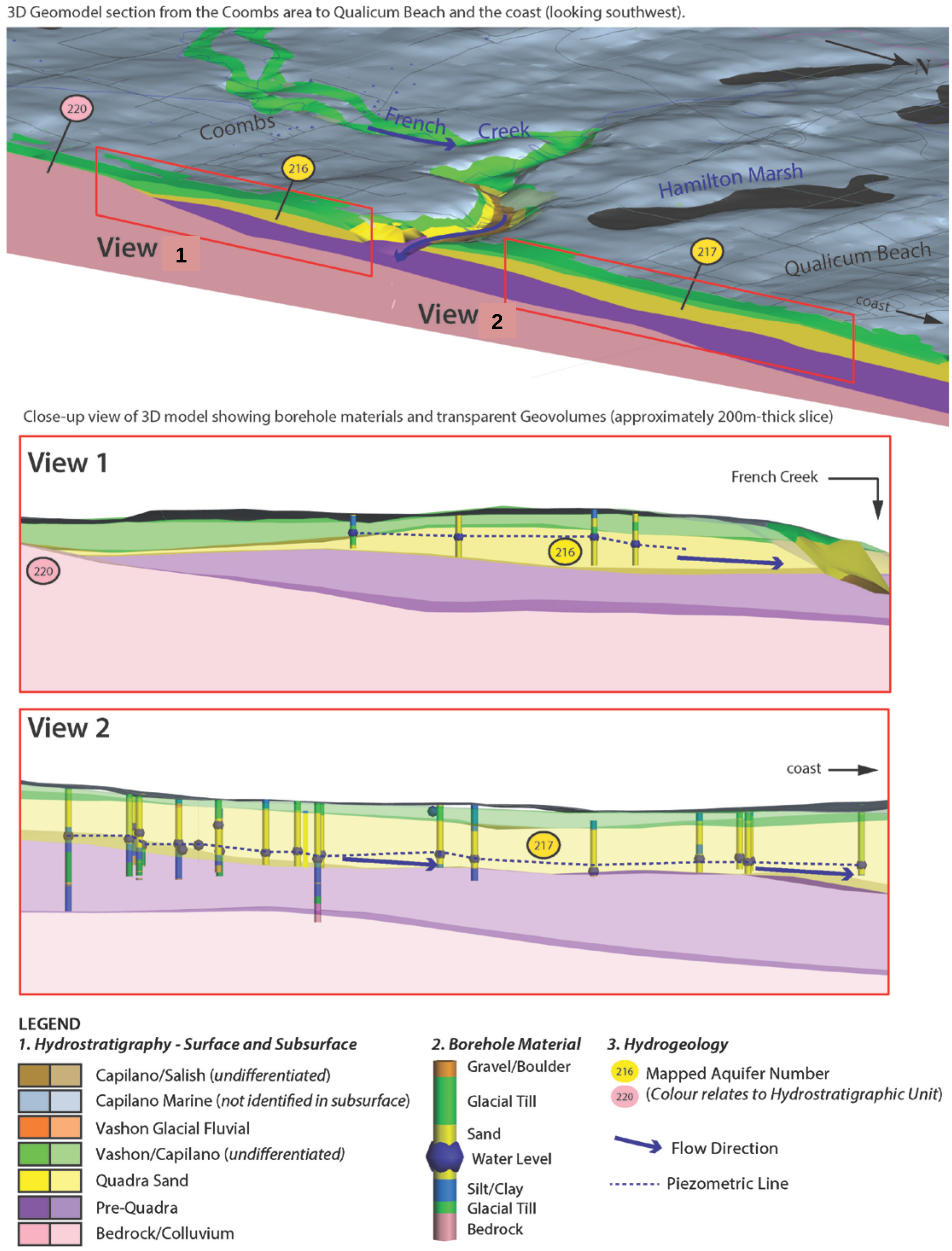


Figure 42: WR3 (FC) – Hydrogeological Conceptual Model – French Creek

View 1 shows how Quadra sand aquifer (216) is exposed in French Creek and the aquifer likely contributes important baseflow to the creek. View 2 shows Quadra sand aquifer (217) has a strong component of flow towards the ocean. The model also shows the underlying Haslam bedrock aquifer (220) which is highly developed further to the southwest of this location. Exchange of groundwater with the surface water system in French Creek is apparent based on the physical model and previous studies completed in French Creek. Further verification of actual water volumes being exchanged between the creek and the aquifers is required.

5.3.4 Significant Recharge Areas

Significant recharge areas within WR3 (FC) were determined as part of the assessment of infiltration across the region base on topography, mapped textural soil characteristics, land cover (bare land, vegetation, impermeable surfaces), and leaf area index. These areas are important for maintaining recharge to aquifers and base flow to creeks and rivers. The preliminary assessment presented herein is based on the integration of numerous datasets which may be incomplete and therefore will require further field verification. Figure 43 shows significant recharge areas mapped within WR3 (FC) as part of the water budget project.

Significant recharge areas extend to the upper reaches of WR3 (FC) all the way to coastal areas near the Town of Qualicum Beach. Better definition of these areas should be completed as the current modelling completed by Waterline and KWL was done on a 1 km square grid. Some of the areas indicated are highly developed and others are less developed. Future development planning need to consider these areas to ensure aquifer recharge continues to be maintained. As noted, the recharge catchment area is relatively small compared with the other water region. The following sections of this report show that water levels measured in many MOE observation wells completed in mapped aquifers within WR3 (FC) are in decline. Therefore, the protection of areas contributing recharge to aquifers is imperative to the future sustainability of groundwater resources in this region.

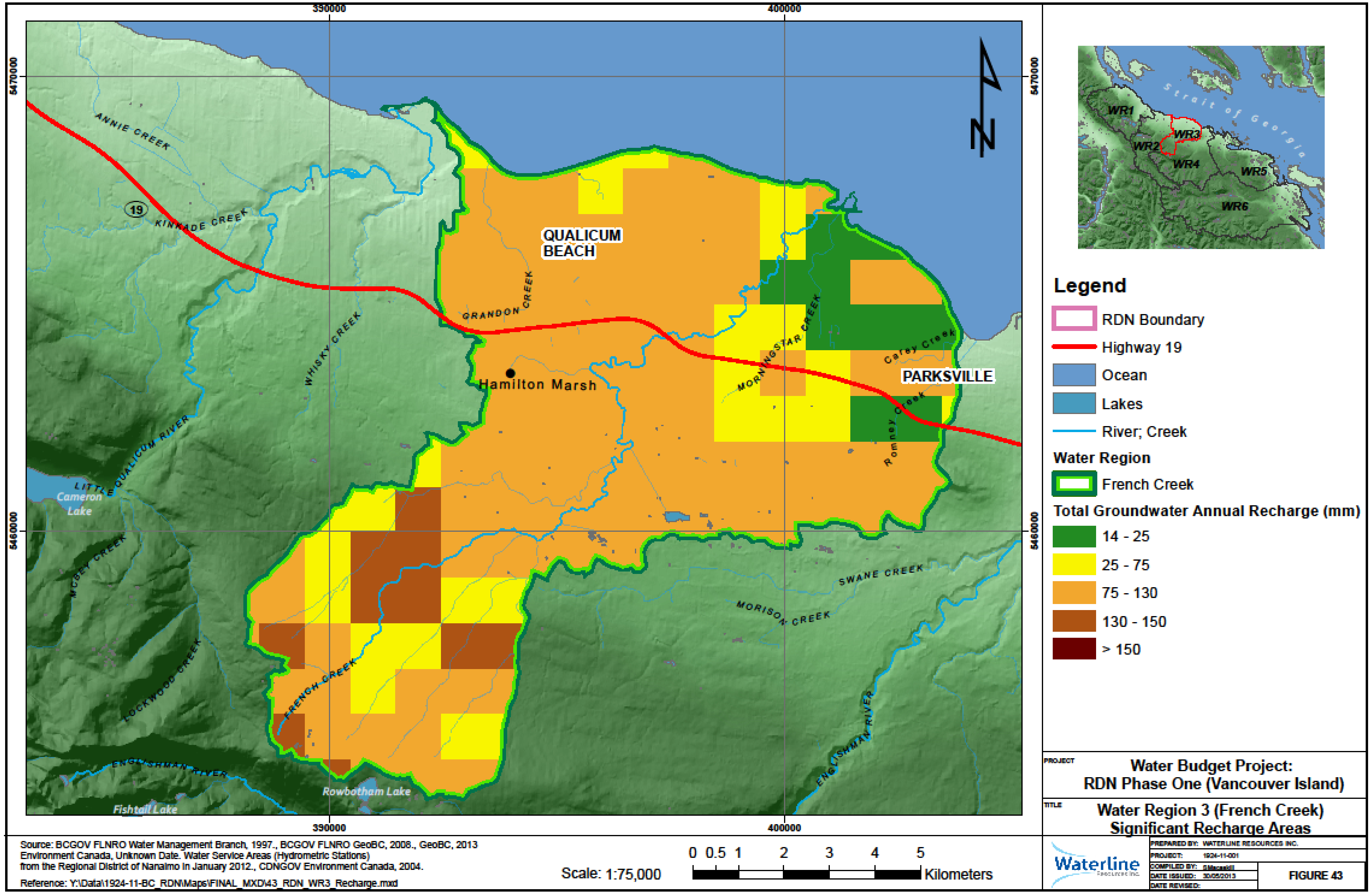


Figure 43: WR3 (FC) – Significant Recharge Areas

5.3.5 Groundwater Level Monitoring – BC MOE Observation Well Network

Long-term water level monitoring data provides an indication of an aquifer's response to global, regional, and local environmental changes in climate, groundwater pumping, and the impacts (if any) of other activities related land development. Long-term records also allows for establishing hydraulic linkages between the groundwater and surface water systems.

Figure 44 shows the locations of MOE observation wells and long-term water level monitoring records in relation to community water supply wells identified from the MOE Wells Database (E.g.: Large municipal users, the RDN, private utilities wells). Although numerous community wells are listed in the database, Waterline understands that not all of these wells shown on Figure 44 are currently active.

One of the problems encountered by Waterline during the water budget project was that community well owners generally do not cross reference active production wells to respective well logs in the MOE database. Often wells are referred to by local names (E.g.: RDN well # 1, #2, etc…). As water budget calculations required that production wells be assigned to specific aquifers, it is important that cross-referencing with the MOE well logs be done. Well owners are encouraged to report the MOE Well tag number so that accurate water level and groundwater extraction volumes can be allocated to the corresponding well and aquifer.

Water level monitoring records are available for six MOE observation wells in WR3 (FC) (Figure 45 to Figure 50, inclusive. MOE well 287 is completed in Aquifer 220 (Figure 45), MOE well 314 in Quadra sand Aquifer 216 (Figure 46), and four MOE wells in Quadra Sand aquifer 217 (Well # 295, 304, 303, and 321). Water levels in MOE observation wells were plotted along with the Coombs, Winchels Elementary, or Springwood Elementary precipitation record, the Englishman River Stage (level, # 08HB0034) and the PDO trend where appropriate.

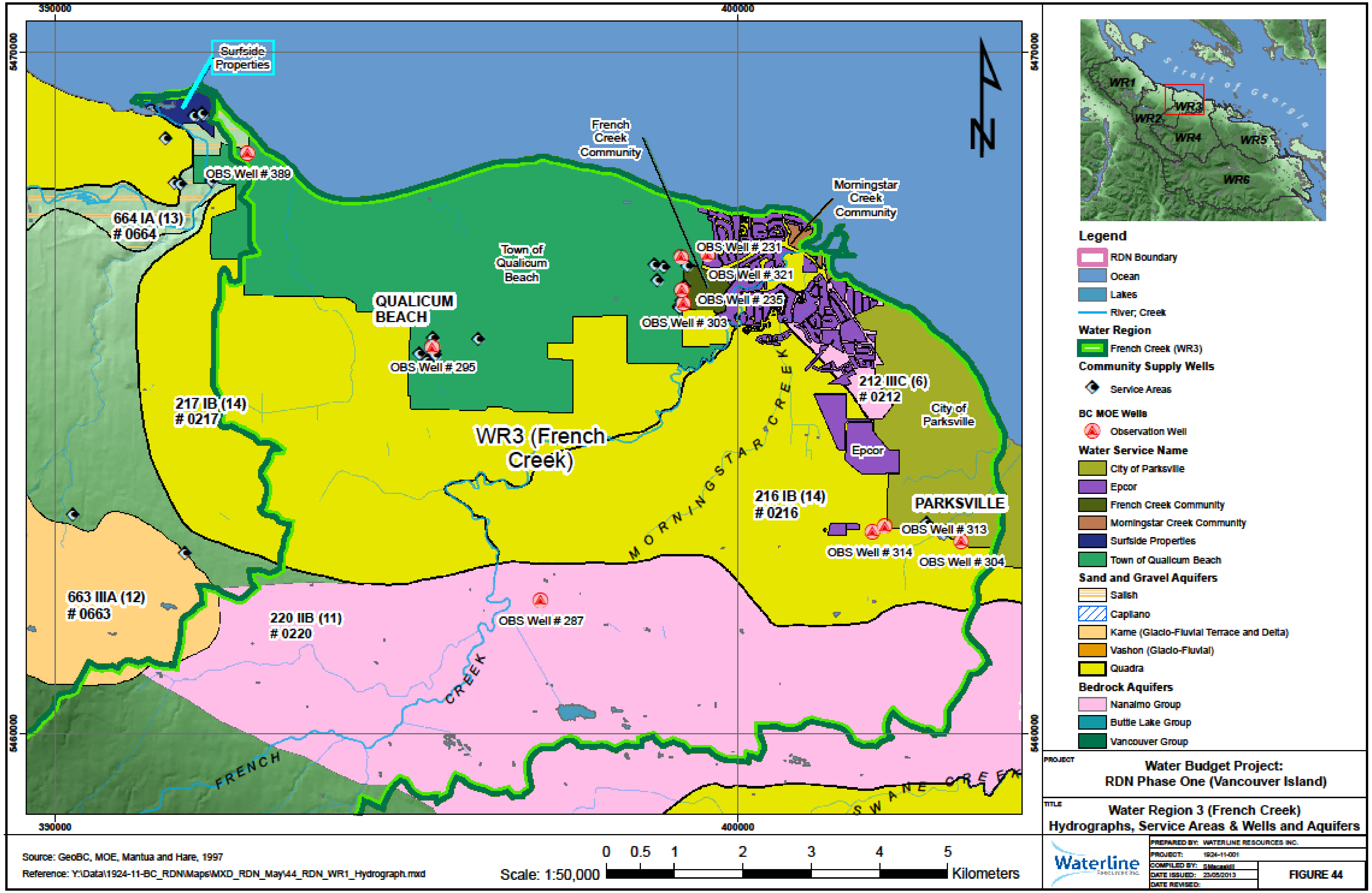


Figure 44: WR3 (FC) – MOE Well Hydrographs, Service Areas & Wells, and Aquifers.

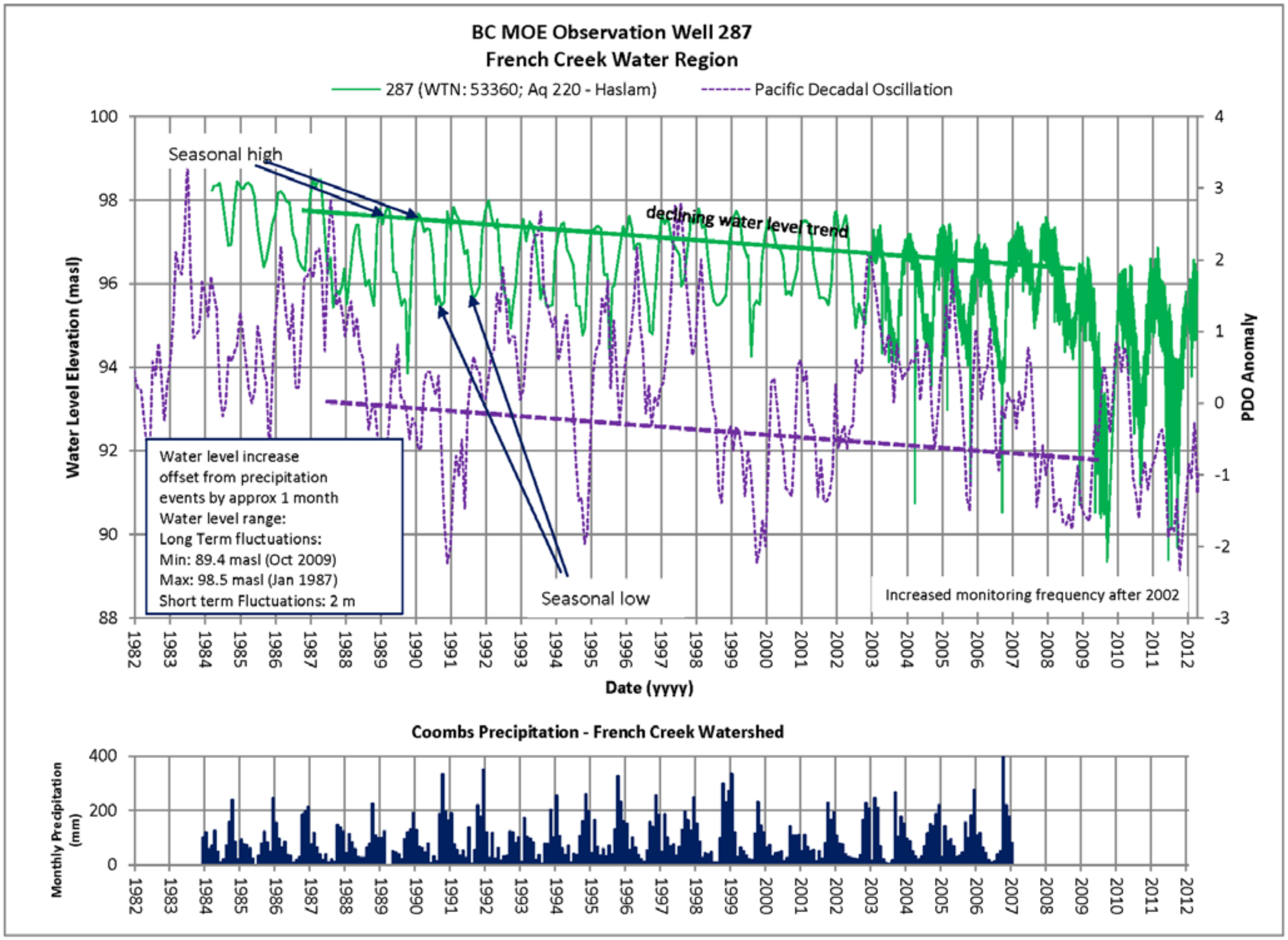


Figure 45: WR3 (FC) – Water Level Hydrograph BCMOE 287.

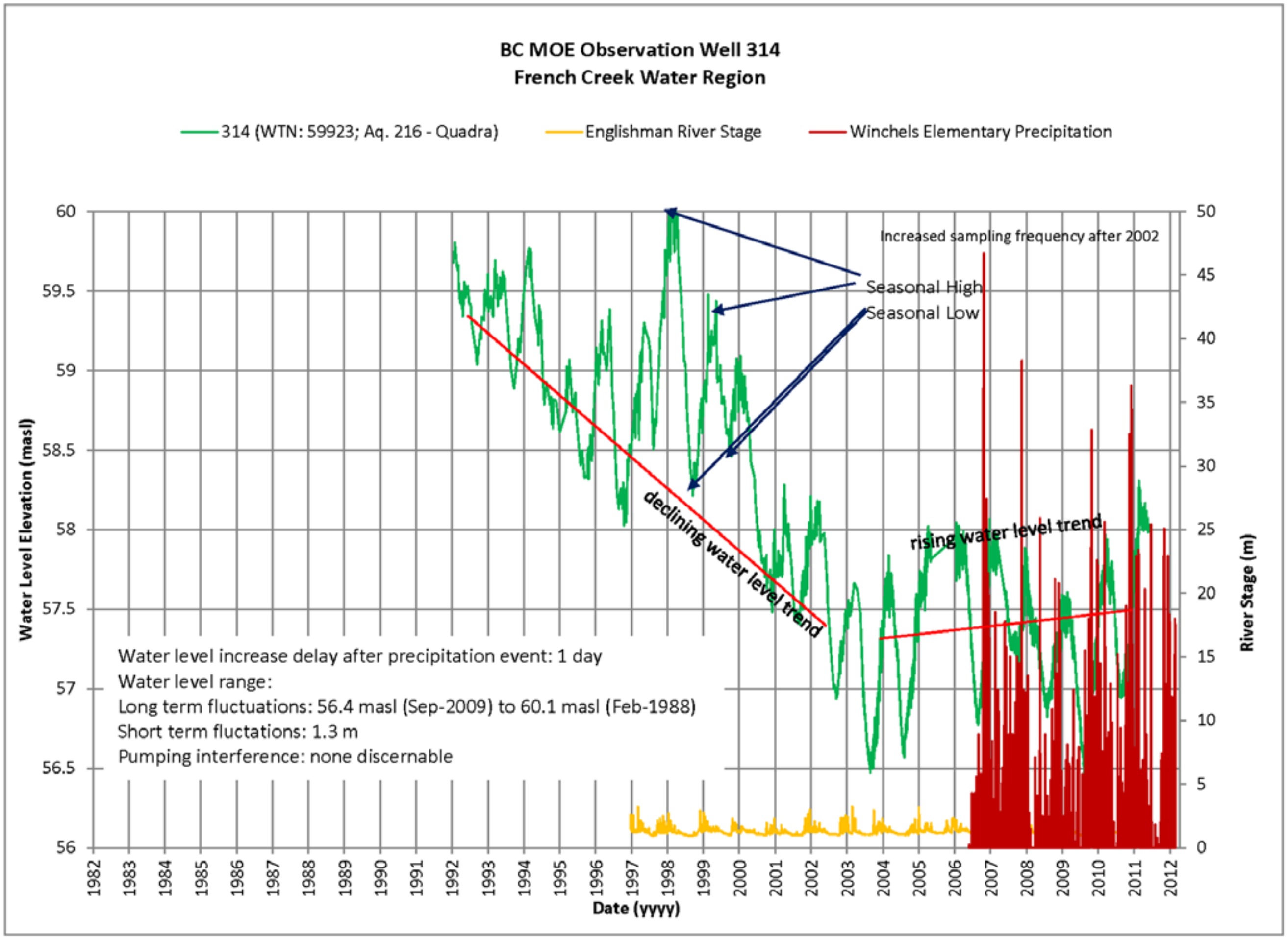


Figure 46: WR3 (FC) – Water Level Hydrograph BCMOE 314.

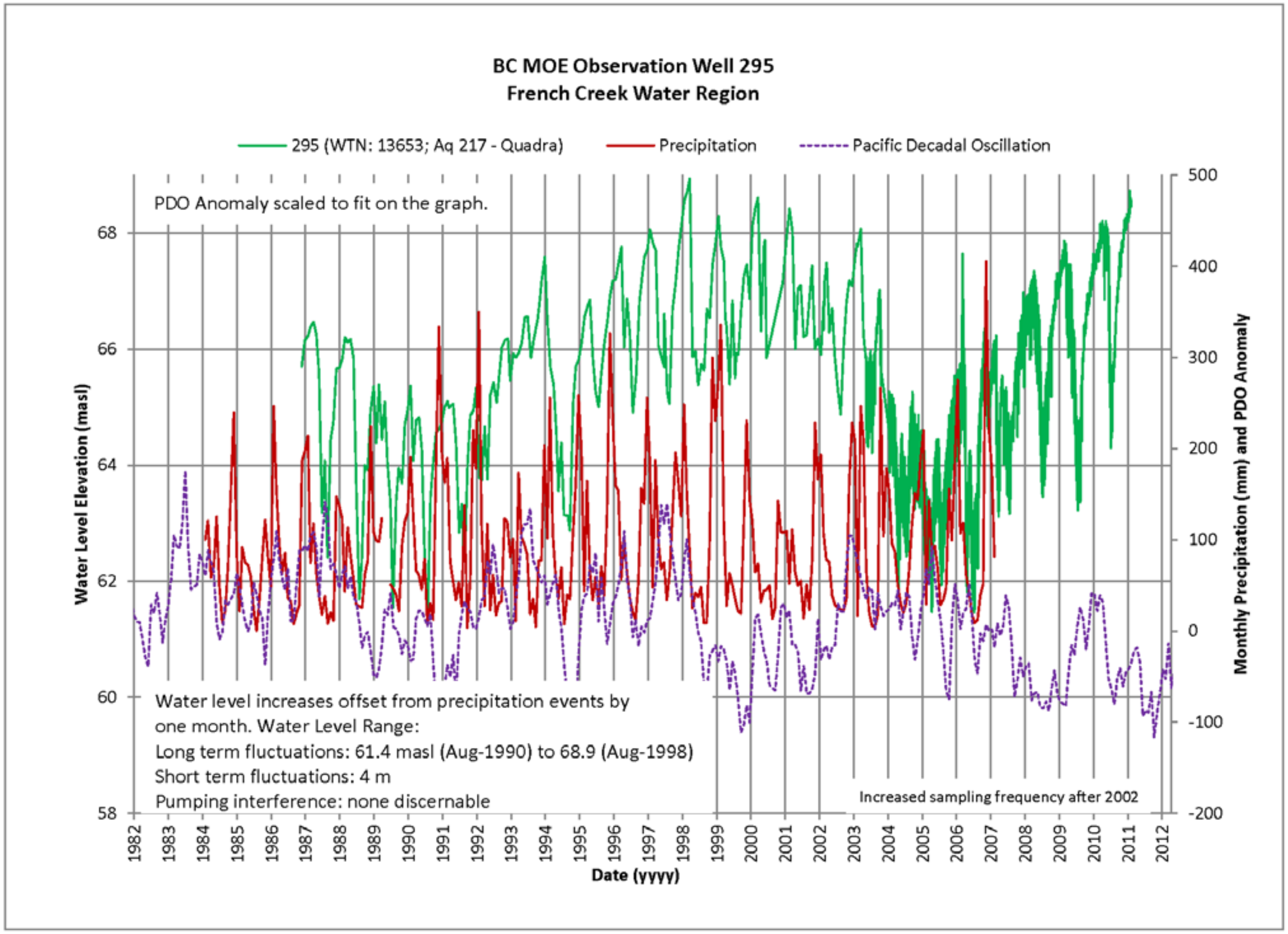


Figure 47: WR3 (FC) – Water Level Hydrograph BCMOE 295.

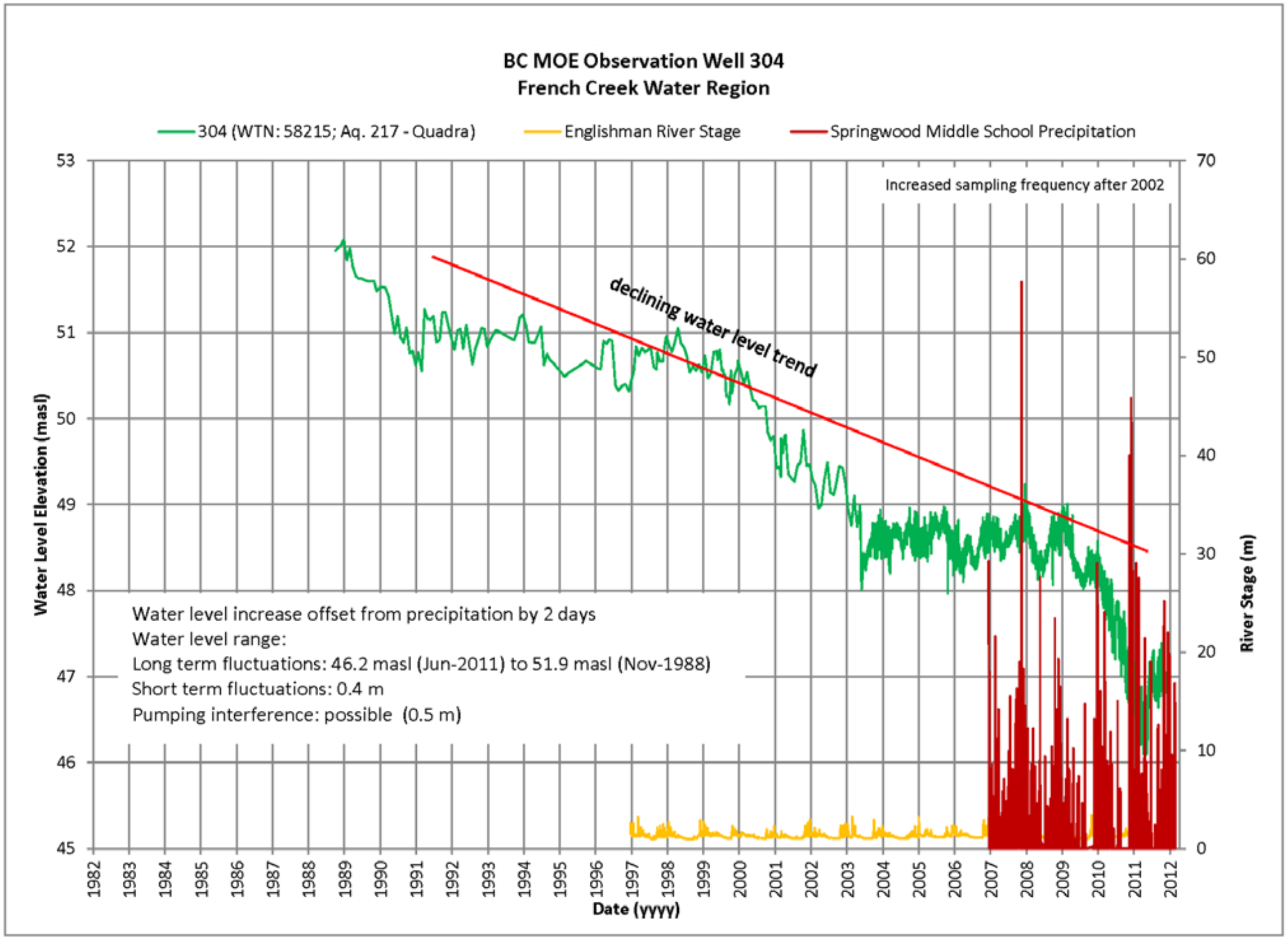


Figure 48: WR3 (FC) – Water Level Hydrograph BCMOE 304.

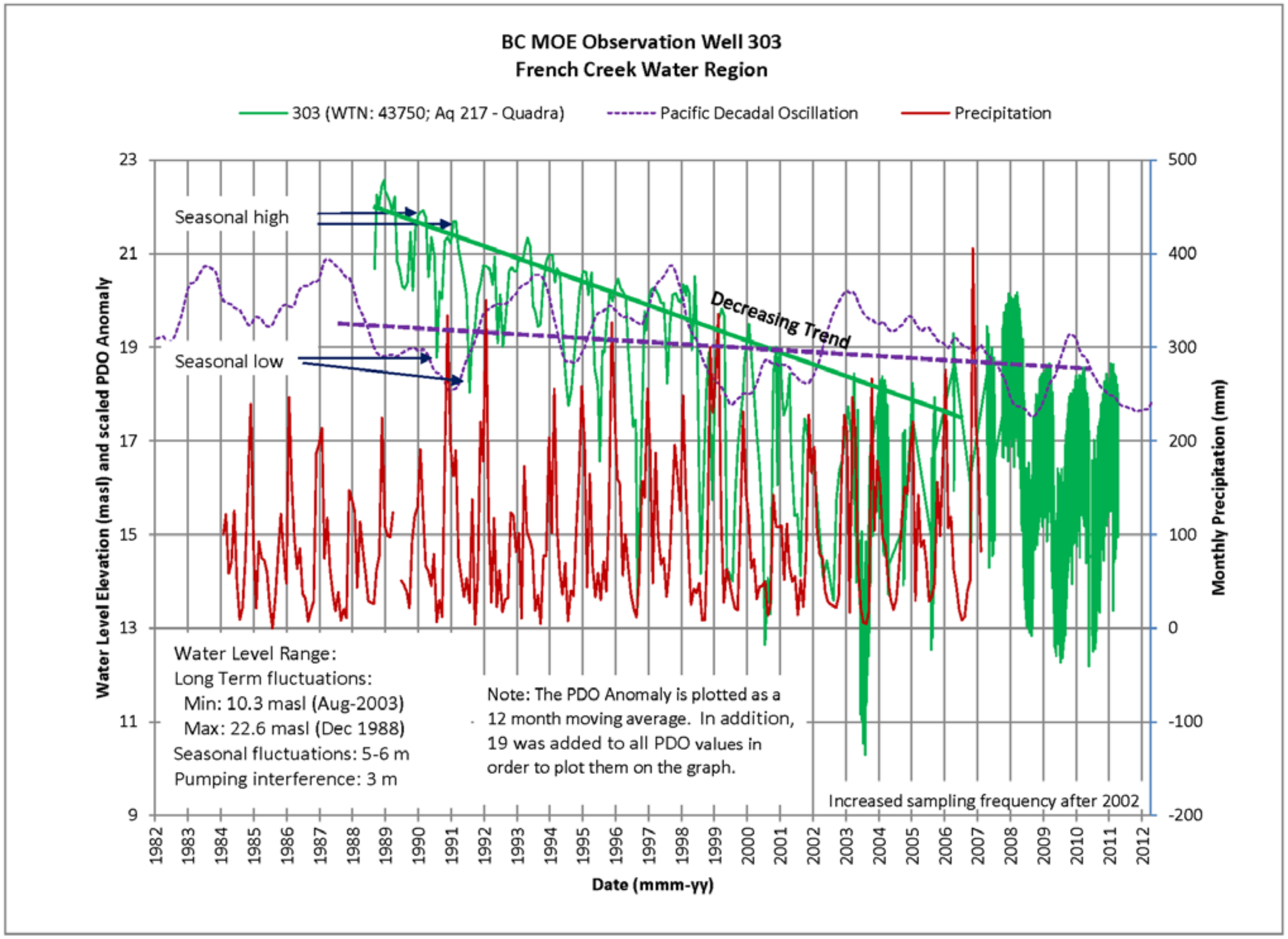


Figure 49: WR3 (FC) – Water Level Hydrograph BCMOE 303.

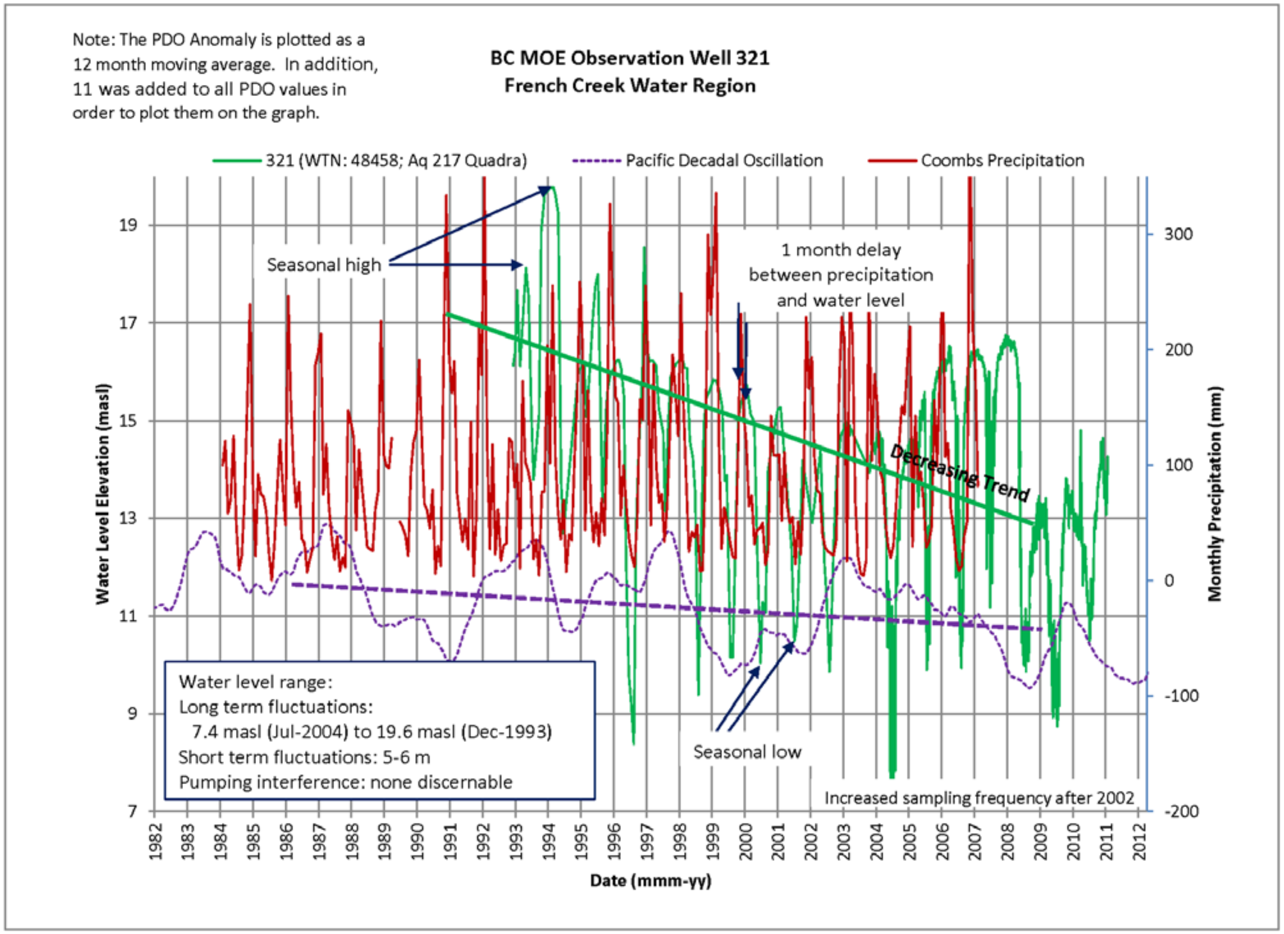


Figure 50: WR3 (FC) – Water Level Hydrograph BCMOE 321.

All MOE observation wells in WR3 (FC), with the exception of MOE well 295 (Figure 44), show significant water level declines from about 1993 to present day. This is likely caused the result of a combination of factors as follows:

- It is understood that MOE observation wells are impacted by the City of Parksville water supply wells. Specifically, the decline observed in MOE well 304 (Figure 48) in early 2010 is related to the operation of a new pumping well that was commissioned by Parksville at that time;
- WR3 (FC) has the smallest catchment area of all water regions in RDN;
- Significant recharge areas are located in the mid to lower part of the water region, which is where much of the development is located. This means that there is limited opportunity for recharge to aquifers in comparison to other larger water regions;
- There is also a limited areal extent of Quadra sand in this region. Overburden thickness maps have been developed and presented in Appendix C (Map C7). The data shows that the thickness and extent of overburden sediment in the coastal area is less and that aquifers likely have narrow boundaries and limited storage capacity for water;
- The area is densely populated and the demand for water supply in this region is higher than surrounding areas. In addition, increased development may have also resulted in increased impermeable surfaces which are known to result in less recharge; and
- MOE wells 287, 295, 303, and 321 appear to follow the PDO trend which indicates that that long-term climate variability (PDO) related to changes in sea surface temperature in the North Pacific has caused reduced precipitation and aquifer recharge over the last 35 years. This could also account for a portion of the water level decline in aquifers with WR3 (FC).

The lack of regulatory guidance on groundwater use in BC has created a situation where the cumulative effects of groundwater extraction, combined with climate variability, may have exceeded the aquifer recharge capacity within the region or in a given area (more local). Typical groundwater studies submitted for subdivision approval in BC involves a 100 day predictive calculation to assess seasonal water level fluctuations. The situation in WR3 (FC) is a good example of how such short-term predictive assessment is inadequate for planning community water supply that extend over a lifetime (100 years or more).

It is imperative that regulatory agencies implement requirements for cumulative effects analysis as a standard practice for confirming groundwater supply in advance of development approval. Submission of groundwater monitoring and aquifer performance data to a centralized database once a water supply system is operational is also required to confirm theoretical cumulative effects estimates. In the absence of regulatory guidance, at either the provincial or municipal level, there is limited opportunity to properly manage water resources in WR3 (FC) and other regions within the RDN such that sustainable groundwater use can be truly achieved.

5.3.6 Anthropogenic Groundwater Demand

Table 29 summarizes the available groundwater demand data available for WR3 (FC).

Table 29: WR3 (FC) – Summary of Anthropogenic Groundwater Demand Analysis

Aquifer Tag No.	Parksville Spring wood Wells	Town of Qualicum Beach Berwick Wells	Town of Qualicum Beach River Wells	RDN French Creek Water System	Epcor	Epcor - Hills of Columbia (Church Rd, Spring Hill Rd)?	Pintail Estates	Epcor (French Creek Estates)	Other Private Wells (From RDN Water Use Est. based on Zoning compiled on GIS)	Total Ground Water Use Estimate (ANTHout)
	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)
220	NA	NA	NA	NA	NA	NA	NA	NA	2.2E+06	2.2E+06
216	2.8E+06	NA	NA	NA	2.0E+05	NA	NA	NA	1.1E+06	4.1E+06
217	NA	8.2E+05		8.0E+04	2.0E+05	NA	NA	1.9E+06	1.7E+06	4.7E+06
212	NA	NA	NA	NA	2.0E+05	NA	NA	NA	3.1E+05	5.0E+05

Notes: NA means not applicable, ? Means not known or unavailable, ANTHout means anthropogenic water extraction from aquifer.

The annual water use for serviced areas within the RDN (large municipal users, RDN wells, and private utilities) is typically measured and was provided by the RDN or taken from annual reports for 2010. The groundwater demand estimate for non-service areas was calculated from water use data provided by the RDN for serviced areas, and then applied to non-serviced areas based on civic addresses and zoning classification. The method of assessment is further described in Appendix C (Map C21) and Appendix D.

There may also be groundwater discharging from aquifers that is required for conservation of flow in creeks and rivers based on the physical model developed by Waterline. The total groundwater demand for each aquifer, including conservation flow requirements, was compared against the total estimated aquifer recharge to assess the stress on each aquifer. The results are presented in the following section.

5.3.7 Aquifer Water Budgets and Stress Analysis

Table 30 provides a summary of final water budget calculations for each aquifer mapped within WR3 (FC). Detailed water budget calculations are provided in Appendix D (Tables D7 and D8). Water budgets for aquifers that extend from one water region to an adjacent water region (E.g.: Aquifer 217 and 220, Figure 40 and Figure 41) were completed on the portion of the aquifer which lies within each region. The water budget calculations were also designed to be additive so that a complete water budget of an entire mapped aquifer that extends across a water region boundary could be easily developed.

As indicated above, there are a total of 895 overburden and bedrock wells listed in the MOE data base in WR3 (FC) which represents the third largest number of wells in all of the 6 water regions across the RDN on Vancouver Island. It is also recognized that this number may only represent as little as 50% of water wells actually in operation in this region. Given that the French Creek water region is the smallest of the 6 regions and generally receives less recharge, the cumulative effect of the relatively high number of groundwater users per water region area results in increase aquifer stress. There is an urgent need to better manage groundwater extraction in this region.

Based on the water budget estimates for mapped aquifers within WR3 (FC); conditions in Quadra aquifers 216 and 217 indicate a high degree of stress. The water budget assessment agrees with observed water levels monitoring in MOE observation wells where substantial water level declines have been measured although some recovery has been observed since water use demands within the RDN French Creek service area decreased in the mid-2000s.

The water budget estimates for bedrock aquifer 212 indicates a moderate level of stress. Although the water budget assessment for aquifer 220 indicates low to moderate stress, local water level monitoring indicates otherwise. In low productivity aquifers, well to well interference can have a strong local effect that is not necessarily reflected at the water region scale water budget assessment. The reason for this is with the limitation of the water budget calculations to low productivity/yield aquifers where the aquifer recharge calculation is applied to the entire surface area of the aquifer. The problem with this approach is that closely spaced supply wells will inherently cause greater local interference. Again, cumulative effects analysis is required to assess the long-term viability/sustainability of this (and other) low yield aquifers within the RDN.

Table 30: Summary of Water Budget and Stress Analysis – WR3 (FC)

Aquifer Tag No.	Aquifer Lithology	Potential Ground Water-Surface water or Aquifer to Aquifer Interaction	MOE Obs Well	Seas. Fluc.	Long Term Fluc.	WL Trend (up or down)	Total Est. AQ. Rec. (TRin) (Rp/l + Rmb)	Est. Ann. Disch to Cr. & Down Grad Aquifer (Tc out)	Ground Water Use Estimate (ANTHout)	Total Out [TcOut + $ANTH_{out}$]	Stress Anal. % GW Use of the avail. AQ. Rec.	Relative Stress Assess.
			ID	(m)	(m)	U/D	(m^3/yr)		(m^3/yr)	(m^3/yr)	(%)	Lo, Mod, Hi
220	Haslam	FC	287		9.1	D	6.4E+06	5.1E+05	2.2E+06	2.7E+06	42	Lo-Mod
216	Quadra	FC	314	1.60	3.60	D/L	4.5E+07	4.1E+07	4.1E+06	4.5E+07	100	Hi
217	Quadra	FC and Ocean	321, 325, 303	5	12	D/L	8.3E+06	6.3E+06	4.7E+06	1.1E+07	133	Hi
212	NG	Ocean	NA	NA	NA	NA	8.8E+05	0.0E+00	5.0E+05	5.0E+05	58	Mod

Notes: FC means French Creek, NA means not applicable, AQ means aquifer, Seas. Fluc. means seasonal fluctuation, PDO means Pacific Decadal Oscillation, WL means water level, Est means estimated, Disch. means discharge, Rec. means recharge ,Cr. Means creek, TRin means total recharge into aquifer, Rp/l means total recharge from precipitation and/or leakage from overlying aquifer, Rmb means total lateral recharge from upgradient aquifer or mountain block, Tc out means total aquifer groundwater discharge to creek, assess. means assessment , Total out means total discharge from aquifer (not including discharge to ocean), ANTH out mean total groundwater Anthropogenic groundwater extraction from aquifer, aquifer stress color codes: blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high.

More accurate water budget and aquifer stress estimates could only be accomplished using a computer modelling approach, but again the lack of aquifer data would likely render this exercise inconclusive as well. Rigorous testing requirements and complete aquifer test analysis by groundwater practitioners to determine aquifer transmissivity and storativity properties, in addition to long-term groundwater monitoring data in each aquifer would be required to fully assess the actual stress on each aquifer in this region.

5.4 Water Management Planning Within WR3 (FC)

General guidance on water management planning for all water regions is provided in later sections of this document. Specific to WR3 (FC), the following recommendation are presented for consideration by RDN to improve the state of knowledge in the water region:

- At least one observation well should be installed in each mapped aquifer. The only aquifer that does not have an MOE/RDN observation well is Aquifer 212. Waterline understands that MOE is currently planning to install additional observation wells in bedrock aquifer 220 and Quadra aquifer 217;
- Well owners should identify the MOE well plate and tag numbers for each of their active water wells. In this manner, water use and monitoring data can be easily cross-referenced with the BC MOE well records. These include Parksville Springwood wells, the Town of Qualicum Beach Berwick Wells, the Town of Qualicum Beach River Wells, French Creek Water System wells, Epcor Hills of Columbia (Church Road and Spring Hill Road) wells, Pintail Estates wells, and Epcor French Creek Estates wells;
- The significant recharge area map needs to be further updated by further processing of the NRCAN remote sensing data and by field verification;
- Further mapping of the groundwater-surface water interactions is also required in French Creek to confirm the preliminary assessment; Waterline recommends specialized analysis (E.g.: isotopes[27], noble gases) of groundwater samples in this region to assist in determining groundwater age and origin. Thermal imaging of the river during high and low flow many help to quickly pinpoint areas where more detailed studies may be required;
- Reactivation of one of the WSC surface water gauging stations on French Creek is recommended; and
- Weekly flow measurements during the summer period (June to Sept) should be collected as part of the Community Watershed Monitoring Network program for Morning Star Creek, Grandon Creek and Carrey Creek to better understand summer low flows in these smaller watersheds.

[27] Elements of the same family but with different atomic weights. Technique is used to assess recharge elevation and age of water.

6.0 WATER REGION # 4 - ENGLISHMAN RIVER

6.1 Regional Overview

The Englishman River water region (WR4 (ER)) is defined as the area extending from Parksville along the coast to the top of the Englishman River and South Englishman River catchment in the southwest (Figure 51). It is second largest water region within the RDN covering an area of approximately 322 km^2. The region includes several major watersheds as listed in Table 31. The largest watersheds are associated with Englishman and the South Englishman Rivers. One hydrometric station, two climate stations, and approximately 52 surface water diversion licenses exist within the region (Figure 51, and Table 31).

Englishman River Water Service (ERWS) will obtain water in the future from the Englishman River for distribution outside of the water region (Nanoose area). The City of Parksville will also be an ERWS water recipient. Numerous studies have been completed in this water region in relation to the ERWS activities, the City of Parksville well fields and regional aquifer mapping and characterization as indicated below.

Table 31: WR4 (ER) - Watersheds, Wells and Surface Water Licenses

Total Water Region Area	***322 km^2**
Major Watersheds	**Drainage Area[1] (km^2)**
Englishman River (to the mouth including tributaries)	316
Morison Creek (tributary to Englishman River)	38.1
South Englishman River (tributary to Englishman River)	100
Wells and Surface Water Diversion Points	**No.**
# Water Wells listed in MOE DB	245
Surface water diversion licenses	52

Note: Drainage Areas are based on 1:50,000 BC Watershed Atlas. *Total water region area includes areas that drain directly to the ocean and are not part of a Major Watershed. The Englishman River drainage area includes drainage area of tributaries (Morrison Creek and South Englishman River)

According to the MOE Wells Database (BCGOV ENV Water Protection and Sustainability Branch, 2012) WR4 (ER) has the 2nd lowest number of water wells (245 wells) of the six water regions in the RDN. The MOE database likely only represents a fraction of the actual wells currently in use. Many well records may not have been entered into the database and some wells may simply not be in use or have been abandoned. As there is no mandatory requirement for submitting well logs or well abandonment records, it is not possible to determine the groundwater demand from private wells with any degree of certainty, nor is it possible to assess the vulnerability that may exist with improperly abandoned or standing water wells.

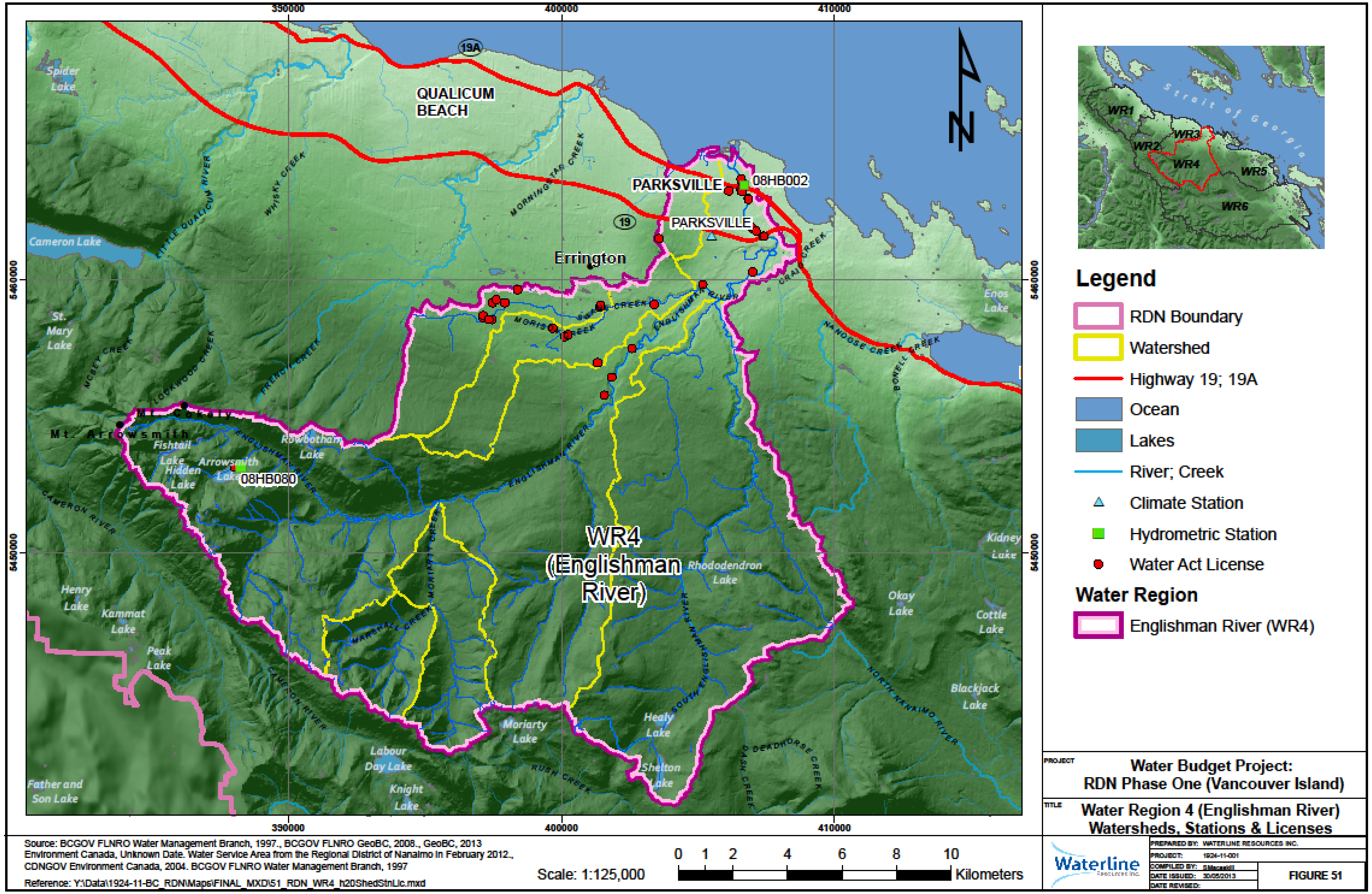


Figure 51: WR4 (ER) – Watersheds, Stations, & Licenses.

6.2 Surface Water Assessment

6.2.1 Terrain and Topography

The Englishman River Water Region (WR4) lies near the City of Parksville and includes the Englishman River Watershed and its major tributaries as well as smaller watersheds lying immediately to the north and south of the Englishman River. The region lies along the course of the Englishman River which rises up to Mount Arrowsmith (1,819) near the headwaters. Mount Arrowsmith lies within a UNESCO Biosphere Reserve and Mt. Arrowsmith Regional Park. The majority of the remainder of the watershed is private forest lands managed by Timberwest and Island Timberlands. The river generally flows north east to the estuary on the shores of the Strait of Georgia.

Some of the major tributaries to the Englishman River include the South Englishman River which flows from Shelton and Healley Lakes near the watershed boundary with the Nanaimo River to the south and Morison Creek which drains the area near Errington. The major watersheds in the WR4 are shown in Table 31.

6.2.2 Climate

The climate for the Englishman River Water Region is similar to the rest of the RDN with cool wet winters and mild dry summers. Significant snowpack accumulations are generally found in the higher elevation sections of the watershed through the winter and spring. The Mount Cokley Snow Course (03B02A) operated by the BC River Forecast Centre, which has been operated since 1980 indicates a normal April 1^{st} snowpack Snow Water Equivalent (SWE) of 864 mm and has a maximum recorded SWE of 2,100 mm on April 1^{st} 1999. A single Environment Canada weather station is located near the region at Coombs which has an average total precipitation of 1,126.4 mm (see Figure 52). This compares with recorded average total annual precipitation of 1,162.7 mm at the Nanaimo Airport. The City of Parksville has also collected daily precipitation data at their works yard since 2004. The total annual precipitation recorded in 2011 at the Parksville Works yard was 846.8 mm. The climate station is located at low elevation in relation to the remainder of the watershed which receives greater rainfall amounts (Figure 51).

Maps showing the distribution of annual total precipitation and average annual temperature over the water region are shown in Figure 53 and Figure 54, respectively. These maps show the influence of elevation on precipitation and temperature with annual precipitation estimated to be greater than 4,000 mm at high elevations.

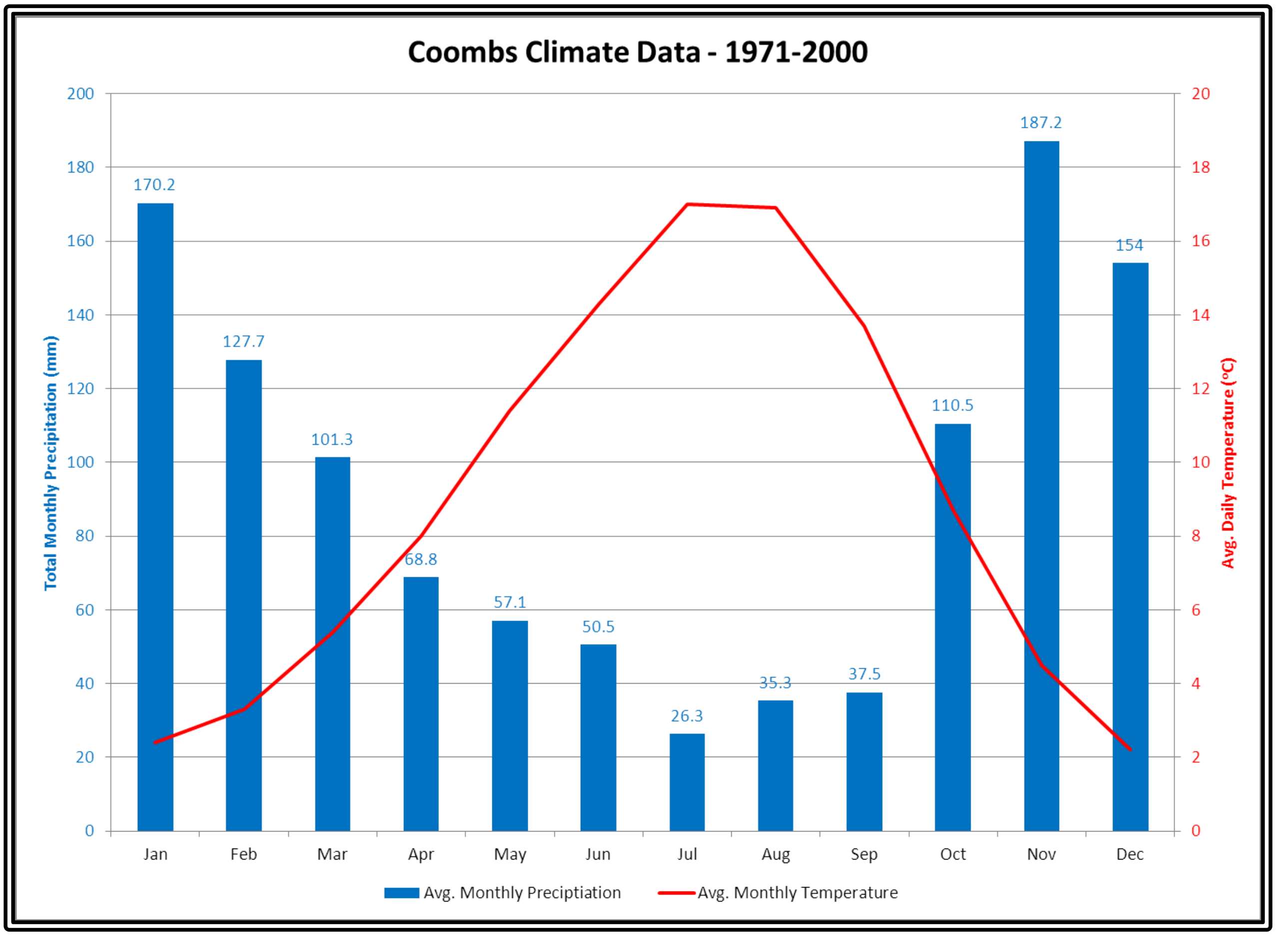


Figure 52: WR4(ER) - Coombs Monthly Climate (1971 to 2000 Normal Period)

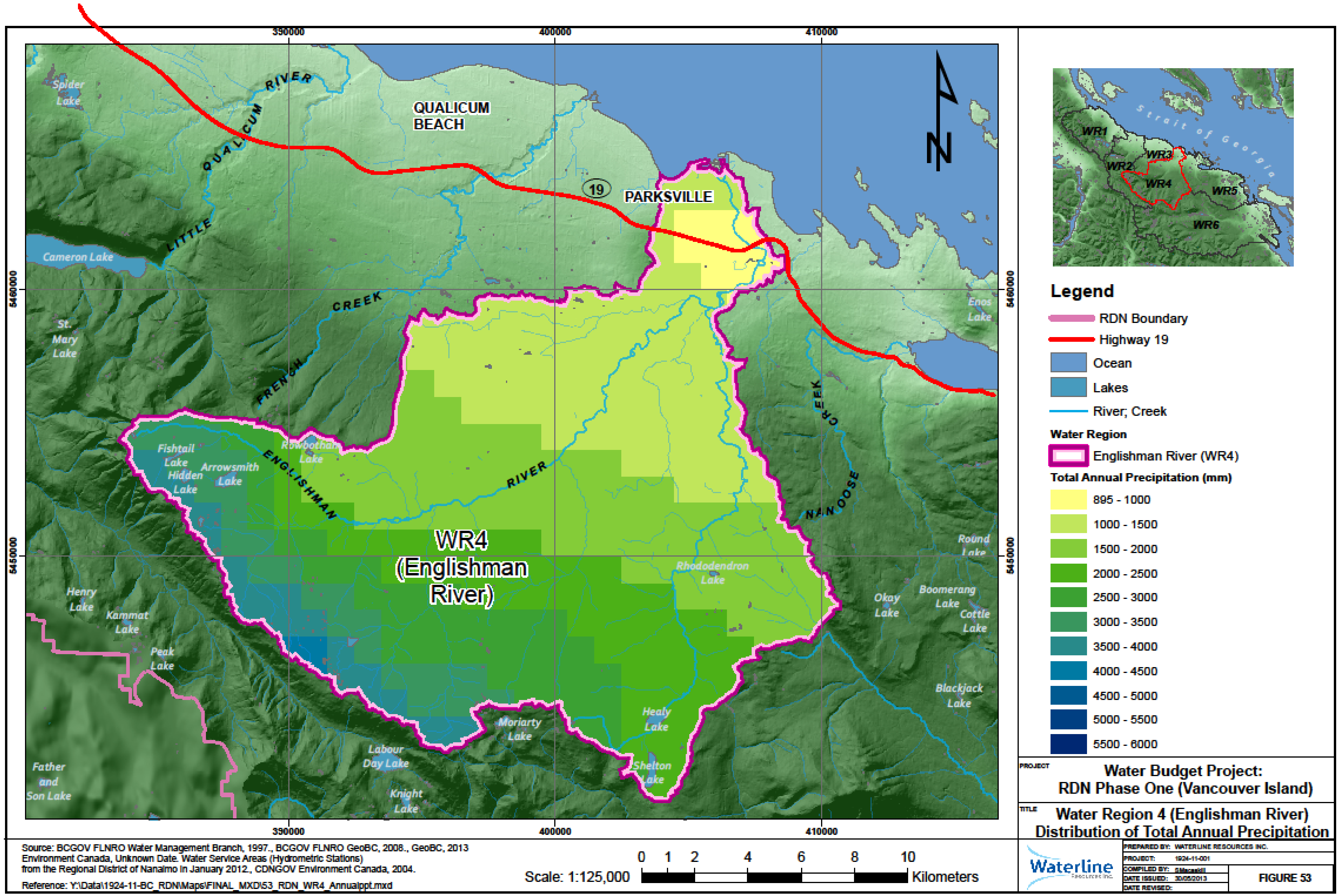


Figure 53: WR4 (ER) - Distribution of Total Annual Precipitation

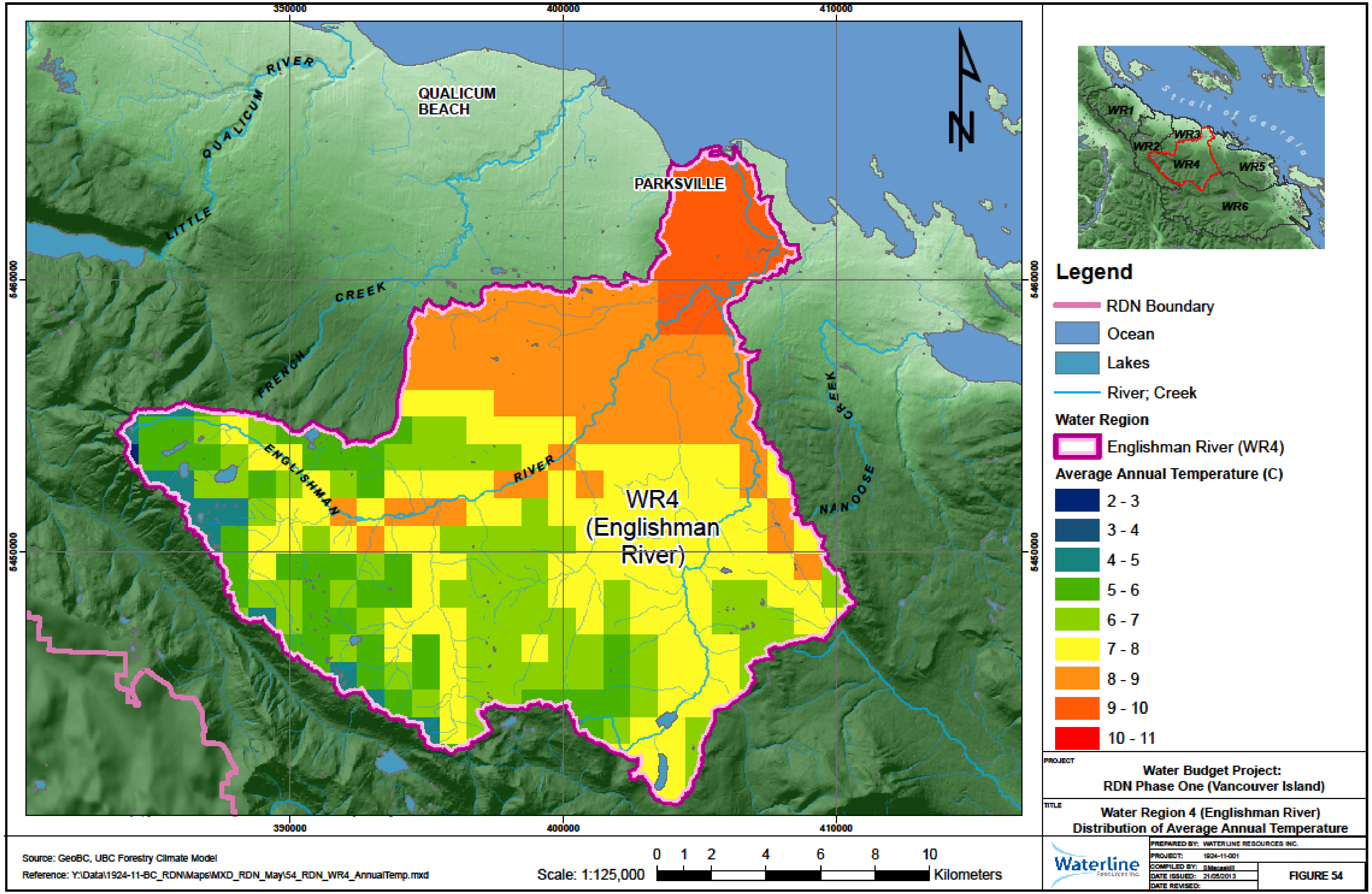


Figure 54: WR4 (ER) - Distribution of Average Annual Temperature

6.2.3 Stream Gauging and Monitoring

A single long term hydrometric gauge is operated by Water Survey of Canada on the Englishman River located at the Highway 19A bridge, upstream of the City of Parksville water supply intake (see Figure 51). The station has continuous flow records for the period from 1913 to 1917 and from 1979 to present. Table 32 lists the mean annual and average summer discharges recorded at the site. It should be noted that this gauge is influenced by summer flow releases from the Arrowsmith Lake dam. Therefore, two periods are shown in the records pre- and post-construction of the dam.

Table 32: WR4 (ER) – Water Survey of Canada Records

Station	Period	Natural or Regulated	Drainage Area to Gauge (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)
Englishman River at Parksville (08HB002)	1913 to 1917 & 1979 to 1998	Natural	316	13.73 m^3/s 432.9 million m^3	1.77 m^3/s 14.0 million m^3
Englishman River at Parksville (08HB002)	1999 to 2011	Regulated	316	13.21 m^3/s 416.4 million m^3	2.28 m^3/s 18.1 million m^3

Hydrographs showing monthly recorded flows for the two periods of record are shown in Figure 55. This clearly shows the increase in summer base flows as a result of construction of the dam for storage and release of summer flows. It should be noted that flows are recorded upstream of the City of Parksville intake and therefore do not indicate the remaining conservation flow in the river and estuary downstream of the intake.

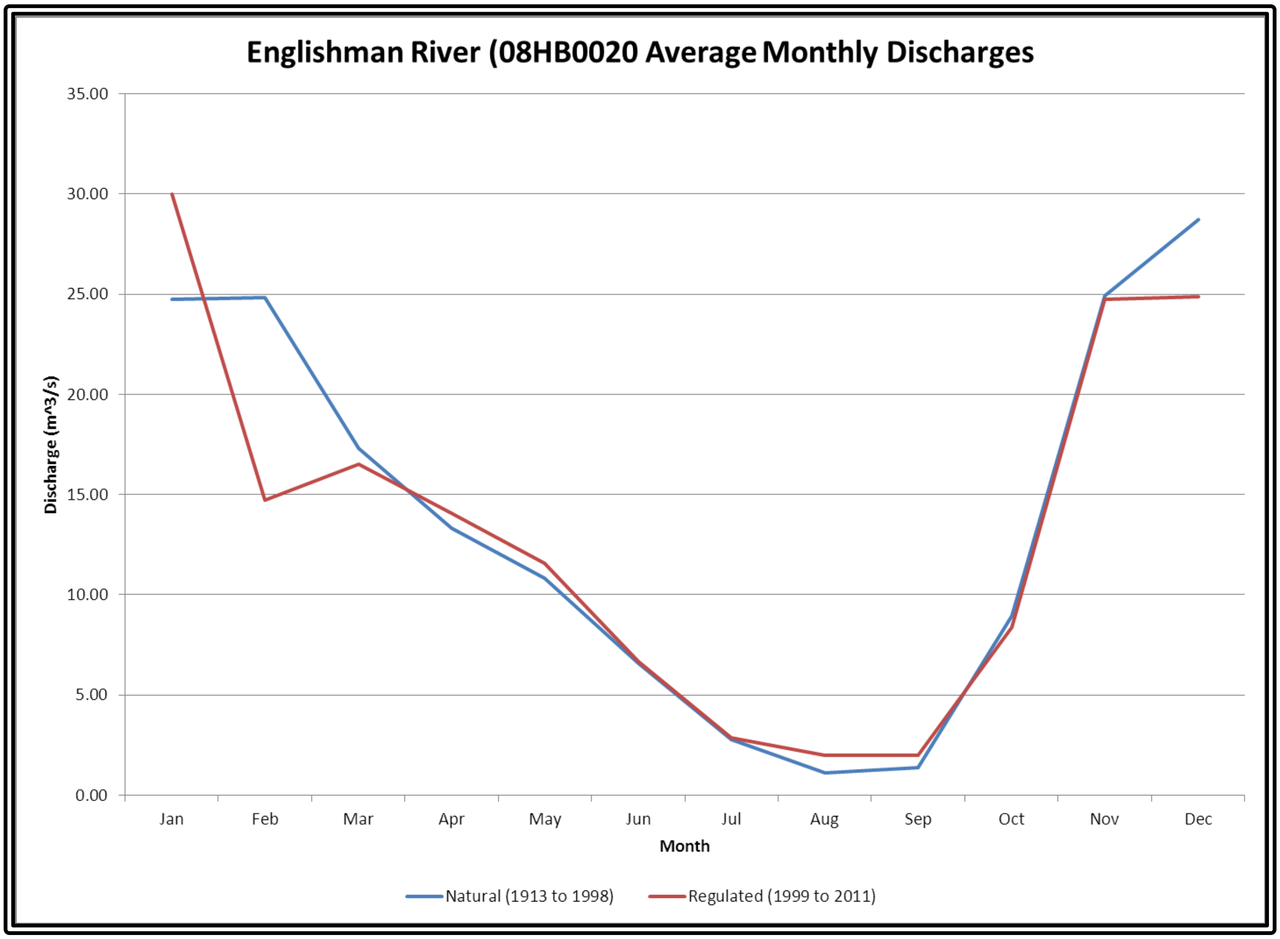


Figure 55: Englishman River Recorded Discharges

6.2.4 Hydrology and Surface Water Resources

The records from the Water Survey of Canada gauge near the mouth of the Englishman River have been used to quantify available water resources for the watershed as a whole. However, both Morison Creek and South Englishman River are not gauged systems. Results from the Regional Hydrologic Model for these systems are shown in Table 33

Table 33: WR4 (ER) – Available Surface Water Resources (Avg. for 1971 to 2000 period)

Watershed	Drainage Area (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)
Morrison Creek	38.1	1.1 m^3/s 34 million m^3	0.040 m^3/s 0.3 million m^3
South Englishman River	100	3.8 m^3/s 119 million m^3	0.23 m^3/s 1.86 million m^3

The Englishman River Water Allocation Plan (Boom and Bryden, 1994) estimated the Morrison Creek and South Englishman River Mean Annual Discharges to be approximately 2.1 m^3/s and

3.3 m^3/s. However, these were based solely on factoring the recorded Englishman River by the watershed area ratios.

6.2.5 Surface Water Demand

Table 34 summarizes the surface water licences in WR4 from the BC Surface Water Licence Database. Table 35 outlines the licenced surface water storage. The location of the surface water licences for WR4 is shown on Figure 51.

Table 34: WR4 (ER) - Surface Water Demand (in m^3)

Type of Demand	Monthly	Annual	Summer (Jul-Sept)
Consumptive Demand			
Agriculture	9,710	117,600	87,420
Domestic	8,730	104,700	34,560
Industrial	1,640	19,600	4,910
Institutional	-	-	-
WaterWorks	697,183	8,366,000	2,761,000
Total Consumptive	717,260	8,607,000	2,888,000
Non- Consumptive Demand			
Power	-	-	
Conservation	18,440,000	221,300,000	55,320,000
Total Non-Consumptive	18,440,000	221,300,000	55,320,000

Table 35: WR4 (ER) - Licenced Surface Water Storage

Type of Demand	Total Storage (Million m^3)
Storage	9.126
Conservation Storage	0
Other Storage	0.079
Total Storage	9.205

The largest licensed water user in WR4 (ER) is the Arrowsmith Water Service for municipal water supply to the City of Parksville and Regional District of Nanaimo under the Englishman River Water Service (ERWS) agreement. The municipal water demand during the summer is supported by storage at Arrowsmith Lake which is controlled by a dam and outlet works. The total licensed storage at Arrowsmith Lake is 9.00 million m^3. The dam was designed to support municipal demand as well as to support minimum conservation flows of 1.13 m^3/s in the Englishman River downstream of the intake.

The ERWS is currently in the process of final design and construction of a relocated intake and treatment plant located upstream of the current intake location. As part of the planning for this process, detailed hydrology studies were carried out by KWL (KWL, 2010). The result of this study indicates that the operating rules for the dam will be altered to meet increased municipal demands while supporting in stream conservation flows. As the proposed new rules have not yet been approved, the stress analysis is based on water license amounts as of 2012.

In addition to allocated water amounts, the AWS records daily withdrawals from the Englishman River. During the summer of 2010, the total volume withdrawn from the Englishman River for municipal water supply was 600,000 m^3. This has been used to assess actual stress in comparison with allocated stress.

6.2.6 Surface Water Stress Analysis

As outlined in Section 2.5.2, a surface water stress analysis for the Englishman River watersheds has been completed. Water budget analysis for other smaller ungauged subwatersheds within WR4(ER) should be completed when data is available and as part of a more detailed Tier 1 or Tier 2 water budget assessment (OMNR 2011). The results of the allocation and actual demand stress analysis for the Englishman River watershed in WR4 (ER) are shown in Table 36. A map showing the relative stress is shown on Figure 56.

Table 36: WR4(ER) – Relative Surface Water Stress Assessment Results

Watershed	Average Natural River Flow Supply (million m^3)	Storage (million m^3)	Conservation Flow (10% of MAD) (million m^3)	Licensed Demand (million m^3)	Allocation Stress	Stress Level	Actual Demand (million m^3)	Actual Stress
Englishman River	14.4	9.2	13.2	2.7	68%	Moderate	0.6	8%

Note: Volumes indicated in the table are average volumes for summer period (Jul to Sep). Average natural river flow is the estimated or recorded unregulated flow in the watershed. Total storage is based on licenced storage volume and assumes all storage is available to support conservation flow and licenced demand for the Jul to Sep period. The 10% of Mean Annual Discharge (MAD) conservation flow is based on current Ministry of Forest, Lands and Natural Resource Operations (MELP, 1996) minimum conservation flow policies for the east coast of Vancouver Island. Licenced demand is the total licenced volume for summer based on consumptive water licences. Allocation stress = (Average Natural supply + storage) / (Conservation Flow + Licenced Demand) Surface water stress color codes: blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high. Values reflect average flow conditions and do not consider drought years.

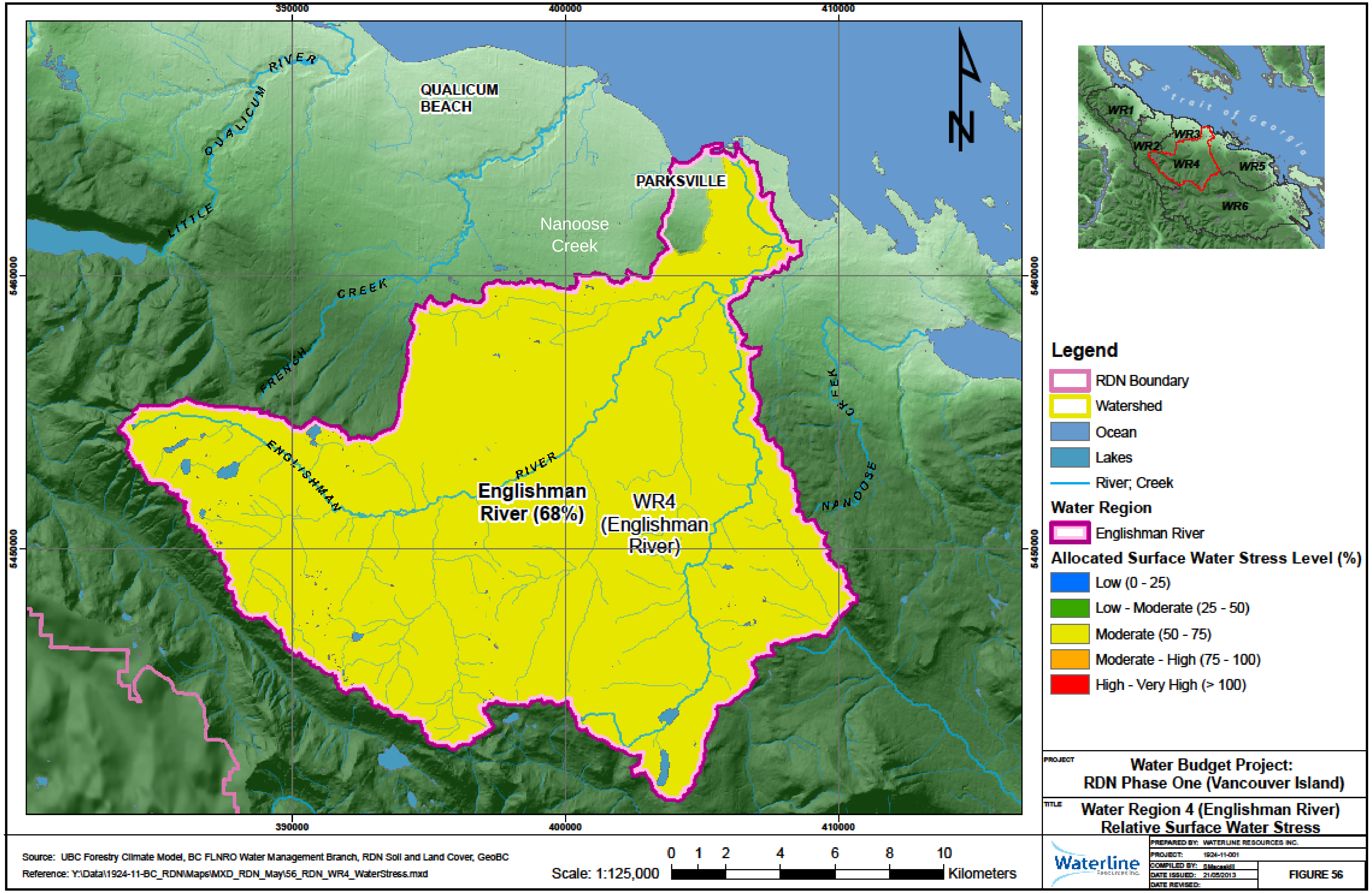


Figure 56: WR4 (ER) - Relative Surface Water Stress

6.3 Groundwater Assessment

6.3.1 Existing Groundwater Studies and Data

Given the regional scale of the Phase One Water Budget Assessment, the most important data compiled and geo-referenced by Waterline was the water well information, elevation data, soil and geology maps, land cover, aggregate resource map, mapped aquifers, and water service areas. Other maps were generated using the input data as part of Waterline's work and some samples are provided in Appendix C for illustration purposes (Eg: overburden thickness (Map C7), piezometric contour maps (Maps C8 and C9), air temperature (Map C14), precipitation (Map C15), runoff (Map C16 and C17), evapotranspiration (Map C18), infiltration (Map C19), Water Service Areas (Map C20), and Water Demand Assessment in Non-service areas (Map C21). All of these maps are provided in Appendix C for the entire RDN study area with an explanation of how the map was geo-reference or created by Waterline. These data and layers are now available in the ARC GIS Geodatabase at the RDN Scale, water region scale, watershed scale, on other local scale needed for site specific assessments. These data will be provided to the RDN in electronic format as part of the ARC GIS Geodatabase system which was constructed by Waterline for use by the RDN. These regional datasets form the framework for construction of the conceptual hydrogeologyical model.

Although only some of the data in certain reports may have been incorporated into Waterline's Geodatabase, the primary studies in the region were used in Waterline's water budget assessment to provide the local hydrogeological are provided in Table 37.

Table 37: WR4 (ER) – Hydrogeology Reference Reports

Author	Year	Study Title
EBA Engineering Consultants Ltd.	2002	Hydrogeological Assessment for Proposed Subdivision
EBA Engineering Consultants Ltd.	2003	Preliminary Hydrogeological Assessment of Water Supply for Proposed Rural Residential Subdivision
EBA Engineering Consultants Ltd.	2004	Report on Testing of Water Source Well PW2
EBA Engineering Consultants Ltd.	2004	Water Supply for Subdivision of Block 564
EBA Engineering Consultants Ltd.	2005	Well Protection Plan and Groundwater Monitoring Plan for River's Edge Subdivision (Block 564)
Levelton	2009	Well Yield San Pareil Well #4 Water Supply Well
Pacific Hydrology Consultants	2006	Groundwater Report and Well Test Analysis of Proposed Rascal Lane Well
Pacific Hydrology Consultants Ltd.	2003	Groundwater Source Evaluation RE Capacity Testing of Water Well at Rascal Trucking Gravel Pit
Wendling, G.	2012	Lower Englishman River Groundwater and Surface Water Interaction. Submitted to Mid Vancouver Island Habitat Enhancement Society
Lowen Hydrogeology Consultants	2010	Arrowsmith Water Service Englishman River Water Intake Study Groundwater Management. Discussion Paper 5-1. Existing Groundwater Supply Evaluation and Aquifer Yield Assessment, Prepared by Dennis Lowen, Alan Kohut and Bill Hodge, January 25, 2010.

6.3.2 Description of Aquifers and Water Wells

A total of four unconsolidated aquifers and two bedrock aquifers have been mapped within WR4 (ER). Table 38 provides a summary of information on mapped aquifers within WR4(ER). Quadra sand aquifers (209, 216, and 219) are reported to have moderate yield/productivity and are generally confined to semi-confined with low to moderate vulnerability and moderate to heavy use. The unconfined Salish aquifer 221 located at the mouth of the Englishman River has been mapped as high productivity with moderate use, but high vulnerability (Table 38).

Table 38: WR4 (ER) – Summary of Mapped Aquifers

Aquifer Tag No.	Aquifer Lithology	Location Within Water Region	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	Developed Aquifer Surface Area	Confined, Semi, or Unconfined, Aquifer Vulnerability Code	Yield
				(m^2)		(L/M/H)
209	Quadra	Upper ER close to Thrust Fault	Haslam	8.52E+06	Confined, IIC	M
220	Haslam	Upper WR4 (ER)	ER, FC	4.19E+06	Confined, IB	L
216	Quadra	Lower WR4 (ER) into FC	ER	6.13E+06	Semi-Confined, IB	M
219	Quadra	Along ER	Ocean, ER	9.13E+06	Confined, IIC	M
214	NG	Along Coast		5.62E+06	Semi-Confined, IIIC	L
221	Salish	Mouth of ER	Ocean, ER	4.03E+06	Unconfined, IIA	H

Notes: A/B/C is high/moderate/low vulnerability, I/II/III is heavy/moderate/light use, H/M/L means high/medium/low productivity/yield. All aquifer classification parameters, codes and yield are defined at the following MOE web address http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/Aq_Classification/Aq_Class.html#class. NG means Nanaimo Group.

Wells completed in unconsolidated aquifers are shown on Figure 57 and wells completed in bedrock aquifers are shown on Figure 58. The majority of supply wells are completed in unconsolidated, Quadra sand and gravel aquifers (Aquifer 209 and 216, Figure 57). There are a total of 245 overburden and bedrock wells listed in the MOE data base in WR4 (ER) (Table 31). As there are no regulatory requirements in BC to submit wells logs to MOE for capture in the BC Wells Database, the water wells shown on Figure 57 and Figure 58 likely represents only a fraction of wells actually drilled.

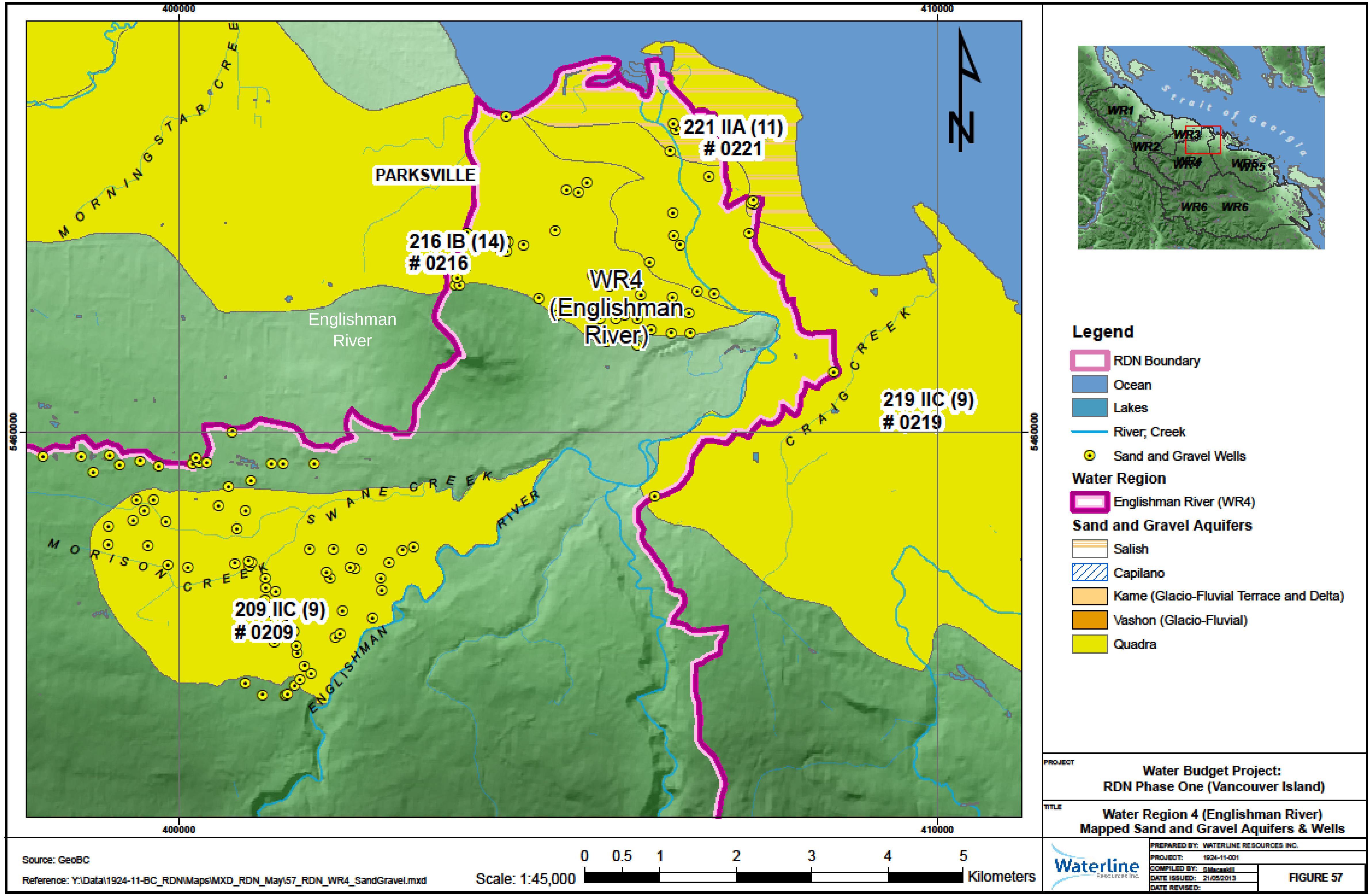


Figure 57: WR4 (ER) – Mapped Sand and Gravel Aquifers & Wells

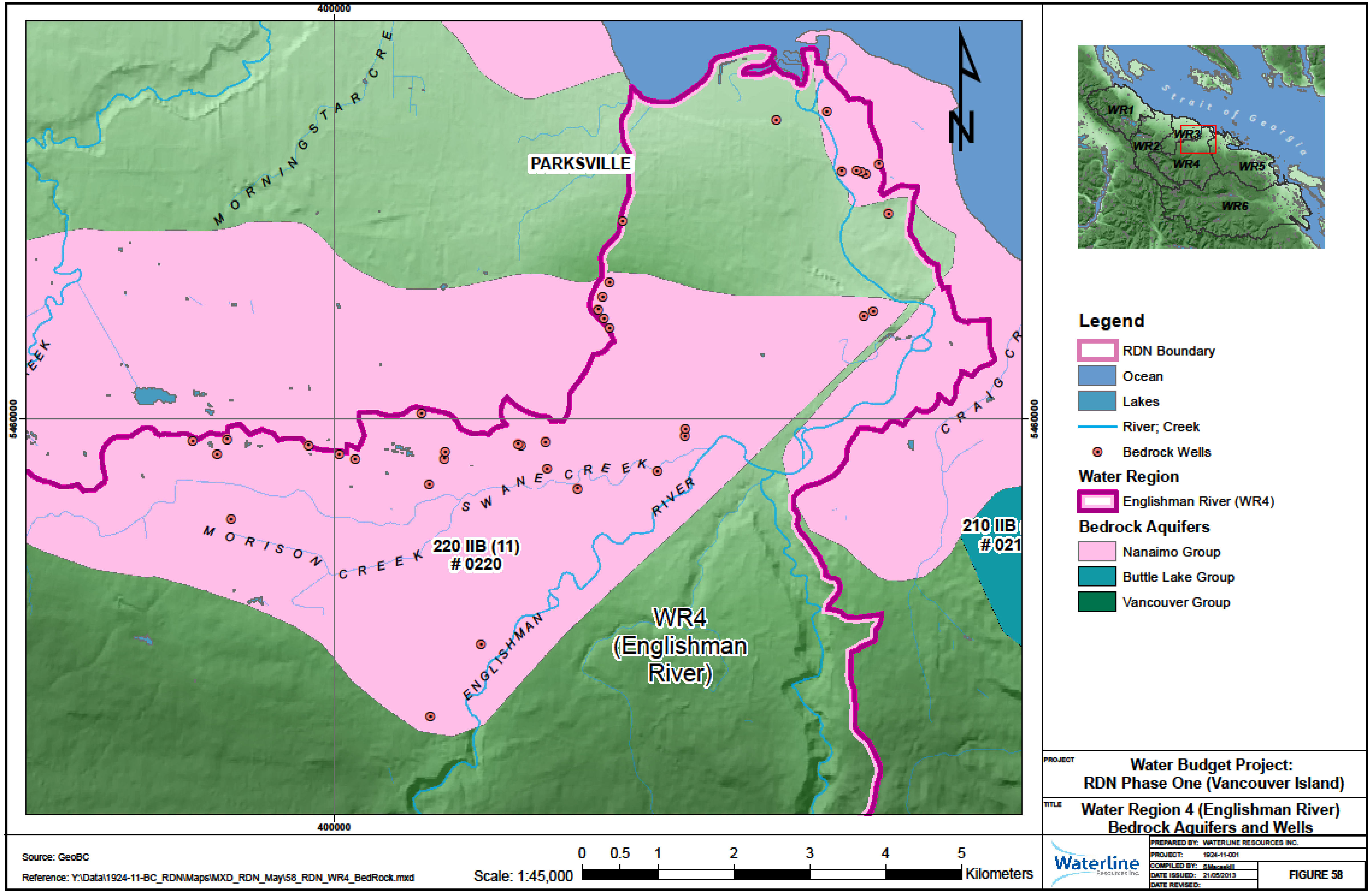


Figure 58: WR4 (ER) – Mapped Bedrock Aquifers & Wells

6.3.3 Groundwater-Surface Water Interaction - Conceptual Hydrogeological Model

A conceptual hydrogeological model of each aquifer with WR4 (ER) was developed in order to understand the key elements and linkages between surface water and groundwater systems required to complete the water budget assessment. Although the conceptual hydrogeological model developed by Waterline includes numerous cross-sectional views developed within the Waterline Geodatabase, only one 3D view into the subsurface will be presented here.

Figure 59 shows a 3D block diagram illustrating the relationship between surface and subsurface geology in WR4 (ER) where major water supply aquifers have been mapped. The schematic shows how the Quadra sand aquifer (219) on the east side of the Englishman River (View 1), and Quadra aquifer 216 on the west side of the river (View 2) may direct groundwater toward the Englishman River Valley and ultimately towards Georgia Strait.

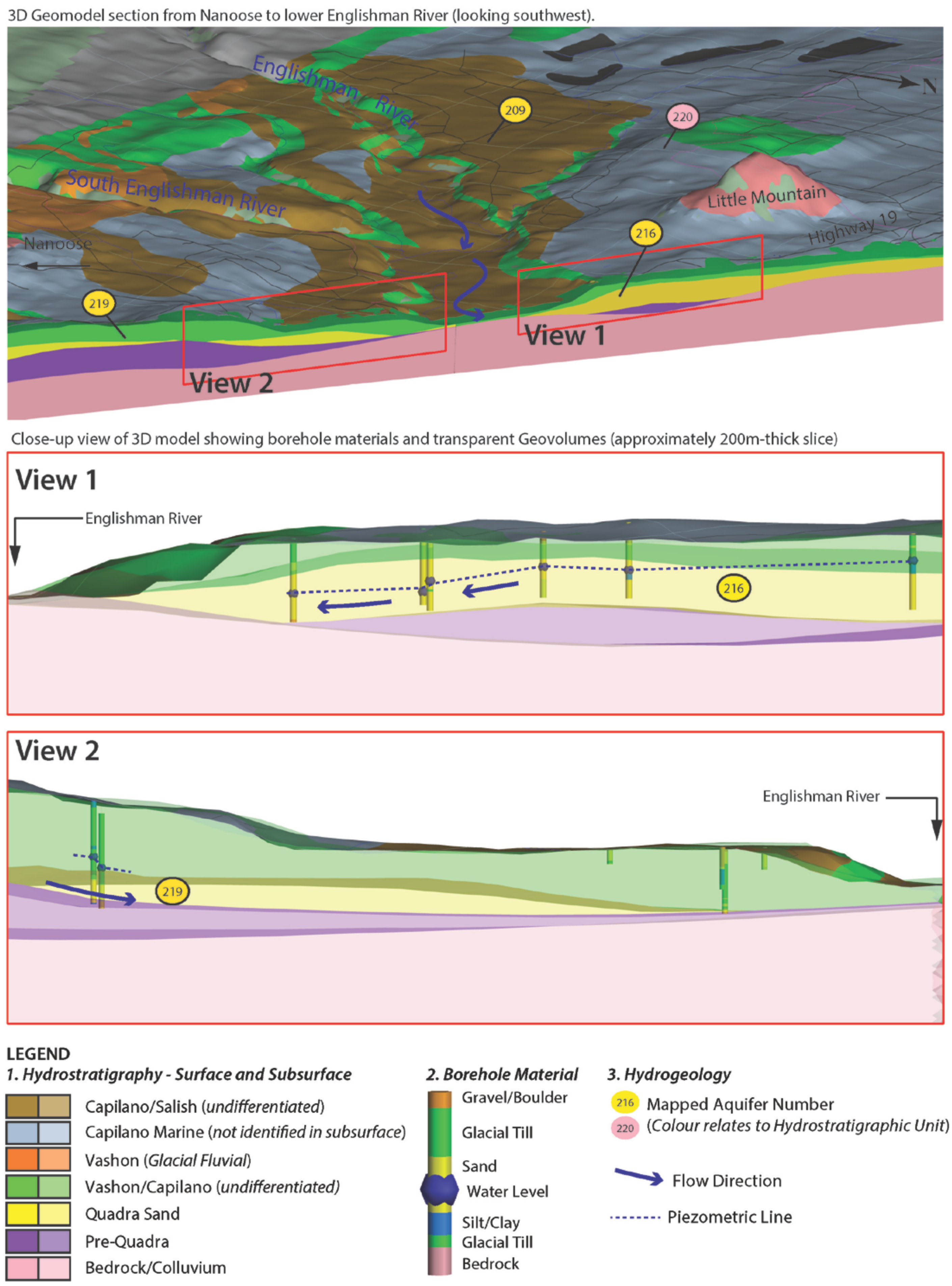


Figure 59: WR4 (ER) – Hydrogeological Conceptual Model – Englishman River

Quadra aquifer 219 to the east of the Englishman River is the location of the ERWS, Aquifer Storage and Recovery project. More recent information regarding groundwater flow in aquifer 219 may be available but was not available for the present study.

6.3.4 Significant Recharge Areas

Significant recharge areas within WR4 (ER) were determined as part of the assessment of infiltration across the region base on topography, mapped textural soil characteristics, land cover (bare land, vegetation, impermeable surfaces), and leaf area index. Better definition of these areas should be completed as the current modelling completed by Waterline and KWL was done on a 1 km square grid.

These areas are important for maintaining recharge to aquifers and base flow to creeks and rivers. The preliminary assessment presented herein is based on the integration of numerous datasets which may be incomplete and therefore will require further field verification. Figure 60 shows significant recharge areas mapped as part of the water budget project.

The unique character of the WR4 (ER) is the large catchment area that exists in the upper part of the water region. In addition, the upper part of the water region is underlain by intensely fractured and folded bedrock. In fact, the Englishman River itself is controlled by a large fault system (see Appendix C (Map C4) showing the bedrock geology map in Appendix D) that occurs in the underlying bedrock which is believed to be a conduit for channeling flow from up gradient areas in the water region where significant recharge areas have been mapped.

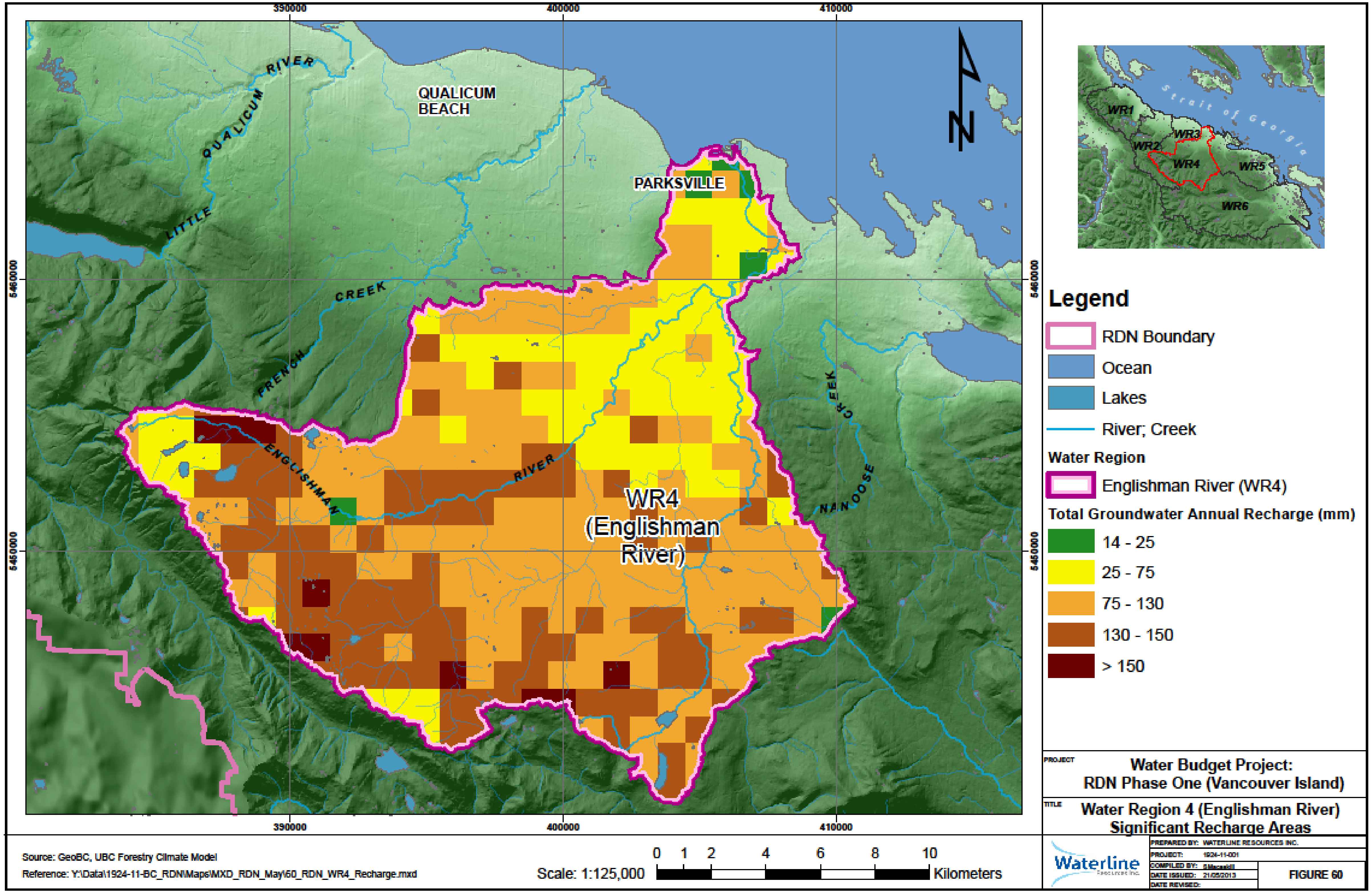


Figure 60: WR4 (ER) – Significant Recharge Areas

6.3.5 Groundwater Level Monitoring - BCMOE Observation Well Network

Long-term water level monitoring data provides an indication of an aquifer's response to global, regional, and local environmental changes in climate, groundwater pumping, and the impacts (if any) of other activities related land development. Long-term records also allow for establishing hydraulic linkages between the groundwater and surface water systems.

Figure 61 shows that there are no MOE observation wells and long-term water level monitoring records in WR4 (ER). Water supply wells in the region were identified from the MOE Wells Database (E.g.: large municipal users, the RDN, private utilities wells). Although numerous community wells are listed in the database, Waterline understands that not all of these wells shown on Figure 61 are currently active.

One of the problems encountered by Waterline during the water budget project was that community well owners generally do not cross reference active production wells to respective well logs in the MOE database. Often wells are referred to by local names (E.g.: RDN well # 1, #2, etc…). As water budget calculations require that production wells be assigned to specific aquifers, it is important that cross-referencing with the MOE well logs be completed. Well owners are encouraged to report the MOE well plate ID so that accurate water level and groundwater extraction volumes can be allocated to the corresponding well and mapped aquifer.

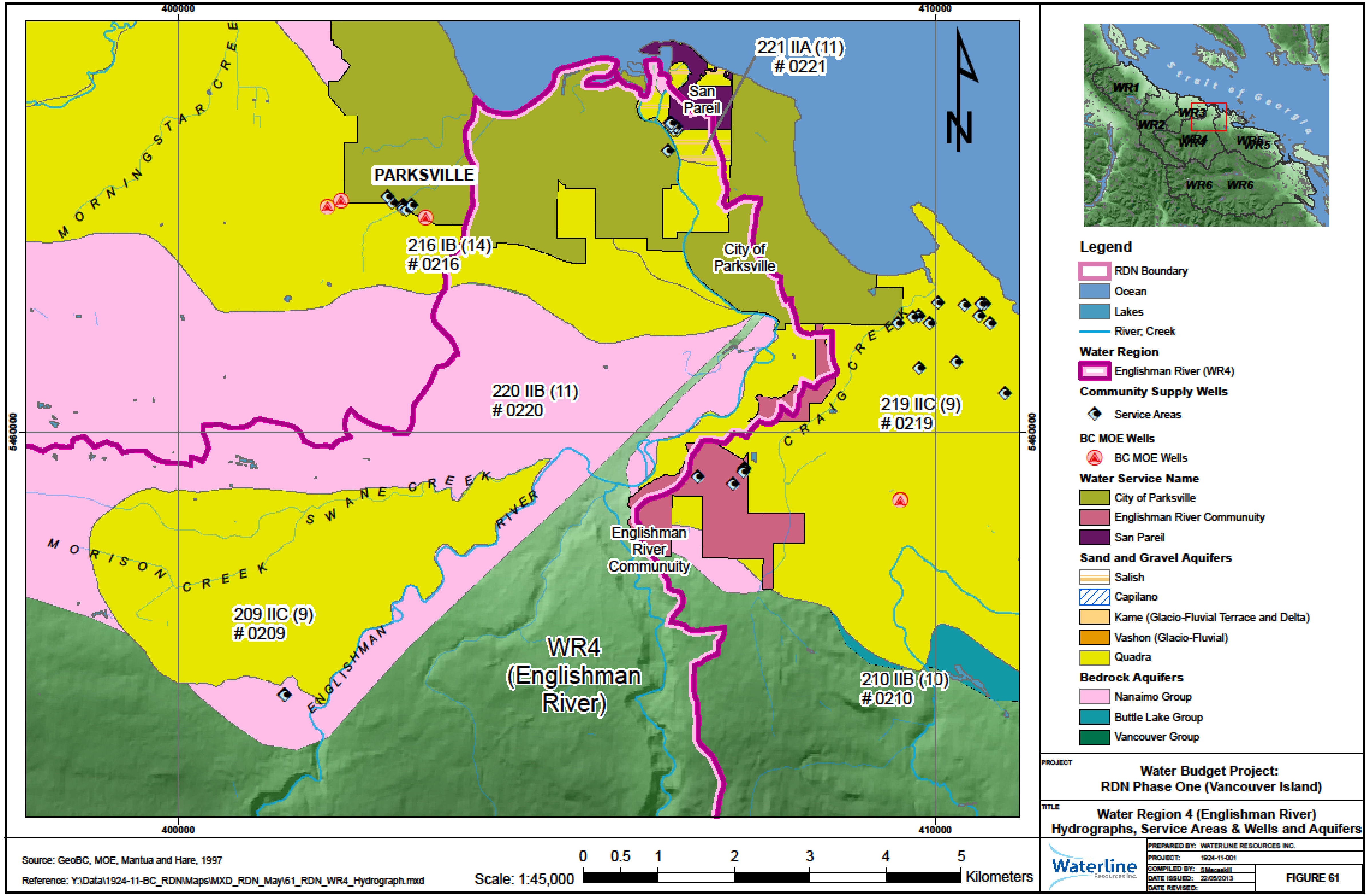


Figure 61: WR4 (ER) – MOE Well Hydrographs, Service Areas & Wells, and Aquifers.

6.3.6 Anthropogenic Groundwater Demand

Table 39 summarizes the available groundwater demand data available for WR4 (ER).

Table 39: WR4 (ER) – Summary of Anthropogenic Groundwater Demand Analysis

Aquifer No.	Parksville Railway (includes Trill well)	RDN San Pareil Well	Other Private Wells (From RDN Water Use Est. based on Zoning compiled on GIS)	Total Ground Water Use Estimate (ANTHout)
	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)
209	NA	NA	1.1E+06	9.77E+06
220	NA	NA	1.2E+06	1.22E+06
216	?	NA	7.6E+05	4.76E+06
219	NA	NA	8.3E+03	6.05E+06
214	NA	NA	1.4E+05	1.40E+05
221	NA	8.0E+04	9.5E+04	1.75E+05

Notes: NA means not applicable, ? Means not known or unavailable, ANTHout means anthropogenic water extraction from aquifer.

The annual water use for serviced areas within the RDN (large municipal users, RDN wells, and private utilities) is typically measured and was provided by the RDN or taken from annual reports for 2010. The groundwater demand estimate for non-service areas was calculated from water use data provided by the RDN for serviced areas, and then applied to non-serviced areas based on civic addresses and zoning classification. The method of assessment is further described in Appendix C (Map C21) and Appendix D.

There may also be groundwater discharging from aquifers that is required for conservation of flow in creeks and rivers based on the physical model developed by Waterline. The total groundwater demand for each aquifer, including conservation flow requirements, was compared against the estimated aquifer recharge to assess the stress on each aquifer. The results are presented in the following section.

6.3.7 Aquifer Water Budgets and Stress Analysis

Table 40 provides a summary of the final water budget calculations for each aquifer mapped within WR4 (ER). Detailed water budget calculations are provided in Appendix D (Tables D7 and D8). Water budgets for aquifers that extend from one water region to an adjacent water region (E.g.: Aquifer 209, 216, 219, Figure 57) were completed on the portion of the aquifer which lies within each region. The water budget calculations were also designed to be additive so that a complete water budget of an entire mapped aquifer that extends across a water region boundary could be easily developed.

As indicated above, there are a total of 245 overburden and bedrock wells listed in the MOE data base in WR4 (ER) which represents the one of the lowest number of wells in all of the 6 water regions across the RDN on Vancouver Island. It is also recognized that this number may only represent as little as 50% of water wells actually in operation in this region. This generally agrees with the lower indicated demand for groundwater in WR4 (ER) in comparison to other regions. Nevertheless, there is a need to better manage groundwater extraction as the population increases in this region.

Table 40: Summary of Aquifer Stress Analysis – WR4 (ER)

Aquifer Tag No.	Aquifer Lithology	Potential Ground Water-Surface water or Aquifer to Aquifer Interaction	MOE Obs Well	Seas. Fluc.	Long Term Fluc.	WL Trend (up or down)	Total Est. AQ. Rec. (TRin) (Rp/l + Rmb)	Est. Ann. Disch to Cr. & Down Grad Aquifer (Tc out)	Ground Water Use Estimate (ANTHout)	Total Out [TcOut + $ANTH_{out}$]	Stress Anal. % GW Use of the avail. AQ. Rec.	Relative Stress Assess.
			ID	(m)	(m)	U/D	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(%)	Lo, Mod, Hi
209	Quadra	Haslam	NA	NA	NA	NA	2.15E+07	8.67E+06	9.77E+06	9.77E+06	45	Lo-Mod
220	Haslam	ER	287	2.5	9.1	D	9.73E+05	1.72E+04	1.22E+06	1.22E+06	125	Hi
216	Quadra	ER	314	1.60	3.60	D/L	6.04E+06	4.00E+06	4.76E+06	4.76E+06	79	Mod. Hi
219	Quadra	Ocean, ER	NA	NA	NA	NA	1.83E+07	6.04E+06	6.05E+06	6.05E+06	33	Lo-Mod
214	NG	Ocean	NA	NA	NA	NA	6.18E+05	0.00E+00	1.40E+05	1.40E+05	23	Lo
221	Salish	Ocean, ER	NA	NA	NA	NA	2.87E+05	0.00E+00	1.75E+05	1.75E+05	61	Mod

Notes: ER means Englishman River, NA means not applicable, AQ means aquifer, Seas. Fluc. means seasonal fluctuation, PDO means Pacific Decadal Oscillation, WL means water level, Est means estimated, Disch. means discharge, Rec. means recharge ,Cr. Means creek, TRin means total recharge into aquifer, Rp/l means total recharge from precipitation and/or leakage from overlying aquifer, Rmb means total lateral recharge from up gradient aquifer or mountain block, Tc out means total aquifer groundwater discharge to creek, assess. means assessment , Total out means total discharge from aquifer (not including discharge to ocean), ANTH out mean total groundwater Anthropogenic groundwater extraction from aquifer, aquifer stress color codes: blue=low, green =low to moderate, yellow =moderate , brown =moderate to high, red=high to very high.

Based on the water budget estimates for mapped aquifers within WR4 (ER), overall conditions appear to be variable with low to high stress indicated. Water budget estimates for Quadra aquifer 216 and Haslam bedrock aquifer 220 indicate a moderate to high and high level of stress in the water region, respectively. Dense development and substantial demand for water (E.g. RDN, City of Parksville, Epcor, and private wells) likely contribute to the stress assessed for Quadra aquifer (216). This may be exacerbated in localized areas where the water wells are in close enough proximity to be competing for the groundwater resource (well-to-well interference).

Salish aquifer 221 exhibits moderate stress. Quadra aquifers 209 and 219 exhibit low to moderate stress, while the Nanaimo Group bedrock aquifer 214 exhibits low stress.

More accurate water budget and aquifer stress estimates could only be accomplished using a computer modelling approach, but again the lack of aquifer data would likely render this exercise inconclusive as well. Rigorous testing requirements and complete aquifer test analysis by groundwater practitioners to determine aquifer transmissivity and storativity properties, in addition to long-term groundwater monitoring data in each aquifer would be required to fully assess the actual stress on each aquifer in this region.

6.4 Water Management Planning Within WR4 (ER)

General guidance on water management planning for all water regions is provide in later sections of this document. Specific to WR4 (ER), the following recommendation are presented for consideration by RDN to improve the state of knowledge in the water region:

- At least one observation well should be installed in each mapped aquifer. Mapped aquifers that currently do not have MOE monitoring wells include Aquifers 209, 219, 214, and 221;
- Well owners should identify the MOE well plate and tag numbers for each of their active water wells. In this manner, water use and monitoring data can be easily cross-referenced with the BC MOE well records. These include the Parksville Railway wells, and the RDN San Pareil wells;
- The significant recharge area map needs to be further updated by further processing of the NRCAN remote sensing data and by field verification;
- Further mapping of the groundwater-surface water interactions is also required in Englishman River to confirm that significant recharge is being directed through the extensive bedrock fault network. Waterline recommends specialized analysis (E.g.: isotopes[28], noble gases) of groundwater samples in this region to assist in determining groundwater age and origin. Thermal imaging of the river during high and low flows may help to quickly pinpoint areas where more detailed studies may be required;
- Arrowsmith Lake Reservoir Level and Discharge Data collected by the Arrowsmith Water Service be obtained at regular intervals and be included in the Regional Water Database;
- Shelton Lake and South Englishman River Flow data collected by the BC Conservation Foundation be obtained at regular intervals and be included in the Regional Water Database; and
- Weekly flow measurements during the summer period (June to Sept) should be collected as part of the Community Watershed Monitoring Network program for Morrison Creek and Swane Creek to better understand summer low flows in these smaller watersheds.

[28] Elements of the same family but with different atomic weights. Technique is used to assess recharge elevation and age of water.

7.0 WATER REGION # 5 - SOUTH WELLINGTON TO NANOOSE

7.1 Regional Overview

The South Wellington to Nanoose water region (WR5-SW-N) is defined as the area extending from the Nanoose Peninsula in the northwest part of the water region to South Nanaimo in the southeast, and from the coast around Departure Bay to the top of Mount Benson (Figure 62). It is 3rd largest water region within the RDN covering an area of approximately 322 km^2 (Table 41).

The region is densely populated as it encompasses the City of Nanaimo, District of Lantzville, and the Nanoose Peninsula. There are approximately 23 watersheds and subwatersheds in WR5 (SW-N), the largest of which is associated with Bonell and Nanoose Creeks which drain into Nanoose Bay (Figure 62). Nine hydrometric stations, seven climate stations, and approximately 248 surface water diversion licenses exist within the region (Figure 62, and Table 41).

Table 41: WR5 (SW-N) - Watersheds, Wells and Surface Water Licenses

Total Water Region Area	***315 km^2**
Major Watersheds	**Drainage Area[1] (km^2)**
Craig Creek	11.7
Nanoose Creek	34.0
Bonell Creek	51.2
Millstone River	100
Chase River	28.7
Beck Creek	13.9
Wells and Surface Water Diversion Points	**No.**
# Water Wells listed in MOE DB	1685
Surface water diversion licenses	248

Note: Drainage Areas are based on 1:50,000 BC Watershed Atlas. *The total water region area includes areas which drain directly to the ocean and are not within a major watershed area.

According to the MOE Wells Database (BCGOV ENV Water Protection and Sustainability Branch, 2012) WR5 (SW-N) has the second highest number of water wells (1685 wells) of the six water regions in the RDN. The MOE database likely only represents a fraction of the actual wells currently in use. Many well records may not have been entered into the database and some wells may simply not be in use or have been abandoned. As there is no mandatory requirement for submitting well logs or well abandonment records, it is not possible to determine the groundwater demand from private wells with any degree of certainty, nor is it possible to assess the vulnerability that may exist with improperly abandoned or standing water wells.

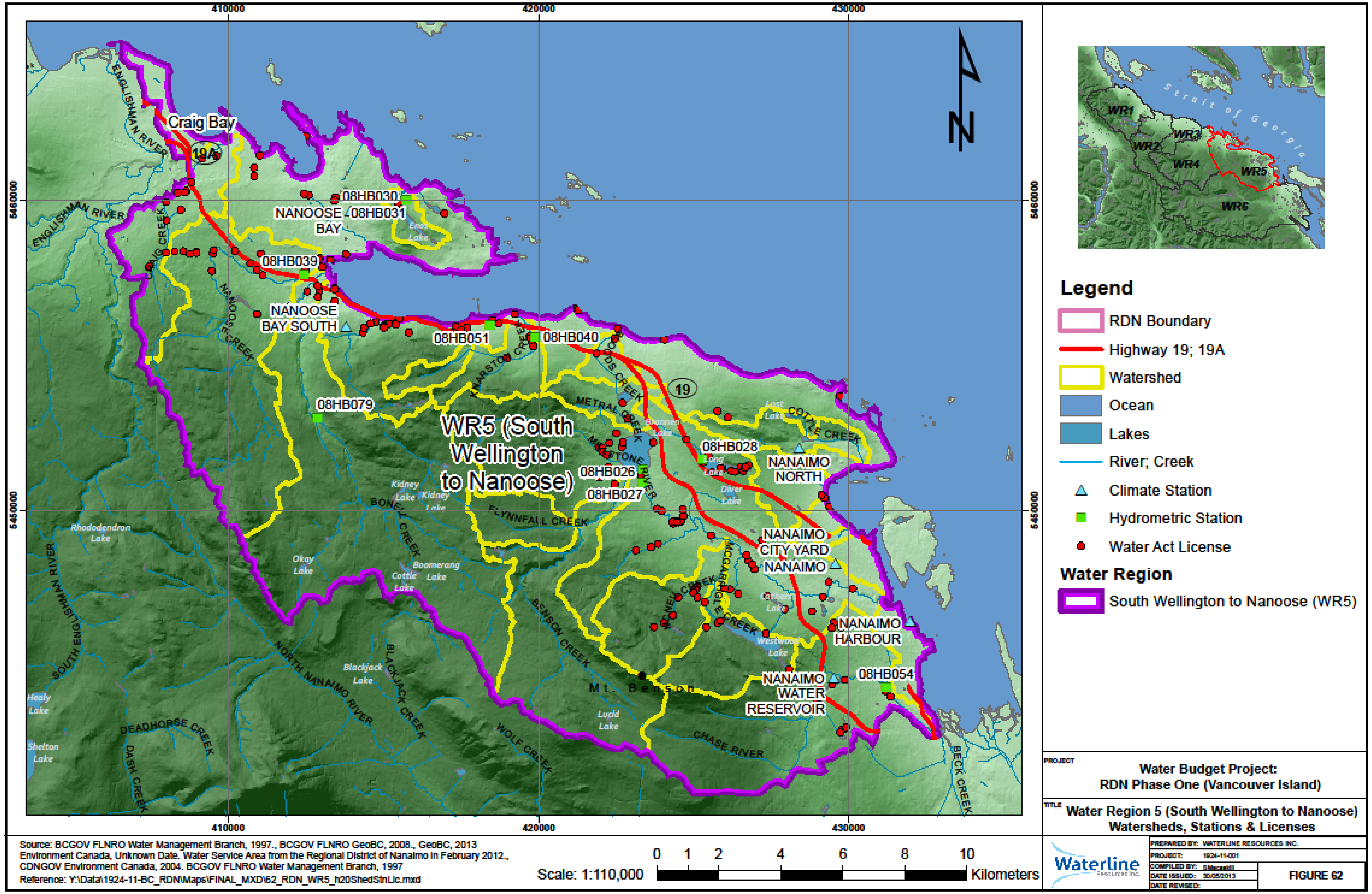


Figure 62: WR5 (SW-N) – Watersheds, Stations & Licenses

7.2 Surface Water Assessment

7.2.1 Terrain and Topography

The South Wellington to Nanoose Water Region (#6) includes all of the watersheds and lands between the Englishman River watershed and the Nanaimo River Watershed. Four major watersheds lie within the region including Nanoose Creek, Bonell Creek, Millstone River and Chase River. In addition, the water region includes all the smaller watersheds which flow into the Strait of Georgia from Craig Bay near Parksville to the Nanaimo River estuary south of Nanaimo. The major watersheds in the WR5 (SW-N) are shown in Figure 62.

The majority of the lands in the water region lie within privately managed forest lands. The lower portions of the water region consist of a range of land uses from rural development with agriculture land to high density residential, commercial and light industrial development within the City of Nanaimo.

The highest point in the water region is Mount Benson at 1,023 m. The north-east slopes of Mount Benson lie within the Mount Benson Regional Park. In general, the major watersheds all flow from the slopes of Mount Benson with streams on the west side of the mountain generally flowing north towards Nanoose Harbour and streams on the east side of the mountain flowing east and south towards Nanaimo Harbour. There are several lakes in the region with the largest being Brannen Lake in the Millstone Watershed followed by Long Lake, Westwood Lake, and Diver Lake. There are also many other smaller lakes.

7.2.2 Climate

The climate for the South Wellington to Nanoose Water Region is similar to the rest of the RDN with cool wet winters and mild dry summers. Two Environment Canada weather stations lie within the region at the Nanaimo City Yard on Labieux Road and in Departure Bay. Climate station locations are shown on Figure 62.

The average total annual precipitation recorded at the Nanaimo City Yard and Departure Bay for the 1971 to 2000 period was 937.8 mm and 1,140.9 mm, respectively. Figure 63 shows the monthly distribution of temperature and precipitation recorded at the Departure Bay climate station. No temperature data is available for the Nanaimo City Yard station.

Compared to other Water Regions, the South Wellington and Nanaimo Water Region lies predominantly at lower elevation and therefore does not likely accumulate as much snowpack as other areas. There are no snow observation stations within the region.

Both of the Environment Canada stations lie at lower elevation within the water region and are therefore not representative of precipitation at higher elevations. Maps showing the distribution of annual total precipitation and average annual temperature over the water region are shown in Figure 64 and Figure 65, respectively. These maps show that precipitation increases with elevation with a maximum total annual precipitation amounts of approximately 2,000 mm to 2,500 on Mount Benson.

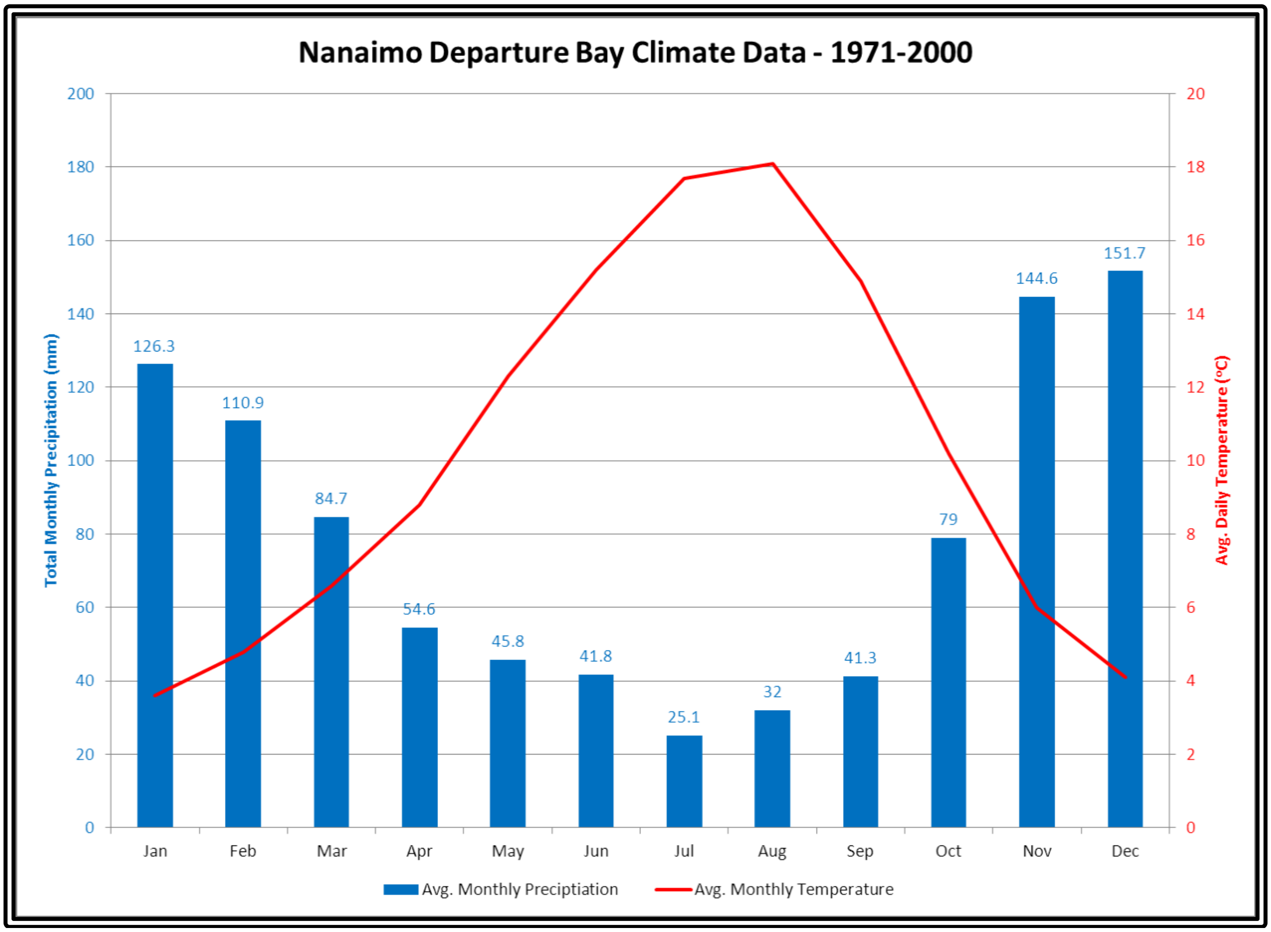


Figure 63: WR5 (SW-N) – Departure Bay Monthly Climate (1971 to 2000 Normal)

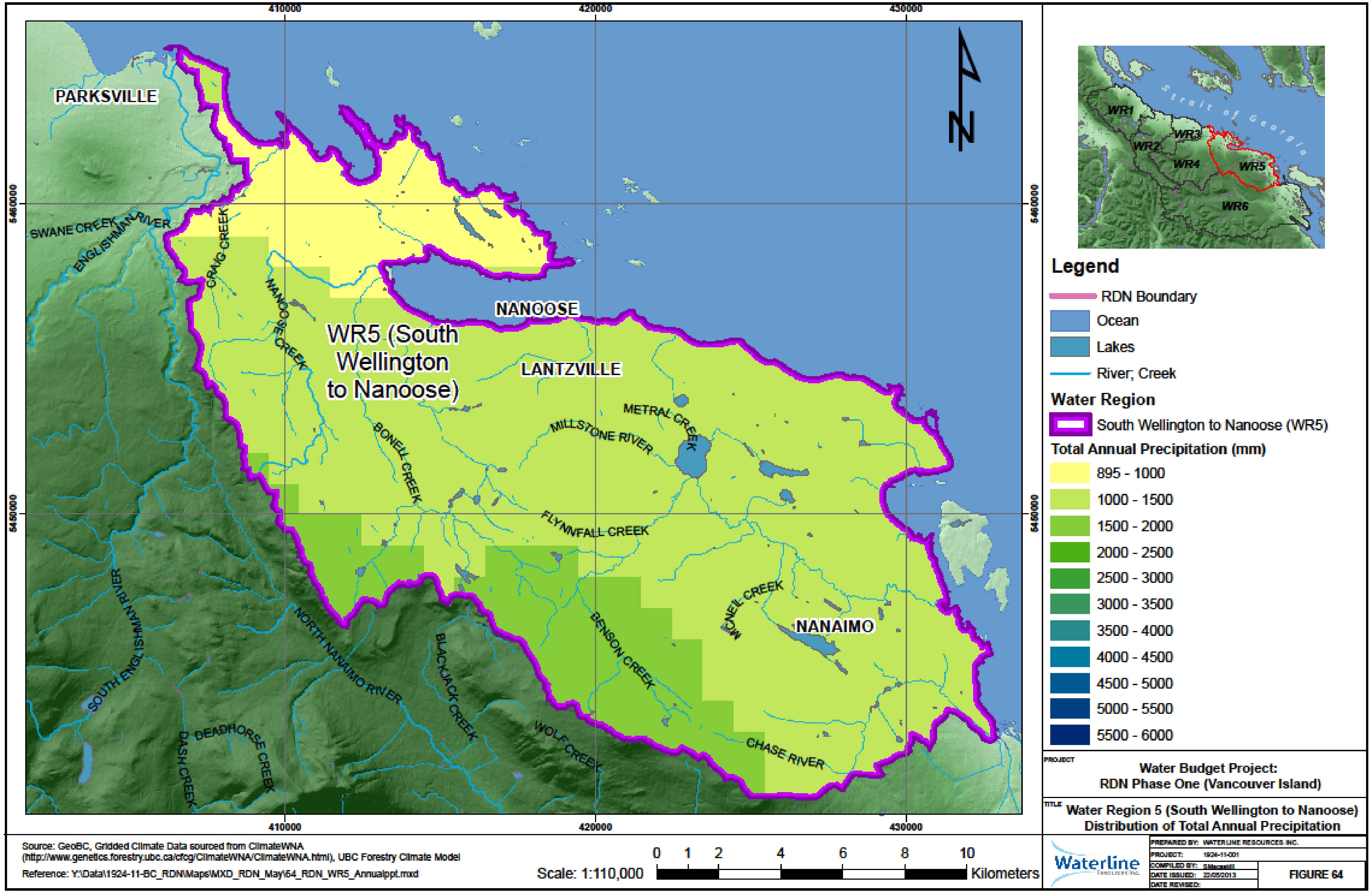


Figure 64: WR5 (SW-N) - Distribution of Total Annual Precipitation

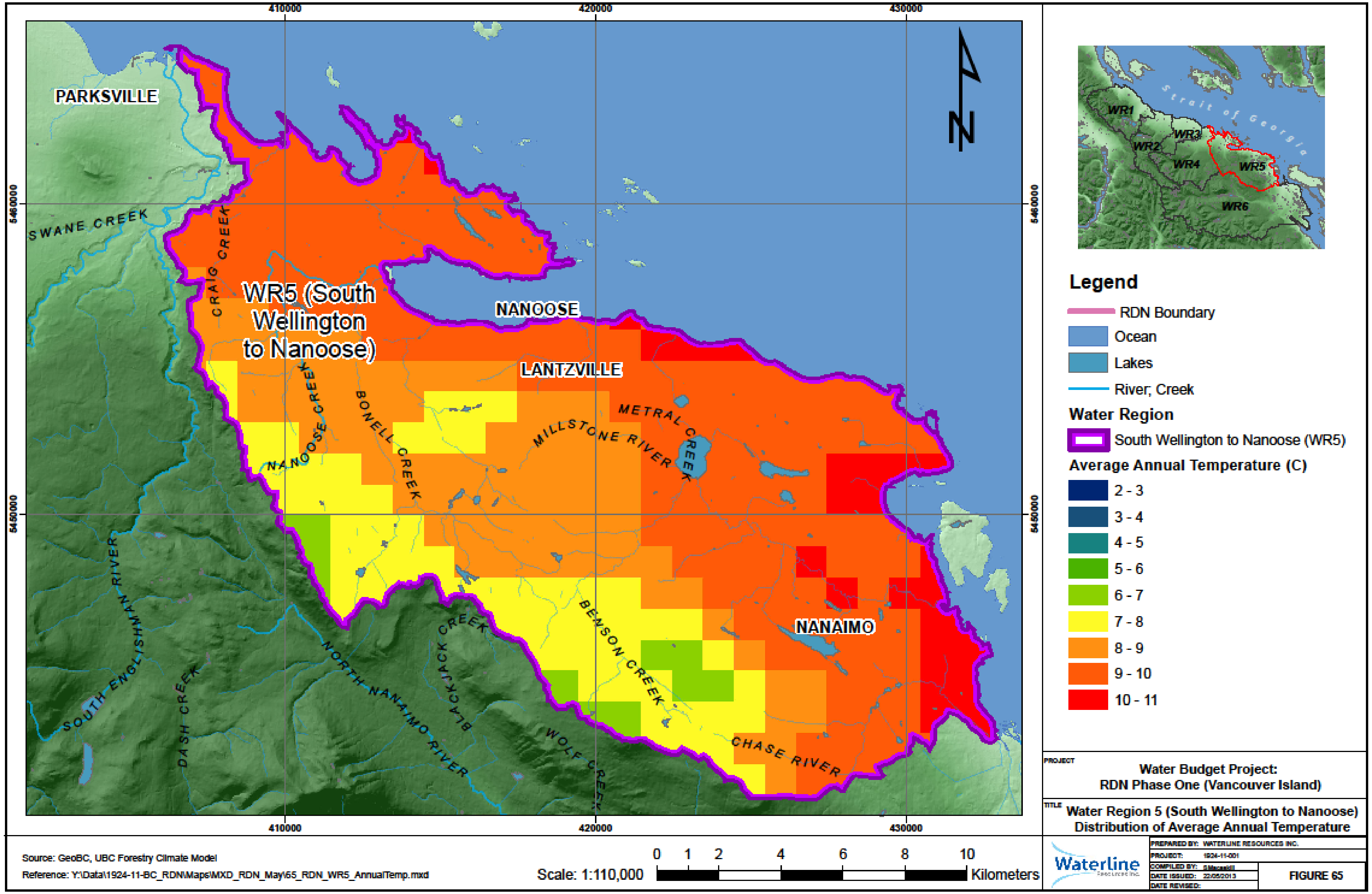


Figure 65: WR5 (SW-N) - Distribution of Average Annual Temperature

7.2.3 Stream Gauging and Monitoring

One active and four discontinued water survey of Canada hydrometric stations are located within the South Wellington to Nanoose Water Region. There are also three discontinued lake levels gauges at Brannen Lake, Long Lake and Enos Lake. The details for each of the stations are included in Table 42.

Table 42: WR5 (SW-N) – Water Survey of Canada Records

Station	Period	Natural or Regulated	Drainage Area to Gauge (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)
Millstone River at Nanaimo (08HB032)	1961 to Present	Natural (with Summer Releases from Westwood Lake since 2008)	86.2	2.55 m^3/s 80.4 million m^3	0.073 m^3/s 0.580 million m^3
Millstone River near Wellington (08HB027)	1961 to 1974	Natural	46.1	1.56 m^3/s 49.2 million m^3	0.056 m^3/s 0.455 million m^3
Enos Creek near Nanoose (08HB030)	1962 to 1978	Regulated	1.68	0.04 m^3/s 49.2 million m^3	0.0 m^3/s
Chase River near Nanaimo (08HB054)	1976 to 1978	Regulated		Summer Only	0.064 m^3/s 0.506 million m^3
Nanoose Creek at the Mouth (08HB039)	1970 to 1972	Natural		Summer Only	0.016 m^3/s 0.127 million m^3
Bonell Creek near Nanoose (08HB079)	1991	Natural		Summer Only	-

Monthly average hydrographs for Millstone River at Nanaimo are shown in Figure 66. The figure provides an indication of the impact that regulation in the system has had on river flows.

7.2.4 Hydrology and Surface Water Resources

The Regional Hydrological Model has been used to estimate mean annual discharge and volume as well as summer average discharge and volume for the major ungauged watersheds in the South Wellington to Nanoose Area. The recorded flows for Millstone River have been adjusted using watershed area ratio to estimate the available surface water resources for Millstone River. The results are shown in Table 43.

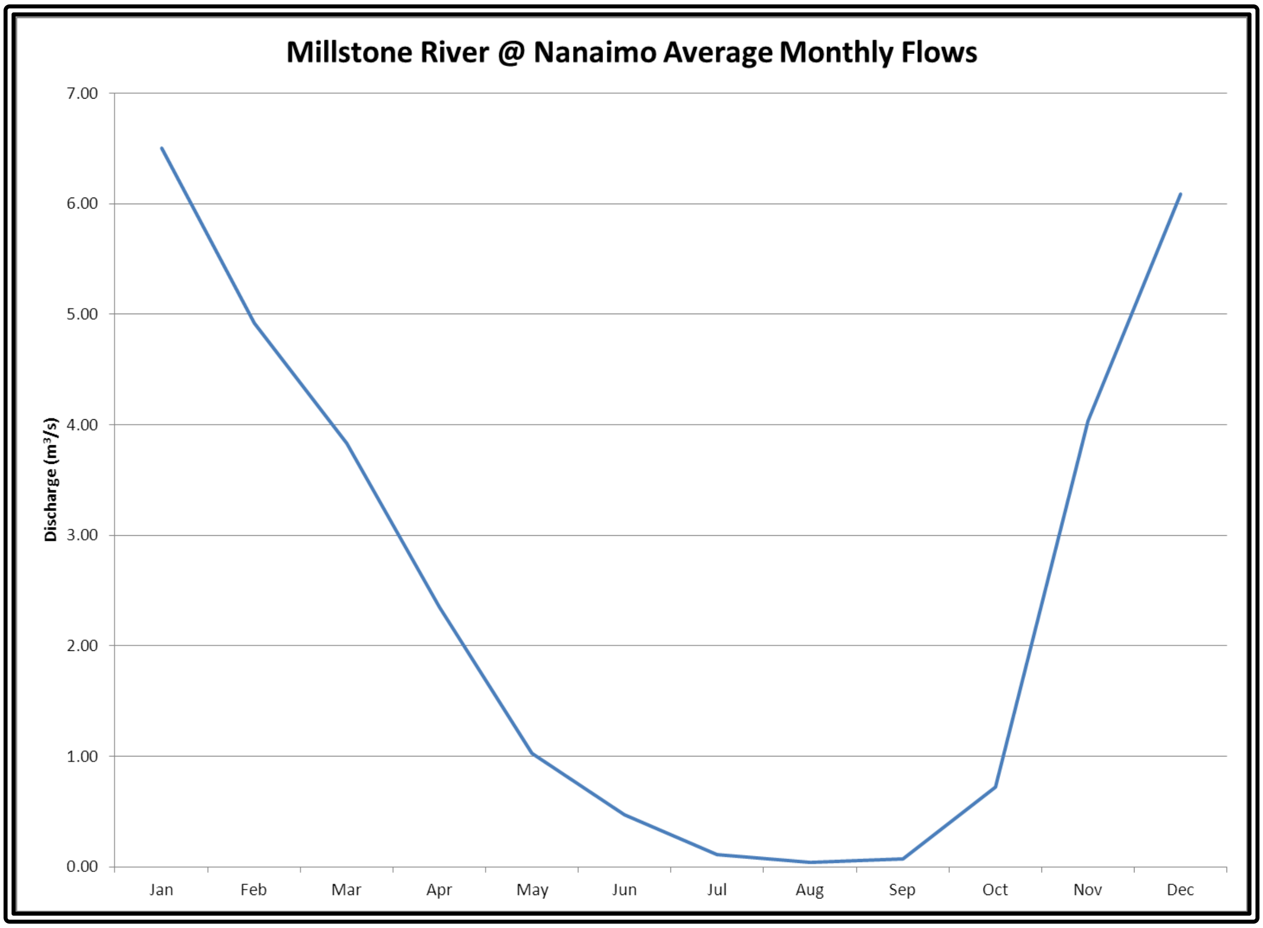


Figure 66: WR5 (SW-N) – Millstone River at Nanaimo Monthly Hydrograph

Table 43: WR5 (SW-N) – Natural (Unregulated) Surface Water Resources (1971 to 2000)

Watershed	Drainage Area (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)	Previous Estimate of MAD (m^3/s)
Craig Creek	11.7	0.21 m^3/s 6.62 million m^3	Less than 0.01 m^3/s	0.25
Nanoose Creek	34.0	0.87 m^3/s 27.4 million m^3	Less than 0.01 m^3/s	0.97
Bonell Creek	51.2	1.59 m^3/s 50.1 million m^3	0.01 m^3/s 0.08 million m^3	1.79
Chase River	28.7	0.73 m^3/s	Less than 0.01 m^3/s	0.96
Millstone River	100	2.95 m^3/s 93.1 million m^3	0.084 m^3/s 0.67 million m^3	2.32
Beck Creek	13.9	0.28 m^3/s 8.72 million m^3	Less than 0.01 m^3/s	0.13

Notes: Previous estimates of MAD from the BC Ministry of Environment Water Allocation Plans (Cook and Baldwin, 1994) have been included for reference. Drainage Areas are based on 1:50,000 BC Watershed Atlas

7.2.5 Surface Water Demand

Table 44 summarizes the surface water licences in WR5 taken from the BC Surface Water Licence Database. Table 45 outlines the licenced surface water storage. The locations of the surface water licences for WR5 are shown in Figure 62.

Table 44: WR5 (SW-N) - Surface Water Demand

Type of Demand	Monthly (m^3/month)	Annual (million m^3)	Summer (Jul-Sept) (million m^3)
Consumptive Demand			
Agriculture	34,800	0.418	0.313
Domestic	23,100	0.277	0.093
Industrial	1,980	0.023	0.006
Institutional	-	-	-
WaterWorks	125,000	1.51	0.496
Total Consumptive	185,400	2.23	0.908
Non- Consumptive Demand			
Power	699,840	8,398,080	
Conservation	-	-	
Total Non-Consumptive	699,840	8,398,080	

Table 45: WR5 (SW-N) - Licensed Surface Water Storage

Type of Demand	Total Storage (Million m^3)
Storage	0.38
Conservation Storage	0.39
Other Storage	3.29
Total Storage	4.07

7.2.6 Surface Water Stress Analysis

As outlined in Section 2.5.2, a surface water stress analysis for the major watersheds has been completed. Water budget analysis for other smaller ungauged subwatersheds within WR5 (SW-N) should be completed when data is available and as part of a more detailed Tier 1 or Tier 2 water budget assessment (OMNR 2011). The results of the allocation and actual demand stress analysis for the watersheds in WR5 (SW-N) are shown in Table 46. A map showing the relative stress for each watershed evaluated is shown in Figure 67.

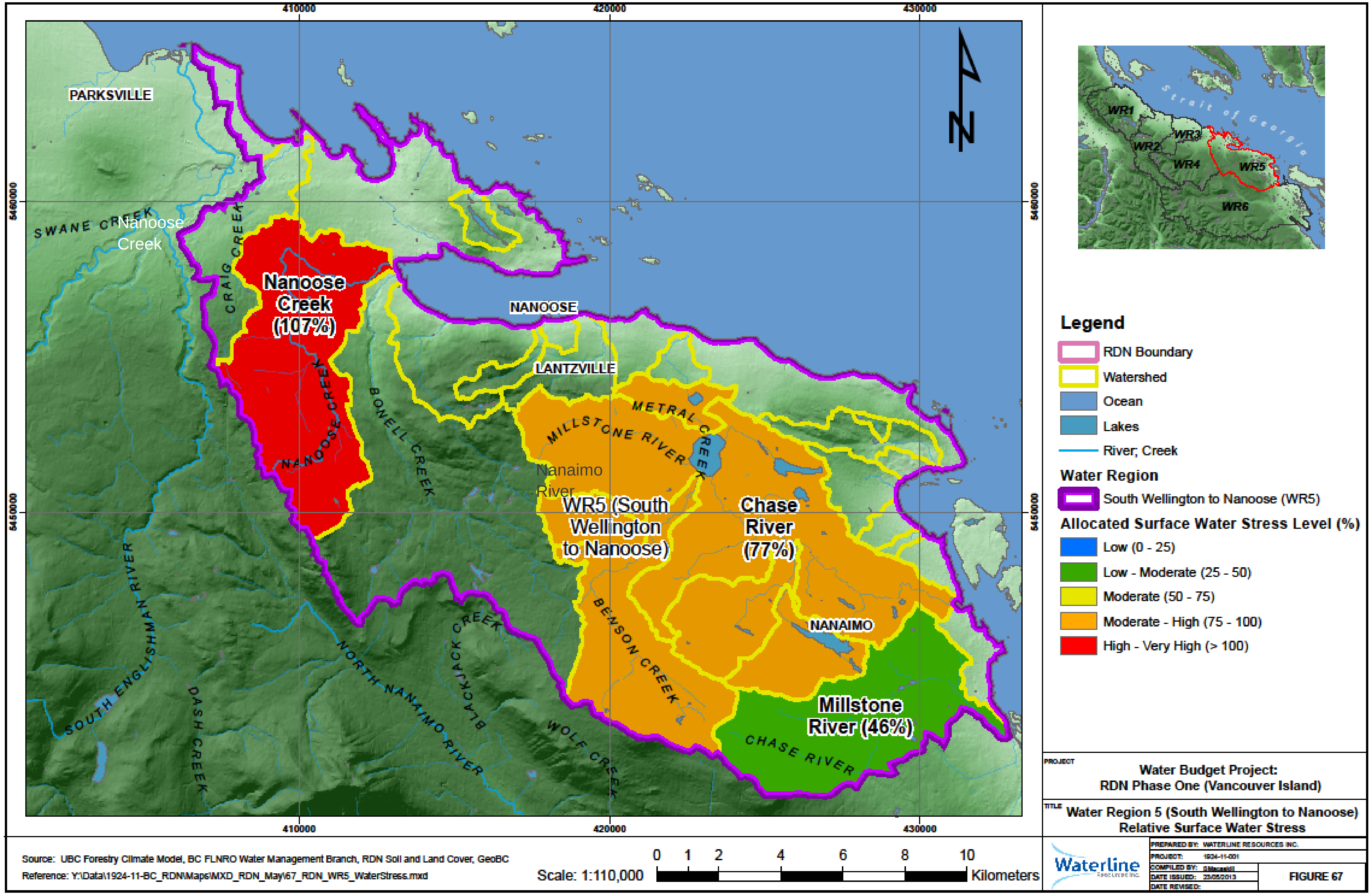


Figure 67: WR5 (NR) - Relative Surface Water Stress

Table 46: WR5 (SW-N) – Relative Surface Water Stress Assessment Results

Watershed	Average Natural River Flow Supply (million m^3)	Storage (million m^3)	Conservation Flow (10% of MAD) (million m^3)	Licensed Demand (million m^3)	Allocation Stress	Stress Level
Nanoose Creek	0.6	0.0	0.7	0.02	**107%**	**High**
Millstone River	0.67	4.07	2.21	0.9	**46%**	**Moderate**
Chase River	0.6	0.5	0.6	0.3	**77%**	**Moderate to High**

Note: Volumes indicated in the table are average volumes for summer period (Jul to Sep). Average natural river flow is the estimated or recorded unregulated flow in the watershed. Total storage is based on licenced storage volume and assumes all storage is available to support conservation flow and licenced demand for the July to September period. The 10% of Mean Annual Discharge (MAD) conservation flow is based on current Ministry of Forest, Lands and Natural Resource Operations (MELP, 1996) minimum conservation flow policies for the east coast of Vancouver Island. Licenced demand is the total licenced volume for summer based on consumptive water licences. Allocation stress = (Average Natural supply + storage) / (Conservation Flow + Licenced Demand) Surface water stress color codes: blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high. Values reflect average flow conditions and do not consider drought years.

7.3 Groundwater Assessment

7.3.1 Existing Groundwater Studies and Data – WR5 (SW-N)

Given the regional scale of the Phase One Water Budget Assessment, the most important data compiled and geo-referenced by Waterline was the water well information, elevation data, soil and geology maps, land cover, aggregate resource map, mapped aquifers, and water service areas. Other maps were generated using the input data as part of Waterline's work and some samples are provided in Appendix C for illustration purposes (Eg: overburden thickness (Map C7), piezometric contour maps (Maps C8 and C9), air temperature (Map C14), precipitation (Map C15), runoff (Map C16 and C17), evapotranspiration (Map C18), infiltration (Map C19), Water Service Areas (Map C20), and Water Demand Assessment in Non-service areas (Map C21). All of these maps are provided in Appendix C for the entire RDN study area with an explanation of how the map was geo-reference or created by Waterline. These data and layers are now available in the ARC GIS Geodatabase at the RDN Scale, water region scale, watershed scale, on other local scale needed for site specific assessments. These data will be provided to the RDN in electronic format as part of the ARC GIS Geodatabase system which was constructed by Waterline for use by the RDN. These regional datasets form the framework for construction of the conceptual hydrogeologyical model.

Although only some of the data in certain reports may have been incorporated into Waterline's Geodatabase, the primary studies in the region were used in Waterline's water budget assessment to provide local hydrogeological context are provided in Table 47.

Table 47: WR5 (SW-N) – Hydrogeology Reference Reports

Author	Year	Study Title
EBA Engineering Consultants Ltd.	2005	Madrona Heights Water Supply Assessment
EBA Engineering Consultants Ltd.	2006	New Production Well Madrona Well #8
Hodge Hydrogeology Consulting	2008	Testing of TW1-07 Claudet Road / Nanoose, BC
Hodge Hydrogeology Consulting	2009	Nanoose Well No.7 (Claudet Rd) Report Addendum
Hodge Hydrogeology Consulting	2009	2009 Pumping Test Results- ADDENDUM to report, Claudet Road
Hodge Hydrogeology Consulting	2009	Report on Groundwater Quantity and Quality for PW1-2008, Lot 1, Plan 26234, DL 62, Claudet Road, Nanoose Land District, BC
Levelton	2009	Well Yield Confirmation Madrona Heights Subdivision
Lowen Hydrology Consulting	2006	Well Water Source Development
Pacific Hydrology Consultants	1991	Completion Report – Evaluation of Confirmatory Pump Testing of Ring Contracting (Madrona No. 7) Well
Pacific Hydrology Consultants Ltd.	1984	Progress Report – Test Drilling Program – Madrona Point Water System
Pacific Hydrology Consultants Ltd.	1984	Capacity of Madrona Point Well No. 2
Pacific Hydrology Consultants Ltd.	1986	Madrona Water Specified Area – Test Production Drilling & Construction & Testing of Madrona Point Well No. 4
Pacific Hydrology Consultants Ltd.	1987	Madrona Water Specified Area – Construction & Testing of Wells No. 5 & No. 6
Pacific Hydrology Consultants Ltd.	1988	Completion Report – Construction & Testing of Fairwinds Test Well No. 1
Pacific Hydrology Consultants Ltd.	1990	Completion Report – Construction & Testing of Fairwinds Wells 2 and 3
Pacific Hydrology Consultants Ltd.	1990	Evaluation of the Capacity of Craig Bay Estates Campground Well No. 2-1984 and potential for developing Additional Groundwater Supplies for Golf Course Irrigation at Craig Bay Estates
Pacific Hydrology Consultants Ltd.	1990	Completion Report - Test Production Drilling, Construction and Testing of Production Well – Lot A DL 22 Plan 445R Nanoose District
Pacific Hydrology Consultants Ltd.	2007	Nanoose Bay Water Supply Fairwind Well#3 Pilot Study Report
Pacific Hydrology Consultants Ltd.	2008	Completion Report Evaluation and Capacity Testing of Fairwinds Community & Resort Wells 3-08 4-08 5-08
Pacific Hydrology Consultants Ltd.	2008	Water Source Assessment Study for Electoral Area E
Terracon Geotechnique Ltd.	1994	Regional Groundwater Study - Nanoose Peninsula
Lowen Hydrogeology Consultants	2010	Arrowsmith Water Service Englishman River Water Intake Study Groundwater Management. Discussion Paper 5-1. Existing Groundwater Supply Evaluation and Aquifer Yield Assessment, Prepared by Dennis Lowen, Alan Kohut and Bill Hodge, January 25, 2010.

7.3.2 Description of Aquifers and Water Wells

A total of three unconsolidated aquifers and six bedrock aquifers have been mapped within WR5 (SW-N) (Table 48). Quadra and Capilano aquifers (219, 215, and 167) exhibit moderate yield, and are generally confined low vulnerability and moderate use. With the exception of Aquifer 213, bedrock aquifers within WR5 (SW-N) are exhibit low productivity, moderate to light use, and moderate to low vulnerability.

The majority of supply wells are completed in unconsolidated Quadra and Capilano sand and gravel aquifers (Figure 68). However, underlying bedrock aquifers are also being developed for water supply (Figure 69). There are a total of 1685 overburden and bedrock wells listed in the MOE data base in WR5 (SW-N) (Table 41). As there are no regulatory requirements in BC to submit wells logs to MOE for capture in the BC Wells Database, the water wells shown on Figure 68 and Figure 69 likely represents only a fraction of wells actually drilled.

Table 48: WR5 (SW-N) – Summary of Mapped Aquifers

Aquifer Tag No.	Aquifer Lithology	Location Within Water Region	Potential Groundwater-Surface Water or Aquifer to Aquifer Interaction	Developed Aquifer Surface Area	Confined, Semi, or unconfined, Aquifer Vulnerability Code	Yield
				(m^2)		**(L/M/H)**
219	Quadra	Nanoose Penninsula	Nanoose Creek, Ocean	2.13E+07	Confined, IIC	M
214	NG	Nanoose NW Bay Rd. Area	Ocean	5.62E+06	Semi-Confined, IIIC	L
210	Buttle Lake Group - Fourth Lake Formation & Mount Hall Gabbro	Mid. Nanoose Cr.	Nanoose Creek, downgrad Fault Contact & NG	4.11E+06	Confined, IIB	L
218	Benson Fm, IP, VG	Nanoose Penninsula, Fairwinds area	Ocean	1.36E+07	Confined, IIB	L
213	VG	Lower and Upper Lantzville	Coal Works and Ocean	4.19E+07	Confined, IIC	M
215	Quadra	Entire Aquifer Nanoose Reserve to North Nanaimo – Bayshore Dr.	Ocean	1.46E+07	Confined, IIC	M
166	VG & NG	Long Lake to Stephen Point, Nanaimo.	Radial Flow to Long Lk., Dep. Bay, Neck Pt. etc… Ocean	1.20E+07	Confined, IIIB	L
211	VG & NG	Mt Benson to Parkway	Underground Coal Works	2.16E+07	Confined, IIB	L
167	Vashon or Quadra	Below Westwood Lk	Aq 211	2.36E+06	Confined, IIIC	M

Notes: A/B/C is high/moderate/low vulnerability, I/II/III is heavy/moderate/light use, H/M/L means high/medium/low productivity/yield. All aquifer classification parameters, codes and yield are defined at the following MOE web address http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/Aq_Classification/Aq_Class.html#class. NG means Nanaimo Group, IP means Island Plutonic Suite, VG means Vancouver Group (Karmutsen Formation).

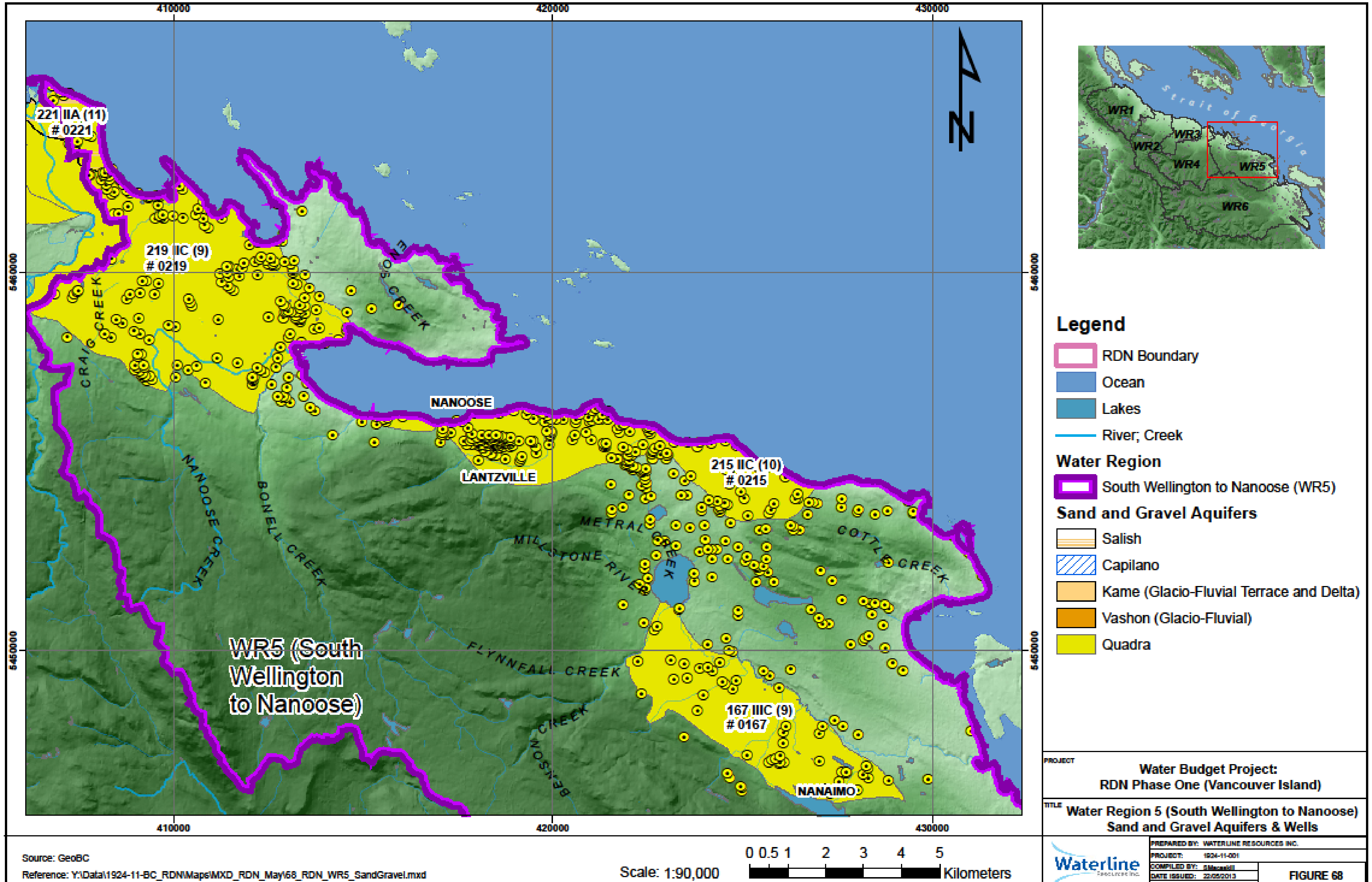


Figure 68: WR5 (SW-N) – Mapped Sand and Gravel Aquifers & Wells

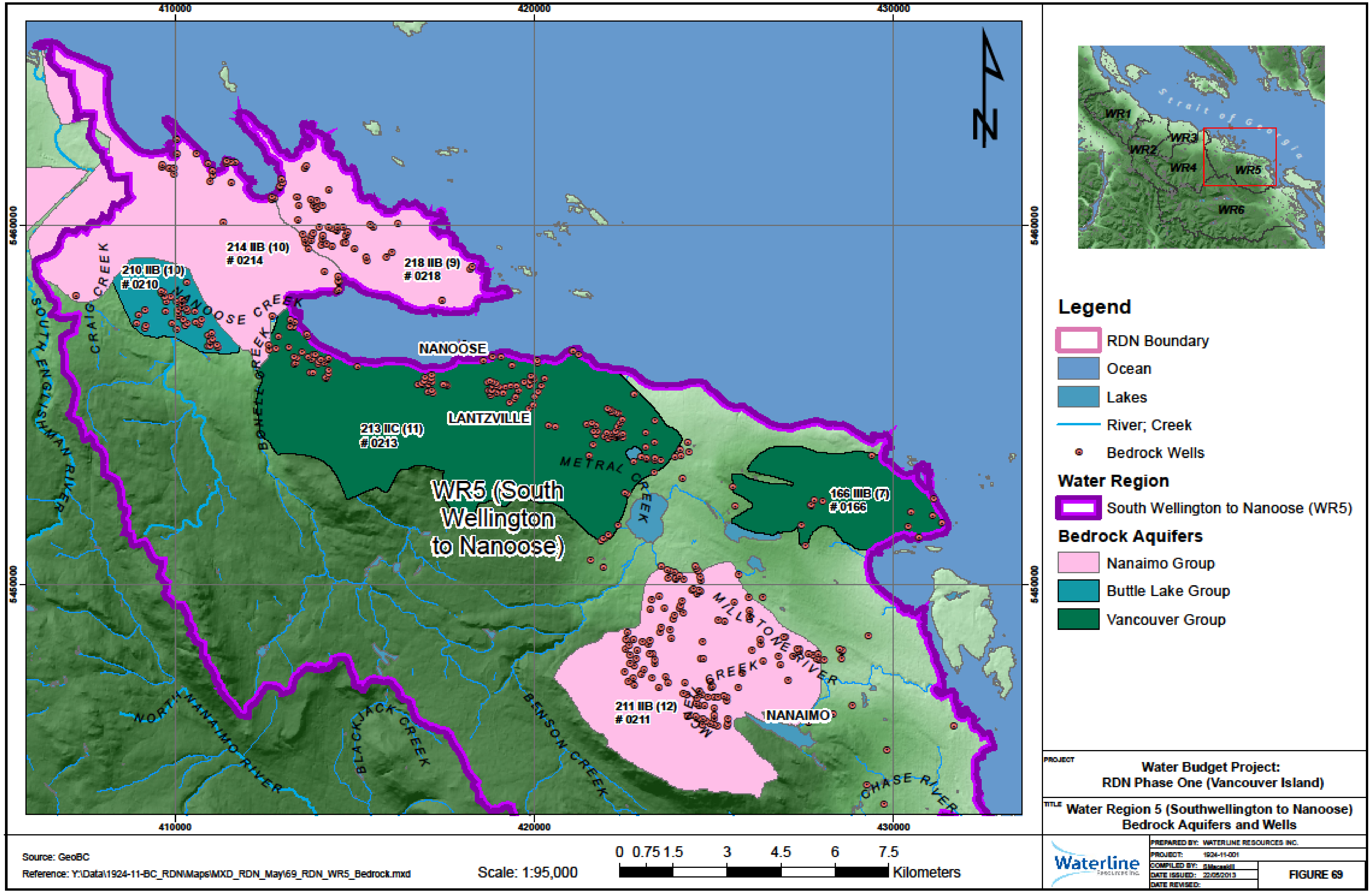


Figure 69: WR5 (SW-N) – Mapped Bedrock Aquifers & Wells

7.3.3 Groundwater-Surface Water Interaction - Conceptual Hydrogeological Model

A conceptual hydrogeological model of each aquifer with WR5 (SW-N) was developed in order to understand the key elements and linkages between surface water and groundwater systems required to complete the water budget assessment. Although conceptual hydrogeological model developed by Waterline includes numerous cross-sectional views developed within the Waterline Geodatabase, only one 3D view into the subsurface will be presented here.

Figure 70 shows a 3D block diagram illustrating the relationship between surface and subsurface geology in the Lantzville area of WR5 (SW-N) where major water supply aquifers have been mapped. View 1 show how the Quadra sand aquifer (0215) is highly developed with closely spaced supply wells beneath the District of Lantzville. Quadra aquifer 215 appears to thin to the east and overlies bedrock aquifer 213 which is less well developed in the Lantzville area.

Figure 71 shows a 3D block diagram illustrating the relationship between surface and subsurface geology in the Nanoose Creek area of WR5 (SW-N). View 1 shows the Quadra aquifer pinching out to the north as it abuts onto bedrock aquifer 218 near Northwest Bay. View 2 shows how the Quadra sand aquifer (0219) may be interacting with Nanoose Creek.

Water levels in wells measured at the time of drilling provide an indication of groundwater flow and indicated that groundwater is flowing downward from the Quadra aquifer to the deeper bedrock aquifer, and both flow systems are directing water towards the ocean.

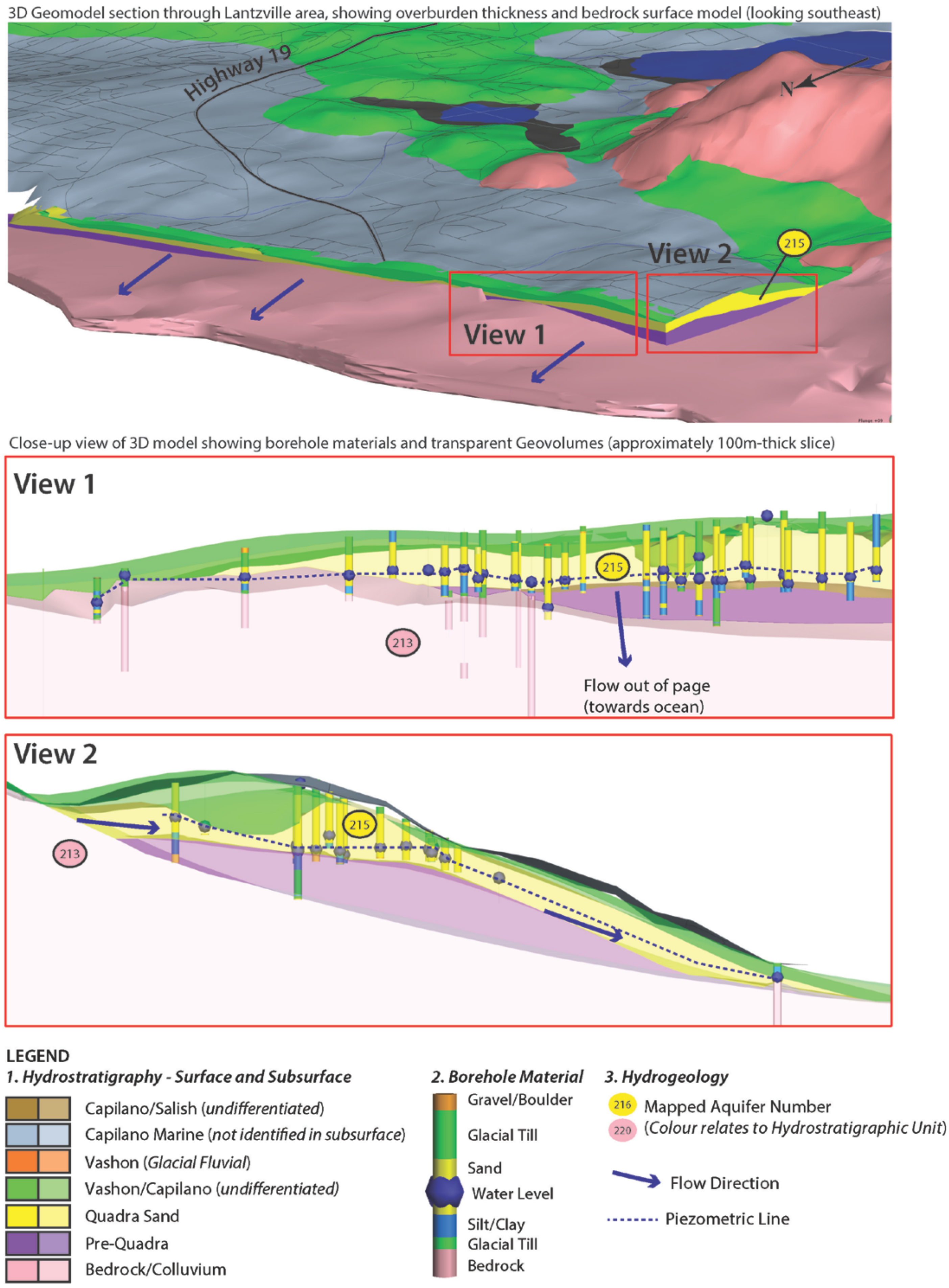


Figure 70: WR5 (SW-N) – Hydrogeological Conceptual Model – Lantzville Area

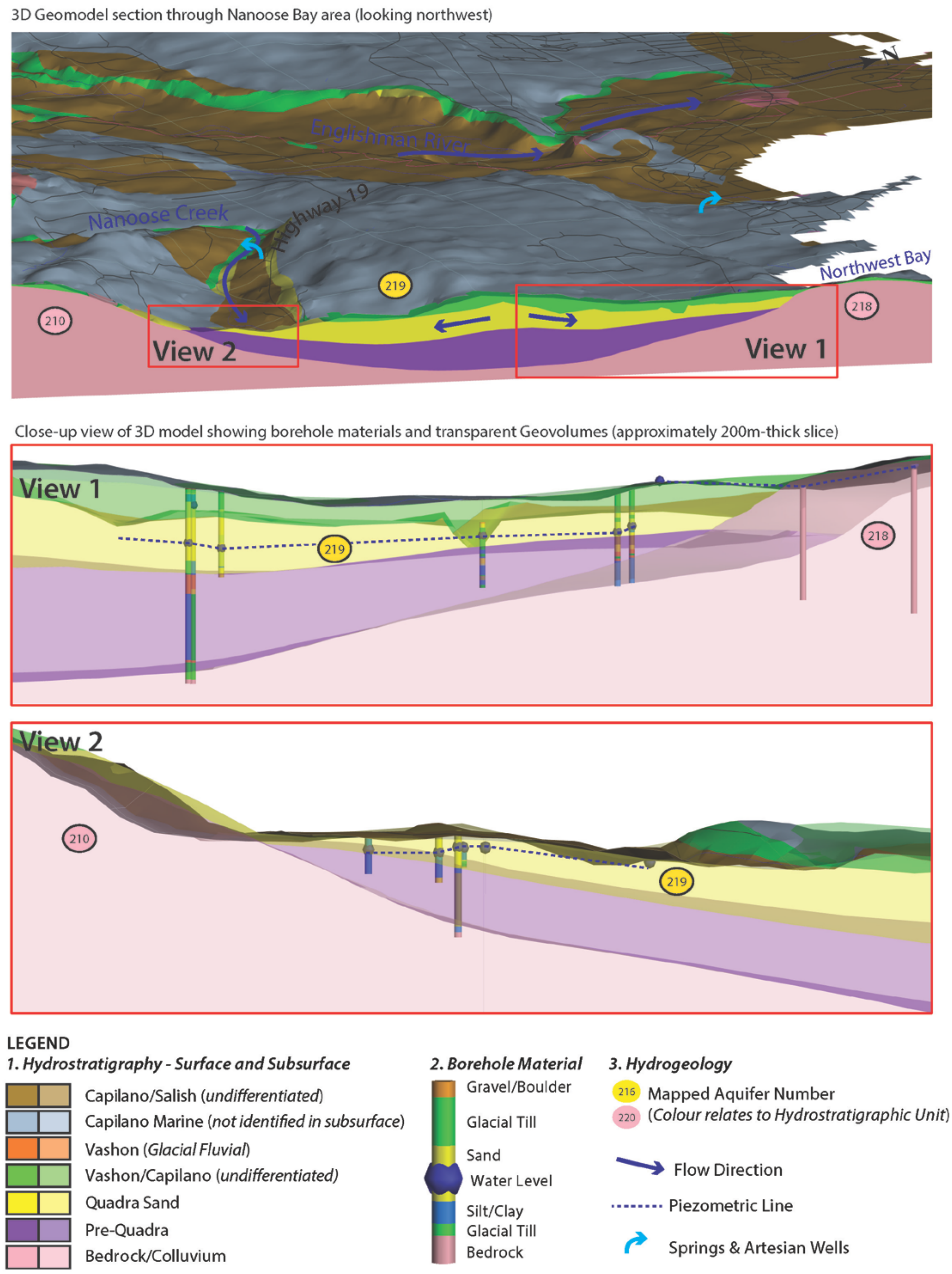


Figure 71: WR5 (SW-N) – Hydrogeological Conceptual Model – Nanoose Area

7.3.4 Significant Recharge Areas

Significant recharge areas within WR5 (SW-N) were determined as part of the assessment of infiltration across the region base on topography, mapped textural soil characteristics, land cover (bare land, vegetation, impermeable surfaces), and leaf area index. These areas are important for maintaining recharge to aquifers and base flow to creeks and rivers. The preliminary assessment presented herein is based on the integration of numerous datasets which may be incomplete and therefore will require further field verification. Figure 72 shows significant recharge areas mapped in WR5 (SW-N) as part of the water budget project.

Significant recharge areas are shown in red/orange and extend to the upper reaches of WR5 (SW-N) and into the up part of Nanoose Creek, Bonell Creek, Benson Creek, Millstone River, and Chase River. Some of the areas indicated are moderately developed (Benson Meadows, Millstone River). Future development planning needs to consider these areas to ensure that aquifer recharge continues to be maintained. There is a need to develop protection zones around critical areas contributing recharge to underlying aquifers to ensure the future sustainability of groundwater resources in this region. Better definition of these areas should be completed as the current modelling completed by Waterline and KWL was done on a 1 km square grid.

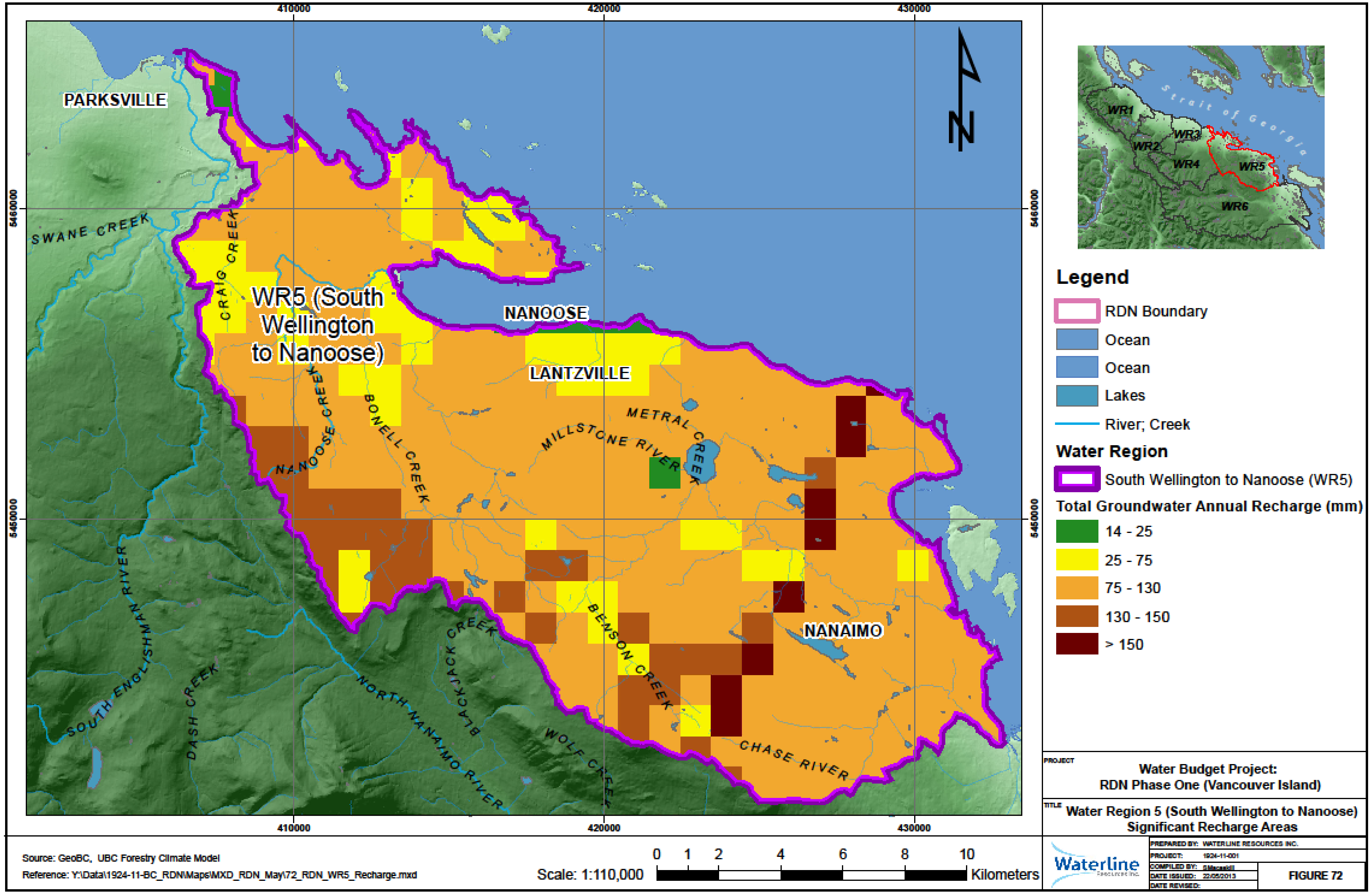


Figure 72: WR5 (SW-N) – Significant Recharge Areas

7.3.5 Groundwater Level Monitoring - BCMOE Observation Well Network

Long-term water level monitoring data provides an indication of an aquifer's response to global, regional, and local environmental changes in climate, groundwater pumping, and the impacts (if any) of other activities related land development. Long-term records also allow for establishing hydraulic linkages between the groundwater and surface water systems.

Figure 73 shows the locations of MOE observation wells and long-term water level monitoring records in relation to community water supply wells identified from the MOE Wells Database (E.g.: Large municipal users, the RDN, private utilities wells). Although numerous community wells are listed in the database, Waterline understands that not all of these wells shown on Figure 73 are currently active.

One of the problems encountered by Waterline during the water budget project was that community well owners generally do not cross-reference active production wells to respective well logs in the MOE database. Often wells are referred to by local names (E.g.: RDN well # 1, #2, etc…). As water budget calculations require that production wells be assigned to specific aquifers, it is important that cross-referencing with the MOE well logs be done. Well owners are encouraged to report the MOE well plate number so that accurate water level and groundwater extraction volumes can be allocated to the corresponding MOE well log and mapped aquifer.

Water level monitoring records are available for five MOE observation wells in WR5 (SW-N) (Figure 74 to Figure 78, inclusive). MOE well 393 is completed in Quadra sand aquifer 219 (Figure 74), MOE well 394 in Benson Formation aquifer 218 (Figure 75), MOE wells 340 and 232 in Quadra sand aquifer 215 near Lantzville, and MOE well 388 in Karmutsen Formation (volcanic bedrock) aquifer 211 near Benson Meadows. Water levels in MOE observation wells were plotted along with the Nanaimo City Yard precipitation record and the PDO trend, where appropriate.

MOE well 393 completed in Quadra Aquifer 219 shows seasonal variation in water level, but the record is too short to establish a long-term trend. MOE well 394 completed in Aquifer 218 along the coast in Nanoose Bay clearly shows tidal influence, but the water level has been stable over the several months it has been operating. MOE observation wells (340 and 232, Figure 76, and Figure 77) completed in the Quadra sand aquifer 215 beneath Lantzville exhibit declining water levels over the period of record which dates back to 1982 (well 232). The long-term hydrographs for MOE wells 232, 340, and perhaps even 388 appear to follow the PDO trend suggesting that long-term climate variability is affecting aquifer recharge. MOE well 388 completed in bedrock aquifer 211 near Benson Meadows exhibits over 8 m of fluctuation seasonally with essentially full water level recovery during the rainy winter season.

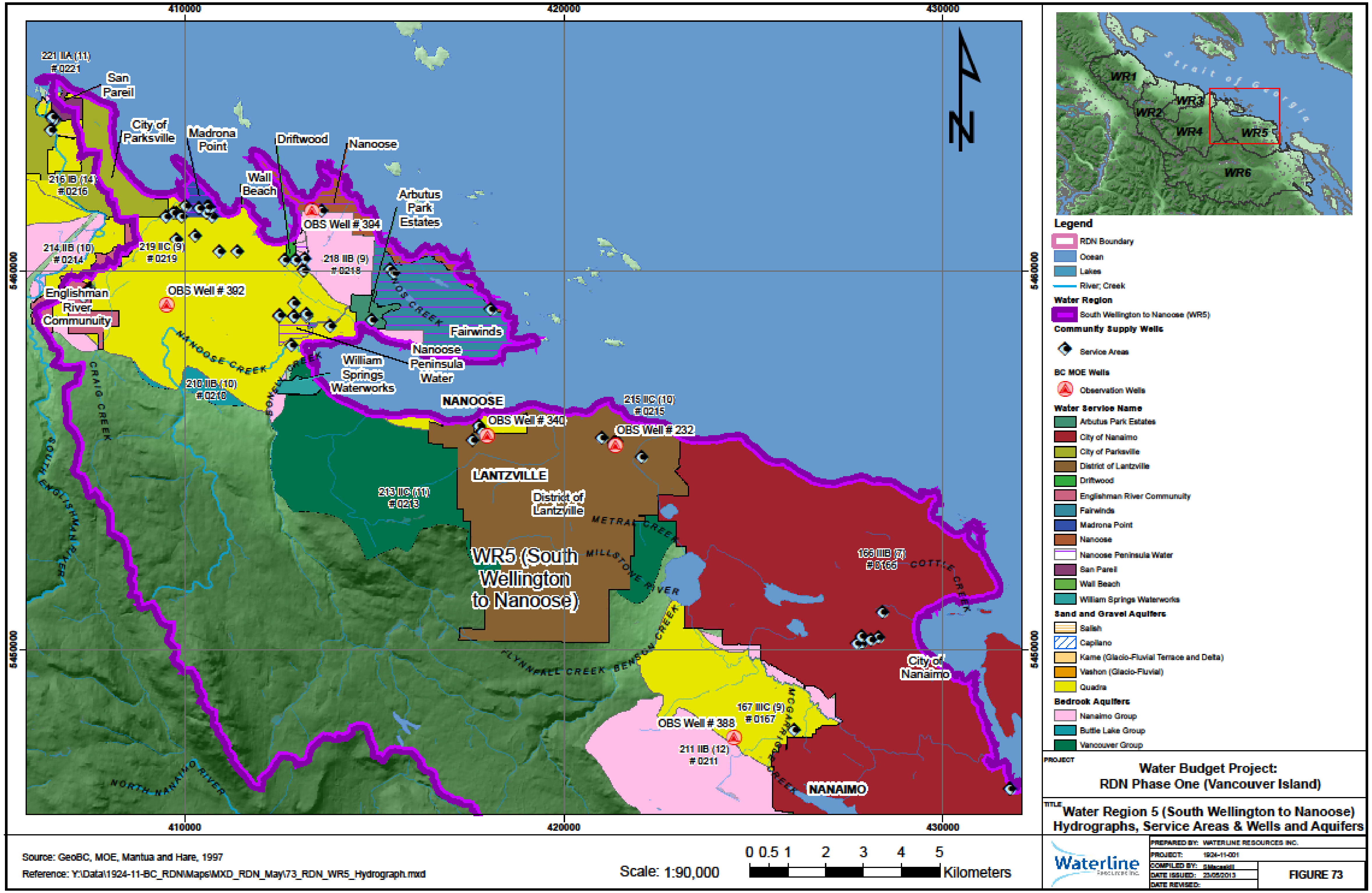


Figure 73: WR5 (SW-N) – MOE Well Hydrographs, Service Areas & Wells, and Aquifers.

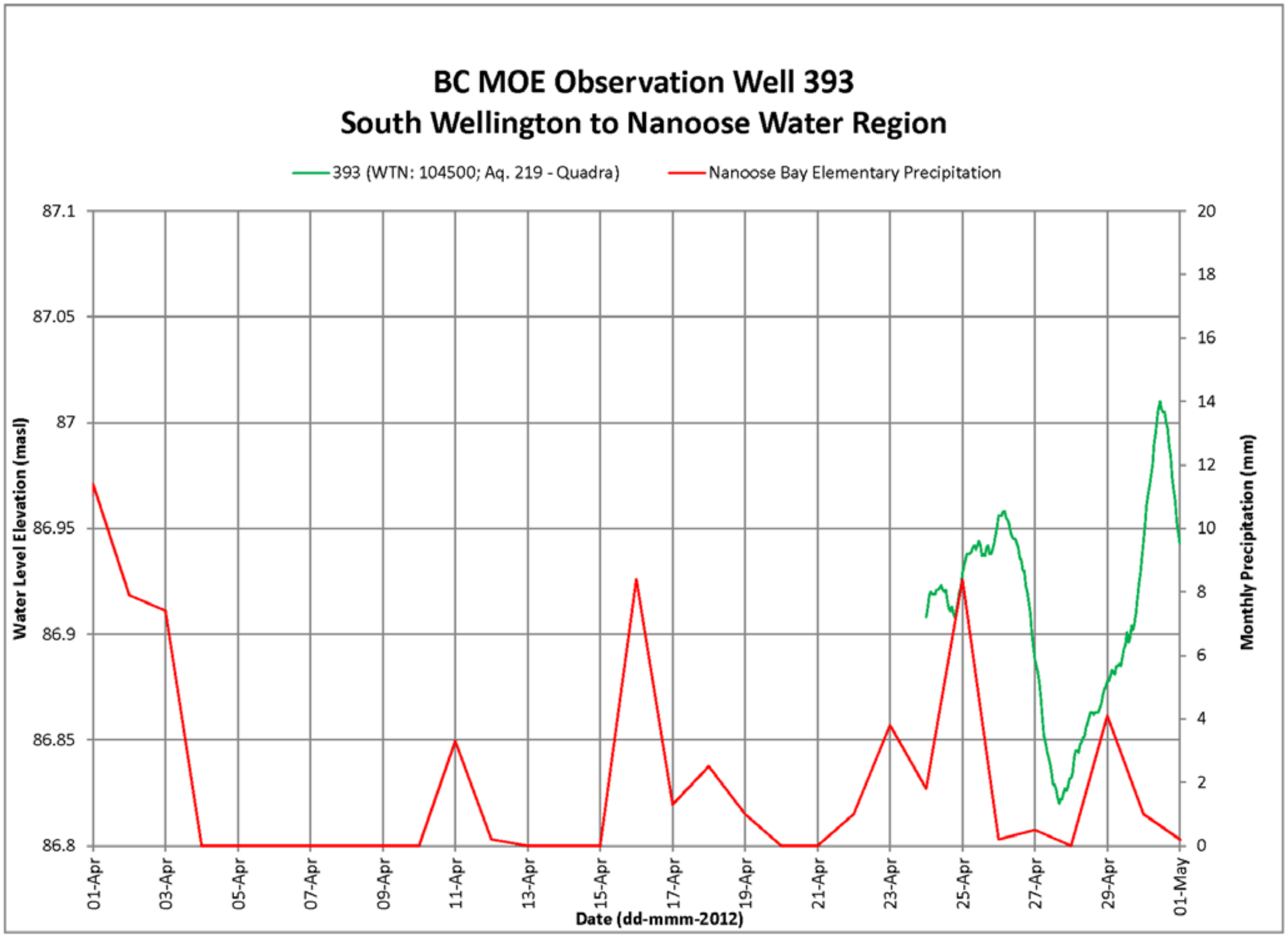


Figure 74: WR5 (SW-N) – Water Level Hydrograph BCMOE 393.

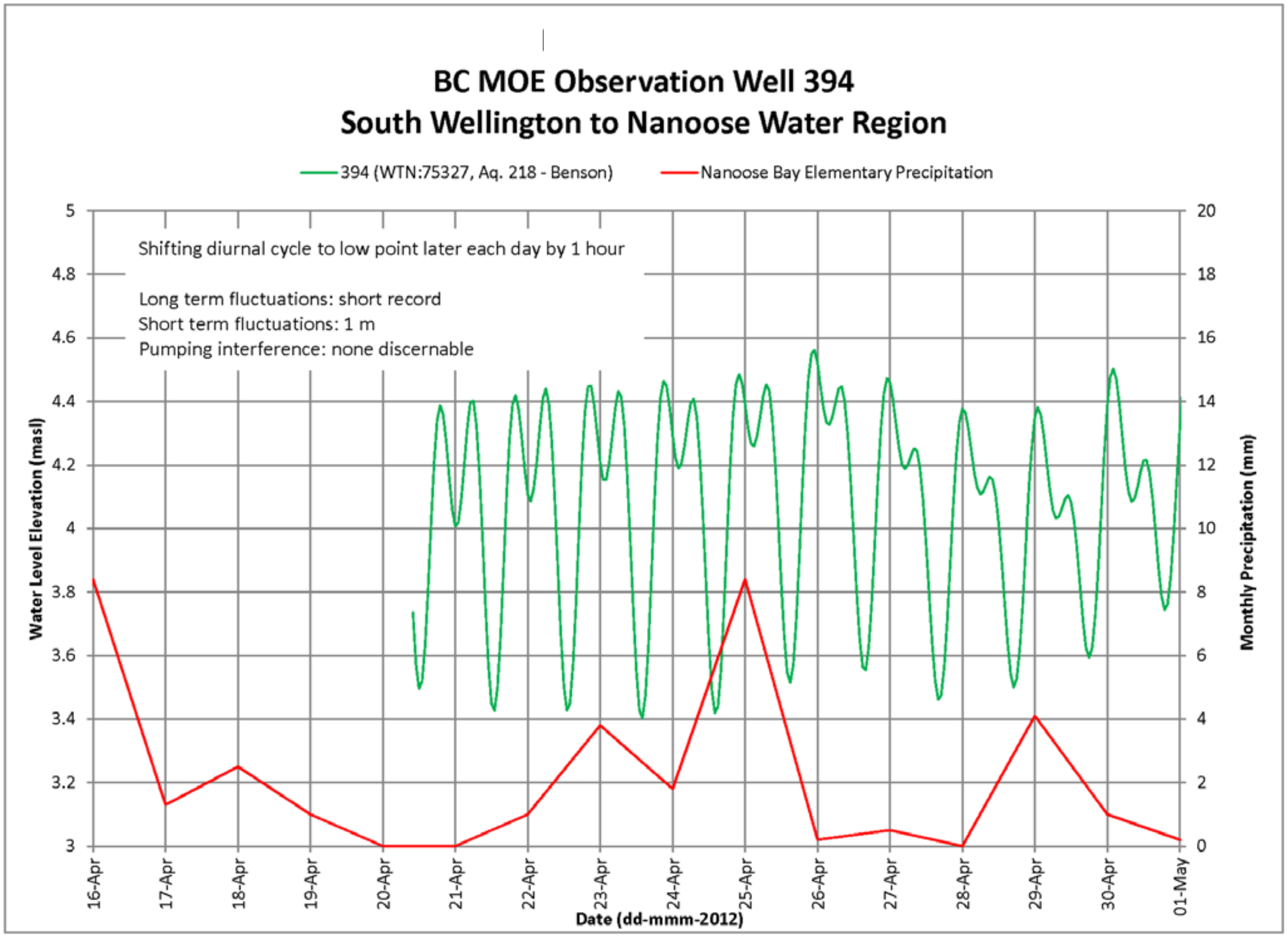


Figure 75: WR5 (SW-N) – Water Level Hydrograph BCMOE 394.

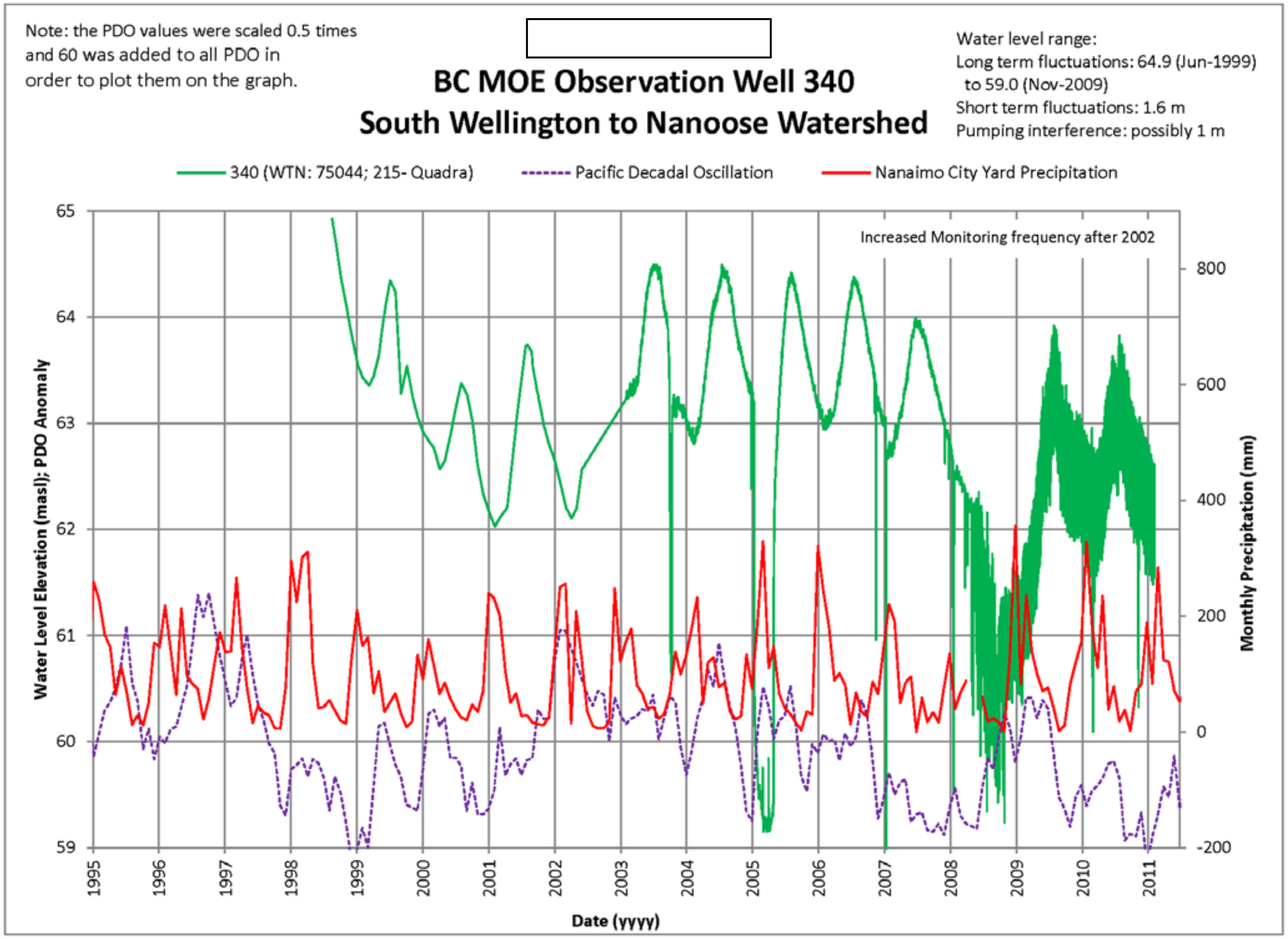


Figure 76: WR5 (SW-N) – Water Level Hydrograph BCMOE 340.

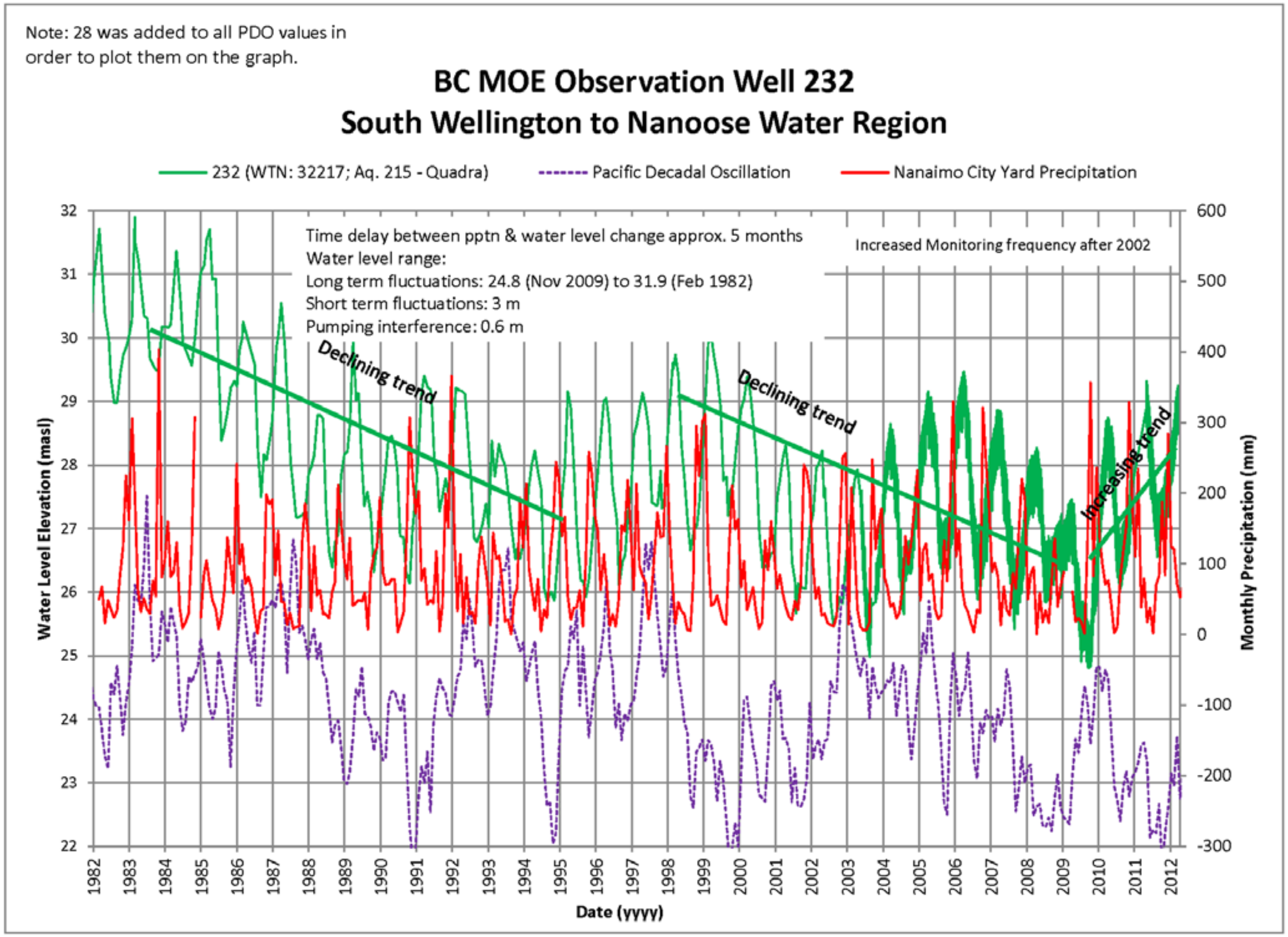


Figure 77: WR5 (SW-N) – Water Level Hydrograph BCMOE 232.

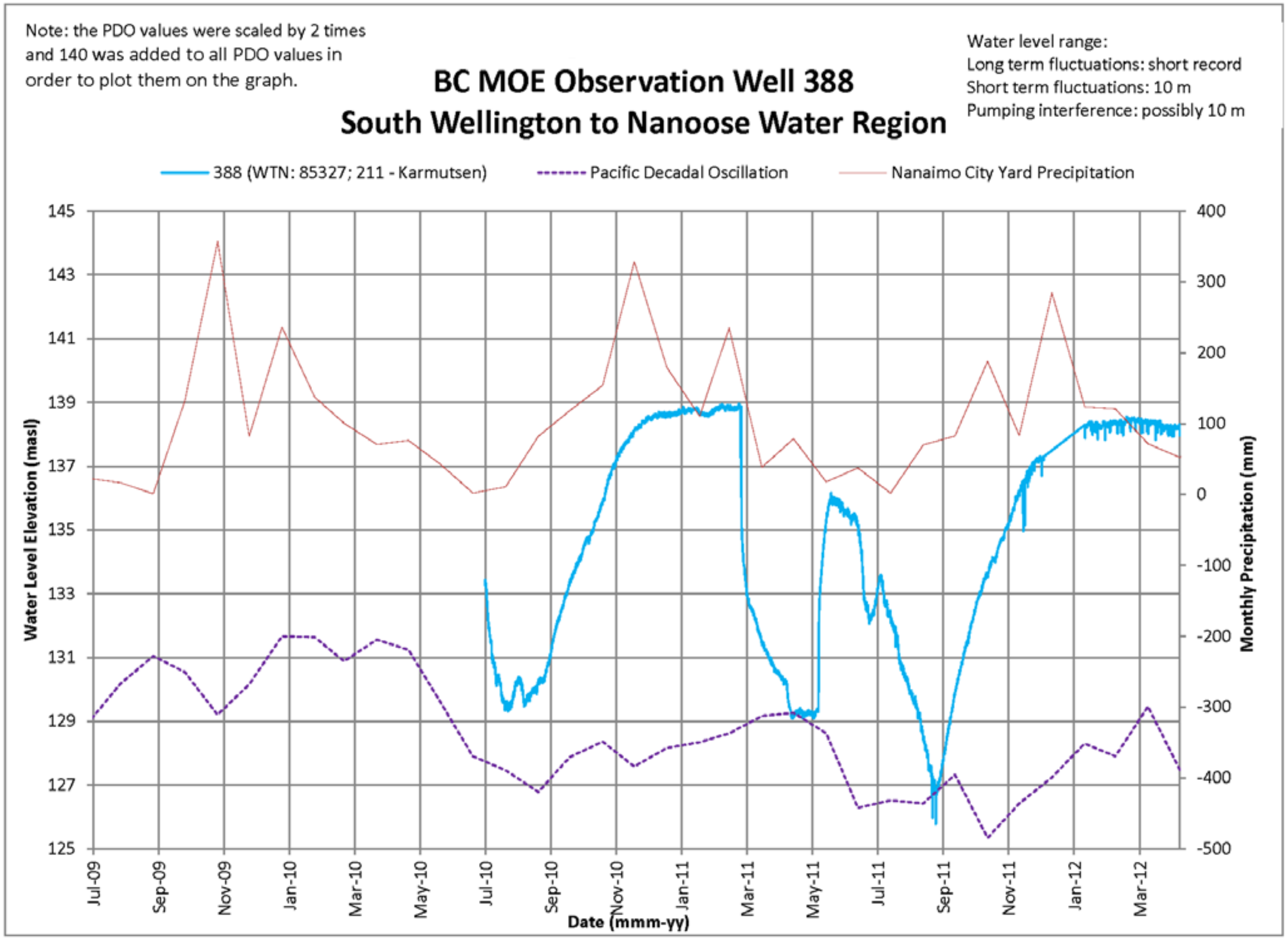


Figure 78: WR5 (SW-N) – Water Level Hydrograph BCMOE 388

7.3.6 Anthropogenic Groundwater Demand

Table 49 summarizes the available groundwater demand data available for WR5 (SW-N). The annual water use for serviced areas within the RDN (large municipal users, RDN wells, and private utilities) is typically measured and was provided by the RDN or taken from annual reports for 2010. The groundwater demand estimate for non-service areas was calculated from water use data provided by the RDN for serviced areas, and then applied to non-serviced areas based on civic addresses and zoning classification. The method of assessment is further described in Appendix C (Map C21) and Appendix D.

There may also be groundwater discharging from aquifers that is required for conservation of flow in creeks and rivers based on the physical model developed by Waterline. The total groundwater demand for each aquifer, including conservation flow requirements, was compared against the estimated aquifer recharge to assess the stress on each aquifer.

7.3.7 Aquifer Water Budgets and Stress Analysis

Table 50 provides a summary of the final water budget calculations for each aquifer mapped within WR5 (SW-N). Detailed water budget calculations are provided in Appendix D (Tables D7 and D8). Water budgets for aquifers that extend from one water region to an adjacent water region (E.g.: Aquifer 219, Figure 68) were completed on the portion of the aquifer which lies within each region. The water budget calculations were also designed to be additive so that a complete water budget of an entire mapped aquifer that extends across a water region boundary could be easily developed.

As indicated above, there are a total of 1685 overburden and bedrock wells listed in the MOE data base in WR5 (SW-N) which represents the second largest number of wells in all of the 6 water regions across the RDN on Vancouver Island. It is also recognized that this number may only represent as little as 50% of water wells actually in operation in this region. This clearly demonstrates that the demand for groundwater in WR5 (SW-N) is very high and that there is an urgent need to better manage groundwater extraction in this region.

Based on the water budget estimates for mapped aquifers within WR5 (SW-N) Aquifers 219 (Nanoose Creek area), 214 (Nanoose coastal area), 213 (bedrock aquifer in Lantzville), and 166 (Neck Point to Stephenson Point) indicate low stress. Aquifer 213 was reported to be locally stressed in the Superior Road area (HB Lanarc, 2010), but this is not reflected in the aquifer-wide water budget assessment.

The water budget assessment for Aquifer 210 (Nanoose Creek above Hwy 19) indicates a moderate to high stress. Aquifer 218 (Nanoose Peninsula) indicates high degree of stress on the aquifer. Water levels in bedrock aquifer (218) should be monitored closely as its hydrograph demonstrates a tidal influence and the potential for salt water intrusion likely exists.

Although there are a number of wells completed in Aquifer 167, it appears that there is little groundwater use based on the higher number of wells completed in the deeper bedrock aquifer (Aquifer 221). However, as Aquifer 167 overlies Aquifer 211 which indicates stress, "conservation" recharge flux has been allocated to Aquifer 167 in order to ensure that the underlying aquifer continues to receive recharge.

Table 49: WR5 (SW-N) – Summary of Anthropogenic Groundwater Demand Analysis

Aquifer Tag No.	RDN Rivers Edge	RDN Nanoose Bay Water Service Wall Brook wells).	RDN Nanoose Bay Madrona Wells	RDN Nanoose Bay Water Service Nanoose, Fairwinds, & Westbay wells	RDN Fairwinds Arbutus	District of Lantzville	Nanoose First Nation	Other Private Wells (From RDN Water Use Est. based on Zoning from GIS)	Total Ground Water Use Est. (ANTH out)
	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)
219	5.5E+04	?	1.0E+05	5.8E+04	1.5E+05	NA	NA	2.4E+06	2.8E+06
214	NA	NA	NA	NA	NA	NA	NA	4.4E+02	4.4E+02
210	NA	NA	NA	NA	NA	NA	NA	3.2E+05	3.2E+05
218	NA	NA	NA	NA	1.5E+05	NA	NA	1.2E+05	2.7E+05
213	NA	NA	NA	NA	NA	?	?	7.2E+05	7.2E+05
215	NA	NA	NA	NA	NA	NA	NA	4.4E+05	4.4E+05
166	NA	NA	NA	NA	NA	NA	NA	0.0E+00	0.0E+00
211	NA	NA	NA	NA	NA	NA	NA	2.3E+06	2.3E+06
167	NA	NA	NA	NA	NA	NA	NA	0.0E+00	0.0E+00

Notes: NA means not applicable, ? Means not known or unavailable, ANTHout means anthropogenic water extraction from aquifer.

Table 50: Summary of Water Budget and Stress Analysis – WR5 (SW-N)

Aquifer Tag No.	Aquifer Lithology	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	MOE Obs Well	Seas. Fluc.	Long Term Fluc.	WL Trend (up or down)	Total Est. AQ. Rec. (TRin) (Rp/l + Rmb)	Est. Ann. Disch to Cr. & Down Grad Aquifer (Tc out)	Ground Water Use Estimate (ANTHout)	Total Out [TcOut + $ANTH_{out}$]	Stress Anal. % GW Use of the avail. AQ. Rec.	Relative Stress Assess.
			ID	(m)	(m)	U/D	(m^3/yr)		(m^3/yr)	(m^3/yr)	(%)	Lo, Mod, Hi
219	Quadra	Nanoose Creek, Ocean	392, 393	?	?	L	1.6E+08	1.56E+07	2.8E+06	1.83E+07	11	Lo
214	NG	Ocean	NA	NA	NA	NA	6.2E+05	0.00E+00	4.4E+02	4.40E+02	0	Lo
210	Buttle Lake Group - Fourth Lake Formation & Mount Hall Gabbro	Nanoose Creek, downgrad Fault Contact & NG	NA	NA	NA	NA	3.1E+06	2.45E+06	3.2E+05	2.77E+06	89	Mod-Hi
218	Benson Fm, IP, VG	Ocean	394	?	?	?	2.0E+06	4.06E+06	2.7E+05	4.33E+06	212	V. High
213	VG	Coal Works and Ocean	NA	NA	NA	NA	1.4E+07	4.12E+05	7.2E+05	1.13E+06	8	Lo
215	Quadra	Ocean	340, 232	1.6, 3.0	5, 7	D/L	6.3E+07	6.05E+07	4.4E+05	6.09E+07	97	Mod-Hi
166	VG & NG	Radial Flow to Long Lk., Dep. Bay, Neck Pt. etc… Ocean	NA	NA	NA	NA	2.2E+06	0.00E+00	0.0E+00	0.00E+00	0	Lo
211	VG & NG	Underground Coal Works	388	10.0	?	precip	3.8E+06	9.18E+06	2.3E+06	1.15E+07	306	V. High
167	Capilano	Benson Fm	NA	NA	NA	NA	3.6E+07	1.77E+07	0.0E+00	1.77E+07	49	Lo-Mod

Notes: SW-N means South Wellington to Nanoose, NA means not applicable, AQ means aquifer, Seas. Fluc. means seasonal fluctuation, PDO means Pacific Decadal Oscillation, WL means water level, Est means estimated, Disch. means discharge, Rec. means recharge ,Cr. Means creek, TRin means total recharge into aquifer, Rp/l means total recharge from precipitation and/or leakage from overlying aquifer, Rmb means total lateral recharge from up gradient aquifer or mountain block, Tc out means total aquifer groundwater discharge to creek, assess. means assessment , Total out means total discharge from aquifer (not including discharge to ocean), ANTH out mean total groundwater Anthropogenic groundwater extraction from aquifer, aquifer stress color codes: blue=low, green =low to moderate, yellow =moderate , brown =moderate to high, red=high to very high.

Aquifer 211 (Benson Meadows) also was classified as having a high degree of stress based on the water budget estimates. This aquifer is located high in the watershed and has limited catchment for recharge. Many surface water licences divert potential aquifer recharge from streams crossing the area. There is also relatively high well density so well to well interference may be affecting water levels in this low productivity aquifer. The aquifer is immediately up gradient of coal workings that may represent a groundwater sink. Long-term monitoring and cumulative impact assessment is highly encouraged in this area.

The water budget estimate for the Quadra aquifer (215) in Lantzville indicates a moderate to high level of stress. Aquifer 215 has a relatively small catchment area (i.e. limited recharge potential) and little to no mountain block recharge. The well to well density is high in this area.

More accurate water budget and aquifer stress estimates could only be accomplished using a computer modelling approach, but again the lack of aquifer data would likely render this exercise inconclusive as well. Rigorous testing requirements and complete aquifer test analysis by groundwater practitioners to determine aquifer transmissivity and storativity properties, in addition to long-term groundwater monitoring data in each aquifer would be required to fully assess the actual stress on each aquifer in this region.

7.4 Water Management Planning Within WR5 (SW-N)

General guidance on water management planning for all water regions is provide in later sections of this document. Specific to WR5 (SW-N), the following recommendations are presented for consideration by RDN to improve the state of knowledge in the water region:

- At least one observation well should be installed in each mapped aquifer. Mapped aquifers that currently do not have MOE observation wells include aquifers 214, 210, 213, 166, and 167;
- Well owners should identify the MOE well plate and tag numbers for each of their active water wells. In this manner, water use and monitoring data can be easily cross-referenced with the BC MOE well records. These include River's Edge wells, Nanoose Bay Water Service Wall Brook wells, Nanoose Bay Water Service Madrona wells, Nanoose Bay Water Service Nanoose, Fairwinds, and Westbay wells, Fairwinds and Arbutus wells, District of Lantzville (Harby Road) wells, and Nanoose First Nation wells;
- The significant recharge area map needs to be further updated by further processing of the NRCAN remote sensing data and by field verification;
- Reactivation of WSC surface water gauge for Nanoose Creek (08HB030) and Enos Creek (08HB039) is recommended;
- Reactivation of WSC lake level gauges on Brannen Lake and Enos Lake is recommended;
- Summer lake level and discharge data from Westwood Lake should be obtained from the City of Nanaimo or the BC Conservation Foundation and included in the Regional Water Database; and
- Collect weekly summer base flow measurements (June to Sept) for Bonell Creek, Chase River and Beck Creek as part of the Community Watershed Monitoring Network program to better understand summer base flow discharges in smaller watersheds in the region.

8.0 WATER REGION # 6 - NANAIMO RIVER

8.1 Regional Overview

The Nanaimo River water region (WR6-NR) is defined as the area extending from the coast at the Nanaimo River Estuary and Cedar, west to the top of the Nanaimo River catchment (Figure 79). It should be noted that the actual water region boundary in the southernmost part of WR6 (NR) was extended beyond the RDN boundary to coincide with the drainage basin. Although the RDN has no jurisdiction over this area, the water budget assessment needed to be completed at the basin scale and water resource management of this area will need to be a joint effort with the Cowichan Valley Regional District.

WR6 (NR) is largest water region within the RDN covering an area of approximately 939 km^2 (Table 51). The region is densely populated as it encompasses the communities of Cedar, South Wellington, Extension, and Cassidy. There are a total of 10 watersheds and subwatersheds in WR6 (NR), the largest of which is associated with the Nanaimo River (Figure 79). Five hydrometric stations, four climate stations, and approximately 359 surface water diversion licenses exist within the region (Figure 79, and Table 51).

The two largest water users in this area include the City of Nanaimo and Harmac Forest Products. It should be noted that the City of Nanaimo also pumps water outside of the Nanaimo River watershed for use in WR5 (SW-N).

Table 51: WR6 (NR) - Watersheds, Wells and Surface Water Licenses

Total Water Region Area	***939 km^2**
Major Watersheds	**Drainage Area[1] (km^2)**
Nanaimo River (including all tributaries)	829.5
Haslam Creek (tributary to Nanaimo River)	128.7
Hokken Creek (tributary to Haslam Creek)	14.6
South Nanaimo River (tributary to Nanaimo River)	213.3
Jump Creek (tributary to South Nanaimo River)	61.7
Sadie Creek (tributary to Nanaimo River)	29.3
Beck Creek	13.9
Berkley Creek (tributary to Nanaimo River)	9.2
Boulder Creek (tributary to Nanaimo River	12.1
Stark Creek (Tributary to Nanaimo River)	13.7
Wells and Surface Water Diversion Points	**No.**
# Water Wells listed in MOE DB	2686
Surface water diversion licenses	359

Note: Drainage Areas are based on 1:50,000 BC Watershed Atlas. *Total water region area includes areas which drain directly to the ocean and do not lie within a major watershed. The Nanaimo River drainage area includes all tributaries.

According to the MOE Wells Database (BCGOV ENV Water Protection and Sustainability Branch, 2012) WR6 (NR) has the highest number of water wells (2686 wells) of the six water regions in the RDN. The MOE database likely only represents a fraction of the actual wells currently in use. Many well records may not have been entered into the database and some wells may simply not be in use or have been abandoned. As there is no mandatory requirement for submitting well logs or well abandonment records, it is not possible to determine the groundwater demand from private wells with any degree of certainty, nor is it possible to assess the vulnerability that may exist with improperly abandoned or standing water wells.

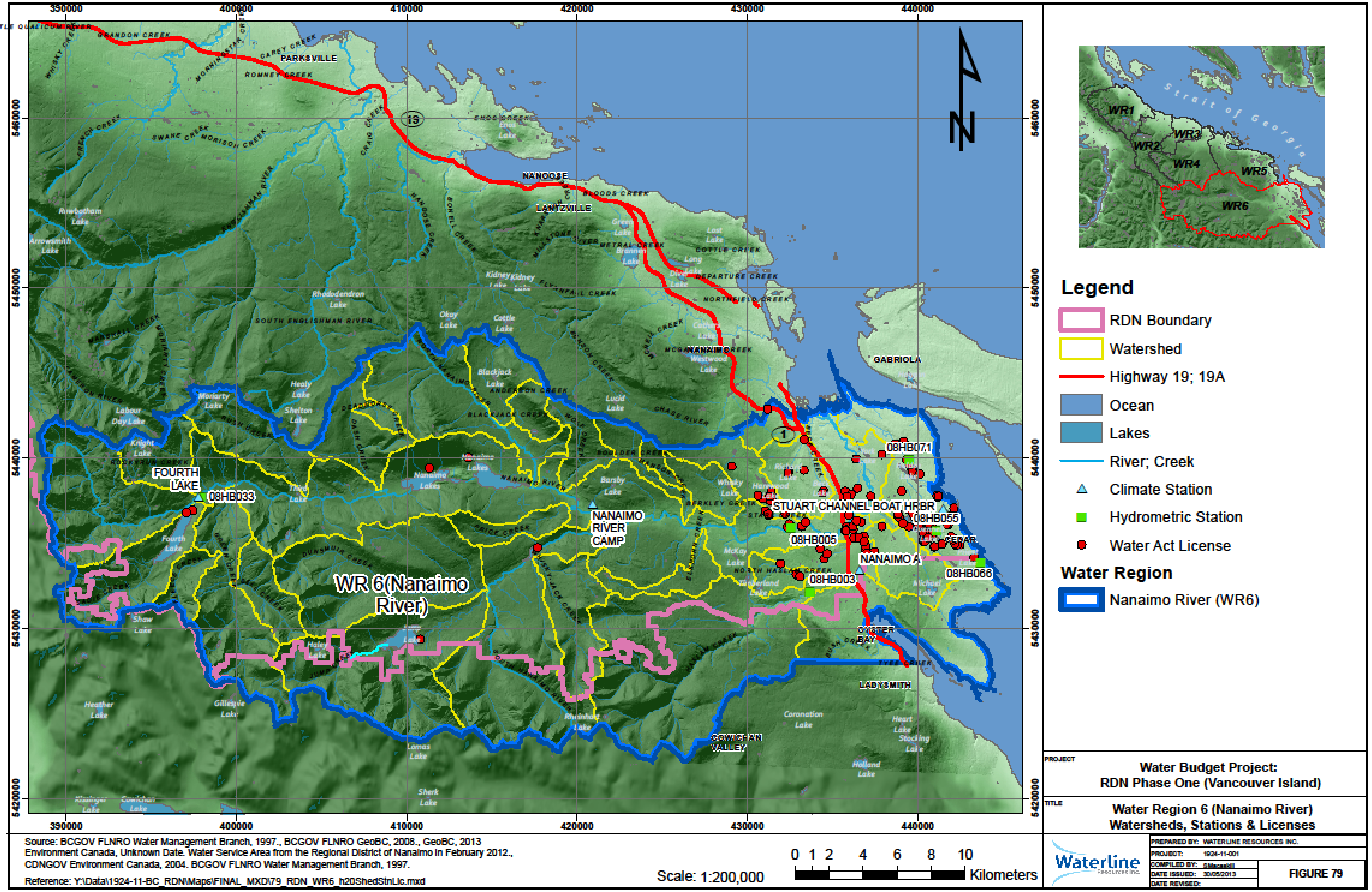


Figure 79: WR6 (NR) – Watersheds, Stations & Licenses

8.2 Surface Water Assessment

8.2.1 Terrain and Topography

The Nanaimo River Water Region (WR6) includes the Nanaimo River Watershed and its major tributaries as well as that part of southern NRD (Cedar and North Oyster) which drain directly to the ocean. The southern edge of the watershed crosses into the Cowichan Valley Regional District including a large part of Haslam Creek. The majority of the upper watershed is private forest lands managed by Timberwest. The lower part of the watershed consists primarily of rural development with agriculture land, low density residential development and some light industrial development.

The region rises from sea level at the Nanaimo River estuary and Stuart Channel up to Mount El Capitain (1,537 m) near Jump Lake. There are four main lakes within the watershed including Fourth Lake, Second and First Nanaimo Lakes and Jump Lake. Dams located at Fourth Lake and Jump Lake is used as surface water storage for the Harmac Pulpmill and City of Nanaimo Municipal Water Supply, respectively.

Some of the major tributaries to the Nanaimo River which have surface water licences include Haslam Creek, South Nanaimo River, Jump Creek and Sadie Creek. The major watersheds in the WR6 (NR) are shown in Figure 79.

8.2.2 Climate

The climate for the Nanaimo River Water Region is similar to the rest of the RDN with cool wet winters and mild dry summers. A single Environment Canada weather station is located at the Nanaimo Airport at lower elevation in the water region. The average total annual precipitation for the 1971 to 2000 period is 1,162.7 mm. Figure 80 shows the monthly distribution of temperature and precipitation recorded at the Nanaimo Airport. Climate station locations are shown on Figure 79.

Significant snowpack accumulations are generally found in the higher elevation sections of the watershed through the winter and spring. The Jump Creek Snow Pillow (03B23P), operated by the BC River Forecast Centre, is located above Jump Lake at Elevation 1,134 m near the watershed divide with Cowichan River to the south. The station has been operational since 1995 and indicates a normal April 1st snowpack SWE of about 1,300 mm and has a maximum recorded SWE of 3,000 mm on April 1st 1999 (see Figure 81). A snow course was also operated in the watershed at Green Mountain (Elevation 1,400 m) from 1954 to 1985 with an average April 1st snowpack SWE of 1,480 mm.

Maps showing the distribution of annual total precipitation and average annual temperature over the water region are shown in Figure 82 and Figure 83, respectively. These maps show the influence of the Vancouver Island Mountains on precipitation and temperature with annual precipitation estimated to be greater than 5,000 mm at the head waters of Saddie Creek.

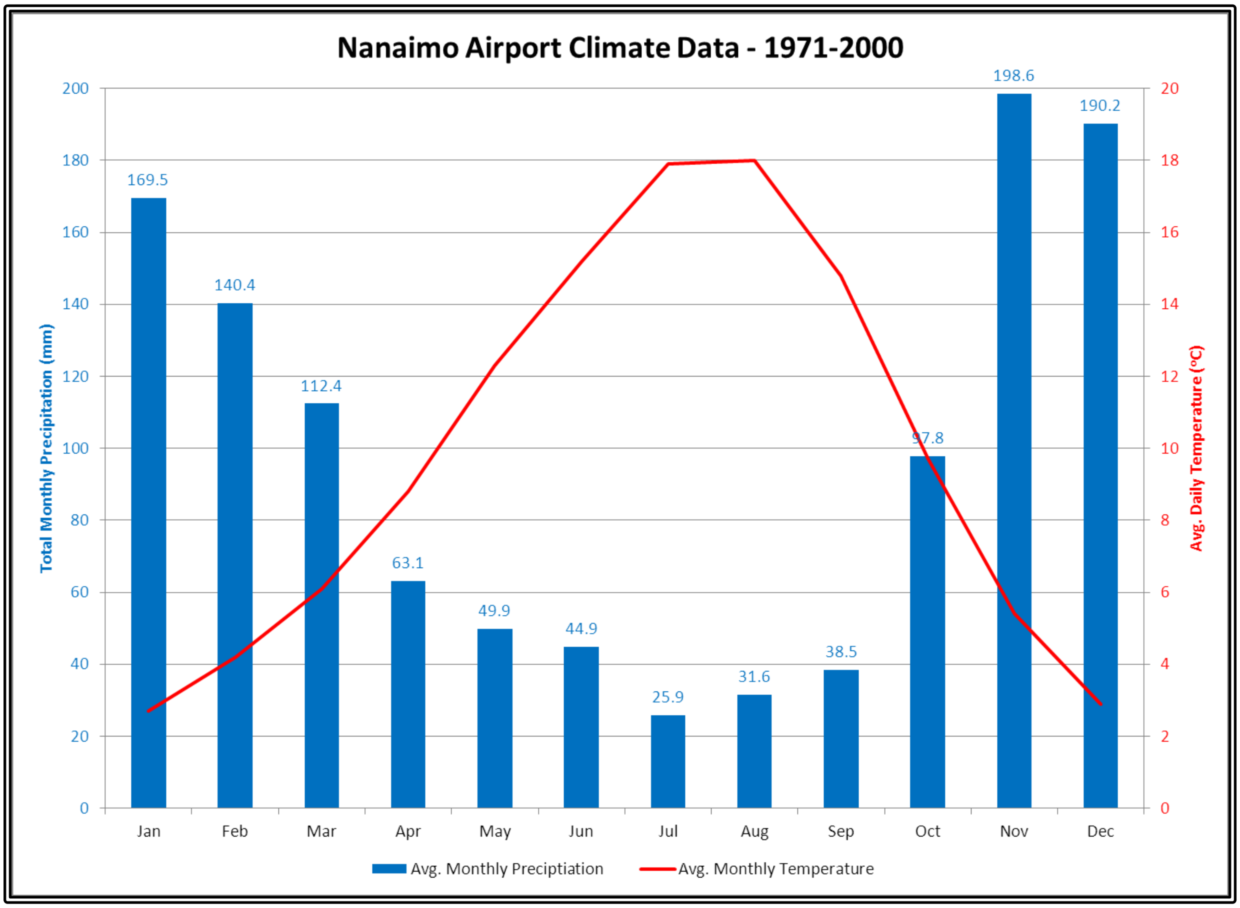
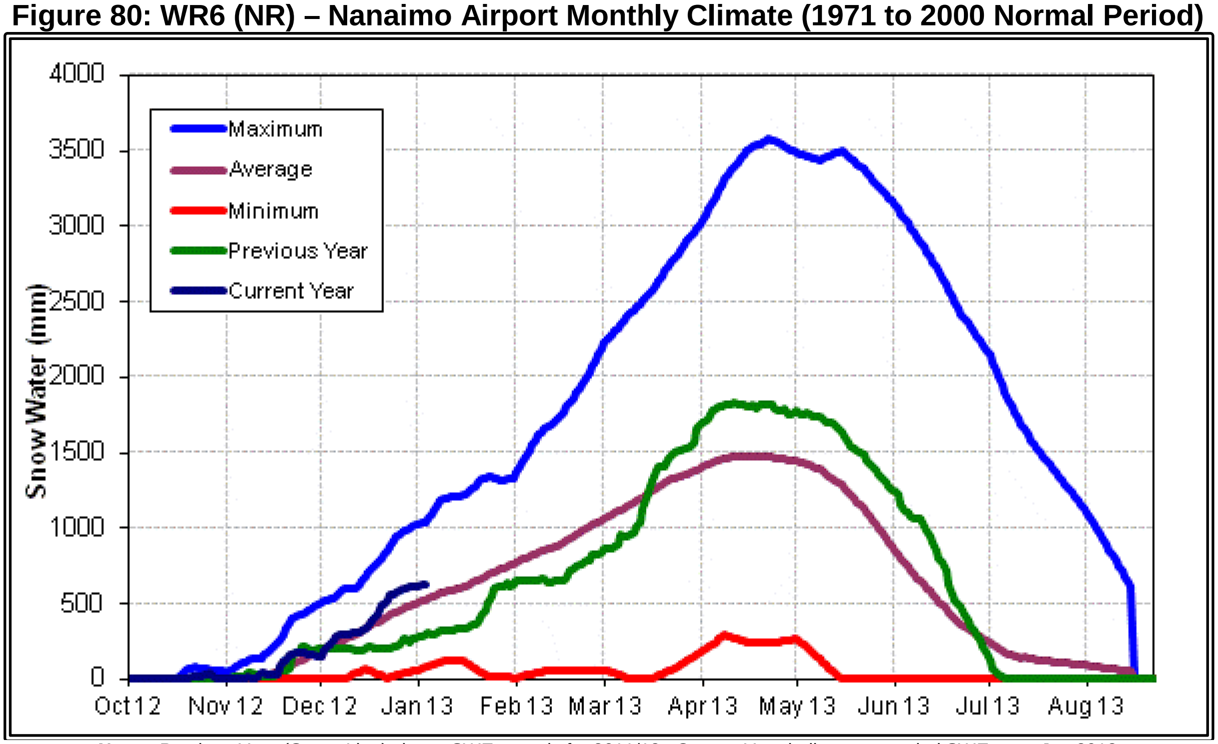


Figure 80: WR6 (NR) – Nanaimo Airport Monthly Climate (1971 to 2000 Normal Period)



Notes: Previous Year (Green Line) shows SWE records for 2011/12. Current Year indicates recorded SWE up to Jan 2013

Figure 81: WR6 (NR) – Jump Creek Snow Pillow

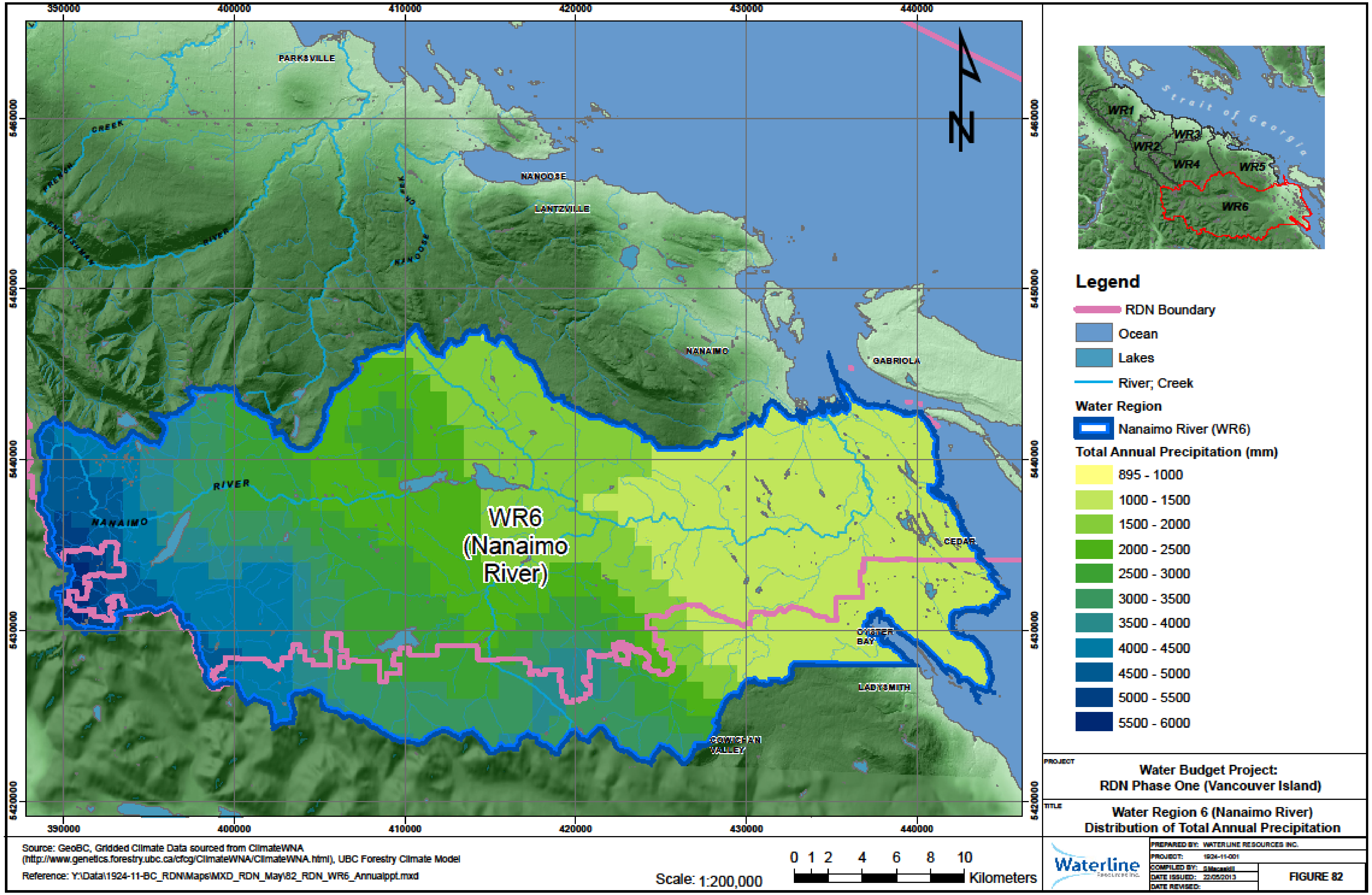


Figure 82: WR6 (NR) - Distribution of Total Annual Precipitation

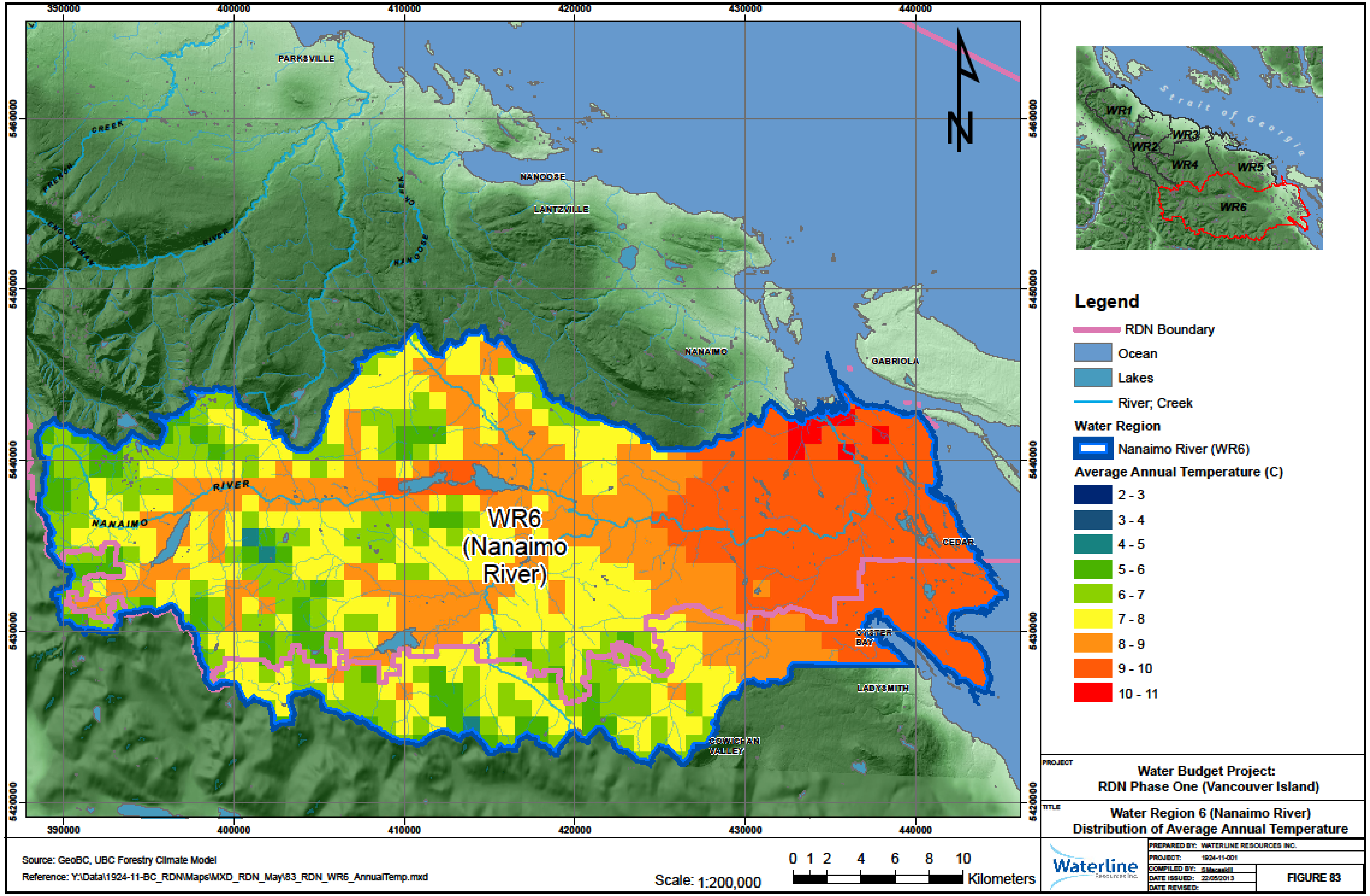


Figure 83: WR6 (NR) - Distribution of Average Annual Temperature

8.2.3 Stream Gauging and Monitoring

Three active and three discontinued water survey of Canada hydrometric stations are located within the Nanaimo River Watershed. The details for each of the stations are included in Table 52.

Table 52: WR6 (NR) – Water Survey of Canada Records

Station	Period	Natural or Regulated	Drainage Area to Gauge (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)
Nanaimo River near Cassidy (08HB034)	1965 to Present	Regulated since 1963	676	39.8 m^3/s 1,255 million m^3	7.51 m^3/s 59.7 million m^3
Nanaimo River near Extension (08HB005)	1913 to 1927 1948 to	Natural	645	40.5 m^3/s 1,277 million m^3	7.74 m^3/s 61.5 million m^3
Haslam Creek near Cassidy (08HB003)	1914 to1915 1948 to 1962 1992 to	Natural	95.6	4.38 m^3/s 138 million m^3	0.307 m^3/s 2.44 million m^3
South Nanaimo River near Junction	1997 to Present	Regulated	211	14.1 m^3/s 444.7 million m^3	1.98 m^3/s 15.8 million m^3
Jump Creek at the Mouth	1970 to Present	Regulated since 1974	62.2	4.82 m^3/s 0.416 million m^3	1.75 m^3/s 13.9 million m^3
Nanaimo River above Rockyrun Creek (08HB033)	1963 to 1964	Regulated	75.6	N/A	N/A

Monthly average hydrographs for Nanaimo River near Extension and Nanaimo River near Cassidy are shown in Figure 84. The figure provides an indication of the impact that regulation in the system has had on river flows.

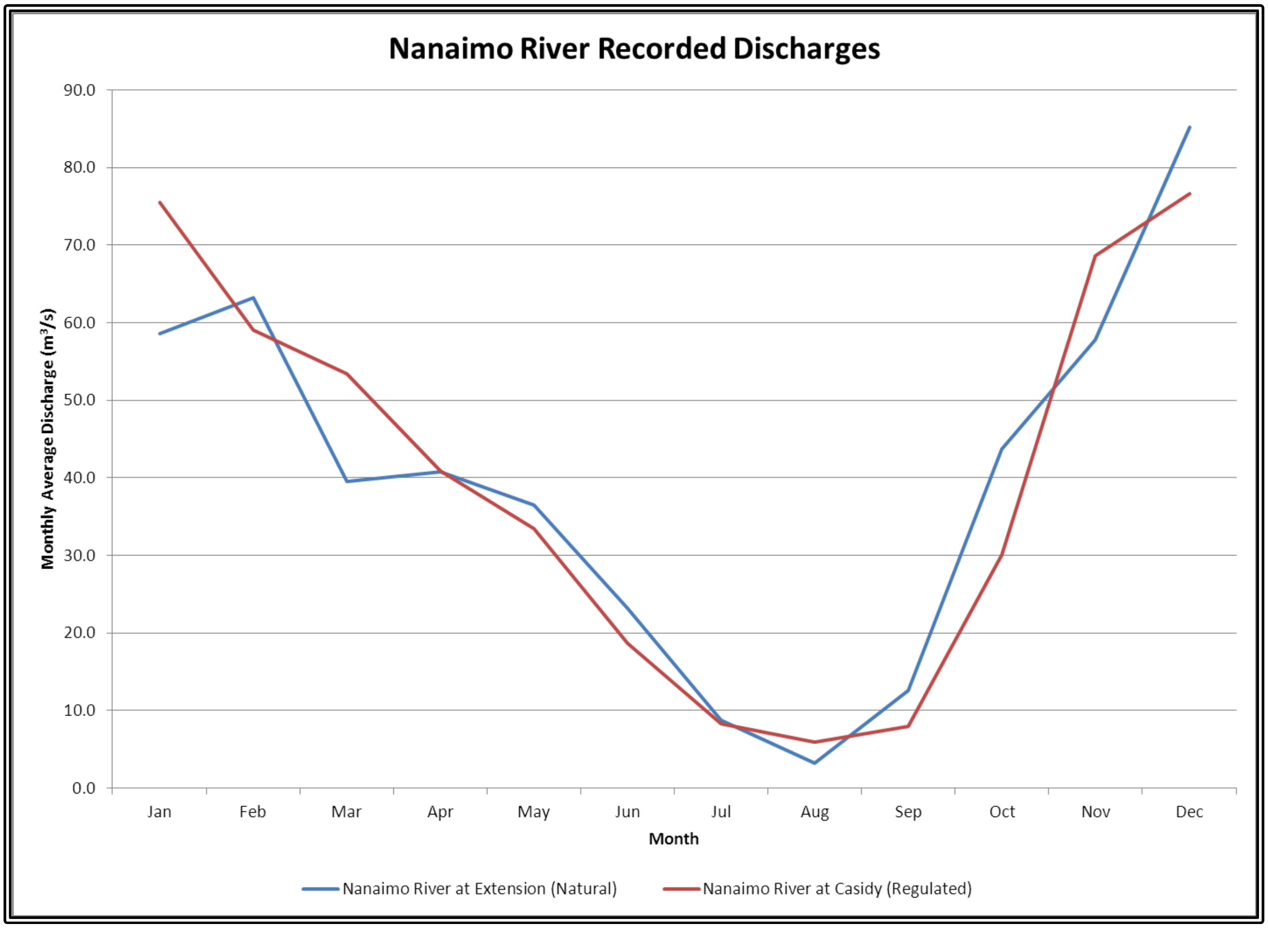


Figure 84: Nanaimo River Recorded Discharges

8.2.4 Hydrology and Surface Water Resources

The Regional Hydrological Model has been used to estimate mean annual discharge and volume as well as summer average discharge and volume for the Nanaimo River and the major tributaries. The results are shown in Table 53.

Table 53: WR6 (NR) – Natural (Unregulated) Surface Water Resources (1971 to 2000)

Watershed	Drainage Area (km^2)	Mean Annual Discharge (m^3/s) and Volume (million m^3)	Mean Summer Discharge (m^3/s) and Volume (million m^3)
Nanaimo River to the mouth (including all tributaries)	830	58.3 m^3/s 1,839 million m^3	7.83 m^3/s 62.2 million m^3
Haslam Creek to the Mouth	129	6.26 m^3/s 197 million m^3	0.378 m3/s 3.0 million m^3
South Nanaimo River	213	16.8 m^3/s 530 million m^3	1.2 m^3/s 9.54 million m^3
Jump Creek	61.7	5.25 m^3/s 165 million m^3	0.36 m^3/s 2.86 million m^3
Sadie Creek	29.3	4.09 m^3/s 128 million m^3	0.506 m^3/s 4.02 million m^3

Flows in the Nanaimo River are regulated at Fourth Lake Dam and Jump Creek Reservoir to support demands at the Harmac Pulpmill and the City of Nanaimo, respectively. Through and agreement with the Department of Fisheries and Oceans and BC Ministry of Forests, Lands and Natural Resource Operations a summer flow of 3.9 m^3/s at the Nanaimo River at Cassidy gauge should be maintained, with roughly 1.0 m^3/s from the Jump Creek dam and 2.9 m^3/s from the Forth Lake dam. During extreme low flow years, a minimum flow of 1.4 m^3/s is required to be maintained below the water intakes for the mill and 0.28 m^3/s in Jump Creek. Currently, the City of Nanaimo is in the planning and design process for construction of a new surface water reservoir on the South Nanaimo River. However, the details of the dam are preliminary and have not been included in the assessment.

8.2.5 Surface Water Demand

Table 54 summarizes the surface water licences in WR6 from the BC Surface Water Licence Database. Table 55 outlines the licenced surface water storage. The locations of the surface water licences for WR6 are shown on Figure 79.

Table 54: WR6 (NR) - Surface Water Demand

Type of Demand	Monthly (m^3/month)	Annual (million m^3)	Summer (Jul-Sept) (million m^3)
Consumptive Demand			
Agriculture	28,300	0.340	0.254
Domestic	2,400	0.0288	0.095
Industrial	9,910,000	118	29.7
Institutional	68	0.0008	0.00027
Water Works	5,390,000	64.7	21.4
Total Consumptive	15,330,000	184	51.3
Non- Consumptive Demand			
Power	699,840	8,398,080	
Conservation	-	-	
Total Non-Consumptive	699,840	8,398,080	

Table 55: WR6 (NR) - Licensed Surface Water Storage

Type of Demand	Total Storage (Million m^3)
Storage	64.3
Conservation Storage	0
Other Storage	0.87
Total Storage	65.1

The two largest water users in the Nanaimo River Water Region are the Harmac Pulpmill and the City of Nanaimo for Municipal Water Supply. The mill has a licence to withdraw up to 3.82 m^3/s (118 million m^3) while the City of Nanaimo has a licence to withdraw up to 64.7 million m^3 annually. However, both use less than their allocated amount. Actual recorded withdrawals for 2010 are included in Table 56.

Table 56: WR6 (NR) - Recorded Surface Water Withdrawal in 2010

Water User	Total Annual Volume (Million m^3)	Total Summer Volume (Million m^3)
City of Nanaimo	15.7	5.30
Harmac Pulp Mill	39.8	9.95
Total Recorded Withdrawal	55.5	15.5

Notes: Recorded withdrawal values were from Nanaimo River Baseline Report (Nanaimo Area Land Trust, 2011)

8.2.6 Surface Water Stress Analysis

As outlined in Section 2.4.2, a surface water stress analysis for each of the major watersheds has been completed. Water budget analysis for other smaller ungauged subwatersheds within WR6 (NR) should be completed when data is available and as part of a more detailed Tier 1 or Tier 2 water budget assessment (OMNR 2011). The results of the allocation and actual demand stress analysis for the watersheds in WR6 (NR) are shown in Table 57. A map showing the relative stress for each watershed is shown in Figure 85.

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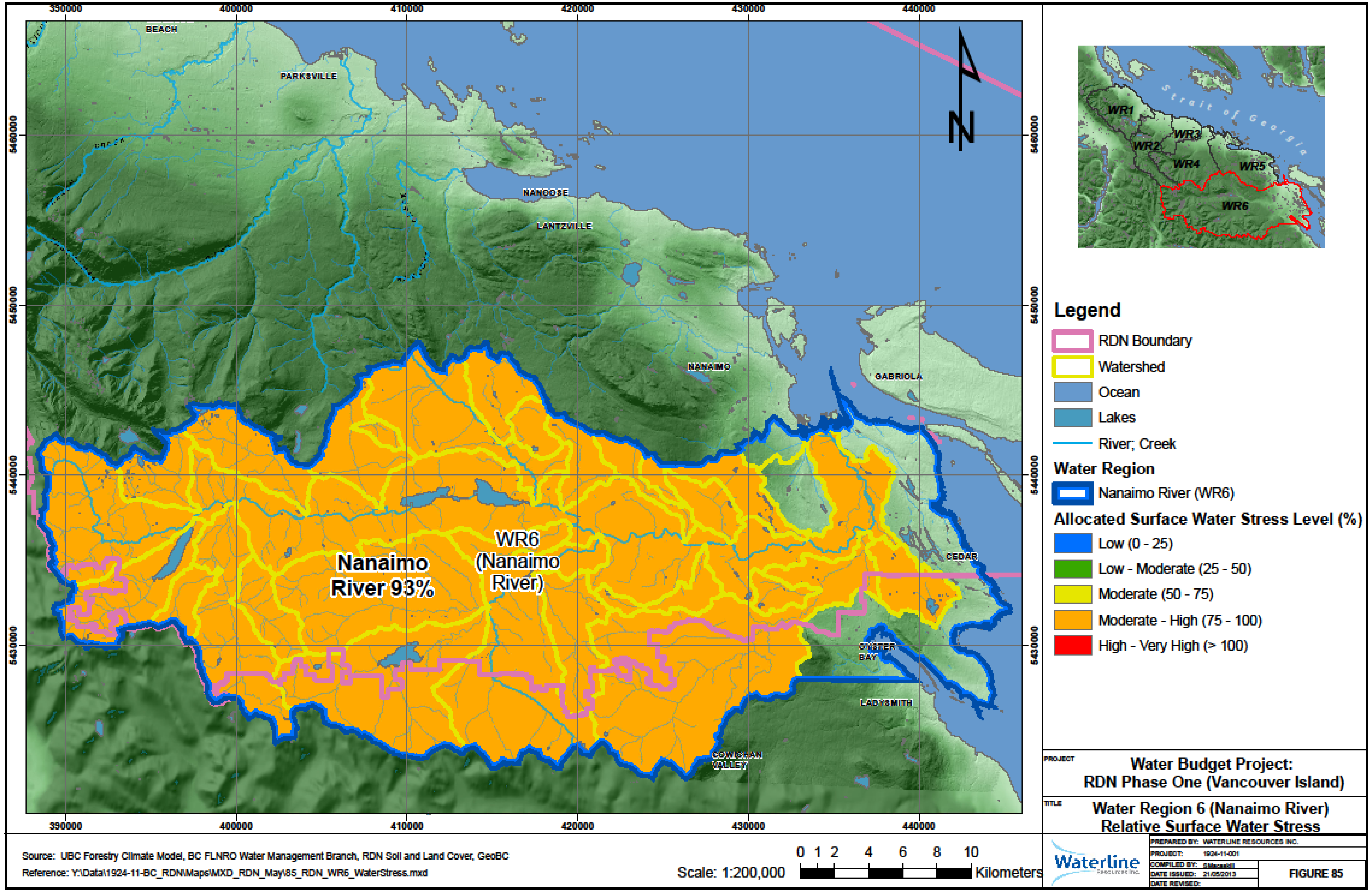

Figure 85: WR6 (NR) - Relative Surface Water Stress

Table 57: WR6 (NR) - Surface Water Stress Analysis

Watershed	Average Natural River Flow Supply (million m^3)	Storage (million m^3)	Conservation Flow (10% of MAD) (million m^3)	Licensed Demand (million m^3)	Allocation Stress	Stress Level	Actual Demand (million m^3)	Actual Stress
Nanaimo River	62.2	64.2	45.8	51.5	**93%**	Moderate to High	15.5	**58%**

Notes: Volumes indicated in the table are average volumes for summer period (Jul to Sep). Average natural river flow is the estimated or recorded unregulated flow in the watershed. Total storage is based on licensed storage volume and assumes all storage is available to support conservation flow and licenced demand for the Jul to Sep period. The 10% of Mean Annual Discharge (MAD) conservation flow is based on current Ministry of Forest, Lands and Natural Resource Operations (MELP, 1996) minimum conservation flow policies for the east coast of Vancouver Island. Licenced demand is the total licenced volume for summer based on consumptive water licences. Allocation stress = (Average Natural supply + storage) / (Conservation Flow + Licenced Demand). Actual Stress = (Average Natural supply + storage) / (Conservation Flow + Average Recorded Surface Water Demand). Surface water stress color codes: blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high. Values reflect average flow conditions and do not consider drought years.

8.3 Groundwater Assessment

8.3.1 Existing Groundwater Studies and Data – WR6 (NR)

Given the regional scale of the Phase One Water Budget Assessment, the most important data compiled and geo-referenced by Waterline was the water well information, elevation data, soil and geology maps, land cover, aggregate resource map, mapped aquifers, and water service areas. Other maps were generated using the input data as part of Waterline's work and some samples are provided in Appendix C for illustration purposes (Eg: overburden thickness (Map C7), piezometric contour maps (Maps C8 and C9), air temperature (Map C14), precipitation (Map C15), runoff (Map C16 and C17), evapotranspiration (Map C18), infiltration (Map C19), Water Service Areas (Map C20), and Water Demand Assessment in Non-service areas (Map C21). All of these maps are provided in Appendix C for the entire RDN study area with an explanation of how the map was geo-reference or created by Waterline. These data and layers are now available in the ARC GIS Geodatabase at the RDN Scale, water region scale, watershed scale, on other local scale needed for site specific assessments. These data will be provided to the RDN in electronic format as part of the ARC GIS Geodatabase system which was constructed by Waterline for use by the RDN. These regional datasets form the framework for construction of the conceptual hydrogeologyical model.

Although only some of the data in certain reports may have been incorporated into Waterline's Geodatabase, the primary studies in the region were used in Waterline's water budget assessment to provide the local hydrogeological are provided in Table 58.

Table 58: WR6 (NR) – Hydrogeology Reference Reports

Author	Year	Study Title
Associated Engineering	2007	South Nanaimo River-Watershed Yield Assessment (2007)
Associated Engineering	2009	Nanaimo River Fourth Lake Yield Assessment
GW Solutions, Vancouver Island University	2010	Area A Groundwater Assessment and Water Budget
Levelton	2011	RDN Observation Well Holden Corso and Lofthouse Roads, Cedar
Pacific Hydrology Consultants	1990	OCI Boat Harbour Development - Water Supply Completion Report
Piteau Associates	1992	Water Well Testing for Pylades Development
Piteau Associates	1995	Pylades Well – Pumping Test – 2380 Bissel Road Cedar
Piteau Associates	2001	North Cedar Improvement District Hydrogeologic Assessment to Identify New Well Source

Author	Year	Study Title
SRK Consulting	2007	TEL_17-123-432f_rpt_Cassidy Aquifer - Completion Report
Thurber Engineering Ltd.	2006	Water 2006S Nanaimo Lakes Groundwater Study

8.3.2 Description of Aquifers and Water Wells

A total of three unconsolidated aquifers and three bedrock aquifers have been mapped within WR6 (NR) (Table 59). The Capilano aquifer 161 (Cassidy Aquifer) was mapped as having high productivity, is highly developed, and is also high vulnerable due to its unconfined nature. The underlying Vashon sand and gravel aquifer (#160, Lower Cassidy Aquifer) exhibits moderate productivity, low vulnerability, and is not well developed. Bedrock aquifers in Extension (164) and South Wellington (165) exhibit low yield, moderate demand, and moderate vulnerability. The Cedar/Yellow Point aquifer (Aquifer 162) exhibits low productivity/yield, high demand, and high vulnerability. It should be noted that aquifers 963 and 964 are newly mapped aquifers in this region and water budgets were not included in the current water budget assessment.

Table 59: WR6 (NR) – Summary of Mapped Aquifers

Aquifer Tag No.	Aquifer Lithology	Location Within Water Region	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	Developed Aquifer surface Area	Confined, Semi, or unconfined, Aquifer Vulnerability Code	Yield
				(m2)		(L/M/H)
160	Vashon	Lr. Cassidy	NR	6.0E+06	Semi-Confined, IIC	M
161	Capilano	Cassidy	NR	3.0E+07	Unconfined, IIA	H
162	NG	Cedar, Yellowpoint	NR, Ocean	7.9E+07	Unconfined, IA	L
163	Quadra	North Holden Lk., Cedar	Ocean	1.6E+06	Unconfined, IIB	M
164	NG	Extension	NR	6.2E+06	Confined, IIB	L
165	NG	South Wellington	NR	1.7E+07	Confined, IIB	L

Notes: A/B/C is high/moderate/low vulnerability, I/II/III is heavy/moderate/light use, H/M/L means high/medium/low productivity/yield. All aquifer classification parameters, codes and yield are defined at the following MOE web address http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/aquifers/Aq_Classification/Aq_Class.html#class. NG means Nanaimo Group.

Figure 86 shows the three sand and gravel aquifers mapped in WR6 (NR) with associated supply wells listed in the MOE Wells Database. Figure 87 shows the three bedrock aquifers with associated supply wells listed in the MOE Wells Database. There are a total of 2686 overburden and bedrock wells listed in the MOE data base in WR6 (NR) (Table 51). As there are no regulatory requirements in BC to submit wells logs to MOE for capture in the Wells Database, the water wells shown on Figure 86 and Figure 87 likely represents only a fraction of wells actually drilled.

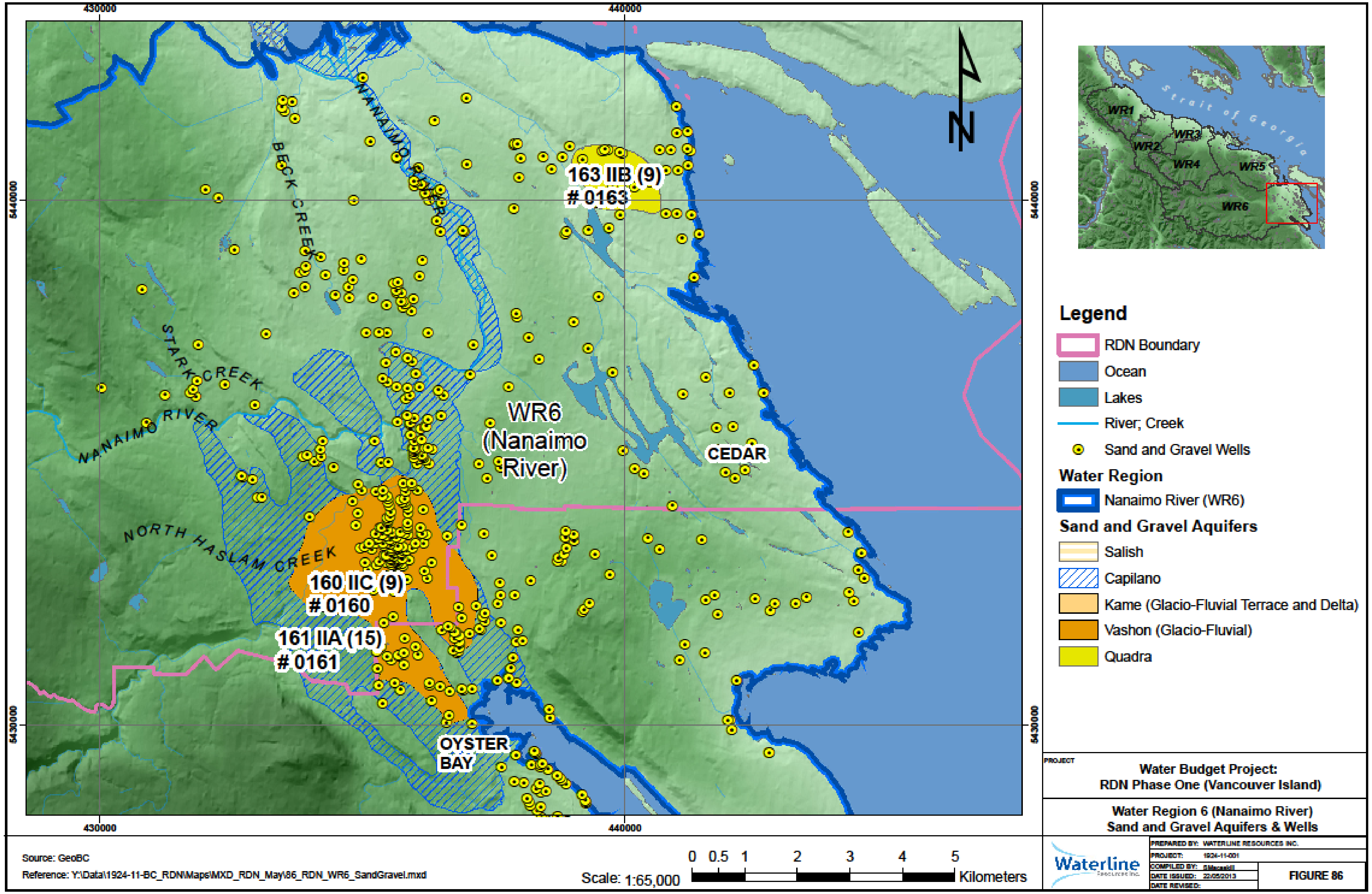

Figure 86: WR6 (NR) – Mapped Sand and Gravel Aquifers & Wells

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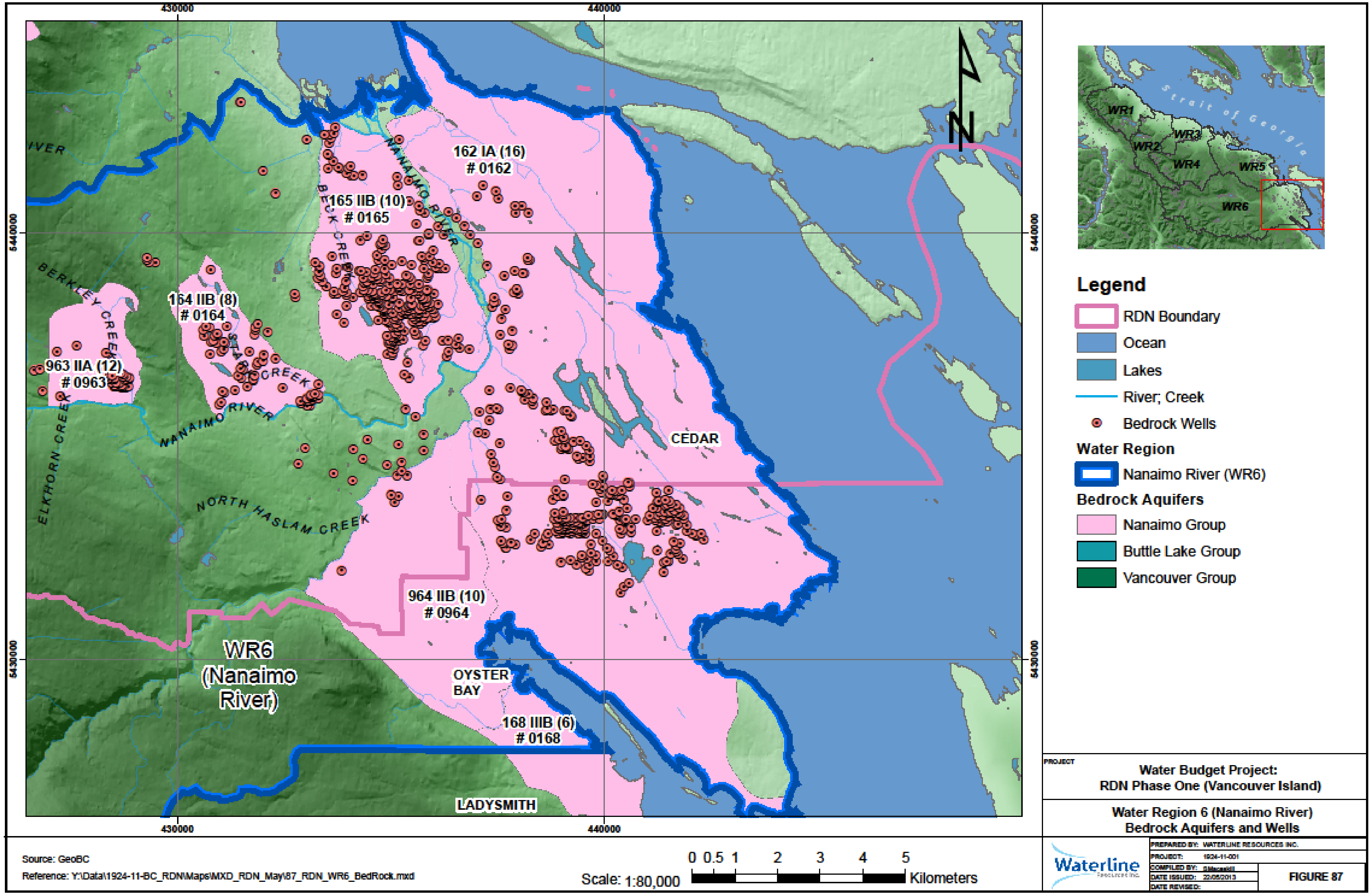

Figure 87: WR6 (NR) – Mapped Bedrock Aquifers & Wells

8.3.3 Groundwater-Surface Water Interaction - Conceptual Hydrogeological Model

A conceptual hydrogeological model of each aquifer with WR6 (NR) was developed in order to understand the key elements and linkages between surface water and groundwater systems required to complete the aquifer water budget assessment. Although conceptual hydrogeological model developed by Waterline includes numerous cross-sectional views developed within the Waterline Geodatabase, only one 3D view into the subsurface will be presented here.

Figure 88 shows a 3D block diagram illustrating the relationship between surface and subsurface geology in the Cassidy area of WR6 (NR) where two major water supply aquifers have been mapped. The schematic shows how the Capilano Aquifer (161) is exposed in Haslam Creek and the Nanaimo River and likely contributes important base flow to the creek during the summer and fall season. View 1 shows the upper Cassidy aquifer (161) with a high water table. The lower Cassidy aquifer (160) is considerably less developed but water levels appear to be high suggesting that it may be connected to overlying upper Cassidy aquifer (161).

8.3.4 Significant Recharge Areas

Significant recharge areas within WR6 (NR) were determined as part of the assessment of infiltration across the region base on topography, mapped textural soil characteristics, land cover (bare land, vegetation, impermeable surfaces), and leaf area index. These areas are important for maintaining recharge to aquifers and base flow to creeks and rivers. Figure 89 shows significant recharge areas mapped in WR6 (NR) as part of the water budget project.

Significant recharge areas are shown in red/orange and extend to the upper reaches of WR6 (NR) into upper Sadie Creek and Rockyrun Creek at the western most part of WR6 (NR), and to Whisky Jack and Boulder Creek in the east of the water region.

Some of the areas indicated are moderately developed (Boulder Creek), but most areas are largely undeveloped. Future development planning needs to consider these areas to ensure that aquifer recharge continues to be maintained. There is a need to develop protection zones around critical areas contributing recharge to underlying aquifers to ensure the future sustainability of groundwater resources in this region. Better definition of these areas should be completed as the current modelling completed by Waterline and KWL was done on a 1 km square grid.

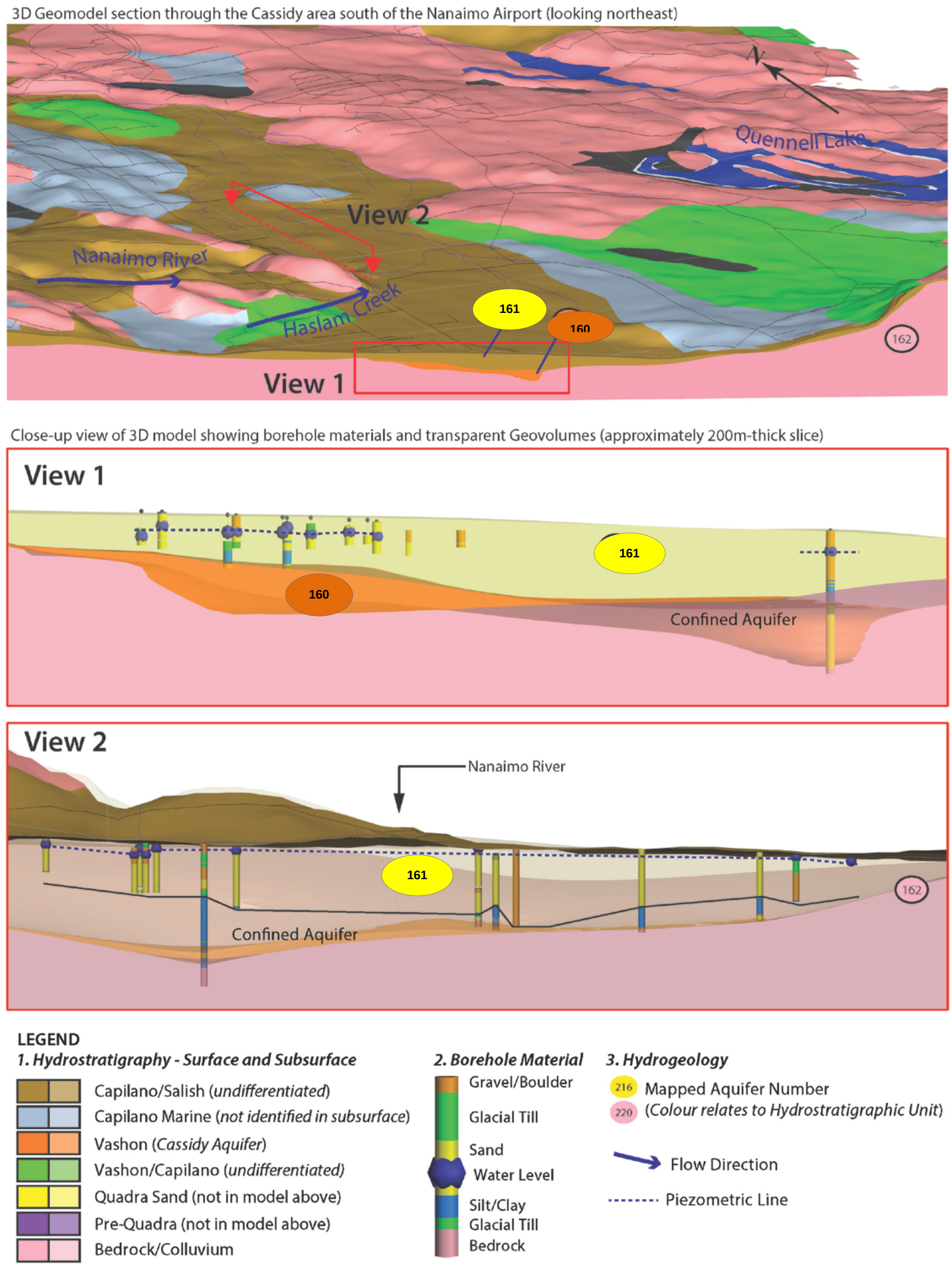

Figure 88: WR6 (NR) – Hydrogeological Conceptual Model – Cassidy Area

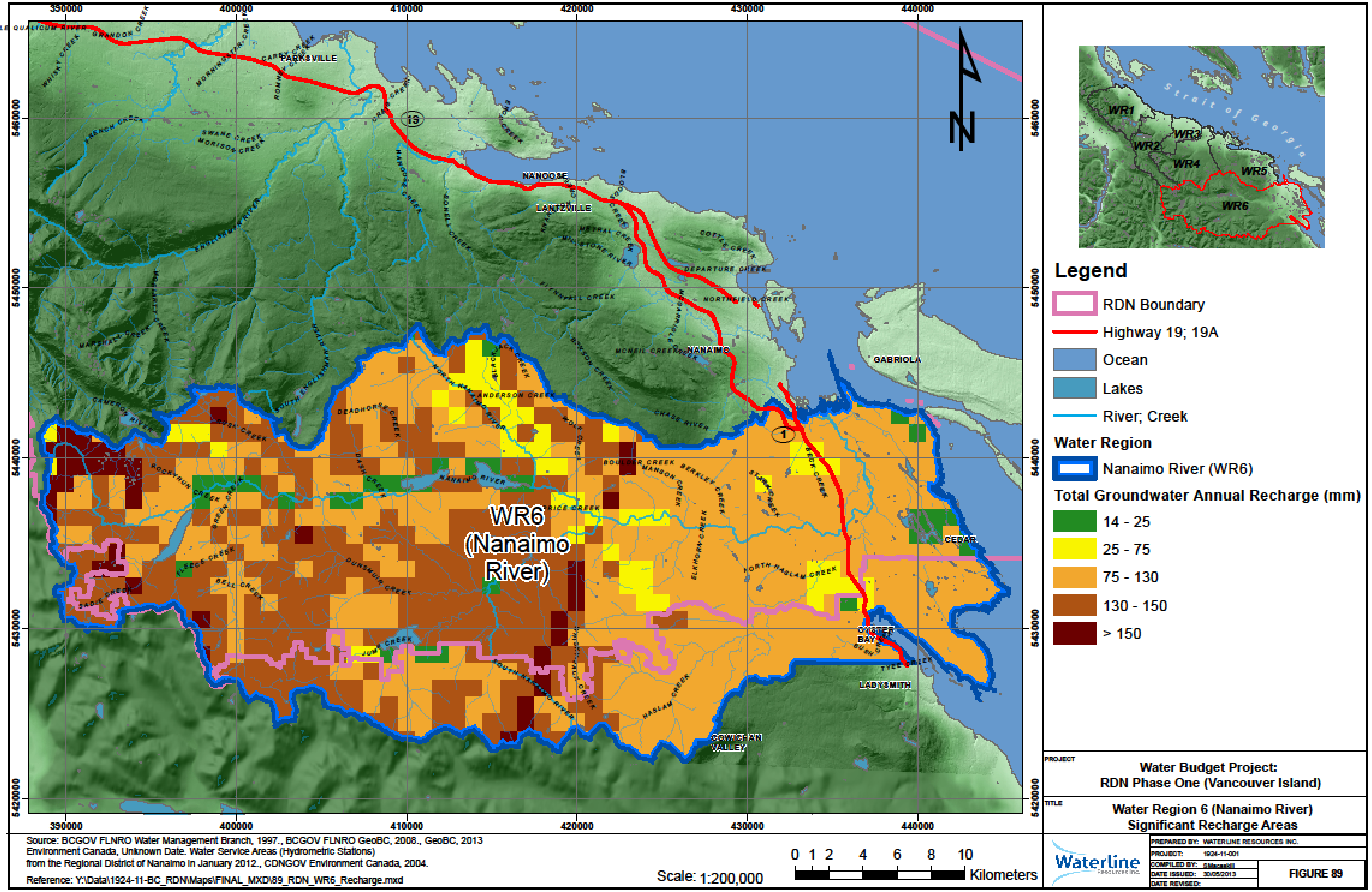

Figure 89: WR6 (NR) – Significant Recharge Areas

8.3.5 Groundwater Level Monitoring – BC MOE Observation Well Network

Long-term water level monitoring data provides an indication of an aquifer's response to global, regional, and local environmental changes in climate, groundwater pumping, and the impacts (if any) of other activities related land development. Long-term records also allow for establishing hydraulic linkages between the groundwater and surface water systems.

Figure 90 shows the locations of MOE observation wells and long-term water level monitoring records in relation to community water supply wells identified from the MOE Wells Database (E.g.: Large municipal users, the RDN, private utilities wells). Although numerous community wells are listed in the database, Waterline understands that not all of the wells shown on Figure 90 are currently active.

One of the problems encountered by Waterline during the water budget project was that community well owners generally do not cross reference active production wells to respective well logs in the MOE database. Often wells are referred to by local names (E.g.: RDN well # 1, #2, etc…). As water budget calculations require that production wells be assigned to specific aquifers, it is important that cross-referencing with the MOE well logs be completed. Well owners are encouraged to report the MOE well plate number so that accurate water level and groundwater extraction volumes can be allocated to the corresponding MOE well log and mapped aquifer.

Water level monitoring records are available for five MOE observation wells in WR6 (NR) (Figure 91 to Figure 96, inclusive). Two MOE wells (330 & 312) are completed in the Cassidy (upper) Aquifer 161 (Figure 91 and Figure 92), MOE well 228 in the Vashon (Lower Cassidy) Aquifer 160 (Figure 93), and three MOE wells in Nanaimo Group Bedrock (Cedar and Yellow Point) Aquifer 162 (Well # 337, 315, and 331 (Figure 94 to Figure 96). Water levels in MOE Wells were plotted along with the Nanaimo Airport precipitation record and the Jump Creek River Stage (level) in the case of MOE well 330 located at the confluence of Jump Creek and the Nanaimo River.

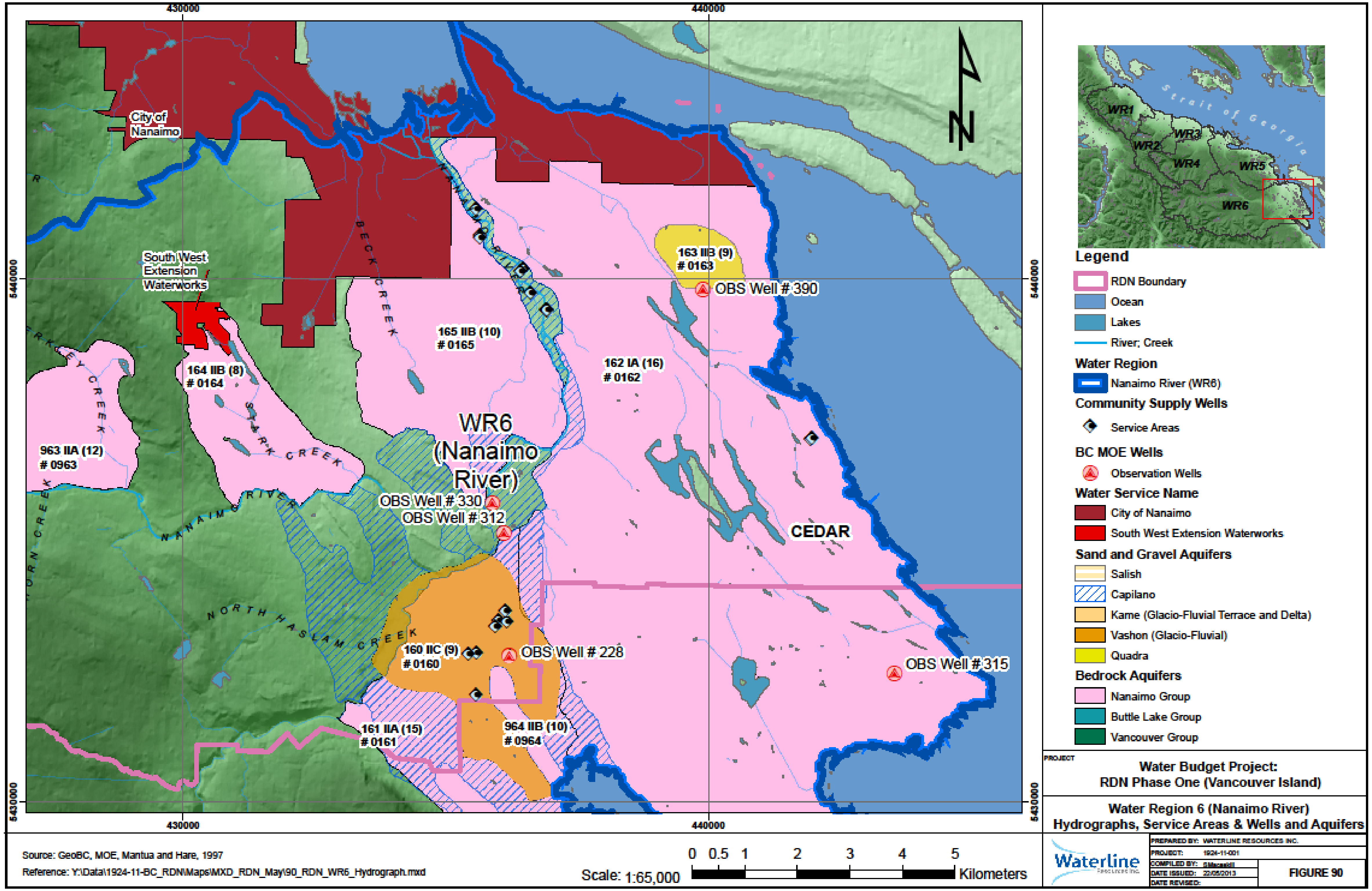

Figure 90: WR6 (NR) – MOE Well Hydrographs, Service Areas & Wells, and Aquifers.

MOE observation wells 330 and 312 completed in Capilano aquifer 161 (Upper Cassidy Aquifer) shows a 2-6 m water level decline since monitoring began until the year 2000. This was followed by a level trend to present day. Both wells also follow the Jump Creek level, Nanaimo Airport precipitation data, and PDO trend suggesting a direct connection to the surface. The data suggests that groundwater pumping significantly affects water levels in the Capilano aquifer 161 (Upper Cassidy Aquifer). High volume wells located near the Nanaimo River, and/or the fact that the flow in the Nanaimo River is regulated, could account for the water level drop in the aquifer observed between 1996 and 2000 (MOE Well 330) and 2003 (MOE Well 312). More information is needed to verify the cause and effect relationship.

Water level data collected in the underlying Lower Cassidy Aquifer (Well 228, Figure 93) shows a much more stable trend as only a few water supply wells extract groundwater from this aquifer. The water level record exhibits close correlation to the local precipitation data and the PDO trend suggesting a direct connection to the surface. This also means that the Lower Cassidy aquifer may be semi-confined and hydraulically connected to the overlying Cassidy aquifer.

The water level hydrograph for MOE well 337, completed in bedrock Aquifer 162 near Henry Roethel Road shows seasonal variations and an overall water level decline of 15m between 2002 and 2010. This decline can likely be attributed to a number of factors including local over-pumping of the aquifer and its location at the top of the watershed where there is a limited catchment area for aquifer recharge. MOE well 315 is also completed in bedrock Aquifer 162 near the coast but shows a relatively stable long-term water level, although Waterline understands that the logger in this well may not be functioning properly. Both MOE wells completed in Aquifer 162 show a one to two month offset from the precipitation record suggesting a semi-confined system. The record for MOE Well 390 is too short to assess the long-term trend.

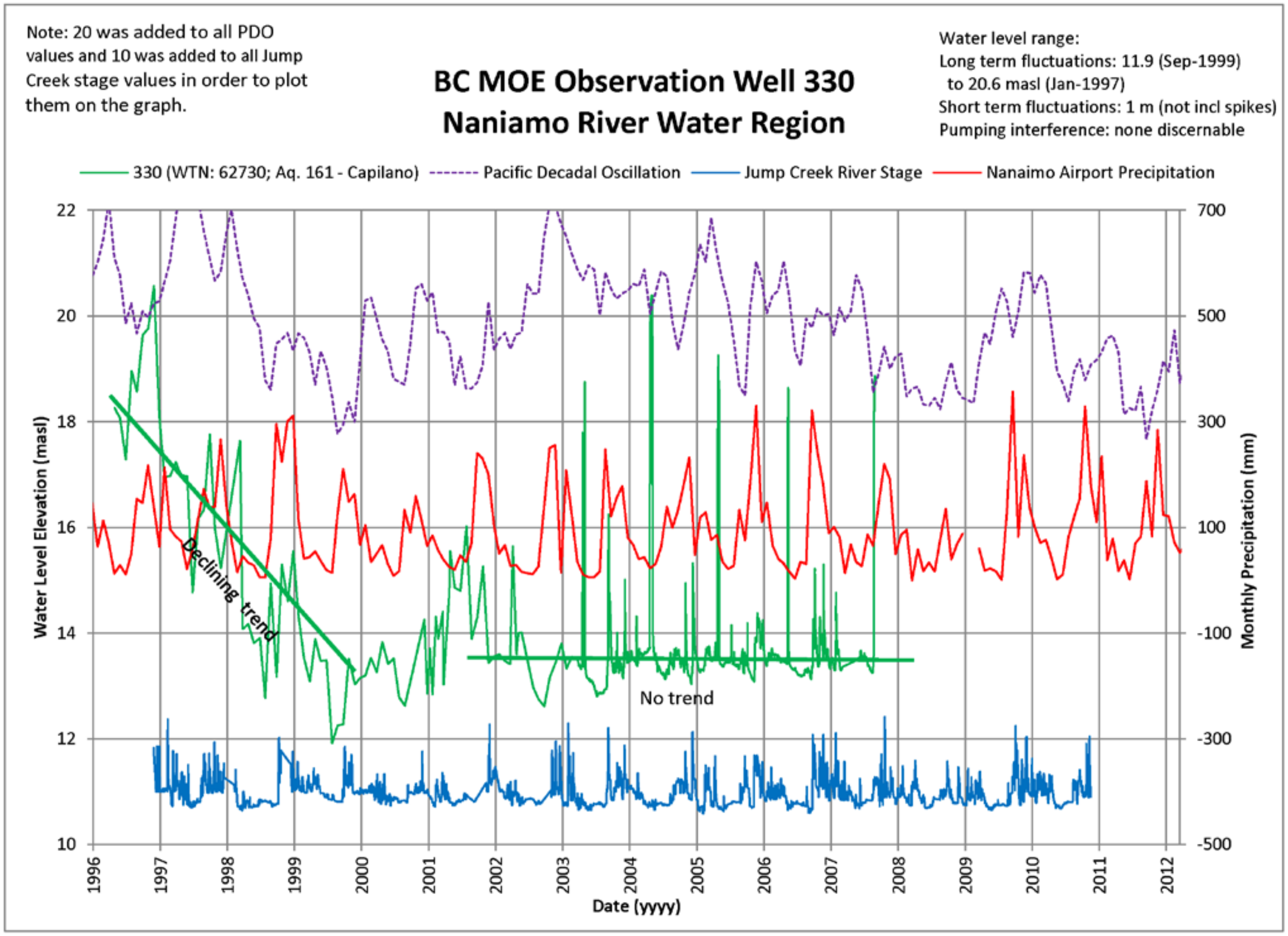

Figure 91: WR6 (NR) – Water Level Hydrograph BCMOE 330.

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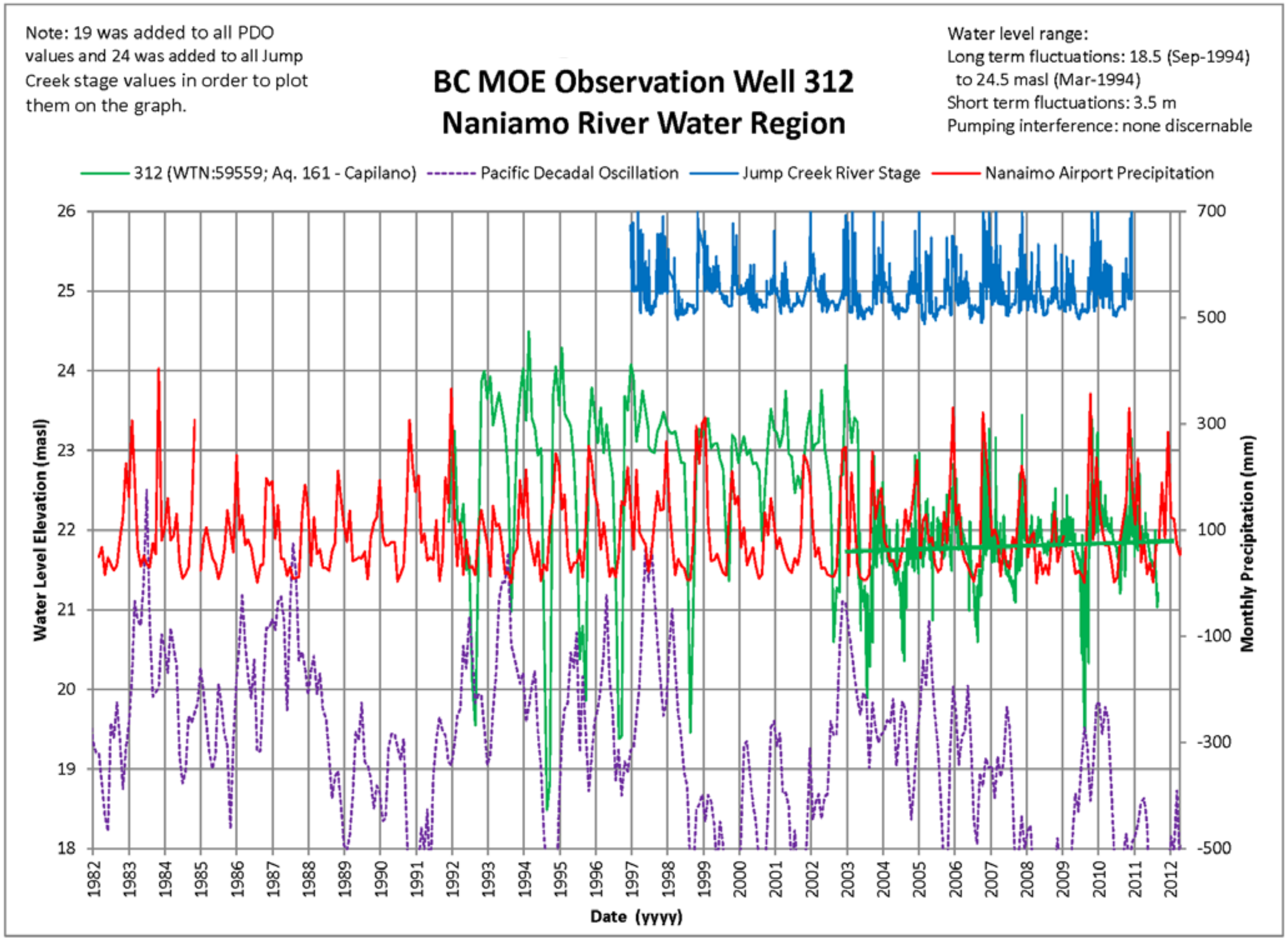

Figure 92: WR6 (NR) – Water Level Hydrograph BCMOE 312.

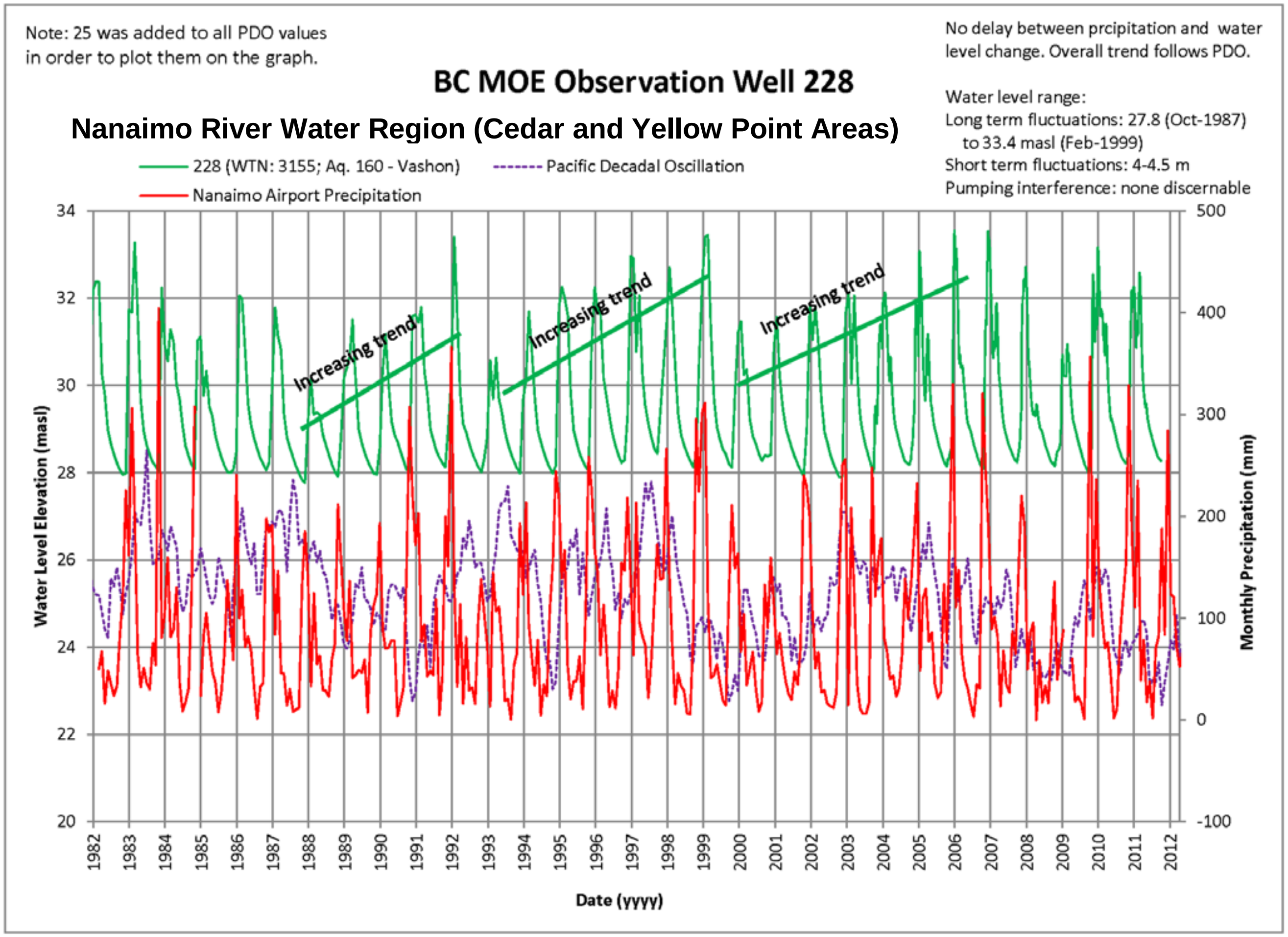

Figure 93: WR6 (NR) – Water Level Hydrograph BCMOE 228.

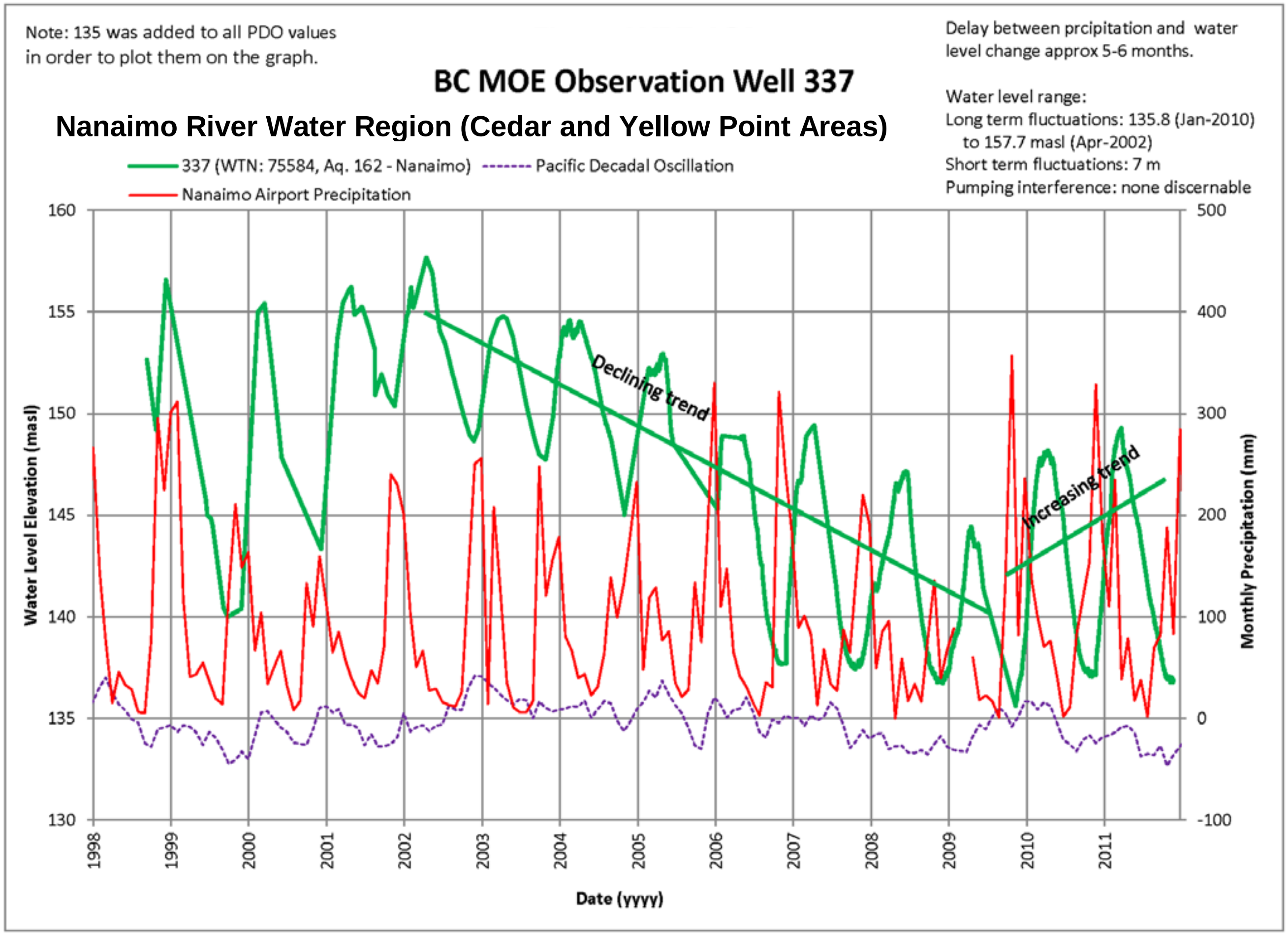

Figure 94: WR6 (NR) – Water Level Hydrograph BCMOE 337.

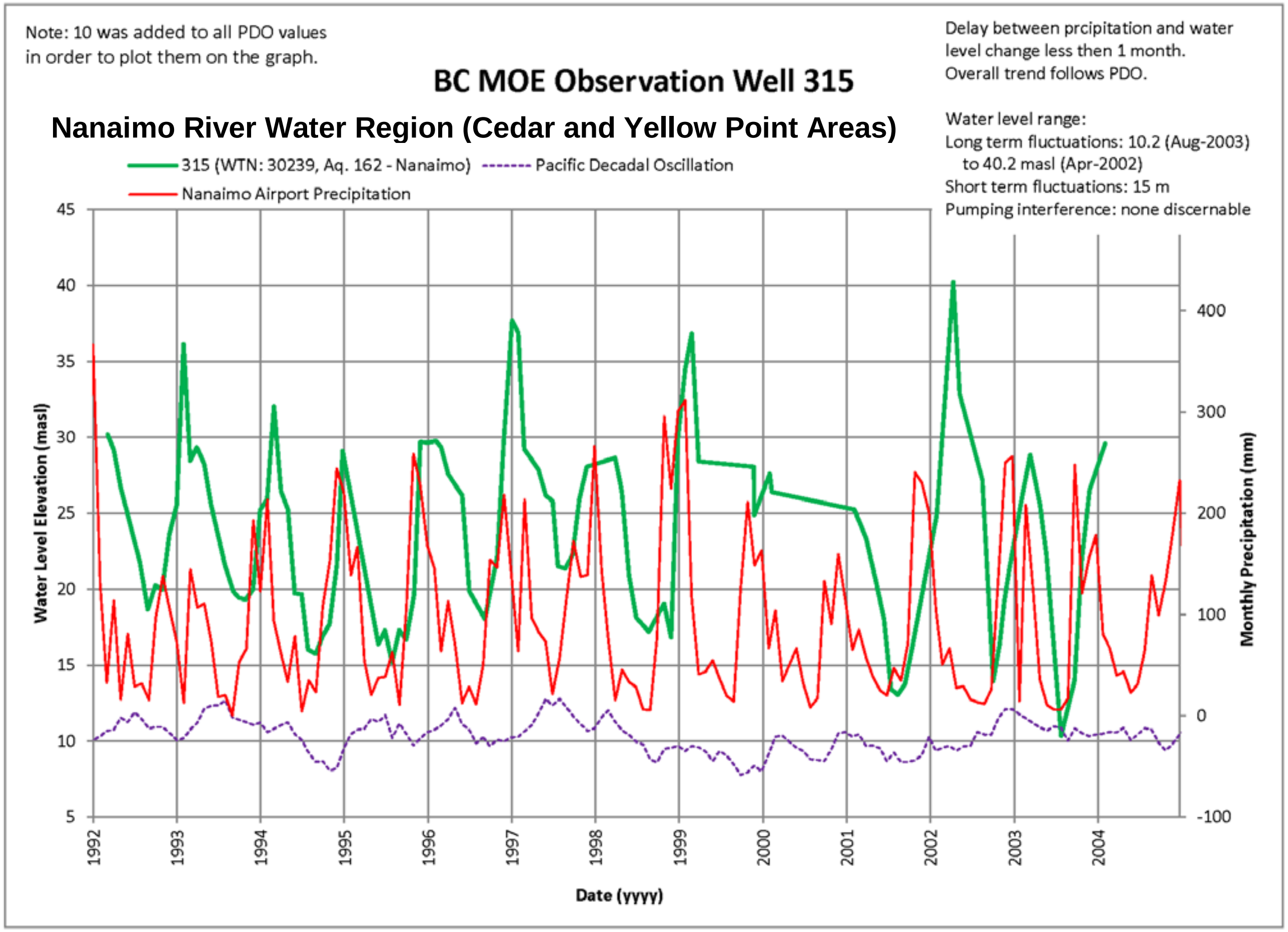

Figure 95: WR6 (NR) – Water Level Hydrograph BCMOE 315.

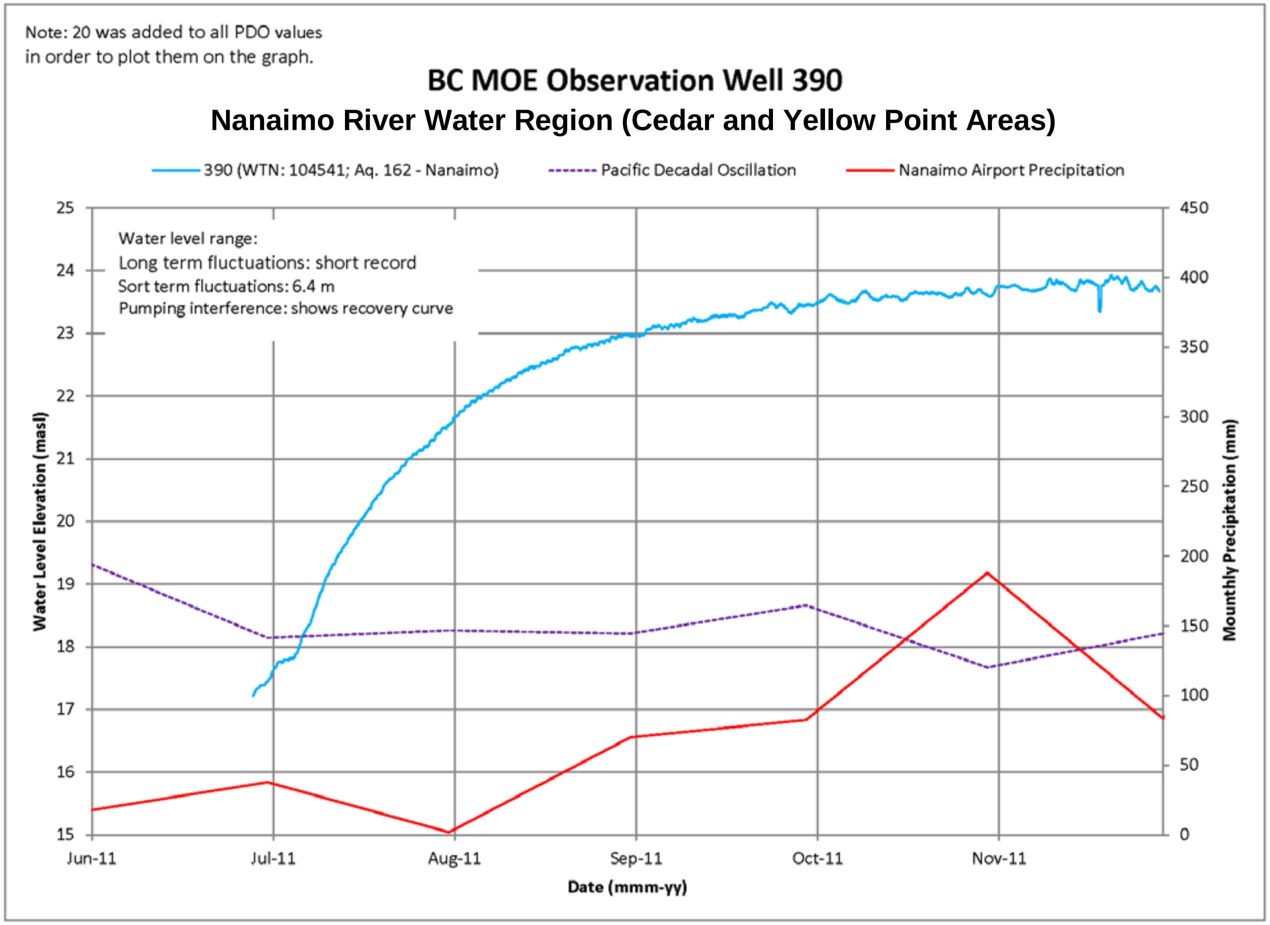

Figure 96: WR6 (NR) – Water Level Hydrograph BC MOE 331.

8.3.6 Anthropogenic Groundwater Demand

Table 60 summarizes the available groundwater demand data available for WR6 (NR).

Table 60: WR6 (NR) – Summary of Anthropogenic Groundwater Demand Analysis

Aquifer Tag No.	North Cedar Water Works	RDN DeCourcy	RDN Pylades	Snuneymuxw First Nation	Nanaimo Airport	Harmac	Other Private Wells (From RDN Water Use Est. based on Zoning compiled on GIS)	Total Ground Water Use Estimate (ANTHout)
	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)	(m^3/yr)
160	NA	NA	NA	NA	2.7E+03	NA	0.0E+00	2.7E+03
161	4.5E+05	NA	NA	?	2.7E+03	3.0E+07	2.0E+06	3.2E+07
162	NA	1.0E+03		NA	NA	NA	1.1E+07	1.1E+07
163	NA	NA	NA	NA	NA	NA	3.1E+05	3.1E+05
164	NA	NA	NA	NA	NA	NA	8.5E+05	8.5E+05
165	NA	NA	NA	NA	NA	NA	1.8E+06	1.8E+06

Notes: NA means not applicable, ? Means not known or unavailable, ANTHout means anthropogenic water extraction from aquifer.

The annual water use for serviced areas within the RDN (large municipal users, RDN wells, and private utilities) is typically measured and was provided by the RDN or taken from annual reports for 2010. The groundwater demand estimate for non-service areas was calculated from water use data provided by the RDN for serviced areas, and then applied to non-serviced areas based on civic addresses and zoning classification. Harmac appears to be the largest single user of groundwater in the region. The method of assessment is further described in Appendix C (Map C21) and Appendix D.

There may also be groundwater discharging from aquifers that is required for conservation of flow in creeks and rivers based on the physical model developed by Waterline. The total groundwater demand for each aquifer, including conservation flow requirements, was compared against the estimated aquifer recharge to assess the stress on each aquifer. The results are presented in the following section.

8.3.7 Aquifer Water Budgets and Stress Analysis

Table 61 provides a summary of the final water budget calculations for each aquifer mapped within WR6 (NR). Detailed water budget calculations are provided in Appendix D (Tables D7 and D8). Water budgets for aquifers that extend from one water region to an adjacent water region (E.g.: Aquifer 161 and 162, Figure 90) were completed as a single aquifer, respectively, regardless of the RDN boundary. The rationale for this was that despite the jurisdictional issues, the RDN will need to consider the water demand and balance for the entire aquifer, not just that portion that lies within its boundary.

Based on the water budget estimates for mapped aquifers within WR6 (NR), moderately high to highly stressed aquifers appear to dominate this region. Only aquifer 165 located in South Wellington exhibits a moderate stress level. The most stressed aquifers include the Upper Cassidy Aquifer (161), the Cedar Yellow Point aquifer (162), and the small Quadra Aquifer 163 mapped near the Holden Cross Road and Haro Road. Many of the aquifers have moderate to higher density wells that likely contribute to well to well interference, particularly in the lower productivity bedrock aquifers with limited recharge.

As indicated above, there are a total of 2686 overburden and bedrock wells listed in the MOE data base in WR6 (NR) which represents the largest number of wells in all of the 6 water regions across the RDN on Vancouver Island. It is also recognized that this number may only represent as little as 50% of water wells actually in operation in this region. This clearly shows that the demand for groundwater in WR6 (NR) is very high and that there is an urgent need to better manage groundwater extraction in this region.

Aquifer stress in this region is primarily due to anthropogenic water use and the lack of monitoring which would otherwise allow proper management of aquifer levels. The main reason for the high indicated stress on Aquifer 163 is due to the small areal extent of the mapped aquifer which limits recharge, and the agricultural water demand values assigned base on the method described in Appendix C (Map C21).

More accurate water budget and aquifer stress estimates could only be accomplished using a computer modelling approach, but again the lack of aquifer data would likely render this exercise inconclusive as well. Rigorous testing requirements and complete aquifer test analysis by groundwater practitioners to determine aquifer transmissivity and storativity properties, in addition to long-term groundwater monitoring data in each aquifer would be required to fully assess the actual stress on each aquifer in this region.

Table 61: Summary of Aquifer Stress Analysis – WR6 (NR)

Aquifer Tag No.	Aquifer Lithology	Potential Groundwater-Surface water or Aquifer to Aquifer Interaction	MOE Obs Well	Seas. Fluc.	Long Term Fluc.	WL Trend (up or down)	Total Est. AQ. Rec. (TRin) (Rp/l + Rmb)	Est. Ann. Disch to Cr. & Down Grad Aquifer (Tc out)	Ground Water Use Estimate (ANTHout)	Total Out [TcOut + $ANTH_{out}$]	Stress Anal. % GW Use of the avail. AQ. Rec.	Relative Stress Assess.
			ID	(m)	(m)	U/D	(m^3/yr)		(m3/yr)	(m^3/yr)	(%)	Lo, Mod, Hi
160	Vashon	NR	228	4, 4.5	0	L	1.26E+07	7.84E+06	2.7E+03	7.8E+06	62	Mod-Hi
161	Capilano	NR	330, 312	0, 3.5	9, 6	Aban., D/L	1.26E+08	1.05E+08	2.0E+07	1.2E+08	99	Mod-Hi
162	NG	NR, Ocean	337, 315, 390	7, 15	5, 10	D/L	1.30E+07	3.31E+06	1.1E+07	1.4E+07	110	Hi
163	Quadra	Ocean	?	?	?	?	2.87E+05	1.14E+06	3.1E+05	1.4E+06	502	V.Hi
164	NG	NR	?	?	?	?	1.11E+06	5.05E+03	8.5E+05	8.6E+05	77	Mod-Hi
165	NG	NR	?	?	?	?	3.20E+06	4.13E+05	1.8E+06	2.2E+06	68	Mod

Notes: NR means Nanaimo River, NA means not applicable, AQ means aquifer, Seas. Fluc. means seasonal fluctuation, PDO means Pacific Decadal Oscillation, WL means water level, Est means estimated, Disch. means discharge, Rec. means recharge ,Cr. Means creek, TRin means total recharge into aquifer, Rp/l means total recharge from precipitation and/or leakage from overlying aquifer, Rmb means total lateral recharge from upgradient aquifer or mountain block, Tc out means total aquifer groundwater discharge to creek, assess. means assessment , Total out means total discharge from aquifer (not including discharge to ocean), ANTH out mean total groundwater Anthropogenic groundwater extraction from aquifer, aquifer stress color codes: blue=low, green =low to moderate, yellow =moderate, brown =moderate to high, red=high to very high .

8.4 Water Management Planning Within WR6 (NR)

General guidance on water management planning for all water regions is provide in later sections of this document. Specific to WR6 (NR), the following recommendations are presented for consideration by RDN to improve the state of knowledge in the water region:

- At least one observation well should be installed in each mapped aquifer. Mapped aquifers that currently do not have MOE observation wells include Aquifer 164 and 165;
- Well owners should identify the MOE well plate and tag numbers for each of their active water wells. In this manner, water use and monitoring data can be easily cross-referenced with the BC MOE well records. These included North Cedar Water Works wells, RDN DeCourcy well(s), Nanaimo Airport wells, and Harmac supply wells;
- The significant recharge area map needs to be further updated by further processing of the NRCAN remote sensing data and by field verification;
- Further mapping of the groundwater surface water interactions is also required in Haslam Creek and the Nanaimo River to confirm the interactions between mapped aquifers 161 and 160. Waterline recommends specialized analysis (E.g.: isotopes[29], noble gases) of groundwater samples in this region to assist in determining groundwater age and origin. Thermal imaging of the river during high and low flows may help to quickly pinpoint areas where more detailed studies may be required;
- Reactivation of WSC surface water gauging station for Haslam Creek (08HB003) is recommended;
- Summer base flows (June to Sept) in Hokkenen Creek and Holden Creek should be collected as part of the Community Watershed Monitoring Network to gain a better understanding of summer base flows in smaller watersheds in the region; and
- Reservoir level and discharge data for Jump Creek and Forth Lake should be collected from the City of Nanaimo and Harmac at regular intervals and uploaded to the regional water database.

9.0 KNOWLEDGE AND DATA GAPS

9.1 Early Warning Monitoring and Cumulative Effects Analysis

Although an abundance of water-related information is being collected each year within the RDN, insufficient regulatory guidance and the inability of MOE/RDN to electronically track this information creates large data/knowledge gaps. This severely impedes the RDN's ability to properly manage watersheds and aquifers in a sustainable manner. In the absence of regulatory guidance, water users and groundwater practitioners are left to develop studies that may not be consistent with other studies or may not sufficiently advance the state of knowledge in a watershed or water region. Studies are often focussed on local scale issues, whereas a more regional approach may be necessary to understand the project impact and cumulative effects of numerous water users in a water region. There is a need for developing a consistent approach and consistent data requirements for all water-related studies.

Monitoring of surface water and groundwater use and its corresponding effects on creek/river flows and aquifer performance will provide an early warning system to help prevent over use. It is

[29] Chemical elements of the same family but with different atomic weights. Technique is used to assess origin, recharge elevation, and age of water.

the only way that cumulative impacts to a watershed and underlying aquifers can be accurately quantified and appropriate water resource management strategies developed. In the absence of these data, unrestricted extraction of groundwater in particular, can lead to aquifer dewatering and supply wells running low or dry without much notice. This was the case in the Cowichan Valley Regional District in the summer and early fall of 2012 when low flows and declining groundwater levels reached critical levels.

Typical groundwater studies submitted for subdivision approval in BC involves a 100 day predictive calculation to accommodate for seasonal fluctuations in water levels. Although these short-term predictive assessments may be adequate for addressing seasonal variations, the approach is inadequate for planning community water supply that extend over a lifetime (100 years or more).

It is imperative that cumulative effects analysis becomes standard hydrogeological practice for confirming water supply in advance of land development. Submission of groundwater monitoring and following up with submission of aquifer performance data, once a groundwater supply system becomes operational, should also be required to confirm theoretical predictions upon which the approval was granted. In the absence of regulatory guidance, there is limited opportunity to properly manage water resources within the RDN such that sustainable use can be achieved.

9.2 Mandatory Submission and Review of Well Logs

An electronic tracking system for assigning well permit, well tag, and mapped aquifer numbers is needed. This information can provide the cross-referencing of production well logs with monitoring information needed to develop accurate water budget estimates. The system should be universally applied to all water wells but consideration should also be given to include other types of monitoring wells that are drilled for investigative purposes. These may include environmental monitoring wells, wells used for remediation, geotechnical wells, geothermal wells, etc…. The rationale is that any activity occurring in the subsurface that has the potential to affect the quality or quantity of fresh groundwater resources needs to be considered as part of water resource management planning. Waterline understands that extending the requirements beyond water supply wells would create some challenges. However; it should be noted that protection of fresh water resources for present and future residents of RDN/BC is at stake.

Hydrogeologists rely on high quality well data to complete groundwater related assessments, therefore it is essential that more effort be made to elevate the quality of data collected by drillers and ultimately compiled in the MOE Wells database. This should be done in coordination/consultation with the BC Water Well Drillers Association. A system is needed that makes it easy for drillers to submit high quality well log information to MOE. Well log information should also be reviewed by a hydrogeologist prior to uploading to the BC Wells database to ensure that all information is being captured. This includes well screen interval, lithology/aquifer name, pumping test data, hand held GPS location, etc…. Although this may seem an onerous and expensive task, it would more than offset the long-term cost of installing new MOE wells or conducting countless studies to try to sort out the information at a later date.

Mandatory submission of all well logs should be made a requirement. At present, provincial legislation calls for voluntary submission to MOE. This is problematic as some drillers have elected to not submit logs to MOE. In the absence of provincial legislation, a stronger stance is required by the BC Water Well Drillers Association to make on-going licensing of drillers conditional on the submission of high quality well logs. Every well drilled in an aquifer within the RDN should be treated a potential monitoring point from which conceptual hydrogeological models can be developed and sustainable groundwater management can be accomplished. The public should be made aware that groundwater is a shared resource and not owned by individual landowners, despite the fact that wells and pumping equipment may be owned by individuals. Landowners are encouraged to submit well logs to MOE or the RDN as a cross-reference or check to ensure that drillers are submitting their well logs.

9.3 Standard of Practice for Aquifer Testing and Cumulative Effects Analysis

Standards of practice for conducting hydrogeological investigations are not unique to BC. Although the geology and regulatory system may differ, standard approaches to water supply investigations are well established in other jurisdictions and guidance documents have been developed which can be easily applied to aquifers in BC in the absence of formal legislation.

In advance of undertaking the water budget project, MOE reviewed historical groundwater study files and undertook the re-interpretation of over 100 aquifer tests conducted within the RDN over the last 20 years or more in an effort to estimate the hydraulic parameters of mapped aquifers. This exercise provided fundamental information required by Waterline for completing preliminary water budget assessments. Such analysis should be made a requirement every time an aquifer test is conducted.

Controlled aquifer testing is needed to quantitatively assess hydraulic characteristics of aquifers (transmissivity and storativity) and to fully assess the lateral extent, geometry, and aquifer boundaries. These data are essential for improving water budget calculations. There is an opportunity to collect high quality aquifer testing and groundwater monitoring information with every groundwater study or new well that is drilled and tested within the RDN. However, a clear and concise guidance document for individuals involved in aquifer testing and analysis (well owners, drillers, pump installers, and hydrogeologists) must be made available by the RDN. BC Certificate of Public Convenience Certificate Application Guideline is a useful reference and can be found at the following web address:
http://www.env.gov.bc.ca/wsd/water_rights/water_utilities/cabinet/appen5_guidelines_for_groundwater_reports_and_%20well_testing.pdf

There are numerous existing documents from other jurisdictions that provide similar guidance, such as Alberta Environment's Guide to Groundwater Authorization (updated March 2011). This document provides an excellent reference for groundwater practitioners detailing groundwater investigation and analysis approach. The document can be viewed at the following web address: http://environment.gov.ab.ca/info/library/8361.pdf.

There is also a need for assessment of cumulative effects for all new projects being proposed within the RDN if a stable, long-term groundwater supply is required. The standard practice by groundwater practitioners has generally been to complete a well capacity rating over a 100 day period to assess if sufficient supply exists for a newly proposed development. This practice is inadequate for considering the long-term cumulative effects of groundwater extraction on individual aquifers or even areas within aquifers. As was demonstrated with the long-term climate variability assessment using the Pacific Decadal Oscillation, it is possible to slowly dewater an aquifer during long periods of pumping as the total recharge to an aquifer declines over decades.

The situation in WR3 (FC) is a good example of how short-term predictive assessment is inadequate for planning community water supply that extends over a lifetime (100 years or more).

9.4 New MOE/RDN Observation Wells

The availability of high quality monitoring data will serve to increase the accuracy and certainty of water budget assessments. This will be important as the RDN moves to proactive watershed management planning and increasing the Tier level of assessment similar to the approach taken by the Ontario Ministry of Natural Resources (OMNR 2011). As indicated in the final summary of water budgets developed for each water region, at least one observation well should be installed in each mapped aquifer. There is also a need for coordinated regional water level monitoring in private wells so that present-day water table geometry (piezometric surface for confined aquifers) can be determined and areas of excessive drawdown identified. Some of the challenges and data needs include the following:

- Capturing volunteer landowner water level and water quality data. Some effort has been made by Vancouver Island University in this regard by creating an on-line database. However; to date, very little data has been collected.
- More data is needed in highly stressed areas. The RDN plans to install data loggers in existing wells to help supplement existing water level data from MOE's observation well network. Waterline has provided recommendations to the RDN for observation well locations based on a search of the Waterline Geodatbase constructed as part of the Water Budget Project.
- Significant recharge Areas identified as part of the present study need to be further refined. Observation wells will also need to be identified in these areas as well.
- Multi-level monitoring wells will need to be installed along creek/river margins where aquifers and surface water systems are suspected to interact. Water levels in aquifers that feed base flow to rivers/creeks will need to be maintained to ensure the protection of aquatic ecosystems. Other methods may be used to better define areas of interest, including; the installation of seepage meters at the base of rivers/creeks, thermal imaging of creeks/rivers to determine areas where groundwater may be upwelling, and electrical conductivity and temperature surveys. Surface water gauging above and below a critical reach where groundwater is suspected to discharge can also be used to assess/measure groundwater interactions with rivers/creeks.
- Observation wells also need to be installed in areas along the coast where salt water intrusion may be occurring or suspected to occur. Proper instrumentation including data loggers that measure changes in electrical conductivity of the groundwater will be required.
- Although water quality could not be addressed as part of the present study, largely due to the poor condition of the electronic data, future studies need to consider water quality assessment as it provides further confirmation on regional linkages between aquifers and surface water flow regimes.

9.5 Reactivation of Discontinued Water Survey of Canada Gauges

Some of the major creeks and rivers within the RDN lack surface water flow data. Although new hydrometric stations may be required, an immediate and less expensive solution would be to reactivate previously discontinued Water Survey of Canada gauges. This approach requires less work as rating curves are already established and historical data already exists. There may also be a need to install new hydrometric stations in un-gauged creeks/rivers which has already been discussed for each specific water region.

9.6 Reporting System to Track Surface and Groundwater Use

The MOE/RDN need to establish an electronic tracking system to collect actual measured surface water and groundwater use information. As was shown for the Nanaimo River surface water budget assessment, using the licensed allocation values to complete the water budget calculation is misleading and may incorrectly indicate the level of stress on the river. Groundwater extraction volumes for large users also need to be tracked in a consistent manner. The RDN water service data is in a relatively good condition, however; data for large municipal users or private utilities was not always available. The Water Use Reporting Tracker web application previously developed by Vancouver Island University, or currently being developed by the Okanagan Water Basin should be considered for this purpose.

10.0 Recommended RDN Action Plan

10.1 Provincial and/or Local (RDN) Regulatory Guidance

Provincial regulatory change is underway with the BC Water Act modernization process (http://livingwatersmart.ca/water-act/groundwater.html) initiated in about 2005. However, after about 6 years of public consultation, MOE officials have indicated that another 4-5 years may be needed before formal legislation is established (Ted White, February 2012). The RDN simply cannot afford to wait for provincial guidance in this matter, as some of the mapped aquifers are already showing signs of stress. Increased demand for water supply resulting from population growth and coupled with climate change predictions that will likely cause a long-term reduction in aquifer recharge, has the potential for negative impact to all aquifers within the RDN.

Surface water and groundwater protection initiatives are most often driven by regulation, policies or guidelines. Although people generally want to do what is right for the environment, the tendency is always to do the minimum requirement at the minimum expense.

The stated purpose of the Drinking Water and Watershed Protection Program is to learn more about water within the RDN, use this information to make better land use decisions, and help communities protect the environment. In order to continue to move the watershed protection and management forward, a series of guidelines will need to be developed to ensure that high quality surface water and groundwater information is collected in a suitable electronic format. Once the Waterline Geodatabase has been transferred to the RDN and a user interface constructed, the final electronic format will be determined.

10.2 Community Engagement

Community engagement is the foundation for successful water and watershed management. As part of the Drinking Water and Watershed Protection Program the RDN initiated team Water Smart in partnership with Town of Qualicum Beach, Fairwinds Community & Resort, City of

Nanaimo, City of Parksville and District of Lantzville. The proactive approach taken by the RDN and its partners in this regard is to be commended. The RDN website is a very useful resource providing the public with useful information regarding groundwater and surface water in a user friendly and easily read format. Once the final geodatabase is complete, Waterline recommends that community sessions be held where the groundwater and surface water information is openly shared and discussed with the public.

10.3 Near-Term Priorities

10.3.1 Geodatabase and User Interface

Waterline constructed a geodatabase to facilitate surface and groundwater budget assessments for each defined water region as part of the Phase One Water Budget Assessment Project. The finalized geodatabase, along with datasets are also intended to serve as a data repository for use by the RDN to store and update future water and environmental related information. It is important to have these data available electronically as the RDN moves toward fully integrated watershed planning.

The geodatabase structure developed by Waterline is intended for sole use by the RDN. It should be treated like any other software program and should not be distributed to a third party in its raw or original form. The intent is for the database to be managed and updated by/for the RDN so that high quality, up-to-date water maps and data tables can be maintained and made publically available via a web-based, secure user interface. The centralized geodatabase concept works best if the RDN is in charge of maintaining and updating the system and have control over editing and data processing.

Making the information publically available will allow water managers and practitioners to have current and consistent data future water and environmental-related projects within the RDN. It is anticipated that the web-based user interface would initially be similar to the RDN Water Map where key reports and maps are made available on-line. As the web interface is further developed, it should be possible for users to upload electronic groundwater and surface water data on-line. The data could include monthly/annual water use, water levels, water chemistry, aquifer properties interpreted from pumping test analysis, cross-sections, time-series data (MOE Hydrographs and selected water chemistry parameters), hyperlinks to raw data (BC Wells Database, WSC Time series data, VIAH water chemistry, etc…), and a geo-referenced copy of any final reports. The RDN will likely need to develop guidelines, policies, and templates for data collection and submission as part of their planning and watershed management initiatives.

Although the Phase One Water Budget is focussed on surface water and groundwater, the database can (and should) be expanded to accommodate other forms of environmental and infrastructure data (E.g.: fisheries, geotechnical, air, soil, LIDAR, land use, etc.). Waterline does not recommend separating the water-related datasets from other RDN datasets. As was demonstrated by the Waterline's work, having multi-disciplinary data allows scientists and engineers to consider human-environment interactions, and provides a basis for assessing cause and effect response in surface water or groundwater/aquifer systems.

The hope is that every water study or related environmental study that is completed within the RDN will allow for the advancement of knowledge regarding water management and protection. This of course is the primary objective of the Drinking Water and Watershed Protection Program. The database system will allow for the filling of data gaps mentioned previously, and also provide a basis for the RDN and its partners to initiate more detailed assessments required for accurate water budgeting and watershed management.

10.4 Medium-Term Priorities

10.4.1 Focus on Areas of High Stress

Major watersheds exhibiting moderately high to high apparent stress include the following:

- French Creek,
- Nanoose Creek,
- Chase River, and
- The Nanaimo River.

Mapped aquifers exhibiting moderately high to high apparent stress include the following:

- Quadra Sand Aquifer 421 located in WR1 (BQ) adjacent to Nile Creek;
- Haslam Formation Bedrock Aquifer 220 which extends across 3 regions including WR1 (BQ), WR2 (LQ), and WR3 (FC);
- Vashon (Kame) Aquifer 663 at the top of Whisky Creek in WR2 (LQ);
- Quadra Sand Aquifer 217 extending from WR2 (LQ) to WR3 (FC);
- Quadra Sand Aquifer 216 in WR3 (FC) and extending into WR4 (ER);
- Buttle Lake Group Bedrock Aquifer 210 in upper Nanoose Creek;
- Benson Formation bedrock Aquifer 218 located on the Nanoose Peninsula;
- Quadra Sand Aquifer 215 beneath the District of Lantzville;
- Vancouver Group and Nanaimo Group bedrock aquifer 211 located at Benson Meadows;
- Upper Cassidy (Capilano) Aquifer 161;
- Nanaimo Group bedrock Aquifer 162 located in the Cedar-Yellow Point Area; and
- Quadra Sand Aquifer 163 located in an isolated pocket in the Cedar area.

Waterline recommends that the RDN select one or two water regions to complete Tier 1 or 2 Water Budget assessments (OMNR 2011). This allows RDN to develop a complete template for future water planning in all water regions across the RDN. It may make sense to select area in Nanaimo Lowland so that numerical modelling being completed by the Geological Survey of Canada can be used to further refine aquifer water budget estimates. Given the stress assessment for both surface and groundwater, the French Creek Water Region may be a suitable candidate for a pilot study.

10.5 Long-Term Priorities

10.5.1 Other Important Data Sources

There are other important sources of geological, geotechnical and environmental data that would be useful to have compiled in the Geodatabase. These include, but are not limited to: septic suitability studies; geotechnical investigations; fisheries in stream flow suitability surveys, water quality reports and contaminant/environmental investigations.

10.5.2 Remote Sensing Data (Land Cover & LAI)

The significant recharge area map needs to be further updated by further processing of the NRCAN Remote sensing data. The present Phase one Water Budget study is only accurate to 1 km^2 due to the limitation of the surface water model and computation time. These data should be verified in the field to confirm the assessment provided as part of the Waterline study. Some of the areas identified may occur on private land and any protection measured developed by the RDN need to take these and other issues into consideration. It is also possible to further refine the data to a 10 m^2 grid accuracy which would improve the maps provided in this report.

10.5.3 LIDAR Data

All Waterline geodata was referenced to 1:20,000 elevation trim data which has an accuracy of +/- 10 m. Although it may be sufficient for regional mapping scale to develop conceptual level assessments, it may not be sufficiently detailed for Tier 1, 2 or 3 assessments (OMNR 2011). For instance, development of geomodels near the coast and assessment of the potential for salt water intrusion risk may not be possible to ensure protection and management strategies can be developed. Competing LIDAR surveys over the entire RDN could help resolve this issue. Although not currently a priority, Waterline recommends that the RDN consider running LIDAR so that all data contained in the geodatabase can be referenced to a more accurate datum.

11.0 CLOSURE

Surface and groundwater are renewable resources but a balance must be struck between water needed to maintain healthy ecosystems and the demand for water by humans. Although the Phase One Water Budget project sets the framework for assessing water availability versus water demand, considerable gaps exist in the data which need to be filled to provide a more accurate picture of current and future water conditions. The objective in water management is to achieve “sustainability" of water resources. This is simply not possible in the absence of proper monitoring data.

The BC Water Act Modernization process appears to be focussed on public consultation and attempting to address the issue of water rights which has caused considerable delay in developing legislation. No matter who owns the rights to the water, sustainable management practices need to be implemented as water supply wells continue to be drilled and aquifers exploited as the demand for water continually rises.

Approaches to water management are relatively well understood and not unique to the province British Columbia. Developing guidelines that lead to improved knowledge of surface water and groundwater systems within each water region has been done by other jurisdiction across

Canada and is simply good practice. The absence of Provincial guidelines which include standards of practice for all water practitioners and mandatory monitoring and data submission requirements (i.e.: well logs are only one example), risks the continuance of non-sustainable water management practices.

On-going land development and increasing water demand, combined with the potential effects of climate change will undoubtedly continue to place stress on surface water and groundwater resources in ways that we cannot predict or understand with current datasets. The RDN has taken a proactive step with the initiation of the phase one water budget project. The cooperation of residents, water purveyors, drillers, water practitioners, corporations, municipal/provincial/federal regulatory officials is needed in order to move forward to a sustainable future.

Respectfully submitted,

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12.0 REFERENCES

Andre Pugin, 2011. Natural Resources Canada GSC Seismic, Geological Survey of Canada.

Associated Engineering (2007) South Nanaimo River-Watershed Yield Assessment (2007).
Ministry of Agriculture and Lands (2013). Water Demand Model

BCGOV ENV Water Protection and Sustainability Branch, 2008 (revision). Ground Water Wells (Spatial View). downloaded from https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=49998 in February 2012.

BCGOV ENV Water Protection and Sustainability Branch, 2012 (Revision). Ground Water Aquifers downloaded in March 2013. URL: https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=3841.

BCGOV ENV Water Protection and Sustainability Branch , 2012. Aquifer Classification Database. Data available from https://a100.gov.bc.ca/pub/wells/public/common/aquifer_report.jsp, 2013

BCGOV ENV Water Protection and Sustainability Branch, 2013 (Revision). Ground Water Aquifers downloaded from https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=3841 in 2013

BC MELP, 1996. BC Ministry of Environment, Lands and Parks. Regional Water Management Policy of Vancouver Island. Vancouver Island Region. Nanaimo, BC.

BC Ministry of Agriculture, Food, and Fisheries, (2002). Water Conservation Factsheet Order No. 619.000-1. Downloaded fromhttp://www.agf.gov.bc.ca/resmgmt/publist/600Series/619000-1.pdf in June 2012.

BC MOE (2012). Ministry of Environment; Government of British Columbia. BC Observation Well Network Time Series data. Downloaded In February 2012. URL: http://www.env.gov.bc.ca/wsd/data_searches/obswell/map/obsWells.html

BC MOE (1993). Nanaimo River Water Management Plan. Downloaded from http://www.env.gov.bc.ca/wsd/water_rights/wap/ in June 2012.

Boom, A. and G. Bryden 1994: Englishman River Water Allocation Plan. British Columbia Ministry of Environment, Lands and Parks, Vancouver Island Region. Downloaded from http://www.env.gov.bc.ca/wsd/water_rights/wap/ in June 2012.

Braybrook, C., G. Bryden and A. Dambergs 1995: Nile Creek to Trent River Water Allocation Plan. British Columbia Ministry of Environment, Lands and Parks, Vancouver Island Region. Downloaded from http://www.env.gov.bc.ca/wsd/water_rights/wap/ in June 2012.

Bryden. G., T.J. Welyk and S. Gannon, 1994: French Creek Water Allocation Plan. British Columbia Ministry of Environment, Lands and Parks, Vancouver Island Region. Downloaded from http://www.env.gov.bc.ca/wsd/water_rights/wap/ in June 2012.

Carmichael, V. (2012). Summary tables of Aquifer parameter values for historical water wells tests perform across RDN. Provided to Waterline in Excel Format, March 2012.

CDNGOV Environment Canada, 2004. Climate Station. Downloaded from https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=7270&recordSet=ISO19115 in February 2012.

CDNGOV Statistics Canada, 2009. Census Division Boundaries. Downloaded from https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?from=search&edit=true&showall=showall&recordSet=ISO19115&recordUID=56799 in February 2012

Cook. B. and J. Baldwin, 1994: Chase to Nanoose Water Allocation Plan. British Columbia

Donnelly, M., (2012). Personal communication regarding Qualicum Beach and Horne Lake WWD discharging water to Nile Creek for river level conservation measures.

Donnelly, M (2013) Personal Communication regarding the addition of new MOE wells in the RDN.

Earle, S. PhD. (2007) Geology and Geological History of Vancouver Island. Vancouver Island University, Department of Geology.

EBA Engineering Consultants Ltd. (2006) New Production Well Madrona Well #8.

EBA Engineering Consultants Ltd. (2005) Madrona Heights Water Supply Assessment.

EBA Engineering Consultants Ltd (2005). Mt. Arrowsmith Final Aquifer Modeling Project, Parksville Area.

EBA Engineering Consultants Ltd. (2005) Well Protection Plan and Groundwater Monitoring Plan for River's Edge Subdivision (Block 564).

EBA Engineering Consultants Ltd. (2004) Report on Testing of Water Source Well PW2.

EBA Engineering Consultants Ltd. (2004) Water Supply for Subdivision of Block 564.

EBA Engineering Consultants Ltd (2003). Drinking Water Protection Plan – Mt. Arrowsmith Watersheds.

EBA Engineering Consultants Ltd. (2003) Preliminary Hydrogeological Assessment of Water Supply for Proposed Rural Residential Subdivision.

EBA Engineering Consultants Ltd. (2002) Hydrogeological Assessment for Proposed Subdivision.

Farmwest Model (2012) Pacific Field Corn Association in partnership. URL: http://www.farmwest.com/climate/et

Floyd, W., 2012. Snowmelt Energy Flux Recovery during Rain-on-snow in Regenerating Forests. Thetis submitted for partial fulfillment for degree of doctor of philosophy. University of British Columbia.

Fyles, J. G., 1963, Surficial geology of the Horne Lake and Parksville map-areas, Vancouver Island, British Columbia. Geological Survey of Canada, Mem. 318, 142p.

GW Solutions, Vancouver Island University (2010) Area A Groundwater Assessment and Water Budget.

Hamon, W.R., 1961. Estimating potential evapotranspiration. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, v. 87, p. 107-120.

HB Lanarc, (2010). Drinking Water & Watershed Protection. Watershed Snapshot Report 2010.

Hodge Hydrogeology Consulting (2009) Nanoose Well No.7 (Claudet Rd) Report Addendum.

Hodge Hydrogeology Consulting (2009) 2009 Pumping Test Results- ADDENDUM to report, Claudet Road.

Hodge Hydrogeology Consulting (2009) Report on Groundwater Quantity and Quality for PW1-2008, Lot 1, Plan 26234, DL 62, Claudet Road, Nanoose Land District, BC.

Hodge Hydrogeology Consulting (2008) Testing of TW1-07 Claudet Road / Nanoose, BC.

Jungen, J.R., 1940. Soils of Southern Vancouver Island, Ministry Of Environment Surveys Resource Mapping Branch. Technical Report 17.

KWL, 2010. Englishman River Hydrological Modeling Study.

Land Cover Appendix: NRCANs remote sensing (Sephy downloaded]

Tennant, D.L. 1976. In stream flow regimens for fish, wildlife, recreation and related environmental resources. Completion Report, Billings, MT: US Fish and Wildlife Service.

Lapsevic, P. (2013). MNFLRO Personal Communication regarding comments made on Waterline Draft Water Budget Report, February 2013.

Levelton (2011) RDN Observation Well Holden Corso and Lofthouse Roads, Cedar.

Levelton (2009) Well Yield San Pareil Well #4 Water Supply Well.

Levelton (2009) Well Yield Confirmation Madrona Heights Subdivision.

Lowen Hydrogeology Consultants (2010). Arrowsmith Water Service Englishman River Water Intake Study Groundwater Management. Discussion Paper 5-1. Existing Groundwater Supply Evaluation and Aquifer Yield Assessment, Prepared by Dennis Lowen, Alan Kohut and Bill Hodge, January 25, 2010.

Lowen Hydrology Consulting (2006) Well Water Source Development.

McCabe, G. J. and S.L. Markstrom, 2007. A Monthly Water-Balance Model Driven by a Graphical User Interface. US Geological Survey Open-File Report 2007-1088.

Mantua, N.J. and S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American

MAL, 2013. Ministry of Agriculture, Sustainable Agriculture Management Branch. Agricultural Water Demand Model. Results submitted to RDN 2013-04-17.

Meteorological Society, 78, pp. 1069-1079. M.C. Wright & Associates , 1995, Whalley Creek Fish Habitat Assessment.

Metherall, C. (2011a). Personal Communication regarding GSC Nanaimo Lowland Study. RDN Drinking water and watershed protection coordinator.

Metherall, C. (2011b). Personal communication with Christina Metherall. RDN Drinking water and watershed protection coordinator.

Minobe, S. 1997: A 50-70 year climatic oscillation over the North Pacific and North America. Geophysical Research
Letters, Vol 24, pp 683-686.

Ministry of Environment, Lands and Parks, Vancouver Island Region. Downloaded from http://www.env.gov.bc.ca/wsd/water_rights/wap/ in June 2012.

Ministry of the Environment (1994). French Creek Water Allocation Plan.

Ministry of Water, Land and Air Protection Ministry of Sustainable Resource Management Nanaimo Regional Office (2002) French Creek Watershed Study.

Muller, J. E. and J. A. Jeletzky, 1970, Geology of the Upper Cretaceous Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia,

Ontario Ministry of Natural Resource (2011). Water Budget & Water Quantity Risk Assessment Guide. Drinking Water Source Protection Program. Prepared by Aqua Resources.

Pacific Hydrology Consultants Ltd. (1997). Completion Report: Installation and Testing of Well 8-97 and Re-evaluation of Groundwater Supply Potential of Quadra Sand Aquifer at Deep Bay.

Pacific Hydrology Consultants Ltd. (2007). Groundwater Study at Deep Bay Waterworks District.

Pacific Hydrology Consultants Ltd. (2007). Completion Report: Groundwater Study at Deep Bay Waterworks District.

Pacific Hydrology Consultants Ltd. (1990) Pump Testing and Capacity of Hills of Columbia Well No 7.

Pacific Hydrology Consultants Ltd. (1994) Construction and Testing of New Test Wels R-1 and R-4 and Testing of Existing Anderson Test Well I-88 for French Creek Estates in the French Creek Area of Vancouver Island.

Pacific Hydrology Consultants Ltd.. (1994) Completion Report: Test-Production Drilling/Well Construction and Capacity Testing of Hills of Columbia Well 11-94 in the French Creek Area of Nanoose District.

Pacific Hydrology Consultants Ltd. (1994). Construction and Testing of Test Wells R-5 and R-8 for French Creek Estates in the French Creek Area of Vancouver Island.

Pacific Hydrology Consultants Ltd. (1995) Construction and Testing of Test Wells R-7 and R-7A for French Creek Estates in the French Creek Area of Vancouver Island.

Pacific Hydrology Consultants (2006) Groundwater Report and Well Test Analysis of Proposed Rascal Lane Well.

Pacific Hydrology Consultants Ltd. (2003) Groundwater Source Evaluation RE Capacity Testing of Water Well at Rascal Trucking Gravel Pit.

Pacific Hydrology Consultants (1991) Completion Report – Evaluation of Confirmatory Pump Testing of Ring Contracting (Madrona No. 7) Well.

Pacific Hydrology Consultants Ltd. (1984) Progress Report – Test Drilling Program – Madrona Point Water System.

Pacific Hydrology Consultants Ltd. (1984) Capacity of Madrona Point Well No. 2.

Pacific Hydrology Consultants Ltd. (1986) Madrona Water Specified Area – Test Production Drilling & Construction & Testing of Madrona Point Well No. 4.

Pacific Hydrology Consultants Ltd. (1987) Madrona Water Specified Area – Construction & Testing of Wells No. 5 & No. 6.

Pacific Hydrology Consultants Ltd. (1988) Completion Report – Construction & Testing of Fairwinds Test Well No. 1.

Pacific Hydrology Consultants Ltd. (1990) Completion Report – Construction & Testing of Fairwinds Wells 2 and 3.

Pacific Hydrology Consultants Ltd. (2007) Nanoose Bay Water Supply Fairwind Well#3 Pilot Study Report.

Pacific Hydrology Consultants Ltd. (1990) Completion Report - Test Production Drilling, Construction and Testing of Production Well – Lot A DL 22 Plan 445R Nanoose District.

Pacific Hydrology Consultants Ltd. (2008) Completion Report Evaluation and Capacity Testing of Fairwinds Community & Resort Wells 3-08 4-08 5-08.

Pacific Hydrology Consultants Ltd. (1990) Evaluation of the Capacity of Craig Bay Estates Campground Well No. 2-1984 and potential for developing Additional Groundwater Supplies for Golf Course Irrigation at Craig Bay Estates.

Pacific Hydrology Consultants Ltd. (2008) Water Source Assessment Study for Electoral Area E.

Pacific Hydrology Consultants (1990) OCI Boat Harbour Development - Water Supply Completion Report.

Paradis, D. (2013). Personal communication regarding the GSC drilling program conducted in March 2013 near the Kame Delta aquifer (661).

Piteau Associates (1992) Water Well Testing for Pylades Development.

Piteau Associates (1995) Pylades Well – Pumping Test – 2380 Bissel Road Cedar.

Piteau Associates (2001) North Cedar Improvement District Hydrogeologic Assessment to Identify New Well Source.

Pirani, Z. and G. Bryden, 1996: Qualicum River Water Allocation Plan. British Columbia Ministry of Environment, Lands and Parks, Vancouver Island Region. Downloaded from http://www.env.gov.bc.ca/wsd/water_rights/wap/ in June 2012.

Regional District of Nanaimo, Unknown Date. Water Service Areas from the Regional District of Nanaimo in February 2012

RDN (2011) Population Statistics taken from RDN Website. URL: http://www.rdn.bc.ca/cms.asp?wpID=440

RDN Website: www.rdn.ca Drinking Water and Watershed Protection Program (DWWP).

Ronneseth, K. (2012). Personal communication via e-mail with BC Ministry of Environment (MOE) regarding updates to all the aquifer maps across the RDN.

SRK Consulting (2007) TEL_17-123-432f_rpt_Cassidy Aquifer - Completion Report.

Thorntwaite, C.W., 1948. An approach towards a rational classification of climate: Geographical Review, v. 38. p. 55-94.

Thurber Engineering Ltd. (2006) Water 2006S Nanaimo Lakes Groundwater Study.

Terracon Geotechnique Ltd. (1994) Regional Groundwater Study - Nanoose Peninsula.

Unknown Source, Date. 1: 20,000 TRIM contours from the Regional District of Nanaimo in January 2012

Van der Gulik, T., (2012). Personal communication regarding a simplified method to calculate the water demand for agricultural parcels based on Farmwest Model.

Wang, T., Hamann, A., & Spittlehouse, D. (2012). ClimateBC (Version 4.70) [Software]. Downloaded from http://www.genetics.forestry.ubc.ca/cfcg/ClimateBC/ClimateBC.html in June 2012

Wang, T., Hamann, A., Spittlehouse, D., and Aitken, S. N. 2006. Development of scale-free climate data for western Canada for use in resource management. International Journal of Climatology, 26(3):383-397.

Wang, T., Hamann, A., Spittlehouse, D.L., Murdock, T., 2012. ClimateWNA - High-Resolution Spatial Climate Data for Western North America. Journal of Applied Meteorology and Climatology 51, 16-29. Data available from http://www.genetics.forestry.ubc.ca/cfcg/climate-models.html.

Wendling, G. (2012) Lower Englishman River Groundwater and Surface Water Interaction. Submitted to Mid Vancouver Island Habitat Enhancement Society.

Westrek Geotechnical Services Ltd., (2012, May 3). Surficial Geology Suitability Analysis for Mass Carcass Disposal Sites for the Nanaimo Regional District.

Winkler, R. 2010. Weather – Snow Measurement: Compendium of Forest Hydrology and Geomorphology in BC, Chapter 17. BC Ministry of Forest and Range. Forest Science Program. p 568 – 573.