14 December 2016

## FINAL REPORT

# Water Monitoring Plan for Nanoose (Electoral Area E), District of Nanaimo, BC

**Submitted to:**
Julie Pisani, Drinking Water and Watershed Protection
Program Coordinator
Regional District of Nanaimo
6300 Hammond Bay Road
Nanaimo, BC V9T 6N2


**Report Number: 1547004-004-R-Rev0**

**Distribution:**

1 electronic copy - Regional District of Nanaimo
1 hard copy - Regional District of Nanaimo
1 hard copy - Golder Associates Ltd.

REPORT

# Executive Summary

As requested by the Regional District of Nanaimo (RDN), Golder Associates Ltd. (Golder) developed a Water Monitoring Plan to address data gaps for Electoral Area E and provide the RDN with a dataset that could eventually support development of a numerical hydrogeological model for the area. While the focus of the Water Monitoring Plan is primarily on water quantity (i.e., supply and use that includes human and ecosystem requirements), it is anticipated that the data from the proposed monitoring locations in the Water Monitoring Plan would be considered along with water quality data from other programs to support protection and management of water resources in Electoral Area E.

Golder conducted a detailed review and analysis of background information, including the Geodatabase and hydrogeological conceptual model (Conceptual Model) that were developed under Phase 1 of the RDN's Water Budget Project. A Project Area was defined, comprising Electoral Area E and adjacent watersheds. The Geodatabase was updated with new information that has become available for the Project Area since the database was compiled in 2013, the existing climate, surface water and groundwater monitoring network was assessed, and data gaps were identified.

Seven climate stations were identified in the Geodatabase for the Project Area; however, the three stations that were formerly operated by Environment Canada are no longer active. Two active climate stations are monitored under the School-Based Network, one is monitored by the City of Parksville and one by the Fairwinds Golf Course. The existing climate stations are predominantly located in low elevation areas.

A total of 262 surface water licenses were identified for the five major watersheds and 11 sub-watersheds that are located within the Project Area. Over ninety percent of the annual licensed surface water use in the Project Area is water supply for the Englishman River for waterworks. One hydrometric station on the Englishman River is currently monitored by the Water Survey of Canada. Hydrometric stations were formerly monitored by the Water Survey of Canada at seven other locations within the Project Area, but are not longer monitored.

The Project Area is underlain by four overburden aquifers and four bedrock aquifers. A total of 1,294 water wells were identified in the Project Area, distributed across the eight aquifers. The wells are interpreted to be used primarily for domestic purposes, with some identified for water supply systems, commercial/industrial use, and irrigation. It is anticipated that the domestic wells are also used for agricultural purposes (i.e., irrigation, livestock watering, etc.) on some of the Rural and Rural Residential properties.

The RDN currently operates two production wells to supply groundwater to the San Pareil Water Service Area, two wells to supply the Englishman River Water Service Area and 11 wells to supply the Nanoose Bay Peninsula Water System (the Nanoose Water System). A production well that is located near Parker Road in Nanoose Bay, will be operational in the future to supply the Nanoose Water System. For each of the 15 production wells that it currently operates within the Project Area, the RDN monitors water levels (static and pumping levels) with an electronic data loggers (i.e., pressure transducers) and production volumes (i.e., volumes of groundwater pumped) with flow meters. In addition to the 16 water supply wells that are currently being operated by the RDN (including the Parker Road well), eight wells associated with the RDN's various wellfields are not currently in use. The RDN currently monitors static water levels in one of these unused wells (Nanoose Well no. 7).

The BC Ministry of Environment (BC MoE) currently maintains seven observation wells within the Project Area. The RDN collects continuous groundwater level data in 17 privately owned volunteer wells. Fourteen of these volunteer wells are located in the Nanoose Bay area, in the vicinity of the Parker Road well, and the other three volunteer wells are located south of Nanoose Bay, near Snaw-Naw-As First Nation (FN) Indian Reserve (IR) and near Lantzville.

Based on the results of the data analysis, a Water Monitoring Plan was developed to build upon the existing monitoring network, address the data gaps identified in the Project Area and refine the Conceptual Model for Electoral Area E. Under the plan, monitoring data will be collected at strategic locations to establish baseline conditions, and assess seasonal variability and long term climatic trends. The dataset from the proposed monitoring locations will be used to refine water budgets for Electoral Area E and inform planning and land use decisions that support sustainable development. The proposed monitoring locations are prioritized for implementation relative to the relative stress assigned to watersheds and aquifers during the Phase 1 Water Budget. It is recommended that monitoring locations with a priority ranking of “Primary” be established first to address data gaps at priority locations. Monitoring locations that are assigned a priority ranking of “Secondary” should then be established to supplement the dataset and assess variability within the Project Area. It is anticipated that the proposed monitoring locations will be implemented based on financial requirements and practical considerations such as opportunities for potential partners, land ownership and site access. Proposed monitoring locations are summarized as follows:

- Climate monitoring stations with a primary priority ranking are proposed for upper elevation (headwater) areas of Nanoose Creek and/or Bonnell Creek, and on the Nanoose peninsula to assess conditions in aquifer recharge areas. A climate station near the Snaw-Naw-As FN IR is identified as a secondary priority to assess spatial variability and refine estimates of groundwater recharge to Aquifer 215.
- Hydrometric monitoring stations are proposed as a primary priority for the upper and lower reaches of Nanoose Creek, and at Enos Lake and Enos Creek to support assessment of surface water and groundwater interaction in these areas. A secondary priority was assigned to hydrometric stations proposed for Knarston Creek and Bonell Creek. Manual water level measurements are also recommended as a secondary priority to assess baseflow during the dry summer for watershed with relative high stress rankings.
- Groundwater monitoring wells are proposed for five primary locations to refine the existing monitoring network at strategic locations of the Project Area to assess groundwater conditions in specific aquifers. Groundwater monitoring wells are proposed as a secondary priority at an additional four locations. Where possible, RDN-owned wells have been identified as potential monitoring wells. In other areas, it is recommended that the RDN consider expanding its network of privately owned volunteer wells.

By working with the Snaw-Naw-As FN and stakeholders such as community stewardship groups to implement the Water Monitoring Plan, the RDN will support its broader outreach and public education program, and build capacity at the local level. These partnerships will also provide the opportunity for the technical aspects of the Water Monitoring Plan to be informed by traditional and local knowledge that provides an important socio-cultural context to water resources in the area. Potential partners such as federal and provincial government agencies were also identified as opportunities to achieve complementary objectives and leverage collective financial resources.

Supplemental activities that will complement the data from the proposed monitoring locations above include detailed assessments of land use activities and water use to refine water budgets. Water quality monitoring could also be implemented at key surface water and groundwater monitoring locations to assess variation in water quality over time and monitor potential impacts from land use activities.

It is recommended that the RDN build on the strong relationships that it has with other stakeholders to partner on monitoring initiatives. Based on the collective objectives and financial resources available, a preliminary list of potential monitoring locations should be drafted. Once preliminary locations are identified, background information should be reviewed and a site reconnaissance conducted to assess site conditions, land ownership, access and general conformance of the data objectives. Detailed designs should then be developed for the monitoring stations, including budgets with capital costs for equipment installation and acquisition, and on-going costs for monitoring and maintenance. A data management plan should be developed in consultation with partnering stakeholders.

# Study Limitations

This report has been prepared for the exclusive use of the Regional District of Nanaimo. The scope of work for this Study was intended to provide a regional scale overview only and did not include such items as detailed subsurface investigations or hydrogeological field studies. In evaluating the requirements of the Water Monitoring Plan for Nanoose, BC, Golder Associates Ltd. has relied in good faith on information provided by sources noted in this report. We accept no responsibility for any deficiency, misstatements or inaccuracy contained in this report as a result of omissions, misstatements or fraudulent acts of others.

The factual information, descriptions, interpretations, comments, conclusions and recommendations contained herein are specific to the project described in this report and do not apply to any other project or site. Under no circumstances may this information be used for any other purposes than those specified in the scope of work unless explicitly stipulated in the text of this report or formally authorized by Golder Associates Ltd. The final version of this report and its content supersedes any other text, opinion or preliminary version by Golder Associates Ltd.

Plans, electronic files and similar material used to develop the Water Monitoring Plan herein are instruments of service, not products. If new information is discovered in the future, Golder Associates Ltd. should be requested to re-evaluate the conclusions of this report and to provide amendments as required prior to any reliance upon the information presented herein. The report, which includes all tables and figures, must be read and understood collectively, and can only be relied on in its totality.

The hydrogeological services performed as described in this report were conducted in a manner consistent with the level of care and skill normally exercised by other members of the engineering and science professions currently practising under similar conditions, subject to the quantity and quality of available data, the time limits and financial and physical constraints applicable to the services. Unless otherwise specified, the results of previous work provided by sources other than Golder and quoted and/or used herein are considered as having been obtained according to recognised and accepted professional rules and practices, and therefore deemed valid. Golder Associates Ltd. makes no warranty, expressed or implied, and assumes no liability with respect to the use of the information contained in this report at the subject site, or any other site, for other than its intended purpose.

Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Golder Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

# Table of Contents

**TABLES**



**FIGURES**



**APPENDICES**

# 1.0 INTRODUCTION

As requested by the Regional District of Nanaimo (RDN), Golder Associates Ltd. conducted a detailed review and analysis of background information, including the Geodatabase and hydrogeological conceptual model (Conceptual Model) that were developed under Phase 1 of the RDN's Water Budget Project, and developed a Water Monitoring Plan for the Electoral Area E Water Monitoring Project (the Water Monitoring Project). The Water Monitoring Plan was developed in accordance with the scope of work outlined in our work plan titled "Work Plan and Cost Estimate for Task 3: Water Monitoring Plan for Electoral Area E Water Monitoring Project, District of Nanaimo, BC" and dated 27 July 2016 (Golder Reference No. 1547004-002-WP-Rev1) and the terms and conditions outlined in the contract between the RDN and Golder titled "Regional District of Nanaimo Hydrogeologist Consultant Services Two (2) Year Standing Offer Agreement" (the Contract) and dated 9 February 2016.

The information presented in this letter should be interpreted and used in accordance with the limitations and considerations set out in Golder Associates Ltd.'s *Study Limitations*, provided at the beginning of this report.

## 1.1 Background and Objective

The RDN's Drinking Water and Watershed Protection (DWWP) program was established in cooperation with local stakeholders to proactively protect and manage water resources in the region. One of the projects under the DWWP is the RDN Water Budget Project. During Phase 1 of the Water Budget Project (Phase 1 Water Budget), water budgets were developed for seven water regions to assess water resources (surface and ground) and water uses, and to provide a preliminary indication of the level of stress on the region's aquifers. Based on the results of the Phase 1 Water Budget, Electoral Area E, located in the Nanoose area of Water Region 5 (WR5), was identified as a high priority area where monitoring is required to inform land use decisions and support sustainable management of water resources.

On 9 June 2016, the RDN, Drawing Out Ideas and Golder facilitated a Public Feedback Session titled "Help Shape Our Water Future" in Nanoose, BC. In preparation for the Public Feedback Session, Golder conducted a preliminary review of background information to understand existing water resources and monitoring locations in Nanoose. The Public Feedback Session provided residents with the opportunity to share their local knowledge, values and priorities related to water use in Nanoose, and identify opportunities for participants to contribute to water-related monitoring. The results from the Public Feedback Session reinforced the importance that residents place on water for a variety of needs that range from human use for drinking water, agriculture and irrigation, and cultural practices, to ecosystem requirements that support aquatic habitat and wetlands. It was acknowledged that monitoring is required to manage and protect such a valuable resource. The results of the Public Feedback Session were captured and illustrated by Drawing Out Ideas in the graphic that is provided in Appendix A.

The objective of the current scope of work was to build upon the work done to date with a detailed review of available information and, with consideration of the input from the Public Feedback Session, to develop a Water Monitoring Plan that will address data gaps for Electoral Area E and provide the RDN with a dataset that could eventually support development of a numerical hydrogeological model for the area. While the focus of the Water Monitoring Plan is primarily on water quantity (i.e., supply and use that includes human and ecosystem requirements), it is anticipated that the data from the proposed monitoring locations in the Water Monitoring Plan will be considered along with water quality data from other programs to support protection and management of water resources in Electoral Area E.

## 1.2 Acknowledgements

Golder would like to thank Ms. Julie Pisani, Mr. Chris Midgley and Mr. Randy Alexander of the RDN for their direction and support in developing the Water Monitoring Plan. We would also like to thank the members of the DWWP Technical Advisory Committee (TAC) and the RDN Area E Water Monitoring / Phase 2 Water Budget Sub Committee for their review of the Draft Water Monitoring Plan, input and suggestions. Mr. Bob Rogers, Director of Electoral Area E, Mr. Lawrence Mitchell, Councillor and Mr. Mark Stephens, Director of Operations, of the Snaw-Naw-As First Nation and the residents who participated in the Public Feedback Session shared their knowledge and helped shape the scope for the project. We thank them for their contributions.

# 2.0 SCOPE OF WORK

Golder's scope of work for the Water Monitoring Plan included the following:

- conduct a detailed background review and data analysis comprising:
  - review background information including the Geodatabase and Conceptual Model that were developed by Waterline Resources Inc. (Waterline; 2013) for the RDN water regions
  - define a Project Area for the Water Monitoring Project and clip the Geodatabase to the Project Area
  - update the Geodatabase with new information that has become available for the Project Area since the database was compiled in 2013
  - identify and assess the monitoring sites that are currently operated within the Project Area
  - identify data gaps in the existing monitoring network and propose locations for monitoring stations to address the identified data gaps and refine the Conceptual Model for Electoral Area E
- prepare a factual letter report that presents the results of the detailed background review and data analysis and attend a progress meeting (Progress Meeting no. 1) with the RDN to discuss the interim results
- prepare a draft Water Monitoring Plan that, based on feedback from Progress Meeting no. 1, refines and prioritizes the proposed monitoring locations and presents:
  - options for installing monitoring stations and collecting monitoring data
  - potential partner organizations

- preliminary cost estimates for the respective options

- attend a progress meeting with the RDN (Progress Meeting no. 2) to discuss the results of the draft Water Monitoring Plan
- attend a DWWP TAC meeting to present the Draft Water Monitoring Plan and receive feedback from the TAC
- participate in one Public Meeting in Nanoose to share the Draft Monitoring Plan with local residents
- prepare a report that documents the results of the detailed background review and data analysis and presents the Water Monitoring Plan that incorporates feedback from Progress Meeting no. 2, the DWWP TAC meeting and the Public Meeting

# 3.0 METHODS

Golder compiled and reviewed available background information including:

- the existing Geodatabase and Conceptual Model
- data available on-line from the BC MoE Water Resources Atlas (WRA), the Government of Canada Climate Normals and Water Survey of Canada databases
- well operation and water level elevation data for the municipal supply wells that are operated by the RDN in the Nanoose area
- reports prepared by consultants, government agencies and academia that document water resources relevant to the Nanoose area
- information from the Public Feedback Session that was hosted in Nanoose on 9 June 2016

Golder analysed the information in the Geodatabase using ArcGIS software. For the purposes of the current project, Golder clipped the Geodatabase to a Project Area that includes Electoral Area E and adjacent areas that were considered to be relevant to the Nanoose area based on the extent of key elements of the Conceptual Model, including local watersheds and underlying aquifers that are described in subsequent sections. As presented on Figure 1, the northwest corner of the Project Area extends into adjacent Water Region 4 (WR4: Englishman River). The border of the Project Area extends south from the Strait of Georgia along the western edge of surficial aquifers until it intersects with the boundary of WR5. From that point, the edge of the Project Area follows the border of WR5 into upland areas along the western boundary of the Craig Creek watershed and the southern boundaries of the Nanoose Creek, Bonell Creek and Benson Creek watersheds. The eastern boundary of the Project Area extends through the central portion of WR5, along the eastern boundaries of the Benson Creek watershed to Brannen Lake, and the Metral Creek and Bloods Creek watersheds to the Salish Sea (Georgia Straight) (Figure 1).

Golder updated the Geodatabase with the following information since the Geodatabase was originally compiled in 2013:

- information from the BC MoE WRA database (BC MoE, 2016), including:
  - water well records for privately owned wells
  - observation wells that are operated by the BC MoE as part of the Provincial Groundwater Observation Well Network
  - updated surface water licences that have been issued by the Ministry of Forests, Lands and Natural Resource Operations (FLNRO)
  - information regarding Aquifer 1098, located east of Englishman River and south of Craig Bay, which was mapped in 2014 and classified by the BC MoE in 2015
- information available from the Government of Canada (2016) Canadian Climate Normals database regarding the Nanoose Bay Auto Climate Station (Climate ID No. 1025376)
- the location of a climate station at the Fairwinds Golf Course

The datasets in the Conceptual Model that describe the hydrostratigraphy were analysed and wells in the Geodatabase were assigned to mapped aquifers based on aquifer composition and the locations and depths of the wells. Overburden aquifers 221, 219 and 1098 were assigned to the Vashon, Quadra and Pre-Quadra hydrostratigraphic units in the Conceptual Model, respectively. The results of the analysis were spot-checked against information provided in water well records (i.e., well logs) for a random sample of wells to confirm that wells were assigned to appropriate aquifers; a detailed review of the information on each well log was not conducted. Wells that were located outside of the areas of mapped aquifers were assigned to adjacent aquifers based on lithological information on the well log, if available.

Golder analysed the information in the Conceptual Model, updated Geodatabase and supporting documentation to identify existing monitoring stations, including those that are currently operational and those that have been discontinued. The data were analysed with consideration to the geospatial relationships between the monitoring points and the elements of the Conceptual Model (i.e., surface water features, aquifers, water wells, etc.) to identify data gaps in the current monitoring network. The data provided in the Conceptual Model, Geodatabase (Phase 1 Water Budget) and the BC MoE WRA were assumed to be correct and suitable for the purposes of the Water Monitoring Project; the quality of the data were not verified by Golder.

Based on the results of the analysis, a Water Monitoring Plan was developed for the area. Locations for new monitoring stations were identified and prioritized to provide information required to refine the Conceptual Model for Electoral Area E. The Water Monitoring Plan discusses potential opportunities for the RDN to partner with other organizations, and preliminary costs were developed to support the RDN in the planning and decision-making process.

# 4.0 RESULTS AND DISCUSSION

The Phase 1 Water Budget Geodatabase and Conceptual Model that were developed by Waterline (2013) provide the technical basis to assess the flow of water in the RDN's water regions and the interactions between elements of the water cycle, including surface water features (e.g., rivers, creeks, lakes, etc.) and aquifers in the subsurface. The water budgets and stress analyses that were conducted with the Conceptual Model provided the RDN with the technical basis to identify watersheds and aquifers that were considered to be under relatively high stress (i.e., water demand high relatively to water availability) for prioritization of efforts; however, the water budgets and stress analyses are qualitative in nature. As noted by Waterline (2013), numerical modeling would be required to conduct more quantitative assessments of water availability and the potential impacts of increased demand and/or climate change. Development and calibration of numerical models requires detailed information such as precipitation, streamflow and groundwater level data, as well as land cover and water use activities.

The following sections describe the main elements of the Conceptual Model that was developed under Phase 1 and the monitoring stations that are currently (and formerly) in place in the Project Area. The Water Monitoring Plan is presented in Section 5.0.

## 4.1 Topography and Climate Stations

The topography in the Project Area ranges from sea level along the coastal areas to over 300 metres above sea level (m asl) in the southern portion of Electoral Area E, within the Bonell Creek watershed, and over 880 m asl in the southern portion of the Project Area, along the edge of the Nanoose Creek watershed (Government of BC, 2016).

Seven climate stations were identified in the Geodatabase for the Project Area. Table 1, below, provides a summary of the climate stations. The locations of the climate stations are presented on Figure 2.

**Table 1: Summary of Climate Stations in Water Monitoring Project Area**

| Climate Station | Program[1] | Monitoring Period | Monitoring Frequency | Data Collected | |
|---|---|---|---|---|---|
| | | | | Temp (Y/N)[2] | Precip (Y/N)[2] |
| Ocean Trails Resort | School-Based Network[3] | 2006-present | Hourly | Y | Y |
| Nanoose Bay Elementary | School-Based Network[3] | 2007-present | Hourly | Y | Y |
| Parksville Ops | City of Parksville | 2005-present | 5-minute | N | Y |
| Fairwinds Golf Course | Fairwinds Golf Course | 2008-present | Daily | N | Y |
| Nanoose Bay (1025375)[4] | Environment Canada | 1912-1989 | Daily | N | Y |
| Nanoose Bay South (1025377)[4] | Environment Canada | 1988-2007 | Daily | N | Y |
| Nanoose Bay Auto (1025376)[4] | Environment Canada | 2014-2015 | Daily | N | Y |

Notes:
1. Monitoring program under which the climate station is/was operated
2. Temp=temperature; Precip=precipitation; Y/N=Yes/No
3. School-Based Weather Network (http://www.victoriaweather.ca/)
4. Climate ID number

Four climate stations are currently being operated in the Project Area. The Nanoose Bay Elementary climate station and the Fairwinds Golf Course station are located in Electoral Area E and the Ocean Trails Resort and Parksville Ops climate stations are located on the east side of the Englishman River, in adjacent WR4 (Figure 2). The four climate stations are located in the northern portion of the Project Area, at ground surface elevations of up to 50 m asl.

As part of the School-Based Weather Station Network, climate data including temperature, precipitation, and wind speed and direction, have been collected on an hourly basis at the Nanoose Bay Elementary and Ocean Trails Resort stations since 2007 and 2006, respectively. An example of some of the climate data that are collected at the Nanoose Bay Elementary Climate Station and available on-line is provided in Appendix B. Kerr Wood Leidal Consulting Engineers (KWL; 2015) noted that, based on the monitoring equipment used, the data from some of the school-based stations were not considered to be highly accurate. The Fairwinds Golf Course have collected daily precipitation data with a manual rain gauge since 2008 and the City of Parksville have also collected precipitation data at five minute intervals at the Parksville Ops (Operations Facility) since 2005.

Three Environment Canada climate stations were formerly operated in Electoral Area E but are no longer active. Daily precipitation data were reported for the Nanoose Bay South and Nanoose Bay stations; however, data for the majority of the time period when the Nanoose Bay station was operated (1912-1989) is not available and identified as “missing, invalid or subject to review” on the Canadian Climate Normals database. Hourly temperature and precipitation were reported for the Nanoose Bay Auto station from March 2014 through June 2015.

Under Phase 1, Waterline (2013) extracted monthly temperature and precipitation data from the ClimateBC and ClimateWNA models (Wang et al., 2006; Wang et al., 2012). The data, which are based on a digital elevation model and downscaled climatic variables, predict average annual temperatures that range from 10-11°C on the Nanoose Peninsula to 6-7°C at the higher elevations in the southeastern portion of the Project Area. Precipitation also varies with elevation, with total annual precipitation predicted to range from <1,000 mm on the Nanoose Peninsula to >1,500 mm at the higher elevations (Waterline, 2013). Similar to other areas of the RDN, the monthly data for WR5 were characterised with warm, dry summers and cooler, wet winters.

As presented on Figure 2, currently there are no climate monitoring stations in the higher elevation areas of the Project Area. One or more climate stations in the upper elevations of the Project Area would provide data to verify the precipitation and temperature data from the Climate WNA model, and refine the water budget and stress analysis for Electoral Area E.

## 4.2 Surface Water

### 4.2.1 Watersheds and Surface Water Licenses

Excluding the Englishman River, which is predominantly in adjacent WR4, five major watersheds and 11 sub-watersheds were identified within the Project Area (Figure 3). Water budgets and stress assessments were conducted for four of the major watersheds within the WR5 portion of the Project Area (Waterline, 2013).

A total of 262 surface water licenses were identified in the Geodatabase for the Project Area. Of the 262 surface water licenses identified, 95 were listed with a status of “Abandoned”, “Application Abandoned”, “Canceled” or “Refused Application”. The status of 165 licenses was “Current” and 2 licenses were “Pending”. Table 2 provides a breakdown of current and pending surface water licenses by watershed and Table 3 provides a summary of licensed surface water use. The locations of the surface water licenses is presented on Figure 3.

**Table 2: Watersheds and Surface Water Licenses in Water Monitoring Project Area**

| Watershed | Drainage Area ($km^2$)[1] | Relative Stress Level[2] | No. Current and Pending Surface Water Licenses | Annual Surface Water Demand[3] (million $m^3$) |
|---|---|---|---|---|
| **Major Watersheds** | | | | |
| Bonell Creek | 51.2 | - | 3 | 0.002 |
| Nanoose Creek | 34.0 | High | 19 | 0.050 |
| Benson Creek | 27.6 | Moderate-High | 1 | 0.002 |
| Craig Creek | 11.7 | - | 17 | 0.073 |
| Englishman River[4] | 6.9 | Moderate | 22 | 14.94 |
| Upper Millstone River[5] | 21.1 | Moderate-High | 12 | 0.034 |
| **Sub-watersheds** | | | | |
| Knarston Creek | 5.7 | - | 6 | 0.008 |
| Metral Creek | 3.7 | Moderate-High | 1 | 0.002 |
| Hardy Creek | 2.1 | - | 2 | 0.063 |
| Enos Creek | 2.1 | - | 6 | 0.543 |
| Bloods Creek | 2.0 | - | 3 | 0.002 |
| Unnamed No. 1 & No. 2 (adjacent to Englishman River) | 4.1 | - | - | - |
| Unnamed No. 3 (Nanoose Peninsula, including Maelstrom Creek)[6] | 24.2 | - | 24 | 0.120 |
| Unnamed No. 4 (between Bonell and Hardy) | 11.4 | - | 42 | 0.051 |

| Watershed | Drainage Area ($km^2$)[1] | Relative Stress Level[2] | No. Current and Pending Surface Water Licenses | Annual Surface Water Demand[3] (million $m^3$) |
|---|---|---|---|---|
| Unnamed No. 5 (between Hardy and Knarston) | 1.2 | - | 6 | 0.019 |
| Unnamed No. 6 (between Knarston and Bloods) | 3.8 | - | 4 | 0.003 |
| | | **Total:** | **167** | **15.91** |

Notes:
1. Portion of watershed that is located within Project Area
2. Results of surface water stress assessments conducted under Phase 1 of the Water Budget Project; "-"indicates that a stress assessment was not conducted for the watershed
3. Total consumptive demand (surface water only)
4. Lower portion of the Englishman River watershed; 6.9 km2 of the total watershed area of 416 km2 for the Englishman River is located within the Project Area
5. Upper portion of Upper Millstone River, upstream from Brennan Lake
6. With the exception of Enos Creek watershed, the majority of Nanoose Peninsula is identified in the Geodatabase as an unnamed watershed

**Table 3: Summary of Licensed Surface Water Use in Water Monitoring Project Area**

| Purpose of Surface Water Use | No. of Surface Water Licenses[1] | Annual Surface Water Demand[2] (million $m^3$) |
|---|---|---|
| Domestic | 87 | 0.089 |
| Agriculture (including irrigation, greenhouses and stock watering) | 37 | 0.252 |
| Storage (non-power and conservation) | 15 | - |
| Waterworks and Water Delivery | 6 | 14.88 |
| Land Improvement | 6 | 0.006 |
| Watering and Private Irrigation | 5 | 0.379 |
| Enterprise | 3 | 0.037 |
| Conservation (use) | 2 | 0.063 |
| Processing | 1 | 0.007 |
| Ponds | 1 | 0.003 |
| Fire Protection | 2 | <0.001 |
| Unspecified | 2 | - |
| **Total:** | **167** | **15.91** |

Notes:
1. Surface water licenses identified as "current" or "pending"
2. Total consumptive demand

Over ninety percent of the annual licensed surface water use in the Project Area is water supply for the Englishman River for waterworks. Within Electoral Area E, the surface water licenses in the Enos Creek watershed are for storage and watering for the Fairwinds Golf Club. The majority of the 63 surface water licenses in the unnamed watersheds on the Nanoose Peninsula and in the Craig, Nanoose and Bonell Creek watersheds to the south are for domestic and agricultural (irrigation, stockwatering, greenhouse) purposes. The 42 surface water licences in the unnamed watershed between the Bonell Creek and Hardy Creek watersheds are also predominantly for domestic purposes and some irrigation (Figure 3).

### 4.2.2 Surface Water Monitoring Stations

A total of eight Water Survey of Canada hydrometric stations were identified within the Project Area, six of which were within Electoral Area E. With the exception of a station on the Englishman River, in WR4, the hydrometric stations in the Project Area are discontinued. The station information is summarised in Table 4 and the locations of the stations are presented on Figure 3.

**Table 4: Hydrometric Stations in Water Monitoring Project Area**

| Hydrometric Station Name | Station No. | Monitoring Period | Drainage Area ($km^2$)[1] |
|---|---|---|---|
| Englishman River Near Parksville | 08HB002 | 1913-present | 319 |
| Enos Creek at Outlet of Enos Lake | 08HB030 | 1962-1978 | 1.68 |
| Enos Lake Near Nanoose Bay | 08HB031 | 1962-1978 | -[2] |
| Nanoose Creek at the Mouth | 08HB039 | 1970-1972 | - |
| Bonell Creek Near Nanoose | 08HB079 | 1990-1991 | - |
| Indian Reserve Creek (North Fork) Near Lantzville | 08HB051 | 1975-1979 | - |
| Indian Reserve Creek (South Fork) Near Lantzville | 08HB052 | 1975-1979 | - |
| Knarston Creek at Superior Road | 08HB040 | 1970-1971 | 3.89 |

Notes:
1. Drainage area to the station gauge
2. Data not provided on on-line Wateroffice database (https://wateroffice.ec.gc.ca/)

Manual water level measurements started at the Englishman River Near Parksville Station (Station 08HB002) in 1913 and continuous flow (i.e., discharge) and water level data have been recorded at the station since 1979 and 2011, respectively (Government of Canada, 2016b). An example of the hydrometric data that are currently available for Station 08HB002 is provided in Appendix B.

Water quality monitoring is currently conducted as part of the RDN Community Watershed Monitoring Network by the Nanoose-Lantzville Streamkeepers Society at three monitoring locations within Electoral Area E (RDN, 2016a). The locations of the two water quality monitoring stations along Nanoose Creek and one monitoring station along Craig Creek are presented on Figure 3. The water quality monitoring of field parameters (temperature, turbidity, dissolved oxygen and specific conductance) occurs on a weekly basis for 5 weeks in the summer low flow period (August-September) and for 5 weeks during the fall flush period (October-November). Hydrometric data are not collected under this monitoring program. Water quality monitoring is also conducted at Enos Lake under the Enos Lake Protection and Monitoring Program to inform development in the area (PGL Environmental Consultants, 2016).

As presented in Table 2, surface water stress assessments were conducted for the Nanoose Creek, Benson Creek and Metral Creek watersheds under the Phase 1. Streamflow from each of these un-gauged watersheds (i.e., no active hydrometric station) was estimated based on physical characteristics of the watershed using a regional hydrology approach that was used to develop BC MoE Water Allocation Plans (Boom and Bryden, 1994). The streamflow estimates for these watersheds could not be verified due to an absence of baseflow data. Streamflow for the Englishman River and Millstone River, which flow away from Electoral Area E towards the west and east, respectively, was estimated by Waterline (2013) based on stream flow and climate data.

The lack of active hydrometric stations in any of the major watersheds in the WR5 portion of the Project Area represents a data gap in the existing monitoring network and the Phase 1 water budgets and stress assessments. Hydrometric data, including flow and water level data, are required to link to climate data and refine the estimates of surface water runoff, baseflow and, as discussed in Section 4.3, below, groundwater recharge.

## 4.3 Groundwater

### 4.3.1 Aquifers

The locations of the four unconsolidated aquifers (sediments such as sand and gravel) and 4 bedrock aquifers within the Project Area[1] are presented on Figure 4 and a summary of the aquifer details is presented in Table 5, below.

**Table 5: Aquifers in Water Monitoring Project Area**

| Aquifer Tag No.[1] | Aquifer Classification[2] | Aquifer Materials | Potential Surface Water or Groundwater Interaction |
|---|---|---|---|
| 221 | IIA | Unconfined Sand and Gravel: Salish Sediments[3] | Englishman River<br>Underlying Aquifer: 219 |
| 219 | IIC | Confined Sand and Gravel: Quadra Sand[4] | Nanoose Creek, Craig Creek, Bonell Creek, Englishman River<br>Overlying Aquifer: 221<br>Underlying Aquifers: 1098 and 214<br>Ocean |

[1] Aquifers 167 and 211, which extend slightly into the eastern edge of the Project Area, were not included in the analysis.

| Aquifer Tag No.[1] | Aquifer Classification[2] | Aquifer Materials | Potential Surface Water or Groundwater Interaction |
|---|---|---|---|
| 1098 | IIC | Confined Sand and Gravel: Muir Point Formation[5] | Overlying Aquifer: 219<br>Underlying Aquifers: 214 and 210 |
| 215 | IIC | Confined Sand and Gravel: Quadra Sand[4] | Knarston Creek and Bloods Creek<br>Underlying Aquifer: 213 |
| 214 | IIB | Semi-confined Bedrock: Sedimentary[6] | Craig Creek<br>Overlying Aquifers: 219 and 1098<br>Adjacent Aquifers: 218, 210 and 213<br>Ocean |
| 210 | IIB | Semi-confined Bedrock: Sedimentary and Igneous Intrusive[7] | Nanoose Creek<br>Overlying Aquifers: 219 and 1098<br>Adjacent Aquifer: 214 |
| 213 | IIC | Confined Bedrock: Volcanic[8] | Bonell Creek, Millstone River<br>Adjacent Aquifer: 214<br>Overlying Aquifer: 215<br>Ocean |
| 218 | IIB | Semi-confined Bedrock: Sedimentary and Igneous Intrusive[9] | Enos Lake and Creek, Dolphin Lake<br>Adjacent Aquifer: 214<br>Ocean |

Notes:
1. Aquifer tag no. on the BC MoE Water Resources Database (WRA)
2. MoE aquifer classification based on development (demand relative to aquifer productivity; I/II/III = heavy/moderate/light) and vulnerability to potential contamination from surface sources (A/B/C = high/moderate/low)
3. Relatively recent deltaic and alluvial deposits
4. Pro-glacial fluvial outwash sand deposits
5. Heterogeneous sand and gravel deposits
6. Nanaimo Group
7. Sedimentary rock of Buttle Lake Group-Fourth Lake Formation and igneous intrusive rocks of the Mount Hall Gabbro
8. Vancouver Group-Karmutsen Formation
9. Buttle Lake Group-Nanoose Complex and Island Plutonic Suite

The Quadra sand deposits of Aquifer 219 extend from the northwestern portion of the Project Area through the central portion of Electoral Area E to Nanoose Bay (Figure 4). Groundwater within Aquifer 219 is interpreted to be receive recharge from upslope areas to the southwest and infiltration of precipitation, and generally flow towards Nanoose Bay and the Salish Sea. Surface water features within the area of Aquifer 219 include Nanoose Creek, Craig Creek, Bonell Creek and, in the northwestern portion of the Project Area, the Englishman River. In areas adjacent to the Salish Sea, Aquifer 219 may be at risk of saline intrusion, particularly in areas of heavy groundwater extraction. Although Aquifer 219 is generally confined by deposits including Vashon till and/or Capilano glacio-marine sediments (Fyles, 1963), some groundwater exchange may occur between Aquifer 219 and overlying Aquifer 221 in the northwest corner of the Project Area, in WR4 (Figure 4). Groundwater in the unconfined Salish sediments of Aquifer 221 is recharged by infiltration of precipitation and the hydraulic relationship between the Englishman River and Aquifer 221 is interpreted to be relatively strong (BC MoE, 1996). Benoit et al. (2015) note that groundwater storage in Salish sediments can regulate stream flow in adjacent surface water features.

The majority of Aquifer 219 is underlain by the deeper sand and gravel deposits identified as Aquifer 1098 on the BC MoE WRA. Lowen Hydrogeology Consulting Ltd. (2014) identified the heterogeneous sand, gravel and silt deposits of Aquifer 1098 as the Muir Point Formation which was mapped by Hicock (1990) to range from gravel to organic-rich silt and peat. The Conceptual Model indicates that vertical hydraulic gradient from Aquifer 219 is downwards; however, the silt and clay deposits that confine Aquifer 1098 are anticipated to control the interaction between the two aquifers. Groundwater in Aquifer 1098 is interpreted to be primarily recharged from the upslope areas to the southwest and flows north to the Salish Sea and east to Nanoose Bay (Figure 4).

Aquifer 215, which is also interpreted to host Quadra Sands, is encountered in the eastern edge of Electoral Area E and extends east through Lantzville. The aquifer is also recharged by precipitation infiltration and upslope areas. Knarston Creek and Bloods Creek flow through the area of Aquifer 215.

The overburden aquifers that host Quadra and Muir Point Formation deposits are underlain by three mapped bedrock aquifers. As presented on Figure 4, Aquifer 1098 is primarily underlain by Nanaimo Group sedimentary rocks of Aquifer 214, with Mount Hall Gabbro igneous rocks of Aquifer 210 extending beneath the southern portion of Aquifer 1098. Aquifer 213 hosts volcanic basalt deposits of the Vancouver Group-Karmutsen Formation that extend from the Nanoose Bay area east, including the area beneath Aquifer 215, past the eastern boundary of the Project Area (Figure 4).

Groundwater in bedrock aquifers 214, 210 and 213 is primarily recharged from upslope areas to the south and southwest and flows towards the ocean. Recharge to the bedrock is interpreted to be greater from creeks and wetlands in the upper reaches of the watersheds. In these areas, the surficial geology includes relatively thinner overburden deposits of Vashon moraine (till) and bedrock outcrop (Fyles, 1963). The upper reaches of the Craig Creek and Nanoose Creek watersheds are interpreted to recharge groundwater in Aquifers 214 and 210, and the upper reaches of the Bonell Creek and Millstone River watersheds recharge groundwater in Aquifer 215 (Figure 4). In the lower elevations, the relatively thicker overburden deposits that provide some recharge to the bedrock aquifers have some interaction with smaller surface water features (i.e., creeks and streams). BC MoE (1996b) also note a potential hydraulic connection between Aquifer 214 and adjacent Aquifer 213. Waterline (2013) also noted that Aquifer 213 could also potentially be influenced by underground coal works.

In the Nanoose Peninsula area of Electoral Area E, the sedimentary bedrock deposits of the Buttle Lake Group and, in the eastern portion of the peninsula, igneous intrusive rocks of the Island Plutonic Suite, are mapped as Aquifer 218. Groundwater in Aquifer 218 is recharged by infiltration of precipitation through the relatively thin glaciofluvial and glacial marine deposits. Aquifer 218 is also expected to have some hydraulic connection to adjacent Aquifer 214 and local surface water features including Enos Lake, Enos Creek and Dolphin Lake.

### 4.3.2 Wells

A total of 1,294 wells were identified in the updated Geodatabase for the entire Project Area, with 597 of the wells located within Electoral Area E and 697 wells located in the surrounding areas. As presented in Table 6, below, a total of 125 new wells were identified on the BC MoE WRA and added to the Geodatabase, with 59 wells added for Electoral Area E and 66 wells added for the surrounding Project Area.

**Table 6: Total Wells in Updated Geodatabase for Water Monitoring Project Area**

| | No. Wells in 2013 Geodatabase | No. New Wells added from BC MoE WRA[1] | Total No. Wells in Updated Geodatabase |
|---|---|---|---|
| Electoral Area E | 538 | 59 | 597 |
| surrounding Project Area | 631 | 66 | 697 |
| **Total:** | **1,169** | **125** | **1,294** |

Notes:
1. Well ID no.s identified on MoE WRA that were not in the 2013 Geodatabase

Review of the Geodatabase data indicated that some well locations were assigned more than one well tag number, suggesting that either multiple wells were assigned the same location in the database[2] or some wells were assigned more than one well tag number, as was the case with some of the RDN-owned water supply wells. The wells that were identified on the Geodatabase include some that were reported on the well log as abandoned, closed, decommissioned or dry at the times of drilling, indicating that only a portion of the 1,294 wells identified for the Project Area are actually used. Prior to the introduction of the *Water Sustainability Act* (WSA) in February 2016, water well records (i.e., well logs) were submitted to the BC MoE only on a voluntary basis. As a result, it is expected that not all of the wells that are actually present in the Project Area are recorded in the Geodatabase.

The locations of the wells that are in the Geodatabase for the Project Area are presented on Figure 5 and a summary of the reported well uses is presented in Table 7.

**Table 7: Summary of Well Use in Water Monitoring Project Area**

| Well Use[1] | No. Wells Electoral Area E | No. Wells Surrounding Project Area | Total No. Wells |
|---|---|---|---|
| Private domestic | 351 | 384 | 735 |
| Unknown[2] | 163 | 250 | 413 |
| Water System Supply | 42 | 42 | 84 |
| Commercial/Industrial | 19 | 7 | 26 |
| Irrigation | 10 | 5 | 15 |
| Test, Observation, Abandoned | 12 | 9 | 21 |
| **Total:** | **597** | **697** | **1,294** |

Notes:
1. Well use reported on BC MoE WRA
2. Well use described in the Geodatabase as “unknown”, “other” or left blank

[2] Wells in the BC MoE WRA database are assigned locations based on information available on the well log and may not reflect actual well locations, particularly for older wells that were not located in the field by GPS

The well use information that is provided on a well log may not accurately reflect what the well is actually used for. Therefore, in addition to the well log information, land use activities were also considered to provide a general indication of groundwater use. The distribution of wells within the Project Area and the land use designations, as provided in the Nanoose Bay Official Community Plan (OCP; RDN, 2005), are presented on Figures 6A and 6B.

The majority of the wells in the Project Area are listed as being used for private domestic purposes (735) or unknown uses (413 wells with use listed as “unknown”, “other” or left blank). These wells are predominantly located on properties designated as Rural, Residential and Rural Residential. Groundwater from the majority of these wells is expected to be primarily for household use, including outdoor watering. It is anticipated that groundwater is also used for agricultural purposes (i.e., irrigation, livestock watering, etc.) on some of the Rural and Rural Residential properties.

A total of 84 wells were identified in the Geodatabase for water supply systems, with 42 of these wells located within Electoral Area E. As discussed above, some of the RDN-owned wells were identified in the Geodatabase with multiple well tag numbers, suggesting that the Geodatabase may overestimate the number of wells that are actually used to supply water systems. The locations of the RDN-owned water supply wells in the Project Area and the service area for the Nanoose Water System are presented on Figure 7.

The RDN currently operates two production wells to supply groundwater to the San Pareil Water Service Area system and two production wells to supply the Englishman River Water Service Area system; both of these wellfields are within the Project Area but west of Electoral Area E. Within Electoral Area E, the RDN operates 11 production wells to supply groundwater to the Nanoose Bay Peninsula Water System (the Nanoose Water System). The Nanoose Water System, which is an amalgamation of the Madrona, Wall Beach, Driftwood, Nanoose, Fairwinds, Arbutus Park and West Bay systems, pumps groundwater from its production wells to service areas with relatively higher housing density including the parcels designated as Coast Residential, the Fairwinds and Schooner Cove Neighbourhood developments in the eastern portion of Nanoose Peninsula, and the Red Gap Village located west of Nanoose Bay (Figure 6A). The Nanoose Water System is also supplemented with water from the Englishman River in the summer season (AquaVic Water Solutions Inc., 2013). The Englishman River Water Service is being expanded with a new surface water intake and water treatment plant. When this infrastructure comes online in 2018, surface water from the Englishman River Water Service will supply the Nanoose Water System on a year-round basis (RDN, 2016b).

For each of the 15 production wells that it currently operates, the RDN monitors water levels (static and pumping levels) with an electronic data loggers (i.e., pressure transducers) and production volumes (i.e., volumes of groundwater pumped) with flow meters.

In addition to the 15 water supply wells that are currently being operated by the RDN, eight wells associated with the RDN’s various wellfields are not currently in use. The RDN currently monitors static water levels in one of these unused wells (Nanoose Well no. 7).

A total of 26 wells were identified in the Geodatabase as being used for commercial or industrial purposes, on properties generally along the Island Highway corridor, including the parcels designated as Industrial and Tourist Commercial Lands. Although 15 wells were identified in the Geodatabase for irrigation use primarily on Resource designated parcels, the number of wells actually used for agricultural purposes is anticipated to be higher in the rural areas of the Project Area.

The WSA requires licensing of groundwater for non-domestic use by February 29, 2019. As groundwater licenses are issued over the next three years, more information will be available from the BC MoE regarding the quantities of groundwater that are used for non-household purposes.

Table 8, below, provides a breakdown of wells in the Project Area by aquifer, and identifies production wells that are owned by the RDN, Snaw-Naw-As First Nation and the District of Lantzville, and monitoring wells under the BC MoE Observation Well Network and RDN groundwater monitoring initiatives. The locations of these production and monitoring wells are presented on Figure 7.

**Table 8: Summary of Production and Monitoring Wells by Aquifer**

| Aquifer[1] | Aquifer Materials[2] | Development (Demand/ Productivity)[3] | Total No. wells[4] | Relative Stress[5] | Production Wells[6] | Monitoring Wells[6] |
|---|---|---|---|---|---|---|
| 221 (IIA) | Unconfined Sand and Gravel | Moderate/High | 24 | Moderate | Active: San Pareil no.s 1, 4<br>Unused: San Pareil no.s 2, 3 | - |
| 219 (IIC) | Confined Sand and Gravel | Low/Moderate | 262 | Low | Active: Englishman River PW2, PW3, Wallbrook no. 1, Madrona no. 8<br>Unused: Englishman River PW1, Madrona no. 3[7], West Bay no. 1 | BC MoE Obs Well no. 395<br>BC MoE Obs Well no. 396<br>4 RDN Volunteer (Private) Monitoring wells (Parker Rd.)[8] |
| 1098 (IIC) | Confined Sand and Gravel | Moderate/ Moderate | 116 | - | Active: Madrona no. 4, Nanoose no.s 2, 3, 4, West Bay no. 3, Fairwinds F1, F2, F3<br>Unused: Nanoose no. 7 | BC MoE Obs Well no. 393<br>BC MoE Obs Well no. 397<br>Nanoose no. 7<br>4 RDN Volunteer (Private) Monitoring wells (Parker Rd.) |
| 215 (IIC) | Confined Sand and Gravel | Moderate/ Moderate | 259 | Moderate-High | Active: Snaw-Naw-As FN IR, Lantzville no.s 6, 9, 12<br>Unused: - | BC MoE Obs Well no. 232<br>BC MoE Obs Well no. 340<br>1 RDN Volunteer (Private) Monitoring wells (Northwind Dr.) |
| 214 (IIB) | Semi-confined Bedrock | Low/Low | 83 | Low | Active: -<br>Unused: Nanoose no. 1[8], Parker Road well[9] | 6 RDN Volunteer (Private) Monitoring wells (Parker Rd.) |
| 210 (IIB) | Confined Bedrock | Moderate/Low | 78 | Moderate-High | Active: -<br>Unused: - | - |
| 213 (IIC) | Confined Bedrock | Moderate/ Moderate | 366 | Low | Active: Lantzville Well no. 4<br>Unused: - | 2 RDN Volunteer (Private) Monitoring wells (Seablush Dr. and Elm Rd.) |
| 218 (IIB) | Semi-confined Bedrock | Moderate/Low | 90 | Very High | Active: Nanoose no. 6<br>Unused: - | BC MoE Obs Well no. 394 |

Notes:

1. Aquifer tag no. and classification from the BC MoE Water Resources Database (WRA)
2. Descriptions of aquifer units provided in Table 5
3. Level of development (i.e., groundwater demand) relative to aquifer productivity, from BC MoE WRA
4. Number of wells identified in the Geodatabase for the portion of the aquifer that is within the Project Area; 16 wells identified along the eastern edge of the Project Area were not included in the analysis
5. Results of water stress assessments for aquifers conducted under Phase 1 of the Water Budget Project; Low/Moderate/High/Very High; stress assessment for Aquifer 221 was conducted as part of WR4: Englishman River water budget and Aquifer 1098 was not mapped at the time of the Phase 1 Water Budget
6. Production wells currently being operated by the RDN, Snaw-Naw-As First Nation and the District of Lantzville and observation wells identified under the BC MoE Observation Well Network or for RDN monitoring programs
7. Well identified in Geodatabase; however, status of well not currently known and field inspection recommended to confirm well conditions
8. Wells are screened in unconsolidated deposits that are inferred to be Quadra sand and gravel
9. Parker Road well not yet operational but will be used to supply the Nanoose Bay Peninsula Water System

### 4.3.3 Analysis of Existing Groundwater Monitoring Well Network

#### *Aquifer 221 (IIA)*

Aquifer 221 has a relatively small mapped area of approximately 4 $km^2$, is unconfined and has a high vulnerability to potential surface contamination. Aquifer 221 is inferred to regulate baseflow in the Englishman River and recharge underlying Aquifer 219.

This aquifer is moderately developed relative to the high productivity of the sand and gravel deposits and was assigned a relative stress of Moderate in the Phase 1 Water Budget. Based on their locations, the four production wells in the San Pareil wellfield are inferred to have a relatively strong hydraulic connection to the Englishman River, approximately 70-100 m west of the wellfield (Figure 7). Two of the four wells at the San Pareil wellfield (SP no. 1 and SP no. 4) are used to supply the San Pareil Water System. The remaining 20 wells identified in the Geodatabase for Aquifer 221 are listed as being used for private domestic or unknown uses.

The RDN maintains production records for SP no. 1 and SP no. 4. The water levels in SP no. 2 and SP no. 3 are not regularly monitored. The BC MoE has not established a monitoring well in this aquifer under its observation well network.

#### *Aquifer 219 (IIC)*

With a mapped area of approximately 38 $km^2$, Aquifer 219 is one of the largest aquifers in the Project Area. Although Benoit et al. (2015) report the Quadra sands are heavily exploited in the Nanaimo lowlands, in the Nanoose area groundwater demand from wells completed in the Quadra deposits of Aquifer 219 is classified by the BC MoE as low relative to the moderate productivity of the aquifer. Under the Phase 1 Water Budget, Aquifer 219 was assigned a relative stress of Low. As presented on Figure 5, the 262 wells that are completed in Aquifer 219 are generally distributed across the aquifer, with a higher well density along the outer edges of the aquifer. Eighteen of the wells that are reported to be used for commercial and industrial purposes in the Project Area are completed in Aquifer 219. The majority of the other wells in the aquifer are used primarily for domestic and agricultural uses.

The Geodatabase listed 15 wells in Aquifer 219 as being used for water supply systems. Seven of these wells were identified as being owned by the RDN and either active (i.e., used for production) or currently unused. The remaining eight wells in Aquifer 219 that were listed for water supply are inferred to have been drilled as test wells during land development and/or have been closed since the time of drilling.

The RDN currently operates four production wells, located in three wellfields, which are screened in Aquifer 219. In the western portion of the Project Area, outside Electoral Area E, the Englishman River wellfield is located between the Englishman River and Craig Creek. Englishman River production wells PW2 and PW3 are currently in operation. In 2012, in collaboration with the RDN the BC MoE equipped Englishman River PW4 with monitoring equipment and added the well to its observation well network as BC MoE Observation Well no. 395. An example of the continuous water level data collected for BC MoE Observation Well no. 395 is provided in Appendix B. Englishman River PW1 is currently not being used for water supply.

In the northern portion of Aquifer 219, the RDN operates Wallbrook Well no. 1 (formerly Madrona Well no. 7) and Madrona Well no. 8. These wells are approximately 500 m south of the ocean and approximately 180 m and 160 m southeast from Craig Creek, respectively (Figure 7). BC MoE Observation Well no. 396, which was formerly RDN-owned Madrona Well no. 1, was established in 2012 to monitor groundwater levels in the northern portion of Aquifer 219. This observation well is located less than 400 m from the ocean.

The RDN currently does not operate West Bay Well no. 1, located less than one km northwest of Nanoose Bay (Figure 7). RDN records indicate that Madrona Well no. 3 was drilled at a location over 1.5 km east of Wallbrook Well no. 1 and southeast from Madrona Well no. 8, but Madrona Well no. 3 was not used for production. It is unknown if Madrona Well no. 3 was closed or is unused but available for monitoring.

Water levels in four privately owned wells that are interpreted to be screened in Aquifer 219 are being monitored by the RDN as part of an assessment for the RDN's water supply well at Parker Road, near Nanoose Bay (Figure 7). The Parker Road supply well is discussed further in the section for Aquifer 214, below.

The well labeled as WBx on Figure 7 indicates the approximate location of a well that was drilled for the RDN as part of the West Bay wellfield. The property is currently privately owned and the status of the well is unknown. If the well has not been closed, it may be available as a potential location for monitoring.

### *Aquifer 1098 (IIC)*

As discussed in Section 4.3.1, the deeper unconsolidated deposits underlying Aquifer 219 were classified by the BC MoE as separate Aquifer 1098 in 2015. Aquifer 1098 extends over an area of approximately 17 $km^2$, generally within the central portion of Aquifer 219. Groundwater demand in this aquifer is classified by the BC MoE to be moderate relative to the aquifer's moderate productivity. The 116 wells in the Geodatabase that are interpreted to be completed in Aquifer 1098 are generally located within the central and northeastern portion of the aquifer, consistent with the areas where Lowen (2014) mapped the aquifer as being relatively deepest. The majority of the wells in Aquifer 1098 are reported to be used for private domestic use or irrigation, with four wells identified in the Geodatabase for commercial and industrial use and 20 wells used for water supply systems. Of the 20 wells that are identified in the Geodatabase for water supply, nine wells are owned by the RDN and are either active or unused, and the remaining 11 wells are inferred to have been drilled as test wells and/or have been closed since the time of drilling.

Most of the production wells that the RDN currently operates in the Madrona, Nanoose and Fairwinds wellfields were previously reported to be completed in Aquifer 219; however, based on well depths and lithological information, some of these wells are interpreted to be completed in Aquifer 1098 (Figure 7):

- Madrona Well no. 4 is located approximately 1,200 m south from the ocean and approximately 170 m southeast from Craig Creek
- Nanoose Well no.s 2, 3 and 4 are located in the northeast corner of Aquifer 1098, near the headwaters of Maelstrom Creek
- Fairwinds Well no.s 1, 2 and 3 and West Bay Well no. 3, in the eastern portion of the aquifer, are approximately 1 km northeast of Nanoose Bay

Review of production records for the RDN's active production wells indicated that, during the dry season of 2014 when production (i.e., pumping) rates increased, pumping levels (i.e., water levels in a well during pumping) were below "critical" water level thresholds[3] in Fairwinds Well no. 1 and West Bay Well no. 3, and below a "low" threshold level in Madrona Well no. 4, potentially indicating an area of Aquifer 1098 is under relatively higher stress during the dry season.

In the area of the Nanoose wellfield, the RDN monitors water levels in Nanoose Well no. 7; this well is not currently used to supply the Nanoose Water System. The static water level in Nanoose Well no. 7 was reported to be at a depth of zero m below ground surface (i.e., at ground surface) for each month in 2014, suggesting either artesian conditions or potential errors in the data being collected with the pressure transducer.

The BC MoE also established Observation Well no.s 397 and 393 near the Fairwinds wellfield and approximately 4 km west of Nanoose Bay, respectively (Figure 7). These wells were added to the BC MoE Observation Well Network to monitor water levels in Aquifer 219 (Well no. 397) and "an unmapped, developed surficial aquifer" (Well no. 393) prior to Aquifer 1098 being classified by the BC MoE. Based on the locations and depths of the respective observation wells, both are interpreted to be screened within Aquifer 1098. BC MoE Observation Well no. 397 is approximately 500 m south and upslope of Maelstrom Creek. BC MoE Observation Well no. 393 is located within the Nanoose Creek watershed, approximately 600 m north of the creek.

Near Nanoose Bay, water levels in four privately owned wells that are interpreted to be screened in Aquifer 1098 are being monitored by the RDN as part of the Parker Road monitoring program (Figure 7).

### *Aquifer 215 (IIC)*

The mapped area of Aquifer 215 that is located within the Project Area is 14 km$^2$. The BC MoE has classified this sand and gravel aquifer as having moderate groundwater demand relative to moderate aquifer productivity. Under the Phase 1 Water Budget, Aquifer 215 was assigned a relative stress of Moderate to High. As presented on Figure 6B, more than half of the 259 wells that are completed in Aquifer 215 are located in the residential area immediately south, and upgradient of, the Snaw-Naw-As First Nation (FN) Indian Reserve (IR), with fewer wells located to the east. Wells that are reported to be completed in overburden deposits south of the mapped aquifer extent are interpreted to also be completed in Quadra deposits and are assigned to Aquifer 215.

The majority of the wells in Aquifer 215 are listed in the Geodatabase for private domestic use on predominantly residential properties. Ten wells were identified in the Geodatabase to be used for water supply systems and two wells were reported to be used for commercial industrial purposes on properties adjacent to the Island Highway.

[3] Threshold levels were established by the RDN to prevent over pumping a well and potentially damaging a pump. The pumping level in a well depends upon a number of factors including the pumping rate, efficiency of the well, etc.

The Snaw-Naw-As FN and the District of Lantzville (Lantzville) both operate production wells to supply groundwater to their respective community water systems. The Snaw-Naw-As FN supply well is located in the southwest corner of the IR (Figure 7). Lantzville currently operates three production wells (Lantzville Well no.s 6, 9 and 12) that are screened in Aquifer 215 and located in a wellfield that is over 2 km east of Electoral Area E (Figure 7).

Based on a review of the well logs for the remaining six wells that were identified in the Geodatabase for water supply systems, one is a well that was previously used by the Snaw-Naw-As FN but is no longer used, three were drilled for Lantzville and two wells were drilled to supply mobile parks that are located along the eastern edge of the Project Area.

Under its Observation Well Network, the BC MoE currently monitors two wells that are completed in Aquifer 215. BC MoE Observation Well no. 340 was established in 1999 at a location south of the Snaw-Naw-As FN IR and approximately 550 m south of Nanoose Bay. In addition to Observation Well no. 340, the RDN collects continuous groundwater level data with a pressure transducer that is installed in a privately owned volunteer well located along Northwind Drive and approximately 300 m north of the wetland along a tributary of Knarston Creek (Figure 7). In 2013, the RDN also collected one-time manual water level measurements from four privately owned wells along Northwind Drive.

In 1979, the BC MoE established Observation Well no. 232 to monitor groundwater levels in Aquifer 215 in a well that is within the area of the Lantzville wellfield (Figure 7). This observation well is approximately 550 m west of Bloods Creek.

### *Aquifer 214 (IIB)*

Bedrock Aquifer 214 extends beneath a large portion of Aquifer 219 and Aquifer 1098. The mapped extent of Aquifer 214 covers an area of approximately 34 km$^2$. Aquifer 214 is classified with low demand relative to low aquifer productivity and was assigned a relative stress of Low under the Phase 1 Water Budget. The 83 wells in this aquifer are listed as being used for domestic or irrigation purposes. As presented on Figures 5 and 6, wells in Aquifer 214 are primarily located along the northern and eastern edge of the mapped aquifer on properties generally designated as Rural Residential, where water supply is from private domestic wells, and Coast Residential parcels that are serviced by the Nanoose Water System.

The RDN water supply well at Parker Road, near Nanoose Bay, is constructed in Aquifer 214 (Figure 7). Although this well is not currently being pumped, it will be operated in the future to supply the Nanoose Water System (RDN, 2016b). In addition to the supply well, six privately owned wells that are completed in Aquifer 214 are included in the RDN monitoring program near Parker Road. These wells are generally located adjacent to Maelstrom Creek.

The BC MoE Observation Well Network does not currently include a well that is installed in Aquifer 214.

Nanoose Well no. 1, reported in the Geodatabase to be located approximately 80 m southwest from Nanoose Well no. 7, is interpreted to be completed in Aquifer 214. It is unknown if the well was closed or is available for monitoring.

### *Aquifer 210 (IIB)*

Bedrock Aquifer 210 is overlain by relatively thin overburden deposits of Aquifer 219 and/or Aquifer 1098. The mapped area of Aquifer 210 is approximately 5 $km^2$. Aquifer 210 is inferred to be recharged by precipitation, and discharge into Nanoose Creek, which flows through the center of the aquifer, and recharge Aquifer 219 to the north.

Aquifer 210 is moderately developed, with 78 wells. The wells that are completed in Aquifer 210 are used for private domestic or irrigation purposes primarily on properties that are designated as Rural. Under the Phase 1 Water Budget, Aquifer 210 was assigned a relative stress of Moderate to High.

Neither the BC MoE nor the RDN currently monitor water levels in wells that are completed in Aquifer 210. In 2013, the RDN manually measured groundwater levels (i.e., one-time measurements) for two volunteer wells that are inferred to be completed in Aquifer 210. Groundwater level measurements were also collected for a third volunteer well. The well tag no. for the third well is not documented and, therefore the well log could not be reviewed to identify which aquifer the well is completed in. The three two privately owned wells were drilled for domestic water supply for properties along Matthew Road.

### *Aquifer 213 (IIC)*

The mapped area of bedrock Aquifer 213 (approximately 42 $km^2$) extends from its contact with bedrock Aquifer 214 near Nanoose Bay, to the eastern edge of the Project Area (Figure 5). Groundwater in Aquifer 213 is recharged by infiltration of precipitation and from the creeks and wetlands in the headwaters of the local watersheds, including the watersheds of Bonell Creek, Knarston Creek and Millstone River. In the lower elevation areas adjacent to the ocean, Aquifer 213 is also inferred to receive groundwater recharge from the unconsolidated deposits of Aquifer 215.

The classification for Aquifer 213 is moderate demand relative to moderate productivity and a low relative stress assessment under the Phase 1 Water Budget. Relatively higher well densities are observed on Residential properties in the northwestern portion of the aquifer, near Nanoose Bay, and along the eastern portion of the Project Area, near Brannen Lake.

The 366 wells that are completed in Aquifer 213 are reported to be primarily used for private domestic purposes, with a few listed for irrigation. In addition to the three production wells that are screened in Aquifer 215, Lantzville also operates one production well (Lantzville Well no. 4) that is screened in Aquifer 213 (Figure 7).

The BC MoE Observation Well Network does not include a well that is installed in Aquifer 213. In 2016, the RDN established a volunteer monitoring well along Seablush Drive, in the western portion of Aquifer 213 (Figure 7). A pressure transducer was deployed in this privately owned well to collect continuous water level data.

The RDN collects continuous water level data from a privately owned volunteer well that is located in the eastern portion of the Project Area along Elm Road, northwest of Green Lake and southeast of Bloods Creek (Figure 7). The RDN collected one-time manual groundwater level measurements from 10 privately owned volunteer wells along Elm Road and Aulds Road in 2013.

### *Aquifer 218 (IIB)*

The approximately 16 km$^2$ mapped area of bedrock Aquifer 218 underlies the Nanoose Peninsula. As discussed in Section 4.3.1, the overburden deposits that overlie Aquifer 218 are relatively thin and the aquifer is interpreted to have a relatively strong hydraulic relationship with surface water features including Enos Creek and Lake, and Dolphin Lake.

Aquifer 218 is classified with moderate demand relative to the low productivity of the aquifer and the stress assessment that was conducted under the Phase 1 Water Budget assigned a ranking of Very High to Aquifer 218. As presented on Figure 7, the Nanoose Water System provides water service to the subdivisions in the northeastern and eastern portions of the Nanoose Peninsula. Therefore, with the exception of the RDN's Nanoose Well no. 6, located in the northern portion of the Nanoose Peninsula, these subdivisions do not place water demand on Aquifer 218, as the water for the Nanoose Water System is supplied by surface water from the Englishman River and RDN wellfields that are completed in other aquifers.

The majority of the 90 wells that were identified for Aquifer 218 are located in the central portion of the peninsula on properties designated as Rural and Rural Residential (Figure 6A). The wells on these properties are listed for private domestic use.

Located approximately 240 m west of Nanoose Well no. 6, former Nanoose Well no. 5 was added to the BC MoE Observation Well Network in 2012 as Observation Well no. 394.

## 5.0 WATER MONITORING PLAN

The Water Monitoring Plan that is proposed in the following sections was developed to build upon the existing monitoring network, address the data gaps identified in the Project Area and refine the Conceptual Model for Electoral Area E. The Water Monitoring Plan is intended to provide the RDN with the technical basis to manage water resources at the watershed and aquifer scale. The monitoring data that will be collected at the strategic locations presented in Section 5.1 will be used to establish baseline conditions, and assess seasonal variability and long term climatic trends. The dataset from the monitoring locations will be used to refine water budgets for Electoral Area E and identify watersheds and aquifers that have relatively higher water stress, particularly during the dry summer season, and areas with relatively lower water stress. This information will inform planning and land use decisions that support sustainable development. The monitoring data will also support other, related initiatives such as drainage and flood forecasting, fire weather forecasting and fire management initiatives.

By working with the Snaw-Naw-As FN and stakeholders such as community stewardship groups to implement the Water Monitoring Plan, the RDN will support its broader outreach and public education program, and build capacity at the local level. These partnerships will also provide the opportunity for the technical aspects of the Water Monitoring Plan to be informed by traditional and local knowledge that provides an important socio-cultural context to water resources in the area. Potential partners such as federal and provincial government agencies are also identified and discussed in Section 5.1 as opportunities to achieve complementary objectives and leverage collective financial resources.

In addition to the water monitoring locations presented in Section 5.1, the supplemental activities in Section 5.2 are also provided to support refinement of the Conceptual Model and water budgets for the Project Area, and broader initiatives that protect the region's water resources.

## 5.1 Recommendations for Monitoring Stations

Based on the analysis of the Conceptual Model and the updated Geodatabase, locations for climate and hydrometric monitoring stations and groundwater monitoring wells are proposed to address data gaps in the existing monitoring network. A detailed review of potential monitoring locations, including a field reconnaissance, will be required to select specific sites for monitoring stations and wells. In addition to technical considerations such as stream channel stability and well completion details, practical aspects such as land ownership, telecommunication options and site access should also be considered when selecting specific monitoring locations.

The proposed monitoring locations are prioritized for implementation based on the relative water stress assigned to the watersheds and aquifers during the Phase 1 Water Budget, and other technical considerations presented in the following sections. Station locations consider land use activities and focus on areas where water use is relatively higher. For example, rather than the developed areas that are serviced by the Nanoose Water System, the extraction points for the water supply were considered (i.e., the surface water supply from the Englishman River and the RDN's wellfields) as areas of relatively higher water stress with the potential to impact local aquatic habitats.

The proposed monitoring locations are intended to build a complementary dataset (i.e., climate, hydrometric and groundwater level data) that is appropriate to assess relationships between elements of the Conceptual Model at the watershed and aquifer scale. Additional monitoring would be required to assess site-specific conditions and the potential influence from specific surface water diversions and/or pumping individual wells. An example of a site-specific program is the monitoring that has been conducted to assess the potential impacts from operation of the RDN's supply well at Parker Road.

It is recommended that monitoring locations with a priority ranking of "Primary" be established first to address data gaps at priority locations. Monitoring locations that are assigned a priority ranking of "Secondary" should then be established to supplement the dataset and assess variability within the Project Area. It is anticipated that the proposed monitoring locations will be implemented based on financial requirements and practical considerations such as opportunities for potential partners, land ownership and site access. These aspects are also discussed in the following sections.

### 5.1.1 Climate Stations

#### *Monitoring Locations and Data Collection*

Climate data provide necessary input to water budget and stress assessments for both watersheds and aquifers. As discussed in Section 4.1 and presented on Figure 2, four climate stations are currently being operated in the coastal areas of the Project Area, at elevations <50 m asl. Proposed climate monitoring stations were identified to provide data required to establish baseline conditions, refine variables used for the stress assessments under the Phase 1 Water Budgets (i.e., evapotranspiration, surface water runoff, groundwater recharge, etc.) and provide input to future numerical modeling for the Project Area. The proposed climate monitoring stations are prioritized based on gaps within the existing monitoring network, with consideration of the stress rankings for watersheds and aquifers. Recommendations for climate monitoring stations are summarised and presented in Table 9 and the general locations are presented on Figure 8.

**Table 9: Recommendations for Climate Monitoring Stations**

| Climate Monitoring Location | Priority Ranking[1] | Rationale | Data Collection Requirements |
|---|---|---|---|
| Headwater area of Nanoose Creek and/or Bonell Creek | Primary | Provide climate data for upper elevation area(s) of the watershed to establish baseline conditions and assess geospatial variability of climate data to refine water budgets. Nanoose Creek (surface water stress ranking of High) and the upper elevation areas are groundwater recharge areas for downgradient overburden and bedrock aquifers. | Continuous (hourly) data: precipitation, air temperature/relative humidity, wind speed/direction, atmospheric pressure |
| Nanoose Peninsula | Primary | Monitor microclimate in the central area of the Nanoose peninsula at relatively higher elevation to refine estimates of runoff to surface water features and groundwater recharge for bedrock Aquifer 218 (stress ranking of Very High). | Continuous (hourly) data: precipitation, air temperature/relative humidity, wind speed/direction |
| Snaw-Naw-As First Nation (FN) Indian Reserve (IR) | Secondary[2] | Monitor climate conditions in the eastern portion of Electoral Area E to assess variability and refine estimates of groundwater recharge to Aquifer 215 (stress ranking of Moderate-High). | Continuous (hourly) data: precipitation, air temperature/relative humidity, wind speed/direction |

Notes:

1. Relative priority ranking recommended for implementation to address data gaps in the existing monitoring network
2. A climate station could also be established in the area immediately south of the Snaw-Naw-As FN IR; however, the Pleasant Valley Elementary climate station, located less than 500 m east of the Project Area, is monitored under the School-Based network and provides climate data for this area of the RDN.

Consistent with the results of the KWL (2015) Regional Climate and Hydrometric Monitoring Network Scoping Study, it is recommended that each climate station include the following main components:

- air temperature/relative humidity sensor
- wind speed and wind direction sensor
- rain gauge
- data logger
- power source (power main or battery and solar panel)

In addition to the pressure transducer that would be installed at the climate station proposed for the headwater area of Nanoose Creek and/or Bonell Creek to monitor atmospheric pressure, data would also be available at nearby monitoring stations, including the Nanoose Bay Elementary climate station, and stations in adjacent water regions.

A tipping bucket rain gauge is recommended for the climate stations in lower elevation areas (i.e., Nanoose Peninsula and Snaw-Naw-As FN IR) whereas a total volume gauge (e.g., type-B) is recommended for the higher elevation headwater areas of Nanoose Creek and/or Bonell Creek where both liquid and freezing precipitation could be expected in the winter. Based on considerations such as site access and the requirements of potential partners, discussed below, the data logger could be connected via telecommunications to provide real-time data retrieval. Telecommunications options include wired internet connections in developed areas, supervisory control and data acquisition (SCADA) systems, mobile data network and by satellite in remote areas. Alternatively, data could be downloaded from the data logger manually by field staff during regularly scheduled visits.

### *Potential Partnerships*

As discussed in Section 4.1, climate stations are currently being operated in the Project Area by:

- the School-Based Weather Network
- City of Parksville
- Fairwinds Golf Course

As part of their scoping study, KWL (2015) also noted that climate monitoring stations have been established by timber companies and the BC Ministry of Forests, Lands and Natural Resource Operations (BC MFLNRO) at elevations between 200 and 1,000 m asl to support fire management activities including wildfire preparedness and suppression, and research. There may be an opportunity for the RDN to partner with one of these stakeholders to supplement an existing climate station or establish a new climate station in the upper elevations of the Project Area. Based on the data requirements of these potential partner organizations, it is anticipated that real-time data collection would be required.

Environment Canada formerly operated the Nanoose Bay climate station from 1912-1989. The RDN could consider re-establishing a climate monitoring station at the former Nanoose Bay station location in partnership with Environment Canada or establishing a new climate monitoring station at the RDN Nanoose Wastewater Treatment Plant which is located on Nanoose Road, on the same property where BC MoE Observation Well no. 397 is located (Figure 7).

More accurate weather monitoring equipment could also be provided to Nanoose Bay Elementary School and/or the Fairwinds Golf Course to improve the quality of the data that are collected at these existing stations. The Nanoose Bay Elementary location is at a lower elevation and may not reflect conditions in the central portion of the Nanoose Peninsula.

A climate station could also be established in the area immediately south of the Snaw-Naw-As FN IR. This may provide an opportunity for the RDN to partner with the Snaw-Naw-As FN to implement a program that builds public awareness and supports local community initiatives while developing a data set for input to the RDN’s Water Budget Project. If a climate station is not established near the Snaw-Naw-As FN IR, the Pleasant Valley Elementary climate station, located less than 500 m east of the Project Area, is monitored under the School-Based network. Climate data from this station can be used to assess variability at lower elevations in the vicinity of the Project Area.

When identifying potential partnerships for climate stations, the RDN should consider roles and responsibilities for the installation, operation and maintenance of the stations. In addition to the data collection, storage and distribution aspects outlined by KWL (2015), the RDN should develop a data management plan that includes a schedule for regular assessment of the data quality and analysis and interpretation of the results.

For telecommunication options that include real-time data transfers, the RDN may consider coordinating with the City of Nanaimo to evaluate the possibility of using the communication systems (radio network based systems) that the City of Nanaimo currently has in place for similar climate monitoring stations. These systems provide the advantage that they are continuously monitored relative to specific threshold alarms and the health of the systems (i.e., for sensor malfunctions and transmission capabilities).

### *Preliminary Costs for Climate Stations*

As discussed above, the costs for climate stations will depend upon the location, equipment used, partner agencies involved and staffing. A range of preliminary costs is provided in Table 10, below, to support planning and the decision-making process.

**Table 10: Preliminary Costs per Climate Station**

| Item | Preliminary Cost | |
|---|---|---|
| | Local Site[1] | Remote Site[2] |
| Climate monitoring equipment, including data logger and telemetry | $6,000 | $20,000 |
| Equipment acquisition and installation[3] | $7,500 | $15,000 |
| **Total Installation Costs:** | **$13,500** | **$35,000** |
| Annual maintenance (assumes 4 visits per year), and monthly data quality review | $5,000 - $7,500 | $6,000 - $9,000 |

Notes:
1. Sites in populated areas with power main access (e.g., existing secured property) and data download is either manual or via mobile network communication
2. Sites in remote headwater areas of watersheds where satellite telemetry is used to collect real-time data; assumes that site is accessible by vehicle
3. Assumes site access is granted and no works required to clear the area or install fencing or protective housing for the equipment; costs to be refined based on staff/partner agency who will conduct the work

The preliminary costs can be refined once the roles and responsibilities of the potential partners have been clarified, including staff that will acquire, install and maintain the climate stations, and potential costs for site access and preparation are assessed.

## 5.1.2 Surface Water Stations

### *Monitoring Locations and Data Collection*

Surface water flow data are required to predict available surface water supplies for watersheds, refine the surface water stress assessments that were conducted for the major watersheds in the Project Area and conduct stress assessments for minor watersheds that were not included in the Phase 1 Water Budget. Furthermore, seasonal surface water flow data are required to assess baseflow during the dry season and the interaction between surface water and groundwater. Recommendations for hydrometric monitoring stations are provided in Table 11, below, and the locations are presented on Figure 8.

**Table 11: Recommendations for Hydrometric Monitoring Stations**

| Hydrometric Monitoring Location | Priority Ranking | Rationale | Data Collection Requirements |
|---|---|---|---|
| Lower Nanoose Creek | Primary | Re-establish a baseline station for Nanoose Creek (High surface water stress) to monitor surface water flow and assess seasonal and long-term trends. Nanoose Creek also provides recharge to bedrock Aquifers 210 (Moderate-High stress ranking) and 214, and overburden Aquifers 219 and 1098. | Continuous water level measurements[1] |
| Upper Nanoose Creek | Primary | Establish a station in the upper reaches of the Nanoose Creek watershed, upstream from wetlands and surface water licenses. Data from this hydrometric station and a nearby climate station will be used to refine estimates of surface water runoff and groundwater recharge. | Continuous water level measurements |
| Enos Creek/Enos Lake | Primary | Monitor water levels in Enos Lake and discharge along Enos Creek to assess available surface water in the lake and baseflow from Aquifer 218 (Very High water stress).[2] | Continuous or manual water level measurements |
| Knarston Creek | Secondary | Establish baseline conditions for Knarston Creek to assess surface water availability and hydraulic connection to overburden Aquifer 215 (Moderate-High stress ranking) | Manual water level measurements |
| Bonell Creek | Secondary | Establish baseline conditions for Bonell Creek and compare data to Nanoose Creek to assess variability with Project Area and calibrate surface water runoff estimates for other nearby watersheds; Bonell Creek is inferred to recharge overburden Aquifer 219 and bedrock Aquifer 213 | Continuous water level measurements |
| Selected watersheds and sub-watersheds | Secondary | Monitor discharge at strategic locations in the Project Area to assess baseflow during the dry summer season: watersheds and sub-watersheds should be prioritized based on relative stress rankings (surface water: Craig Creek, Benson Creek, Metral Creek; Aquifers 215, 210, 218) and/or surface water licenses and well density | Manual water level measurements during the dry summer season |

Notes:

1. Water level data are converted to discharge (i.e., flow) estimates based on a rating curve
2. Lake and/or creek monitoring may be conducted to assess the surface water licenses for Enos Lake

If, based on the results of the dry season discharge monitoring, specific creeks are interpreted to have a high surface water stress ranking, the RDN may wish to expand their hydrometric monitoring network to these locations.

Equipment for a hydrometric station would include the following:

- water level sensor and data logger
- manual water level gauge (staff gauge)
- benchmarks (fixed control points with surveyed elevations)

At each hydrometric station, a detailed survey would first be required to measure the channel cross-section. Discharge measurements are then collected at different water levels (including low and high water levels) to create a rating curve.

Once the hydrometric station equipment is installed, continuous water level data in the stream are measured with the water level sensor, and recorded and stored on the data logger. Several types of water level sensors are available, including pressure transducers, radar, and bubbler systems. The water level sensor will be selected based on local site conditions:

- pressure transducer sensors are more suitable for remote locations with no existing crossing structures, with the sensor mounted inside a pipe in the active channel, and with a cable that connects to a datalogger that is secured on the stream bank, above the high water level
- radar type sensors are suitable for locations where an existing structure already exists, such as a bridge, on which the instrument can be attached
- bubbler systems may be suitable for locations where an enclosure with a power source is available at the site and the stream contains a high suspended solid load that would interfere with pressure transducer and radar sensors

Data from the loggers can be transmitted to a central database by a variety of telemetry methods (e.g., radio modules, mobile networks or satellite systems). The water level data are then used to calculate a volumetric discharge based on the rating curve.

The active channel of a stream is not fixed, and its cross section profile will change over time as the streambed and its banks shift. These changes will affect the rating curve. Regular measurements are therefore required to monitor these changes to the channel conditions and maintain an up to date rating curve. To minimize these changes, hydrometric stations should be located along reaches of a channel that are relatively stable (i.e., areas with limited erosion or scour).

It is recommended that hydrometric stations be established at locations where there are climate data that are representative of the watershed and groundwater level data for the adjacent aquifers. These data would provide the basis to assess local surface water runoff, groundwater recharge and baseflow from aquifers to surface water bodies.

### *Potential Partnerships*

Currently, no active hydrometric stations are currently being monitoring in Electoral Area E. Surface water monitoring (water level and surface water temperature) has been conducted at three locations along Maelstrom Creek as part of the Parker Road monitoring program and hydrometric data are collected for the Englishman River, located in adjacent WR4, at Water Survey of Canada hydrometric station 08HB002.

As discussed in Section 4.2.2, hydrometric stations were previously active in the Project Area including the stations at the mouth of Nanoose Creek and at Enos Lake. These stations could potentially be re-established under the Water Monitoring Project in collaboration with the Water Survey of Canada. In addition to building the database for the RDN's Water Budget Project, the hydrometric data could also provide information for smaller watersheds. The BC MFLNRO may also be a potential partner for the RDN for installation and maintenance of one or more of the proposed hydrometric stations. Assessment of the hydraulic connection between groundwater in an aquifer and water in an adjacent surface water body is a key consideration for the allocation of groundwater licenses under the WSA.

The RDN may also wish to consider working with academic institutions, local stewardship groups and/or members of the Snaw-Naw-As FN to conduct manual discharge monitoring during the dry summer seasons. This would likely require that a training program be provided and follow up quality assurance checks be conducted to validate the consistency and quality of the data. Health and safety aspects of working around water should also be considered and appropriate training provided and mitigative measures implemented to protect members of the public if they are engaged in surface water monitoring activities.

### *Preliminary Costs for Hydrometric Stations*

A range of preliminary costs for hydrometric stations are provided in Table 12, below. The range of preliminary costs will be refined depending upon factors such as the station locations, equipment used and partner agencies involved. In addition, cost savings may be realized if more than one station is installed at a time.

**Table 12: Preliminary Costs per Hydrometric Station**

| Item | Preliminary Cost | |
|---|---|---|
| | Local Site[1] | Remote Site[2] |
| Hydrometric station equipment, including data logger and telemetry | $5,000 | $10,000 |
| Equipment acquisition and installation[3] | $5,000 | $10,000 |
| Monitoring and development of rating curve[4] | $15,000 | $15,000 |
| **Total Installation Costs:** | **$25,000** | **$35,000** |
| Annual maintenance (assumes 2 visits per year), and monthly data quality review[4] | $6,000 - $9,000 | $10,000 - $15,000 |

Notes:

1. Local, low discharge (i.e., small) stream, real-time data download via mobile network
2. Remote, high discharge (i.e., large) stream, real-time data download via satellite telemetry
3. Assumes site access is granted and no works required to clear the area or install fencing or protective housing for the equipment; costs to be refined based on staff/partner agency who will conduct the work
4. Includes site visits to collect manual water level measurements at different flow events for the first year by local staff. The preliminary cost may change depending upon the party that carries out the activity

## 5.1.3 Groundwater Monitoring Wells

### *Monitoring Locations and Data Collection*

Groundwater level data are required to assess directions of groundwater flow within, and between, aquifers, calculate hydraulic gradients and assess interaction with surface water features. One or more observation wells have been established in the majority of the aquifers in the Project Area; however, new observation wells can be established at strategic locations to obtain data required to refine the Conceptual Model and stress assessments from the Phase 1 Water Budget, and develop and calibrate a numerical model of groundwater flow in the Project Area. . During the Public Feedback Session that was held on 9 June 2016, some of the local residents indicated that they would also be interested in volunteering their wells for monitoring. Therefore, RDN-owned wells have been considered in addition to opportunities to supplement the RDN network with privately owned wells.

Table 13, below, summarizes wells that are proposed for groundwater level monitoring at the general locations presented on Figure 8.

**Table 13: Recommendations for Groundwater Monitoring Stations**

| Groundwater Monitoring Location | Priority Ranking | Rationale | Potential Monitoring Wells | Data Collection Requirements |
|---|---|---|---|---|
| Central portion of Aquifers 219, 1098 and 214 | Primary | Establish monitoring wells[1] that are completed in overburden Aquifers 219 and 1098, and underlying bedrock Aquifer 214 to measure vertical gradients and monitor seasonal and long-term trends in the central portions of the aquifers, upgradient from the discharge zones adjacent to the ocean; data will provide information regarding the relationship between the aquifer units | Madrona Well no. 3 (Aquifer 219)[2]<br>Privately-owned wells in neighbourhood approximately 2.5 km northwest of Nanoose Bay (Figure 8) | Continuous (hourly to daily) water level and temperature data[3] |
| Aquifer 219, near Nanoose Bay | Primary | Monitor water levels in overburden Aquifer 219 near the Fairwinds and West Bay wellfields where groundwater use and aquifer stress is inferred to be relatively high | West Bay Well no. 1 (Aquifer 219), Parker Road wells[4] | Continuous (hourly to daily) water level and temperature data |
| Aquifer 219 adjacent to the lower reach of Nanoose Creek | Primary | A relatively shallow well completed in Aquifer 219 to assess hydraulic relationship between the aquifer and Nanoose Creek (stress ranking High), particularly during the dry summer season; the monitoring well should be located relatively close to the hydrometric station at the mouth of Nanoose Creek | Privately owned wells, potentially WBx | Continuous (hourly to daily) water level and temperature data |
| Aquifer 218, central portion of Nanoose Peninsula | Primary | Monitoring well located in the central portion of the Nanoose Peninsula and completed in Aquifer 218 (stress ranking Very High) to assess groundwater levels in the upper elevation area, upgradient from Enos Lake and the contact with adjacent Aquifer 214 | Privately owned wells | Continuous (hourly to daily) water level and temperature data |
| Upper Nanoose Creek, Aquifers 210 and 219 | Primary | Establish monitoring wells in overburden Aquifer 219 or 1098 (Matthew Road area) and bedrock Aquifer 210 (stress ranking Moderate-High) to establish baseline groundwater level conditions; data from the wells can be analysed to assess vertical gradients | Privately owned wells | Continuous (hourly to daily) water level and temperature data |
| Coastal area of Aquifer 214 | Secondary | Establish one or more monitoring wells that are constructed in Aquifer 214 in the coastal areas to monitor water levels in the area where Wallbrook Well no. 1 and Madrona Well no. 8 are pumping groundwater from overlying Aquifer 219, and to assess potential for saline intrusion to Aquifer 214 | Privately owned wells | Continuous (hourly to daily) water level, temperature and electrical conductivity data |

| Groundwater Monitoring Location | Priority Ranking | Rationale | Potential Monitoring Wells | Data Collection Requirements |
|---|---|---|---|---|
| Coastal area of Aquifer 213 and/or Aquifer 215 | Secondary | Establish one or more monitoring wells that are constructed in bedrock Aquifer 213 or relatively deep deposits of overburden Aquifer 215 (stress ranking Moderate-High) in the coastal areas to monitor water levels and potential for saline intrusion | Privately owned wells | Continuous (hourly to daily) water level, temperature and electrical conductivity data |
| South of Snaw-Naw-As FN, Aquifer 213 | Secondary | Establish a monitoring well in the area south of Snaw-Naw-As First Nation Indian Reserve in Northwind Dr. area in bedrock Aquifer 213; data from this well can be analysed with data from existing BC MoE Observation Well no. 340 and the RDN Volunteer well that are both constructed in overburden Aquifer 215 to assess vertical gradients and long-term trends in these aquifers | Privately owned wells | Continuous (hourly to daily) water level and temperature data |
| Aquifer 219 adjacent to the Englishman River and Craig Creek | Secondary | Water level data from Englishman River PW no. 1 could support analysis of drawdown from operation of PW2 and PW3 and potential influence on nearby Englishman River and/or Craig Creek | Englishman River PW1 | Continuous (hourly to daily) water level and temperature data |

Notes:
1. It is recommended that separate monitoring wells are established rather than nested piezometers completed in the same borehole
2. Well identified in Geodatabase; however, status of well not currently known and field inspection recommended to confirm well conditions
3. In addition to installation of an electronic pressure transducer and data logger in the well to collect water level data, a transducer is also required at ground surface to monitor changes in atmospheric (i.e., barometric) pressure
4. One or more wells that are currently monitored for the Parker Road supply well could be established as a long-term monitoring well

In addition to the locations presented in Table 13, the RDN could also consider installing a monitoring well in Aquifer 221 to assess seasonal and long-term trends in the aquifer and the hydraulic relationship between the aquifer and the Englishman River. As this aquifer is located entirely in adjacent WR4, this monitoring location has not been included in the Water Monitoring Plan for Electoral Area E.

The groundwater monitoring locations that are presented in Table 13 could be established using existing wells or, alternatively, new wells could be drilled at these strategic locations. Ideally, the monitoring wells would not be regularly operated and situated outside the zone of influence (i.e., drawdown cone) from nearby pumping wells to permit collection of static groundwater levels. For cost effectiveness, it is anticipated that existing wells will be used for groundwater level monitoring. Although the potential wells that are identified in Table 13 are proposed based on information provided on the respective well logs, alternative existing wells may also satisfy the criteria. Where possible, unused RDN wells have been proposed. In other locations, privately owned wells could potentially be monitored; however, it would be necessary for the RDN to secure long-term access to these wells for monitoring.

It is understood that the RDN may revise the network of privately owned volunteer wells near Parker Road once a baseline has been established during regular operation of the supply well. If, in the future, the Parker Road well network is reduced, it is recommended that the RDN retain at least one monitoring well in each of overburden Aquifers 219 and 1098 and bedrock Aquifer 214. In other areas, candidate wells include the privately owned volunteer wells where the RDN collected one-time manual water level measurements in 2013.

For each of the proposed new monitoring wells, a pressure transducer would be installed to collect absolute pressure and water temperature data at a regular (e.g., hourly) frequency. Monitoring wells that are established along coastal areas should be equipped with pressure transducers that also measure electrical conductivity to support assessment of potential saline intrusion. Monitoring wells may also require attachment of an upgraded lid that is vented to equalize with atmospheric pressure and equipped with a hook from which the cable and pressure transducer are installed. For wells that are actively pumped, it is recommended that a sounding tube also be installed in the well to prevent the pressure transducer and water level meter (during manual water level measurements) from becoming entangled in the pump and/or pump drop tube. The RDN may also wish to consider deploying transducers in actively pumped wells with direct read cables. This permits downloading and/or programming of the transducer from the wellhead without having to physically retrieve the transducer from the well.

Following deployment of the transducers, the data should be downloaded on a regular (e.g. quarterly) basis. Manual groundwater level measurements should also be collected during these monitoring events to convert the raw data from the pressure transducer to groundwater levels. The absolute pressure data that are retrieved from the pressure transducers should also be corrected for changes in atmospheric pressure. This can either be accomplished using data from a nearby climate station (accounting for changes in elevation between the well and the station) or with one or more barologger pressure transducers that are deployed at ground surface at representative sites to monitor changes in barometric (i.e., atmospheric) pressure.

At each monitoring well location, the elevation of the well casing should also be surveyed to establish a datum from which depth to groundwater measurements can be converted to groundwater elevations and hydraulic gradients within, and between, aquifers can be calculated.

### *Potential Partnerships*

As discussed in Section 4.3.3, the BC MoE currently maintains seven observation wells in the Project Area. These observation wells are located in Aquifers 219 (two wells), 1098 (two wells), 215 (two wells) and 218 (one well) at the locations presented on Figure 7. The RDN could potentially look for opportunities to partner with the BC MoE to establish additional monitoring wells at strategic locations in the Project Area such as bedrock Aquifer 210 and the central portion of Aquifer 218 that is not serviced by the Nanoose Water System. Aquifers 210 and 218 were assigned relative stress rankings of Moderate to High and Very High, respectively, in the Phase 1 Water Budget.

BC MoE observation wells are typically established on properties that are publically owned such as parks, municipal properties, etc. so that long term site access to the wells can be secured. If the BC MoE is interested in partnering with the RDN to expand its observation well network in the Project Area and wells that meet the criteria (i.e., well completion details, secure property, etc.) are not identified, new wells could be drilled at strategic locations. This would require higher capital costs to drill and construct the wells.

The RDN may also wish to expand its network of privately owned volunteer wells as a cost-effective option to address the data gaps at the proposed locations identified in Table 13. Programs that involve the use of privately owned wells that are volunteered by community members provide an opportunity to raise awareness and educate the public on the importance of groundwater protection and conservation; however, oversight from technical staff is required to maintain the quality of the data. As discussed above, if existing wells are selected for monitoring, long-term access to the wells should be secured. Owners of the privately owned wells that were included in the round of one-time manual water level measurements in 2013 may be interested in volunteering their well for continuous monitoring.

### *Preliminary Costs for Groundwater Monitoring Wells*

The costs to equip an existing well as a monitoring well will depend on a number of factors including the well depth, wellhead conditions, etc. The range of preliminary costs that are presented in Table 14, below, are provided to give an indication of the costs for monitoring equipment and on-going monitoring.

**Table 14: Preliminary Costs per Groundwater Monitoring Well**

| Item | Preliminary Cost |
|---|---|
| Pressure transducer and cable[1,2] | \$750 - \$1,200 |
| Wellhead upgrades (vented lid, drop tube, etc. *if necessary*)[2] | \$100 - \$300 |
| **Total Installation Costs:** | **\$850 - \$1,500** |
| Annual maintenance (assumes 4 visits per year) and quarterly data quality review[3] | \$2,000 - \$3,000 |

Notes:
1. Cost depends upon transducer model, and type and length of cable; cost for direct-read cables dependent upon length
2. Cost will depend upon wellhead conditions and work required; in-well work (e.g., placement of drop tube) should be done by a qualified well driller or pump installer who is registered with the BC Ground Water Association
3. Cost does not include optical reader and software to download data from transducers (\$200-\$300) or water level meter to collect manual water level measurements (cost dependent upon manufacturer and tape length)

The costs above assume that existing wells are used for monitoring. If a privately owned well does not comply with the minimum construction requirements of the BC Groundwater Protection Regulation, it is recommended that the RDN encourage the well owner to upgrade the well to support best practices. If well upgrades are coordinated with in-well work that is required to install the monitoring equipment (e.g., placement of a droptube, vented lid, etc.), the efficiencies could be passed along as a cost savings for the well owner.

The cost to drill a new well will depend upon a number of factors including aquifer materials, well depth and construction. If the RDN wishes to drill a new well, a qualified well driller should be contacted to provide a quote to drill and construct a well based on the anticipated depth and subsurface conditions. The well should be drilled and constructed under the direction of a professional hydrogeologist to confirm that the well meets the objectives of the monitoring program.

## 5.2 Supplemental Activities to Address Data Gaps

The supplemental activities presented in the following sections are also provided to complement the data that will be collected at the monitoring locations described above.

### 5.2.1 Land Use and Water Use Assessments

The RDN can also leverage information from a variety of complementary activities to refine input to both the input and discharge parameters for the water budgets. The RDN and Vancouver Island University (VIU) wetland mapping project will inventory wetlands in the region and assess how they influence groundwater recharge and regulate baseflow to creeks and streams. In addition to the wetland study, GIS-based tools, combined with field studies to ground-truth the data and models, can also be used to identify and assess smaller first-order streams and parameters such as vegetative cover in undeveloped areas and to refine estimates of evapotranspiration and groundwater recharge for the water budget equations.

As discussed in Section 4.3.2, the relatively new WSA requires licensing of groundwater for non-domestic use. Although the groundwater license information would provide the RDN with an understanding of the locations of groundwater extracted by other non-domestic users, it is anticipated that the licensed volumes would not necessarily reflect the volumes of groundwater actually extracted. The RDN should work with the BC MFLNRO and water users to measure actual surface water and groundwater use. This would be best achieved through the use of water meters. In the absence of water meter data, a variety of methods could be used to refine the estimates of surface water and groundwater use in the Project Area. In its Regional Growth Strategy (2011) the RDN is committed to supporting local agriculture and aquaculture that depend on sustainable water resources. For the Agricultural Land Reserve (ALR), the Agricultural Water Demand Model that was developed by van der Gulik et al. (2013) and the BC Agriculture Water Calculator that is available on-line from the Government of British Columbia (2016b) are tools that can be used to estimate annual irrigation water use at the parcel level based on a variety of input parameters including soil type, irrigated area, irrigation method and crop type. A survey could be conducted to refine the input parameter information for the BC Agriculture Water Model and the associated water budgets. The refined water use estimates, coupled with the results from the monitoring stations discussed in Section 5.1, could be used to direct agricultural development to areas with relatively lower water stress, inform crop selection and irrigation methods, and raise awareness for conservation and best farming practices. This would support the objective of improving opportunities for on-farm water supply, as outlined in the RDN's Agricultural Area Plan (Upland Consulting, 2012).

The RDN currently monitors discharge from its production wells and surface water intake from the Englishman River and collects data from water meters that are connected to the residential connections to the Nanoose Water System. Water meter readings are collected twice a year, in April and September. The RDN could consider collecting water meter data on a more frequent basis to assess use during key times of the year such as the peak dry season in August and mid- to late September when groundwater levels and baseflow in creeks and streams are lowest. The data from the water meters could also be analysed to assess water use patterns with respect to lot size, landscaped area and dwelling size. This information could be used to predict use for future build out, that will occur primarily in the Lakes District Neighbourhood and Schooner Cove Neighbourhood Plan area.

### 5.2.2 Water Quality Monitoring

While the focus of the Water Monitoring Plan is primarily on water quantity (i.e., supply and use), water quality monitoring could also be implemented at key surface water and groundwater monitoring locations. In addition to the three surface water quality monitoring stations that are monitored as part of the RDN Community Watershed Monitoring Network (see Section 4.2.2), and monitoring programs that are conducted for specific areas or developments, water quality monitoring could be conducted to assess variation in water quality over time and monitor potential impacts from land use activities, including non-point sources of contamination such as manure spreading on agricultural properties and specific sources of contamination such as contaminated sites that are registered on the BC MoE Site Registrar. Further assessment would be required to identify specific objectives for additional water quality monitoring and associated monitoring locations.

## 6.0 RECOMMENDATIONS

The following recommendations are provided for implementation of the Water Monitoring Project for Electoral Area E:

- Building on the strong relationships that it has with other stakeholders, the RDN should obtain formal commitments from other organizations to partner on monitoring initiatives. Based on the collective objectives and financial resources available, the elements of the Water Monitoring Plan should be prioritised for implementation.
- Based on the priorities identified above, a preliminary list of potential monitoring locations should be drafted. In support of this task, the RDN should confirm the conditions of its former production wells that are not well documented (e.g., Madrona Well no. 3 and WBx). Once preliminary locations are identified, background information such as well logs should be reviewed and a site reconnaissance conducted to assess site conditions, land ownership, access and general conformance of the data objectives.
- Following the site reconnaissance and discussions with land owners to obtain access to the proposed monitoring sites, detailed designs should be developed for the monitoring stations, including budgets with capital costs for equipment installation and acquisition, and on-going costs for monitoring and maintenance.
- The RDN should also work with stakeholders to develop a data management plan that outlines roles, responsibilities and schedules for data collection, regular assessment of the quality of the data, analysis, storage and distribution of the data.
- Based on the organizations who will be involved in the Water Monitoring Project, the RDN may also wish to assess the capabilities of the partner groups and identify requirements to build the capacity to conduct regular water monitoring.

**GOLDER ASSOCIATES LTD.**

PROFESSIONAL GEOSCIENTIST
PROVINCE OF BRITISH COLUMBIA
M. A. BOLTON
#29787
14 Dec 2016

Mark Bolton, MSc, PGeo
Associate, Senior Hydrogeologist

Reviewed by:

Jillian Sacré, MSc, PGeo
Principal, Senior Hydrogeologist

MAB/JS/smh



\\golder.gds\gal\burnaby\final\2015\3 proj\1547004 rdn_watermonitoring_nanoose\1547004-004-r-rev0\1547004-004-r-rev0-rdn water monitoring plan_final-14dec_16.docx

# 7.0 REFERENCES

AquaVic Water Solutions Inc., 2013. Water Conservation Plan. Prepared for the Regional District of Nanaimo (RDN). October 2013.

Benoit, N., D. Paradis, J.M. Bednarski, T. Hamblin and H.A.J. Russel, 2015. Three dimensional hydrostratigraphic model of the Nanoose-Deep Bay Area, Nanaimo Lowland, British Columbia. Geological Survey of Canada, Open File 7796.

BC Ministry of Environment (BC MoE), 1996. Aquifer Classification Work Sheet. Aquifer Reference No. 92F/8-Aquifer No. 221. January 1996.

BC Ministry of Environment (BC MoE), 1996b. Aquifer Classification Work Sheet. Aquifer Reference No. 92F/8-Aquifer No. 214. January 1996, updated March 2012.

Boom, A. and G. Bryden, 1994. Englishman River Water Allocation Plan. British Columbia Ministry of Environment, Lands and Parks (BC MELP), Vancouver Island Region. Available on-line at: http://www.env.gov.bc.ca/wsd/water_rights/wap/. Accessed in August 2016.

Fyles, J.G., 1963. Surficial Geology, Parksville, Vancouver Island, British Columbia. Geological Survey of Canada, "A" Series Map 1112A.

Government of British Columbia, 2016. Base Map Contour Data. Available on-line at: http://maps.gov.bc.ca/ess/sv/imapbc/. Accessed September 2016.

Government of British Columbia, 2016b. BC Agriculture Water Calculator. Available on-line at: http://www.bcagriculturewatercalculator.ca/. Accessed September 2016.

Government of Canada, 2016. Historical Climate Data. Available on-line at: http://climate.weather.gc.ca/. Accessed September 2016.

Government of Canada, 2016b. Hydrometric Station Data. Environment Canada Wateroffice available on-line at: https://wateroffice.ec.gc.ca/. Accessed September 2016.

Hicock, S.R., 1990. Last Interglacial Muir Point Formation, Vancouver Island, British Columbia. Geographié physique et Quaternaire. Vol. 44, no. 3. p. 337-340.

Kerr Wood Leidal Consulting Engineers (KWL), 2015. Regional Climate and Hydrometric Monitoring Network Scoping Study. KWL Reference No. 0536.010. April 2015.

PGL Environmental Consultants, 2016. Enos Lake Protection and Monitoring Program. Fairwinds: Lake District Nanoose Bay, BC. PGL File: 467501.01.

Regional District of Nanaimo (RDN), 2005. Nanoose Bay Official Community Plan: Electoral Area E – Nanoose, Fairwinds & Red Gap. Bylaw No. 1400.

Regional District of Nanaimo (RDN), 2011. Shaping Our Future Regional Growth Strategy. RDN Bylaw No. 1615. November 2011.

Regional District of Nanaimo (RDN), 2016a. Drinking Water & Watershed Protection website. Available on-line at: http://www.rdn.bc.ca/cms.asp?wpID=1748. Accessed August 2016.

Regional District of Nanaimo (RDN), 2016b. Personal correspondence. Ms. Julie Pisani, Drinking Water and Watershed Protection Program Coordinator. October 2016.

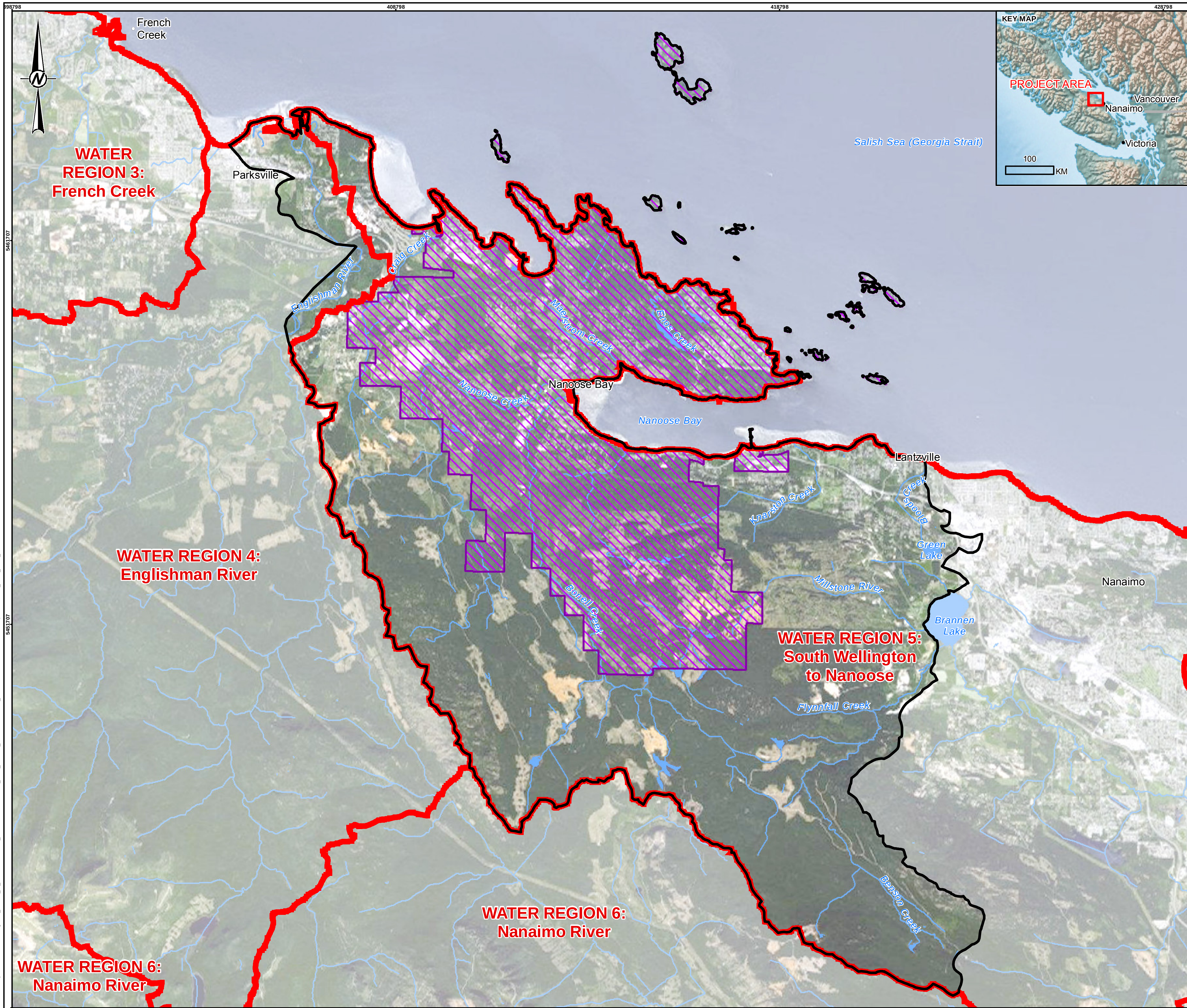
Upland Consulting, 2012. Growing Our Future Together Regional District of Nanaimo Agricultural Area Plan. August 2012.

van der Gulik, T., D. Neilson, R. Fretwell and S. Tam, 2013. Agricultural Water Demand Model. Report for the Regional District of Nanaimo. Partially funded by: British Columbia Conservation Foundation, Regional District of Nanaimo, Agriculture and Agri-Food Canada. May 2013.

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

Wang, T., A. Hamann, D. Spittlehouse, and T.N. Murdock, 2012. ClimateWNA – High-resolution spatial climate data for western North America. Journal of Applied Meteorology and Climatology, Vol. 61, p. 16-29.

Waterline Resources Inc., 2013. Water Budget Project: RDN Phase One (Vancouver Island). Waterline Reference No. 1924-11-001. June 2013.




**LEGEND**

- PROJECT AREA
- RDN WATER REGION
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

0 2 4

1:100,000 KILOMETRES

**REFERENCE(S)**

1. WATERCOURSE, WATER REGIONS, ELECTORAL AREA E OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.
5. INSET MAP: SERVICE LAYER CREDITS: SOURCES: ESRI, GEBCO, NOAA, NATIONAL GEOGRAPHIC, DELORME, HERE, GEONAMES.ORG, AND OTHER CONTRIBUTORS

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

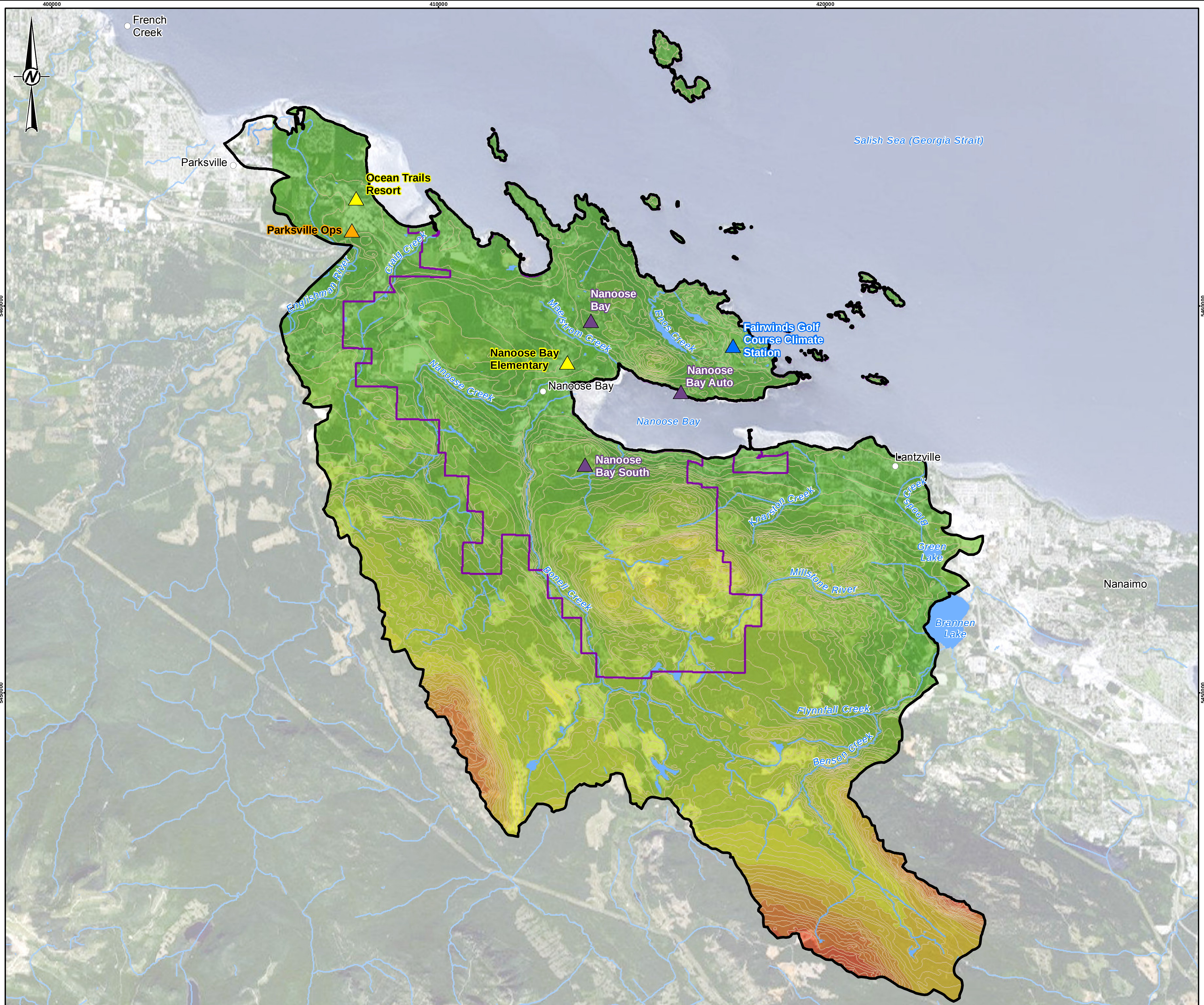
PROJECT
ELECTORAL AREA E WATER MONITORING PROJECT

TITLE
**SITE PLAN**

CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 15470004 | 3000 | 0 | 1 |




LEGEND

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

**ACTIVE CLIMATE MONITORING STATION**

- MONITORING STATION - CITY OF PARKSVILLE
- MONITORING STATION - PRIVATE
- MONITORING STATION - SCHOOL-BASED

**INACTIVE CLIMATE MONITORING STATION STATIONS**

- MONITORING STATION - ENVIRONMENT CANADA

**ELEVATION (metres above sea level; m.a.s.l )**

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000
- 1000 - 1100
- CONTOUR (20 m)

0 2 4

1:100,000 KILOMETRES

**REFERENCE(S)**

1. WATERCOURSE, ELECTORAL AREA E OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. MONITORING STATIONS, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.
5. CONTOURS AND ELEVATION MODEL DERIVED FROM CONTOURS OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
ELECTORAL AREA E WATER MONITORING PROJECT

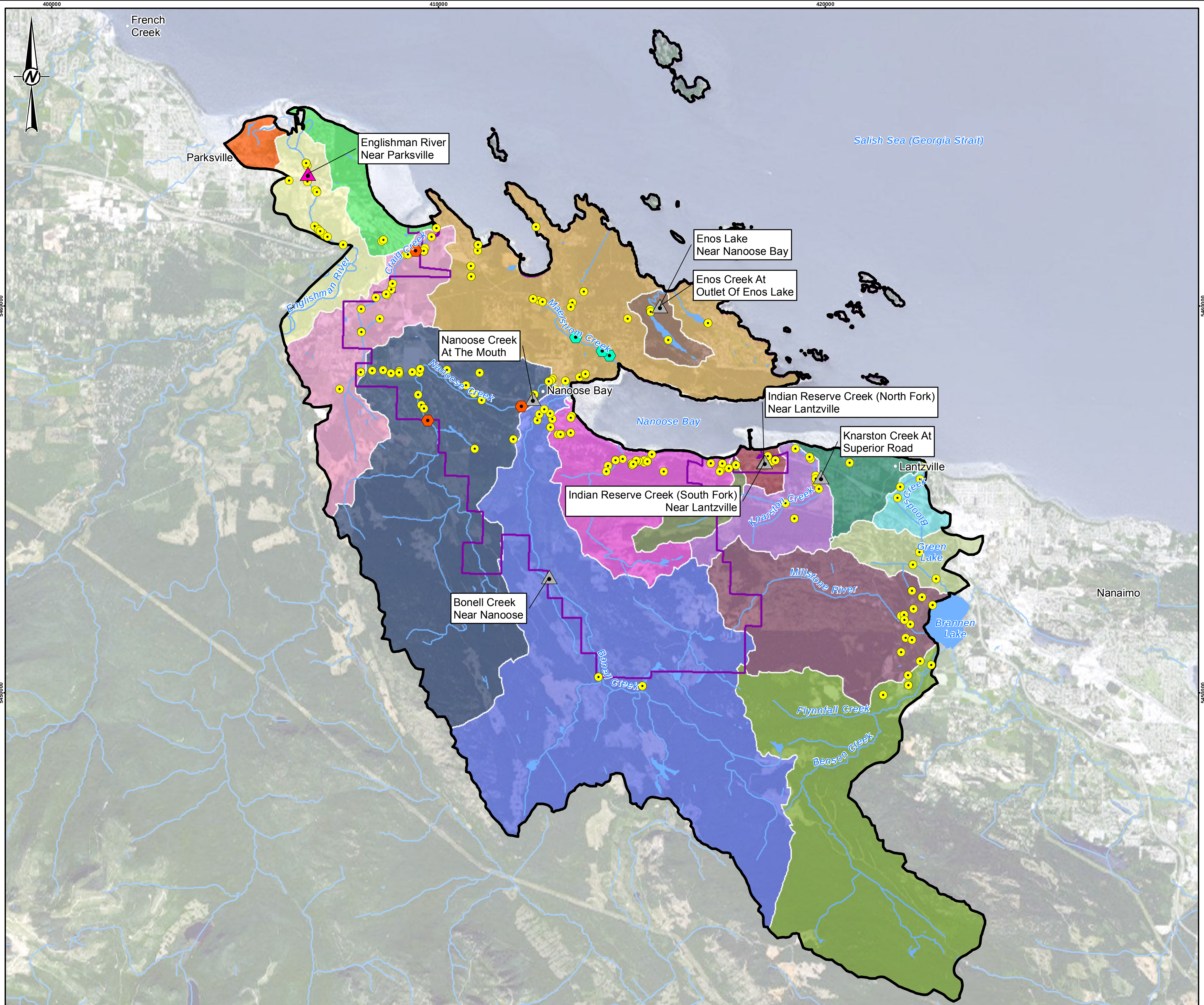
TITLE
**TOPOGRAPHY AND CLIMATE MONITORING STATIONS**

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 2 |




**LEGEND**

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

**HYDROMETRIC MONITORTING STATION**

- HYDROMETRIC STATION - ACTIVE
- HYDROMETRIC STATION - DE-ACTIVATED

**LICENSE**

- SURFACE WATER LICENSE

**MONITORING STATION**

- COMMUNITY WATER QUALITY MONITORING STATION
- PARKER ROAD MONITORING PROGRAM STATION

**MAJOR WATERSHED**

- BENSON CREEK
- BONELL CREEK
- CRAIG CREEK
- ENGLISHMAN RIVER
- MILLSTONE RIVER
- NANOOSE CREEK

**SUB-WATERSHED**

- BLOODS CREEK
- ENOS CREEK
- HARDY CREEK
- KNARSTON CREEK
- METRAL CREEK
- UNNAMED NO. 1
- UNNAMED NO. 2
- UNNAMED NO. 3
- UNNAMED NO. 4
- UNNAMED NO. 5
- UNNAMED NO. 6
- UNNAMED NO. 7

0 2 4

1:100,000 KILOMETRES

**REFERENCE(S)**

1. WATERSHEDS,WATERCOURSE, ELECTORAL AREA E, SURFACE WATER LICENSE OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. HYDROMETRIC STATIONS, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.
5. CONTOURS AND ELEVATION MODEL DERIVED FROM CONTOURS OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
ELECTORAL AREA E WATER MONITORING PROJECT

TITLE
**WATERSHEDS AND SURFACE WATER FEATURES**

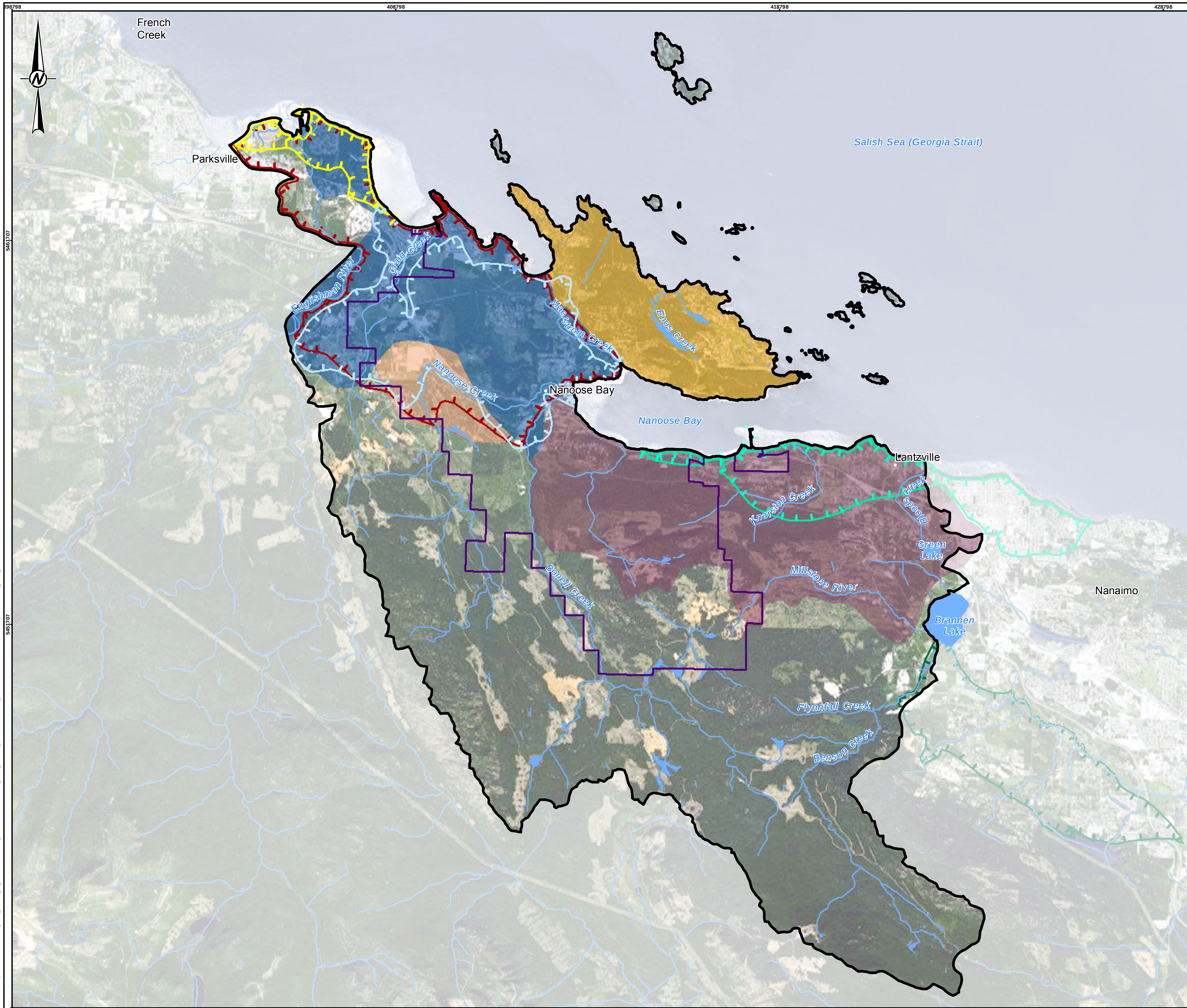
CONSULTANT
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 3 |

25mm

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B




**LEGEND**

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

**SAND AND GRAVEL AQUIFER**

**AQUIFER NUMBER**

- 0167
- 0215
- 0219
- 0221
- 1098

**BEDROCK AQUIFER**

**AQUIFER NUMBER**

- 0210
- 0213
- 0214
- 0218

0 2 4

1:100,000 KILOMETRES

**REFERENCE(S)**

1. AQUIFERS,WATERCOURSE, ELECTORAL AREA E, SURFACE WATER LICENSE OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. AQUIFER 1098, HYDROMETRIC STATIONS, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
ELECTORAL AREA E WATER MONITORING PROJECT

TITLE
**AQUIFERS IN WATER MONITORING PROJECT AREA**

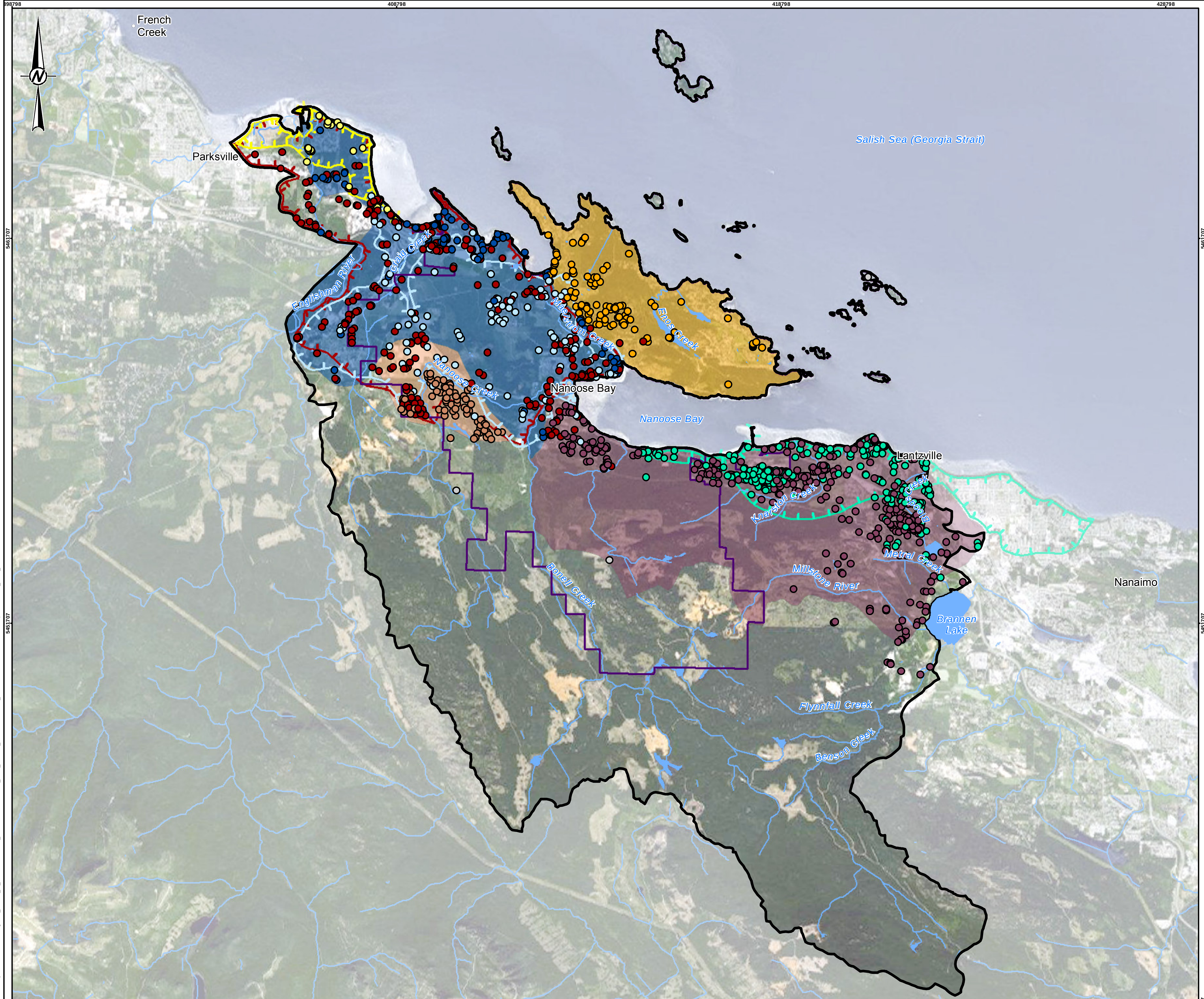
CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 4 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B




**LEGEND**

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

**SAND AND GRAVEL AQUIFER**

**AQUIFER NUMBER**

- 0215
- 0219
- 0221
- 1098

**BEDROCK AQUIFER**

**AQUIFER NUMBER**

- 0210
- 0213
- 0214
- 0218

**GROUNDWATER WELL IN AQUIFER**

**AQUIFER NUMBER**

- 0210
- 0213
- 0214
- 0215
- 0218
- 0219
- 0221
- 1098
- GROUNDWATER WELL NOT IN PROJECT AREA AQUIFER

0 2 4

1:100,000 KILOMETRES

**REFERENCE(S)**

1. AQUIFERS,WATERCOURSE, ELECTORAL AREA E DATA OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. AQUIFER 1098, GROUNDWATER WELL, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
ELECTORAL AREA E WATER MONITORING PROJECT

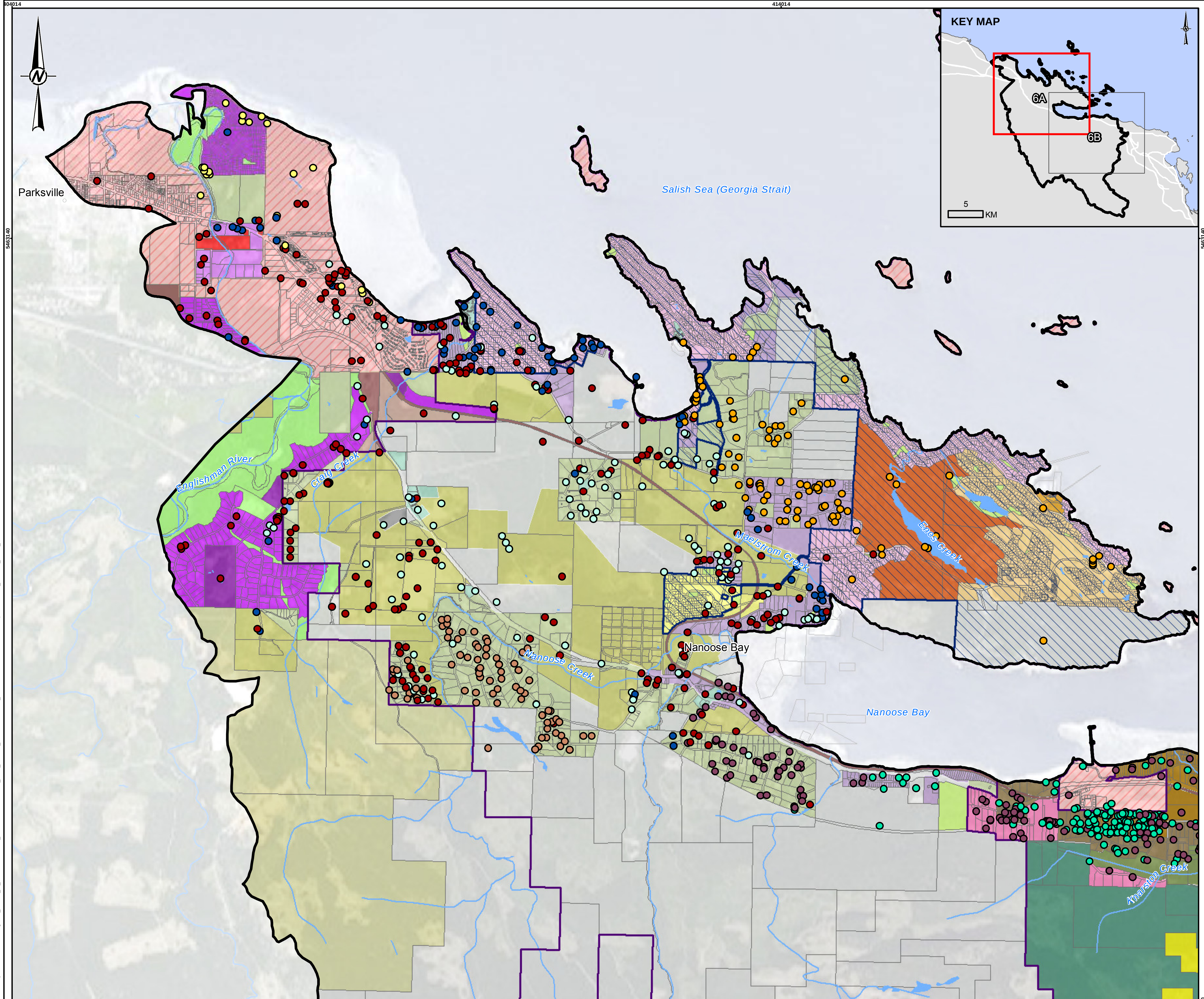
TITLE
**WELLS BY AQUIFER**

CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 5 |




**LEGEND**

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

**GROUNDWATER WELL IN AQUIFER**

**AQUIFER NUMBER**

- 0210
- 0213
- 0214
- 0215
- 0218
- 0219
- 0221
- 1098

**RDN LAND USE DESIGNATION**

- COAST RESIDENTIAL
- COMMERCIAL
- FAIRWINDS
- INDUSTRIAL
- PARK LANDS
- PARKLAND / GREENSPACE / NATURAL AREA
- RED GAP VILLAGE
- RESOURCE
- RESOURCE LANDS WITHIN ALR
- RESOURCE LANDS WITHIN FLR
- RURAL
- RURAL RESIDENTIAL
- RURAL RESIDENTIAL 1
- RURAL RESIDENTIAL 2
- RURAL RESIDENTIAL 3
- RURAL RESOURCE
- SCHOONER COVE NEIGHBOURHOOD
- SCHOONER COVE NEIGHBOURHOOD PLAN AREA
- THE LAKES DISTRICT NEIGHBOURHOOD PLAN AREA
- TOURIST COMMERCIAL LANDS
- TRANSPORTATION CORRIDOR

**LANTZVILLE LAND USE DESIGNATION**

- COMMERCIAL/INDUSTRIAL
- ESTATE RESIDENTIAL
- FOOTHILLS COMPREHENSIVE DEVELOPMENT AREA
- RESIDENTIAL
- RESOURCE-AGRICULTURE
- RESOURCE-FORESTRY
- RESOURCE-OPEN SPACE
- RURAL RESIDENTIAL
- TRANSPORTATION CORRIDOR
- VILLAGE COMPREHENSIVE DEVELOPMENT AREA
- NO LAND USE DESIGNATION
- PARCEL

0 1 2

1:50,000 KILOMETRES

**REFERENCE(S)**

1. AQUIFERS,WATERCOURSE, LANDUSE, ELECTORAL AREA E, SURFACE WATER LICENSE OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. AQUIFER 1098, HYDROMETRIC STATIONS, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.
5. INSET MAP DATA OBTAINED FROM IHS ENERGY.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

ELECTORAL AREA E WATER MONITORING PROJECT

TITLE

**LAND USE DESIGNATIONS: NANOOSE AREA**

CONSULTANT

Golder Associates

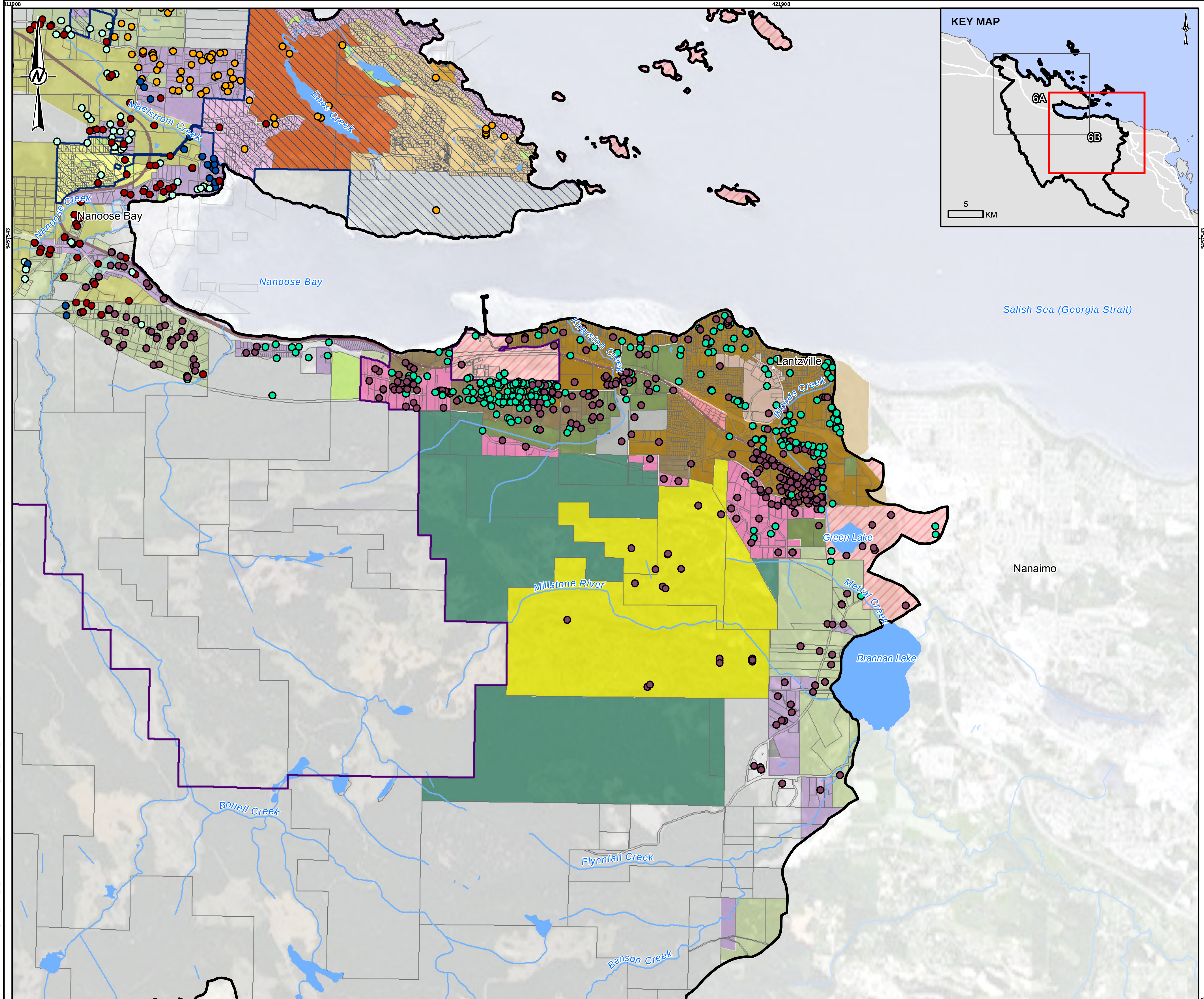
| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 6A |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm

0




**LEGEND**

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

**GROUNDWATER WELL IN AQUIFER**

**AQUIFER NUMBER**

- 0210
- 0213
- 0214
- 0215
- 0218
- 0219
- 0221
- 1098

**RDN LAND USE DESIGNATION**

- COAST RESIDENTIAL
- COMMERCIAL
- FAIRWINDS
- INDUSTRIAL
- PARK LANDS
- PARKLAND / GREENSPACE / NATURAL AREA
- RED GAP VILLAGE
- RESOURCE
- RESOURCE LANDS WITHIN ALR
- RESOURCE LANDS WITHIN FLR
- RURAL
- RURAL RESIDENTIAL
- RURAL RESIDENTIAL 1
- RURAL RESIDENTIAL 2
- RURAL RESIDENTIAL 3
- RURAL RESOURCE
- SCHOONER COVE NEIGHBOURHOOD
- SCHOONER COVE NEIGHBOURHOOD PLAN AREA
- THE LAKES DISTRICT NEIGHBOURHOOD PLAN AREA
- TOURIST COMMERCIAL LANDS
- TRANSPORTATION CORRIDOR

**LANTZVILLE LAND USE DESIGNATION**

- COMMERCIAL/INDUSTRIAL
- ESTATE RESIDENTIAL
- FOOTHILLS COMPREHENSIVE DEVELOPMENT AREA
- RESIDENTIAL
- RESOURCE-AGRICULTURE
- RESOURCE-FORESTRY
- RESOURCE-OPEN SPACE
- RURAL RESIDENTIAL
- TRANSPORTATION CORRIDOR
- VILLAGE COMPREHENSIVE DEVELOPMENT AREA
- NO LAND USE DESIGNATION
- PARCEL

0 1 2

1:50,000 KILOMETRES

**REFERENCE(S)**

1. AQUIFERS,WATERCOURSE, LANDUSE, ELECTORAL AREA E, SURFACE WATER LICENSE OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. AQUIFER 1098, HYDROMETRIC STATIONS, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.
5. INSET MAP DATA OBTAINED FROM IHS ENERGY.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

ELECTORAL AREA E WATER MONITORING PROJECT

TITLE

**LAND USE DESIGNATIONS: Snaw-Naw-As FIRST NATION IR AND DISTRICT OF LANTZVILLE AREA**

CONSULTANT

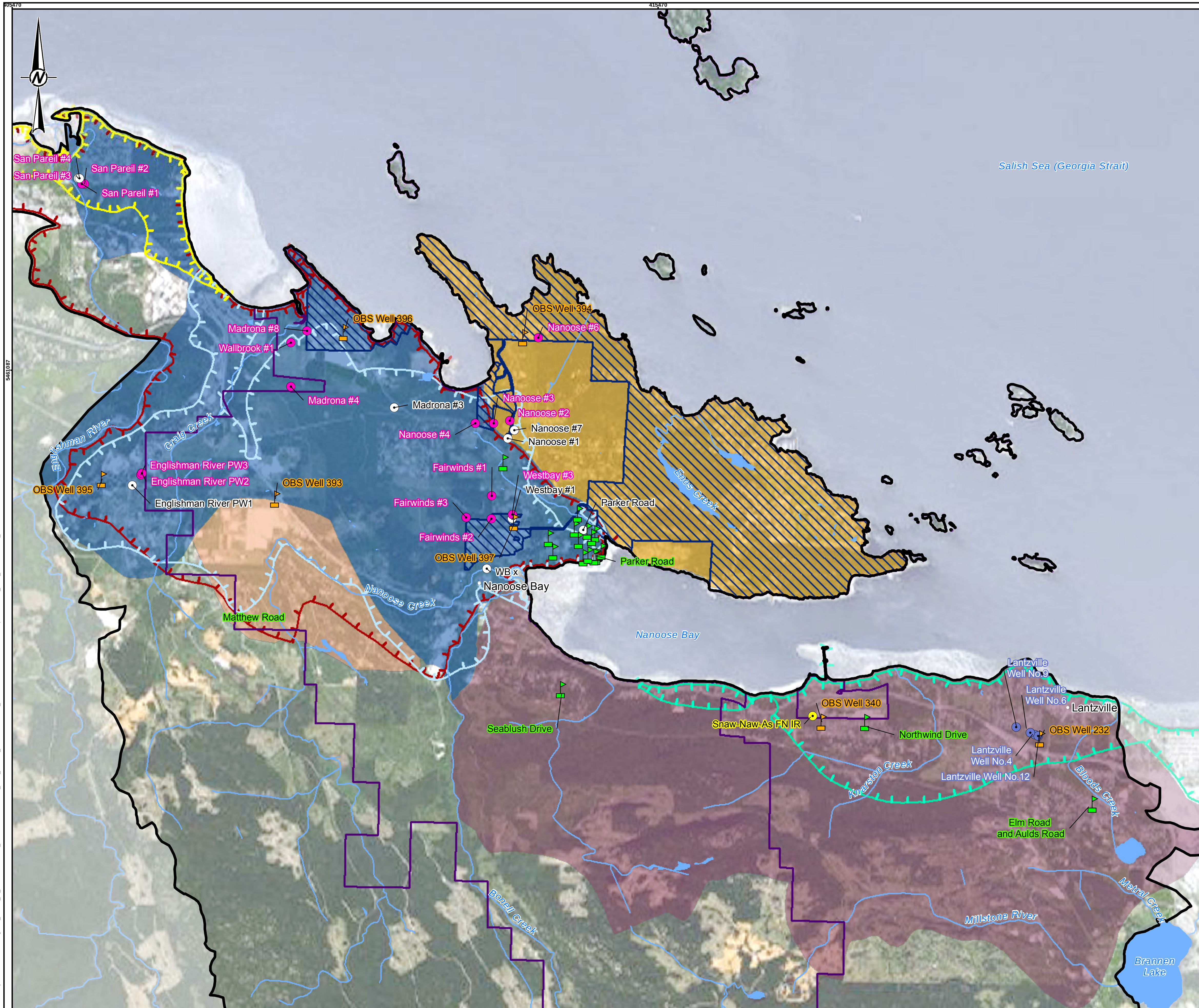
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 6B |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25mm




LEGEND

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN
- NANOOSE BAY PENINSULA WATER SYSTEM

SAND AND GRAVEL AQUIFER

AQUIFER NUMBER

- 0215
- 0219
- 0221
- 1098

BEDROCK AQUIFER

AQUIFER NUMBER

- 0210
- 0213
- 0214
- 0218

MONITORING WELL

- BC MINISTRY OF ENVIRONMENT MONITORING WELL
- RDN VOLUNTEER (PRIVATE) MONITORING WELL

PRODUCTION WELL

- PRODUCTION WELL - SNAW-NAW-AS FIRST NATION INDIAN RESERVE
- PRODUCTION WELL - DISTRICT OF LANTZVILLE

ACTIVE RDN PRODUCTION WELL

- PRODUCTION WELL - RDN

UNUSED RDN PRODUCTION WELL

- PRODUCTION WELL - RDN

0 1 2

1:60,000 KILOMETRES

REFERENCE(S)

1. AQUIFERS, MONITORING WELLS, WATERCOURSE, ELECTORAL AREA E DATA OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. AQUIFER 1098, GROUNDWATER WELL, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
ELECTORAL AREA E WATER MONITORING PROJECT

TITLE
**MONITORING AND PRODUCTION WELLS**

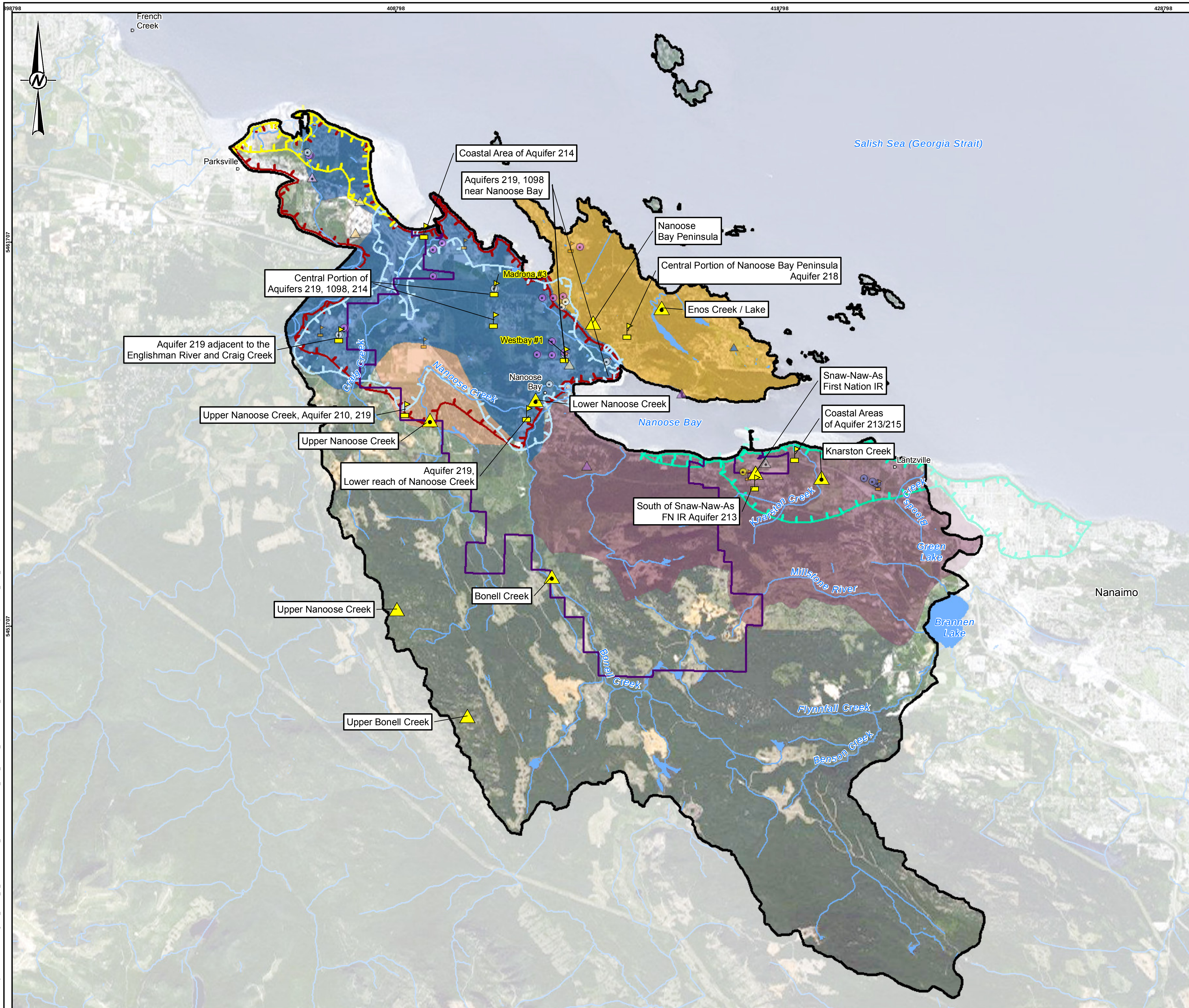
CONSULTANT

Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 7 |

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B




**LEGEND**

- PROJECT AREA
- ELECTORAL AREA E
- WATERBODY
- WATERCOURSE
- CITY / TOWN

**SAND AND GRAVEL AQUIFER**

**AQUIFER NUMBER**

- 0215
- 0219
- 0221
- 1098

**BEDROCK AQUIFER**

**AQUIFER NUMBER**

- 0210
- 0213
- 0214
- 0218

**EXISTING CLIMATE MONITORING STATION**

**ACTIVE CLIMATE MONITORING STATION**

- MONITORING STATION - CITY OF PARKSVILLE
- MONITORING STATION - PRIVATE
- MONITORING STATION - SCHOOL-BASED

**INACTIVE CLIMATE MONITORING STATION STATIONS**

- MONITORING STATION - ENVIRONMENT CANADA

**EXISTING HYDROMETRIC MONITORTING STATION**

- HYDROMETRIC STATION - ACTIVE
- HYDROMETRIC STATION - DE-ACTIVATED

**EXISTING MONITORING WELL**

- BC MINISTRY OF ENVIRONMENT MONITORING WELL

**EXISTING PRODUCTION WELL**

- PRODUCTION WELL - SNAW-NAW-AS FIRST NATION INDIAN RESERVE
- PRODUCTION WELL - DISTRICT OF LANTZVILLE

**ACTIVE RDN PRODUCTION WELL**

- PRODUCTION WELL - RDN

**UNUSED RDN PRODUCTION WELL**

- PRODUCTION WELL - RDN

**RECOMMENDATION FOR NEW CLIMATE MONITORING STATIONS**

- CLIMATE STATION

**RECOMMENDATION FOR NEW GROUNDWATER MONITORING WELLS**

- GROUNDWATER MONITORING WELL

**RECOMMENDATION FOR NEW HYDROMETRIC STATIONS**

- HYDROMETRIC STATION

0 2 4

1:100,000 KILOMETRES

**REFERENCE(S)**

1. AQUIFERS,WATERCOURSE, ELECTORAL AREA E, SURFACE WATER LICENSE OBTAINED FROM REGIONAL DISTRICT OF NANAIMO.
2. AQUIFER 1098, HYDROMETRIC STATIONS, WATERBODIES, CITY AND TOWN DATA CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENSE – BRITISH COLUMBIA.
3. PROJECT AREA CREATED BY GOLDER ASSOCIATES LTD.
4. IMAGERY COPYRIGHT © ESRI AND ITS LICENSORS. SOURCE: GEOEYE IKONOS. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20041103.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

ELECTORAL AREA E WATER MONITORING PROJECT

TITLE

**RECOMMENDATIONS FOR MONITORING LOCATIONS**

CONSULTANT

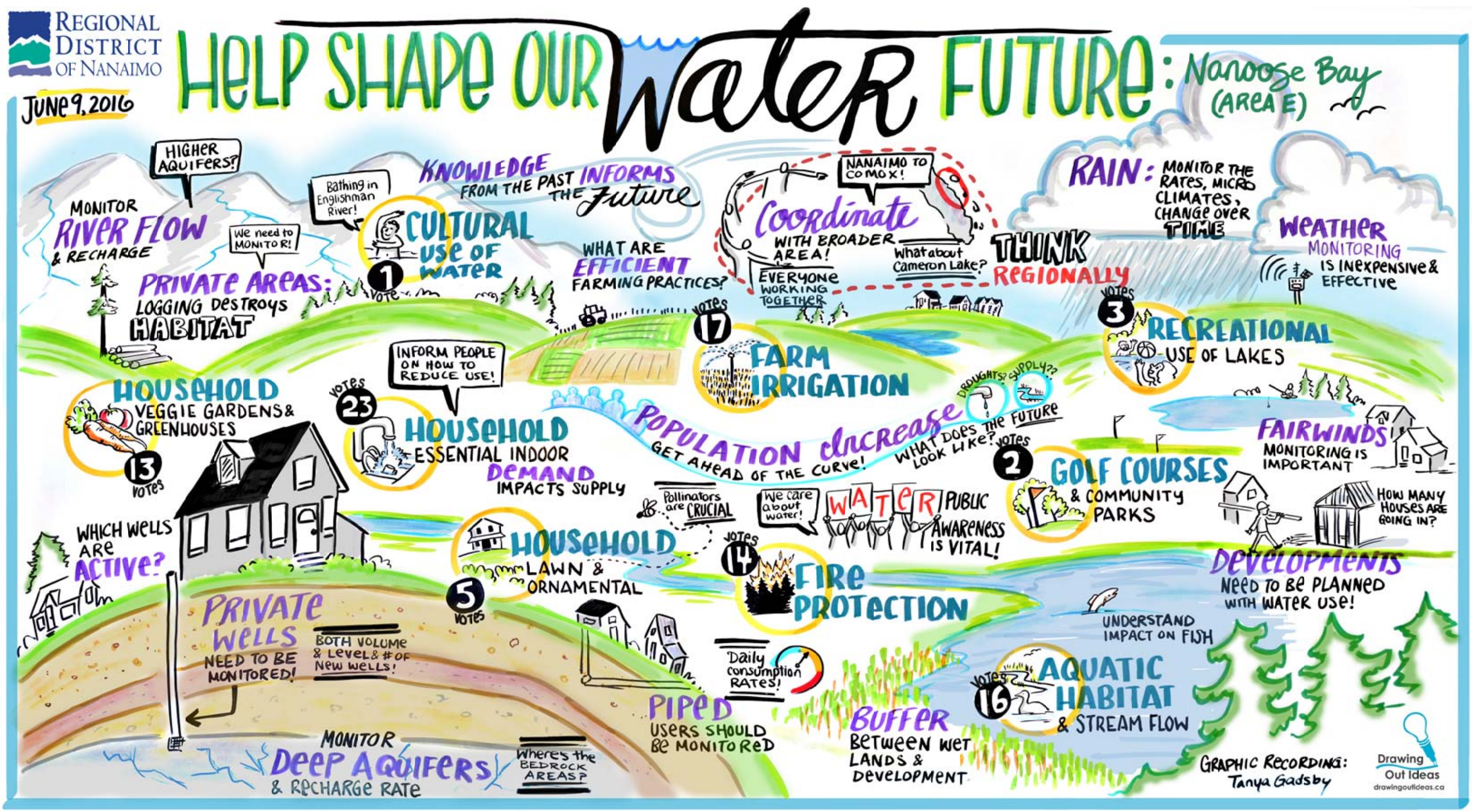
Golder Associates

| | |
|---|---|
| YYYY-MM-DD | 2016-12-13 |
| DESIGNED | MB |
| PREPARED | AD |
| REVIEWED | MB |
| APPROVED | JS |

| PROJECT NO. | CONTROL | REV. | FIGURE |
|---|---|---|---|
| 1547004 | 3000 | 0 | 8 |

# APPENDIX A

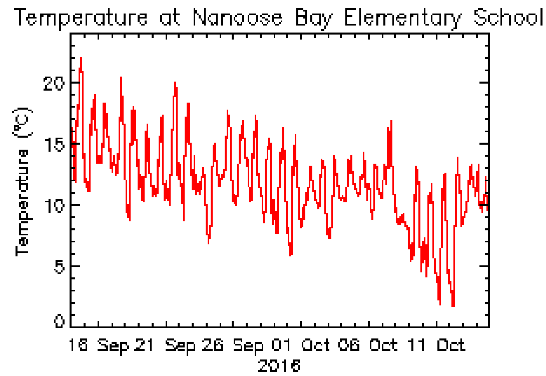
## Results of Public Feedback Session (9 June 2016), Prepared by Drawing Out Ideas

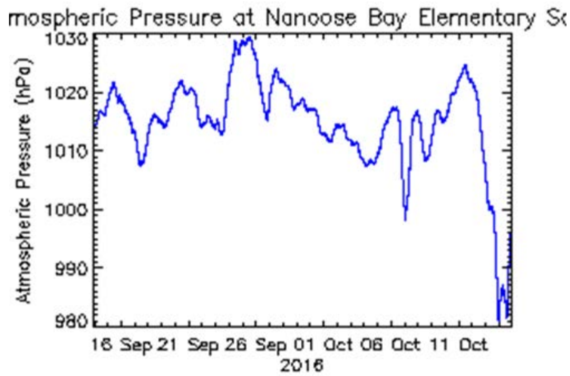


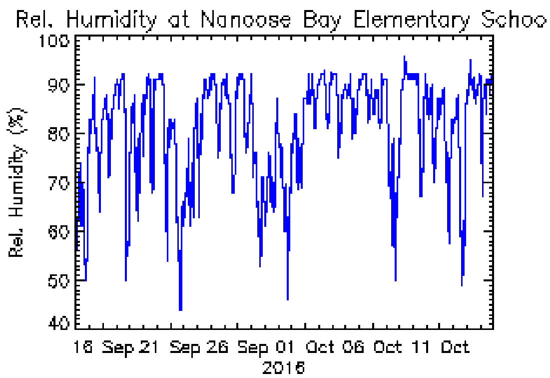
REGIONAL DISTRICT OF NANAIMO
HELP SHAPE OUR WATER FUTURE: Nanoose Bay (AREA E)
JUNE 9, 2016
HIGHER AQUIFERS?
MONITOR RIVER FLOW & RECHARGE
We need to MONITOR!
Bathing in Englishman River!
KNOWLEDGE FROM THE PAST INFORMS THE Future
CULTURAL USE OF WATER
1 VOTE
PRIVATE AREAS: LOGGING DESTROYS HABITAT
WHAT ARE EFFICIENT FARMING PRACTICES?
NANAIMO TO COMOX!
Coordinate WITH BROADER AREA!
EVERYONE WORKING TOGETHER
What about Cameron Lake?
THINK REGIONALLY
RAIN: MONITOR THE RATES, MICRO CLIMATES, CHANGE OVER TIME
Weather MONITORING IS INEXPENSIVE & EFFECTIVE
3 VOTES
RECREATIONAL USE OF LAKES
17 VOTES
FARM IRRIGATION
INFORM PEOPLE ON HOW TO REDUCE USE!
HOUSEHOLD VEGGIE GARDENS & GREENHOUSES
13 VOTES
23 VOTES
HOUSEHOLD ESSENTIAL INDOOR
DEMAND IMPACTS SUPPLY
DROUGHTS? SUPPLY??
POPULATION increase GET AHEAD OF THE CURVE!
WHAT DOES THE FUTURE LOOK LIKE?
2 VOTES
GOLF COURSES & COMMUNITY PARKS
FAIRWINDS MONITORING IS IMPORTANT
HOW MANY HOUSES ARE GOING IN?
WHICH WELLS ARE ACTIVE?
Pollinators are CRUCIAL
We care about water!
WATER PUBLIC AWARENESS IS VITAL!
HOUSEHOLD LAWN & ORNAMENTAL
5 VOTES
14 VOTES
FIRE PROTECTION
DEVELOPMENTS NEED TO BE PLANNED WITH WATER USE!
UNDERSTAND IMPACT ON FISH
PRIVATE WELLS NEED TO BE MONITORED!
BOTH VOLUME & LEVEL & # OF NEW WELLS!
Daily consumption RATES!
16 VOTES
AQUATIC HABITAT & STREAM FLOW
PIPED USERS SHOULD BE MONITORED
BUFFER BETWEEN WET LANDS & DEVELOPMENT
MONITOR DEEP AQUIFERS & RECHARGE RATE
Where's the BEDROCK AREAS?
GRAPHIC RECORDING: Tanya Gadsby
Drawing Out Ideas
drawingoutideas.ca

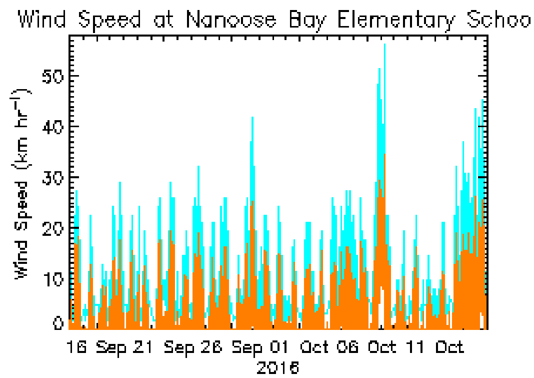
# APPENDIX B

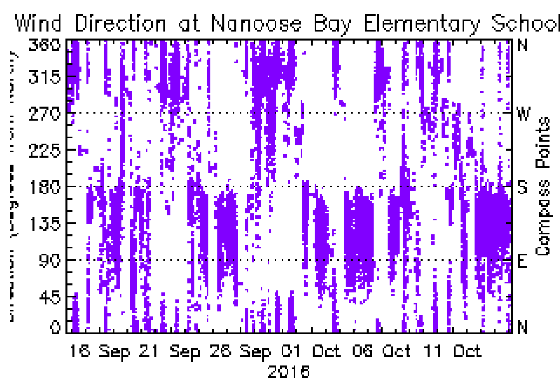
## Examples of Data Collected at Climate, Hydrometric and Groundwater Monitoring Stations

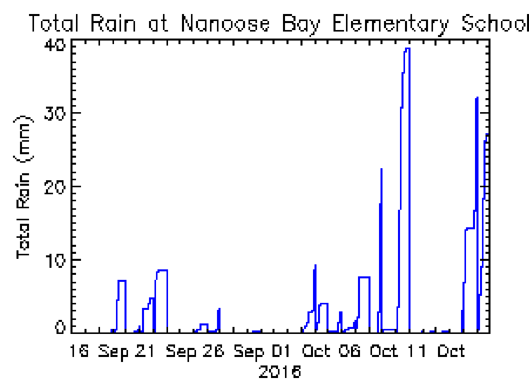

Temperature at Nanoose Bay Elementary School
Temperature (°C)
0
5
10
15
20
16 Sep 21 Sep 26 Sep 01 Oct 06 Oct 11 Oct
2016

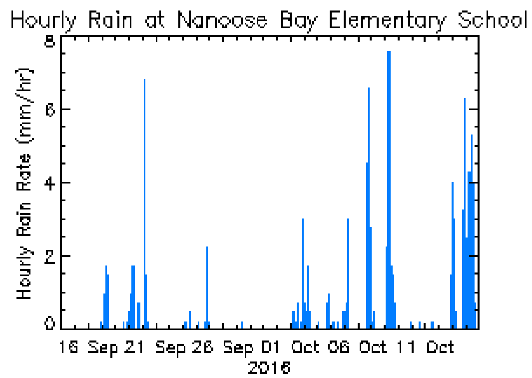

mospheric Pressure at Nanoose Bay Elementary Sc
Atmospheric Pressure (hPa)
980
990
1000
1010
1020
1030
16 Sep 21 Sep 26 Sep 01 Oct 06 Oct 11 Oct
2016

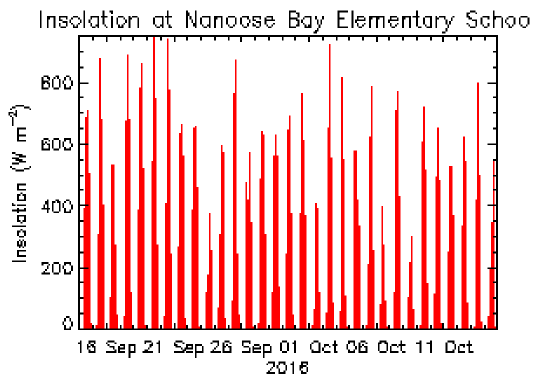

Rel. Humidity at Nanoose Bay Elementary Schoo
Rel. Humidity (%)
40
50
60
70
80
90
100
16 Sep 21 Sep 26 Sep 01 Oct 06 Oct 11 Oct
2016

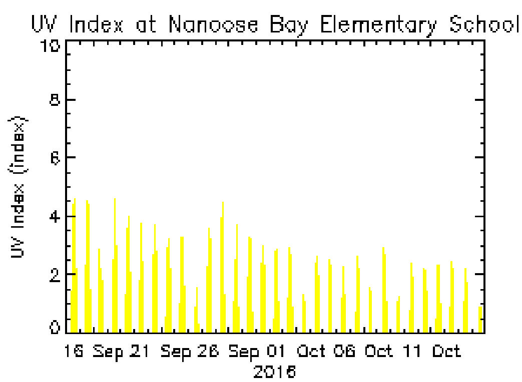

Wind Speed at Nanoose Bay Elementary School
Wind Speed (km hr-1)
0
10
20
30
40
50
16 Sep 21 Sep 26 Sep 01 Oct 06 Oct 11 Oct
2016

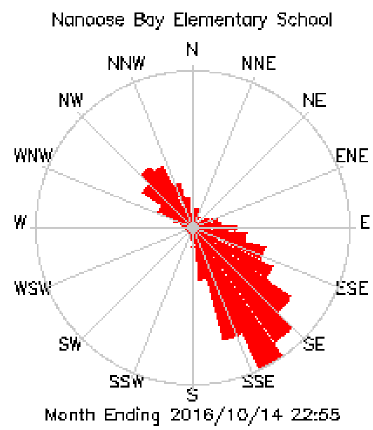

Wind Direction at Nanoose Bay Elementary School
0
45
90
135
180
225
270
315
360
N
E
S
W
N
Compass Points
16 Sep 21 Sep 26 Sep 01 Oct 06 Oct 11 Oct
2016

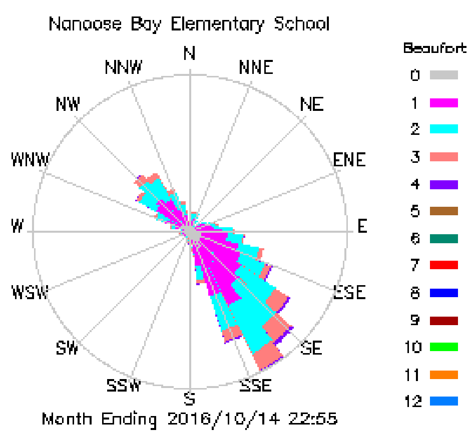

Total Rain at Nanoose Bay Elementary School
Total Rain (mm)
0
10
20
30
40
16 Sep 21 Sep 26 Sep 01 Oct 06 Oct 11 Oct
2016

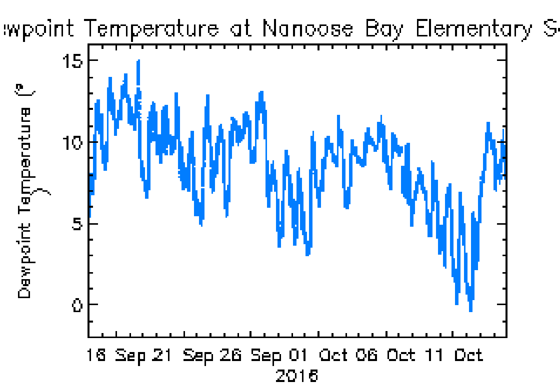


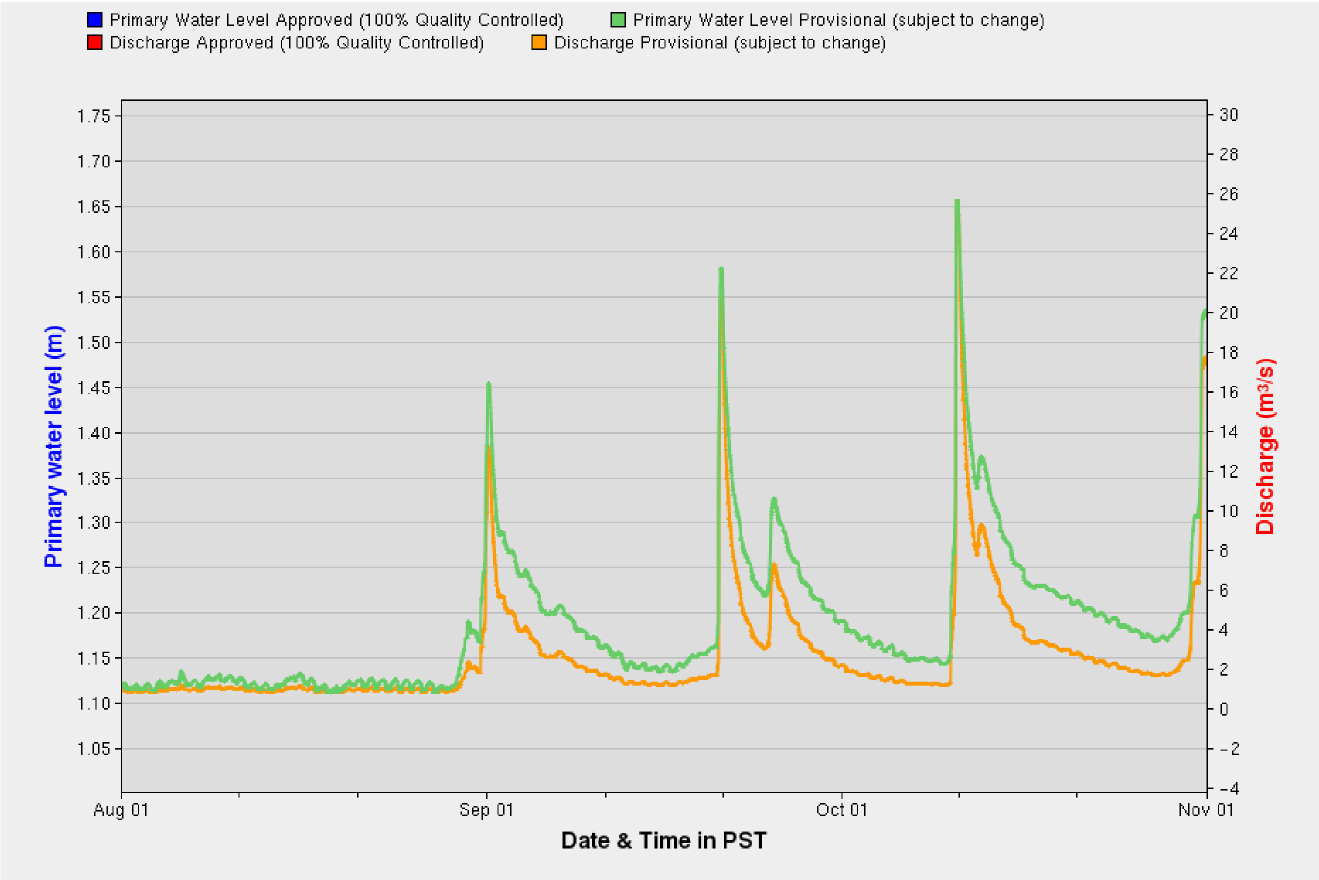




*Climate data collected for the Nanoose Bay Elementary School Climate Station for the period 14 September 2016 – 14 October 2016, downloaded from: http://www.victoriaweather.ca/station.php?id=110&type=month on 15 October 2016.*

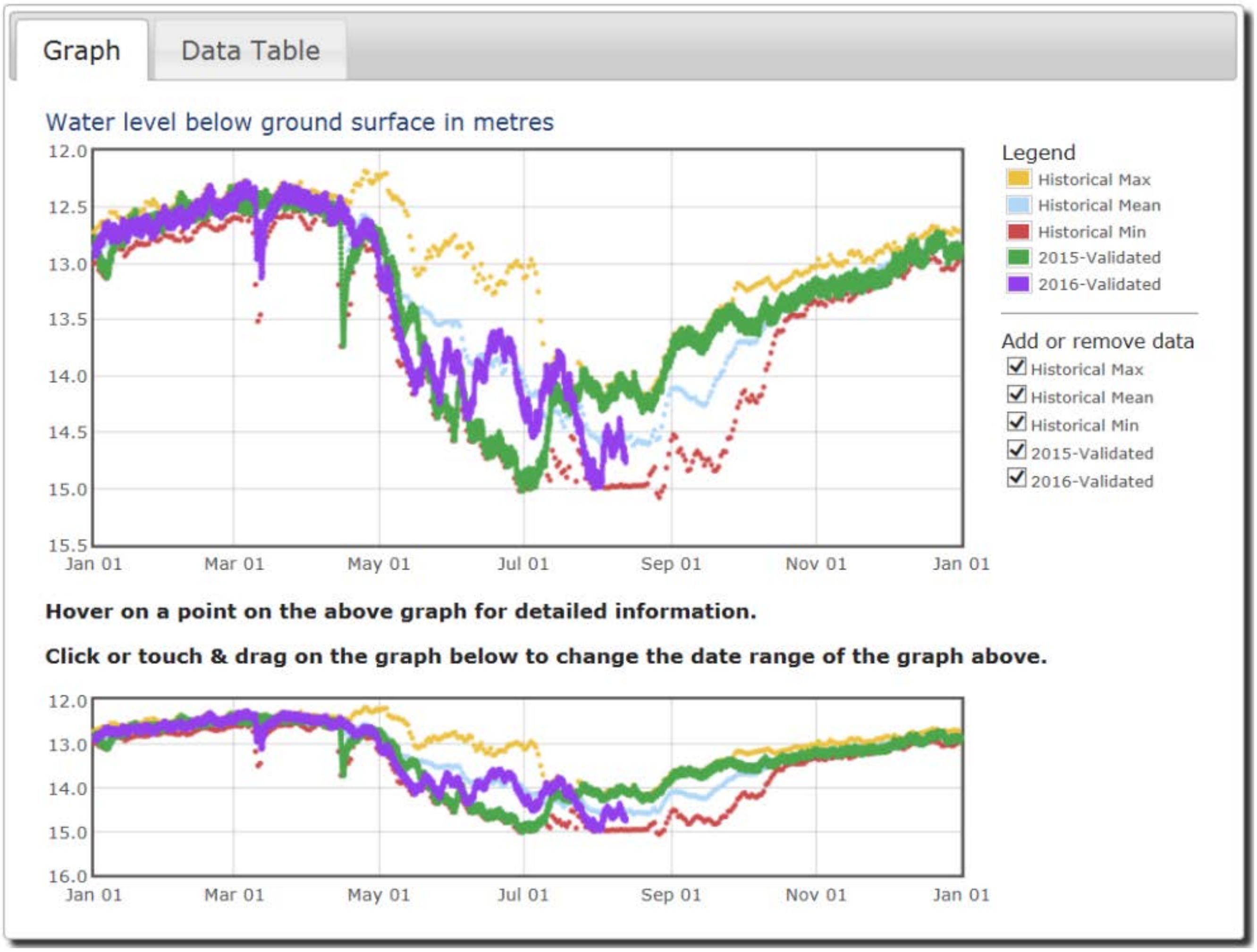
\\golder.gds\gal\burnaby\final\2015\3 proj\1547004 rdn_watermonitoring_nanoose\1547004-004-r-rev0\appendix b - examples of monitoring data\01 nanoose bay elementary_climate.docx




*Hydrometric data collected for Englishman River Near Parksville Station 08HB002 for the period 01 August 2015 – 31 October 2015, downloaded from: https://wateroffice.ec.gc.ca/report/report_e.html?type=realTime&stn=08HB002 on 15 October 2016.*

Observation Well #395
OBS WELL 395 - NANOOSE (RIVER'S EDGE DR.)

Water levels for the last two calendar years, along with historical statistics




*Groundwater level data collected for BC Ministry of Environment (MoE) Observation Well no. 395 for the period 01 January 2015 – 31 December 2016, downloaded from: https://wateroffice.ec.gc.ca/report/report_e.html?type=realTime&stn=08HB002 on 15 October 2016.*

\\golder.gds\gal\burnaby\final\2015\3 proj\1547004 rdn_watermonitoring_nanoose\1547004-004-r-rev0\appendix b - examples of monitoring data\03 bcmoe obs well 395_groundwater.docx

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

For more information, visit golder.com


| | |
|---|---|
| Africa | + 27 11 254 4800 |
| Asia | + 86 21 6258 5522 |
| Australasia | + 61 3 8862 3500 |
| Europe | + 44 1628 851851 |
| North America | + 1 800 275 3281 |
| South America | + 56 2 2616 2000 |

solutions@golder.com
www.golder.com

**Golder Associates Ltd.**
**2nd floor, 3795 Carey Road**
**Victoria, British Columbia, V8Z 6T8**
**Canada**
**T: +1 (250) 881 7372**