REPORT

Refined Water Budget (Phase 3) for Nanoose (Electoral Area E)

Regional District of Nanaimo, BC

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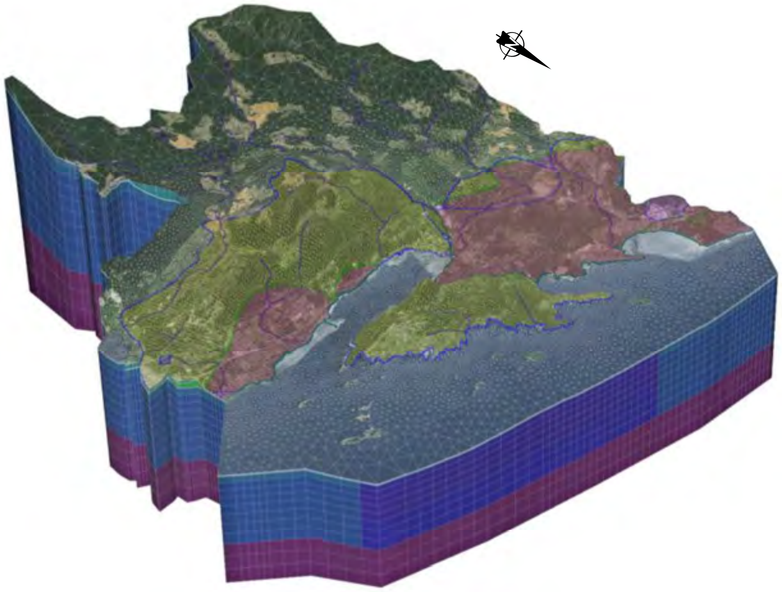

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Executive Summary

Golder Associates Ltd. (Golder) was retained by the Regional District of Nanaimo (RDN) to conduct a Refined Water Budget for the Nanoose area (Project Area). Building upon the strong work that had been done to date for the Water Budget Project that included compilation of a Geodatabase and development of a Conceptual Model of water resources in the RDN (Phase 1) and development of a Water Monitoring Plan for Electoral Area E (Phase 2), the objective of the current project (Phase 3) was to develop and calibrate a three-dimensional (3D) regional-scale numerical groundwater flow model for the Project Area that was used to develop refined water budgets for the aquifers in the Project Area.

Golder compiled and analysed data that had become available since Phase 1 to refine the Conceptual Model. In support of Phase 3, and on behalf of the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and the RDN, Golder refined Aquifer No.s 219 and 1098; these refined boundaries were incorporated into the Conceptual Model and Golder provided the province with an updated Master Well Spreadsheet, polygon shape files and Aquifer Description Sheets under separate cover. Golder developed the numerical model using FEFLOW software and calibrated the model to steady-state conditions and to seasonal fluctuations between the wet and dry seasons. Model uncertainty associated with the hydrogeological boundaries and parameters was assessed using a limited sensitivity analysis. The calibrated model was then used to develop refined water budgets for the aquifers in the Project Area, including assessment of potential effects to baseflow in major creeks within the area, and identification of areas that are predicted to have relatively higher water stress in the future under anticipated climate change, development and land cover scenarios.

Golder used the calibrated model to conduct water budget analyses for average and dry and wet conditions for the aquifers in the Project Area. Future scenarios were simulated to understand how climate change and future development might affect groundwater conditions in the Project Area. The results of the model simulations predict that climate change (i.e., longer, hotter and drier summers, and more intense precipitation in the winter; Scenario 1) could have a significant effect on dry and wet season groundwater conditions within the Project Area compared to Base Case conditions (i.e., current level of development and long-term pumping rates for supply wells). Comparison of predicted water levels for Scenario 1 to water levels predicted for the Base Case indicates that groundwater levels could decline in each of the overburden aquifers, with the exception of Aquifer 221, which is strongly controlled by regulated flow in the Englishman River. Water levels could decline on average by up to 3 m in the area of Aquifer 215 (Quadra Sand) and up to 9 m in the upland portions of Aquifer 213 (Vancouver Group Volcanic Bedrock) and central portion of Aquifer 218 (Sedimentary/Igneous Intrusive Bedrock) at the end of the dry season. For Scenario 1, water levels in overburden Aquifers 219 and 1098 could also potentially decrease by approximately 2 to 3 m compared to Base Case conditions; groundwater use is relatively high in these aquifers. In coastal areas of Aquifer 219 along Nanoose Bay and Nanoose Peninsula, where hydraulic gradients are relatively flat, water levels are predicted to decline and could increase the risk of saltwater intrusion. Baseflow in the creeks within the Project Area is predicted to decline by approximately 40% in Craig Creek and 30% in Nanoose Creek and Bonell Creek during the summer months in the future due to climate change.

The results of the analysis indicated that the simulated water demand at full build-out (Scenario 2) will not have a significant effect on the groundwater conditions in the Project Area, with groundwater declines predicted to be <1 m in the overburden and bedrock aquifers relative to Base Case conditions. Baseflow in Craig Creek is predicted to decline by approximately 10% for both dry and wet season relative to Base Case conditions, whereas baseflows in Nanoose Creek and Bonell Creek are predicted to be minimally affected by the increase in future

water demand, as a small part of the planned new development, and associated water demand, at full build-out is located within the watersheds for these creeks. The results from Scenario 2 indicate that current and future groundwater withdrawals for water supply represent a small component of the overall flow within the aquifers.

The conversion of currently undeveloped land to new development and the resulting increased coverage with impervious surfaces (Scenario 3) is predicted to affect groundwater conditions mostly in the area of Aquifer 218 (Nanoose Peninsula). In this area, groundwater levels in Aquifer 218 could decline up to 10 m from the predicted water levels in the Base Case as a result of reduced infiltration. This has the potential to increase the risk of saltwater intrusion along the coastline of the peninsula; however, the development along the coastline in the Nanoose Peninsula is largely serviced by the RDN Nanoose Bay Peninsula Water Service Area (NBPWAS) and no additional pumping from Aquifer 218 is anticipated to occur in the future. In Scenario 3, a smaller decline (up to 2 m) is also predicted in the area of Aquifers 219, 1098 and 214. For Scenario 3, reductions in baseflow were predicted to be 20% for Craig Creek relative to Base Case conditions, with smaller reductions predicted for Nanoose Creek (7%) and Bonell Creek (2%). It was noted that the Scenario 3 simulation may be conservative as it assumed that the increase in impermeable surfaces results in a loss of water from the aquifer system as surface water run-off from impermeable surfaces will be transported to the ocean via the stormwater system; however, some portion of surface water run-off from impermeable surfaces is anticipated to be transported to areas where it infiltrates into the ground. Furthermore, simulations of changes in land cover have not considered the effects of enhanced recharge through storm water management, such as stormwater infiltration and injection; these measures could reduce the effects to groundwater levels.

Two additional simulations, Scenarios 4 and 5, were conducted to evaluate the combined effects of future Scenarios 1 to 3 on groundwater conditions in the Project Area. For Scenario 4, the combined effects of both climate change (Scenario 1) and an increase in impervious ground cover in previously undeveloped areas (Scenario 3) were simulated. Water level effects in overburden aquifers are predicted to be greatest in the central portion of Aquifers 219 and 1098 with declines of 5 to 6 m over a broader area, compared to localized declines of 3 to 4 m and 1 to 2 m for individual Scenarios 1 and 3, respectively. Similar to Scenario 3, bedrock Aquifer 218, which receives a significant portion of recharge from precipitation, could potentially be affected; water levels in the central portion of the aquifer are predicted to decline by up to 20 m for Scenario 4 compared to declines of in the range of 10 m for Scenario 1 and 16 m for Scenario 3. For Scenario 4, baseflow at the end of the dry season is predicted to decrease by 55% in Craig Creek and 30% in Nanoose Creek and Bonell Creek relative to Base Case conditions; values which are greater than the sums of the baseflow reductions predicted for Scenarios 1 and 3 for the respective creeks.

Scenario 5, which included the combined effects of Scenarios 1, 2, and 3, resulted in no significant changes in water levels in the overburden and bedrock aquifers relative to those predicted for Scenario 4, consistent with the conclusion that the additional groundwater withdrawals for water supply in the future represent a relatively small change to groundwater conditions. Baseflow in Craig Creek is predicted to further decline (by approximately 5%) for both dry and wet season in Scenario 5 compared to flow predicted for Scenario 4, whereas baseflows in Nanoose Creek and Bonell Creek are predicted to be minimally affected by the increase in future water demand compared to Scenario 4.

The results of the above analyses provide a basis for the RDN to identify and implement planning measures to manage water resources in the Nanoose area and support sustainable groundwater withdrawals. It is recommended that the RDN consider the results of the water balance analyses to identify and target groundwater conservation and water management programs in areas that are predicted to be the most affected by climate change and changes to land cover. In particular, stormwater management programs can be developed and implemented to support groundwater recharge in the area of Nanoose Peninsula.

Study Limitations

This report has been prepared for the exclusive use of the Regional District of Nanaimo (RDN). 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 site-specific hydrogeological assessments. In evaluating the requirements of the Refined Water Budget for Nanoose (Electoral Area A), BC, Golder Associates Ltd. (Golder) 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. The final version of this report and its content supersedes any other text, opinion or preliminary version by Golder.

Plans, electronic files and similar material used to develop the Water Budgets herein are instruments of service, not products. If new information is discovered in the future, Golder 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 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 area, 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 accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

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1.0 INTRODUCTION

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, Waterline Resources Inc. (WRI; 2013) compiled a database of data and information related to water resources within the RDN (Geodatabase), developed a Conceptual Model of surface water and groundwater flow within seven water regions and developed preliminary water budgets to identify areas of relatively higher water stress. The results from Phase 1 provided the technical basis to identify areas that were considered high priority for monitoring programs that were required to inform land use decisions and support sustainable management of water resources.

Under Phase 2 of the Water Budget Project for the Nanoose (Electoral Area E) area, Golder (2016) conducted a detailed review of available information and, with consideration of the input from a Public Feedback Session with the community, 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. Following presentation of our Water Monitoring Plan, the RDN engaged with stakeholders and implemented monitoring programs in targeted areas of Nanoose.

The objective of the current project (Phase 3) was to build upon the strong work done to date in Phases 1 and 2 of the Water Budget Project and develop and calibrate a numerical model for the Nanoose area and, using the model, develop refined water budgets for the aquifers in the Nanoose area, including assessment of potential effects to baseflow in major creeks within the area, and predict areas of relatively higher water stress in the future under anticipated climate change, development and land cover scenarios. The Project Area for this study is presented on Figure 1.

1.2 Acknowledgements

Golder would like to thank Ms. Julie Pisani, Mr. Murray Walters and Mr. Randy Alexander of the RDN for their direction and support in developing the Refined Water Budget and providing requested data and information. We would also like the participants who attended a meeting on 16 April 2019 at the RDN office to discuss complementary studies and identified opportunities for collaboration, including Chief Gord Edwards of the Snaw-Naw-As First Nation (SNAFN), Chief Ron Sam of the Songhees Nation and Chief Negotiator for the Te'mexw Treaty Association (TTA), Mr. Wayne Edwards SNAFN Negotiator, Mr. Peter Wainwright of the TTA, Mr. Bob Rogers, Director of Electoral Area E, Mr. Ian Thorpe, Chair of the Regional District of Nanaimo Board, Ms. Pat Lapcevic and Ms. Jessica Doyle of the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), Dr. Gilles Wendling and Mr. Antonio Barroso of GW Solutions Inc. (GSI), Mr. Murray Walters, RDN Water Services Manager and Ms. Julie Pisani, RDN DWWP Program Coordinator. Through this meeting, we were able to develop a common understanding of the area and share data that benefited our respective studies. Through this collaboration, FLNRORD partnered with the RDN and provided funds through the BC Ministry of Environment and Climate Change Strategy (ENV) to include refinement of Aquifer No.s 219 and 1098. Golder included the refined aquifer boundaries in the numerical model that was developed for the Refined Water Budget. Under separate cover Golder provided the province with an updated Master Well Spreadsheets that correlate registered water wells to Aquifer No.s 219 and 1098, updated polygon shape files showing the refined lateral extents of the aquifers and updated Aquifer Description Sheets for each aquifer.

In addition to the information provided by GSI, in preparing the Refined Water Budget for Nanoose, we referred to data and information provided by a number of other sources, as referenced in our report. We recognize the contributions of these organizations, including the Geodatabase and Conceptual Model that WRI (2013) developed on behalf of the RDN.

2.0 SCOPE OF WORK

The scope of work for Phase 3 of the Water Budget included the following tasks:

- Task 1: Compilation and analysis of new data: Data and information that had become available since the Conceptual Model was developed in Phase 1 were compiled and analysed.
- Task 2: Data extraction, processing and analysis: Data was extracted from the Conceptual Model, supplemented with the new data (Task 1) and processed to be in formats that were consistent with the numerical model input requirements.
- Task 3: Model development, calibration and limited sensitivity analysis: Golder developed a three-dimensional (3D) regional-scale numerical groundwater flow model representative of the Project Area (Figure 1) and calibrated the model to steady-state conditions and to seasonal fluctuations between the wet and dry seasons. Model uncertainty associated with the hydrogeological boundaries and parameters was assessed using a limited sensitivity analysis.
- Task 4: Water Budget Analysis: Using the calibrated numerical model, Golder conducted water budget analyses for the aquifers in the Project Area, including assessment of potential effects to baseflow in major creeks within the area, to assess potential effects from climate change, increased demand associated with future development and potential changes to land cover.
- Task 5: Reporting and Deliverables: The results of the Phase 3 Refined Water Budget for Nanoose Area E are presented in this report.

3.0 DATA COMPILATION AND REVIEW

Data and information that that had become available since development of the Conceptual Model in Phase 1 were compiled and reviewed to refine the understanding of groundwater conditions within the Nanoose area. The following sections describe the methods used to compile the data and present the results of the data review.

3.1 Methods

Golder conducted a comprehensive data gathering exercise to obtain geologic, hydrologic and hydrogeologic information. For the purposes of Phase 3 of the Water Budget Project (i.e., the current project), Golder defined a Project Area that comprised Electoral Area E and adjacent aquifers and watersheds. Electoral Area E is included in Water Region #5 (WR#5 – South Wellington to Nanoose) of the RDN. The extent of the Project Area is illustrated on Figure 1.

Data for the Project Area were assembled by means of correspondence with the RDN and other organizations, and on-line searches of publicly available information sources. The RDN coordinated the gathering of information from the District, other municipalities, government agencies and other consultants that document water resources relevant to the Nanoose area. Table 1 provides a summary of the data that were compiled, reviewed and used to update the Conceptual Model and develop the numerical groundwater flow model.

Table 1: Summary of Data Sources Used to Update Conceptual Model of Nanoose Area

Information	Source(s)
Regional Topography	Digital elevation model (DEM) contour dataset with a 2 m interval provided by RDN (2019). LiDAR topographic data with 0.5 m resolution provided for coastline areas by RDN (2019). Bathymetry Contours from Coastal BC Bathymetry in the B.C. Data Catalogue (2019)
Orthophoto imagery (georeferenced)	Base map obtained in high resolution from Google Earth. Imagery from 2016.
Geology and Hydrostratigraphy	WRI Phase 1 Water Budget (2013) BC ENV Water Well Database (BC Data Catalogue 2019) Area E Aquifer Description Sheets (1996, 2012) BC ENV Aquifer Delineation GSC (2015): 3-D Model of the Nanoose Deep Bay Area GSC (2016): Deep Bay Area Groundwater Study Atlas Lantzville Groundwater Model (GSI 2015) Muir Point Formation (Hicock 1990) Golder (2019): Assessment of Parker Road Well
Hydrogeological Properties of Stratigraphic Units	WRI Phase 1 Water Budget (2013) Carmichael (2013) Compendium of Re-evaluated Pumping Test in the RDN GSC (2016): Deep Bay Area Groundwater Study Atlas Information on hydraulic testing in the Foothill area and Aquifer 1098 provided by GSI (2019)
Groundwater Levels	BC ENV Water Well Database (BC Data Catalogue 2019) BC Provincial Groundwater Observation Network (BC Data Catalogue 2019) RDN Volunteer Monitoring Wells (RDN 2019) Water level information provided by GSI (Foothill Area and West Bay #4 well), (RDN 2019)

Information	Source(s)
Production Well Data from Water Providers and Municipalities	RDN 2010-2018 Production well data and well reports (RDN 2019) Lantzville 2018 Production well data (RDN 2019) Snaw-Naw-As First Nation 2018 Production Well Data (GSI 2019)
Surface Water Discharge	Three hydrometric stations in three creeks in the Project Area: Craig Creek (provided by FLNRO/RDN), Nanoose Creek and Bonell Creek (from Aquarius Web Portal 2019)
Climate	Fairwinds Golf Course Private Weather Station (provided by RDN 2019) ENV Canada Weather stations in the area (Government of Canada 2019a) UVIC School Based Weather Station Network (UVIC 2019) RDN Upper Nanoose Creek Watershed Weather Station (from Aquarius Web Portal 2019) Forecast Climate Change for Nanaimo from Pacific Climate Impact Consortium (PCIC 2019)
Groundwater Recharge	Recharge rates were estimated by WRI (2013) as part of the Phase 1 Water Budget Study. Rates were determined based on climate data, landcover, soil characteristics and using a water balance model developed by USGS (McCabe and Markstrom 2007)
Land Use and Zoning Information	Land use and zoning map provided by RDN (October 2019) Land Use Inventory Database provided by RDN (2019) Agricultural Land Use Inventory Database provided by RDN (Ministry of Agriculture 2012)
Water Use in non-serviced area	Agricultural Water Demand Study (Ministry of Agriculture 2013) RDN 2018 Metered Water Use (RDN 2019) City of Nanaimo 2018-2019 Metered Water Use (RDN 2019)

3.2 Results

3.2.1 Topography and Climate Data

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 along the edge of the Nanoose Creek watershed (Figure 2). Coastal bathymetry information (depth of the sea floor) available from the BC Data Catalogue (2019) for the area of Nanoose Bay was incorporated with the available topography data. The sea floor in the Nanoose Bay area and around the Nanoose Peninsula is shallow (between 0 to 30 m) and then it deepens up to 200 m below sea level approximately 3 km from the coast. The combined topography and bathymetry information was used to build the numerical hydrogeological model to allow for an appropriate representation of aquifer discharge to the ocean along the coast.

The climate of the Nanoose area is characterized by cool wet winters and mild dry summers. Eight climate stations were identified in the Project Area. Table 2, below, provides a summary of data that were available for the climate stations. The locations of the climate stations are presented on Figure 2.

Table 2: Summary of Climate Stations located within the 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
Upper Nanoose Creek Watershed (BCA04120)[4]	RDN	2018-present	Hourly	Y	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

Five climate stations are currently being operated in the Project Area; their locations are shown on Figure 2. Four climate stations are located in the northern portion of the Project Area, at ground surface elevations of up to 50 m asl. The Nanoose Bay Elementary climate station and the Fairwinds Golf Course station are located in Electoral Area E. The Ocean Trails Resort and Parksville Ops climate stations are located on the east side of the Englishman River. The Upper Nanoose Creek Watershed station, established by the RDN in partnership with Mosaic Forest Management in the summer of 2018, is located close to the headwaters of Nanoose Creek in the south-east portion of the Project Area, at an elevation of approximately 500 m asl.

As reported in Golder RDN Water Monitoring Plan (2016), the data from some of the school-based stations were not considered to be highly accurate based on the monitoring equipment used. Therefore, the data collected at these locations were reviewed for completeness and consistency with general patterns observed but were not used for the purposes of the project. At the Fairwinds Golf Course station, precipitation data were collected daily with a manual rain gauge since 2008 and the City of Parksville also collected precipitation data at five-minute intervals at the Parksville Ops (Operations Facility) since 2005; the data from these two stations were considered representative of the respective areas. Hourly precipitation and temperature were collected at the Upper Nanoose Creek Watershed station. However, only one complete year of data (2019) had been collected at this location.

A summary of precipitation reported for the Fairwinds Golf Course station for the period 2008-2018 is presented in Table 3, below.

Table 3: Fairwinds Precipitation 2008-2018

Year	Fairwinds Monthly Precipitation (mm)												
	January	February	March	April	May	June	July	August	September	October	November	December	Total
2008	144	27	46	30	41	38	16	27	11	70	91	146	688
2009	41	38	83	22	49	11	17	16	60	116	286	67	808
2010	219	92	83	95	78	27	3	30	92	76	142	237	1175
2011	76	132	194	40	72	24	51	10	62	52	140	67	919
2012	138	87	124	70	38	73	14	3	3	164	145	194	1054
2013	84	65	72	43	70	48	0	30	92	21	91	41	657
2014	111	172	140	48	33	13	29	14	38	157	92	103	951
2015	89	149	46	25	3	14	30	21	46	60	119	294	898
2016	140	126	242	29	38	64	25	10	51	258	210	122	1313
2017	56	122	102	100	27	24	0	5	43	97	260	127	962
2018	295	60	64	95	0	35	11	5	103	75	118	237	1097
Average	**127**	**97**	**109**	**54**	**41**	**34**	**18**	**15**	**55**	**104**	**154**	**149**	**957**
max	**295**	**172**	**242**	**100**	**78**	**73**	**51**	**30**	**103**	**258**	**286**	**294**	**1313**
min	**41**	**27**	**46**	**22**	**0**	**11**	**0**	**3**	**3**	**21**	**91**	**41**	**657**

Average annual precipitation at the Fairwinds station for the period 2008-2018 is approximately 957 mm. The majority of the precipitation occurs from October through March. The driest year within the last 10 years was 2013, with 657 mm of total annual precipitation. There are no snow observation stations within the Project Area. Average monthly temperatures recorded in 2019 at the Nanaimo Airport weather station range from approximately 0.2 °C in February and 19.3 °C in August, with an average annual temperature of approximately 10.2 °C.

The precipitation data observed at the Fairwinds monitoring station are in agreement with the climate data (Nanaimo Departure Bay Climate Data 1971-2000) described by WRI (2013) in Phase 1 for the Water Region #5 (South Wellington to Nanoose). The Fairwinds station, like the school-based stations, is located at a relatively low elevation (<50 m asl) within the Project Area and precipitation data collected at this station are not representative of greater precipitation that occurs at higher elevations.

The Upper Nanoose Creek station is located at approximately 500 m asl and can be used to evaluate climate conditions at higher elevations. However, only one complete year of data (2019) had been collected to date. Total precipitation at the Upper Nanoose station in 2019 was approximately 843 mm. The majority of the precipitation in 2019 occurred from September through February. Monthly temperatures recorded in 2019 at this station range from approximately -1.9 °C in February to 17.5 °C in August, with an average annual temperature of approximately 8.6 °C. Once a longer-term data set is available from this station, a refined analysis of groundwater recharge can be conducted.

As discussed in Section 3.2.4.2, for Phase 3 of the Water Budget Project, groundwater recharge was estimated using the same approach that was adopted by WRI (2013) in Phase 1 (i.e., gridded recharge calculated using gridded climate temperature and precipitation, land cover and soil characteristics data, and using a water balance model developed by USGS; McCabe and Markstrom 2007).

3.2.2 Surface Water

3.2.2.1 Watersheds and Creek Flow Monitoring

Excluding the Englishman River, which is predominantly in adjacent Water Region 4, five major watersheds and 11 sub-watersheds were identified within the Project Area (Figure 3).

Four Water Survey of Canada hydrometric stations were identified within the Project Area, three of which are located within Electoral Area E and the fourth, the Englishman River, located near Parksville. The hydrometric stations in the Project Area are currently active, with the exception of the Englishman River station that was deactivated in 2018. The hydrometric station information is summarised in Table 4, below, and the locations of the stations are presented on Figure 3.

Table 4: Hydrometric Stations in Project Area

Hydrometric Station Name	Station No.	Monitoring Period	Monitoring Frequency	Drainage Area (km^2)[1]
Englishman River Near Parksville	08HB002	1913-2018	Daily	319
Nanoose Creek Near HWY 19	08HB0010	2017-present	Hourly	34[2]
Bonell Creek d/s of HWY 19 Bridge	08HB0017	2017-present	Hourly (Summer Only)	51[2]
Craig Creek Near Northwest Bay Road	08HB0005	2016-present	30 minutes (Summer Only)	12[2]

Notes:

1. Drainage area to the station gauge
2. Data not provided on on-line Aquarius Web Portal (http://aqrt.nrs.gov.bc.ca). An estimate was provided based on BC Watershed Atlas (WRI 2013)

The measurements at the three active hydrometric stations are continuous (every 30 minutes or hourly). The Craig Creek and Bonell Creek stations are active only over the summer (low flow measurements). Nanoose Creek station has continuous measurements over the entire year with monthly manual measurements. Stream flow data from the three active stations in the Project Area are provided in APPENDIX A.

As shown in the hydrographs in APPENDIX A, the hydrometric responses in the three monitored creeks are strongly correlated to seasonal precipitation patterns. Streamflow in the creeks peaks during the winter months whereas during the dry summer months (June to August) streamflow is significantly reduced (e.g., less than 0.1 litres per second [L/s] in Bonell Creek and 0 L/s in Nanoose Creek in July and August). These observations suggest that portions of the water courses are ephemeral and have negligible flow during the dry summer months. No other information was identified regarding flow conditions for other water courses within the Project Area.

3.2.2.2 Surface Water Licenses

As part of the Water Monitoring Plan for the Nanoose Area E (Golder 2016), a total of 262 surface water licenses were identified in 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 5 provides a breakdown of current and pending surface water licenses by watershed and Table 6 provides a summary of licensed surface water use.

Table 5: Watersheds and Surface Water Licenses in the Project Area

Watershed	Drainage Area (km²)[1]	Relative Stress Level[2]	No. Current and Pending Surface Water Licenses	Annual Surface Water Demand[3] (million m³)
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
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 6: Summary of Licensed Surface Water Use in 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 (i.e., 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. The surface water licences information was used in combination with groundwater wells included in the BC ENV WELLS database to estimate water use for the areas outside of municipal water service (Section 3.2.5.2).

3.2.3 3D Hydrostratigraphic Interpretation

Four unconsolidated aquifers and four bedrock aquifers are mapped within the Project Area. A summary of aquifer details is presented in Table 7, below. As discussed in Section 3.2.3.3, the extents of select aquifers were refined by Golder based on interpretation of available data.

Table 7: Aquifers in the 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 Underlying Aquifer: 219
219	IIC	Confined Sand and Gravel: Quadra Sand[4]	Nanoose Creek, Craig Creek, Bonell Creek, Englishman River Overlying Aquifer: 221 Underlying Aquifers: 1098 and 214 Ocean
1098	IIC	Confined Sand and Gravel: Muir Point Formation[5]	Overlying Aquifer: 219 Underlying Aquifer: 213
215	IIC	Confined Sand and Gravel: Quadra Sand[4]	Knarston Creek and Bloods Creek
214	IIB	Semi-confined Bedrock: Sedimentary[6]	Craig Creek Overlying Aquifers: 219 and 1098 Adjacent Aquifers: 218, 210, and 213 Ocean
210	IIB	Semi-confined Bedrock: Sedimentary and Igneous Intrusive[7]	Nanoose Creek Overlying Aquifers: 219 and 1098 Adjacent Aquifer: 214
213	IIC	Confined Bedrock: Volcanic[8]	Bonell Creek, Millstone River Adjacent Aquifer: 214 Overlying Aquifer: 215 Ocean
218	IIB	Semi-confined Bedrock: Sedimentary and Igneous Intrusive[9]	Enos Lake and Creek, Dolphin Lake Adjacent Aquifer: 214 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

3.2.3.1 Preprocessing of Well Records and Hydrogeological Data

The primary source of subsurface information for the project was the Conceptual Model from Phase 1 of the Water Budget Project (WRI 2013), the ENV BC WELLS database, together with the associated lithological intervals. These data sources, which contained over 1,400 well records and over 5,300 unique lithological intervals for the Project Area at the time of download in June 2019, were assessed and used to characterize the vertical and, for some aquifers, lateral extents of the aquifer units. The collection and entry of water well data into the provincial database, well information and lithological descriptors were highly variable in terms of documentation and overall data quality, with substantial variation depending upon the age of the well record, drilling company, and database architecture at the time of data entry. As a result, some types of inconsistencies are commonly observed in well records throughout the province while other errors tend to be specific to the region of study, and the drillers and operators in that region. Data preprocessing that was conducted as part of this project included the following:

- conversion from imperial units (feet, imperial and US gallons per minute) to metric (meters, litres per minute)
- removal of duplicate or blank entries
- correction of overlapping lithology interval data (i.e., from-to intervals of 0-2 m, 0-5 m, 0-9 m became 0-2 m, 2-5 m, 5-9 m)
- manual supplementation of information into data records from PDF well logs for areas of limited information
- correction of intervals with missing depth data in critical areas

Golder has noted from past data standardization projects with the WELLs database, that soil and lithological interval descriptors are often entered into different fields (i.e., raw lithology, material description) in the same well record. This can result in data gaps, as the descriptors entered into the material description field are not necessarily included in the download of the WELLS database with lithology from DataBC. As a result, individual well records in critical areas of interest were obtained using the online provincial search tool and manually entered into the project database.

3.2.3.2 Lithology Standardization and Grouping

The availability and quality of the data for entries in the lithological interval data from the WELLs database were highly variable and dependent on the driller and age of the well record. As a result of this variability, substantial standardization and groupings of the lithological dataset was required for effective interpretation of subsurface stratigraphy and conditions. The method of standardization for the lithological intervals associated with this project primarily consistent of keyword scripts to extract relevant hydrostratigraphic data descriptors from the lithology field. The scripts were adjusted for terminologies, nomenclature, and formatting used on individual well records and iteratively adjusted and checked manually against raw data records. Similar methods were used to extract other information from the lithology and general remarks fields, including well yields, water levels and water bearing zones. Once the relevant lithological descriptors were extracted and standardized, they were grouped into categories that facilitated visualization and interpretation of the subsurface data in 3D. The preliminary grouping classifications used in this project was based on soil texture (e.g., “sand”, “gravel”, “till”, “clay”, “silt”). Table 8, below, presents the lithological descriptor classification using two classification schemes.

Table 8: Lithological Descriptor Classification

Example Lithological Descriptor (from Keyword Scripts)	Soil Texture Classification	Permeability Classification
Sandy Gravel	Gravel	Permeable
Gravel		
Silty Gravel		
Gravelly Sand	Sand	
Sand (Fine / Medium / Coarse / Clean)		
Silty Sand		
Sandy Silt		
Silt	Till/Clay	Low Permeability
Clayey Silt		
Clay		
Silty Clay		
Till		
Hardpan		
Bedrock / Rock Descriptors	Bedrock	Bedrock

The above groupings and classifications provided the basis to facilitate visualization of the data in 3D. The full raw lithologies were then queried to map and delineate the extents of the aquifers. Inconsistencies with keyword scripting and automated data processing tend to be regionally specific and dependent upon the driller or consultant entering the data into the database. For this project, the soil texture was considered for an initial classification; however, due to the complex sequencing of similar materials, manual review of raw well logs, well yield and stratigraphic elevation data was required to separate stacked aquifer units. In areas proximal to high topographic relief, some considerable disagreement in stratigraphic elevation correlations between wells was observed; this is likely due to errors introduced due to poor lateral (XY) accuracy of the well collar when projected onto the topography. In areas of disagreement, the wells with most lithological detail or decent correlation with adjacent wells were given more weight in the lithological standardization process.

3.2.3.3 Data Visualization

Golder imported the refined well records and hydrogeological data into Leapfrog® Hydro software (Leapfrog) to visualize the data in 3D and develop a model of the Project Area. Topography for the conceptual model was derived from a 2 m-interval contoured digital elevation model (DEM) provided as a shapefile (2mContours.shp) by RDN (2019). The topographic surface was overlaid with a 2016 orthoimage derived from Google Earth and regional bedrock and surficial geology mapping information was also imported into the model.

Existing aquifer boundaries from the Conceptual Model and available from BC ENV were used for reference purposes for defining the lateral extent of the aquifers. Golder visualized the data in Leapfrog and reviewed lithological information in the conceptual model to delineate the vertical extent of the four unconsolidated aquifers and four bedrock aquifers within the Project Area. As discussed in Section 1.2, in conjunction with Phase 3 of the Water Budget Project, Golder refined the lateral and vertical extents of unconsolidated Aquifers 1098 and 0219 for the RDN and the province; the updated Master Well Spreadsheets, polygon shape files and Aquifer Description Sheets for each aquifer were provided to the province under separate cover. . Although Aquifers 1098 and 0219 are inferred to be within unconsolidated deposits units of different ages and depositional environments, available well logs in the area of these aquifers typically do not provide lithological descriptions with sufficient detail to easily differentiation between units of similar grain size. Therefore, to distinguish between the Quadra Sand (Aquifer 0219) and the Muir Formation deposits (Aquifer 1098), Golder conducted a detailed review of the lithological sequences of well logs and the description of sediment sorting, colour, saturation and reported presence of organic debris (i.e., wood or peat) and visualization of the information were used as criteria to facilitate separation of the aquifer units. Aquifer mapping for the Project Area, as provided in the Conceptual Model and refined by Golder, is presented on Figure 4.

Three-dimensional geological volumes of the hydrogeological units were calculated using the contact orientation inferred from digitized geology maps and results from the lithological standardization described in Section 3.2.3.2. Minor deviations between the extents of the aquifer units and lithologies of individual water well records were attributed to limitations associated with the lithological descriptions and spatial accuracy. Figure 5 presents the locations of the water wells that were used to construct the 3D geological model and assignment of the wells to the identified stratigraphic units.

The following assumptions were applied to the vertical and lateral boundaries of the key hydrostratigraphic units in the Project Area based on the available data:

- Aquifer 221:
  - aquifer comprises of near shore deltaic and fluvial deposits consisting of primarily sand and gravel with silt and minor amounts clay
  - deposits are geomorphologically constrained by morainal deposits near the mouth of the Englishman River
  - Salish Sediments were assumed to be unconfined based on surficial geology mapping
- Aquifer 219:
  - aquifer was inferred to comprise thick deposits of relatively well sorted Quadra Sands with some gravel; a number of borehole descriptions indicate the top sections of the unit as being unsaturated
  - aquifer was interpreted to be separated from underlying AQ 1098 by a continuous low permeability layer described as till or clay in the water well records
- Aquifer 1098:
  - aquifer was interpreted to comprise Muir Point Formation deposits of silty sand, sand and gravel with some clay lenses
  - aquifer deposits generally include more gravel and silt than the overlying Quadra deposits

  - the aquifer generally overlies a basal low permeability till layer, described in some water well records as being blue or gray in colour
- Aquifer 215
  - aquifer was interpreted to comprise the confined Quadra Sands; formation is described as dry for top portion of the aquifer, similar to deposits of Aquifer 219
  - aquifer deposits are generally constrained to the hill slopes near east Lantzville
  - confined by material described as clay, silty clay, till
- bedrock aquifers (Aquifers 210, 213, 214, 218):
  - bedrock aquifers are generally mapped based on areas of groundwater use and the aquifer extents do not necessarily reflect by the extents of the bedrock units
  - bedrock aquifers in the Project Area, as mapped by the province, extend across the boundaries of various bedrock units of different composition and competency
  - the mapped extents of bedrock formations (e.g., Vancouver Group, Nanaimo Group, etc.) were utilized to construct hydrogeological units for the numerical model rather than the volumes of bedrock within the areas of the currently mapped bedrock aquifers; however, bedrock aquifer volumes based on current aquifer delineation were considered for the water budget analysis (Section 6.0)

Figures 6 to 8 below present an angled view of the Project Area and cross-sections that were generated in Leapfrog along two trend lines. Following generation of the 3D geological volumes for each aquifer, the Leapfrog model was exported with separate surfaces for the major hydrostratigraphic units and imported into the numerical groundwater modeling software.

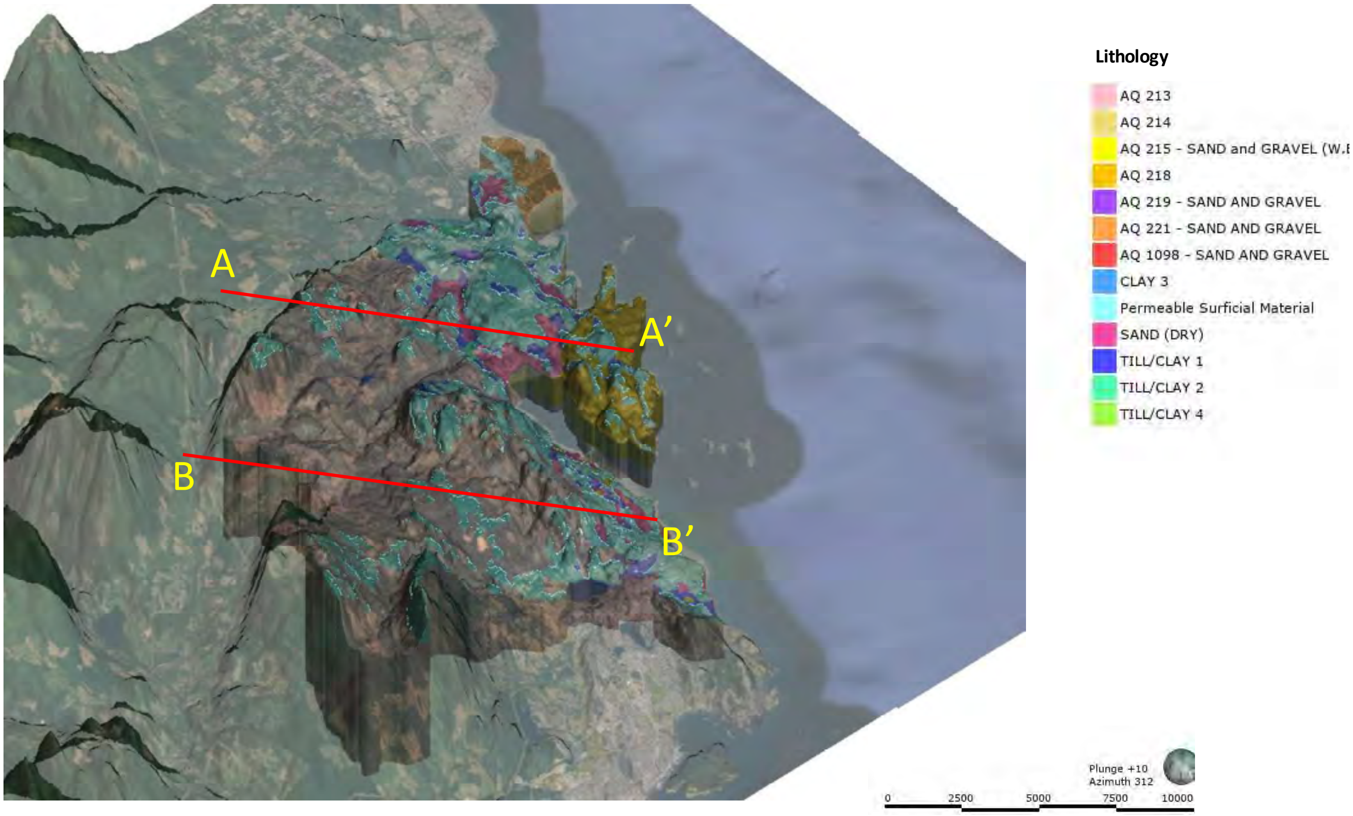

Figure 6: Angled view of Hydrogeological Model visualized in Leapfrog (vertical exaggeration 3:1)

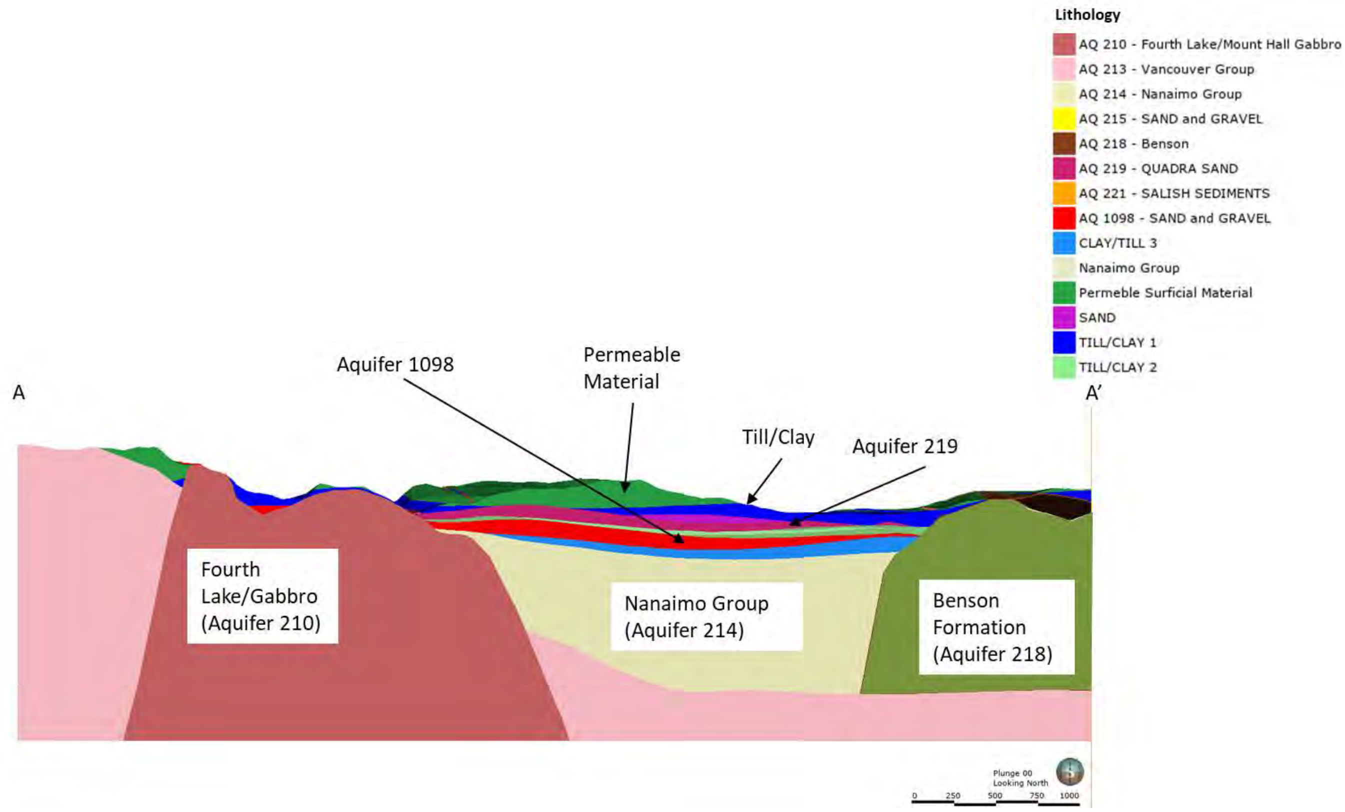

Figure 7: 2D View of Hydrogeological Model–Section A-A' (vertical exaggeration 3:1)

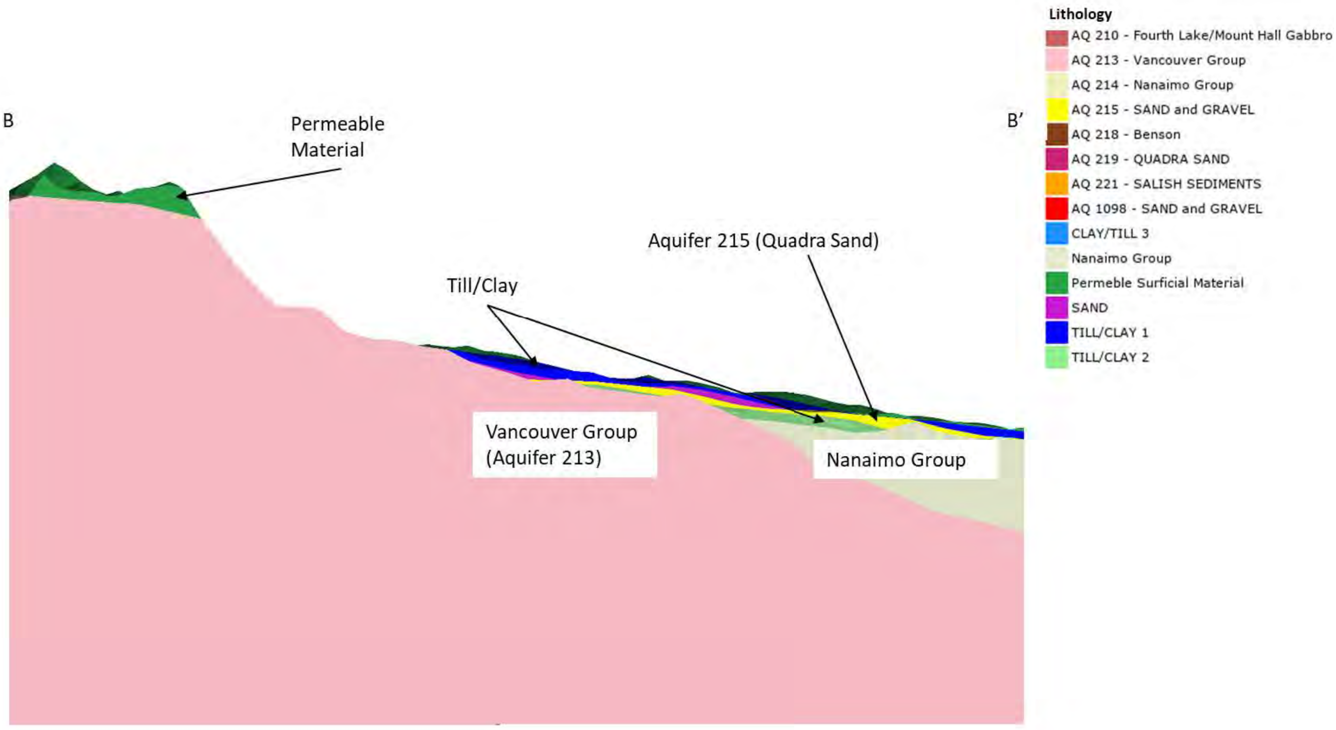

Figure 8: 2D View of Hydrogeological Model–Section B-B' (vertical exaggeration 3:1)

3.2.3.4 Refined Aquifer Delineation

As discussed in Section 1.2, on behalf of the RDN and FLNRORD, Golder was retained to refine the mapping and classification of Aquifers 219 and 1098. The refined vertical and lateral extents of these aquifers were used to refine the Conceptual Model of the Project Area and were imported into the numerical model (Section 5.0) and also provided to the province under separate cover. For the purposes of this project, based on visualization and review of available information, Golder also made slight refinements to the extents of Aquifer 221 and bedrock Aquifers 218 and 214.

A summary of the refinements that were made to the existing aquifer boundaries is presented in Table 9.

Table 9: Summary of Refinements to Aquifer Boundaries within Project Area

Aquifer No.	Aquifer Refinements			
	South Boundary	North Boundary	East Boundary	West Boundary
219	**Moved approximately 750m to 1 km to north along the base of mountains in the vicinity of Highway 19** Lithological descriptions of materials on logs for wells south of the refined boundary were more consistent with lithology inferred to correlate with Aquifer 1098; wells in this area re-assigned to Aquifer 1098 and aquifer boundary was refined	**Portions of the Aquifer boundary north coast of the Salish Sea were moved approximately 200-300 m to the south** Boundary moved based on shallow or outcropping bedrock identified on well logs and surficial geology mapping east of Craig's Bay in the vicinity of Observation Well 396	**Extended approximately 600 m to the east** Boundary extended to include wells at the base of the mountains south of Highway 19 near Nanoose Bay with logs that describe aquifer materials as brown sand, with some sections of dry material, consistent with the description of Quadra Sands in the area	**Moved up to approximately 1,800 m east** In the northwest corner, north of Highway 19, the boundary western boundary was moved east and aligned with the Englishman River
1098	**Shifted approximately 300-500m to the south-east in vicinity of Matthew Rd** Includes wells re-assigned from Aquifer 219 that were inferred to correlate with materials that are coarser grained and grey in colour **Decreased extent of the south-eastern lobe by approximately 450m to the east in the vicinity of Morello Rd. and by approximately 300m to the west in vicinity of Sea Blush Dr.** Shallow bedrock reported on logs for wells near Morello Rd. and Sea Blush Dr. with no indication that the aquifer deposits extend above the shallow bedrock in these areas	**In the vicinity of Craig's Bay, shifted approximately 500 m south** Based on shallow or outcropping bedrock identified on well logs and surficial geology mapping east of Craig's Bay, in the vicinity of Observation Well 396	**Decreased the eastern extent of aquifer by approximately 1,200 m in the vicinity of Nanoose Bay** No wells identified in the area to Qualicum National Wildlife Area to support the extension of the aquifer eastward near Nanoose Beach Rd. **Narrow portion of aquifer extending onto Nanoose Peninsula removed** No wells identified in the narrow portion of the aquifer to support extension of the aquifer out into this area	**No refinements to the western boundary**
221	**Decreased extent of south-eastern edge of aquifer by approximately 600-900 m towards to the north** Refined towards the north based on surficial geology and geomorphology to exclude the terrace in the vicinity of the Englishman River near Craig's Bay	**No refinements to the northern boundary**	**No refinements to the eastern boundary**	**No refinements to the western boundary**

Aquifer No.	Aquifer Refinements			
	South Boundary	**North Boundary**	**East Boundary**	**West Boundary**
218	**Moved boundary to the northwest by approximately 150-250 m in vicinity of Delanice Way** Lithological descriptions on logs for wells in the vicinity of Delanice Way more consistent with sedimentary bedrock of Nanaimo Group bedrock of Aquifer 214 **Extended aquifer boundary approximately 350–400 m south in the vicinity of the Parker Rd.** Bedrock lithology described on logs for wells in the vicinity of Parker Rd suggest bedrock deposits that are more consistent with greywacke, argillite, andesite flows and limestone of the Benson Formation of Aquifer 218, as described by GSC (1979)	**No refinements to the northern boundary**	**No refinements to the eastern boundary**	**No refinements to the western boundary**
214	**Extended boundary to the north-east by approximately 150-250 m in vicinity of Delanice Way** Extended to include wells reassigned from Aquifer 218 to Aquifer 214 based on lithological description of sedimentary bedrock **Refined aquifer boundary by moving it approximately 350-400 m to the north in the vicinity of the Parker Rd.** Excluded wells in the vicinity of Parker Rd. that were reassigned to Aquifer 218 based on lithologic descriptions inferred to be consistent with the Benson Formation.	**No refinements to the northern boundary**	**No refinements to the eastern boundary**	**No refinements to the western boundary**

3.2.4 Hydrogeology

As discussed in Section 3.2.3.3, four unconsolidated aquifers and four bedrock aquifers are present in the Project Area (Figure 4). Data related to the hydrogeological parameters and water levels for these aquifers are described below.

3.2.4.1 Hydrogeological Parameters

Information on hydrogeologic parameters was obtained from water well records contained within the BC ENV water well database and hydrogeological reports completed within the Project Area and summarized in Table 1.

In general, the water well records derived from the BC ENV database contained information on well yield (i.e., rate at which the well was pumped or estimated by the driller at the time of drilling), total depth drilled and static water level measured at the time of drilling. This information was incorporated in the customized water well database that was developed for the creation for the geological model of the Project Area (Section 3.2.3.3). The well yields that were recorded on the well records were generally estimated by drillers by injecting air into the well to lift the water to surface (i.e., air-lift method). Well yields estimated from this method are considered to be less accurate that those derived from pumping tests. Figure 9 presents a spatial distribution of well yields from the BC ENV database in the Project Area. The circles displayed on Figure 9 show the locations where yield was reported as included in the Conceptual Model. Each value was associated with an aquifer based on hydrostratigraphic interpretation conducted as part of the study (see Section 3.2.3). Reported yields are generally interpreted to be influenced by the permeability of the screened unit, the total depth drilled, topographic slope location and, in bedrock, the presence of fractures or structural features. In bedrock units, well yields were generally lower in wells that were drilled to greater depths, as presented on Figure 10, below. This observation is attributed to a general decrease in hydraulic conductivity with depth that is typically observed in bedrock.

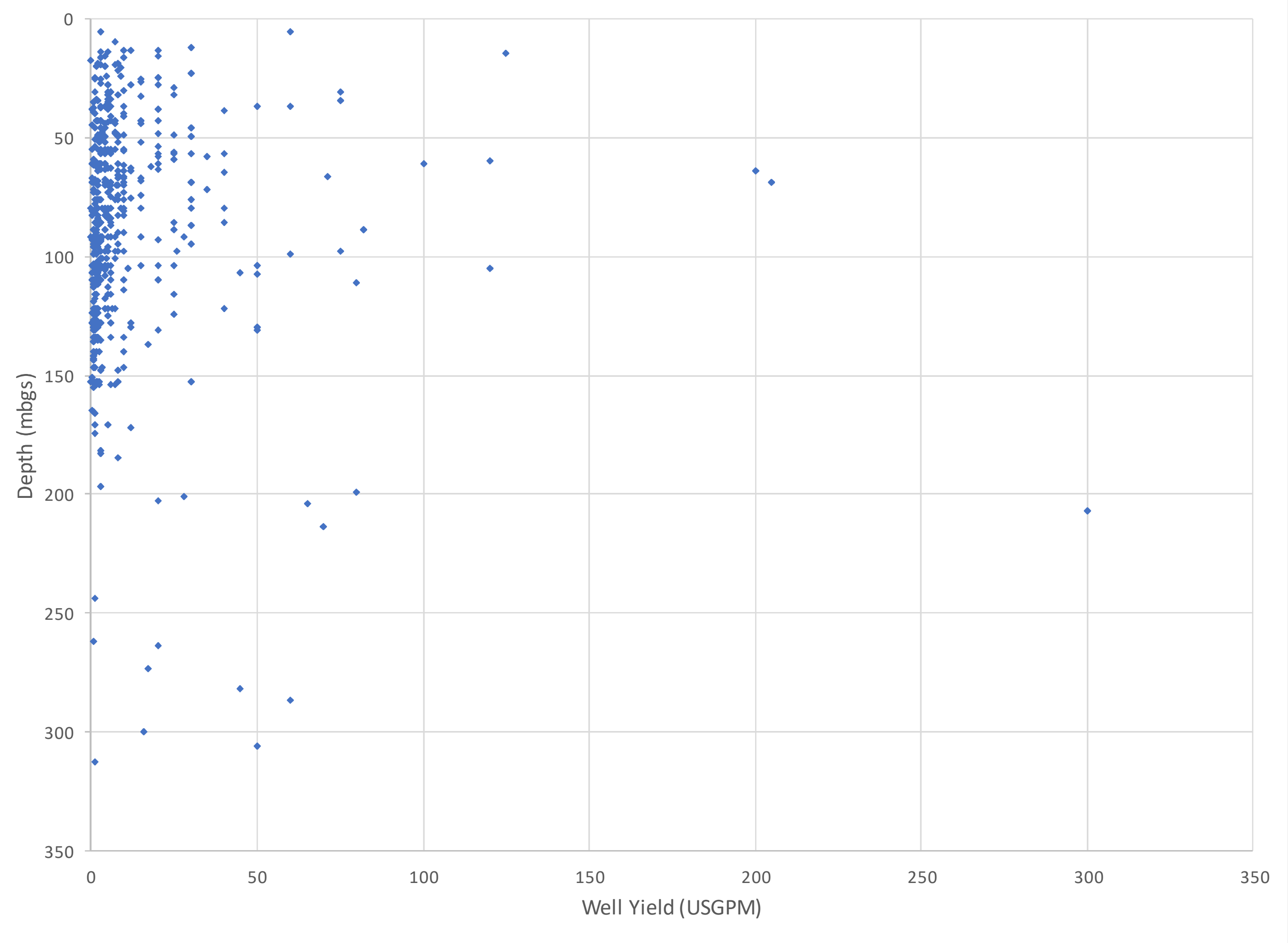

Figure 10: Well Yield Versus Total Well Depth in Bedrock Groundwater Wells

Additional hydrogeological information, including transmissivity, hydraulic conductivity and storage coefficients, was assembled through a review of available hydrogeological reports, as listed in Table 1. A summary of hydrogeological parameters that were derived from available information sources is presented in Table 10. Figure 11 presents a spatial distribution of measured hydraulic conductivity in the Project Area. The circles displayed on Figure 11 show the locations where hydraulic conductivity was estimated from hydraulic testing as included in the Conceptual Model. Each value was associated with an aquifer based on hydrostratigraphic interpretation conducted as part of the study (see Section 3.2.3).

Table 10: Summary of Hydrogeological Parameters of the Units in the Project Area

Hydrogeological Unit	Hydraulic Conductivity K (m/s)			Storativity		Source
	Min	Max	Geometric Mean	Min	Max	
Surficial Till	5.0x10^{-9}	2.5x10^{-7}	-[1]	-	-	GCS 2016
Till/Clay (Aquitard)	5.0x10^{-8}	5.0x10^{-6}	-[1]	-	-	GCS 2016
Unconfined Sand and Gravel: Salish Sediments (Aquifer 221)	3.4x10^{-4}	3.0x10^{-3}	2.6x10^{-3}	-	-	Carmichael 2013
Confined Sand and Gravel: Quadra Sand (Aquifer 219)	9.5x10^{-6}	4.0x10^{-3}	6.0x10^{-4}	3.3x10^{-7}	2.0x10^{-2}	Carmichael 2013
Confined Sand and Gravel: Muir Point Formation (Aquifer 1098)	9.0x10^{-6}	8.0x10^{-4}	-[1]	-	-	GCS 2016 Pumping Test data (GSI 2019)
Confined Sand and Gravel: Quadra Sand Aquifer (Aquifer 215)	3.9x10^{-5}	4.0x10^{-3}	3.0x10^{-4}	8.0x10^{-5}	9.8x10^{-3}	Carmichael 2013
Sedimentary/Igneous Intrusive Bedrock: Fourth Lake/Mount Gabbro Formation (Aquifer 210)	1x10^{-10}	5.0x10^{-4}	-[1]	-	-	GCS 2016
Volcanic Bedrock: Vancouver Group (Aquifer 213)	1.4x10^{-7}	4.2x10^{-6}	2.8x10^{-6}	-	-	Carmichael, 2013 Pumping Test data Foothills (GSI 2019)
Sedimentary Bedrock: Nanaimo Group (Aquifer 214)	1x10^{-10}	5.0x10^{-4}	-[1]	-	-	GCS 2016
Sedimentary/Igneous Intrusive Bedrock: Benson Formation (Aquifer 218)	1.2x10^{-6}	4.1x10^{-5}	1.0x10^{-5}	1.9x10^{-5}	5.5x10^{-5}	Carmichael 2013

Notes:

1. Geometric mean not provided in the GSC report (2016)

Hydrogeological parameters presented in Carmichael (2013) were estimated from pumping test data generally conducted on higher capacity wells that were intended to be used for supplying drinking water systems or for private domestic wells. Therefore, the hydraulic conductivity values estimated by Carmichael (2013) at those locations are considered to represent the most productive portion of the corresponding aquifer unit (i.e., estimates that represent the higher end of the range). The range of values provided by the GSC (2016) is based on a wider range of literature, particularly for the bedrock aquifers, and is considered more representative of the bulk hydraulic conductivity of each of the units. As discussed above, in bedrock formations a reduction of hydraulic conductivity with depth is commonly observed due to the increase in compressive stress and associated closing of fractures. These considerations were taken into account when assigning hydraulic conductivity in the numerical groundwater model and during model calibration.

3.2.4.2 Groundwater Recharge

Precipitation during the wet season is the primary source of groundwater recharge to the aquifer system (overburden and bedrock) in the Project Area. The amount of recharge is a function of the amount of precipitation lost by evapotranspiration and by surface water runoff. Runoff or storm water attenuation is affected by topography, vegetative cover, the presence of surficial material, and the hydraulic conductivity of the aquifer material. In the dry summer months, when a precipitation deficit is inferred to occur, limited recharge from precipitation is expected.

Groundwater recharge estimates, presented as total annual, summer and winter values, were previously provided by Waterline (2013) as part of the Phase 1 Water Budget Project. Recent climate data, as described in Section 3.2.1, were consistent with those reported in the Phase 1 Water Budget and, therefore, the groundwater recharge estimates presented in Phase 1 were considered applicable for the current Phase 3 Water Budgets. Figure 12 presents the distribution of total annual groundwater recharge values for the Project Area, as estimated by Waterline (2013). Figures 13 and 14 present groundwater recharge estimates for the wet and dry seasons, respectively, in the Project Area.

In addition to recharge from precipitation, groundwater can also be recharged by anthropogenic sources. To quantify groundwater recharge from human sources, properties connected to the municipal sewer system within the RDN water-serviced area were identified, as illustrated on Figure 15, and assumed to contribute insignificant amounts of groundwater recharge from wastewater. For properties that are not connected to municipal sewer systems (i.e., are serviced with private septic systems), published rates of return indicate that approximately 60% to 85% of per capita household consumption of water becomes wastewater, with the lower percentage applicable to semiarid regions such as the southwestern United States and the higher percentage applicable to northern regions of the United States during cold weather (Tchobanoglous and Burton 1991). For the Project Area, it was assumed that 70% of all groundwater withdrawals in areas that are not serviced by the municipal sewerage system would recharge the aquifer system via septic water return or irrigation (during the dry season). This is considered conservative given that the Project Area is located in a temperate rainforest climate.

The amount of groundwater recharge as a result of leakage from water distribution pipes servicing properties within the RDN water service area is estimated to be 15% of the total water use, consistent with estimates provided by the GVRD (1999).

3.2.4.3 Groundwater Levels and Hydraulic Heads

Long-term water level monitoring data were assembled and reviewed for four RDN volunteer observation wells, six observation wells that are maintained by BC ENV (Provincial Groundwater Observation Well Network; PGOWN) and 15 Parker Road wells (Golder 2019). Hydrographs for the volunteer observation wells, PGOWN observation wells and Parker Road wells are included in APPENDIX B and the locations of the observation wells are shown on Figure 15. APPENDIX B also includes hydrographs for the PGOWN wells with statistical analysis on historical water levels conducted by BC ENV

For other wells, where survey (i.e., elevation) data were not available, Golder used static groundwater levels measured at the time of drilling and recorded in the BC ENV well database and topographic information to estimate hydraulic head elevations.

In general, water levels in each well varied seasonally with precipitation. To assess long-term trends for the wells with sufficient monitoring data (i.e., PGOWN wells), a linear trend line was statistically fit to each hydrograph.
As summarized in Table 11, the results of water level monitoring for wells with a monitoring period of seven years or more indicates that overall water levels are generally steady to slightly increasing over the monitored periods except for one monitoring well (OBS Well 395) which is completed in Aquifer 219 and located in the vicinity of the RDN Englishman River pumping wells (PW1, PW2, and PW3). However, in some of the PGOWN wells (340, 394, and 395) seasonal low levels at the end of the dry season seem to slightly decrease starting in 2017, whereas the seasonal high levels are steady or slightly increase. For the RDN volunteer observation wells and the Parker Road wells it was not possible to assess long-term trends as not enough monitoring data were available.
In addition to this, it should be noted that the RDN volunteer observation wells and the Parker Road wells are private domestic wells that might be subject to pumping for portions of the year; information on pumping rates and pumping schedule for these wells was not available. Based on the hydrogeological assessment conducted by Golder for the Parker Road Well B1 (Golder 2019), in the area between Parker Road and Nanoose Bay low groundwater water levels together with increase of electrical Conductivity (EC) associated with pumping of the Parker Road Well were observed during the dry season. This area was identified as potentially subject to saltwater intrusion into the bedrock aquifer.

The available water level information described above were used as targets during the numerical model calibration (see Section 5.5.1).

Table 11: Water Levels in Monitoring Wells in the Project Area

Well ID	Well Type	Lithology	Aquifer	Seasonal Head Range[1] (m)	Monitoring Period	Average Interpreted Trend
OBS Well 340	PGOWN Monitoring Well	bedrock	213	0.6-2.5	2008-2019	Steady
OBS Well 232	PGOWN Monitoring Well	overburden	215	1.5-3	2008-2019	Increasing (approx. 1 m since 2008)
OBS Well 394	PGOWN Monitoring Well	bedrock	218	1.2-2.2	2012-2019	Slightly Increasing (<0.5 m)
OBS Well 395	PGOWN Monitoring Well	overburden	219	2.5-3	2012-2019	Slightly Decreasing (<0.5 m)
OBS Well 393	PGOWN Monitoring Well	overburden	219	0.1-0.3	2011-2019	Slightly Increasing since 2016 (<0.5 m)
OBS Well 396	PGOWN Monitoring Well	overburden	219	0.8-2	2012-2019	Slightly Increasing (<0.5 m) since 2012
OBS Well 397	PGOWN Monitoring Well	overburden	1098	ND[2]	2012-2019	ND[2]
VOW13	RDN Voluntary Private Monitoring Well	bedrock	213	6-8	2016-2018	NA[3]
VOW25	RDN Voluntary Private Monitoring Well	bedrock	214	1.0	2017-2018	NA[3]

Well ID	Well Type	Lithology	Aquifer	Seasonal Head Range[1] (m)	Monitoring Period	Average Interpreted Trend
VOW27	RDN Voluntary Private Monitoring Well	bedrock	218	7.0	2017-2018	NA[3]
VOW26	RDN Voluntary Private Monitoring Well	bedrock	218	9.0	2017-2018	NA[3]
B1, B2, B3, B4, B5, B6, B7, B9	Parker Road Wells	bedrock	218	4-5	2015-2018	NA[3]
O1	Parker Road Well	overburden	219	1.3	2015-2018	NA[3]
O2, O3, O4, O5, O6, O7	Parker Road Well	overburden	1098	1.5-3	2015-2018	NA[3]

Notes:

1. For the PGOWN wells, the seasonal range was estimated based on raw water level data and results of BC ENV statistical analysis on historical water levels. For the Parker Road wells, the seasonal range was estimated base on 2016 water levels (before activation of the Parker Road Well B1).
2. ND = Not determined as water level dataset for this well was missing significant portion of data over the monitoring period
3. NA = not available (not enough data to determine a long-term water level trend)

3.2.5 Groundwater Use

Estimates of groundwater use by municipal water supply systems were derived from municipal pumping records that were provided by the RDN and other water systems. Potential groundwater use outside of the municipal water service areas was estimated based on land use information. Further information is provided in the following sections.

3.2.5.1 Municipal Water Supply System Service Areas

Groundwater use by municipal/community water supply systems was estimated using information from the following sources:

- RDN production wells pumping records (2010-2018) and wells reports provided by the RDN.
- Lantzville production wells pumping records for 2018 provided by the District of Lantzville 2019.
- SNAFN production well pumping records for 2018 provided by GSI (2019).

A summary of pumping volumes for the active municipal wells for 2018 is presented in Table 12 and the locations of the municipal production wells are shown on Figure 15. The pumping data indicate that the total volume pumped from the RDN production wells was approximately 540,000 cubic metres (m^3) in 2018 (average of 1,500 m^3/day) and the total volume pumped from all municipal/community wells was approximately 800,00 m^3 in 2018 (average of 2,200 m^3/day); however, groundwater use was relatively higher in the dry summer season. Table 12 also includes production rates during wet (October through April) and dry season (May through September).

For some of the production wells (i.e., Englishman River wells) dry season pumping rates are up to 70% higher than the wet season pumping rates.

Table 12: Production rates for Municipal/Community Water Supply Wells in the Project Area

Well	Well Tag No.	Aquifer	2018 Production Rates (m^3/day)		
			Average Annual	Dry season	Wet Season
Regional District of Nanaimo					
SP Well No. 1	34156	221	140	192	102
SP Well No.4 (2004)	94530	221	136	210	82
ER PW No. 2	90381	219	48	86	20
ER PW No. 3	94515	219	131	237	56
MD Well No. 4	75341	1098	46	78	22
Wallbrook Well No.1 (formerly MD7)	96789	219	193	248	155
MD Well No. 8	96542	214	40	68	20
FW Well No. 1	75320	1098	232	247	222
FW Well No. 2	75321	1098	138	155	126
FW Well No. 3	75322	1098	152	163	144
WB Well No. 3	75319	1098	239	161	295
		Subtotal:	1,495	1,845	1,244
Snaw-Naw-As First Nation					
Snaw-Naw-As FN IR #0	96194	215	85	83	86
		Subtotal:	85	83	86
District of Lantzville					
Well 4	108680	215	192	254	153
Well 6	52042	215	194	250	158
Well 9	108678	215	92	120	74
Well 12	96583	215	147	199	112
		Subtotal:	625	823	498
		Total:	2,205	2,751	1,828

3.2.5.2 Properties Outside Municipal Service Areas

Groundwater use for properties located outside of municipal serviced areas was estimated in Phase 1 (Waterline 2013) by assigning water use to parcels based on zoning and land use. The approach used for Phase 3 was similar; however, the present evaluation is based on more recent metered use information provided by the RDN and other providers and on refined estimates of water use on agricultural parcels that were based on more recent studies.

Land use was identified within the Agricultural Land Reserve (ALR) using survey data contained within the RDN Agricultural Land Use Inventory (ALUI; 2012) and the RDN Agricultural Water Demand Model (2013) provided by the BC Ministry of Agriculture. The database includes attributes on crop production, livestock facilities, agricultural infrastructure, water management activities, non-farm activities and watercourse features. Within the agriculture land use inventory, each property was assigned a primary land use activity based on what was visually observed during a survey. Secondary and tertiary land use activities were also recorded, if observed to be present. For properties where agriculture land use was assigned, up to four different agricultural activities were recorded depending on what was observed during the inventory.

For areas outside of the ALR, land use was identified by zoning information provided by the RDN in GIS format and updated to October 2019. Land use areas identified by zoning, along with areas identified by the ALUI survey, are shown in Figure 16.

For the purpose of estimating groundwater use for each of the properties that are not serviced by municipal water supply systems, a spatial correlation between the lots, the groundwater wells included in the BC ENV WELLS database and the surface water licenses was conducted to identify lots that are anticipated to use groundwater as the main source of water. Lots where a groundwater well was identified were then considered for the estimate of groundwater use as described in this section. If more than one water well was identified in a property, only one well was considered for the water use estimate. In properties with residential use where no wells were identified, a residential water use was conservatively assigned.

Land use categories contained within each information source are summarized in APPENDIX C. Depending on the property's land use, an estimated water usage was assigned using one of the following methods:

- For residential and commercial properties, water use was estimated using metered water usage data provided by the RDN and the City of Nanaimo for residential and commercial properties in 2018 and 2019. Typical water requirements were estimated based on the average daily water usage for all RDN and City of Nanaimo metered residential and commercial properties to provide updated values that represent recent water use compared to the estimates that were developed in Phase 1. Water use data provided by the RDN and the City of Nanaimo are summarized in APPENDIX C. Based on the water consumption data provided within the RDN, an average value of 607 L/day/unit was used for residential properties and an average value of 813 L/day/account was used for commercial properties, as calculated in APPENDIX C.
- For daily livestock watering requirements, the quantity of water required for each type of livestock on a given property was estimated from ranges provided with the Agricultural Water Demand study (2013).
- Irrigation requirements for different types of crops in the region were also estimated from values provided with the Agricultural Water Demand study (2013). For each crop type, the property owner was assumed to have applied enough groundwater to meet the crop growing requirements over the dry season period (May through September). As a conservative assumption, it was assumed that water used for irrigation within the non-serviced areas is mainly derived from groundwater, rather than surface water sources.

Tables summarizing the values that were used for the Phase 3 water budgets for irrigation requirements are presented in APPENDIX C.

4.0 CONCEPTUAL HYDROGEOLOGICAL MODEL

Phase 1 of the Water Budget (Waterline 2013) included development of a conceptual hydrogeological model (Conceptual Model) for the RDN that was based on available data at the time. The conceptual model provided a representation of the hydrogeological and hydrological setting. For Phase 3, Golder updated the Conceptual Model based on review of more recent information (i.e., refined hydrostratigraphy, groundwater levels, groundwater use, etc.) described in Section3.0, and then used the refined conceptual model to construct a numerical model for the Project Area. The updated conceptual model for the Project Area is discussed in the sections below. An updated version of the GIS files from Phase 1 are provided separately.

4.1 Hydrogeological Units

The Nanoose region is situated on unconsolidated Quaternary sediments comprised primarily of sand and gravel. These sediments make up a series of aquifers, some of which are hydraulically connected, which overlie bedrock. Aquitards, which are composed of less permeable silt and clay deposits of lacustrine origin, are inferred to lie between many of these aquifers. Based on the 3D hydrostratigraphic interpretation, the aquitard separating Aquifers 219 and 1098 is interpreted to generally be laterally continuous, whereas the aquitard underlying Aquifer 215 is interpreted to be discontinuous in some areas, resulting in a hydraulic connection between the overburden aquifer and the underlying bedrock Aquifer 213.

As discussed in Section 3.2.3, within the Project Area, four aquifers have been assigned to the unconsolidated deposits and four bedrock aquifers have also been assigned within the bedrock formations. The extents of the aquifers within the Project Area are presented on Figure 4. Based on 3D hydrostratigraphic interpretation, the boundaries of some of the aquifers were modified, as described in Section 3.2.3.4. A summary of the hydrostratigraphic units is presented in Table 13 below.

Table 13: Hydrostratigraphic Units in the Nanoose Area E

Unit	Aquifer Tag No.[1]	Aquifer Classification[2]	Estimated Hydraulic Conductivity (m/s)
Surficial Till	-	-	1×10^{-7}
Till/Clay (Aquitard)	-	-	5×10^{-8}
Unconfined Sand and Gravel: Salish Sediments	221	IIA	2×10^{-3}
Confined Sand and Gravel: Quadra Sand	219	IIC	6×10^{-4}
Confined Sand and Gravel: Muir Point Formation	1098	IIC	1×10^{-4}
Confined Sand and Gravel: Quadra Sand	215	IIC	6×10^{-4}

Unit	Aquifer Tag No.[1]	Aquifer Classification[2]	Estimated Hydraulic Conductivity (m/s)
Sedimentary/Igneous Intrusive Bedrock: Fourth Lake/Mount Gabbro (Aquifer 210)	210	IIB	$3x10^{-6}$
Volcanic Bedrock: Vancouver Group (Aquifer 213)	213	IIC	$3x10^{-6}$
Sedimentary Bedrock: Nanaimo Group (Aquifer 214)	214	IIB	$1x10^{-6}$
Sedimentary/Igneous Intrusive Bedrock: Benson Formation (Aquifer 218)	218	IIB	$1x10^{-5}$

Notes:

1.Aquifer tag no. on the BC ENV Water Resources Database (WRA)

2.BC ENV 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 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). In the Nanoose Peninsula area of Electoral Area E, the sedimentary bedrock deposits of the Benson Formation and, in the eastern portion of the peninsula, igneous intrusive rocks of the Island Plutonic Suite, are mapped as Aquifer 218.

As previously discussed, a reduction of hydraulic conductivity with depth is assumed in bedrock due to the increase in compressive stress and associated closing of fractures.

4.2 Groundwater Flow Directions

The hydraulic heads that were estimated from static water levels measured at the time of drilling and recorded in the BC ENV well database using topographic information provided the basis to interpret groundwater flow directions across the Project Area and within the aquifers. Contours for groundwater levels within the overburden aquifers and shallow bedrock are shown on Figures 17 and 18, respectively.

Overall, the water table within the overburden and shallow bedrock is inferred to be a subdued impression of the local topography. Groundwater flows from higher elevations into the low-lying areas including valleys, surface water courses and the ocean throughout the Project Area. Based on available water level data, water levels in both overburden and bedrock units vary seasonally with the precipitation; seasonal fluctuations are estimated to vary from less than 0.5 m to approximately 3 m in the overburden and from 1 m to 6-8 m in the bedrock.

4.3 Groundwater Recharge and Discharge Areas

As presented on Figure 4, 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. Groundwater within Aquifer 219 is interpreted to 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 vulnerable to 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 is interpreted to occur between Aquifer 219 and overlying Aquifer 221 in the northwest corner of the Project Area, in WR#4 (Englishman River) (Figure 4). Groundwater in the unconfined Salish Sediments of Aquifer 221 is recharged by infiltration of precipitation and the hydraulic connection 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 the 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. 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.

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 relatively 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 interpreted to recharge groundwater in Aquifer 215 (Figure 4). In the lower elevations, the relatively thicker overburden deposits that provide some recharge to the bedrock aquifers are interpreted to 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.

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.

5.0 NUMERICAL GROUNDWATER MODEL

The refined Conceptual Model for the Project Area that is described in Section 4.0 was used as a basis for the development of a 3D numerical groundwater flow model that is described in the following sections.

5.1 Model Selection

The model was constructed using FEFLOW, a 3D finite element code developed by DHI-WASY Institute in Germany (DHI-WASY 2018). FEFLOW is capable of simulating 3D groundwater flow in complex geological settings under a variety of boundary conditions and hydrogeological stresses. FEFLOW is widely used for hydrogeological modelling and is well recognized by regulators, the research community and professional hydrogeologists.

5.2 Model Extent and Mesh Configuration

The extent of the numerical model was based on our understanding of groundwater flow conditions in the Project Area, with model boundaries set based on watershed boundaries and sufficiently distant from the aquifer boundaries to allow adequate representation of groundwater flow conditions in the Project Area.

The extent of the model domain is presented on Figure 19. The model encompasses the entirety of Electoral Area E, the aquifer boundaries and the main and sub-watersheds and are bounded by the Englishman River to the west, the ocean to the north and watershed boundaries to the east and south. The model extends a maximum of approximately 23 km in length (NE-SW) and 19 km in width (NW-SE), with a total planar area of approximately 260 km^2.

Vertically, the model was divided into 19 separate layers. The elevation of layer one was set to the ground elevation, whereas the elevation of the bottom of layer 19 was set at -1,000 m asl. The remaining layers were evenly distributed between the top and bottom layers with divisions placed strategically to accommodate the 3D hydrostratigraphic model and accurately reproduce the hydrogeological units identified in the conceptual model. Horizontal mesh discretization progressively increased from element size of approximately 250 m at the limits of the model domain to 50 m within the aquifer boundaries, in the vicinity of the production wells and near creeks and waterbodies. The horizontal and vertical grid spacing provided sufficient regional representation of the major aquifers in 3D with the required degree of accuracy.

Following construction and calibration, the model was used in the water budget analysis that is discussed in Section 6.0.

5.3 Model Boundary Conditions

Boundary conditions in a numerical model provide linkage between the model domain and the hydrologic and hydrogeologic conditions that are outside of the model area. Four types of boundary conditions were used in the numerical model for the Project Area. The boundary conditions, which are illustrated on Figure 20, included specified head boundaries, head-dependent boundaries, specified flux boundaries and no-flow boundaries.
A specified head boundary is a boundary that assigns a specific hydraulic head to a node in the model. The model will allow water to exit or enter the model domain at this node in order to maintain the assigned hydraulic head.

In a head-dependent boundary a reference hydraulic head value is assigned to the node and a hydraulic conductance is assigned to the elements surrounding the node to simulate surface water bodies that have a restricted connection with groundwater. A specified flux boundary describes a node or element in the model that is assigned a specific flux, such areal recharge rate or a pumping rate. A no-flow (zero-flux) boundary is a special case of the specified flux boundary that is assigned to nodes or elements across which the flux is set to zero. No-flow boundaries are commonly set along groundwater flow divides.

Boundary conditions were applied to the numerical model as follows:

- Specified Head boundaries were applied to the shoreline and the portion of the Salish Sea that is represented in the model and set to mean sea levels (0 m asl). In addition to this, specified heads were also used to represent the portion of the Englishman River that was included in the model along the northwest boundary of the model domain, as this watercourse is considered to be a permanent water body and its hydraulic connection with groundwater is considered to be strong. The water level elevations assigned to these boundaries were based on elevation data of the river profile throughout the domain.
- Head-dependent boundaries that only permit outflow of groundwater were applied along the other rivers and creeks. In the absence of specific information, these waterbodies were considered to be intermittent; groundwater outflow along these boundaries only occurred where the calculated water table rose to the elevation of the creek bed (i.e., discharge only). The assumption that intermittent water bodies do not act as a significant source of groundwater recharge is considered conservative in terms of the objectives of the groundwater budgets (i.e., it conservatively assumes less available groundwater recharge). Boundary conductance along all streams was adjusted during model calibration, as discussed in Section 5.5.2.
- No-flow (zero flux) boundaries were used to simulate inferred groundwater divides along the perimeter of the model. These boundaries were assigned in all model layers based on the assumption that groundwater divides correspond to topographic divides (i.e., watersheds). A no-flow boundary was also assigned at the base of the model under the assumption that groundwater flow at greater depth has a negligible influence on the identified unconsolidated and bedrock aquifers.
- A specified-flux (recharge) boundary was assigned to the top of the model (i.e., ground surface) to simulate recharge from precipitation and human sources, including septic water return and pipe leakage. Recharge rates that were applied in the model were variable and derived from previous estimates from Waterline (2013) and refined by Golder for the wet and dry season. A specified flux boundary (sink) was also assigned to the properties outside the municipal water service areas (residential and agricultural water consumption, see Section 3.2.5.2) to simulate groundwater use from private groundwater wells. Water use assignment was verified using the well assignment to aquifers included in the updated Conceptual Model as shown on Figure 5. Where aquifer assignment was not specified, the water use was assigned to the top of the shallowest aquifer identified in the area. Production wells that are operated by the RDN and other suppliers were simulated by assigning specified flux boundaries to nodes that represent the locations and depths of individual well screens. The flux values assigned to these boundaries were varied to simulate average annual, average dry and average wet conditions, as discussed in Section 5.5.

5.4 Hydrostratigraphy and Initial Model Parameters

The initial estimates of the model parameters are presented in Table 14. Some of these parameters were adjusted during model calibration, as discussed in Section 5.5. The initial hydraulic conductivity values for individual aquifers were assigned based on the literature review of available studies and testing as described in Section 3.2.4.1. For each major aquifer, one hydraulic conductivity zone represented the three-dimensional extent of the aquifer established in the conceptual model and the hydraulic conductivity of the units was assumed to be isotropic. These assumptions are appropriate considering the regional scale of the groundwater numerical model. The extents of hydrogeological units (aquifers, aquitards and bedrock formations) that were incorporated into the numerical model and cross-sections across the model domain are shown on Figure 21.

Initially, all hydrostratigraphic units were assigned a uniform value of specific storage and specific yield based on values presented in the literature (Maidment 1993) and they are also summarized in Table 14. Initial hydrogeological parameters were later adjusted during model calibration (see Section 5.5.2).

Table 14: Initial Hydrogeological Parameters used in the Groundwater Numerical Model

Unit	Estimated Hydraulic Conductivity (m/s)	Specific Storage (1/m)	Specific Yield[1]
Surficial Till	$1x10^{-7}$	$1x10^{-4}$	0.2
Till/Clay (Aquitard)	$5x10^{-8}$	$1x10^{-4}$	0.1
Unconfined Sand and Gravel: Salish Sediments (Aq. 221)	$2x10^{-3}$	$5x10^{-5}$	0.2
Confined Sand and Gravel: Quadra Sand (Aq. 219)	$6x10^{-4}$	$5x10^{-5}$	0.2
Confined Sand and Gravel: Muir Point Formation (Aq. 1098)	$1x10^{-4}$	$5x10^{-5}$	0.2
Confined Sand and Gravel: Quadra Sand (Aq. 215)	$6x10^{-4}$	$5x10^{-5}$	0.2
Sedimentary/Igneous Intrusive Bedrock: Fourth Lake/ Mount Gabbro (Aq. 210)	$3x10^{-6}$ $1x10^{-7}$ (below -350 m asl)	$1x10^{-5}$	$3x10^{-5}$
Volcanic Bedrock: Vancouver Group (Aq. 213)	$3x10^{-6}$ $1x10^{-7}$ (below -350 m asl)	$1x10^{-5}$	$3x10^{-5}$
Sedimentary Bedrock: Nanaimo Group (Aq. 214)	$1x10^{-6}$ $1x10^{-7}$ (below -350 m asl)	$1x10^{-5}$	$3x10^{-5}$
Sedimentary/Igneous Intrusive Bedrock: Benson Formation (Aq. 218)	$1x10^{-5}$ $1x10^{-7}$ (below -350 m asl)	$1x10^{-5}$	$3x10^{-5}$

Notes:

1. unitless parameter

5.5 Model Calibration

The hydrogeologic numerical model was calibrated to the average annual conditions, and to the transition between average conditions during wet and dry seasons (i.e., seasonal fluctuations) to provide a calibration to both steady-state and transient (seasonal) conditions. Calibration simulations were run repeatedly, and the model parameters were adjusted in each simulation, until the model was capable of matching the calibration targets, discussed below.

5.5.1 Calibration Targets

5.5.1.1 Average Annual Conditions

The numerical model was first calibrated to steady groundwater conditions represented by average annual conditions. The calibration targets for this simulation included water levels obtained from the BC ENV well database for approximately 900 wells. As discussed in Section 3.2.4.3, the water level data from the BC ENV database are somewhat variable as they span several decades and at different times of the year (i.e., different seasons), were collected by various drilling contractors, and were reported for many wells with undocumented screen intervals. Moreover, additional variability was likely introduced while converting depth-to-water measurements to water elevation based on approximate ground elevation at each well location. Nevertheless, these water levels are considered suitable to provide a general representation of average hydrogeologic conditions throughout the Project Area.

The calibration targets also included average baseflow estimates for three creeks where active hydrometric stations exist: Craig Creek, Nanoose Creek and Bonell Creek.

In the steady-state simulation the specified flux boundaries were set as follows:

- Recharge from precipitation and human sources was set to the average annual values representing current conditions, as presented on Figure 12.
- Groundwater use outside the water serviced area was set to average annual values, as presented in Figure 22A.
- Pumping rates assigned to the RDN wells and other municipal wells were set to average annual rates calculated based on annual withdrawals recorded in 2018-2019 (Table 12).

5.5.1.2 Average Seasonal Conditions

The model was calibrated to transient groundwater conditions represented by average seasonal conditions during both wet and dry seasons. The calibration targets for this simulation consisted of the measured average changes in hydraulic heads between these two seasons (seasonal fluctuations) in the PGOWN observation wells, the RDN volunteer observation wells and the Parker Road wells. As described in Section 3.2.4.3, the RDN volunteer observation wells and the Par6ker Road wells are private domestic wells that are subject to pumping for portions of the year and have a limited data set (one to three year). For these reasons, fluctuations observed in those wells might not be representative of average seasonal fluctuations and therefore were not considered as reliable targets during model calibration; however, the data from these wells were considered during calibration. The number of wells considered in the transient simulation is relatively small when compared to the dimensions of the Project Area.

A summary of the monitoring wells that were used to calibrate the numerical model to average seasonal conditions is provided in Table 11. Water level observed in the RDN volunteer wells and in the Parker Road wells, together with limited water level datasets (1 year or less; 2013 and 2016) provided by GSI (2019) for the area of Foothills (Aquifer 213) and in the area of Englishman River (Aquifers 219 and 1098) were reviewed. Review of these data showed that seasonal fluctuations observed in overburden aquifers were consistent with those observed at the PGOWN wells. For bedrock units, some local variability was observed in the area of Foothills.

The following changes were made to the specified flux boundaries to simulate average seasonal conditions:

- Recharge from precipitation and human sources was varied between the seasons. For the first seven months of model simulation the recharge was set to the average wet recharge rates, and for the remaining five months it was set to the average dry recharge rates. Figures 13 and 14 present respective values of wet and dry recharge assigned to the model.
- Similar to recharge, the groundwater use by private users outside municipal water serviced area was varied between the wet and dry seasons, as presented on Figures 22B and 22C. Groundwater use was applied over the parcel's area and it is expressed in mm/y.
- Pumping rates assigned to the production wells were varied between the dry and wet season, as shown in Table 12.

The hydraulic heads calculated by the steady-state model were used as initial conditions for the transient simulation. The transient model was then run over several dry and wet cycles, until the water table fluctuations between the seasons stabilized over time.

5.5.2 Calibration Results

During model calibration some model parameters, including hydraulic conductivity, storage properties and recharge, were adjusted to improve the match between model predictions and calibration targets. The following section provides results of model calibration including a comparison of measured versus predicted hydraulic heads and base flows, along with a summary of changes made to the model to reproduce these conditions. The model parameters that resulted in best calibration are presented in Table 15. The adjustments in hydraulic conductivity values and recharge rates made during calibration were relatively small and are considered to be in reasonable agreement with measured ranges of hydraulic conductivity and the current understanding of groundwater and hydrological conditions at the site.

During calibration, the model input parameters were adjusted as follows:

- The hydraulic conductivity assigned to the shallow till and aquitards was increased from its initial value during model calibration. An adjustment to this parameter was expected considering that its initial value was based on literature data and not field measurements.
- For the overburden aquifers, the hydraulic conductivities of Aquifers 215, 219, and 1098 was decreased from the initial estimates to improve calibration to observed water levels and baseflow measured in Craig Creek and Nanoose Creek.

- For the bedrock formations, the hydraulic conductivity values were decreased from initial values; a decreasing trend with depth was also refined based on the available data and the assumption that in bedrock a reduction of hydraulic conductivity with depth is commonly observed due to the increase in compressive stress and associated closing of fractures.
- In addition to adjustments to hydraulic conductivity, minor increases (+15% of the initial values) were made to the recharge applied at the top of the model in the highest elevation areas of the model (Foothills and Aquifer 218). The model underpredicted the hydraulic heads in these areas and this change was necessary to improve the match between observed and predicted water levels.
- When run for transient simulations of the wet and dry season, the steady-state model initially underpredicted seasonal fluctuations in some of the bedrock observation wells. Therefore, for the calibration to seasonal fluctuations, recharge rates applied at the top of the model were adjusted for both dry and wet season over the entire model domain without altering total annual recharge that the model was calibrated to. Recharge occurring during the wet season was increased from 70% up to approximately 80% of total annual recharge and recharge during the dry season was decreased from 30% to approximately 20% of total annual recharge. This change improved the match between observed and predicted water level fluctuations in the observation wells.
- The conductance in the creeks in the Project Area was reduced by up to 1.5 orders of magnitude lower than hydraulic conductivity of surrounding material to improve calibration to observed water levels in the vicinity of the creeks and baseflow measured in Craig Creek, Nanoose Creek and Bonell Creek; this is consistent with deposition of finer-grained materials during low-flow periods.

Table 15: Calibrated Groundwater Model Parameters

Unit	Depth (mbgs)	Hydraulic Conductivity (m/s)	Specific Storage (1/m)	Specific Yield[1]
Surficial Till	-	1x10^{-6}	1x10^{-4}	0.2
Till/Clay (Aquitard)	-	3x10^{-7}	1x10^{-4}	0.1
Unconfined Sand and Gravel: Salish Sediments (Aq. 221)	-	2x10^{-3}	5x10^{-5}	0.2
Confined Sand and Gravel: Quadra Sand (Aq. 219)	-	5x10^{-5}	5x10^{-5}	0.2
Confined Sand and Gravel: Muir Point Formation (Aq. 1098)	-	3x10^{-5}	5x10^{-5}	0.2
Confined Sand and Gravel: Quadra Sand (Aq. 215)	-	2x10^{-5}	5x10^{-5}	0.2
Sedimentary/Igneous Intrusive Bedrock: Fourth Lake/Mount Gabbro (Aq. 210)	0-50	5x10^{-7}	1x10^{-5}	3x10^{-5}
	50-600	3x10^{-7}	1x10^{-5}	
	Below 600	1x10^{-8}	1x10^{-6}	

Unit	Depth (mbgs)	Hydraulic Conductivity (m/s)	Specific Storage (1/m)	Specific Yield[1]
Volcanic Bedrock: Vancouver Group (Aq. 213)	0-50	5x10^{-7}	1x10^{-5}	3x10^{-5}
	50-600	3x10^{-7}	1x10^{-5}	
	Below 600	1x10^{-8}	1x10^{-6}	
Sedimentary Bedrock: Nanaimo Group (Aq. 214)	0-50	5x10^{-7}	1x10^{-5}	3x10^{-5}
	50-600	3x10^{-7}		
Sedimentary/Igneous Intrusive Bedrock: Benson Formation (Aq. 218)	0-50	5x10^{-7}	1x10^{-5}	3x10^{-5}
	50-600	7x10^{-8}		

Notes:

1. unitless parameter

5.5.2.1 Measured Versus Predicted Hydraulic Head

Figure 23 presents the hydrogeological conditions that were predicted by the calibrated model for the average annual conditions and a comparison of measured versus predicted hydraulic heads for the average annual conditions at the wells with available water level data, along with a 1:1 reference line for comparison (points which fall on this 1:1 line would indicate that the predicted hydraulic head matches the measured hydraulic head).

Overall, the graph on Figure 23 shows that, for average annual conditions, the model can reproduce the observed regional hydraulic gradient in the Project Area. The mean error between measured and predicted hydraulic head was approximately 4.9 m. This indicates that model predicted hydraulic heads were on average slightly higher than measured data (by approximately 4.9 m); however, this is a mean value over the model domain. Relatively greater uncertainty was observed in the upper elevation areas of the bedrock units where there is less information. The normalized root-mean-square (RMS) error, which considers the scale of head variation across the model domain, was less than 5% which is typically considered representative of a reasonable calibration.

As presented on Figure 23, predicted hydraulic heads by the calibrated model are consistent with a regional water table that is generally a subdued reflection of topography with groundwater divides generally corresponding to surface water divides. The majority of the regional groundwater discharge is predicted to be ultimately directed to the Salish Sea.

Table 16 summarizes a comparison of average seasonal fluctuations (between dry and wet season) of hydraulic heads measured in the PGOWN monitoring wells and those predicted by the model at these locations. In the majority of the PGOWN monitoring wells, the model predictions are relatively close to the range of seasonal fluctuations observed in these wells. Fluctuation of water levels in the unconsolidated aquifers (215 and 219) is well reproduced in the model. However, predicted seasonal fluctuations in Observation Well 395 in Aquifer 219 are smaller compared to the observed range; this well is located in the vicinity of the Englishman River and the water level might be locally influenced by this boundary.

Seasonal fluctuations in bedrock Aquifers 213 and 218 were more difficult to match, as the influence of changes in recharge from precipitation on water levels can be affected by the location of the observation wells and local conditions that are difficult to reproduce in a regional-scale model. Observation well 340, which is completed in Aquifer 213, is in an area of localized higher elevation compared to the surrounding area. Water levels are expected to fluctuate more in response to changes in recharge at this location relative to the surrounding aquifer.

Observation Well 394, which is installed in bedrock Aquifer 218, is located at a topographic high in the Nanoose Peninsula and the water level is expected to be influenced by precipitation and the model overpredicts the fluctuations at this location. However, this is considered conservative for the purpose of the Phase 3 water balance analysis.

Table 16: Model Predicted and Measured Average Seasonal Fluctuations in Available Observation Wells

Well ID	Well Type	Lithology	Aquifer	Observed Seasonal Head Range (m)[1]	Predicted Seasonal Head Range (m)[2]
OBS Well 340	PGOWN Monitoring Well	bedrock	213	0.6-2.5	0.4
OBS Well 232	PGOWN Monitoring Well	overburden	215	1.5-3	2.3
OBS Well 394	PGOWN Monitoring Well	bedrock	218	1.2-2.5	5.8
OBS Well 395	PGOWN Monitoring Well	overburden	219	2.5-3	0.5
OBS Well 393	PGOWN Monitoring Well	overburden	219	0.1-0.3	0.5
OBS Well 396	PGOWN Monitoring Well	overburden	219	0.8-2	1.0

Notes:

1. Observed at the well location
2. Predicted over the area of the aquifer where the observation well is located

5.5.2.2 Measured Versus Predicted Baseflow

Creek flow data from the three monitored watercourses in the Project Area (Craig Creek, Nanoose Creek and Bonell Creek, see Section 3.2.2) was also assessed during calibration. Average creek flows calculated from automated or manual measurements during the summer months (July-August) in 2018 and 2017 were used as targets for calibration. Measured creek flows and calibration creek flows are shown in Table 17, below. The model predicts average baseflow in the Craig Creek well (within 10% of measured value). Based on the data review in Section 3.2.2, discharge data collected at the Craig Creek hydrometric station are considered reliable.

Calibration values for Nanoose Creek deviated from measured averages, but were not considered unreasonable, since for this watercourse, measurements were sparse and not continuous (once a month), and creek flow data could be highly variable (Table 4 and Appendix A). Predicted baseflow in Bonell Creek is higher than measured average but within the range of measurements over the July-August period. Based on available information, Bonell Creek's watershed has a greater extent compared to the other two creeks; no information on the status of the creek at higher elevation and connection to groundwater was available at the time of the study. Baseflow model predictions are considered conservative for the purpose of the study as it is assumed that more water is discharged from the aquifers to the creeks. However, further characterization of the creeks and hydrologic studies are required to refine the understanding of the surface water/groundwater interaction in the Project Area.

Table 17: Comparison Between Predicted and Observed Baseflow

Watercourse	Creek Flows (m^3/d)			
	Minimum	Average	Maximum	Calibrated Model Average
Craig Creek	490	**740**	1200	**820**
Nanoose Creek	240	**540**	5030	**1790**
Bonell Creek	<10	**710**	5940	**1590**

Overall, the model is considered to be reasonably well calibrated to observed conditions considering the degree of uncertainty in the hydraulic head and baseflow data set. Therefore, the calibrated model is considered capable of predicting the water balance for individual aquifers in the Project Area at a regional scale.

5.6 Limited Sensitivity Analysis

The results from the calibrated model presented in Section 5.5.2 are considered to provide representative estimates of current groundwater conditions in the Project Area. However, as input parameters to the model are subject to some uncertainty, the actual current groundwater conditions (groundwater levels and flow) might differ from what was predicted with the model. Following model calibration, model uncertainty associated with the hydrogeological boundaries and parameters was assessed with a limited sensitivity analysis. During model calibration, the estimated hydraulic conductivity of the bedrock formations and the degree of hydraulic connection of the creeks with groundwater within the Project Area were considered to have the highest degree of uncertainty, primarily reflecting a lack of information.

The steady state model of annual average conditions was then run for the following scenarios as part of the sensitivity analysis:

- upper bound bedrock: hydraulic conductivity of all bedrock units increased by a factor of 3
- lower bound bedrock: hydraulic conductivity of all bedrock units decreased by a factor of 3
- creeks fully connected: creeks in the Project Area were considered to be in strong hydraulic connection with groundwater (i.e., no restriction for groundwater to flow to the creeks)

The upper and lower bound range for hydraulic conductivity of the bedrock units is considered reasonable based on the available data (Table 10).

Results of the limited sensitivity analysis are summarized in Table 18 below. These results indicate that the predicted current groundwater conditions (hydraulic heads and flow) are sensitive to hydraulic conductivity of the bedrock units and hydraulic connection between waterbodies and groundwater represented in the model. As expected, predicted baseflow to the creeks is very sensitive to both hydraulic conductivity of the bedrock and hydraulic connection to groundwater. On average, groundwater levels in the groundwater wells used during calibration could be approximately 28% higher or 16% lower than what was predicted with the calibrated model as result of the assigned hydraulic conductivity of the bedrock. The average water level change was calculated using the observation wells that were used for model calibration.

Table 18: Results of Limited Sensitivity Analysis

Watercourse	**Baseflow (m^3/day)**			
	Calibrated Model	**Upper Bound K[1]**	**Lower Bound K[1]**	**Creeks Fully Connected[2]**
Craig Creek	740	200	1100	300
Nanoose Creek	540	350	5470	4020
Bonell Creek	710	170	4450	3870
	Average Water level Change Over the Model Domain (%)			
		Upper Bound K[1]	**Lower Bound K[1]**	**Creeks Fully Connected**
	-	28%	-16%	14%

Notes:

1. K = hydraulic conductivity (m/s)
2. No restriction to flow from groundwater to creeks

6.0 WATER BUDGET ANALYSIS

6.1 Scope of Water Budget Analysis

The preliminary water budgets that were prepared in Phase 1 of the Water Budget Project provided a first step towards understanding groundwater and surface water conditions in the RDN's water regions. Using a simple accounting approach, which was appropriate for the information available and the scope for Phase 1, the amounts of water entering and exiting aquifers and watershed were estimated to identify systems that were considered to be under "stress" (i.e., systems where water use was high relative to water availability); however, as WRI (2013) noted, these were conceptual assessments to provide a relative comparison between systems. As discussed in Section 1.1, the results from Phase 1 were used to identify areas that were considered high priority for monitoring further assessment to inform land use decisions and support sustainable management of water resources.

For the current Phase 3 project, water budget analysis was conducted with the calibrated numerical model. The resulting water budgets, which are presented for individual aquifers, enabled geospatial analysis within the Project Area that reflects the hydraulic relationships between aquifer units that are dependent upon on the extents and properties of the aquifer and aquitard units. For example, a decrease in recharge affected the overall aquifer system, reducing groundwater levels not only in shallow aquifers but also those in underlying aquifer units.

Using the numerical model, water budget analyses were conducted to assess the sustainability of current and future groundwater withdrawals. The calibrated hydrogeological model was used to conduct the water budget assessment for the aquifers identified within the Project Area. As discussed in Section 3.2.3, in the water budget analysis the volumes of the bedrock aquifers were estimated based on the refined aquifer delineation in the updated Conceptual Model and not from the extent of the bedrock formations or groups.

The water budget analysis estimated water quantity input to, and output from, the aquifers within the Project Area and the resulting groundwater levels within the respective aquifers. Transient simulations were conducted to estimate the water budget for current conditions and long-term future scenarios for both the wet and the dry season; model predictions obtained with the transient simulations are considered representative of the end of the wet season and the end of the dry season.

6.1.1 Current Conditions

The calibrated steady-state and transient model results were used to conduct a water budget analysis to assess current water supply and demand for the identified aquifers in the project Area; herein referred to as the "Base Case". The pumping schedule and water consumption rates simulated in this scenario were based on the current conditions described in Section 3.2.5.

6.1.2 Future Scenarios

The calibrated model was used to predict groundwater conditions under long-term conditions to the year 2050, in line with the RDN's planning horizon. In the long-term, the Englishman River Water Service (ERWS) will represent the main source of water supply for Electoral Area E and it will be supplemented with three main production wells and seven back-up production wells. Pumping conditions for the future scenarios were based on estimated well capacity as presented in a long-term water planning document for the RDN (Kerr Wood Leidal; KWL 2014) and in discussion with the RDN. As advised by the RDN, it was assumed that three primary production wells will operate at full capacity during the dry season and at a reduced rate in the wet season, based on the current pumping schedules. The production wells that are operated by other providers were assumed to be operated in the future at the current rates. Table 19 presents a list of production wells and their pumping schedules, as implemented in the model for both the Base Case and future scenarios.

Table 19: Long-Term Production Rates Implemented in the Model for the Base Case and Future Scenarios

Well	Well Tag No.	Provider	Aquifer	Long-Term Production Rates (m^3/day)	
				Dry season	Wet Season
Regional District of Nanaimo					
FW Well No. 1	75320	RDN	1098	346	310
FW Well No. 3	75322	RDN	1098	190	169
WB Well No. 4	NA	RDN	1098	743	663
			Sub-Total	1279	1142
Snaw-Naw-As First Nation					
Snaw-Naw-As FN IR #0	96194	Snaw-Naw-As First Nation	215	83	86
District of Lantzville					
Well 4	108680	District of Lantzville	215	254	153
Well 6	52042	District of Lantzville	215	250	158
Well 9	108678	District of Lantzville	215	120	74
Well 12	96583	District of Lantzville	215	199	112
			Sub-Total	823	497
Total (m^3/day)				2185	1725

The transient model was first run under the Base Case hydrogeological conditions (calibrated model with future pumping schedule as described in Table 19) and then under each of the three future scenarios described below to predict conditions during the wet season and the dry season. Each scenario provides an independent assessment of how groundwater conditions could potentially change compared to the Base Case (e.g., under the same pumping schedule of Table 19).

6.1.2.1 Scenario 1 – Potential Climate Change

The study of the potential for, and effect of, climate change is being undertaken by many agencies and institutions and is on-going. Despite studies of climate change being “in-progress”, it is generally accepted that as climate changes, there are, and will be, direct effects to watersheds (Pike et al. 2010). By mid-century, British Columbia is expected to become warmer and wetter, with higher annual average temperatures and precipitation. On Vancouver Island, it is expected that the summers will be longer, hotter and drier and precipitation events will be more intense during the winter months. To assess potential climate change scenarios for the Nanaimo region, Golder obtained data online from Pacific Climate Impacts Consortium (PCIC) The data were drawn from a set of Global Climate Model projections that were based on results from a number of different Global Climate Models, each considering a high and low greenhouse gas emissions scenario; both the mid-point value and the range in values are reported. Table 20, below, provides a summary of changes in mean temperature, precipitation and snowfall relative to a baseline historical period (1961 – 1990) projected to the 2020s, 2050s, and 2080s for the Nanaimo region.

Table 20: Summary of Projected Climate Change for the Nanaimo Region

Climate Variable	Season	Median	Range (10th to 90th percentile)
Projected changes to the 2020s (2010-2039)			
Mean Temperature (°C)	Annual	+0.9 C	+0.4 C to +1.3 C
Precipitation (%)	Annual	+3%	-2% to +7%
	Summer	-8%	-19% to +9%
	Winter	+2%	-3% to +9%
Snowfall (%)	Winter	-24%	-46% to -5%
	Spring	-31%	-62% to -6%
Projected changes to the 2050s (2040-2069)			
Mean Temperature (°C)	Annual	+1.6 C	+1 C to +2.4 C
Precipitation (%)	Annual	+6%	-2% to +12%
	Summer	-18%	-28% to +1%
	Winter	+5%	-4% to +15%
Snowfall (%)	Winter	-39%	-59% to -21%
	Spring	-54%	-72% to -18%
Projected changes to the 2080s (2070-2099)			
Mean Temperature (°C)	Annual	+2.6 C	+1.4 C to +3.8 C
Precipitation (%)	Annual	+8%	-0% to 17%
	Summer	-18%	-38% to +1%
	Winter	+10%	-1% to +22%
Snowfall (%)	Winter	-54%	-77% to -27%
	Spring	-73%	-87% to -22%

The data presented in Table 20 illustrate a range in predicted effects to climate in the Nanaimo region in the future, depending upon which Global Climate Model projection is applied; however, all of the projected changes for the 2020s, 2050s, and 2080s using the various models predict that, to some degree, the percentage of annual rain will increase and the percentage of snowfall will decrease. For the purposes of the Phase 3 water budget analysis, median values for projected precipitation were considered. Based on a review of historical precipitation data over the last 10 years in the Project Area (2008-2018, Table 3) and the projected reduction in precipitation in the summer for the 2050s period, the dry season groundwater recharge rates across the Project Area were conservatively decreased by the median predicted reduction in precipitation (i.e., 18%, as presented in Table 20) to simulate drier conditions in the summer. The length of the dry season was also increased to a period of 6 months from a period of 5 months that is currently observed. Although the climate models predict a median increase in precipitation during the winter months, precipitation is anticipated to occur in more intense storm events (Allen 2019). As a conservative assumption for the water balance analysis, it was assumed that the rate of groundwater recharge (i.e., infiltration) would be controlled by the aquifer properties and that additional precipitation during storm events would not result in greater groundwater recharge but rather greater overland flow and surface water discharge to the ocean.

Hotter and drier summers, combined with a longer growing season, could potentially result in increased groundwater extraction to meet higher irrigation demands in the future. Future changes in annual crop water requirements above a reference period (1981-2010) were estimated by Gilchrist (2017) for two climate change scenarios (stabilization scenario and high-emission scenario[1]). The results of the study predicted that, relative to current water use, for the Nanoose Bay area, approximately 40% to 50% more water will be required in the 2050s to maintain adequate soil moisture for crops in a warming climate. To simulate increased groundwater extraction resulting from climate change, a 40% increase in water consumption was applied to the numerical model for properties that are identified for agricultural or rural land use.

6.1.2.2 Scenario 2 – Increased Water Demand

For properties outside the municipal service area, future increased water demand was predicted based on application of the estimated residential groundwater use of 607 L/day/unit , as presented in Section 3.2.5.2, to all properties that will be developed at full build-out, as provided by the RDN (APPENDIX D) and summarized in Table 21 (Full Build-Out). Water use for the non-serviced areas was increased in proportion with planned development (i.e., anticipated dwellings), with groundwater extraction applied to lots that are currently unoccupied but zoned for development. Groundwater use was applied to the shallowest aquifer identified in the area of future development. As discussed in Section 6.1.2, water use within the RDN service area was accounted for with the production rates presented in Table 19 and the assumption that additional water was supplied from the ERW system.

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[1] RCP 4.5 and RCP 8.5 climate change scenarios developed by the Intergovernmental Panel in Climate Change

Table 21: Summary of Full Build-Out Information from RDN

Subdivision Lots/ Dwelling Units	Current			Full Build-Out		
	Electoral Area E	Outside RDN Water Service Area	Inside RDN Water Service Areas	Electoral Area E	Outside RDN Water Service Area	Inside RDN Water Service Areas
Number of Lots	3646	1043	2603	6476	1326	5150
Number of Dwelling Units	3370	872	2498	8766	1709	7057 (5303 max by OCP)[1]

Notes:

1. Note that the maximum dwelling count specified in the Official Community Plan (OCP) overrides potential dwelling units (by Zoning) within the Growth Containment Boundaries and Neighbourhood Plans area

Based on discussions with the RDN, the estimate of increased future water demand only considered increased residential development, as no information was available regarding potential future agricultural development in the Project Area.

6.1.2.3 Scenario 3 – Changes in Land Cover

The effect of potential changes to land cover under future development scenarios (i.e., potential increases in impervious surfaces) was also predicted. The RDN provided spatial information on maximum allowed parcel coverage with impervious surface for Electoral Area E in GIS format (updated to December 2019). For parcels where new development is planned and where a change in land is expected (i.e., conversion from natural to impervious surface), the groundwater recharge rate was reduced by the percentage of maximum coverage for the parcel. Figure 24 presents the maximum allowed parcel coverage with impervious surface for Electoral Area E as provided by RDN.

As a conservative approach, the effects of enhanced recharge that could potentially be realized through improved stormwater management, such as stormwater infiltration and injection, were not considered for the simulation of this scenario.

6.1.2.4 Combined Scenarios

At the request of RDN, two additional scenarios were considered to evaluate the combined effects of different future climate or future development. The following two scenarios were developed:

- Scenario 4: effects of both climate change and changes in land cover on groundwater conditions in 2050 in the Project Area were estimated (combined Scenario 1 and 3)
- Scenario 5: combined effects of all three future conditions (climate change, future build-out and changes in land cover) on 2050 groundwater conditions in the Project Area were assessed

6.2 Results

6.2.1 Current Conditions

Water budgets for each of the aquifers within the Project Area under current conditions are presented in Tables 1D and 2D (APPENDIX E) and groundwater contours for the unconsolidated aquifers and bedrock aquifers are presented on Figures 25 and 26 respectively.

As presented in Tables 1D and 2D, the water budgets have been summarized with respect to major sources of groundwater inflow and outflow to illustrate the relative contribution of groundwater recharge, surface water and anthropogenic water use to groundwater flow within the aquifers.

Aquifer 221 is the only shallow, unconfined aquifer within the Project Area. This aquifer is hydraulically connected to the Englishman River. The Englishman River also represents the model boundary in this area and therefore Aquifer 221 is only partially represented in the model. The river and recharge from the ground surface (precipitation and anthropogenic sources) are the dominant sources of water. Outflow from Aquifer 221 is mostly to the Salish Sea. Under current conditions, water consumption from RDN and private users constitutes 2% of aquifer outflow.

Aquifer 219 and Aquifer 1098 extend approximately over the same area, they are both confined, and they are separated by an aquitard. Aquifer 219 is a large, intermediate-depth confined aquifer. The main source and sink for water in this aquifer is flow to and from aquitards. Under current conditions, pumping from RDN production wells and water users constitutes approximately 8% of total outflow. Aquifer 1098 is located at greater depth than Aquifer 219. Under current conditions, pumping from RDN production wells constitutes approximately 7% of total outflow. Groundwater flow direction in the area of these two aquifers is generally toward the Salish Sea and Nanoose Peninsula. The areas along the coast in the area of Nanoose Bay and north of the peninsula, where the topography is mostly flat and the hydraulic gradient is low, could potentially be at risk of saltwater intrusion.

Aquifer 215 is a partially confined overburden aquifer that extends from the eastern edge of Electoral Area E through Lantzville. The portion of the aquifer east of Lantzville was not included in the model domain, as a watershed divide cuts through its extent. Infiltration from upgradient areas represents the dominant source of water to Aquifer 215. Recharge from precipitation is also a small source of water in the areas where the surficial till is not present. Knarston Creek and Bloods Creek flow through the area of Aquifer 215; however, they receive a small groundwater contribution from the aquifer as outflow is mostly to the underlying aquitard and bedrock and ultimately to the Salish Sea. Under current conditions, pumping from water system production wells (Lantzville and SNAFN) and private water users constitutes approximately 9% of total outflow.

Groundwater in bedrock Aquifers 214, 210, and 213 is primarily recharged from upslope areas at higher elevations and at lower elevations from overlying overburden aquifer units through aquitards. Under current conditions, one RDN production well is pumping from Aquifer 214 at relatively small rates (<1% of outflow). Groundwater in Aquifer 218 is recharged by infiltration of precipitation through the relatively thin glaciofluvial and glacial marine deposits (approximately 40% of flow into the aquifer). The rest of the recharge comes from adjacent units (Aquifers 214, 219, and 1098). Coastal areas of aquifers 213, 214 where hydraulic gradient is relatively low (Nanoose Bay) could potentially be subject to saltwater intrusion, However, groundwater flow within bedrock aquifers is highly variable and occurs along discrete fractures and features. As a result, saltwater intrusion can extend into upland areas as well due to changes in groundwater recharge and/or extraction. Detailed assessment would be required to assess the potential for saltwater intrusion in specific areas.

The three monitored creeks received recharge from groundwater mostly at lower elevations, under the assumption that these waterbodies were considered to be intermittent. However, as mentioned for model calibration (Section 5.5.2.2) further characterization of the creeks and hydrologic studies are required to refine the understanding of the surface water/groundwater interaction in the Project Area.

6.2.2 Future Scenarios

The results of the water budget analysis for the future scenarios are presented in Tables 3D, 4D and 5D (APPENDIX E). In addition to a summary of the major sources of groundwater inflow and outflow, and the total fluid volume of each aquifer, average changes in groundwater levels that are predicted for each of the future scenarios are also presented in Tables 3D and 4D. Each of the future scenarios are discussed in more detail in the following sections. Table 5D summarizes the predicted changes in baseflow from Base Case in the three creeks that were used for model calibration for the three simulated scenarios.

The total fluid volume of the aquifer represents the volume of water stored in the aquifer based on the storage properties assigned in the model (see Table 15). This parameter is directly related to water levels if the aquifer is unconfined or partially confined (i.e., a decrease in fluid volume would correspond to a decrease in water level within the aquifer). For confined aquifers, a decrease in water levels might occur in response to a change in hydrometric pressure without a decrease in fluid volume, unless the water level drops below the bottom of the confining unit.

The water budget analysis of future scenarios is a regional-scale assessment that is intended to identify broader patterns. The results are not considered representative of local conditions for individual wells or properties. Site-specific investigations would be required to assess conditions at the local scale.

6.2.2.1 Base Case

In the Base Case scenario, the calibrated model was updated with the future pumping schedule described in Table 19 to simulate long-term groundwater conditions and to provide a basis to assess changes to groundwater levels and flow separately for each of the three future scenarios.

In the long-term water plan for RDN’s Nanoose Bay Peninsula Water Service Area (NBPWAS), three primary RDN wells FW Well No. 1, FW Well No. 3, and WB Well No. 4, will pump from Aquifer 1098 only and operation of the other RDN production wells will be discontinued. The three RDN production wells will increase pumping from 8% up to 10% of total flow trough Aquifer 1098. The change to the long-term pumping schedule for the RDN production wells is predicted to slightly affect flow in the neighbouring aquifers 221, 219, and 213. For instance, increased pumping in Aquifer 1098 is predicted to slightly increase flow through the aquitard separating it from Aquifer 219.

6.2.2.2 Scenario 1 – Potential Climate Change

Predicted declines in water level as result of climate change for overburden and bedrock aquifers are presented on Figures 27 and 28, respectively.

As discussed in Section 6.1.2.1, for this scenario the dry season groundwater recharge rates across the Project Area were conservatively decreased by the median predicted reduction in precipitation (i.e., 18%, as presented in Table 20) to simulate drier conditions in the summer. The length of the dry season was also increased to a period of 6 months from a period of 5 months that is currently observed. To simulate increased groundwater extraction resulting from climate change during dry season, a 40% increase in water consumption was applied to the numerical model for properties that are identified for agricultural or rural land use.

Under Scenario 1, the fluid aquifer volume for Aquifer 215 is predicted to decrease approximately by 6% from the Base Case scenario as a result of changes in climate and the water level could potentially decline on average by approximately 3 m by the end of the dry season. Aquifer 215, which is partially confined and shallow, receives water from recharge through the confining shallow till.

The fluid aquifer volume for Aquifer 219 is predicted to decrease as well by approximately by 3% from the Base Case scenario and the water level could potentially decline on average by approximately 2 m in both dry and wet season. Although 219 is a confined aquifer, it is relatively shallow and recharge through the confining shallow till as a primary source of water. In addition, Aquifer 219 has the highest concentration of private groundwater users and demand for irrigation during the dry season increases water withdrawal by approximately 30% from the Base Case. The portion of Aquifer 219 that is close to the coast along Nanoose Bay and north of Nanoose Peninsula is characterized by relatively flat hydraulic gradients. The decrease in water levels predicted for Scenario 1 could increase the risk of potential saltwater intrusion in these areas.

No significant decrease in fluid volume is predicted for deep, confined Aquifer 1098 for Scenario 1; however, water level declines in Aquifer 1098 are predicted to be similar to those predicted for Aquifer 219 as the two aquifers are interconnected through aquitard deposits.

No significant changes to the water budget or water levels for Aquifer 221 are predicted for Scenario 1 compared to the Base Case. However, changes in water level in the Englishman River due to climate change and surface water withdrawal were not considered in the model simulations since no information was currently available. It is anticipated that the dam in the headwaters of the Englishman River will capture sufficient water during the wet season to be released over the duration of the dry season and thereby regulate flow in the river and provide a consistent water level in the Englishman River during the dry season. Potential effects of climate change on the water level in the river reservoir and consequently in the river were not part of the scope of this study. If flows were to vary from this assumption, changes could significantly influence water levels in Aquifer 221.

The fluid volumes of Aquifers 210 and 213, which are primarily recharged from upslope areas, are predicted to potentially reduce by approximately 0.1 to 0.2% and 1%, respectively, from Base Case values as a result of climate change. Water levels in Aquifer 210 are predicted to decline on average by approximately 3 m during both the dry and wet seasons whereas the average water level decline for Aquifer 213 is predicted to be 5 m by the end of the wet season and 9 m by the end of the dry season. By the end of the dry season, the water levels in the higher elevation area of these aquifers are predicted to decrease by up to 5 m in Aquifer 210 and 18 m in Aquifer 213.

Aquifer 214 receives recharge from upland areas including adjacent bedrock Aquifer 210 and overlying unconsolidated Aquifers 219 and 1098. The fluid volume in Aquifer 214 is predicted to not change significantly for the climate change scenario, but the water levels in the aquifer are predicted to decline on average approximately 2 m during both the dry and wet seasons, and up to 3 m in upland areas by the end of the dry season.

Aquifer 218, which is located on the Nanoose Peninsula, receives recharge primarily from adjacent aquifers and, during the wet season, precipitation. The fluid volume in Aquifer 218 is predicted to decrease by approximately 1% as a result of climate change and flow through the aquifer could decrease by approximately 15%. Water levels in the aquifer are predicted to decline on average by 2 m during the wet season and 5 m during the dry season and, by the end of the dry season, groundwater levels are predicted to decline by up to 10 m in the central portion of Aquifer 218.

The reduction in precipitation during the dry season due to climate change is predicted to have a significant effect on flow within all three creeks. In addition to a decrease in overland flow of surface water within the watersheds, Scenario 1 predicts a baseflow reduction of approximately 40% in Craig Creek and 30% in Nanoose Creek and Bonell Creek at the end of the dry season. Additional hydrologic and climate data would be required to refine these estimates to baseflow.

In summary, the results of the water budget analyses for Scenario 1 predicted that the reduction in groundwater recharge and the associated increased demand for irrigation water during a longer dry season could potentially affect flow and water levels in the aquifers within the Project Area, particularly flow within shallow Aquifer 215 and water levels in the upper elevation portion of bedrock Aquifer 213 and the central portion of bedrock Aquifer 218. It is anticipated that baseflow in creeks will also decline during the dry season as a result of less surface water runoff and decreased flow through the aquifers.

6.2.2.3 Scenario 2 – Increased Water Demand

No significant changes in flow are predicted as a result of increased development in Scenario 2 relative to the Base Case scenario. Water levels within overburden Aquifers 221 and 215 are predicted not to change and minor declines of less than 1 m are predicted for overburden Aquifers 219 and 1098, where the majority of the future development outside of the RDN water service area is planned. Water level declines of negligible to less than 1 m are also predicted for the bedrock aquifers.

Baseflow in Craig Creek is predicted to decline by approximately 10% for both dry and wet season in Scenario 2 compared to Base Case conditions. Baseflows in Nanoose Creek and Bonell Creek are predicted to be minimally affected by the increase in future water demand, as a small part of the planned new development at full build-out is located within the watersheds for these creeks.

The results of the Scenario 2 simulations suggest that the increased water demand associated with future development will have a relatively minor effect on water resources within the Project Area. These results reflect the distribution of development full build-out; most of the future development is planned for areas within the RDN's water service area and additional water supply will be sourced from the ERW system and not the underlying aquifers in the Nanoose area.

6.2.2.4 Scenario 3 – Changes in Land Cover

Predicted declines in water level resulting from an increase in impervious ground cover in areas previously undeveloped are presented on Figure 29 for overburden aquifers and Figure 30 for bedrock aquifers.

Changes in groundwater conditions (flow and water levels) for Scenario 3 are predicted to occur within the areas where undeveloped land is anticipated to be altered due to development. The water budget results for Scenario 3 predict that changes to water levels in overburden aquifers relative to Base Case conditions would occur in the areas of overburden Aquifer 219 and underlying Aquifer 1098. Although the fluid volumes of these aquifers are not predicted to change, the water levels within these confined aquifers are predicted to decline by approximately 2 m during both the wet and dry seasons.

The volumes of bedrock Aquifers 210, 213, and 214 are predicted to decrease by 0.1% or less and the water levels are predicted to not change in Aquifer 213 and decrease by up to 2 m in Aquifers 210 and 214 by the end of the dry season. However, the fluid volume of Aquifer 218, which receives a significant portion of recharge from precipitation, is predicted to decrease by 2% in response to the simulated changes in land cover and water levels in the aquifer are predicted to decrease by and average of 10 m during both the wet and dry seasons, with declines of up to 15 m observed in the central portion of the aquifer. These results suggest that the water levels in Aquifer 218 are sensitive to changes in land cover which could reduce the amount of precipitation that infiltrates the ground and recharges the aquifer. Furthermore, as this is a coastal aquifer, the decline in water levels would lower hydraulic gradients across the aquifer and has the potential to increase the risk of saltwater intrusion along the coastline of the peninsula. However, the development along the coastline in the Nanoose Peninsula is largely serviced by the RDN NBPWAS and the Englishman River and, therefore, no additional pumping from Aquifer 218 is anticipated to occur in the future.

The Scenario 3 simulation may be conservative as it assumes that the increase in impermeable surfaces results in a loss of water from the aquifer system. Although surface water run-off from impermeable surfaces will be transported to the ocean via the stormwater system, some portion of surface water run-off from impermeable surfaces is anticipated to be transported to areas where it infiltrates into the ground.

Similar to Scenario 2, a 20% reduction in baseflow relative to Base Case conditions is predicted for Craig Creek at the end of the dry season; a smaller effect (approximately 7% reduction) to Nanoose Creek baseflow is predicted under Scenario 3 and a minimal change (2%) is predicted for baseflow to Bonell Creek at the end of the dry season.

6.2.2.5 Combined Scenarios

Based on the results of previous three scenarios, two additional simulations were conducted to evaluate the combined effects of different factors on groundwater conditions in the Project Area.

Scenario 4 – Climate Change and Changes in Land Cover

The first combined scenario (Scenario 4) simulates the effects of both climate change (Scenario 1) and increase in impervious ground cover in areas previously undeveloped (Scenario 3). The reduction in recharge caused by climate change during the dry season over the entire Project Area is combined with a year-round reduction in recharge (during both dry and wet season) in areas of potential development.

Predicted declines in water level for Scenario 4 are presented on Figure 31 for overburden aquifers and Figure 32 for bedrock aquifers. As expected, the concurrent reduction in recharge due to the two factors considered in this scenario could further decrease the water levels, particularly in aquifers where undeveloped land is anticipated to be altered due to development. Similar to Scenario 1 (climate change), the water budget results for Scenario 4 predict that declines in water levels relative to Base Case conditions would occur in areas of the overburden aquifers except Aquifer 221, which is strongly controlled by regulated flow in the Englishman River. Water level effects in overburden aquifers are predicted to be greatest in the central portion of Aquifers 219 and 1098 with declines of 5 to 6 m over a broader area, compared to localized declines of 3 to 4 m and 1 to 2 m for individual Scenarios 1 and 3, respectively. Similar to Scenario 3, bedrock Aquifer 218, which receives a significant portion of recharge from precipitation, could potentially be significantly affected by these changes; water levels in the central portion of the aquifer are predicted to decline by up to 20 m for Scenario 4 compared to declines in the range of 10 m Scenario 1 and 16 m for Scenario 3.

The reduced recharge in Scenario 4 is predicted to increase the reduction in baseflow in the three monitored creeks. A 55% reduction in baseflow relative to Base Case conditions is predicted for Craig Creek at the end of the dry season and approximately 30% reductions to Nanoose Creek and Bonell Creek baseflow; values which are greater than the sums of the baseflow reductions predicted for Scenarios 1 and 3 for the respective creeks.

Scenario 5 – Climate Change, Changes in Land Cover and Increased Water Demand

The second combined scenario (Scenario 5) combines the first three simulated scenarios (Scenario 1, 2, and 3). The reduction in recharge caused by the two factors in Scenario 4 is combined with increased water demand associated with future development, as specified in Scenario 2.

Predicted declines in water level for Scenario 5 are presented on Figure 33 for overburden aquifers and Figure 34 for bedrock aquifers. Based on these results, no significant changes in water levels in the overburden and bedrock aquifers are predicted relative to those predicted for Scenario 4, consistent with the conclusion that the additional groundwater withdrawals for water supply in the future represent a relatively small change to groundwater conditions.

Baseflow in Craig Creek is predicted to further decline (by approximately 5%) for both dry and wet season in Scenario 5 compared to flow predicted for Scenario 4. Baseflows in Nanoose Creek and Bonell Creek are predicted to be minimally affected by the increase in future water demand compared to Scenario 4, as a small part of the planned new development at full build-out is located within the watersheds for these creeks.

7.0 DISCUSSION AND RECOMMENDATIONS

7.1 Development and Use of the Numerical Model

The numerical hydrogeologic model that was developed for Phase 3 of the Water Budget Project represents a compilation and interpretation of geological, hydrological, climate and groundwater use data from across the area of Nanoose Bay Electoral Area E. The model provides a technical basis to identify areas of potential water stress and inform water management. This Model should be considered a "working tool", which should be periodically refined as additional information becomes available.

The hydrogeological model is a regional-scale model capable of assessing average groundwater conditions over large areas. As such, it can be used as an effective planning tool in assessing long-term groundwater management strategies. The model is considered appropriate for estimating the water budgets for individual aquifers and capable of assessing regional effects on the water levels due to future changes such as changes in climate, projected population growth and proposed land-use changes. Without additional refinements to site-specific conditions, the present model is not suitable for local scale applications such as well field design and optimization.

7.2 Aquifer Water Budgets

The hydrogeological model was used to conduct water budget analyses for average and dry and wet conditions for the aquifers in the Project Area. The results of these analyses provide a basis for the RDN to identify and implement planning measures to manage water resources in the Nanoose area and support sustainable groundwater withdrawals. The analyses also provide the basis to understand how climate change and future development might affect groundwater conditions in the area.

The results of model predictions predict that climate change (Scenario 1) could have a significant effect on dry and wet season groundwater conditions within the Project Area compared to Base Case conditions. Comparison of predicted water levels for Scenario 1 to water levels predicted for the Base Case indicates that groundwater levels could decline on average by up to 3 m in the area of Aquifer 215 (Quadra Sand) and up to 9 m in the area of Aquifer 213 (Vancouver Group Volcanic Bedrock) at the end of the dry season. For Scenario 1, water levels in overburden aquifers 219 and 1098 could also potentially decrease by approximately 2-3 m compared to Base Case conditions. Baseflow in the creeks within the Project Area, particularly Craig Creek, is also predicted to decline during the summer months in the future during to the longer, hotter summers that are anticipated in the future.

Overall, the water budget analyses indicated that current and future groundwater withdrawals for water supply by municipal providers represent a small component of the overall flow within the aquifers. In addition, the analysis indicates that the simulated water demand at full build-out (Scenario 2) will not have a significant effect on the groundwater conditions in the Project Area.

The conversion of currently undeveloped land to new development and the resulting increased coverage with impervious surfaces (Scenario 3) is predicted to affect to groundwater conditions in the area of Aquifer 218 (Nanoose Peninsula). In this area, groundwater levels in Aquifer 218 could decline an average of up to 10 m from the predicted water levels in the Base Case as a result of reduced infiltration. In this scenario, a smaller decline (up to 2 m) is also predicted in the area of Aquifers 219, 1098 and 214. Future predictions of the effects from changes in land cover have not considered the effects of enhanced recharge through storm water management, such as stormwater infiltration and injection.

Predicted decline in water levels due to climate change (Scenario 1) or reduced infiltration (Scenario 3), portions of the aquifer 219 (Quadra Sand) and 218 (bedrock – Benson Formation) located close to the coast where hydraulic gradients are relatively flat could potentially be risk of saltwater intrusion.

It is recommended that the RDN consider the results of the water balance analyses to identify and target groundwater conservation and water management programs in areas that are predicted to be the most affected by climate change and changes to land cover. In particular, stormwater management programs can be developed and implemented to support groundwater recharge in the area of Nanoose Peninsula.

7.3 Additional Data Requirements and Model Refinement

Additional data were identified during the development of the numerical model that, if obtained, could assist with the refinement of the model calibration and ongoing assessment of the model predictions to reduce the uncertainty in the model predictions. Recommendations for additional data gathering are summarized below.

- Climate monitoring data: climate monitoring at the five climate monitoring stations currently active in the Project Area (see Table 2) should continue, in particular at the Nanoose Creek watershed station, recently installed in 2018. The data collected at these locations will provide information required to establish local 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 numerical modeling for the Project Area.
- Groundwater Levels: In addition of the existing PGOWN monitoring wells and the four RDN volunteer monitoring wells that were added in 2017 based on Golder's recommendations (Golder 2016), it is recommended that monitoring wells be installed at strategic locations to assess hydraulic heads within individual aquifers. These monitoring data would provide a means to assess the water levels that are predicted by the numerical model and allow for future refinement of the model, as necessary. At a minimum, additional monitoring wells are recommended for Aquifers 213, 218, and 219, where declines in hydraulic heads are predicted, together with other aquifers where significant future groundwater development is planned.
- Creeks and Rivers Baseflow: Similar to groundwater water levels, baseflow data for local water courses is limited, particularly over time. It is recommended that regular baseflow monitoring be continued on Craig Creek, Nanoose Creek and Bonell Creek. In addition to this, as proposed in the monitoring plan (Golder 2016), installation of new hydrometric stations in creeks located in the eastern portion of the Project Area is suggested as no flow information is currently available for this area. Information on the status of the higher reaches of the waterbodies and inferred connection with groundwater in the Project Area would allow to confirm model assumptions. This monitoring data would also provide a mean of assessing the reductions in baseflow predicted by the numerical model and allow for future refinement of the model, if necessary.
- Additional hydraulic testing in bedrock aquifers: during model calibration and sensitivity, hydraulic conductivity of bedrock units has been identified as parameter with high degree of uncertainty. Additional hydraulic testing (long-term pumping tests) would allow to refine estimates of hydraulic conductivity for these units/aquifers and reduce uncertainty in model predictions.

- Water Quality: While the focus of this project was 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 currently monitored, 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 effects 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 ENV Site Registrar. Further assessment would be required to identify specific objectives for additional water quality monitoring, including relevant water quality parameters, and associated monitoring locations.

8.0 CLOSURE

We trust the information contained in this report is sufficient for your present needs. Should you have any additional questions regarding the project, please do not hesitate to contact the undersigned.

Golder Associates Ltd.

Willis

Robyn Willis, BASc, EIT, GIT
Junior Geological Engineer

23 APRIL 2020

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9.0 REFERENCES

Aquarius WebPortal. 2019. http://aqrt.nrs.gov.bc.ca. Accessed August 2019.

BC Data Catalog. 2019. https://catalogue.data.gov.bc.ca/dataset. Accessed May 2019.

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

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

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

Benoit N, Russel HAJ. 2016. Nanoose Bay - Deep Bay Area, Nanaimo Lowland Groundwater Study Atlas, Regional District of Nanaimo, British Columbia. Geological Survey of Canada, Open File 7877.

Carmichael V. 2013. Compendium of re-evaluated pumping tests in the Regional District of Nanaimo, British Columbia. Ministry of Environment, Environmental Sustainability Division, February 2013.

District of Lantzville. 2019. Email Correspondence between RDN and the District on groundwater extraction from the municipal pumping wells, dated 25 November 2019.

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

Golder (Golder Associates Ltd.). 2016. Water Monitoring Plan for Nanoose (Electoral Area E), District of Nanaimo, BC. Golder Reference No. 1547004-004-R-Rev0. December 2015.

Golder (Golder Associates Ltd.). 2019. Hydrogeological Assessment for Parker Road Well, Regional District of Nanaimo, BC. Golder Reference No. 1896192-002-R-Rev0. March 2019.

GVRD (Greater Vancouver Regional District). 1999. Water, Regional Water Demand by Sector.

Government of Canada. 2019a. Hydrometric Station Data. Environment Canada Water Office available on-line at: https://wateroffice.ec.gc.ca/. Accessed September 2019.

Government of Canada. 2016b. Historical Climate Data. Available on-line at: http://climate.weather.gc.ca/. Accessed September 2019.

Groundwater Solutions Inc. 2015. 3D Conceptual Groundwater Model of Lantzville, British Columbia. Project #15-13, dated April 2015.

GSI (Groundwater Solutions Inc). 2019. Email Correspondence between RDN and GSI dated 21 October 2019.

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

McCabe GJ, Markstrom SL. 2007. A Monthly Water-Balance Model Driven by a Graphical User Interface. US Geological Survey Open-File Report 2007-1088.

KWL (Kerr Wood Leidal). 2014. Technical Memorandum - ERWS Water Intake, Treatment Plant and Supply Mains. Revision 1. June 2014.

PCIC (Pacific Climate Impacts Consortium). https://pacificclimate.org/analysis-tools/plan2adapt.

RDN (Regional District of Nanaimo). 2019. Personal correspondence. Ms. Julie Pisani, Drinking Water and Watershed Protection Program Coordinator. Accessed April-December 2019.

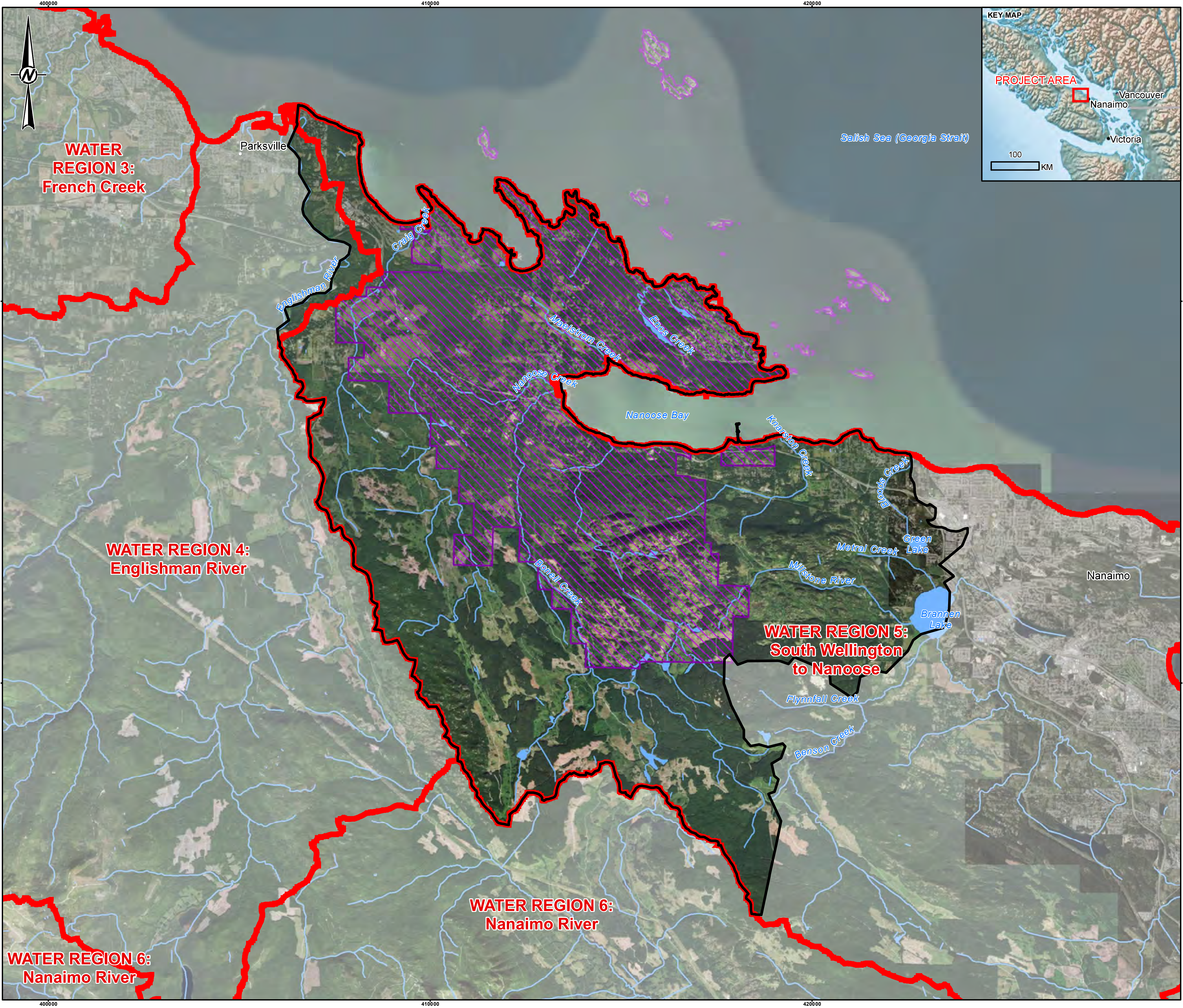
RDN (Regional District of Nanaimo). 2019. Correspondence and information exchange with Ms. Julie Pisani, Drinking Water and Watershed Protection Program Coordinator. May to December 2019.

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

Tchobanoglous G and Burton FL. 1991. Wastewater Engineering Treatment Disposal and Reuse. Third Edition. McGraw-Hill Inc. USA.

University of Victoria School Base Climate Network. 2019. http://www.victoriaweather.ca, http://www.nanaimoweather.ca. Accessed August 2019.

Van Der Gulik T, Neilsen D, Fretwell R, Tam S. 2013. Agricultural Water Demand Model, Report for the Regional District of Nanaimo. Ministry of Agriculture, May 2013.



LEGEND

▭ PROJECT AREA
🟥 RDN WATER REGION
▨ ELECTORAL AREA E
🟦 WATERBODY
— WATERCOURSE
◦ CITY / TOWN

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REFERENCE(S)

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CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SITE PLAN

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CB
REVIEWED	AP
APPROVED	MB

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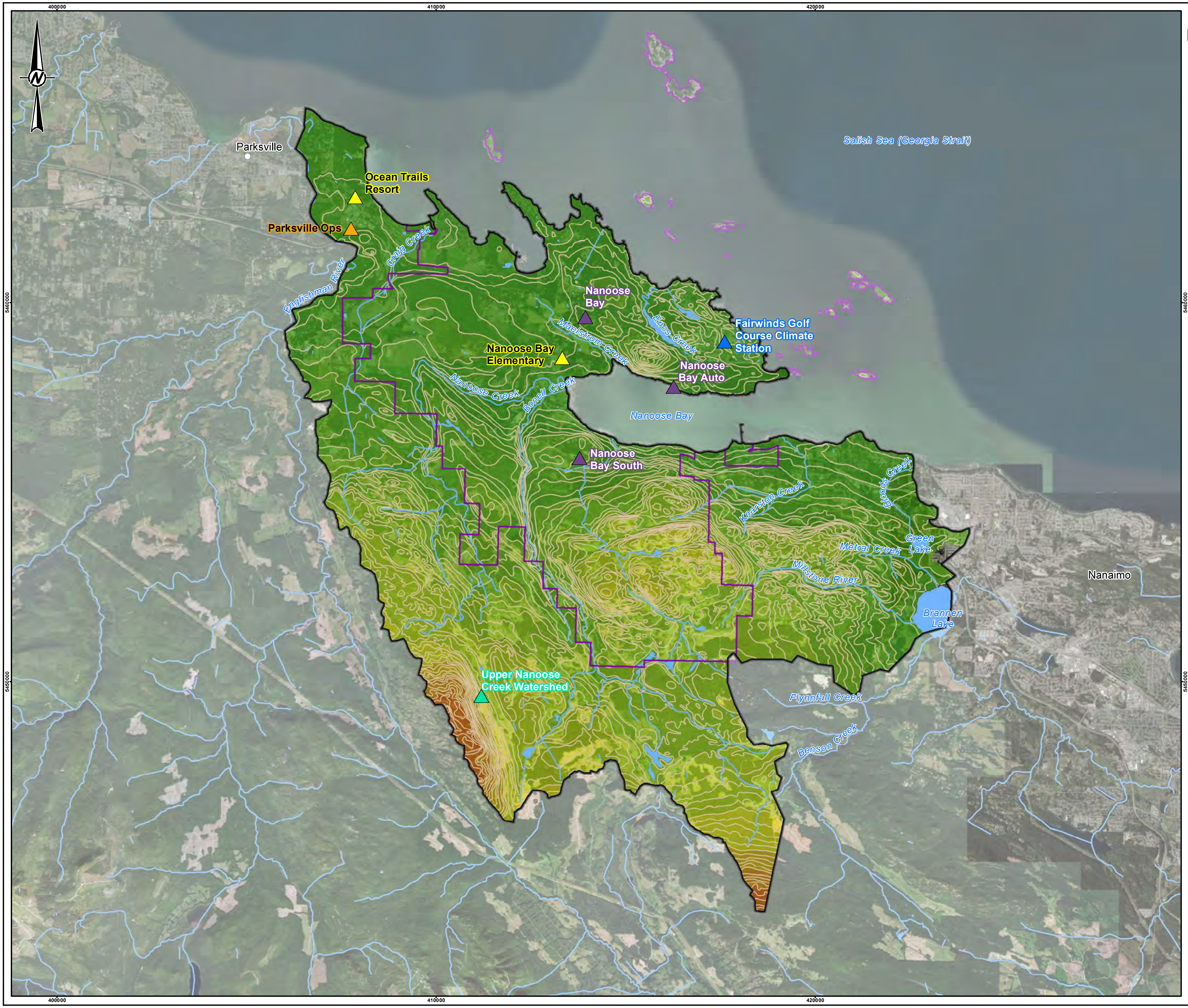

LEGEND

▭	PROJECT AREA
▭	ELECTORAL AREA E
🟦	WATERBODY
—	WATERCOURSE
○	CITY / TOWN

ACTIVE CLIMATE MONITORING STATION

▲	MONITORING STATION - MOSAIC/RDN
▲	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

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REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
TOPOGRAPHY AND CLIMATE MONITORING STATIONS

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	CB
REVIEWED	AP
APPROVED	MB

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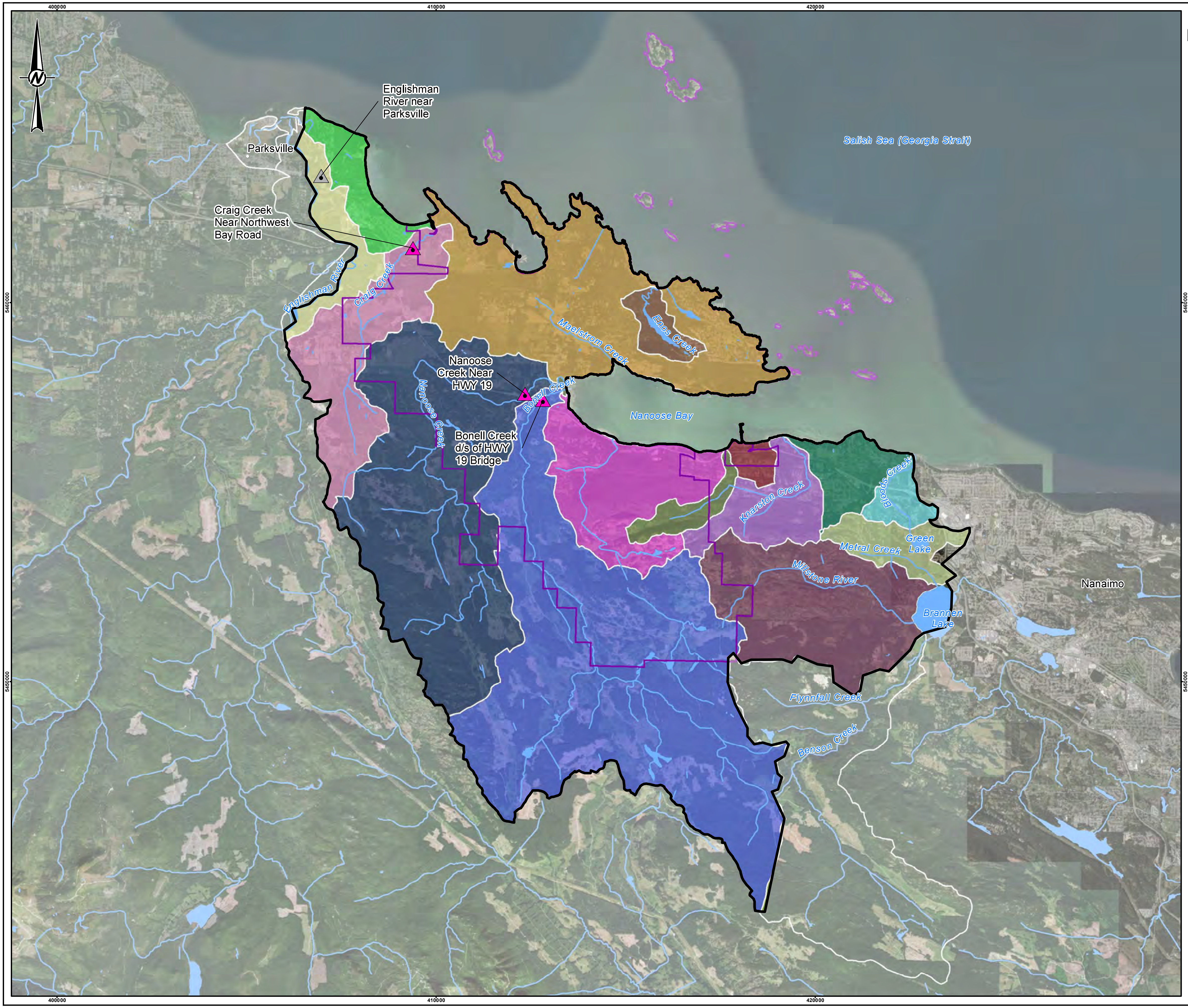

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🟦	WATERBODY
—	WATERCOURSE
○	CITY / TOWN

HYDROMETRIC MONITORTING STATION

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

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. 2
🟧	UNNAMED NO. 3
🟪	UNNAMED NO. 4
🟥	UNNAMED NO. 5
🟩	UNNAMED NO. 6
🟪	UNNAMED NO. 7

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PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
WATERSHEDS AND SURFACE WATER FEATURES

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

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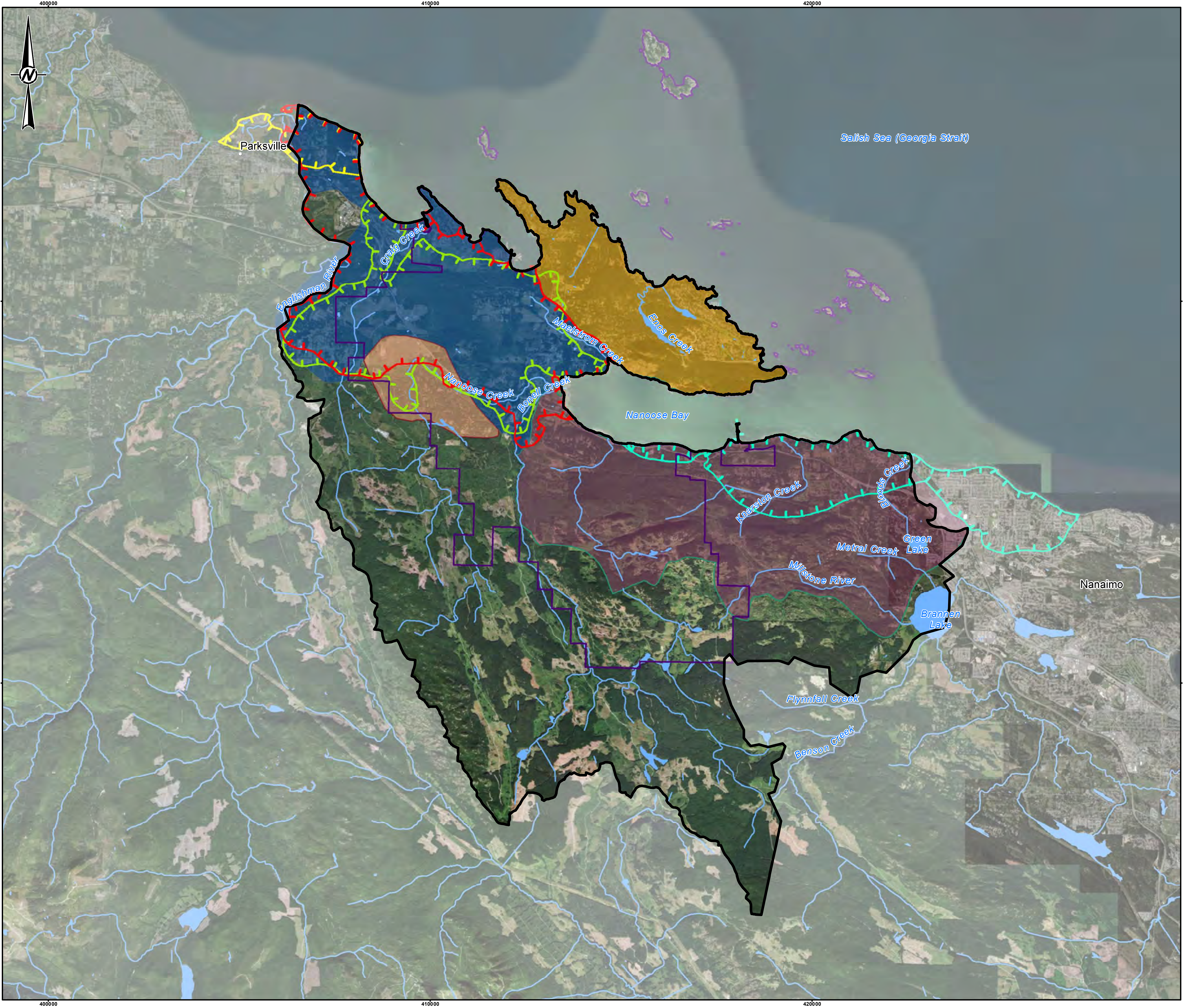

LEGEND

▭ PROJECT AREA
▭ ELECTORAL AREA E
🟦 WATERBODY
— WATERCOURSE
◦ CITY / TOWN

OVERBURDEN AQUIFER

AQUIFER NUMBER

▭ AQ1098
▭ AQ215
▭ AQ219
▭ AQ221

BEDROCK AQUIFER

AQUIFER NUMBER

▨ AQ210
▨ AQ213
▨ AQ214
▨ AQ218

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CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
AQUIFERS IN PROJECT AREA

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
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PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

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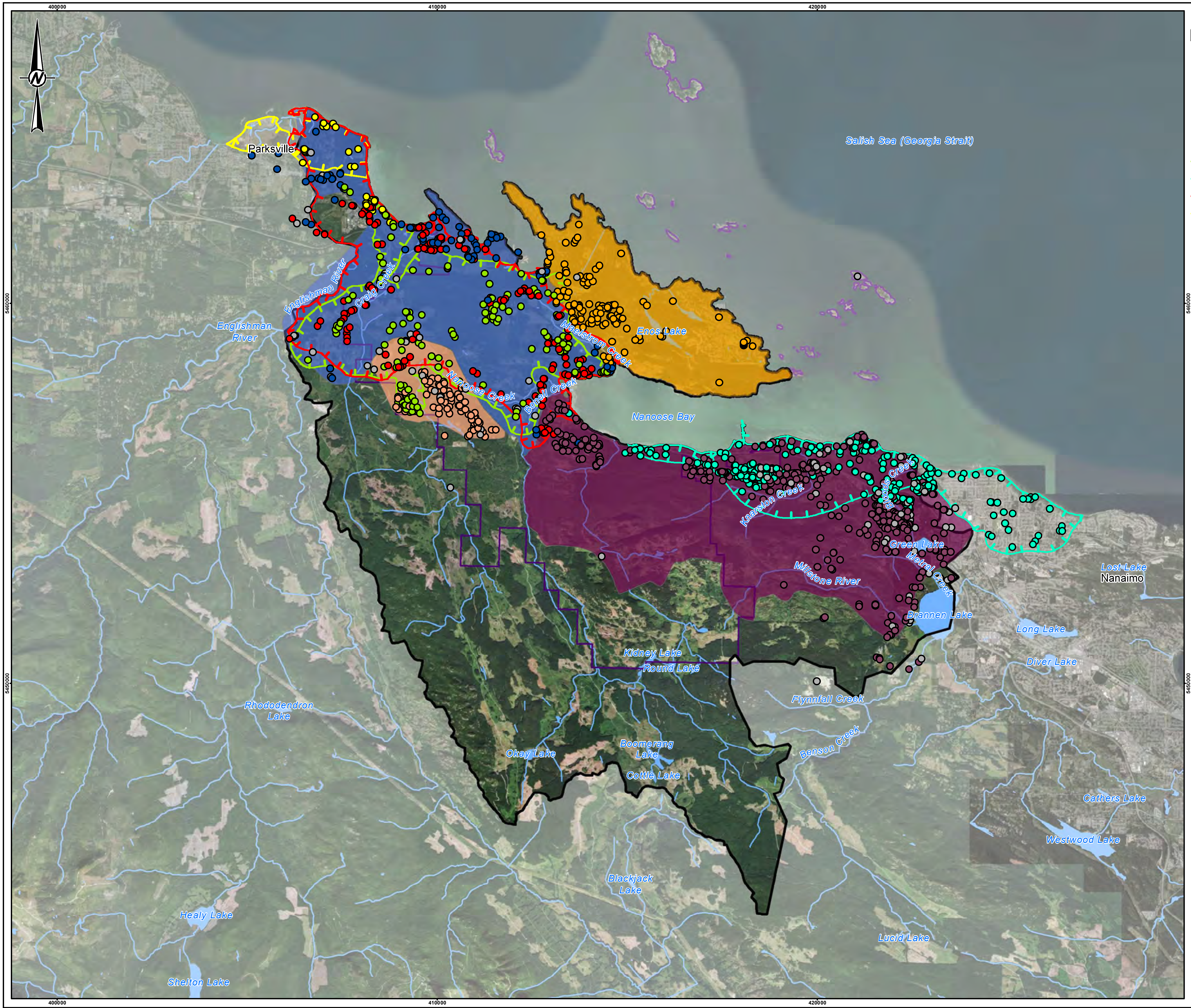

LEGEND

- ▭ PROJECT AREA
- ▭ ELECTORAL AREA E
- 🟦 WATERBODY
- — WATERCOURSE
- ○ CITY / TOWN

OVERBURDEN AQUIFER

AQUIFER NUMBER

- 🟩 AQ1098
- 🟩 AQ215
- 🟥 AQ219
- 🟨 AQ221

BEDROCK AQUIFER

AQUIFER NUMBER

- 🟧 AQ210
- 🟪 AQ213
- 🟦 AQ214
- 🟨 AQ218

GROUNDWATER WELL IN AQUIFER

AQUIFER NUMBER AND FORMATION

- ● AQ 1098
- ● AQ 215
- ● AQ 219
- ● AQ 221
- ● Benson Formation (218)
- ● Fourth Lake/Mount Hall Gabbro (210)
- ● Nanaimo Group (214)
- ● Vancouver Group (213)
- ● Unassigned
- ○ GROUNDWATER WELL NOT IN PROJECT AREA AQUIFER

0 2 4

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REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

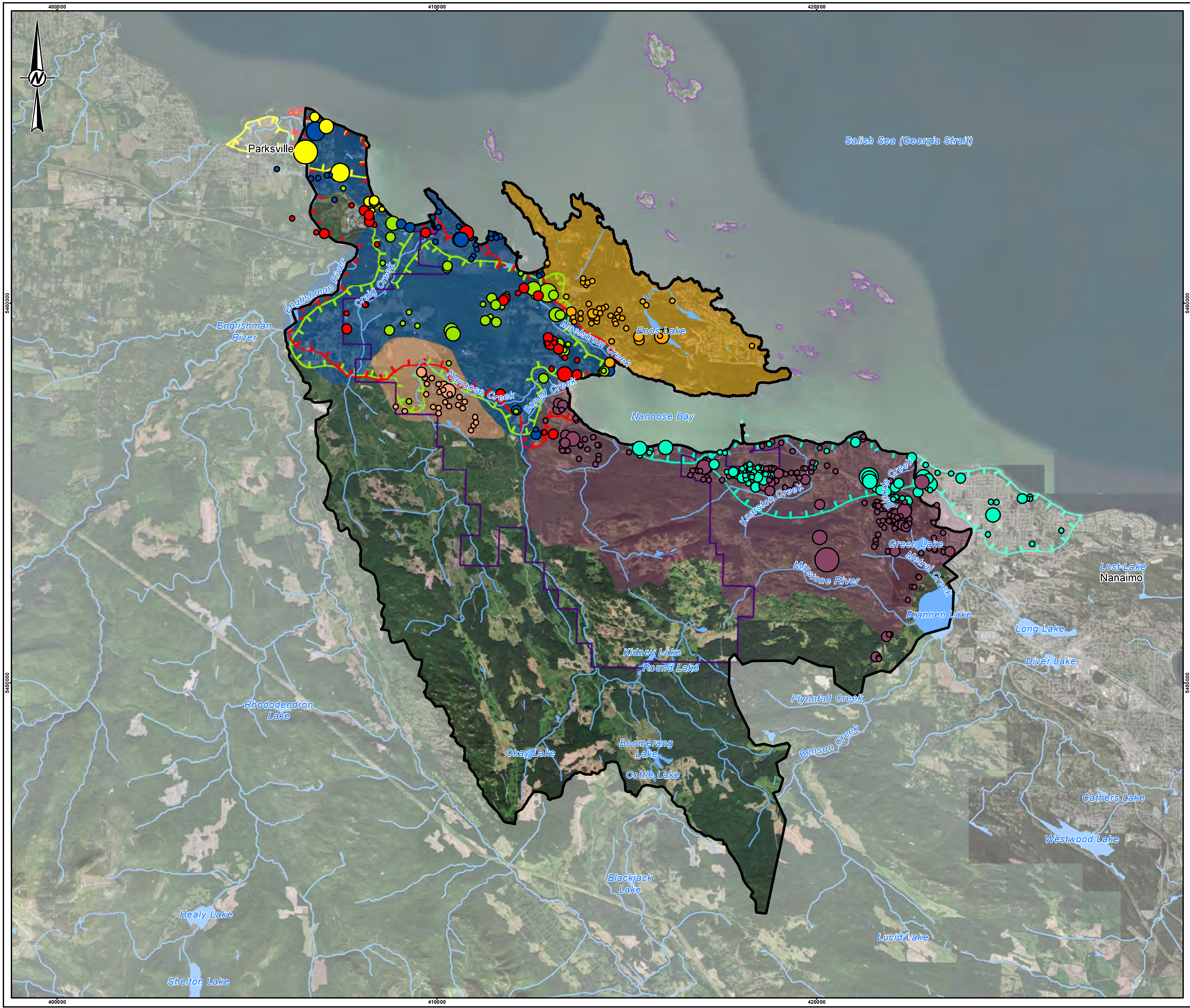
TITLE
WELLS BY AQUIFER

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	5

25mm
0
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

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ1098
- AQ215
- AQ219
- AQ221

BEDROCK AQUIFER

AQUIFER NUMBER

- ■ AQ210
- ■ AQ213
- ■ AQ214
- ■ AQ218

WELL YIELD (USGPM) BY AQUIFER

AQ 1098

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

AQ 210

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

AQ 213

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

AQ 214

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

AQ 215

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

AQ 218

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

AQ 219

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

AQ 221

- ● 0.0 - 14.0
- ● 14.0 - 45.0
- ● 45.0 - 100.0
- ● 100.0 - 250.0
- ● 250.0 - 800.0

0 2 4

1:100,000 KILOMETRES

NOTE(S)

1. THE CIRCLES REPRESENT SINGLE WELLS WHERE A VALUE FOR YIELD WAS REPORTED IN THE BC ENV DATABASE AND THEY ARE CONSIDERED REPRESENTATIVE OF THE CORRESPONDENT AQUIFER UNIT.

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
WELL YIELD BASED ON AQUIFER ASSIGNMENT

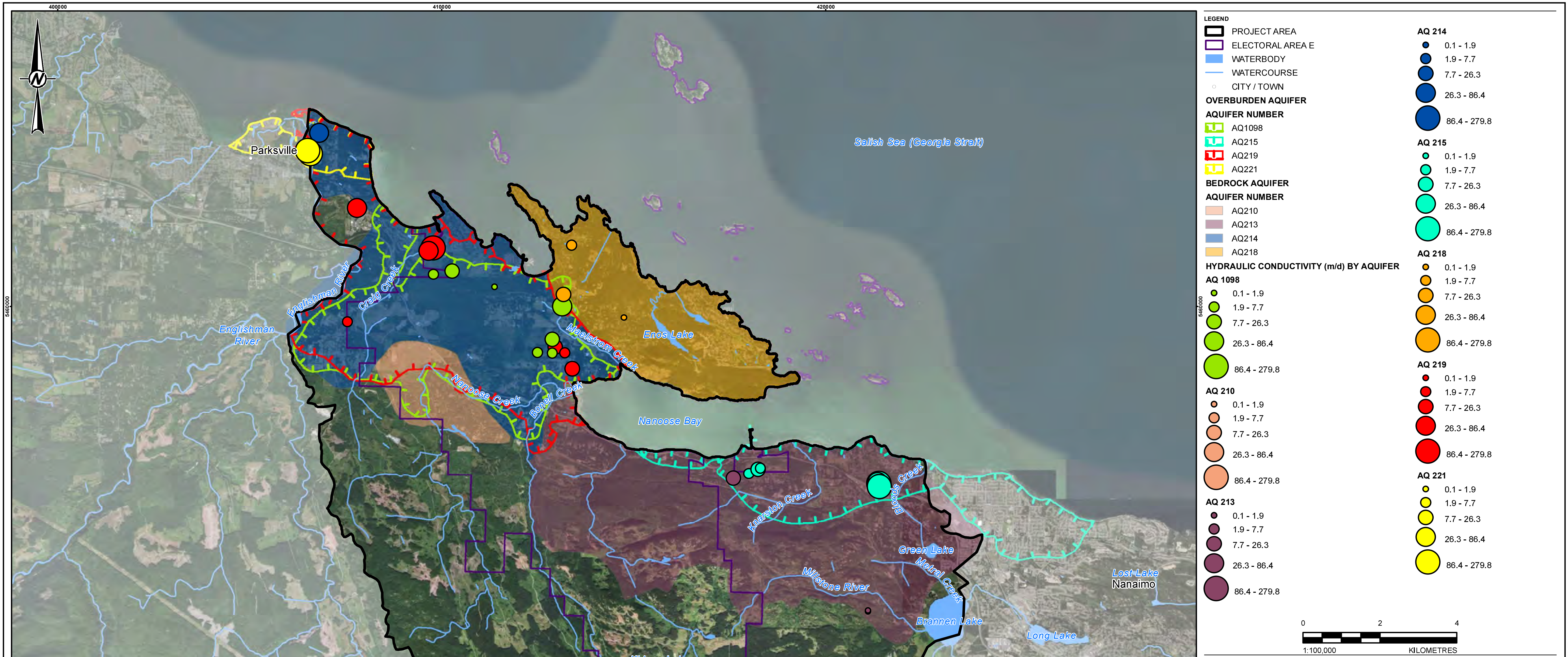
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	9

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_9_YIELD.mxd PRINTED ON: 2020-04-07 AT: 12:43:36 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
0



NOTE(S)

1. THE CIRCLES REPRESENT SINGLE WELLS WHERE A VALUE FOR HYDRAULIC CONDUCTIVITY WAS REPORTED IN THE BC ENV DATABASE AND THEY ARE CONSIDERED REPRESENTATIVE OF THE CORRESPONDENT AQUIFER UNIT.

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
ESTIMATED HYDRAULIC CONDUCTIVITY BASED ON AQUIFER

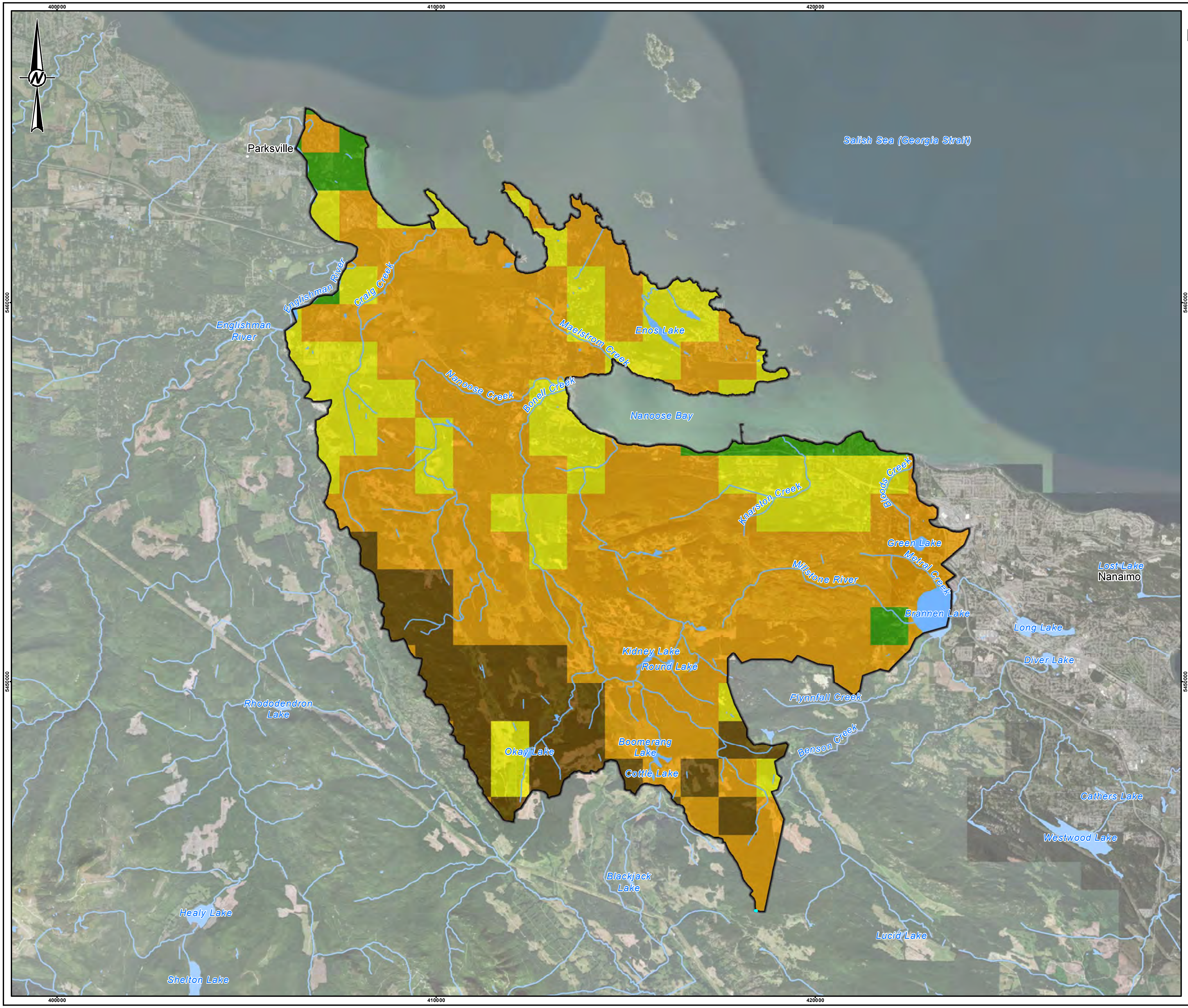
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	11

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_11_HYDRAULIC_CONDUCTIVITY.mxd PRINTED ON: 2020-04-07 AT: 12:46:09 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
0



LEGEND

▭	PROJECT AREA
🟦	WATERBODY
—	WATERCOURSE
○	CITY / TOWN

TOTAL ANNUAL GROUNDWATER RECHARGE (mm)

🟩	16.0 - 25.0
🟨	25.0 - 75.0
🟧	75.0 - 130.0
🟫	130.0 - 141.0

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: DIGITALGLOBE. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20160912.
5. GROUNDWATER RECHARGE DERIVED FROM WATERLINE (2013)

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
TOTAL ANNUAL GROUNDWATER RECHARGE

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	CDAB
REVIEWED	AP
APPROVED	BM

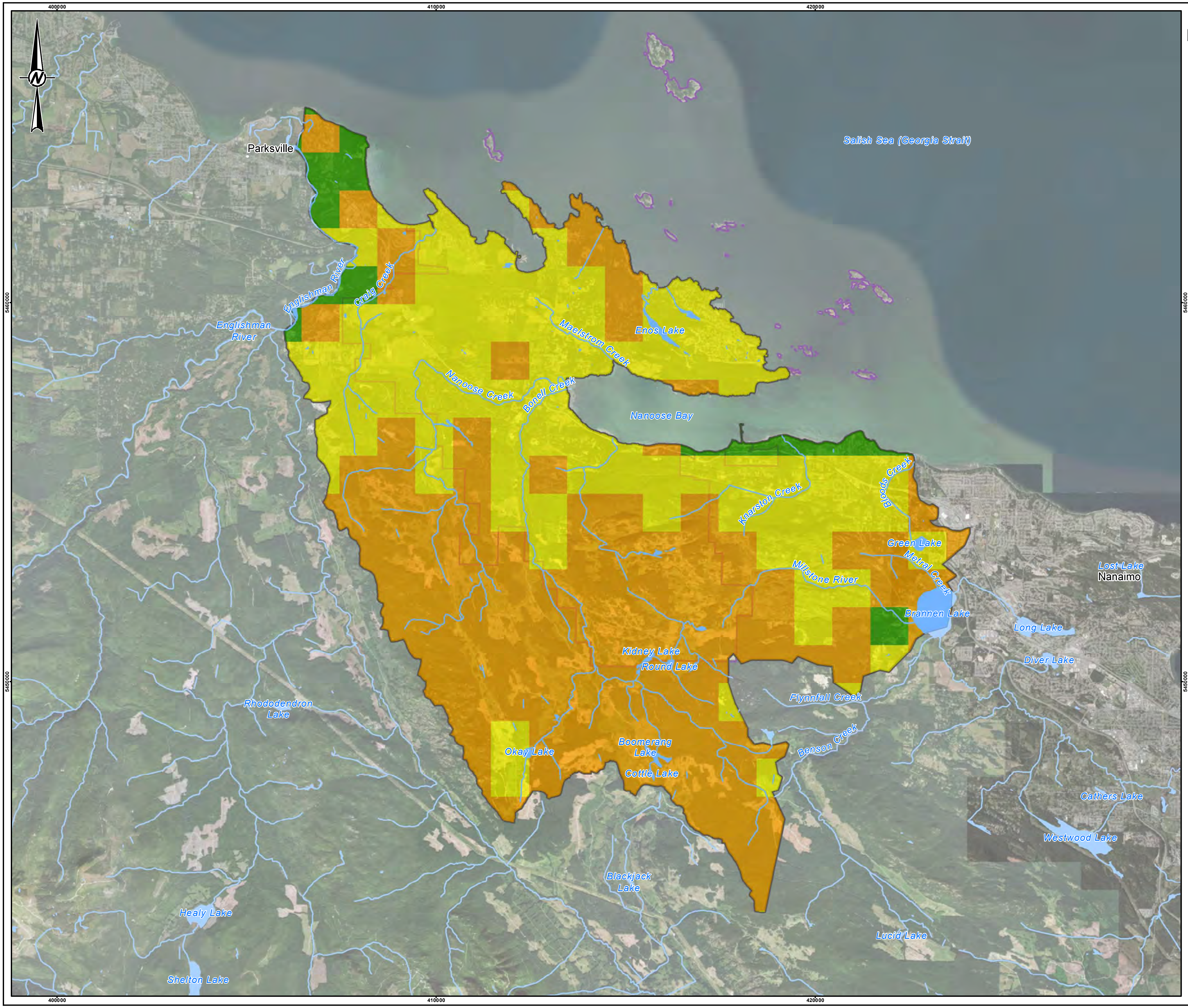
PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	12

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_12_TOTAL_ANNUAL_GROUNDWATER_RECHARGE.mxd PRINTED ON: 2020-04-07 AT: 12:46:40 PM

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 RECHARGE DURING WET SEASON (mm)

- 🟩 13.0 - 25.0
- 🟨 25.0 - 75.0
- 🟧 75.0 - 90.2

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.
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5. GROUNDWATER RECHARGE FOR THE WET SEASON (OCTOBER THROUGH APRIL) ESTIMATED FROM TOTAL ANNUAL, SUMMER AND WINTER GROUNDWATER RECHARGE IN WATERLINE (2013).

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
GROUNDWATER RECHARGE (WET SEASON)

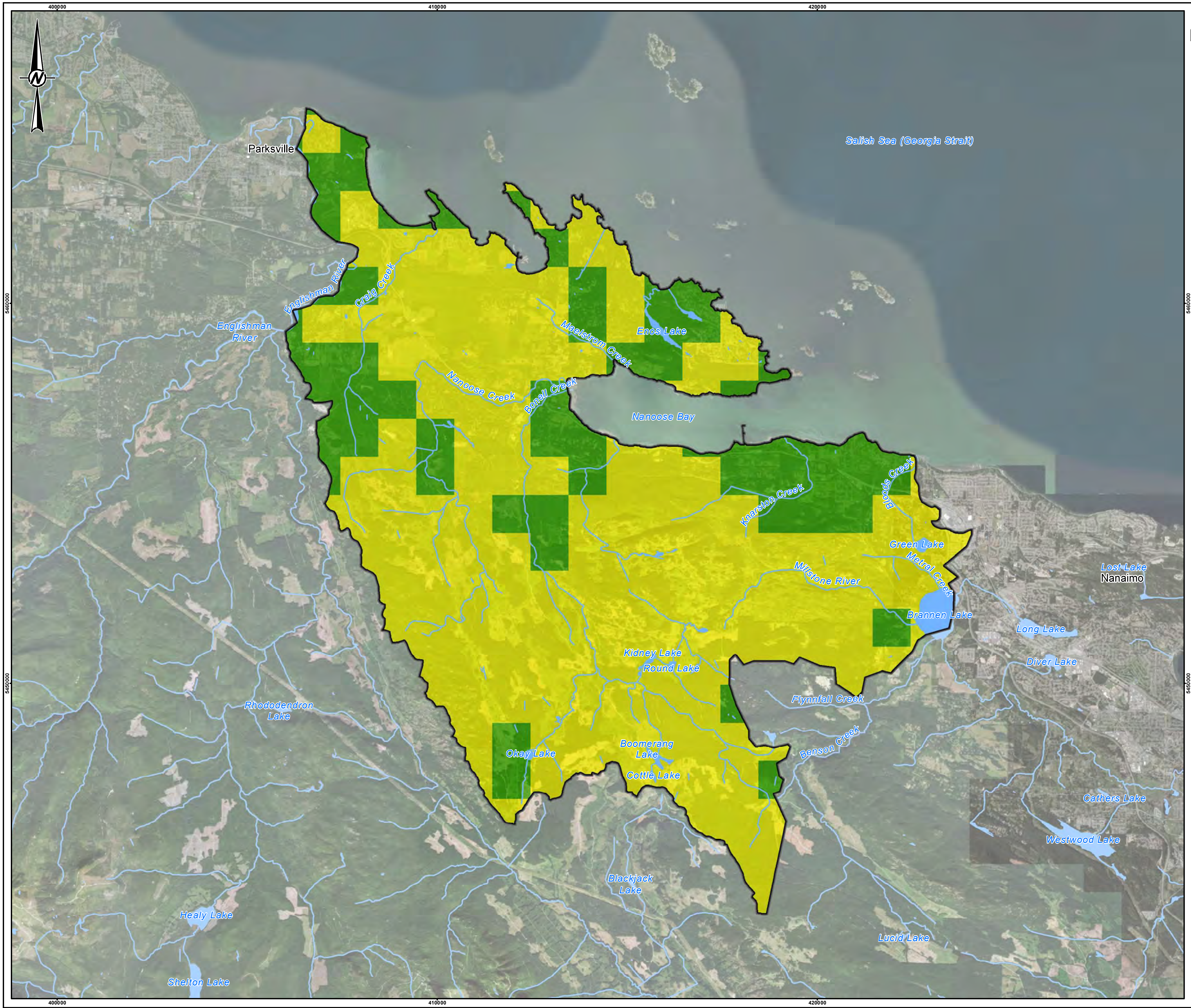
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	13

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_13_GROUNDWATER_RECHARGE_WET_SEASON.mxd PRINTED ON: 2020-04-07 AT: 12:47:07 PM

0 25mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



LEGEND

▭ PROJECT AREA
🟦 WATERBODY
— WATERCOURSE
○ CITY / TOWN

GROUNDWATER RECHARGE DURING DRY SEASON (mm)

🟩 3.0 - 25.0
🟨 25.0 - 50.8

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: DIGITALGLOBE. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20160912.
5. GROUNDWATER RECHARGE FOR THE DRY SEASON (MARCH THROUGH SEPTEMBER) ESTIMATED FROM TOTAL ANNUAL, SUMMER AND WINTER GROUNDWATER RECHARGE IN WATERLINE (2013).

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
GROUNDWATER RECHARGE (DRY SEASON)

CONSULTANT
GOLDER

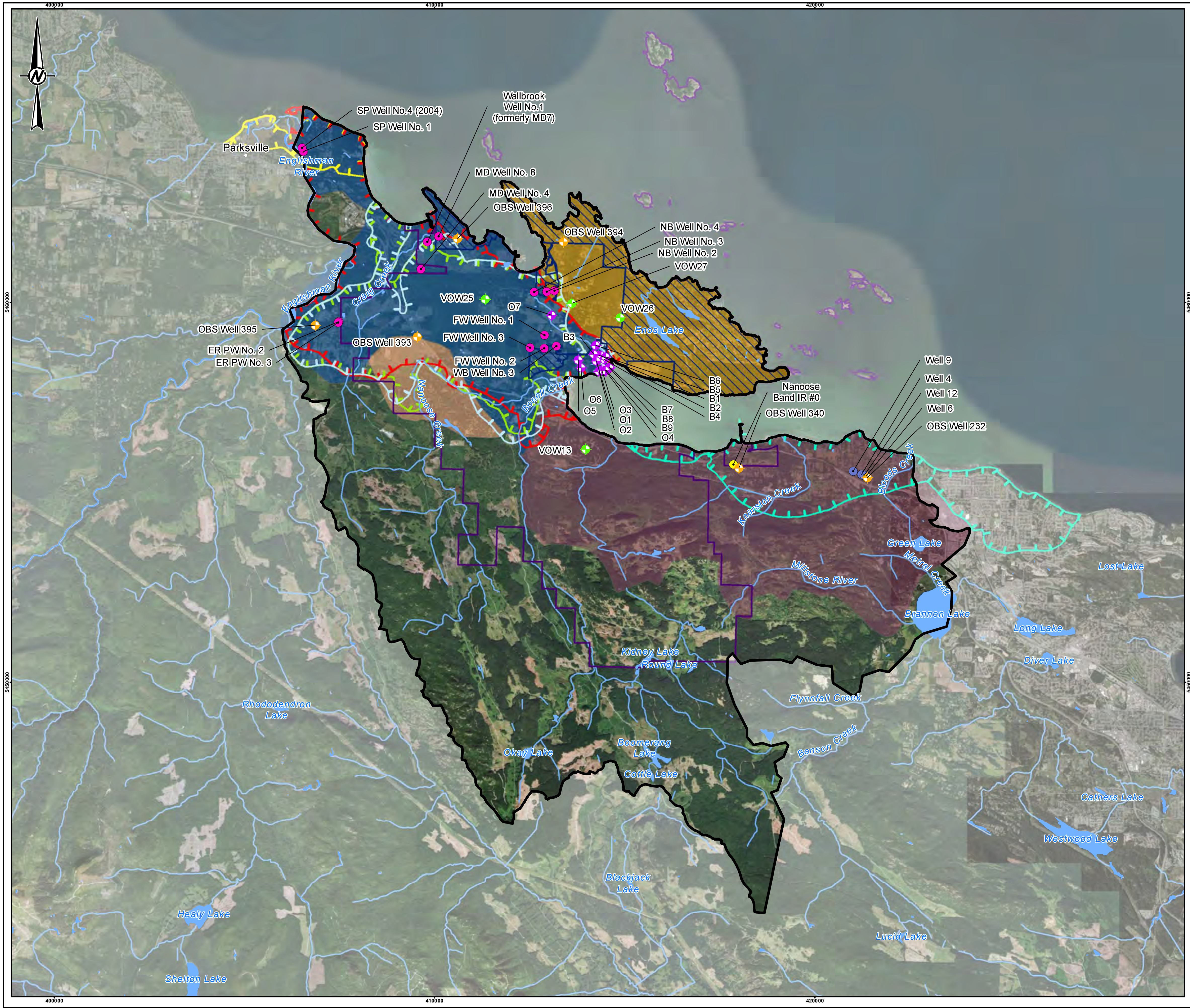
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	14

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_14_GROUNDWATER_RECHARGE_DRY_SEASON.mxd PRINTED ON: 2020-04-07 AT: 12:47:41 PM

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
- ▨ NANOOSE BAY PENINSULA WATER SYSTEM

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ1098
- AQ215
- AQ219
- AQ221

BEDROCK AQUIFER

AQUIFER NUMBER

- AQ210
- AQ213
- AQ214
- AQ218

MONITORING WELL

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

PUMPING WELL

- ● DISTRICT OF LANTZVILLE PRODUCTION WELL
- ● SNAW-NAW-AS FIRST NATION PRODUCTION WELL
- ● RDN PRODUCTION WELL

0 2 4
1:100,000 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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
LOCATION OF MONITORING WELLS AND MUNICIPAL PRODUCTION WELLS

CONSULTANT
GOLDER

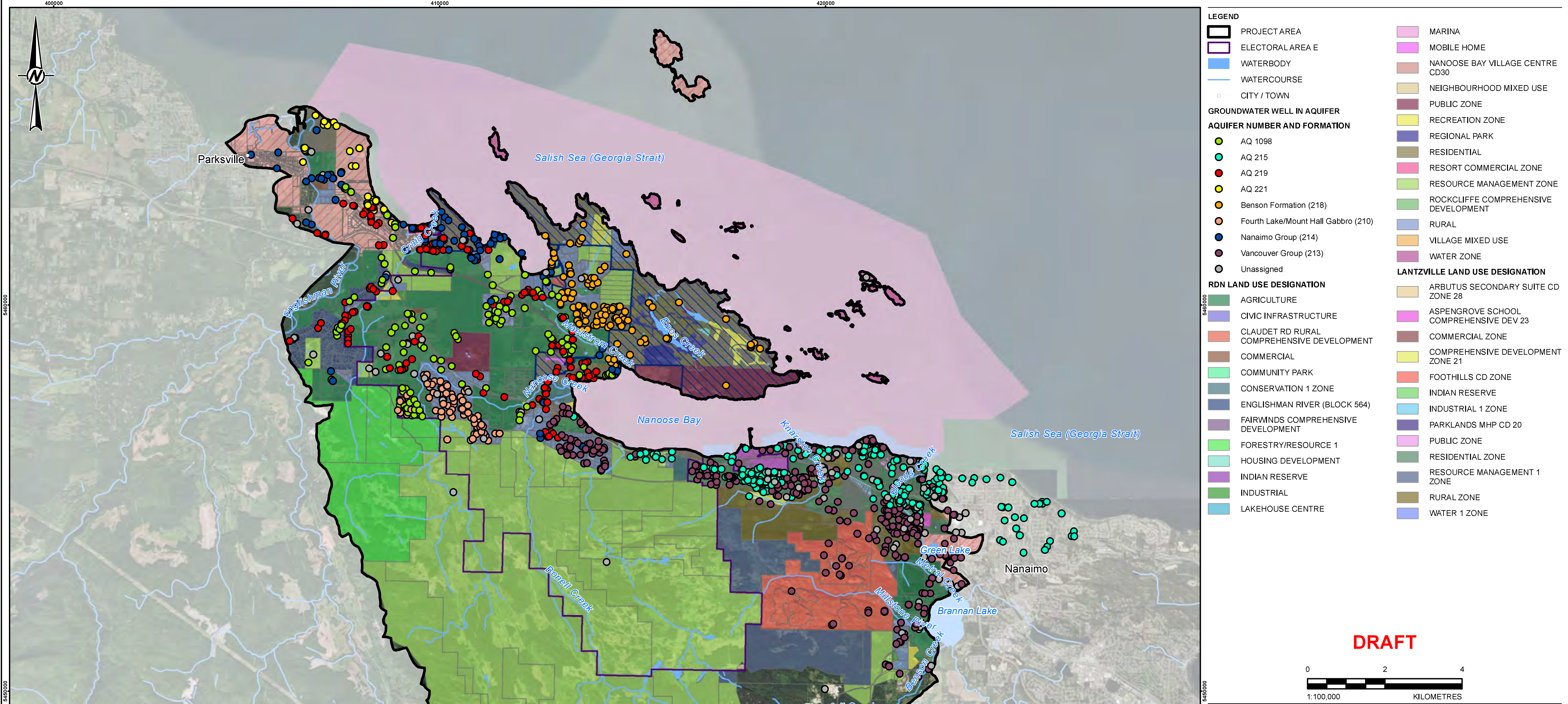
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	15

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_15_LOCATION_OF_MONITORING_WELLS_AND_MUNICIPAL_PRODUCTION_WELLS.mxd PRINTED ON: 2020-04-07 AT: 12:48:09 PM

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

25mm
0



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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
LAND USE DESIGNATION – NANOOSE AREA E

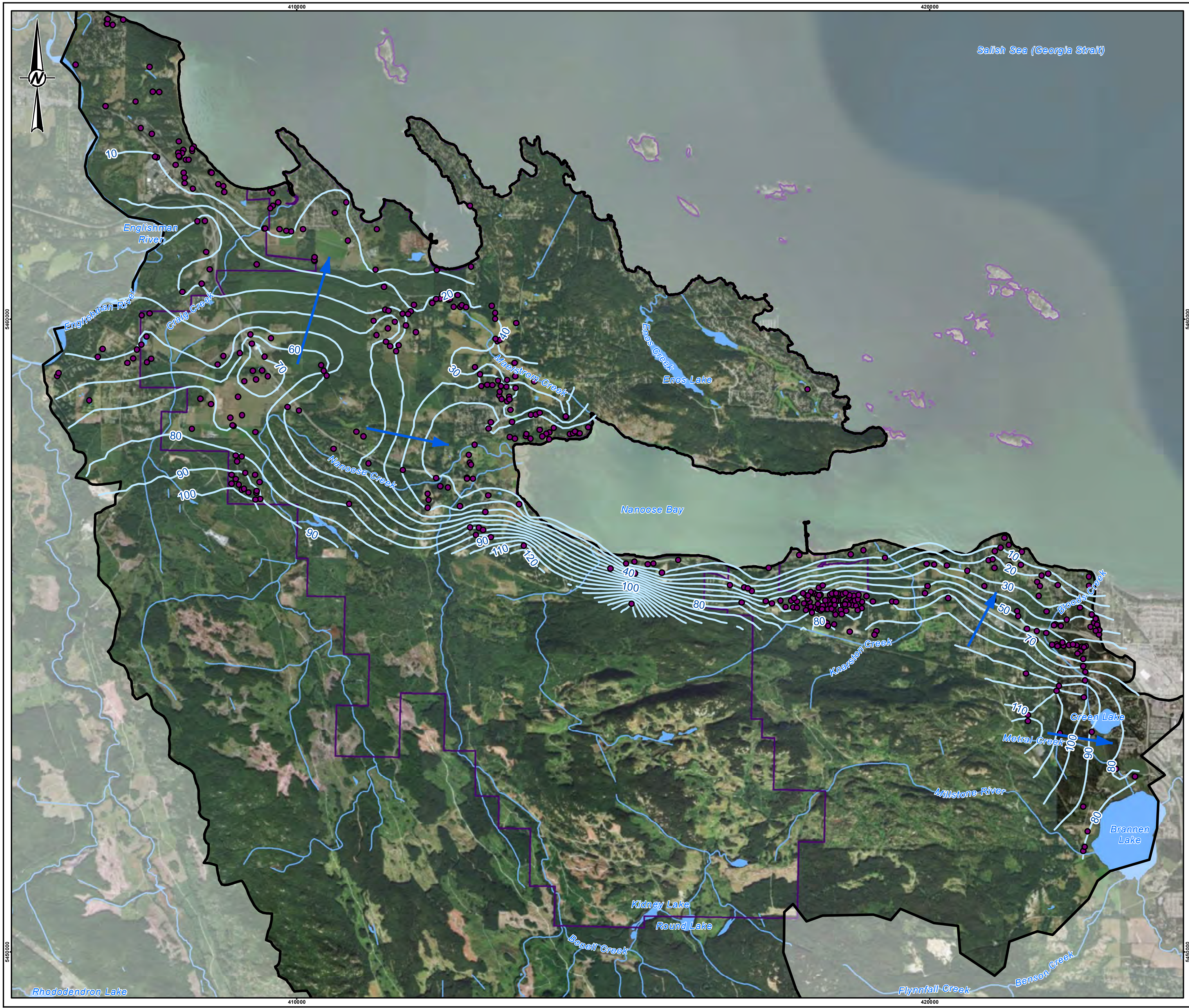
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	16

25mm
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_16_LAND_USE_DESIGNATION_NANOOSE_AREA_E.mxd PRINTED ON: 2020-04-07 AT: 12:49:00 PM



LEGEND

- ▭ PROJECT AREA
- ▭ ELECTORAL AREA E
- 🟦 WATERBODY
- — WATERCOURSE
- ○ CITY / TOWN
- ● WELL COMPLETED IN OVERBURDEN
- — HYDRAULIC HEAD CONTOUR (MASL)
- ➔ INTERPRETED DIRECTION OF GROUNDWATER FLOW

0 1.5 3

1:60,000 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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
HYDRAULIC HEAD CONTOURS (OVERBURDEN - AVERAGE ANNUAL CURRENT CONDITIONS)

CONSULTANT
GOLDER

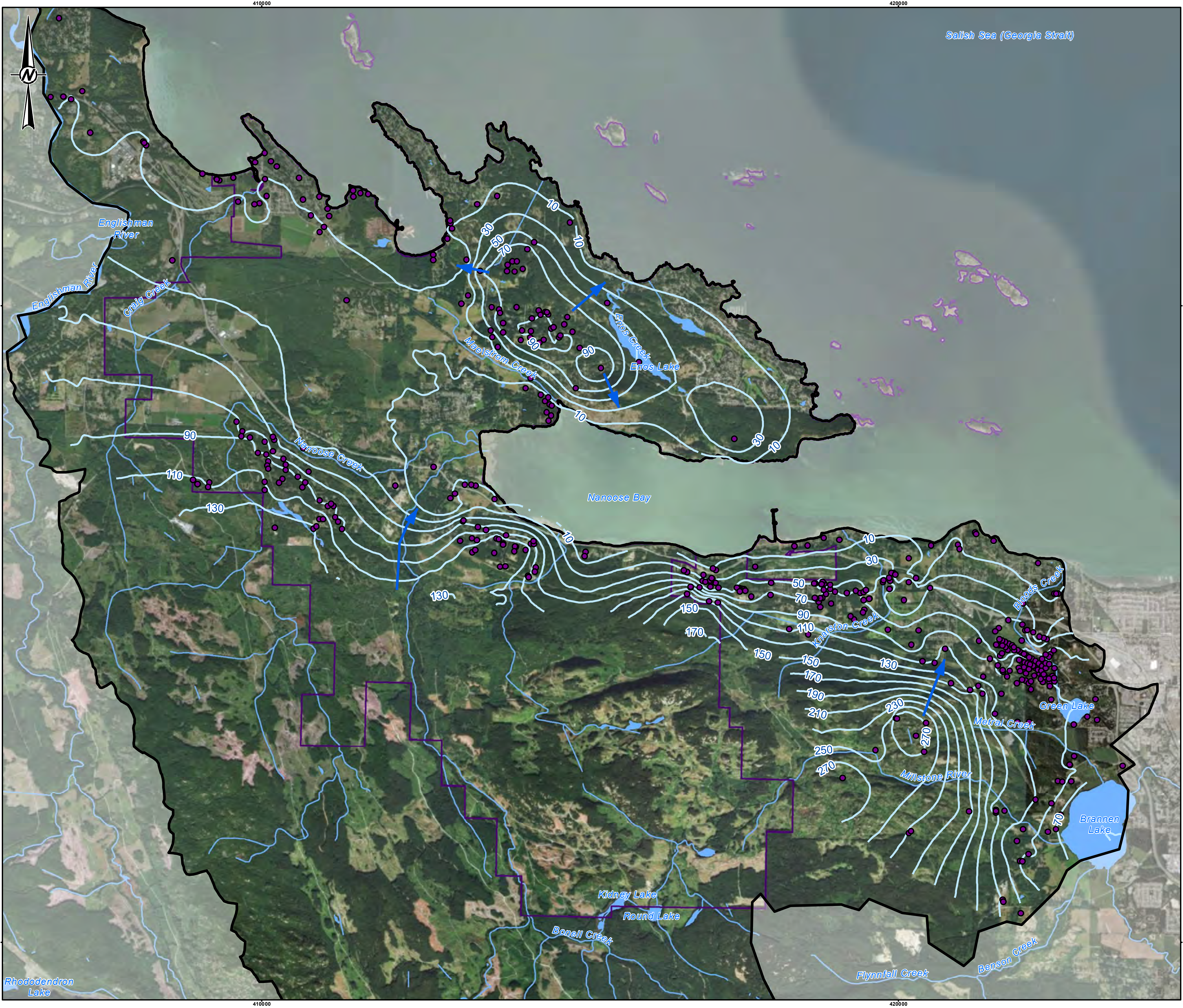
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	17

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

25mm 0

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_17_HYDRAULIC_HEAD_CONTOURS_OVERBURDEN.mxd PRINTED ON: 2020-04-07 AT: 12:49:14 PM



LEGEND

- ▭ PROJECT AREA
- ▭ ELECTORAL AREA E
- 🟦 WATERBODY
- — WATERCOURSE
- ○ CITY / TOWN
- ● WELL COMPLETED IN BEDROCK
- — HYDRAULIC HEAD CONTOUR (MASL)
- ➤ INTERPRETED DIRECTION OF GROUNDWATER FLOW

0 1.5 3

1:60,000 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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
HYDRAULIC HEAD CONTOURS (BEDROCK - AVERAGE ANNUAL CURRENT CONDITIONS)

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

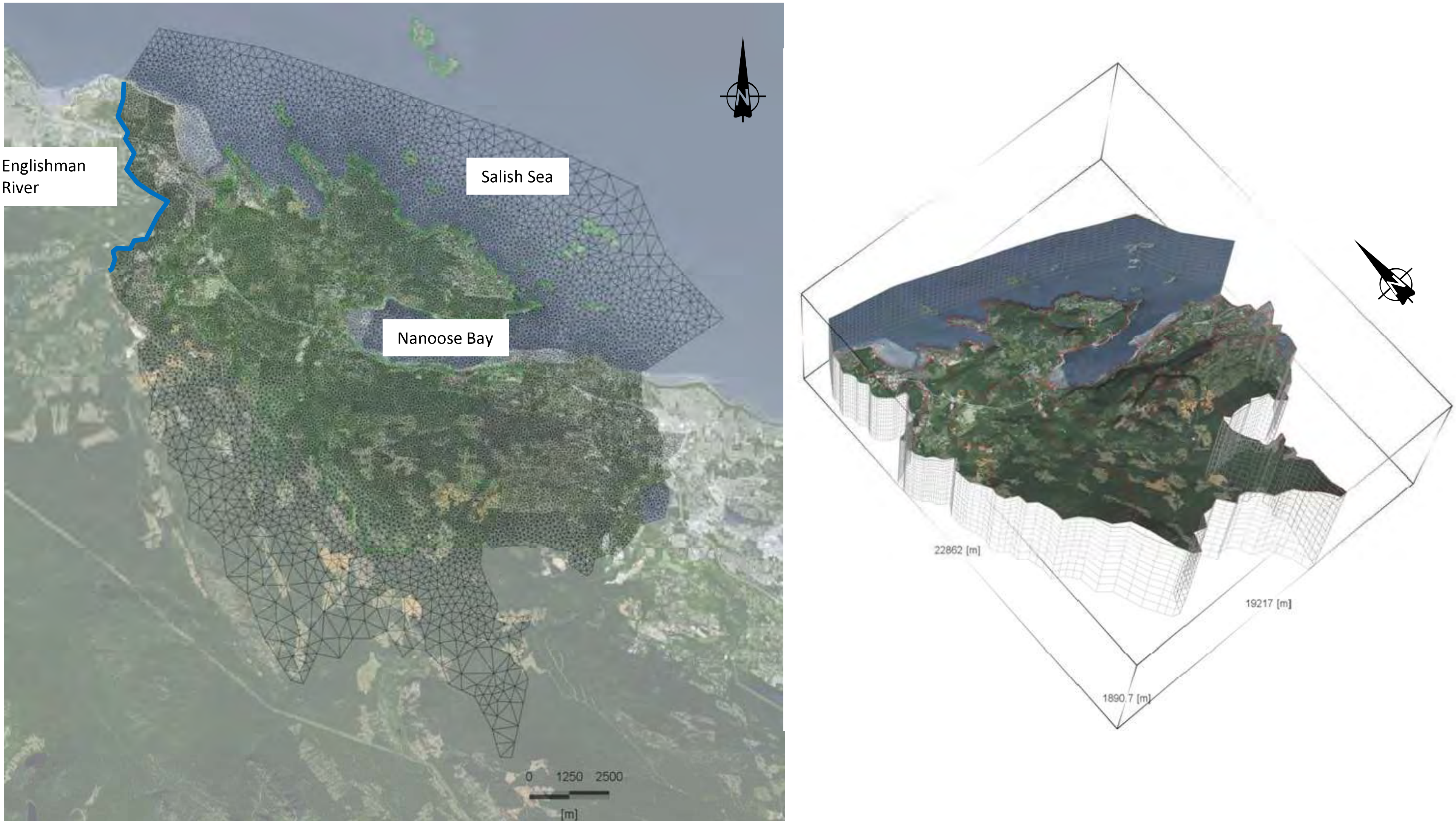
PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	18

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_18_HYDRAULIC_HEAD_CONTOURS_BEDROCK.mxd PRINTED ON: 2020-04-07 AT: 12:49:38 PM

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

25mm

0



CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

CONSULTANT
GOLDER

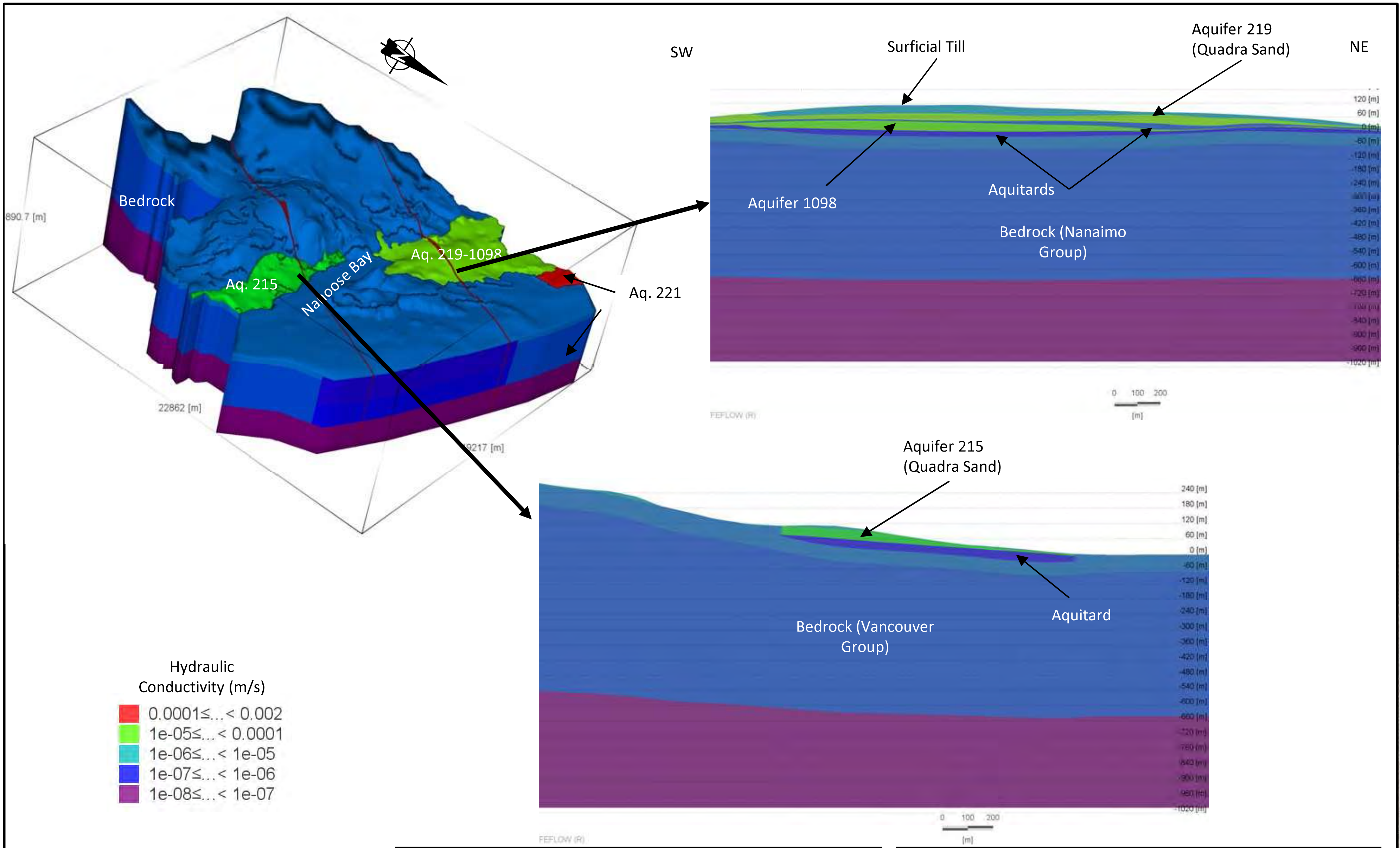
YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE

3-D GROUNDWATER NUMERICAL MODEL EXTENT

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	0	19

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

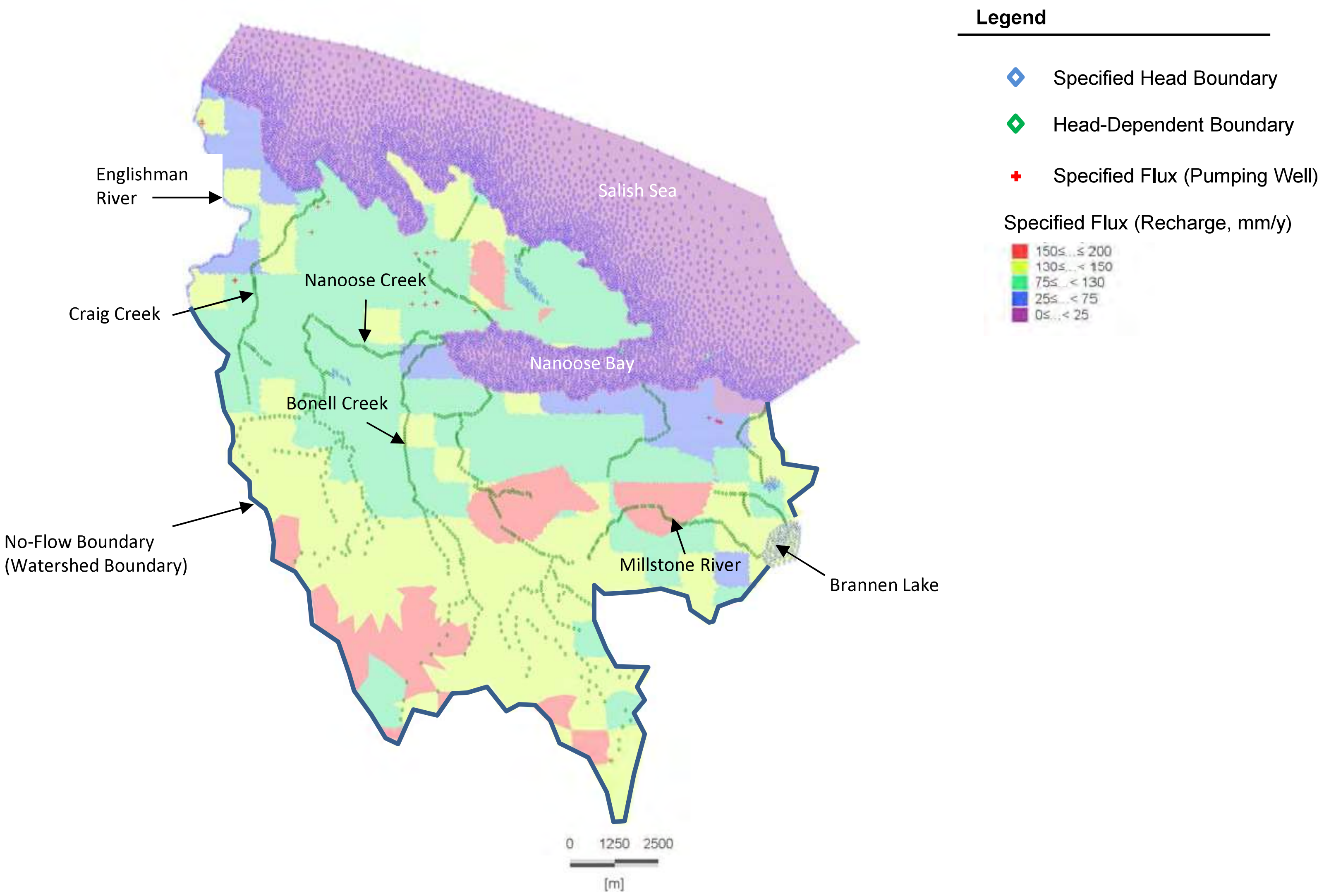
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
3-D GROUNDWATER NUMERICAL MODEL HYDROSTRATIGRAPHY

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	0	20

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



CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

CONSULTANT

GOLDER

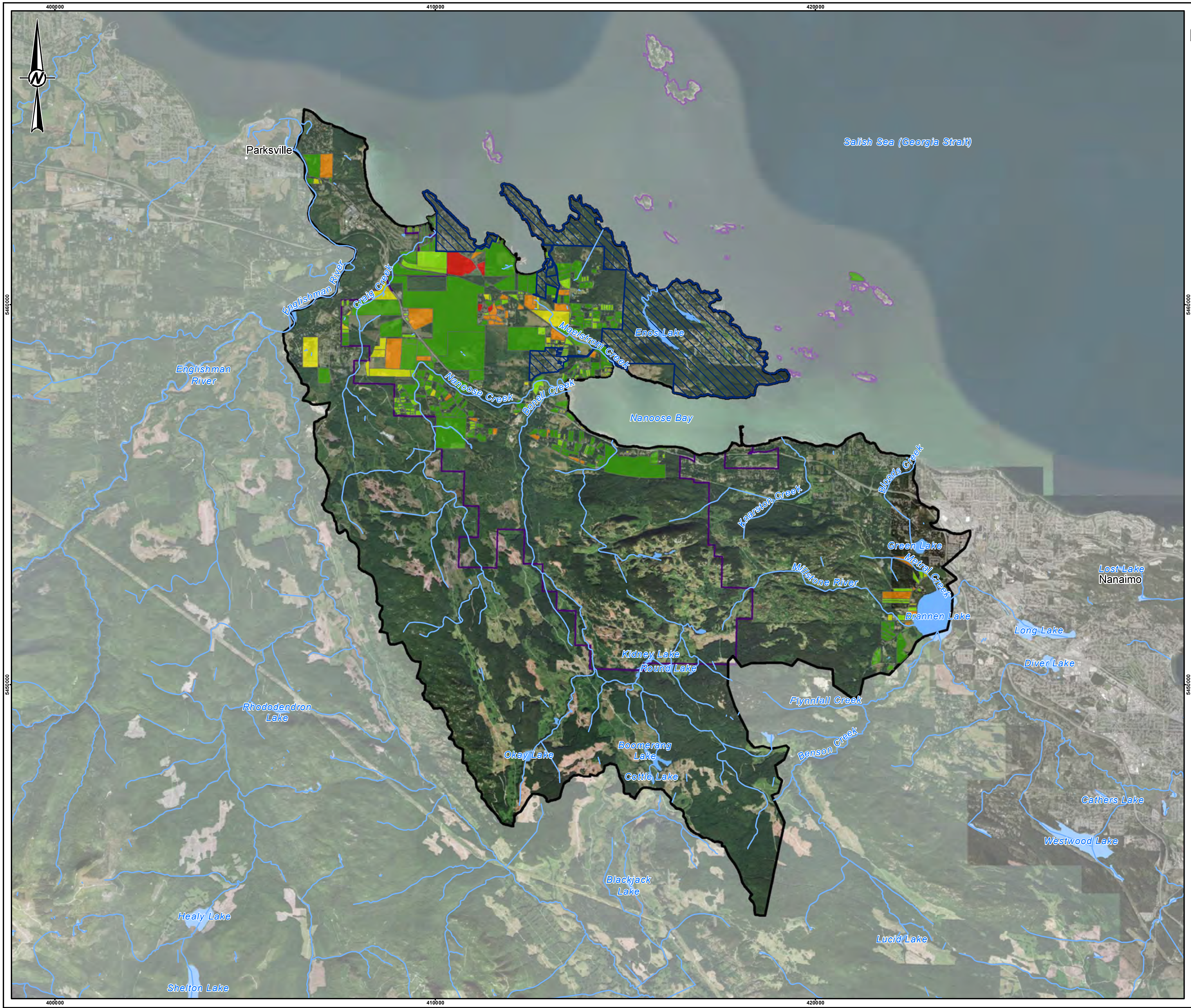
YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE

3-D GROUNDWATER NUMERICAL MODEL BOUNDARY CONDITIONS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	0	21

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



LEGEND

- ▭ PROJECT AREA
- ▭ ELECTORAL AREA E
- 🟦 WATERBODY
- — WATERCOURSE
- ○ CITY / TOWN
- ▨ NANOOSE BAY PENINSULA WATER SYSTEM

ESTIMATED WATER USE (mm/y)

- 🟥 >500
- 🟧 100 - 500
- 🟨 50 - 100
- 🟩 20 - 50
- 🟩 0 - 20

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
ESTIMATED WATER USE FOR THE PROPERTIES OUTSIDE OF THE WATER SERVICED AREA (CURRENT AVERAGE ANNUAL)

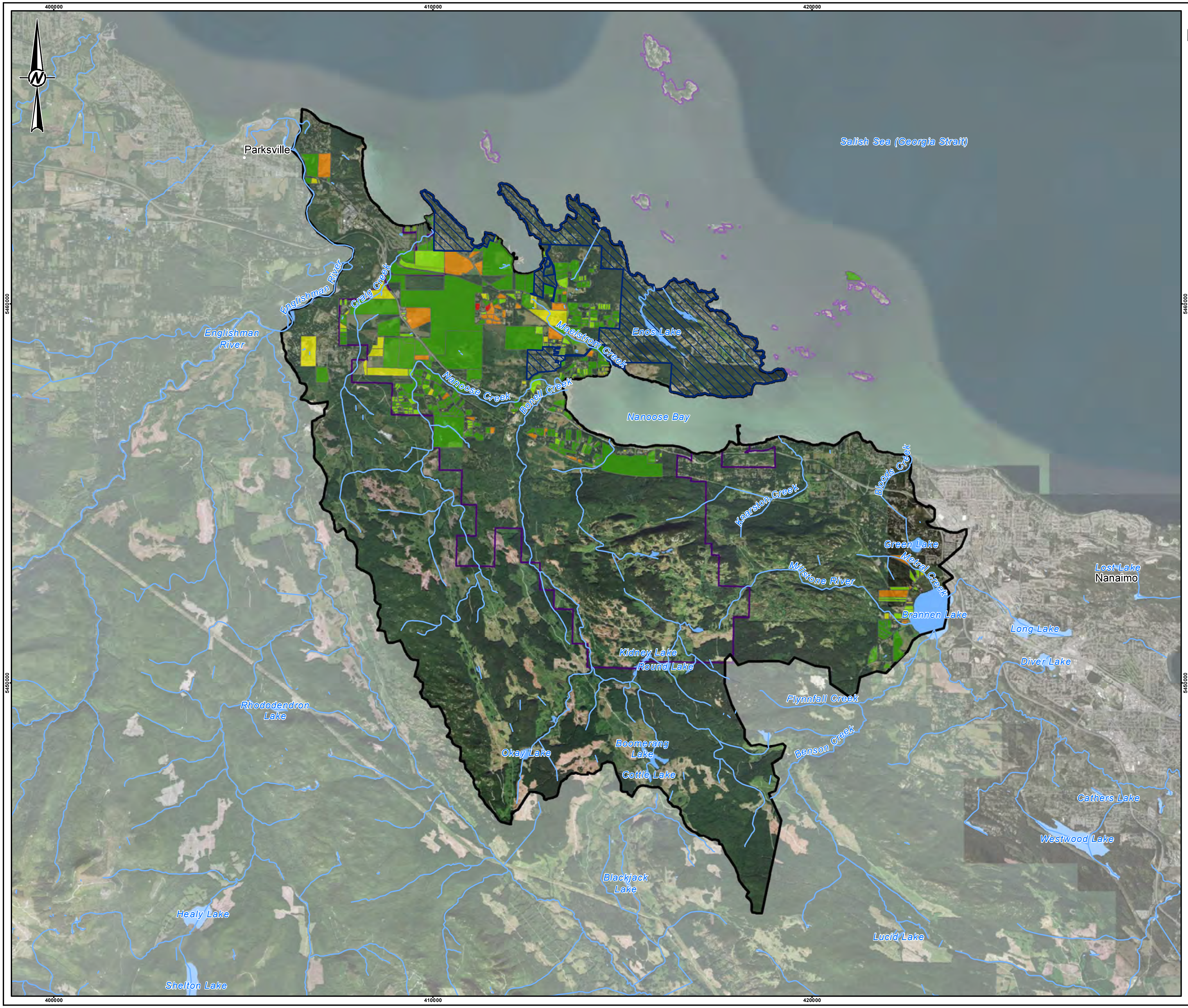
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	22A

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_22A_ESTIMATED_WATER_USE_OUTSIDE_OF_WATER_SERVICED_AREA_YEAR_TOTAL.mxd PRINTED ON: 2020-04-07 AT: 12:51:41 PM

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
- ▨ NANOOSE BAY PENINSULA WATER SYSTEM

ESTIMATED WATER USE (mm/y)

- 🟥 >500
- 🟧 100 - 500
- 🟨 50 - 100
- 🟩 20 - 50
- 🟩 0 - 20

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: DIGITALGLOBE. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 2016129.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
ESTIMATED WATER USE FOR THE PROPERTIES OUTSIDE OF THE WATER SERVICED AREA (CURRENT WET SEASON)

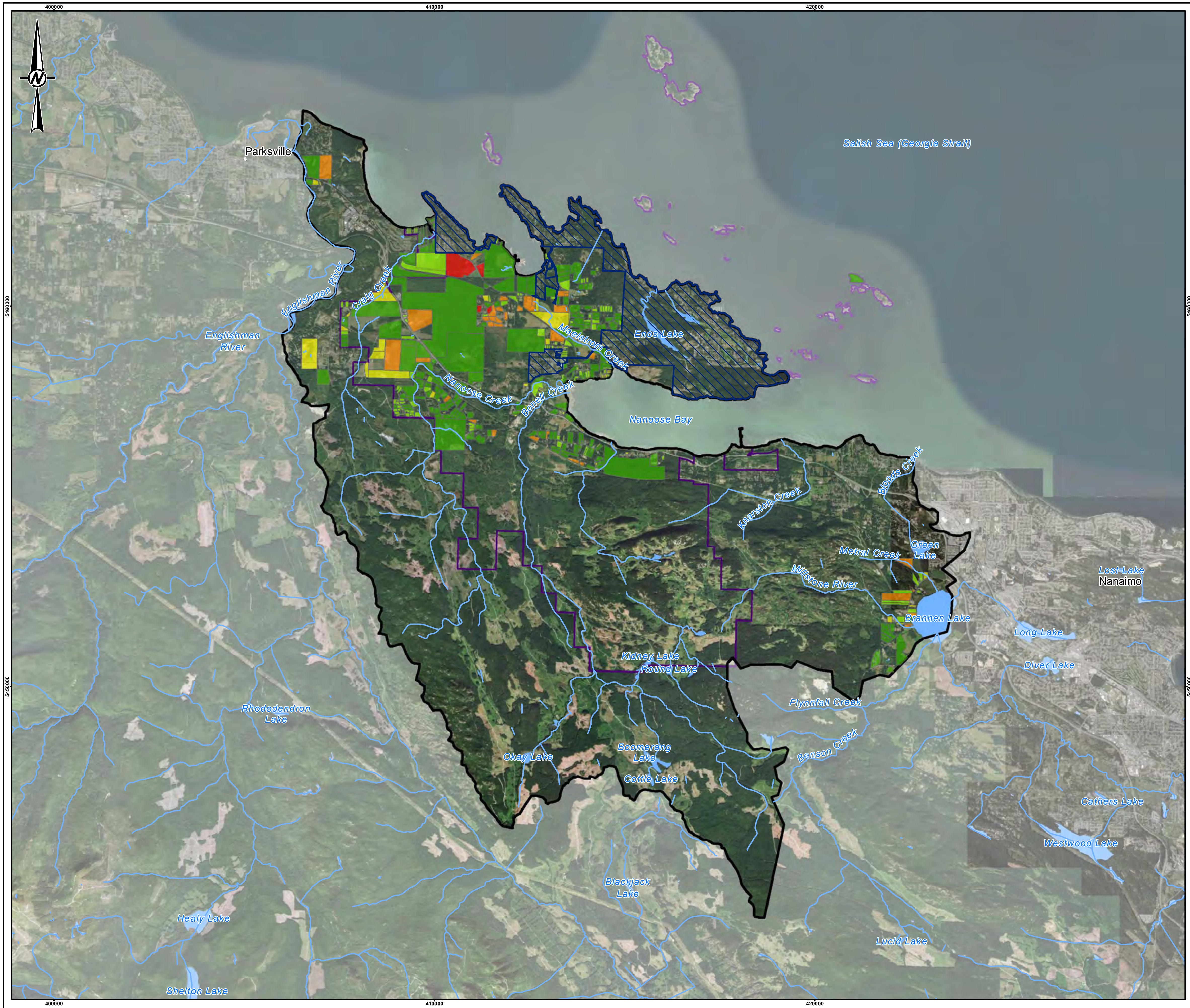
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	22B

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_22B_ESTIMATED_WATER_USE_OUTSIDE_OF_WATER_SERVICED_AREA_WET_SEASON.mxd PRINTED ON: 2020-04-07 AT: 12:52:19 PM

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
- ▨ NANOOSE BAY PENINSULA WATER SYSTEM

ESTIMATED WATER USE (mm/y)

- 🟥 >500
- 🟧 100 - 500
- 🟨 50 - 100
- 🟩 20 - 50
- 🟩 0 - 20

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
ESTIMATED WATER USE FOR THE PROPERTIES OUTSIDE OF THE WATER SERVICED AREA (CURRENT DRY SEASON)

CONSULTANT
GOLDER

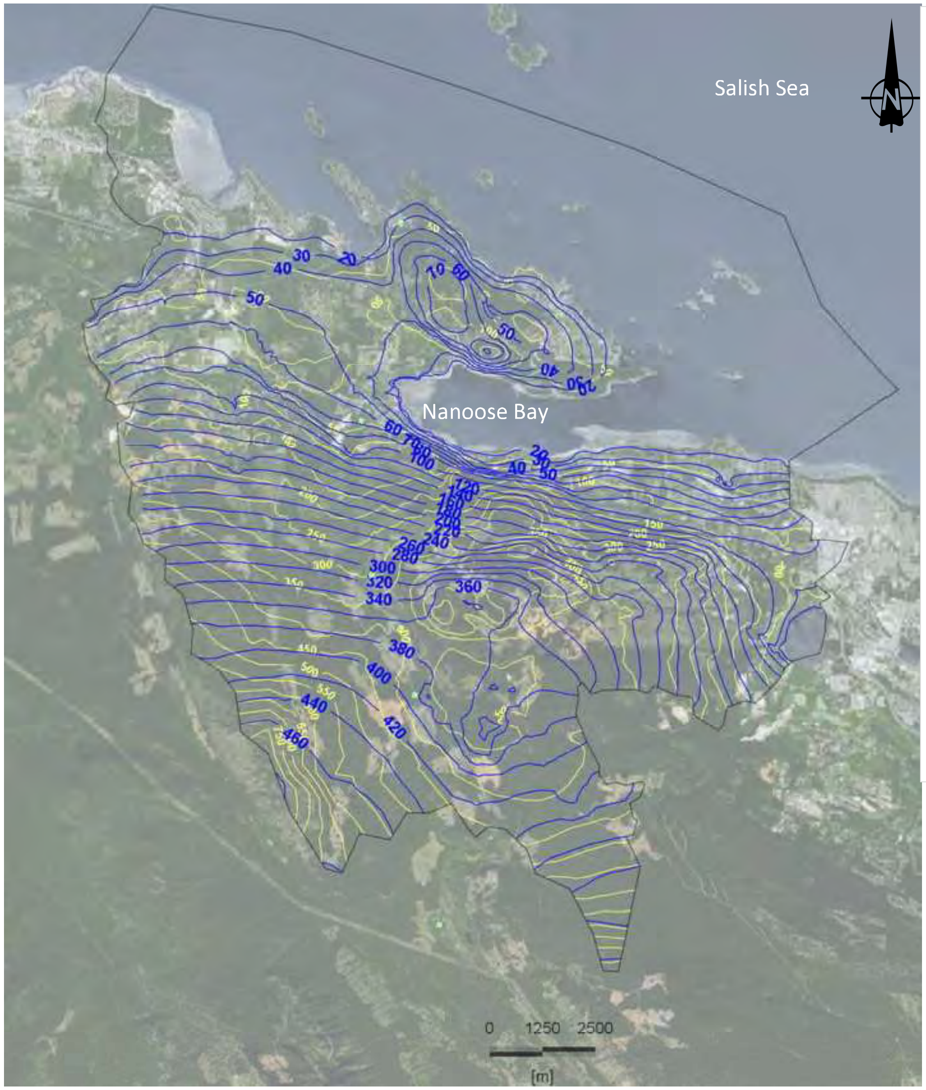
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MP

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	22C

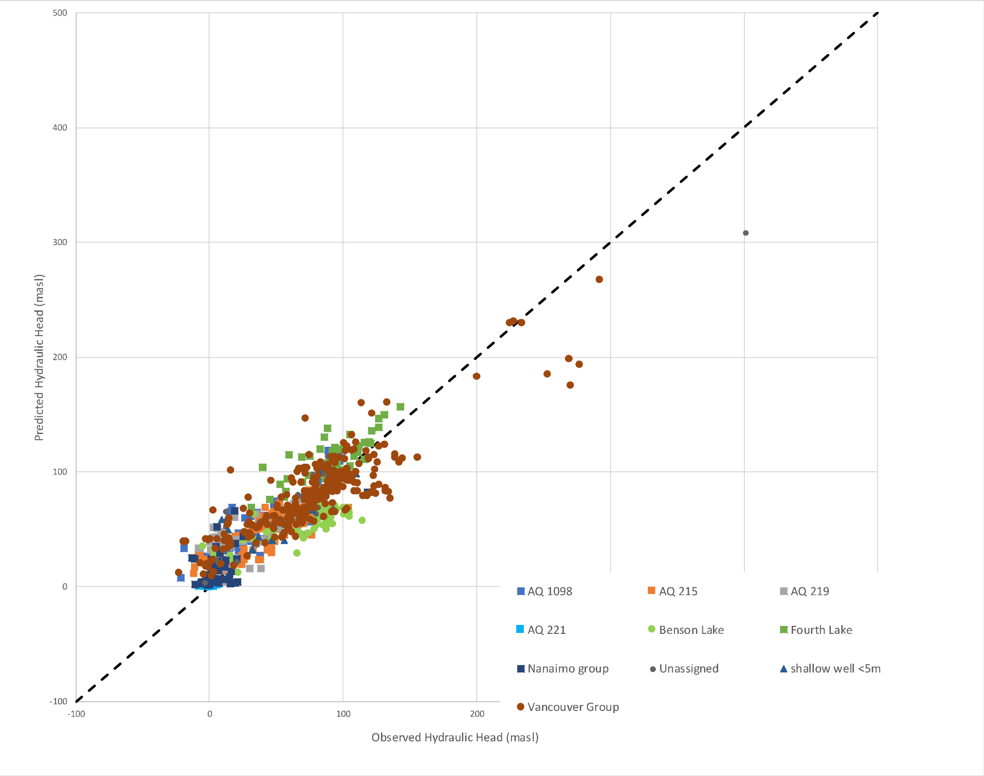
PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_22C_ESTIMATED_WATER_USE_OUTSIDE_OF_WATER_SERVICED_AREA_DRY_SEASON.mxd PRINTED ON: 2020-04-07 AT: 12:52:22 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
0

A. Plan View of Calibrated Hydraulic Heads (2006)



B. Comparison of Predicted and Observed Hydraulic Heads



Legend

▬ Hydraulic Head Contour (masl)

▬ Topographic Contour (masl)

▬ Model Boundary

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

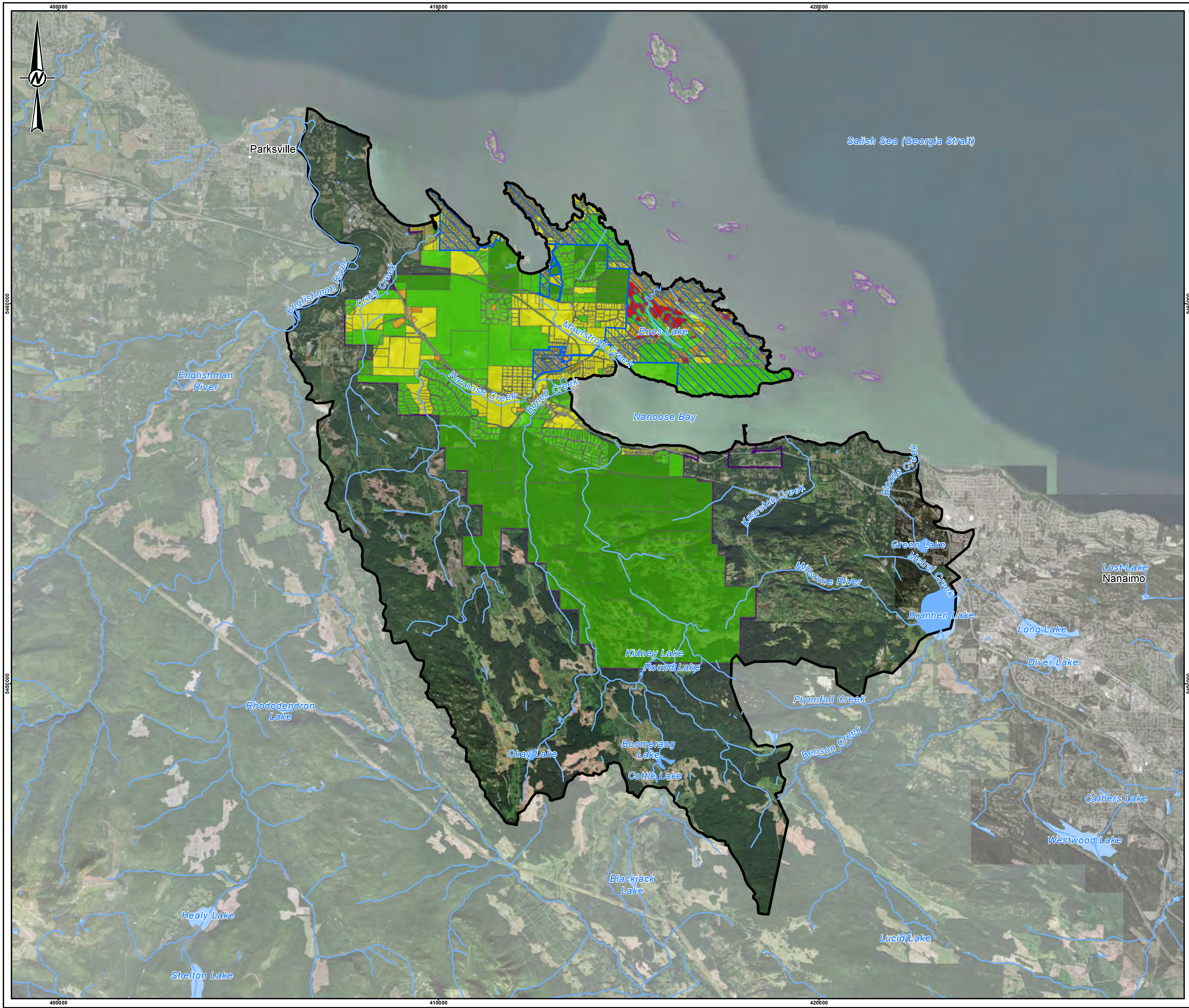
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
CALIBRATED HYDRAUYLIC HEAD CONTOURS (AVERAGE ANNUAL CONDITIONS)

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	0	23

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



LEGEND

- ▭ PROJECT AREA
- ▭ ELECTORAL AREA E
- 🟦 WATERBODY
- — WATERCOURSE
- ○ CITY / TOWN
- ▨ NANOOSE BAY PENINSULA WATER SYSTEM

MAXIMUM ALLOWED PARCEL COVERAGE (%)

- 🟩 0
- 🟩 0 - 20
- 🟨 20 - 40
- 🟧 40 - 60
- 🟥 60 - 80

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.
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5. THE MAXIMUM PARCEL COVERAGE INFORMATION WAS PROVIDED BY RDN.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
MAXIMUM ALLOWED PARCEL COVERAGE FOR CHANGES IN LAND COVER SCENARIO

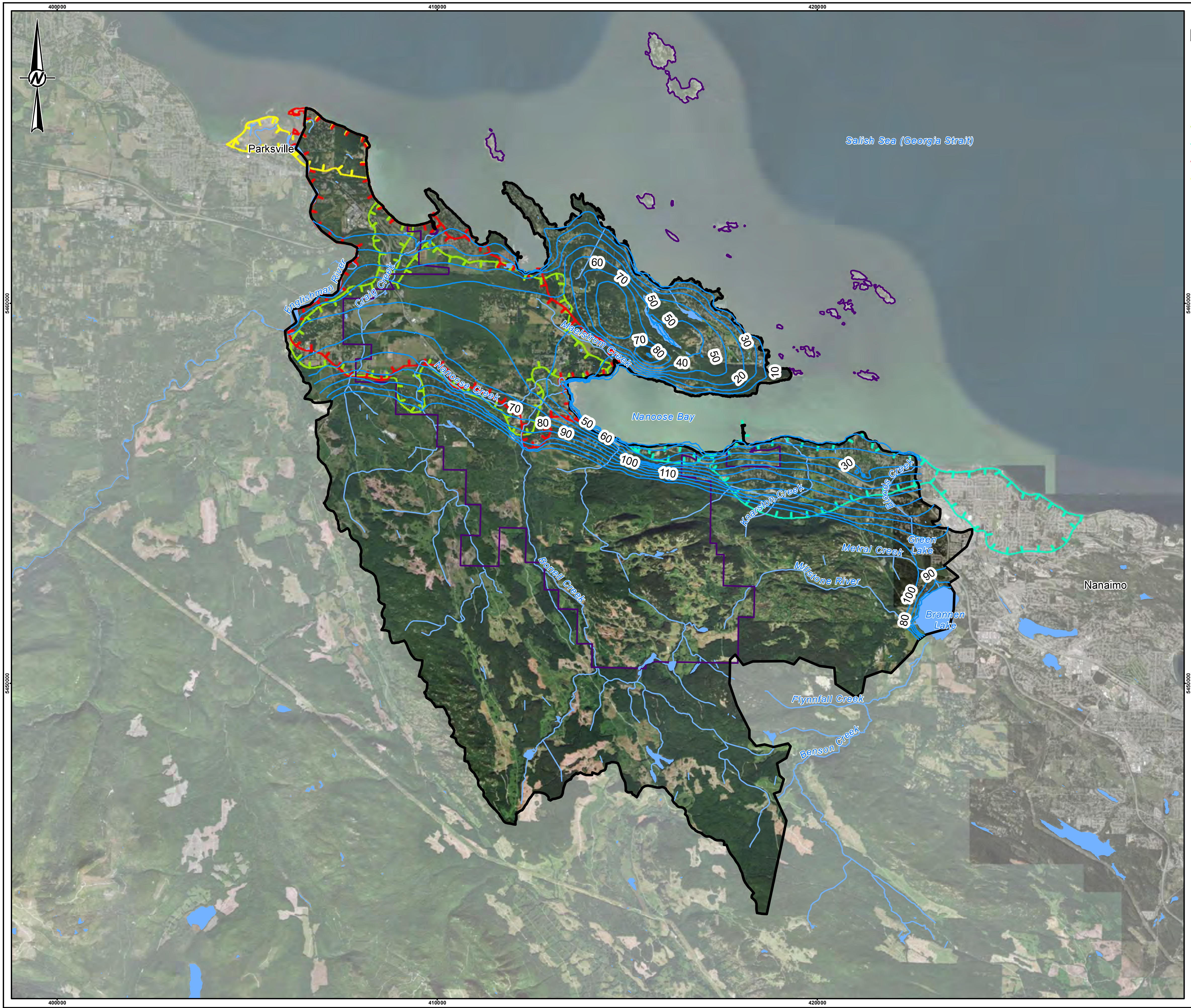
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	0	24

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_24_MAXIMUM_PARCEL_COVERAGE_FOR_CHANGES_IN_LAND_COVER_SCENARIO.mxd PRINTED ON: 2020-04-07 AT: 12:52:52 PM

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
- ○ CITY / TOWN

OVERBURDEN AQUIFER
AQUIFER NUMBER

- 🟩 AQ1098
- 🟦 AQ215
- 🟥 AQ219
- 🟨 AQ221
- — PREDICTED GROUNDWATER CONTOURS (masl)

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
PREDICTED GROUNDWATER CONTOURS
(CURRENT CONDITIONS - OVERBURDEN AQUIFERS)

CONSULTANT
GOLDER

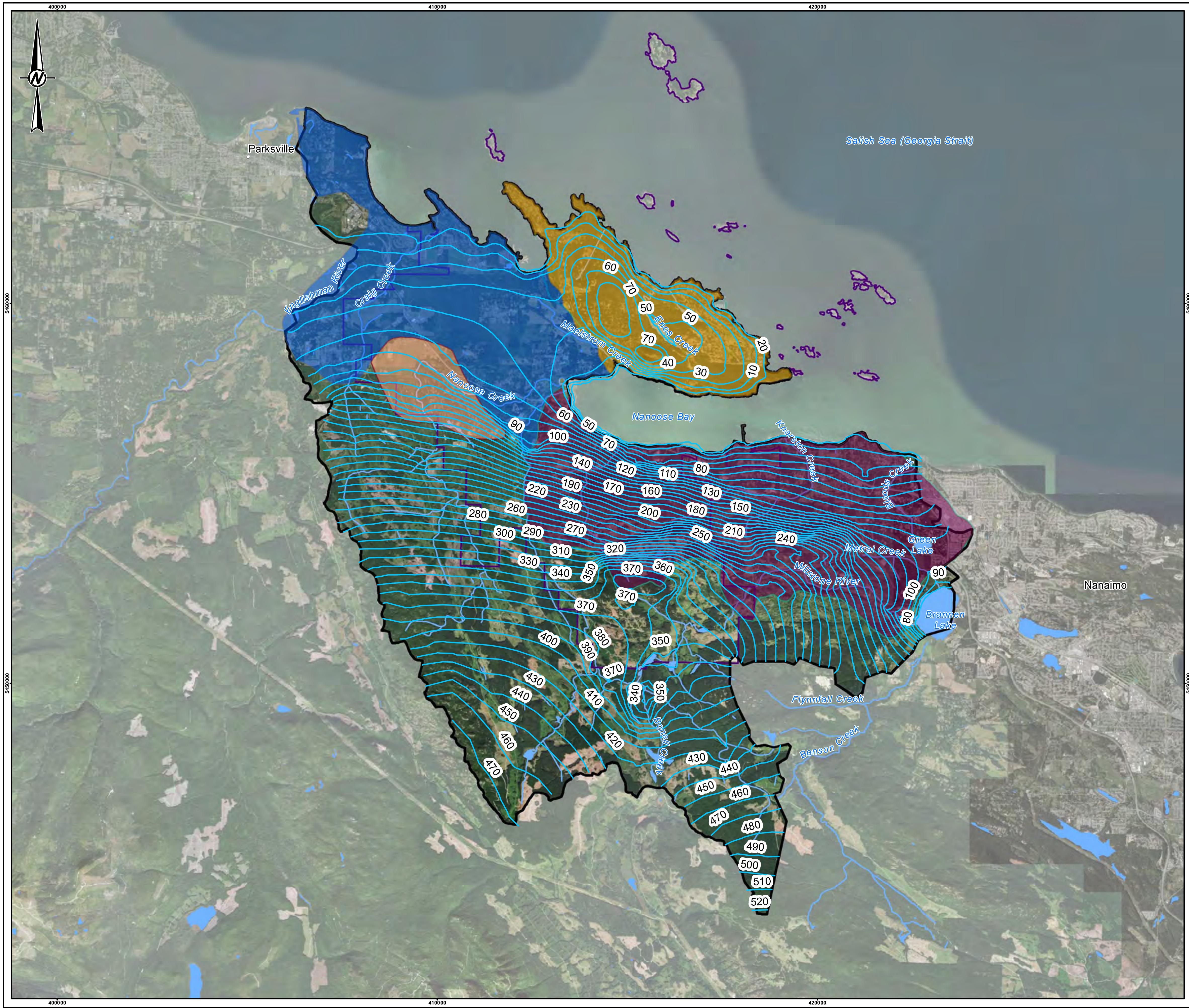
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	25

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_25_GROUNDWATER_CONTOURS_CURRENT_CONDITIONS_OVERBURDEN.mxd PRINTED ON: 2020-04-07 AT: 12:53:18 PM

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
- ○ CITY / TOWN

BEDROCK AQUIFER

AQUIFER NUMBER

- 🟧 AQ 210
- 🟪 AQ 213
- 🟦 AQ 214
- 🟨 AQ 218
- — PREDICTED GROUNDWATER CONTOURS (masl)

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
PREDICTED GROUNDWATER CONTOURS (CURRENT CONDITIONS - BEDROCK AQUIFERS)

CONSULTANT

GOLDER

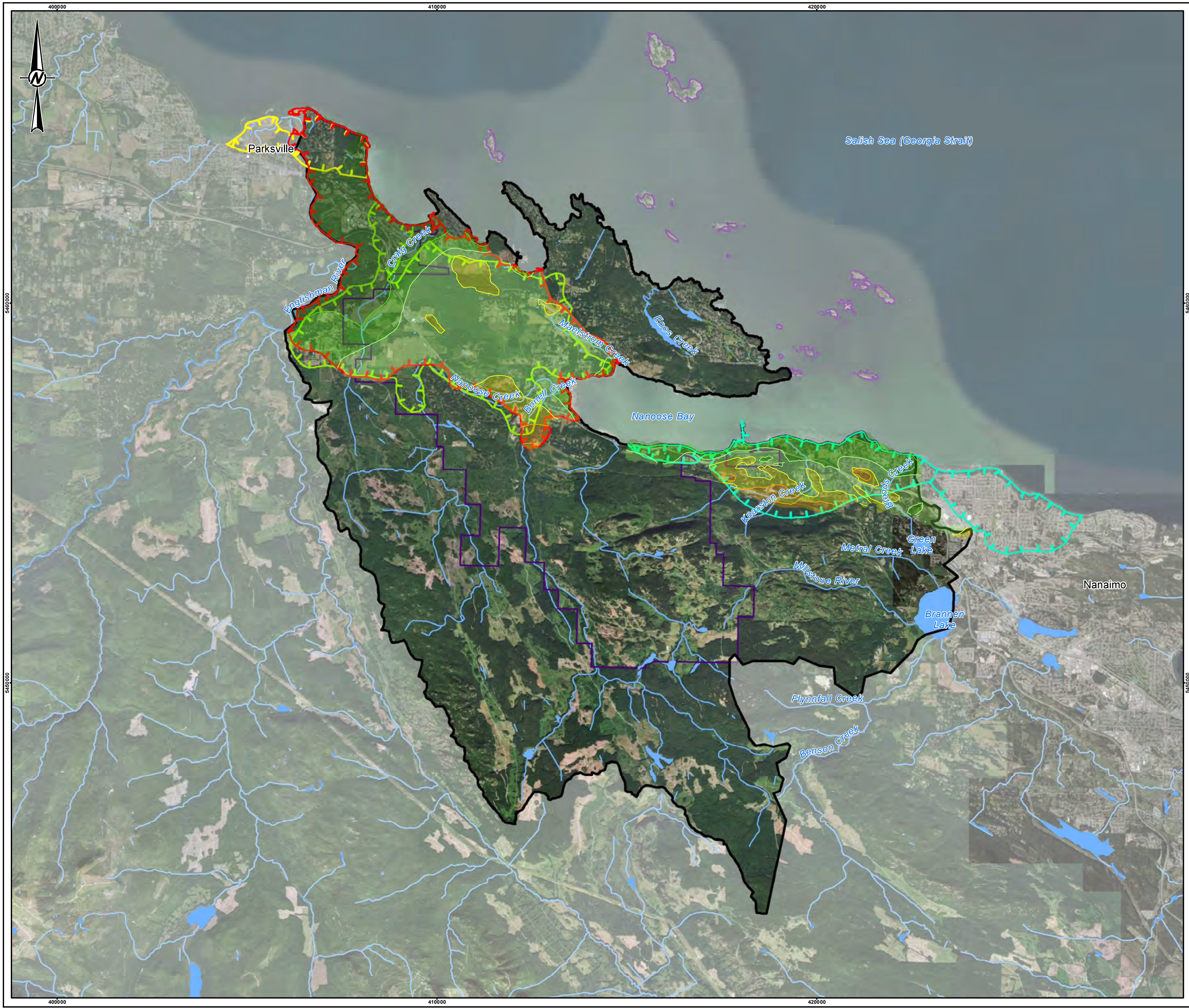
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	26

25mm

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

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_26_GROUNDWATER_CONTOURS_CURRENT_CONDITIONS_BEDROCK.mxd PRINTED ON: 2020-04-07 AT: 12:54:11 PM



LEGEND

- PROJECT AREA
- ELECTORAL AREA E
- CITY / TOWN

OVERBURDEN AQUIFER

AQUIFER NUMBER

- AQ1098
- AQ215
- AQ219
- AQ221

DECLINE IN WATER LEVEL

- 0 -1 m
- 1 - 2 m
- 2 - 3 m
- 3 - 4 m
- 4 - 5 m

DECLINE IN WATER LEVEL (CONTOURS)

- 1 m
- 2 m
- 3 m
- 4 m

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SCENARIO 1 POTENTIAL CLIMATE CHANGE: PREDICTED DECLINE IN WATER LEVEL (DRY SEASON) IN OVERBURDEN

CONSULTANT
GOLDER

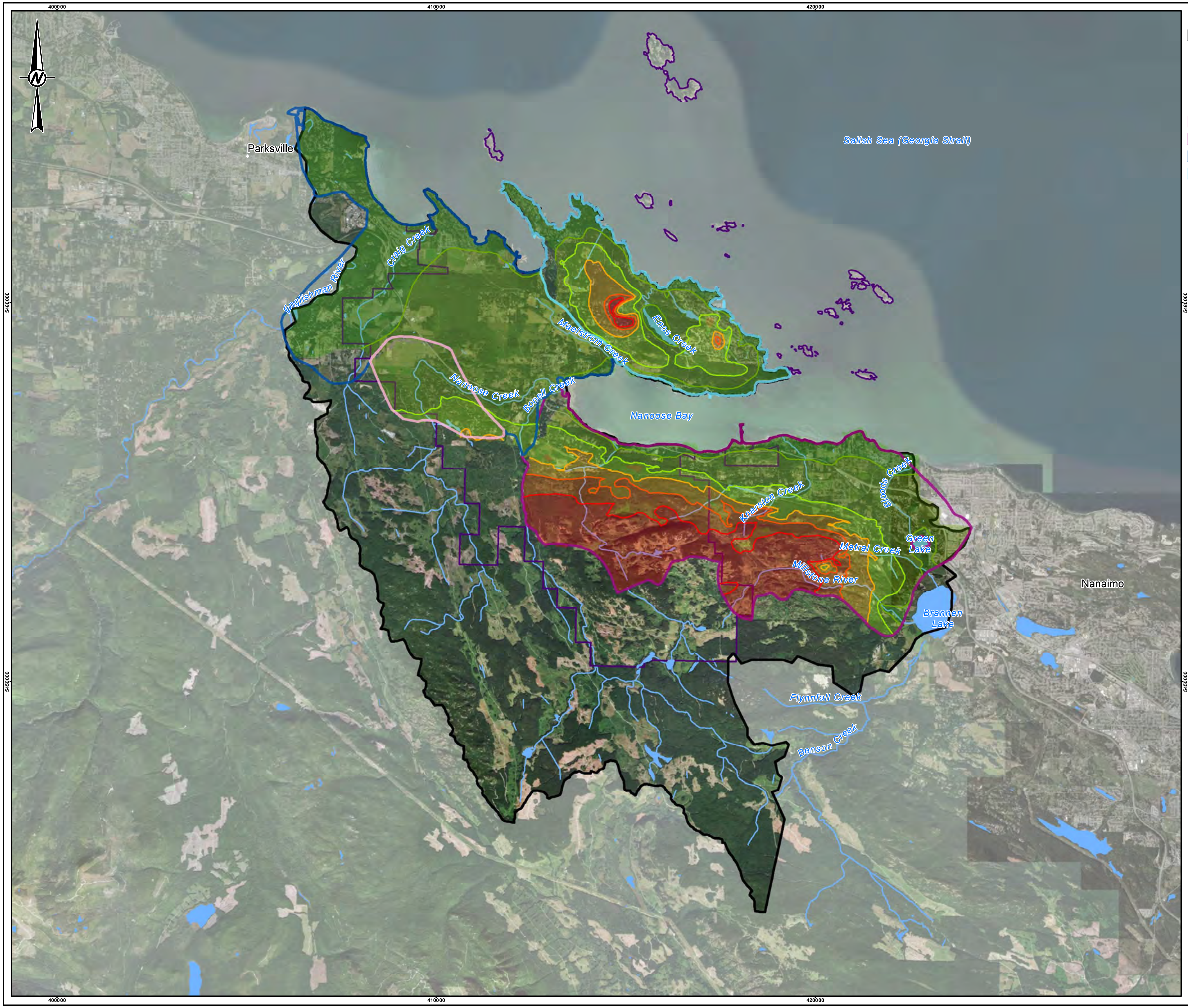
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/RKW
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	27

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_27_SCENARIO1_CLIMATE_CHANGE_SCENARIO_DECLINE_IN_WATERLEVEL_OVERBURDEN.mxd PRINTED ON: 2020-04-07 AT: 12:54:19 PM

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
- ○ CITY / TOWN

BEDROCK AQUIFER

AQUIFER NUMBER

- ▭ AQ210
- ▭ AQ213
- ▭ AQ214
- ▭ AQ218

DECLINE IN WATER LEVEL

- 🟩 0 - 2 m
- 🟩 2 - 4 m
- 🟩 4 - 6 m
- 🟨 6 - 8 m
- 🟧 8 - 10 m
- 🟥 > 10 m

DECLINE IN WATERLEVEL (CONTOURS)

- — 2 m
- — 4 m
- — 6 m
- — 8 m
- — 10 m

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SCENARIO 1 POTENTIAL CLIMATE CHANGE: PREDICTED DECLINE IN WATER LEVEL (DRY SEASON) IN BEDROCK

CONSULTANT
GOLDER

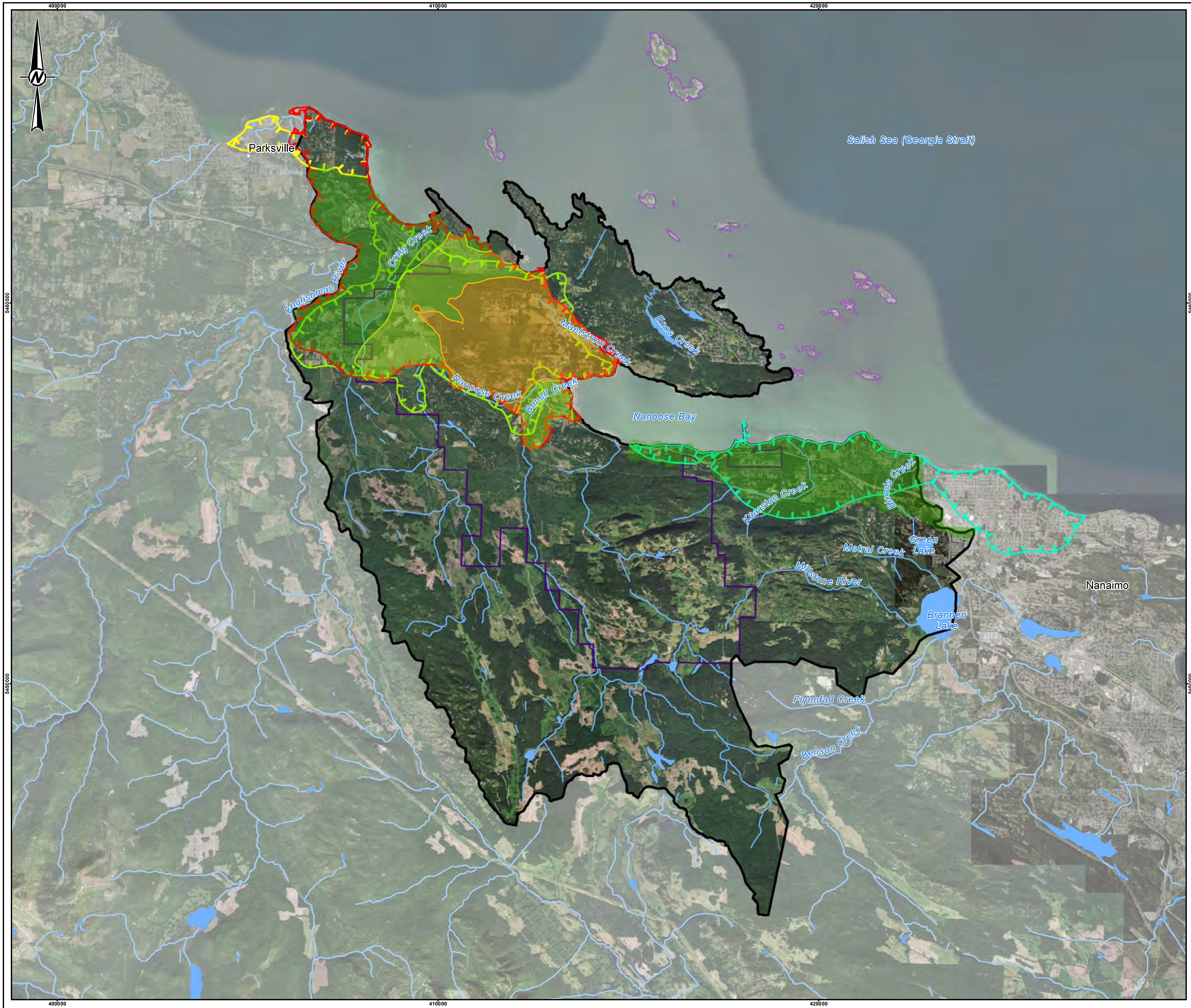
YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	28

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_28_SCENARIO1_CLIMATE_CHANGE_SCENARIO_DECLINE_IN_WATERLEVEL_BEDROCK.mxd PRINTED ON: 2020-04-07 AT: 1:04:40 PM

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
○	CITY / TOWN

OVERBURDEN AQUIFER

AQUIFER NUMBER

🟩	AQ1098
🟦	AQ215
🟥	AQ219
🟨	AQ221

DECLINE IN WATERLEVEL

🟩	0 m
🟩	0 - 1 m
🟧	1 - 2 m
🟥	2 - 3 m

DECLINE IN WATERLEVEL (CONTOURS)

—	0 m
—	1 m
—	2 m
—	3 m

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SCENARIO 3 CHANGES IN LANDCOVER: PREDICTED DECLINE IN WATER LEVEL (DRY SEASON) IN OVERBURDEN AQUIFERS

CONSULTANT

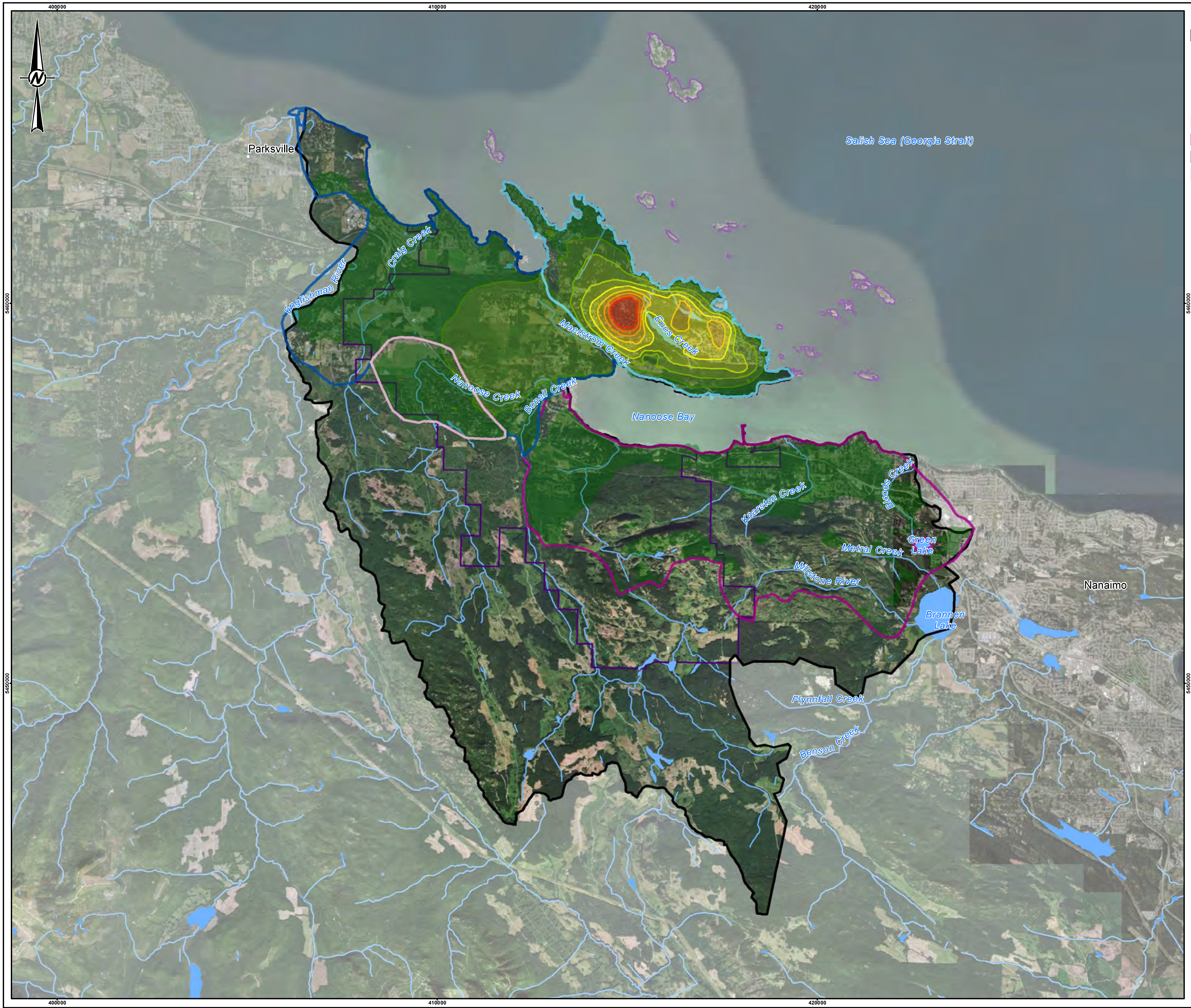
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/RKW
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	29

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_29_SCENARIO3_LANDCOVER_DECLINE_IN_WATERLEVEL_OVERBURDEN.mxd PRINTED ON: 2020-04-07 AT: 12:58:09 PM

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
◦ CITY / TOWN

BEDROCK AQUIFER
AQUIFER NUMBER
▭ AQ210
▭ AQ213
▭ AQ214
▭ AQ218

DECLINE IN WATER LEVEL
🟩 0 - 2 m
🟩 2 - 4 m
🟩 4 - 6 m
🟨 6 - 8 m
🟨 8 - 10 m
🟨 10 - 12 m
🟧 12 -14 m
🟧 14 -16 m
🟥 >16 m

DECLINE IN WATERLEVEL (CONTOURS)
— 2 m
— 4 m
— 6 m
— 8 m
— 10 m
— 12 m
— 14 m
— 16 m

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SCENARIO 3 CHANGES IN LANDCOVER: PREDICTED DECLINE IN WATER LEVEL IN BEDROCK AQUIFERS

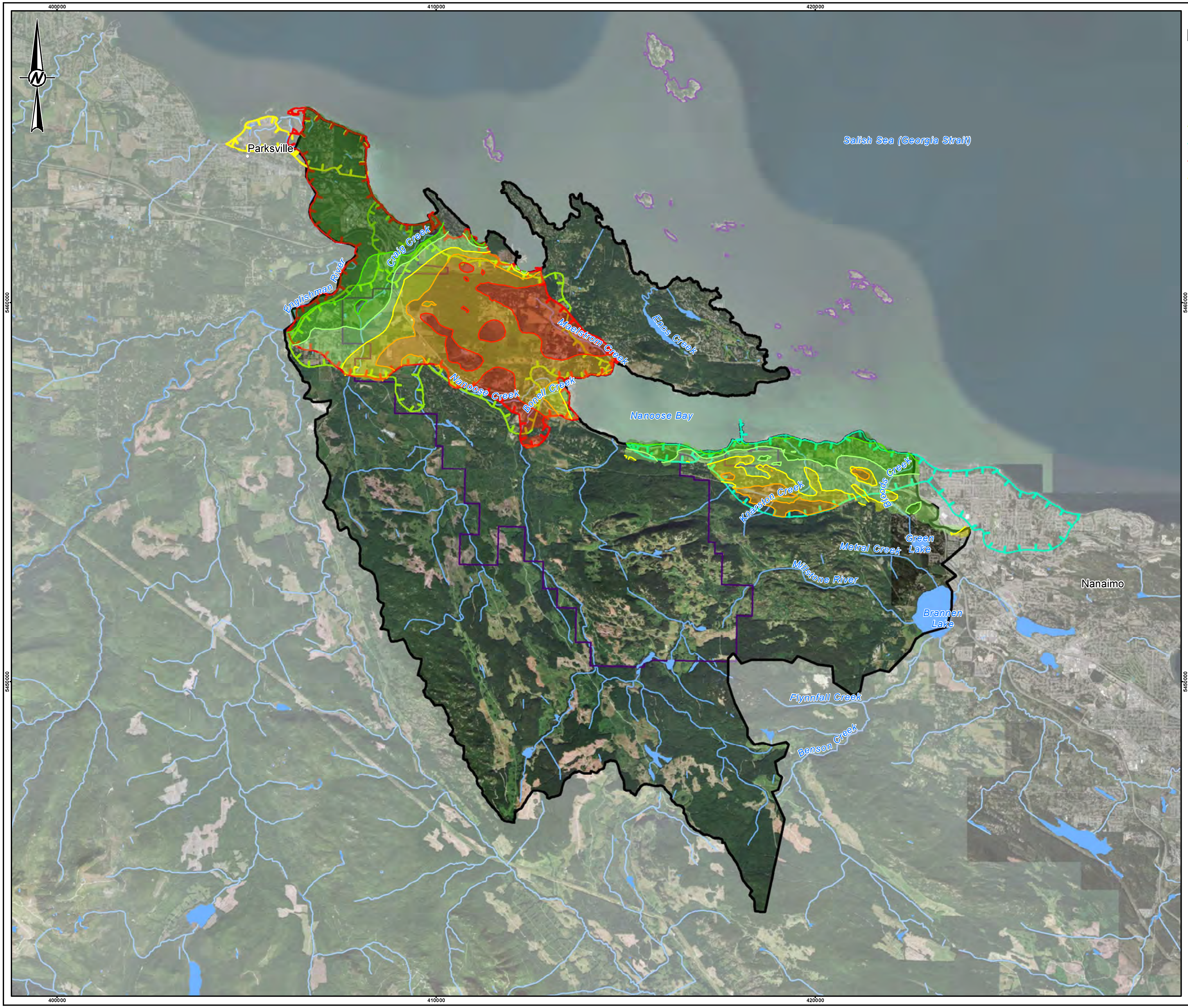
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/RKW
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	30

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
0

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_30_SCENARIO3_LANDCOVER_DECLINE_IN_WATERLEVEL_BEDROCK.mxd PRINTED ON: 2020-04-07 AT: 12:58:44 PM



LEGEND

▭ PROJECT AREA

▭ ELECTORAL AREA E

○ CITY / TOWN

OVERBURDEN AQUIFER

AQUIFER NUMBER

AQ1098

AQ215

AQ219

AQ221

DECLINE IN WATER LEVEL

0 - 1 m

1 - 2 m

2 - 3 m

3 - 4 m

4 - 5 m

5 - 6 m

DECLINE IN WATERLEVEL (CONTOURS)

— 1 m

— 2 m

— 3 m

— 4 m

— 5 m

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT

REGIONAL DISTRICT OF NANAIMO

PROJECT

REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE

SCENARIO 4 (SCENARIO 1 AND 3 COMBINED) – PREDICTED DECLINE IN WATER LEVEL IN OVERBURDEN AQUIFERS

CONSULTANT

GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	31

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_31_SCENARIO_4_(SCENARIO_1_AND_3_COMBINED)_PREDICTED_DECLINE_IN_WATER_LEVEL_IN_OVERBURDEN_AQUIFERS.mxd PRINTED ON: 2020-04-07 AT: 12:58:59 PM

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
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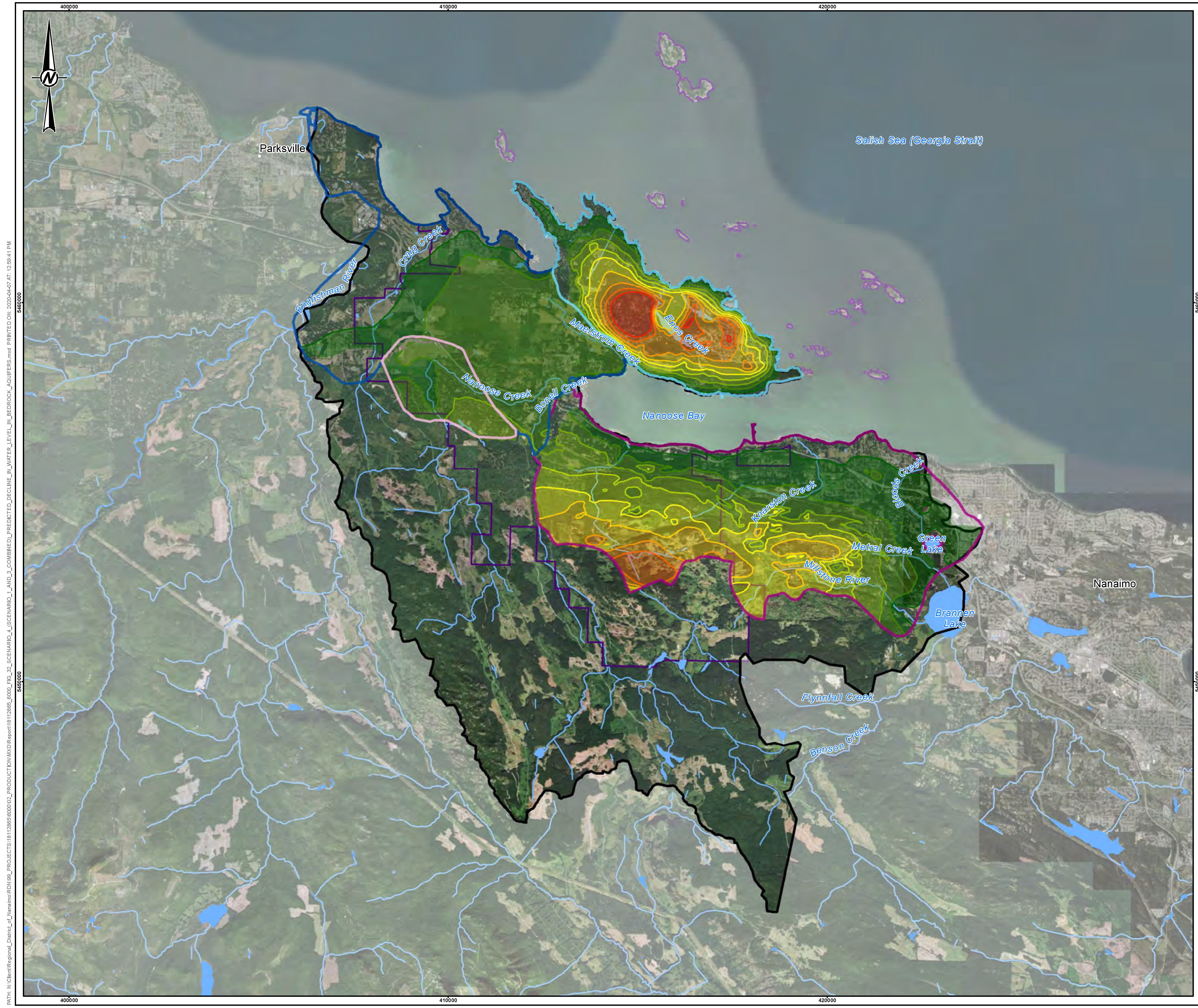

LEGEND

- ▭ PROJECT AREA
- ▭ ELECTORAL AREA E
- ○ CITY / TOWN

BEDROCK AQUIFER

AQUIFER NUMBER

- ▭ AQ210
- ▭ AQ213
- ▭ AQ214
- ▭ AQ218

DECLINE IN WATER LEVEL

- 🟩 2 - 4 m
- 🟩 4 - 6 m
- 🟩 6 - 8 m
- 🟨 8 - 10 m
- 🟨 10 - 12 m
- 🟨 12 - 14 m
- 🟧 14 - 16 m
- 🟧 16 - 18 m
- 🟥 18 - 20 m

DECLINE IN WATERLEVEL (CONTOURS)

- — 2 m
- — 4 m
- — 6 m
- — 8 m
- — 10 m
- — 12 m
- — 14 m
- — 16 m
- — 18 m

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SCENARIO 4 (SCENARIO 1 AND 3 COMBINED) – PREDICTED DECLINE IN WATER LEVEL IN BEDROCK AQUIFERS

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	32

25mm
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
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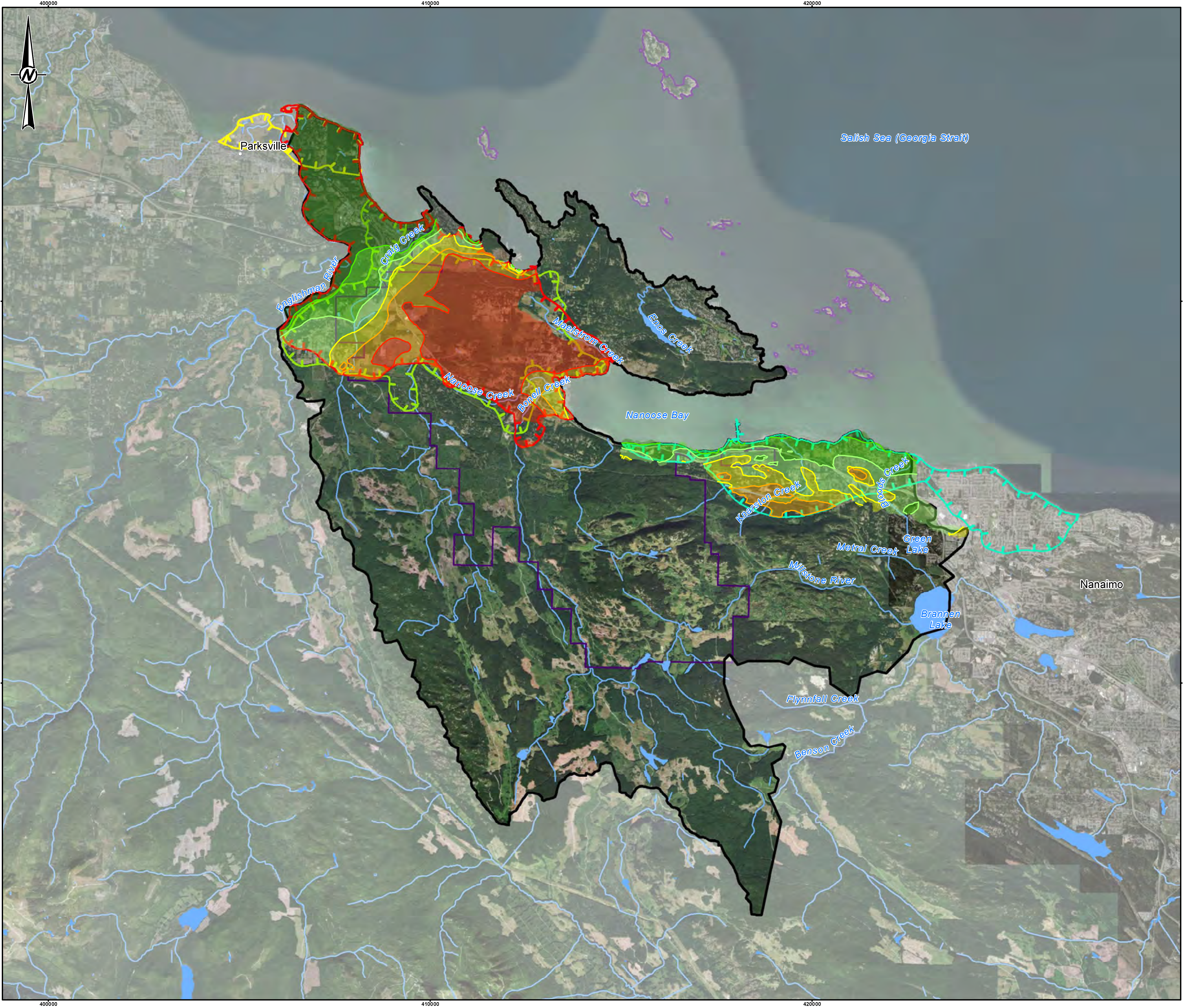

LEGEND

▭	PROJECT AREA
▭	ELECTORAL AREA E
○	CITY / TOWN

OVERBURDEN AQUIFER

AQUIFER NUMBER

🟩	AQ1098
🟦	AQ215
🟥	AQ219
🟨	AQ221

DECLINE IN WATER LEVEL

🟩	0 - 1 m
🟩	1 - 2 m
🟩	2 - 3 m
🟨	3 - 4 m
🟧	4 - 5 m
🟥	5 - 6 m

DECLINE IN WATERLEVEL (CONTOURS)

—	1 m
—	2 m
—	3 m
—	4 m
—	5 m

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: DIGITALGLOBE. USED UNDER LICENSE, ALL RIGHTS RESERVED. IMAGERY DATE: 20160912.

COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SCENARIO 5 (SCENARIO 1, 2 AND 3 COMBINED) – PREDICTED DECLINE IN WATER LEVEL IN OVERBURDEN AQUIFERS

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	33

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm
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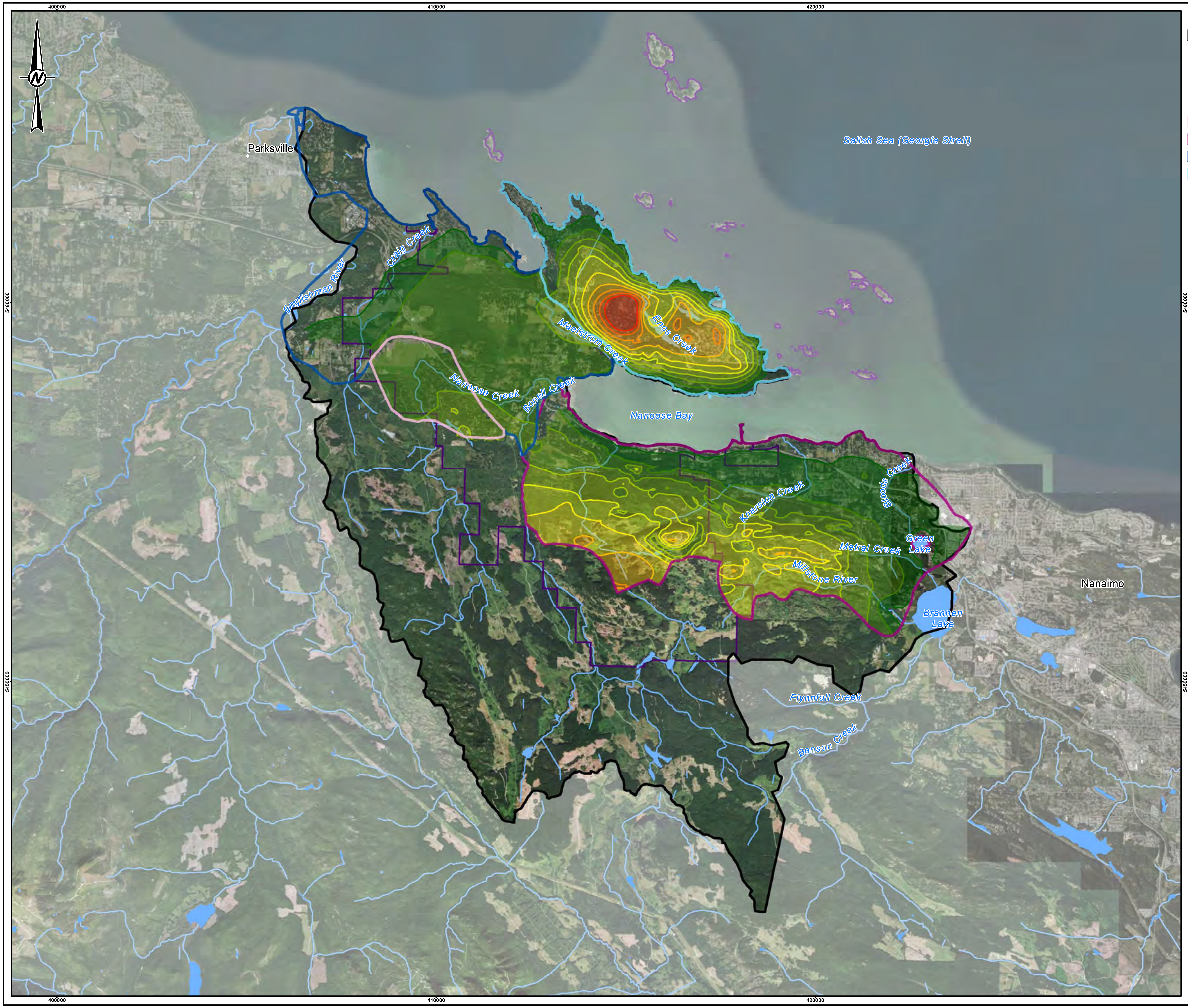

LEGEND

▭ PROJECT AREA
▭ ELECTORAL AREA E
○ CITY / TOWN

BEDROCK AQUIFER

AQUIFER NUMBER

▭ AQ210
▭ AQ213
▭ AQ214
▭ AQ218

DECLINE IN WATER LEVEL

🟩 2 - 4 m
🟩 4 - 6 m
🟩 6 - 8 m
🟨 8 - 10 m
🟨 10 - 12 m
🟨 12 - 14 m
🟧 14 - 16 m
🟧 16 - 18 m
🟧 18 - 20 m
🟥 > 20 m

DECLINE IN WATERLEVEL (CONTOURS)

— 2 m
— 4 m
— 6 m
— 8 m
— 10 m
— 12 m
— 14 m
— 16 m
— 18 m
— 20 m

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.
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COORDINATE SYSTEM: NAD83 UTM ZONE 10.

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

TITLE
SCENARIO 5 (SCENARIO 1, 2 AND 3 COMBINED) – PREDICTED DECLINE IN WATER LEVEL IN BEDROCK AQUIFERS

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-07
DESIGNED	AP
PREPARED	AD/CDAB
REVIEWED	AP
APPROVED	MB

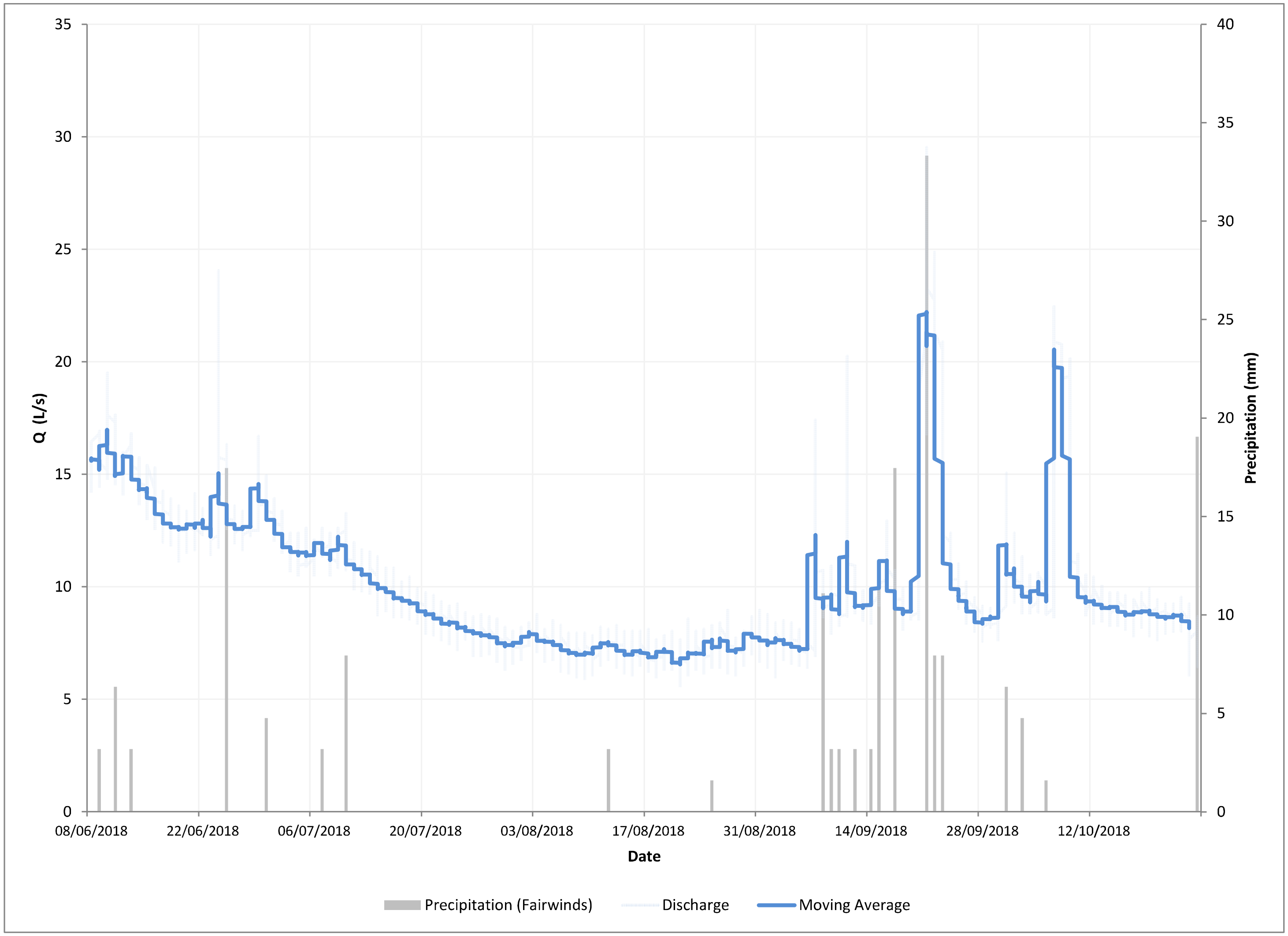
PROJECT NO.	CONTROL	REV.	FIGURE
18112865	6000	A	34

25mm
0
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

PATH: N:\Client\Regional_District_of_Nanaimo\RDN\99_PROJECTS\18112865\6000\02_PRODUCTION\MXD\Report\18112865_6000_FIG_34_SCENARIO_5_(SCENARIO_1_2_3_COMBINED)__PREDICTED_DECLINE_IN_WATER_LEVEL_IN_BEDROCK_AQUIFERS.mxd PRINTED ON: 2020-04-07 AT: 1:00:28 PM

APPENDIX A

Stream Flow Data



Notes:
Stream Flow Data provided by FLNRO (May 2019)
Precipitation from Fairwinds Climate Station provided
By RDN (May, 2019)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

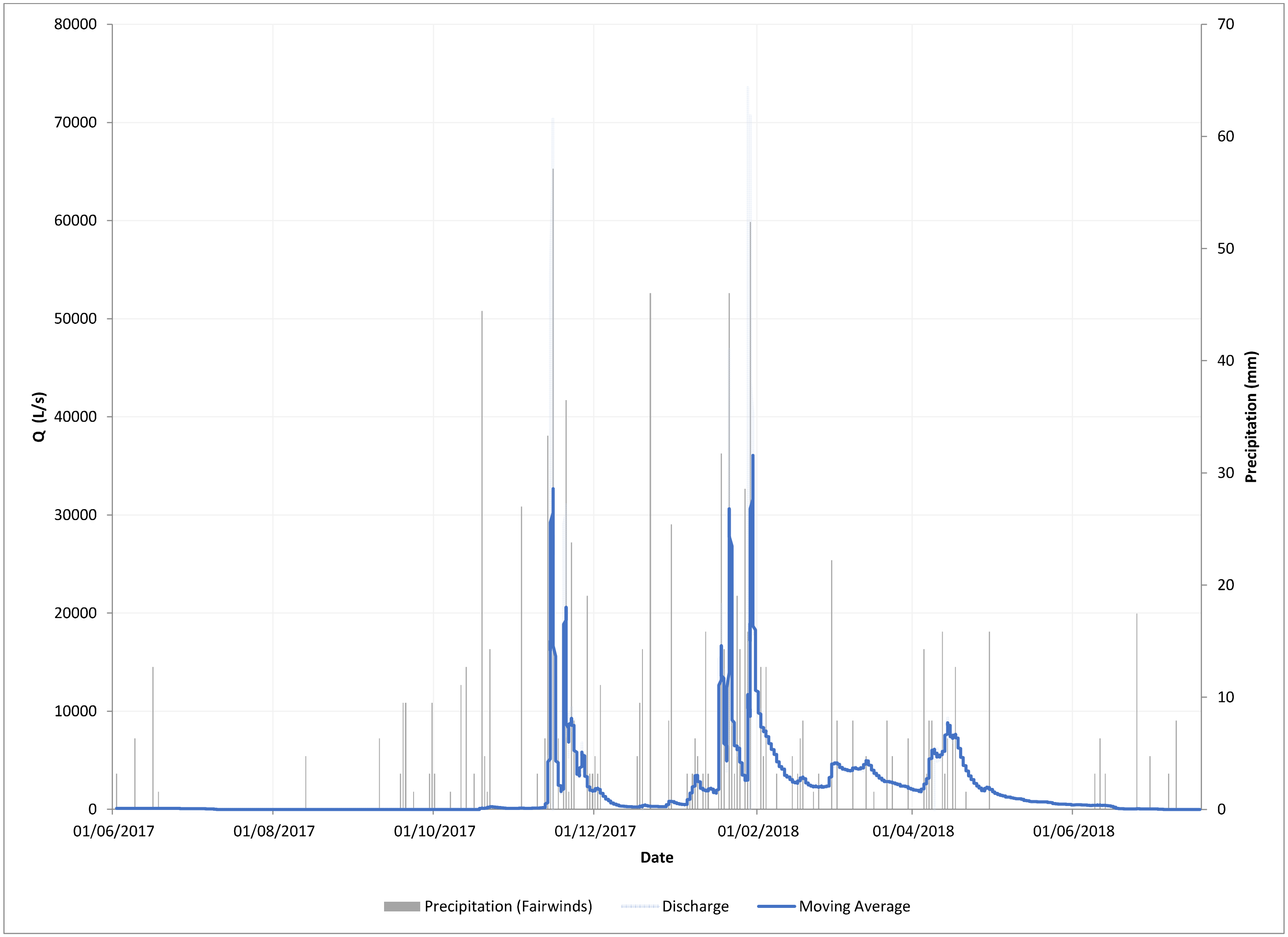
CONSULTANT
GOLDER

YYYY-MM-DD	2020-03-31
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
STREAM FLOW DATA AT CRAIG CREEK NEAR NORTHWEST BAY ROAD (2018)

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	A	A1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



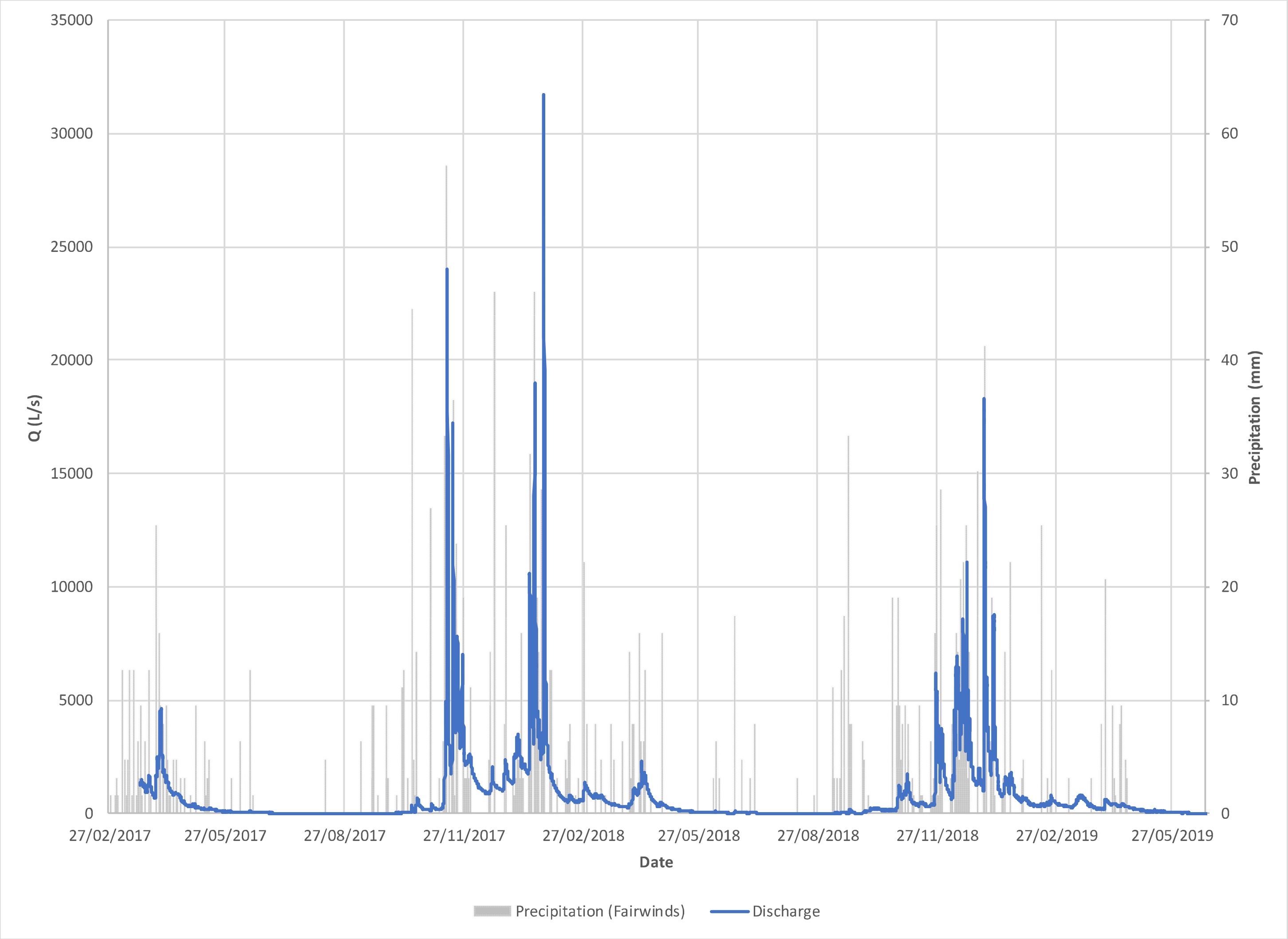
Notes:
Stream Flow Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca)
Precipitation from Fairwinds Climate Station provided
By RDN (May, 2019)

CLIENT	REGIONAL DISTRICT OF NANAIMO
PROJECT	REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E
CONSULTANT	GOLDER
YYYY-MM-DD	2020-03-31
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
STREAM FLOW DATA AT BONELL CREEK
D/S OF HWY 19 BRODGE
(2017-2018)

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	A	A2

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Notes:
Stream Flow Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca)
Precipitation from Fairwinds Climate Station provided
By RDN (May, 2019)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

CONSULTANT

GOLDER

YYYY-MM-DD	2020-03-31
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

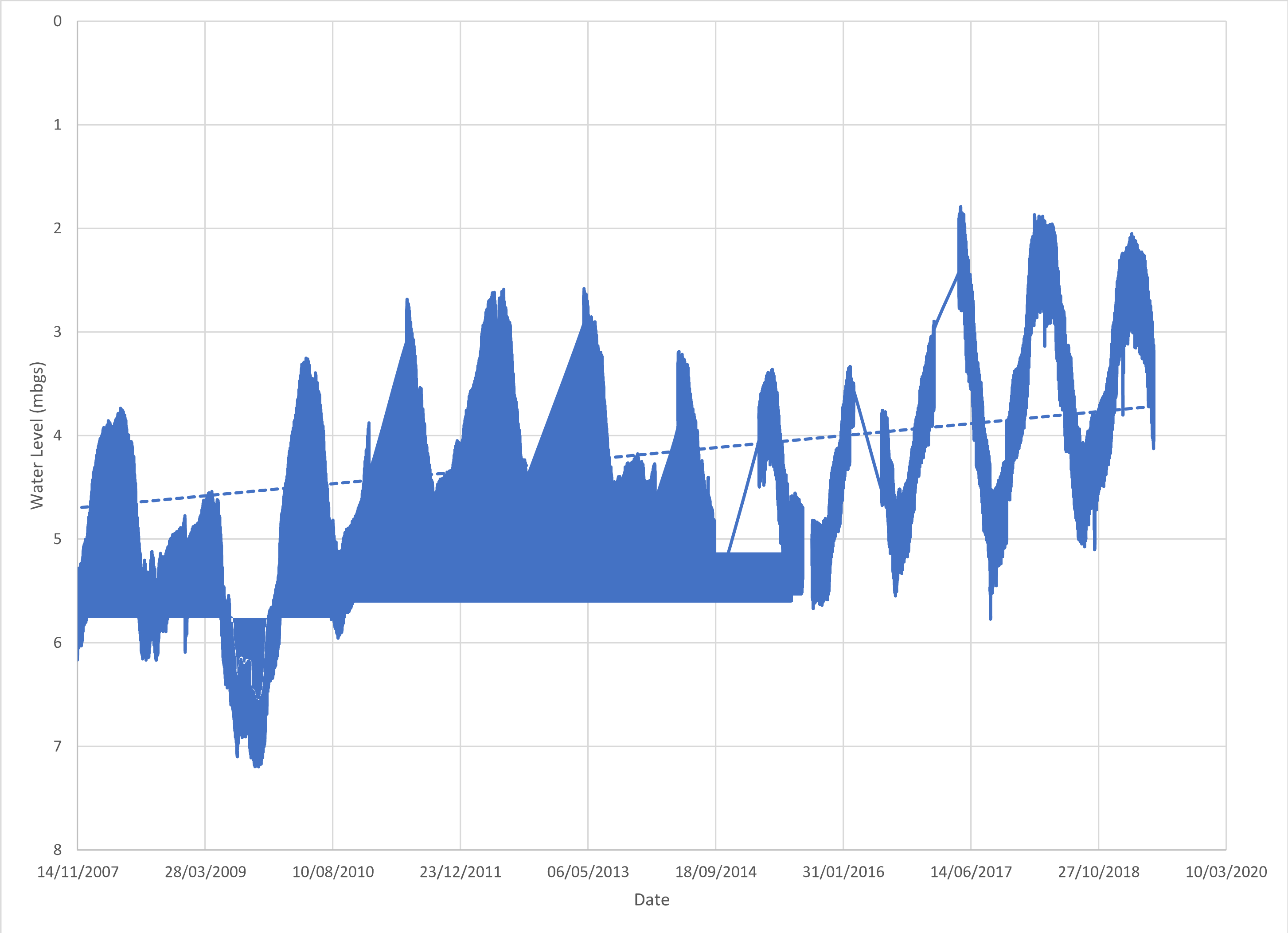
TITLE
STREAM FLOW DATA AT NANOOSE CREEK NEAR HWY 19 (2017-2019)

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	A	A3

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0

APPENDIX B

Hydrographs for PGOWN and RDN Voluntary Monitoring Wells



Notes:
Stream Flow Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
BC ENV OBS WELL 232
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	**6000**	**0**	**B1**

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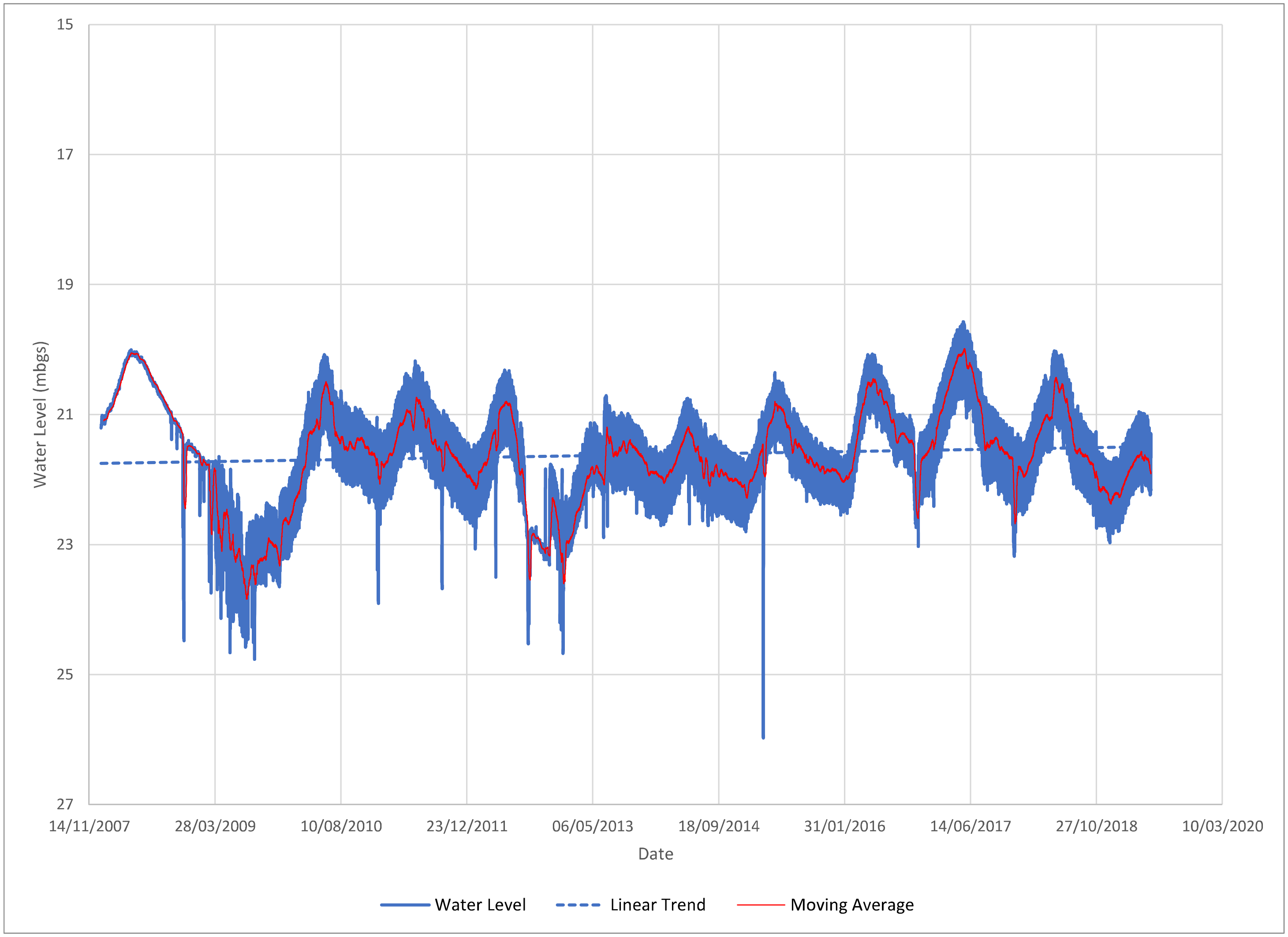


Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

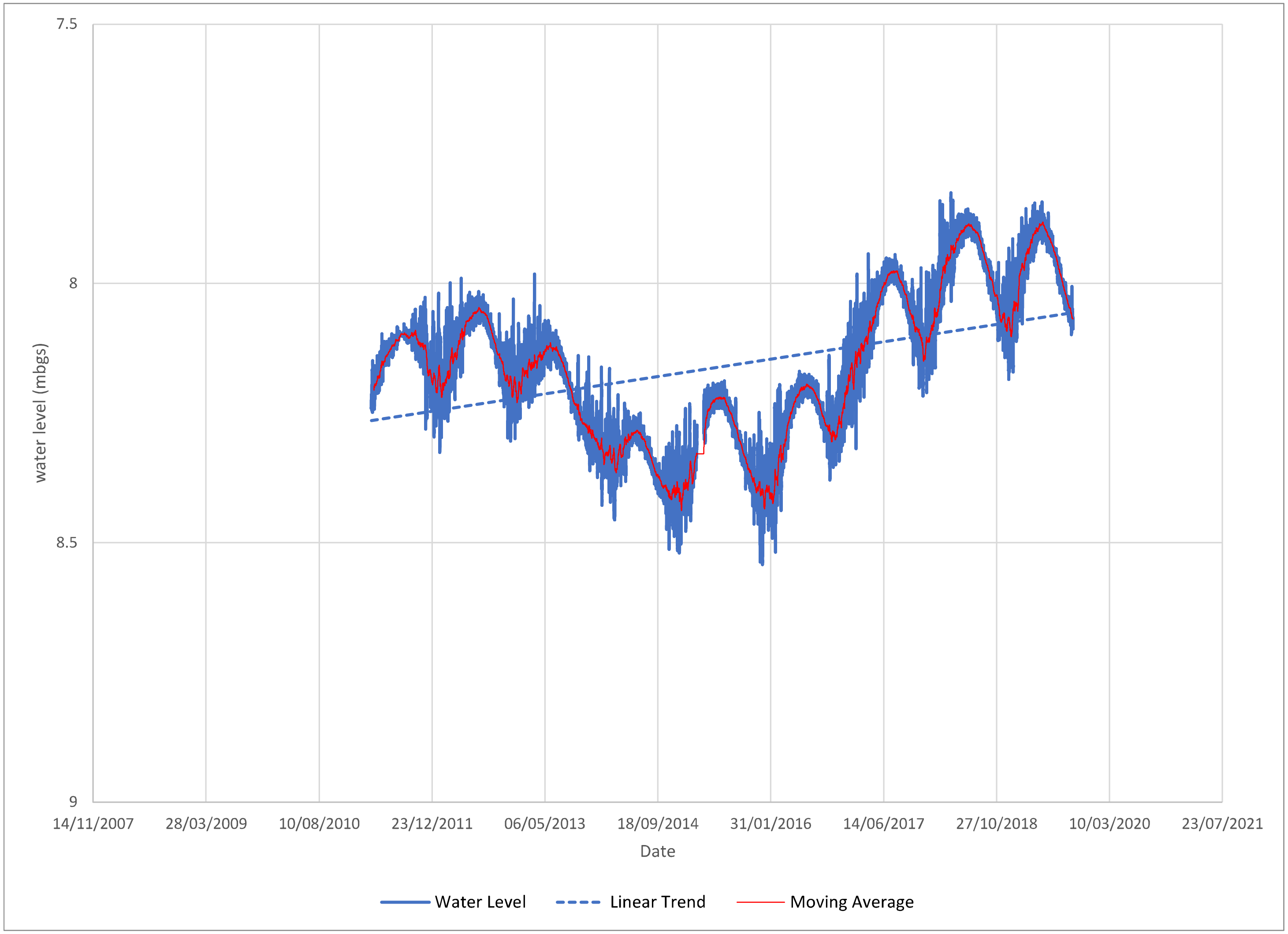
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
BC ENV OBS WELL 340
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	**6000**	**0**	**B2**

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
0 1 in



Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

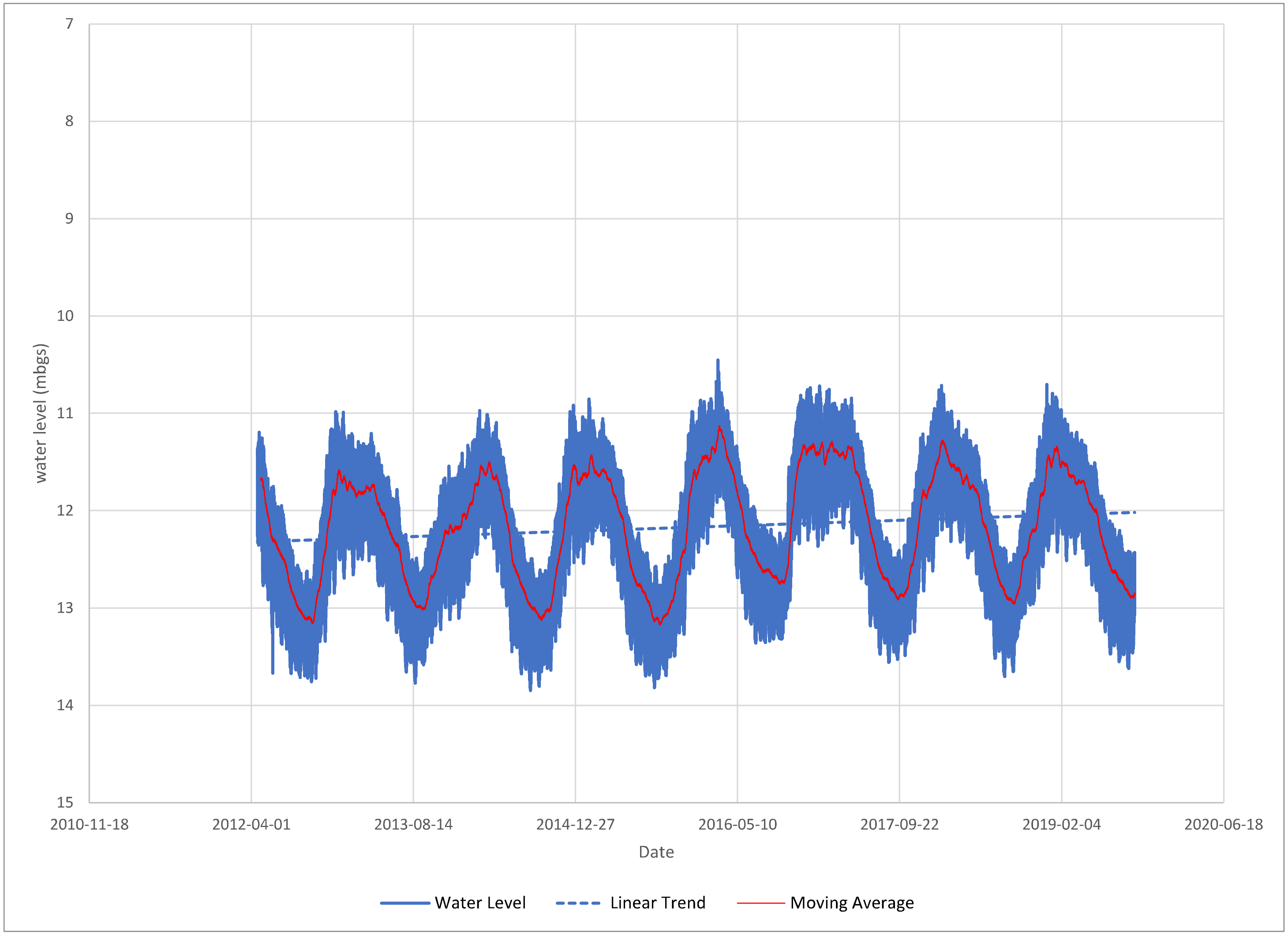
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
BC ENV OBS WELL 393
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	**6000**	**0**	**B3**

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

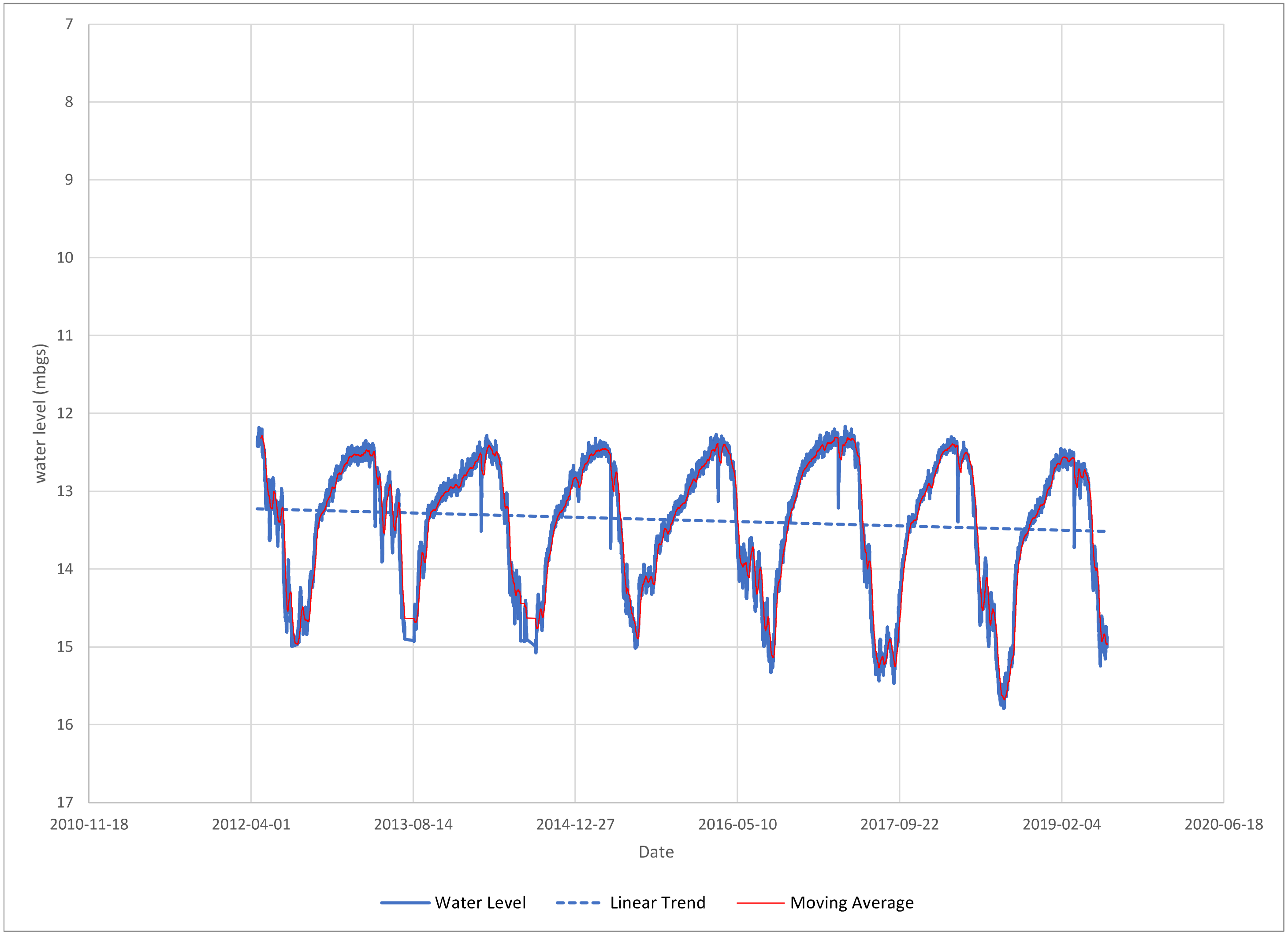
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
BC ENV OBS WELL 394
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	**6000**	**0**	**B4**

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

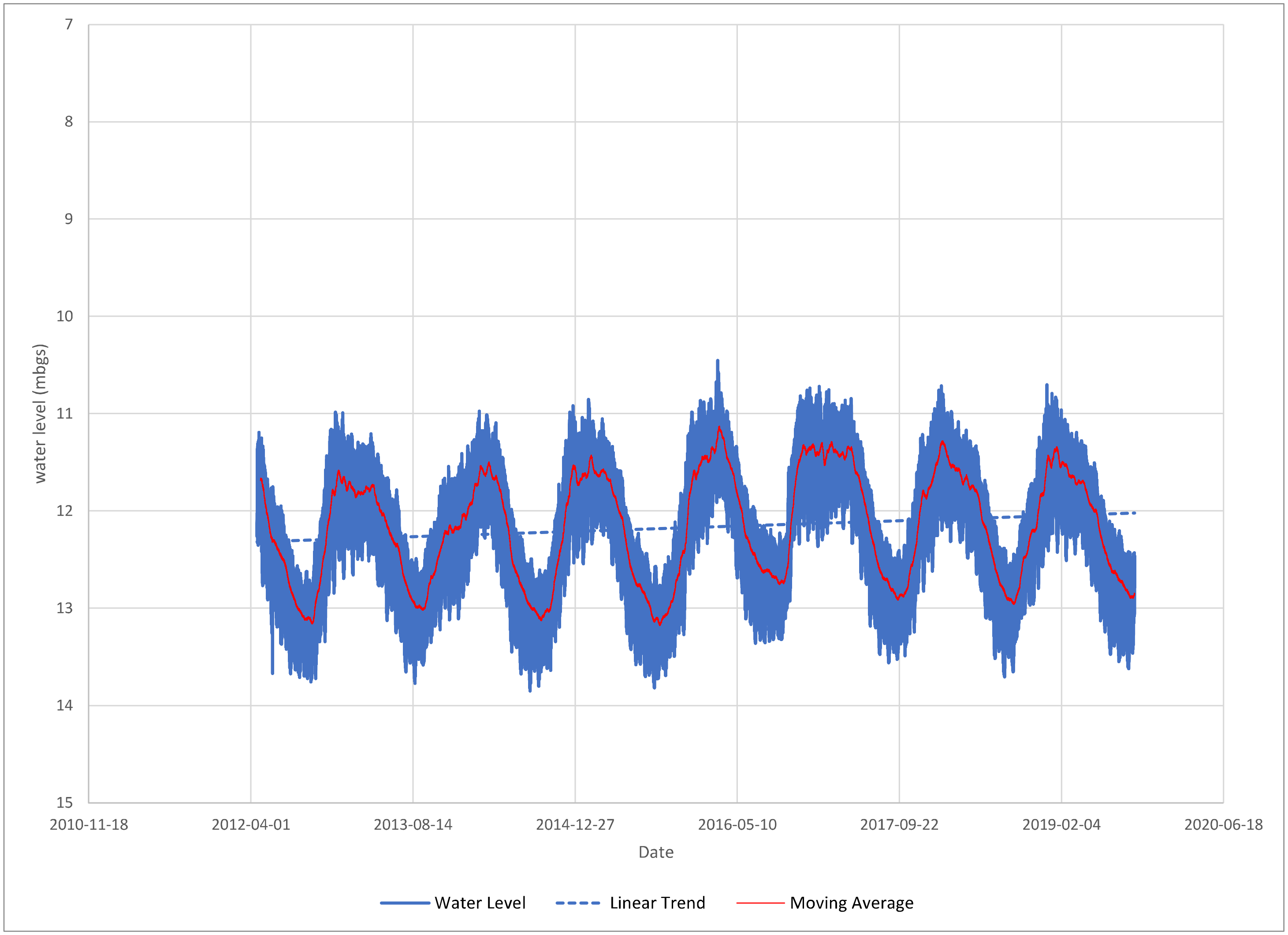
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
BC ENV OBS WELL 395
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	0	B5

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT	REGIONAL DISTRICT OF NANAIMO
PROJECT	REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E
CONSULTANT	GOLDER
YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

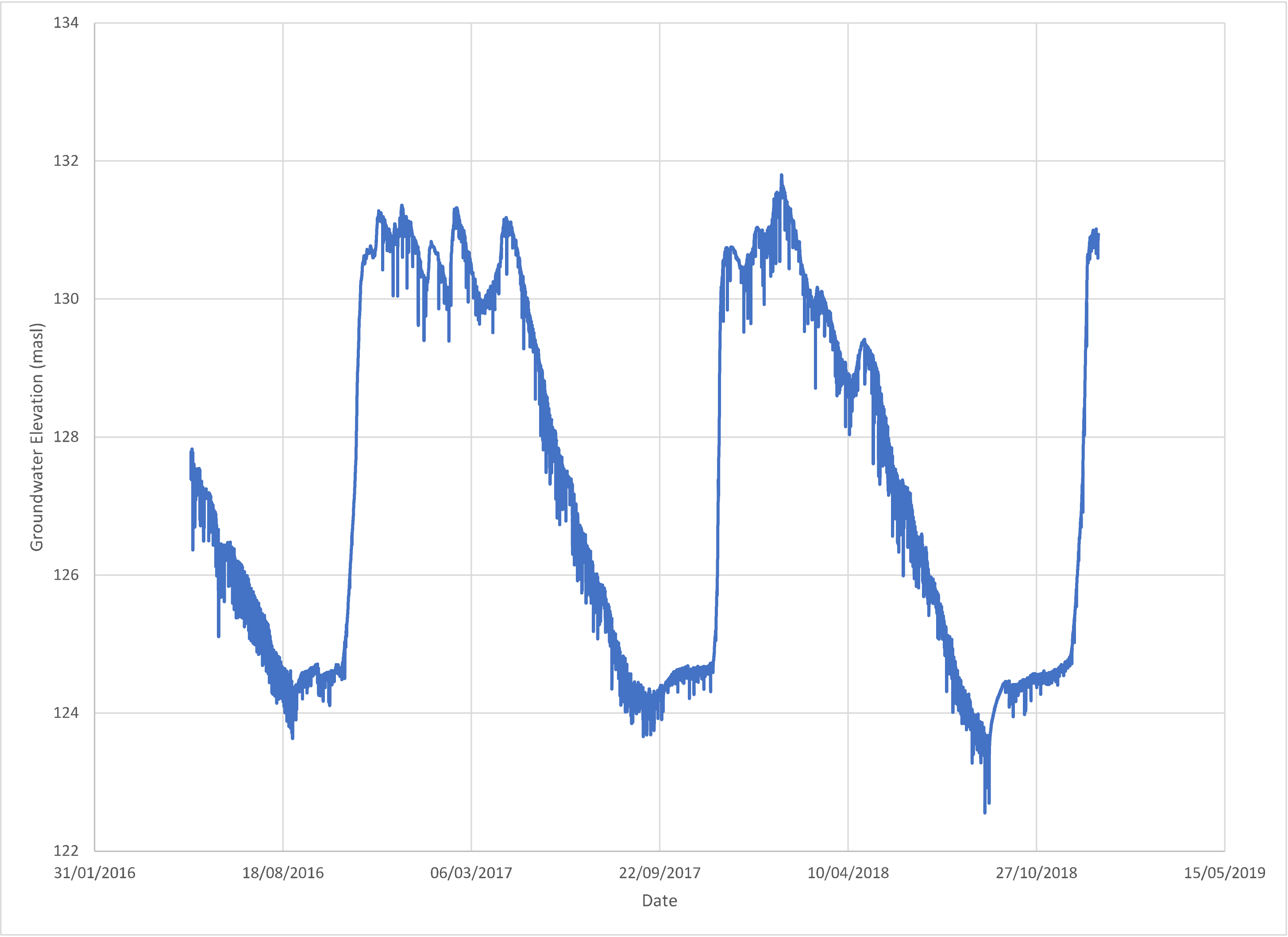
TITLE

BC ENV OBS WELL 396
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	0	B6

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

0
1 in



Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT REGIONAL DISTRICT OF NANAIMO	PROJECT REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

CONSULTANT

GOLDER

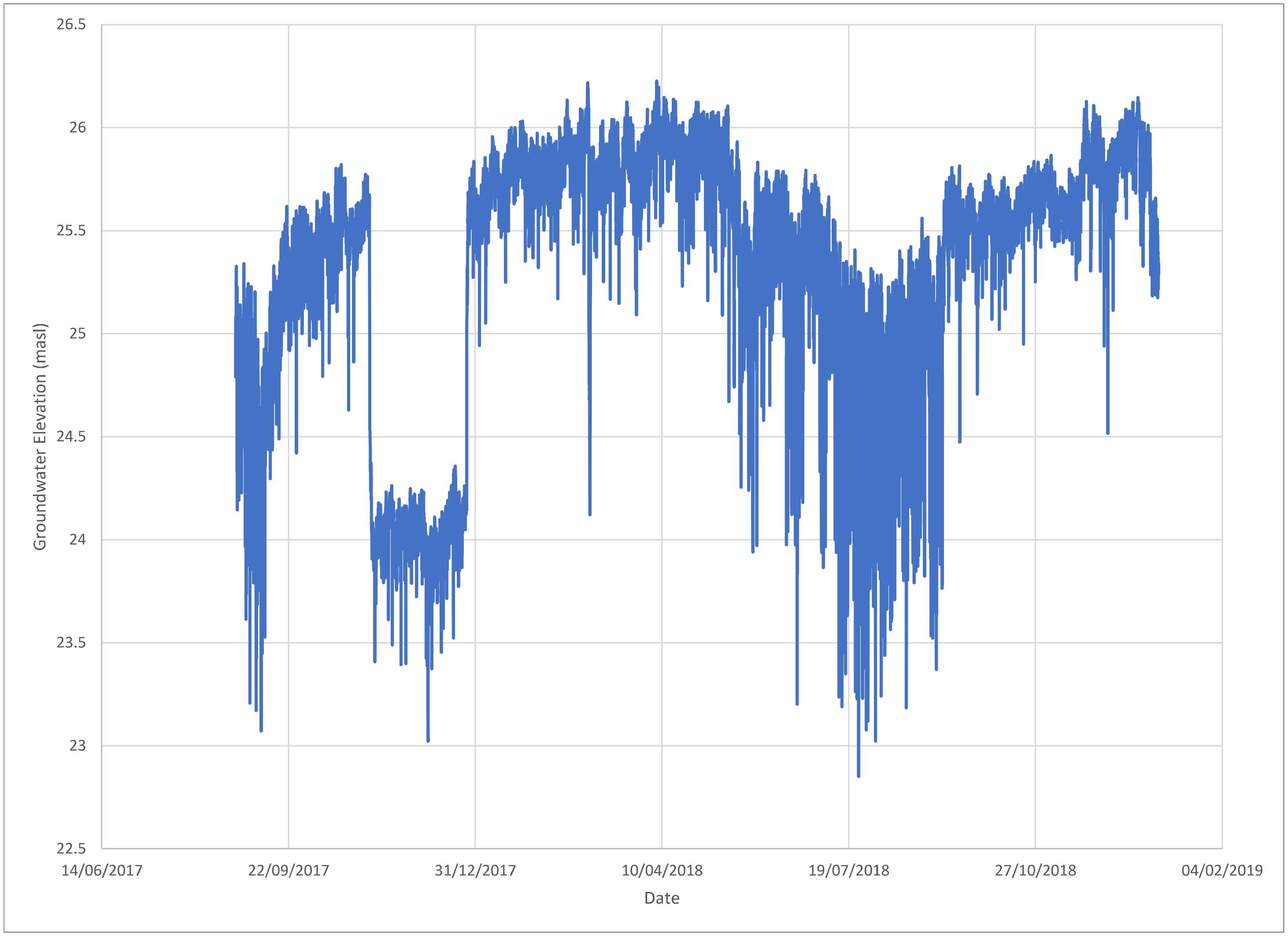
YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE

RDN VOLUNTARY WELL VOW13
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	**6000**	**0**	**B7**

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

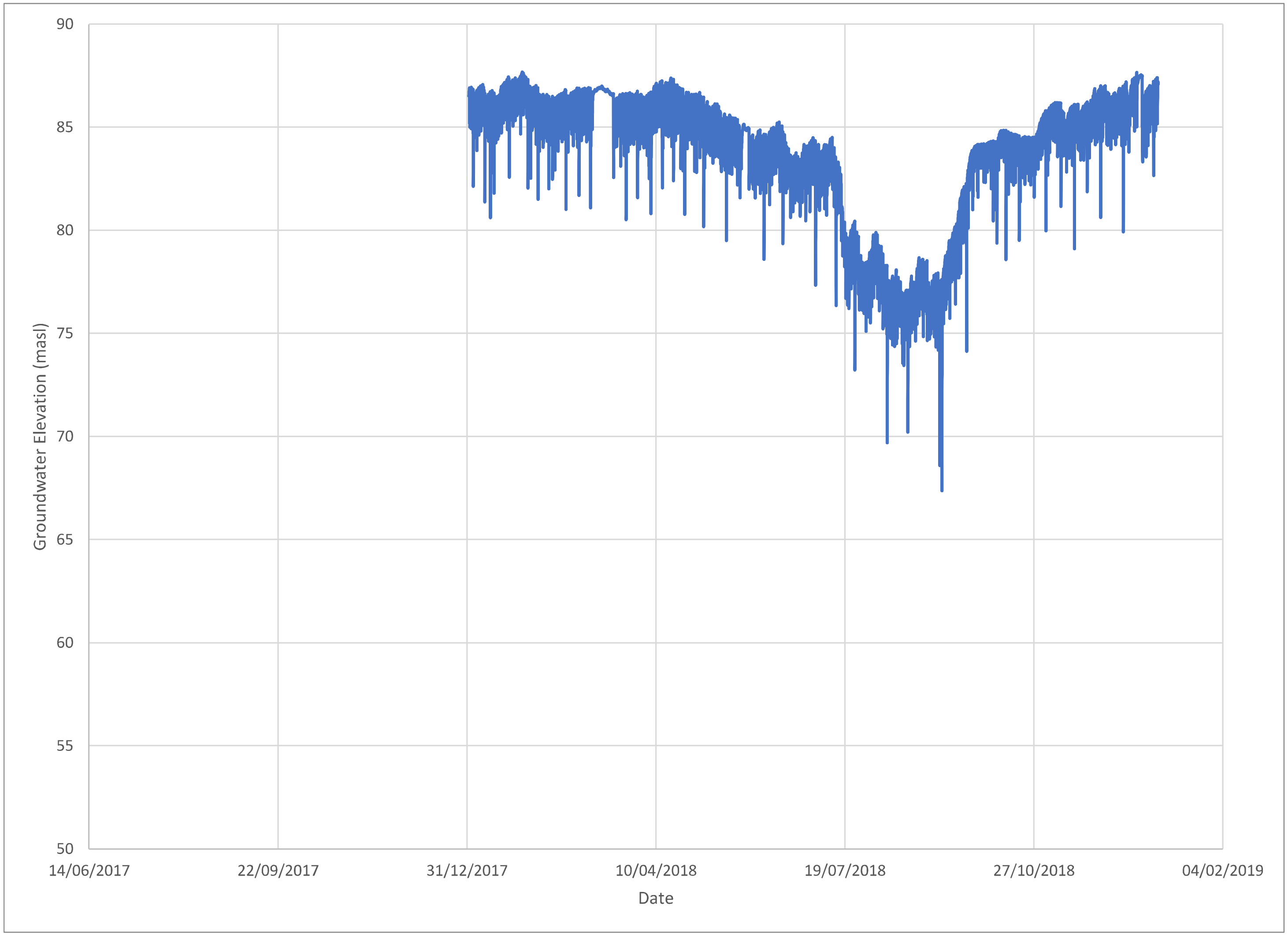
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
RDN VOLUNTARY WELL VOW25
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	**6000**	**0**	**B8**

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



Notes:
Groundwater Level Data from Aquarius Web Portal
(http://aqrt.nrs.gov.bc.ca/Data/Map/Parameter/GW%20Elevation/Statistic/LATEST/Interval/Latest)

CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

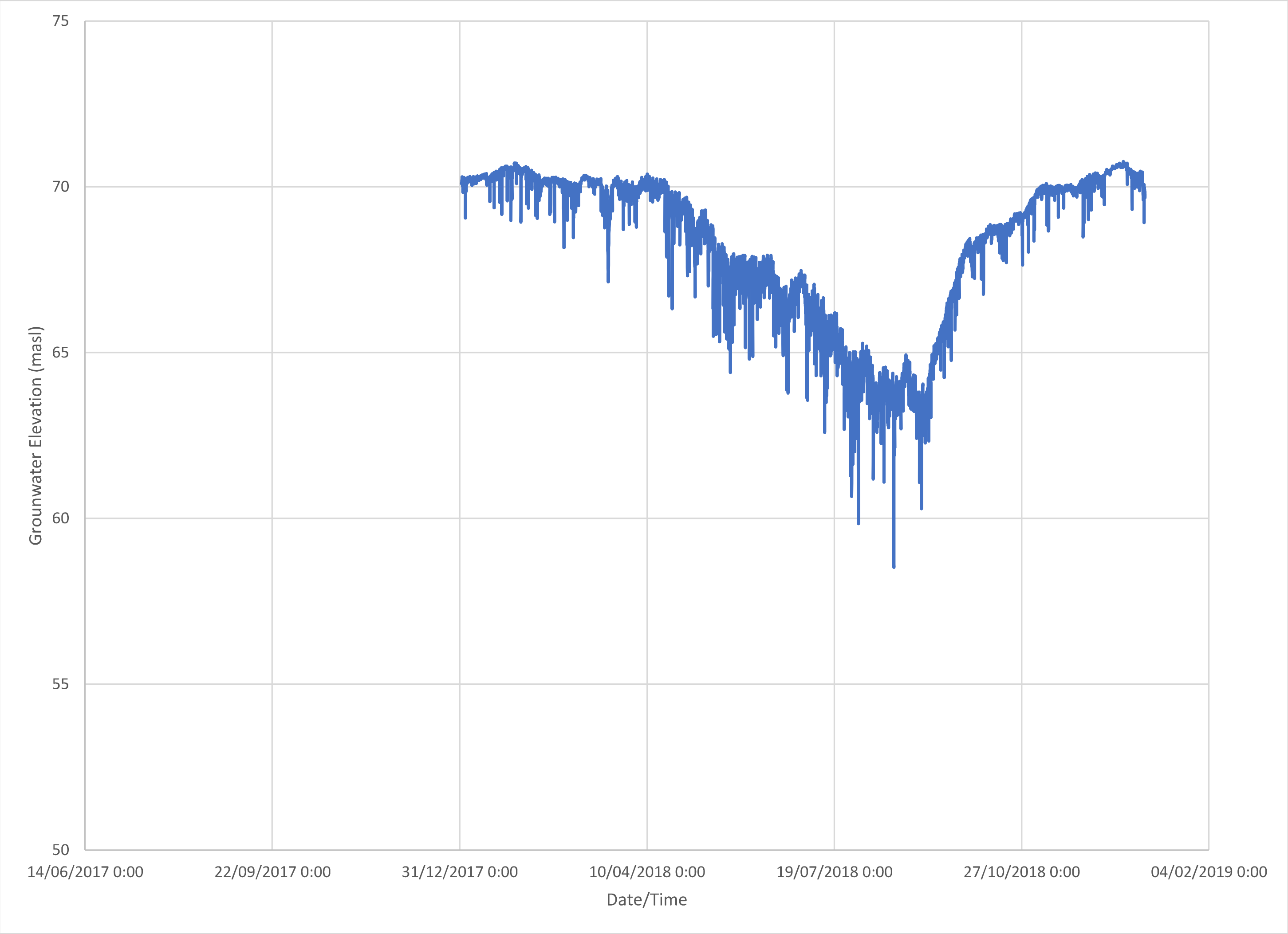
CONSULTANT
GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE
RDN VOLUNTARY WELL VOW26
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	**6000**	**0**	**B9**

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0



CLIENT
REGIONAL DISTRICT OF NANAIMO

PROJECT
REFINED WATER BUDGET (PHASE 3) FOR NANOOSE AREA E

CONSULTANT

GOLDER

YYYY-MM-DD	2020-04-06
PREPARED	AP
DESIGN	AP
REVIEW	MB
APPROVED	MB

TITLE

RDN VOLUNTARY WELL VOW27
WATER LEVELS

PROJECT No.	PHASE	Rev.	FIGURE
18112865	6000	0	B10

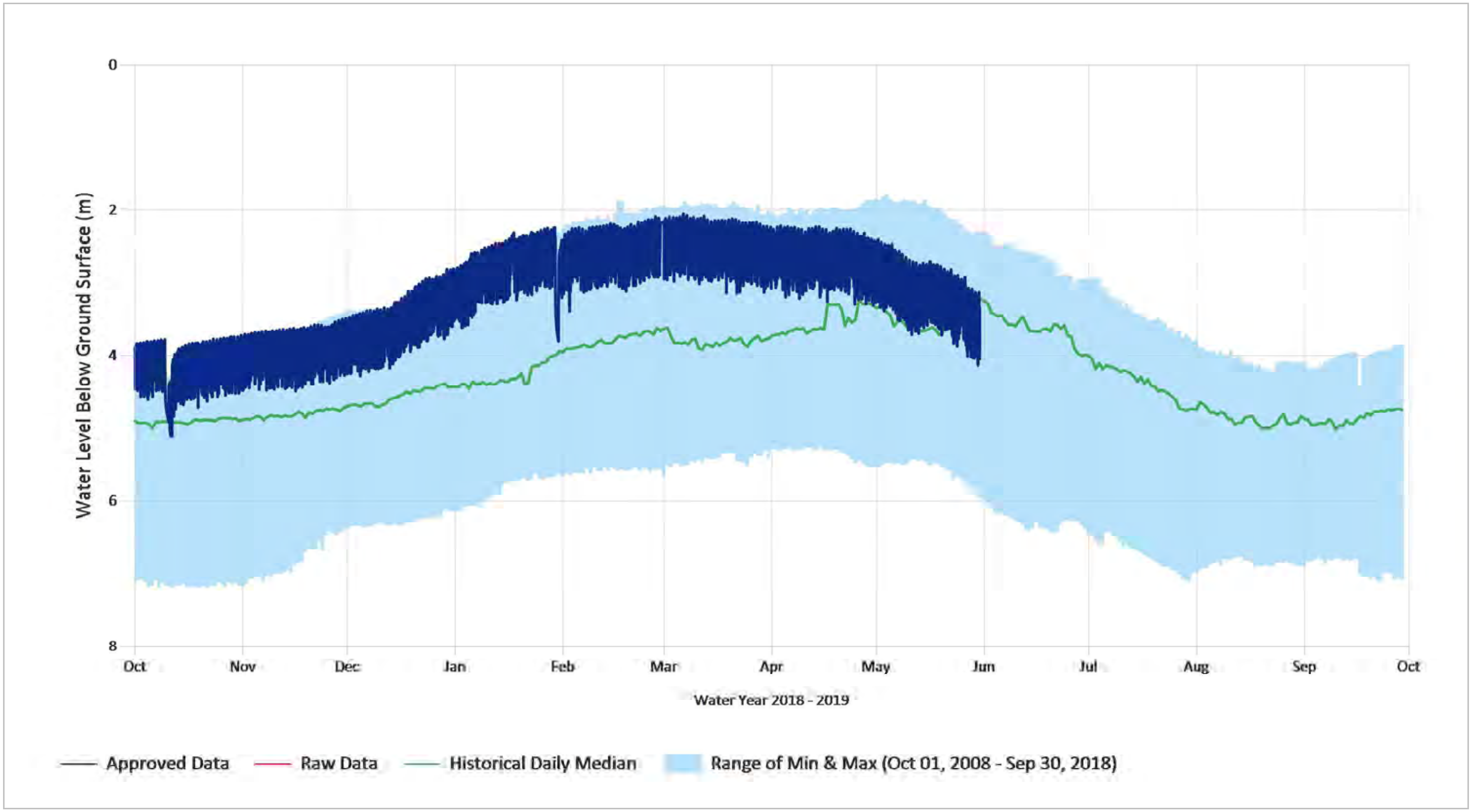
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
1 in
0

Groundwater Level Statistics Chart

Plot created: August 28, 2019 02:46

OW232: OBS WELL 232 - LANTZVILLE (HARBY RD.)

Latitude: 49.246194 Longitude: -124.080176



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

Data last appended: May 30, 2019 18:00 UTC

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

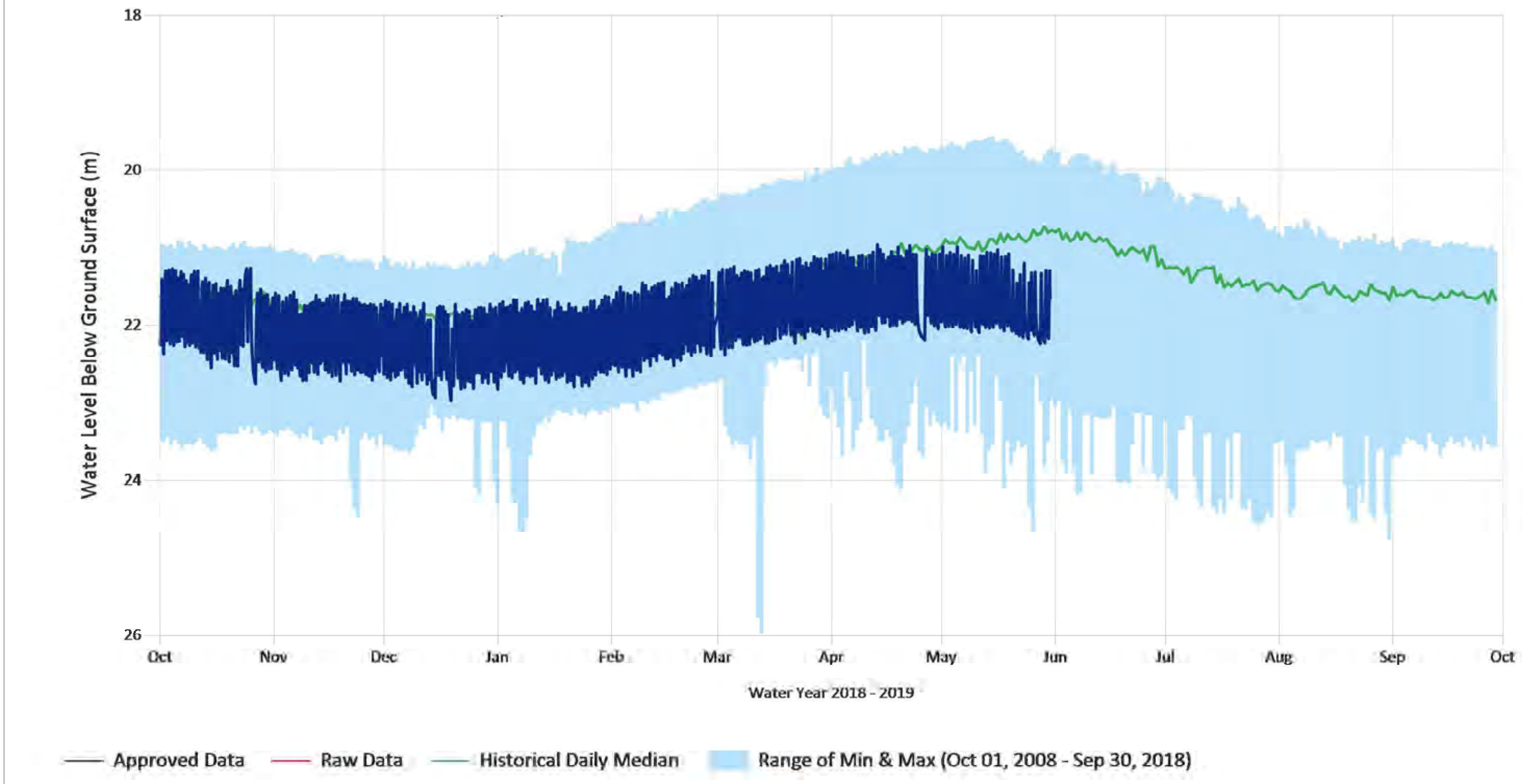
Status: Active

Groundwater Level Statistics Chart

Plot created: August 28, 2019 03:14

OW340: OBS WELL 340 - LANTZVILLE (VALMAR ROAD)

Latitude: 49.24808 Longitude: -124.126688



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

Data last appended: May 30, 2019 14:00 UTC-08:00

Status: Active

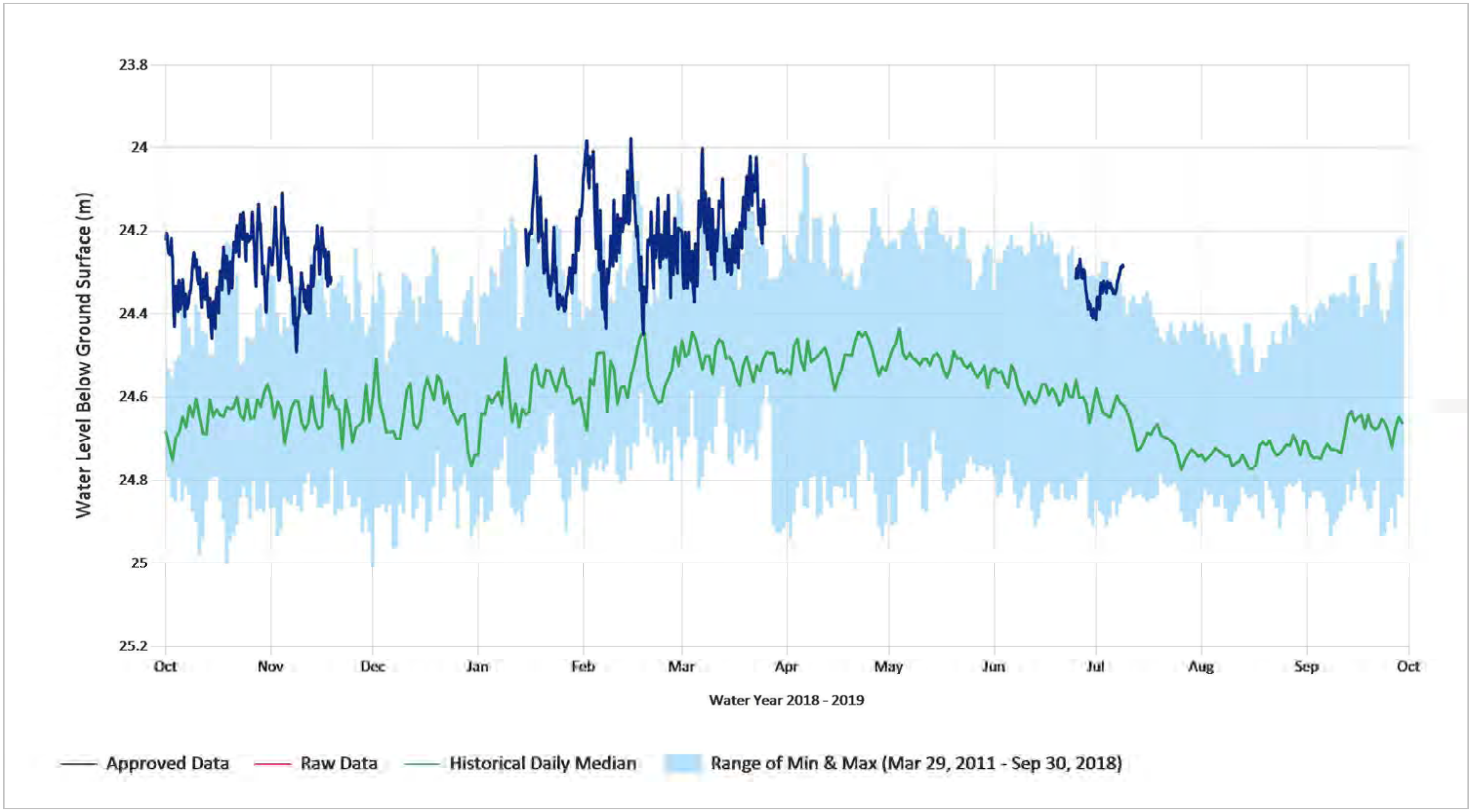
BRITISH
COLUMBIA

Groundwater Level Statistics Chart

Plot created: August 28, 2019 03:30

OW392: OBS WELL 392 - NANOOSE (DAWSON RD DEEP)

Latitude: 49.277942 Longitude: -124.243617



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

Data last appended: July 8, 2019 21:00 UTC

Status: Active

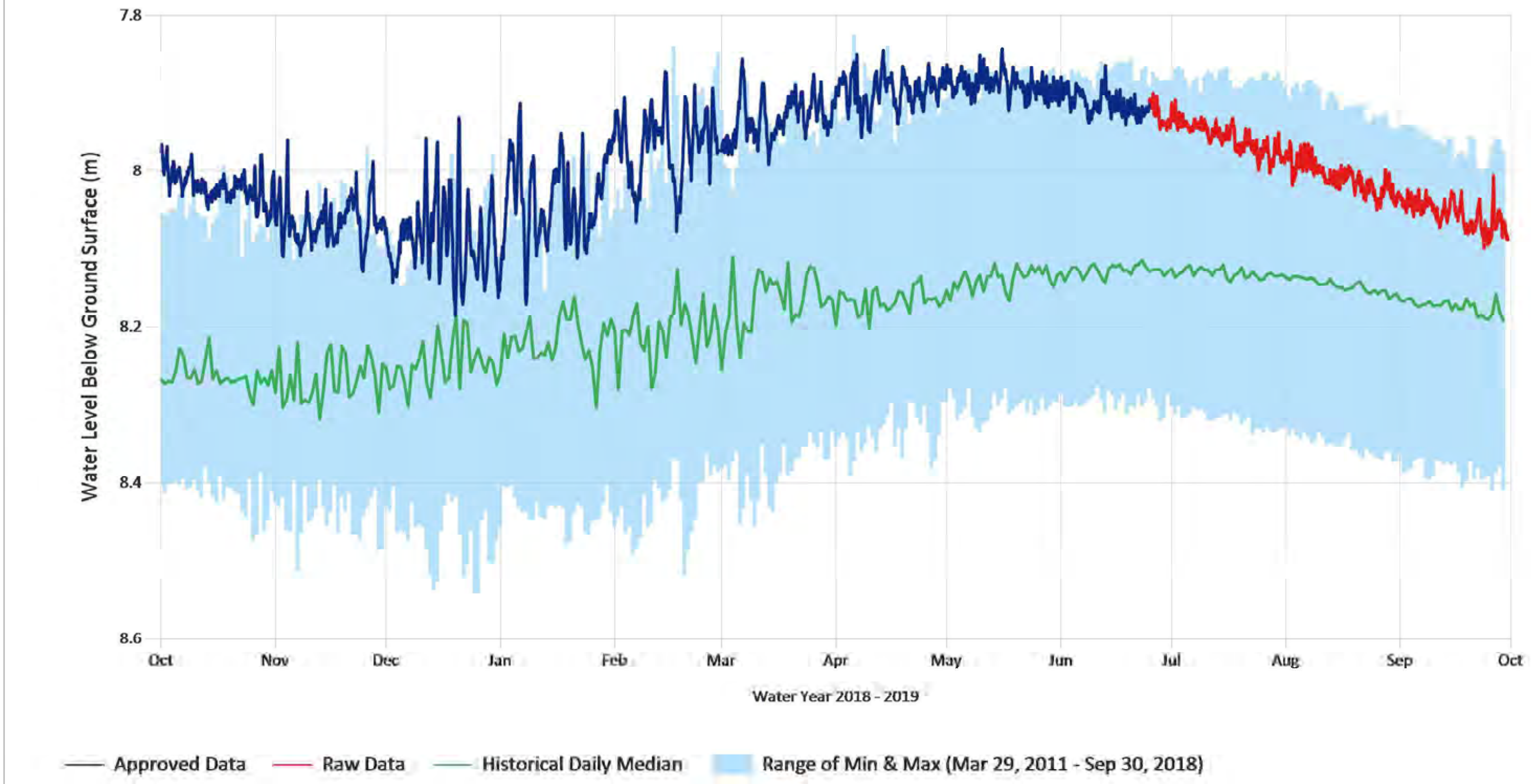
BRITISH
COLUMBIA

Groundwater Level Statistics Chart

Plot created: September 30, 2019 03:42

OW393: OBS WELL 393 - NANOOSE (DAWSON RD SHALLOW)

Latitude: 49.277942 Longitude: -124.243617



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

Data last appended: September 30, 2019 05:00 UTC

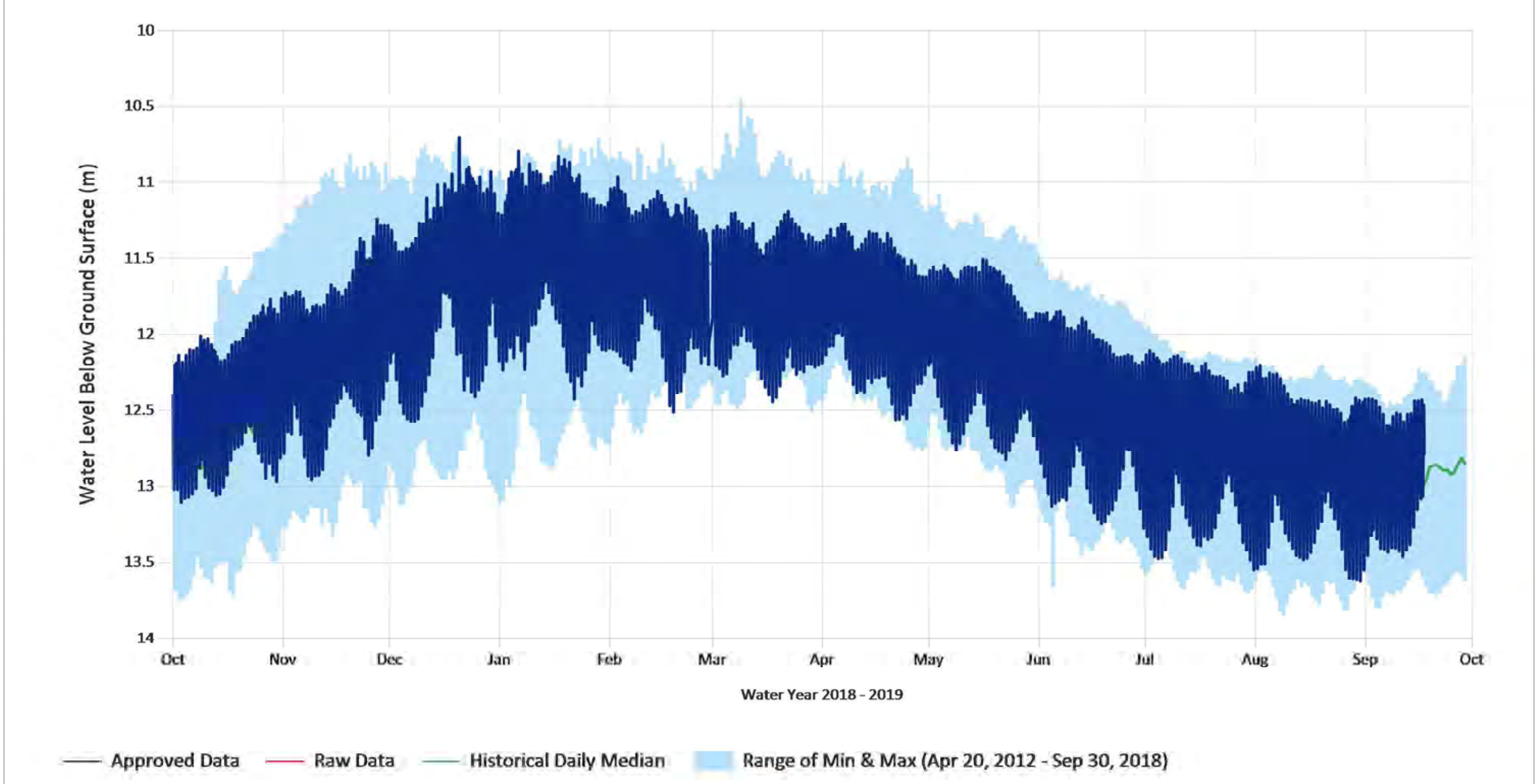
Status: Active

Groundwater Level Statistics Chart

Plot created: September 30, 2019 03:42

OW394: OBS WELL 394 - NANOOSE (NUTTAL DR.)

Latitude: 49.300963 Longitude: -124.191389



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

Data last appended: September 17, 2019 12:00 UTC-08:00

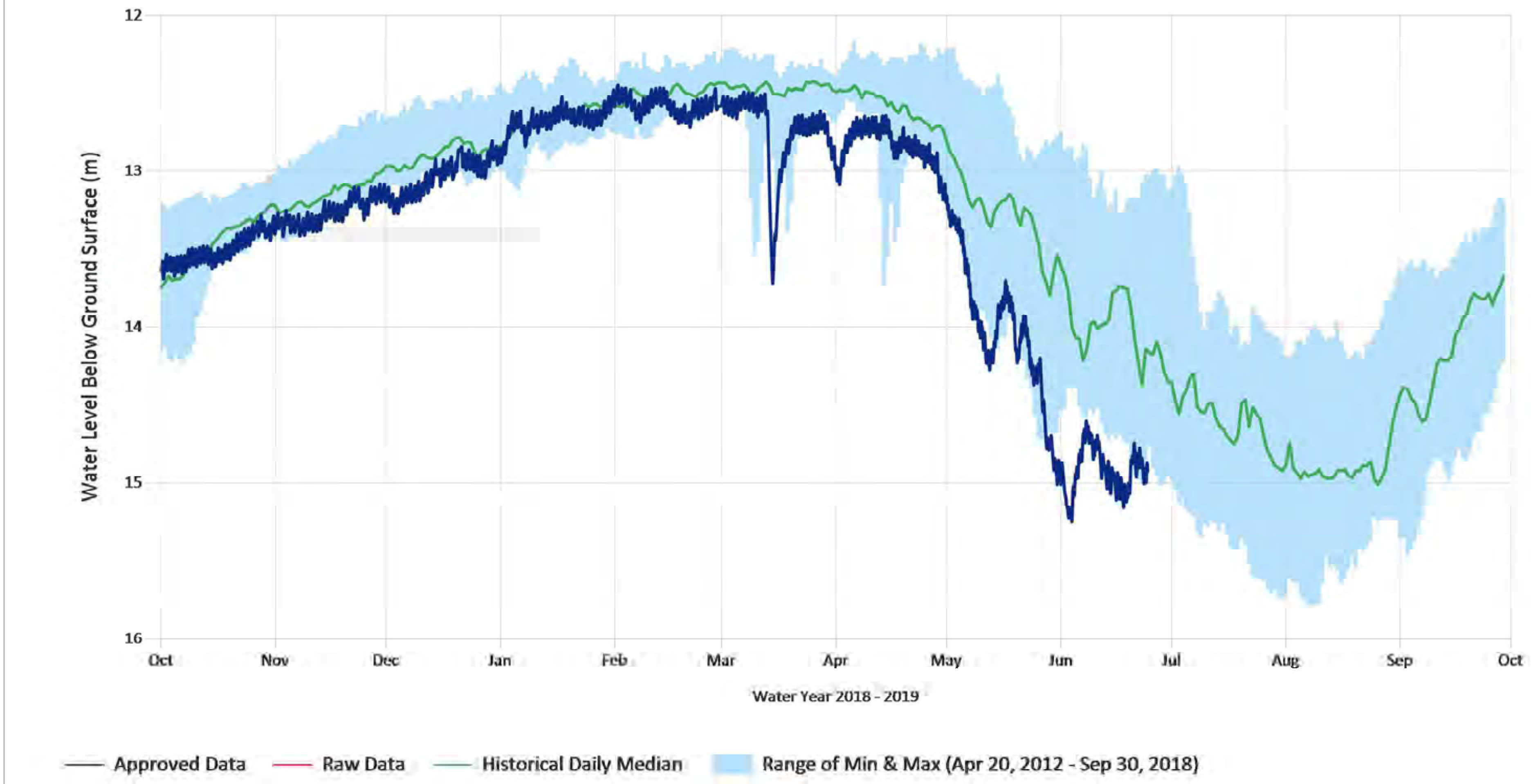
Status: Active

Groundwater Level Statistics Chart

Plot created: August 28, 2019 03:31

OW395: OBS WELL 395 - NANOOSE (RIVER'S EDGE DR.)

Latitude: 49.28029 Longitude: -124.280608



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

Data last appended: June 24, 2019 13:00 UTC-08:00

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

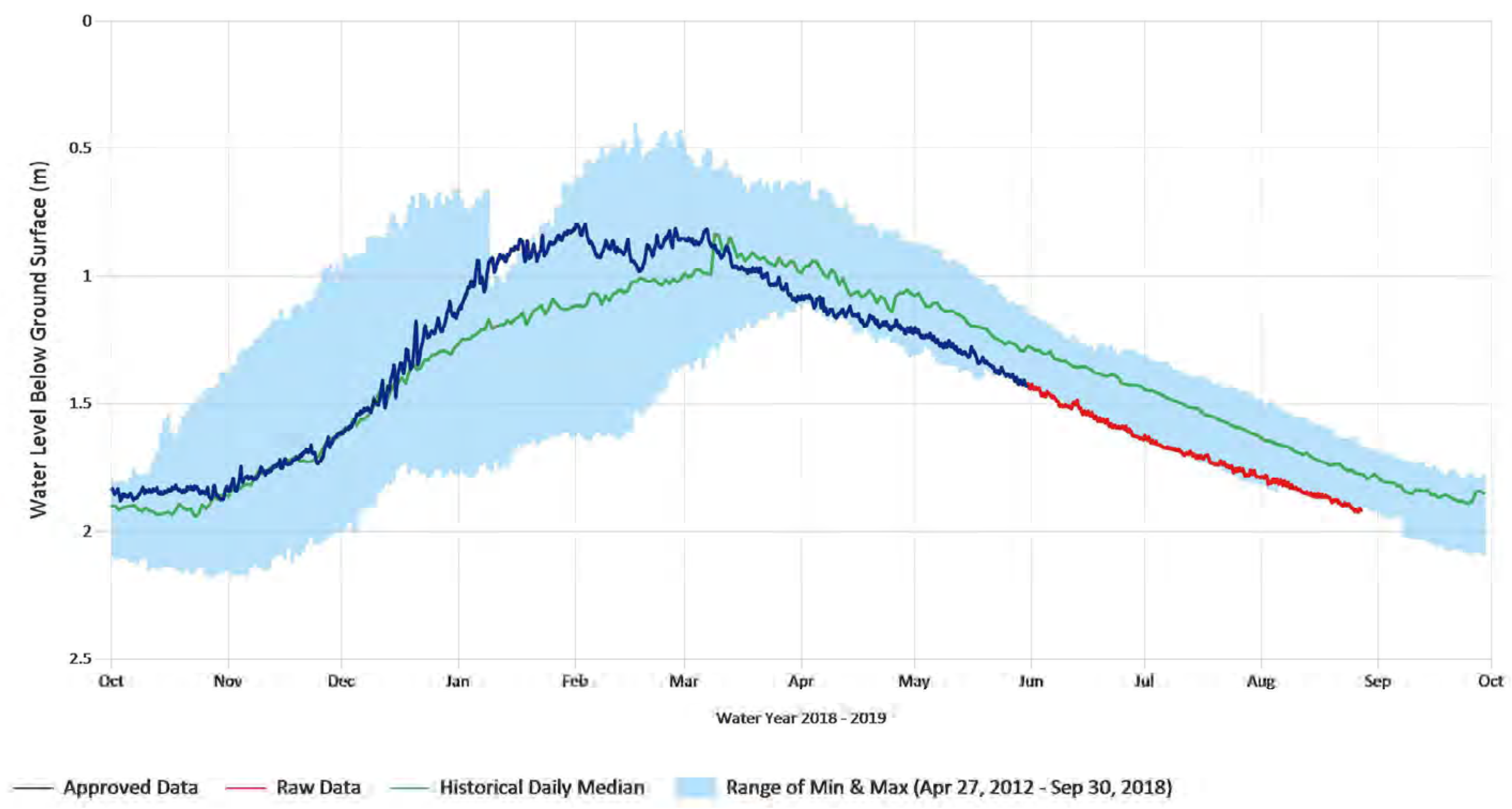
Status: Active

Groundwater Level Statistics Chart

Plot created: August 28, 2019 03:31

OW396: OBS WELL 396 - NANOOSE (BALLENAS RD.)

Latitude: 49.301308 Longitude: -124.229637



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

Data last appended: August 27, 2019 11:00 UTC

Status: Active

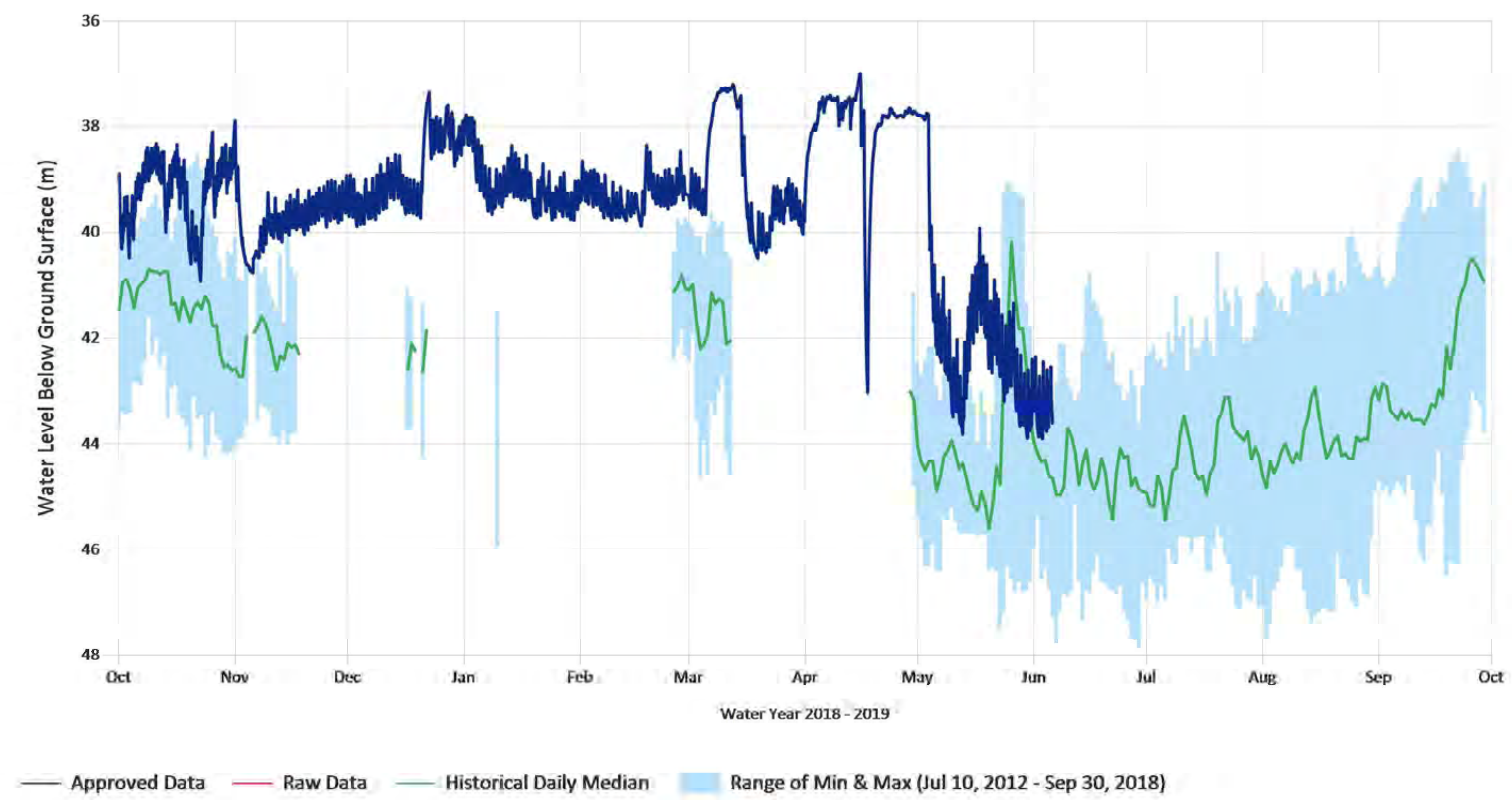
BRITISH
COLUMBIA

Groundwater Level Statistics Chart

Plot created: August 28, 2019 03:32

OW397: OBS WELL 397 - NANOOSE (NORTHWEST BAY RD.)

Latitude: 49.275221 Longitude: -124.192762



The statistics (median/min/max) are based on the previous 10 years of available data prior to the current Water Year

The statistics (median/min/max) are only displayed for wells with at least two years of data

The Groundwater Level Statistics Chart is only available for Active Wells

Data last appended: June 5, 2019 22:00 UTC

Status: Active

APPENDIX C

Estimated Water Usage by Land Use

Table C1: Properties Contained Within the Land Use Inventory and the Agricultural Land Use Inventory

Land Use Category	N. Parcels	Area (ha)
Agriculture	13	166
Dumps & deposits	1	2
Forestry	6	797
Gravel extraction	1	32
Industrial	3	35
Military	1	104
No apparent use	72	226
Protected area / park / reserve	8	283
Recreation & leisure	3	43
Residential	187	995
Transportation	12	69
Utilities	2	30

Coverage Type	N. Lots	Area (ha)
Anthropogenic - Artificial Waterbodies	42	7
Apples	3	1
Bare area	7	5
Berries	1	0
Blueberries	1	0
Camp site / RV park	1	13
Cedar hedging	1	1
Closed	2	0
Community hall	1	0
Dormitory	1	0
Dump deposit	2	4
Estate house	6	1
Extraction, mine	1	1
Farm	139	28
Forage corn	1	5
Grapes	1	0
Grass	149	510
Grass / open treed	8	6
Grassland	34	71
Hazelnut / filbert	2	2
Kennels	1	0
Landscape lawn	67	32
Large house	33	4
Market shops	1	0
Medium house	131	14
Military	1	0
Mixed vegetables	5	7
Natural & Semi-natural - Vegetated Wetlands	20	22
Natural & Semi-natural - Waterbodies	40	51
Not surveyed - Unreported	3	521
Nursery	6	2
Nut trees	1	1
Open	9	9
Parking area	1	0
Pumpkins	1	0
Railroads	6	22
Raspberries	1	0
Residential accessory	56	8
Roads	37	20
Rough grass	16	7
Shrubland	24	39
Single mobile home	8	1
Small house	29	2
Storage	3	0
Stores or shops	1	0
Treed - closed	322	772
Treed - open	77	492
Treed - regen.	7	54
Turf	1	7
Vegetables	4	0
Warehouse structure	2	0

Table C2: Metered Water Use provided by the RDN for Residential and Commercial Properties (2018-2019)

Residential Properties	**Spring**			**Fall**			**Annual**		
Service Code	Count(Account Number)	Sum(Consumption) Spring (m3)	Consumption per unit Spring (m3/unit)	Count(Account Number)	Sum(Consumption) fall (m3)	Consumption per unit Fall (m3/unit)	Annual total consumption (m3/unit)	Annual total consumption (L/unit)	Daily Average Consumption (L/day/unit)
W34	40	3,722	93	39	6,305	162	255	254,717	698
W38	238	22,238	93	334	28,068	84	177	177,473	486
W39	125	16,477	132	125	11,084	89	220	220,488	604
W42	5	308	62	5	684	137	198	198,400	544
W43A	288	31,529	109	290	40,104	138	248	247,764	679
W45	151	19,781	131	151	37,555	249	380	379,709	1,040
W46A	28	2,418	86	28	1,664	59	146	145,786	399
W47	2,213	252,624	114	2,223	328,551	148	262	261,951	718
W51	17	1,019	60	17	828	49	109	108,647	298

Daily Average Consumption for Residential Properties within the RDN (L/day/unit)	607

Commercial Properties					
Service Code	Count(Account Number)	Annual total consumption (m3)	Annual total consumption (m3/unit)	Annual total consumption (L/unit)	Daily Average Consumption (L/day/unit)
C47	57	16,921	297	296,860	813

Notes:

Metered Data provided by RDN on 18 November 2019. Estimated values represent average water consumption for each of the service code area for the period considered (from spring 2018 to spring 2019)

Service Code Areas represent different geographical areas within the RDN.

Table C3: Metered Water use provided by the City of Nanaimo (2018)

Account Type	N. units	2018 Total Consumption (UK Gallons)	Total Consumption (m^3)	2018 Consumption per unit (m^3)	2018 Daily Consumption per unit (L/day)
Residential MLT	22950	759,106,499	3,450,968	150	412
Residential SFD	18910	955,489,678	4,343,744	230	629
Commercial Res	733	34,211,580	155,529	212	581
Government	286	157,725,539	717,035	2507	6869
Municipal	128	79,857,097	363,038	2836	7770
Other	2003	347,145,650	1,578,156	788	2159
Total		2,333,536,043	10,608,470		

Category	Description
Government	school, BC ferry terminal, hospital, federal gov buildings, RDN properties, BC Hydro facilities or gov owned buildings
Municipal	firehall, utility building, park, recreation area or paying field
	lower users: chiropodist, lawyers offices, dentists, daycares, businesses run from home, medical buildings, gas stations, churches
other	High users: fish processing plants, garden nursery, shopping malls and local first nation reserve.

Notes:

Metered Data provided by City of Nanaimo on 22 November 2019. Estimated values represent average water consumption for each of the service code area for 2018.

Table C4: Irrigation and Livestock Water Requirements for Estimate of Water Use in the Non-Serviced Areas

Average Irrigation Requirement from Groundwater[1] (mm)		
Year	**1997 (wet year)**	**2003 (dry year)**
Crop Type		
Apple	241	590
Berry	186	526
Blueberry	111	407
Cranberry	620	1490
Forage	315	724
Golf	407	795
Grape	49	222
Greenhouse	1714	1842
Nursery Floriculture	152	342
Nursery Shrubs/Tress	99	286
Pasture/Grass	322	675
Raspberry	116	478
Recreation Turf	377	698
Strawberry	173	422
Sweetcorn	118	391
Turf Farm	400	795
Vegetable	290	578

Animal Type	Livestock Water Demand[2] (L/day)
Milking Dairy Cow	85
Dry Cow	50
Swine	12.5
Poultry - Broiler	0.17
Poultry - Layer	0.09
Turkey	0.36
Goat	8
Sheep	8
Beef - range, steer, bull, heifer	50
Horses	50

	Number of Animals[3]			
Farm Size	**Cow**	**Horse**	**Chicken**	**Sheep**
Very Small	1	1	100	10
Small	25	25	2500	250
Medium	100	100	10000	1000
Large	200	200	20000	2000

Notes:

[1] Values from Appendix Table A and B (2003 and 1997 Water Demand by Crop with Average Management) of the RDN Agricultural Water Demand Study (May, 2013).
For the purpose of estimating water use in the non serviced properties, 2003 irrigation requirements values were used as conservative assumption.

[2] Values from Table 1 (Livestock water Demand of the RDN Agricultural Water Demand Study (May, 2013).

[3] Scale System for Livestock operations was derived from the ALUI report (2012)

APPENDIX D

Build-Out Information Provided by RDN

APPENDIX D

SUBDIVISION POTENTIAL by ZONING (with Dolphin Lake ppty excluded)

		Results by Water Service Area		Results by Growth Containment Boundaries (GCB)/Neighbourhood Plan Areas					
	Electoral Area E Total	**Outside RDN Water Service Areas**	**Inside RDN Water Service Areas**	**Outside the GCBs**	**Inside the GCBs**	**Redgap Village Center**	**Fairwinds *excludes Lakes Dist. & Schooner Cove NPs**	**Fairwinds: Lakes District**	**Fairwinds: Schooner Cove**
Existing Lots	3646	1043	2603	2630	1016	197	761	5	53
Potential Lots	2830	283	2547	605	2225	20	188	2002	15
Total Lot Buildout	6476	1326	5150	3235	3241	217	949	2007	68

DWELLING UNIT POTENTIAL BY ZONING (with Dolphin Lake ppty excluded)

		Results by Water Service Area		Results by Growth Containment Boundaries (GCB)/Neighbourhood Plan Areas					
	Electoral Area E Total	**Outside RDN Water Service Areas**	**Inside RDN Water Service Areas**	**Outside the GCBs**	**Inside the GCBs**	**Redgap Village Center**	**Fairwinds *excludes Lakes Dist. & Schooner Cove NPs**	**Fairwinds: Lakes District**	**Fairwinds: Schooner Cove**
Existing DUs	3370	872	2498	2367	1003	275	679	0	49
Potential DUs	5396	837	4559 (2805 max by OCP)*	1236	4160 (2406 max by OCP)*	27 (225 max by OCP)*	284 (146 max by OCP)*	3489 (1675 max by OCP)*	360 (360 max by OCP)*
Total DU Buildout	8766	1709	7057 (5303 max by OCP)*	3603	5163 (3409 max by OCP)*	302 (500 max by OCP)*	963 (825 max by OCP)*	3489 (1675 max OCP)*	409 (409 max by OCP)*
Potential Suites	4345	679	3666	1075	3270	19	227	3024	0

* Note that the max OCP dwelling unit count overrides potential dwelling units(by Zoning) within the GCBs/NPs

APPENDIX E

Aquifer Water Budget Results

Table E1: Water Budget Results
Current Conditions - Overburden Aquifers

Aquifer 221	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**8.37E+06**	**8.37E+06**	**8.37E+06**
In (m^3/day)			
Surface Water	22650	22890	22450
Recharge	320	100	530
Flow from other units	730	730	760
Total	23700	23720	23740
Out (m^3/day)			
Surface Water	13300	13270	13370
Flow to other units	10100	10030	10160
Private Users	20	20	20
Municipal Wells	280	400	190
Total	23700	23720	23740

Aquifer 215	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**2.27E+07**	**2.25E+07**	**2.26E+07**
In (m^3/day)			
Surface Water	-	-	-
Recharge	280	100	430
Flow from other units	7520	7870	8150
Total	7800	7970	8580
Out (m^3/day)			
Surface Water	60	60	60
Flow to other units	7020	6910	7930
Private Users	10	10	10
Municipal Wells	710	990	580
Total	7800	7970	8580

Aquifer 1098	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**5.56E+07**	**5.56E+07**	**5.56E+07**
In (m^3/day)			
Surface Water			
Recharge			
Flow from other units	12200	12360	12470
Total	12200	12360	12470
Out (m^3/day)			
Surface Water			
Flow to other units	11390	11560	11660
Private Users			
Municipal Wells	810	800	810
Total	12200	12360	12470

Aquifer 219	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**5.22E+07**	**5.24E+07**	**5.24E+07**
In (m^3/day)			
Surface Water			
Recharge			
Flow from other units	18420	18570	19820
Total	18420		19820
Out (m^3/day)			
Surface Water			
Flow to other units	17030	16980	19240
Private Users	1020	1020	350
Municipal Wells	370	570	230
Total	18420	18570	19820

Table E2: Water Budget Results
Current Conditions - Bedrock Aquifers

Aquifer 210	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**4.49E+04**	**44892**	**44912**
In (m^3/day)			
Surface Water	-	-	-
Recharge	-	-	-
Flow from other units	3830	3900	3990
Total	3830	3900	3990
Out (m^3/day)			
Surface Water			
Flow to other units	3820	3890	3980
Private Users	10	10	10
Municipal Wells			
Total	3830	3900	3990
Aquifer 213	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**5.99E+05**	**5.98E+05**	**6.00E+05**
In (m^3/day)			
Surface Water			
Recharge			
Flow from other units	18670	17930	22290
Total	18670	17930	22290
Out (m^3/day)			
Surface Water			
Flow to other units	18620	17880	22240
Private Users	50	50	50
Municipal Wells			
Total	18670	17930	22290
Aquifer 214	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**2.32E+05**	**2.32E+05**	**2.32E+05**
In (m^3/day)			
Surface Water	-	-	-
Recharge	-	-	-
Flow from other units	8830	9080	9190
Total	8830	9080	9190
Out (m^3/day)			
Surface Water	-	-	-
Flow to other units	8790	9010	9170
Private Users	-	-	-
Municipal Wells	40	70	20
Total	8830	9080	9190
Aquifer 218	**Average Conditions**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**1.73E+05**	**1.72E+05**	**1.74E+05**
In (m^3/day)			
Surface Water			
Recharge	1610	1020	2550
Flow from other units	2860	2830	3680
Total	4470	3850	6230
Out (m^3/day)			
Surface Water	-	-	-
Flow to other units	4440	3820	6210
Private Users	30	30	20
Municipal Wells			
Total	4470	3850	6230

Table E3: Water Budget Results
Future Scenarios - Unconsolidated Aquifers

Aquifer 221	BASE CASE		Scenario 1 - CLIMATE CHANGE		Scenario 2 - FUTURE BUILDOUT		Scenario 3 - CHANGE IN LAND COVER		Scenario 4 - CLIMATE CHANGE AND LAND COVER		Scenario 5 - SCENARIO 1,2,3 COMBINED	
Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season
Aquifer Fluid Volume (m^3)	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06	8.37E+06
%change			0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)	
Surface Water	22520	22290	22540	22290	22520	22290	22520	22290	22540	22290	22540	22290
Recharge	100	530	80	530	100	530	100	530	80	530	80	530
Flow from other units	730	760	710	740	730	760	730	760	710	740	710	740
Total	23350	23580	23330	23560	23350	23580	23350	23580	23330	23560	23330	23560
	Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)	
Surface Water	13290	13390	13280	13380	13290	13390	13290	13390	13270	13380	13280	13380
Flow to other units	10040	10170	10030	10160	10040	10170	10040	10170	10040	10160	10030	10160
Private Users	20	20	20	20	20	20	20	20	20	20	20	20
Municipal Wells	-	-	-	-	-	-	-	-	-	-	-	
Total	23350	23580	23330	23560	23350	23580	23350	23580	23330	23560	23330	23560
Range of water level change (m)			-	-	-	-	-	-	-	-	-	-
Average Water level difference (m)			no change	no change	no change	no change	no change	no change	no change	no change	no change	no change

Aquifer 215	BASE CASE		Scenario 1 - CLIMATE CHANGE		Scenario 2 - FUTURE BUILDOUT		Scenario 3 - CHANGE IN LAND COVER		Scenario 4 - CLIMATE CHANGE AND LAND COVER		Scenario 5 - SCENARIO 1,2,3 COMBINED	
Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season
Aquifer Fluid Volume (m^3)	2.29E+07	2.30E+07	2.16E+07	2.17E+07	2.29E+07	2.30E+07	2.29E+07	2.30E+07	2.16E+07	2.16E+07	2.15E+07	2.16E+07
%change			-6%	-6%	0%	0%	0%	0%	-6%	-6%	-6%	-6%
	In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)	
Surface Water	-	-										
Recharge	90	430	70	430	90	430	90	430	70	430	70	430
Flow from other units	7900	8170	7360	7760	7900	8170	7880	8140	7350	7740	7340	7740
Total	7990	8600	7430	8190	7990	8600	7970	8570	7420	8170	7410	8170
	Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)	
Surface Water	60	60	60	60	60	60	60	60	60	60	60	60
Flow to other units	6930	7950	6370	7540	6930	7950	6910	7920	6360	7520	6350	7520
Private Users	10	10	10	10	10	10	10	10	10	10	10	10
Municipal Wells	990	580	990	580	990	580	990	580	990	580	990	580
Total	7990	8600	7430	8190	7990	8600	7970	8570	7420	8170	7410	8170
Range of water level change (m)			-1 to -5	-1 to -4	-	-	-	-	-1 to -5	-1 to -4	-1 to -5	-1 to -4
Average Water level difference (m)			-3	-2	no change	no change	no change	no change	-3	-2	-3	-2

Aquifer 1098	BASE CASE		Scenario 1 - CLIMATE CHANGE		Scenario 2 - FUTURE BUILDOUT		Scenario 3 - CHANGE IN LAND COVER		Scenario 4 - CLIMATE CHANGE AND LAND COVER		Scenario 5 - SCENARIO 1,2,3 COMBINED	
Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season
Aquifer Fluid Volume (m^3)	5.56E+07	5.56E+07	5.55E+07	5.55E+07	5.56E+07	5.56E+07	5.55E+07	5.56E+07	5.55E+07	5.55E+07	5.55E+07	5.55E+07
%change			0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)	
Surface Water	-	-	-									
Recharge	-	-	-									
Flow from other units	12910	12880	12330	12410	12810	12830	12600	12630	12100	12110	11980	12020
Total	12910	12880	12330	12410	12810	12830	12600	12630	12100	12110	11980	12020
	Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)	
Surface Water												
Flow to other units	11630	11740	11050	11270	11530	11690	11320	11490	10820	10970	10700	10880
Private Users												
Municipal Wells	1280	1140	1280	1140	1280	1140	1280	1140	1280	1140	1280	1140
Total	12910	12880	12330	12410	12810	12830	12600	12630	12100	12110	11980	12020
Range of water level change (m)			-1 to -3	-1 to -2	<-1	<-1	-1 to -2	-1 to -2	-2 to 5	-2 to 5	-2 to 5	-2 to 5
Average Water level difference (m)			-2	-2	<-1	<-1	-2	-2	-3	-3	-3	-3

Aquifer 219	BASE CASE		Scenario 1 - CLIMATE CHANGE		Scenario 2 - FUTURE BUILDOUT		Scenario 3 - CHANGE IN LAND COVER		Scenario 4 - CLIMATE CHANGE AND LAND COVER		Scenario 5 - SCENARIO 1,2,3 COMBINED	
Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season	End of Dry Season	End of Wet Season
Aquifer Fluid Volume (m^3)	5.19E+07	5.19E+07	5.07E+07	5.08E+07	5.19E+07	5.19E+07	5.10E+07	5.12E+07	4.90E+07	4.91E+07	4.71E+07	
%change			-2%	-2%	0%	0%	-2%	-1%	-6%	-5%	-9%	
	In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)		In (m^3/day)	
Surface Water												
Recharge												
Flow from other units	18920	20100	17980	19360	18660	20130	18100	19040	17200	18220	17300	18220
Total	18920	20100	17980	19360	18660	20130	18100	19040	17200	18220	17300	18220
	Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)		Out (m^3/day)	
Surface Water												
Flow to other units	17900	19750	16690	19010	17270	19420	17080	18690	15910	17870	15640	17510
Private Users	1020	350	1290	350	1390	710	1020	350	1290	350	1660	710
Municipal Wells	-	-	-	-		-	-	-	-	-	-	-
Total	18920	20100	17980	19360	18660	20130	18100	19040	17200	18220	17300	18220
Range of water level change (m)			-1 to -2	-1 to -2	<-1	<-1	0 to -2	0 to -2	-2 to 5	-2 to 5	-2 to 5	-2 to 5
Average Water level difference (m)			-2	-2	<-1	<-1	-2	-2	-3	-3	-3	-3

Table E4: Water Budget Results
Future Scenarios - Bedrock Aquifers

Aquifer 210	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILDOUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - CLIMATE CHANGE AND LAND**		**Scenario 5 - SCENARIO 1,2,3 COMBINED**	
Season	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**44900**	**44950**	**44830**	**44880**	**44890**	**44940**	**44880**	**44930**	**44800**	**44850**	**44750**	**44820**
%change			**-0.2%**	**-0.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**-0.2%**	**-0.2%**	**-0.3%**	**-0.3%**
	In (m^3/day)		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**	
Surface Water												
Recharge												
Flow from other units	3790	3830	3620	3680	3800	3840	3790	3830	3620	3690	3640	3700
Total	3790	3830	3620	3680	3800	3840	3790	3830	3620	3690	3640	3700
	Out (m^3/day)		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**	
Surface Water												
Flow to other units	3780	3820	3610	3670	3780	3820	3780	3820	3610	3680	3620	3680
Private Users	10	10	10	10	20	20	10	10	10	10	20	20
Municipal Wells												
Total	3790	3830	3620	3680	3800	3840	3790	3830	3620	3690	3640	3700
Range of water level change (m)			-2 to -5	-2 to -5	<-1	<-1	-1 to -2	-1 to -2	-5 to -8	-2 to -7	-5 to -8	-2 to -7
Average Water level difference (m)			-3	-3	<-1	<-1	-1	-1	-6	-5	-6	-5
Aquifer 213	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILDOUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - CLIMATE CHANGE AND LAND**		**Scenario 5 - SCENARIO 1,2,3 COMBINED**	
Season	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**5.98E+05**	**6.03E+05**	**5.91E+05**	**5.97E+05**	**5.98E+05**	**6.03E+05**	**5.97E+05**	**6.03E+05**	**5.91E+05**	**5.97E+05**	**5.91E+05**	**5.97E+05**
%change			**-1%**	**-1%**	**0%**	**0%**	**0%**	**0%**	**-1%**	**-1%**	**-1%**	**-1%**
	In (m^3/day)		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**	
Surface Water												
Recharge												
Flow from other units	17350	21660	16030	21260	17350	21650	17310	21610	15990	21200	15990	21210
Total	17350	21660	16030	21260	17350	21650	17310	21610	15990	21200	15990	21210
	Out (m^3/day)		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**	
Surface Water												
Flow to other units	17300	21610	15980	21210	17300	21600	17260	21470	15940	21150	15940	21160
Private Users	50	50	50	50	50	50	50	50	50	50	50	50
Municipal Wells												
Total	17350	21660	16030	21260	17350	21650	17310	21520	15990	21200	15990	21210
Range of water level change (m)			-2 to -13	0 to -10	-	-	-	-	-2 to -13	0 to -10	-2 to -13	-2 to -12
Average Water level difference (m)			-9	-5	no change	no change	no change	no change	-8	-5	-8	-7
Aquifer 214	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILDOUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - CLIMATE CHANGE AND LAND**		**Scenario 5 - SCENARIO 1,2,3 COMBINED**	
Season	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**	**2.32E+05**
%change			**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
	In (m^3/day)		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**	
Surface Water												
Recharge												
Flow from other units	8440	8630	8010	8220	8370	8550	8240	8160	7820	7990	7750	7900
Total	8440	8630	8010	8220	8370	8550	8240	8160	7820	7990	7750	7900
	Out (m^3/day)		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**	
Surface Water												
Flow to other units	8440	8630	8010	8220	8370	8550	8240	8160	7820	7990	7750	7900
Private Users					-	-						
Municipal Wells	-		-	-	-	-	-					
Total	8440	8630	8010	8220	8370	8550	8240	8160	7820	7990	7750	7900
Range of water level change (m)			-1 to -3	-1 to -2	<-1	<-1	0 to -2	0 to -2	-2 to -4	-2 to -4	-2 to 5	-2 to 5
Average Water level difference (m)			-2	-2	<-1	<-1	-2	-2	-3	-3	-3	-3
Aquifer 218	**BASE CASE**		**Scenario 1 - CLIMATE CHANGE**		**Scenario 2 - FUTURE BUILDOUT**		**Scenario 3 - CHANGE IN LAND COVER**		**Scenario 4 - CLIMATE CHANGE AND LAND**		**Scenario 5 - SCENARIO 1,2,3 COMBINED**	
Season	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**
Aquifer Fluid Volume (m^3)	**1.72E+05**	**1.76E+05**	**1.70E+05**	**1.74E+05**	**1.72E+05**	**1.73E+05**	**1.69E+05**	**1.72E+05**	**1.68E+05**	**1.70E+05**	**1.67E+05**	**1.70E+05**
%change			**-1%**	**-1%**	**0%**	**-1%**	**-2%**	**-2%**	**-2%**	**-3%**	**-3%**	**-4%**
	In (m^3/day)		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**		**In (m^3/day)**	
Surface Water												
Recharge	510	2550	420	2550	510	2550	410	2040	330	2020	330	2020
Flow from other units	3040	3690	2620	3650	3030	3700	2330	2990	1940	2850	1940	2850
Total	3550	6240	3040	6200	3540	6250	2740	5030	2270	4870	2270	4870
	Out (m^3/day)		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**		**Out (m^3/day)**	
Surface Water												
Flow to other units	3520	6220	3010	6180	3500	6210	2710	5010	2240	4850	2230	4830
Private Users	30	20	30	20	40	40	30	20	30	20	40	40
Municipal Wells	-	-	-	-	-	-	-	-				
Total	3550	6240	3040	6200	3540	6250	2740	5030	2270	4870	2270	4870
Range of water level change (m)			-1 to -10	0 to -4	<-1	<-1	-1 to -15	-1 to -15	-2 to -25	-2 to -20	-2 to -25	-2 to -20
Average Water level difference (m)			-5	-2	<-1	<-1	-10	-10	-15	-15	-15	-15

Table E5: Predicted Baseflow in the Monitored Creeks for Future Scenarios

Baseflow (m^3/day)	Base Case		Scenario 1 - Climate Change		Scenario 2 - Future Buildout		Scenario 3 - Change Land Cover		Scenario 4 - CLIMATE CHANGE AND LAND COVER		Scenario 5 - SCENARIO 1,2,3 COMBINED	
Watercourse	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**	**End of Dry Season**	**End of Wet Season**
Craig Creek	1000	1390	570	860	890	1260	810	1150	430	620	370	520
Nanoose Creek	1830	2220	1300	1610	1790	2160	1710	2050	1200	1470	1160	1410
Bonell Creek	1680	2020	1110	1420	1560	2010	1550	1990	1090	1400	1080	1400